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SURFACE WATER SECTION
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SWS Contract Report 282

SEDIMENT TRANSPORT AND HYDRAULICS OF FLOW IN THE KANKAKEE RIVER, ILLINOIS - PHASE II

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INTRODUCTION

In October 1978, the State Water Survey initiated a study of the hydraulics of flow and sediment transport of the Kankakee River in Illinois and Indiana. The study plan called for a two-year program with one year of data collection and one year of analysis. A working draft of the report for this project was sent to the contracting agency in August 1980. The final report was printed in May 1981 (Bhowmik et al., 1980).

During the writing of the original final report by Bhowmik et al. (1980), it was decided to limit its content to the specific contract requirement. However, in the course of field data collection, a considerable volume of field data was collected which did not apply directly to the content of that report.

This report serves three purposes:

1. To discuss and review the data collected during the intial study period that was not considered in the original report.
2. To discuss and review the data collected after the conclusion of the original study.
3. To evaluate the sediment transport analyses of the original report given an additional year of field data collection.

Plan of the Report

This report contains three main sections: Data Collection, Analysis of Data, and Summary and Conclusions. A more detailed discussion of the historical and technical backgrounds may be found in the original publication (Bhowmik et al., 1980).

Acknowledgments

This work was accomplished as part of the regular work of the Illinois State Water Survey under the administrative guidance of Stanley A. Changnon, Jr., Chief, and Michael L. Terstriep, Head, Surface Water Section.

The following Water Survey personnel participated in the field data collection and surveys and the analysis of the data: David J. Kisser, Kevin Falk, David Jennings, Richard Allgire, D. Kevin Davie, Allen P. Bonini, and Margaret Sexton.

The following graduate and undergraduate students at the University of Illinois assisted in the analysis of the data: Konstantinos Dovantzis, Dale Goeke, Pam Shipplett, and John Nicol.

The following agencies and individuals provided assistance in the completion of the field surveys: the Division of Water Resources of the Illinois Department of Transportation provided copies of field notes for previous surveys of the Kankakee River, Six Mile Pool; the city of Kankakee provided office facilities for the survey crew making the survey of the Six Mile Pool; and many residents of the area provided river access to the survey crew on the Momence Wetlands.

The following Water Survey personnel assisted in the preparation of the report: Pamela Lovett, Kathy Brown, and Lynn Dorner typed the rough draft; John Brother, Jr., William Motherway, Linda Riggin, and Bruce Ferguson prepared the illustrations. J. Loreena Ivens edited the report, and Pamela Lovett prepared the camera-ready copy.

DATA COLLECTION

Drainage Basin

The drainage basin of the Kankakee River and the locations of some of its more important gaging stations are depicted in figure 1. The total drainage area of the Kankakee River at its mouth at the Illinois River is 5,165 square miles. The drainage area at the Wilmington gage is 5,150 square miles, which is 99.7 percent of the total drainage area of the Kankakee River. The drainage area of the Kankakee River at the Illinois-Indiana state line is 1,920 square miles. The drainage area of the Singleton Ditch at the Illinois-Indiana state line is 220 square miles, whereas the drainage area of the Kankakee River at the Momence gaging station below its confluence with the Singleton Ditch is 2,294 square miles (Healy, 1979). Thus, about 93 percent of the drainage area at the Momence gaging station is located in Indiana. Similarly, for the gaging station on the Iroquois River at Iroquois, 95 percent of the drainage area is located in Indiana. The geologic features of the drainage basin are discussed in a study by the Illinois State Geological Survey (Gross and Berg, 1980).

State Line Sand Bar

The original project called for the establishment of a temporary water and sediment discharge monitoring station on the Kankakee River at the Illinois-Indiana state line. During the course of data collection at this station, a moving sand bar was observed immediately upstream of the bridge. For a period of two months, this sand bar was monitored during each field trip to record its movement. In addition to this monitoring, two detailed surveys were performed to establish the initial and final position of this bar for an interval of three months. The results of this program were

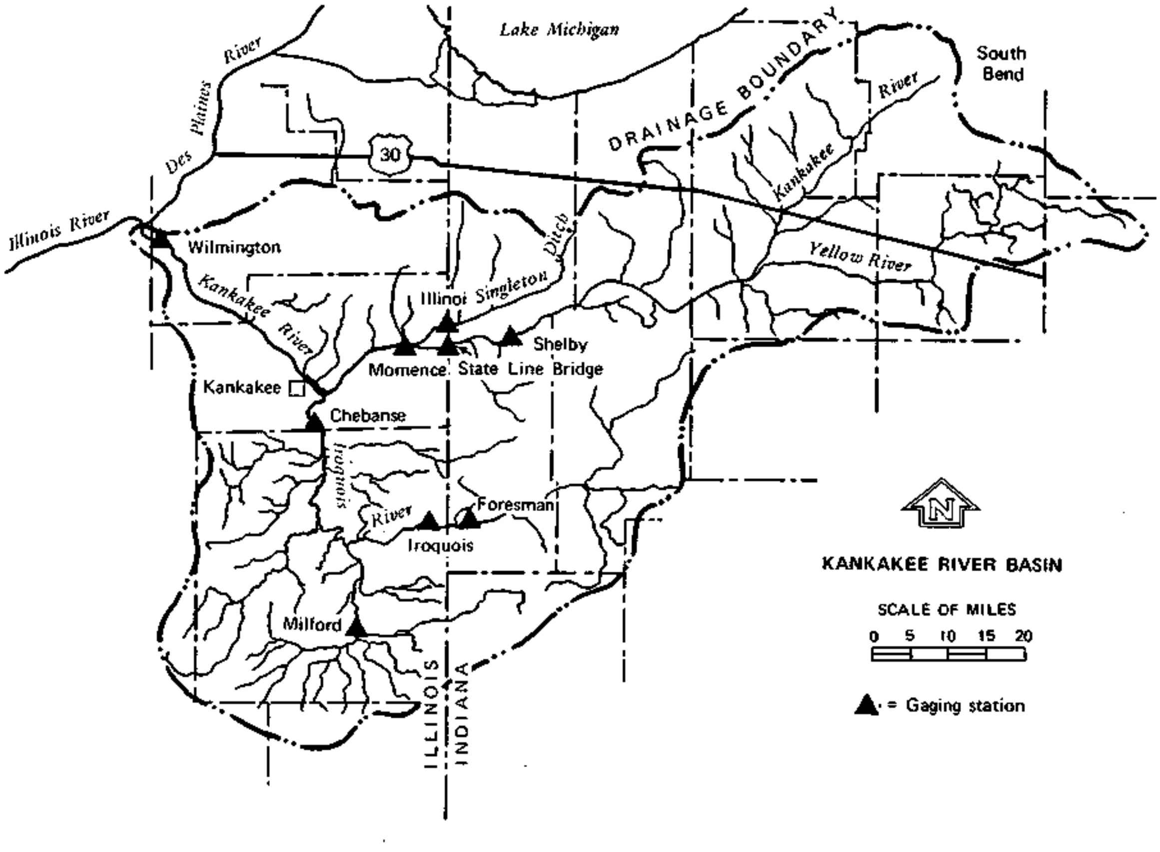


Figure 1. Drainage basin of the Kankakee River and associated gaging stations

discussed in Bhowmik et al. (1980). A considerable volume of data was also collected on this sand bar to determine its effects on the hydraulics of the river. These data are discussed in this report.

In order to determine the hydraulic conditions of flow over the sand bar, a series of cross sections were established to measure the velocity profiles of the river. This was done on August 15-16, 1979, at the five cross sections located 15, 312, 528, 1035, and 2100 feet upstream of State Line Bridge (figure 2). Velocity data were again collected from these same cross sections as well as one more station located 74 feet downstream of the bridge, on November 5-7, 1979 (figure 2).

To measure the velocity profiles of the river, a marked steel cable was stretched across the river at each cross section and point velocity data were collected at horizontal intervals of 5 feet and vertical intervals of 1 foot. All velocity measurements were made using a Price-type vertical axis current meter. Water surface profiles were determined by level surveying.

Other Sand Bar Monitoring

While traveling the Kankakee River by boat, investigators observed that there were a number of sand deposits or sand bars in the river in Illinois, some of which extended from a few hundred feet to about one mile long. A decision was made to survey a few of these sand bars and monitor them for a period of time to observe and document their movement. Figure 3 shows the locations of the major open river sand bars on the Kankakee River in Illinois. Sand bars 2, 3, and 4 and the one near the state line were surveyed in detail to develop contour maps. Table 1 indicates the dates when the various sand bars were surveyed. Contour maps of these sand bars

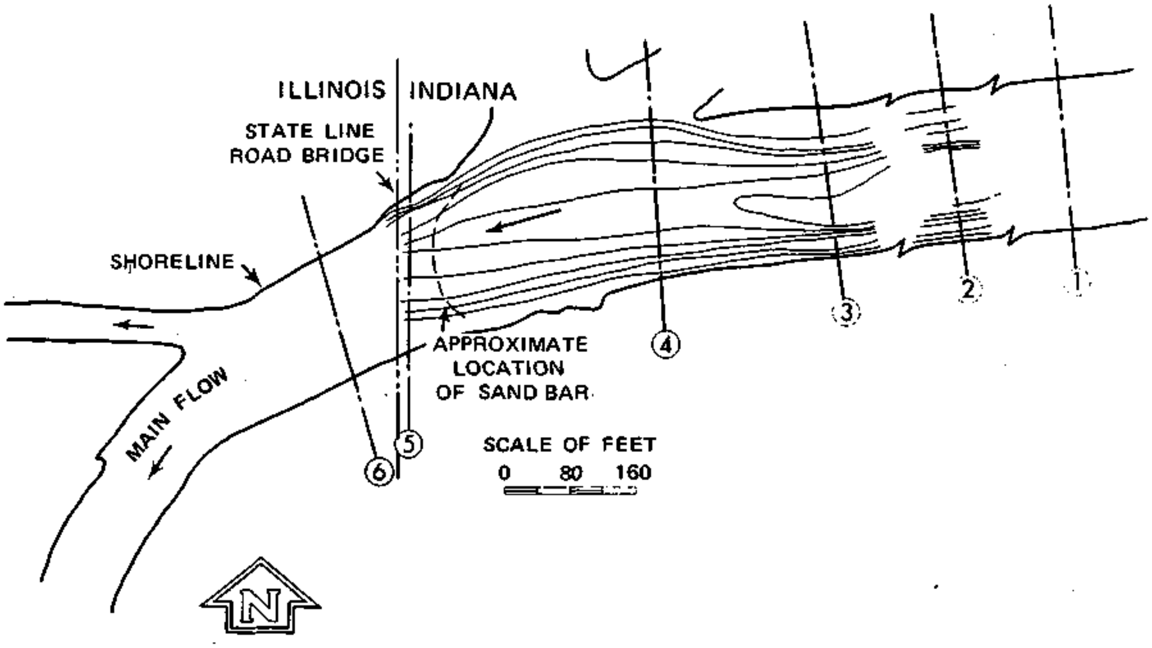


Figure 2. Cross-section locations on the state line sand bar

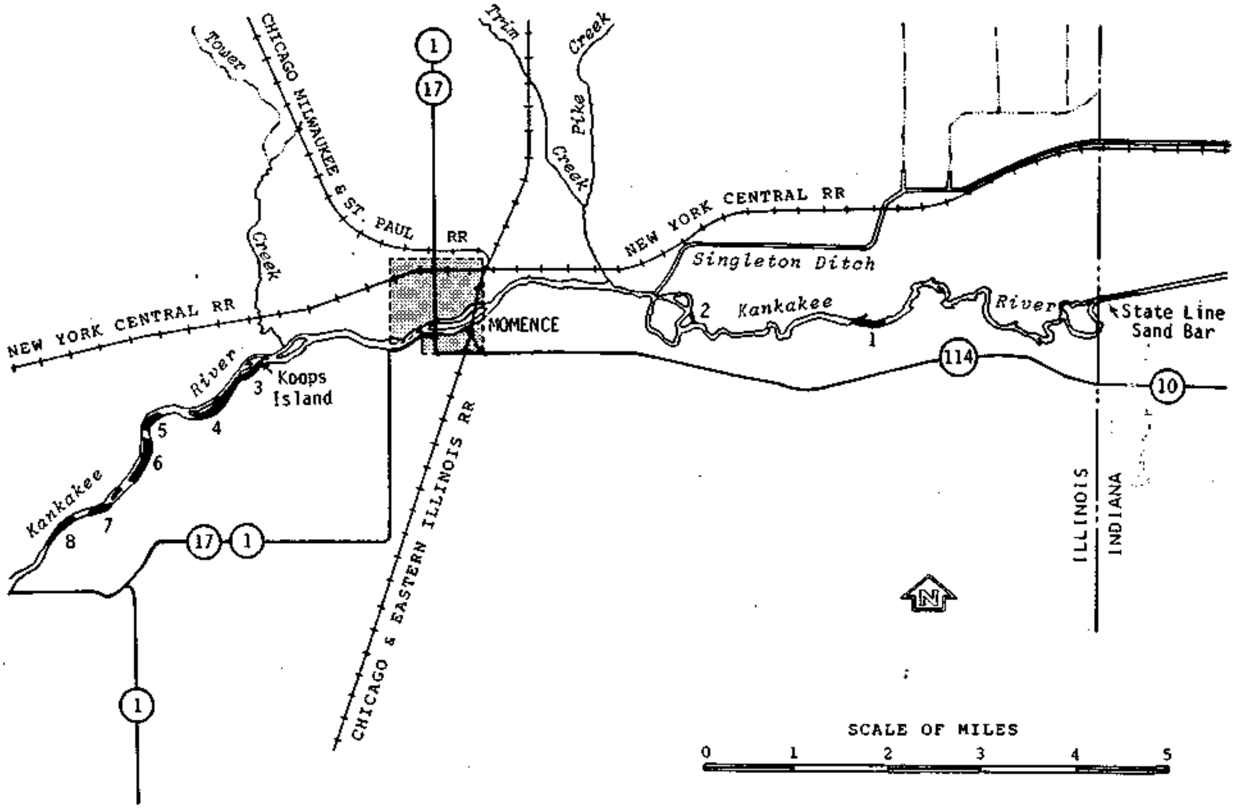


Figure 3. Locations of major open river sand bars in Illinois

and the adjoining river bed were developed. With the exception of the State Line sand bar, these sand bars were surveyed only once and were not monitored in any other way. The survey of sand bar number 3 near Koop's Island was included in Bhowmik et al. (1980).

Table 1. Sand Bar Surveying

Sand bar name/number	Dates	Comments
State Line	July 25, 1979	Detailed survey
State Line	Nov. 5-6, 1979	Detailed survey
2	Sept. 18-20, 1979	Detailed survey
3	Aug. 29-30, 1979	Detailed survey
4	Oct. 3-16, 1979	Detailed survey

Momence Wetlands

During the original contract period, the Water Survey contracted the services of Dodson & Associates of Mattoon, Illinois, to survey and establish permanent surveying monuments for developing a base line through the Momence Wetlands from the confluence of the Kankakee River and Singleton Ditch to the Illinois-Indiana state line. This survey was completed in July 1980 (Dodson, 1980). The Dodson cover map for the traverse line is shown in figure 4.

In September 1980, this base line was used to locate a series of 36 cross sections of the river in the Wetlands (figure 4). This series of cross sections was developed to be used as preliminary data for determining sedimentation and scour rates in the Wetlands. It is hoped that these cross sections will be resurveyed at 5- to 10-year intervals in order to evaluate long-term changes in the Momence Wetlands.

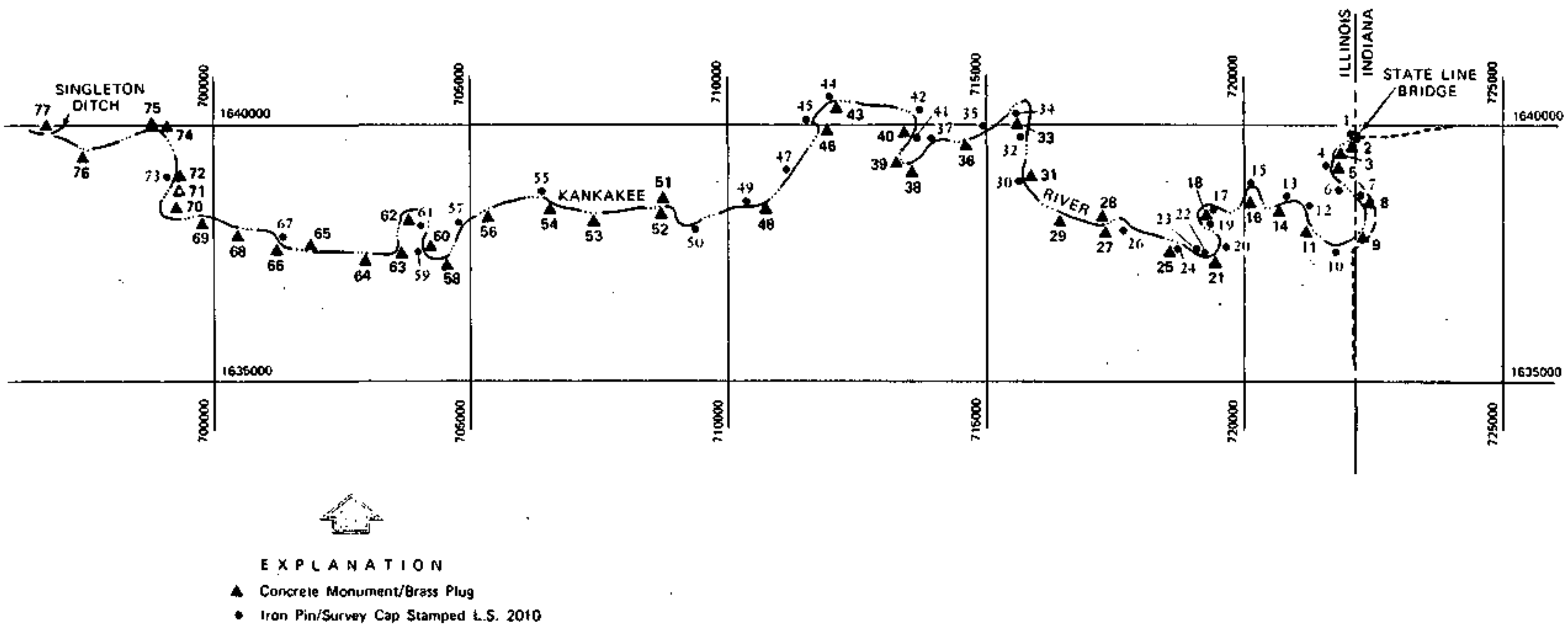


Figure 4. Locations of cross sections in the Momence Wetlands

Six Mile Pool

The Illinois Division of Water Resources (DOWR) collected and analyzed a set of cross-sectional data from the Kankakee River in 1966-1967 and again in 1977-1978, after which the raw data and the associated analyses were made available to the Water Survey. A further analysis of these data was made and the results were presented in Bhowmik et al. (1980).

In November 1980, 36 of these cross sections were resurveyed in an effort to define the sedimentation rate in Six Mile Pool near the city of Kankakee (figure 5). This survey was made by Water Survey personnel using the following procedures:

1. The DOWR's base line was recovered as much as possible.
2. Where the DOWR base line could not be recovered, the line was resurveyed.
3. the DOWR cross sections were then located and surveyed.

The cross sections were surveyed by stretching a marked plastic cable across the river and measuring depths at 10-foot intervals using a marked 2-inch diameter aluminum pole.

Sediment Transport Data

Bhowmik et al. (1980) presented a detailed analysis of the sediment transport characteristics of the Kankakee and Iroquois Rivers based on daily suspended sediment data collected at the four index stations used in the original study during the 1979 water year. These four index stations are described in table 2.

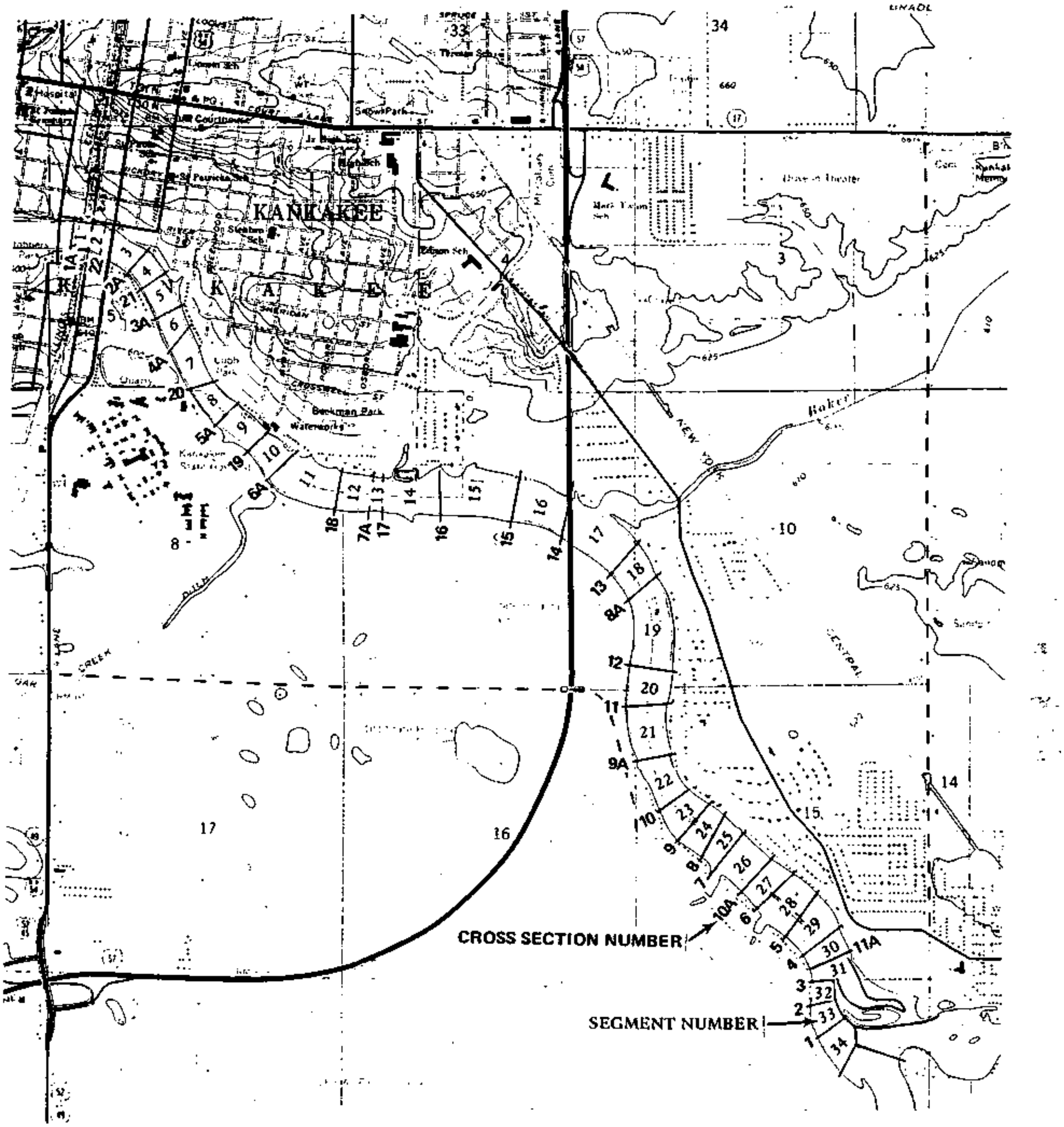


Figure 5. Locations of cross sections in Six Mile Pool

Table 2. Gaging Station Locations and Descriptions

Station number	Location	Watershed area (sq mi)	Length of record for water discharge	Average discharge (cfs)
05520500	Kankakee River at Momence, IL	2294	1916-present	1930
05525000	Iroquois River at Iroquois, IL	686	1945-present	536
05526000	Iroquois River near Chebanse, IL	2091	1925-present	1610
05527500	Kankakee River near Wilmington, IL	5150	1916-present	4090

In this report, the reliability of making a sediment transport analysis based on one year of data will be evaluated by comparing the 1979 sediment transport relationships with the 1980 relationships and the combined 1979 and 1980 relationships.

The sediment transport data for 1980 were collected by the U.S. Geological Survey utilizing the standard procedure given by Guy and Norman (1970). A depth-integrating suspended sediment sampler, the US DH-59, was used to collect the suspended sediment samples. This sampler works on the principle that the sampled water is collected at the same rate as the velocity of the surrounding stream. The sampler is lowered into the water at a constant rate to 3 inches above the bed of the stream and then is withdrawn at a constant rate. The sample is collected as long as the sampler is in the water and the water is moving. This sampler works fairly well as long as the sampler is not lowered or retrieved at more than about 60 percent of the flow velocity. For all the index stations, one daily sample was normally collected near the center of the stream. However, once every six weeks and more frequently during flood seasons, about 10 to 12 samples were collected across the width of the stream in order to calibrate the sampling site at the center of the stream. This detailed sampling was needed to find out whether or not the sample collected from the centerline of the stream was measuring an average suspended sediment concentration of the stream at that particular station. The detailed samples are often used to adjust the daily samples to reflect an average concentration in the stream cross section. For detailed methodology, the reader is referred to the publication by Guy and Norman (1970).

ANALYSES OF DATA

Most of the data analysed for this report were collected in water year 1980. However, some of the data collected in the previous year are also included in this report to clarify the sedimentation and the sediment transport processes in the river.

Cross-Sectional Data

Momenoe Wetlands

As previously mentioned, cross-sectional data from the Momence Wetlands area were collected in 1980. These cross sections extended from State Line Bridge through the confluence of the Kankakee River with the Singleton Ditch upstream of Momence. Bhowmik et al. (1980) presented an analysis of the cross-sectional data collected by the Illinois Department of Transportation, Division of Water Resources, extending from the mouth of the Singleton Ditch up to the Kankakee Dam in Kankakee. Some additional data collected from the Six Mile Pool in 1980 will be discussed in the next subsection.

Appendix A, pages A-l through A-13, shows the plots of all the cross sections. Since no historical cross-sectional data from this segment of the river are available, no comparative analyses can be made at this time. However, this set of cross-sectional data will be extremely valuable in the future for monitoring or identifying changes that may occur in the river course, shape, and size in the Momence Wetlands area consequent to changes that may occur in the upstream reaches of the river. Data from all the cross sections were plotted with the zero distance on the plot at or near the left edge of the river looking downstream.

Illustrations shown in Appendix A indicate that at a number of places, the shapes of the sections are either trapezoidal or skewed to the right or to the left. Whenever the shape of the cross section is trapezoidal, it indicates that the section is either located at a straight reach of the river or at a crossing between two bends (Bhowmik, 1979). On the other hand, when the cross section is skewed to one side, a skew to the left indicates that the cross section is in a bend to the right and a skew to the right indicates that the cross section is in a bend to the left. Attempts were made to locate all of the cross sections in such a manner that representative samples of straight and curved reaches were documented.

Six Mile Pool

Cross-sectional data from Six Mile Pool near Kankakee were collected by the Illinois Division of Water Resources (DOWR) in 1966-1967 and again in 1977-1978. The Illinois State Water Survey resurveyed the same cross sections in Six Mile Pool in 1980. Locations of these cross sections are shown in figure 5. The DOWR collected cross section data not only from Six Mile Pool but also from the reach of the river extending from the Kankakee Dam up to the confluence of the Singleton Ditch near Momence (Bhowmik et al., 1980). Data analyzed for the present report are those from within Six Mile Pool.

The 1978 and 1980 data were utilized to compute the capacity of the Pool on a segmental basis below a mean pool elevation of 595 feet above mean sea level. Segment volumes were computed by determining the surface area of the river between two cross sections, determining an average depth for the two confining cross sections, and then multiplying the surface area by the average depth. This procedure was followed for all of the segments.

Table 3 shows the segmental capacity of the lake. These data are plotted in figure 6 to illustrate the changes that have occurred in the two years since 1978. Obviously both erosion and scour have taken place in those two years. It appears that near the upstream reach of the pool, depositon of sediment has exceeded the scour. Whereas near the downstream reach, the river's scouring of its bed has been relatively more than the deposition of sediment. As a matter of fact, the 1980 capacity of the pool was about 34 acre feet more than the 1978 capacity. This indicates that the Kankakee River is behaving as a dynamic system in which it is not only scouring and depositing sediment, but also within Six Mile Pool is more or less keeping its sediment load flushing in the downstream direction.

Detailed plots of the cross sections for 1978 and 1980 are shown in Appendix B. An examination of these plots will show some interesting variability along the river within the pool. Normally in any pool created by a dam, the fine sediments are deposited in the deeper portion of the pool usually near the dam. The coarse particles, mostly sand fraction materials in this case, should be deposited near the upstream part of the pool. The cross section plots have been arranged starting with the cross sections near the dam on page B-2 and moving upstream to the cross sections near the confluence of the Kankakee and Iroquois rivers on page B-10. The index map for the cross sections is again shown on page B-l. All of the cross sections have been plotted from the left side of the river to the right side looking downstream, i.e., the starting distance is close to the left edge of the river.

