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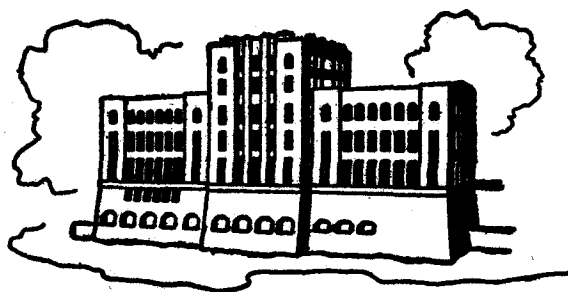
**ASSESSMENT OF AVAILABLE FIELD
SEDIMENTATION DATA FOR
GREAT-II WATERSHED**

by

Tatsuaki Nakato and John Vadnal

Submitted to

**GREAT-II Sediment and Erosion Work Group
U.S. Army Corps of Engineers
Rock Island District
Rock Island, Illinois**



IIHR Report No. 216

**Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa 52242**

November, 1978

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ABSTRACT

An inventory study concerning available stream sedimentation and flow data for the GREAT-II (Great River Environmental Action Team II) watershed was conducted for the Sediment and Erosion Work Group of GREAT-II. The study area covered the Upper Mississippi River and its tributaries between Guttenberg, Iowa, and Saverton, Missouri. These data were utilized to obtain rough estimates of annual sediment yields at individual sediment sampling stations by simply correlating monthly averaged suspended-sediment discharges with monthly averaged stream discharges. Based on these estimates, major sediment source areas were identified, and recommendations regarding installation of new sediment sampling stations for further base-line data were made. A review of some existing methodologies in estimating sediment yields also was made, and a plan of study to determine quantities of sediment delivered by tributary sources into the Mississippi River was proposed.

ACKNOWLEDGEMENTS

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ASSESSMENT OF AVAILABLE FIELD SEDIMENTATION DATA
FOR GREAT-II WATERSHED

I. INTRODUCTION

The sediment yield from any watershed is determined primarily by physiographical and climatic factors. However, sediment production can be significantly affected by human activities, such as agricultural practices, urbanization, road and highway construction, mining operations, etc. Therefore, increased sediment production will persist on the earth as long as human activities continue.

The major objective is to maintain balance, or harmony, between acceptable sediment yields and those human activities that affect soil and water resources. The processes of sediment entrainment and the eventual transportation into the ocean, are extremely complicated, and the controlling mechanisms in each phase of sediment movement from upland to lowland areas are quite different from each other.

Excessive sediment yields produce many problems: loss of invaluable topsoil from farm lands; degradation of water quality; reduction of lake and reservoir capacities; choking of navigation channels; degradation of fish and wildlife habitat; to mention just a few. The list of problems is nearly endless, and their close interrelationships make it very difficult to develop general solutions. However, the extreme gravity of the situation makes it important to develop such solutions.

The study reported herein was a part of the comprehensive investigation conducted by the Sediment and Erosion Work Group of GREAT-II (Great River Environmental Action Team II), which is concerned with the Upper Mississippi River and its tributaries between Guttenburg, Iowa, and Saverton, Missouri. The primary objective was to identify existing sediment data together with corresponding flow data for the GREAT-II study area, in order to determine whether or not information is available concerning sediment outputs which are adequate for future planning. The second objective was to obtain a rough estimate of sediment yield for each sediment station by simply correlating monthly averaged sediment discharges with monthly averaged

water discharges, so that major sources of sediment from the tributaries to the Mississippi River could be identified. The third objective was to review some of the methodologies which have been developed and utilized in estimating sediment yields from available sediment data. The final objective was to provide, from the study, recommendations on the potential necessity of installing new sediment stations, to provide base-line data, and a plan of study to determine quantities of sediment delivered by tributary sources into the Mississippi River.

II. INVENTORY STUDY OF STREAM SEDIMENTATION DATA FOR GREAT-II WATERSHED AND PRELIMINARY ESTIMATES OF SEDIMENT YIELDS

Suspended-sediment transport rate data and the stream flow data for part of the GREAT-II watershed were gathered from various agencies in order to test the adequacy of sediment data for identifying the major sediment sources in tributary basins of this Mississippi River corridor. Only sediment sampling stations operated on a daily basis were selected, because sediment data collected at an equal sampling frequency (in this case daily) have equal statistical validity. The 17 COE and 15 USGS stations selected to be in the present study are shown in figure 1-A. Note that identification numbers 1 through 18, and 30 through 44 represent the COE stations and the USGS stations, respectively.

For each station, monthly averaged suspended-sediment loads (Q_s , in tons/day) and water discharges (Q , in cfs) were compiled and plotted in a log-log format by means of a computer, to ascertain the applicability of power-law type relationships between Q and Q_s . Empirical formulas to determine sediment yields at individual stations were thus determined using the least-squares method. Table 1 summarizes the principal results of the present study: mean sediment yields in tons/mi²/yr, power-law relationships between Q and Q_s , minimum and maximum suspended-sediment loads, and total suspended-sediment yields in tons/yr for the individual periods of record studied. Since no data on bed-load transport rates were available, the sediment data analyzed herein included only suspended-sediment loads.

The quality of the sediment data and their relationships with water

discharges analyzed are summarized for each sediment sampling station as follows:

A. COE Stations (Iowa, Illinois, and Missouri)

COE(1) Mississippi River @ East Dubuque, Illinois
 Lat/Long: 42°29'50"/90°38'50"
 Drainage area: 82,000 sq mi
 Agency: COE
 Period of sediment records: 33 yrs

This suspended-sediment collection station is operated by the U.S. Army Corps of Engineers, Rock Island District [COE(RI)]. Sediment samples are collected daily except for winter months. Sediment records extend from the water year 1943 (Oct. 1942) to the present. Samples are obtained using a US D-49 depth-integrating sampler.

This station was chosen for the study because of its length of records of daily sampling and to be the farthest upstream study point along the Mississippi River. It is of interest due to the station's location below the influence of the Turkey, Grant, and Platte River Basins, and in monitoring sediment flow along the Mississippi River.

The present evaluation studied the water years 1968 through 1974. The monthly averages of sediment discharge used are considered reliable, except possibly during the winter months. Since there are no daily water-discharge measurements taken here, water data from the downstream Mississippi River station at Clinton were used by applying a correction factor. The method used by COE(RI) is:

$$Q_{E.DUB} = \sqrt{(D.A.)_{E.DUB.} / (D.A.)_{CLINTON}} Q_{CLINTON}$$

in which Q denotes flow discharge and D.A. represents drainage area. Water-discharge records for Clinton are good except those for the winter period, which are poor.

For the period of study, the minimum and maximum daily suspended-sediment discharges are 314 and 84,396 tons/day, respectively. The mean sediment yield is 56.64 tons/sq mi/yr. This quantity compares favorably with the COE's estimated mean suspended-sediment yield of 37.8 tons/sq mi/yr for the years 1943 through 1966 [COE(RI) computes total yield by dividing suspended-sediment yield by 0.9 to adjust for bed load].

A least-squares analysis of the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 1.98 \times 10^{-7} Q^{2.25}$$

with a standard deviation of 0.275 (see figure 2). The exponent of 2.25 is similar to that of 2.44 found at the downstream station at Keokuk. Continuing records from this station will be beneficial for future studies of the movement of suspended sediment.

COE(3) Mississippi River @ Keokuk, Iowa
 Lat/Long: 40°23'35"/91°22'25"
 Drainage area: 119,000 sq mi
 Agency: COE
 Period of sediment records: 31 yrs

This sediment sample collection station is operated by the COE(RI). Samples are taken daily using a US D-49 depth-integrating sampler.

This station was selected in the present study because of its length of daily sediment records. It is situated below the Iowa, Cedar, Skunk, and Rock River tributaries, providing useful sediment information from these drainage areas, and it also serves as an intermediate point along the Mississippi River for the GREAT-II study reach.

The present study concentrated on the water years 1968 through 1975. The water-discharge records of the USGS station at Keokuk were used for this study, which computes discharge from operation records of both turbines in the power plant and spillway gates in the dam.

For the period studied, the minimum and maximum daily suspended-sediment loads are 580 and 317,960 tons/day, respectively. The mean sediment yield is 112.92 tons/sq mi/yr.

A least-squares analysis of the average monthly water discharge, Q (cfs), and suspended-sediment load, Q_s (tons/day), gives the approximation:

$$Q_s = 2.39 \times 10^{-8} Q^{2.44}$$

with a standard deviation of 0.214 (see figure 3). The results from this station are felt to be accurate for estimating suspended-sediment loads.

COE(4) Mississippi River @ Hannibal, Missouri
 Lat/Long: 39°43'24"/91°21'49"
 Drainage area: 137,300 sq mi
 Agency: COE
 Period of sediment records: 31 yrs

This sediment sample collection station is under the jurisdiction of the COE(RI). Sediment records are complete from the present back through

water year 1944 when the station was first established. Samples are taken daily with a US D-49 depth-integrating sampler.

This station was selected for the study because of its long period of data collection and its location as the last station along the Mississippi River in the GREAT-II study area. The major tributary upstream from this station is the Des Moines River.

The water years 1968 through 1974 were studied in this evaluation. The daily sediment measurements are considered good for this station. No flow rate measurement has been made at Hannibal, so water-discharge information was obtained using data from the stations at Keokuk and Keosauqua, Iowa. The COE(RI) method employs a correction factor:

$$Q_{\text{HANN}} = \sqrt{\frac{(D.A.)_{\text{HANN}}}{[(D.A.)_{\text{KEO}} + (D.A.)_{\text{KEOS}}]}} (Q_{\text{KEO}} + Q_{\text{KEOS}})$$

Water-discharge records for the Des Moines River at Keosauqua are good except for those during the winter period, which are poor. Flow has been regulated by Red Rock Dam since March 12, 1969 which is located 91.0 mi upstream from the Keosauqua station.

For the period studied, the minimum and maximum daily suspended-sediment loads are 1,450 and 441,462 tons/day, respectively. The mean sediment yield is 188.52 tons/sq mi/yr which compares favorably with the mean yield of 204 tons/sq mi/yr estimated by COE(RI) for the years 1944 through 1966. Note that for total yield, COE(RI) divides by 0.9 to account for bed load.

A least-squares analysis of average monthly water discharge, Q (cfs), and suspended-sediment load, Q_s (tons/day), gives the relation:

$$Q_s = 3.19 \times 10^{-4} Q^{1.66}$$

with a standard deviation of 0.329 (see figure 4). The exponent is smaller than those typical of upstream reaches along the Mississippi River. Since the exponent at this station is 1.66, compared to the exponent of 2.44 for Keokuk, more suspended sediment is being transported per unit discharge. The water discharges at both stations are usually well below the point of intersection of two $Q \sim Q_s$ curves at 194,540 cfs, with several days a year surpassing this flow. Hence, for a given discharge, Q , more suspended sediment is flowing past the station at Hannibal implying that the concentration of suspended sediment, Q_s/Q , is higher at Hannibal for the normal discharge

range. It is believed that this increase is due to the sediment input from the Des Moines River, which flows into the Mississippi River 2.7 mi downstream from the Keokuk station.

