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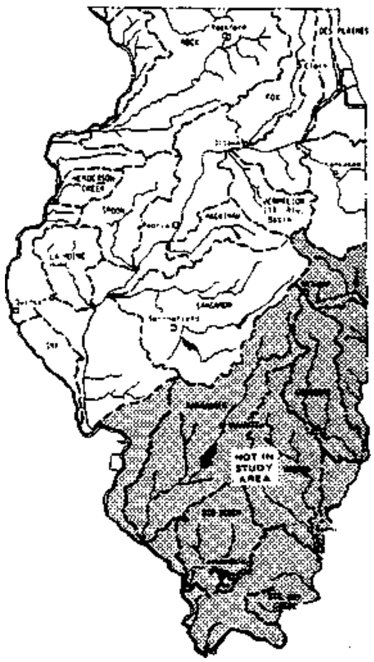
SEDIMENT YIELD OF STREAMS IN NORTHERN AND CENTRAL ILLINOIS

by

J. Rodger Adams, Nani G. Bhowmik, Allen P. Bonini,
Anne M. Klock, and Misganaw Demissie



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INTRODUCTION

Erosion and sedimentation are natural processes that cannot be prevented. However, human activities have accelerated these processes. It is essential that functional relationships between the various physical, geomorphic, and sediment-related parameters be developed and presented in an understandable fashion so the amount of sediment eroded from a watershed can be estimated.

Erosion and sedimentation impact many agencies and businesses. The impacts of eroded soil on natural systems are also varied and widespread. Sediment has been recognized by the Illinois State Water Plan Task Force (1984) as the number one pollution problem facing the State of Illinois. Even though a sufficient data base is not available at the present time, it is essential to quantify the amount of sediment carried by Illinois streams in order to help identify proper management techniques and practices to deal with sediment problems.

This report reflects an effort to quantify sediment yields in Illinois streams. Brief reviews of the literature and of sediment transport theory, followed by discussions relating to the present study, constitute the introductory section. The various types of sediment data, their sources, and their quantities are then outlined. The various geomorphic and hydraulic parameters, methods of determining them, and tabulated values complete the data description. Station, basin, and regional analyses constitute the next three sections. The last major section details the recommended techniques for estimating sediment loads at gaged and ungaged locations.

Literature Review

As noted by Rouse and Ince (1957), river hydraulics has been vital to human endeavor since the beginning of recorded history. Unless otherwise credited, this brief historical review follows their account. The first clear and correct qualitative description of streams transporting sediment in alluvial channels was given by Domenico Guglielmini about 1700. Pierre du

Buat discussed the scour of a channel by the water flowing in it in 1796 (Graf, 1971). The gradual discovery of the proper relation between velocity, depth, channel roughness, and slope occupied open channel researchers through the 19th century. From 1908 to 1914 G. K. Gilbert conducted the classic series of experiments on sediment transport by flowing water. His results have been used by modern researchers who have added much to our fundamental knowledge of sediment transport.

Despite the continued study, Rouse (1938) apologized for including a chapter on sediment transport in his seminal book, Fluid Mechanics for Hydraulic Engineers. A collection of fourteen significant papers in hydraulics between 1935 and 1960 included three on sediment transport and four on open channel flow (McNown, 1982).

In the 1970's several comprehensive texts on sediment transport were produced by Graf (1971), an American Society of Civil Engineers (ASCE) committee (Vanoni, 1975), and Simons and Senturk (1977). A brief summary of sediment transport was given by Bhowmik et al. (1980), in the first of a series of reports on the Kankakee River. The following review and definitions are purposely brief, and the reader is referred to the above-mentioned sources for greater detail.

Analytical Approaches

For the purpose of analysis, the total sediment load is often split into two parts: bed load and suspended load. Bed load is defined as that sediment in the bed layer moved by saltation, rolling, or sliding. The bed layer is a flowing layer several grain diameters thick immediately above the bed. Suspended load is defined as that sediment load that is moved by upward components of turbulent currents and that stays in suspension for a considerable time. There is no sharp division between saltation and suspension. The distinction is made between two different methods of hydraulic transport: movement due to shear force and movement due to suspension (Simons and Senturk, 1977).

Many empirical and semi-theoretical equations have been proposed to predict bed load. These expressions fall into one of three different but related approaches: 1) the du Boys-type equations (shear stress relationships); 2) the Schoklitsch-type equations (discharge relationships); and 3) the Einstein-type equations, based upon statistical considerations of the lift force (Graf, 1971). When any of these equations are applied, care should be taken to limit their use to similar flow conditions and particle characteristics, since they contain many experimentally determined constants.

Suspended load is defined as that sediment surrounded by fluid that stays in suspension for an appreciable length of time. Sediment particles settle because of their weight, but fluid turbulence counterbalances this motion. Just as there exists an active exchange between bed material and bed load, there is an active exchange between bed load and suspended load.

The suspended load per unit width of channel q_s is

$$q_s = \gamma_s \int_t^D \bar{V}\bar{C}\, dy \qquad (1)$$

where $\bar{V}$ and $\bar{C}$ are the time averaged velocity and concentration distributions, γ_s is the unit weight of the sediment particles, and t is the thickness of the bed layer. The total suspended load for a stream can be obtained by integrating equation 1 across the width of the stream. An expression for $\bar{C}$ in terms of Ct at a distance t above the bed can be obtained based on assumptions about the sediment diffusion coefficient and the velocity distribution. This equation is:

$$\bar{C}/C_t = \{[(D-y)/y]\ t/(D-t)\}^z \qquad (2)$$

where

$$z = \omega/\beta\kappa V_* \qquad (3)$$

Here β is a constant, κ is the von Karman constant, and ω is the particle fall velocity. Several researchers have shown that for fine particles $\beta = 1$ and for coarse particles $\beta < 1$. Von Karman's constant κ is equal to 0.4 in open channel flow without sediment but is reduced for sediment laden flow (Vanoni and Nomicos, 1960). In general, many researchers have found agreement with equation 2; but the values of z have been determined by fitting the data and not from theory. Equation 2 is used in equation 1 to determine q_s. When attempting to determine the suspended load one must remember that only the suspended load due to bed material is calculated from the above equations. Considerable quantities of fine particles may be carried into a stream from erosion of adjacent land surfaces and transported in suspension. This component of the suspended sediment load is called the wash load.

The total load is equal to the sum of the bed load and suspended load. Some researchers have done work on obtaining total load directly, rather than as a sum of two components. Actually the total load that can be predicted is the total bed material load, which is made up of particle sizes that can be found in the bed. The wash load is made up of particles finer than those found in the bed and is dependent on the supply available from the watershed. Selected references from many research efforts are those by Lane and Kalinske (1941), Einstein (1950), Laursen (1958), Bagnold (1966), Toffaleti (1969), and Shen and Hung (1971).

Still, the question remains as to how to determine the total load if some field data are available. If the hydraulic and suspended sediment load data are available, the total suspended sediment load can be computed. In many instances, especially in the case of streams flowing on sandy beds, it is easy to measure the suspended sediment load. However, instruments to measure the bed load are not yet well developed. Thus, an empirical relationship is needed to determine the total load based on the hydraulic data and the measured suspended sediment load. Simons and Senturk (1977) have indicated that for large and deep rivers, the amount of bed load may be 5 to 25 percent of the suspended load. Total bed load may be small in these rivers, but it is important since bed load influences the bed stability and determines the bed form and particle roughness of the channel.

Sediment Measurement Studies

Field methods for sediment transport data collection have been developed and standardized by U.S. agencies with interest and responsibility for streams, rivers, lakes, and navigation. Guy and Norman (1970) describe the instruments and methods for obtaining suspended sediment samples for concentration and particle size determination. The samplers obtain depth-integrated isokinetic samples over the water depth from the surface to about 0.3 feet above the bed. Some samplers can collect a time-integrated sample at a point. The unmeasured zone near the bed is often considered to be bed load. A bed load sampler is under development (Helley and Smith, 1971), but calibration for different sized particles and clogging by fines and organic particles are serious problems. A recent field study in Illinois used this sampler to obtain bed load data from nine streams. Graf (1983) reported some problems but concluded that the data were useful.

When attempting to extend suspended sediment transport data by means of any of the analytical methods, a major problem results from using a "total suspended load" measurement with equations which describe the transport of bed material. There is no way to divide the measured load into wash load and stream bed material load. In Illinois, many stream channels are formed in geologically homogeneous materials.

A sediment-budget study in the Rock Island District reach of the Mississippi River concluded that bed load ranged from 6 to 26 percent of the suspended load and averaged 11 percent for the tributaries (Nakato, 1981). This is compatible with the estimate given by Simons and Senturk (1977).

The Illinois State Water Survey has studied sediment for many years. The earlier studies were devoted to the problem of sediment deposition in lakes. Approximately 100 lakes have been surveyed for sediment accumulation, a number of them more than once. The sixth sedimentation survey of Lake Decatur on the Sangamon River was completed early in 1984 (Bogner et al., 1981). This lake has lost 35 percent of its capacity due to sediment in 61 years for an average capacity loss rate of 0.58 percent per year. Recently, erosion of topsoil from prime farmland and its contribution to instream sediment and lake sedimentation has become a critical issue. The Illinois State Water Plan Task Force (1984) identified erosion and sediment control as the top priority critical issue for the state, and stream and lake use management and stream data measurements as the top two operating issues.

Bank erosion and sediment transport by the Illinois River are the subjects of two reports (Lee and Bhowmik, 1979; Bhowmik and Schicht, 1980). Sedimentation in backwater lakes along the Illinois River is of concern to fish and waterfowl interests as well as hydrologists and sedimentation engineers. Sedimentation surveys of a number of these lakes were reported by Lee and Stall (1976, 1977). Bellrose et al.(1983) summarized the impact of backwater lake sedimentation on the useful life of these lakes for recreation or as productive aquatic habitats.

A controversy over the effect of channelization and channel maintenance along the Kankakee River in Indiana on the hydrology and sediment transport of the river in Illinois led to an intensive, multi-year investigation of the Kankakee River. The first report (Bhowmik et al., 1980) included an extensive hydrologic analysis and presented a comprehensive picture of the river basin characteristics. As the data base increased in length, additional analysis was completed (Bhowmik and Bogner, 1981), and a clear understanding of the sediment transport characteristics and the impact of channel clearing on the floods and hydraulics of the river was presented (Demissie et al., 1983).

On the basis of the lake sedimentation data and the concern about the fate of erosion products from the land surface, a program for instream sediment measurement was proposed. After an ambitious beginning in 1981 with 50 suspended sediment monitoring stations (Bonini et al., 1983), this program was merged into the Water Survey's statewide benchmark network with 18 stations in Water Year 1984. The U.S. Geological Survey has also monitored suspended sediment transport in Illinois since 1975 and has published the results in their annual water resources data reports. Lazaro et al. (1984) used five years of weekly suspended sediment data to determine the long-term sediment transport by Bay Creek at Nebo, Illinois.

Although much interest is focused on the local streams in Illinois, the state is bounded by many miles of the Mississippi and Ohio Rivers and is divided by the Illinois River. Navigation has secondary but definite impacts on the sediment transport and suspension characteristics of these rivers. While participating in the development of a master plan for managing the Upper Mississippi River, Water Survey scientists investigated several impacts which are proportional to the frequency and size of barge tows. Resuspension and lateral redistribution of sediment by commercial tows were studied by Bhowmik et al. (1981a). Pulse inputs of water and sediment to side channels and backwater lakes occur as the result of the hydrodynamics of tow passage (Bhowmik et al., 1981b). The Master Plan (Upper Mississippi River Basin Commission, 1982) recommended long-term resource monitoring, erosion control, and navigation traffic impact monitoring.

Following this involvement in a multi-disciplinary project on large river dynamics, resources, biology, and uses, the Water Survey became a part of the large river project in the National Science Foundation Long Term Ecological Research (LTER) program. The water, sediment, and nutrient fluxes are both the environment and the energy source for the biota that live in the river. Not quite three years into the first five-year period, early results have been presented at technical meetings. Sediment budget calculations for Pool 19 were reported by Adams and Bhowmik (1983). Adams (1984) has also discussed the implications of LTER for the future management of the Upper Mississippi River.

Regional Studies

Since sediment transport or lake sedimentation data are available at only a few locations in individual river basins or even in an entire state, several larger regional studies have been made. In 1970, the Upper Mississippi River Comprehensive Basin Study (UMRCBS) Coordinating Committee published Appendix G: Fluvial Sediment (UMRCBS,1970). A method based on a relation between annual sediment yield and drainage area for each Land Resource Area (LRA) was proposed and has been used since then to estimate sediment loads. The LRA's are determined by similarity of factors such as soils, climate, water resources, land use, and type of agriculture. Researchers at the University of Wisconsin investigated the relation between floods and sediment yield, and variations in climate and land use (Knox et al., 1975), in the Upper Mississippi Valley. A general, broad-area description of sediment transport in the Mississippi River Basin has been compiled by the Environmental Laboratory at the Waterways Experiment Station (Keown et al., 1981). Griffiths (1982) studied suspended sediment yields of watersheds in New Zealand. He used various regression techniques and regional analysis to relate sediment yields in 47 river basins.

Background

The Illinois State Water Plan Task Force (1984) lists erosion and sediment control as the first of ten critical issues concerning the water resources of the state. The problem statement for one of seven operating issues presents the rationale for research in this area very clearly: "The collection and dissemination of streamflow, water quality, and suspended sediment data suffers from serious funding problems resulting in part from the fragmentation that exists in planning, operation, and funding of these important information networks. Furthermore, end users of the data take the data collection effort for granted and do not participate in planning or funding."

The maximum suspended sediment data collection effort in Illinois was made in Water Year 1981, which was the first year of the Water Survey's Instream Sediment Monitoring Program. In that year the Water Survey operated 27 intensive and 23 weekly stations and the U.S. Geological Survey (USGS) monitored 29 stations. (The USGS sediment monitoring program was initiated in 1975 and was expanded to the Water Year 1981 level.) Subsequent funding limits forced the USGS to reduce its sediment monitoring effort, so that in Water

Year 1983, only four stations were monitored. Similarly, the Water Survey sediment monitoring effort was reduced to about 20 stations in Water Year 1983. Presently the Water Survey has 18 suspended sediment stations included in its benchmark network of water resources data.

As data collection efforts have declined, agencies have become concerned that their staff would not have the time or interest to analyze the available data. Therefore the Illinois State Water Survey, in cooperation with the U. S. Army Corps of Engineers, Rock Island District (COE-RID), initiated this cooperative project to determine the present state of knowledge with respect to instream sediment loads of Illinois streams and rivers within the administrative jurisdiction of the Rock Island District. Figure 1 shows the area of the state that falls within this boundary.

The objectives of the present investigation are as follows:

a) Compile available data. This includes suspended sediment data for the sediment stations within the jurisdiction of the COE-RID as well as all lake sedimentation data.

b) Perform statistical analyses of the data.

1) Develop predictive sediment load equations as a function of water discharge for each station.
2) For stations with three or more years of data, develop seasonal sediment transport equations and sediment load duration curves.
3) Evaluate and select watershed geomorphic and hydraulic parameters to correlate with the instream sediment load.
4) Develop watershed and regional sediment loads and compare with existing estimates of sediment production rates for various land resource areas.

c) Recommend a technique for estimating the stream sediment load from existing information within the administrative jurisdiction of the COE-RID in Illinois.

Description of Study Area

The area of interest includes that portion of Illinois which is within the Rock Island District, U.S. Army Corps of Engineers. This is the Illinois River Basin upstream of the La Grange Lock and Dam excluding six counties in northeastern Illinois which are in the Chicago District, and the Mississippi River and its tributaries in Illinois upstream of Lock and Dam 22 at river

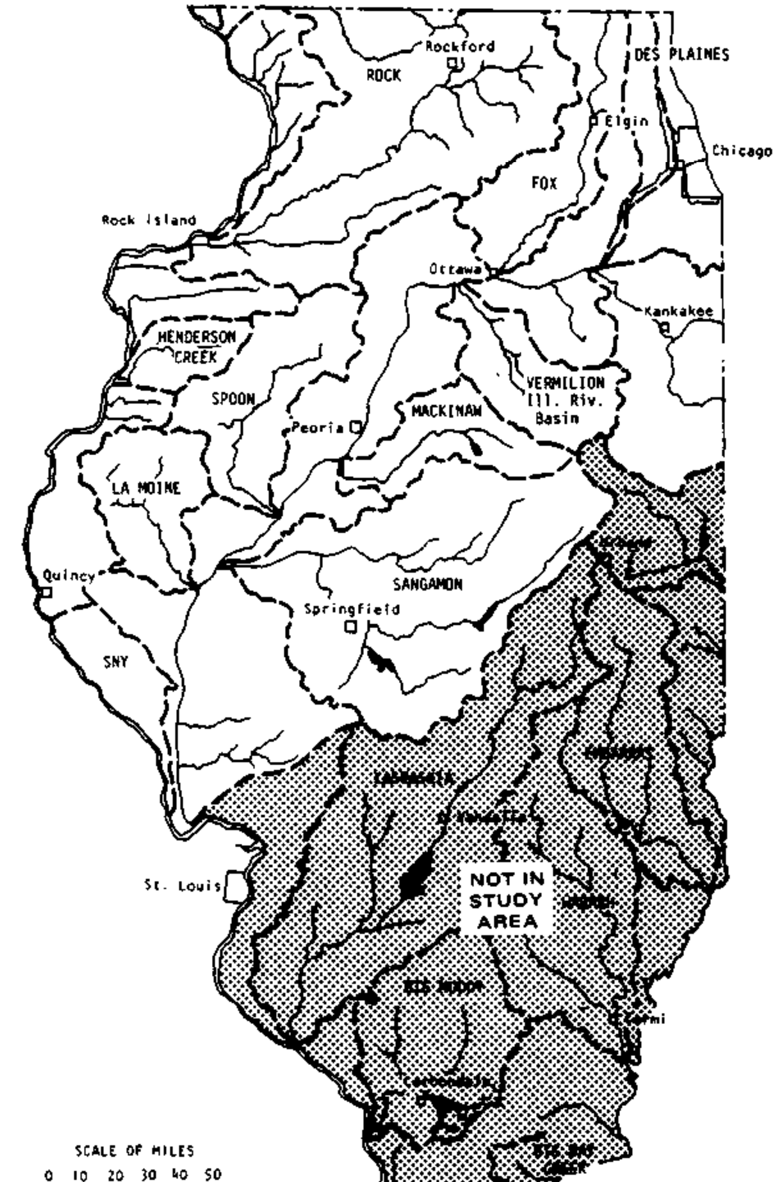

Figure 1. Map of study area

mile 301.2 near Saverton, Missouri. The boundary area shown in figure 1 includes the Illinois River station at Valley City, a station on Macoupin Creek, stations within the six counties in northeastern Illinois, and several lake sedimentation survey sites in the lower Illinois River Basin. These areas are included in this study even though they are not within the Rock Island District territory.

The physiographic divisions of Illinois (Leighton et al., 1948) are outlined in figure 2. Most of the study area is in the Central Lowland Province. Except for the Wisconsin Driftless Section in the northwest corner, the entire area was glaciated. The large valleys of the Mississippi and Illinois Rivers were formed during glacial recession by melt water. The Galesburg, Springfield, and Bloomington Ridged Plains differ in the number of moraines and the amount of valley incision. The Springfield Plain is flat and has shallow stream valleys. The Galesburg Plain has four moraines and large, steep-walled, and terraced stream valleys. The Bloomington Ridged Plain has low, broad morainic ridges with intervening wide and flat or gently rolling ground moraine deposits. The Rock River Hill Country has a mature drainage pattern with deep valleys and occasional bed rock exposure. The Kankakee Plain is a mixture of glacial features with some ancient sand deposits of glacial Lake Chicago as well as later morainal features.

The study area is also described by Land Resource Areas (LRA) as shown in figure 3. The delineation of LRA's is based on agricultural utility. Each LRA is characterized by a particular combination of soil type, slope, erodibility, climate, water, land use, and type of farming. These are described in detail in Appendix G of the comprehensive basin study (UMRCBS, 1970). LRA 108, the Illinois and Iowa deep loess and drift area, includes much of the study area, particularly the upland portions of the Galesburg, Springfield, and Bloomington Ridged Plains. LRA 105, the northern Mississippi Valley loess hills area, is nearly coterminous with the Wisconsin driftless section. LRA 109 is the Iowa and Missouri heavy till plain, and LRA 110 is the northern Illinois and Indiana heavy till plain. LRA 115, the Central Mississippi Valley wooded slopes area, occurs in the Illinois and Mississippi River Valleys and adjoining bluffs. Finally, there is a small portion of LRA 95, the southeastern Wisconsin drift plain.

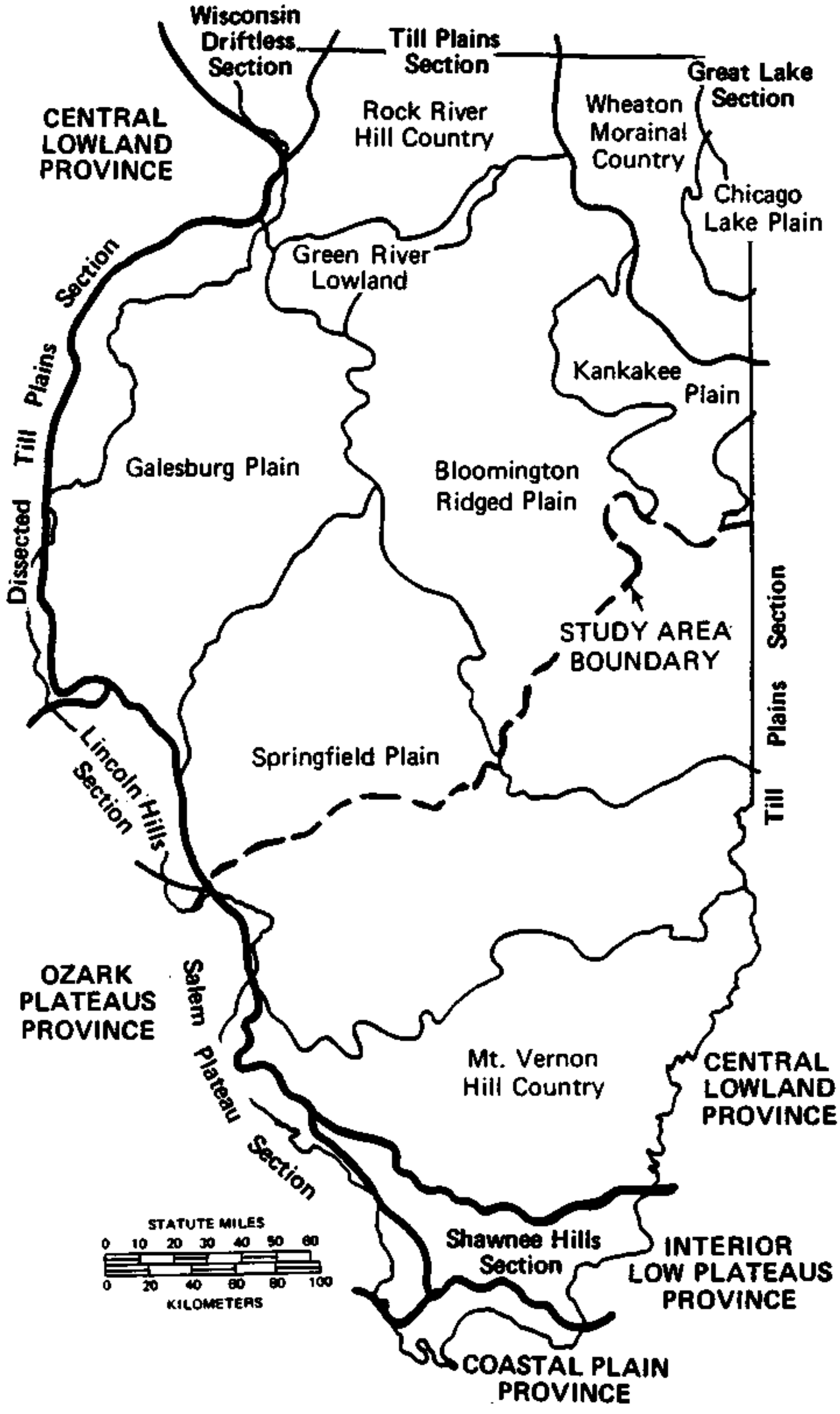

Figure 2. Physiographic divisions of Illinois (after Leighton et al., 1948)

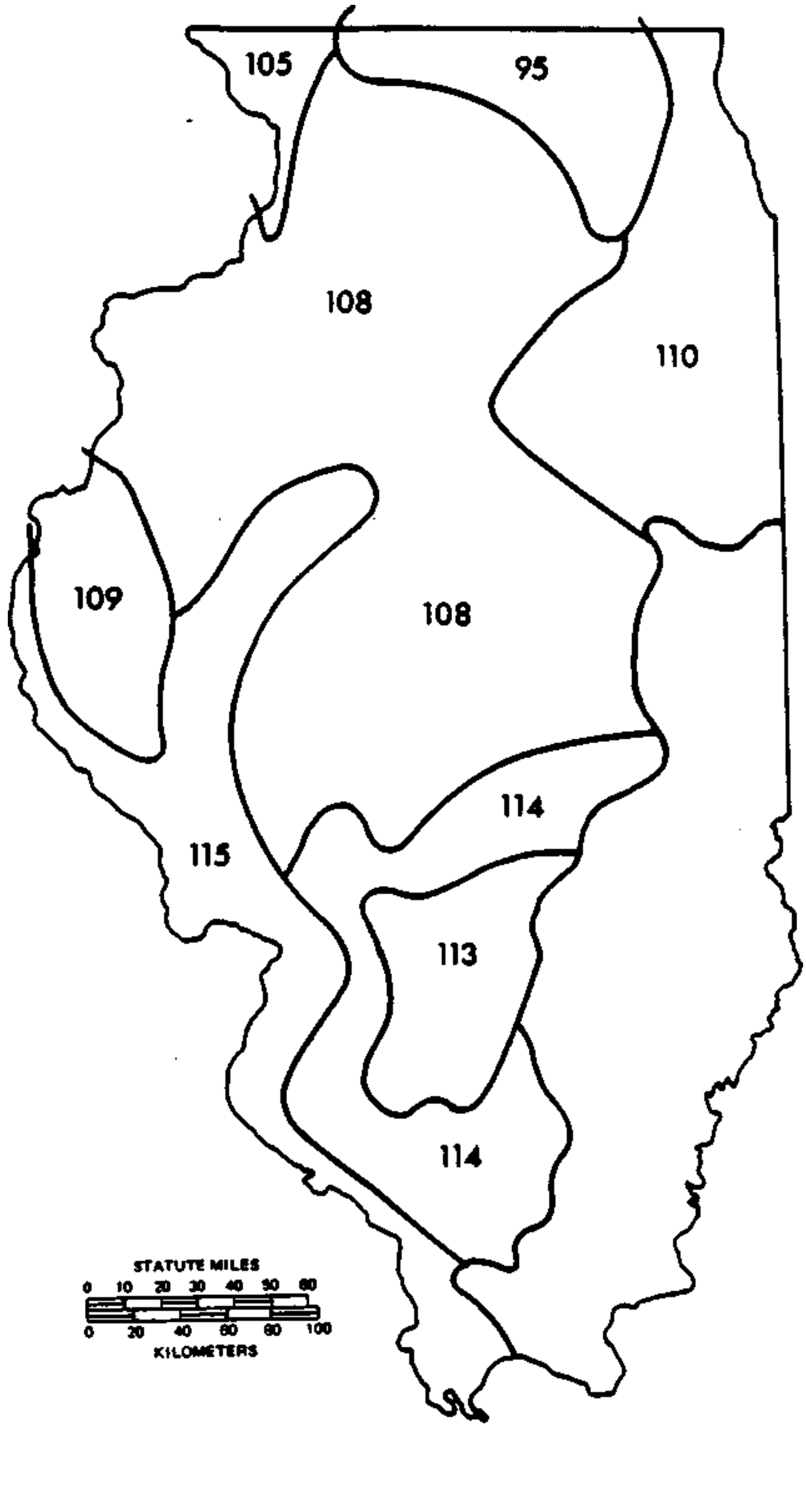

Figure 3. Map of Land Resource Areas in the Upper Mississippi River Basin in Illinois (after UMRCBS, 1970)

The mean annual precipitation in inches for the period 1951 to 1980 is shown by the isohyetal lines in figure 4. There is a difference of about 10 inches per year between the northern and southern parts of the state. The isohyetal lines do not follow a clear trend but are quite convoluted. The nine crop reporting districts and the average precipitation in each district are also shown in figure 4.

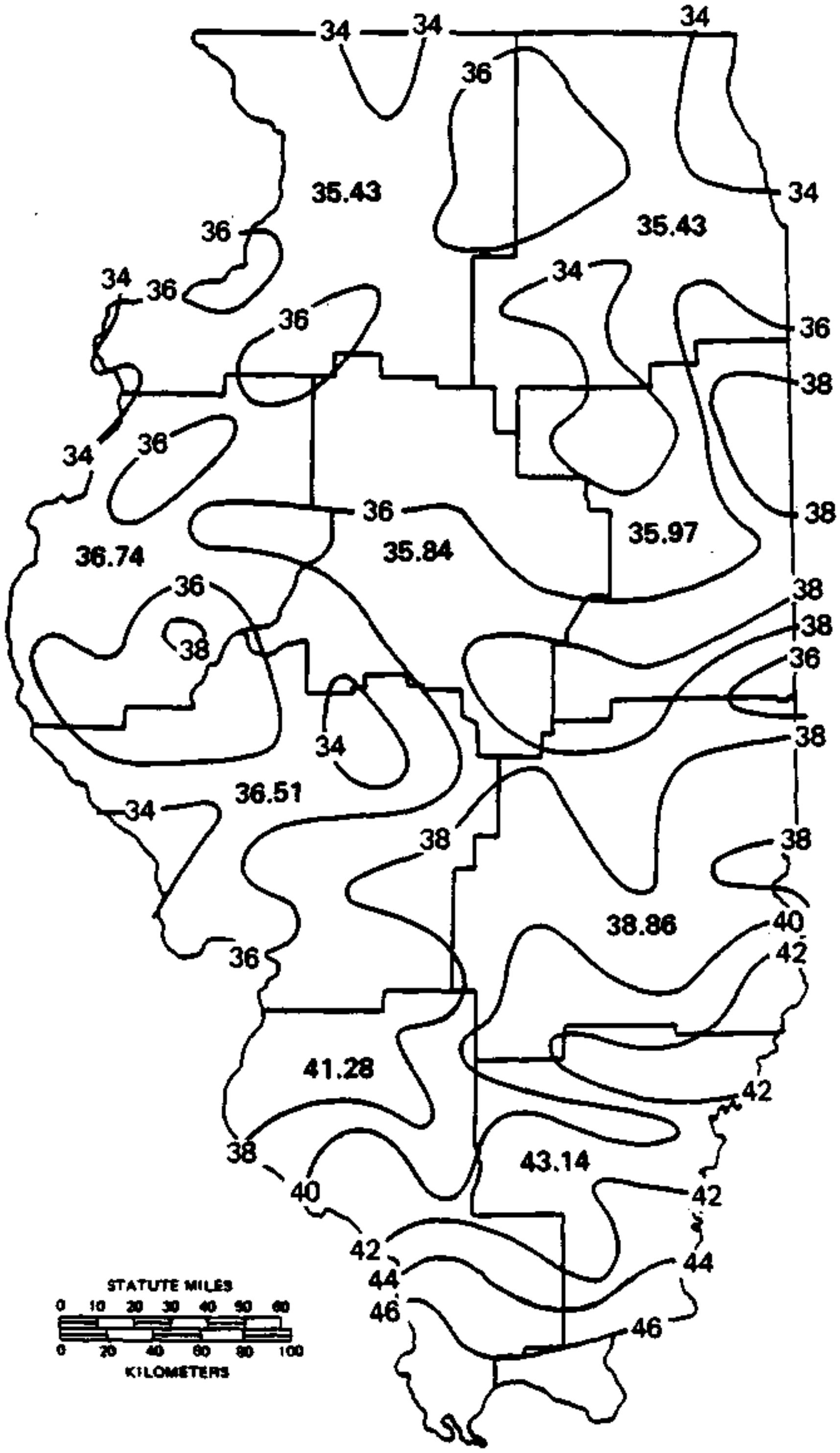

Figure 4. Average annual precipitation in Illinois for the period 1951-1980

DATA DESCRIPTION

A key element in this project was the creation and maintenance of a data base that would be used in all analyses. The basic information was divided into two major categories: sediment data and geomorphic data. Descriptions of the sources and types of information that were obtained for each of these categories is given below.

It was apparent from the start of the data gathering process that the only manageable way to handle the large amount of data was to store, retrieve and manipulate the data sets in a computer. The University of Illinois' Control Data Corporation Cyber 175 and IBM 4341 were chosen as the hardware systems to handle the various data sets. FORTRAN programs, some of which had been developed for the Water Survey's Sediment Monitoring Program, were adopted, modified, and developed to process the data sets and to generate the results presented later in this report.

Suspended Sediment Data

Sediment data refers to water discharge data as well as suspended sediment concentration or load data. This report deals mainly with sediment data collected at monitoring stations within the Illinois portion of the Rock Island District, U.S. Army Corps of Engineers, although data have been gathered from sites throughout the state.

The first step in gathering all pertinent sediment data for this project was to identify the agency sources for sediment data. The U.S. Geological Survey (USGS), Illinois State Water Survey (SWS), U.S. Army Corps of Engineers (COE), and Illinois Environmental Protection Agency (IEPA) were all identified as having some sediment data on file. Lists of available sediment data from these agencies were compiled. It became obvious in compiling these lists that the data set for the study area was going to be a heterogeneous mix of record lengths, data types, and collection frequencies. The USGS data were the most extensive data and included mean daily water and suspended sediment discharge data for 24 stations with record lengths of from 1 to 7 years. The SWS data included instantaneous daily and instantaneous weekly water and suspended sediment discharge data for 34 stations with record lengths of from 1 to 2 years. The COE data included instantaneous daily suspended sediment concentration data and daily water discharge data for three stations with record lengths of 14 or 15 years.

Table 1 summarizes the data within the Rock Island District that were obtained from these three agencies. The table also summarizes the data obtained from the rest of the state. This table includes a listing of each station by SWS station code and includes the USGS station number and station name. The drainage area, river basin, period of record, and type and frequency of record, including the monitoring agencies and years that they collected data, are also listed. Three stations were monitored by more than one agency during their period of record. In all but two cases the data used in this report reflect data collected through Water Year 1982. All of these data were obtained in machine readable form.

Figure 5 shows the locations of the suspended sediment monitoring stations in Illinois. The stations are identified by their 3-digit station codes. Of the 59 stations within the Rock Island District, only three are located on the main stem of the Mississippi River and two are located on the main stem of the Illinois River.

The IEPA sediment data, collected as part of their Ambient Water Quality Monitoring Network, were obtained through the USGS WATSTORE system and included instantaneous water discharge and suspended sediment concentration data for approximately 113 stations. Record lengths varied tremendously, ranging from 4 to more than 20 years. Sampling frequency ranged from bi-weekly to monthly to bi-monthly. The IEPA data set was not used in the statistical analyses generated for this report because the sampling frequency was sporadic; many stations did not have a continuous record of water discharge, limiting the potential analyses; and in most cases depth integrating techniques were not used to measure the suspended load.

Bed Load Data

The bed load carried by a stream can be determined either by measuring the sediment moving near the bed or by monitoring the movement of bed forms such as sand bars.

