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SEDIMENT TRANSPORT
IN THE ILLINOIS RIVER

By

Ming T. Lee, Ph.D., P.E., Associate Engineer

and

Nani G. Bhowmik, Ph.D., P.E., Engineer

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INTRODUCTION

A 5-year study and demonstration program to determine the effects of increased Lake Michigan diversion on water quality of the Illinois Waterway and on the susceptibility of the Illinois Waterway to additional flooding is authorized in Section 166 of the Water Resources Development Act of 1976 (P.L. 94-587). It is planned during the 5-year demonstration program to increase Lake Michigan diversion from the presently authorized 3200 cfs to a maximum of 10,000 cfs.

The incremental flow may or may not have any effect on the regime of the river. In order to better understand the effects of the increased flow on the sediment transport of the Illinois River, the U.S. Army Corps of Engineers through the Illinois Division of Water Resources funded the Illinois State Water Survey to study the state of knowledge concerning transport of sediment in the river and its tributaries, and also to assess the impacts of the proposed Lake Michigan diversion on sediment transport in the river.

The report is divided into five main parts. The first consists of a search for existing sediment transport data from the Illinois River Basin. The second part consists of the following: 1) an explanation of the methodology used to derive the sediment rating curves at four gaging stations, and 2) the determination of the sediment yield at these four stations based. on the rating curves already developed and data supplied by the Corps of Engineers for 1971, 1973, and 1977 water years.

The third part is an analysis of the data collected by the Chicago Sanitary District during the 1940 flushing experiment in the Chicago Sanitary and Ship Canal. The fourth is an analysis of the probable effects of diversion on sediment load. Finally, the fifth part describes a monitoring and research program.

Objectives

The objectives of this study were: 1) to search for available sediment data and corresponding discharge data in the Illinois River Basin; 2) to develop relationships between sediment load and water discharge at a few selected locations based on existing data; 3) to make a qualitative assessment of the sediment transport in the Illinois River due to increased diversion, based on existing data; and 4) to make recommendations for further requirements of additional sediment data needed to assess the effects of increased diversion on sediment transport rates in the Illinois River.

Acknowledgments

The work described here was conducted by the authors as part of their regular duties at the Illinois State Water Survey under the guidance of Richard J. Schicht, Head of the Hydrology Section, and under the general supervision of Dr. William C. Ackermann, Chief, Illinois State Water Survey. This report was reviewed by Mr. Schicht.

Norman Nedergang of the U.S. Army Corps of Engineers, Chicago District, provided the estimated streamflows and stage records. Dennis Dreher, Northeastern Illinois Planning Commission, provided the suspended solids data at a few locations. The United States Geological Survey provided the other suspended sediment data.

The art work was prepared by William Motherway and John Brother. The draft and final manuscripts were typed by Ginny Johnson and Pam Lovett. J. Loreena Ivens edited the final report, assisted by Patricia A. Motherway who also prepared the camera copy.

DESCRIPTION OF THE STUDY AREA

The Illinois Waterway extends from Lake Michigan at Chicago to the Mississippi River at Grafton, Illinois (figure 1). The total drainage area including the Lake Michigan watershed is 28,900 square miles, and the total length of the Illinois River Waterway is 327 miles. The Illinois River Waterway and the Illinois River, which begins at the confluence of the Kankakee and Des Plaines Rivers, coincide downstream from that point except at Marseilles where the Waterway bypasses a rapid in the river by a canal about 2 miles long.

There are nine locks and dams in the Illinois River as shown in figure 1. These structures have changed the original free-flow river to a somewhat controlled river. The present river profile is shown in figure 2. This Waterway is a major navigation channel in the state of Illinois. According to a report by the Illinois Division of Water Resources, about 44 million tons of raw materials and agricultural products were transported through the Waterway in 1975 (Water Resources Center, 1977).

The Illinois Waterway receives not only the normal inflows from its tributaries but also an additional flow from Lake Michigan. At present 3200 cfs of water is diverted from Lake Michigan. Plans call for a demonstration program by the U.S. Army Corps of Engineers to investigate the effects of increasing Lake Michigan diversion gradually to 10,000 cfs.

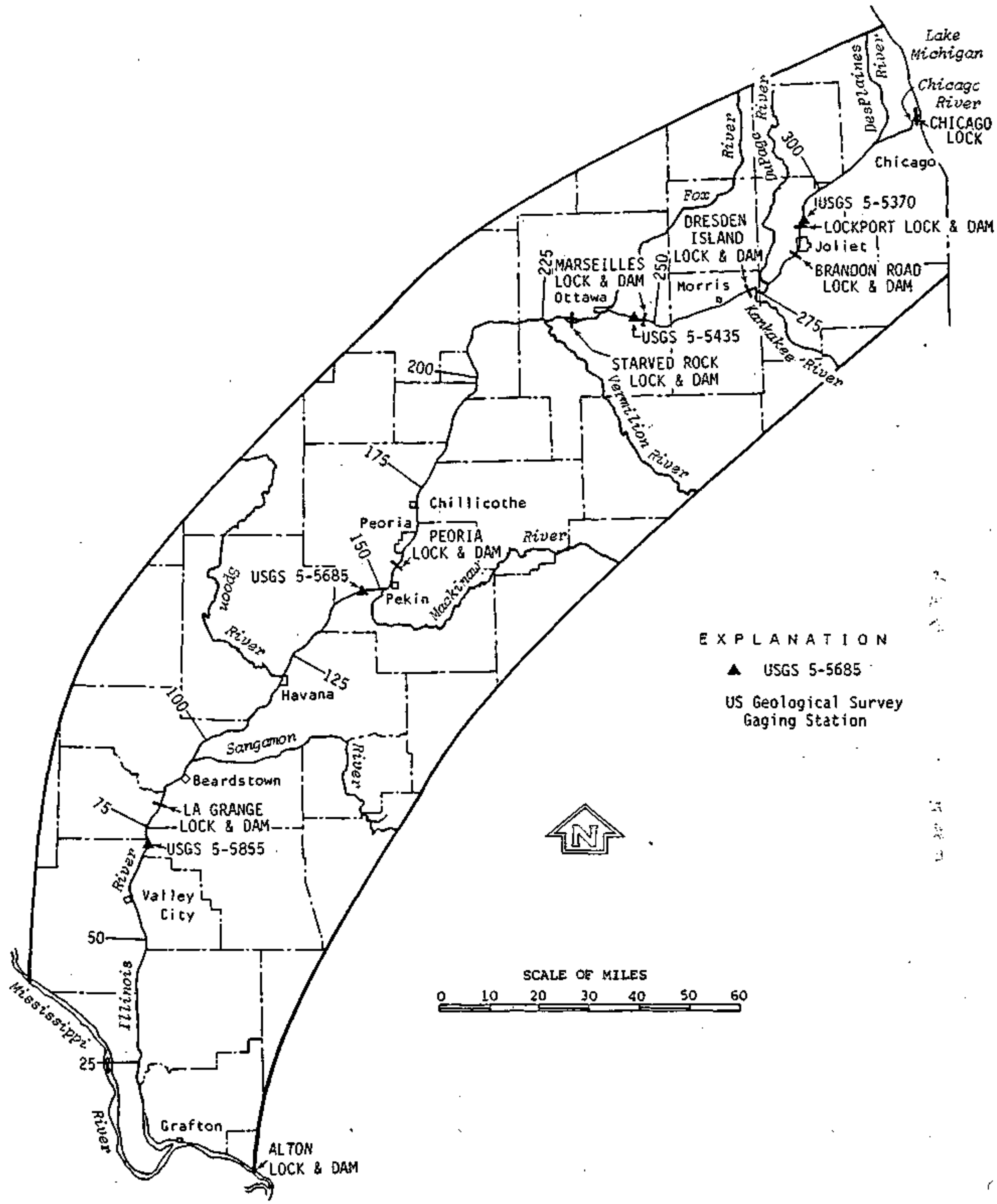


Figure 1. Illinois Waterway location map

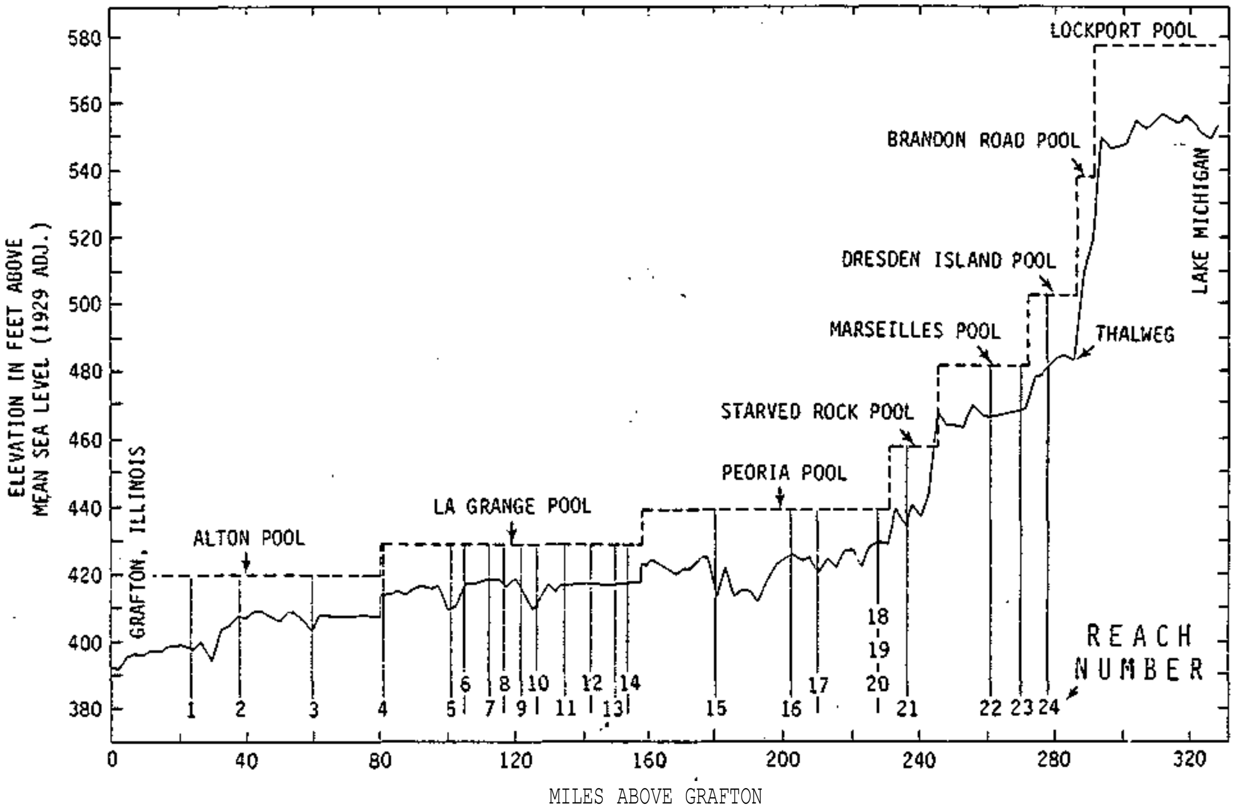


Figure 2. Profile of the Illinois River

AVAILABLE SEDIMENT DATA

An extensive search of existing records revealed that some sediment data are available in the following government agency files: 1) the United States Geological Survey (USGS), 2) the Illinois Environmental Protection Agency (IEPA), 3) the Metropolitan Sanitary District of Greater Chicago (MSDGC), 4) the Northeastern Illinois Planning Commission (NIPC - Section 208 planning data), and 5) the Illinois State Water Survey (ISWS). Data from these sources were compiled and used in this study.

The sources, locations, and time periods for which suspended sediment and the corresponding discharge data are available are tabulated in table 1.

Only two monthly suspended sediment stations exist on the Illinois River, namely, Marseilles and Valley City (USGS, 1977). Most of the remaining sampling stations are located in the northeastern section of Illinois, where most of the data were gathered as a part of 208 planning efforts by the Northeastern Illinois Planning Commission (Polls, 1978). Some data on the Spoon River were collected by the Illinois State Water Survey (Evans and Schnepper, 1977) and other data are from a special study in the Fox Chain of Lakes for Nippersink Creek and the Fox River (Brabets, 1977). This study was conducted by the USGS

Table 1. Sediment Data Inventory, Illinois River Basin, 1978

Agency operating the station	Location	Sampling period	Sampling interval	Method of data collection	Reference
ISWS	Spoon River @ Modena	1971-73	Weekly	TSS	Evans (1977)
ISWS	Spoon River @ Elmore	" "	"	"	"
ISWS	Spoon River @ London Mills	" "	"	"	"
ISWS	Spoon River @ Seville	" "	"	"	"
ISWS	Spoon River near Havana	" "	"	"	"
ISWS	Spoon River @ London Mills	1974-75	"	Depth integration	"
ISWS	Spoon River @ Seville	" "	"	"	"
USGS	Illinois River @ Marseilles	1975-now	Monthly	"	USGS
USGS	Illinois River @ Valley City	" "	"	"	"
MSDGC	Fox River @ Wilmont	Six 10-day periods 1976-77	8-hour or daily	TSS	Elmore (1977) and Polls (1978)
MSDGC	Nippersink Creek @ Spring Grove	"	"	"	"
MSDGC	Fox River @ McHenry Dam	"	"	"	"
MSDGC	Kishwaukee River @ Belvidere	"	"	"	"
MSDGC	Fox River @ Algonquin	"	"	"	"
MSDGC	Fox River @ South Elgin	"	"	"	"

Note.: I SWS = Illinois State Water Survey
MSDGC = Metropolitan Sanitary District of Greater Chicago
SDC = Sanitary District of Chicago, former name of MSDGC
USGS = United States Geological Survey
PHS = Public Health Service, U.S. Dept. of Health, Education, 6 Welfare
TSS = Total Suspended Solids
I EPA = Illinois Environmental Protection Agency

Table 1. Continued

Agency operating the station	Location	Sampling period	Sampling interval	Method of data collection	Reference
MSDGC	Fox River @ Montgomery	Six 10-day periods 1976-77	8-hour or daily	TSS	Elmore(1977) and Polls(1978)
MSDGC	Fox River @ Yorkville	"	"	"	"
MSDGC	Des Plaines River @ Russell	"	"	"	"
MSDGC	Des Plaines River @ Half Day	"	"	"	"
MSDGC	Des Plaines River @ Des Plaines	"	"	"	"
MSDGC	Salt Creek @ Rolling Meadows	"	"	"	"
MSDGC	W. Br. of DuPage River @ W. Chicago	"	"	"	"
MSDGC	Salt Cr. @ Elmhurst	"	"	"	"
MSDGC	Des Plaines River @ River Grove	"	"	"	"
MSDGC	Salt Cr. @ W. Springs	"	"	"	"
MSDGC	Des Plaines River @ Riverside	"	"	"	"
MSDGC	Illinois River @ Dresden Dam	"	"	"	"
MSDGC	Kankakee River @ Wilmington	"	"	"	"
MSDGC	Hickory Creek @ Joliet	"	"	"	"
MSDGC	Des Plaines River @ Joliet	"	"	"	"
MSDGC	DuPage River @ Shorewood	"	"	"	"
MSDGC	Des Plaines River @ Lockport	"	"	"	"
MSDGC	E. Br. DuPage River @ Naperville Road	"	"	"	"