COE(5) Wapsipinicon River @ DeWitt, Iowa
 Lat/Long: 41°45'55"/90°32'00"
 Drainage area: 2,330 sq mi
 Agency: COE
 Period of sediment records: 33 yrs

This sediment sample collection station is under the jurisdiction of the COE(RI). A depth-integrating US D-43 sampler is used to collect samples, which are taken daily except during winter months.

The station's duration of records makes it a good choice for this study. It is the only station on this river currently collecting samples, and it provides important information on the amount of erosion occurring within its drainage area in northeast Iowa. The primary tributaries of the Wapsipinicon River are the Little Wapsipinicon River and Buffalo Creek.

The water years 1968 through 1975 were studied in this report. Daily sediment measurements, except during winter months, provide for an accurate estimate of the monthly averages which are used. The daily water-discharge data of the USGS gaging station located there were employed. These records are good except for those during the winter period, which are poor.

The minimum and maximum daily suspended-sediment loads for the period studied were 26.2 and 30,212 tons/day, respectively. The mean sediment yield was 342.96 tons/sq mi/yr.

A least-squares analysis of the mean monthly water discharge, Q (cfs), and suspended-sediment discharge, Q_s (tons/day), gives the relation:

$$Q_s = 8.36 \times 10^{-3} Q^{1.58}$$

with a standard deviation of 0.384 (see figure 5). The exponent of 1.58 compares favorably with the exponent of 1.63 for the discontinued USGS station at Independence, Iowa. The station at DeWitt will continue to provide useful information on the sediment loads in this river.

COE(6) Iowa River at Marengo, Iowa
 Lat/Long: 41°48'35"/92°04'20"
 Drainage area: 2,794 sq mi
 Agency: COE
 Period of sediment records: 30 yrs

This sediment sample collection station is operated by the COE(RI) and has data records from water year 1945 to the present. Samples are taken daily with a depth-integrating US D-49 sampler.

COE(6) is the first of several stations currently taking samples along the Iowa river. Its long duration of sediment sampling provides reliable data for analysis. The primary tributaries of the Iowa River upstream from the station include the South Fork Iowa River, Salt Creek, and Big Bear Creek.

This report studied the period of water years 1968 through 1975. The daily measurements provide sufficient data for estimating the monthly averages. Water-discharge data from the gaging station at Marengo are used. The records are good except for those during the winter period, which are poor.

The minimum and maximum daily suspended-sediment loads are 18.4 and 36,841 tons/day, respectively. The mean sediment yield of this study is 506.76 tons/sq mi/yr. The figure is high compared to the COE's mean yield of 328 tons/sq mi/year for the water years 1945 through 1964. For total load, COE(RI) divides by 0.9 to account for bed load.

A least-squares analysis of the average monthly water discharge, Q (cfs), and suspended-sediment load, Q_s (tons/day), gives the relation:

$$Q_s = 7.33 \times 10^{-3} Q^{1.66}$$

with a standard deviation of 0.365 (see figure 6). This station will continue monitoring the movement of sediment along the Iowa river.

COE(7) Iowa River @ Coralville Dam, Iowa
 Lat/Long: 41°43'20"/91°31'30"
 Drainage area: 3,115 sq mi
 Agency: COE
 Period of sediment records: 13 yrs

This sediment sample collection station is under the jurisdiction of the COE(RI). Sediment sampling is done daily with a depth-integrating US D-49 sampler.

The station is important for monitoring the amount of sediment deposited in Coralville Reservoir. Its long period of daily sampling provides reliable

data for determining monthly averages of sediment loads. There are no major tributaries entering the Iowa River between Marengo and this station.

This study observed the water years 1968 through 1974. The sediment data are considered accurate for estimating monthly averages. Since there is no water-discharge gaging station situated here, the data from Iowa City are used by applying a correction factor, the COE(RI) method is:

$$Q_{\text{COR.DAM}} = \sqrt{\frac{(D.A.)_{\text{COR.DAM}}}{(D.A.)_{\text{I.C.}}}} Q_{\text{I.C.}}$$

The minimum and maximum daily suspended-sediment loads for this study are 4 and 3,146 tons/day, respectively. The mean sediment yield is 45.24 tons/sq mi/yr. The Coralville Dam station is situated at the outlet work at the left end of the dam. Consequently, only a small amount of sediment is still in suspension since the decreasing flow velocity and energy gradient upstream of the dam reduces the sediment transport capacity. Thus, deposition of suspended sediment results, which explains why the calculated value of sediment is so low.

A least-squares analysis of average monthly water discharge, Q (cfs), and suspended-sediment load, Q_s (tons/day), gives the relation:

$$Q_s = 9.54 \times 10^{-3} Q^{1.31}$$

with a standard deviation of 0.344 (see figure 7).

COE(8) Skunk River below Squaw Creek @ Ames, Iowa
 Lat/Long: 42°00'30"/93°35'40"
 Drainage area: 556 sq mi
 Agency: COE
 Period of sediment records: 7 yrs

This sediment sample collection station is under the jurisdiction of the COE(RI). Sediment samples are taken daily with a depth-integrating US D-43 sampler.

This station's daily measurements provide sufficient data for estimating mean monthly sediment loads. It is the only station on the Skunk River with a period of sediment data collection (a station was established at Augustain in October 1975 to start collecting sediment samples). The only major tributary upstream is Squaw Creek.

This report studied the water years 1968 through 1974. The set of sediment data used is considered a good indicator of the amount being transported by the river. Water-discharge records from the USGS gaging station at Ames were used, and the records are good except those for the winter period, which are poor.

The minimum and maximum daily suspended-sediment loads are 0.1 and 6,097 tons/day, respectively. The mean sediment yield for this period is 509.88 tons/sq mi/yr.

A least-squares analysis of average monthly water discharge, Q (cfs), and suspended-sediment load, Q_s (tons/day), gives the relation:

$$Q_s = 1.35 \times 10^{-1} Q^{1.37}$$

with a standard deviation of 0.322 (see figure 8).

COE(9) Des Moines River, @ Stratford, Iowa
 Lat/Long: 42°15'15"/93°59'50"
 Drainage area: 5,452 sq mi
 Agency: COE
 Period of sediment records: 7 yrs

This sediment sample collection station is under the jurisdiction of the COE(RI). Sediment samples are taken daily using a depth-integrating US D-49 sampler.

This station was used in the evaluation because of its record of daily sampling. It is the farthest upstream of several stations currently monitoring the transport of sediment along the Des Moines River. The major tributaries upstream include the East Fork River, Lizard Creek, and Boone River.

The water years 1969 through 1974 are reported on herein. The daily measurements of suspended sediment are considered sufficient to calculate the average monthly loads used in the study. The water-discharge records from the USGS gaging station near Stratford are employed. These records are good except for those of the winter months, which are poor.

The minimum and maximum daily suspended-sediment loads for this period are 7.8 and 11,729 tons/day, respectively. The mean sediment yield is 157.92 tons/sq mi/yr.

A least-squares analysis between the average monthly suspended sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 3.14 \times 10^{-3} Q^{1.64}$$

with a standard deviation of 0.285 (see figure 9).

COE(10) Des Moines River @ Boone, Iowa
 Lat/Long: 42°04'40"/93°55'55"
 Drainage area: 5,490 sq mi
 Agency: COE(RI)
 Period of sediment records: 35 yrs

This sediment sample collection station is operated by the COE(RI). Suspended-sediment samples are taken daily except during winter months. A depth-integrating US D-43 sampler is used.

This station was chosen for its long period of daily measurements and as an intermediate point along the Des Moines River. No major tributaries drain into this river along the reach from Stratford to Boone, so the results obtained at both stations should be similar.

This report studied the water years 1968 through 1974. The daily suspended-sediment data used (excluding the winter months) are sufficient to estimate average monthly loads. Since there is no record of flow measurement here, the records from the upstream station at Stratford are used without correction. The records are good except for those during the winter months, which are poor.

For the period studied, the minimum and maximum daily suspended-sediment loads are 4.8 and 22,284 tons/day, respectively. The calculated mean sediment yield is 199.68 tons/sq mi/yr, which is larger than the yield of 157.92 tons/sq mi/yr at Stratford, possibly indicating a source of sediment production in this reach. The yield compares favorably with the yield of 204 tons/sq mi/yr calculated by the COE(RI) for the water years 1940 through 1967 (note: COE(RI) divides by 0.9 to calculate total load to adjust for bed load).

A least-squares analysis of average monthly water discharge, Q (cfs), versus average monthly suspended-sediment load, Q_s (tons/day), gives the relation:

$$Q_s = 8.17 \times 10^{-3} Q^{1.58}$$

with a standard deviation of 0.290 (see figure 10). The exponent (1.58) is similar to the exponent of 1.64 for Stratford.

COE(11) Des Moines River @ Tracy, Iowa
 Lat/Long: 41°16'55"/92°51'30"
 Drainage area: 12,479 sq mi
 Agency: COE(RI)
 Period of sediment records: 35 yrs

This sediment sample collection station is operated by the COE(RI). Sediment records extend back to water year 1941. Suspended-sediment samples are taken daily, except during the winter months. Samples are obtained using a D-49 depth-integrating sampler.

This station was selected for the study because of its records of daily sampling, and as the last study point along the Des Moines River. The station is located 11.9 mi downstream from Red Rock Dam, and includes the drainage areas of the tributaries White Breast Creek, North, Middle, South, and Raccoon Rivers. It is the only sediment sampling station below Saylorville with recent records of the Des Moines River.

The water years 1968 through 1975 were studied in this report. The daily measurements, except during winter months, are considered adequate for estimating the average monthly suspended-sediment loads used herein. Water-discharge records of the USGS gaging station at Tracy were employed. These data are considered good except those for the winter period which are fair.

The minimum and maximum daily suspended-sediment loads for this study period are 25.2 and 11,596 tons/day, respectively. The mean sediment yield is 75.84 tons/sq mi/yr which is very low compared with the COE(RI) estimate of 647 tons/sq mi/yr for the water years 1941 through 1967 (the COE(RI) figure is adjusted for bed load). There has been a drastic drop in sediment load in recent years since the average annual load for 1941 to 1967 was 9,000,000 tons, while for the present study (1968-1975) the average annual load was about 900,000 tons. This reduction is due to the Red Rock Dam, which was placed in operation in March 1969. The dam traps a large percentage of the suspended sediment in transport.

A least-squares analysis of the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 1.00 \times 10^{-1} Q^{1.13}$$

with a standard deviation of 0.357 (see figure 11). This exponent is significantly smaller than those at the upstream stations on the Des Moines River (i.e. Boone, 1.58; Stratford, 1.64; and Saylorville, 1.67). The coefficient is an order of magnitude larger. This difference is also due to the influence of the trapping of sediment at the Red Rock Dam.

COE(12) Raccoon River @ Van Meter, Iowa
 Lat/Long: 41°32'00"/93°57'10"
 Drainage area: 3,441 sq mi
 Agency: COE(RI)
 Period of sediment records: 35 yrs

This sediment sample collection station is under the jurisdiction of the COE(RI). Sediment records began in water year 1940. Samples are collected daily except during the winter months. A depth-integrating US D-49 sampler is used.