A review of available instrumentation for bed load measurement indicates that basically one field instrument is available for measuring the bed load (Hubbell, 1964; Helley and Smith, 1971). This is an experimental sampler called the Helley-Smith Bed Load Sampler. Its development and limitations are given by Helley and Smith (1971). This sampler was designed for sampling coarse materials where the diameter of the bed materials varies from 2 to 10

TABLE 1. SUMMARY OF AVAILABLE SEDIMENT DATA FOR ILLINOIS

STA. CODE	USGS STA.NO.	USGS STATION NAME	DRAINAGE AREA	RIVER BASIN	PERIOD OF RECORD	TYPE AND FREQUENCY OF RECORD (COLLECTING AGENCY, YEARS COLLECTED) MEAN DAILY	INSTANTANEOUS DAILY	INSTANTANEOUS WEEKLY
		(STATIONS WITHIN THE ROCK ISLAND DISTRICT)						
101	05418950	APPLE RIVER NEAR ELIZABETH	207	APPLE	1981-82			SWS 1981-82
102	05435500	PECATONICA RIVER AT FREEPORT	1326	ROCK	1981-82			SWS 1981-82
103	05437500	ROCK RIVER AT ROCKTON	6363	ROCK	1981-82		SWS 1981	SWS 1981-82
104	05438500	KISHWAUKEE RIVER AT BELVIDERE	538	ROCK	1981-81			SWS 1981-82
105	05440000	KISHWAUKEE RIVER NEAR PERRYVILLE	1099	ROCK	4/79-81	USGS 4/79-81		
106	05439500	SOUTH BRANCH KISHWAUKEE RIVER NEAR FAIRDALE	387	ROCK	1981-82		SWS 1981	SWS 1981-82
107	05550000	FOX RIVER AT ALGONQUIN	1403	FOX	1981		SWS 1981	SWS 1981
108	05529000	DES PLAINES RIVER AT DES PLAINES	360	DES PLAINES	1981			SWS 1981
109	05532500	DESPLAINES RIVER AT RIVERSIDE	630	DES PLAINES	4/79-82	USGS 4/79-82		
110	05551200	FERSON CREEK NEAR ST. CHARLES	51.7	FOX	1981-82			SWS 1981-82
111	05439000	SOUTH BRANCH KISHWAUKEE RIVER AT DEKALB	77.7	ROCK	1980-81	USGS 1980-81		
112	05444000	ELKHORN CREEK NEAR PENROSE	146	ROCK	1981		SWS 1981	SWS 1981
113	05446500	ROCK RIVER NEAR JOSLIN	9549	ROCK	5/80-82	USGS 5/80-82		
114	05551540	FOX RIVER AT MONTGOMERY	1732	FOX	1981-82			SWS 1981-82
115	05539000	HICKORY CREEK AT JOLIET	107	DES PLAINES	1981			SWS 1981
116	05540500	DUPAGE RIVER AT SHOREWOOD	324	DUPAGE	1981		SWS 1981	SWS 1981
117	05552500	FOX RIVER AT DAYTON	2642	FOX	1981			SWS 1981
118	05556500	BIG BUREAU CREEK AT PRINCETON	196	BUREAU	1981-82		SWS 1981	SWS 1981-82
119	05447500	GREEN RIVER NEAR GENESEO	1003	GREEN	3/78-81	USGS 3/78-81		
120	05466500	EDWARDS RIVER NEAR NEW BOSTON	445	EDWARDS	1/79-81	USGS 1/79-81		
121	05466000	EDWARDS RIVER NEAR ORION	155	EDWARDS	1981-82			SWS 1981-82
122	05555300	VERMILION RIVER NEAR LENORE	1251	VERMILION	6/80-81	USGS 6/80-81		
123	05542000	MAZON RIVER NEAR COAL CITY	455	MAZON	1981-82		SWS 1981	SWS 1981-82
124	05527500	KANKAKEE RIVER NEAR WILMINGTON	5150	KANKAKEE	1979-82	USGS 1979-82		
125	05520500	KANKAKEE RIVER AT MOMENCE	2294	KANKAKEE	1979-82	USGS 1979-81	SWS 1982	
126	05568800	INDIAN CREEK NEAR WYOMING	62.7	SPOON	1981	USGS 1981		
127	05467000	POPE CREEK NEAR KEITHSBURG	183	POPE CR	1981		SWS 1981	SWS 1981
191		MISSISSIPPI RIVER AT EAST DUBUQUE	81600	MISSISSIPPI	1967-81		COE 1967-81	
203	05437630	SPRING CR. AT MCFARLAND RD. NEAR ROCKFORD	2.44	ROCK	6/79-81	USGS 6/79-81		
204	05437632	SPRING CR. AT ROCK VALLEY COLLEGE AT ROCKFORD	2.81	ROCK	6/79-81	USGS 6/79-81		
227	05543500	ILLINOIS RIVER AT MARSEILLES	8259	ILLINOIS	1975-82	USGS 1975-82(INTERMITTENT)		
228	05469000	HENDERSON CREEK NEAR OQUAWKA	432	HENDERSON	4/78-81	USGS 4/78-81		
229	05569500	SPOON RIVER AT LONDON MILLS	1062	SPOON	1981-82		SWS 1981	SWS 1981-82
230	05566500	EAST BRANCH PANTHER CREEK AT EL PASO	30.5	MACKINAW	1981			SWS 1981
231	05554490	VERMILION RIVER AT MCDOWELL	551	VERMILION			1981	SWS 1981
232	05526000	IROQUOIS RIVER NEAR CHEBANSE	2091	KANKAKEE	1979-82	USGS 1979-81	SWS 1982	
233	05525000	IROQUOIS RIVER AT IROQUOIS	686	KANKAKEE	1979-82	USGS 1979-80	SWS 1981-82	
234	05525500	SUGAR CREEK AT MILFORD	446	KANKAKEE	1981			SWS 1981
235	05564400	MONEY CREEK NEAR TOWANDA	49.0	MACKINAW	1981			SWS 1981
236	05567510	MACKINAW RIVER BELOW CONGERVILLE	776	MACKINAW	1981			SWS 1981
237	05568005	MACKINAW RIVER BELOW GREEN VALLEY	1092	MACKINAW	1981		SWS 1981	SWS 1981
238	05570350	BIG CREEK AT ST. DAVID	28.0	SPOON	1976-80	USGS 1976-80		
239	05570370	BIG CREEK NEAR BRYANT	41.2	SPOON	1976-82	USGS 1976-82		
240	05570380	SLUG RUN NEAR BRYANT	7.12	SPOON	1976-80	USGS 1976-80		

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TABLE 1. CONCLUDED

STA. CODE	USGS STA.NO.	USGS STATION NAME	DRAINAGE AREA	RIVER BASIN	PERIOD OF RECORD	TYPE AND FREQUENCY OF RECORD (COLLECTING AGENCY, YEARS COLLECTED) MEAN DAILY	INSTANTANEOUS DAILY	INSTANTANEOUS WEEKLY
241	05570000	SPOON RIVER AT SEVILLE	1636	SPOON	1981	USGS 1981		
242	05584500	LA MOINE RIVER AT COLMAR	655	LA MOINE	1981-82		SWS 1981	SWS 1981-82
243	05495500	BEAR CREEK NEAR MARCELLINE	349	BEAR CREEK	1981		SWS 1981	SWS 1981
244	05584685	GRINDSTONE CREEK NEAR BIRMINGHAM	45.4	LA MOINE	1981	USGS 1981		
245	05585000	LA MOINE RIVER AT RIPLEY	1293	LA MOINE	1981	USGS 1981		
246	05583000	SANGAMON RIVER NEAR OAKFORD	5093	SANGAMON	1981	USGS 1981		
247	05582000	SALT CREEK NEAR GREENVIEW	1804	SANGAMON	1981-82			SWS 1981-82
248	05578500	SALT CREEK NEAR ROWELL	355	SANGAMON	1981-82		SWS 1981	SWS 1981-82
249	05572000	SANGAMON RIVER AT MONTICELLO	550	SANGAMON	1981-82			SWS 1981-82
252	05576500	SANGAMON RIVER AT RIVEKTON	2618	SANGAMON	1981-82		SWS 1981	SWS 1981-82
253	05586100	ILLINOIS RIVER AT VALLEY CITY	26564	ILLINOIS	2/80-83	USGS 2/80-83		
254	05576022	SOUTH FORK SANGAMON RIVER BELOW ROCHESTER	870	SANGAMON	1981-82		SWS 1981	SWS 1981-82
292		MISSISSIPPI RIVER AT BURLINGTON	113600	MISSISSIPPI	1968-81		COE 1968-81	
293	05474500	MISSISSIPPI RIVER AT KEOKUK	119000	MISSISSIPPI	1968-81		COE 1968-81	
359	05587000	MACOUPIN CREEK NEAR KANE	868	MACOUPIN	1981		SWS 1981	SWS 1981
444	05584680	GRINDSTONE CREEK NEAR INDUSTRY	35.5	LA MOINE	1981	USGS 1981		
		(STATIONS NOT WITHIN THE ROCK ISLAND DISTRICT)						
250	03336900	SALT FORK NEAR ST. JOSEPH	134	VERMILION	1981-82		SWS 1981	SWS 1981-82
251	03339000	VERMILION RIVER NEAR DANVILLE	1290	VERMILION	1981			SWS 1981
255	05591200	KASKASKIA RIVER AT COOKS MILLS	473	KASKASKIA	1/79-83	USGS 1/79-83		
356	03343550	EMBARRAS RIVER NEAR OAKLAND	542	EMBARRAS	1/79-82	USGS 1/79-82		
357	03344000	EMBARRAS RIVER NEAR DIONA	919	EMBARRAS	1981-82		SWS 1981	SWS 1981-82
358	05592100	KASKASKIA RIVER NEAR COWDEN	1330	KASKASKIA	1981		SWS 1981	SWS 1981
360	05592800	HURRICANE CREEK NEAR MULBERRY GROVE	152	KASKASKIA	1981		SWS 1981	SWS 1981
361	05592500	KASKASKIA RIVER AT VANDALIA	1904	KASKASKIA	1981-82		SWS 1981	SWS 1981-82
362	03345500	EMBARRAS RIVER AT STE. MARIE	1516	EMBARRAS	1981-82		SWS 1981	SWS 1981-82
363	03346000	NORTH FORK EMBARRAS RIVER NEAR OBLONG	318	EMBARRAS	1981-82			SWS 1981-82
364	03378900	LITTLE WABASH RIVER AT LOUISVILLE	745	L. WABASH	3/77-81	USGS 3/77-81		
365	05593520	CROOKED CREEK NEAR HOFFMAN	254	KASKASKIA	1981		SWS 1981	SWS 1981
366	05594000	SHOAL CREEK NEAR BREESE	735	KASKASKIA	1981-82			SWS 1981-82
367	05594800	SILVER CREEK NEAR FREEBURG	464	KASKASKIA	1981-82		SWS 1981	SWS 1981-82
368	03380500	SKILLET FORK AT WAYNE CITY	464	L. WABASH	1981			SWS 1981
369	03379600	LITTLE WABASH RIVER AT BLOOD	1387	L. WABASH	1981-82			SWS 1981-82
370	03381500	LITTLE WABASH RIVER AT CARMI	3102	L. WABASH	1981-82		SWS 1981	SWS 1981-82
371	05597000	BIG MUDDY RIVER AT PLUMFIELD	794	BIG MUDDY	1981-82			SWS 1981-82
373	05599500	BIG MUDDY RIVER AT MURPHYSBORO	2169	BIG MUDDY	5/80-83	USGS 5/80-83		
374	05597500	CRAB ORCHARD CHEEK NEAR MARION	31.7	BIG MUDDY	1981			SWS 1981
375	03382170	BRUSHY CREEK NEAR HARCO	13.3	SALINE	2/80-81	USGS 2/80-81		
376	03382100	SOUTH FORK SALINE RIVER NEAR CARRIER MILLS	147	SALINE	1980-81	USGS 1980-81		
377	03384450	LUSK CREEK NEAR EDDYVILLE	42.9	LUSK	1/80-81	USGS 1/80-81		
378	03612000	CACHE RIVER AT FORMAN	244	CACHE	1981-82		SWS 1981	SWS 1981-82
379	05594100	KASKASKIA RIVER NEAR VENEDY STATION	4393	KASKASKIA	5/80-83	USGS 5/80-83		

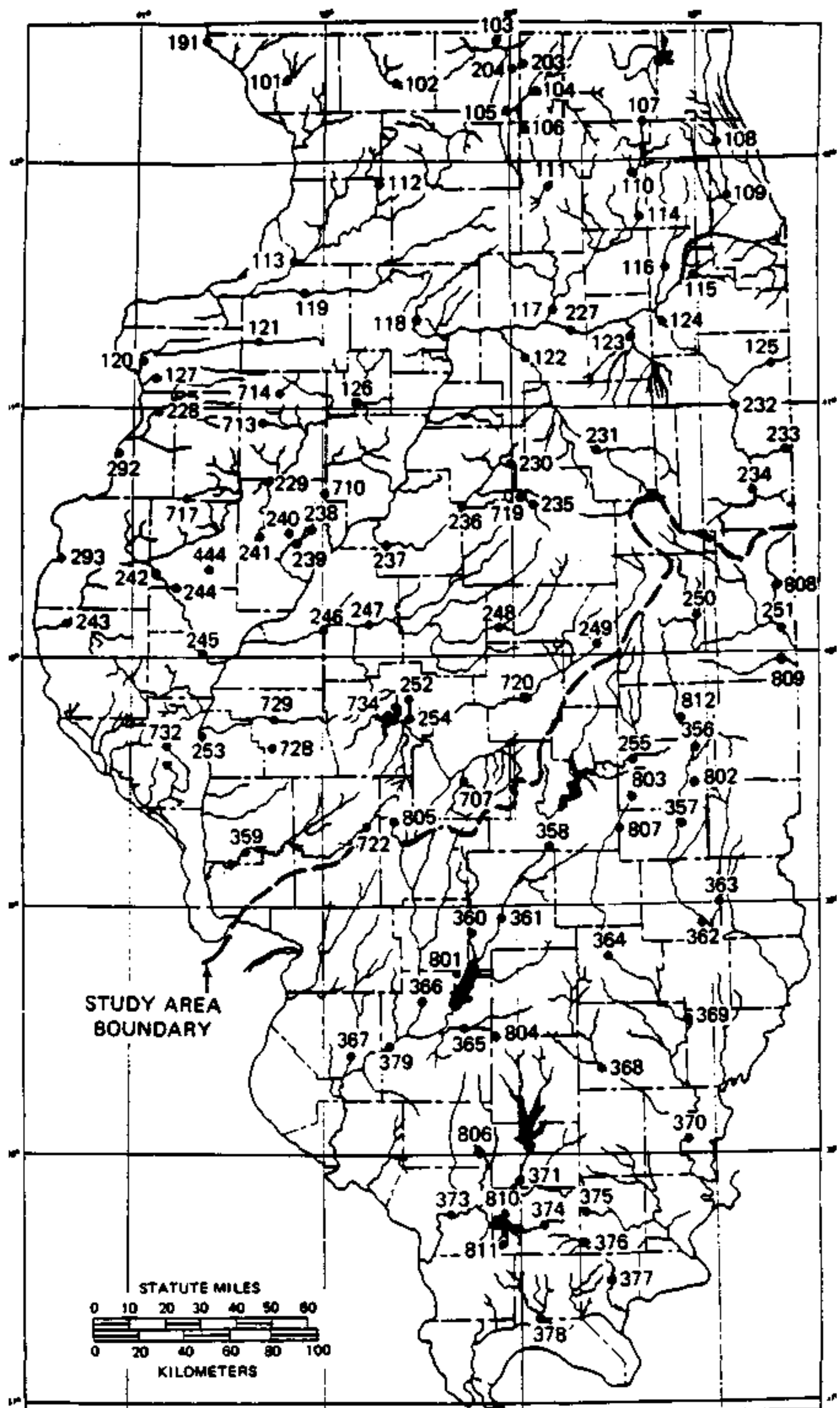

Figure 5. Map of Illinois showing suspended sediment and lake monitoring stations and study area boundary

ram and the flow velocity ranges up to 10 feet per second. The mesh opening of the collection bag is 0.25 mm. Therefore, when the median diameter of the bed materials is less then 0.25 mm the mesh may get clogged or some of the bed load collected inside the bag may pass through the mesh.

Very few attempts have been made to measure the bed load in Illinois. The Helley-Smith sampler was used by Bhowmik et al. (1980) to collect bed load samples from three sites on the Kankakee River. Analyses of these data estimated that at the state line bridge about 1.6 percent of the total load was bed load. At another station, the bed load was about 1 percent of the total load. However, at the state line bridge a sand bar was monitored, and indications were that between 9 and 14 percent of the total sediment load that year was contributed by this sand bar. Movement of the sand bar at this location is a special case (Bhowmik et al., 1980), and similar movement at other streams and rivers may or may not occur regularly.

Graf (1983) analyzed bed load data from nine streams and developed rating curves for the bed load transport for six river basins. Bed load data that were collected were in the sand-sized fraction, with median diameters from 0.25 to 0.50 mm. Bed load rating curves for gaging stations on Henderson Creek and the Kaskaskia, Edwards, Kishwaukee, Spoon, and Rock Rivers were developed. Some of these rating curves are:

Rock River near Joslin

$$Q_{sb} = 6.55 \times 10^{-7} Q_w^{2.0} \quad (4)$$

where Qsb is bed load discharge in tons per day and Q_w is the water discharge in cfs.

Edwards River near New Boston

$$Q_{sb} = 7.0 \times 10^{-3} Q_w^{1.5} \quad (5)$$

based on the Schoklitsch (Shulits, 1935) relationship.

Henderson Creek near Oquawka

$$Q_{sb} = 7.1 \times 10^{-10} Q_w^{3.3} \quad (6)$$

In addition to the above rating equations, Graf (1983) developed preliminary rating curves for a few other locations. However, the preliminary rating curves were developed based on very few measurements, and their use is limited.

Lake Sedimentation Data

Long-term lake sedimentation data from the state of Illinois can also be used in the analysis of sediment yields of Illinois streams. The Illinois State Water Survey has been conducting lake sedimentation surveys since the mid-1930's and has data for a number of lakes. All of the available lake sedimentation data were compiled and reduced to a standard format for use with this project.

Lake sedimentation data are given in terms of the total volume of deposited sediment from the date of construction of the lake to the last sedimentation survey. A methodology was developed to convert this accumulated volume of sediment into an equivalent sediment load at a hypothetical section located at the spillway.

Brune (1953) developed an empirical relationship between trap efficiency of reservoirs and their capacity-inflow ratio (figure 6). The trap efficiency for a particular lake is used to convert the volume of deposited sediment in the lake to the volume of the sediment delivered to it by the stream because a portion of the sediment will pass through the lake and over the spillway to downstream reaches.

In order to use Brune's relationship, the capacity-inflow ratio must be computed. Sedimentation surveys yield an accurate value for the capacity of a lake. Since most spillways are not maintained as gaging stations, long-term inflow data are not available at these locations. An estimate of the long-term average inflow rates must be made for each of the lakes.

Terstriep et al. (1982) divided the state of Illinois into ten areas of hydrologic homogeneity for low flow analyses. They observed that a fairly good relationship exists between the drainage areas of the gaging stations and the average annual flows within each region of hydrologic homogeneity. Relationships between drainage area, DA, and the average annual flow, AQW, were developed for each of the regions using existing gaging station records. These relationships can be used to estimate the average annual flow for each of the lakes within each region. This average annual flow, when converted into inflow volume for a year, yields the inflow needed in Brune's curve (see figure 6).

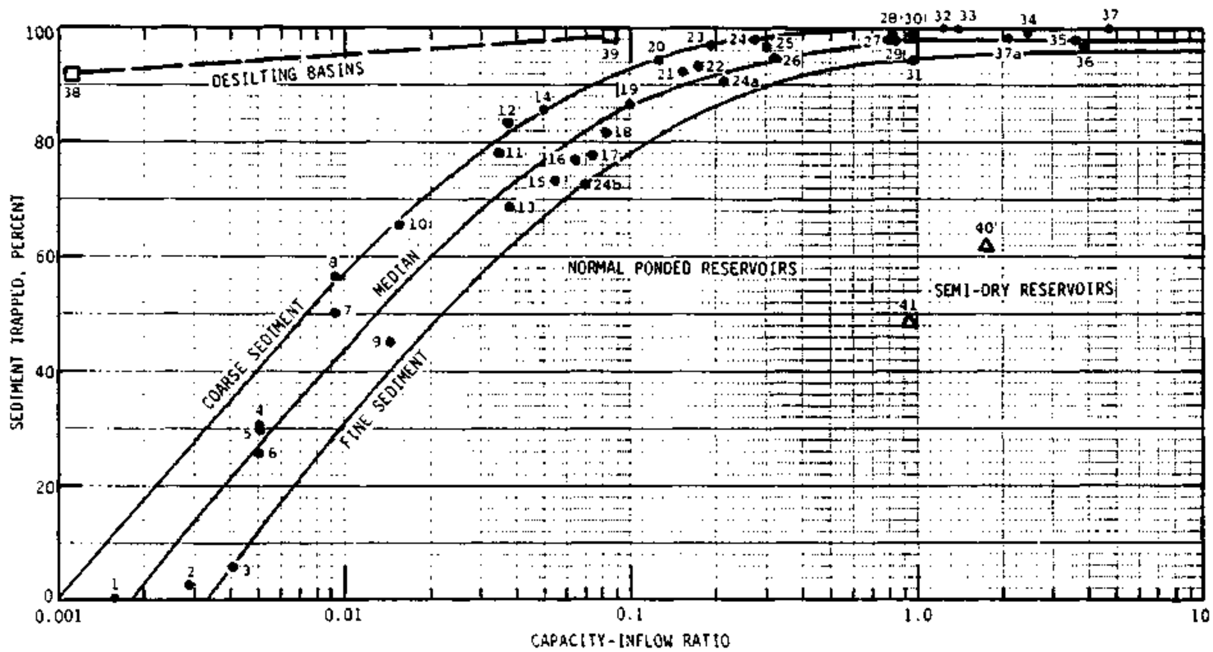

Figure 6. Trap efficiency of a man-made lake (after Brum, 1953)

Lake sedimentation data for lakes with drainage areas greater than or equal to 10 square miles within the study area shown in figure 1 were selected. These lakes are identified in figure 5 by the 700-series station codes. The data for these lakes were tabulated (table 2) and the total annual sediment yield was computed as follows:

1) With known DA, the average annual inflow, AQW, was computed from the regional AQW versus DA relationship.
2) The capacity-inflow ratio, C/I, was then computed. The capacity used was the original capacity of the lake (table 2).
3) With known C/I values, the trap efficiency was estimated from figure 6.
4) The measured volume of the sediment within each lake was then divided by the trap efficiency to determine the average annual sediment load at the dam site.
5) The sediment load determined in step 4 was then used as the sediment load of the stream at that particular section (table 2).

Numerical values for four geomorphic variables for all of the lakes are also given in table 2. These are the geomorphic parameters that were selected by the multiple regression method for use in the regional analysis of sediment yields of Illinois streams.

Geomorphic and Hydraulic Data

The geomorphic characteristics of a river basin play an important role in the determination of soil erosion and its delivery to the stream. Thus it is quite feasible to develop functional relationships between the geomorphic and hydraulic parameters and the sediment load transported by streams in a basin. Based on this premise, a number of these parameters were determined for the river basins and gaging stations where suspended sediment or lake sedimentation data are available. The numerical values for the geomorphic and hydraulic parameters for all of the sediment monitoring stations used in this study are given in appendix A. The definitions of all the parameters as well as the techniques that were utilized for determining these parameters are given below.

TABLE 2. HYDRAULIC, SEDIMENT LOAD, AND GEOMORPHIC DATA FOR RESERVOIRS WITHIN THE ROCK ISLAND DISTRICT IN ILLINOIS

STA. CODE	NAME OF LAKE	YEAR OF LAST SEDIMENT SURVEY	AGE SINCE ORIGINAL CAPACITY SURVEYED	DRAINAGE AREA (SQ.MI.)	ORIGINAL CAPACITY (ACRE-FT)	INFLOW (I) (ACRE-FT)	C/I	TRAP EFFICIENCY	DEPOSITED SEDIMENT (TONS/ACRE)	ANNUAL SEDIMENT YIELD (TONS/SQMI)	ANNUAL SEDIMENT LOAD (TONS)	TOTAL STREAM LENCTH LU(MI)	MAIN STREAM LENGTH LS(MI)	BASIN SHAPE BS
707	TAYLORVILLE	1977	15	131	9406	15476	.610	.967	1.55	1026	134490	111.0	24.3	1.63
710	CANTON NO.36	1960	21	15.0	3513	7446	.470	.960	2.40	1536	23194	30.6	9.0	.49
713	BRACHEN	1962	39	89.1	2881	37965	.076	.810	2.80	2212	197120	11.4	4.2	.04
714	CALHOUN	1947	23	13.1	424.7	14965	.028	.670	1.93	1843	24150	17.3	6.9	1.38
717	SPRING	1962	35	20.2	608.6	12045	.050	.770	1.20	997	20147	29.5	7.1	1.48
719	BLOOMINCTON	1955	26	61.0	6654	24236	.270	.937	1.02	697	42498	81.8	24.3	6.30
720	DECATUR	1983	61	925	19730	503700	.035	.705	.78	708	654900	147.1	40.3	.85
722	CARLINVILLE	1959	30	26.1	1725	16060	.110	.878	1.45	1057	27544	29.1	7.8	1.21
728	JACKSONVILLE	1952	12	10.8	7058	6935	1.02	.980	1.69	1104	11920	13.6	7.5	5.00
729	MAUVAISSETERRE	1979	58	32.6	1505	19345	.080	.842	.99	760	24779	32.7	13.2	4.58
732	PITTSFIELD(NEW)	1979	18	11.2	3454	7446	.062	.775	5.59	4616	51471	33.8	7.0	2.91
734	SPRINGFIELD	1977	42	265	63039	127750	.492	.950	1.39	936	248152	141.4	15.3	1.60

Definitions and Methodology

Drainage Area, DA. The drainage area is defined as the watershed area above a specific stream location on a river basin. The drainage area, in square miles, is determined by planimetering this area from topographic maps. The drainage areas of Illinois streams at various locations are given by Ogata (1975).

Stream Order, U. According to Strahler (1957), the visible, unbranched streams shown on topographic maps are defined as first-order streams. Where two first-order streams join, a second-order stream begins, and so forth.

Figure 7 shows a hypothetical example of this stream order method. This technique was utilized by Stall and Fok (1968) and by Bhowmik and Stall (1979) to determine the stream order of many Illinois streams. Data from these studies were used to determine the stream order of the various streams used in this project.

Total Number of Stream Segments, NU. A stream segment is a single stream path uninterrupted or forked by tributaries. If the stream path forks or is intersected by a tributary, then two new segments are formed. For example, branch A of the hypothetical stream in figure 7 has a total of 17 stream segments. For a detailed description, see Chow (1964).

Total Stream Length, LU. The total stream length is the sum of the lengths of all the streams within a drainage basin. Stream lengths can be measured from topographic maps with either a map wheel or a digitizer. Stream length is normally expressed in miles.

Mean Stream Length, LA. The mean stream length is defined as the ratio of the total stream length, LU, to the number of stream segments, NU. It is generally expressed in miles.

Drainage Density, DD. The drainage density is defined as the ratio of the total stream length, LU, to the drainage area, DA, of the basin. This parameter is expressed in miles per square mile.

Basin Length, LB. The basin length is measured as the distance in a straight line from the basin outlet to the most distant point at the headwaters of the main stream (figure 8). Basin length is expressed in miles.

Basin Width, BW. The basin width is defined as the distance of a straight line drawn normal to the basin length line at the point at which the basin has maximum width (figure 8). Basin width is expressed in miles.

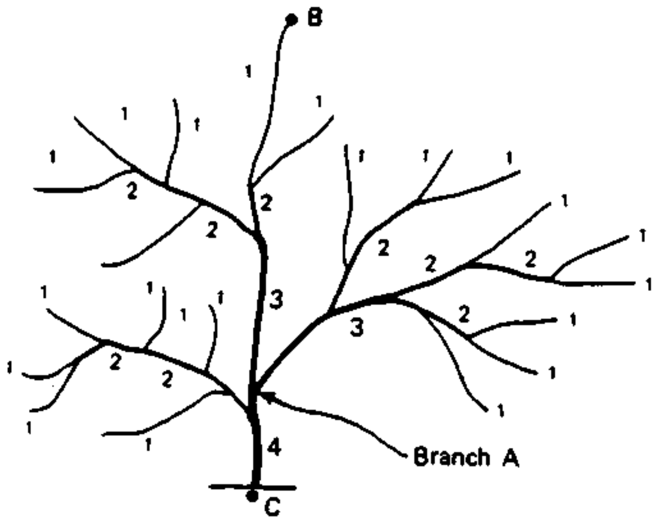

Figure 7. Horton-Strahler stream ordering system

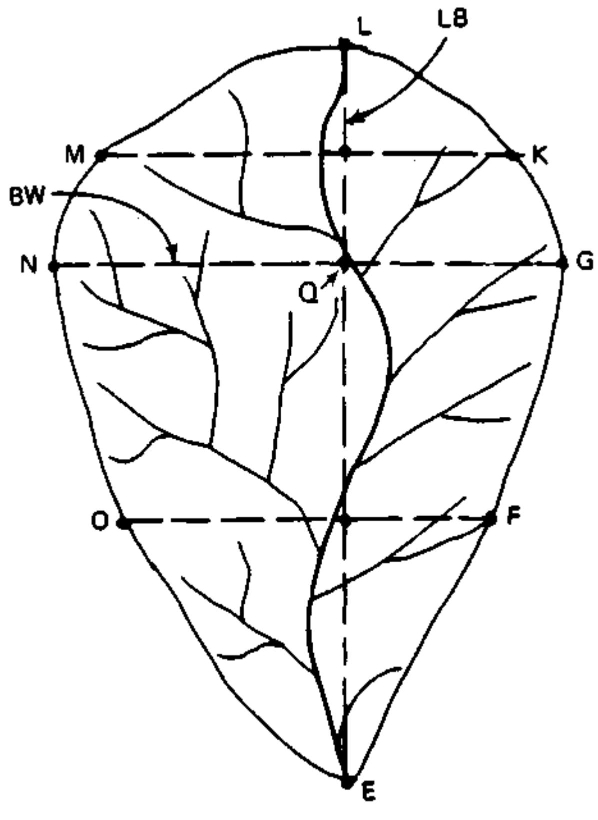

Figure 8. Definition sketch for basin length, basin width, and average basin relief

Total Basin Relief, H. The total basin relief is the difference in elevation between the highest point on the headwaters of the main stem of the stream and the outlet point of the stream. In figure 7, H is the difference in elevations between points B and C. Normally, topographic maps are used to determine the total basin relief. Total basin relief is expressed here in feet.

Average Basin Relief, HA. The average basin relief is determined by the following technique, which refers to information given in figure 8. Lines MK and OF are drawn parallel to the basin width, line NG, and normal to the basin length, line LE. Line MK bisects line LQ and line OF bisects line QE. The differences in elevations between points F, G, K, L, M, N, and 0 and point E are determined from the topographic map. The average of these seven elevation differences is called the average basin relief and is expressed in feet.

Relief Ratio, RR. The relief ratio is determined by dividing the total basin relief, H, by the basin length, LB, and is expressed in ft/mile.

Basin Shape, BS. The basin shape is the ratio of the square of the basin length, LB, to drainage area, DA.

Stream Frequency, F. The stream frequency is the ratio of the total number of stream segments, NU, to the drainage area, DA. It is expressed as stream segments per square mile.

Main Stem Length, LS. The length of the main stem is measured from a topographic map. In figure 8, this will be the distance from point L to point E along the main stream, in miles.

Sinuosity, SS. The sinuosity is defined as the ratio of the stream length to the down valley length. The sinuosities for streams used in this investigation were computed from the relationships given by Bhowmik and Stall (1979).

Incision, IC. The incision is defined as the difference in elevation between the top of the floodplain and the bed of the stream at the same flood-plain cross section. The incision for Illinois streams was computed following the procedure given by Bhowmik and Stall (1979). It is expressed in ft.

Circularity Ratio, CR1. This circularity ratio is obtained by dividing the drainage area by the area of a circle having the same perimeter as that of the basin. Thus in figure 8, the perimeter, P, of the basin will be the distance from point E through F, G, K, L, M, N, 0 and back to E. Once this distance, P, is measured on the topographic maps, the area of a circle with this perimeter is computed as $P^2/4\pi$ and is used in conjunction with the drainage area to compute the circularity ratio, CR1.

Circularity Ratio, CR2. This circularity ratio is obtained by dividing the drainage area by the area of a circle having a diameter equal to the basin width.

Circularity Ratio, CR3. This circularity ratio is obtained by dividing the drainage area by the area of an ellipse which is given by π (LB)(BW).

Precipitation, PRECIP. The mean annual precipitation, in inches, for each station was tabulated from figure 4.

Average Water Discharge, AQW. The average water discharge, in cfs, for USGS stations were tabulated from the USGS water resources data reports. These values were tabulated for each station using the most recent USGS publication available at a given site. Average water discharge values for stations which were not monitored by the USGS were estimated using the ratio of the drainage areas multiplied by the AQW at a nearby station.

Average Annual Water Volume,AQWV. Average annual water volume is obtained by converting AQW from cubic feet per second to cubic feet per year.

Discharge/Drainage Area Ratio, QWDA. This ratio is obtained by dividing the average water discharge AQW by the drainage area DA. This ratio is expressed in cubic feet per second per square mile.

Average Stream Velocity, VS. The average stream velocity, in fps, for each station was computed from the hydraulic geometry equations developed by Stall and Fok (1968). For stations located in river basins where no equations were defined, stream velocity was estimated using an equation from a nearby river basin.

Top Width of the Stream, WT. The width of the stream at the surface, WT (ft), for each station was computed from the hydraulic geometry equations developed by Stall and Fok (1968). For stations located in river basins where no equations were developed, WT was estimated using an equation from a nearby river basin.

Average Depth of the Stream, DS. The average depth of the stream, DS (ft), was computed from the hydraulic geometry equations developed by Stall and Fok (1968). For stations located in river basins where no equations were developed, DS was estimated using an equation from a nearby river basin.

STATION ANALYSES

Sediment Transport Equations

Tributary Stations

Tributary stations are defined as those sediment stations within the Rock Island District which are not located on the main stems of the Illinois or Mississippi Rivers. Data for these stations were collected and compiled by either the USGS or the SWS.

Methods. The objective of this analysis was to develop predictive sediment transport equations for each sediment station based on the available sediment record. Two types of sediment transport equations were developed for each station. These were based on a least-squares linear regression analysis of the logarithms of the measured sediment discharge and the logarithms of the corresponding water discharge. It was discovered in the process of developing these equations that some of the sediment discharge and/or water discharge values were zero. In these instances the zero data pair was excluded from the analysis. Attempts to replace zero data with very small positive values (i.e., 10^{-3} through 10-70) were not successful. Elimination of the zero data pairs should have very little effect on the load estimations, since a very small fraction of the total annual load is transported during low discharge periods.

The first type of equation that was developed is referred to as the annual regression equation (ARE) and represents the relationship between sediment discharge (tons/day) and water discharge (cfs) based on the data collected for one particular water year. The second type of equation is referred to as the period of record regression equation (POR) and represents the relationship between sediment discharge (tons/day) and water discharge (cfs) for all the sediment data collected at the station.

Since the sediment data obtained from the USGS represent mean daily sediment and water discharges, the transport equations for stations monitored by the USGS represent the relationship between mean daily sediment and water discharges. The sediment data obtained from the SWS represent instantaneous sediment and water discharges. Therefore the transport equations for stations monitored by the SWS represent the relationship between instantaneous sediment and water discharges. There were three instances (station codes 125, 232, and 233) where sediment data were collected by the USGS in some years and by the

SWS in other years. The SWS instantaneous data were treated as if they were mean daily values in these three cases and combined with the USGS data in order to develop the POR equation.

On the basis of the method described by Porterfield (1972), the resultant transport equations and the appropriate mean daily water discharge data obtained from the USGS were used to calculate daily sediment load values. These values were summed for each water year to obtain an estimate of the annual sediment load for each station for each year that samples were collected.

Results. The general form of the sediment transport regression equation is:

$$Q_s - a(Q_w)^m \qquad (7)$$

where Qs is sediment load (tons/day), a is the coefficient of the regression equation, Q_w is the water discharge (cfs), and m is the slope of the regression equation.

Appendix B summarizes the regression equation parameters, including the standard error of the estimate and the correlation coefficient for all the tributary stations. The statistics are listed in ascending station code order. For each station the POR statistics are listed first and are indicated by the three-digit station code. Then the ARE statistics for that station are listed for all appropriate water years. (The fourth and fifth digits of the station code indicate the appropriate water year; i.e., 10181 represents station 101, Water Year 1981). Stations where the POR and ARE statistics are identical reflect the fact that data were available for only one year at those sites. The correlation coefficients were greater than or equal to 0.80 for all but 11 of the regression equations representing only five stations. Sixty-two percent of the regression equations had correlation coefficients greater than or equal to 0.90.

Figure 9 shows the four sediment transport plots for Henderson Creek near Oquawka (228). Figures 9a, b, and c show the data collected in each of the three water years. Figure 9d shows the data for the period of record. Similar plots were generated for each POR and ARE data set listed in appendix B.

These sediment transport equations were used to calculate an estimate of the annual sediment load at each station for each year that samples were collected. The primary purpose of this was to compare the estimated loads to

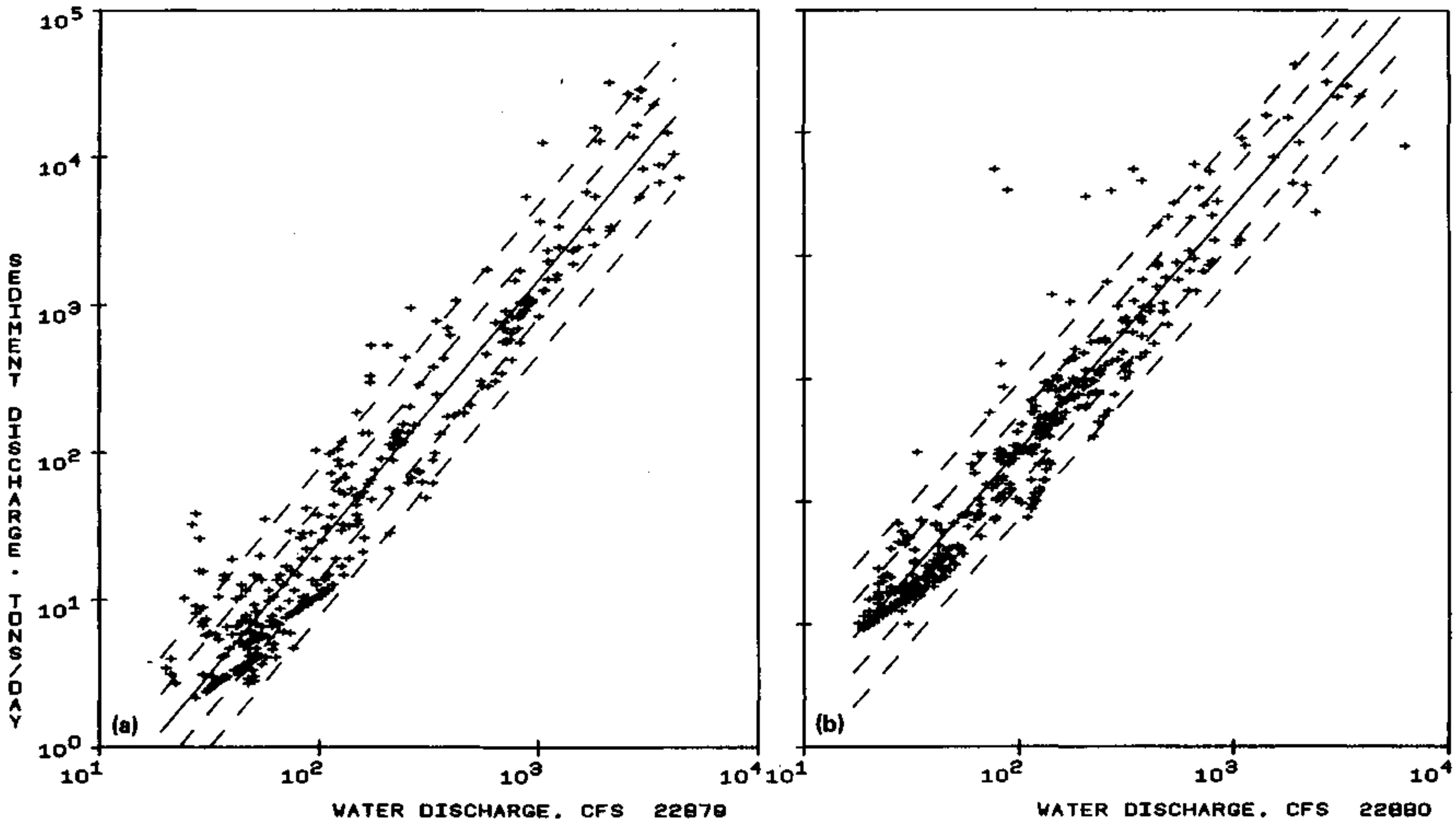

Figure 9. Suspended sediment discharge versus water discharge for Henderson Creek near Oquawka, Illinois

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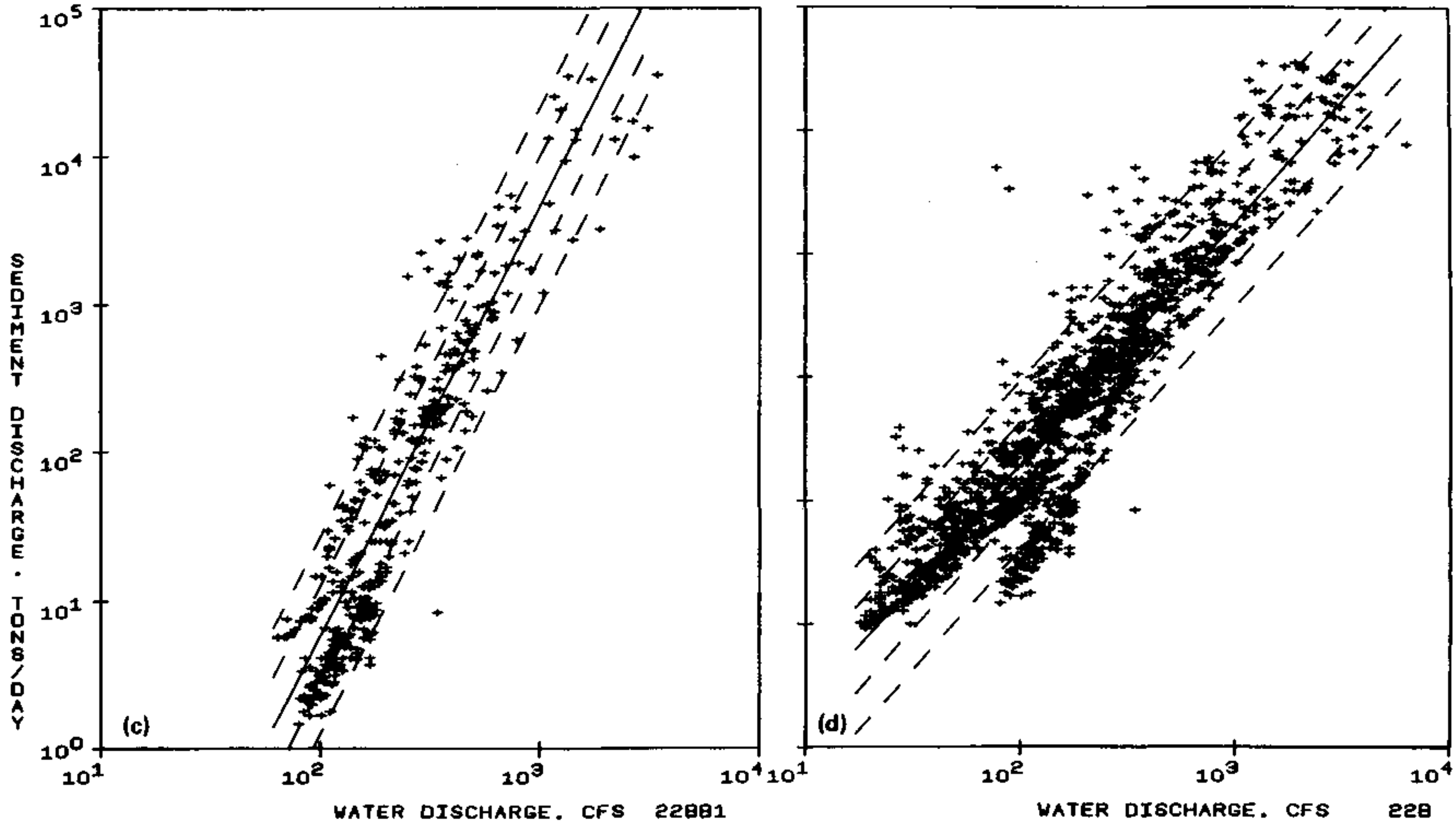

Figure 9. Concluded

the measured loads. For stations where mean daily measured loads were not available, the calculated loads are assumed to be the best estimate of the annual load for each year (Bonini et al., 1983).