Table 1. Continued

Agency operating the station	Location	Sampling period	Sampling interval	Method of data collection	Reference
MSDGC	Cal-Sag Channel @ Alsip	Six 10-day periods 1976-77	8-hour or daily	TSS	Elmore(1977) and Polls(1978)
MSDGC	Chicago Sanitary and Ship Canal @ Lockport	"	"	"	"
MSDGC	W. Br. DuPage River @ Naperville Road	"	"	"	"
MSDGC	E. Br. DuPage River @ Lisle	"	"	"	"
MSDGC	M. Fk. N. Br. Chicago River @ Deerfield	"	"	"	"
MSDGC	W. Fk. N. Br. Chicago River @ Northbrook	"	"	"	"
MSDGC	Skokie River @ Northfield	"	"	"	"
MSDGC	N. Shore Channel @ Wilmette	"	"	"	"
MSDGC	N. Br. Chicago River @ Niles	"	"	"	"
MSDGC	N. Br. Chicago River @ Chicago	"	"	"	"
MSDGC	Chicago River @ Outer Drive	"	"	"	"
MSDGC	Chicago Sanitary and Ship Canal @ Cicero Ave.	"	"	"	"
MSDGC	Calumet River @ Ewing Avenue	"	"	"	"
MSDGC	Calumet River @ 130 St.	"	"	"	"
MSDGC	Grand Calumet River @ State Line Road	"	"	"	"
MSDGC	Little Calumet River @ Calumet City	"	"	"	"
MSDGC	Thorn Creek @ Thornton	"	"	"	"

Table 1. Continued

Agency operating the station	Location	Sampling period	Sampling interval	Method of data collection	Reference
MSDGC	Little Calumet River @ Dixmoor	Six 10-day periods 1976-77	8-hour or daily	TSS	Elmore(1977) and Polls(1978)
MSDGC	Little Calumet River @ Calumet Park	"	"	"	"
MSDGC	Cal-Sag Channel @ Sag Bridge	"	"	"	"
MSDGC	Chicago Sanitary and Ship Canal @ Rt 83	"	"	"	"
USGS	Nippersink Cr. @ Spring Grove	12/74-9/75	2/week	Depth integration	Brabets(1977)
USGS	Fox River @ Channel Lake	"	"	"	"
MSDGC	Chicago Sanitary and Ship Canal @ Lockport	11/74-9/75	Hourly	TSS	Mohlman(1940)
SDC	Chicago Sanitary and Ship Canal @ Cass St.	1940	"	"	"
SDC	Chicago Sanitary and Ship Canal @ Brandon Road	1940	"	"	"
SDC	Chicago Sanitary and Ship Canal @ Marseilles	1940	"	"	"
PHS	Illinois River Mile 70 to 270	Three 30-day periods	Daily	"	PHS(1963)
IEPA	Kankakee River @ Momence	July 1978 to present	Monthly	Depth integration	USGS(1979)
IEPA	Iroquois River @ Iroquois	"	"	"	"
IEPA	Sugar Creek @ Milford	"	"	"	"
IEPA	Iroquois River near Chebanse	"	"	"	"
IEPA	Kankakee River near Wilmington	"	"	"	"
IEPA	Des Plaines River @ Russell	"	"	"	"

Table 1. Continued

Agency operating the station	Location	Sampling period	Sampling interval	Method of data collection	Reference
IEPA	Des Plaines River near Gurnee	July 1978 to present	Monthly	Depth integration	USGS(1979)
IEPA	Des Plaines River near Des Plaines	"	"	"	"
IEPA	Salt Creek @ Western Springs	"	"	"	"
IEPA	North Branch Chicago River @ Deerfield	"	"	"	"
IEPA	North Branch Chicago River @ Niles	"	"	"	"
IEPA	Chicago Sanitary and Ship Canal @ Lockport	"	"	"	"
IEPA	W. Branch DuPage River near Warrenville	"	"	"	"
IEPA	DuPage River @ Shorewood	"	"	"	"
IEPA	Mazon River near Coal City	"	"	"	"
IEPA	Fox River near Channel Lake	"	"	"	"
IEPA	Nippersink Creek near Spring Grove	"	"	"	"
IEPA	Fox River @ Algonquin	"	"	"	"
IEPA	Poplar Creek @ Elgin	"	"	"	"
IEPA	Blackberry Creek near Yorkville	"	"	"	"
IEPA	Fox River @ Dayton	"	"	"	"
IEPA	Vermilion River @ McDowell	"	"	"	"
IEPA	Vermilion River near Lenore	"	"	"	"
IEPA	Illinois River @ Hennepin	"	"	"	"

Table 1. Continued

Agency operating the station	Location	Sampling period	Sampling interval	Method of data collection	Reference
IEPA	Des Plaines River near Schiller Park	July 1978 to present	Monthly	Depth integration	USGS(1979)
IEPA	Spoon River at Rt 116 Bridge @ London Mills	"	"	"	"
IEPA	Spoon River @ Seville	"	"	"	"
IEPA	Illinois River @ Power Co., Havana	"	"	"	"
IEPA	Sangamon River @ Fisher	"	"	"	"
IEPA	Sangamon River @ Allerton Park near Monticello	"	"	"	"
IEPA	South Fork Sangamon River @ Kincaid	"	"	"	"
IEPA	S. Fk. Sangamon River below Rochester	"	"	"	"
IEPA	Sangamon River @ Riverton	"	"	"	"
IEPA	Sangamon River @ Petersburg	"	"	"	"
IEPA	Des Plaines River @ Lockport	"	"	"	"
IEPA	E. Br. DuPage River @ Rt 34 Bridge, Lisle	"	"	"	"
IEPA	DuPage River near Naperville	"	"	"	"
IEPA	Fox River @ South Elgin	"	"	"	"
IEPA	Fox River @ Montgomery	"	"	"	"
IEPA	Sangamon River @ Rt 48, Decatur	"	"	"	"
IEPA	Sangamon River near Niantic	"	"	"	"
IEPA	Sangamon River @ Roby	"	"	"	"

Table 1. Continued

Agency operating the station	Location	Sampling period	Sampling interval	Method of data collection	Reference
IEPA	Big Bureau Creek @ Princeton	July 1978 to present	Monthly	Depth integration	USGS(1979)
IEPA	Illinois River @ Lacon	"	"	"	"
IEPA	Illinois River @ Water Co., Peoria	"	"	"	"
IEPA	Illinois River @ Pekin	"	"	"	"
IEPA	Mackinaw River below Congerville	"	"	"	"
IEPA	Mackinaw River below Green Valley	"	"	"	"
IEPA	Indian Creek near Wyoming	"	"	"	"
IEPA	Salt Creek near Rowell	"	"	"	"
IEPA	Lake Fork near Cornland	"	"	"	"
IEPA	Kickapoo Creek @ Waynesville	"	"	"	"
IEPA	Kickapoo Creek near Lincoln	"	"	"	"
IEPA	Salt Creek near Greenview	"	"	"	"
IEPA	Sangamon River near Oakford	"	"	"	"
IEPA	La Moine River @ Colmar	"	"	"	"
IEPA	La Moine River @ Ripley	"	"	"	"
IEPA	Macoupin Creek near Kane	"	"	"	"
IEPA	Illinois River @ Hardin	"	"	"	"

Table 1. Concluded

Agency operating the station	Location	Sampling period	Sampling interval	Method of data collection	Reference
IEPA	Sugar Creek near Hartsburg	July 1978 to present	Monthly	Depth integration	USGS(1979)
IEPA	Indian Creek @ Arenzville	"	"	"	"
IEPA	Mauvaise Terre Creek near Merritt	"	"	"	"
IEPA	Calumet-Sag Channel @ Sag Bridge	"	"	"	"

to assess the sediment yield in the Fox River Basin. The USGS (1979) in cooperation with IEPA started a data collection program in Illinois in which depth-integrated suspended sediment samples are being collected from 130 locations some of which are in the Illinois River Basin.

In 1940, the Sanitary District of Chicago conducted a flushing experiment on the Chicago Sanitary and Ship Canal by increasing diversion from Lake Michigan (Mohlman, 1941). This experiment, which lasted for 10 days, was authorized by the U.S. Supreme Court. Samples related to suspended load were collected at 14 stations along the Chicago Sanitary and Ship Canal and the Illinois River.

In 1962 and 1963, the U.S. Public Health Service made an investigation of water quality parameters in the Illinois River. During this investigation, daily total suspended solids data were collected along the Illinois River at a number of locations for three 30-day periods during two summers (Public Health Service, 1963).

Except for the 1940 flushing experiment and the 1963 U.S. Public Health study, all the data were collected after 1970. The sampling intervals varied anywhere from daily to monthly.

Two basic methods were used to measure the suspended sediment samples in the river. One of them is called the total suspended solids method (TSS) and the other, the depth integration method.

The total suspended solids method, as described by Polls (1978) and Elmore (1977), includes both the organic and inorganic suspended solids in water. In the depth integration method, suspended sediment samples are usually collected at several verticals in the cross section and a composite sediment load is estimated excluding organic materials. The laboratory procedures needed to determine the suspended sediment load based on depth-integrated samples are given by Guy (1969).

Various sources were searched for data related to particle size distribution of the bed and bank materials along the Illinois River. It was found that the only data available are those given by Bhowmik and Schicht (1979).

METHODOLOGY

Sediment Rating Curves

The sediment rating curve is a relationship between streamflow and sediment load. Sediment rating curves are widely used to estimate the sediment load in a stream where adequate water discharge data are available but the sediment record is not of sufficient length. Vanoni (1975) has mentioned that in the sediment rating curve method, it is assumed that a direct runoff from a given area represents the integrated effect of most characteristics of the drainage basin and the superimposed environment as they relate to sediment production. The fine sediment fraction that forms the wash load of a stream is readily entrained in the runoff and, being relatively insensitive to the flow parameters, forms the bulk of the suspended load in the stream. The suspended load can easily be sampled. On the other hand, the transport of the coarse sediment fraction, i.e., bed load, depends upon a balance between supply and flow parameters and may or may not be adequately sampled by suspended sediment samplers. However, if a sediment rating curve is developed on the basis of the suspended sediment load measured in the field, the relationship can be put to practical use for estimating the sediment'load in the stream.

Based on the available field data, four rating curves at four different locations along the Illinois River have been developed and are presented/fin the following subsections.

The technique utilized is similar to that used by Bhowmik (1977) in a research proposal submitted to the U.S. Army Corps of Engineers, Chicago District.

> At this point it is imperative that the reader be fully aware that the data base for all subsequent analyses is extremely scanty at best. As far as sediment transport in rivers is concerned, the available data are not at all sufficient to develop any meaningful and reliable relationships. Still, an attempt was made to develop rating curves which may shed some light as to the sediment transport rates in the Illinois River.

1. Lockport. This station is located at Division Street, Lockport, Illinois. Grab samples were collected by the Metropolitan Sanitary District of Greater Chicago (MSDGC) in June, September, and December 1976, and in March 1977. The data were collected at intervals of either 8 or 24 hours. On the basis of these data, analyses for 16 water quality parameters were made (Elmore, 1977). Streamflow at the time of data

collection was determined on the basis of data from an adjacent temporary USGS gaging station.

The total suspended solids and streamflow data at Lockport were gathered from the files of the Northeastern Illinois Planning Commission (NIPC). These data were collected in 1976 and 1977 and are tabulated in Appendix A.

The total suspended solids and the corresponding streamflow data were plotted on log-log paper as shown in figure 3. It should be noted that the sediment load corresponds to the total suspended solids measured in the field rather than the sediment load based on data collected by the depth integration method. A linear regression equation based on these data is given by equation 1.

$$Q_s = Q_w^{1.367}/342.8 \quad (1)$$

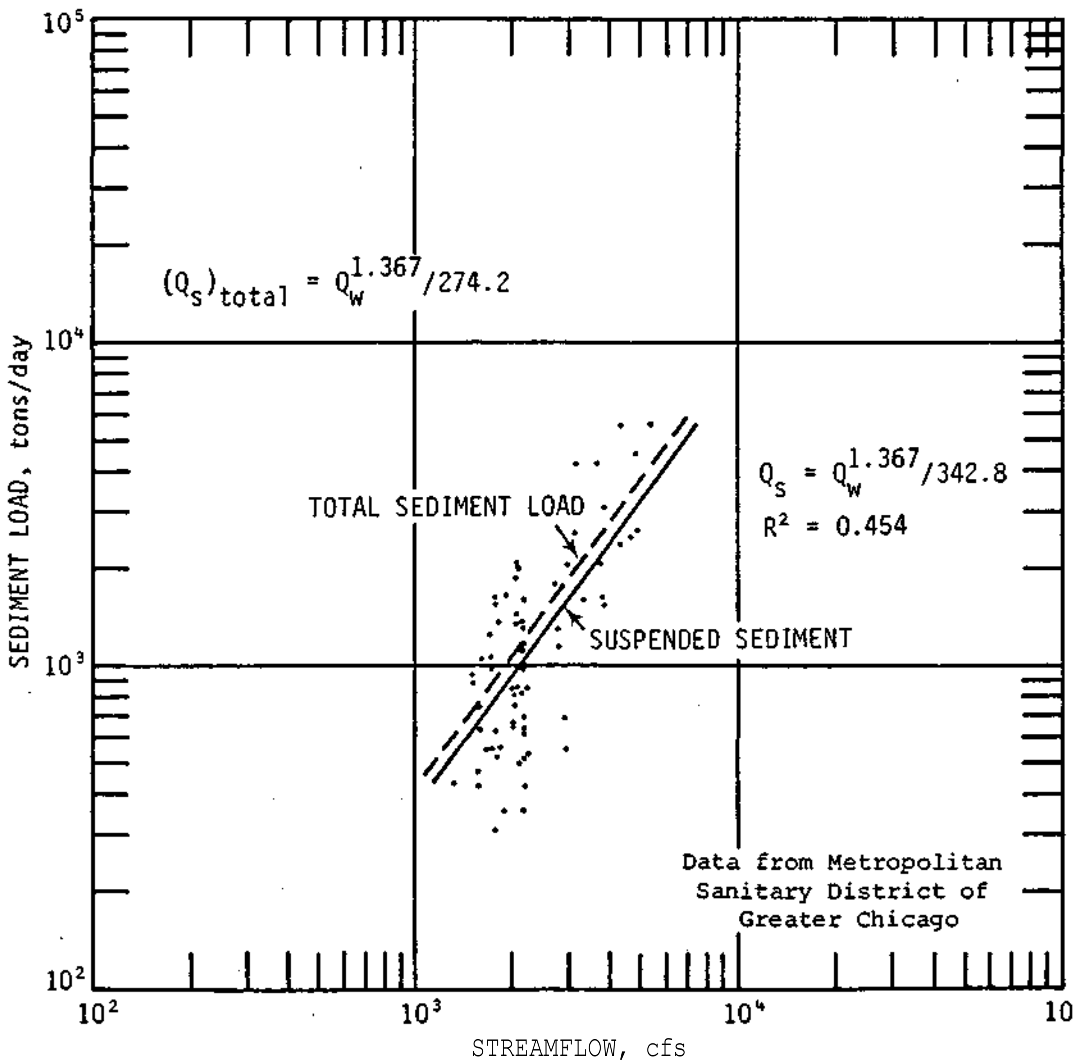


Figure 3. Suspended sediment load and total sediment load rating curves at Lockport, Illinois

where Q_s is the suspended solids load in tons per day, and Q_w is streamflow in cfs. The square of the correlation coefficient, R^2, for this regression line is 0.454.