This station was utilized in the study because of its record of daily sampling, and to observe sediment transport on the Raccoon River. This measuring station has the only suspended-sediment record on the Raccoon River, and it is important for estimating the amount of sediment being discharged into the Des Moines River at Des Moines. The major tributaries are the North, Middle, and South Raccoon Rivers.

This study used data from the water years 1968 through 1974. The daily measurements (except during winter months) are sufficient for estimating average monthly suspended-sediment loads. Water-discharge records from the USGS gaging station at Van Meter are used. The records are good except those for the winter period, which are poor.

The minimum and maximum daily suspended-sediment loads for this period are 7.8 and 78,538 tons/day, respectively. The mean sediment yield is 679.08 tons/sq mi/yr. The COE(RI) value for the water years 1940 through 1966 is 737 tons/sq mi/yr [COE(RI) computes total yield by dividing by 0.9 to adjust for bed load].

A least-squares analysis of the average monthly suspended-sediment load, Q_s (tons/day) and water discharge, Q (cfs), gives the relation:

$$Q_s = 4.68 \times 10^{-3} Q^{1.76}$$

with a standard deviation of 0.364 (see figure 12).

COE(13) North River @ Norwalk, Iowa
 Lat/Long: 41°27'25"/93°39'10"
 Drainage area: 349 sq mi
 Agency: COE(RI)
 Period of sediment records: 13 yrs

This sediment sample collection station was established in water year 1963 and is operated by the COE(RI). Suspended-sediment samples are taken daily except during winter months. Samples are obtained using a depth-integrating US D-49 sampler.

This station was chosen in the study for its recent record of daily measurements and to estimate the amount of suspended sediment in the North River. This measuring station has the only suspended-sediment record on the river, which flows directly into the Des Moines River. There are no major tributaries of the North River.

The water years 1968 through 1974 are studied in this report. The daily measurements (except during winter months) supply adequate information for estimating average monthly suspended-sediment loads. Water-discharge records of the USGS gaging station near Norwalk are used. These records are good except those for the winter period, which are poor.

The minimum and maximum daily suspended-sediment loads for the study are 0.0 and 3,734 tons/day, respectively. The mean sediment yield is 529.32 tons/sq mi/yr.

A least-squares analysis of the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 1.10 \times 10^{-1} Q^{1.45}$$

with a standard deviation of 0.436 (see figure 13).

COE(14) Middle River @ Indianola, Iowa
 Lat/Long: 41°25'25"/93°35'05"
 Drainage area: 503 sq mi
 Agency: COE(RI)
 Period of sediment records: 13 yrs

This sediment sample collection station is currently operated by the COE(RI). Suspended-sediment samples are taken daily using a depth-integrating US D-49 sampler.

This station is used in the report because of its record of daily measurements and to estimate the amount of suspended sediment in the Middle River. This suspended-sediment sampling station is the only one on the

river, which flows directly into the Des Moines River. The primary tributary to the Middle River is Clanton Creek.

This report studied the period of water years 1968 through 1974. The daily sampling provides sufficient data to estimate the average monthly suspended-sediment loads used in the study. Water-discharge records from the USGS gaging station at Indianola are employed. These data are fair except those for the winter period, which are poor.

For the study period, the minimum and maximum daily suspended-sediment loads are 0.2 and 28,356 tons/day, respectively.

The mean sediment yield is 2,030.04 tons/sq mi/yr. With this large value of yield, the region appears to be a high sediment source.

A least-squares analysis of the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 2.35 \times 10^{-2} Q^{1.90}$$

with a standard deviation of 0.429 (see figure 14).

COE(15) South River @ Ackworth, Iowa
 Lat/Long: 41°20'15"/93°29'05"
 Drainage area: 460 sq mi
 Agency: COE(RI)
 Period of sediment records: 13 yrs

This sediment sample collection station, established in 1962, is under the jurisdiction of the COE(RI). Suspended-sediment samples are taken daily using a depth-integrating US D-49 sampler.

This station was selected for its duration of daily sampling and to estimate the amount of sediment in transport along the South River. This station is the only one with sediment records for this river which drains directly into the Des Moines River. The only major tributary is Otter Creek.

The period of water years 1968 through 1975 is studied herein. The daily measurements provide adequate information for calculating the average monthly suspended-sediment loads used in the study. The water-discharge records are from the USGS gaging station near Ackworth. These records are good except those during the winter period, which are poor.

For the study period, the minimum and maximum daily suspended-sediment loads are 0.4 and 37,350 tons/day, respectively. The mean sediment

yield is 2,332.08 tons/sq mi/yr. This yield is relatively high, indicating an erosion drainage area. The Middle and South River drainage areas appear to transport a large quantity of sediment to the Des Moines River, which eventually settles out (or is trapped) at the Red Rock Dam.

A least-squares analysis of the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 1.06 \times 10^{-1} Q^{1.67}$$

with a standard deviation of 0.456 (see figure 15).

COE(16) Whitebreast Creek @ Dallas, Iowa
 Lat/Long: 41°14'41"/93°16'08"
 Drainage area: 342 sq mi
 Agency: USGS
 Period of sediment records: 8 yrs

See USGS (44).

COE(17) Hadley Creek @ Kinderhook, Illinois
 Lat/Long: 39°41'35"/91°08'55"
 Drainage area: 72.7 sq mi
 Agency: COE(RI)
 Period of sediment records: 35 yrs

This sediment sample collection station, established in 1940, is operated by the COE(RI). Samples are collected daily except during winter months, with additional samples taken during river rises. A depth-integrating US D-43 sampler is used.

This station was selected for its daily sampling records, which usually provide a good correlation between suspended-sediment load and water discharge, and also to estimate the yield for this drainage area. Hadley Creek has no major tributaries and flows directly into the Mississippi River.

The water years 1968 through 1974 are studied in this evaluation. The monthly averages of suspended-sediment loads are considered representative of actual amounts except during the winter months. The water-discharge records from the USGS gaging station at Kinderhook are used herein. The records are fair except those for the winter periods, which are poor.

The minimum and maximum daily suspended-sediment loads for this period are 0.06 and 88,336 tons/day, respectively. The mean sediment yield is 9,621.72 ton/sq mi/yr. This yield is not a representative value because there are some months with enormously high yields, thereby giving an average value much larger than the normal. The mean sediment yield calculated

by the COE(RI) for the water years 1946 through 1967 is 1,552 tons/sq mi/yr. [COE(RI) calculates total yield by dividing by 0.9 to adjust for bed load].

A least-squares analysis of the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 2.39 \times 10^{-1} Q^{1.58}$$

with a standard deviation of 0.713 (see figure 16).

COE(18) Bay Creek @ Nebo, Illinois
 Lat/Long: 39°26'35"/90°47'45"
 Drainage area: 162 sq mi
 Agency: COE(RI)
 Period of sediment records: 33 yrs

This sediment sample collection station was established in 1942, and it is operated by the COE(RI). Suspended-sediment samples are collected daily except during the winter months, with additional samples taken during river rises. A depth-integrating US D-43 sampler is used.

The station was selected for its duration of sediment records and to provide an estimate of the sediment yield for the river basin. It is the only sediment collection station operated on Bay Creek, which flows directly into the Mississippi River. There are no major tributaries for this creek.

This report studied the water years 1968 through 1974. The daily measurements, except during the winter months, are sufficient for estimating representative values of average monthly suspended-sediment loads. The water-discharge records for the USGS gaging station at Nebo are used in the study. These records are good except those during the winter periods, which are poor.

For the period studied, the minimum and maximum daily suspended-sediment loads are 0.97 and 24,742 tons/day, respectively. The mean sediment yield is 3,683.40 tons/sq mi/yr. This value is a little high because of several months with above average yields. The mean yield calculated by COE(RI) for the water years 1947 through 1967 is 1,925 tons/sq mi/yr [COE(RI) calculates total yield by dividing by 0.9 to adjust for bed load].

A least-squares analysis of the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 7.09 \times 10^{-2} Q^{1.83}$$

with a standard deviation of 0.634 (see figure 17).

B. USGS Stations (Iowa)

USGS (30) Turkey River @ Garber, Iowa
 Lat/Long: 42°44'24"/91°15'42"
 Drainage area: 1,545 sq mi
 Agency: USGS
 Period of sediment study: 5 yrs (1957-1962)

This sediment sample collection station is under the jurisdiction of the USGS. Suspended-sediment samples were taken on a daily basis during the water years 1958 through 1962, for which monthly and yearly summaries are published and available. Sediment sampling was discontinued after 1962.

This station is included in the report because samples were taken daily, thereby allowing representative estimates of the monthly averages of suspended-sediment discharge to be calculated.

This collection station is the only one with daily records established on the Turkey River; therefore its data are of interest for computing a sediment yield for its drainage basin. The major tributaries of the Turkey River are the Little Turkey River, Crane Creek, and the Volga River.

The water years 1958 through 1962 were studied in this evaluation. Water and sediment discharge records are good except for those during the winter months, which are poor. The minimum and maximum daily suspended-sediment discharges are 2.0 and 29,100 tons/day, respectively. The mean sediment yield is 1,203.96 tons/sq mi/yr.

A least-squares analysis of the average monthly suspended-sediment load, Q_s (tons/day), versus water discharge, Q (cfs), gives the relation:

$$Q_s = 9.07 \times 10^{-4} Q^{2.10}$$

with a standard deviation of 0.631 (see figure 18).

USGS (31) Wapsipinicon River @ Independence, Iowa
 Lat/Long: 42°27'49"/91°53'42"
 Drainage area: 1,048 sq mi
 Agency: USGS
 Period of sediment study: 3 yrs (1967-1970)

This sediment sample collection station is operated by the USGS. Suspended-sediment samples were taken on a daily basis during water years 1968 through 1970, for which monthly and yearly summaries are available. Periodic sediment samples have been taken since 1970.

This station was chosen for its daily measurements, which allow representative estimates to be made of the average monthly suspended-sediment loads. It also serves as an additional study point along the Wapsipinicon River; COE(RI) has a station at DeWitt. The major tributary upstream is the Little Wapsipinicon River.

This evaluation studied the period of water years 1968 (1 Dec. 1967 to 30 Sept. 1968) through 1970. Sediment discharge records are good except during the winter months when the river flow was affected by ice. Water-discharge records during this period are excellent. The minimum and maximum daily suspended-sediment discharges are 1.2 and 2,100 tons/day, respectively. The mean sediment yield is 60.60 tons/sq mi/yr. The mean yield for the DeWitt station [COE(5)] for these 3 yrs is 222 tons/sq mi/yr. suggesting a fairly erosive drainage area between the two stations.

A least-squares analysis of average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 1.97 \times 10^{-3} Q^{1.63}$$

with a standard deviation of 0.377 (see figure 19).

The exponent of 1.63 is approximately equal to that found at the DeWitt station (1.58), although the coefficient of 1.97×10^{-3} is roughly one-fourth of that at DeWitt (8.36×10^{-3}).