Appendix C lists the calculated and measured annual loads and yields for all of the tributary stations for all years. The results are listed by station code and water year. For each water year the annual load estimated by the appropriate ARE is listed first, followed by the annual load generated by the POR and then the measured annual load, if available.

Although the correlation coefficients for the various regression equations tend to be high, there is no indication that either the ARE's or the POR's are better able to consistently predict the annual loads when these values are compared to the measured loads. This does not mean that the sediment transport equations are not useful. If a limited amount of data is collected during a year, then developing a sediment transport equation, in combination with the method referred to in the previous section, can be used to make a reasonable estimate of the annual load (Bonini et al., 1983). If enough historical daily sediment record exists at the site, then the shift-control method (Colby, 1956) (also referred to as the hydrograph-shifting method [Frost and Mansue, 1984]) may yield a better estimate of the annual load.

Main Stem Stations

All stations on the main stem of the Illinois or Mississippi River are considered main stem stations. These include the Illinois River stations at Marseilles (227) and Valley City (253). and the Mississippi River stations at East Dubuque (191), Burlington (292), and Keokuk (293). Data for the Illinois River stations were provided by the USGS, while the COE collected the data for the Mississippi River stations.

The objective of this analysis was to develop predictive sediment transport equations for each main stem station using all available sediment data. Several types of sediment transport equations of the form outlined in equation 7 were developed for all the main stem stations except Marseilles.

The Illinois River at Marseilles had very little sediment data. The USGS collected monthly data from May 1975 to February 1979, and continued to collect data intermittently from March 1979 to September 1982. The data included mean daily water and suspended sediment discharge. The period of record regression equation (POR) was computed and can be used to estimate a mean daily sediment load at Marseilles. The equation is:

$$Qs = 0.678x10^{-3}(Q_w)^{1.65} \qquad (8)$$

The correlation coefficient is 0.79 and the standard error of the estimate is 0.4077. The regression plot is shown in figure 10.

Annual regression equations and a period of record regression equation were developed for the Illinois River at Valley City. These transport equations represent the relationship between mean daily sediment and water discharges. The equations, and appropriate mean daily water discharge records obtained by the USGS, were used to develop calculated sediment load values and to obtain an estimate of the annual sediment load for each year that samples were collected. Table 3 summarizes the regression equation parameters, while table 4 lists the calculated and measured annual loads for the Valley City station. Loads based on the annual regression equation were 16 to 24 percent lower than the measured annual load. Loads based on the period of record equation were from 15 percent above to 27 percent below the measured annual loads. The period of record sediment transport plot for Valley City is shown in figure 11.

The three Mississippi River stations are the only stations where 14 or 15 years of nearly continuous, daily instantaneous sediment concentration data exist. Consequently, these stations were analyzed in greater detail.

On a few occasions, multiple sediment concentrations were recorded on a single day. When this occurred, the daily concentration was computed as the mean value of these readings. Daily concentration and water discharge readings were used to compute daily sediment load values. The water and sediment load data were used to compute annual regression equations for each water year and to compute the period of record equation. These transport equations represent the relationship between instantaneous daily sediment load and daily water discharge. The period of record sediment transport plots for stations 191, 292, and 293 are shown in figures 12, 13, and 14, respectively.

The annual regression equations were used to estimate sediment loads for days with no sediment concentrations. Measured and estimated loads were summed to obtain the annual, seasonal, and monthly measured loads for each water year. The measured loads were used to develop four additional regression equations.

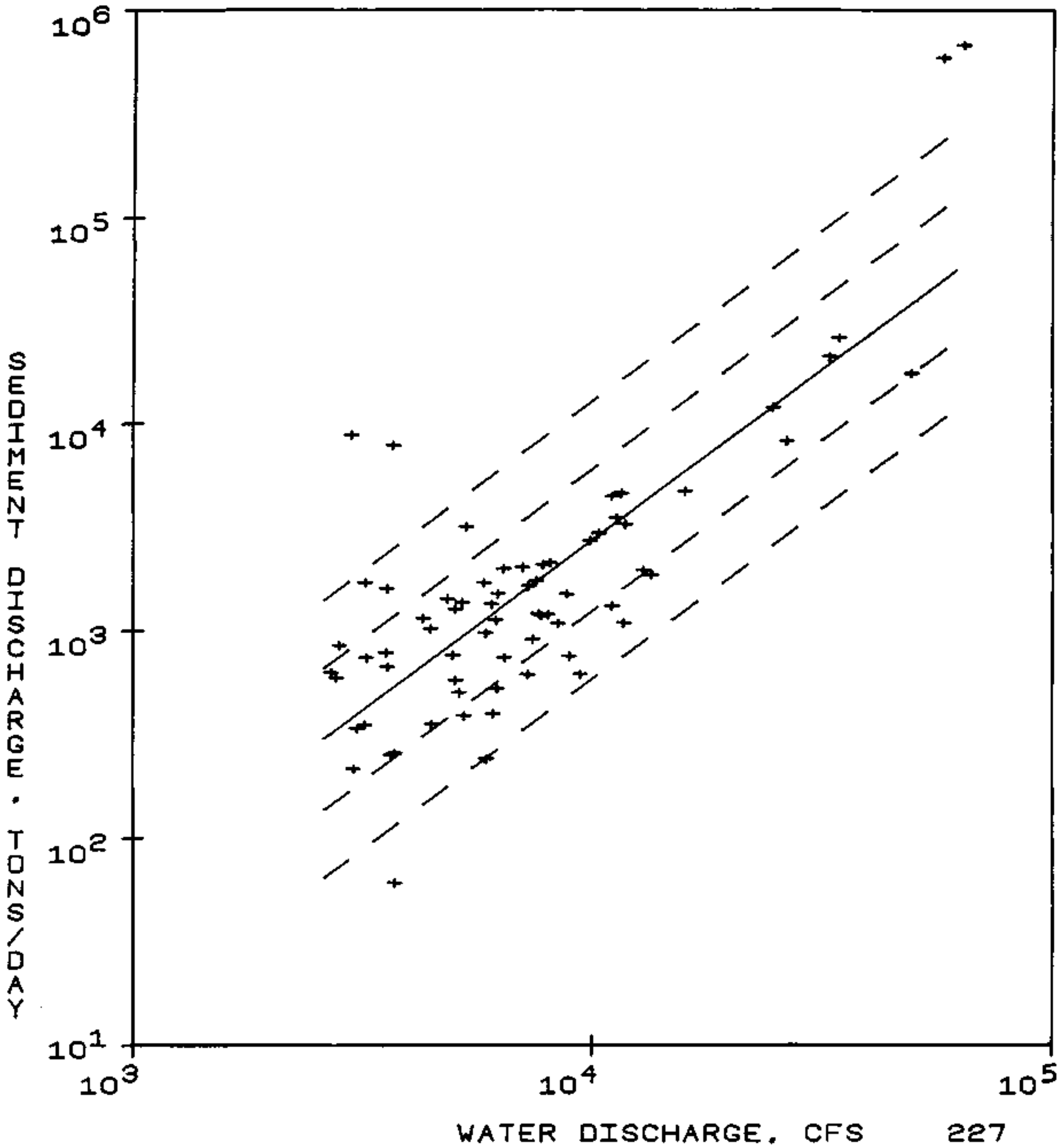

Figure 10. Suspended sediment discharge versus water discharge for Illinois River at Marseilles, Illinois

TABLE 3. STATISTICAL PARAMETERS FOR THE PERIOD OF RECORD AND ANNUAL REGRESSION EQUATIONS FOR THE ILLINOIS RIVER AT VALLEY CITY

STATION CODE	COEFFICIENT	SLOPE	STANDARD ERROR OF ESTIMATE	CORRELATION COEFFICIENT
25381	.0843402	1.1875286	.2513957	.8560805
25382	.2738931	1.0727617	.3352830	.6863847
25383	1.6212325	.8696317	.2811065	.7519497
253	.3518733	1.0447466	.3073550	.7419622

TABLE 4. CALCULATED AND MEASURED ANNUAL SEDIMENT LOADS FOR THE ILLINOIS RIVER AT VALLEY CITY

STATION CODE	TYPE	ANNUAL LOAD (TONS)	ANNUAL YIELD (TONS/SQ MI)	ANNUAL YIELD (TONS/ACRE)
25381	ARE	6177673.	233.	.36
	POR	5735984.	216.	.34
	MEAS	7350548.	277.	.43
25382	ARE	6861236.	258.	.40
	POR	6543077.	246.	.38
	MEAS	9018570.	340.	.53
25383	ARE	5015613.	189.	.30
	POR	7113278.	268.	.42
	MEAS	6182190.	233.	.36

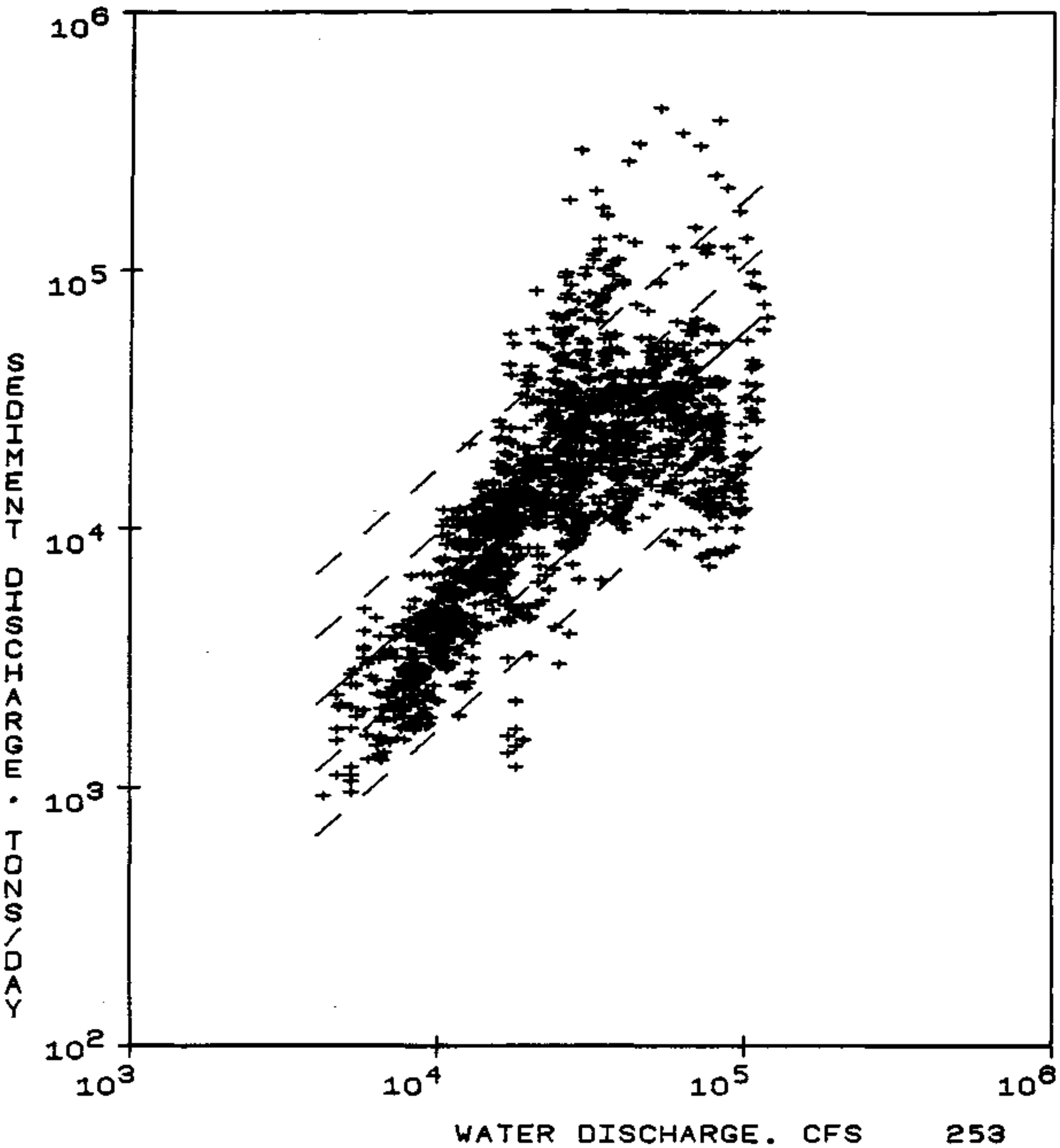

Figure 11. Suspended sediment discharge versus water discharge for Illinois River at Valley City, Illinois

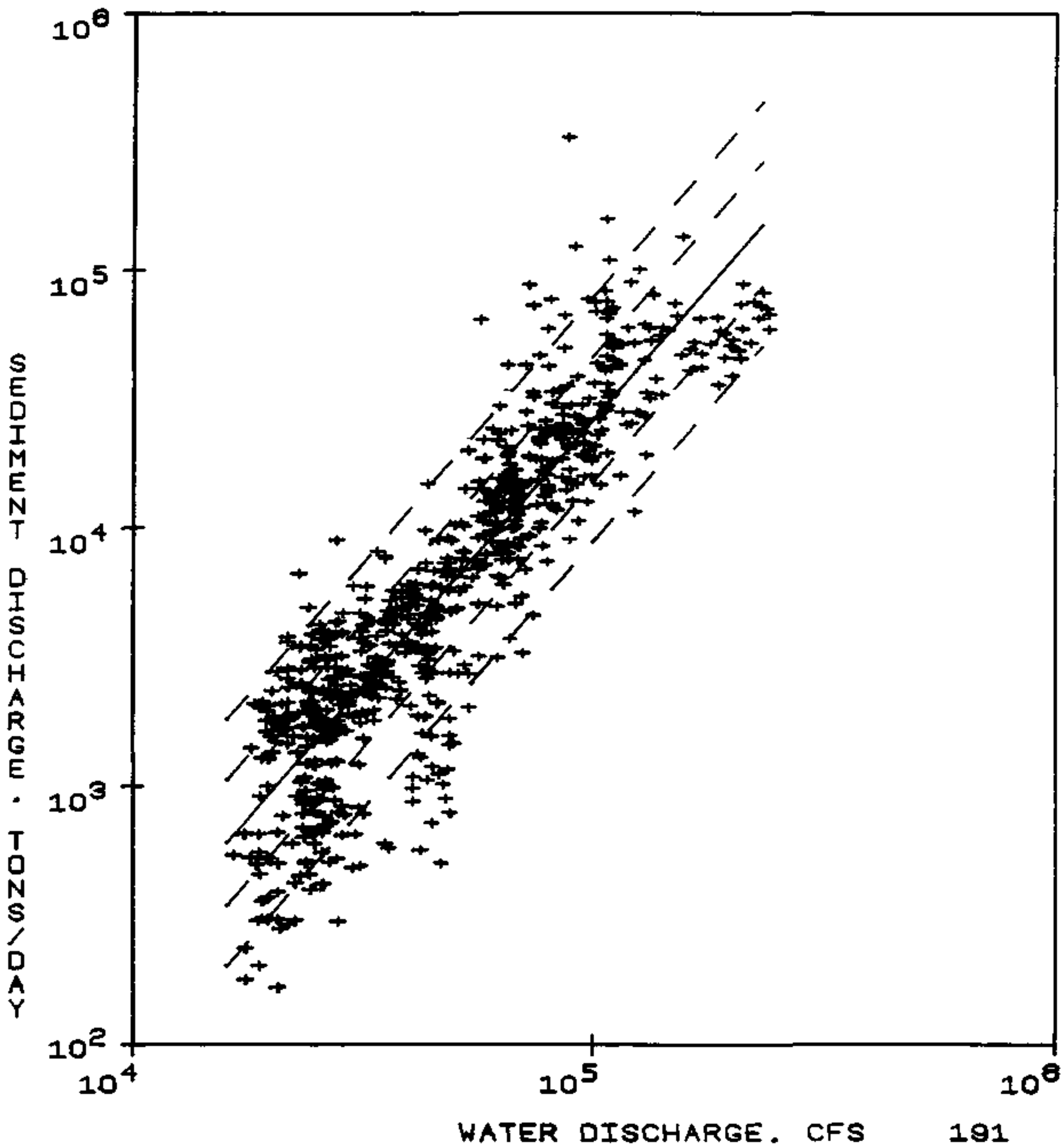

Figure 12. Suspended sediment discharge versus water discharge for Mississippi River at East Dubuque, Illinois

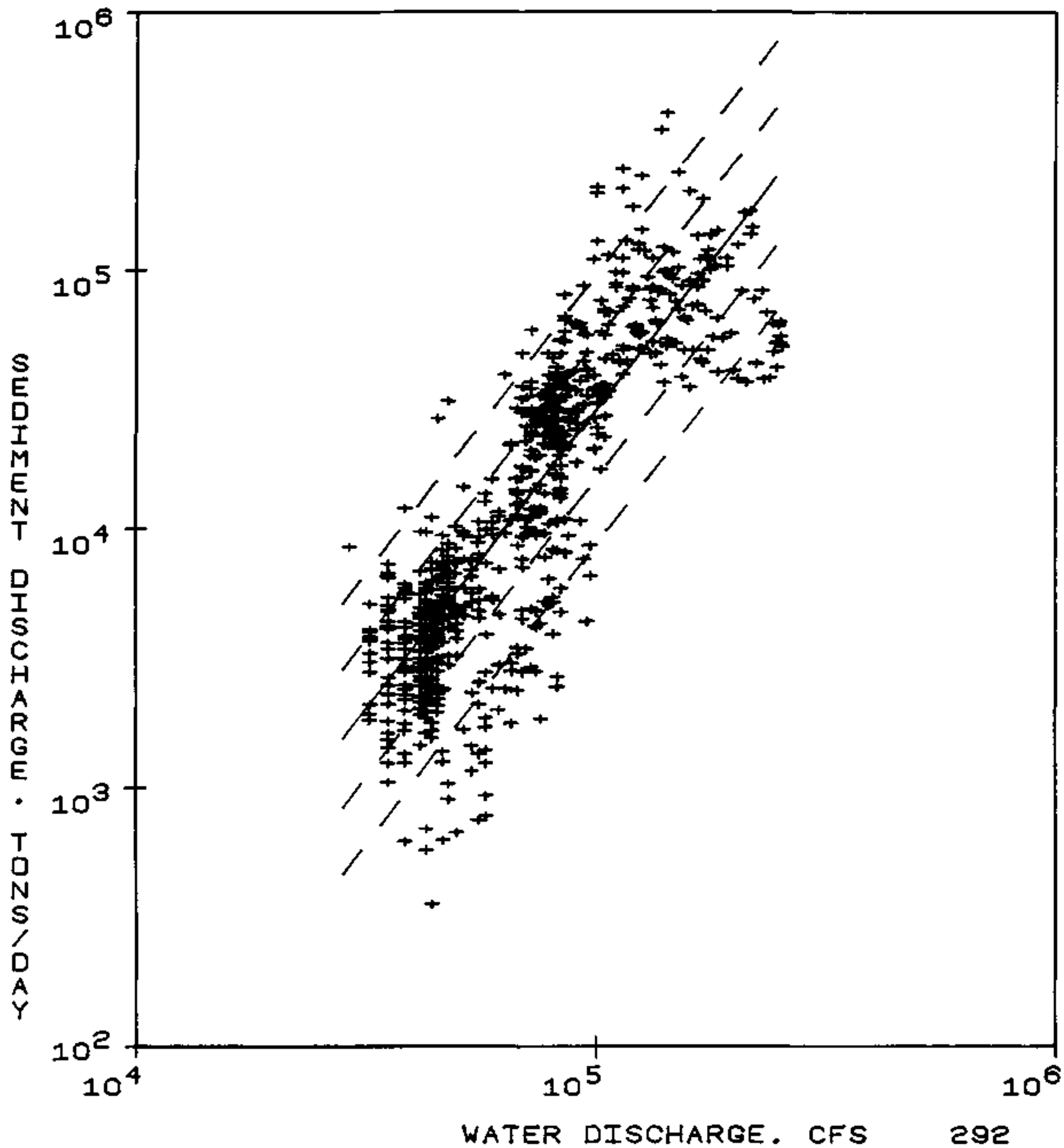

Figure 13. Suspended sediment discharge versus water discharge for Mississippi River at Burlington, Iowa

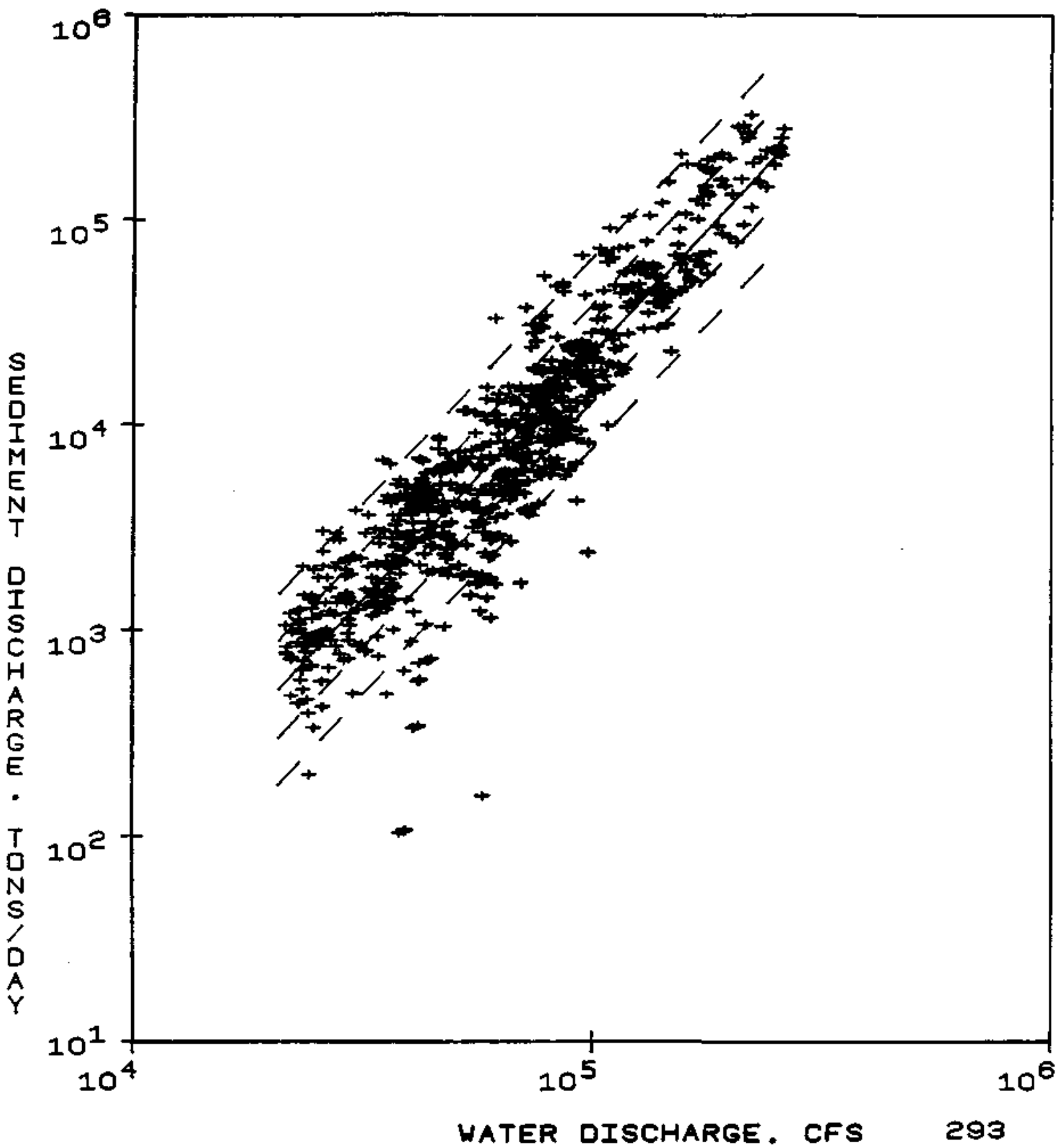

Figure 14. Suspended sediment discharge versus water discharge for Mississippi River at Keokuk, Iowa

The annual load regression equation (ALRE) defines a relationship between the total measured sediment load for a water year (tons/year) and the total measured water discharge (cfs-days) for that water year. This may be used to estimate annual sediment loads. Seasonal load regression equations (SLRE) explain the relationship between the total measured sediment load for a season (tons/season) and the total water discharge (cfs-days) for that season. The combined monthly regression equation (CMRE) relates the total measured sediment load for any month (tons/month) to the total measured water discharge (cfs-days) for that month. Individual monthly regression equations (IMRE) relate the total measured sediment load for a particular month (tons/month) and the total measured water discharge (cfs-days) for that month.

Appendix D summarizes the regression equation parameters, including the standard error of the estimate and the correlation coefficient for each of the six types of regression equations at each station. For each station the ARE's are listed first and can be identified by a five-digit code. The first three digits indicate the station and the last two indicate the water year; i.e., ARE's for Keokuk during Water Years 1968 through 1981 are given by 29368 to 29381. The POR equation is listed next and is indicated by the three-digit station code. The annual load regression equation (ALRE) is listed next and is represented by the three-digit station code followed by two zeros. The three seasonal load regression equations appear next and are indicated by the station code followed by the numbers 21 (October-January), 22 (February-May), or 23 (June-September). The combined monthly equation is indicated by the station code followed by the number 31. Lastly, the individual monthly regression equations are indicated by the station code and the numbers 01 (January) through 12 (December). Eighty-two percent of the equations had correlation coefficients greater than 0.80, while 46 percent had correlation coefficients greater than 0.90.

The annual regression equations and the period of record regression equations were used with daily water discharge records obtained from the C0E to calculate daily sediment loads. These daily loads were summed to obtain estimates of the annual, seasonal, and monthly loads for each water year. The annual load regression equation and the measured annual water discharge were used to estimate the annual sediment load for each water year. The three seasonal load equations were used to compute the sediment load for each season in every water year. The annual load was estimated by summing the three seasonal loads. Monthly loads were estimated with the combined monthly equation and the individual monthly equations. The monthly loads were summed to yield estimates of seasonal loads as well as annual loads for each water year.

Appendix E lists the calculated and measured annual loads for each of the Mississippi River stations during representative water years. All stations experienced low flows during Water Year 1977 and high flows during Water Year 1973. One water year representing an average annual flow for each station is also listed. None of six types of regression equations has an apparent advantage in adequately predicting annual sediment loads when these loads are compared to measured loads. However, each of these types of regression equations may be used to estimate the annual sediment load.

Seasonal Analyses

Tributary Stations

Methods. The objective of the seasonal analyses was to attempt to identify sediment transport equations which could be used to predict sediment loads on a seasonal basis. The first step in this process was to identify and define the appropriate seasons within the context of a water year calendar. An intuitive process involving an evaluation of the typical seasonal storm event patterns that occur in Illinois was used to help identify three seasons for this analysis. The three seasons were defined as being from October through January, February through May, and June through September.

Once these seasons were identified, the ARE and POR sediment transport equations were used to calculate daily sediment loads which were summed to estimate the total load for each season for all stations. For stations with three or more years of record, seasonal sediment transport equations (SRE's) were developed from the relationship between the instantaneous or mean daily sediment discharge and the instantaneous or mean daily water discharge for each season for the period of record of each station. These equations were in the same form as equation 7. The regression statistics for the seasonal equations are given in appendix F. These equations were then combined with the appropriate mean daily water discharge data to obtain the calculated daily sediment loads. These were summed for each season, yielding a total seasonal sediment load.

One other method for predicting sediment loads was considered. It consisted of developing seasonal load regression equations (SLRE's) based on the relationship between the total measured sediment load for a season and the total measured water discharge for that season. This method was rejected for the tributary stations due to the limited size of the data set. The number of data points for each curve would be equal to the number of years of record for each station. This would mean that most of the equations would be defined by only one or two data points.

Results. Appendix G lists the calculated and measured seasonal loads and their percentages relative to their total annual load for all of the tributary stations. The seasonal loads were calculated using the station ARE and POR equations and the daily water discharge data for the respective seasons. These values are followed by the measured loads, if available. For the 10 stations with three or more years of record, the seasonal loads estimated from the appropriate seasonal regression equations (SRE) are listed before the values derived from the ARE. There are no percentages associated with the results from the SRE's since the loads from these equations do not directly relate to the other SRE-derived values listed for that particular year.

There is no apparent advantage to using the SRE, ARE, or POR to predict sediment load on a seasonal basis. However, close examination of the percentage values does yield interesting results. It appears that the relative percentages of the total load based on results generated from the ARE's and POR's tend to compare favorably to the measured percentage of the total load for each of the three seasons. The percentage data also show that the February-May and June-September seasons each carries a much higher percentage of the total annual load than the October-January season. In addition, there does not appear to be a geographical pattern to the seasonal percentage load results.

This information can be useful in efforts to establish an efficient and effective sediment sampling program. It also has a potential use in evaluating and predicting the relative effects of seasonal differences in tillage practices, cropping patterns, and pesticide applications on stream sediment and water quality.

Main Stem Stations

The objective of the seasonal analysis was to define sediment transport equations which could predict seasonal loads at the following main stem stations: Illinois River at Valley City (253) and the Mississippi River at East Dubuque (191), Burlington (292), and Keokuk (293). There were not enough data to analyze the Marseilles station on a seasonal basis.

The Valley City station was analyzed according to the same procedure used to analyze the tributary stations. The seasonal regression equations for Valley City are listed in table 5, while the measured seasonal loads and the seasonal load estimates based on these equations and the ARE and POR equations can be found in table 6.

Seasonal loads for the Mississippi River stations were estimated from the annual regression equation, the period of record equation, and the seasonal load regression equations, as well as the combined monthly and the individual monthly regression equations. Seasonal regression equations were not developed for the Mississippi River stations. None of the five types of equations shows an apparent advantage in adequately predicting sediment loads on a seasonal basis. However, each may be used to estimate a seasonal load. Table 7 lists the average measured seasonal load and seasonal water discharge for each of the Mississippi River stations.

Monthly Loads

Monthly loads for the three Mississippi River stations were estimated with the annual regression equation, the period of record regression equation, and the combined and individual (IMRE) monthly regression equations. Again there is no apparent pattern to indicate that any one of the four types of regression equations consistently yields better estimates of monthly sediment loads, but all yield reasonable estimates of these values. Table 8 summarizes the average measured monthly sediment loads and water discharges for each of the Mississippi River stations.

TABLE 5. STATISTICAL PARAMETERS FOR THE SEASONAL REGRESSION EQUATIONS FOR THE ILLINOIS RIVER AT VALLEY CITY

STATION CODE	COEFFICIENT	SLOPE	STANDARD ERROR OF ESTIMATE	CORRELATION COEFFICIENT
25321	.2061403	1.0890062	.2467161	.8034880
25322	4.1929444	.7933036	.3401222	.5945857
25323	.0223573	1.3405014	.2715865	.8151413

TABLE 6. CALCULATED AND MEASURED SEASONAL SEDIMENT LOADS FOR THE ILLINOIS RIVER AT VALLEY CITY

STATION CODE	TYPE	OCTOBER-JANUARY (TONS)	(%)	FEBRUARY-MAY (TONS)	(%)	JUNE-SEPTEMBER (TONS)	(%)
25381	SRE	660850.		1678018.		4629092.	
	ARE	686388.	11.1	2122918.	34.4	3368366.	54.5
	POR	742771.	12.9	1963439.	34.2	3029774.	52.8
	MEAS	890950.	12.1	3249088.	44.2	3210510.	43.7
25382	SRE	920563.		2889888.		2116181.	
	ARE	1045292.	15.2	4134230.	60.3	1681715.	24.5
	POR	1024193.	15.7	3895101.	59.5	1623783.	24.8
	MEAS	1291920.	14.3	3970520.	44.0	3756130.	41.6
25383	SRE	2482619.		2615626.		1294058.	
	ARE	1809155.	36.1	2323874.	46.3	882584.	17.6
	POR	2617084.	36.8	3419734.	48.1	1076461.	15.1
	MEAS	2677570.	43.3	2169590.	35.1	1335030.	21.6

TABLE 7. AVERAGE, MEASURED SEASONAL SEDIMENT LOADS AND WATER DISCHARGES FOR THE MISSISSIPPI STATIONS

STATION CODE	SEASON	LOAD (TONS)	DISCHARGE (CFS-DAYS)
191	OCT - JAN	447912.	4164060.
	FEB - MAY	2201058.	7807606.
	JUNE - SEPT	1531107.	5730124.
292	OCT - JAN	1274440.	7859470.
	FEB - MAY	5610494.	13184598.
	JUNE - SEPT	4493946.	9135550.
293	OCT - JAN	1066304.	6167628.
	FEB - MAY	6756818.	11865407.
	JUNE - SEPT	3075620.	8506042.

TABLE 8. AVERAGE, MEASURED MONTHLY SEDIMENT LOADS AND WATER DISCHARGES FOR THE MISSISSIPPI STATIONS

STATION CODE	MONTH	LOAD (TONS)	DISCHARGE (CFS-DAYS)
191	OCT	165540.	1182533.
	NOV	146152.	1263686.
	DEC	63793.	895420.
	JAN	72426.	822420.
	FEB	81183.	806406.
	MAR	473847.	1654753.
	APR	1029328.	2883086.
	MAY	616699.	2463360.
	JUNE	730889.	1862446.
	JULY	400918.	1577126.
	AUG	193772.	1139250.
	SEPT	205527.	1151300.
292	OCT	466323.	1857605.
	NOV	351521.	1954440.
	DEC	200515.	1864371.
	JAN	256080.	2183054.
	FEB	307631.	1900736.
	MAR	1366453.	3050648.
	APR	1938530.	4212549.
	MAY	1997879.	4020662.
	JUNE	2058210.	2866286.
	JULY	1292443.	2482500.
	AUG	625803.	1953657.
	SEPT	517490.	1833106.
293	OCT	324122.	1642628.
	NOV	332201.	1761471.
	DEC	202708.	1391307.
	JAN	207272.	1372221.
	FEB	280033.	1351300.
	MAR	1607899.	2799435.
	APR	2547473.	3978742.
	MAY	2321412.	3735928.
	JUNE	1557614.	2766757.
	JULY	872263.	2351414.
	AUG	282264.	1705685.
	SEPT	363477.	1682185.

GENERALIZED ANALYSES

Average Annual Sediment Load

Flow-Duration Method

One important use of suspended sediment data is to estimate the long-term average amount of sediment that will be transported by a stream. The flow-duration, sediment-rating curve method (Miller, 1951; Lee and Bhowmik, 1979) was used in this study to calculate this long-term average annual sediment load.

To use this technique, it is necessary to have a reliable, long-term flow duration curve for the station being analyzed. Ten of the stations in this study did not meet this criterion. Long-term flow duration curves were not available for seven of these stations (station codes 114, 203, 204, 240, 244, 252, and 444). The remaining three stations (station codes 108, 109, and 116) were located in areas that are experiencing drastic changes in their watershed conditions due to urbanization. The curves for these stations reflect historical watershed conditions rather than the present situation, and are not useful in this context.