In order to estimate the total sediment load, the bed load must be added to the suspended solids load. Field data related to bed load are almost non-existent. Some qualified estimate must be made to determine the bed load in a river. Simons and Senturk (1977) indicated that for a river system similar to the Illinois River, about 5 to 25 percent of the sediment load is probably carried as bed load. If it is assumed that about 20 percent of the total sediment load is transported by the river as bed load, then the relationship given by equation 1 can be modified to determine the total sediment load in the river. This modified relationship is given by equation 2.

$$(Q_s)_{total} = Q_w^{1.367}/274.2 \qquad (2)$$

where $(Q_s)_{total}$ is the total sediment load in tons per day.

2. Dresden Dam. This station is located at the Dresden Dam on the Illinois River. The grab samples were collected by MSDGC during the months of May, August, and November of 1976, and February and April of 1977. Samples were collected at either 8- or 24-hour intervals. Analyses for 16 water quality parameters were made (Elmore, 1977). Streamflows at the time of sampling were estimated from an adjacent USGS temporary gaging station. These data are tabulated in Appendix B.

The total suspended solids data and streamflow data were plotted on log-log paper as shown in figure 4. A linear regression equation was derived from this set of data. The relationship is given by equation 3.

$$Q_s = Q_w^{1.806}/8817 \qquad (3)$$

The square of the correlation coefficient, R^2, for this set of data is 0.792.

Here also, if it is assumed that the bed load is about 20 percent of the total sediment load, then the relationship for total load is as given in equation 4.

$$(Q_s)_{total} = Q_w^{1.806}/7054 \qquad (4)$$

3. Marseilles. This station is located on the right bank about 0.4 mile downstream from the Marseilles Lock and Dam near River Mile 247. This is a stream gaging station operated by the USGS, and was established in 1919. In addition to the streamflow measurement, the USGS has been collecting suspended sediment load and other water quality data at this station since 1975 as a part of their National Stream-Quality Accounting Network stations.

Depth-integrated samplers were used to collect the suspended sediment samples. Samples were collected at four verticals in the river cross section. The samples were analyzed to determine the suspended sediment concentration. Techniques followed to determine the suspended sediment concentrations are given by Guy (1969). The sediment load in tons per day can be determined by

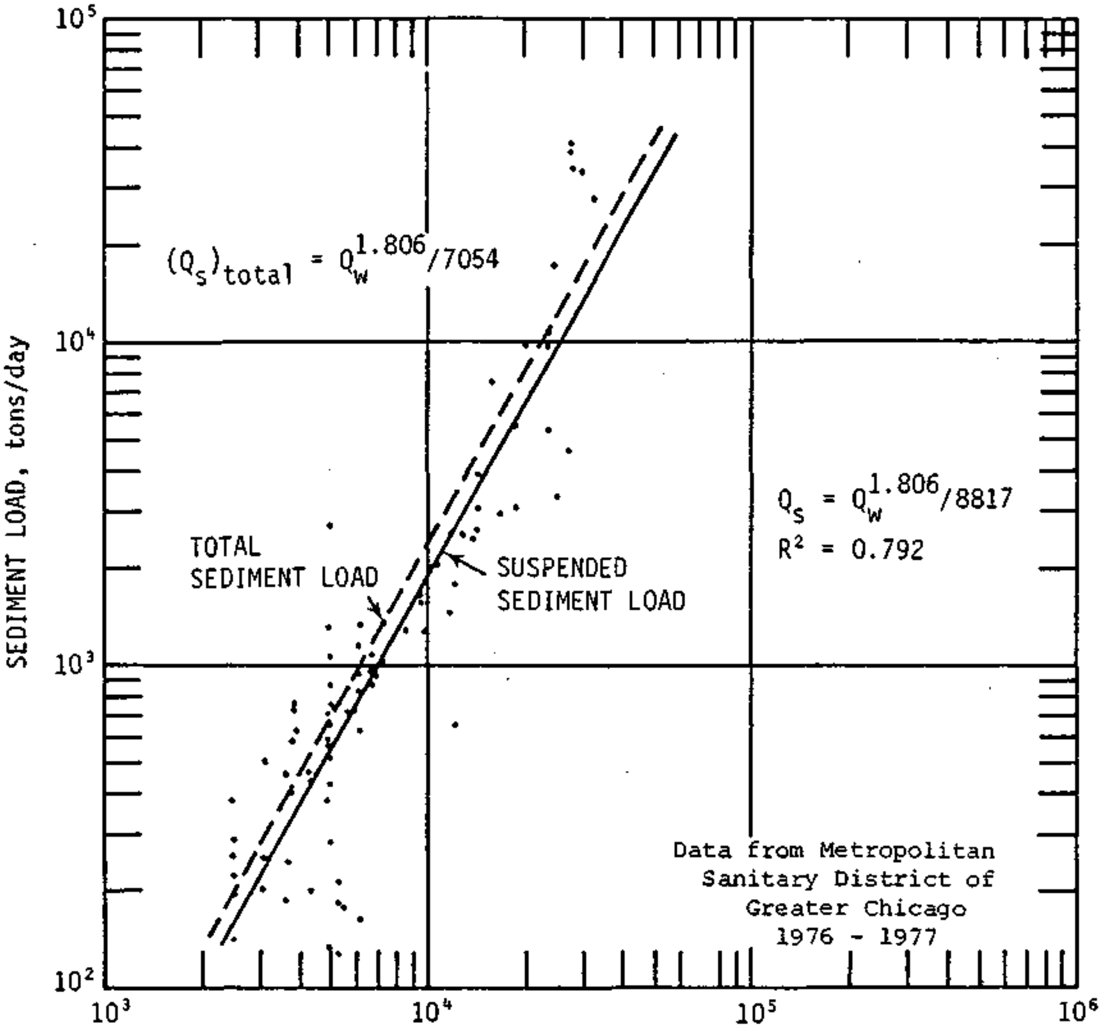


Figure 4. Suspended sediment load and total sediment load rating curves at Dresden Dam

the conversion equation $Q_s = 0.0027 CQ_w$, where C is the sediment concentration in parts per million and Q_w is water discharge in cfs. This equation is valid for C equal to or less than 1000 ppm. The suspended sediment and streamflow data collected to date at Marseilles are tabulated in Appendix C.

Suspended sediment loads in tons per day were plotted against the streamflow discharge in cfs on log-log paper as shown in figure 5. The least square method was used to define the best fitted line. The relationship thus derived is given by equation 5.

$$Q_s = Q_w^{1.483}/371.5 \quad (5)$$

Here, the value of R^2 is 0.772. Again, if we assume that the bed load is only 20 percent of the total sediment load, then the equation for the total load is given by equation 6.

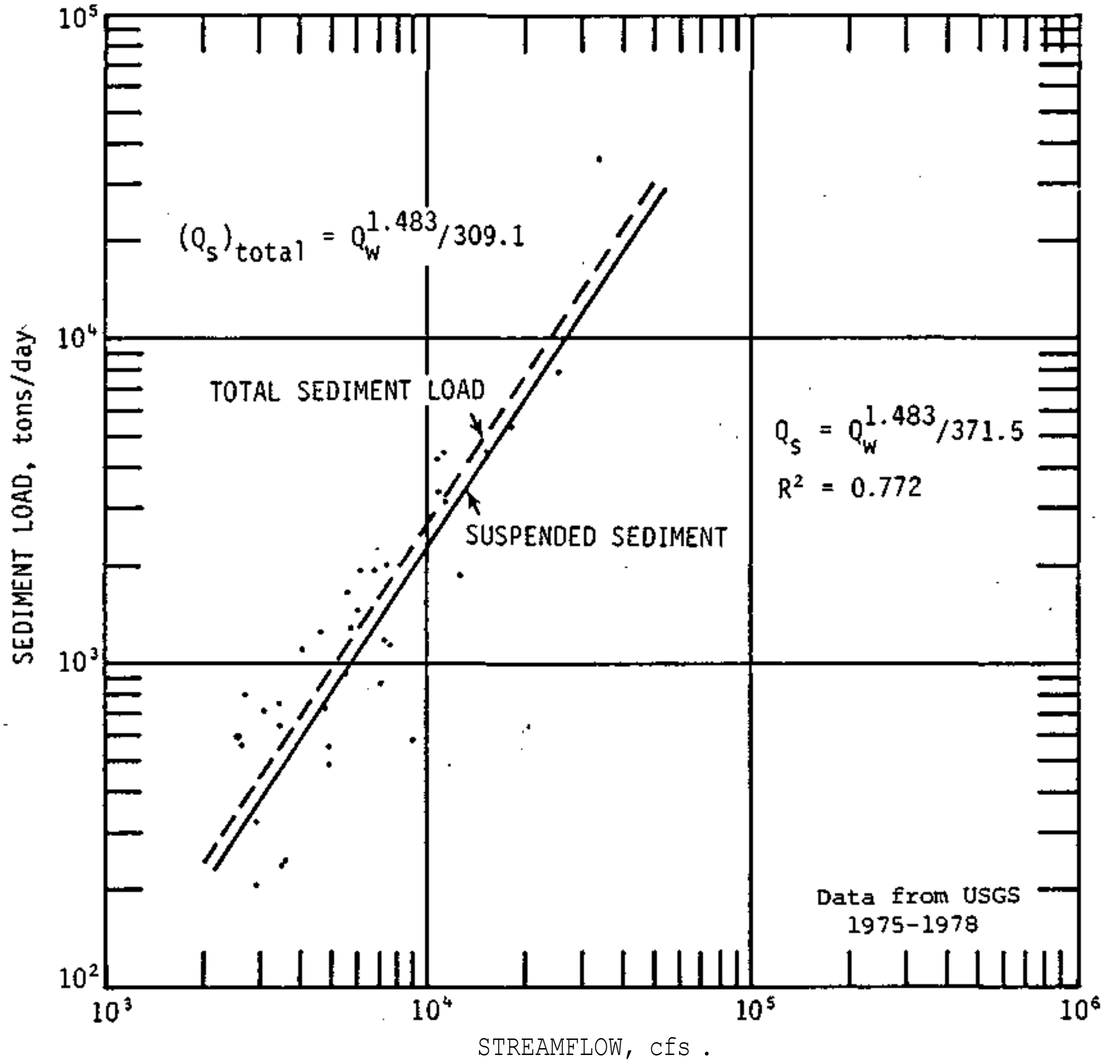


Figure 5. Suspended sediment load and total sediment load rating curves at Marseilles, Illinois

$$(Q_s)_{total} = Q_w^{1.483}/309.1 \qquad (6)$$

4. Valley City. This station is located about 0.5 mile east of Valley City near River Mile 61.4. This is also a gaging station operated by the USGS. The station is slope-rated and the records of streamflow are determined from the Meredosia stream gaging station which is about 9.4 miles upstream of Valley City. The suspended sediment data and other water quality data have been collected by the USGS since 1975 as a part of their National Stream-Quality Accounting Network stations. The suspended sediment and the corresponding streamflow data to date are tabulated in Appendix D.