USGS(32) Iowa River @ Rowan, Iowa
 Lat/Long: 42°45'36"/93°37'23"
 Drainage area: 429 sq mi
 Agency: USGS
 Period of sediment study: 5 yrs (1957-1962)

This sediment sample collection station is under the jurisdiction of the USGS. Suspended-sediment samples were taken daily between the water years 1959 and 1962, for which records of the monthly and yearly summaries are available. Periodic sediment samples have been taken since 1962.

This station was chosen for its daily records and as an upstream initial monitoring point along the Iowa River. There are no major tributaries to the Iowa River upstream of Rowan.

Data for the water years 1958 through 1962 are examined herein. Water and sediment discharge records are considered good except during the winter months when the river flow is affected by ice. The minimum and maximum daily suspended-sediment discharges are 0.1 and 282 tons/day, respectively.

The mean sediment yield is 25.80 tons/sq mi/yr.

A least-squares analysis between the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 2.86 \times 10^{-2} Q^{1.33}$$

with a standard deviation of 0.322 (see figure 20).

USGS(33) Iowa River @ Iowa City, Iowa
 Lat/Long: 41°39'24"/91°32'27"
 Drainage area: 3,271 sq mi
 Agency: USGS
 Period of sediment study: 9 yrs (1967-1976)

This sediment sample collection station is under the jurisdiction of the USGS, with sediment records from 1943 to the present. Samples are collected on a daily basis.

This station was selected in the study for its record of daily measurements from which average monthly figures can be obtained. It also serves as an intermediate study point along the Iowa River. The only major tributary located between this station and the COE(RI) station upstream at the Coralville Dam [COE(7)] is Clear Creek.

The water years 1968 through 1976 are examined herein. Water and sediment discharge records are excellent. The minimum and maximum daily suspended-sediment loads are 13.0 and 17,362 tons/day, respectively. The mean sediment yield is 132.24 tons/sq mi/yr.

A least-squares analysis of the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 7.05 \times 10^{-3} Q^{1.49}$$

with a standard deviation of 0.305 (see figure 21).

USGS(34) Ralston Creek @ Iowa City, Iowa
 Lat/Long: 41°39'50"/91°30'48"
 Drainage area: 3.01 sq mi
 Agency: USGS
 Period of sediment study: 9 yrs (1967-1976)

This sediment sample collection station is operated by the USGS. Suspended-sediment samples are taken daily for which monthly and yearly summaries are published from water year 1952 to the present.

This station is included because of its length of sediment records. Although Ralston Creek is small, the sediment data obtained from it are useful for correlating suspended sediment and water discharge. Ralston Creek

flows directly into the Iowa River. The only tributary is the South Branch Ralston Creek.

The water years 1968 through 1976 were examined herein. Water and sediment discharge records are good except during the winter months of each year. Also, there is no flow on many days throughout the year. The minimum and maximum daily suspended-sediment discharges are 0.0 and 167 tons/day, respectively. The mean sediment yield is 758.10 tons/sq mi/yr.

A least-squares analysis between average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 5.64 \times 10^{-1} Q^{1.37}$$

with a standard deviation of 0.482 (see figure 22).

USGS(35) Fourmile Creek @ Lincoln, Iowa
 Lat/Long: 42°13'32"/92°36'39"
 Drainage area: 13.78 sq mi
 Agency: USGS
 Period of sediment study: 5 yrs (1969-1974)

This sediment sample collection station is under the jurisdiction of the USGS. Suspended-sediment samples were taken on a daily basis during the water years 1970 through 1974, after which time the station was discontinued.

This station is included for its length of sediment records of daily measurements. With these data, reasonable monthly averages of sediment and water discharge may be computed and correlated. Fourmile Creek flows into Wolf Creek, which drains into the Cedar River.

The water years 1970 through 1974 are examined in this report. Water and sediment discharge records are considered good except during winter months, which are poor. Flow is affected by ice during the winter months of each year. The minimum and maximum daily suspended-sediment loads for the study period are 0.2 and 283 tons/day, respectively. The mean sediment yield is 660.24 tons/sq mi/yr.

A least-squares analysis of the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 3.84 \times 10^{-1} Q^{1.40}$$

with a standard deviation of 0.355 (see figure 23).

USGS(36) Half Mile Creek @ Gladbrook, Iowa
 Lat/Long: 42°12'40"/92°36'39"
 Drainage area: 1.33 sq mi
 Agency: USGS
 Period of sediment study: 5 yrs (1969-1974)

This sediment sample collection station is operated by the USGS. Suspended-sediment samples were taken daily during the water years 1970 through 1974, at which date the station was discontinued.

This station is included herein for its length of sediment records. Daily measurements provide sufficient data for determining average monthly values of sediment discharge. A correlation between these values and monthly averages of water discharge is important in predicting sediment yields for the region. There are no tributaries to Half Mile Creek which drains into Fourmile Creek.

During the study period of water years 1970 through 1974, sediment and water discharge records are considered fair except during winter months, which are poor. Flow is affected by ice during the winter months of each year. Also, many days throughout the year have no flow. The minimum and maximum daily suspended-sediment loads are 0.0 and 5.0 tons/day, respectively. The mean sediment yield is 197.28 tons/sq mi/yr.

A least-squares analysis between the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 4.80 \times 10^{-1} Q^{1.32}$$

with a standard deviation of 0.328 (see figure 24).

USGS(37) Fourmile Creek @ Traer, Iowa
 Lat/Long: 42°12'07"/92°33'44"
 Drainage area: 19.51 sq mi
 Agency: USGS
 Period of sediment study: 5 yrs (1969-1974)

This sediment sample collection station is under the jurisdiction of the USGS. Suspended-sediment samples were taken on a daily basis during the water years 1970 through 1974, at which date sediment records were discontinued.

This station is included for its length of sediment records. This set of daily data enables reasonable monthly averages of sediment discharges to be computed and correlated with mean water discharges. Fourmile Creek flows directly into the Wolf Creek, located within the Iowa River Basin.

The water years 1970 through 1974 are examined in this report. Water and sediment discharge records are considered good except during winter months, which are poor. Flow is affected by ice during the winter months. The minimum and maximum daily suspended-sediment loads are 0.1 and 267 tons/day, respectively. The mean sediment yield is 432.72 tons/sq mi/yr.

A least-squares analysis between the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 1.98 \times 10^{-1} Q^{1.54}$$

with a standard deviation of 0.279 (see figure 25).

USGS(38) Cedar River @ Cedar Rapids, Iowa
 Lat/Long: 41°58'14"/91°40'01"
 Drainage area: 6,510 sq mi
 Agency: USGS
 Period of sediment study: 10 yrs (1944-1954)

This sediment sample collection station is operated by the USGS. Suspended sediment samples were taken daily during the water years 1944 through 1954.

This station is included for its records of daily sampling. This is the only daily sampling station to operate on the Cedar River, consequently, its data are useful for studying sediment flow along the river. The Cedar River is the major tributary to the Iowa River.

The water years 1945 through 1954 are examined in this evaluation. Water and sediment discharge records are considered good except during winter months, which are fair. Flow is affected by ice during the winter months. The minimum and maximum daily suspended-sediment discharges are 8.4 and 49,500 tons/day, respectively. The mean sediment yield is 134.64 tons/sq mi/yr.

A least-squares analysis of average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 2.89 \times 10^{-4} Q^{1.86}$$

with a standard deviation of 0.308 (see figure 26).

It should be emphasized that these figures are for the water years 1945 through 1954, and they are not intended to be representative of current sediment loads.

USGS(39) Des Moines River @ Saylorville, Iowa
 Lat/Long: 41°41'50"/93°40'07"
 Drainage area: 5,841 sq mi
 Agency: USGS
 Period of sediment study: 9 yrs (1967-1976)

This sediment sample collection station is under the jurisdiction of the USGS and was established in 1961. Suspended-sediment samples are taken on a daily basis for which monthly and yearly summaries have been published.

This station is included for its long record of daily sampling, and as an intermediate point along the Des Moines River. There are no major tributaries in the river reach between the upstream COE(RI) sediment sampling station at Boone [COE(10)] and Saylorville.

The water years 1968 through 1976 are evaluated in this report. Water and sediment discharge records are good except those for the winter period, which are fair. Flow is affected by ice during the winter months. The minimum and maximum daily suspended-sediment loads are 7.1 and 22,700 tons/day, respectively. The mean sediment yield is 221.88 tons/sq mi/yr. This figure is comparable to the mean yield of 199.68 tons/sq mi/yr at the upstream station at Boone [COE(10)].

A least-squares analysis between the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 4.26 \times 10^{-3} Q^{1.67}$$

with a standard deviation of 0.255. The exponent at the Boone station is 1.58 (see figure 27).

USGS(40) Des Moines River @ Des Moines, Iowa
 Lat/Long: 41°37'39"/93°38'41"
 Drainage area: 6,245 sq mi
 Agency: USGS
 Period of sediment study: 6 yrs (1955-1961)

This sediment sample collection station was under the jurisdiction of the USGS, but is no longer in operation. Samples were taken on a daily basis during the water years 1955 through 1961, for which the monthly and yearly summaries of suspended-sediment discharge have been published. Sampling was discontinued after 1961.

The station is included herein for its record of daily sampling, and may be of interest for comparing the past records of this station to current data being obtained from other sediment stations along the Des Moines River, i.e., COE(RI): Stratford [COE(9)], Boone [COE(10)], and Tracy [COE(11)]; USGS: Saylorville [USGS(39)].

The water years 1956 through 1961 are studied herein. Sediment and water discharge records are considered good except during the winter months when ice affects the flow. The minimum and maximum daily suspended-sediment loads are 3.6 and 15,200 tons/day, respectively. The mean sediment yield is 103.32 tons/sq mi/yr.

A least-squares analysis between the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 4.37 \times 10^{-3} Q^{1.70}$$

with a standard deviation of 0.289 (see figure 28).

The exponent of 1.70 is similar to other exponents along this reach of the Des Moines River except that of Tracy (i.e., COE(RI): 1.64 at Stratford, 1.58 at Boone, and 1.13 at Tracy; USGS: 1.67 at Saylorville. The mean yield of 103.32 tons/sq mi/yr is significantly lower than those at the neighboring stations. Because of the different study periods, a comparison is not reasonable, although it does suggest that the amount of suspended sediment being carried from the land has increased over the last 20 years.

USGS(41) East Fork Hardin Creek @ Churdan, Iowa
 Lat/Long: 42°06'27"/94°22'12"
 Drainage area: 24 sq mi
 Agency: USGS
 Period of sediment study: 5 yrs (1952-1957)

This sediment sample collection station is operated by the USGS. Samples were taken on a daily basis during the water years 1953 through 1957, for which monthly and yearly summaries have been published. Periodic sediment samples have been taken since 1957.

This station is included for its record of daily sampling which is useful for correlating suspended-sediment load and water discharge. This stream is a part of Hardin Creek, which flows directly into the North Raccoon River.

The water years 1953 through 1957 are reported on herein. Water and sediment discharge records are good except those during the winter months or during low flows, which are poor. Flow is affected by ice during the winter months. No flow occurs on many days during the year. The minimum and maximum daily suspended-sediment loads are 0.0 and 40.0 tons/day, respectively. The mean sediment yield is 36.00 tons/sq mi/yr.