The flow duration curves for each of the remaining stations were divided into as many as 36 flow class intervals. The median flow value between each interval was then used in the appropriate ARE to calculate sediment load values for each flow class increment. Each of these sediment load values was then multiplied by the incremental difference between the appropriate two flow class intervals. This yielded up to 35 fractional total sediment loads for each station. These fractional values were summed for each station and multiplied by 365 days to get the long-term average annual sediment load.

Table 9 lists the long-term average annual sediment load for these stations. The results for five of the sediment stations (station codes 101, 122, 231, 236, and 237) were based on the flow duration tables for nearby gaging stations. The flow duration data for these gaging stations were adjusted according to the ratio of the drainage area for the sediment site to the drainage area for the gaging station.

These long-term average annual sediment load values will be used as input for the multiple regression analysis. They will also be used in a later section to develop regional relationships.

TABLE 9. LONG-TERM AVERAGE ANNUAL SEDIMENT LOAD BASED ON THE FLOW-DURATION, SEDIMENT-RATING CURVE METHOD

STA. CODE	USGS STATION NUMBER	USGS STATION NAME	AVERAGE ANNUAL SEDIMENT LOAD (TONS)	AVERAGE ANNUAL SEDIMENT YIELD (TONS/SQ MI)
101	05418950	APPLE RIVER NEAR ELIZABETH	53986	261
102	05435500	PECATONICA RIVER AT FREEPORT	204501	154
103	05437500	ROCK RIVER AT ROCKTON	471884	74
104	05438500	KISHWAUKEE RIVER AT BELVIDERE	41026	76
105	05440000	KISHWAUKEE RIVER NEAR PERRYVILLE	115865	105
106	05439500	SOUTH BRANCH KISHWAUKEE RIVER NEAR FAIRDALE	51060	132
107	05550000	FOX RIVER AT ALGONQUIN	49425	35
110	05551200	FERSON CREEK NEAR ST. CHARLES	5411	105
111	05439000	SOUTH BRANCH KISHWAUKEE RIVER AT DEKALB	6598	85
112	05444000	ELKHORN CREEK NEAR PENROSE	43863	300
113	05446500	ROCK RIVER NEAR JOSLIN	948067	99
115	05539000	HICKORY CREEK AT JOLIET	17346	162
117	05552500	FOX RIVER AT DAYTON	182005	69
118	05556500	BIG BUREAU CREEK AT PRINCETON	80225	409
119	05447500	GREEN RIVER NEAR GENESEO	262283	262
120	05466500	EDWARDS RIVER NEAR NEW BOSTON	253985	571
121	05466000	EDWARDS RIVER NEAR ORION	103506	668
122	05555300	VERMILION RIVER NEAR LENORE	233383	187
123	05542000	MAZON RIVER NEAR COAL CITY	102572	225
124	05527500	KANKAKEE RIVER NEAR WILMINGTON	350112	68
125	05520500	KANKAKEE RIVER AT MOMENCE	103850	45
126	05568800	INDIAN CREEK NEAR WYOMING	115908	1849
127	05467000	POPE CREEK NEAR KEITHSBURG	1056581	5774
191		MISSISSIPPI RIVER AT EAST DUBUQUE	3346540	41
228	05469000	HENDERSON CREEK NEAR OQUAWKA	258684	599
229	05569500	SPOON RIVER AT LONDON MILLS	990206	932
230	05566500	EAST BRANCH PANTHER CREEK AT EL PASO	1826	60
231	05554490	VERMILION RIVER AT MCDOWELL	87934	160
232	05526000	IROQUOIS RIVER NEAR CHEBANSE	245566	117
233	05525000	IROQUOIS RIVER AT IROQUOIS	57071	83
234	05525500	SUGAR CREEK AT MILFORD	88707	199
235	05564400	MONEY CREEK NEAR TOWANDA	3056	164
236	05567510	MACKINAW RIVER BELOW CONGERVILLE	260390	336
237	05568005	MACKINAW RIVER BELOW GREEN VALLEY	595341	545
238	05570350	BIG CREEK AT ST. DAVID	5799	207
239	05570370	BIG CREEK NEAR BRYANT	15866	385
241	05570000	SPOON RIVER AT SEVILLE	2158941	1320
242	05584500	LA MOINE RIVER AT COLMAR	463137	707
243	05495500	BEAR CREEK NEAR MARCELLINE	421100	1207
245	05585000	LA MOINE RIVER AT RIPLEY	938643	726
246	05583000	SANGAMON RIVER NEAR OAKFORD	1537143	302
247	05582000	SALT CREEK NEAR GREENVIEW	643545	357
248	05578500	SALT CREEK NEAR ROWELL	28769	81
249	05572000	SANGAMON RIVER AT MONTICELLO	71774	130
253	05586100	ILLINOIS RIVER AT VALLEY CITY	4472123	168
254	05576022	SOUTH FORK SANGAMON RIVER BELOW ROCHESTER	178481	205
292		MISSISSIPPI RIVER AT BURLINGTON	12101837	107
293	05474500	MISSISSIPPI RIVER AT KEOKUK	7112144	60
359	05587000	MACOUPIN CREEK NEAR KANE	787262	907

Sediment-Duration Method

For stations with many years of continuous water discharge and sediment concentration data, long-term average annual sediment load may be estimated by either the flow-duration, sediment-rating curve method or the sediment-duration method. Both methods were used to estimate average annual sediment load for the Mississippi River stations at East Dubuque (191), Burlington (292), and Keokuk (293). These were the only stations where 14 or 15 years of continuous, daily water discharge record and nearly continuous, daily instantaneous sediment concentration data existed. Since the methodology and results obtained by the flow-duration, sediment-rating curve method have already been presented, this discussion will be limited to explaining the sediment-duration method and comparing the results obtained by both flow-duration methods for the three Mississippi River stations.

The sediment-duration method requires a long-term flow duration curve as well as a long-term concentration-duration curve. These curves are divided into 25 four-percent segments. The midpoint discharge and midpoint concentration of each segment are used in the following relationship to compute the long-term average annual sediment load for a particular station:

$$\overline{Q}_s = [\sum_{i=1}^{25} (0.04)\,(Q_{wi})\,(C_i)\,(0.0027)]\ 365 \qquad (9)$$

where $\overline{Q}_s$ is the long-term average annual sediment load (tons), Q_{wi} is the midpoint discharge for the ith four-percent segment (cfs), and C_i is the midpoint concentration for the ith four–percent segment (mg/l). The concentration-duration curves for the three Mississippi River stations can be seen in figure 15.

Table 10 summarizes the results obtained by both flow-duration methods. The loads obtained by the flow-duration, sediment-rating curve method were 10 to 42 percent lower than the estimates obtained by the sediment-duration method. The flow-duration, sediment rating curve method predicted loads which were from 6 percent above to 35 percent below the measured values, while the sediment-duration method predicted loads which were from 18 percent higher to 1 percent lower than the measured loads. The sediment-duration method gives better estimates of the average annual sediment load.

The flow-duration computations were repeated for the Keokuk station (293) using the 14-year concentration-duration curve with a flow-duration curve for these 14 years of record and one based on 102 years of record. The average

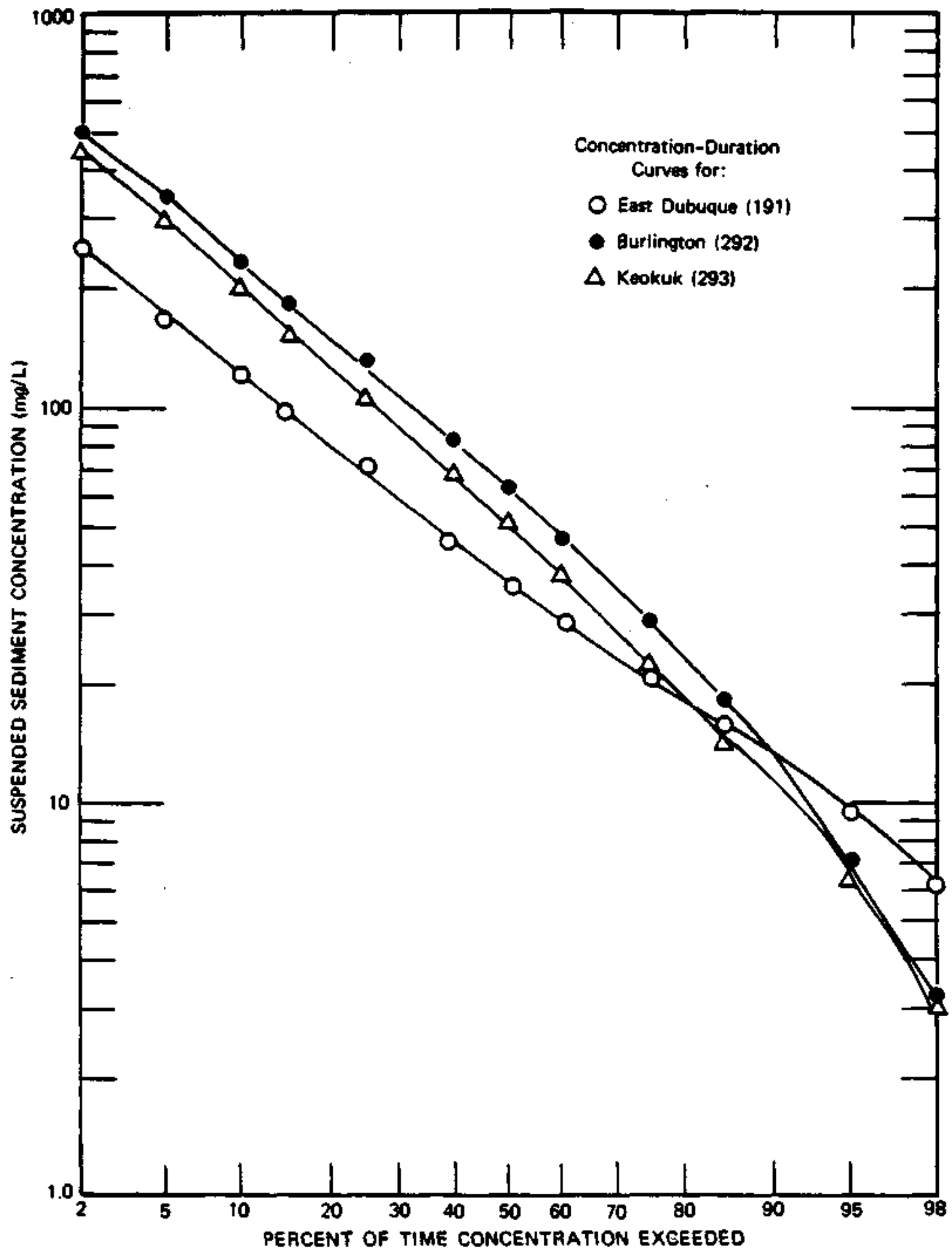

Figure 15. Concentration-duration plot for Mississippi River stations at East Dubuque, Burlington, and Keokuk

TABLE 10. COMPARISON OF FLOW DURATION METHODS: AVERAGE ANNUAL SEDIMENT LOAD ESTIMATES

STATION CODE	PERIOD OF RECORD: FLOW DURATION	PERIOD OF RECORD: CONC DURATION	AVERAGE ANNUAL WATER DISCHARGE (CFS)	AVERAGE ANNUAL SEDIMENT LOAD (TONS): MEASURED	AVERAGE ANNUAL SEDIMENT LOAD (TONS): FLOW-DURATION SEDIMENT-RATING CURVE METHOD	AVERAGE ANNUAL SEDIMENT LOAD (TONS): SEDIMENT-DURATION METHOD
191	14	14	48,498	4,180,078	3,346,540	4,316,125
292	15	15	82,684	11,378,882	12,101,837	13,447,695
293	14	14	72,710	10,898,743	7,112,144	10,837,945
	102	14	62,640	NOT AVAILABLE	5,549,989	9,555,335

annual water discharge for the 14-year period is 16 percent higher than that of the 102-year period. This produces a significant difference in annual load estimates. When the annual load regression equation for Keokuk was evaluated for each of the discharges, the annual load based on the 14-year discharge was 48 percent higher than the load based on the 102-year discharge. Sediment loads computed with the 14-year flow-duration curve were 13 to 28 percent higher than those computed with the 102-year flow-duration curve. Flow-duration curves based on the longest available record will more accurately reflect average conditions. Consequently the average annual sediment load based on the 102-year flow-duration curve at Keokuk is a better estimate of the long-term average annual sediment load than the one based on the 14-year curve.

Multiple Regression Analyses

Multiple regression analysis was used to develop a statistically valid model which could easily predict long-term average annual sediment loads using the geomorphic and hydraulic parameters described earlier in this report. The multiple regression analysis was completed in two phases:

1) Selection of the most statistically significant geomorphic and hydraulic parameters.
2) Application of these parameters to define multiple regression equations for the sediment yield areas.

Phase one will be discussed in this section, while the second phase will be discussed in the regional analyses section.

All multiple regression computations were performed with the Statistical Analysis System (SAS), version FF, which was developed by and leased from SAS Institute, Inc., for use on the University of Illinois' IBM 4341.

Several requirements had to be met in order to select a unique group of geomorphic and hydraulic parameters which yield a statistical model with the best predictive capability. The model had to be easy to use and contain a reasonable number of parameters which are simple to obtain. Statistics require that the number of data points used to define a model must be greater than the number of parameters used in the analysis. Furthermore, since the goal of this analysis was to produce a predictive model, the correlation coefficient for the model had to be maximized.

During the discussion of the individual station analyses, the relationship between sediment load and water discharge was defined by equation 7, which described a multiplicative relationship between sediment load and water discharge. Estimates of sediment load could be improved by including more variables in a similar multiplicative relationship. This technique was used to define the statistical model for estimating average annual sediment load as:

$$\overline{Q}_s = b(\alpha_1)^{C_1} (\alpha_2)^{C_2} (\alpha_3)^{C_3} \ldots (\alpha_n)^{C_n} \tag{10}$$

where b and C_1 through C_n are constants, and α_1 through α_n represent geomorphic and hydraulic parameters determined by the multiple regression analysis.

Data for the first phase of the multiple regression analysis included 24 geomorphic and hydraulic parameters (see appendix A) defined for each of 43 suitable sediment monitoring stations located in the study area (see figure 5). The Illinois and Mississippi River main stem stations, as well as the Big Creek stations at St. David (238) and near Bryant (239), which are considered anomalous, were excluded from the multiple regression study. Stations where long-term average annual sediment loads could not be determined by the flow-duration method were also excluded. The lake stations were not included in this phase of the multiple regression analysis.

The SAS Univariate procedure (SAS Institute, Inc., 1982a) was used to analyze the average annual sediment load data. Since the data exhibited a highly skewed probability distribution, a logarithmic transformation was used to normalize the distribution. Furthermore, it was necessary to use a logarithmic transformation on the 24 geomorphic and hydraulic parameters to preserve the multiplicative relationship outlined in equation 11. The transformed relationship is described as:

$$\log (\overline{Q}_s) = C_0 + C_1 \log(\alpha_1) + C_2 \log(\alpha_2) + \ldots C_n \log (\alpha_n) \tag{11}$$

where C_0 = log b, and all other variables are defined as before.

The original goal of the multiple regression analysis was to select unique groups of parameters that describe average annual sediment load for each river basin, sediment yield area, crop district, or Land Resource Area. In order to select a reasonably sized group of parameters from the original 24, statistics would require each region to contain at least 25 sediment monitoring stations. Since none of the regions contained this many stations, the entire study area was used to define the most significant geomorphic and hydraulic parameters which describe average annual sediment load. This was achieved by comparing all possible combinations of the parameters for the 43 gaging stations and selecting those parameters which yielded the highest correlation coefficient for each N-parameter model. The SAS Maximum R^2 procedure (SAS Institute Inc., 1982b) produced the results listed in table 11.

The correlation coefficient increased and the root mean square error decreased as the number of parameters used in a model increased. Note also that the correlation coefficients were greater than 79 percent for all models. The statistical significance of each parameter is measured by the model F values. The smaller the F probability, the more significant the parameter (SAS Institute, Inc., 1983). General statistical practice considers any parameter with an F value larger than 0.05 to be insignificant. The F values for the first 6 models were all less than 0.05. Beyond model 6, at least one F value was greater than 0.05. Therefore statistically significant multiple regression equations can be defined using any of the 6 models derived in phase one of the analysis.

Flood Event Transport

Even though there are reasonably good relations between the annual sediment load and the annual water discharge and drainage area, the spread of the data exceeds one log cycle. Thus, it is possible to over- or underestimate the annual sediment load by 100 percent or more.

One important consideration in annual sediment load measurements and calculations is the realization that most of the annual sediment load is transported during flood events which take place in a relatively short period of time of the year (Bhowmik et al., 1980; Demissie et al., 1983; Demissie, 1984). In the Kankakee River basin in Illinois, 3 years of data from 4 gaging stations showed that 50 percent of the annual sediment load was transported in only 4 to 53 days of the year. Other studies have shown that a large percentage of the annual sediment load is generated by a few storms each year. Wischmeier (1962) estimated that 75 percent of the soil loss from a small watershed was caused by an average of four storms per year. In a similar study, Piest (1963) analyzed data from 72 small watersheds in 17 states and concluded that 3 to 46 percent of the annual sediment yield occurred during large storms; 3 to 22 percent occurred during medium storms; and 34 to 92 percent occurred during small storms. Storms were defined as follows: large

TABLE 11. MULTIPLE REGRESSION ANALYSIS
PHASE 1 - RESULTS

MODEL NUMBER	CORRELATION COEFFICIENT (PERCENT)	ROOT MEAN SQUARE ERROR OF THE LOGARITHMIC MODEL	PARAMETERS* SELECTED	PROBABILITY >F
1	79.3	0.42	LU	0.0001
2	82.2	0.40	AQWV	0.0219
			LU	0.0001
3	85.2	0.37	AQWV	0.0018
			LU	0.0001
			BS	0.0111
4	87.5	0.35	DA	0.0138
			AQWV	0.0015
			LU	0.0001
			BS	0.0116
5	88.8	0.34	DA	0.0045
			AQWV	0.0006
			LU	0.0005
			HA	0.0195
			DS	0.0089
6	90.4	0.32	DA	0.0052
			AQWV	0.0003
			LU	0.0001
			HA	0.0198
			BS	0.0206
			DS	0.0165
7	90.9	0.31	H	0.1972
			DA	0.0041
			AQWV	0.0002
			LU	0.0001
			HA	0.0092
			BS	0.0108
			DS	0.0122

*PARAMETER CODES DEFINED ON PAGES 25 TO 28 storms are storms with return period greater than 2 years; medium storms are storms with return period from 1 to 2 years; and small storms are storms with return period less than 1 year. Dickinson et al. (1975) reported that about 50 percent of the annual sediment load for streams in southern Ontario, Canada, were transported in the months of March and April. In the Atlantic drainage of the U.S., Meade (1982) found that 50 percent of the annual load was discharged in 10 percent of the time.

Another important observation is the fact that there is a very good relationship between the sediment load during floods and the annual sediment load (Demissie, 1984). The existence of very good relations between the annual sediment load and the sediment load during a few floods will influence the strategy for sediment yield monitoring programs and the procedures for calculating the annual sediment loads of streams. For example, the development of equations relating annual sediment load and the sediment load during the annual flood will provide a simple procedure for estimating the total sediment yield based on the sediment load during the annual flood. Such a procedure will result in significant savings of effort and money for agencies responsible for monitoring and evaluating watershed erosion, reservoir sedimentation, and conservation practices. It could also serve as an important tool in project design of reservoirs where limited or no sediment data are available.

Temporal Distribution of Sediment Load in a Year

In order to illustrate the importance of flood flows in the transport of sediment, the distribution of the sediment load throughout the year will be examined first. Generally there is a very good correlation between water discharge and sediment load; thus it is expected that sediment load will be high when the water discharge is high. To illustrate the positive correlation between the water discharge and sediment load, the daily water and sediment discharges for the Iroquois River near Chebanse (232) for Water Years 1979 and 1980 are shown in figures 16 and 17 respectively. Water Year 1979 was relatively wet, and several flood events took place in the spring and summer months. From October to February the water discharges were very low, as were the sediment loads. In general, the peak sediment discharges correspond very well to the peak water discharges even though the highest sediment load did not occur during the highest flood. Water Year 1980 (figure 17), on the other

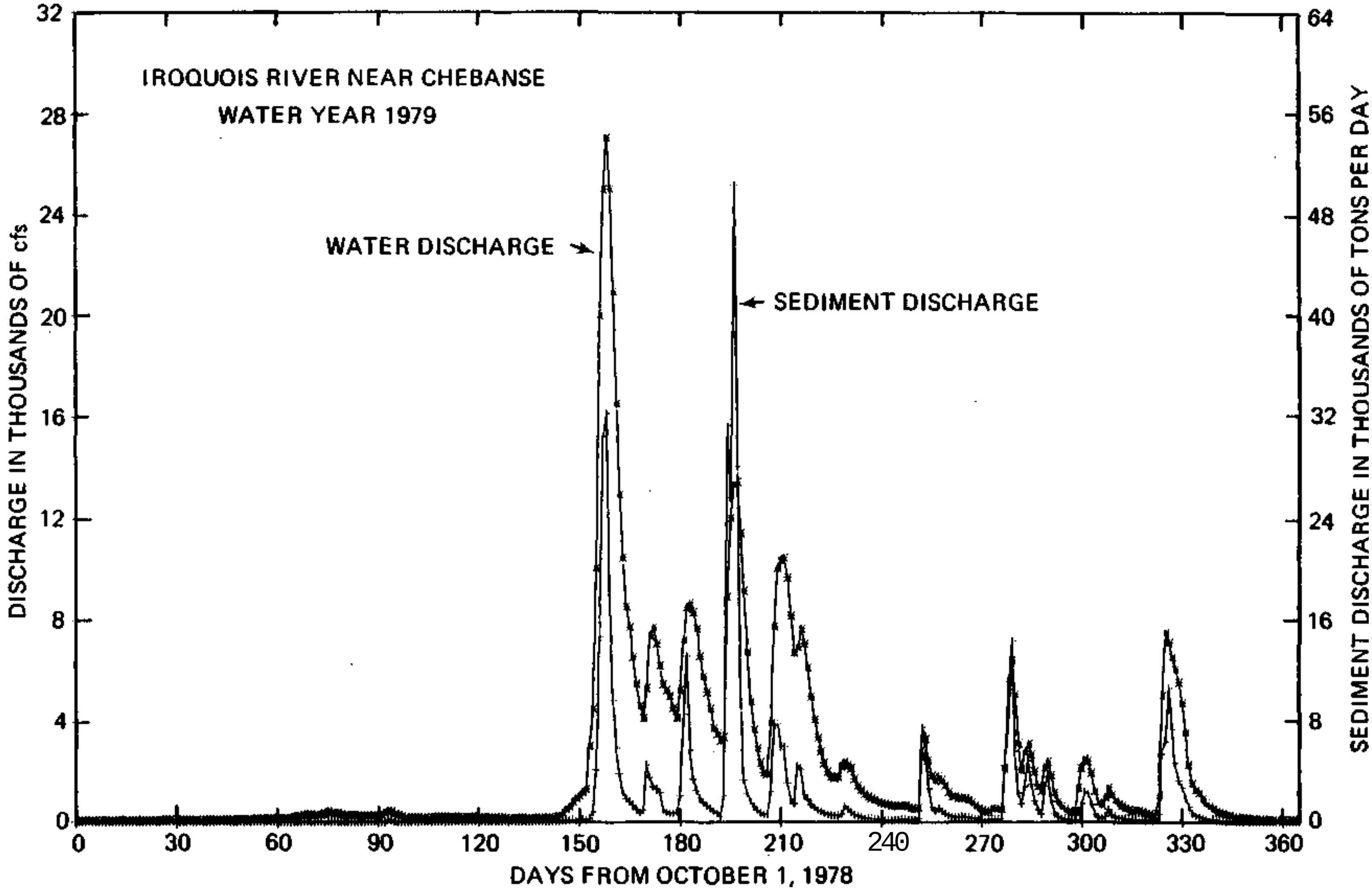

Figure 16. Daily water and suspended sediment discharge for the Iroquois River near Chebanse, Hater Year 1979

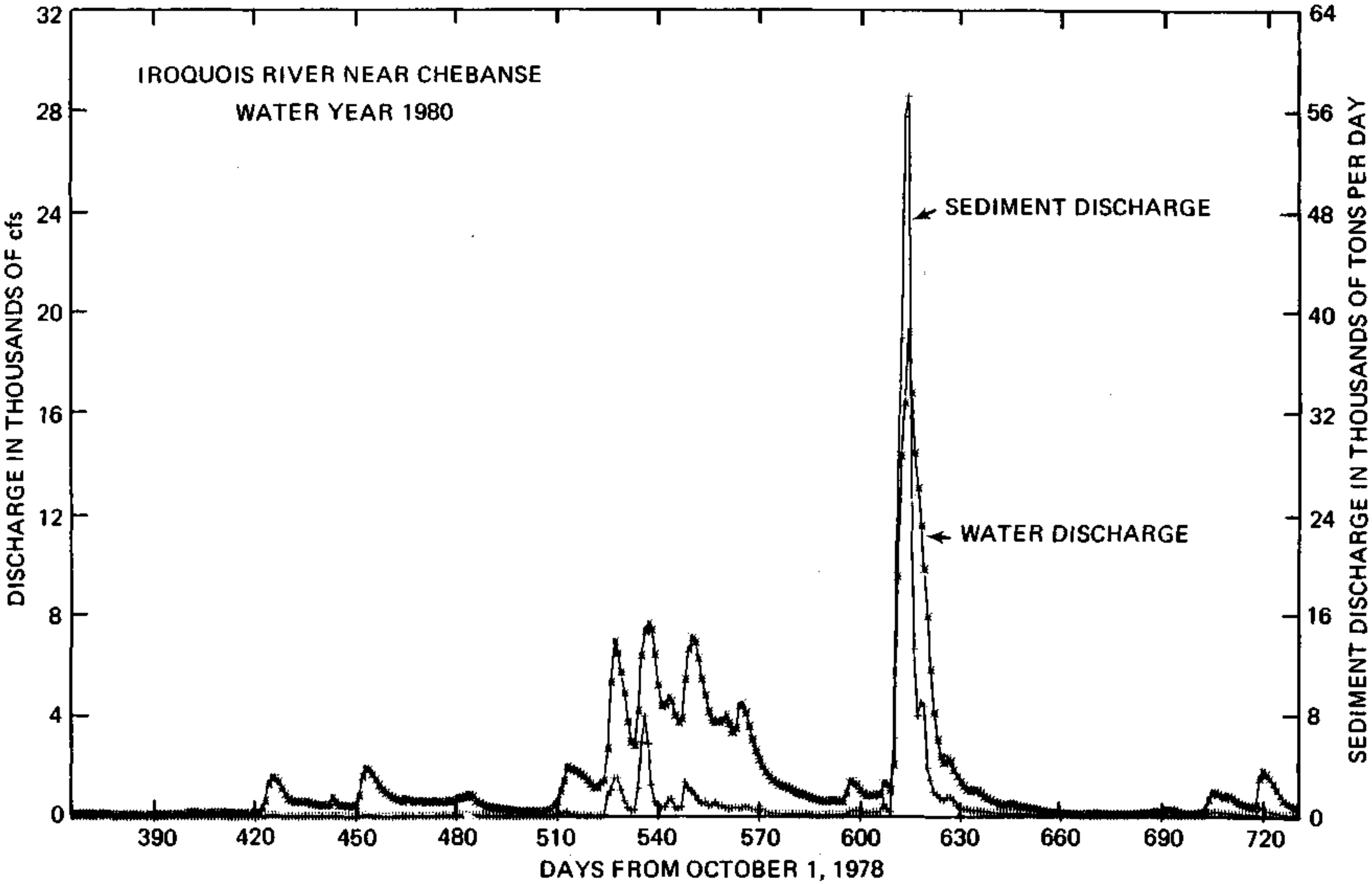

Figure 17. Daily water and suspended sediment discharge for the Iroquois River near Chebanse, Water Year 1980

hand, was a relatively dry year. There were fewer floods in 1980 than in 1979, and the annual water discharge was also less. However, in terms of the relation between sediment load and water discharge, it is still observed that the peak sediment loads occurred during the peak water discharges. Except for very short periods of time in June (during the annual flood) and in March (early spring), the sediment load in the stream was extremely low throughout the year.

The relation between the sediment load and the water discharge for the Iroquois River near Chebanse is shown in figure 18. In general there is a very good relation between the water discharge and the sediment load; however, there is a wide scatter of the data points around the regression line in a region. This is because of the many different factors, other than water discharge, which influence the sediment discharge in a stream.

The sediment load distributions and the relations between sediment load and water discharge for other streams and even for other stations on the same river will be different from the examples shown for the Iroquois River near Chebanse. However, in general there is a good relation between the sediment load and water discharge, and furthermore the peak sediment loads for any stream occur during flood events.

Cumulative Sediment Transport

The importance of floods in the transport of a large percentage of the annual sediment load can be illustrated very clearly by constructing cumulative sediment transport curves (Demissie et al., 1983). This is shown in figure 19 for the Iroquois River near Chebanse. The curves were constructed by ranking the daily sediment loads first and then calculating the cumulative sum from the peak sediment load to the lowest in any year. The sediment loads and the time were then converted to percent sediment load and percent time by dividing them by the annual sediment load and the total number of days in a year, respectively. The general form of the curves will be similar for any stream. The main difference in the curves from stream to stream and from year to year is the slope of the curves in the initial stages. These differences are caused by differences in the sediment-carrying characteristics of the streams and in the variability of the flow in a year and from year to year. Generally the curves are steeper for very dry years than for wet years, as shown in figure 19 by the nearly vertical curve for 1980, which

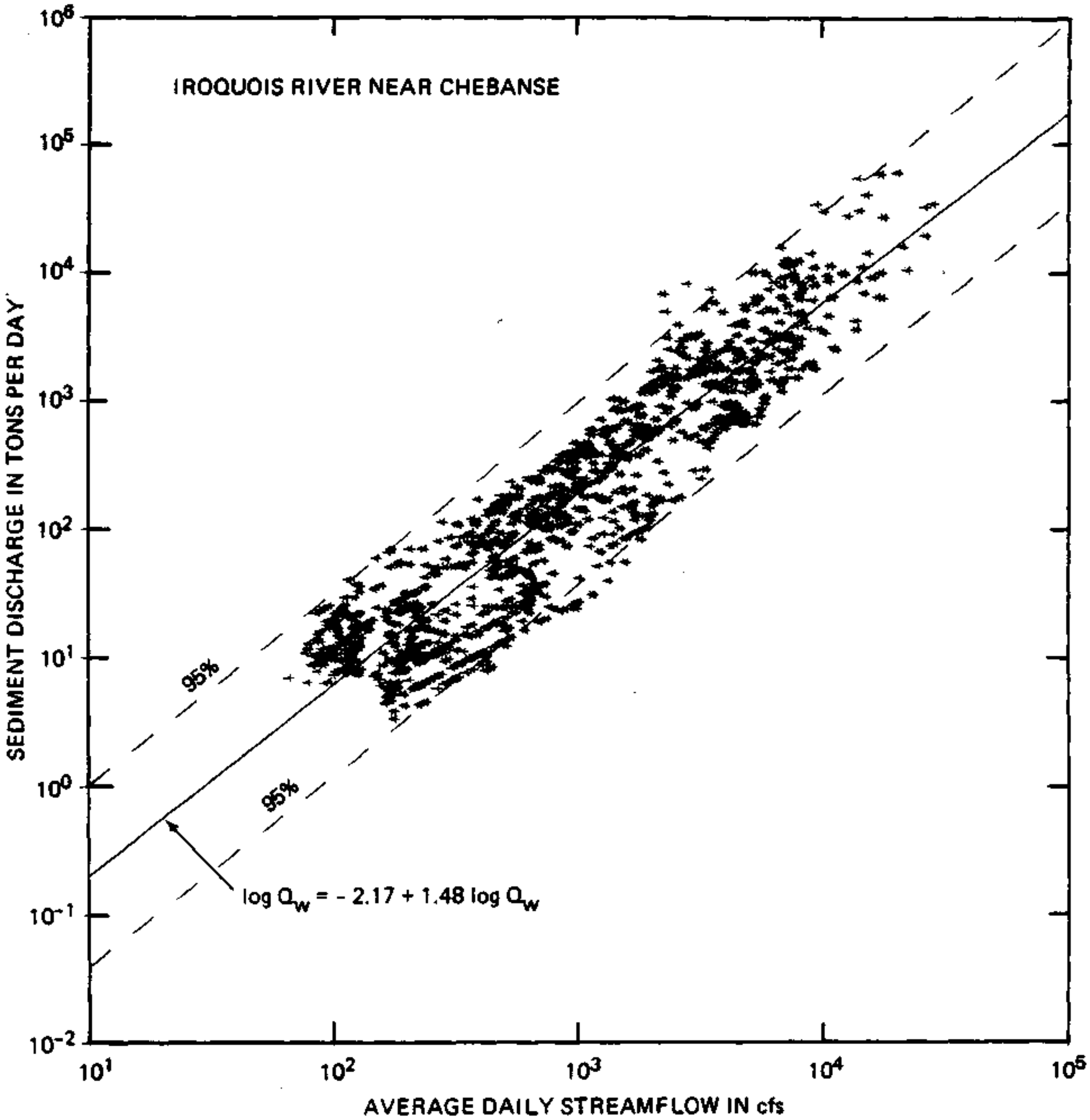

Figure 18. Daily suspended sediment load versus water discharge for the Iroquois River near Chebanse

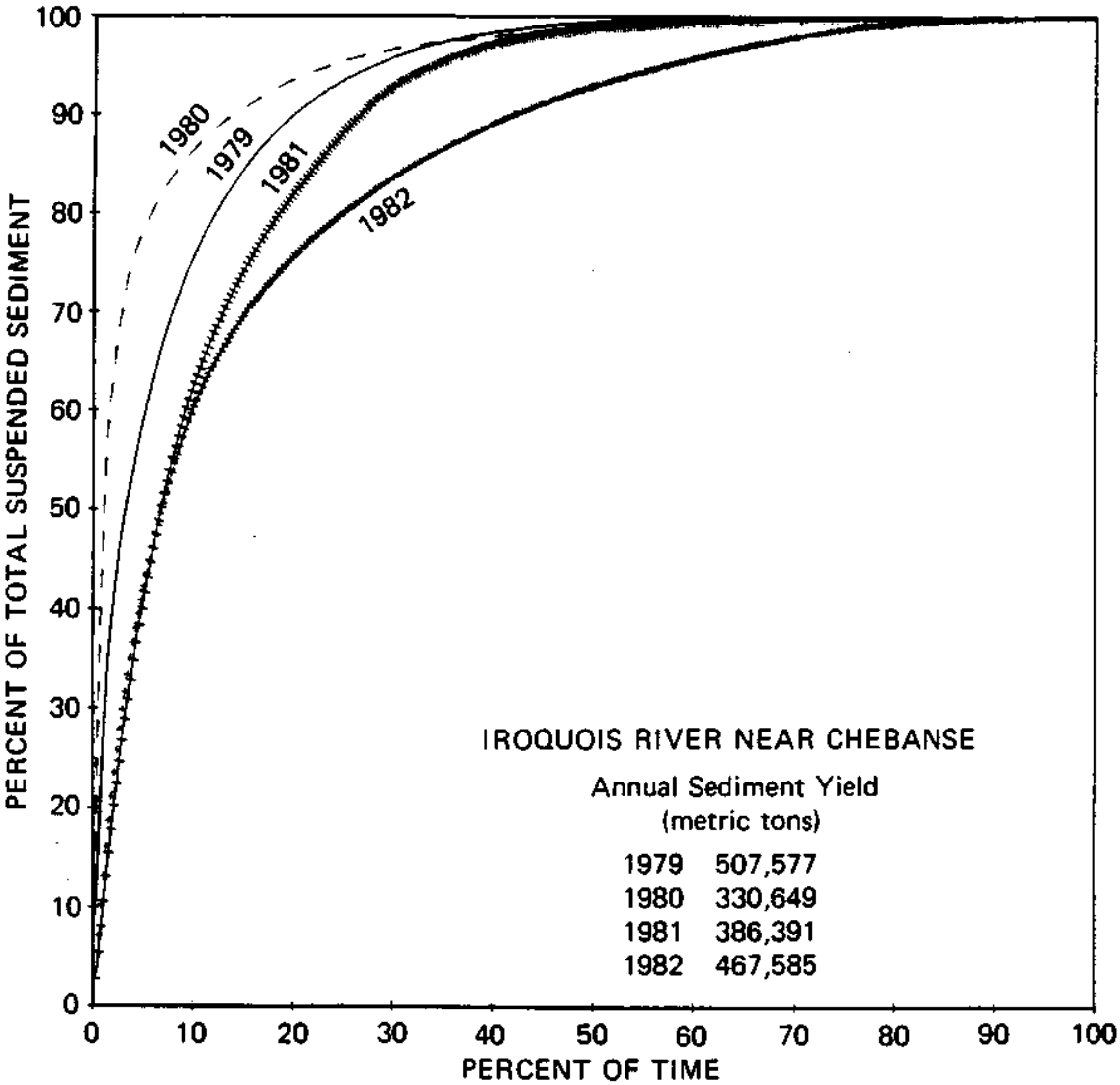

Figure 19. Cumulative sediment transport curves for the Iroquois River near Chebanae

was the driest year among the four years considered. This is because very few floods occur during dry years and those very few floods carry most of the annual sediment load. Table 12 shows the percent of time in a year during which 50 and 80 percent of the annual sediment load were transported in the Iroquois River.

TABLE 12. PERCENT OF TIME DURING WHICH 50 AND 80 PERCENT OF THE ANNUAL SEDIMENT LOAD PASSED A STATION

PERCENT OF ANNUAL LOAD	1979	1980	1981	1982
50	3.5	1.2	6.8	4.2
80	12.5	6.0	18.5	14.8

As shown in table 12, 50 percent of the annual sediment load passed the station in only 1.2 to 6.8 percent of the time (4 to 24 days).

The cumulative curves show how many days, in percent time, a certain percent of the annual sediment load is transported by a stream. They are also useful in examining the differences in sediment transport characteristics of different streams and the variation of sediment transport from year to year. However, their predictive capability is limited unless the peak sediment loads are measured or the parameters of the curves are related to some characteristics of the watershed, discharge, precipitation, or stream.