These data were plotted on log-log paper with Q_s versus Q_w as shown in figure 6. A linear regression equation was derived and is given below.

$$Q_s = Q_w^{1.07}/3.27 \qquad (7)$$

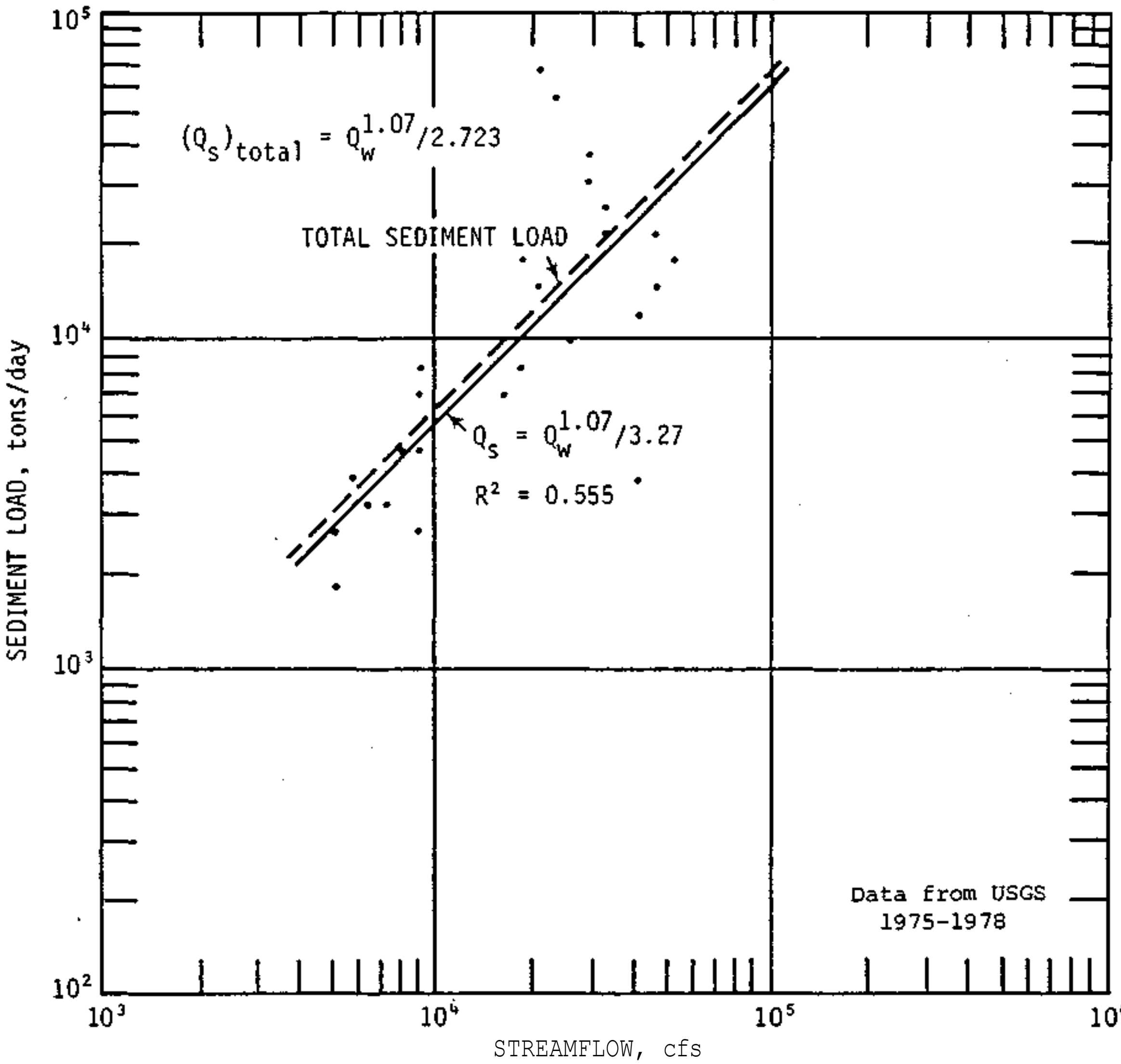


Figure 6. Suspended sediment load and total sediment load rating curves at Valley City, Illinois

The value of R^2 for this equation is 0.555. Again, assuming that about 20 percent of the total load is bed load, the equation for total sediment load is given by equation 8.

$$(Q_s)_{total} = Q_w^{1.07}/2.723 \quad (8)$$

Confidence Test

In order to assess the reliability of the linear regression equations developed thus far, a confidence-interval analysis was conducted for the data from the Marseilles gaging station. The (1-a) confidence interval for log $Q_s = A + B (\log Q_w)_o$ is given by Miller and Freund (1965) by equation 9.

$$CI = A + B (\log Q_w)_o \pm t_{\alpha/2} S_e \sqrt{1 + \frac{1}{n} + \frac{[(\log Q_w)_o - \overline{\log Q_w}]^2}{s_x^2 (n-1)}} \quad (9)$$

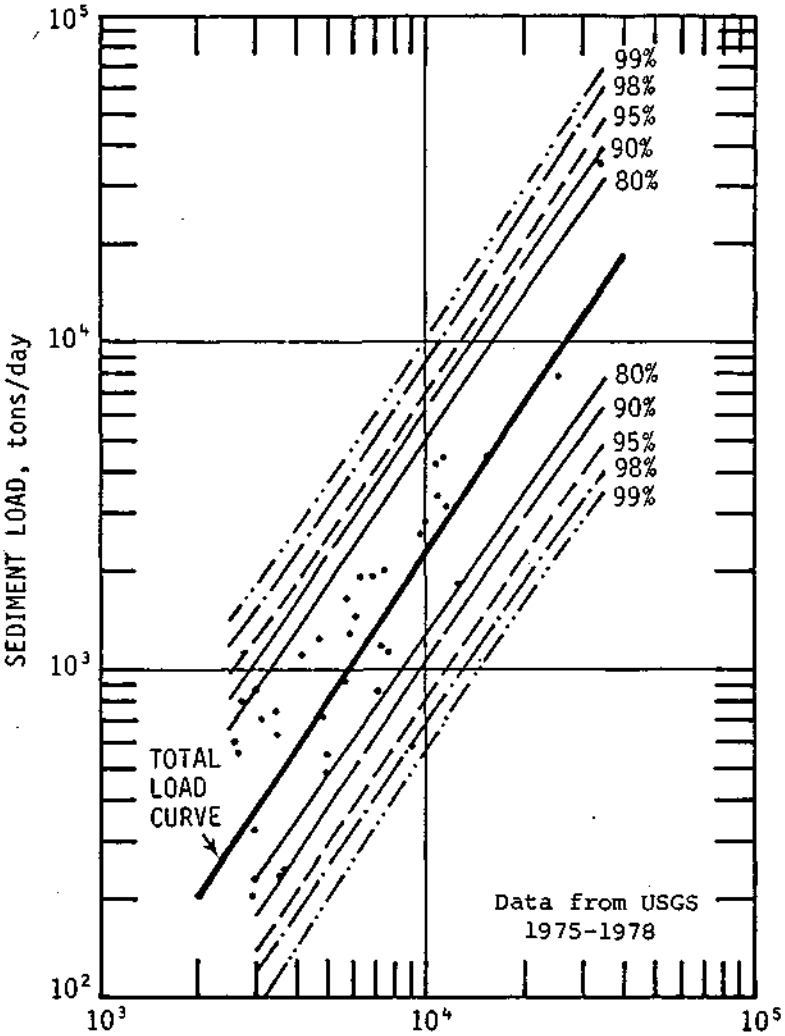
where CI is the confidence interval; a, generally expressed in percent, is the estimated sample values that may fall outside the confidence interval; A and B are regression equation coefficients; $t_{a/2}$ is the student t-distribution with $a/2$ probability; $(\log Q_W)_o$ is the value of log Q_w, where log Q_s value is to be predicted; S_e is the standard error of estimate; s_x^2 is the sample variances of log Q_w; n is the total number of samples; and log Q_w is the mean of the log Q_w samples.

With equation 9, the confidence intervals at 80, 90, 95, 98, and 99 percent levels were computed for the sediment rating curves at Marseilles (figure 5). The results are shown in figure 7. For a given discharge, say 3162 cfs, the estimated total sediment load becomes 417 tons per day (figures 5 and 7). For an 80 percent confidence interval, the predicted Q_s varies from 232 to 894 tons per day corresponding to a discharge of 3162 cfs (figure 7). This indicates that there is an 80 percent probability that the sample values will fall within this interval. This also indicates that the estimated value can be underestimated by 50 percent or overestimated by 100 percent.

Long-Term Sediment Yield

The flow duration and sediment rating curve method as given by Vanoni (1975) was used to determine the long-term sediment yield at various gaging stations on the Illinois River. The equations for sediment rating curves at various locations are given by equations 1 through 8. In the development of the flow duration curves, the streamflows are arranged in descending magnitude, and then the percent of time any specific flow is equaled or exceeded is computed. The flow-duration curve is a graphical relationship between the streamflow and the corresponding time in percent when the flow is equaled or exceeded. Data for the flow-duration curve at Marseilles were taken from Curtis (1969). The discharge, percent of time the flow exceeded or equaled, the incremental discharge between any two time periods, and the corresponding total sediment load in tons per day for the Marseilles gaging station are given in table 2. Various parameters in table 2 are as follows:

- Col. 1: percent of time the discharge exceeded the indicated value in Column 3
- Col. 2: increment between two succeeding intervals in Column 1
- Col. 3: discharge in cfs
- Col. 4: median discharge in cfs for the indicated intervals of Column 3
- Col. 5: total sediment load in tons per day corresponding to the median discharge, Column 4, computed by equation 6
- Col. 6: fraction of mean flow in cfs obtained by multiplying Columns 2 and 4
- Col. 7: fraction of mean total sediment load in tons per day obtained by multiplying Columns 2 and 5



STREAMFLOW, cfs

Figure 7. Confidence interval of total sediment rating curve at Marseilles, Illinois

The sum of Column 6 is 9208 cfs and the corresponding sum of Column 7 is 2792 tons per day. The annual total sediment yield at Marseilles can now be computed and is given in equation 10.

$$\text{Annual total sediment yield} = 2792 \times 365 = 1.019 \times 10^{6} \text{ tons} \quad (10)$$

The drainage area at Marseilles is 8259 square miles. Thus the total sediment yield is 123 tons per square mile per year or 0.193 tons per acre per year. This is exactly the same value that was obtained by Bhowmik (1977) for the Marseilles gaging station for the 1976 water year based on about 18 sets of suspended sediment data.

Table 2. Long-Term Total Sediment Load Estimated for the Illinois River at Marseilles

Percent of time discharge exceeded: Ordinate	Percent of time discharge exceeded: Increment	Water discharge (cfs): Ordinate	Water discharge (cfs): Median	Total sed. load in (tons/day)	Fraction of mean flow (cfs)	Fraction of mean total sed. load (tons/day)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0.0		69,000				
0.1	0.1	61,000	65,000	44,400	65	44
0.1	0.0	54,000	57,500	37,000	0	0
0.2	0.1	48,400	51,000	31,000	51	31
0.4	0.2	43,000	45,500	26,200	91	52
0.9	0.5	38,000	40,500	22,000	203	110
1.4	0.5	34,000	36,000	18,500	180	93
2.1	0.7	30,000	32,000	15,500	224	109
3.2	1.1	26,000	28,000	12,700	308	140
4.4	1.2	23,000	24,500	10,500	294	126
5.6	1.2	21,000	22,000	8,906	264	107
8.4	2.8	18,000	19,500	7,450	546	209
10.9	2.5	16,000	17,000	6,080	425	152
14.4	3.5	14,000	15,000	5,050	525	177
16.6	2.2	13,000	13,500	4,320	297	95
22.9	6.3	11,000	12,000	3,630	756	229
26.8	3.9	10,000	10,500	2,970	410	116
32.7	5.9	8,900	9,450	2,540	558	150
39.8	7.1	7,900	8,400	2,140	596	152
48.3	8.5	7,000	7,450	1,790	633	152
57.4	9.1	6,200	6,600	1,490	600	136
68.3	10.9	5,500	5,850	1,250	638	136
79.0	10.7	4,900	5,200	1,050	556	112
90.6	11.6	4,300	4,600	875	534	102
96.5	5.9	3,800	4,050	724	339	43
98.8	2.3	3,400	3,600	608	83	14
99.6	0.8	3,000	3,200	511	26	4
99.8	0.2	2,700	2,850	430	6	1
99.9	0.1	2,400	2,550	365	0	0
100.0	0.1	2,100	2,250	303	0	0

If we assume that the average erosion rate in the watershed is approximately 5 tons per acre per year (Lee and Stall, 1977), the sediment delivery ratio becomes 0.04 which means that about 4 percent of the eroded sediment from the watershed is being transported by the Illinois River. This value seems reasonable considering such a large watershed.

SEDIMENT TRANSPORT BASED ON 1940 FLUSHING EXPERIMENT

The Sanitary District of Chicago performed a flushing experiment from noon December 2 to noon December 12, 1940. The permit to conduct the flushing experiment was issued by the U.S. Supreme Court. During the experiment, the diversion from Lake Michigan was increased from about 1500 cfs to about 8400 cfs within a period of 1 day. Discharge at Lockport during this experiment averaged about 9973 cfs. Although the experiment lasted for 10 days, the basic data were collected for a period of about 20 days.

Water samples were collected at 14 stations along the Chicago Sanitary and Ship Canal and the Illinois River. These samples were analyzed to determine various water quality parameters. Data from the following 8 stations were used for the present study.

1. Chicago River Lock near Lake Michigan (River Mile 327)
2. 18th Street Bridge (River Mile 323)
3. Summit Bridge (River Mile 313)
4. Lockport, Joliet (River Mile 292)
5. Cass Street, Joliet (River Mile 288)
6. Brandon Road Dam, Joliet (River Mile 286)
7. Marseilles (River Mile 246)
8. Chillicothe (River Mile 173)

The locations for the first 6 stations are shown in figure 8.

The sampling schedule at the more important stations consisted of collecting water samples hourly for suspended solids. Samples for dissolved oxygen, biochemical oxygen, and turbidity analyses were collected every 4 hours. Results of this experiment are presented in the following subsections. The basic data are given in table 3.

1. Chicago River Lock. The results of analysis show that the suspended solids concentration was about 49 ppm on the fourth day of diversion. Subsequently, the concentration decreased to about 20 ppm with no appreciable change during the experiment (table 3).

2. 18th Street Bridge. The suspended solids concentration was about 50 ppm on December 3 and 4, 1940. However, the concentration decreased to about 25 ppm during the latter part of the experiment (table 3). Apparently very little scouring took place in this section of the Chicago River.

3. Summit Street Bridge. At Summit Street Bridge (River Mile 313), the maximum 24-hour average total suspended solids concentration was 115 ppm. The concentration decreased to about 50 ppm during the last 5 days of the test and remained about the same level after the completion of the test (table 3).