A least-squares analysis between the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 2.16 \times 10^{-1} Q^{1.08}$$

with a standard deviation of 0.378 (see figure 29).

USGS(42) Des Moines River below Raccoon River @ Des Moines, Iowa
 Lat/Long: 41°34'30"/93°35'48"
 Drainage area: 9,879 sq mi
 Agency: USGS
 Period of sediment study: 3 yrs (1944-1947)

This sediment sample collection station was operated on a daily basis by the USGS between the water years 1945 through 1947. The station has since been discontinued, but monthly and yearly summaries of sediment records have been published and are available.

This station is included for its record of daily suspended-sediment sampling. The Raccoon River discharges into the Des Moines River 0.8 mi upstream from this station.

This investigation studied the water years 1945 through 1947. Water and discharge records are good except during the winter months when ice affects the flow, which are poor. The minimum and maximum daily suspended-sediment loads are 57 and 110,000 tons/day, respectively. The mean sediment yield is 498.36 tons/sq mi/yr.

A least-squares analysis between the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 3.34 \times 10^{-4} Q^{1.96}$$

with a standard deviation of 0.299 (see figure 30).

Since these data are over 30 years old, no comparison is attempted with the recent data from neighboring stations.

USGS(44) White Breast Creek @ Dallas, Iowa
 Lat/Long: 41°14'41"/93°16'08"
 Drainage area: 342 sq mi
 Agency: USGS
 Period of sediment study: 7 yrs (1967-1974)

This sediment sample collection station was operated on a daily basis by the USGS from October 1967 to September 1973, after which date sampling was discontinued (Note: COE(RI) has since taken over this station starting in October 1974). Also, sediment records for the water years 1946 through 1966 are available from the COE(RI).

This station is included for its record of daily sampling and to monitor the flow of sediment along the river. Since White Breast Creek flows directly into the Des Moines River upstream of the Red Rock Dam, its contribution of sediment that can accumulate behind the dam is important to observe.

The water years 1968 through 1975 except 1974 are evaluated herein. Water and sediment discharge records are good except for those during the winter period when ice affects the flow, which are poor. The minimum and maximum daily suspended-sediment loads are 0.2 and 15,885 tons/day, respectively. The mean sediment yield is 1210.68 tons/sq mi/yr. The mean sediment yield for the water years 1946 through 1966 obtained by COE(RI) is 1,632 tons/sq mi/yr (COE(RI) calculates total yield by dividing by 0.9 to adjust for bed load).

A least-squares analysis between the average monthly suspended-sediment load, Q_s (tons/day), and water discharge, Q (cfs), gives the relation:

$$Q_s = 2.12 \times 10^{-1} Q^{1.51}$$

with a standard deviation of 0.520 (see figure 31).

Data from suspended-sediment sampling stations in Wisconsin were compiled for the water years 1969 through 1976, except 1971. A total of 28 stations with frequent samples was considered for the GREAT-II watershed. Of these, only one station collects suspended sediment samples daily: Willow Creek at Madison. The data acquired are inadequate to estimate values of mean sediment yield. In most sediment stations sampling was done periodically, usually during peak flows. The data, hence, do not furnish representative values of annual suspended-sediment yields. Estimates of sediment yields for Wisconsin were made by Hindall (1976). Lack of suspended-sediment data for the Illinois portion of the GREAT-II watershed precluded estimates of mean sediment yield.

III. IDENTIFICATION OF POTENTIAL SEDIMENT SOURCES AND RECOMMENDATIONS ON FURTHER SEDIMENT DATA REQUIRED

Although only recent sediment data extending over rather short time periods were utilized in estimating mean sediment yields for the individual watersheds listed in table 1, even these crude estimates are very useful for identification of major sediment source areas in the GREAT-II study reach. As can be seen in table 1, the mean annual sediment yield per unit area exceeds 500 tons/sq mi/yr at the following sediment sampling stations: Iowa River at Marengo (507 tons/sq mi/yr); Skunk River at Ames (510 tons/sq mi/yr); Raccoon River at Van Meter (679 tons/sq mi/yr); North River at Norwalk (529 tons/sq mi/yr); Middle River at Indianola (2,030 tons/sq mi/yr); South River at Ackworth (2,332 tons/sq mi/yr); Hadley Creek at Kinderhook (9,622 tons/sq mi/yr); Bay Creek at Nebo (3,683 tons/sq mi/yr); Turkey River at Garber (1,204 tons/sq mi/yr); Ralston Creek at Iowa City (758 tons/sq mi/yr); and Fourmile Creek at Lincoln (660 tons/sq mi/yr). These values surely attest to the fact that these watersheds experience excessive erosion. It is, however, important to recognize that some of these watersheds have very small drainage areas, resulting in minor influences on the total sediment yield. The following are the sediment sampling stations which recorded total annual sediment yields amounting to over 10^6 tons/yr: Mississippi River at East

Dubuque (4.64×10^6 tons/yr); Mississippi River at Keokuk (1.34×10^7 tons/yr); Mississippi River at Hannibal (2.59×10^7 tons/yr); Iowa River at Marengo (1.42×10^6 tons/yr); Des Moines River at Boone (1.10×10^6 tons/yr); Raccoon River at Van Meter (2.34×10^6 tons/yr); Middle River at Indianola (1.02×10^6 tons/yr); South River at Ackworth (1.07×10^6 tons/yr); Turkey River at Garber (1.86×10^6 tons/yr); Des Moines River at Saylorville (1.30×10^6 tons/yr); and Des Moines River at Des Moines (below the Raccoon River) (4.92×10^6 tons/yr). Although it was extremely difficult to draw regionalized curves with the available data points analyzed in the present study, an attempt to obtain tentative curves was made, and the result is shown in figure 1-B. It should be noted that the estimated mean sediment yield (in tons/sq mi/yr) at each station is also given in parenthesis in the figure.

Total sediment yields estimated in the present study are listed in table 2 for 24 sampling stations, together with the estimated values reported in the Upper Mississippi River Comprehensive Basin Study-Appendix G (1970) for comparison. Note that the total sediment yields shown in table 2 were obtained by dividing the suspended-sediment yields by 0.9 to account for bed loads, as has been done by COE(RI). The agreement between the two sets of the estimates is seen to be quite good, despite the difference in time periods analyzed, except for sampling stations on the Iowa River above Coralville; on Ralston Creek at Iowa City; on the Des Moines River at Tracy; on Hadley Creek at Kinderhook; and on Bay Creek at Nebo. The extremely low values obtained in this study for the Iowa River at Coralville and the Des Moines River at Tracy are believed to be attributable to the dams constructed on these streams in the late 1960's. Data for Hadley Creek and Bay Creek were found to scatter widely, resulting in high standard deviations about the fitted lines (0.71 and 0.63, respectively, as seen in table 1); the discrepancy between the present estimates and COE's appears to be due to the scatter in data points.

In order to study in detail the sediment-movement regime of the Mississippi River in the GREAT-II study reach, it is essential to evaluate sediment inputs from its tributaries at their mouths. This task requires adequate and dependable suspended sediment data collected at the mouths of the major tributaries. It is, therefore, strongly recommended that new sediment stations be established (or old discontinued stations be reinstated) at the following locations to monitor directly sediment inflows to the Mississippi River (see figure 1-A): Garber, Iowa, on the Turkey River; Potosi, Wisconsin, on the Grant River; Maquoketa, Iowa, on the Maquoketa River; Joslin, Illinois, on the Rock River; Silvis, Illinois, on the Green River; Wapello, Iowa, on the Iowa River; Augusta, Iowa, on the Skunk River (already established in

October, 1975); and St. Francisville, Missouri, on the Des Moines River. Although bed-load discharges were never recorded in the GREAT-II area, primarily due to the lack of adequate bed-load sampling techniques, serious consideration should be given to initiating bed-load sampling using Helley-Smith bed-load samplers (Johnson, et al. 1977, Nakato and Kennedy 1977). The recommended bed-load sampling operation should be conducted at the aforementioned sediment stations, and also at the DeWitt station on the Wapsipinicon River. This recommendation is based on the fact that there have been chronic shoaling problems in the Mississippi River which result from substantial discharges of coarse sediment inputs (mainly the sand portion) from the tributaries. The following tributaries are believed to be responsible for shoaling problems found in individual pools: Turkey River for Pool 11 (Guttenberg-Dubuque); Maquoketa River for Pool 13 (Bellevue-Clinton); Wapsipinicon River for Pool 14 (Clinton-LeClair); Iowa River for Pool 18 (New Boston-Burlington); Skunk River for Pool 19 (Burlington-Keokuk); and Des Moines River for Pool 20 (Keokuk-Canton).

IV. REVIEW OF SOME SEDIMENT-YIELD PREDICTING METHODS

Sediment movement from a watershed to a river generally is divided in two separate phases: upland phase and lowland phase. The upland phase includes sheet erosion, rill erosion, inter-rill erosion, and gully erosion; while, the lowland phase is related to in-channel sediment movement. The factors responsible for the physical processes of sediment movement in each phase are entirely different. The independent variables considered normally for the upland erosion are climatic conditions (amount, intensity, and duration pattern of runoff; temperature; etc.), topography (watershed slope; watershed slope-length; etc.), soils (soil type; soil condition; soil sizes; etc.), and land use (vegetative cover; conservation practice factor; etc.). In the lowland stream phase, variables such as depth of flow, channel slope, wash load, water temperature, median size of bed material, size distribution of bed sediment, etc. become important. These variables are interrelated in such a complex manner that the establishment of exact mathematical formulations is extremely difficult. Since various approaches concerning sediment yields have been critically reviewed by many investigators (for

example, Vanoni 1975, Onstad et al. 1977, and others), only a few topics which are closely related to the present study will be discussed herein.

Among several different methods for estimating sheet erosion, the prediction model (the so-called universal soil loss equation), developed by Wischmeier and Smith (1965), has been most frequently utilized. The equation is given by

$$E = RKLSCP$$

where E = the average annual soil loss per unit area; R = the rainfall factor; K = the soil erodibility factor; L = the slope-length factor; S = the slope-gradient factor; C = the cropping-management factor; and P = the erosion-control practice factor. More detailed definitions of these quantities are given by Wischmeier and Smith (1965) and Vanoni (1975).