Table 3. Segmental Capacities (1978 and 1980) of Six Mile Pool

Segment*	1980 capacity acre-feet	1978 capacity acre-feet
1	29.5	26.2
2	21.2	20.4
3	91.5	92.6
4	50.7	51.4
5	82.5	85.5
6	67.6	66.2
7	111.3	104.2
8	78.8	70.7
9	109.8	96.6
10	86.4	84.7
11	167.3	166.5
12	96.4	88.3
13	34.7	32.3
14	130.7	125.6
15	131.4	127.9
16	121.5	124.5
17	138.1	136.7
18	94.3	91.5
19	136.6	132.4
20	113.1	100.1
21	67.3	64.0
22	77.6	73.7
23	40.1	50.0
24	27.7	33.0
25	38.8	42.3
26	53.5	55.3
27	39.8	41.1
28	55.7	69.4
29	60.6	75.0
30	42.6	44.8
31	73.1	71.8
32	29.9	28.7
33	44.4	41.6
34	37.3	33.0
Totals	2581.8	2548.0

*See Figure 5 for segment location

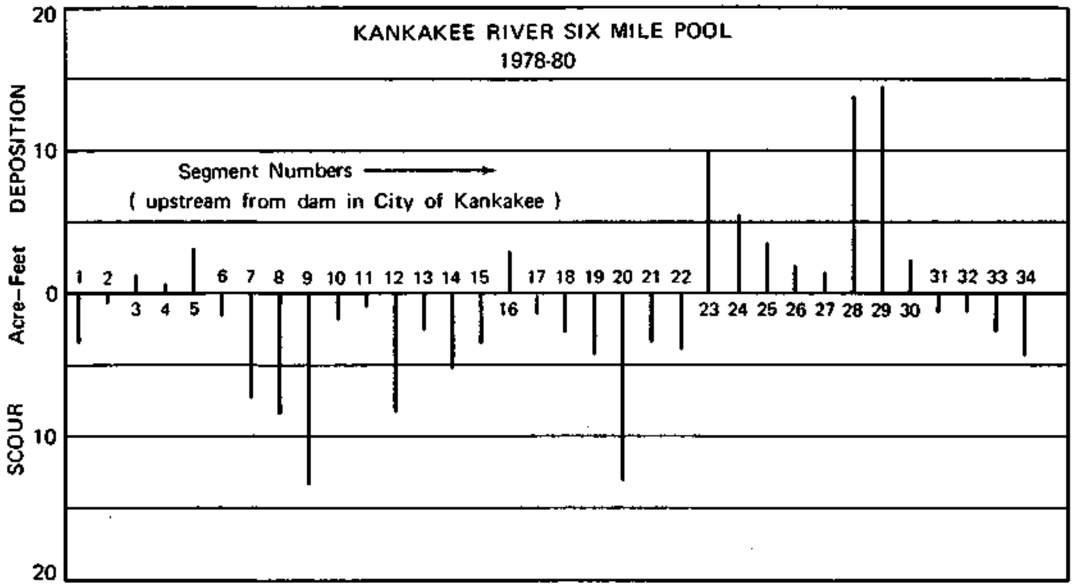


Figure 6. Changes in the segmental capacities in Six Mile Pool between 1978 and 1980

Except at cross sections 22 (page B-2), 4A (page B-3), and 19 (page B-4), not much sedimentation has occurred in this segment of the lake upstream of the dam. The sedimentation at section 19 (page B-4) near the right side of the river is typical of a point bar which forms near the inside bank of a bend. Some man-made filling took place on the right side of the river at section 7A (page B-4) and apparently the river tried to compensate for this loss of area by scouring its bed near the left side of its bank. Sections 16, 15, and 14 (page B-5) showed a gradual deposition of sediment near the left side of the river from 1959 to 1978 to 1980. All of these areas happen to be near the inside bank of the bend nearest the downstream reach of the river. Thus even though the river is flowing through a pool (with a negligible trap efficiency, Bhowmik et al., 1980), a depositional pattern similar to a point bar is being developed at this location. The river is behaving just like a free-flowing stream even within the confines of the pool.

The next significant sedimentation occurred on the left side of the river at sections 10, 9, 8, and 7 (pages B-7 and B-8). There is an island in the middle of the river at these locations and the river is filling up the left channel at these areas. Some scour also took place at all of these locations in the right hand channel. The remainder of the cross sections showed both scour and deposition except at section 5 (right channel) where some sedimentation has occurred. Net scour took place at sections 1-90° and 1-205° (page B-10).

Thus, in general it appears that both sedimentation and scour have taken place in Six Mile Pool. At a number of locations, the river behaved just like a free-flowing stream with typical point bar formations near the inside bank of the bend. There was sediment deposition at a number of places, but the net deposition was relatively small. It appears that Six Mile Pool is acting more or less like a self-cleaning conduit over a period of years.

Sediment Discharge

Sediment discharge data collected for water year 19,79 (October 1, 1978 through September 30, 1979) have already been analyzed and reported by Bhowmik et al. (1980). Additional sediment data collected for water year 1980 were analyzed and are presented here. No bed load or bed material data were collected in water year 1980. Some of these results were presented by Bhowmik (1981a, 1981b).

Suspended Load

Suspended sediment data have been collected by the U.S. Geological Survey for the stations at Momence, Iroquois, Chebanse, and Wilmington (figure 1). Daily sediment samples that were collected were converted into daily sediment load in tons per day.

Figure 7 shows the time series distribution of water discharge and sediment load for the Momence gaging station for the 1979 and 1980 water years. For water year 1979 (top part of figure 7), the highest sediment peak and the water flow peak occurred at the same time. Subsequently in the spring of 1979, although water discharge was fairly high, the sediment load remained low except for a few peaks in the months of April and May. In water year 1980 (lower part of figure 7), the water discharge was fairly steady at a lower level for a prolonged period of time without any sharp peaks. Sediment discharge remained fairly steady during the spring

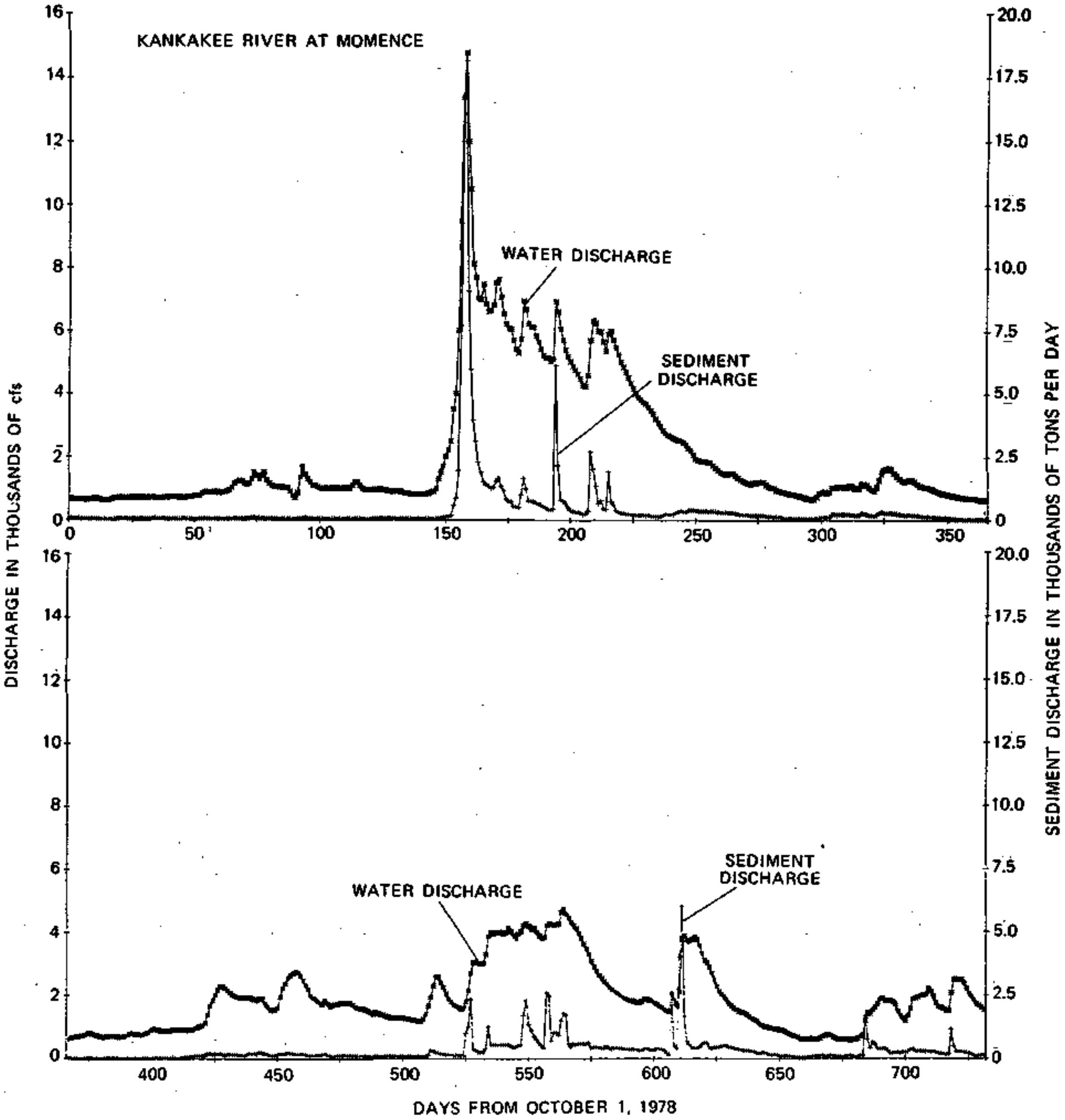


Figure 7. Suspended, sediment load and water discharge versus time in days for the Kankakee River at Momence (Water Years 1979 and 1980)

and early summer seasons except for one sharp peak in the month of June 1980, 611 days after October 1, 1978.

The annual variabilities of sediment load and water discharge shown in figure 7 are presented somewhat differently in figure 8. Here the mean monthly sediment yields in tons per square mile of the drainage area is plotted against the mean monthly water yield in tons per square mile of the drainage area. It appears that, on the average, the sediment yield per unit of drainage area in water year 1980 was relatively smaller than that present in water year 1979. Otherwise, the general variation over the year remained almost the same.

The regression relationship between the sediment loads, Q_s in tons per day, with discharge, Q_w in cfs, was developed for the Momence station from the data for water years 1979 and 1980 and is shown in figure 9. The 80 and 95 confidence limits are also shown. The correlation coefficient for this set of data is 0.81.

Plots similar to figures 7 through 9 for the Momence station were also developed for the other three stations at Iroquois, Chebanse, and Wilmington. Time series distribution of water discharge and sediment discharge for water years 1979 and 1980 for the Iroquois station on the Iroquois River is shown in figure 10. For this station, a fairly good correlation existed between the water discharge and the sediment discharge for both water years. This high correlation is again demonstrated in figure 11 where the relationship between the mean monthly sediment yield and the mean monthly water yield in tons per square mile of the drainage area is shown. The relative sediment and water yield at various times of the year for both water years remained fairly close. Comparatively, for the same water yield, the basin generated more sediment load in the summer

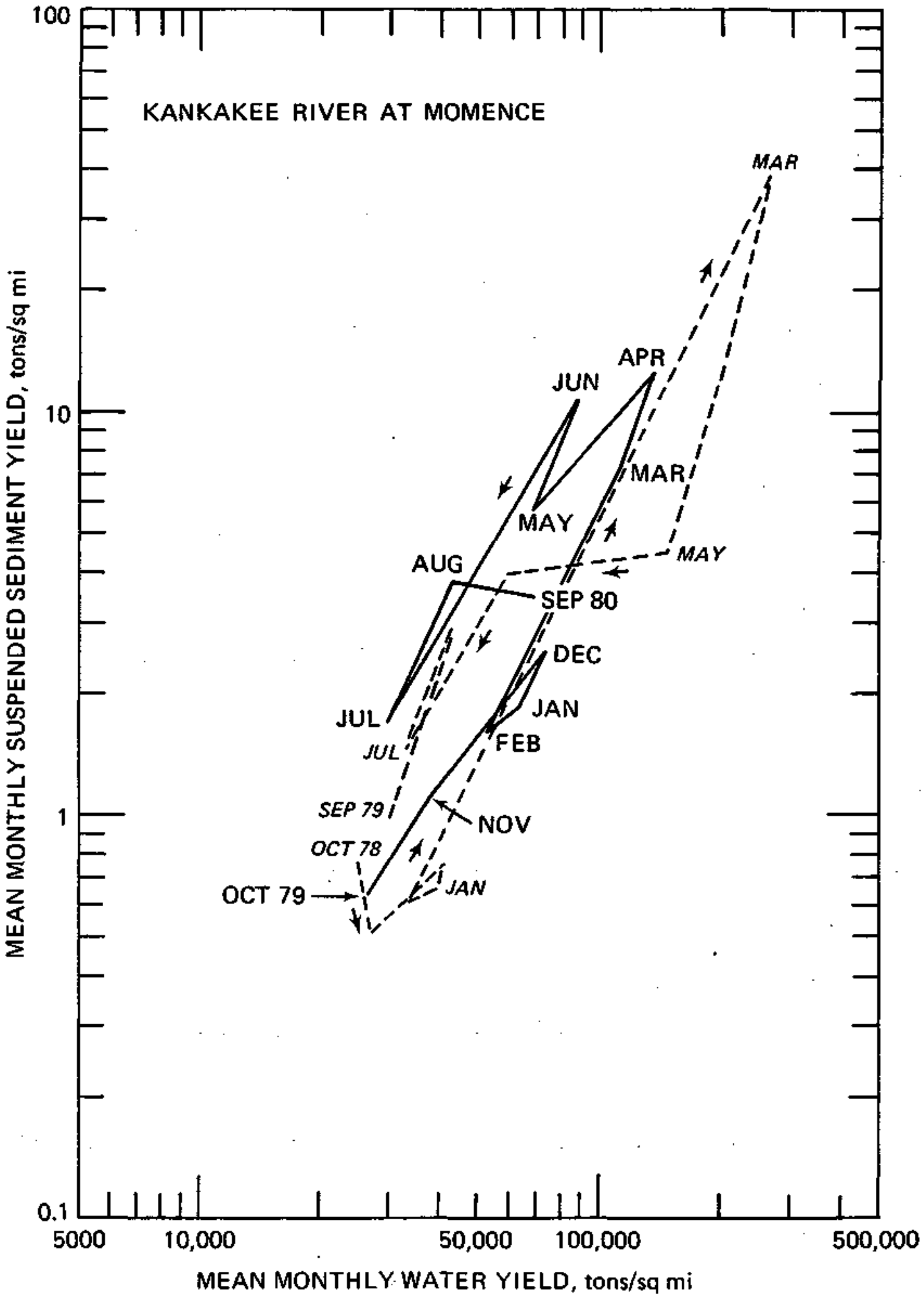


Figure 5. Relationship between mean monthly sediment yield and water yield for the Kankakee River at Momence (Water Years 1979 and 1980)

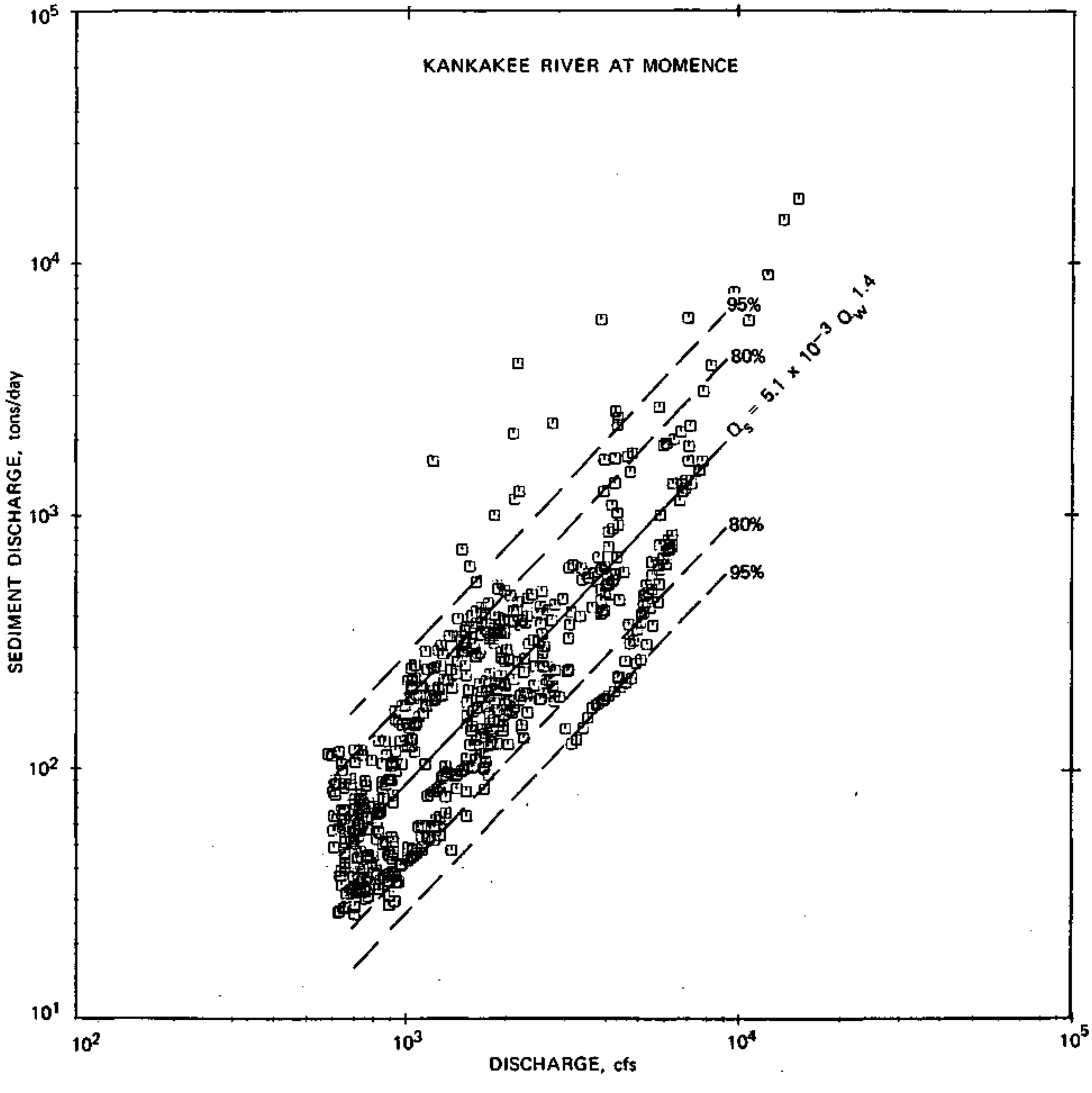


Figure 9. Relationship between suspended sediment load Q_s and water discharge Q_w for the Kankakee River at Momence (Water Years 1979 and 1980)

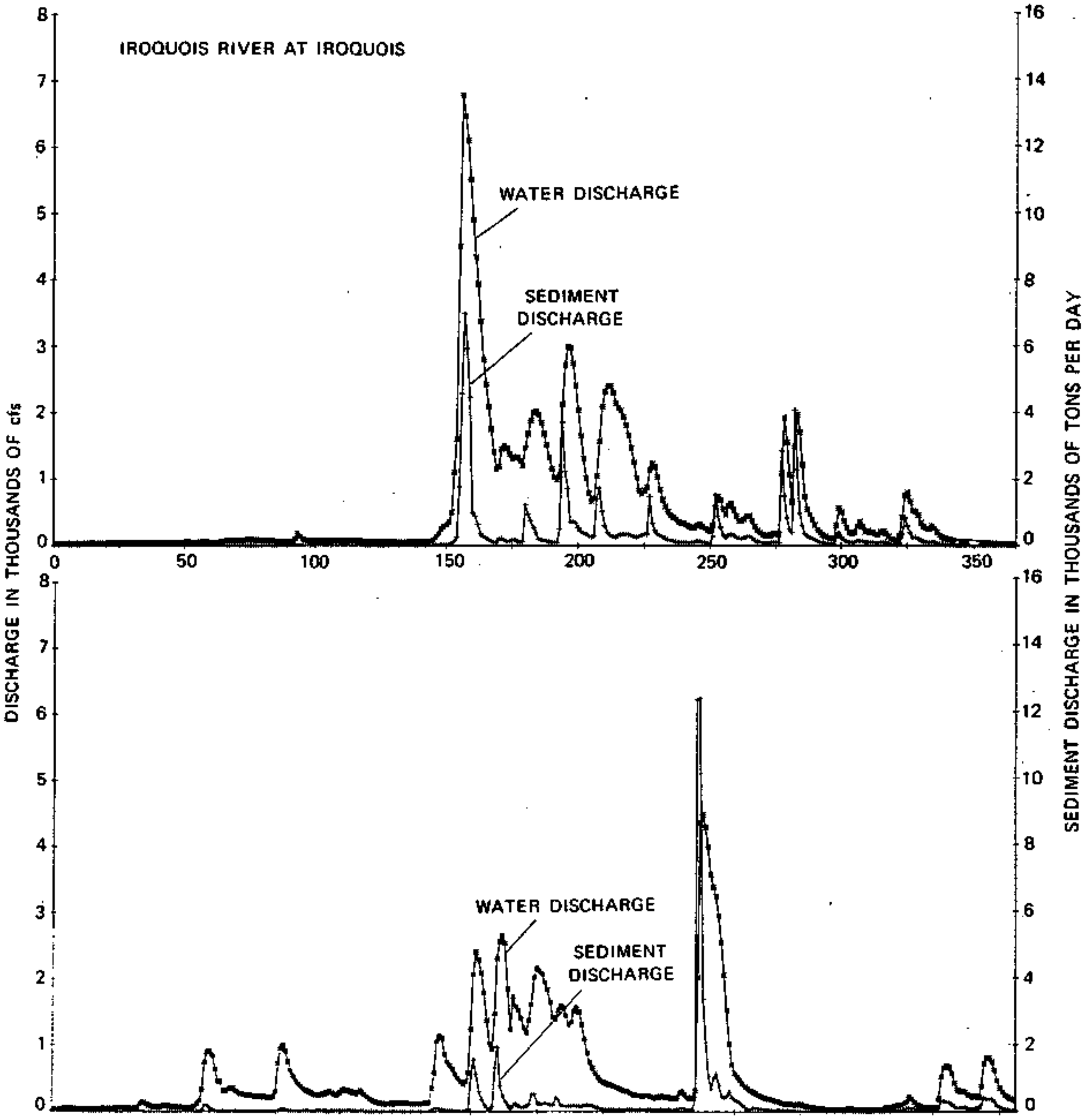


Figure 10. Suspended sediment load and water discharge versus time in days for the Iroquois River at Iroquois (Water Years 1979 and 1980)

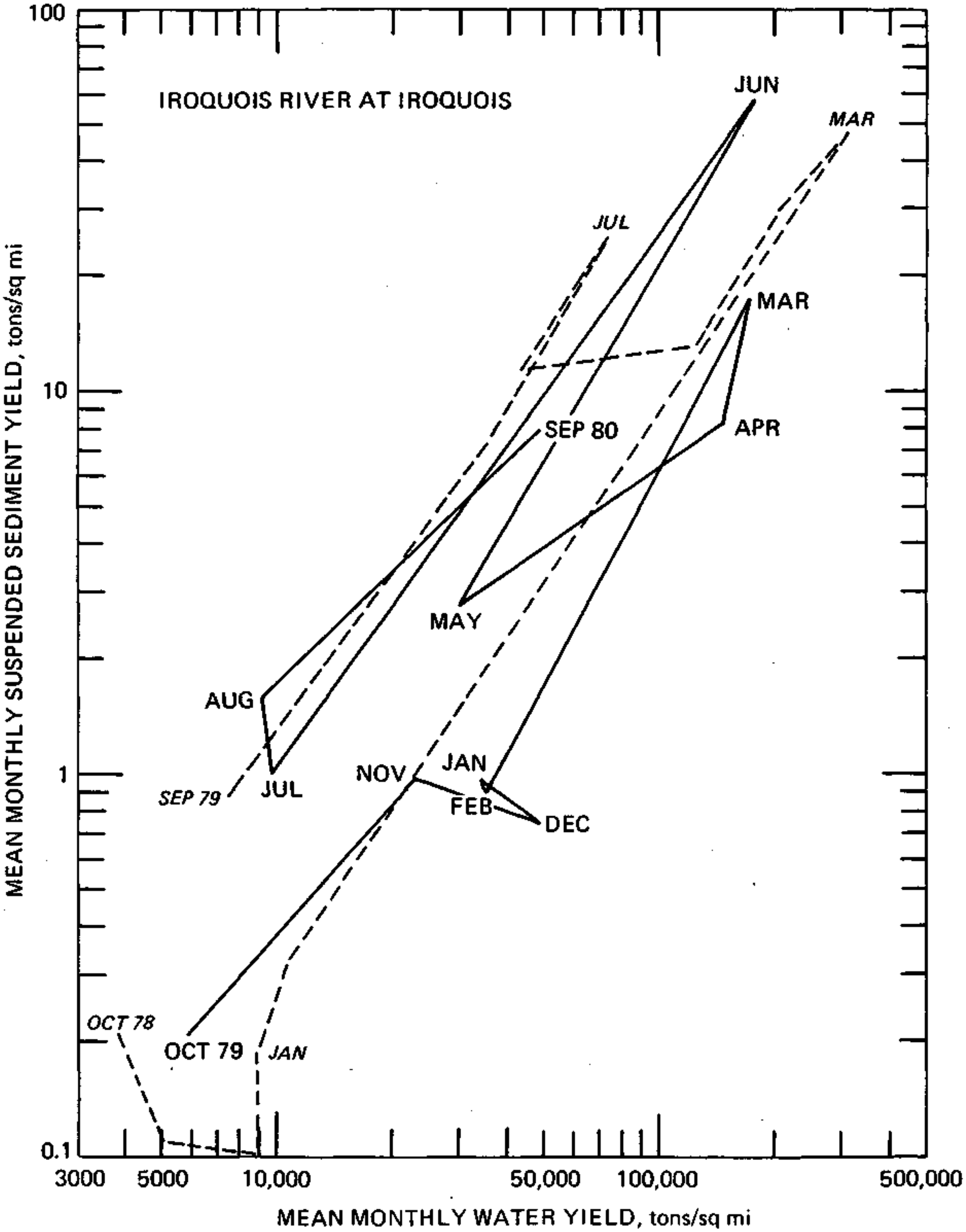


Figure 11. Relationship between mean monthly sediment yield and water yield for the Iroquois River at Iroquois (Water Years 1979 and 1980)

than during the winter months. The regression relationship between the sediment load, Q_s, and the water discharge, Q_w, is shown in figure 12.

Time series distribution of the water discharges and the sediment discharges for water years 1979 and 1980 for the Iroquois River near Chebanse (figure 1) is shown in figure 13. Good correlation between the peaks and valleys of Q_s and Q_w existed for both years. The highest sediment peak was observed in water year 1980 during a storm event in June 1980.

The variation between the unit monthly sediment yield and unit water yield for the 1980 water year for the Chebanse station is given in figure 14. Here again, the sediment yield during the summer months was considerably higher than that present in the winter months for the same relative water yields. The regression relationship between the sediment discharge and the water discharge for this station is given in figure 15'. The confidence intervals of 80 and 95 percent are also shown.

The final illustrations in this series are given in figures 16 though 18 for the Wilmington station. The Wilmington station is located near the mouth of the Kankakee River (figure 1) and, therefore, should represent approximately the total sediment load in the Kankakee River for water years 1979 and 1980.