4. Lockport. The total suspended solids concentration at Lockport (River Mile 292) increased from 16 ppm on November 27, 1940, to a maximum of 491 ppm on December 3 and was at about this level during the first 5 days of the test (table 3). Then, the total suspended solids concentration decreased to about 150 ppm on December 11 at the end of the test. During the test the discharge

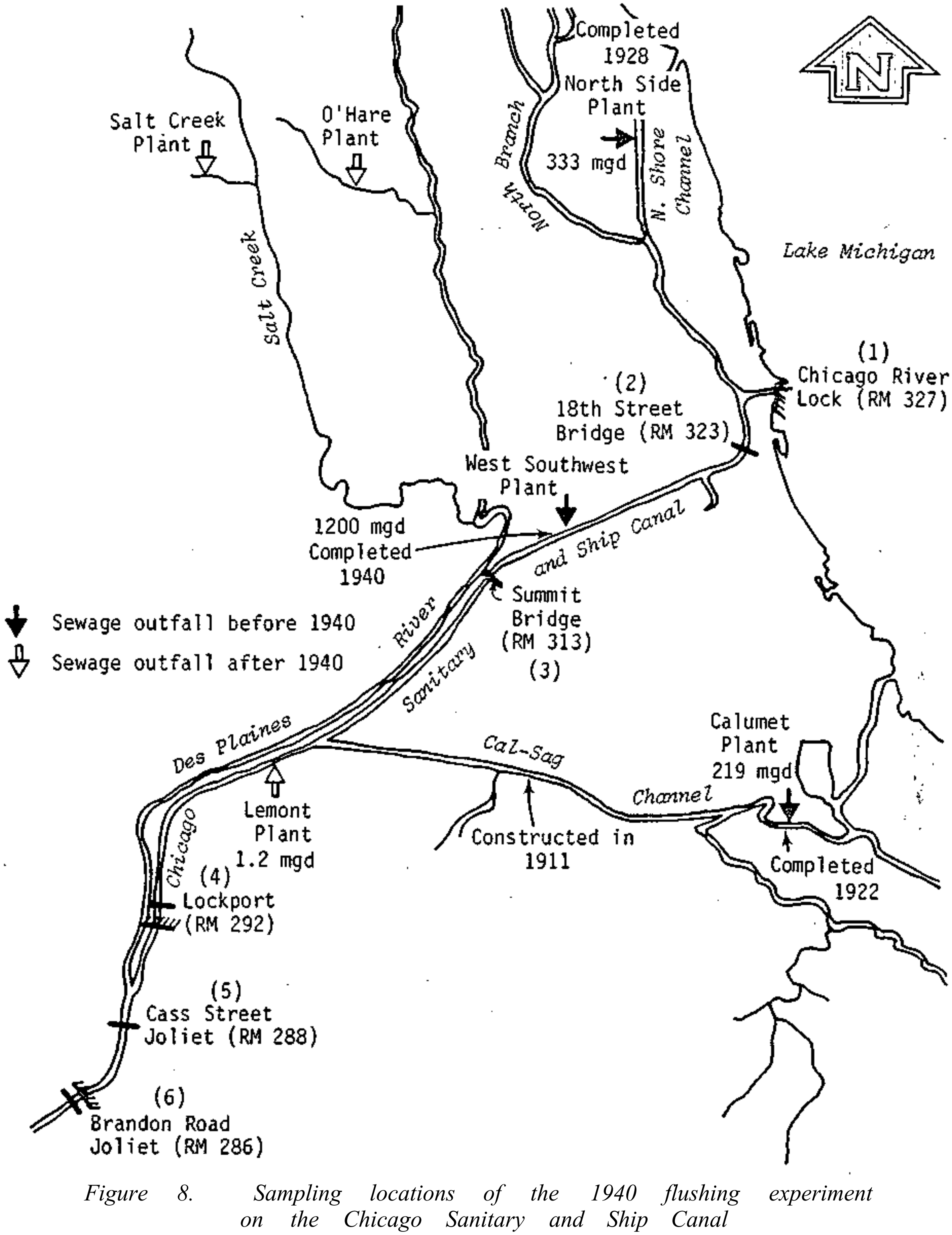


Figure 8. Sampling locations of the 1940 flushing experiment on the Chicago Sanitary and Ship Canal

Table 3. Suspended Solids Data of the 1940 Flushing Experiment at Chicago Sanitary and Ship Canal

	Inside Chicago Lock RM 327			18th Street Bridge RM 323			Summit Bridge RM 313			Lockport RM 292		
Date	Discharge (cfs)	Concentration (ppm)	Suspended solids load (tons/day)	Discharge (cfs)	Concentration (ppm)	Suspended solids load (tons/day)	Discharge (cfs)	Concentration (ppm)	Suspended solids load (tons/day)	Discharge (cfs)	Concentration (ppm)	Suspended solids load (tons/day)
1940												
Nov. 27	1369	-	-	1369	-	-	-	-	-	2866	16	124
28	1716	-	-	1716	-	-	-	-	-	3214	19	165
29	1361	-	-	1361	-	-	1361	38	140	2849	17	132
30	1562	-	-	1562	-	-	1562	50	211	2999	15	121
Dec. 1	1258	-	-	1258	-	-	1258	38	129	2708	18	131
2	9231	-	-	9231	-	-	9231	101	2517	10770	327	9490
3	8262	-	-	8262	54	1205	8262	114	2543	9828	491	13000
4	8692	-	-	8692	48	1126	8692	115	2699	10246	489	13490
5	8307	49	1099	8307	-	-	8307	79	1772	9857	319	8470
6	8088	19	452	8088	14	306	8088	84	1834	9645	264	6860
7	8193	-	-	8193	36	796	8193	52	1150	9679	193	5035
8	8453	-	-	8453	21	479	8453	48	1096	9949	179	4800
9	8278	27	604	8278	24	536	8278	52	1162	9843	172	4565
10	8266	16	357	8266	25	558	8266	54	1205	9819	161	4260
Dec. 11	8539	14	323	8539	29	669	8539	50	1153	10090	148	4020
12	2231	-	-	2231	18	108	2231	53	319	3772	48	478
13	1020	13	36	1020	-	-	1020	42	116	2543	19	130
14	890	15	36	890	27	65	890	39	94	2356	17	108
15	2989	21	170	2989	37	299	2989	56	452	4534	39	476
16	1511	-	-	1511	37	151	1511	47	192	3148	23	195

Table 3. Concluded

	Cass Street, Joliet RM 288			Brandon Road RM 286			Marseilles RM 246			Chillicothe RM 173		
Date	Discharge (cfs)	Concentration (ppm)	Suspended solids load (tons/day)	Discharge (cfs)	Concentration (ppm)	Suspended solids load (tons/day)	Discharge (cfs)	Concentration (ppm)	Suspended solids load (tons/day)	Discharge (cfs)	Concentration (ppm)	Suspended solids load (tons/day)
1940												
Nov. 27	2963	-	-	2963	19	152	3930	29	308	5460	-	-
28	3301	-	-	3301	18	160	5030	25	340	5460	25	369
29	2929	21	166	2929	14	110	5370	19	275	4270	32	369
30	3069	22	182	3069	15	124	4880	19	250	3390	23	210
Dec. 1	2778	20	150	2778	14	109	4450	17	204	5460	24	354
2	10845	440	12850	10845	75	2192	6960	86	1616	6000	26	421
3	9903	504	13450	9903	65	1735	13300	75	2693	8980	34	824
4	10316	482	13400	10316	73	2030	12200	58	1910	9320	73	1837
5	9224	379	10145	9924	91	2435	12200	53	1746	11100	59	1768
6	9710	282	7400	9710	79	2069	12600	46	1565	11100	49	1469
7	9754	216	5680	9754	109	2861	12200	63	2075	11500	61	1894
8	10047	216	5850	10045	78	2112	12600	57	1939	11800	52	1657
9	9955	198	5310	9955	69	1850	12900	51	1776	13100	47	1662
10	9946	188	5040	9946	64	1715	13100	57	2016	10700	55	1589
Dec. 11	10245	177	4885	10245	77	2124	13000	53	1860	12600	39	1327
12	3947	63	670	3947	31	330	11700	39	1232	13100	43	1521
13	2703	30	218	2703	21	153	5610	16	242	10700	31	896
14	2491	28	188	2491	23	154	4170	14	158	8980	21	509
15	4649	46	576	4649	36	457	3930	18	191	7250	17	333
16	3238	30	261	3238	48	419	7100	15	288	6870	35	649

varied from a maximum of 10,770 cfs to a minimum of 9645 cfs with 10,090 cfs on December 11 when the concentration was 148 ppm. After the completion of the test, the concentration decreased to about 30 ppm.

5. Cass Street, Joliet. This station is about 4 miles downstream of Lockport (River Mile 288). The variability of the total suspended solids concentrations was similar to that observed at Lockport during the test.

6. Brandon Road Dam. At Brandon Road (River Mile 286) which is 2 miles downstream of Cass Street, Joliet, the maximum daily average total suspended solids concentration was about 60 to 90 ppm as shown in table 3. Toward the end of the test, the total suspended solids concentration decreased slightly. The sampling was done downstream of the Brandon Road lock and dam. Obviously, most of the suspended solids had deposited in the pool upstream of the Brandon Road dam.

7. Marseilles. Farther downstream at Marseilles (River Mile 246), the total suspended solids concentration was 20 ppm before the test. For the first 24 hours of the test, the total suspended solids concentration increased to about 86 ppm. On the last day of the test, the total suspended solids concentration decreased "to 53 ppm and back to 17 ppm or less after the test was completed. This was almost the same concentration that was observed before the start of the test.

8. Chillicothe. At Chillicothe (River Mile 173), which is about 73 miles downstream from Marseilles, the total suspended solids concentration averaged 26 ppm prior to the test. No appreciable increase occurred until December 4 (the second day of the test). The average total suspended solids concentration reached a high value of 73 ppm on December 4, 1940. During the 10-day test period, the total suspended solids averaged about 50 ppm. After the test, the average concentration came down to about 30 ppm. These data indicate only a moderate increase in concentration at Chillicothe.

Figure 9 shows the variations of the discharge and the computed suspended solids load at the eight stations during the flushing experiment. Figure 9a shows the variability of the discharge. The discharge was kept more or less steady for the duration of the test. Increase in discharge in the downstream direction is related to an increase in drainage area and a consequent increase in flow from local inflows. However, at each station, the flow was approximately steady from December 1 through December 11.

The variability of the suspended solids load at various stations, figure 9b, depicts a different story. There is a sudden and rapid increase in suspended solids load at the Lockport and Cass Street, Joliet, stations. This 12-to 13-fold increase in suspended solids load remained more or less steady for the first 3 days of the test. The suspended solids load increased from 150 tons per day to 13,000 tons per day. After this initial surging increase, the suspended solids load showed a steady decrease in value to about 5000 tons per day on December 7, even though the discharge remained more or less constant during this period of the test. The other 6 stations showed a moderate increase in suspended solids load for the duration of the test.

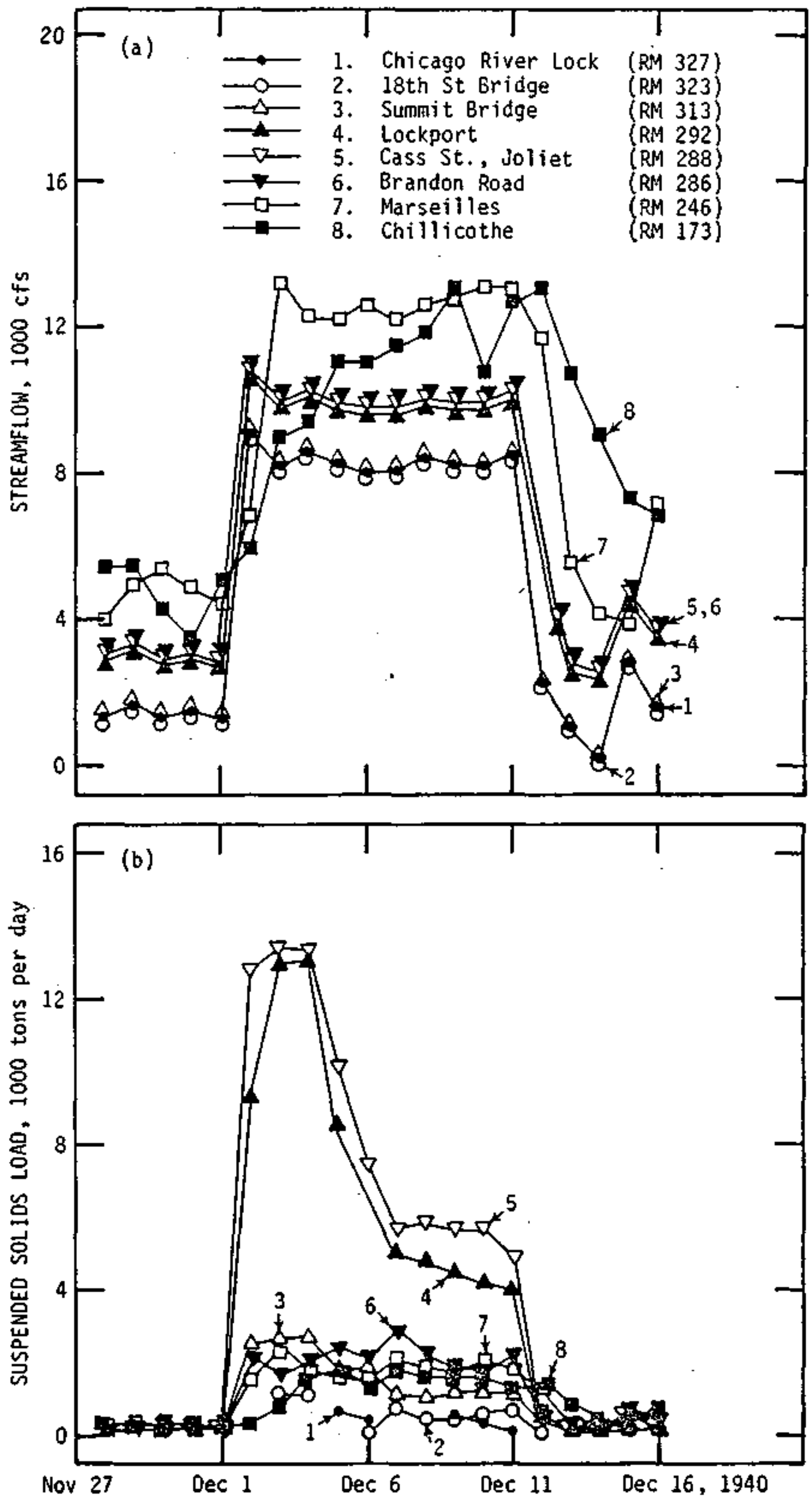


Figure 9. Streamflow (a) and the total suspended solids load (b) at 8 stations based on the 1940 flushing experiment

The probable reason for this rapid and sudden increase in suspended solids load at the Lockport and Cass Street stations can be explained as follows. Both stations are located downstream of sewage outfalls. In all probability, large amounts of sludge had deposited on the bed and banks of the Sanitary and Ship Canal. As soon as the discharge was increased about 3-fold, an increase in average velocity occurred. This in turn must have been responsible for scouring the bed and the banks of the Canal. However, after 3 days of operation, the stream must have attained some stability and the flow and the carrying capability of the flow reached an equilibrium state, as a result of which the suspended solids concentration dropped. It is true that the increased flow was still scouring the bed and banks of the Canal, but with reduced intensity. It is also true that the Canal at this location might have developed some armor coating after a few days of increased flow. At the end of the test, the suspended solids concentration at the Lockport and Cass Street stations had dropped to or near the pre-test concentration levels.

The six stations either upstream or downstream of these two stations, did not show much variability in comparison with the pre-test conditions. The Canal upstream of Summit Bridge was possibly very stable and relatively free of any sludge deposits. This may explain why the solids concentration was low at the Chicago River Lock and Summit Bridge stations (see figures 8 and 9 and table 3). The increased solids concentration at the four stations downstream of Lockport showed moderate increases. Obviously, the lock and dam at Lockport, Brandon Road, Marseilles, and Starved Rock (between the Marseilles and Chillicothe stations) had considerably slowed down the flow velocity with an associated deposition of the suspended solids upstream of these locks and dams.