Since sediment yield is a consequence of gross erosion in the watershed and the transport process of eroded sediment, only a part of the material eroded in upland areas is carried out of the watershed. The fraction of gross erosion (T) transported off the given watershed as sediment yield (Y) is commonly called the sediment-delivery ratio (DR), which is expressed as

$$DR = Y/T$$

To determine an average sediment-delivery ratio, the magnitude of the sediment yield at a given point in a watershed, and the total amount of erosion must be known. The former can be obtained by reservoir surveys or sediment measurements in the stream, and the latter can be determined with the universal soil loss equation. Maner (1962) analyzed data from the Blackland Prairie in Texas and obtained the following empirical relationship between drainage area (A in sq mi) and sediment-delivery ratio (DR in percent):

$$\log DR = 1.87680 - 0.14191 \log (10A)$$

Maner (1958) also developed a relationship between relief-length ratio (R/L) and sediment-delivery ratio for the Red Hills physiographic area in Oklahoma and Texas as

$$\log DR = 2.943 - 0.824 \text{ antilog } (R/L)$$

Williams and Berndt (1972) developed a procedure to calculate sediment yields using the modified universal soil loss equation and sediment-delivery ratio. In formulating the modified equation, the K, LS, C, and P factors were weighted according to the drainage area so that the source erosion could be computed for the entire watershed in one equation. A procedure for computing the erosion-control practice factor (P) was also established on a watershed basis using factors such as percentages of the watershed with straight rows, terracing, etc. Sediment-delivery ratios were computed for five small watersheds in Texas, which were then correlated with watershed characteristics; one of the predictive equations is given by

$$DR = 0.627 (SLP)^{0.403}$$

in which DR is the sediment-delivery ratio, and SLP is the percent slope of the main stem channel.

Williams (1972) recognized the fact that runoff is significantly affected by antecedent soil moisture, and replaced the rainfall energy factor (R) in the universal equation with the runoff factor (volume of runoff times peak runoff rate for a storm). The modified universal equation was derived to predict sediment yield for individual storms (note that the original universal equation predicts annual sediment yield). In deriving the equation, data from 18 watersheds in both Texas and Nebraska (drainage areas varying between 3 and 4,380 acres) were utilized. These data contained a total of 778 individual storms. The final expression that best fitted the data is

$$Y = 95 (Qq_p)^{0.56} K LS C P$$

in which Y is sediment yield in tons, Q is volume of runoff in acre-ft, and q_p is the peak flow rate in cfs. The other factors, K, LS, C, and P are all area-weighted to determine a single value for each watershed. A comparison of predicted yields with those obtained by the universal equation showed that the universal equation overpredicted sediment yield for years with low rainfall factors and underpredicted sediment yield for years with high rainfall factors.

Onstad and Foster (1975) developed a single-storm sediment-yield model for small watersheds by introducing modified universal soil loss equations for both the detachment capacity and the transport capacity. The detachment

capacity on segment j , E_j , is given by

$$E_j = \frac{W_j (\text{KCPS})_j}{185.85} (x_j^{1.5} - x_{j-1}^{1.5})$$

where x_j is the distance from the upper end of the slope to the lower end of segment j , and the energy term, W_j , is given as a function of both the rainfall and runoff energy;

$$W = 0.5 R_{st} + 15 Q q_p^{1/3}$$

where R_{st} is the storm-rainfall factor, Q is the storm runoff volume in in., and q_p is the storm peak runoff rate in in./hr. The transport capacity, T_c , at any downslope point, x , is similarly given by

$$T_c = \frac{\bar{K} \text{W} \text{K} \text{S} \text{C} \text{P}}{185.58} x^{1.5}$$

in which \bar{K} is an average soil erodibility factor weighted on the basis of the contribution of each segment to the different types of soils. In this model, detailed hydrological factors such as storm-runoff volume, storm-peak runoff, etc. are incorporated into the expression for the detachment capacity. The model is capable of predicting the sediment movement regime by simply comparing magnitudes of detachment and the transport capacities in the watershed; sediment deposition occurs when the detachment capacity exceeds the transport capacity, and erosion takes place in the opposite case.

Among sediment-yield predicting methods, various multiple regression analysis techniques have been quite frequently utilized; however, only a few methods are presented herein.

Flagman (1972a) selected four independent variables in obtaining an empirical equation to predict sediment yields in the western United States by incorporating factors related to climate, geology, topography, soil characteristics, land use, etc. The four variables x_1 , x_2 , x_3 , and x_4 are the ratio of the average annual precipitation (in.) to the average annual temperature (F°), watershed slope (percent), percent of soil particles coarser than 1 mm in the top 2-in. of the soil surface, and a soil aggregation index by pH-values, respectively. The final expression for the annual sediment yield, Y (acre-ft/sq mi/yr), was obtained using sediment deposition data in reservoirs as follows:

$$\log(Y+100) = 6.21 - 2.19 \log(x_1+100) + 0.060 \log(x_2+100) \\ - 0.016 \log(x_3+100) + 0.042 \log(x_4+100)$$

A comparison of measured and calculated values of Y shows that this empirical formula can predict annual sediment yields fairly accurately for values of Y greater than 0.01. The author suggested that more detailed sampling of soil and compensation for exceptional storms exceeding normal measurements during the period of record can further improve the accuracy of the equation. The interesting point in this approach is that only a few independent variables can delineate the sediment yields quantitatively despite the great range in climate, geography, soil properties, and land-use conditions.

Malcolm (1977) classified drainage areas into four different categories: wooded areas, rural areas, urban areas, and severely exposed watersheds, and developed sediment discharge equations for the individual zones. The annual sediment discharge, S(acre-ft/yr), was assumed to be a function of only the drainage area, A (sq mi), as given by

$$S = KA^b$$

where K and b are empirical constants. Values of K and b were determined for each classification of the drainage basin using data based on lake-deposit measurements in the eastern United States. Combinations of K and b, (K,b), for each category are (0.068, 0.80), (0.354, 0.99), (2.96, 0.67), and (34.5, 0.84), respectively. Note that these values were obtained by a regression analysis. Although the exponents, b, are relatively constant, the intercept, K, is seen to increase considerably with a decreasing soil cover.

Flaxman (1972b) also utilized a regression analysis to obtain the empirical relationship between sediment concentration, Y(mg/l), and flow discharge, X(cfs), in the following form:

$$Y = ax^m$$

in which a and m are empirical constants. Various values for a and m were obtained for different watersheds in the West. Larger values of the constant, a, are found to be associated with data from dry areas, while smaller values are obtained in humid areas where watershed surfaces are generally well protected by vegetative covers. Watersheds with $m < 1$ are characterized by

greater availability of sediment during low and moderate discharges; erosion takes place during low-intensity storms or during the early or late stages of a large storm. Values of the index, m , as small as 0.16 or 0.25 are reported for data obtained from southeastern Arizona, known for trenching which extends through its alluvial valley. On the other hand, watersheds with $m > 1$ are characterized by a greater susceptibility to erosion during periods of melting snow: very low sediment concentrations during low or moderate discharges relative to the concentration at higher discharges. A multiple regression analysis was also performed to correlate the quantity a , with average annual runoff, X_1 , and the quantity m , resulting in

$$a = \text{antilog} (5.9085 - 1.4964 \log X_1 - 2.2386 m)$$

It is noted that the values of a and m for the same watershed would change considerably after major floods which tend to alter the watershed characteristics by enlarging sediment-source areas or creating new sediment sources.

Hindall (1976) analyzed sediment data collected throughout Wisconsin and developed, by a regression technique, sediment-yield prediction equations for four geographical regions in Wisconsin. These four equations were derived by correlating mean suspended-sediment yields with drainage area, stream flow, topography, soil characteristics, climatic conditions, surface cover conditions, etc. A total of fourteen independent variables, including drainage area, average water discharge, two-year flood discharge, channel slope, runoff factor, etc. was introduced in this approach. The result, however, shows that only a few factors are important in estimating sediment yields for certain geographical regions. It is reported that the standard error of estimate for these equations ranges between 28 to 38 percent.

Besides these watershed-specific prediction models, the following methods have been extensively used by various agencies: flow-duration, sediment-rating curve method (by Corps of Engineers (COE) and Bureau of Reclamation (BOR)); gross-erosion and sediment-delivery ratio procedure (by Soil Conservation Service (SCS)); reservoir sediment accumulation measurements (by COE, BOR, and SCS); and suspended-sediment load measurements (by COE, BOR, SCS, and USGS). Detailed descriptions of these techniques can be found in many references (e.g., Vanoni 1975).

V. DESIGN OF STUDY

The following list summarizes major items which are considered to be important in accomplishing the Sediment and Erosion Work Group tasks for the GREAT-II program:

1. Select from the GREAT-II study area representative watershed(s) which has (have) adequate information (in both data quality and data-record length) on runoff as well as sediment yield. Candidates would be the Des Moines River basin (upper and middle river basins) and the Iowa River basin.
2. Test several existing methods, some of which are presented in the report, on selected watersheds and determine the method which best can be utilized for estimating annual sediment yields.
3. Develop, if necessary, a new predictive method for selected watersheds using multiple regression techniques. Some of the approaches are described in the previous chapter.
4. Obtain for each pool in the Mississippi River a correlation between annual dredging volume in the channel and tributary sediment input to identify major sediment sources in the Mississippi River corridor.

VI. SUMMARY

The principal results of this study may be summarized as follows:

1. An inventory of suspended-sediment data together with stream flow data available in the GREAT-II study area was completed. Based on this phase of the study, the inadequacy in number of sediment sampling stations was pointed out, and recommendations were presented for locating new sampling stations on major tributaries of the Mississippi River.
2. An approximate estimate of sediment yield at each station was made by correlating monthly averaged water discharges with monthly averaged suspended sediment discharges. The results were not only useful in identifying potential sources of excessive sediment discharges into the Mississippi River, but also were used to make recommendations for new sediment stations.
3. Based on the approximate estimates, tentative regionalized curves were provided.

4. Several sediment-yield predictive methods, which are pertinent to the Sediment and Erosion Work Group tasks, were reviewed.
5. Recommendations for further study of the sediment-yield regime of the Mississippi River in the GREAT-II reach were set forth.

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Table 1. Summary of principal quantities obtained in the study (COE stations)

I.D. No.	Waterway	Location	Drain. Area (mi ²)	Record Period (yr)	Sampling Freq.*	Period of Record Compiled (water yr)	Mean Sed. Yield (tons/mi ² /yr)	Power-Law Fitting $Q_s = aQ_b$	Standard Deviation About Fitted Line	Min. Daily Load (tons/day)	Max. Daily Load (tons/day)	Total Yield (tons/yr)
1	Miss. R.	E. Dubuque	82,000	33	B	'68-'74	56.64	1.98×10^{-7}	0.275	314	84,396	4.64×10^6
2	Miss. R.	Burlington	114,000	33	B							
3	Miss. R.	Keokuk	119,000	31	A	'68-'75	112.92	2.39×10^{-8}	0.214	580	317,960	1.34×10^7
4	Miss. R.	Hannibal	137,300	31	A	'68-'74	188.52	3.19×10^{-4}	0.329	1,450	441,462	2.59×10^7
5	Wapsi. R.	DeWitt	2,330	33	B	'68-'75	342.96	8.36×10^{-3}	0.384	26.2	30,212	7.99×10^5
6	Iowa R.	Marengo	2,794	28	A	'68-'75	506.76	7.33×10^{-3}	0.365	18.4	36,841	1.42×10^6
7	Iowa R.	Coralville	3,115	13	A	'68-'74	45.24	9.54×10^{-3}	0.344	4	3,146	1.41×10^5
8	Skunk R.	Ames	556	7	A	'68-'74	509.88	1.35×10^{-1}	0.322	0.1	6,097	2.83×10^5
9	Des M. R.	Stratford	5,452	7	A	'69-'74	157.92	3.14×10^{-3}	0.285	7.8	11,729	8.61×10^5
10	Des M. R.	Boone	5,511	35	B	'68-'74	199.68	8.17×10^{-3}	0.290	4.8	22,284	1.10×10^6
11	Des M. R.	Tracy	12,479	35	B	'68-'75	75.84	1.00×10^{-1}	0.357	25.2	11,596	9.46×10^5
12	Raccoon R.	Van Meter	3,441	35	B	'68-'74	679.08	4.68×10^{-3}	0.364	7.8	78,538	2.34×10^6
13	North R.	Norwalk	349	13	B	'68-'74	529.32	1.10×10^{-1}	0.436	0	3,734	1.85×10^5
14	Middle R.	Indianola	503	13	A	'68-'74	2,030.04	2.35×10^{-2}	0.429	0.2	28,356	1.02×10^6
15	South R.	Ackworth	460	13	A	'68-'75	2,332.08	1.06×10^{-1}	0.456	0.4	37,530	1.07×10^6
17	Hadley Cr.	Kinderhook	72.7	35	C	'68-'74	9.621.72	2.39×10^{-1}	0.713	0.06	88,336	6.99×10^5
18	Bay Cr.	Nebo	162	33	C	'68-'74	3,683.40	7.09×10^{-2}	0.634	0.97	24,742	5.97×10^5