Figure 16 gives the time series distribution of the water discharge and sediment discharge for water years 1979 and 1980 for this station. There is a fairly good correlation between the peaks of water discharge and the sediment discharge except for the storm in the month of June 1980 shown in the bottom part of figure 16 close to 610 days from October 1, 1978. During this storm event, the highest sediment peak was observed to occur

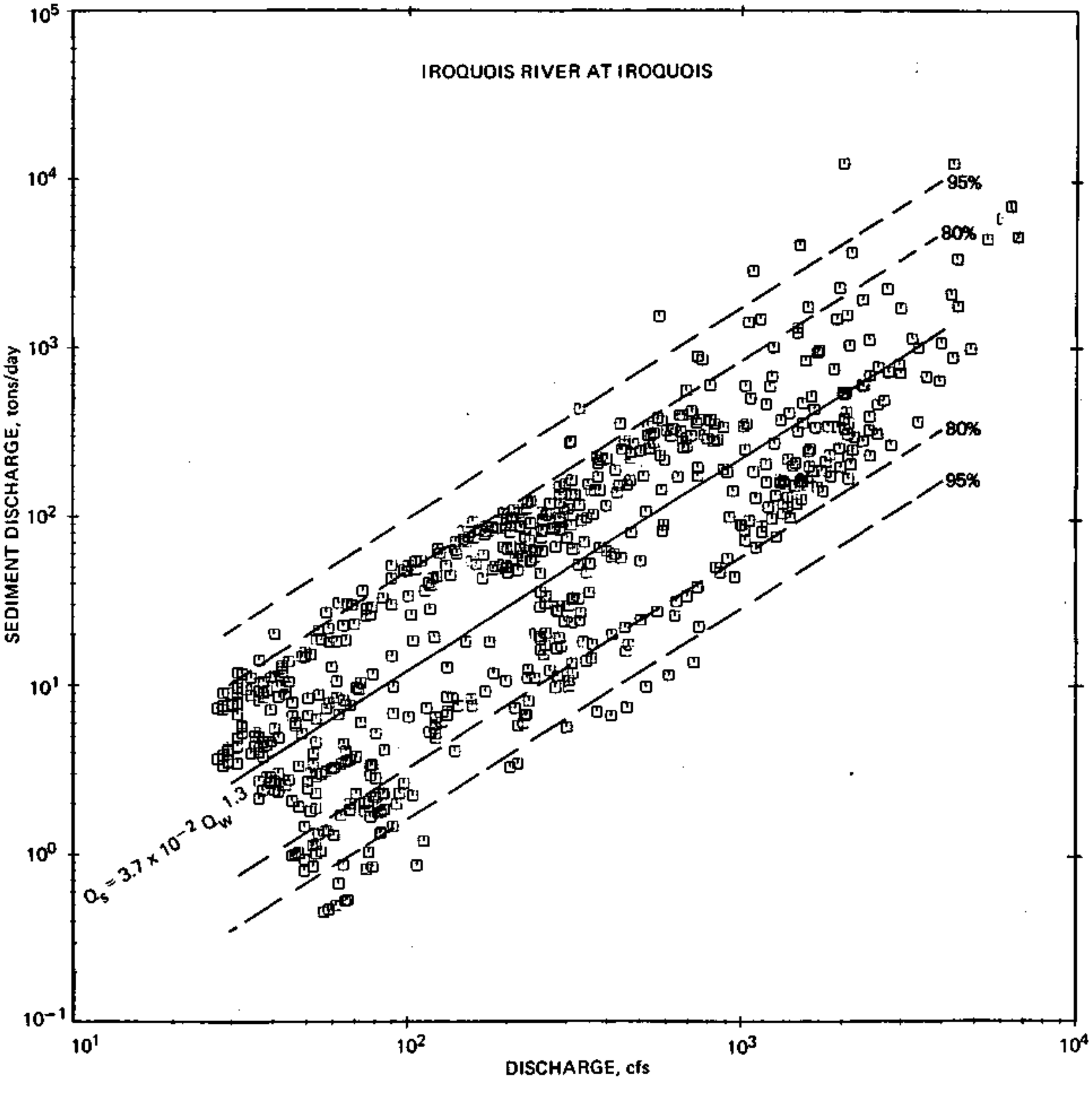


Figure 12. Relationship between suspended sediment load and water discharge for the Iroquois River at Iroquois (Water Years 1979 and 1980)

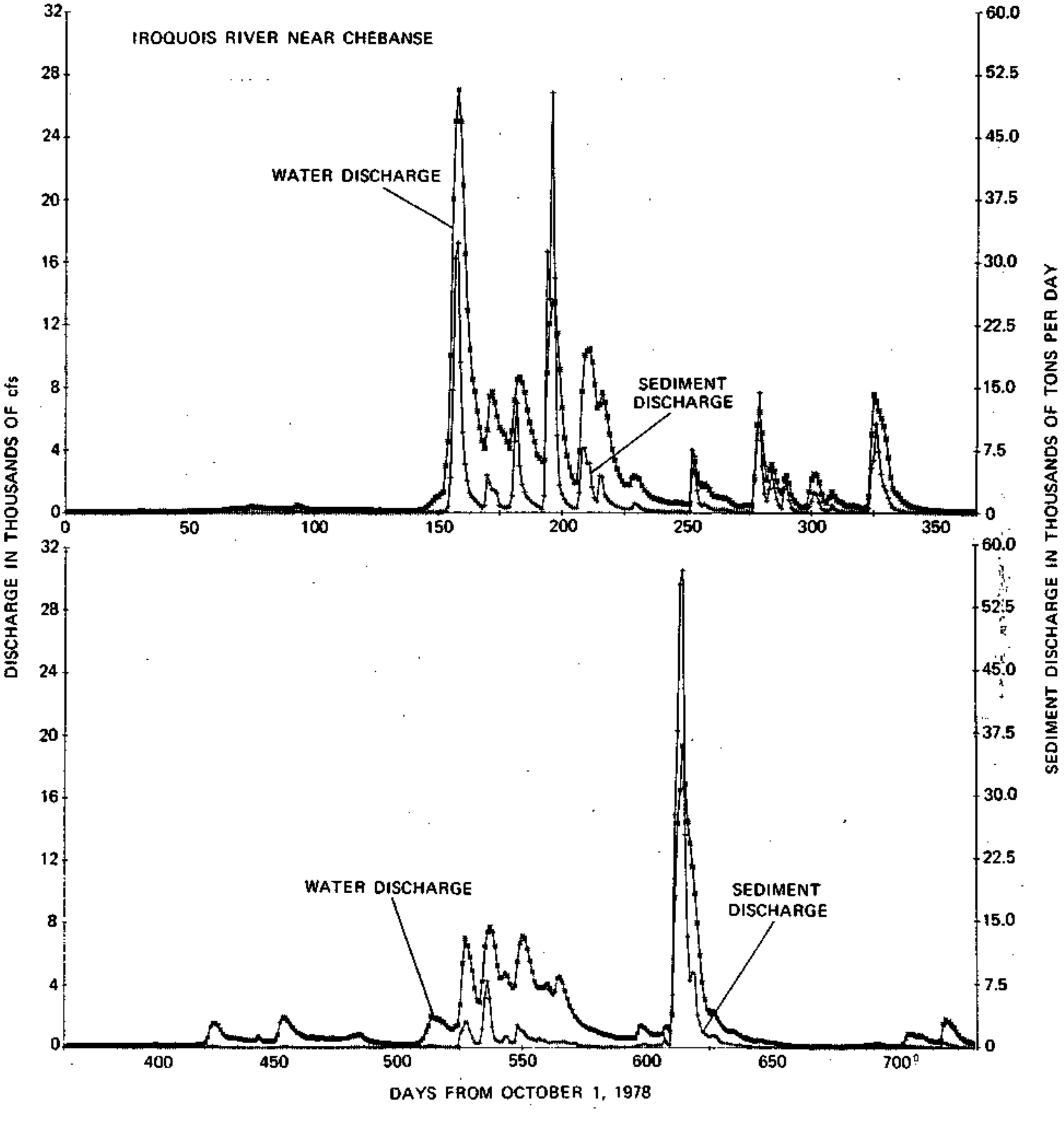


Figure 13. Suspended sediment load and watev discharge versus time in days for the Iroquois River near Chebanse (Water Years 197.9 and 1980)

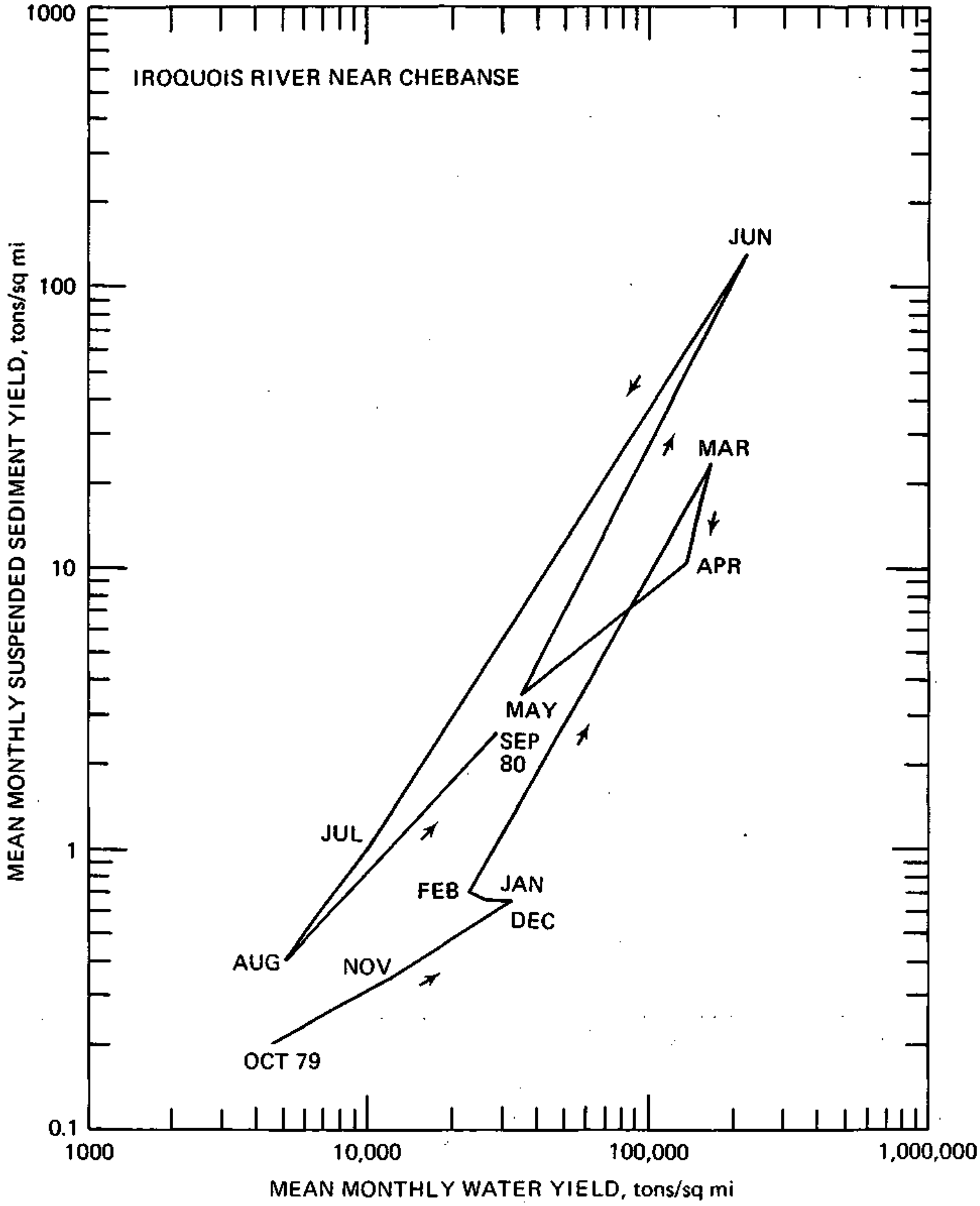


Figure 14. Relationship between mean monthly sediment yield and water yield for the Iroquois River near Chebanse (Water Year 1980)

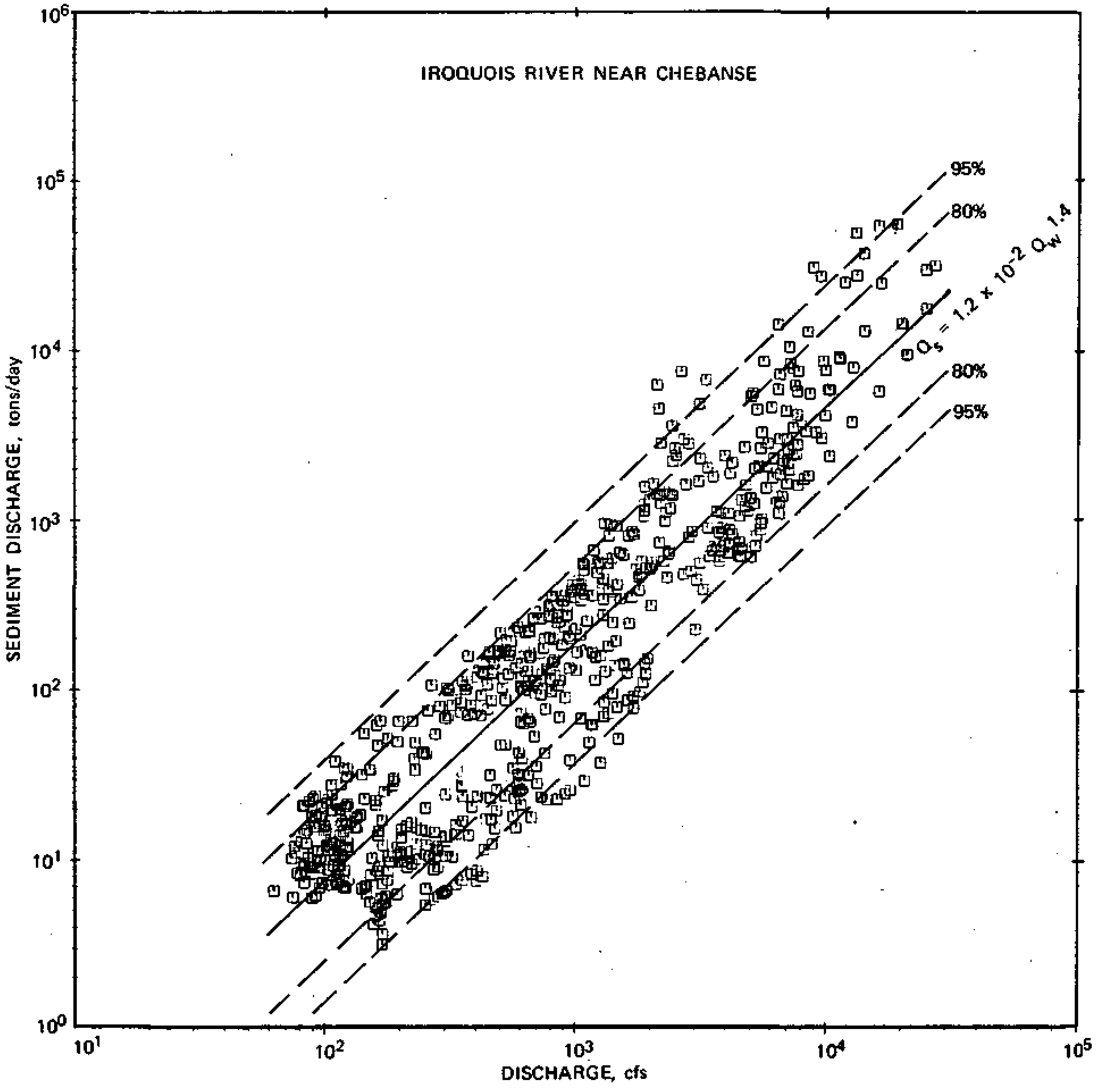


Figure 15. Relationship between suspended sediment load Q_s and water discharge Q_w for the Iroquois River near Chebanse (Water Years 1979 and 1980)

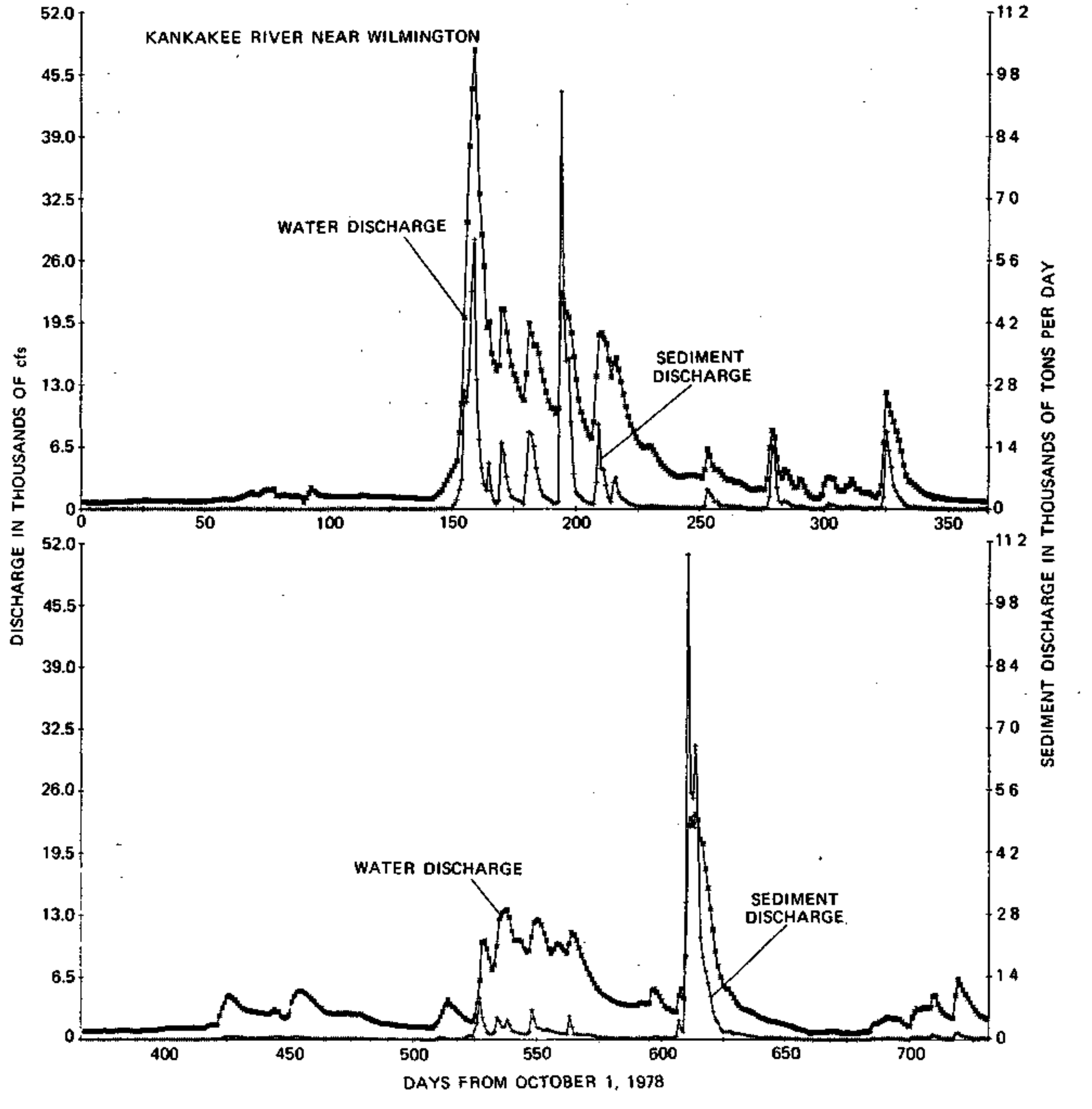


Figure 16. Suspended sediment load and water discharge versus time in days for the Kankakee River near Wilmington (Water Years 1979 and 1980)

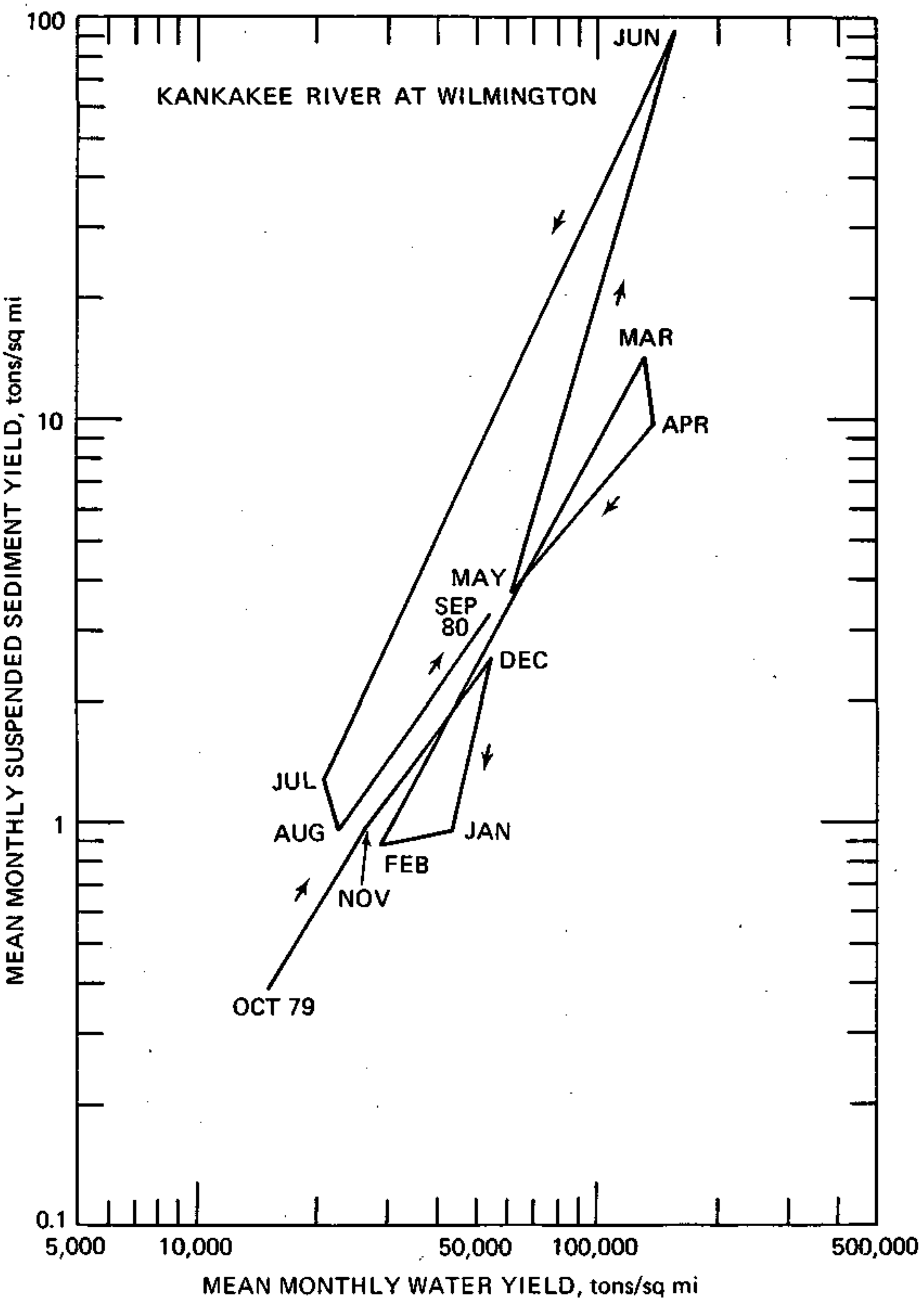


Figure 17. Relationship between mean monthly sediment yield and water yield for the Kankakee River near Wilmington (Water Year 1980)

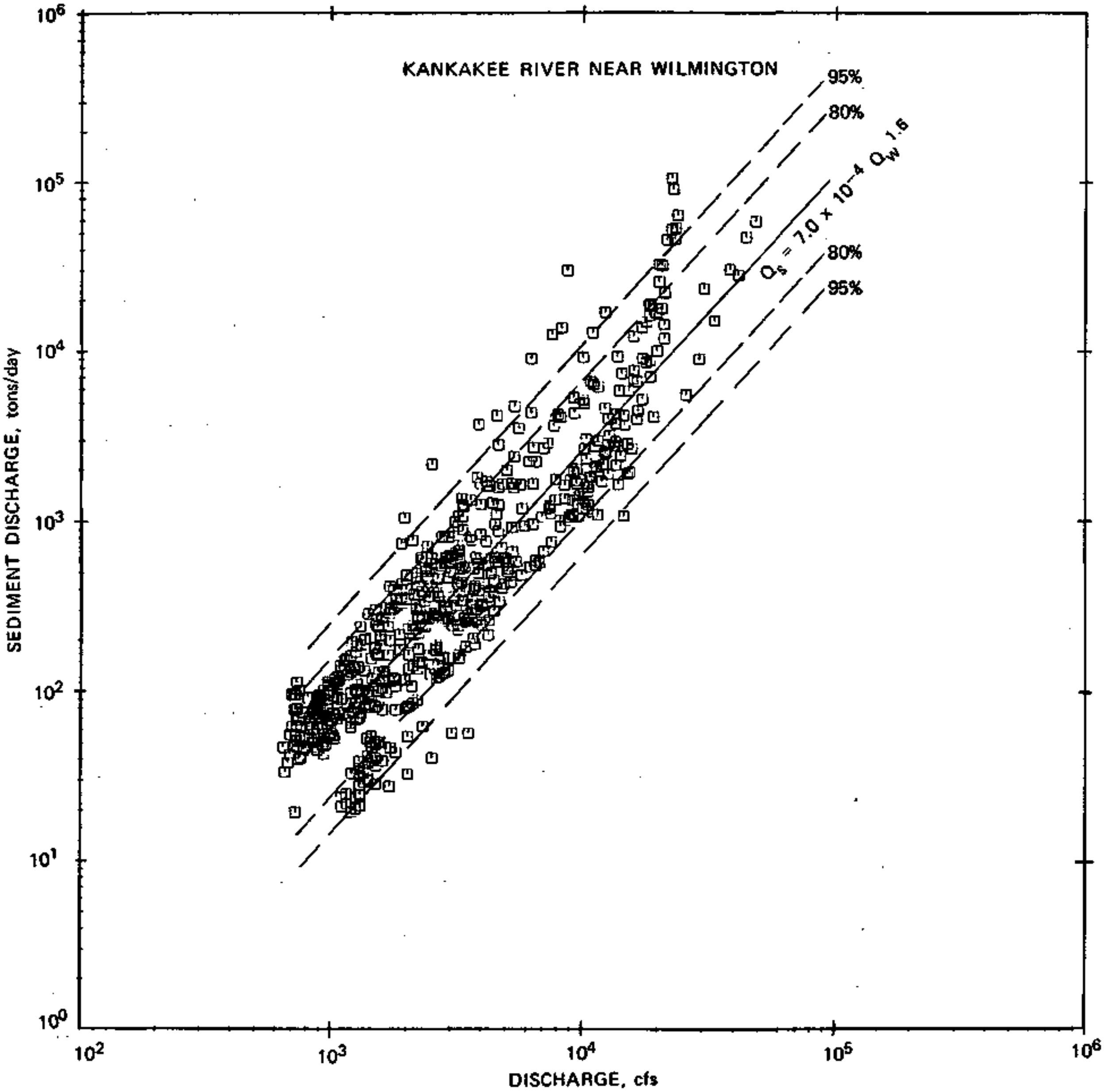


Figure 18. Relationship between suspended sediment load and water discharge for the Kankakee River near Wilmington (Water Years 1979 and 1980)

even though the peak water discharge was lower than that observed in the 1979 water year.

It appears that the storm flows that occurred on the basin early in the month of June 1980 (from June 1 to 7) produced enough sediment load to significantly affect all four stations in the basin. The peak sediment load at the Momence station in water year 1980 (611 days from October 1, 1978, figure 7) was highest during this storm event. Stations at Iroquois (bottom part of figure 10, 612 days from October 1, 1978) and Chebanse (bottom part of figure 13, 614 days from October 1, 1978) also registered the highest load during this storm event in water year 1980. As far as the suspended sediment load is concerned, it is apparent that the Irpquois River basin (figures 10 and 13) has contributed a significantly higher load than that contributed by the main stem of the Kankakee River (figure 7).

The variation of the mean monthly sediment yield and the water yield per unit of drainage area for the Wilmington station is given in figure 17. The regression relationship between the sediment discharge and the water discharge for the 1979 and 1980 data for this station is given in figure 18. Compared to the other three stations, the spread of the data points for this station is relatively small.

Figures 7 through 18 contain a graphic analysis of the sediment and water discharge data for the four main gaging stations on the Kankakee River in Illinois. In the next subsection, some generalized comments and analyses of these data are presented.

Generalized Analyses - Suspended Load

Combined analyses of the suspended sediment load data from two water years have been presented. However, a generalized analysis of the

Table 4. Regression Equations*

$$Q_s = mQ_w^p$$

Station	1979 Water Year		1980 Water Year		1979 and 1980 Water Years	
	m	p	m	p	m	p
Momence	5.113×10^{-3}	1.3911	5.625×10^{-3}	1.4150	5.075×10^{-3}	1.4107
Iroquois	2.308×10^{-2}	1.3700	7.589×10^{-2}	1.1084	3.742×10^{-2}	1.4571
Chebanse	7.623×10^{-3}	1.4867	2.293×10^{-2}	1.2842	1.178×10^{-2}	1.4038
Wilmington	5.585×10^{-4}	1.6726	1.001×10^{-3}	1.6087	7.031×10^{-4}	1.6484

*Figures 9, 12, 15, and 18 in this report and figure 51, 55, 59, and 63 and table 9 in Bhowmik et al. (1980) show the coefficients and exponents of the regression equations up to "two" significant figures. However, in the computation of the sediment load, the coefficients and exponents given in this table should be used.

Table 5. Standard Statistical Parameters for the Regression Equations

Station	Number of data points	Intercept	Regression coefficient	Standard error of regression coefficient	t-value	Correlation coefficient	Standard error of estimate
(A) WATER YEAR 1980							
Momence	366	-2.25	1.42	0.05	26.1	0.81	0.25
Iroquois	366	-1.12	1.11	0.04	25.4	0.80	0.44
Chebanse	366	-1.64	1.28	0.03	37.7	0.89	0.37
Wilmington	366	-3.00	1.61	0.04	43.1	0.91	0.26
(B) WATER TEARS 1979 and 1980							
Momence	731	-2.29	1.41	0.03	43.4	0.85	0.26
Iroquois	731	-1.43	1.26	0.03	44.4	0.85	0.45
Chebanse	731	-1.93	1.40	0.02	65.6	0.92	0.36
Wilmington	731	-3.15	1.65	0.03	58.4.4	0.91	0.32

suspended sediment load data from the Kankakee River should be interesting and of value to the basic understanding of the sediment transport mechanics in the river.

Regression Equations. Regression equations developed between Q_s and Q_w for the four gaging stations from the data for water years 1979 and 1980 were shown in figures 9, 12, 15, and 18. Equation 1 shows the general regression equation between Q_s and Q_w.

$$Q_s = m\ Q_W P \qquad (1)$$

where Q_s is in tons per day, Q_w, is in cfs, m is the coefficient, and p is the exponent which is obtained from the regression analyses. Table 4 summarizes the values of m and p for the four gaging stations for which sediment rating curves have been developed. Here the regression coefficients developed for the 1979, 1980, and the combined 1979 and 1980 water years are shown. A quick review will show that for almost all stations, the values of exponent p did not change significantly from 1979 to 1980, even for the combined data for the 1979 and 1980 water years. There are some variabilities in the values of m over the two-year period. However, when the regression lines of water years 1979 and 1980 for each station are plotted together, the difference between the shapes of these two lines becomes almost negligible. Thus it appears that the Kankakee River may be in a unique position in which a certain average relationship does exist between Q_s and Q_w, at least for the 1979 and 1980 water years. Table 5 shows some standard statistical parameters for these regression equations.

Cumulative Movement of Sediment Load. An examination of figures 7, 10, 13, and 16 will show that the bulk of the suspended sediment load moved during the storm events. If an arbitrary selection is made for the span of the storm events in each water year, a generalized estimate of the cumulative sediment load that moved during the storm events for each water year can be made. Such an analysis is shown in table 6. In water year 1979, about 70 to 80 percent of the total yearly sediment load passed at all four stations in a period of about 60 to 75 days. For the 1980 water year, the storm flows in many cases were prolonged for a substantial period of time and consequently the number of storm days was much larger. Thus for water year 1980, about 70 to 90 percent of the annual sediment load passed in a period of 70 to 115 days. On the average, for water years 1979 and 1980, about 70 to 80 percent of the annual sediment load passed the four stations in a period of about 65 to 85 days per year.