Relations between Annual Sediment Load and Sediment Load during Flood Events

As was discussed in preceding sections, a large percentage of the annual load is transported during floods which occur in a relatively short period of time in a year. Development of relations between the annual sediment load and the sediment load during major floods will provide a very powerful tool for predicting annual sediment loads based on the sediment loads during the floods. Such relations were developed based on data from the USGS and the SWS. Thirty gaging stations in Illinois with daily water and sediment discharge data were used to develop the relations. The period of record used was 1978 to 1982. Ten stations had only one year of data, while 20 stations had 2 to 5 years of data. A listing of the stations used in the analysis are shown in table 13.

TABLE 13. GAGING STATIONS USED IN DEVELOPING RELATIONS BETWEEN ANNUAL SEDIMENT LOAD AND SEDIMENT LOAD DURING FLOOD EVENTS

NAME OF STREAM	DRAINAGE AREA (MI^2)
BIG MUDDY RIVER AT MURPHYSBORO, IL	2,169
BIG CREEK AT ST. DAVID, IL	26.7
DES PLAINES RIVER AT RIVERSIDE, IL	630
EDWARDS RIVER NEAR NEW BOSTON, IL	445
KASKASKIA RIVER AT COOKS MILLS, IL	473
LAMOINE RIVER AT RIPLEY, IL	1,293
SOUTH BRANCH KISHWAUKEE RIVER AT DEKALB, IL	77.7
SOUTH FORK SALINE RIVER NEAR CARRIER MILLS, IL	147
SLUG RUN NEAR BRYANT, IL	7.9
SPRING CREEK AT ROCK VALLEY COLLEGE AT ROCKFORD, IL	2.81
BIG CREEK NEAR BRYANT, IL	40.3
BRUSHY CREEK NEAR HARCO, IL	13.3
EMBARRAS RIVER AT STATE HWY. 133 NEAR OAKLAND, IL	542
GRINDSTONE CREEK NEAR BIRMINGHAM, IL	45.4
GREEN RIVER NEAR GENESEO, IL	1,003
HENDERSON CREEK NEAR OQUAWKA, IL	432
IROQUOIS RIVER NEAR CHEBANSE, IL	2,091
IROQUOIS RIVER AT IROQUOIS, IL	686
INDIAN CREEK NEAR WYOMING, IL	62.7
KANKAKEE RIVER AT MOMENCE, IL	2,294
KISHWAUKEE RIVER NEAR PERRYVILLE, IL	1 ,099
KASKASKIA RIVER NEAR VENEDY STATION, IL	4,393
KANKAKEE RIVER NEAR WILMINGTON, IL	5,150
LUSK CREEK NEAR EDDYVILLE, IL	42.9
LITTLE WABASH RIVER AT LOUISVILLE, IL	745
ROCK RIVER NEAR JOSLIN, IL	9,549
SPRING CREEK AT MCFARLAND RD. NEAR ROCKFORD, IL	2.44
SANGAMON RIVER NEAR OAKFORD, IL	5,093
ILLINOIS RIVER AT VALLEY CITY, IL	26,564
VERMILION RIVER NEAR LENORE, IL	1,251

The annual water hydrograph was first examined to identify the highest, the second highest, the third highest, and the fourth highest floods in any particular year. Then the total sediment discharge during those floods was calculated by summing up the daily sediment discharges during the flood periods.

The relations between the sediment load during the highest annual flood and the annual sediment load for all the stations is shown in figure 20. As may be seen in figure 20, the two sediment loads are well correlated with a correlation coefficient of 0.94. The equation which relates the two loads is:

$$\log (QSA) = 0.57 + 1.02 \log QS1 \qquad (12)$$

where QS1 is the sediment load during the highest flood, in tons, and QSA is the annual sediment load, in tons.

It is important to note that the drainage areas of the gaging stations used in this analysis range from 2.44 to 26,564 sq mi. The scatter of the data points in figure 20 can be reduced by grouping stations. However, since the correlation with all the data points included is very good, it was felt that was not necessary. Furthermore, the results in figure 20 show that the relation is general and applicable for a wide range of watersheds in Illinois.

Another important observation from figure 20 and equation 12 is that the slope of the regression line is greater than 1.0. This implies that the percentage of the annual sediment load transported by the annual flood is different for small and large rivers. In general the larger the stream, the smaller the percentage. On the average, for a small stream with an annual sediment load of 1000 tons, 23 percent of the annual sediment is transported by the annual flood. On the other hand, for a large river like the Illinois River, with an annual sediment load in the range of 10^6 tons, the highest flood transports 20 percent of the annual load. The durations of the annual flood for all the streams considered here range from 3 to 21 days with a mean duration of 9.2 days. This represents only 2.5 percent of the time on the average.

When the sediment transported during the two highest floods is considered, the relation between the annual sediment load and the sediment load during the floods is better than when only the annual flood is considered. The correlation coefficient improves from 0.94 to 0.97, with a corresponding reduction in the standard error of the estimate. This is shown in figure 21,

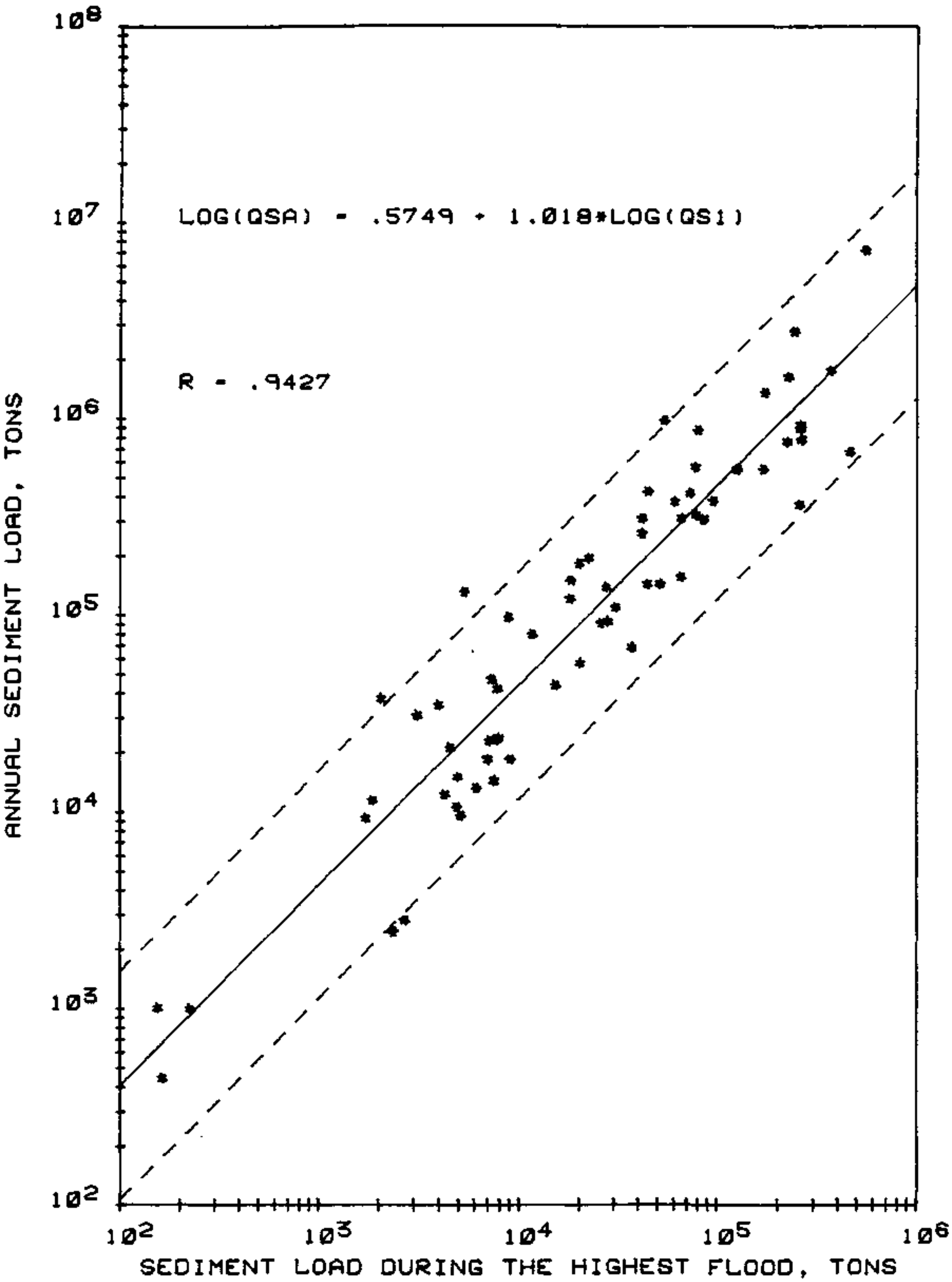

Figure 20. Annual sediment load versus the sediment load during the highest flood

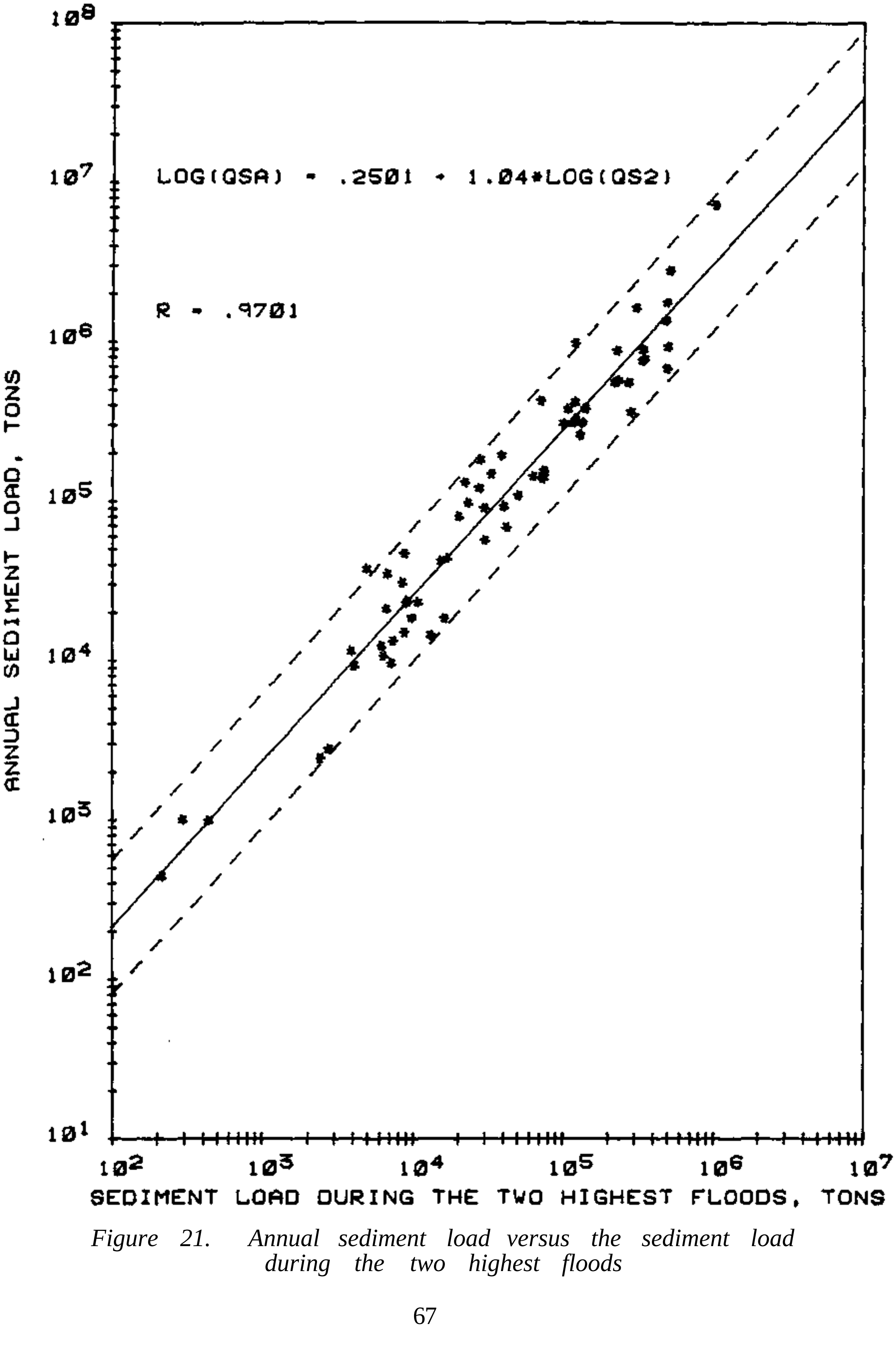

Figure 21. Annual sediment load versus the sediment load during the two highest floods

where the sum of the sediment load during the highest and second highest floods is plotted against the annual sediment load. The regression equation between the two loads is:

$$\log (QSA) = 0.25 + 1.04 \log (QS2) \qquad (13)$$

where QS2 is the sediment load during the two highest floods, in tons. Again the slope of the regression line is greater than one, indicating that, for smaller streams, a larger percentage of the annual sediment load is transported during floods than for larger streams. The combined duration of the two floods ranges from 7 to 38 days with a mean duration of 17 days, which represents only 4.7 percent of the time in a year. The percentage of the annual sediment load transported by the two highest floods for a small stream with an annual sediment load of 1000 tons is 43, while for a stream with an annual load of 10^6 tons the value is 32 percent.

Further improvements in the relations between the annual sediment load and the sediment load during flood events is achieved if the third and fourth highest floods are included. The relations for the three and four highest loads are as follows:

$$\log (QSA) = 0.16 + 1.04 \log (QS3) \qquad (14)$$

$$\log (QSA) = 0.12 + 1.03 \log (QS4) \qquad (15)$$

The corresponding correlation coefficients are 0.98 and 0.99. QS3 and QS4 are the sediment loads during the three and four highest floods, respectively. Further reduction in the scatter of the points from the regression line is evident in figures 22 and 23 for the three and four highest floods, respectively. Based on equation 14 the three highest floods transport 52 percent of the annual sediment load for a small stream with an annual sediment load of 1000 tons, and 40 percent for a larger stream with an annual sediment load of 10^6 tons.

The percentages for the four highest floods increase to 62 percent for the small stream and 50 percent for the large stream. These percentages are average values; the actual percentages vary from year to year and from stream to stream.

Methods of Regionalization

One of the primary objectives of this study was to identify and evaluate methods for estimating sediment loads at gaging stations with an historical sediment record. This was done in earlier sections of this report. The

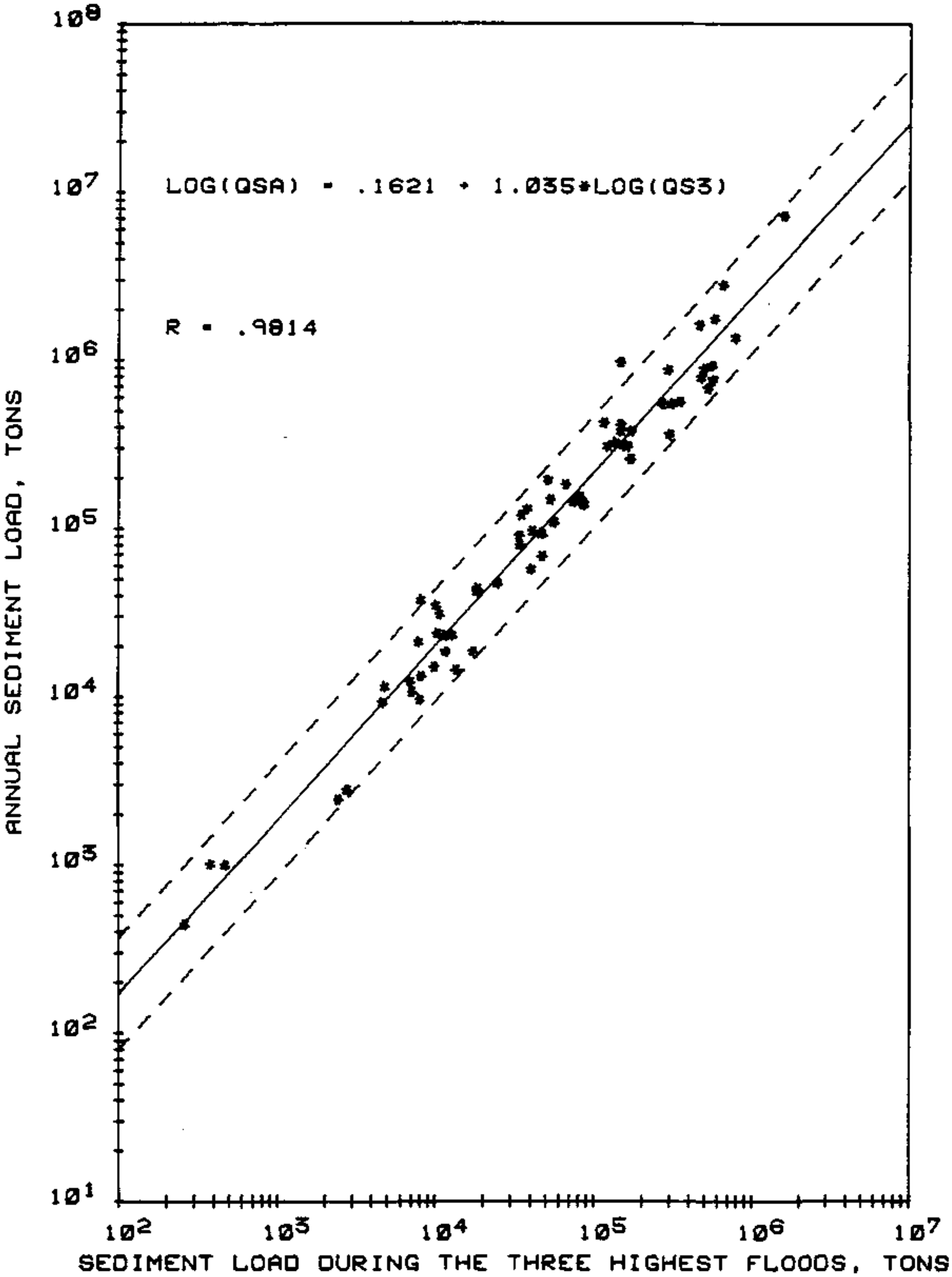

Figure 22. Annual sediment load versus the sediment load during the three highest floods

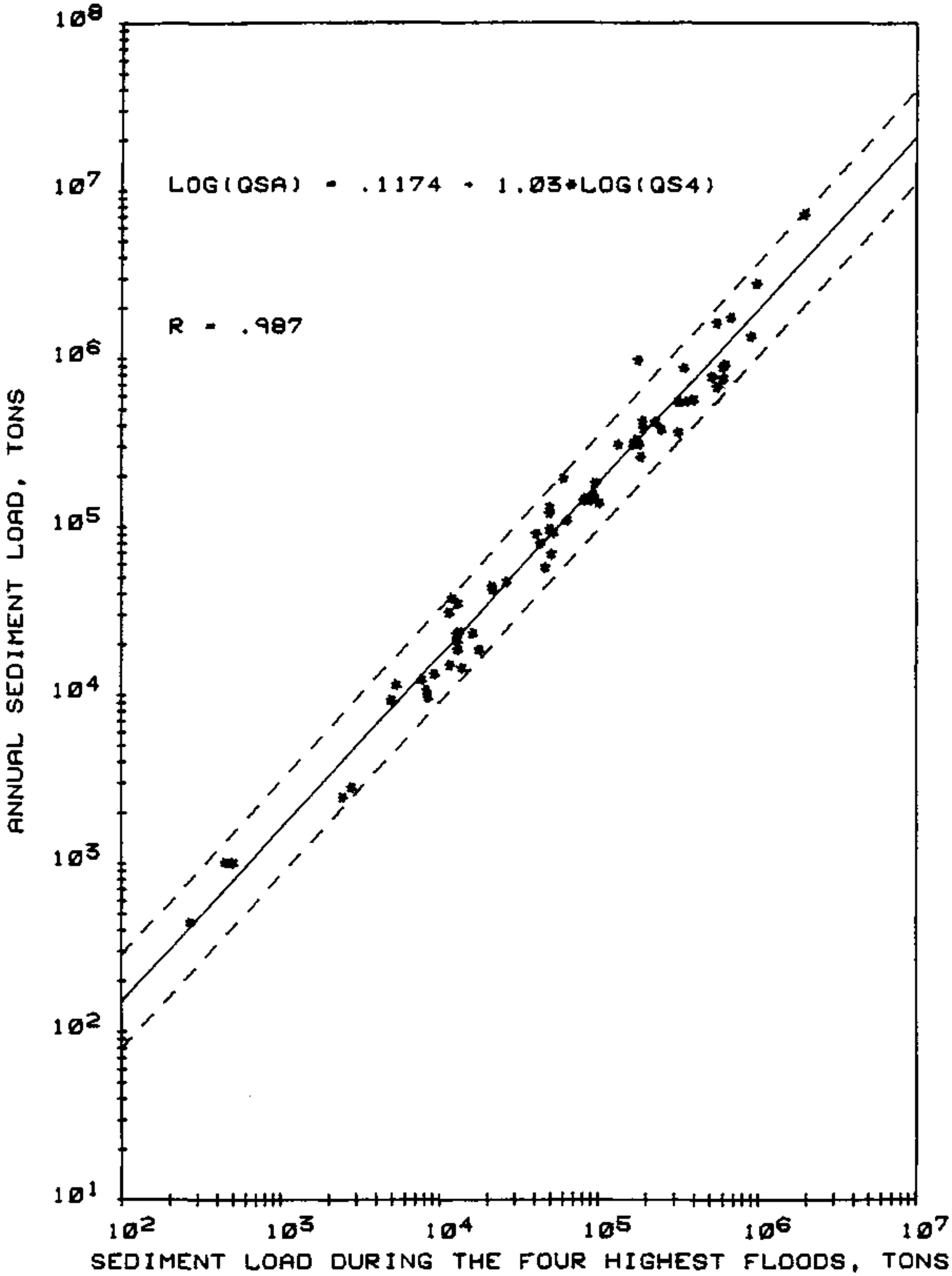

Figure 23. Annual sediment load versus the sediment load during the four highest floods

usefulness of this type of information is limited unless it can be transferred to other gaged or ungaged sites along a stream. One way to expand the usefulness of the results is to regionalize the data so that areas with similar characteristics are related to one another by a simple relationship or single equation.

Three parameters were initially examined for possible use as methods for regionalizing the data. These included the physiographic divisions of Illinois developed by Leighton et al. (1948) (see figure 2), the Land Resource Areas (LRA) in Illinois (UMRCBS, 1970) (see figure 3), and the mean annual precipitation in Illinois for the period 1951-1980 (see figure 4). The results for the first two parameters were encouraging. The next section of this report provides a detailed discussion of these analyses.

Examination of the precipitation factor failed to yield a positive relationship that could possibly be used to regionalize the data. This result was expected since precipitation was not identified by the multiple regression analysis as a significant factor in predicting sediment load.

One additional factor was developed in an attempt to establish some regionalization of the data. This factor was termed the unit area flood flow value and was equal to the ratio between the ten percent flow duration value (the discharge value which is equalled or exceeded ten percent of the time) and the drainage area for each station. The results of this analysis failed to reflect any pattern of regionalization. Further analysis of this parameter was not pursued.

REGIONAL ANALYSES

Land Resource Areas

The Upper Mississippi River Comprehensive Basin Study (1970) identified nine LRA's in Illinois (see figure 3). These LRA's were grouped into five categories. Regression equations relating sediment yield (tons/square mile/year) to drainage area were developed for each category on the basis of the available sediment data and the assumption that all of the equations should have the same slope (-0.12). Figure 24 shows the plots of those five regression lines (solid lines).

Nearly all of the sediment data for Illinois that were used by the UMRCBS to develop the regression relationships were lake sedimentation data. One question that arises from this is whether or not the previously derived equations accurately reflect the currently available instream sediment data.

In order to evaluate this question, the average annual sediment yield versus drainage area for all tributary sediment stations within the LRA boundary areas for Illinois were plotted on figure 24. The number next to each data point is the station code for each station. The various symbols indicate the LRA in which the station is found. Also plotted on this figure are data points from 12 lakes with station codes in the 700's as listed in table 2.

It is difficult to decipher very much from this cluttered figure; therefore figures 25 through 29 were developed to represent the results for each of the five categories of LRA's. In these figures the original LRA regression lines are indicated by the dashed lines. It appears in figures 25 and 26 that the currently available data are not well represented by the original regression equations. This also seems to be true for figures 27, 28, and 29 although the results for these curves are less obvious because of the limited number of data points associated with each of these curves.

Close examination of the data points in figure 25 suggests some degree of linearity for LRA's 95, 110. (Although the original line refers to LRA 98 as well, this LRA does not occur in Illinois and thus has not been included in the analysis.) A least-squares regression line was developed for these data and is indicated by the solid line in figure 25. The equation for this line is defined as follows:

$$\overline{Q}_s/DA=360\ (DA)^{-0.19} \quad (16)$$

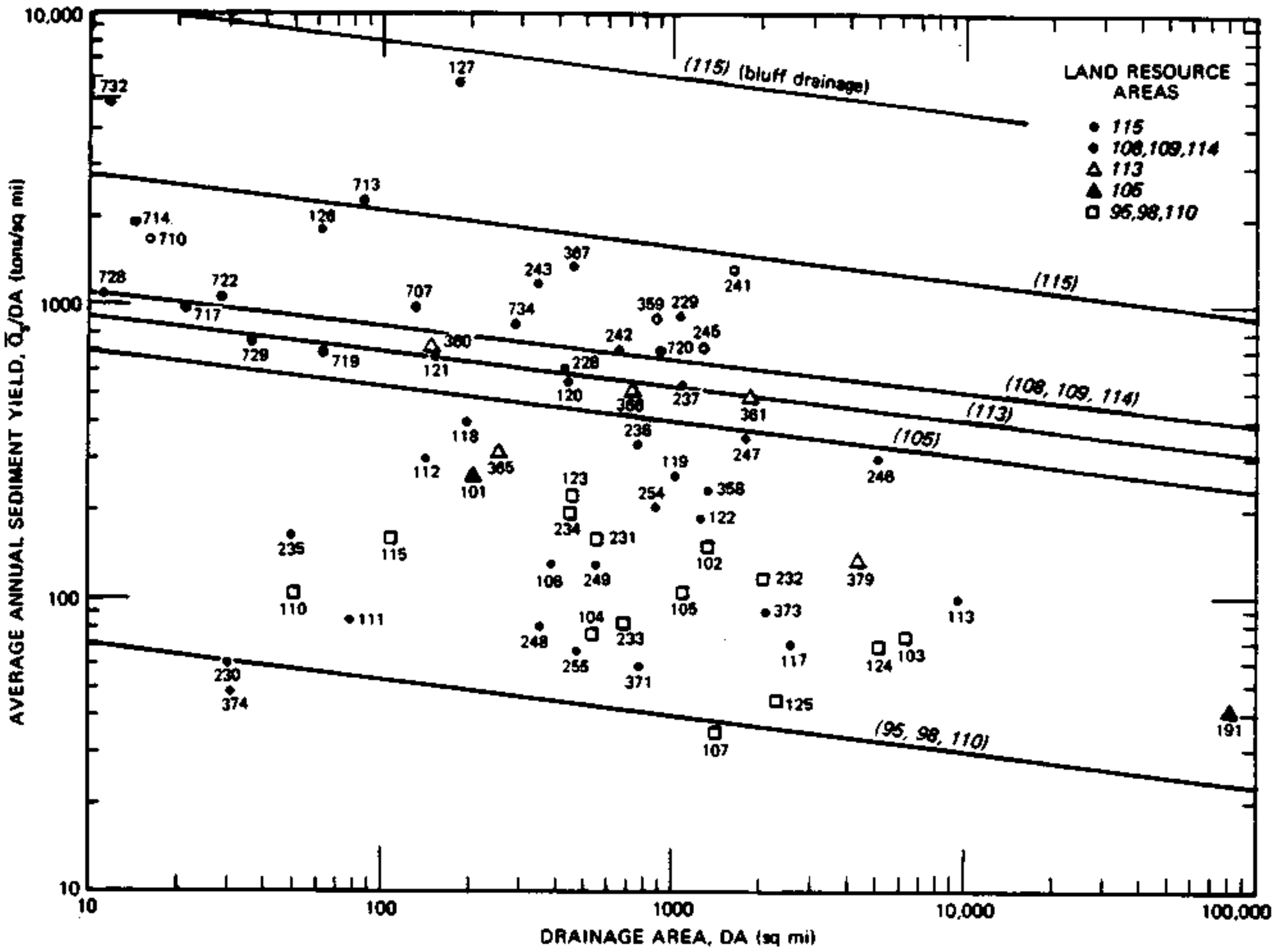

Figure 24. Average annual sediment yield versus drainage area for lake and suspended sediment monitoring stations in Illinois (after UMRCBS, 1970)

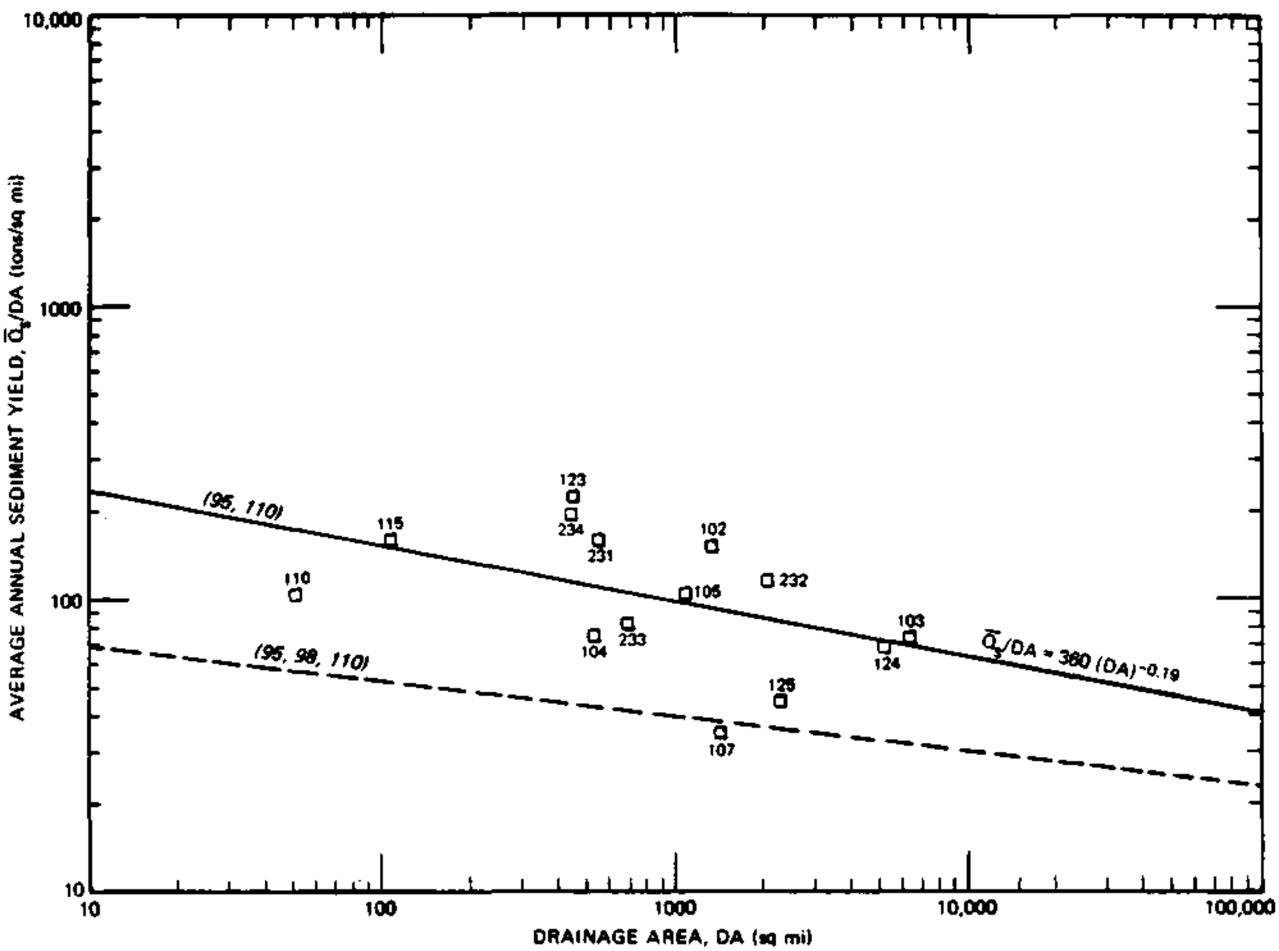

Figure 25. Average annual sediment yield versus drainage area for Land Resource Areas 95, 98, 110 in Illinois

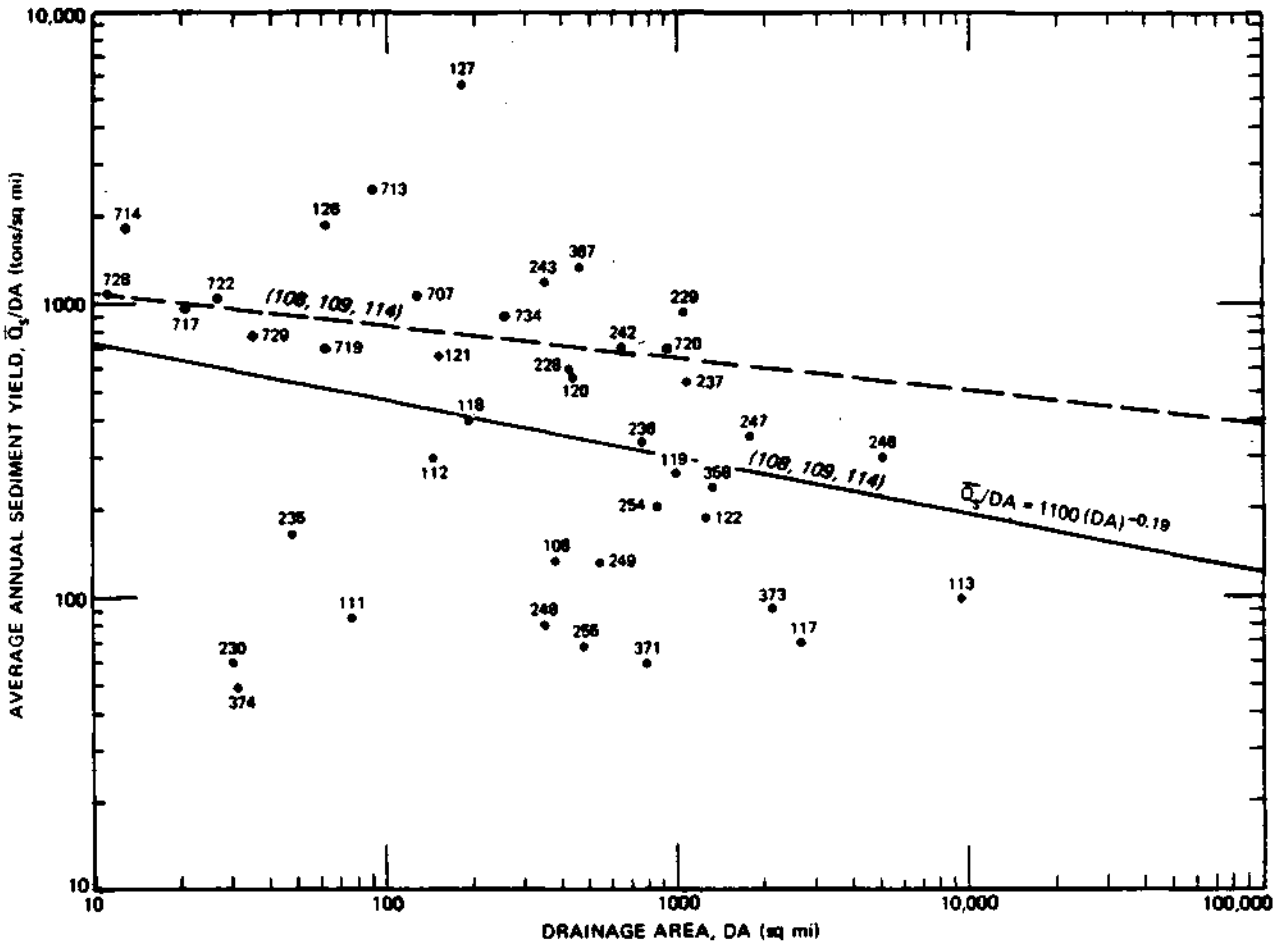

Figure 26. Average annual sediment yield versus drainage area for Land Resource Areas 108, 109, 114 in Illinois

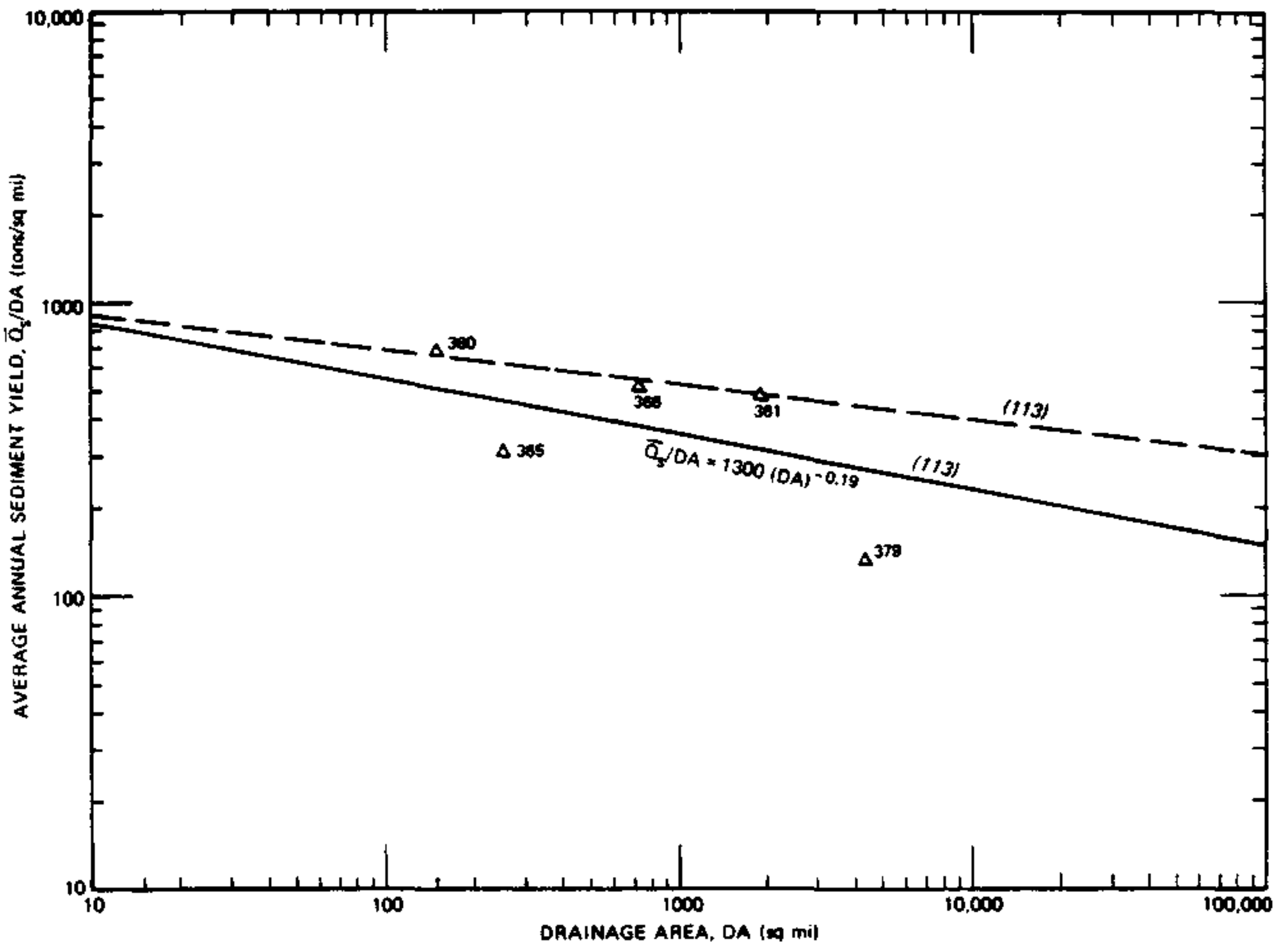

Figure 27. Average annual sediment yield versus drainage area for Land Resource Area 113 in Illinois