MONTHLY AVERAGED DATA NOT AVAILABLE YET

* A = Daily
 B = Daily except winter months
 C = Daily except winter months, with additional samples during rises

Table 1. Cont'd (USGS stations)

I.D. No.	Waterway	Location	Drain. Area (mi ²)	Record Period (yr)	Sampling Freq.	Period of Record Compiled (water yr)	Mean Sed. Yield (tons/mi ² /yr)	Power-Law Fitting $Q_s = aQ^b$		Standard Deviation About Fitted Line	Min. Daily Load (tons/day)	Max. Daily Load (tons/day)	Total Yield (tons/yr)
								a	b				
30	Turkey R.	Garber	1,545	5	A	'58-'62	1,203.96	9.07×10^{-4}	2.10	0.631	2	29,100	1.86×10^6
31	Wapsi R.	Independence	1,048	3	A	'68-'70	60.60	1.97×10^{-3}	1.63	0.377	1.2	2,100	6.35×10^4
32	Iowa R.	Rowan	429	5	A	'58-'62	25.80	2.86×10^{-2}	1.33	0.322	0.1	282	1.11×10^4
33	Iowa R.	Iowa City	3,271	33	A	'68-'76	132.24	7.05×10^{-3}	1.49	0.305	13	17,362	4.33×10^5
34	Ralston Cr.	Iowa City	3.01	24	A	'68-'76	758.16	5.64×10^{-1}	1.37	0.482	0	167	2.28×10^3
35	Fourmile Cr.	Lincoln	13.78	5	A	'70-'74	660.24	3.48×10^{-1}	1.40	0.355	0.2	283	2.50×10^3
36	Half Mile Cr.	Gladbrook	1.33	5	A	'70-'74	197.28	4.80×10^{-1}	1.32	0.328	0	5	2.62×10^2
37	Fourmile Cr.	Traer	19.51	5	A	'70-'74	432.72	1.98×10^{-1}	1.54	0.279	0.1	267	8.44×10^3
38	Cedar R.	Cedar R.	6,510	11	A	'45-'54	134.64	2.89×10^{-4}	1.86	0.308	8.4	49,500	8.77×10^5
39	Des M. R.	Saylorville	5,841	15	A	'68-'76	221.86	4.26×10^{-3}	1.67	0.255	7.1	22,700	1.30×10^6
40	Des M. R.	Des M.	6,245	6	A	'56-'61	103.32	4.37×10^{-3}	1.70	0.289	3.6	15,200	6.45×10^5
41	E. Fork H.Cr.	Churdan	24	5	A	'53-'57	36.00	2.16×10^{-1}	1.08	0.378	0	40	8.64×10^2
42	Des. M. R.	Des M.*	9,879	3	A	'45-'47	498.36	3.34×10^{-4}	1.96	0.299	57	110,000	4.92×10^6
43	Middle R.	Indianola	503	13	A	SEE COE-DATA (COE (14))							
44	White. Cr.	Dallas	342	7	A	'68-'74	1,210.68	2.12×10^{-1}	1.51	0.520	0.2	15,885	4.14×10^5

* Below the Raccoon River

Table 2. Comparison of the estimated total sediment yields with those from the COE study

Agency	Waterway and Location	(1)	(2)*	(3)
		Suspended Yield (tons/sq mi/yr)	Estimated Total Yield (tons/sq mi/yr)	COE's Estimated Total Yield (tons/sq mi/yr)
USGS	Turkey R. @ Garber, Ia.	1,203.96	1,338	1,000
COE	Miss. R. @ E. Dubuque, Ill.	56.64	63	42
COE	Wapsipinicon R. @ DeWitt, Ia.	342.96	381	221
USGS	Iowa R. @ Rowan, Ia.	25.80	29	34
COE	Iowa R. @ Marengo, Ia.	506.76	563	365
COE	Iowa R. above Coralville, Ia.	45.24	50	445
USGS	Iowa R. @ Iowa City, Ia.	132.24	147	260
USGS	Ralston Cr. @ Iowa City, Ia.	758.16	842	1,800
USGS	Cedar R. @ Cedar Rapids, Ia.	134.64	150	120
COE	Miss. R. @ Keokuk, Ia.	112.92	125	79
COE	Des Moines R. @ Boone, Ia.	199.68	222	223
USGS	Des Moines R. @ Saylorville, Ia.	221.88	246	180
USGS	Des Moines R. @ Des Moines, Ia.	103.32	115	180
USGS	E.F. Hardin Cr. @ Churdan, Ia.	36.00	40	65
COE	Raccoon R. @ Van Meter, Ia.	679.08	754	779
USGS	D.M. River blw Raccoon R @ D.M., Ia.	498.36	554	330
COE	North R. @ Norwalk, Ia.	529.34	588	941
COE	Middle R. @ Indianola, Ia.	2,030.04	2,256	2,300
COE	South R. @ Ackworth, Ia.	2,332.08	2,591	2,946
USGS	Whitebreast Cr. @ Dallas, Ia.	1,210.68	1,345	2,215
COE	Des Moines R. @ Tracy, Ia.	75.84	84	675
COE	Miss. R. @ Hannibal, Mo.	188.52	209	181
COE	Hadley Cr. @ Kinderhook, Ill.	9,621.72	10,757	4,102
COE	Bay Cr. @ Nebo, Ill.	3,683.40	4,093	3,730