It is obvious that the storm days utilized in table 6 were selected arbitrarily and considerable judgment was needed in their selection. Another way of analyzing these data would be to select a specified discharge of a certain return period and then compute the sediment load for all the discharges at or about this specified value. One such value would be the average annual flood flow which has an approximate recurrence interval of 2.33 years. The U.S. Geological Survey (Carns, 1973) has developed a methodology for computing flood flows of Illinois streams with various return periods. The modified equations as proposed by the U.S. Geological Survey were utilized to compute the two-year discharges at all four gaging stations. In comparing the average discharges for the 1979, 1980, and the combined 1979 and 1980 water years and the two-year discharge, the Q_2 values at all the stations are much higher than the average discharges for each of the water years.

If the Q_2 values given in table 7 are selected and the suspended sediment load corresponding to the discharges which equaled or exceeded

Table 6. Total Percent of Sediment Load Transported During Storm Episodes

Station	Water Year 1979		Water Year 1980		Water Years 1979 & 1980	
	Total number of days	Cumulative % of suspended sediment load	Total number of days	Cumulative % of suspended sediment load	Total number of days	Cumulative % of suspended sediment load
Momence	58	73	117	68	175	71
Iroquois	77	69	82	81	159	74
Chebanse	64	72	73	93	137	80
Wilmington	60	80	108	88	168	83

Table 7. Average Discharge, Q_w, and 2-year Discharge, Q_2

Station	Average Q_w, cfs Water Year 1979	Average Q_w, cfs Water Year 1980	Average Q_w, cfs Water Years 1979 & 1980	Q_2, cfs
Momence	2,171	1,879	2,025	6,230
Iroquois	586	521	553	3,520
Chebanse	2,144	1,498	1,821	11,500
Wilmington	5,074	3,954	4,513	21,100

this value in each water year are taken, then the sediment load that was moved by a flow of Q_2 or greater in each year can be estimated. This was done for the four gaging stations and these values are shown in table 8. This table shows that on the average, Q_2 values were exceeded for only 2 to 22 days in a single water year and the annual sediment load carried by this flow varied from 5 to 48 percent.

The cumulative sediment load was also analyzed following a slightly different procedure. In this case, the cumulative sediment loads corresponding to the water discharges which equaled or exceeded the average annual discharge were determined to find out the sediment load carried by this flow. Table 9 shows these values for the 1979 and 1980 water years. In water year 1979, the storm flows exceeded the average annual flows for 93 to 99 days at the four stations. These flows carried about 79 to 91 percent of the annual sediment load. Similarly for the 1980 water year, the storm flows exceeded or equaled the average annual discharge for 84 to 145 days and this flow carried about 61 to 91 percent of the total yearly sediment load.

The suspended sediment load analyses presented in tables 6 through 9 show the variation of the yearly suspended load that is carried by storms of different magnitude and duration. It is clear that the storm events do carry a substantial amount of the total yearly sediment load and that a detailed quantification of the sediment load during storm events should yield a fairly good estimate of the yearly sediment load in the basin. Thus it is feasible to develop a data collection and sediment monitoring program in which intensive sampling would be done during a 90- to 120-day period of storm events and less frequent sampling would be done at other times. This sampling program should cover most of the variabilities in the

Table 8. Cumulative Percent of Sediment Load Transported during Main Storm Episodes where the Water Discharge Equaled or Exceeded the Q_2 Values

	Water Year 1979		Water Year 1980		Water Years 1979 & 1980	
Station	Total number of days	Cumulative X of suspended sediment load	Total number of days	Cumulative % of suspended sediment load	Total number of days	Cumulative % of suspended sediment load
Momence	22	48	-		22	27
Iroquois	8	26	5	10	13	19
Chebanse	10	32	7	46	17	38
Wilmington	2	5	5	33	7	17

Table 9. Cumulative Percent of Sediment Load Transported during Main Storm Episodes where the Water Discharge Equaled or Exceeded the Average Discharge for the Year

	Water Year 1979		Water Year 1980	
Station	Total number of days*	Cumulative % of suspended sediment load	Total number of days*	Cumulative % of suspended sediment load
Momence	98	82	145	61
Iroquois	98	79	94	65
Chebanse	99	88	84	91
Wilmington	93	91	104	87

* Total number of days discharge equaled or exceeded the average discharge for the year.

watershed, should be cost effective, and should yield data from which a fair estimation of yearly sediment load can be easily made.

Sediment Load Budget. Based on two years of suspended sediment load data, a generalized budget of the sediment load can be made. Table 10 shows the yearly sediment load and the water discharge at four stations for the 1979 and 1980 water years.

The gaging station at Chebanse on the Iroquois River (figure 1) should represent not only the sediment load passing the Iroquois station, but also the sediment load generated in the watershed between these two stations and the depositional and erosional characteristics of the river between these stations. The gaging station at Wilmington should measure the approximate total suspended sediment load carried by the river in those two years. The erosional and depositional characteristics of the watershed and the river are also reflected in this sediment load.

Table 10 clearly shows the suspended sediment load at all four stations in water year 1980 was comparatively smaller than that observed during the 1979 water year. It should be pointed out that the suspended sediment load measured at the Momence and Wilmington stations, in all probability measured the total sediment load transported by the river at these locations (Bhowmik et al., 1980). The yearly average sediment yields based on two years of data are given in the last column of table 10.

The individual sediment yield for each station (table 10) was converted into sediment yield per unit area by dividing this value by the corresponding drainage area for that station. Thus a comparison of the sediment yield from various stations can be made on a unit area basis. Relationships between sediment load in tons per square mile and the

Table 10. Total Water and Suspended Sediment Yield

	Water Year 1979		Water Year 1980		Water Years 1979 & 1980		
	Q_w	Q_s	Q_w	Q_s	Q_w	Q_s	Average yearly yield, Q_s
Station	10 ft	tons	10 ft	tons	10 ft	tons	tons
Momence	685	157,700	594	122,000	1,279	279,700	139,850
Iroquois	185	93,100	165	68,600	350	161,700	80,850
Chebanse	676	558,500	474	366,000	1,150	924,500	462,250
Wilmington	1,600	932,800	1,250	683,000	2,850	1,615,800	808,000

drainage areas are shown in figure 19. Data for the 1979 and 1980 water years are plotted separately. Similar to table 10, this plot also indicates that the sediment yield in 1980 was comparatively lower than that observed during the 1979 water year. Moreover, it appears that the two stations on the Iroquois River follow a different pattern than the two stations on the main stem of the Kankakee River. Comparatively, the Iroquois River basin yielded more suspended sediment load per unit area than the main stem of the Kankakee River. For example, the Chebanse station yielded 175 tons of sediment per square mile of drainage area in 1980 compared to 53.2 tons of sediment per square mile of drainage area for the Momence station. This is in spite of the fact that the drainage area at both of these stations is approximately the same size.

Once long-term data are available, a relationship between the sediment load per unit area and the drainage area can be developed. This relationship in turn can be utilized to estimate the sediment load at various locations in the drainage basin. Thus if a rough estimate is to be made of the suspended sediment load at State Line Bridge for the 1980 water year, then the sediment load of 53.2 tons per square mile at the Momence station should be multiplied by 1920, the drainage area in square miles at State Line Bridge. With this interpolation, the total suspended sediment load at State Line Bridge for the 1980 water year becomes 102,144 tons. This is smaller than the 131,900 tops of suspended load that was estimated to have passed the state line bridge in water year 1979 (Bhowmik et al., 1980).

Flow Hydraulics at State Line Sand Bar. A sand bar near the state line was monitored in 1979 and some of these results were reported by

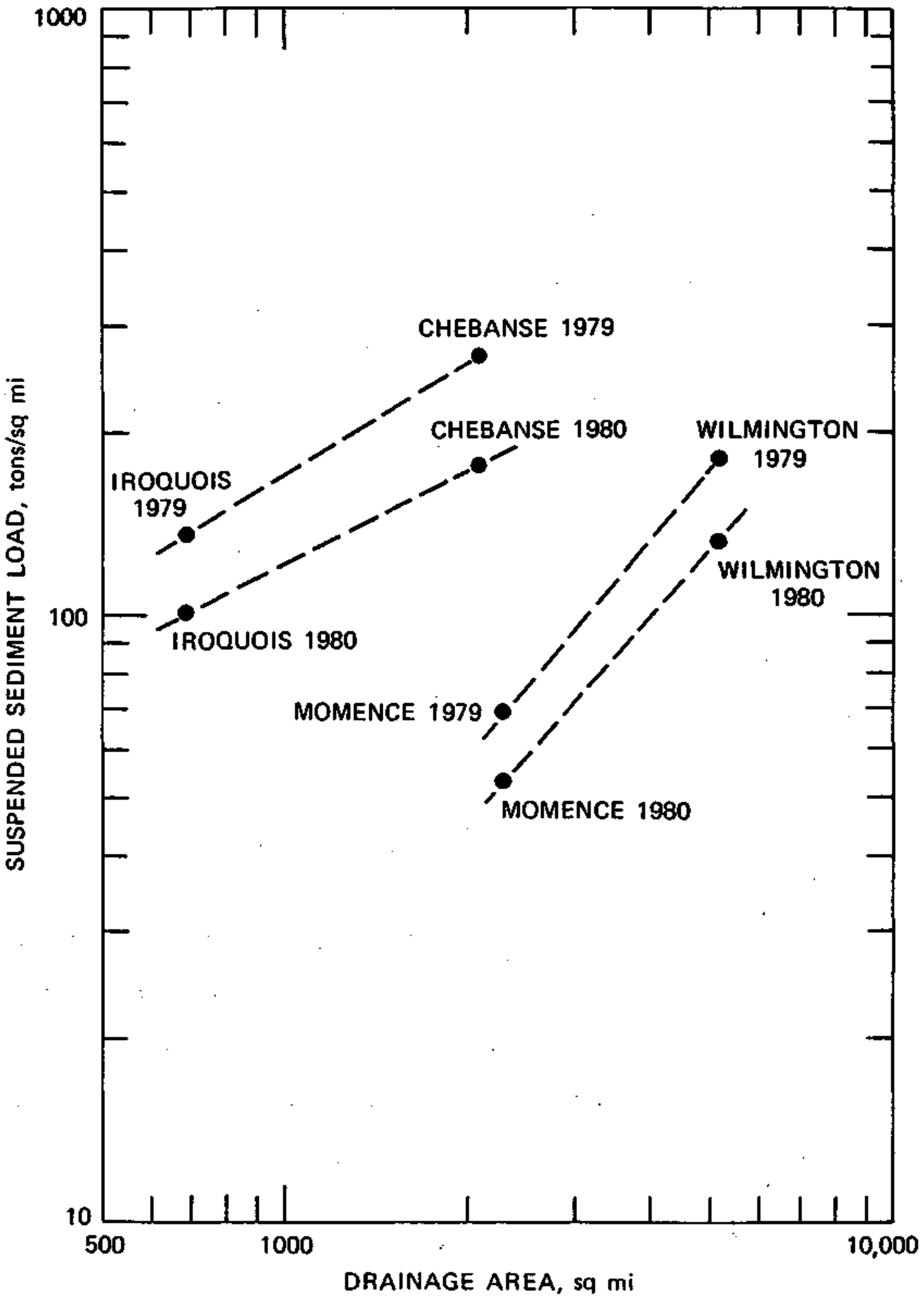


Figure 19. Relationship between total suspended load and drainage area for four gaging stations (Water Years 1979 and 1980)

Bhowmik et al. (1980). Additional hydraulic data that were collected in 1979 and 1980 have been analyzed and the results are presented here.

Velocity data were collected from 4 to 6 cross sections just upstream and downstream of State Line Bridge during the months of August and November 1979. During this time, the sand bar near the state line was moving from the straight reach of the Kankakee River in Indiana to the meandering segment of the river in Illinois. The locations where the velocity data were collected are shown in figure 2.

Figure 20 shows the vertical velocity distributions at cross sections 2, 3, 4, and 5 near the centerline of the river for the data collected on August 15 and 16, 1979. The presence of the sand bar near the state line has effectively reduced the depth of water in the downstream direction, from section 2 through 5 (figure 20). The leading edge of the sand bar was at or near section 5 and the tail end of the bar was in between sections 2 and 1. Even though the depth of water was decreasing in the downstream direction on top of the sand bar, the vertical velocity distribution near the centerline of these sections remained fairly symmetrical and appears to be logarithmic in nature.

Figure 21 shows another set of vertical velocity distributions from near the centerline of the river at cross sections 1 through 6 for the data collected on November 6 and 7, 1979. By this time, the leading edge of the sand bar had already moved into Illinois (section 5 is near the Indiana side of State Line Bridge) partially covering section 6 and, consequently, there is a steady decrease of water depths from sections 2 to 6 (figure 21). Here again, the vertical velocity distribution appears to be logarithmic in nature.

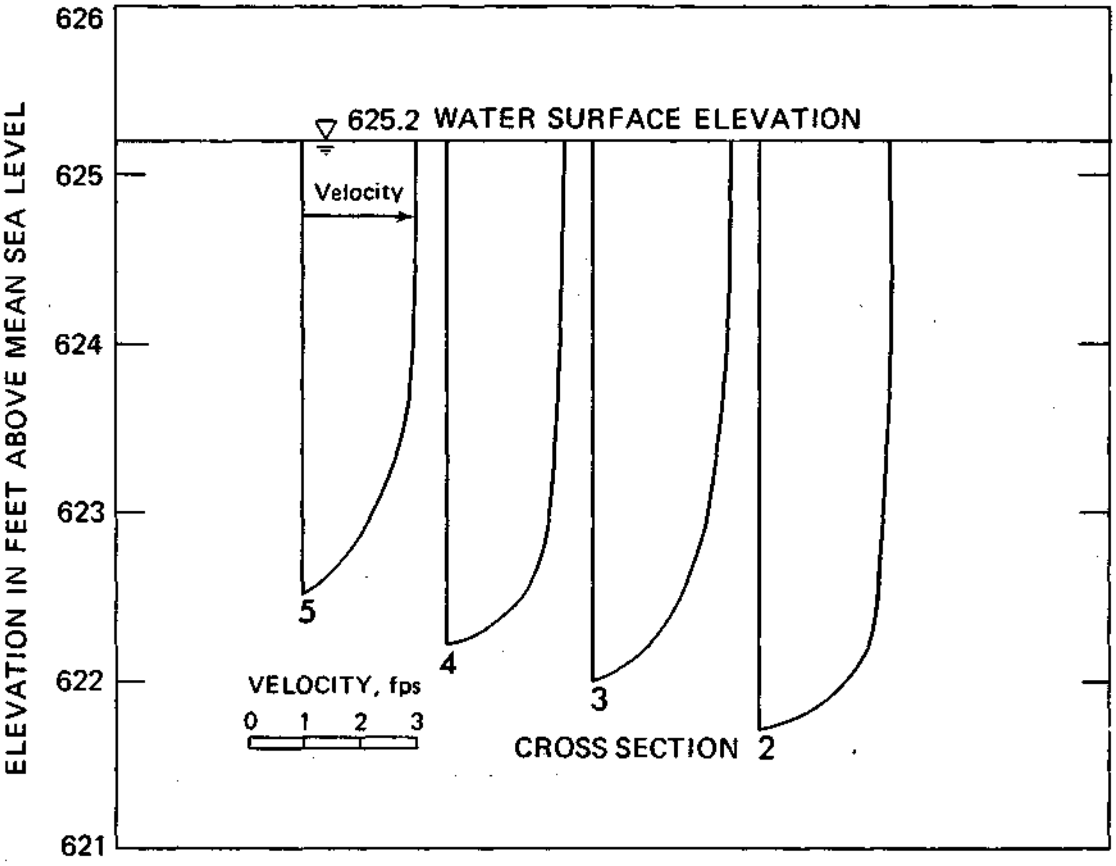


Figure 20. Vertical velocity distribution at the centerline of the river on top of the sand bar near State Line Bridge, August 15 and 16, 1979

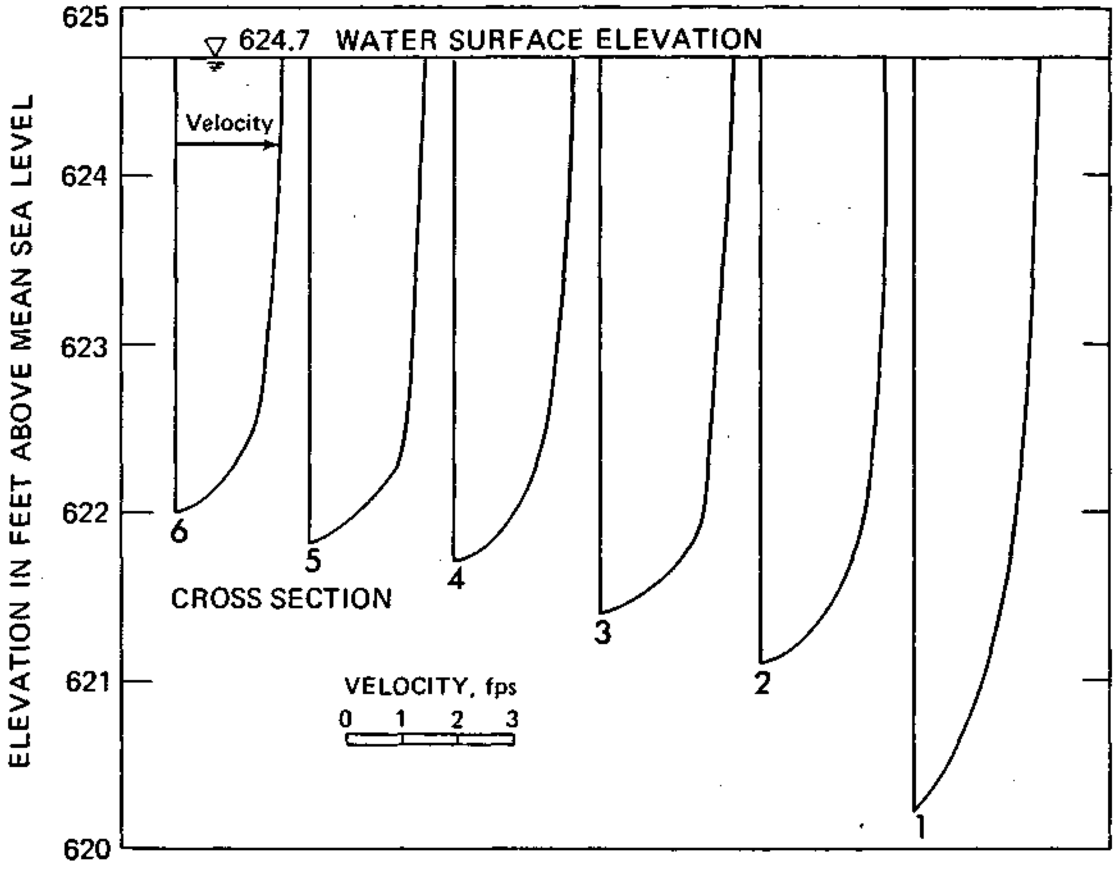


Figure 21. Vertical velocity distribution at the centerline of the river on top of the sand bar near State Line Bridge, November 6 and 7, 1979

The velocity distribution data collected on August 15 and 16, 1979, were utilized to develop isovels at each section. These isovels are shown in figure 22 for cross sections 2, 3, 4, and 5. The isovels shown are for the non-dimensional velocities obtained by dividing the point velocities, u, with the average velocity V, at each section. The uniformity of the sand bar across the whole width of the river is clearly indicated on these plots. The transverse profile of the river bed is almost horizontal at sections 2, 3, and 4, although the depth of water decreased in the downstream direction from section 2 to 4. The maximum velocity is swinging from the center at section 2 to the left side of the river at sections 3 and 4. The leading edge of the sand bar at section 5 almost divided the river into two separate conveyance channels. The maximum velocity at section 5 is now near the right side of the channel.

The measured discharges at all four sections are also shown in figure 22. At sections 2, 3, and 4, the measured discharges are within 0.6 percent of each other. The discharge at section 5, which was measured one day prior to the measurement at sections 2, 3, and 4, is somewhat higher than those present at the other sections. This is to be expected from a natural river where the flow can change continuously depending upon the inflow characteristics of the basin.

Figures 23 and 24 show the isovels developed for sections 1 through 6 from the velocity data collected on November 6 and 7, 1979. Here again, the non-dimensional velocity, $\mathbf{u/\overline{V}}$, is shown as the third variable. Data from sections 4, 5, and 6 were collected on November 6 and data from sections 1, 2, and 3 on November 7, 1979. The locations of these sections are shown in figure 2. By this time, the leading edge of the sand bar had already moved into Illinois and the leading edge of the bar covered the

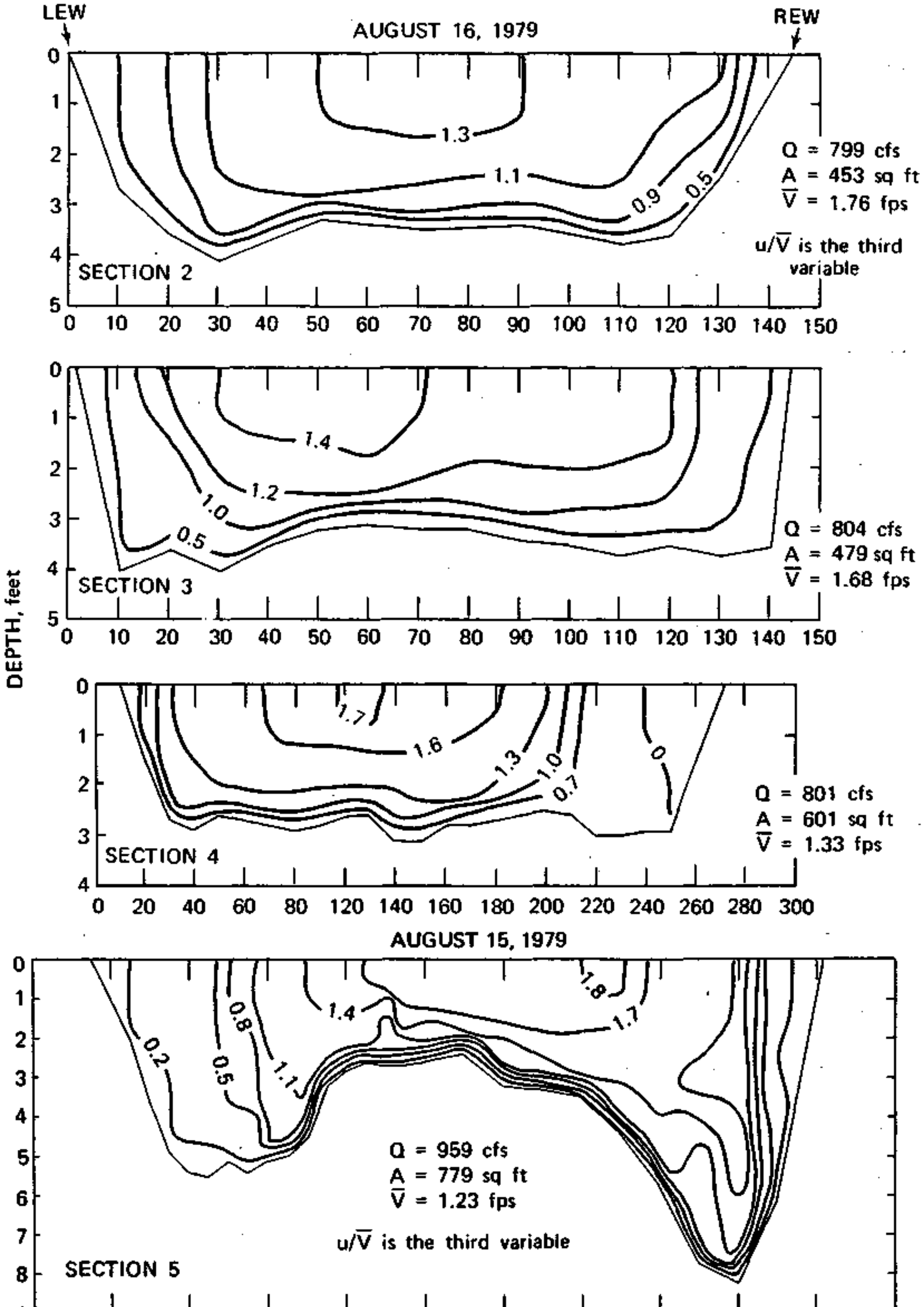


Figure 22. Isovels in the Kankakee River near State Line Bridge, August 15 and 16, 1979, sectional view

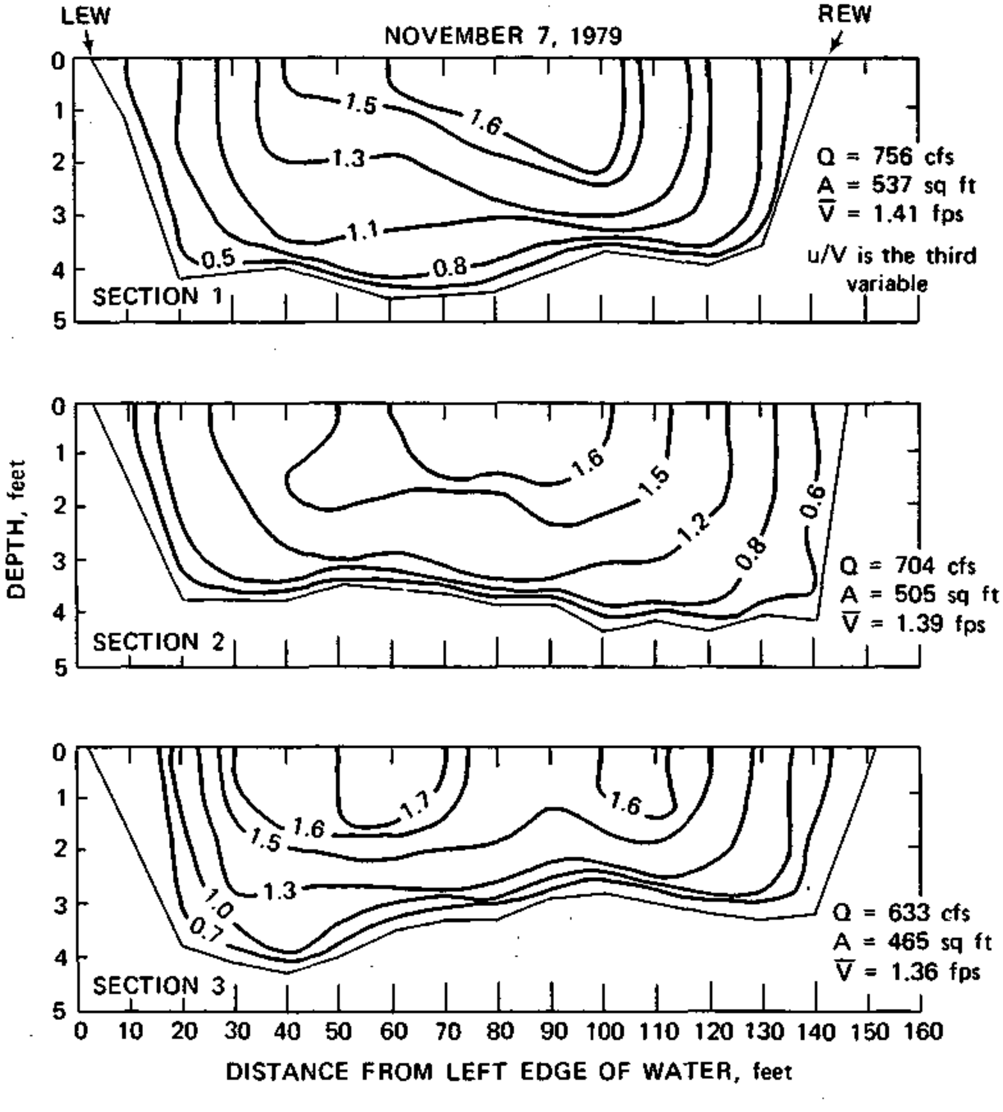


Figure 23. Isovels in the Kankakee River near State Line Bridge, November 7, 1979, sectional view

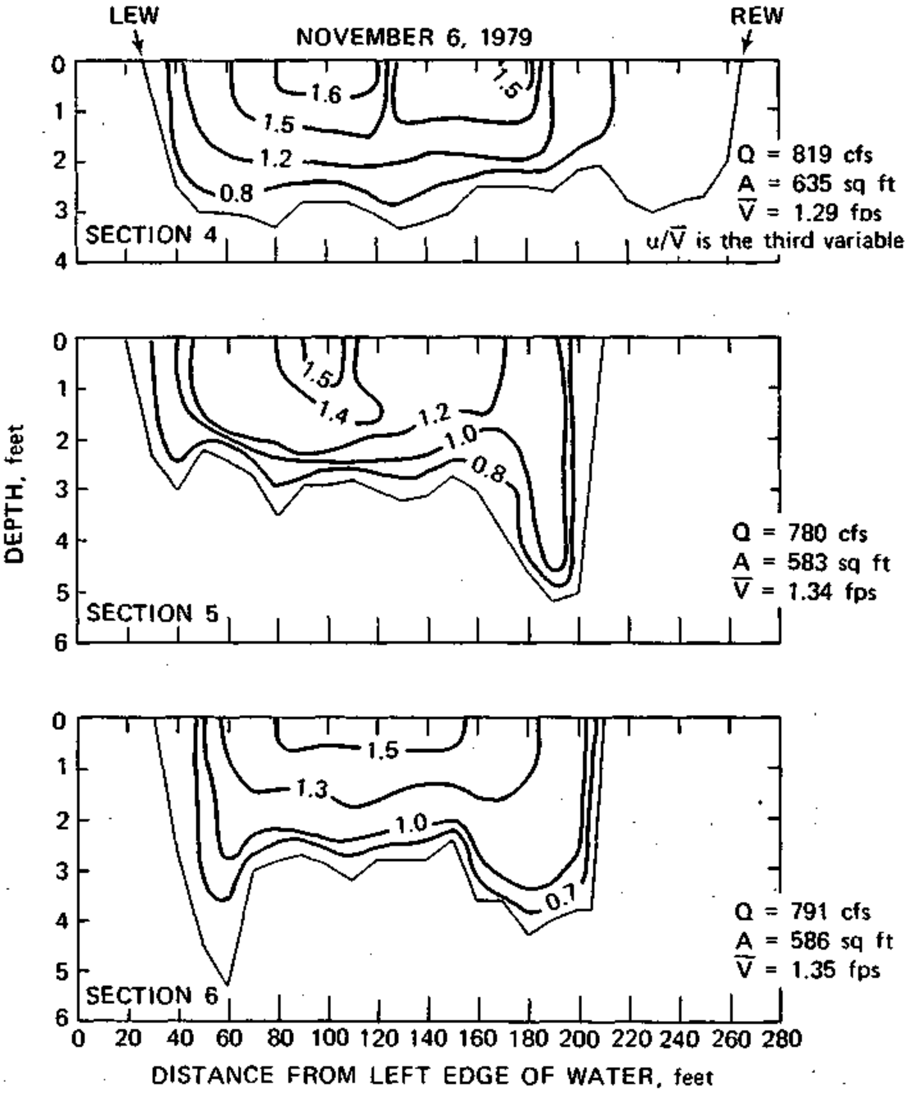


Figure 24. Isovels in the Kankakee River near State Line Bridge, November 6, 1979, sectional view

central part of the river at section 6. A gradual decrease in the water depths near the central part of the channel from section 1 to 6 can be seen in figures 23 and 24. It appears that the core of the maximum velocity remained close to the centerline at sections 1, 2, and 3, shifted to the left at sections 4 and 5, and more or less returned near the central part of the channel at section 6.