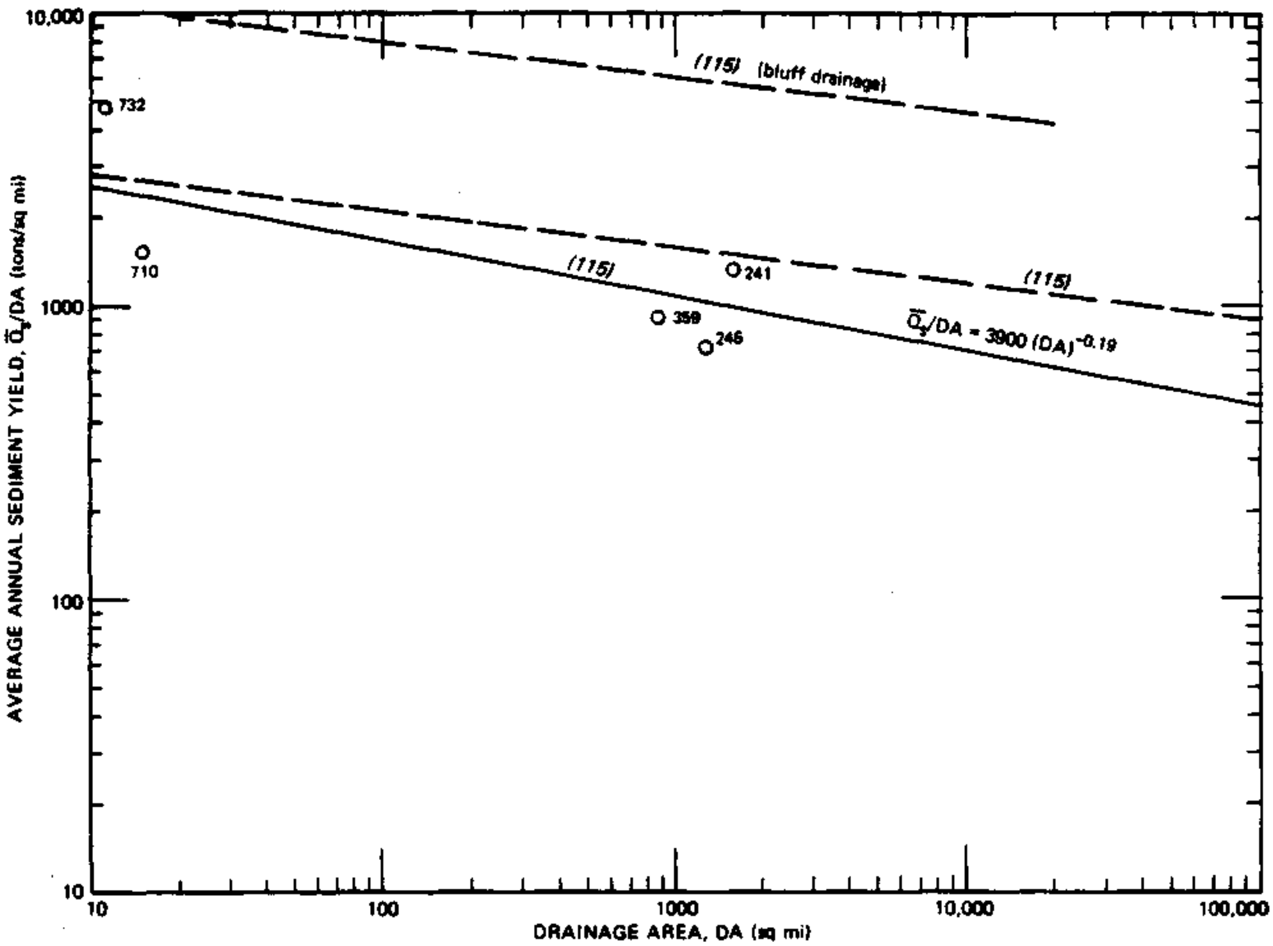

Figure 28. Average annual sediment yield versus drainage area for Land Resource Area 115 in Illinois

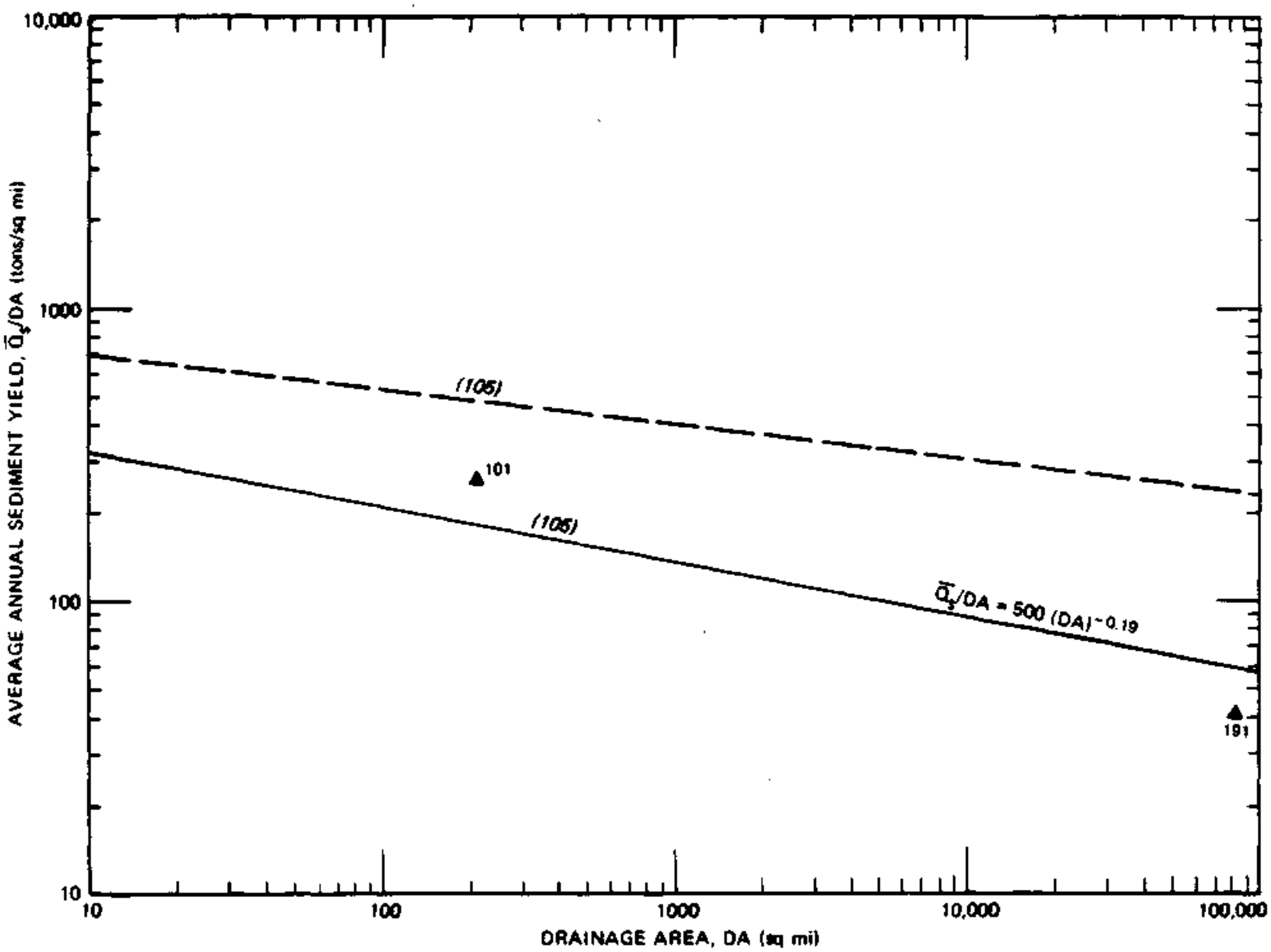

Figure 29. Average annual sediment yield versus drainage area for Land Resource Area 105 in Illinois

where Q_s is the average annual sediment load in tons, and DA is the drainage area in square miles. The correlation coefficient for this equation is -0.46. The slope of the line is -0.19, which is similar to the original slope of -0.12.

Similar least-squares regression analyses were performed on the data for each of the other four LRA categories. For the data for LRA's 108, 109, 114 the slope of the regression equation was -0.23. The correlation coefficient was only -0.33. The results for the data in figures 27, 28, and 29 had a high degree of correlation (-0.67, -0.79, and -1.0 respectively) but this must be tempered by the fact that the size of the data set in each of these cases was minimal, which limits the usefulness of this information.

It appears from this analysis that a slope of -0.19, based on the results for LRA's 95, 110 (figure 25), is the best choice for redefining the slope of the regression equations for the remaining four LRA categories. This decision was based on four facts: 1) the results for LRA's 113, 115, and 105 are inconclusive due to the size of the data sets; 2) the correlation coefficient for LRA's 95, 110 was higher than for LRA's 108, 109, 114; 3) the standard error of the estimate for LRA's 95, 110 (0.21886) was much less than that for LRA's 108, 109, 114 (0.49427); and 4) the new slope deviates the least from the old slope of -0.12.

Having defined the new slope for the four remaining LRA categories, it was necessary to redefine the linear regression equation for each category so that the equations would result in parallel lines. These new equations and lines are shown in figures 26 through 29 (solid lines). The regression equation parameters and statistics are listed in table 14.

These redefined regression equations for the LRA's within Illinois will probably generate a better estimate of the average annual sediment yield than the equations developed by the UMRCBS for streams within the Rock Island District in Illinois. In the next section it will be shown that there is an alternative method for regionalizing the results in Illinois.

Sediment Yield Areas

Linear Regression Analyses

Regionalizing the sediment yield data based on the previously defined LRA's had its limitations. Since the LRA's were a given, the current sediment yield data were forced to fit within those predetermined boundaries. The

TABLE 14. REVISED LAND RESOURCE AREA (LRA) REGRESSION EQUATION STATISTICS

LRA REGION	NO. OF DATA PTS.	COEFFICIENT	SLOPE	ROOT MEAN SQ. ERROR	CORRELATION COEFFICIENT
95,110	14	362.25	-0.19	0.210280	-0.46
113	5	1324.99	-0.19	0.218497	-0.67
115	5	3933.07	-0.19	0.193391	-0.79
108,109,114	41	1094.69	-0.19	0.489122	-0.33
105	2	502.74	-0.19	0.219677	-1.00

question is whether or not the sediment yield data for Illinois can be grouped in a way that improves upon the relationships developed using the the LRA boundaries.

In order to assess this possibility, the sediment yield data (tons/square mile/year) for all but two of the tributary stations throughout the state were plotted on a state map. (Data for stations 238 and 239 were not used in these analyses. These stations were part of a sludge disposal study in Fulton County, Illinois, and were not representative of the general area.) These sediment yield data were also plotted against drainage area on a log-log graph. These two plots, along with the physiographic divisions map (see figure 2) and the major watershed boundaries, were carefully examined and the data were tentatively categorized into six regions encompassing the entire state. Regression analyses were performed on the data in these regions. The correlation coefficients of the regression equations range between -0.27 and -0.90.

Although these results were better than those developed using the LRA's, there still seemed to be room for improvement. The data were reexamined and this time sediment load data (tons/year) were plotted on a state map and plotted against drainage area on a log-log graph. These results were carefully examined and the data were categorized once again into six regions, called Sediment Yield Areas (SYA) (figure 30). These SYA's were very similar to those developed previously, based on the sediment yield versus drainage area relationship. However, there was a marked improvement in the correlation coefficients for these new regions (regions IV, V, and VI were grouped together in performing the regression analysis for all cases). These correlation coefficients ranged from 0.91 to 0.96 and the slopes of the lines ranged from 0.667 to 0.936 (table 15). Station 362 appears to be an anomaly. Although it was located in the middle of SYA II, the results for this station were much higher than expected for sites in this region based on the currently available record. The data for station 362 may have reflected site-specific disruptive activities in the upstream watershed, and for this reason they were not included in the SYA analysis. As additional years of sediment record are accumulated for this station, it may be necessary to reevaluate the appropriateness of this assumption.

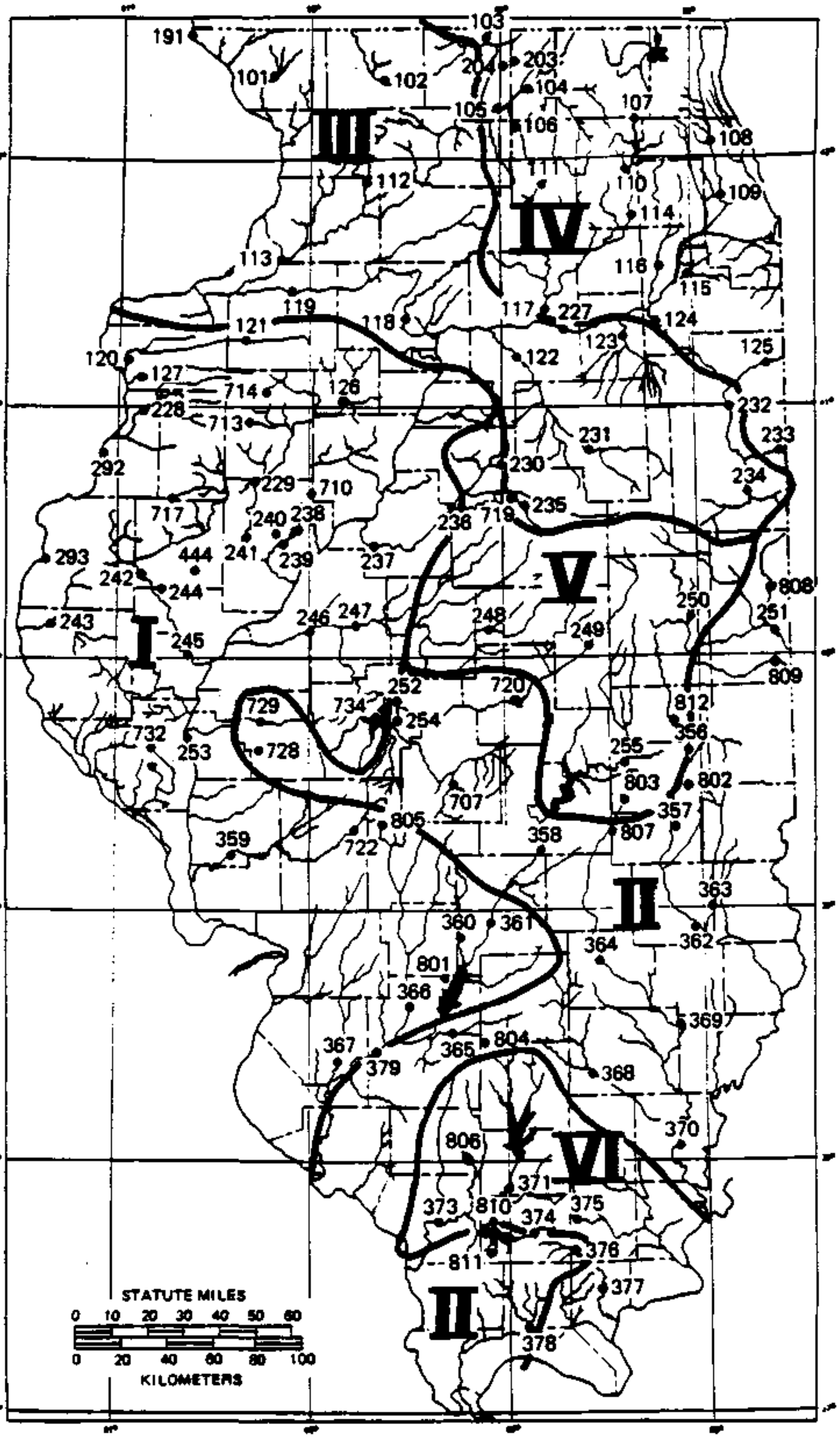

Figure 30. Map showing Sediment Yield Areas in Illinois

TABLE 15. SEDIMENT YIELD AREA (SYA) REGRESSION EQUATION STATISTICS

SYA REGION	NO. OF DATA PTS.	COEFFICIENT	SLOPE	ROOT MEAN SQ. ERROR	CORRELATION COEFFICIENT
I	25	5031.39	0.707	0.244185	0.91
II	17	2724.66	0.667	0.157882	0.95
III	13	1015.15	0.749	0.166322	0.95
IV,V,VI	22	118.01	0.936	0.220962	0.96

It was necessary to identify a common slope for the equations for each SYA group to assure that the regression lines would be parallel. In this case the slope for SYA I (0.71) was used to redefine the equations for the remaining regions. This slope was selected for three reasons. First, SYA I and its equation were defined by the greatest number of data points. Second, SYA I defines the area with the highest, and most critical, sediment load versus drainage area relationship in Illinois. Finally, the slope for SYA I is close to the average of the slopes for SYA II and SYA III.

Figure 31 shows the results of the sediment load versus drainage area plot for the tributary stations. The stations are identified by their station codes, and the various symbols indicate the SYA where each station is located. The solid lines represent the regression equations for the four SYA categories based on the common slope of 0.71. The equations for each line are also included on this figure. The regression equation parameters and statistics are listed in table 16.

These results indicate that the regionalized relationships between average annual sediment load (tons/year) and drainage area are a better choice for predicting sediment loads in Illinois streams than the LRA analyses described in the previous section. These regional relationships are identified in figure 30 as Sediment Yield Areas and are defined by the equations shown in figure 31. These equations can be used to estimate sediment loads for any stream location in Illinois with drainage area greater than or equal to 10 square miles.

Multiple Regression Analyses

The second phase of the multiple regression analysis consisted of defining a statistical model for the Sediment Yield Areas. Separate regression equations were developed for SYA's I, II, and III. However SYA's IV, V, and VI were combined for analysis. The analysis was restricted to those portions of the SYA's within the Rock Island District in Illinois.

The number of geomorphic and hydraulic parameters in the model was restricted by the number of suitable sediment monitoring stations and lakes in each region. Since SYA II contained only five suitable data points, the model could contain no more than four parameters. The predictive capability of a model improves as the number of parameters increases. Therefore the

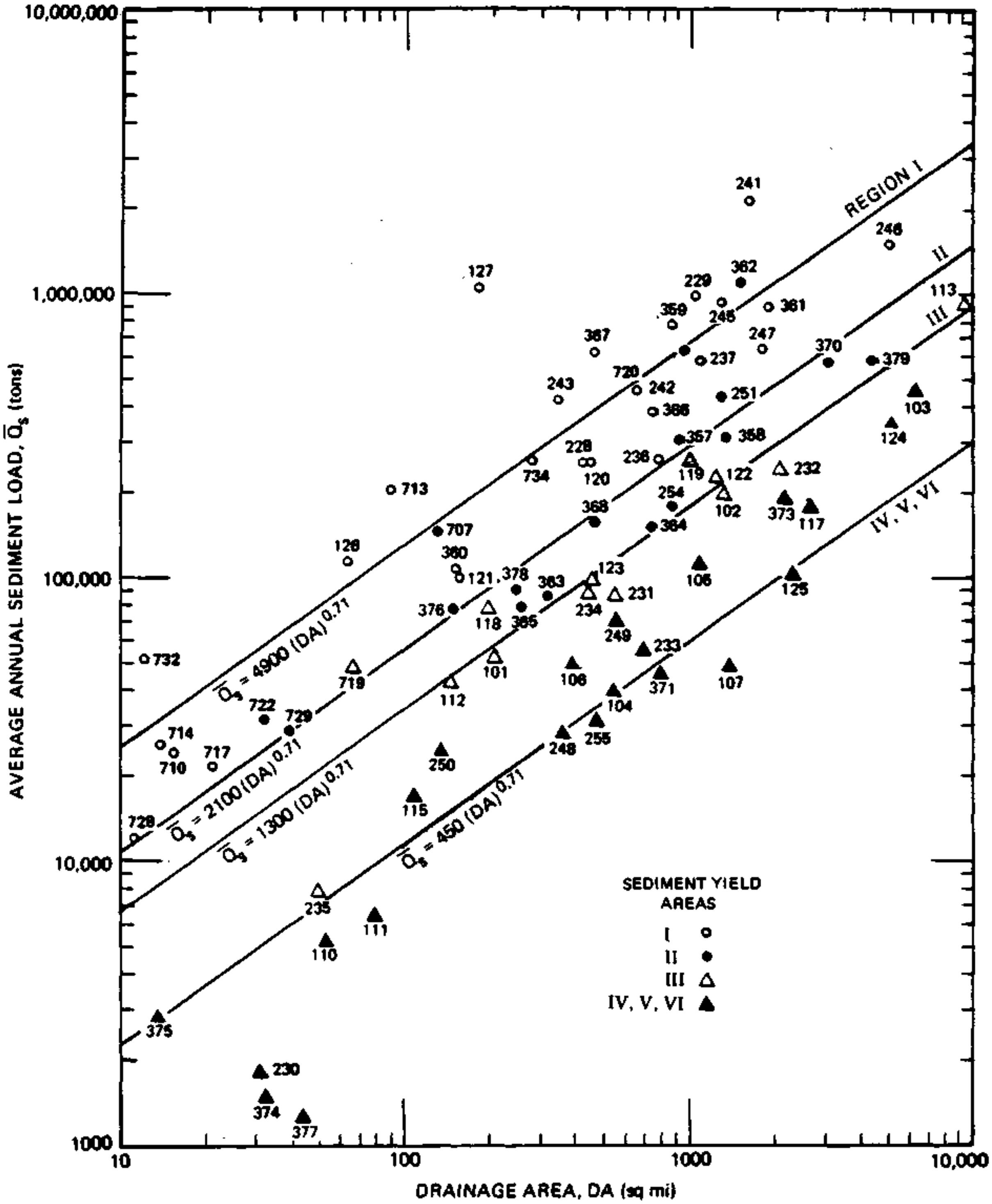

Figure 31. Average annual sediment load versus drainage area for Sediment Yield Areas in Illinois

TABLE 16. SEDIMENT YIELD AREA (SYA) REGRESSION EQUATION STATISTICS - FITTED TO A COMMON SLOPE

SYA REGION	NO. OF DATA PTS.	COEFFICIENT	SLOPE	ROOT MEAN SQ. ERROR	CORRELATION COEFFICIENT
I	25	4936.94	0.71	0.239056	0.91
II	17	2121.28	0.71	0.155956	0.95
III	13	1295.13	0.71	0.161232	0.95
IV,V,VI	22	447.49	0.71	0.277493	0.96

four-parameter model was used. The general form of the model is defined as:

$$\text{Log}(\overline{Q}_s) = C_o + C_1 \log(DA) + C_2 \log(AQWV) + C_3 \log(LU) + C_4 \log(BS) \quad (17)$$

where $\overline{Q}_s$ is the average annual sediment load at a station (tons), DA is the drainage area (square miles), AQWV is the average annual water discharge (cubic feet per year), LU is the total stream length (miles), BS is the basin shape, and C_o through C_4 are constants determined during the multiple regression analysis.

Data for this phase of the multiple regression analysis included the long-term average annual sediment loads and the four geomorphic parameters used in equation 17, for each of the 43 sediment monitoring stations and 12 lakes within the Rock Island District in Illinois.

The statistical results as well as the regression coefficients for each of the SYA regions are listed in table 17. All correlation coefficients were greater than 92 percent, which suggests that these regression equations can be used to accurately estimate the long-term average annual sediment load for any stream location in the Rock Island District in Illinois with drainage area greater than or equal to 10 square miles.

TABLE 17. MULTIPLE REGRESSION ANALYSIS
PHASE 2 - SEDIMENT YIELD AREAS

EQUATION: $\text{Log } \overline{Q}_s = C_0 + C_1) \text{ Log(DA)} + C_2 \text{ Log(AQWV)} + C_3 \text{ Log(LU)} + C_4 \text{ Log(BS)}$

REGION	NUMBER OF DATA POINTS	CORRELATION COEFFICIENT (PERCENT)	ROOT MEAN SQUARE ERROR OF THE LOGARITHMIC MODEL	C_0	C_1	C_2	C_3	C_4
SYA-I	21	91.6	0.27	11.291	1.705	-1.004	-0.090	0.119
SYA-II	6	98.1	0.25	6.428	1.509	-0.346	-0.709	+0.049
SYA-III	13	98.1	0.12	17.999	2.394	-2.049	0.402	0.042
SYA-IV,V,VI	15	97.3	0.18	-1.701	0.225	0.528	0.169	-0.147

RECOMMENDED TECHNIQUES

The generalized analyses performed in the last section are the bases for the recommendations made in this section. Readers must be cautioned that the analyses in this report were performed on the available data which in most cases extended for only a 2-year period. Even though the data base was quite short, a technique was developed which will be useful for determining sediment loads in streams within the boundaries of the Rock Island District.

The recommended techniques are presented in two sections. The first section discusses three techniques which were developed for the tributary streams within the study area, which flow into the Mississippi and Illinois Rivers. The second section discusses regression equations which were developed for the main stems of the Mississippi and Illinois Rivers.

Tributary Streams

Three techniques are recommended for tributary streams and are listed in order of preference: 1) Sediment Yield Area Regional Equations, 2) SYA Multiple Regression Regional Equations, and 3) Land Resource Area Revised Equations.

The new regional division of Illinois into Sediment Yield Areas is an improvement over the Land Resource Area Regionalization for determination of instream sediment loads. Thus the SYA methods are recommended for use in the study area. Because the drainage area is generally available or can be easily measured, the SYA linear regression method is recommended for use. The SYA multiple regression method may be used if the additional geomorphic parameters are available or can be measured or estimated. The revised LRA equations are given as an alternate method and for those who prefer to use a familiar method.

Sediment Yield Area Regional Equations

The state was divided into six areas (figure 30) and four equations were developed to relate average annual sediment load to drainage area. Data from Regions IV, V, and VI were combined to develop a single equation.

The general form of all these equations is

$$(\overline{Q}_s) = a\,(DA)^m \tag{18}$$

where $\overline{Q}_s$ is the average annual sediment load in tons, DA is the drainage area in square miles, m is the slope of the regression equation, and a is the coefficient. The following regression equations should be used to estimate the instream sediment load of tributary streams. For the regional delineation, refer to figure 30.

Region I

$$\overline{Q}_s = 4900\ DA^{0.71} \quad (19)$$

Region II

$$\overline{Q}_s = 2100\ DA^{0.71} \quad (20)$$

Region III

$$\overline{Q}_s = 1300\ DA^{0.71} \quad (21)$$

Regions IV, V, VI

$$\overline{Q}_s = 450\ DA^{0.71} \quad (22)$$

The instream sediment load for streams in Region I is higher than that of the other regions.

The procedure for the use of these equations is:

Step 1. Locate the stream segment on a topographic map. Identify the SYA region from figure 30.

Step 2. Outline the drainage basin. Review the publication by Ogata (1975) to determine if the drainage area at the designated stream section has already been determined. Otherwise, measure the drainage area using a planimeter or a digitizer.

Step 3. The drainage area determined in Step 2 is substituted into the appropriate SYA equation for the region determined in Step 1 to compute the average annual sediment load at the given stream segment.

Example Problem. An example is presented here to demonstrate the use of these regional equations.

Determine the instream average annual sediment load of the Sangamon River at Riverton, which is located in the NE 1/4 of Section 16, Township 16N, Range 4W, in Sangamon County, Illinois.

Note that although the data for this station were tabulated, they were not used to calibrate any of the three methods derived for the tributary stations because there were not enough data to determine long-term flows or sediment loads.

1) The basin is located in SYA II and is identified by station code 252 on figure 30.
2) The drainage area is equal to 2618 square miles and is given in appendix A.
3) The drainage area is substituted into the appropriate equation for the SYA region determined in Step 1 and the average annual sediment load is computed as follows:

$\bar{Q}_s = 2100(DA)^{0.71} = 2100\ (2618)^{0.71}$

$\bar{Q}_s = 2100\ (267.15)$

$\bar{Q}_s = 5.61 \times 10^5$ tons

The average annual sediment load for the Sangamon River at Riverton is 5.61×10^5 tons. This method may be used to determine the average annual sediment load at any stream site where the drainage area is known.

SYA Multiple Regression Regional Equations

The second recommended technique for determining average annual sediment loads for tributary streams in the study area is the SYA Multiple Regression Regional Equation Method. These equations were developed for the regions delineated in figure 30. Data from regions IV, V, and VI were combined for this analysis. The general form of the multiple regression equation is:

$$\bar{Q}_s = b(DA)^{C1}\ (AQWV)^{C2}\ (LU)^{C3}\ (BS)^{C4} \qquad (23)$$

where $\bar{Q}_s$ is the average annual sediment load in tons, DA is the drainage area in square miles, AQWV is the average water volume in cubic feet, LU is the total stream length in miles, and BS is the dimensionless basin shape. The coefficients for each SYA can be found in table 18. The multiple regression equations may be used to estimate the instream sediment load at a location where the values of DA, AQWV, LU, and BS are known or are determined from available data or maps.

TABLE 18. MULTIPLE REGRESSION COEFFICIENTS

REGION	b	C_1	C_2	C_3	C_4
SYA-I	1.97×10^{11}	1.705	-1.004	-0.090	0.119
SYA-II	2.68×10^{6}	1.509	-0.346	-0.709	+0.049
SYA-III	9.98x1017	2.394	-2.049	0.402	0.042
SYA-IV,V,VI	1.99×10^{-2}	0.225	0.528	0.169	-0.147

The procedure for use of these equations is:

Step 1. Locate the stream section on a topographic map. Identify the SYA from figure 30 where the stream segment is located.

Step 2. Outline the drainage basin. Review the publication by Ogata (1975) to determine if the drainage area at the designated stream section has already been determined. Otherwise, measure the drainage area using a planimeter or a digitizer.

Step 3. Determine the average annual water volume, AQWV, from available flow records. An estimate of AQWV can be made for streams in Illinois using the publication by Terstriep et al. (1982).

Step 4. Measure the total stream length, LU, within the drainage basin from the topographic map using a map wheel or a digitizer.

Step 5. Determine the basin shape by measuring the basin length, LB (straight line distance from the basin outlet to the most distant point in miles) and computing the ratio of the square of the basin length, LB, to the drainage area, DA.

Step 6. The coefficients for the SYA region determined in Step 1 are selected from table 18. These coefficients and the four parameters determined in Steps 2 through 5 are substituted into equation 23 to compute the average annual sediment load for the stream section.

Use of the multiple regression method requires determining the average annual water volume, total stream length, and basin length in addition to the drainage area. In most cases, the total stream length and basin length have to be measured on topographic maps.

Example Problem. An example is presented here to demonstrate the multiple regression technique.

Determine the average annual sediment load for the Sangamon River at Riverton. Note that the location, the SYA region, and drainage area are listed in the previous example.

1) The SYA region is II.
2) The drainage area is 2618 square miles.
3) The average annual water volume, AQWV, is not tabulated for this station. Therefore it is estimated using the average volume for a nearby station. For this example, AQWV at Riverton was estimated

using the flow record at the South Fork Sangamon River near Rochester. According to the USGS Water Resources Data for Illinois (1981), the average discharge for the station near Rochester is 558 cfs and its drainage area is 867 square miles. Therefore the average annual water volume at Riverton is estimated as:

$$AQWV = \frac{2618\ mi^2}{867\ mi^3} \quad \frac{558\ ft^3}{sec} \quad \frac{31,536,000\ sec}{year}$$

AQWV = 5.31 x 1010 ft^3

4) The total stream length, LU, was measured on topographic maps and was determined to be 2704.8 miles.

5) The basin length and drainage area were determined and were used to calculate the basin shape, BS, which was equal to 3.16.

6) The coefficients for SYA II were obtained from table 18, and these coefficients along with DA, AQWV, LU, and BS were substituted into the general multiple regression equation to obtain:

$\overline{Q}_s = 2.61 \times 10^5$ tons

Land Resource Area Revised Equations

The Land Resource Areas of the study region are shown in figure 3, and the regression equations were developed following the procedure described in the Upper Mississippi River Comprehensive Basin Study (1970). It is important to note that these are the revised LRA equations, and either these equations or the lines shown in figures 25 through 29 can be used to determine the average annual sediment yield, $\overline{Q}_s/DA$.

The general form of these equations is:

$$\overline{Q}_s \ / \ DA = a(DA)^m \qquad (24)$$

where a and m are respectively the coefficient and the slope of these regression equations, and $\overline{Q}_s$ and DA have already been defined.

LRA 115

$$\overline{Q}_s \ / \ DA = 3900\ (DA)^{-0.19} \qquad (25)$$

LRA 113

$$\overline{Q}_s \ / \ DA = 1300\ (DA)^{-0.19} \qquad (26)$$

LRA 108,109,114

$$\overline{Q}_s \ / \ DA = 1100\ (DA)^{-0.19} \qquad (27)$$

LRA 105

$$\overline{Q}_s \ / \ DA = 500\ (DA)^{-0.19} \qquad (28)$$

LRA 95,110

$$\overline{Q}_s / DA = 360 (DA)^{-0.19} \qquad (29)$$

This analysis indicates that the instream sediment load in LRA 115 is higher than that of the other Land Resource Areas.

The procedure for use of these equations is:

Step 1. Identify the stream segment where average annual sediment load is to be determined and locate it on a topographic map.

Step 2. Determine the LRA for the stream segment using figure 3.

Step 3. Review the publication by Ogata (1975) to determine if the drainage area at the designated stream section has already been determined. Otherwise, determine the drainage area from a topographic map using either a planimeter or a digitizer.

Step 4. On the basis of the location of the stream segment within the specific LRA region, use the appropriate equation to determine the average annual sediment load for the drainage area at the site.

Example Problem. An example problem is presented here to demonstrate the revised LRA technique.

Determine the instream average annual sediment load of the Sangamon River at Riverton. Note that the location and drainage area were determined in the previous examples.

1) The site is indicated by station code 252 on figure 5.
2) According to figure 3, the site is located in LRA region 108.
3) The drainage area was determined in the previous examples and is equal to 2618 square miles.
4) Equation 27 was used with the drainage area for this station to determine that:
$\overline{Q}_s = 6.46 \times 10^5$ tons

All three techniques given above for the tributary streams should yield satisfactory results. However, the SYA Regional Regression Equations are recommended over the Revised LRA Regression Equations. The multiple regression equations for the SYA's may give a better estimate of instream sediment load, but they require measuring two parameters on topographic maps.

Illinois and Mississippi Main Stems

Individual regression equations relating instream sediment load and water discharge have been developed for three gaging stations on the Mississippi River and two on the Illinois River. These equations are recommended for determining the sediment load along the main stems of these two rivers. It is emphasized that the regional equations described above should not be used for determining the sediment load on the main stems of the Illinois and Mississippi Rivers.

Equations for specific gaging stations will now be given.

Mississippi River Main Stem

Two regression equations are recommended for estimating sediment loads at each of the Mississippi River stations. The period of record equation relates the daily sediment load, Q_s, to the daily water discharge, Q_w. The annual load regression equation relates the annual sediment load, $\overline{Q}_s$, to the annual flow, QWA. The QWA is the summation of all the individual average daily flows in cfs for each day of the water year.

The general form of the period of record equation is:

$$Qs = a(Q_w)^m \quad (30)$$

where Qs is the daily sediment load in tons per day, Qw is the daily water discharge in cfs, and a and m are constants which can be found in table 19a.

The general form of the annual load regression equation is:

$$\overline{Q}_s = a\ (QWA)^m \quad (3D$$

where Qs is the annual sediment load in tons, QWA is the annual flow in cfs-days, and a and m are constants which can be found in table 19b.

TABLE 19. MISSISSIPPI RIVER REGRESSION COEFFICIENTS

	STATION	a	m
a. PERIOD OF RECORD EQUATION	EAST DUBUQUE	0.1206×10^{-5}	2.07
	BURLINGTON	0.0843×10^{-6}	2.31
	KEOKUK	0.0204×10^{-6}	2.41
b. ANNUAL LOAD REGRESSION EQUATION	EAST DUBUQUE	0.1908×10^{-9}	2.11
	BURLINGTON	0.0996×10^{-3}	1.48
	KEOKUK	0.2865x10-12	2.63

Illinois River Main Stem

The period of record equations are recommended for estimating daily-sediment loads for the Illinois River stations. The data base was insufficient to develop annual load regression equations.

The period of record equation for the Illinois River at Marseilles is:

$$Q_s = 0.678 \quad (10)^{-3} \quad Q_w^{1.65} \tag{32}$$

where Qs and Qw have already been defined.

The period of record equation for the Illinois River at Marseilles is:

$$Qs = 0.352 \quad Qw^{1.04} \tag{33}$$

The equations given above for the Mississippi and Illinois main stems are recommended for determining the sediment load on these two rivers.

SUMMARY

This project meets two needs: the need for a comprehensive analysis of suspended sediment transport data, and the need for an improvement in the ability to estimate suspended sediment loads in Illinois streams within the Rock Island District, U. S. Army Corps of Engineers. Data available as of January 1, 1984 (through Water Year 1982) were collected for 59 suspended sediment stations and 12 lakes in Illinois. Some additional stream and lake data that were not in the study area were used to complete the data file. Basin geomorphic and hydraulic parameters were also collected or measured for each of the stations.