Figures 10 and 11 show the amount of scour and deposition in the various reaches of the river based on the flushing experiment. These figures were developed from the total amount of suspended solids that had entered and left any specific reach of the river. Only the suspended solids budget for the river is shown. The reach of the river from the Summit Bridge to Cass Street in Joliet showed a considerable amount of scour from the Canal bed and/or banks (figure 10). On the other hand, the reach of the river from Cass Street in Joliet to the Brandon Road lock and dam showed a significant amount of deposition between December 1 through December 11 (figure 11). The reach of the river from Brandon Road to Chillicothe did not show any significant deposition or scour.

It is clear that the scour of the Canal that took place between the Summit Bridge and Cass Street stations was subsequently associated with a similar deposition upstream of the Brandon Road lock and dam. The lock and dam at this location had increased the depth of flow, decreased the flow velocity, and consequently helped in the deposition of the suspended load. This observation is quite interesting in light of the proposed diversion from Lake Michigan, and will be further clarified in the following section.

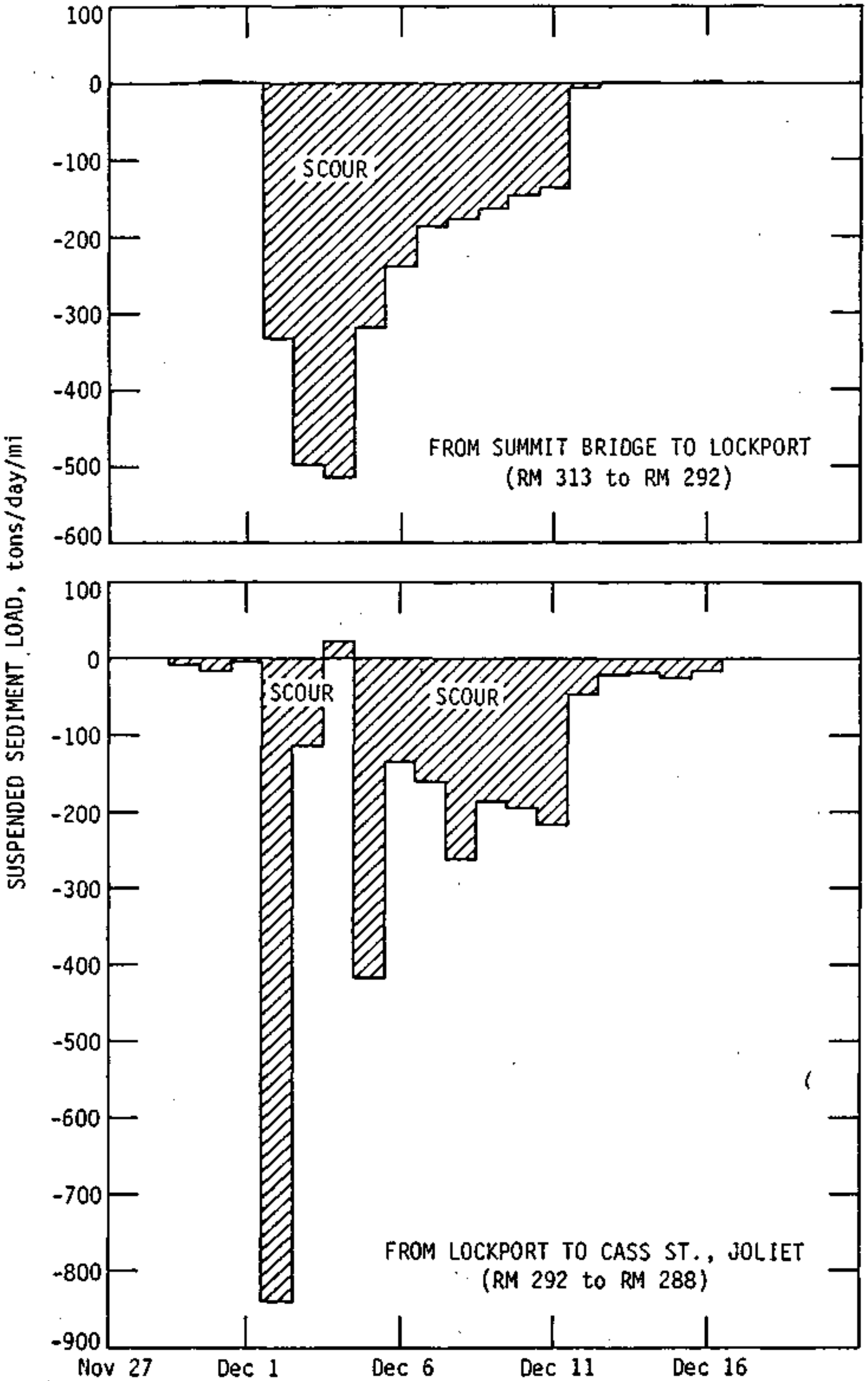


Figure 10. Sediment deposition and scour in the 1940 flushing experiment

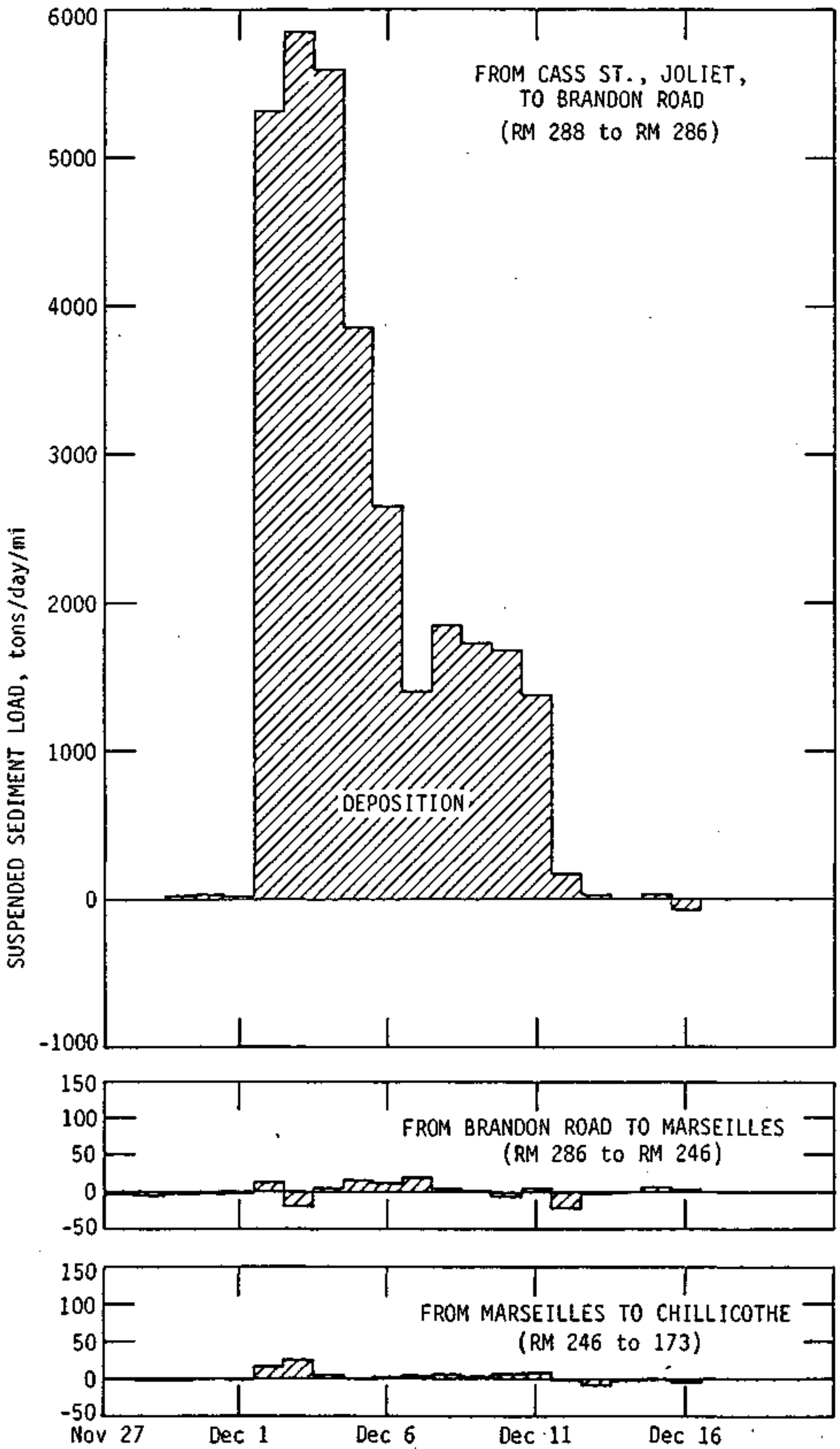


Figure 11. Sediment deposition and scour in the 1940 flushing experiment

PROBABLE EFFECTS OF DIVERSION ON SEDIMENT LOAD

Effects Based on the 1940 Flushing Experiment

If the diversion is raised to 6600 or 10,000 cfs from the presently authorized 3200 cfs, it is reasonable to believe that the increase in sediment load in the Chicago Sanitary and Ship Canal will be similar to those shown in figures 9, 10, and 11 and table 3 for the 1940 flushing experiment. This would be a very significant impact in the reach of the river downstream of Summit Bridge and upstream of the Brandon Road lock and dam (figure 8). The suspended solids may increase in the order of 10- to 60-fold between the Summit Bridge and Cass Street stations. Between Cass Street and the Brandon Road lock, most of the suspended solids will be trapped in the Brandon Road Pool. If the diversion is continued for some time, it is expected that the suspended solids load will decrease gradually with time.

Thus a heavy scouring of the Chicago Sanitary and Ship Canal downstream of sanitary sewage outfalls can be expected. Most of the scouring will be localized depending upon the amount of sludge deposited up to that time. It is also almost certain that the scoured sludge will be deposited in the Brandon Road Pool. The suspended solids which are carried over the Brandon dam will in all probability be deposited farther downstream in the Dresden or Marseilles Pools.

Before 1940, three wastewater treatment plants (the West Southwest, Calumet, and North Side Plants) had outfalls draining to the Sanitary and Ship Canal as shown in figure 8. The West Southwest Plant with a capacity of 1200 million gallons per day (mgd) is located near Summit Bridge. The North Side Plant with a capacity of 333 mgd is located at the North Shore Channel. The Calumet Plant with a capacity of 219 mgd is located at the Cal-Sag Channel. The outfalls from the West Southwest and the Calumet Plants directly drained to the Ship Canal between Summit Bridge and Cass Street. Thus it is suspected that the sludge from these two outfalls, especially the West Southwest Plant, contributed part of the total suspended solids in this reach of the Canal which was subsequently scoured during the 1940 flushing experiment.

The sludge discharge of the North Side Plant with its smaller capacity and greater distance from the Ship Canal probably did not contribute much sludge to the Ship Canal. It is possible that most of the North Side sludge might have traveled downstream before being deposited in the Canal between Summit Bridge and Lockport (figure 8). This may explain why the increase in suspended load between the Chicago River Lock and the Summit Bridge was minimum during the 1940 flushing experiment. However, during the last 40 years, it is probable that a considerable amount of sludge may have deposited in the reach of the Canal upstream of Summit Bridge. If this is true, then the effect of the increased diversion will definitely be felt in the part of the Canal between Summit Bridge and the Chicago Lock in addition to the downstream reach of the Canal below Summit Bridge. This probable effect toward increased sediment load in the Ship Canal will be somewhat different from that observed during the 1940 flushing experiment.

Effects Based on Selected Streamflows and the Sediment Rating Curves

The effects of increased diversion at four selected locations were also investigated on the basis of the sediment rating curves (figures 3, 4, 5, and 6) and the streamflow records supplied by the Army Corps of Engineers for the water years 1971, 1973, and 1977. The discharge and stage records supplied by the Corps of Engineers for 17 locations along the Illinois River showed the variability of the stages and discharges with time for three different flow conditions, namely, the present authorized diversion of 3200 cfs, and the proposed diversions of 6600 and 10,000 cfs. The stage and discharge records shown for the water years 1971, 1973, and 1977 are the computer generated values rather than the measured discharges.

The sediment load was estimated from the rating curve for respective stations based on the discharge at a given time of the year. The technique resulted in a sediment load versus time curve for the specified station for the specific water year. A typical analysis is explained in the next paragraph.

Figure 5, or equation 6, and the corresponding discharge records were used to estimate the total load in the river at the Marseilles gaging station. These results are shown in graphical form in figures 12, 13, and 14 for the water years 1971, 1973, and 1977, respectively. The daily flow and the corresponding daily sediment load are shown. It is quite clear that at this location, the effect of the diversion will be felt in a water year similar to the ones depicted for 1971 and 1977. Water years 1971 and 1977 were relatively dry years and as such the proposed diversions can continue for a relatively longer period of time compared with a wet year such as 1973 when the increased diversion will be extremely limited.

Figures similar to figures 12, 13, and 14 were also developed for the Lockport, Dresden Dam, and Valley City stations. The results are summarized in table 4. In general, for a wet year such as 1973, the impact of increased diversion as far as the sediment load is concerned will be minimum at all locations except at Lockport for an increased diversion of 6600 cfs in which the sediment load can increase by 86 percent. However, for dry years similar to the 1971 and 1977 water years, the sediment load can increase from 172 percent to 337 percent at Lockport when the diversion increases to 6600 cfs and 10,000 cfs, respectively. For the Marseilles gaging station, the increase in sediment load can vary anywhere from 63 to 130 percent corresponding to a diversion of 6600 cfs and 10,000 cfs, respectively. The effect of diversion will be least at the Valley City gaging station. Here, the increase in sediment load can be from 19 to 60 percent corresponding to a diversion of 6600 cfs and 10,000 cfs, respectively.