Some clarification related to the increased water depths at section 5 near the right side of the river is needed in connection with figures 22 and 24. The river upon entering the state of Illinois takes a rather sharp left turn near State Line Bridge. The presence of centrifugal forces (Bhowmik, 1979) will force the high velocity flow to move near the outside bank of the river which in turn will erode the movable bed and bank materials of the river creating a deeper channel at that location. This is what has happened on the right side of the river at section 5 which is near the outside bank of the bend. The channel at this location was found to be deeper during the entire data collection period and it remains so as of the present time.

The data collected in August and November of 1979 were also analyzed in a slightly different manner to demonstrate the pattern of velocity distribution in plan view. All the vertical velocity distribution data were analyzed to compute the average vertical velocity for each vertical, and these average vertical velocities in fps were plotted in the plan view of the river. The vertical average velocities were thus utilized to draw the lines of equal velocity (isovels) and these are shown in figure 25.

The isovels for the August 1979 data shown in figure 25a indicate that the high velocity stayed close to the left bank near section 3 (inside bank of the bend), started to move toward the central part of the channel at

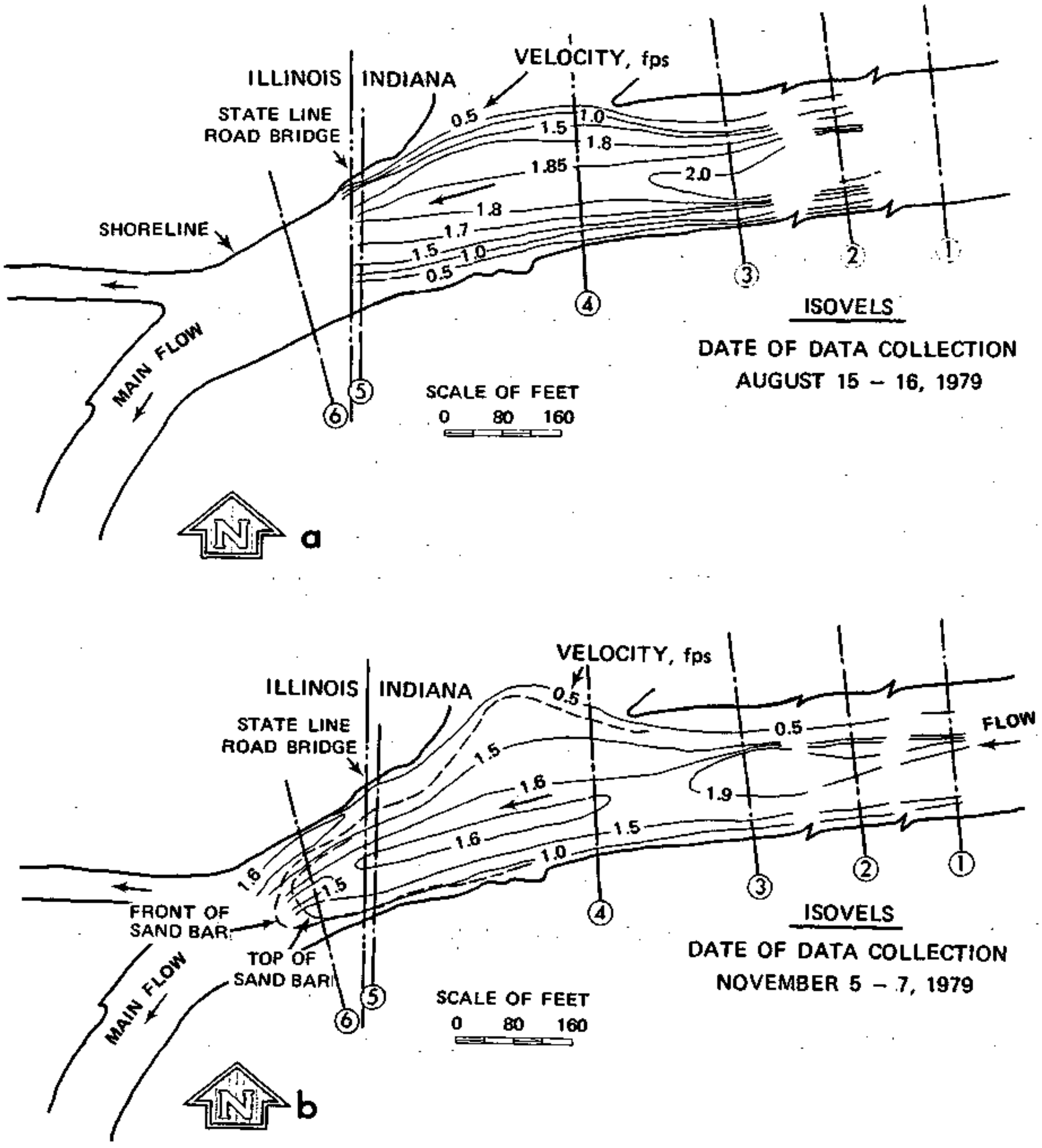


Figure 25. Isovels for the August 15 and 16 (a) and November 6 and 7 (b), 1979, data, plan view, velocity in fps

section 4, and stayed near the center close to section 5. Figure 25b, which shows the November data, exhibits a similar pattern except that the core of the high velocity flow near section 6 is now close to the outside bank of the river. This pattern of velocity distribution in this segment of the river is similar to what is expected from a river with a bend in its alignment (Bhowmik, 1979).

The plan views shown in figure 25 also indicate that the river has started to constrict as it enters the state of Illinois. This constriction in the width of the river and the curvature of the river alignment at this location have an important bearing on the hydraulics of flow at this transition zone between the channelized and the non-channelized reaches of the river. The river not only enters a meandering reach near the state line but also has a constriction in its width. These two factors in combination with the increased gradient in the channelized part of the river in Indiana (Bhowmik et al., 1980) have contributed to the formation of the sand bar at this location.

The hydraulic data collected near the sand bar were also utilized to compute parameters such as shear velocity, V^*, shear stress, τ_0, and shear Reynolds number, R_*. Equations 2, 3, and 4 given below were used to compute these parameters,

$$V_* = (g\ R\ S_e)^{1/2} \tag{2}$$

$$\tau_o = \gamma\ R\ S_e \tag{3}$$

$$R_* - V_*\ \overline{D}/\nu \tag{4}$$

where g is acceleration due to gravity, R is the hydraulic radius computed by the ratio of the cross-sectional area A over the wetted perimeter P,

S_e is the energy grade line, y is the unit weight of water, D is the average depth of water, and v is the kinematic viscosity of water.

Figure 26 shows the values of R^*, τ_0, and V^* for the six sections for both sets of data. The numerical values of these parameters for both sets of data show a gradual increase in the downstream direction. In the case of steady uniform flow in a channel with relatively uniform roughness, the values of the above parameters should not change from one cross section to the next. But in this particular case, the presence of the sand bar has certainly changed this uniform flow characteristic which results in a dramatic change in the values of R_*, τ_0, and V_*. Increase in the values of the τ_Q and V_* in the downstream direction indicates that the flow is accelerating and exerting a relatively large force which should also increase the sediment transport in the river. An analysis will indicate that this is what should be happening in a river under the present conditions.

For an ordinary sand dune, the maximum sediment transport occurs near its tip with a gradual reduction in the transport rate near the tail end where the transport rate is zero. Thus the values of V_* and τ_0 should be higher near the leading edge of the dune. The values of V_* and τ_Q shown in cross sections 1 or 2 were near the tail end of the sand bar with sections 4, 5, and 6 being closer to the leading edge. Consequently, the sediment movement on top of the bar should be higher near sections 5 or 6 with a gradual reduction toward section 1. Figure 26 for sections 2 through 6 demonstrates that this massive sand bar did behave like an ordinary sand dune. As a matter of fact, visual observation in shallow, clear water amply substantiated this correspondence between a sand dune and

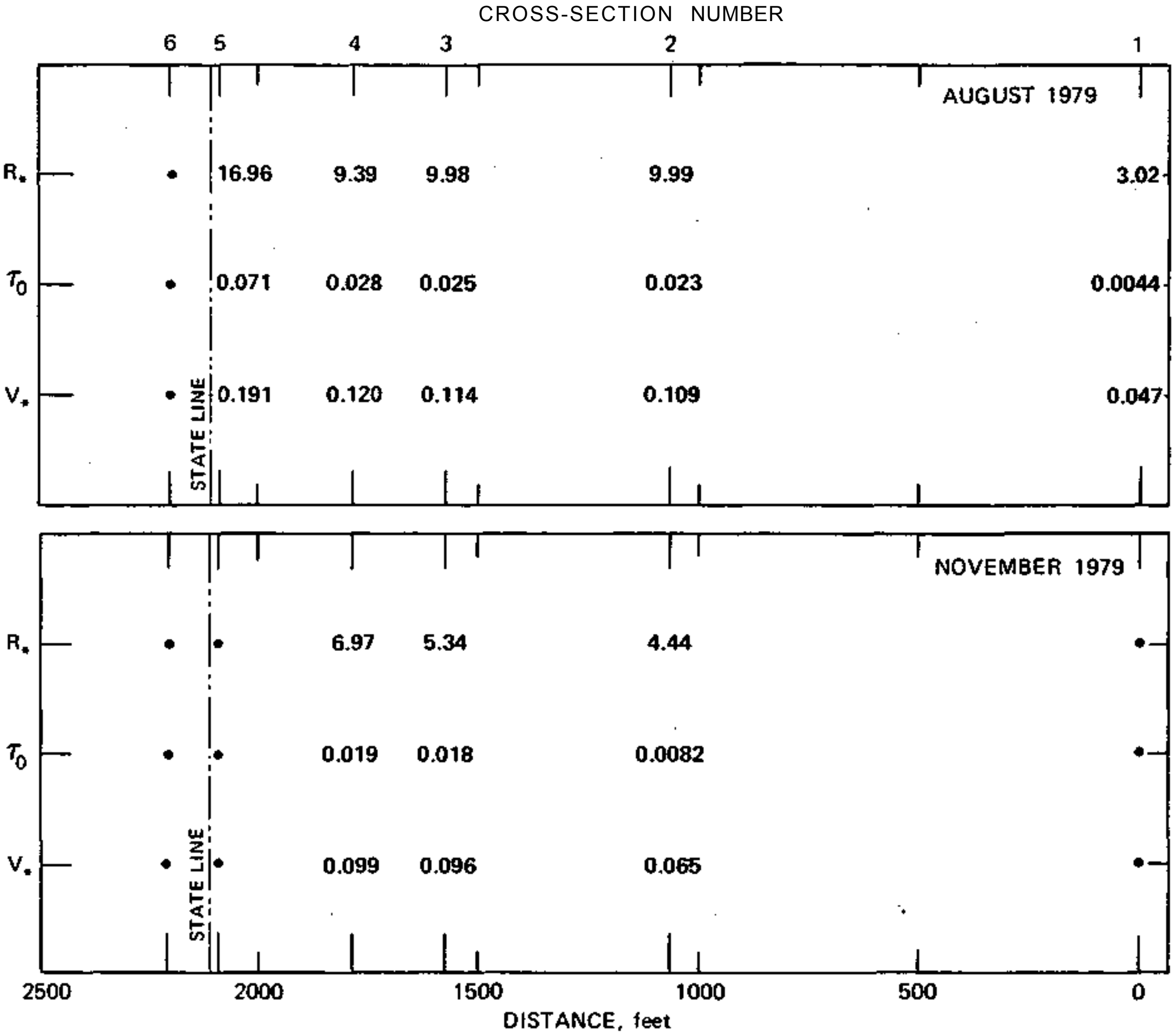


Figure 26. Shear velocity, shear stress, and shear Reynolds number near State Line Bridge

this particular sand bar. The maximum transport rate was observed to occur near the leading edge of the bar.

Momence Wetlands. Cross-sectional data collected from the Momence Wetlands have already been described. These data are presented in Appendix A. Since all the data have been referenced to mean sea level, it becomes easier to determine an average bed slope of the river in the Momence Wetlands. At the same time, if an estimate of the average water depth, D, or hydraulic radius, R, corresponding to various flow discharges can be made, some generalized computations for roughness coefficient can be made. As the hydraulic data from State Line Bridge for the 1979 water year were available (Bhowmik et al., 1980), it was decided to make a rough computation to determine the roughness coefficients at or near the bridge utilizing the average slope of the Momence Wetlands and the hydraulic data from State Line Bridge. It must be cautioned here that in the computation of roughness coefficients at any location, the local hydraulic radius and energy gradient should be used.

Manning's equation shown in equation 5 was used in the computation of the Manning's roughness coefficient, n.

$$V = [(1.486)/(n)](R)^{2/3}\ S_e^{1/2} \qquad (5)$$

where V is the average velocity and the other symbols are as previously defined. For the present computation, the energy slope, S_e, was assumed to be equal to the bed slope.

Table 11 shows some of the computed values of various hydraulic parameters. The first four columns show, respectively, the date of data collection, measured discharge in cfs, measured average depth, D, and the average velocity, V. The measured values of V and D, where

Table 11. Measured and Computed Velocities and Roughness Coefficients for the Data Collected at State Line Bridge

Bed Slope for Momence Wetlands: 0.00023

Date	Discharge Q_w, cfs	Measured average depth $\bar{D}$, ft	Average velocity $\bar{V}$, fps	Computed Manning's roughness n	Average computed velocity corresponding to Manning's n of 0.025	0.030	0.035	0.040	0.042
11/03/78	634.7	2.36	1.39	0.029	1.61	1.35	1.15	1.01	0.94
11/17/78	649.9	2.34	1.41	0.029	1.61	1.34	1.15	1.00	0.93
12/05/78	966.2	3.30	1.44	0.035	2.02	1.68	1.44	1.26	1.17
12/13/78	939.6	3.25	1.44	0.035	2.00	1.67	1.43	1.25	1.16
12/18/78	990.4	3.25	1.52	0.033	2.00	1.67	1.43	1.25	1.16
3/09/79	4368.9	8.48	2.35	0.040	3.79	3.16	2.71	2.37	2.20
3/09/79	4093.9	7.92	2.36	0.038	3.62	3.02	2.59	2.26	2.10
3/13/79	3882.1	8.42	2.11	0.045	3.77	3.14	2.69	2.36	2.19
3/14/79	4013.9	8.39	2.18	0.043	3.76	3.13	2.69	2.35	2.19
3/15/79	3974.4	8.26	2.20	0.042	3.72	3.10	2.66	2.33	2.16
3/16/79	3776.9	8.21	2.10	0.044	3.71	3.09	2.65	2.32	2.16
3/19/79	4367.2	8.43	2.37	0.040	3.77	3.14	2.69	2.36	2.19
3/26/79	3797.2	8.07	2.15	0.043	3.66	3.05	2.62	2.29	2.13
3/29/79	3685.0	8.01	2.10	0.043	3.65	3.04	2.61	2.28	2.12
3/30/79	3782.8	7.89	2.19	0.041	3.61	3.01	2.58	2.26	2.10
3/31/79	3904.2	8.00	2.23	0.041	3.64	3.04	2.60	2.28	2.12
4/01/79	3930.7	8.11	2.21	0.042	3.68	3.06	2.63	2.30	2.14
4/02/79	3662.9	8.10	2.06	0.045	3.68	3.06	2.63	2.30	2.14
4/03/79	3556.1	8.08	2.01	0.046	3.67	3.06	2.62	2.29	2.13
4/04/79	3968.6	8.13	2.23	0.041	3.68	3.07	2.63	2.30	2.14
4/05/79	3869.8	8.15	2.17	0.042	3.69	3.07	2.63	2.30	2.14
4/06/79	3826.3	8.08	2.16	0.042	3.67	3.06	2.62	2.29	2.13
4/10/79	3823.0	8.22	2.12	0.044	3.71	3.09	2.65	2.32	2.16
4/12/79	3864.2	8.18	2.16	0.043	3.70	3.08	2.64	2.31	2.15
4/13/79	3920.8	8.29	2.16	0.043	3.73	3.11	2.66	2.33	2.17
4/16/79	3895.5	8.26	2.15	0.043	3.72	3.10	2.66	2.33	2.16
4/17/79	3722.0	8.15	2.08	0.044	3.69	3.07	2.64	2.31	2.15
4/20/79	3786.4	8.99	2.07	0.048	3.68	3.06	2.63	2.30	2.14
4/23/79	3276.0	8.70	1.86	0.052	3.59	2.99	2.56	2.24	2.09
4/26/79	3450.4	8.61	1.96	0.049	3.57	2.98	2.55	2.23	2.08
4/27/79	3724.8	8.80	2.04	0.048	3.62	3.02	2.59	2.27	2.11
4/28/79	3801.0	8.83	2.13	0.046	3.63	3.03	2.59	2.27	2.11
4/29/79	3935.2	8.88	2.18	0.045	3.65	3.04	2.60	2.28	2.12
4/30/79	3711.0	8.81	2.08	0.047	3.63	3.02	2.59	2.27	2.11
5/01/79	3835.5	8.80	2.15	0.045	3.62	3.02	2.59	2.27	2.11
5/04/79	4334.6	8.91	2.42	0.040	3.66	3.05	2.61	2.29	2.13
5/07/79	3963.7	8.94	2.19	0.045	3.66	3.05	2.62	2.29	2.13
5/10/79	3501.8	8.73	1.98	0.049	3.61	3.00	2.58	2.25	2.10
5/15/79	2949.3	8.46	1.69	0.056	3.53	2.94	2.52	2.21	2.05
5/23/79	2090.1	7.70	1.31	0.068	3.32	2.76	2.37	2.07	1.93
6/01/79	1714.5	7.24	1.10	0.077	3.17	2.64	2.26	1.98	1.84
6/07/79	1472.4	6.81	1.15	0.071	3.06	2.55	2.18	1.91	1.78
6/19/79	1388.5	5.96	1.13	0.066	2.99	2.50	2.14	1.87	1.74
6/26/79	1232.7	5.55	1.08	0.066	2.86	2.38	2.04	1.79	1.66
7/03/79	1220.2	5.63	1.05	0.069	2.87	2.39	2.05	1.79	1.67
7/09/79	951.8	5.03	0.92	0.073	2.67	2.23	1.91	1.67	1.55
7/16/79	837.8	4.72	0.87	0.074	2.56	2.14	1.83	1.60	1.49
7/23/79	749.4	4.31	0.84	0.072	2.41	2.01	1.72	1.51	1.40
7/30/79	874.2	4.63	0.90	0.070	2.53	2.11	1.81	1.58	1.47
8/06/79	1116.6	4.99	1.08	0.062	2.66	2.22	1.90	1.66	1.55
8/13/79	1168.7	5.20	1.08	0.063	2.73	2.28	1.95	1.71	1.59
8/23/79	1528.4	5.87	1.26	0.059	2.97	2.47	2.12	1.85	1.72
8/27/79	1286.4	5.29	1.17	0.059	2.76	2.30	1.97	1.73	1.61
9/04/79	U28.7	4.09	1.33	0.044	2.33	1.94	1.66	1.46	1.35
9/14/79	882.2	2.73	1.59	0.028	1.78	1.48	1.27	1.11	1.03
9/24/79	699.6	2.12	1.64	0.023	1.50	1.25	1.07	0.94	0.87

$\overline{D}$ was assumed to be equal to R, were used to compute the Manning's roughness coefficients shown in column 5 of table 11. In the next four columns, the computed average velocities are given corresponding to the various assumed values of Manning's roughness coefficient n. In all the computations, the average bed slope was utilized as indicated in the subtitle.

The Manning's roughness coefficients shown in column 5 of table 11 for the state line station for water year 1979 are plotted in figure 27. Here the annual variation of n is illustrated. The highest value of n was 0.077 in the month of June 1979, and the lowest value of n was 0.023 in the month of September 1979. Apparently, the effective roughness in the channel was somewhat higher in the month of June as indicated by these rather high values of n. This points to the fact that the roughness coefficients in any stream or river at any point is not constant. This roughness coefficient or parameter changes with stage or discharge and also may change seasonally. Thus it may not be appropriate to select a single value of roughness coefficient for a stream segment and assume it to be true for the whole range of discharges. Similar variability for the roughness coefficients was also observed by Bhowmik (1979) for the Kaskaskia River.

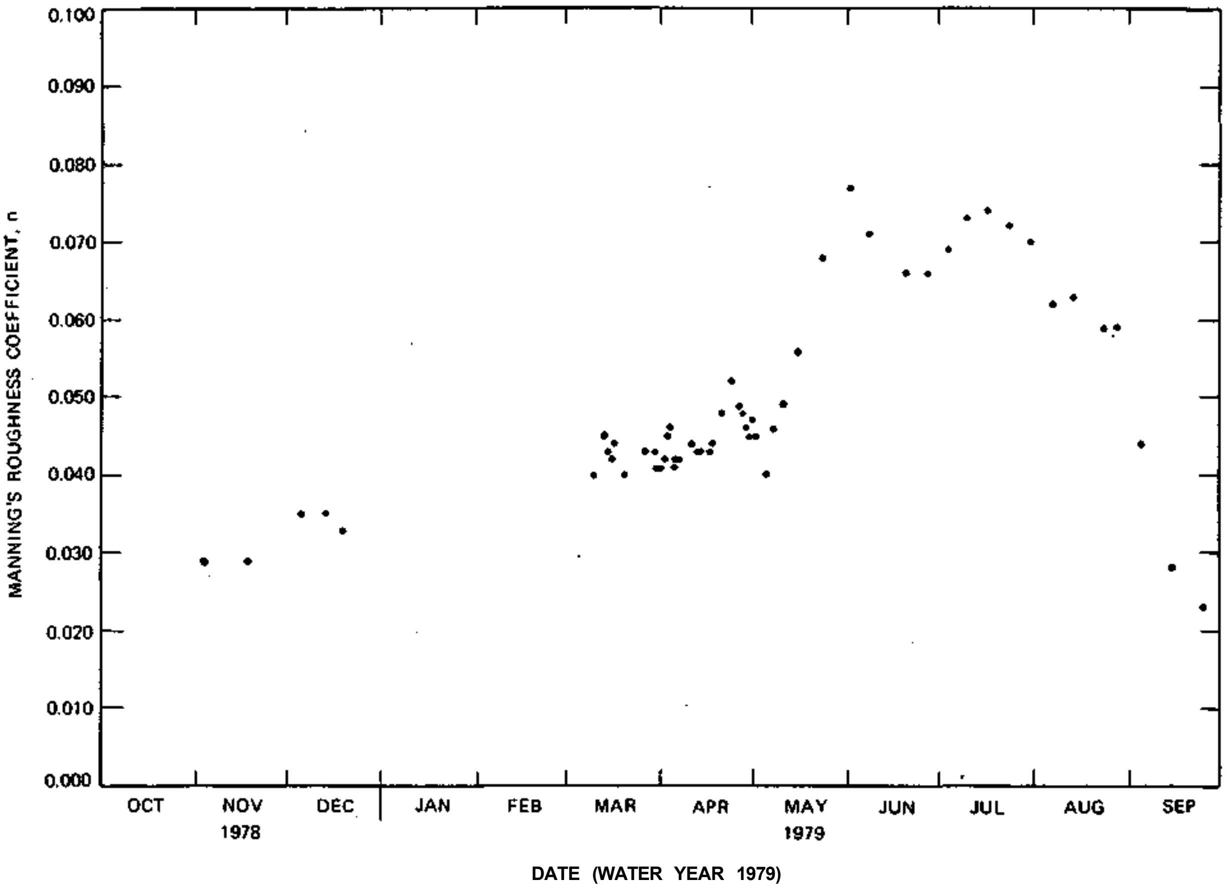


Figure 27. Variation of Manning's roughness coefficient n for Water Year 1979 at State Line Bridge

SUMMARY AND CONCLUSIONS

Sediment transport and the hydraulics of flow in the Kankakee River in Illinois have been investigated during the last three years. The flow and sediment data collected in the first year of the project were analyzed in addition to the available historical data and these results were presented in a previous report. The present report covers the analysis and interpretation of most of the sediment and hydraulic data collected through September 1980, and also some additional data that were collected in the last few years but had not yet been reported.

In addition to the sediment transport and hydraulic data, sounding data from Six Mile Pool and the Momence Wetlands area have been collected. All the cross sections in the Momence Wetlands area are now monumented and surveyed and will be available for future reference. Detailed hydraulic data from the Stateline Sand Bar were also collected.

The sounding data from the Momence Wetlands could not be compared with other historical data because none was available. The river flows through straight and curved reaches and the cross-sectional data show the changes from a trapezoidal shape in the straight segment to a skewed or triangular shape in the bends.

The 1980 sounding data from Six Mile Pool were compared with the 1978 and 1968 sounding data. Sediment deposition similar to point bars near the inside downstream reach of the bends within the pool were observed. Both sedimentation and scour took place within the pool. The river upstream of the dam remained relatively free of sediment deposition. The net result of the sediment deposition and scour between 1978 and 1980 was a slight increase in the capacity of Six Mile Pool. This pool acted as a self-cleaning conduit over the last two to three years.

Regression relationships between suspended sediment load and water discharge for the Momence, Iroquois, Chebanse, and Wilmington stations were developed for the 1979, 1980, and the combined 1979 and 1980 water years. Between the two years for three out of the four stations, some shifts in the regression relationships were observed. Most of the regression relationships appeared to be fairly consistent. The exponents of the regression equations did not change much from one year to the next.

Cummulative summation of the sediment loads for the 1979 and 1980 water years indicated that within a period of 65 to 85 days during storm events, about 70 to 80 percent of the annual sediment load moved at these stations. It was also determined that the flows equal to or greater than the average flows at each station carried about 60 to 90 percent of the yearly sediment load at all four stations.

From the data for the 1979 and 1980 water years, it was estimated that the Momence, Iroquois, Chebanse, and Wilmington stations carried respectively 279,700; 161,700; 924,500; and 1,615,800 tons of suspended sediment load in those two years. On a per unit area basis, the Iroquois River contributed more suspended sediment load in both years than those on the main stem of the Kankakee River.

Hydraulic data collected at and near State Line sand bar were analyzed to determine the isovels for the cross-sectional elevation and plan view. Shear velocity, shear stress, and shear Reynolds number were also computed. The effect of the bend just within the state of Illinois was quite noticeable on the isovels. High velocity flows were concentrated near the outside bank, and the channel is also deeper at that location. Hydraulically the sand bar behaved just like an ordinary sand dune with the highest value of shear stress and shear velocity near the leading edge of the bar where sediment transport also should be the highest.

Hydraulic computations indicated that the roughness parameter changes over the year and no single roughness parameter can be assumed to exist throughout the whole year in a natural river.

REFERENCES

Bhowmik, N. G. 1979. "Hydraulics of Flow in the Kaskaskia River, Illinois." Illinois State Water Survey Report of Investigation 91.

Bhowmik, N. G., A. P. Bonini, W. C. Bogner, R. P. Byrne. 1980. "Hydraulics of Flow and Sediment Transport in the Kankakee River in Illinois." Illinois State Water Survey Report of Investigation 98.

Bhowmik, N. G. 1981a. "Measurement of Suspended Sediment and Bed Load in Sand Bed Channels and the Associated Problems." Erosion and Sediment Transport Measurement Symposium, Florence, Italy, 22-26 June, also published by the International Association of Hydrological Sciences, Publication No. 133.

Bhowmik, N. G. 1981b. "Transport of Sediment in Natural Rivers." Proceedings of ASCE, Water Forum 81, San Francisco, California, August 10-14.

Carns, J. M. 1973. "Magnitude and Frequency of Floods in Illinois." U.S. Geological Survey and the Illinois State Division of Water Resources Management.

Dodson and Associates. 1980. "Kankakee River from the Stateline Bridge to Singleton Ditch." Final Report.

Gross, D. L., and R. C. Berg. 1980. "Geology of the Kankakee River System in Kankakee County, Illinois." Illinois State Geological Survey, Environmental Geology Notes 92.

Guy, H. P., and V. W. Norman. 1970. "Field Methods for Measurement of Fluvial Sediment." U.S. Government Printing Office, Washington, D.C.

Healy, R. W. 1979. "River Mileages and Drainage Areas for Illinois Streams - Volume 2, Illinois River Basin." U.S. Geological Survey, Water Resources Investigation 79-111.