Analyses proceeded in three phases: station, general, and regional. Analysis of each station's suspended sediment data produced yearly and period of record (1 to 15 years) regression equations relating sediment load to daily discharge. For tributary stations with three or more years of suspended sediment data, seasonal regression equations were also derived. The seasons used were October through January, February through May, and June through September.

General analyses focused on three topics: 1) estimating long-term average annual sediment loads from short-term sediment data and from a new method for stations with relatively long records of suspended sediment data, 2) multiple regression analysis, and 3) sediment transport by flood events.

The period of record sediment load equations were used with station flow-duration tables to estimate the long-term average annual sediment loads. These loads were then available for use, along with the geomorphic and hydraulic parameters, in the multiple regression analysis and in the regionalization process.

For the three Mississippi River stations with 14 or 15 years of data, suspended sediment concentration-duration curves were developed. These curves were used with the long-term discharge records to generate an average annual sediment load. The results were closer to the measured loads than the estimates based on the daily sediment regression equation and the flow-duration data. However, at least ten years of sediment data are needed before this method is recommended.

Multiple regression techniques were applied to the geomorphic and hydraulic data and resulted in the selection of four parameters: drainage area, water discharge, total stream length, and basin shape. As many as 6 of the 24 parameters could be included, but the improvements in the correlation coefficients did not justify the increased complexity of the analysis. Statistical considerations also required using no more than four parameters. The four selected parameters were used in the regional analysis.

A relationship between annual sediment load and sediment transported by the four largest floods of the year was developed and presented. This requires rather extensive analysis of the information. However, this concept can help in planning more cost-effective sediment measuring programs. It also provides some insight into the effect of variations in annual runoff volume and sediment load.

Regional analysis produced six Sediment Yield Areas, or SYA's, which are substantially different from the Land Resource Areas (LRA's). Both sediment load (as a function of drainage area) and multiple regression equations are given for each SYA. The instream suspended sediment data were used to revise the regression equations for the LRA's. However, the SYA method gives results that match the measured loads more closely, and they are recommended for use in the study area except for the Illinois and Mississippi River main stem. Sediment loads on these large rivers are best estimated using the station period of record equations.

The recommended techniques are outlined in detail and presented in a form suitable for quick reference. In the SYA sediment load versus drainage area development, stations outside the study area were used, so this SYA method could be applied to the entire state. The recommended methods make use of the available data and yield improved estimates of suspended sediment load in streams in northern and central Illinois.

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NOTATIONS

ALRE = annual load regression equation

AQW = average annual water discharge, ft3/sec (cfs)

AQWV = average annual water volume, ft3

ARE = annual regression equation

a = coefficient in linear regression equation

BS = basin shape

BW = basin width, miles

b = coefficient in multiple regression equation

C = capacity of lake, acre-ft

C = time-averaged suspended seidment concentration, mg/l

C_i = suspended sediment concentration at midpoint of ith interval

CMRE = combined monthly regression equation

C_n = coefficients in multiple regression equation

CR1, CR2, CR3 = circularity ratios

C_t = suspended sediment concentration, at t above bed, mg/1

D = water depth, ft

DA = drainage area, mi^2

DD = drainage density, mi^{-1}

DS = depth of stream, ft

F = stream frequency, number of stream segments per mile

H = total basin relief, ft

HA = average basin relief, ft

I = annual inflow to lake, acre-ft

IC = incision, ft

IMRE = individual month regression equation

LA = mean stream length, miles

LB = basin length, miles

LS = main stem length, miles

LU = total stream length, miles

LRA = Land Resource Area

m = exponent in linear regression equation

NU = total number of stream segments

P = basin perimeter, miles

POR = period of record regression equation

PRECIP = normal annual precipitation, inches

Q_s = suspended sediment load, tons/day

$\overline{Q_s}$ = average annual sediment load, tons

Q_{sb} = bed load, tons/day

QSA = annual sediment load, tons

QSN = sediment load transported during the N largest floods, tons

Q_w = water discharge, cfs

Q_{wi} = water discharge at midpoint of ith segment

QWA = annual water volume, cfs-days

QWDA = AQW/DA, cfs/mi^2

q_s = unit sediment load, pounds/ft width/sec

R = correlation coefficient

RR = relief ratio, ft/mi

SLRE = seasonal load regression equation

SRE = seasonal regression equation

SS = sinuosity

SYA = sediment yield area

t = thickness of bed layer, or unmeasured layer, ft

U = stream order

$\overline{V}$ = time-averaged point velocity, ft/sec

VS = average stream velocity, ft/sec

V_* = shear velocity, ft/sec

WT = stream top width, ft

y = vertical coordinate, ft

z = exponent in suspended sediment equation

α_n = geomorphic parameters in multiple regression analysis

β = constant in expression for z

γ_s = unit weight of sediment, pounds/ft3

κ = von Karman constant

ω = sediment particle fall velocity, ft/sec

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APPENDIX A. GEOMORPHIC AND HYDRAULIC PARAMETERS FOR STATIONS IN THE ROCK ISLAND DISTRICT

CODE	REGION	QWDA	DA	AQW	PRECIP	D
101	3	0.690	207.0	143.0	34.9	5
102	3	0.675	1326.0	895.0	33.8	6
103	4	0.619	6363.0	3940.0	35.6	7
104	4	0.632	538.0	340.0	36.3	6
105	4	0.634	1099.0	697.0	36.4	6
106	4	0.661	387.0	256.0	36.5	4
107	4	0.590	1403.0	830.0	35.0	6
108	4	0.700	360.0	252.0	33.7	5
109	4	0.730	630.0	460.0	34.3	5
110	4	0.760	51.7	39.3	36.0	5
111	4	0.714	77.7	55.5	36.3	3
112	3	0.668	146.0	97.6	35.4	5
113	3	0.623	9549.0	5948.0	35.9	7
114	4	0.590	1732.0	1025.0	35.4	6
115	4	0.790	107.0	84.6	36.0	3
116	4	0.780	324.0	254.0	35.0	4
117	4	0.660	2642.0	1680.0	33.8	6
118	3	0.670	196.0	133.0	35.5	5
119	3	0.600	1003.0	604.0	35.5	4
120	1	0.634	445.0	282.0	34.2	4
121	1	0.684	155.0	106.0	36.0	4
122	3	0.370	1251.0	807.0	34.4	4
123	3	0.723	455.0	329.0	34.4	5
124	4	0.802	5150.0	4130.0	35.4	7
125	4	0.847	2294.0	1942.0	37.8	6
126	1	0.716	62.7	44.9	35.6	3
127	1	0.620	174.0	108.0	34.0	4
203	4	0.833	2.4	2.0	36.2	6
204	4	0.714	2.8	2.0	36.2	6
228	1	0.662	432.0	286.0	34.5	6
229	1	0.648	1062.0	688.0	35.5	6
230	4	0.650	30.5	19.8	35.0	3
231	3	1.470	551.0	385.0	33.8	4
232	3	0.770	2091.0	1611.0	38.2	6
233	4	0.783	686.0	537.0	38.4	5
234	3	0.789	446.0	352.0	37.5	4
235	3	0.720	49.0	35.2	35.2	3
236	1	0.650	767.0	499.0	36.0	6
237	1	0.650	1092.0	710.0	36.4	6
240	1	0.430	7.1	3.4	36.2	3
241	1	0.627	1636.0	1026.0	36.2	6
242	1	0.661	655.0	433.0	35.5	5
243	1	0.582	349.0	203.0	35.4	5
244	1	0.485	45.4	22.0	35.9	2
245	1	0.606	1293.0	784.0	38.0	6
246	1	0.640	5093.0	3261.0	35.0	7
247	1	0.690	1804.0	1245.0	35.5	6
248	4	0.707	335.0	237.0	38.0	5
249	4	0.729	550.0	401.0	38.1	5
252	2	0.644	2618.0	1685.0	34.7	5
254	2	0.641	870.0	558.0	34.2	5
359	1	0.610	868.0	529.0	35.0	6
444	1	0.479	35.5	17.0	35.5	3

CODE	NU	LA	LU	DD	H	HA
101	836	0.64	537.8	2.60	500	387
102	3008	0.80	2408.1	1.82	476	390
103	7167	1.05	7535.9	1.18	314	345
104	343	1.45	495.7	0.92	210	110
105	729	1.39	1051.3	0.96	240	250
106	236	1.37	323.8	0.84	273	181
107	741	1.07	795.5	0.57	200	190
108	344	1.09	376.0	1.04	106	114
109	440	1.07	471.8	0.75	140	130
110	39	1.21	47.3	0.91	180	146
111	53	1.37	72.5	0.93	131	81
112	163	1.10	178.8	1.22	330	217
113	10523	1.08	11326.0	1.19	452	400
114	935	1.17	1091.1	0.63	310	308
115	162	0.84	135.9	1.27	235	183
116	238	0.90	215.0	0.66	250	194
117	1265	1.40	1769.4	0.67	440	438
118	451	0.67	302.4	1.54	371	225
119	842	1.10	911.5	0.90	350	139
120	1547	0.60	930.3	2.10	310	225
121	349	0.10	303.0	2.00	200	161
122	575	1.80	1030.6	1.00	120	205
123	198	1.79	354.6	0.77	173	697
124	8903	0.75	6641.8	1.30	327	266
125	5683	0.61	3467.2	1.51	220	176
126	57	1.39	79.4	1.27	238	153
127	358	0.82	295.2	1.70	260	233
203	1	3.00	3.0	1.23	65	49
204	1	3.75	3.7	1.32	77	61
228	681	0.94	641.0	1.48	270	214
229	1470	1.06	1552.3	1.46	450	308
230	26	1.14	29.5	1.00	70	45
231	231	1.70	480.3	0.90	20	107
232	2794	0.89	2480.4	1.19	170	120
233	1408	0.66	921.6	1.34	95	99
234	336	1.46	492.2	1.10	160	114
235	70	0.28	19.4	0.40	139	97
236	650	1.27	828.1	1.10	215	191
237	999	0.89	885.7	0.10	345	307
240	12	0.84	10.0	1.27	160	141
241	2952	0.88	2585.6	1.58	490	362
242	1689	0.71	1203.1	1.84	295	191
243	1241	0.61	756.2	2.20	170	145
244	39	1.19	46.4	1.02	140	139
245	3448	0.72	2474.3	1.91	307	228
246	3819	1.37	5221.6	1.03	370	278
247	1284	1.41	1811.3	1.00	415	270
248	256	1.35	344.5	1.03	282	188
249	420	1.36	570.9	1.04	265	190
252	1895	1.43	2704.8	1.03	374	170
254	607	1.59	966.1	1.11	207	135
359	1124	1.04	1171.6	1.35	170	179
444	21	1.40	29.3	0.83	85	85

CODE	BS	LB	LS	F	SS	IC
101	0.12	25.00	47.00	4.00	1.25	38.1
102	2.86	61.60	127.30	2.27	1.34	50.3
103	1.39	94.00	146.80	1.13	1.36	63.7
104	1.26	26.00	36.50	0.64	1.33	44.0
105	1.03	33.60	47.30	0.69	1.34	48.9
106	1.80	26.40	52.30	0.61	1.32	41.8
107	3.69	72.00	93.40	0.53	1.12	34.8
108	0.05	4.30	60.10	0.96	1.19	29.6
109	5.89	60.90	84.00	0.70	1.19	31.6
110	1.53	8.90	10.80	0.75	1.16	23.4
111	2.21	13.10	17.50	0.68	1.30	32.9
112	1.65	15.50	32.10	1.12	1.31	36.1
113	3.11	172.40	272.80	1.10	1.37	67.7
114	6.17	103.40	142.50	0.54	1.16	35.7
115	2.89	17.60	24.10	1.51	1.19	25.6
116	4.00	36.00	48.40	0.73	1.31	22.5
117	6.92	135.20	175.10	0.48	1.16	37.5
118	4.90	31.00	42.00	2.30	1.43	37.8
119	3.70	60.60	78.60	0.84	1.33	48.3
120	6.40	53.50	68.70	3.50	1.32	42.7
121	2.00	22.20	25.30	2.30	1.31	36.5
122	1.80	43.00	87.80	0.50	1.32	25.9
123	1.32	24.90	26.80	0.43	1.87	23.4
124	2.51	113.00	156.90	1.73	1.34	31.4
125	3.53	90.00	115.40	2.48	1.33	28.5
126	4.08	16.00	21.90	0.91	1.22	38.1
127	8.20	37.60	45.60	2.10	1.31	37.1
203	6.56	4.00	3.00	0.41	1.26	19.6
204	7.86	4.70	3.70	0.35	1.26	20.0
228	2.30	31.60	41.70	1.60	1.44	44.5
229	2.63	52.80	93.00	1.38	1.53	47.8
230	1.50	6.80	8.10	0.90	1.16	36.0
231	1.45	28.30	39.00	0.50	1.31	24.0
232	0.86	42.40	104.20	1.34	1.33	28.1
233	2.72	43.20	59.00	2.05	1.32	24.6
234	4.03	42.40	29.60	0.75	1.31	23.4
235	14.70	15.10	20.00	1.40	1.16	37.4
236	3.00	48.00	72.90	0.90	1.36	46.6
237	4.60	71.00	112.90	0.90	1.36	47.9
240	0.94	2.72	4.98	1.52	1.04	32.3
241	2.74	67.00	113.90	1.80	1.59	49.5
242	0.69	21.20	61.00	2.58	1.34	46.0
243	0.73	16.00	30.20	3.60	1.40	43.7
244	3.12	11.90	13.80	0.86	1.19	37.1
245	1.78	48.00	108.40	2.67	1.32	48.6
246	1.93	99.20	283.80	0.75	1.10	50.5
247	2.49	67.00	111.00	0.71	1.13	42.3
248	3.62	34.80	50.00	0.76	1.17	31.8
249	3.15	39.00	73.80	0.76	1.15	34.6
252	3.16	91.00	227.40	0.72	1.12	45.1
254	2.56	47.20	78.80	0.70	1.14	37.4
359	2.54	47.00	73.80	1.30	1.14	37.4
444	1.85	8.10	7.80	0.59	1.17	36.4

CODE	RR	CR1	CR2	CR3	WT	DS	VS
101	20.00	0.450	1.350	0.190	78.10	1.62	1.20
102	7.73	0.590	1.300	0.190	178.00	3.09	2.68
103	3.34	0.502	0.870	0.223	485.60	4.65	3.28
104	7.60	0.559	0.510	0.179	99.90	2.44	2.38
105	7.44	0.560	0.670	0.228	157.80	2.95	2.61
106	10.30	0.506	0.630	0.167	80.90	2.25	2.28
107	2.78	0.392	2.360	0.226	173.90	3.78	3.10
108	24.60	0.350	3.790	2.420	138.30	2.86	1.82
109	2.30	0.340	4.090	0.230	193.50	3.23	1.90
110	20.22	0.671	1.770	0.303	21.00	1.27	1.83
111	10.00	0.635	1.470	0.230	28.90	1.48	1.85
112	21.30	0.613	1.820	0.297	43.40	1.74	2.01
113	2.63	0.404	0.900	0.152	629.60	5.17	3.46
114	3.00	0.343	3.050	0.198	199.00	4.04	3.20
115	13.35	0.560	1.680	0.220	66.80	2.19	1.65
116	6.94	0.490	1.610	0.180	68.08	2.32	2.45
117	3.25	0.279	3.050	0.226	260.80	4.64	3.43
118	11.97	0.461	3.710	0.245	48.00	2.73	2.18
119	5.80	0.300	1.900	0.200	70.40	10.63	1.60
120	5.80	1.000	3.300	0.200	88.50	2.33	2.32
121	9.00	2.000	2.000	0.200	45.10	1.77	2.02
122	2.80	0.480	2.200	0.310	192.80	3.83	2.15
123	6.95	0.912	1.095	0.253	117.26	4.81	2.02
124	2.89	0.310	1.560	0.220	329.70	10.49	2.60
125	2.44	0.320	1.660	0.193	229.10	7.97	2.26
126	14.88	0.500	2.950	0.240	28.70	1.60	1.99
127	6.90	0.280	0.760	0.270	48.50	1.82	2.06
203	16.30	0.415	6.340	0.277	3.10	0.60	1.18
204	16.40	0.383	7.300	0.272	3.50	0.63	1.21
228	54.00	0.740	1.600	0.200	56.30	6.36	1.59
229	8.52	0.541	1.940	0.243	102.70	6.05	2.50
230	10.30	1.600	0.430	1.500	25.81	1.41	1.59
231	0.70	2.000	0.990	0.740	140.40	3.06	1.92
232	4.01	0.456	0.680	0.250	219.70	7.72	2.23
233	2.20	0.916	1.380	0.201	133.10	5.29	1.84
234	3.77	0.508	1.750	0.186	109.60	4.57	1.71
235	9.20	0.310	0.770	0.110	33.67	1.66	1.66
236	4.50	0.510	1.700	0.670	157.08	4.36	2.12
237	4.90	2.000	2.600	0.670	191.40	4.93	2.19
240	58.82	0.650	1.010	0.292	11.30	0.60	1.69
241	7.30	0.453	2.220	0.254	124.70	7.41	2.58
242	13.90	0.562	0.700	0.286	75.60	5.17	1.60
243	10.63	0.650	0.550	0.240	56.90	4.12	1.49
244	11.80	0.547	2.620	0.258	22.70	1.98	1.19
245	6.40	0.635	1.240	0.236	102.60	6.61	1.72
246	3.73	0.541	1.120	0.215	331.30	7.62	3.05
247	6.19	0.602	1.680	0.232	195.20	5.82	2.33
248	8.10	0.500	1.260	0.167	82.70	5.39	1.50
249	6.79	0.385	0.960	0.166	106.50	4.27	1.71
252	4.11	0.293	2.310	0.241	236.00	6.41	2.56
254	4.39	0.499	1.860	0.240	134.50	4.82	1.92
359	3.62	0.560	1.570	0.220	222.37	4.59	3.46
444	10.50	0.817	2.440	0.324	20.40	1.81	1.16

APPENDIX B. STATISTICAL PARAMETERS FOR THE PERIOD OF RECORD AND ANNUAL REGRESSION EQUATIONS

STATION CODE*	COEFFICIENT**	SLOPE**	STANDARD ERROR OF ESTIMATE	CORRELATION COEFFICIENT
101	.0095669	1.7095811	.2174954	.9261604
10181	.0051883	1.8477509	.1818888	.9589321
10182	.0174123	1.5831136	.2352428	.8707545
102	.3093833	1.0947876	.2516492	.6907199
10281	.0727841	1.3032804	.2842973	.7076517
10282	7.1102672	.6640126	.1898754	.5280962
103	9.6096936	.6005367	.2612617	.4466339
10381	7.2561918	.6380759	.2653885	.4288265
10382	1.7364514	.7805398	.2207319	.5773580
104	.0920060	1.1942641	.1949269	.8565768
10481	.0377275	1.3267879	.2392235	.7951311
10482	.2652231	1.0373471	.1139103	.9331901
105	.0032751	1.6466355	.2805621	.8790446
10580	.0017186	1.7531087	.2641672	.8997018
10581	.0035678	1.6190137	.2730881	.8105532
106	.0635758	1.3258246	.2046584	.9181496
10681	.0646505	1.3255252	.1773788	.9369229
10682	.0607883	1.3181074	.3165426	.8250717
107	1.0509069	.7328766	.2639013	.5348272
10781	1.0527243	.7329018	.2673513	.5333170
10782	.0451584	1.1790004	.1566645	.5238386
108	.0673405	1.1760446	.2293593	.7651015
10881	.0673405	1.1760446	.2293593	.7651015
109	.0003824	1.8613530	.2267081	.9422178
10980	.0003123	1.9050925	.2145256	.9518695
10981	.0001299	2.0272065	.1876854	.9438376
10982	.0002946	1.8960352	.2505351	.9313797
110	.1122406	1.2664227	.2169929	.8700597
11081	.0387253	1.5215503	.2337556	.8891267
11082	.2252573	1.0868476	.1751894	.8708976
111	.0749495	1.2616653	.2880960	.9205655
11180	.0975790	1.1897001	.2980313	.9218490
11181	.0492383	1.3777872	.2685058	.9245287
112	.0323031	1.6103716	.2288553	.9084150
11281	.0169081	1.7719837	.2088683	.9214222
11282	.0000187	2.6292275	.0343596	.9739716

APPENDIX B. CONTINUED

STATION CODE*	COEFFICIENT**	SLOPE**	STANDARD ERROR OF ESTIMATE	CORRELATION COEFFICIENT
113	.0000658	1.9507239	.2460897	.8567836
11381	.0000135	2.1199164	.2698826	.8106618
11382	.0000148	2.1124223	.2083343	.9178468
114	.0206595	1.2879497	.2171094	.8371286
11481	.0239003	1.2835044	.2658331	.7079295
11482	.0143150	1.3264614	.1635912	.9173780
115	.0198697	1.5455081	.4439457	.8789010
11581	.0198697	1.5455081	.4439457	.8789010
116	.0000744	2.3668288	.3270546	.9067669
11681	.0000744	2.3668288	.3270546	.9067669
117	.0021105	1.6040301	.2822722	.7995452
11781	.0021105	1.6040301	.2822722	.7995452
118	.0078285	1.8031095	.3617313	.9059271
11881	.0069328	1.8340922	.3728346	.8897051
11882	.0105909	1.7043446	.2807798	.9594565
119	.0006079	2.0119779	.2872359	.9230692
11979	.0002849	2.0933735	.2549334	.9584732
11980	.0008714	1.9924234	.2800949	.8888911
11981	.0001672	2.2182639	.2988945	.9132492
120	.0069346	1.8275035	.3964421	.9262427
12080	.0184208	1.7190239	.3363540	.9407792
12081	.0001566	2.4509152	.3317034	.9453754
121	.0166221	1.7851557	.2767679	.9299352
12181	.0039629	2.0943242	.2940864	.9367055
12182	.0537906	1.5309409	.2080293	.9485902
122	.0006779	1.8825675	.4431390	.9369586
12281	.0001179	2.1148785	.3539014	.9624565
123	.0206012	1.4943566	.2097696	.9687713
12381	.0168633	1.5263604	.2110281	.9686139
12382	.0550296	1.3314045	.1664863	.9785189
124	.0005075	1.6737626	.3293646	.8969680
12479	.0005594	1.6724708	.3626162	.9043286
12480	.0010022	1.6085965	.2584068	.9143865
12481	.0000169	2.0798347	.2821986	.9335447
12482	.0011743	1.5457980	.3394374	.8453806

STATION CODE*	COEFFICIENT**	SLOPE**	STANDARD ERROR OF ESTIMATE	CORRELATION COEFFICIENT
125	.0025496	1.5050847	.2849630	.8456399
12579	.0051273	1.3909369	.2592535	.8796625
12580	.0056130	1.4152265	.2491577	.8068261
12581	.0001055	1.8887967	.2976960	.8590567
12582	.0642893	1.1451356	.1991937	.8357079
126	.0044951	2.2527845	.2630790	.9630189
12681	.0044951	2.2527845	.2630790	.9630189
127	.0003639	2.6137933	.2787339	.9487831
12781	.0003701	2.6163078	.2717919	.9521633
12782	.0000519	2.7922173	.0601950	.9910888
203	.0544002	1.1048858	.3283990	.8102199
20380	.0540148	1.0541437	.3178579	.8048677
20381	.0468578	1.2278379	.3164333	.8390742
204	.0529983	1.2152692	.3513098	.8224574
20480	.0641672	1.1506834	.3410745	.8009460
20481	.0394198	1.3996660	.3154497	.8728178
228	.0023581	1.9608138	.4129258	.9235629
22879	.0068665	1.7773090	.3054924	.9580129
22880	.0028534	1.9816339	.3390167	.9511929
22881	.0000094	2.8968052	.4049790	.9220726
229	.0028051	1.8888194	.3701242	.8899263
22981	.0027654	1.8942202	.3804194	.8731114
22982	.0072436	1.7189012	.2701294	.9345553
230	.1867003	1.0734278	.2953718	.8884907
23081	.1142139	1.1919426	.3075792	.8990543
23082	.3190093	1.0158788	.0563665	.9716858
231	.0510144	1.3541986	.2328496	.9493009
23181	.0313944	1.4246308	.2404438	.9520136
23182	.8316312	.8298288	.0867390	.8940381
232	.0084151	1.4585430	.3655268	.9246434
23279	.0074225	1.4896787	.3462906	.9461182
23280	.0228776	1.2844067	.3727088	.8922117
23281	.0010782	1.7326973	.3197963	.9455559
23282	.2510017	1.0538550	.2250470	.9292567
233	.0600328	1.2151316	.4203365	.8626751
23379	.0230281	1.3704184	.4482183	.8920509
23380	.0760472	1.1079805	.4426737	.7993093
23381	.4728528	.9509043	.2547929	.8676973
23382	.8350650	.8400814	.2438232	.8734177

STATION CODE*	COEFFICIENT**	SLOPE**	STANDARD ERROR OF ESTIMATE	CORRELATION COEFFICIENT
234	.0955720	1.2727606	.2379484	.9611401
23481	.0955720	1.2727606	.2379484	.9611401
235	.2028041	1.2315447	.3635132	.9318707
23581	.2028041	1.2315447	.3635132	.9318707
236	.0228777	1.5404081	.2207728	.9723241
23681	.0169097	1.5819526	.2429309	.9617114
23682	.9142352	.7790422	.0607041	.8356061
237	.0016027	1.9154967	.2921226	.9518449
23781	.0016027	1.9154967	.2921226	.9518449
238	.0241086	1.6856562	.4058260	.8583112
23876	.0629952	1.5603764	.3653930	.8436259
23877	.0339176	1.8429354	.2967654	.9221096
23878	.0080452	1.8864579	.3141132	.9119815
23879	.0207933	1.5831160	.3152334	.9148013
23880	.0080568	1.9945602	.3274537	.9049784
239	.0076818	1.9772154	.3999234	.8955665
23976	.0158503	1.9206946	.4244449	.8478291
23977	.0166833	1.9295911	.4052016	.8787329
23978	.0022291	2.2002392	.3563002	.9117793
23979	.0085745	1.8915974	.3632976	.9156264
23980	.0052096	2.0825105	.3009366	.9335690
23981	.0020113	2.3561328	.3342254	.9404172
23982	.0046665	2.0393738	.2671381	.9531519
240	.1854862	1.1670239	.3803887	.8248933
24076	.2346525	1.0534478	.3516587	.8002238
24077	.3656750	1.1399218	.2565714	.9013702
24078	.1008677	1.4959408	.3620065	.8370841
24079	.0830543	1.5317667	.3218749	.9025051
24080	.1103510	1.5785123	.3143752	.8739432
241	.0000917	2.2841227	.2463319	.9725338
24181	.0000917	2.2841227	.2463319	.9725338
242	.0158518	1.6557147	.3405340	.9304522
24281	.0258565	1.5948455	.3205374	.9329609
24282	.0031457	1.8436209	.3769089	.8684936
243	.0190378	1.7114194	.3158764	.9744613
24381	.0190530	1.7125056	.3117993	.9749673
24382	.2889929	.8327429	.2799223	.7564396

APPENDIX B. CONCLUDED

STATION CODE*	COEFFICIENT**	SLOPE**	STANDARD ERROR OF ESTIMATE	CORRELATION COEFFICIENT
244	.0112846	1.9441503	.3920645	.9621231
24481	.0112846	1.9441503	.3920645	.9621231
245	.0013223	1.9389026	.3598209	.9641545
24581	.0013223	1.9389026	.3598209	.9641545
246	.0002352	1.9260384	.3334468	.9659538
24681	.0002352	1.9260384	.3334468	.9659538
247	.0118611	1.5766261	.2507922	.9605822
24781	.0072967	1.6430043	.3149158	.9537057
24782	.0238227	1.4733974	.1666724	.9710865
248	.0413899	1.3008772	.2991093	.9092568
24881	.0561398	1.2626739	.2943454	.8815824
24882	.0677657	1.1235596	.2504235	.9309517
249	.1685943	1.1471191	.2240740	.9578885
24981	.0702815	1.3051594	.2739152	.9529862
24982	.3740508	.9838065	.1170908	.9808835
252	.0132160	1.4401668	.3588399	.8658342
25281	.0173216	1.4136123	.3585951	.8524043
25282	.0127241	1.3825897	.2879582	.9223911
254	.1372268	1.2377548	.3416150	.9549253
25481	.1431749	1.2425518	.3399717	.9562108
25482	.1454119	1.1358226	.2506823	.9659697
359	.0425531	1.5643615	.3665608	.9631371
35981	.0425531	1.5643615	.3665608	.9631371
444	.0177114	1.8472971	.4066572	.9567327
44481	.0177114	1.8472971	.4066572	.9567327

* THE THREE-DIGIT STATION CODE IDENTIFIES THE LINE WITH THE STATION'S PERIOD OF RECORD STATISTICS; THE FIVE-DIGIT STATION CODE INDICATES THE APPROPRIATE WATER YEAR STATISTICS (I.E. 10181 REPRESENTS STATION 101, WATER YEAR 1981)

** THE GENERAL FORM OF THE REGRESSION EQUATION IS:
QS=COEFFICIENT*QW**SLOPE

APPENDIX C. CALCULATED AND MEASURED ANNUAL LOADS AND YIELDS FOR ALL STATIONS (EXCEPT IL AND MISSISSIPPI RIVER MAIN STEMS)

STATION CODE*	TYPE**	ANNUAL LOAD (TONS)	ANNUAL (TONS/SQ MI)	YIELD (TONS/ACRE)
101.81	ARE	81260.	393.	.61
	POR	57697.	279.	.44
101.82	ARE	66744.	322.	.50
	POR	86161.	416.	.65
102.82	ARE	303485.	229.	.36
	POR	310868.	234.	.37
103.81	ARE	526405.	83.	.13
	POR	509419.	80.	.13
103.82	ARE	543643.	85.	.13
	POR	623680.	98.	.15
104.81	ARE	33136.	62.	.10
	POR	36225.	67.	.11
104.82	ARE	54160.	101.	.16
	POR	52244.	97.	.15
105.80	ARE	108693.	99.	.15
	POR	94050.	86.	.13
	MEAS	144785.	132.	.21
105.81	ARE	62685.	57.	.09
	POR	69756.	63.	.10
	MEAS	91755.	83.	.13
106.81	ARE	45651.	118.	.18
	POR	44977.	116.	.18
106.82	ARE	55169.	143.	.22
	POR	60747.	157.	.25
108.81	ARE	21079.	59.	.09
	POR	21079.	59.	.09
109.80	ARE	32492.	52.	.08
	POR	29218.	46.	.07
	MEAS	37629.	60.	.09
109.81	ARE	30059.	48.	.07
	POR	27860.	44.	.07
	MEAS	34886.	55.	.09

APPENDIX C. CONTINUED

STATION CODE*	TYPE**	ANNUAL LOAD (TONS)	ANNUAL (TONS/SQ MI)	YIELD (TONS/ACRE)
109.82	ARE	43122.	68.	.11
	POR	43298.	69.	.11
	MEAS	42360.	67.	.11
110.81	ARE	6010.	116.	.18
	POR	5502.	106.	.17
110.82	ARE	4706.	91.	.14
	POR	5220.	101.	.16
111.80	ARE	7221.	93.	.15
	POR	8257.	106.	.17
	MEAS	9248.	119.	.19
111.81	ARE	6567.	85.	.13
	POR	5545.	71.	.11
	MEAS	13222.	170.	.27
112.81	ARE	59521.	408.	.64
	POR	41071.	281.	.44
113.81	ARE	682997.	72.	.11
	POR	727807.	76.	.12
	MEAS	885856.	93.	.14
113.82	ARE	1545079.	162.	.25
	POR	1481589.	155.	.24
	MEAS	1642588.	172.	.27
115.81	ARE	45402.	424.	.66
	POR	45402.	424.	.66
116.81	ARE	79079.	244.	.38
	POR	79079.	244.	.38
117.81	ARE	194501.	74.	.12
	POR	194501.	74.	.12
118.81	ARE	104778.	535.	.84
	POR	94754.	483.	.76
118.82	ARE	76804.	392.	.61
	POR	111735.	570.	.89
119.79	ARE	693555.	691.	1.08
	POR	743436.	741.	1.16
	MEAS	766286.	764.	1.19

APPENDIX C. CONTINUED

STATION CODE*	TYPE**	ANNUAL LOAD (TONS)	ANNUAL (TONS/SQ MI)	YIELD (TONS/ACRE)
119.80	ARE	134751.	134.	.21
	POR	107625.	107.	.17
	MEAS	196507.	196.	.31
119.81	ARE	386609.	385.	.60
	POR	280754.	280.	.44
	MEAS	568555.	567.	.89
120.80	ARE	182936.	411.	.64
	POR	147030.	330.	.52
	MEAS	313403.	704.	1.10
120.81	ARE	1496897.	3364.	5.26
	POR	440176.	989.	1.55
	MEAS	552742.	1242.	1.94
121.81	ARE	256597.	1655.	2.59
	POR	122837.	792.	1.24
121.82	ARE	104255.	673.	1.05
	POR	186562.	1204.	1.88
122.81	ARE	680835.	544.	.85
	POR	499977.	400.	.62
	MEAS	893028.	714.	1.12
123.81	ARE	138670.	305.	.48
	POR	132210.	291.	.45
123.82	ARE	134289.	295.	.46
	POR	178095.	391.	.61
124.79	ARE	611233.	119.	.19
	POR	561548.	109.	.17
	MEAS	932767.	181.	.28
124.80	ARE	322262.	63.	.10
	POR	295184.	57.	.09
	MEAS	678084.	132.	.21
124.81	ARE	945868.	184.	.29
	POR	579597.	113.	.18
	MEAS	1365482.	265.	.41
124.82	ARE	491380.	95.	.15
	POR	730819.	142.	.22
	MEAS	785748.	153.	.24

APPENDIX C. CONTINUED

STATION CODE*	TYPE**	ANNUAL LOAD (TONS)	ANNUAL (TONS/SQ MI)	YIELD (TONS/ACRE)
125.79	ARE	101505.	44.	.07
	POR	131698.	57.	.09
	MEAS	157708.	69.	.11
125.80	ARE	95811.	42.	.07
	POR	87695.	38.	.06
	MEAS	121280.	53.	.08
125.81	ARE	177564.	77.	.12
	POR	172561.	75.	.12
	MEAS	326491.	142.	.22
125.82	ARE	232142.	101.	.16
	POR	187005.	82.	.13
126.81	ARE	134769.	2149.	3.36
	POR	134769.	2149.	3.36
	MEAS	138840.	2214.	3.46
127.81	ARE	363896.	1989.	3.11
	POR	351745.	1922.	3.00
203.80	ARE	17.	7.	.01
	POR	17.	7.	.01
	MEAS	36.	15.	.02
203.81	ARE	48.	20.	.03
	POR	39.	16.	.03
	MEAS	2449.	1004.	1.57
204.80	ARE	26.	9.	.01
	POR	23.	8.	.01
	MEAS	65.	23.	.04
204.81	ARE	93.	33.	.05
	POR	65.	23.	.04
	MEAS	2814.	1001.	1.56
228.79	ARE	264053.	611.	.96
	POR	368985.	854.	1.33
	MEAS	379096.	878.	1.37
228.80	ARE	300446.	695.	1.09
	POR	211069.	489.	.76
	MEAS	268805.	622.	.97

APPENDIX C. CONTINUED

STATION CODE*	TYPE**	ANNUAL LOAD (TONS)	ANNUAL (TONS/SQ MI)	YIELD (TONS/ACRE)
228.81	ARE	654655.	1515.	2.37
	POR	159753.	370.	.58
	MEAS	385798.	893.	1.40
229.81	ARE	935962.	881.	1.38
	POR	908924.	856.	1.34
229.82	ARE	970001.	913.	1.43
	POR	1586059.	1493.	2.33
230.81	ARE	3462.	114.	.18
	POR	3216.	105.	.16
231.81	ARE	131362.	238.	.37
	POR	124289.	226.	.35
232.79	ARE	453789.	217.	.34
	POR	387501.	185.	.29
	MEAS	558533.	267.	.42
232.80	ARE	134754.	64.	.10
	POR	221863.	106.	.17
	MEAS	364410.	174.	.27
232.81	ARE	399348.	191.	.30
	POR	288029.	138.	.22
	MEAS	425707.	204.	.32
232.82	ARE	435750.	208.	.33
	POR	548730.	262.	.41
233.79	ARE	78581.	115.	.18
	POR	63103.	92.	.14
	MEAS	93130.	136.	.21
233.80	ARE	30857.	45.	.07
	POR	52179.	76.	.12
	MEAS	68666.	100.	.16
233.81	ARE	73709.	107.	.17
	POR	60776.	89.	.14
233.82	ARE	78191.	114.	.18
	POR	94053.	137.	.21
234.81	ARE	89251.	200.	.31
	POR	89251.	200.	.31

STATION CODE*	TYPE**	ANNUAL LOAD (TONS)	ANNUAL (TONS/SQ MI)	YIELD (TONS/ACRE)
235.81	ARE	20513.	419.	.65
	POR	20513.	419.	.65
236.81	ARE	528727.	681.	1.06
	POR	509130.	656.	1.03
238.76	ARE	5062.	181.	.28
	POR	3411.	122.	.19
	MEAS	15531.	555.	.87
238.77	ARE	8469.	302.	.47
	POR	2736.	98.	.15
	MEAS	11866.	424.	.66
238.78	ARE	4544.	162.	.25
	POR	5104.	182.	.28
	MEAS	10598.	379.	.59
238.79	ARE	2962.	106.	.17
	POR	5789.	207.	.32
	MEAS	9571.	342.	.53
238.80	ARE	7609.	272.	.42
	POR	3922.	140.	.22
	MEAS	14407.	515.	.80
239.76	ARE	10930.	265.	.41
	POR	6976.	169.	.26
	MEAS	24912.	605.	.94
239.77	ARE	11418.	277.	.43
	POR	6775.	164.	.26
	MEAS	25408.	617.	.96
239.78	ARE	12619.	306.	.48
	POR	13378.	325.	.51
	MEAS	18551.	450.	.70
239.79	ARE	10023.	243.	.38
	POR	14384.	349.	.55
	MEAS	15141.	367.	.57
239.80	ARE	15129.	367.	.57
	POR	11731.	285.	.44
	MEAS	18655.	453.	.71