It must be pointed out that the increased sediment yield computed and shown in table 4 is based on three typical water years. The 1940 flushing experiment was conducted for only a 10-day period. The total suspended solids were shown to increase 10- to 60-fold in the 1940 flushing experiment at Lockport (figure 9) and only about 3- to 4-fold on the basis of the rating curve

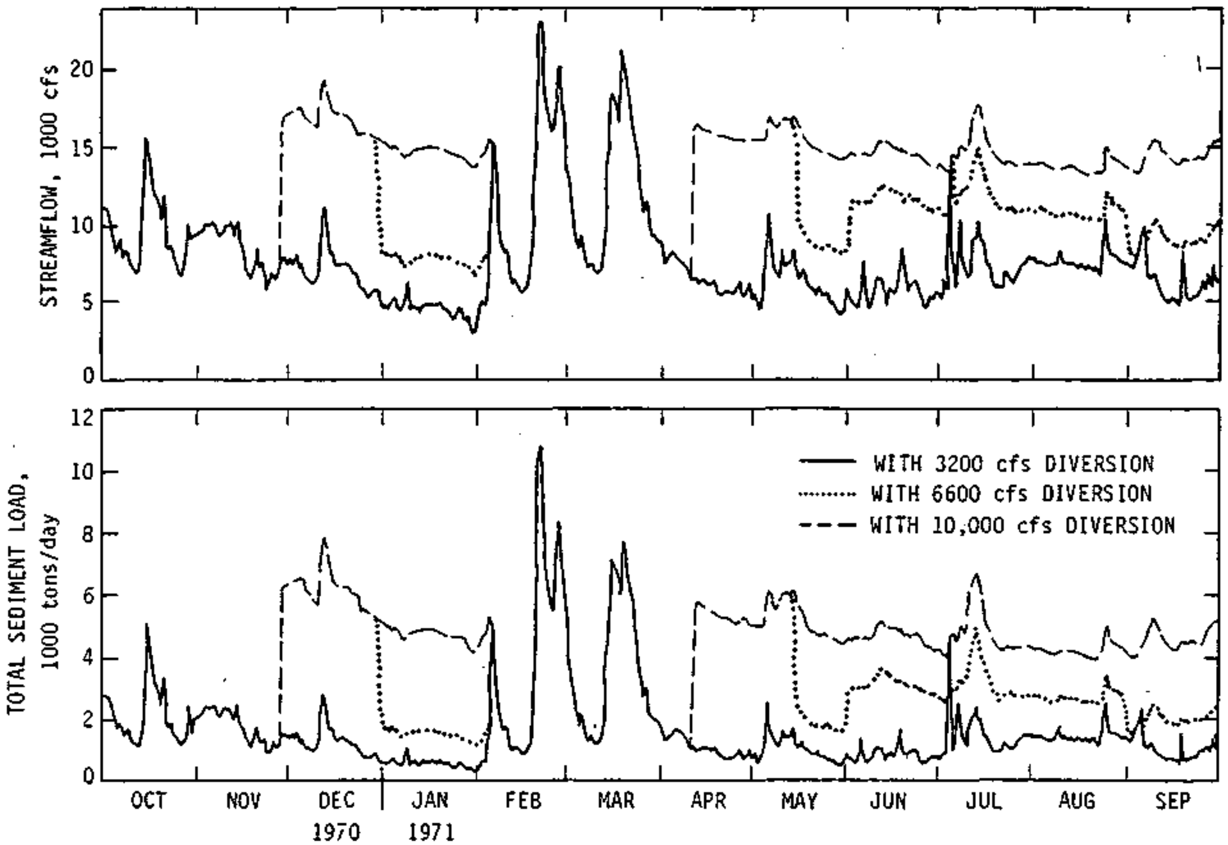


Figure 12. Streamflow and total sediment load for 1971 water year at Marseilles, Illinois

(figure 3 and table 4). In any water year, the increased diversion will take place in only a few selected dry months. Thus the amount of increase in sediment yield may not directly correspond to the average increase in flow in the river.

It is suspected that the rate of increase of the diversion from Lake Michigan will play a major role in the rate of increase in the total suspended solids concentration. If the flow is increased suddenly, a shock-type effect may precipitate a tremendous amount of scour of the Chicago Sanitary and Ship Canal, whereas, a gradual increase in diversion may increase the scour of the Canal at a lower rate. However, this inference needs to be substantiated in the future demonstration program.

RECOMMENDED MONITORING AND RESEARCH PROGRAM

The analysis presented so far indicates that there exists a possibility that some functional relationship can be developed to estimate the sediment transport rate in the Illinois River at a few selected sites. Since the USGS

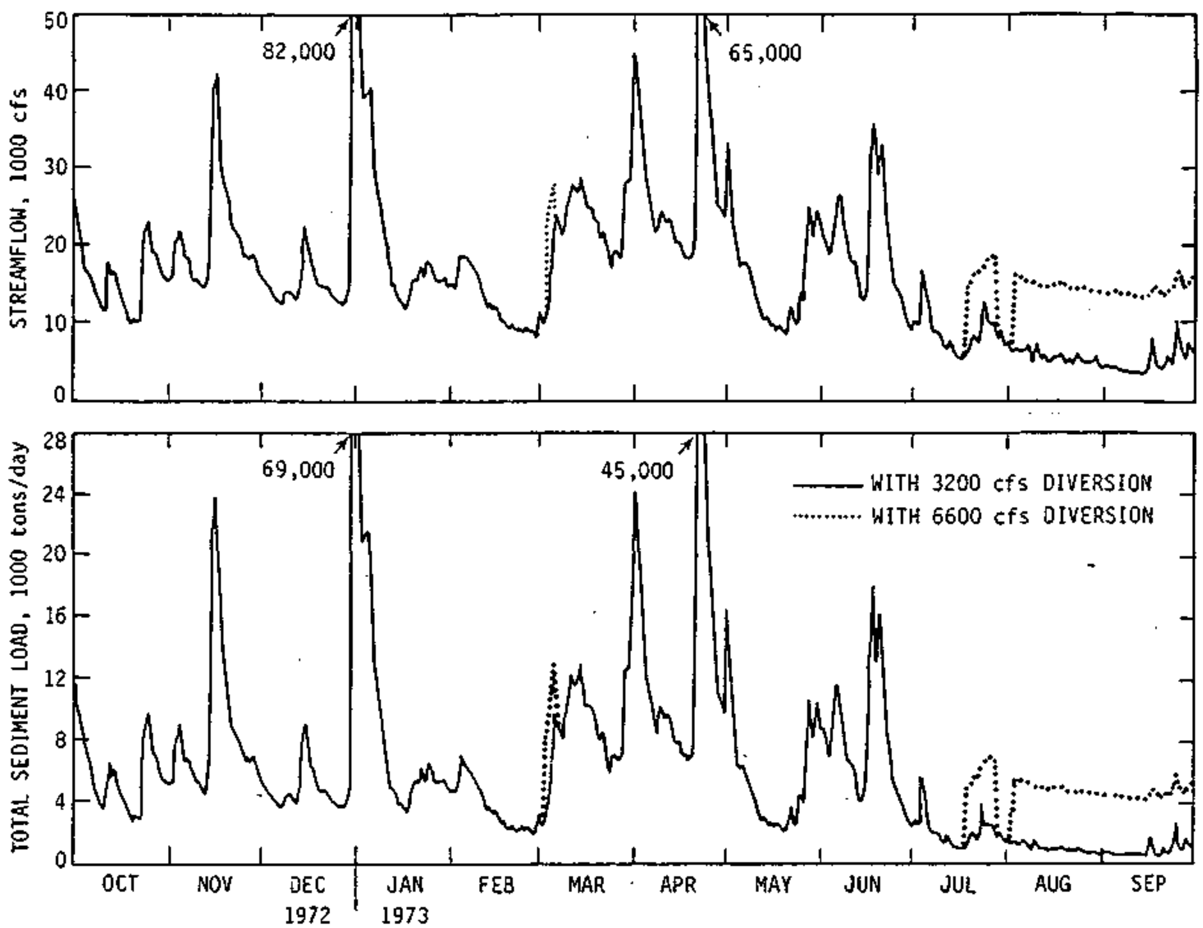


Figure 13. Streamflow and total sediment load for 1973 water year at Marseilles, Illinois

has already established a program of data collection at two gaging sites, it is reasonable to investigate these two sites and further expand the present program.

This proposed research will be somewhat tilted toward basic data collection. Lack of field data related to sediment transport in Illinois streams is quite evident. This proposed research is almost identical to the research proposed by Bhowmik (1977).

The proposed research can be divided in two broad categories: 1) data collection, and 2) theoretical development, analysis of the data, and application of the results. The proposed research is basically for 1 year but may be extended to 2 years.

Data Collection

A brief description of the existing suspended sediment data collection program by the USGS has already been given. The proposed data collection is as follows.

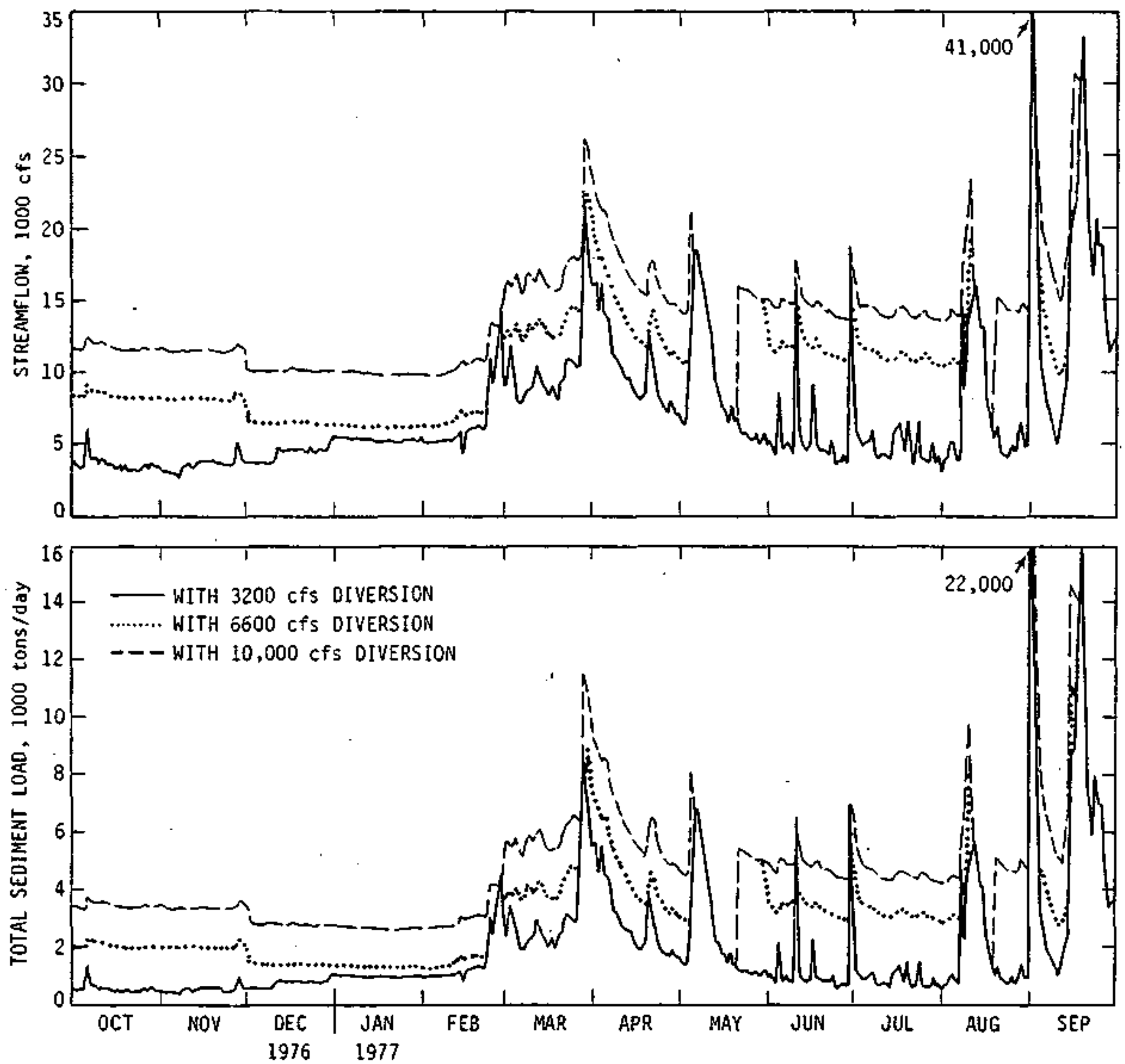


Figure 14. Streamflow and total sediment load for 1977 water year at Marseilles, Illinois

1) Gaging stations at Marseilles and Valley City will be selected as two of the data collection stations.

2) Two additional sediment stations will be selected, one between the 18th Street Bridge and Summit Bridge and another one near Cass Street, Joliet (figure 8). Both stations will be on the Chicago Sanitary and Ship Canal. Since the USGS is already collecting some sediment data, it will be contracted to collect these additional data. During the actual diversion program, data from two additional stations on the Chicago Sanitary and Ship Canal will be collected by State Water Survey personnel. The locations for these stations will be selected later.

Table 4. Impacts of Diversion at Four Stations along the Illinois River

Location and water year	Present diversion of 3200 cfs, total sediment load (million tons/year)	Diversion of 6600 cfs, increase in sediment load (percent)	Diversion of 10,000 cfs, increase in sediment load (percent)
Lockport			
1971	0.092	+174	+298
1973	0.103	+ 86	-
1977	0.088	+172	+337
Dresden Dam			
1971	0.61	+ 88.5	+152.8
1973	1.96	+ 15.1	-
1977	0.56	+ 86.0	+177.1
Marseilles			
1971	0.82	+ 63.4	+106
1973	2.29	+ 12.2	-
1977	0.74	+ 66.2	+130
Valley City			
1971	4.91	+ 19.0	+ 30.4
1973	12.48	+ 3.0	-
1977	3.16	+ 33.4	+ 59.9

3) Data to be collected include: depth-integrated suspended sediment samples, bed material samples, velocity distribution data where suspended sediment samples are to be collected, water surface slope near the gaging stations, water discharge either measured or determined from rating curves, cross section geometry, water temperature, and other related data that may be necessary in estimating the total sediment load. These data will be collected twice a month from the four gaging stations maintained by the USGS.

4) Suspended sediment data will be collected by the equal transit rate (ETR) method. The channel width will be divided into 15 increments of equal widths and 3 depth-integrated samples will be collected from a vertical at the middle of each increment. A total of 900 suspended sediment samples will be collected at each location.

5) Two bed material samples will be collected at each gaging station during each data collection trip for a total of 50 samples at each location.

6) Stream gaging stations will be installed and operated at the selected data collection locations where none is available.

7) During the actual diversion, the frequency of data collection may vary anywhere from 1 to 4 hours at a few selected locations, especially on the Chicago Sanitary and Ship Canal.

Analysis of the Data

1) The suspended sediment samples will be analyzed to determine the concentration in each of the verticals. The bed material samples will be analyzed to determine the size distribution of the bed materials.

2) The suspended sediment data, bed material data, velocity distribution data, water surface slope, discharge data, and any other existing or new data will be analyzed by State Water Survey personnel to determine the total load carried by the Illinois River at the four locations described above. In addition, the data that will be collected during the actual proposed diversion will be analyzed.