NOTATIONS

A = Stream cross sectional area

$\overline{D}$ = Average depth of water

g = Acceleration due to gravity

m = Coefficient

n = Manning's roughness coefficient

P = Wetted perimeter

p = Constant

Q_s = Water discharge

Q_w = Sediment load

Q_2 = 2-year flood flow

R = Hydraulic radius

R_* = Shear Reynolds number

S_e = Energy grade line

u = Point velocity

$\overline{V}$ = Average velocity

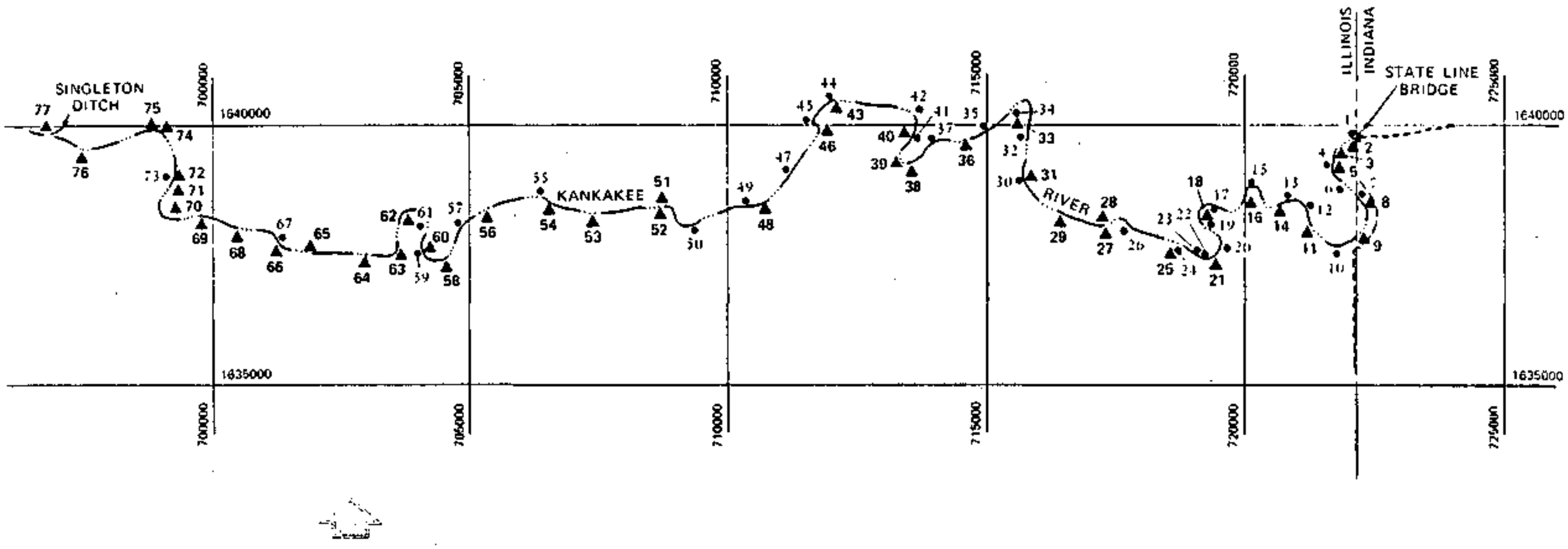
$V*$ = Shear velocity

τ_o = Shear stress

Y = Unit weight of water

v = Kinematic viscosity of water

Appendix A. Cross-Sectional Data for the Momence Wetlands

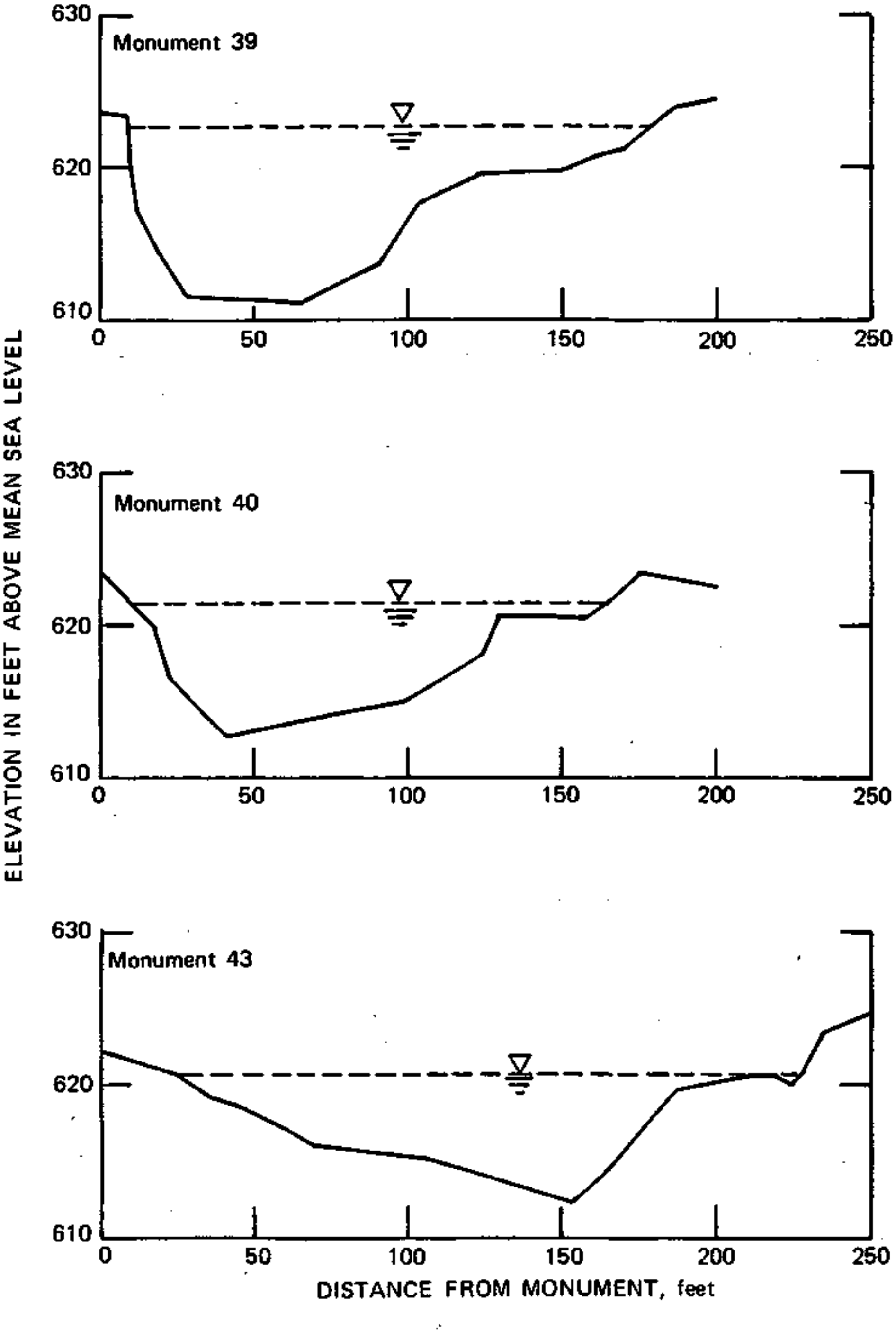


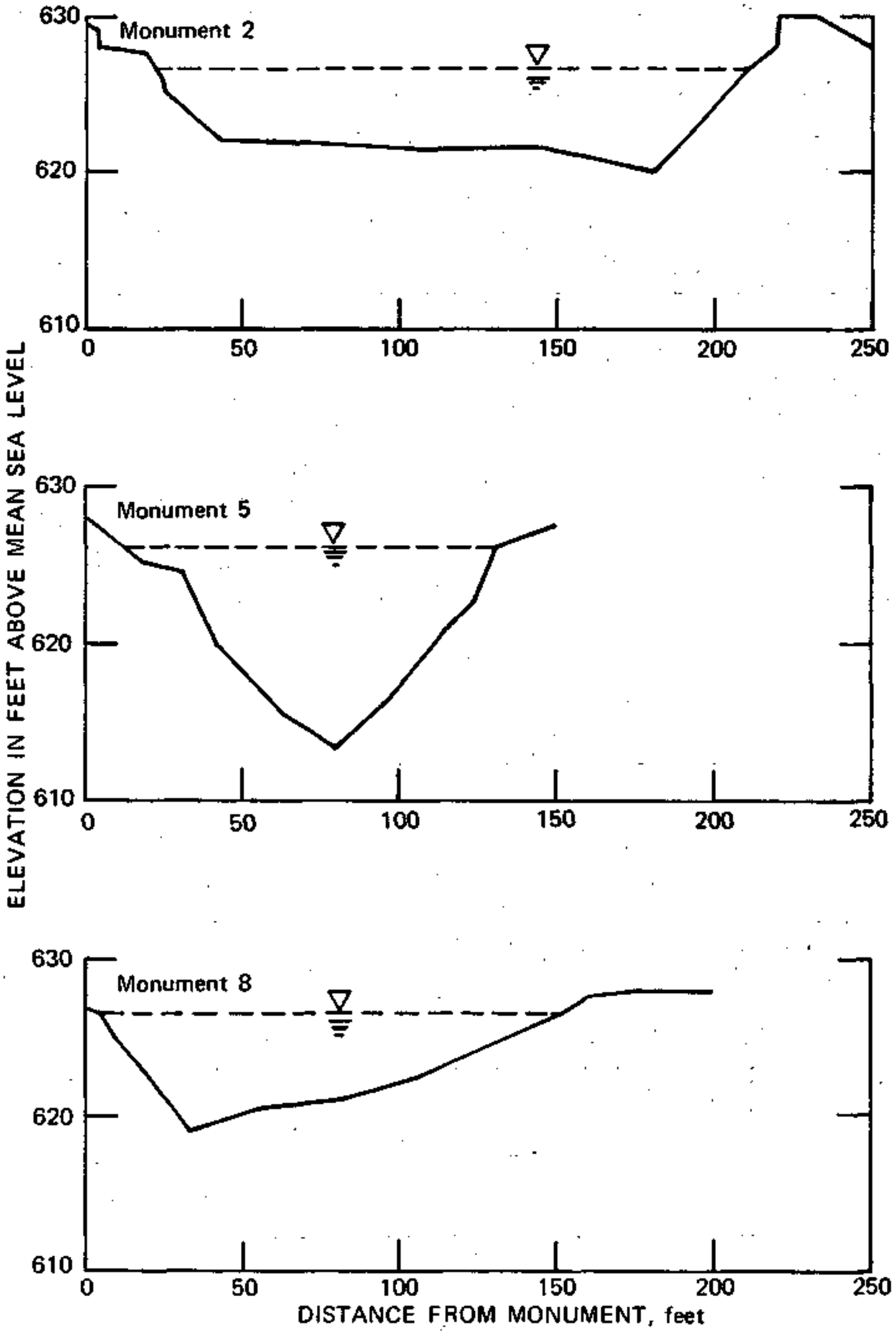
EXPLANATION

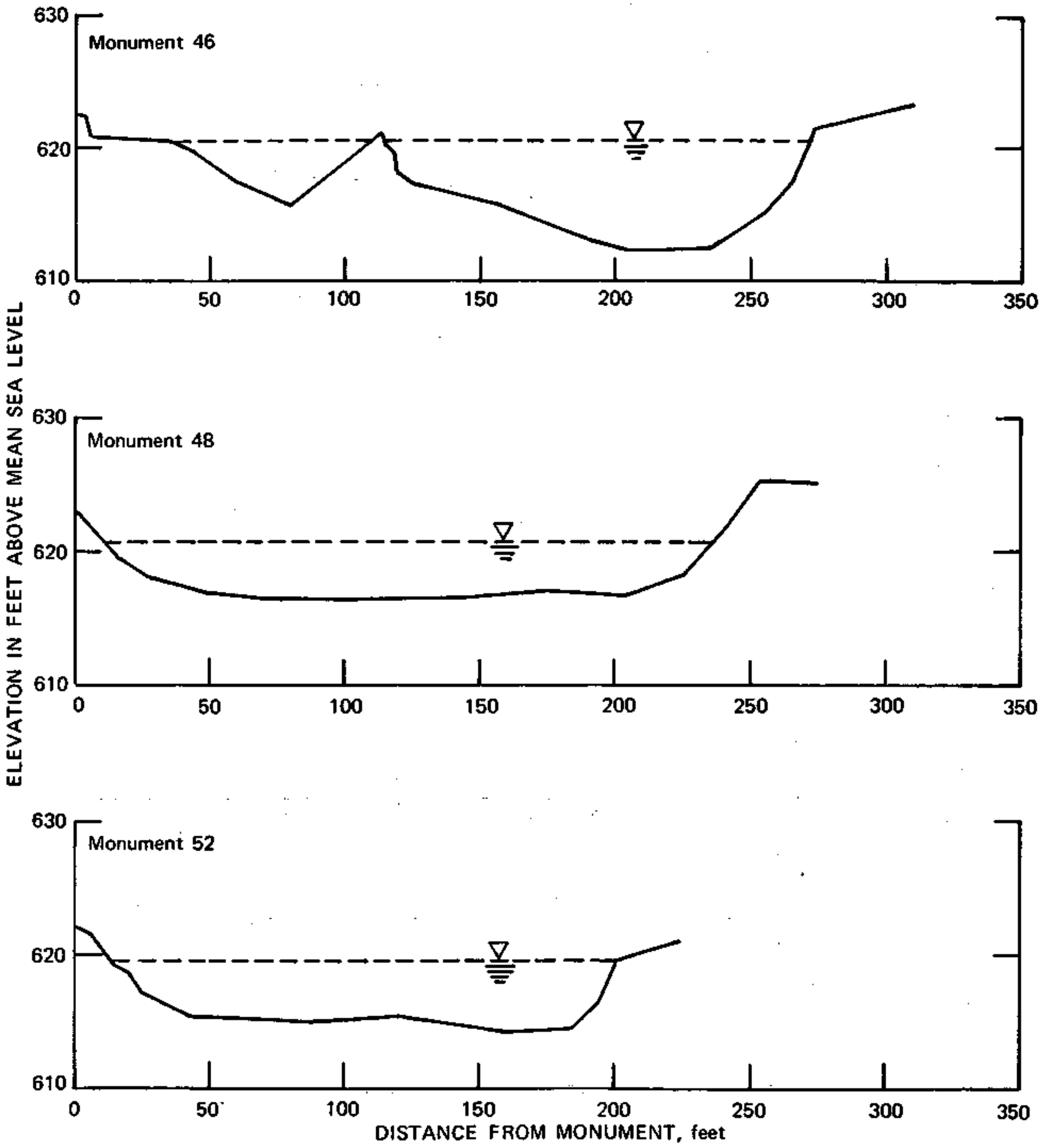
▲ Concrete Monument/Brass Plug

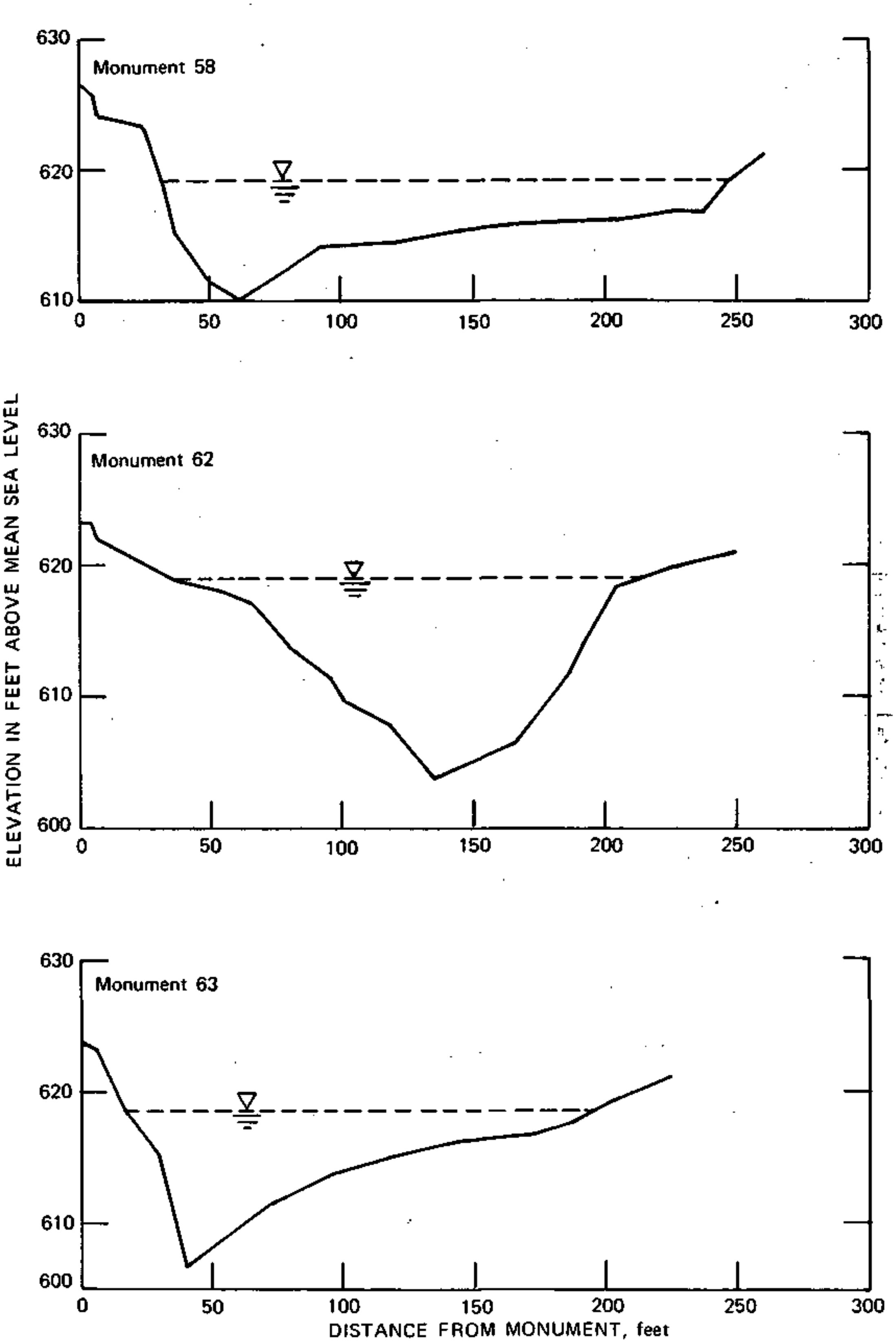
● Iron Pin/Survey Cap Stamped L.S. 2010

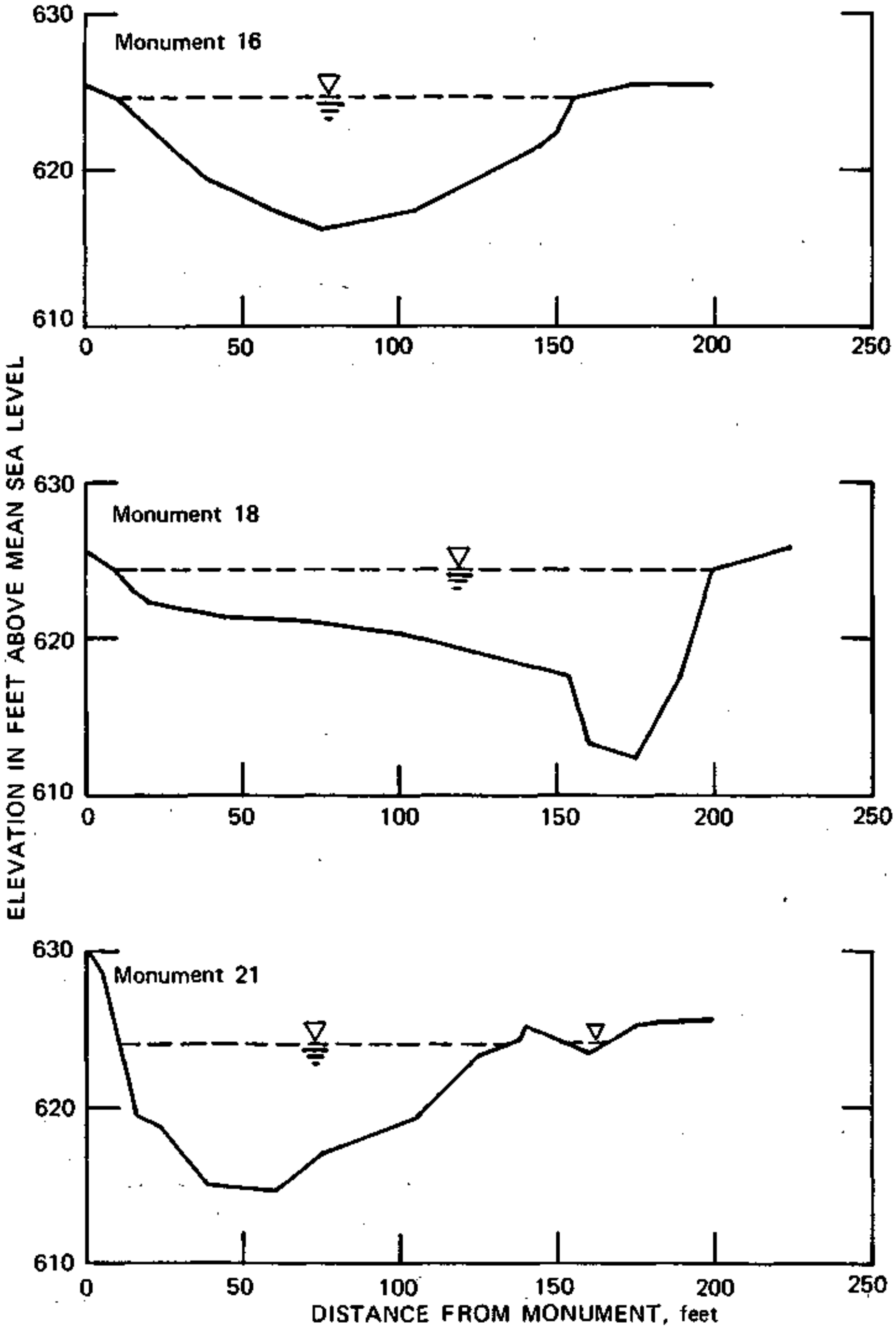
Locations of cross sections in the Momence Wetlands

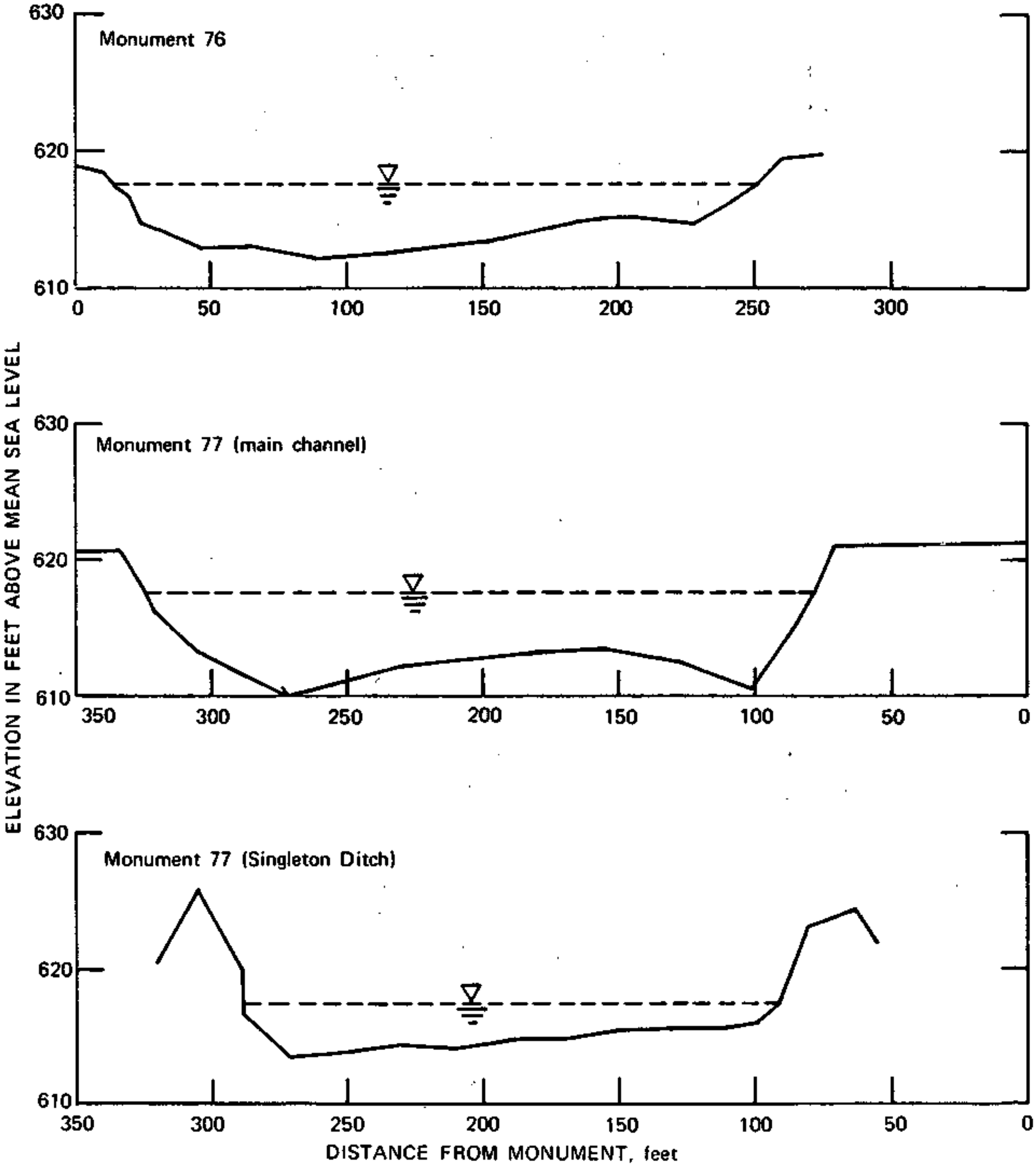

Monument 39
Monument 40
Monument 43
630
620
610
0
50
100
150
200
250
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
DISTANCE FROM MONUMENT, feet

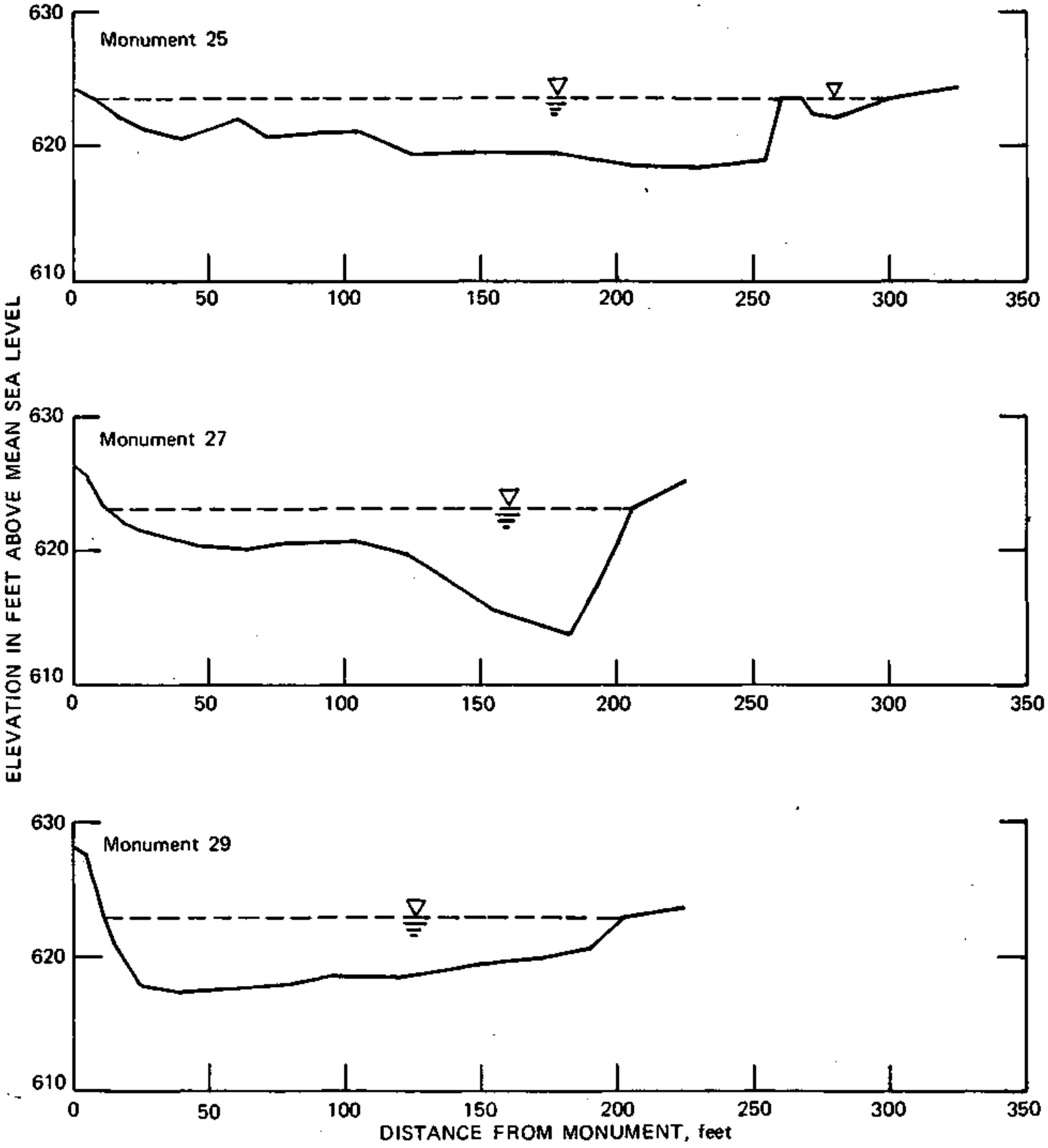

Monument 2
Monument 5
Monument 8
630
620
610
0
50
100
150
200
250
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
DISTANCE FROM MONUMENT, feet