APPENDIX C. CONTINUED

STATION CODE*	TYPE**	ANNUAL LOAD (TONS)	ANNUAL (TONS/SQ MI)	YIELD (TONS/ACRE)
239.81	ARE	16124.	391.	.61
	POR	8748.	212.	.33
	MEAS	21090.	512.	.80
239.82	ARE	16725.	406.	.63
	POR	19277.	468.	.73
	MEAS	23709.	575.	.90
240.76	ARE	434.	61.	.10
	POR	439.	62.	.10
	MEAS	779.	109.	.17
240.77	ARE	365.	51.	.08
	POR	196.	27.	.04
	MEAS	736.	103.	.16
240.78	ARE	782.	110.	.17
	POR	613.	86.	.13
	MEAS	1006.	141.	.22
240.79	ARE	642.	90.	.14
	POR	563.	79.	.12
	MEAS	995.	140.	.22
240.80	ARE	329.	46.	.07
	POR	244.	34.	.05
	MEAS	442.	62.	.10
241.81	ARE	2166963.	1325.	2.07
	POR	2166963.	1325.	2.07
	MEAS	2049265.	1253.	1.96
242.81	ARE	692277.	1057.	1.65
	POR	706875.	1079.	1.69
242.82	ARE	433922.	662.	1.04
	POR	506088.	773.	1.21
243.81	ARE	684866.	1962.	3.07
	POR	678116.	1943.	3.04
244.81	ARE	31294.	689.	1.08
	POR	31294.	689.	1.08
	MEAS	80041.	1763.	2.75
245.81	ARE	2050724.	1586.	2.48
	POR	2050724.	1586.	2.48
	MEAS	1771914.	1370.	2.14

APPENDIX C. CONCLUDED

STATION CODE*	TYPE**	ANNUAL LOAD (TONS)	ANNUAL (TONS/SQ MI)	YIELD (TONS/ACRE)
246.81	ARE	2713716.	533.	.83
	POR	2713716.	533.	.83
	MEAS	2815113.	553.	.86
247.81	ARE	1771546.	982.	1.53
	POR	1581632.	877.	1.37
247.82	ARE	954323.	529.	.83
	POR	1162739.	645.	1.01
248.81	ARE	60634.	171.	.27
	POR	58788.	166.	.26
248.82	ARE	27513.	78.	.12
	POR	60396.	170.	.27
249.81	ARE	145029.	264.	.41
	POR	108681.	198.	.31
249.82	ARE	72005.	131.	.20
	POR	105837.	192.	.30
254.81	ARE	159467.	183.	.29
	POR	147451.	169.	.26
254.82	ARE	169630.	195.	.30
	POR	360190.	414.	.65
359.81	ARE	950491.	1095.	1.71
	POR	950491.	1095.	1.71
444.81	ARE	14187.	400.	.62
	POR	14187.	400.	.62
	MEAS	37869.	1067.	1.67

* THE FIVE-DIGIT STATION CODE CONSISTS OF THE STATION NUMBER FOLLOWED BY A DECIMAL POINT AND THEN THE WATER YEAR

** THE TYPE CODES ARE AS FOLLOWS:
ARE = ANNUAL REGRESSION EQUATION
POR = PERIOD OF RECORD REGRESSION EQUATION
MEAS = MEASURED LOAD

STATION CODE	COEFFICIENT	SLOPE	STANDARD ERROR OF ESTIMATE	CORRELATION COEFFICIENT
19167	.33935817E-05	1.9743094	.2550751	.9098291
19168	.30820747E-08	2.6206800	.2167345	.9381009
19169	.10150979E-03	1.6753119	.3245522	.8206084
19170	.24876696E-07	2.4481672	.3092203	.8258594
19171	.29620722E-05	2.0081189	.2630191	.8705975
19172	.13730179E-07	2.4749391	.3419472	.8224823
19173	.30759740E-04	1.7798004	.3326991	.7941922
19174	.27451414E-08	2.6276828	.2378198	.9235985
19175	.13518593E-05	2.0578094	.2048892	.9393429
19176	.47074040E-05	1.9361554	.3000720	.8306709
19177	.97028841E-05	1.8743294	.2768566	.7458616
19178	.57055904E-09	2.7846186	.2351683	.8882213
19179	.78523914E-06	2.1176959	.2325073	.9112548
19180	.57446709E-06	2.1533757	.2443275	.8753413
19181	.81301307E-07	2.3219449	.1849265	.8831769
191	.12064149E-05	2.0698095	.2892662	.8875765
19100	.19081324E-08	2.1127407	.0536915	.9774424
19121	.34256184E-07	1.9729429	.0951130	.9526785
19122	.37558576E-07	1.9919596	.0665198	.9765482
19123	.41593331E-08	2.1478744	.1368879	.9158629
19131	.10044859E-07	2.1665511	.1697799	.9507493
19101	.32610727E-08	2.2355273	.1450171	.9104019
19102	.16030057E-10	2.6432331	.1250576	.9225650
19103	.18524217E-09	2.4594338	.2015324	.8863954
19104	.57938424E-05	1.7359698	.1019376	.9547399
19105	.73711716E-06	1.8558495	.0909379	.9764615
19106	.79322674E-10	2.5302842	.1448367	.9472972
19107	.86820908E-07	2.0267868	.0913111	.9774208
19108	.11351825E-06	1.9994146	.1220185	.9514802
19109	.16081333E-07	2.1455903	.1033647	.9672576
19110	.23024305E-06	1.9391520	.1304610	.9338290
19111	.11990721E-06	1.9699769	.1308357	.9373364
19112	.45236022E-05	1.6952961	.1774375	.8105580
29268	.86277497E-10	2.9466698	.2053218	.9198686
29269	.11607347E-06	2.2659398	.3896108	.7907353
29270	.61867178E-11	3.2198116	.2807527	.8938151
29271	.20946839E-06	2.2164173	.5281838	.6155165
29272	.59424177E-11	3.1585320	.4074778	.7882865
29273	.12553733E-04	1.8397274	.4204946	.7136306
29274	.89570438E-08	2.5034309	.4162006	.7719002
29275	.11054672E-08	2.6728561	.3440075	.8728357
29276	.10707708E-07	2.4769194	.4156891	.7967076
29277	.55910756E-07	2.3380927	.4438817	.4258628
29278	.55586403E-13	3.5542191	.3983037	.8007372
29279	.28948460E-06	2.1496544	.4813331	.6420168
29280	.18813495E-06	2.1919073	.4552412	.5889671
29281	.49985323E-03	1.5281631	.3499253	.6514084
292	.84281794E-07	2.3073548	.3174431	.8457348

APPENDIX D. CONCLUDED

STATION CODE	COEFFICIENT	SLOPE	STANDARD ERROR OF ESTIMATE	CORRELATION COEFFICIENT
29200	.99579645E-04	1.4753040	.1175272	.8534334
29221	.91941208E-07	1.8993759	.1068157	.9258196
29222	.37302978E-05	1.7034554	.1956597	.8316986
29223	.23619398E-07	2.0459393	.1459092	.8850544
29231	.40760830E-08	2.2150166	.3103325	.8282184
29201	.89615785E-09	2.2521056	.2876218	.7865884
29202	.16264100E-14	3.1990126	.3002325	.8113896
29203	.76798354E-06	1.8759338	.2840011	.7617127
29204	.17684135E-03	1.5095372	.1587708	.8864494
29205	.82054203E-06	1.8584396	.2 854511	.8134506
29206	.23354735E-09	2.4568474	.1785436	.9253882
29207	.14458702E-06	2.0084934	.2079536	.8921592
29208	.40371553E-08	2.2382790	.1247551	.9466342
29209	.25873556E-09	2.4291323	.1554380	.9211825
29210	.26673257E-09	2.4160838	.1174757	.9572456
29211	.96283724E-04	1.5131487	.1683524	.7838341
29212	.65802745E-03	1.3415532	.2370057	.5363882
29368	.68175658E-06	2.0852897	.1986796	.9188069
29369	.10025905E-07	2.4773870	.3580457	.8670099
29370	.12357803E-07	2.4934830	.3839405	.8207969
29371	.60111209E-08	2.5313496	.3889011	.8467486
29372	.28640707E-06	2.2040086	.2795046	.8578084
29373	.38419328E-07	2.3688486	.2659291	.9168335
29374	.16750935E-09	2.8650183	.3377690	.8853785
29375	.10215777E-07	2.4818884	.2437920	.9355729
29376	.61365337E-07	2.3100135	.3466237	.8926296
29377	.43614626E-03	1.4716163	.2838423	.7327065
29378	.13426959E-09	2.8741893	.3089773	.8914173
29379	.86341697E-09	2.6890487	.3982092	.8876945
29380	.17318995E-06	2.2484516	.2689122	.8518565
29381	.43838432E-08	2.5654747	.2469343	.8977375
293	.20400035E-07	2.4092200	.2821574	.9116508
29300	.28648597E-12	2.6272633	.0970478	.9663039
29321	.27655381E-07	1.9911704	.1036335	.9567754
29322	.19211781E-11	2.6064996	.0885149	.9827587
29323	.25277498E-11	2.5947529	.1758988	.9150439
29331	.24020774E-09	2.4138941	.2050233	.9471042
29301	.25531788E-11	2.7058932	.2931730	.8601406
29302	.52078981E-12	2.8478651	.2901763	.8433595
29303	.14806981E-10	2.6199547	.1444801	.9585012
29304	.18163518E-09	2.4300178	.0967659	.9801033
29305	.13946805E-09	2.4435101	.1627968	.9619060
29306	.28566457E-13	3.0355480	.1550196	.9668691
29307	.33948693E-09	2.3843488	.1679598	.9552889
29308	.17225890E-07	2.1067313	.1095154	.9639675
29309	.16617527E-06	1.9665784	.1551273	.9388564
29310	.79032306E-07	2.0157628	.1396731	.9510828
29311	.18162377E-05	1.7934739	.1412314	.9191896
29312	.49646886E-07	2.0390765	.1439000	.9092541

APPENDIX E. MEASURED AND CALCULATED LOADS
FOR THE MISSISSIPPI STATIONS

STATION: EAST DUBUQUE
ID: 191
DRAINAGE AREA: 81600. SQ. MILES

STATION CODE	TYPE	ANNUAL LOAD (TONS)	ANNUAL YIELD (TONS/SQ MI)	ANNUAL YIELD (TONS/ACRE)	TOTAL QW (CFS-DAYS)
19173	MEAS	7375086.	90.381	.141	26224600.
	ARE	6136413.	75.201	.118	
	POR	6960548.	85.301	.133	
	ALRE	9003610.	110.338	.172	
	SLRE	8218661.	100.719	.157	
	CMRE	8749533.	107.225	.168	
	1MRE	9253472.	113.400	.177	
19175	MEAS	4248893.	52.070	.081	18297600.
	ARE	401895 8.	49.252	.077	
	POR	4121676.	50.511	.079	
	ALRE	4208857.	51.579	.081	
	SLRE	4493198.	55.064	.086	
	CMRE	5032587.	61.674	.096	
	IMRE	4409820.	54.042	.084	
19177	MEAS	664201.	8.140	.013	7960060.
	ARE	560605.	6.870	.011	
	POR	517960.	6.348	.010	
	ALRE	725196.	8.887	.014	
	SLRE	766458.	9.393	.015	
	CMRE	589063.	7.219	.011	
	IMRE	698297.	8.558	.013	

APPENDIX E. CONTINUED

STATION: BURLINGTON
ID: 292
DRAINAGE AREA: **113600.** SQ. MILES

STATION CODE	TYPE	ANNUAL LOAD (TONS)	ANNUAL YIELD (TONS/SQ MI)	(TONS/ACRE)	TOTAL QW (CFS-DAYS)
29273	MEAS	18223924.	160.422	.251	45738220.
	ARE	13252890.	116.663	.182	
	POR	29286924.	257.807	.403	
	ALRE	19925591.	175.401	.274	
	SLRE	19996477.	176.025	.275	
	CMRE	24015240.	211.402	.330	
	IMRE	21843307.	192.283	.300	
29277	MEAS	266 8957.	23.494	.037	14724212.
	ARE	1283779.	11.301	.018	
	POR	1609625.	14.169	.022	
	ALRE	3742803.	32.947	.051	
	SLRE	2686836.	23.652	.037	
	CMRE	1549696.	13.642	.021	
	IMRE	2049608.	18.042	.028	
29278	MEAS	13402784.	117.982	.184	30792610.
	ARE	11323007.	99.674	.156	
	POR	9966250.	87.731	.137	
	ALRE	11114902.	97.842	.153	
	SLRE	11178661.	98.404	.154	
	CMRE	8667987.	76.303	.119	
	IMRE	10117832.	89.065	.139	

APPENDIX E. CONCLUDED

STATION: KEOKUK
ID: 293
DRAINAGE AREA: 119000. SQ. MILES

STATION CODE	TYPE	ANNUAL LOAD (TONS)	ANNUAL YIELD (TONS/SQ MI)	ANNUAL YIELD (TONS/ACRE)	TOTAL QW (CFS-DAYS)
29371	MEAS	8652215.	72.708	.114	26302400.
	ARE	7248096.	60.908	.095	
	POR	5919535.	49.744	.078	
	ALRE	8940975.	75.134	.117	
	SLRE	9110629.	76.560	.120	
	CMRE	8361751.	70.267	.110	
	IMRE	8818256.	74.103	.116	
29373	MEAS	28854935.	242.478	.379	43272000.
	ARE	23549354.	197.894	.309	
	POR	20448369.	171.835	.268	
	ALRE	33069656.	277.896	.434	
	SLRE	33558955.	282.008	.441	
	CMRE	29044970.	244.075	.381	
	IMRE	31866097.	267.782	.418	
29377	MEAS	859781.	7.225	.011	11090600.
	ARE	681989.	5.731	.009	
	POR	681477.	5.727	.009	
	ALRE	924816.	7.772	.012	
	SLRE	994145.	8.354	.013	
	CMRE	953006.	8.008	.013	
	IMRE	991168.	8.329	.013	

APPENDIX F. STATISTICAL PARAMETERS FOR THE SEASONAL REGRESSION EQUATIONS

STATION CODE	COEFFICIENT*	SLOPE*	STANDARD ERROR OF ESTIMATE	CORRELATION COEFFICIENT
10921**	.0003188	1.8902427	.2337015	.8987792
10922	.0002341	1.8964842	.2206782	.9525532
10923	.0002803	1.9517046	.1673304	.9670733
11921	.0024388	1.7007334	.1758392	.8736354
11922	.0006960	1.9885176	.2560008	.9436545
11923	.0027209	1.8278775	.2911734	.9011183
12421	.0577895	1.0086353	.2559687	.7354729
12422	.0000514	1.9139764	.3102011	.9214079
12423	.0003775	1.7737778	.2109199	.9471459
12521	.0086312	1.2760163	.1555637	.8287311
12522	.0006597	1.6595436	.2959415	.8281113
12523	.0175794	1.3015916	.2356825	.8182093
22821	.0237199	1.2851955	.3194083	.8095030
22822	.0019423	1.9886470	.3962842	.9346244
22823	.0043484	1.9274375	.3370152	.9324373
23221	.2300890	.7558020	.2642699	.6893223
23222	.0037678	1.5276135	.2863459	.9443907
23223	.0242354	1.4075784	.1737014	.9748337
23321	.0279649	1.2116589	.4325033	.7685393
23322	.0591493	1.1744677	.3355796	.8746710
23323	.1803176	1.1516357	.1822349	.9562934
23821	.0173029	1.6764543	.3811329	.8096222
23822	.0102793	1.8971165	.3909557	.8975555
23823	.0453640	1.6506840	.3149173	.8820062
23921	.0061882	1.9424207	.3799779	.8347709
23922	.0043604	2.0968198	.4027700	.9110660
23923	.0174784	1.8492504	.3284137	.9068064
24021	.1570540	1.0047872	.3812188	.6929277
24022	.1057710	1.4233298	.3595278	.8858484
24023	.2850175	1.1727452	.2956117	.8653247

* THE GENERAL FORM OF THE REGRESSION EQUATION IS:
QS=COEFFICIENT*QW**SLOPE

** THE TWO DIGIT SUFFIX ON THE STATION CODE REFERS TO THE SEASON:
21=0CT0BER-JANUARY; 22=FEBRUARY-MAY; 23=JUNE-SEPTEMBER

APPENDIX G. CALCULATED AND MEASURED SEASONAL LOADS FOR ALL STATIONS (EXCLUDING THE ILLINOIS AND MISSISSIPPI RIVER MAIN STEMS)

STATION CODE*	TYPE**	OCTOBER-JANUARY (TONS)	(%)	FEBRUARY-MAY (TONS)	(%)	JUNE-SEPTEMBER (TONS)	(%)
101.81	ARE	3239.	4.0	18025.	22.2	59995.	73.8
	POR	3094.	5.4	13383.	23.2	41220.	71.4
101.82	ARE	21209.	31.8	39313.	58.9	6222.	9.3
	POR	27278.	31.7	52214.	60.6	6668.	7.7
102.82	ARE	87988.	29.0	120780.	39.8	94717.	31.2
	POR	78654.	25.3	144150.	46.4	88064.	28.3
103.81	ARE	178469.	33.9	185901.	35.3	162035.	30.8
	POR	172743.	33.9	179125.	35.2	157551.	30.9
103.82	ARE	150127.	27.6	231093.	42.5	162423.	29.9
	POR	181730.	29.1	248841.	39.9	193109.	31.0
104.81	ARE	10918.	33.0	11468.	34.6	10750.	32.4
	POR	11983.	33.1	12567.	34.7	11676.	32.2
104.82	ARE	11384.	21.0	28199.	52.1	14577.	26.9
	POR	9758.	18.7	28998.	55.5	13488.	25.8
105.80	ARE	10169.	9.4	26672.	24.5	71852.	66.1
	POR	9794.	10.4	24032.	25.6	60224.	64.0
	MEAS	18569.	12.8	27590.	19.1	98626.	68.1
105.81	ARE	18952.	30.2	21728.	34.7	22005.	35.1
	POR	21003.	30.1	24114.	34.6	24638.	35.3
	MEAS	16337.	17.8	26826.	29.2	48592.	53.0
106.81	ARE	12100.	26.5	14594.	32.0	18958.	41.5
	POR	11919.	26.5	14377.	32.0	18681.	41.5
106.82	ARE	5693.	10.3	31459.	57.0	18017.	32.7
	POR	6200.	10.2	34691.	57.1	19856.	32.7
108.81	ARE	5841.	27.7	8817.	41.8	6421.	30.5
	POR	5841.	27.7	8817.	41.8	6421.	30.5
109.80	SRE	3408.		8324.		21266.	
	ARE	3689.	11.4	11804.	36.3	16999.	52.3
	POR	3369.	11.5	10601.	36.3	15248.	52.2
	MEAS	5158.	13.7	10025.	26.6	22446.	59.7
109.81	SRE	5248.		9692.		14189.	
	ARE	5338.	17.8	13560.	45.1	11161.	37.1
	POR	5195.	18.6	12358.	44.4	10307.	37.0
	MEAS	4710.	13.5	14859.	42.6	15316.	43.9

STATION CODE*	TYPE**	OCTOBER-JANUARY (TONS)	(%)	FEBRUARY-MAY (TONS)	(%)	JUNE-SEPTEMBER (TONS)	(%)
109.82	SRE	4379.		22270.		15849.	
	ARE	4200.	9.7	27931.	64.8	10991.	25.5
	POR	4366.	10.1	27909.	64.5	11022.	25.5
	MEAS	5687.	13.4	20570.	48.6	16102.	38.0
110.81	ARE	1341.	22.3	2049.	34.1	2620.	43.6
	POR	1402.	25.5	1952.	35.5	2148.	39.0
110.82	ARE	813.	17.3	3042.	64.6	851.	18.1
	POR	740.	14.2	3657.	70.1	823.	15.8
111.80	ARE	433.	6.0	1745.	24.2	5043.	69.8
	POR	432.	5.2	1899.	23.0	5927.	71.8
	MEAS	407.	4.4	3171.	34.3	5670.	61.3
111.81	ARE	1151.	17.5	2601.	39.6	2815.	42.9
	POR	1078.	19.4	2251.	40.6	2215.	40.0
	MEAS	833.	6.3	4622.	35.0	7768.	58.8
112.81	ARE	3271.	5.5	12983.	21.8	43268.	72.7
	POR	3145.	7.7	9696.	23.6	28231.	68.7
113.81	ARE	194765.	28.5	266415.	39.0	221817.	32.5
	POR	212059.	29.1	280685.	38.6	235063.	32.3
	MEAS	138918.	15.7	282503.	31.9	464435.	52.4
113.82	ARE	255883.	16.6	965484.	62.5	323712.	21.0
	POR	265969.	18.0	886870.	59.9	328751.	22.2
	MEAS	270095.	16.4	897780.	54.7	474713.	28.9
115.81	ARE	2222.	4.9	8790.	19.4	34390.	75.7
	POR	2222.	4.9	8790.	19.4	34390.	75.7
116.81	ARE	6836.	8.6	21783.	27.5	50459.	63.8
	POR	6836.	8.6	21783.	27.5	50459.	63.8
117.81	ARE	45103.	23.2	76503.	39.3	72895.	37.5
	POR	45103.	23.2	76503.	39.3	72895.	37.5
118.81	ARE	1646.	1.6	26330.	25.1	76802.	73.3
	POR	1620.	1.7	24477.	25.8	68656.	72.5
118.82	ARE	4907.	6.4	30556.	39.8	41341.	53.8
	POR	6057.	5.4	43391.	38.8	62287.	55.7
119.79	SRE	6285.		524408.		168912.	
	ARE	7682.	1.1	523962.	75.5	161910.	23.3
	POR	10060.	1.4	559033.	75.2	174343.	23.5
	MEAS	6970.	.9	603089.	78.7	156227.	20.4

STATION CODE*	TYPE**	OCTOBER-JANUARY (TONS)	(%)	FEBRUARY-MAY (TONS)	(%)	JUNE-SEPTEMBER (TONS)	(%)
119.80	SRE	8857.		47444.		51940.	
	ARE	21814.	16.2	61039.	45.3	51899.	38.5
	POR	17355.	16.1	48799.	45.3	41471.	38.5
	MEAS	21890.	11.1	81853.	41.7	92764.	47.2
119.81	SRE	9654.		77936.		190134.	
	ARE	18315.	4.7	107655.	27.8	260639.	67.4
	POR	17532.	6.2	81246.	28.9	181977.	64.8
	MEAS	10010.	1.8	239566.	42.1	318979.	56.1
120.80	ARE	992.	.5	65770.	36.0	116174.	63.5
	POR	562.	.4	50681.	34.5	95787.	65.1
	MEAS	1383.	.4	110576.	35.3	201444.	64.3
120.81	ARE	15192.	1.0	774352.	51.7	707354.	47.3
	POR	13294.	3.0	197370.	44.8	229512.	52.1
	MEAS	12419.	2.2	244517.	44.2	295806.	53.5
121.81	ARE	10127.	3.9	108090.	42.1	138380.	53.9
	POR	7223.	5.9	49415.	40.2	66198.	53.9
121.82	ARE	3695.	3.5	43637.	41.9	56924.	54.6
	POR	3447.	1.8	70580.	37.8	112535.	60.3
122.81	ARE	5028.	.7	380028.	55.8	295780.	43.4
	POR	5648.	1.1	276248.	55.3	218082.	43.6
	MEAS	8244.	.9	348264.	39.0	536520.	60.1
123.81	ARE	12999.	9.4	73153.	52.8	52518.	37.9
	POR	12761.	9.7	69698.	52.7	49751.	37.6
123.82	ARE	19949.	14.9	107261.	79.9	7080.	5.3
	POR	21917.	12.3	149113.	83.7	7065.	4.0
124.79	SRE	8801.		556265.		87029.	
	ARE	9767.	1.6	546934.	89.5	54531.	8.9
	POR	8944.	1.6	502588.	89.5	50017.	8.9
	MEAS	8295.	.9	772929.	82.9	151543.	16.2
124.80	SRE	16521.		131423.		231375.	
	ARE	32852.	10.2	160823.	49.9	128586.	39.9
	POR	27980.	9.5	146790.	49.7	120415.	40.8
	MEAS	25061.	3.7	148357.	21.9	504666.	74.4
124.81	SRE	16926.		338435.		437522.	
	ARE	26176.	2.8	570210.	60.3	349482.	36.9
	POR	29192.	5.0	319417.	55.1	230989.	39.9
	MEAS	19095.	1.4	690180.	50.5	656207.	48.1

APPENDIX G. CONTINUED

STATION CODE*	TYPE**	OCTOBER-JANUARY (TONS)	(%)	FEBRUARY-MAY (TONS)	(%)	JUNE-SEPTEMBER (TONS)	(%)
124.82	SRE	34174.		653010.		109293.	
	ARE	68082.	13.9	375700.	76.5	47598.	9.7
	POR	88385.	12.1	580589.	79.4	61846.	8.5
	MEAS	46794.	6.0	653469.	83.2	85485.	10.9
125.79	SRE	6396.		109052.		21243.	
	ARE	8363.	8.2	81400.	80.2	11741.	11.6
	POR	9113.	6.9	109354.	83.0	13232.	10.0
	MEAS	6298.	4.0	129463.	82.1	21947.	13.9
125.80	SRE	11506.		41586.		33455.	
	ARE	20973.	21.9	49501.	51.7	25338.	26.4
	POR	18557.	21.2	46304.	52.8	22834.	26.0
	MEAS	14113.	11.6	62466.	51.5	44701.	36.9
125.81	SRE	12065.		72762.		95494.	
	ARE	14722.	8.3	81239.	45.8	81603.	46.0
	POR	19716.	11.4	76319.	44.2	76526.	44.3
	MEAS	11357.	3.5	135114.	41.4	180020.	55.1
125.82	SRE	21338.		128359.		32588.	
	ARE	57312.	24.7	137992.	59.4	36837.	15.9
	POR	37648.	20.1	127452.	68.2	21906.	11.7
126.81	ARE	1432.	1.1	36676.	27.2	96661.	71.7
	POR	1432.	1.1	36676.	27.2	96661.	71.7
	MEAS	1001.	.7	53760.	38.7	84080.	60.6
127.81	ARE	9799.	2.7	188977.	51.9	165120.	45.4
	POR	9494.	2.7	182575.	51.9	159677.	45.4
203.80	ARE	3.	19.3	7.	41.7	6.	39.0
	POR	3.	18.8	7.	42.0	7.	39.2
	MEAS	1.	4.0	9.	26.6	25.	69.4
203.81	ARE	4.	8.7	16.	34.4	27.	56.9
	POR	5.	12.0	15.	39.1	19.	48.9
	MEAS	5.	.2	84.	3.4	2359.	96.3
204.80	ARE	5.	19.8	11.	42.8	10.	37.4
	POR	4.	19.2	10.	43.3	9.	37.5
	MEAS	6.	9.4	12.	18.4	47.	72.2
204.81	ARE	5.	5.1	24.	25.5	64.	69.4
	POR	6.	9.0	22.	33.5	37.	57.5
	MEAS	7.	.3	104.	3.7	2702.	96.0

APPENDIX G. CONTINUED

STATION CODE*	TYPE**	OCTOBER-JANUARY (TONS)	(%)	FEBRUARY-MAY (TONS)	(%)	JUNE-SEPTEMBER (TONS)	(%)
228.79	SRE	716.		368862.		9814.	
	ARE	1878.	.7	255646.	96.8	6530.	2.5
	POR	1489.	.4	361033.	97.8	6464.	1.8
	MEAS	1679.	.4	354410.	93.5	23007.	6.1
228.80	SRE	328.		22759.		265816.	
	ARE	643.	.2	31874.	10.6	267929.	89.2
	POR	488.	.2	22860.	10.8	187721.	88.9
	MEAS	495.	.2	68094.	25.3	200216.	74.5
228.81	SRE	3004.		84296.		77481.	
	ARE	75215.	11.5	384768.	58.8	194671.	29.7
	POR	23127.	14.5	83539.	52.3	53087.	33.2
	MEAS	21329.	5.5	181316.	47.0	183154.	47.5
229.81	ARE	32120.	3.4	390120.	41.7	513722.	54.9
	POR	31393.	3.5	378822.	41.7	498709.	54.9
229.82	ARE	13654.	1.4	607771.	62.7	348575.	35.9
	POR	13943.	.9	985978.	62.2	586138.	37.0
230.81	ARE	111.	3.2	1489.	43.0	1862.	53.8
	POR	138.	4.3	1405.	43.7	1673.	52.0
231.81	ARE	438.	.3	73369.	55.9	57555.	43.8
	POR	536.	.4	68948.	55.5	54805.	44.1
232.79	SRE	1411.		282747.		100999.	
	ARE	2336.	.5	391415.	86.3	60038.	13.2
	POR	2235.	.6	332361.	85.8	52905.	13.7
	MEAS	1666.	.3	408817.	73.2	148050.	26.5
232.80	SRE	2816.		84316.		190653.	
	ARE	8776.	6.5	67492.	50.1	58487.	43.4
	POR	10359.	4.7	105688.	47.6	105815.	47.7
	MEAS	3789.	1.0	81281.	22.3	279340.	76.7
232.81	SRE	2348.		145177.		198528.	
	ARE	6117.	1.5	260937.	65.3	132293.	33.1
	POR	7490.	2.6	175436.	60.9	105103.	36.5
	MEAS	3314.	.8	193338.	45.4	229056.	53.8
232.82	SRE	7276.		375991.		84431.	
	ARE	78528.	18.0	304090.	69.8	53133.	12.2
	POR	65828.	12.0	438607.	79.9	44295.	8.1

APPENDIX G. CONTINUED

STATION CODE*	TYPE**	OCTOBER-JANUARY (TONS)	(%)	FEBRUARY-MAY (TONS)	(%)	JUNE-SEPTEMBER (TONS)	(%)
233.79	SRE	451.		37627.		19489.	
	ARE	716.	.9	67636.	86.1	10228.	13.0
	POR	983.	1.6	52376.	83.0	9744.	15.4
	MEAS	409.	.4	61857.	66.4	30864.	33.1
233.80	SRE	2785.		20445.		34161.	
	ARE	4100.	13.3	16331.	52.9	10426.	33.8
	POR	6104.	11.7	27790.	53.3	18285.	35.0
	MEAS	1970.	2.9	20410.	29.7	46286.	67.4
233.81	SRE	2195.		25483.		40153.	
	ARE	8808.	11.9	38550.	52.3	26351.	35.7
	POR	4803.	7.9	35151.	57.8	20822.	34.3
233.82	SRE	6140.		51951.		14702.	
	ARE	16967.	21.7	51817.	66.3	9407.	12.0
	POR	13484.	14.3	73104.	77.7	7465.	7.9
234.81	ARE	520.	.6	45914.	51.4	42816.	48.0
	POR	520.	.6	45914.	51.4	42816.	48.0
235.81	ARE	172.	.8	7634.	37.2	12707.	61.9
	POR	172.	.8	7634.	37.2	12707.	61.9
236.81	ARE	3148.	.6	201946.	38.2	323632.	61.2
	POR	3410.	.7	195372.	38.4	310347.	61.0
238.76	SRE	300.		2361.		1390.	
	ARE	730.	14.4	3117.	61.6	1215.	24.0
	POR	431.	12.6	2092.	61.3	887.	26.0
	MEAS	1553.	10.0	9085.	58.5	4893.	31.5
238.77	SRE	55.		1063.		2699.	
	ARE	160.	1.9	2715.	32.1	5594.	66.1
	POR	79.	2.9	935.	34.2	1722.	63.0
	MEAS	145.	1.2	4585.	38.6	7135.	60.1
238.78	SRE	869.		4194.		849.	
	ARE	1009.	22.2	3105.	68.3	430.	9.5
	POR	1260.	24.7	3320.	65.1	524.	10.3
	MEAS	1569.	14.8	8083.	76.3	947.	8.9
238.79	SRE	107.		7330.		190.	
	ARE	102.	3.5	2787.	94.1	73.	2.5
	POR	153.	2.6	5525.	95.4	110.	1.9
	MEAS	74.	.8	9356.	97.8	141.	1.5

APPENDIX G. CONTINUED

STATION CODE*	TYPE**	OCTOBER-JANUARY (TONS)	(%)	FEBRUARY-MAY (TONS)	(%)	JUNE-SEPTEMBER (TONS)	(%)
238.80	SRE	59.		476.		5118.	
	ARE	59.	.8	545.	7.2	7005.	92.1
	POR	84.	2.1	505.	12.9	3334.	85.0
	MEAS	57.	.4	625.	4.3	13725.	95.3
239.76	SRE	683.		5256.		1111.	
	ARE	1594.	14.6	7907.	72.3	1428.	13.1
	POR	984.	14.1	5076.	72.8	916.	13.1
	MEAS	5016.	20.1	14706.	59.0	5190.	20.8
239.77	SRE	74.		2858.		4551.	
	ARE	192.	1.7	4515.	39.5	6711.	58.8
	POR	100.	1.5	2668.	39.4	4007.	59.1
	MEAS	356.	1.4	11149.	43.9	13903.	54.7
239.78	SRE	2352.		9305.		1566.	
	ARE	3046.	24.1	8348.	66.1	1226.	9.7
	POR	3460.	25.9	8610.	64.4	1308.	9.8
	MEAS	2414.	13.0	13832.	74.6	2305.	12.4
239.79	SRE	154.		15579.		310.	
	ARE	184.	1.8	9663.	96.4	175.	1.8
	POR	211.	1.5	13962.	97.1	211.	1.5
	MEAS	120.	.8	14169.	93.6	852.	5.6
239.80	SRE	57.		976.		10928.	
	ARE	69.	.5	1095.	7.2	13965.	92.3
	POR	77.	.7	1021.	8.7	10633.	90.6
	MEAS	64.	.3	1563.	8.4	17028.	91.3
239.81	SRE	150.		3037.		6455.	
	ARE	201.	1.2	4873.	30.2	11050.	68.5
	POR	208.	2.4	3036.	34.7	5503.	62.9
	MEAS	133.	.6	8177.	38.8	12780.	60.6
239.82	SRE	128.		18850.		3345.	
	ARE	127.	.8	14350.	85.8	2248.	13.4
	POR	175.	.9	16374.	84.9	2728.	14.2
	MEAS	107.	.4	16439.	69.3	7163.	30.2
240.76	SRE	51.		368.		63.	
	ARE	80.	18.5	307.	70.6	47.	10.9
	POR	73.	16.7	325.	74.0	41.	9.3
	MEAS	123.	15.7	568.	73.0	88.	11.3

STATION CODE*	TYPE**	OCTOBER-JANUARY (TONS)	(%)	FEBRUARY-MAY (TONS)	(%)	JUNE-SEPTEMBER (TONS)	(%)
240.77	SRE	11.		99.		144.	
	ARE	24.	6.4	170.	46.4	172.	47.1
	POR	12.	6.0	91.	46.7	93.	47.3
	MEAS	22.	3.0	383.	52.1	330.	44.9
240.78	SRE	88.		427.		168.	
	ARE	164.	20.9	504.	64.5	114.	14.6
	POR	144.	23.4	361.	58.9	108.	17.7
	MEAS	178.	17.6	626.	62.2	203.	20.2
240.79	SRE	61.		487.		102.	
	ARE	63.	9.9	527.	82.0	52.	8.1
	POR	88.	15.6	409.	72.6	66.	11.7
	MEAS	61.	6.2	841.	84.5	92.	9.3
240.80	SRE	25.		85.		176.	
	ARE	24.	7.4	114.	34.8	190.	57.8
	POR	32.	13.2	98.	40.3	113.	46.4
	MEAS	40.	9.2	115.	26.1	286.	64.7
241.81	ARE	36260.	1.7	724327.	33.4	1406376.	64.9
	POR	36260.	1.7	724327.	33.4	1406376.	64.9
	MEAS	28350.	1.4	886731.	43.3	1134184.	55.3
242.81	ARE	8025.	1.2	199700.	28.8	484553.	70.0
	POR	7027.	1.0	198876.	28.1	500971.	70.9
242.82	ARE	20028.	4.6	331120.	76.3	82774.	19.1
	POR	28781.	5.7	373977.	73.9	103329.	20.4
243.81	ARE	17082.	2.5	180276.	26.3	487507.	71.2
	POR	16932.	2.5	178519.	26.3	482665.	71.2
244.81	ARE	150.	.5	18456.	59.0	12688.	40.5
	POR	150.	.5	18456.	59.0	12688.	40.5
	MEAS	269.	.3	38960.	48.7	40812.	51.0
245.81	ARE	23962.	1.2	713751.	34.8	1313010.	64.0
	POR	23962.	1.2	713751.	34.8	1313010.	64.0
	MEAS	26834.	1.5	556075.	31.4	1189005.	67.1
246.81	ARE	3275.	.1	718497.	26.5	1991944.	73.4
	POR	3275.	.1	718497.	26.5	1991944.	73.4
	MEAS	3382.	.1	834592.	29.6	1977139.	70.2
247.81	ARE	3957.	.2	388533.	21.9	1379056.	77.8
	POR	4512.	.3	359119.	22.7	1218000.	77.0

APPENDIX G. CONCLUDED

STATION CODE*	TYPE**	OCTOBER-JANUARY (TONS)	(%)	FEBRUARY-MAY (TONS)	(%)	JUNE-SEPTEMBER (TONS)	(%)
247.82	ARE	43850.	4.6	786771.	82.4	123701.	13.0
	POR	43786.	3.8	981778.	84.4	137175.	11.8
248.81	ARE	401.	.7	16766.	27.7	43468.	71.7
	POR	345.	.6	16047.	27.3	42396.	72.1
248.82	ARE	2702.	9.8	21996.	79.9	2815.	10.2
	POR	4272.	7.1	51114.	84.6	5009.	8.3
249.81	ARE	798.	.6	58355.	40.2	85876.	59.2
	POR	977.	.9	43711.	40.2	63994.	58.9
249.82	ARE	13785.	19.1	50259.	69.8	7960.	11.1
	POR	16721.	15.8	79269.	74.9	9847.	9.3
254.81	ARE	258.	.2	58866.	36.9	100343.	62.9
	POR	244.	.2	54367.	36.9	92840.	63.0
254.82	ARE	14229.	8.4	111389.	65.7	44012.	25.9
	POR	25989.	7.2	242933.	67.4	91268.	25.3
359.81	ARE	80.	.0	109835.	11.6	840576.	88.4
	POR	80.	.0	109835.	11.6	840576.	88.4
444.81	ARE	162.	1.1	8196.	57.8	5830.	41.1
	POR	162.	1.1	8196.	57.8	5830.	41.1
	MEAS	158.	.4	12760.	33.7	24950.	65.9

* THE FIVE-DIGIT STATION CODE CONSISTS OF THE STATION NUMBER FOLLOWED BY A DECIMAL POINT AND THEN THE WATER YEAR

** THE TYPE CODES ARE AS FOLLOWS:

- SRE = SEASONAL REGRESSION EQUATION
- ARE = ANNUAL REGRESSION EQUATION
- POR = PERIOD OF RECORD REGRESSION EQUATION
- MEAS = MEASURED LOAD