   Various methods are available to compute the total sediment load in a river from field measurements. These methods are discussed by Simons and Sentiirk (1977) and Vanoni (1975) . It is suggested to follow initially any one of these methods to determine the total sediment load.

3) Data related to storm patterns in the watershed for the duration of the data collection program will also be analyzed.

4) The analyzed data will be used to develop a method for predicting sediment transport in the Illinois River.

5) The effect of the increased diversion will be analyzed on the basis of the data collected in the field.

6) These broad-based data will also be utilized to test the various sediment-transport models now available. It is expected that some modifications can be made or incorporated in existing methodologies to attain a better predictability of the sediment transport rates in rivers and streams.

7) The research can be expanded for a second year on the basis of results obtained from the first year's operation.

8) Hopefully, some conclusions can be reached as to the origin of the sediments, i.e., from the watershed, bank erosion, or scour, etc.

Budget

The estimated cost of the proposed program is $202,531 for four stations for 1 year. The major part of the cost (about $125,600) will be spent for contractual services to be provided by the USGS and other professional testing firms. A detailed budget will be submitted whenever it is needed or requested by the funding agency.

SUMMARY AND CONCLUSIONS

A search of all the available sediment load data and the corresponding discharge data has shown that an extremely limited amount of data are available in the Illinois River Basin. The data available were collected by Northern Illinois Planning Commission (NIPC) at Lockport in 1976 and 1977, by NIPC and Metropolitan Sanitary District of Greater Chicago (MSDGC) at Dresden Lock and Dam in 1976 and 1977, by the United States Geological Survey (USGS) at the Marseilles and Valley City gaging stations from 1975 to the present, and by the Sanitary District of Chicago during the 1940 flushing experiment of the Chicago Sanitary and Ship Canal.' All of these data except those collected in 1940 have been tabulated and are presented in the Appendices of this report.

Data that are available as to the size distribution of the bed materials are those collected by Bhowmik and Schicht (1979) for a parallel study of the bank erosion of the Illinois River. These data have already been submitted to the funding agency.

Based on the data collected by the USGS, NIPC, and MSDGC, sediment rating curves have been developed for the Illinois River at Lockport, Dresden Lock and Dam, Marseilles, and Valley City. The data analyzed for the Marseilles and Valley City gaging stations indicated that almost 93 percent of the suspended load are in silt-clay fractions. Because size distribution data of the suspended load were not available at other stations, similar separation of the size fractions could not be made.

Data collected during the 1940 flushing experiment were analyzed for eight stations along the Illinois River. The analyses have shown that considerable amounts of scour took place in the Chicago Sanitary and Ship Canal downstream of sanitary outfalls. Also, most of the suspended solids, which probably consisted of sewage sludge, were deposited in the Brandon Road Pool.

On the basis of the analysis of existing data, the probable increase in the diverted flow, and the time of diversion, some typical computations were made to estimate the probable effects of an increased diversion of 6600 cfs and 10,000 cfs superimposed on three typical dry and wet water years. It is suspected that the impact of the diversion will be felt quite dramatically in the Chicago Sanitary and Ship Canal. The sewage sludge deposited on the bed and banks of the Canal will, in all probability, be washed away at least partially during the initial period of diversion. A gradual decrease in the scour will take place possibly within a few days of the diversion. This decrease will depend upon the rate of increase of the diverted flow. The sludge thus eroded will deposit in the pools downstream of the Sanitary and Ship Canal. In the middle and lower parts of the river, an increase in sediment load will take place with an increase in discharge. But this increase in sediment load will not be more than the load the river would carry if the normal flow increased as a result of local inflows from its tributaries. Thus the most severe effect of the increased diversion will be in the Chicago Sanitary and Ship Canal as far as sediment transport is concerned.

The above conclusions were based on an extremely limited amount of data. Statistically, the reliability of the sediment rating curves developed for this project is not very high. Additional data may or may not substantiate the conclusions made thus far.

A research and monitoring program is proposed to be conducted in the very near future. Estimated cost of the research program is $202,531. It is strongly recommended that the proposed research and monitoring program be adopted.

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APPENDICES

STREAMFLOW AND SUSPENDED SEDIMENT DATA

Appendix A. Streamflow and Suspended Sediment Data, Sanitary and Ship Canal, 16th Street, Lockport (Data collected by NIPC)

Date	Discharge (cfs)	Suspended load: Concentration (ppm)	Suspended load: Load (tons/day)
6/10/76	4760	34	436.97
6/10/76	3755	15	152.08
6/10/76	2145	7	40.54
6/09/76	2152	23	133.64
6/09/76	2157	27	157.24
6/09/76	2130	14	80.51
6/08/76	4785	19	245.47
6/08/76	2151	23	133.58
6/08/76	2185	6	35.40
6/07/76	2127	17	97.63
6/07/76	3752	30	303.91
6/07/76	1855	11	55.09
6/06/76	3742	20	207.07
6/06/76	2165	23	134.45
6/06/76	2160	12	69.98
6/05/76	3772	16	162.95
6/05/76	2190	14	82.78
6/05/76	2160	23	134.14
6/04/76	2145	9	52.12
6/04/76	2190	17	100.52
6/04/76	2160	17	99.14
6/03/76	2125	9	51.64
6/03/76	2207	9	53.63
6/03/76	2165	11	64.30
6/02/76	2140	20	115.56
6/02/76	2197	20	118.64
6/02/76	1760	13	61.78
6/01/76	2690	18	130.73
6/01/76	2705	25	182.59
6/01/76	2260	18	109.84
9/16/76	1311	17	60.17
9/16/76	1735	21	98.37
9/16/76	1335	18	64.88

Appendix A. Continued

Date	Discharge (cfs)	Suspended load: Concentration (ppm)	Suspended load: Load (tons/day)
9/15/76	1724	20	93.10
9/15/76	2024	18	98.37
9/15/76	1751	34	160.74
9/14/76	2004	15	81.16
9/14/76	1506	16	65.06
9/14/76	1496	22	88.86
9/13/76	1722	23	106.93
9/13/76	2007	15	81.28
9/13/76	1692	12	54.82
9/12/76	1758	34	161.38
9/12/76	1767	29	138.36
9/12/76	3282	18	159.51
9/11/76	2877	9	69.91
9/11/76	1719	7	32.49
9/11/76	2878	7	54.39
9/10/76	1566	10	42.28
9/10/76	1577	18	76.64
9/10/76	1876	7	35.46
9/09/76	2016	13	70.76
9/09/76	4960	20	267.84
9/09/76	4229	21	239.78
9/08/76	1705	12	55.24
9/08/76	1991	12	64.51
9/08/76	2000	14	64.80
9/07/76	1741	11	51.71
9/07/76	2770	15	112.18
9/07/76	1554	11	46.16
12/15/76	3044	51	419.16
12/14/76	3121	31	261.23
12/13/76	1894	32	163.64
12/12/76	2959	26	207.72
12/11/76	3207	48	415.63
12/09/76	2055	33	183.10

Appendix A. Concluded

Date	Discharge (cfs)	Suspended load: Concentration (ppm)	Suspended load: Load (tons/day)
12/08/76	2076	20	112.10
12/07/76	2064	36	200.62
12/07/76	2057	23	127.74
12/07/76	2056	26	144.33
12/06/76	3638	43	422.37
12/06/76	2043	38	209.61
12/06/76	2057	24	133.29
3/19/77	1525	22	90.58
3/18/77	4245	49	561.61
3/17/77	1605	20	86.67
3/16/77	1595	25	107.66
3/15/77	1690	17	77.57
3/15/77	1700	27	123.93
3/15/77	2005	17	92.03
3/14/77	1580	15	63.99
3/14/77	1610	14	60.86
3/14/77	2125	15	86.06

Note: No discharge data available from 2/22/77 to 3/1/77

Appendix B. Streamflow and Suspended Sediment Data at Dresden Dam
(Data collected by USGS)

Date	Discharge (cfs)	Suspended load: Concentration (ppm)	Suspended load: Load (tons/day)
2/01/77	4980	10	134
2/01/77	4980	10	134
2/01/77	6050	10	163
2/02/77	3800	8	82
2/03/77	5550	12	180
2/04/77	5250	15	213
2/05/77	5250	9	128
2/06/77	5250	13	184
2/07/77	5250	6	85
4/25/77	4920	53	704
4/25/77	6080	50	821
4/25/77	6080	57	936
4/26/77	6080	70	1149
4/26/77	4920	43	571
4/26/77	6550	54	955
4/27/77	5960	45	724
4/28/77	4900	29	384
4/29/77	3940	60	638
4/30/77	4900	44	582
5/03/76	9500	60	1539
5/03/76	12000	55	1782
5/03/76	9500	63	1616
5/04/76	11750	46	1459
5/04/76	10680	71	2047
5/04/76	12110	20	654
5/05/76	9730	48	1261
5/05/76	8550	55	1270
5/05/76	14250	68	2616
5/06/76	24400	51	3360
5/06/76	18400	110	5465
5/06/76	26650	65	4677
5/07/76	32130	320	27760
5/07/76	27760	462	34628

Appendix B. Continued

Date	Discharge (cfs)	Suspended load: Concentration (ppm)	Suspended load: Load (tons/day)
5/07/76	29780	417	33529
5/08/76	27400	559	41355
5/08/76	27400	522	38618
5/08/76	24100	266	17309
5/09/76	23280	171	10748
5/09/76	23280	153	9617
5/09/76	20780	94	5274
5/10/76	19600	187	9896
5/10/76	15560	179	7520
5/10/76	16740	66	2983
5/11/76	18880	60	3059
5/11/76	13910	65	2441
5/11/76	14130	80	3052
5/12/76	14130	101	3853
5/12/76	12950	73	2552
5/12/76	11750	79	2506
8/02/76	4980	98	1317
8/02/76	5600	47	711
8/02/76	6900	49	913
8/03/76	3800	58	595
8/03/76	3800	39	400
8/03/76	6180	38	634
8/04/76	3120	60	505
8/04/76	6750	48	875
8/04/76	6750	59	1075
8/05/76	3800	71	728
8/05/76	5000	56	756
8/05/76	5000	200	2700
8/06/76	5000	79	1066
8/06/76	7250	69	1351
8/06/76	7250	53	1037
8/07/76	3680	46	457
8/07/76	6180	79	1318

Appendix B. Concluded

Date	Discharge (cfs)	Suspended load Concentration (ppm)	Suspended load Load (tons/day)
8/07/76	5000	21	283
8/08/76	5000	64	864
8/08/76	5000	49	661
8/08/76	5000	38	513
8/09/76	3800	74	759
8/09/76	3800	42	431
8/09/76	4980	32	430
8/10/76	4300	41	476
8/10/76	3120	36	303
8/10/76	4400	17	202
8/11/76	4400	37	440
8/11/76	5000	79	1066
8/11/76	5000	55	742
11/03/76	2500	38	256
11/03/76	2500	43	290
11/03/76	3100	30	251
11/04/76	3100	60	502
11/04/76	2500	33	223
11/04/76	2500	57	385
11/05/76	3680	19	189
11/06/76	1900	19	97
11/07/76	2500	21	142
11/08/76	2500	29	196
11/09/76	2500	23	155
11/10/76	3100	24	201
11/11/76	3680	25	248
11/12/76	2500	30	202

Appendix C. Streamflow and Suspended Sediment Data at Marseilles
(Data collected by USGS)

Date	Discharge (cfs)	Suspended load: Concentration (ppm)	Suspended load: Load (tons/day)	Percent of particle diameter finer than 0.062 mm*
5/08/75	15400	109	4530	NA*
6/11/75	9560	101	2610	NA
7/09/75	7760	55	1150	NA
8/04/75	4970	36	483	NA
9/03/75	7190	45	874	NA
10/06/75	2980	40	322	NA
11/05/75	2930	26	206	NA
12/02/75	12500	56	1890	NA
1/06/76	3550	25	240	NA
2/04/76	9130	24	592	NA
3/02/76	33300	279	25100	NA
4/07/76	10700	148	4280	94
5/04/76	11200	146	4420	91
6/03/76	10900	114	3360	97
7/08/76	5840	82	1290	100
8/03/76	3480	68	639	100
9/01/76	2680	78	564	98
9/30/76	2610	85	597	99
11/03/76	2720	1200	815	96
12/07/76	3130	84	710	97
1/04/77	6040	99	1450	97
2/10/77	5670	51	934	96
3/23/77	10000	105	2840	96
4/28/77	6840	105	1940	96
5/25/77	5630	108	1640	91
6/22/77	6210	114	1910	93
7/27/77	3460	80	747	100
8/29/77	4890	42	555	99
9/28/77	11400	102	3140	97
10/27/77	7400	58	1160	76
11/14/77	4160	98	1100	96
12/13/77	7510	99	2000	95
1/18/78	4730	96	1230	71
2/15/78	4820	56	729	89
3/09/78	3610	25	244	89
4/12/78	25600	115	7950	72

*NA = data not available

Appendix D. Streamflow and Suspended Sediment Data at Valley City
(Data collected by USGS)

Date	Discharge (cfs)	Suspended load: Concentration (ppm)	Suspended load: Load (tons/day)	Percent of particle diameter finer than 0.062 mm*
6/10/75	31300	387	32700	NA*
7/08/75	33000	311	27700	NA
8/19/75	9490	195	5000	NA
9/17/75	8980	148	3590	NA
10/20/75	8060	238	5180	NA
11/12/75	9290	102	2560	NA
12/17/75	23900	973	62800	NA
1/21/76	18500	181	9040	NA
2/12/76	18300	421	20800	NA
4/14/76	30900	461	38500	98
5/19/76	44700	207	25000	95
6/09/76	22200	295	17700	99
7/14/76	9500	120	3080	96
8/19/76	7640	171	3530	96
9/16/76	5310	137	1960	97
10/21/76	5440	204	3000	99
11/29/76	6320	196	3350	96
12/15/76	5690	276	4240	98
2/16/77	10500	114	3230	92
3/08/77	14700	267	10600	94
4/13/77	15400	272	11300	94
4/25/77	13600	225	8260	97
5/11/77	40500	122	13300	70
6/14/77	9000	394	9570	95
7/19/77	9570	124	3200	100
8/10/77	21600	1289	75200	100
9/20/77	27000	155	11300	98
10/18/77	35300	227	21635	67
11/08/77	41000	397	43948	87
12/02/77	14100	240	9137	96
1/12/78	16000	175	7560	80
2/22/78	10000	138	3726	97
3/29/78	41900	172	90051	91
4/27/78	49500	112	14969	78
5/15/78	55600	130	19516	89

*NA = data not available