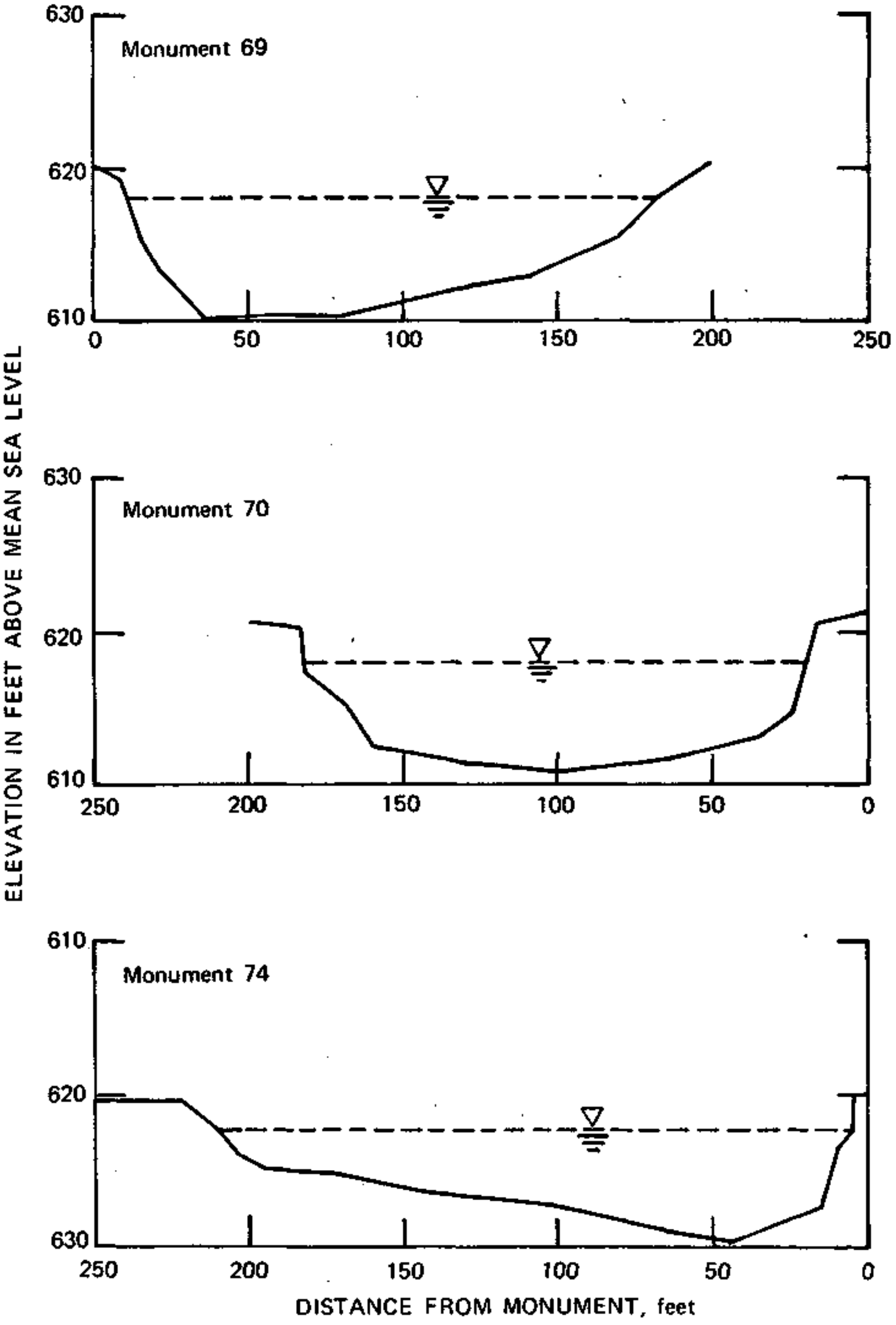

Monument 46
Monument 48
Monument 52
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
610
620
630
0
50
100
150
200
250
300
350
DISTANCE FROM MONUMENT, feet

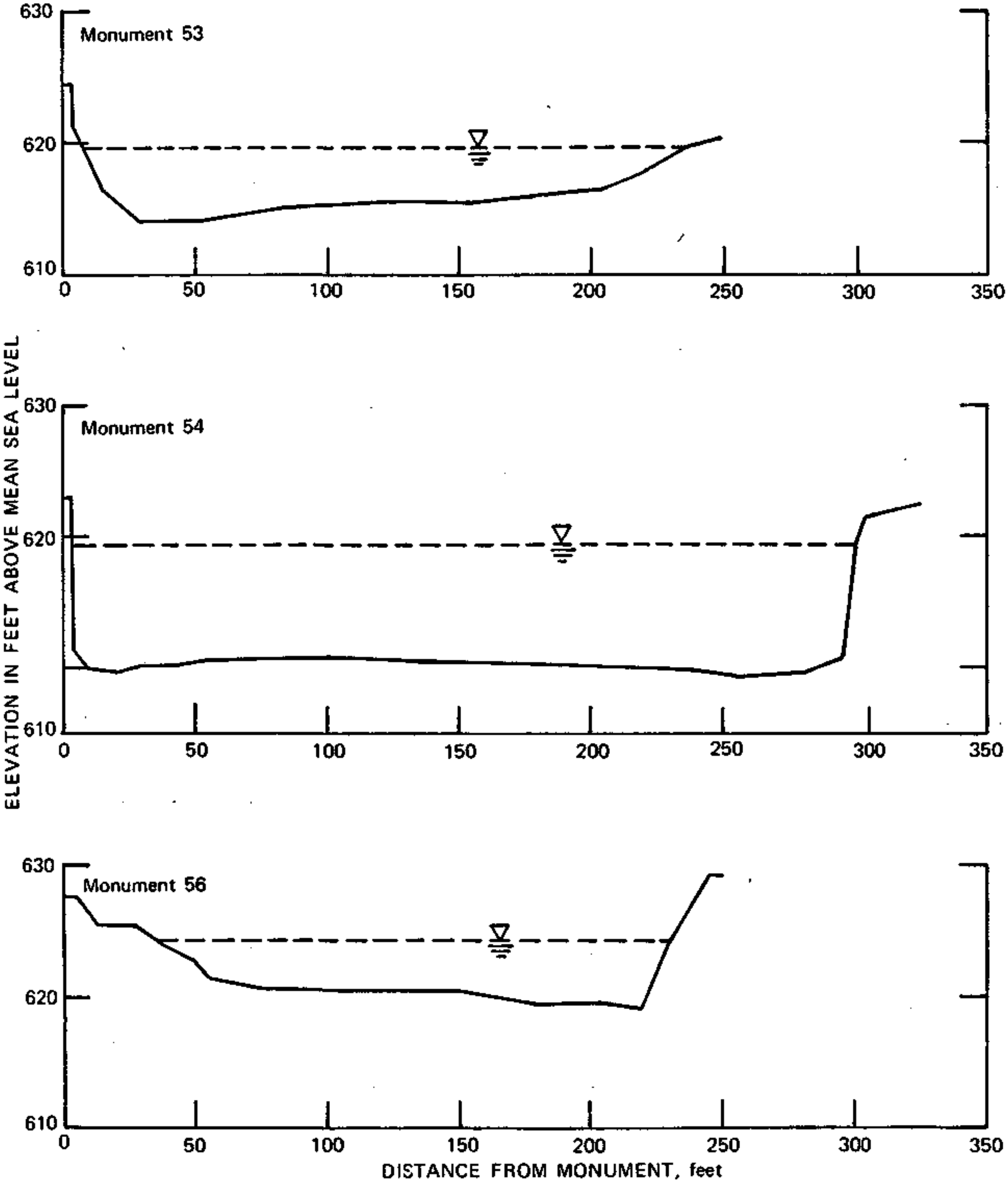

ELEVATION IN FEET ABOVE MEAN SEA LEVEL
Monument 58
630
620
610
0
50
100
150
200
250
300
Monument 62
630
620
610
600
0
50
100
150
200
250
300
Monument 63
630
620
610
600
0
50
100
150
200
250
300
DISTANCE FROM MONUMENT, feet

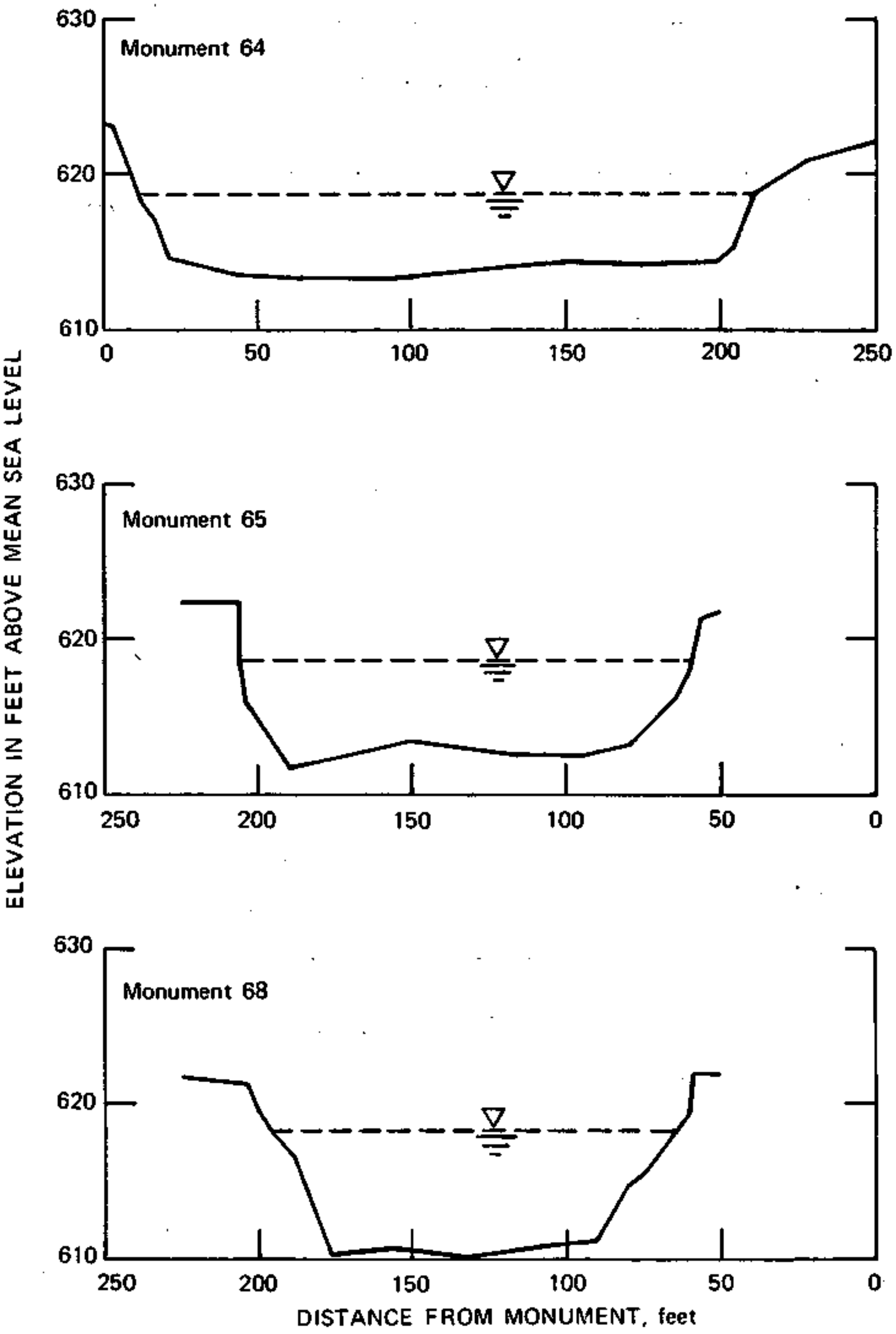

Monument 16
Monument 18
Monument 21
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
630
620
610
0
50
100
150
200
250
DISTANCE FROM MONUMENT, feet

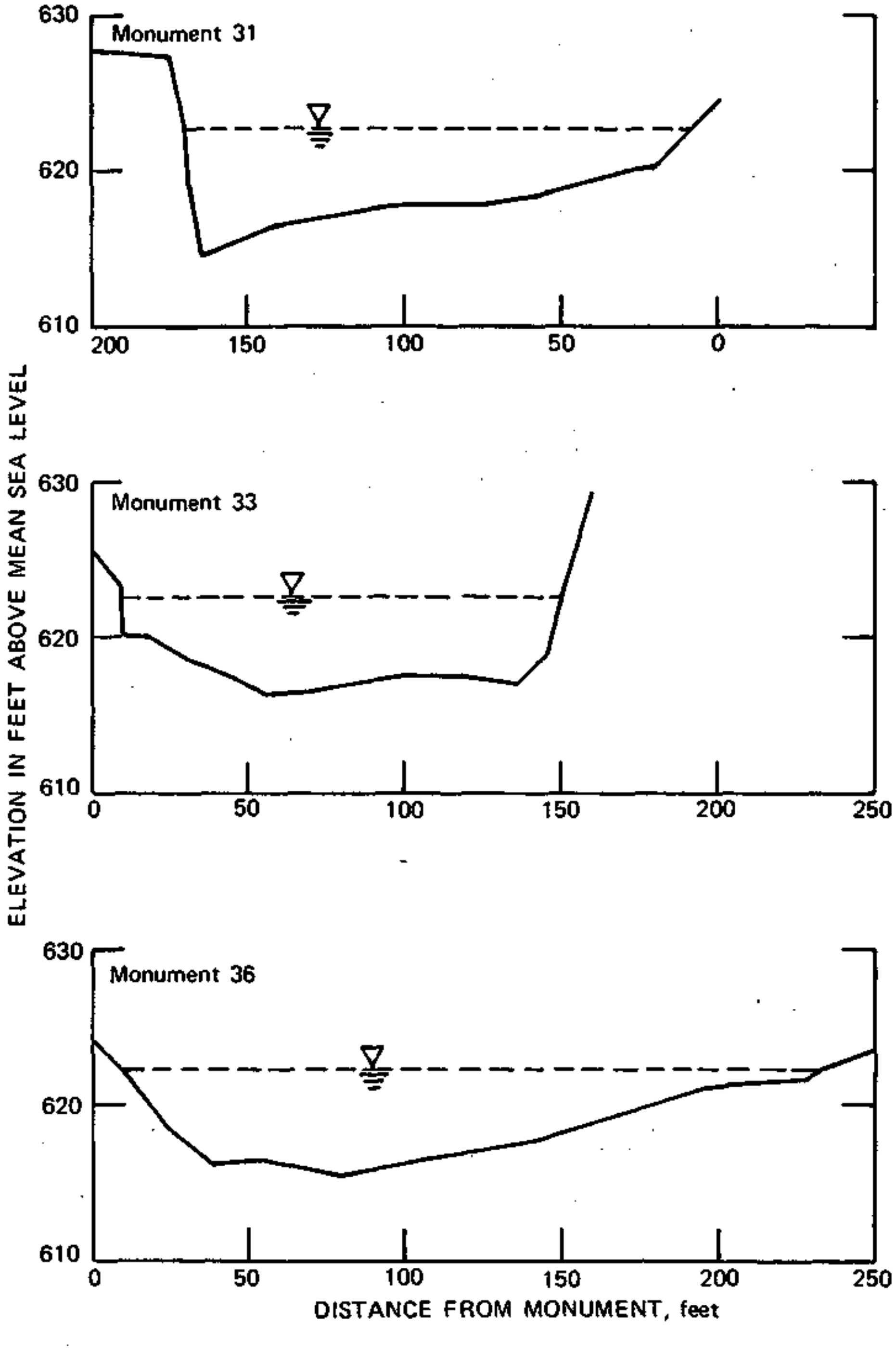

Monument 76
Monument 77 (main channel)
Monument 77 (Singleton Ditch)
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
DISTANCE FROM MONUMENT, feet
630
620
610
0
50
100
150
200
250
300
350

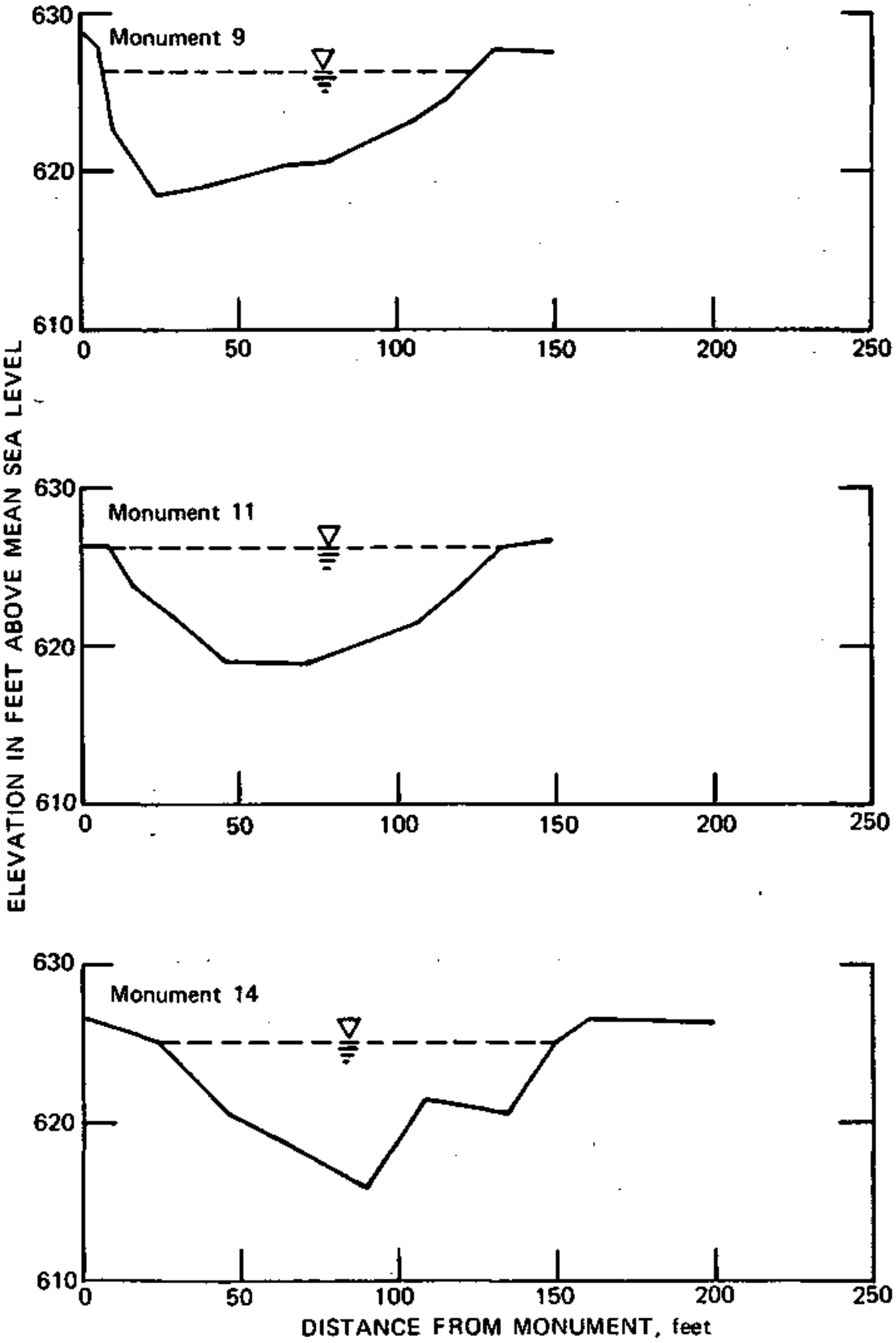

Monument 25
Monument 27
Monument 29
630
620
610
0
50
100
150
200
250
300
350
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
DISTANCE FROM MONUMENT, feet


ELEVATION IN FEET ABOVE MEAN SEA LEVEL
Monument 69
630
620
610
0
50
100
150
200
250
Monument 70
630
620
610
250
200
150
100
50
0
Monument 74
610
620
630
250
200
150
100
50
0
DISTANCE FROM MONUMENT, feet

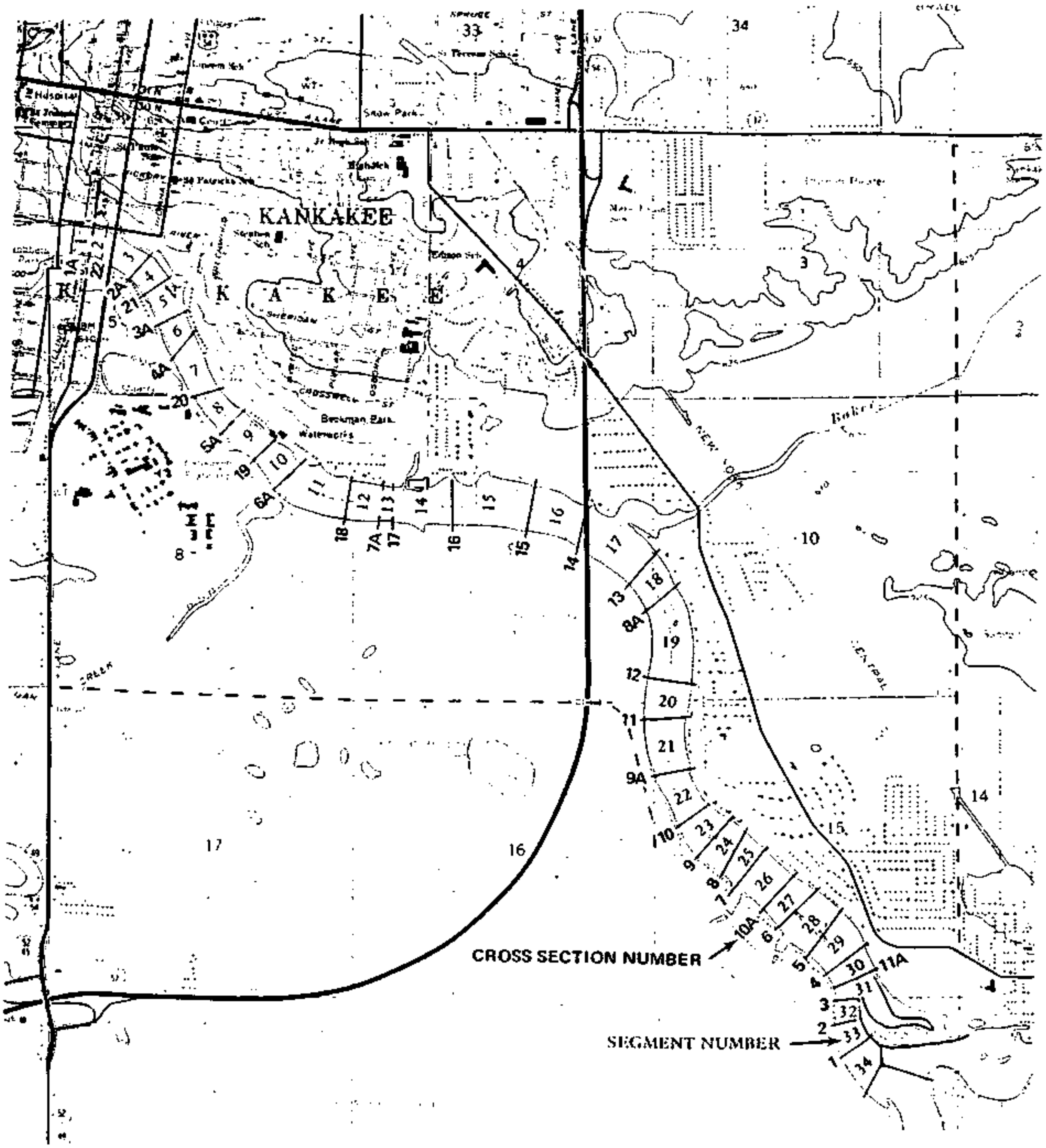

Monument 53
Monument 54
Monument 56
630
620
610
0
50
100
150
200
250
300
350
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
DISTANCE FROM MONUMENT, feet


ELEVATION IN FEET ABOVE MEAN SEA LEVEL
630
Monument 64
620
610
0
50
100
150
200
250
630
Monument 65
620
610
250
200
150
100
50
0
630
Monument 68
620
610
250
200
150
100
50
0
DISTANCE FROM MONUMENT, feet

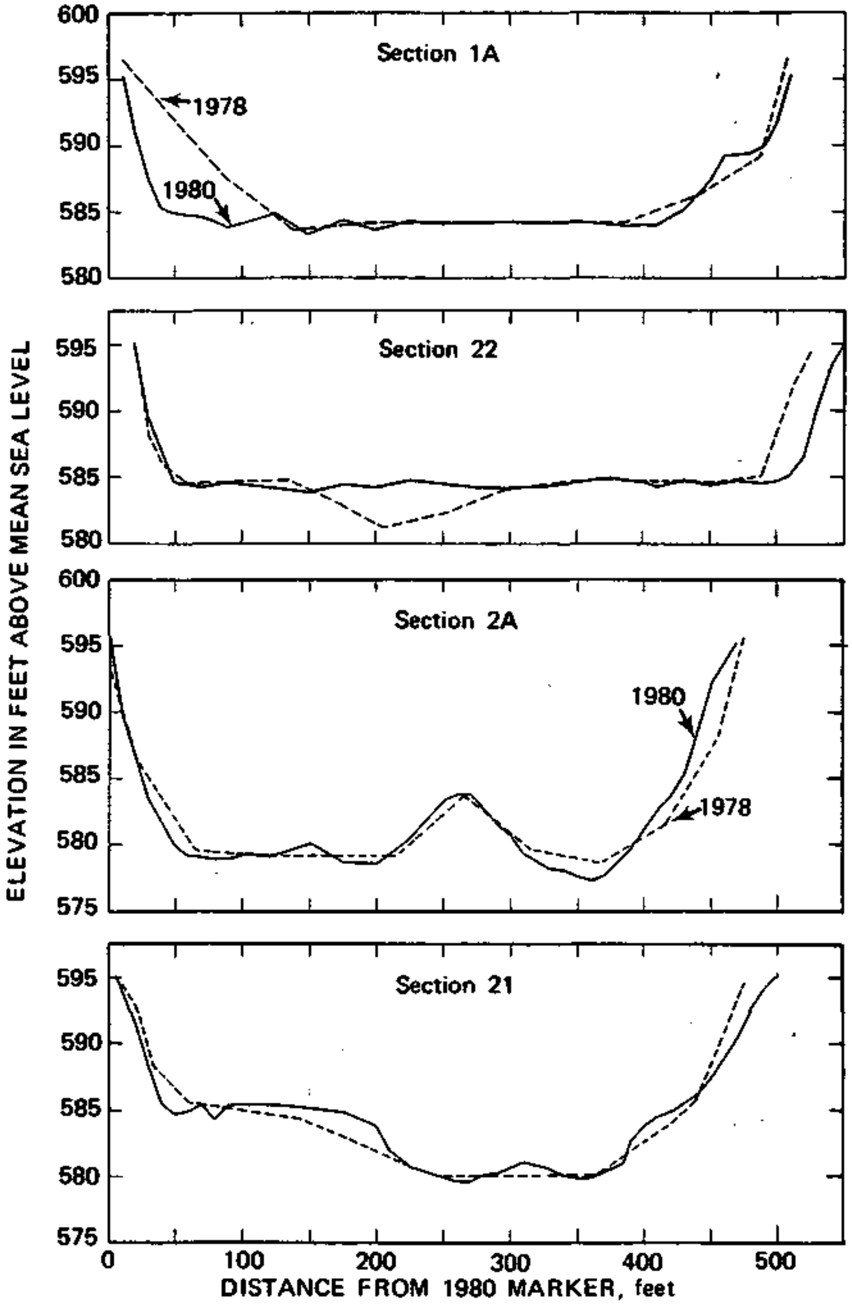

Monument 31
Monument 33
Monument 36
630
620
610
200
150
100
50
0
250
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
DISTANCE FROM MONUMENT, feet

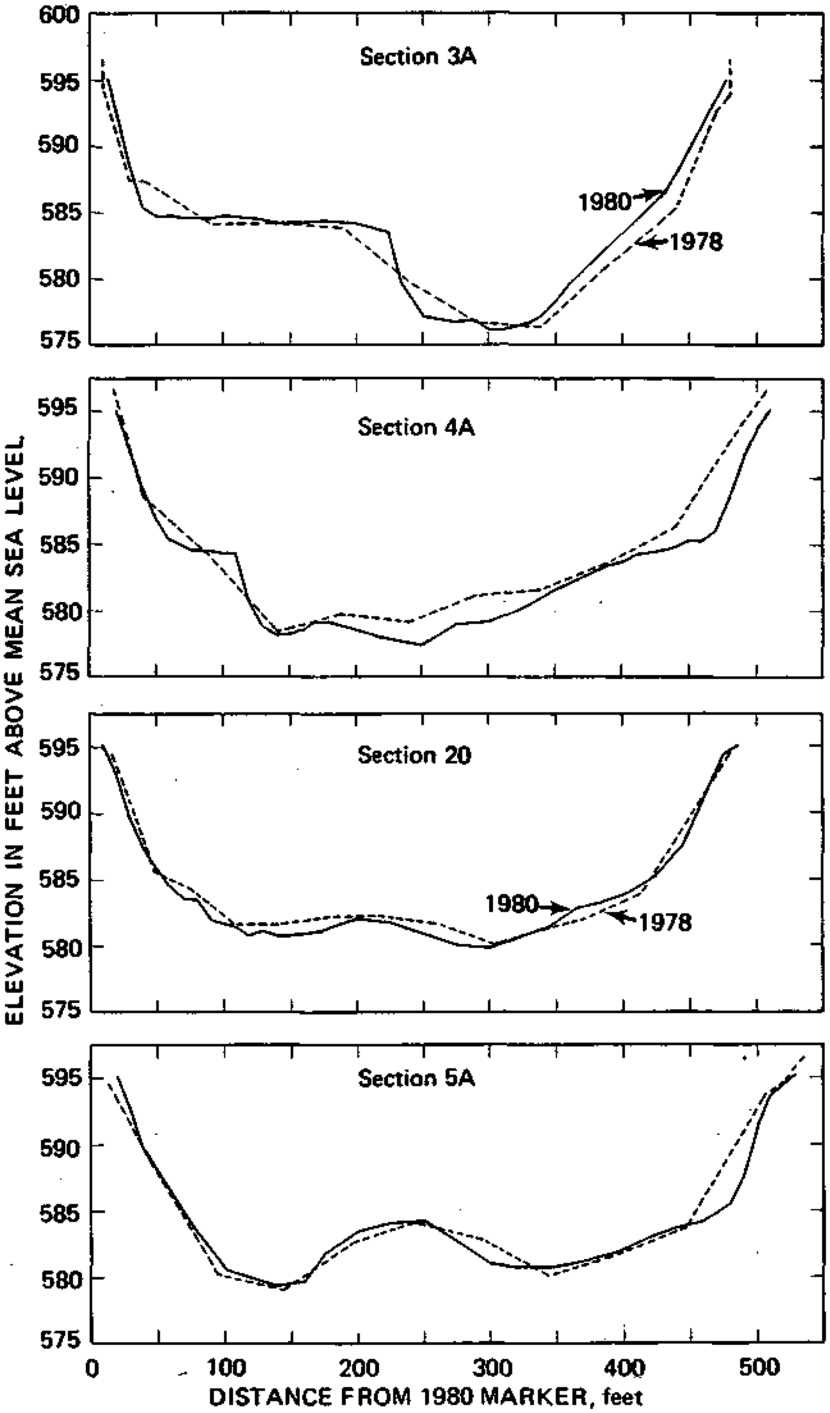

Monument 9
Monument 11
Monument 14
630
620
610
0
50
100
150
200
250
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
DISTANCE FROM MONUMENT, feet

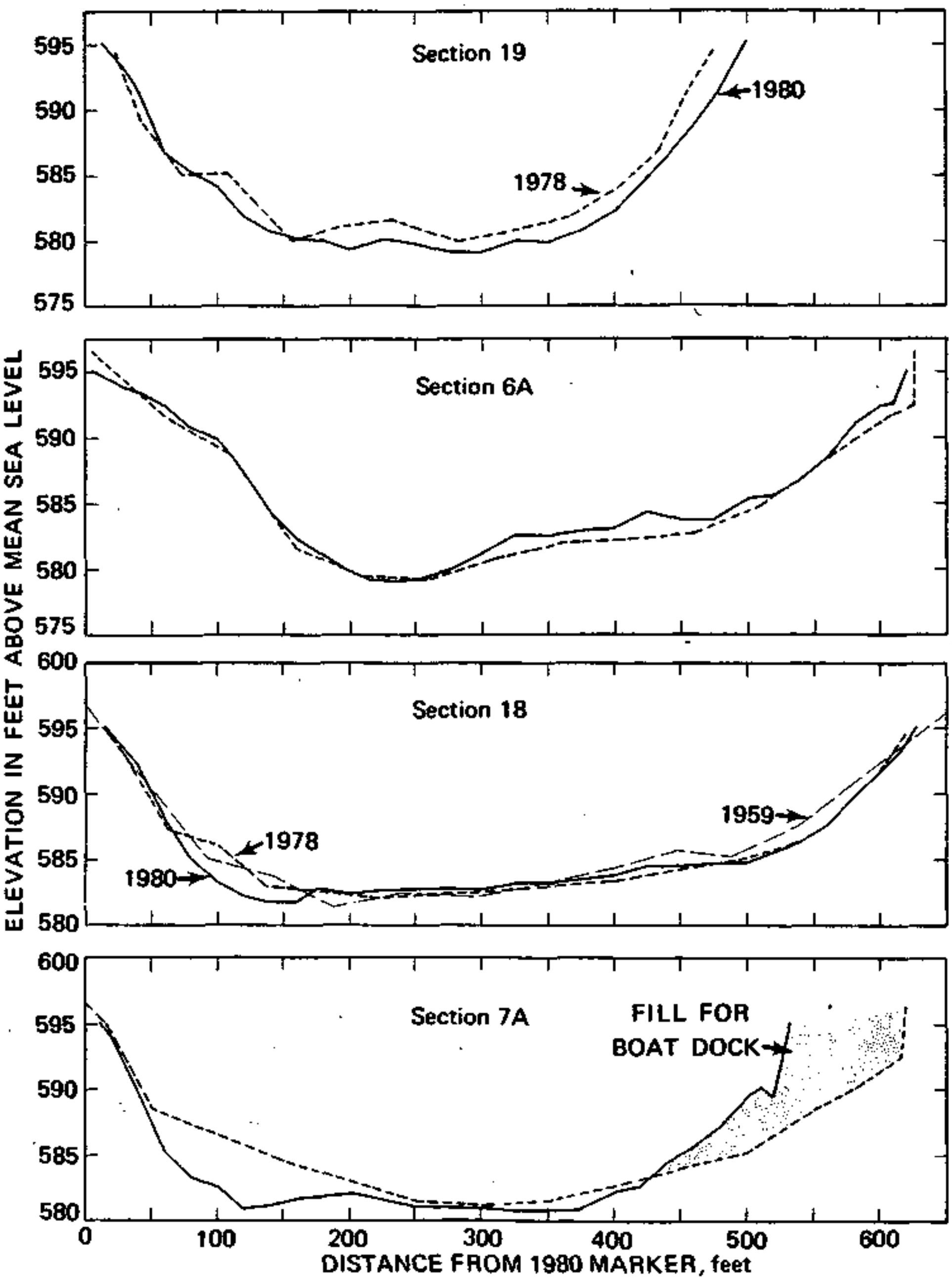
Appendix B. Cross-Sectional Data for Six Mile Pool

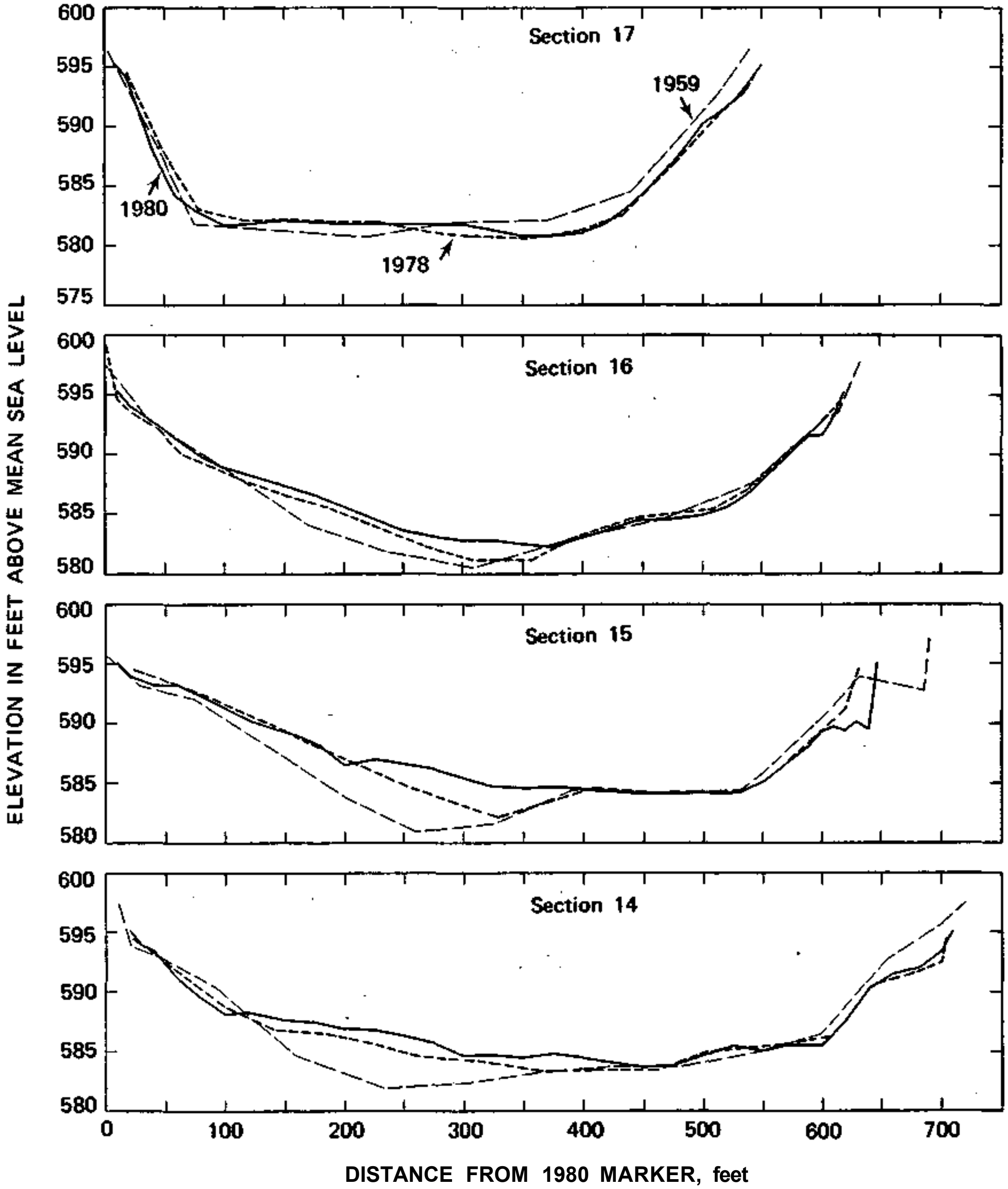


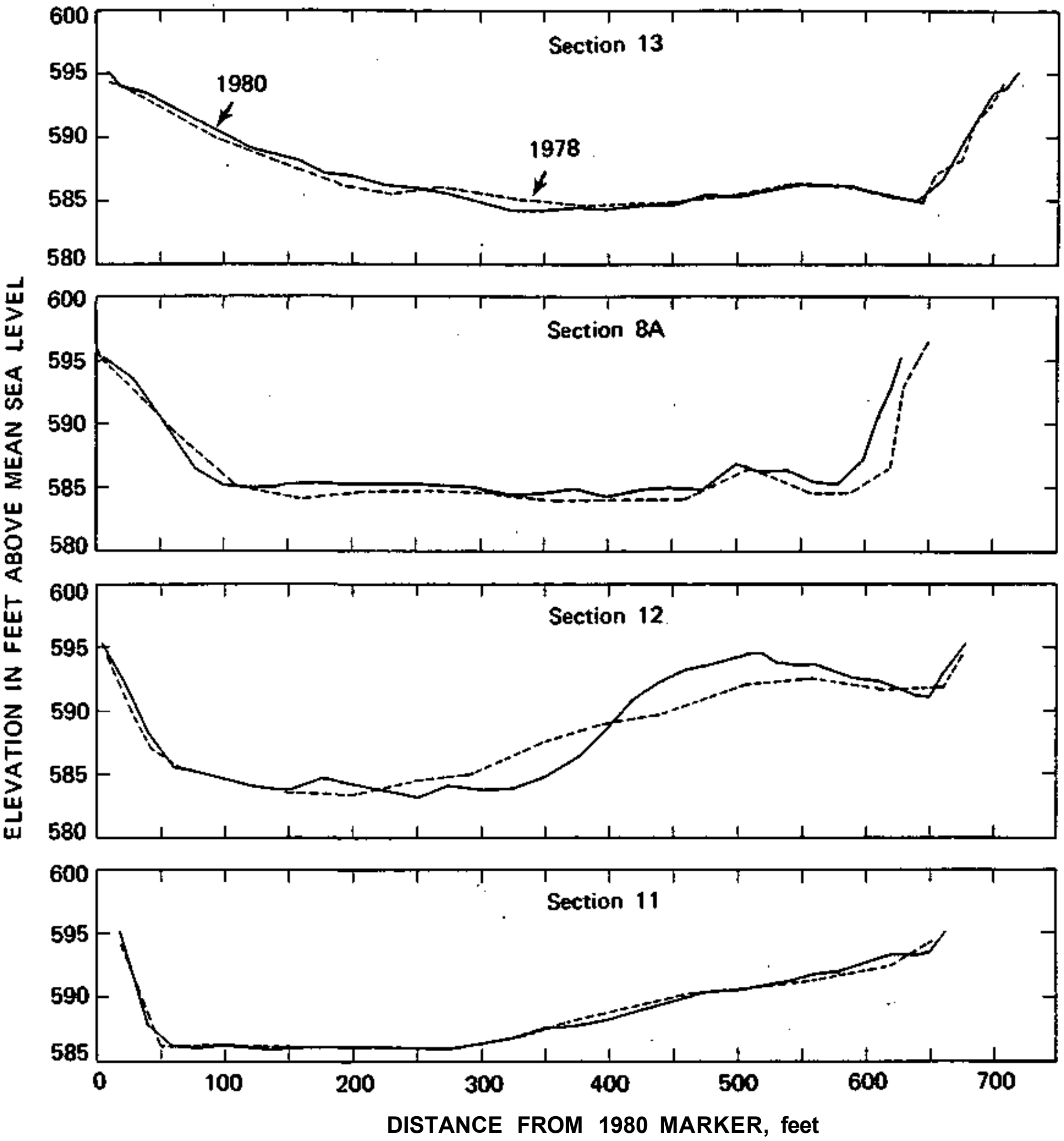
Locations of cross sections in Six Mile Pool

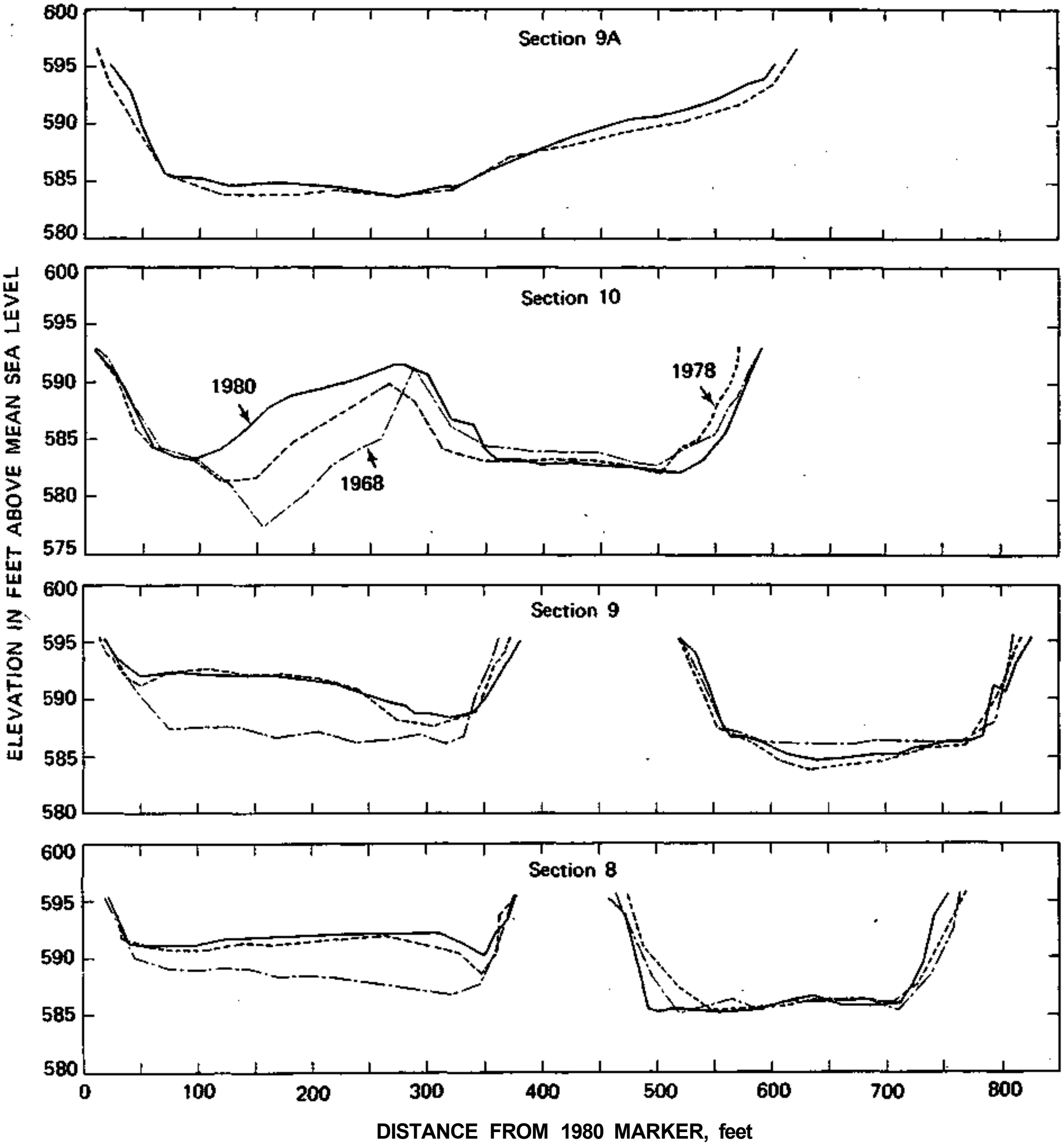

Section 1A
1978
1980
Section 22
Section 2A
1980
1978
Section 21
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
600
595
590
585
580
575
0
100
200
300
400
500
DISTANCE FROM 1980 MARKER, feet

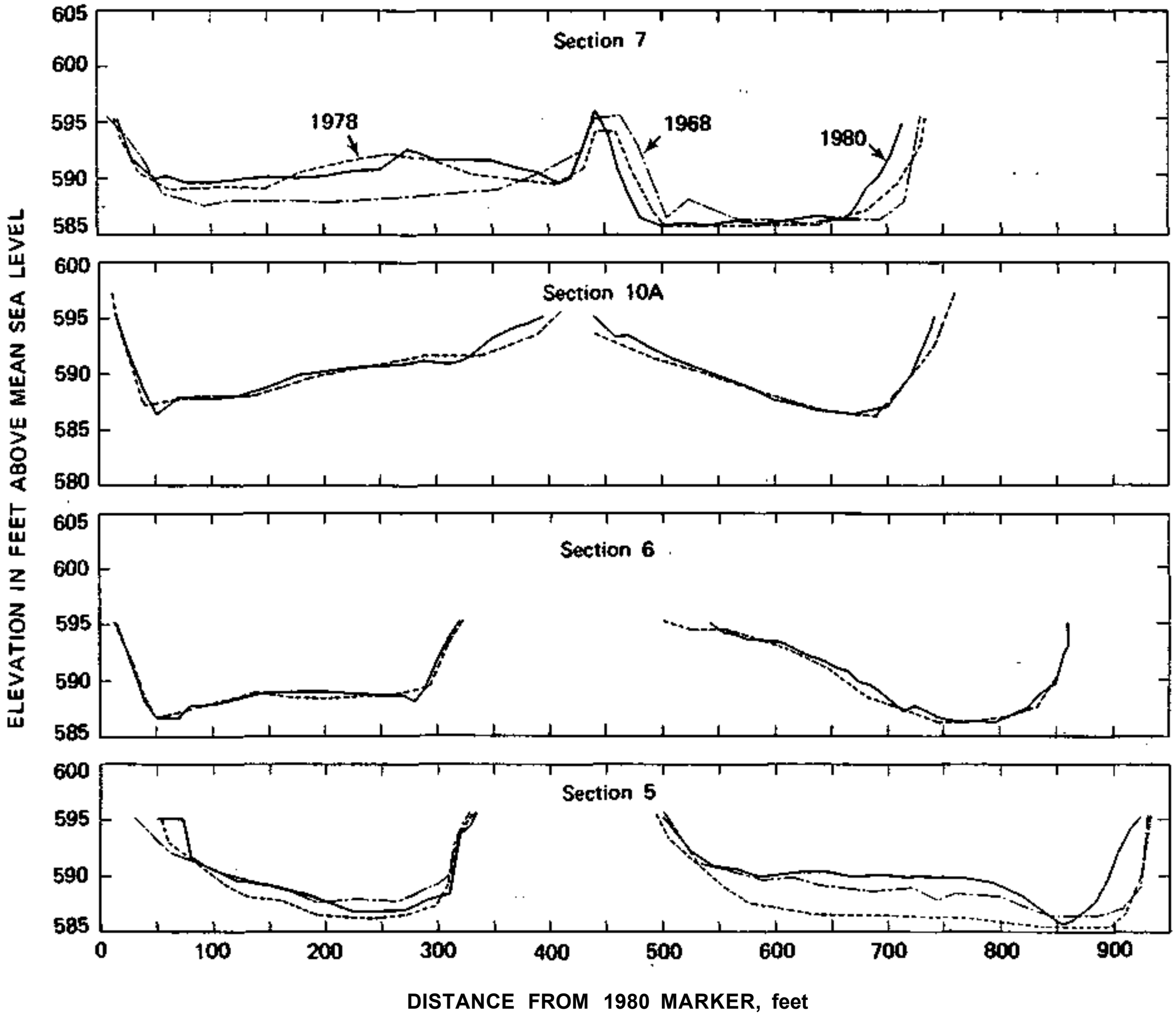

Section 3A
1980
1978
Section 4A
Section 20
1980
1978
Section 5A
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
600
595
590
585
580
575
0
100
200
300
400
500
DISTANCE FROM 1980 MARKER, feet


Section 19
1980
1978
Section 6A
Section 18
1959
1978
1980
Section 7A
FILL FOR BOAT DOCK
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
575
580
585
590
595
600
0
100
200
300
400
500
600
DISTANCE FROM 1980 MARKER, feet

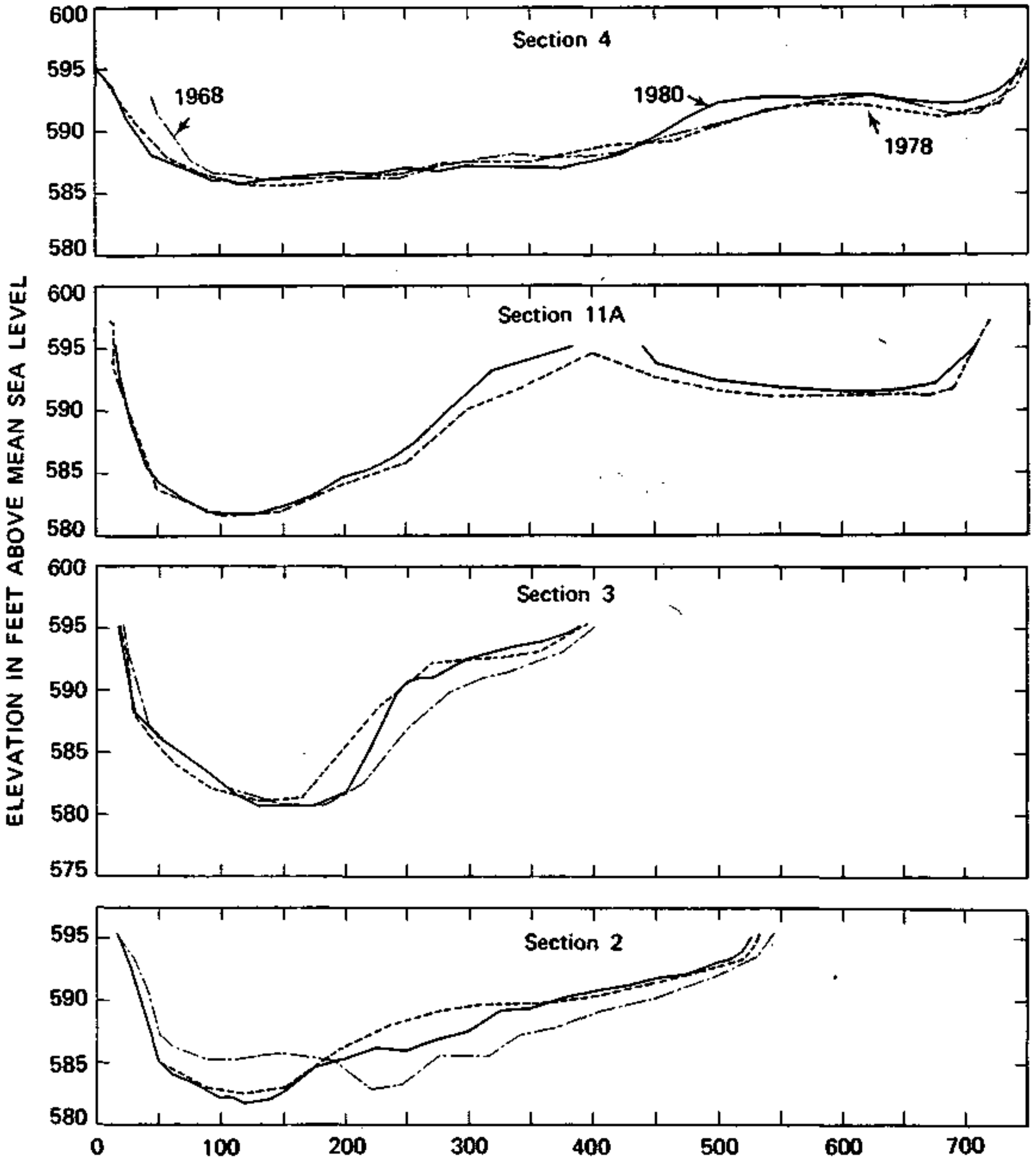
Section 17
1959
1980
1978
Section 16
Section 15
Section 14
600
595
590
585
580
575
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
0
100
200
300
400
500
600
700
DISTANCE FROM 1980 MARKER, feet

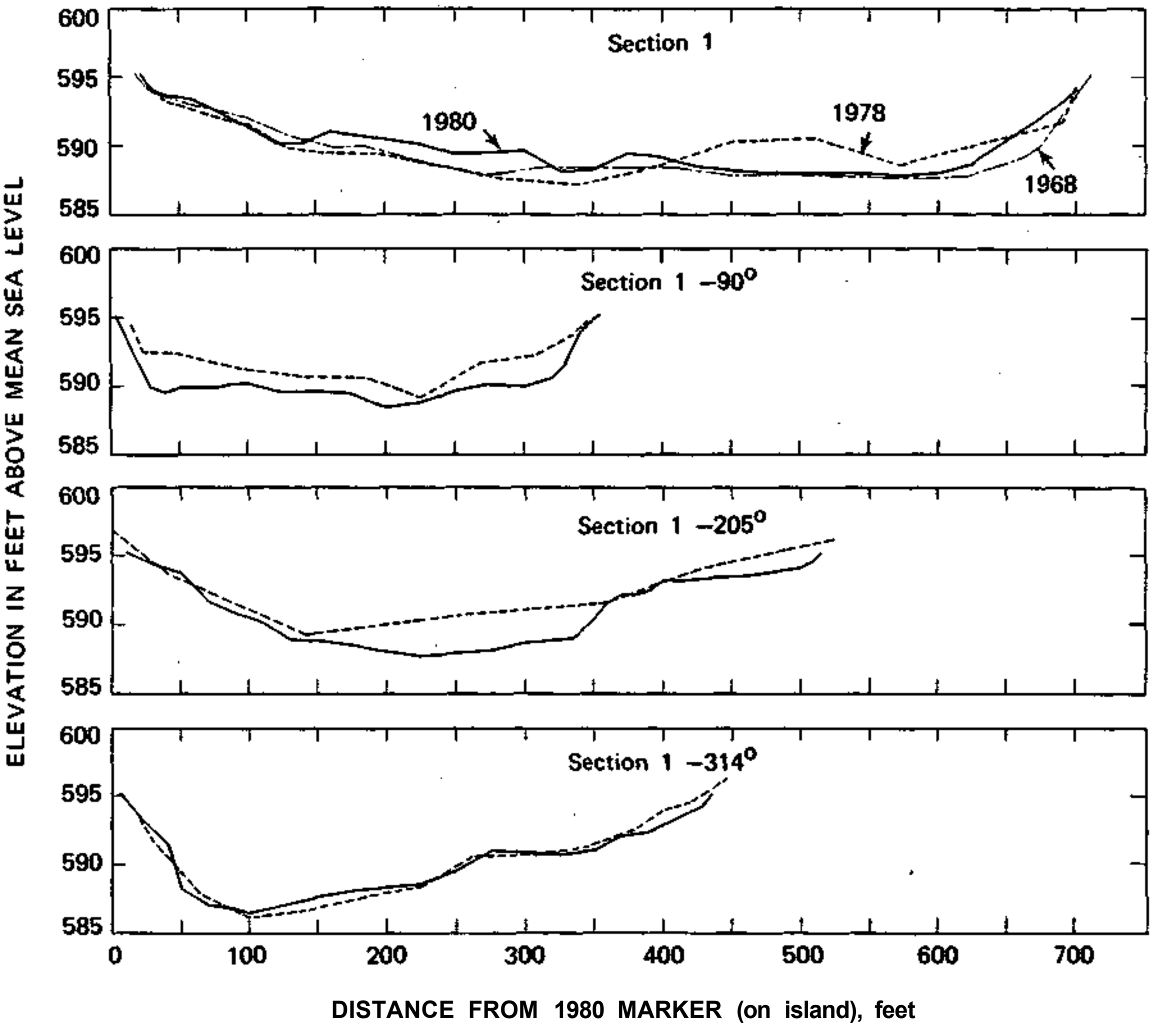

Section 13
1980
1978
Section 8A
Section 12
Section 11
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
600
595
590
585
580
0
100
200
300
400
500
600
700
DISTANCE FROM 1980 MARKER, feet


Section 9A
Section 10
1980
1978
1968
Section 9
Section 8
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
600
595
590
585
580
575
0
100
200
300
400
500
600
700
800
DISTANCE FROM 1980 MARKER, feet



Section 7
1978
1968
1980
Section 10A
Section 6
Section 5
605
600
595
590
585
580
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
0
100
200
300
400
500
600
700
800
900
DISTANCE FROM 1980 MARKER, feet


Section 4
1968
1980
1978
Section 11A
Section 3
Section 2
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
600
595
590
585
580
575
0
100
200
300
400
500
600
700
DISTANCE FROM 1980 MARKER, feet


Section 1
1980
1978
1968
Section 1 –90°
Section 1 –205°
Section 1 –314°
600
595
590
585
0
100
200
300
400
500
600
700
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
DISTANCE FROM 1980 MARKER (on island), feet