* (2)=(1)/0.9

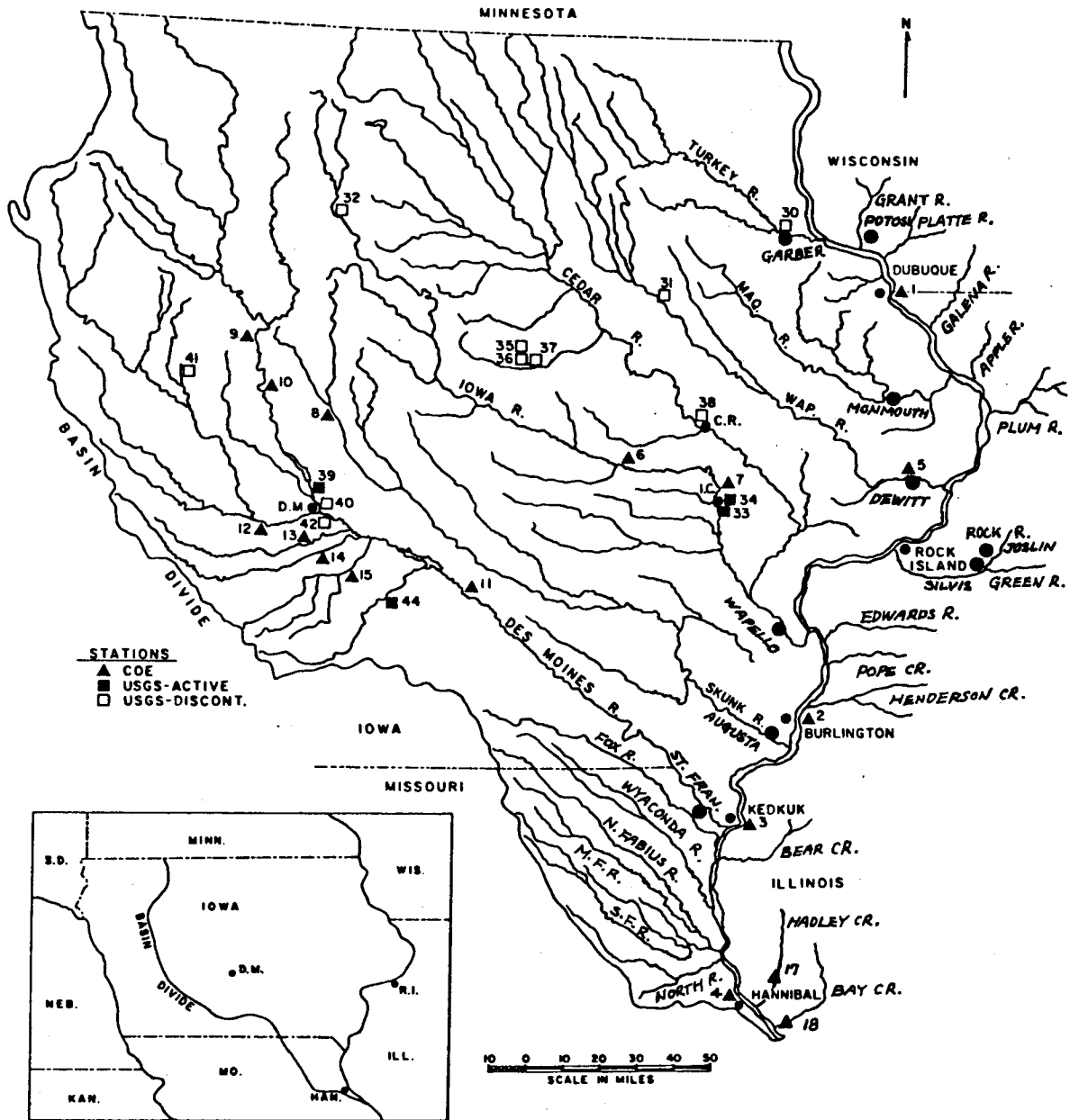


Figure 1-A. Identification of sediment sampling stations

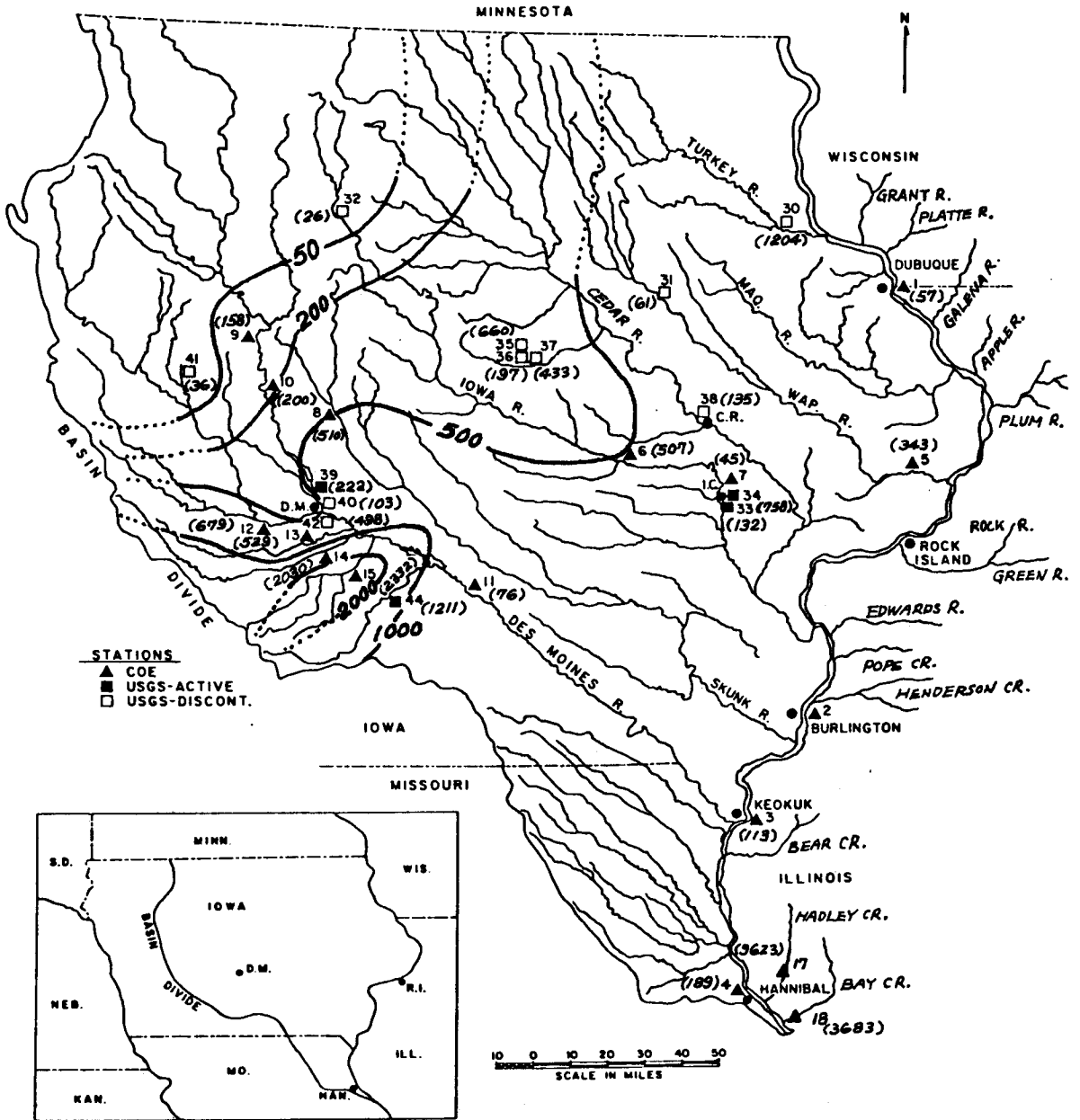


Figure 1-B. Estimated mean sediment yield at each station and tentative regionalized curves

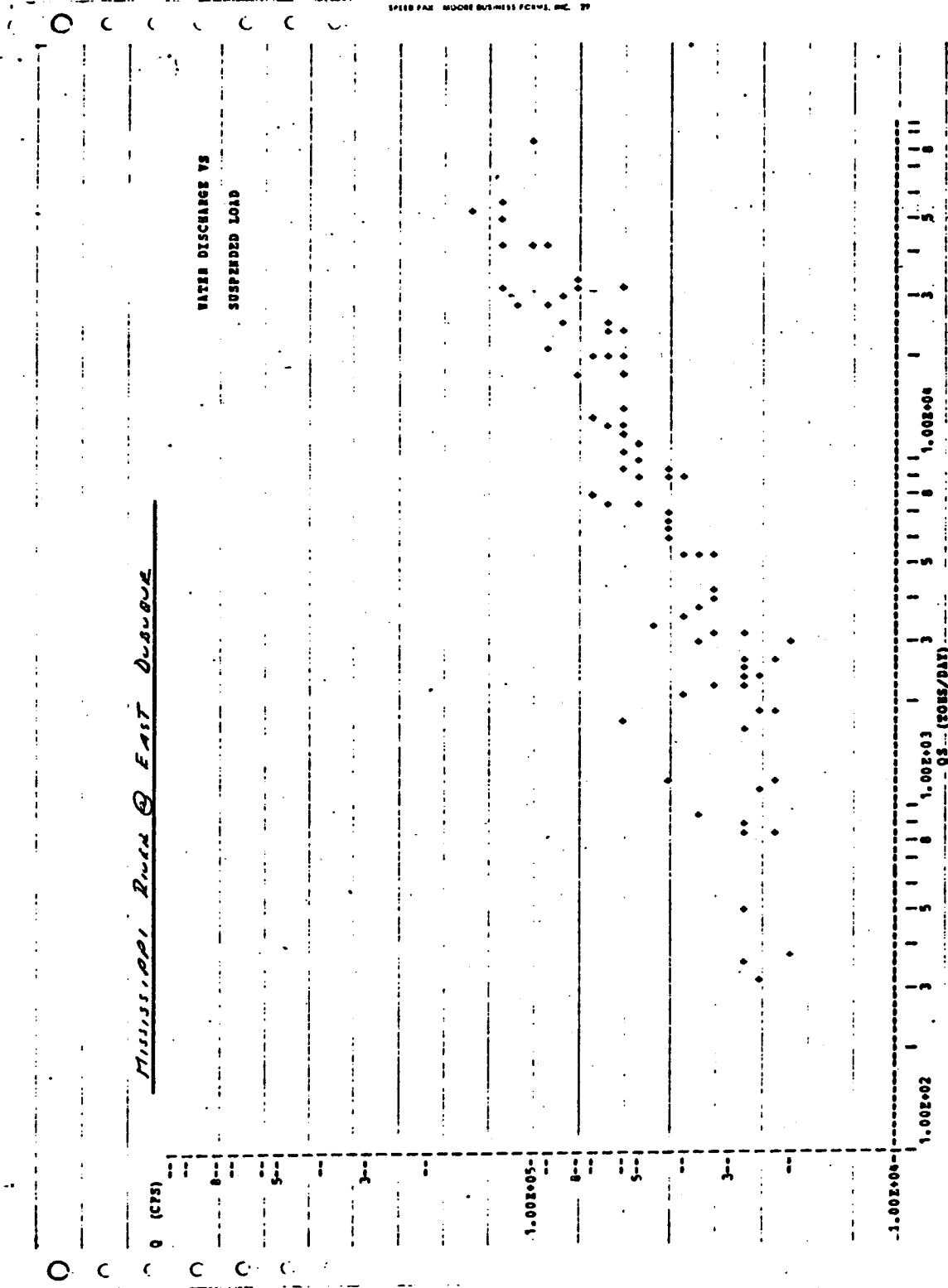


Figure 2. Relationship between Q and Q_s for the Mississippi River at East Dubuque, Illinois

MISSISSIPPI RIVER @ Keokuk

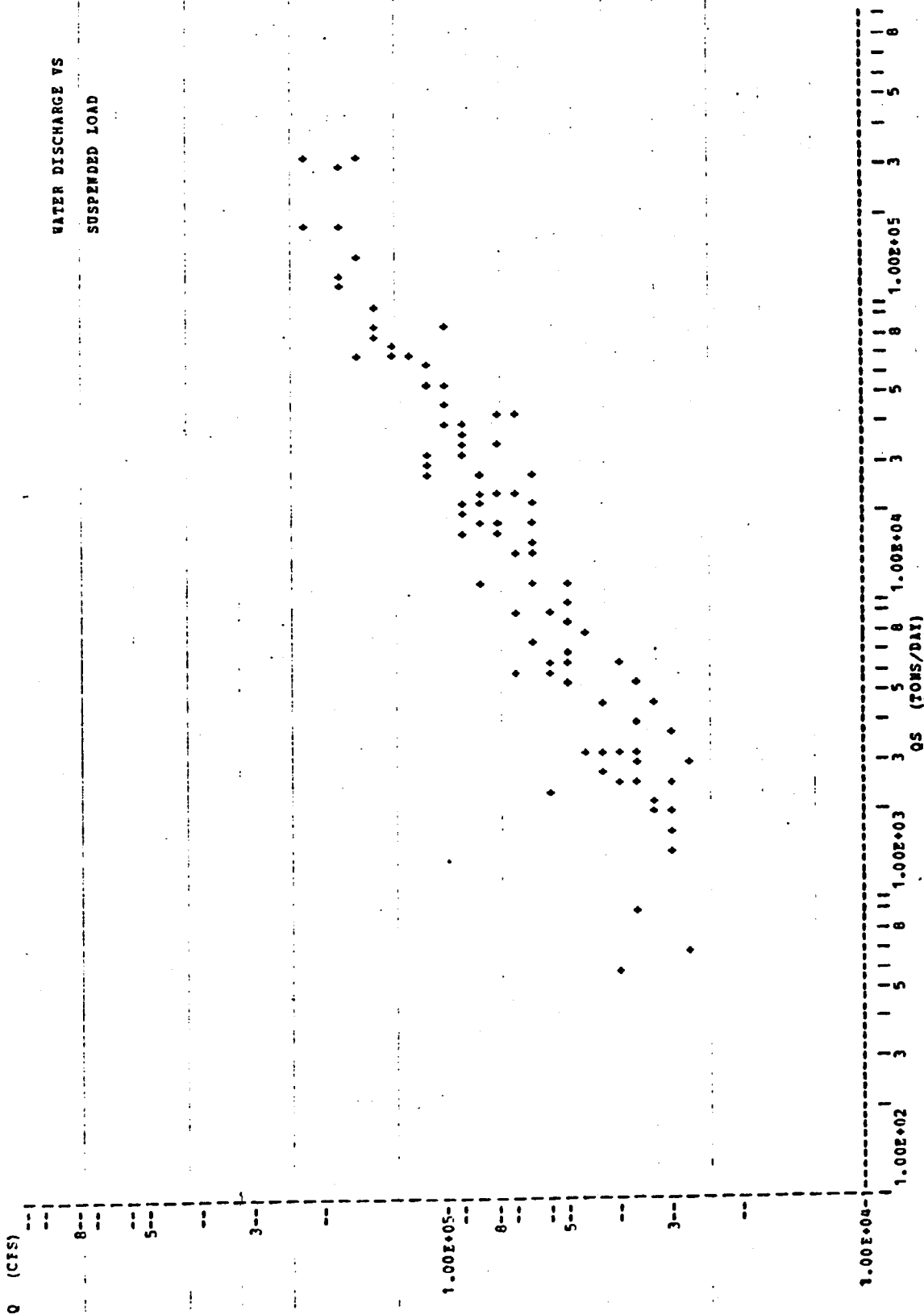


Figure 3. Relationship between Q and Q_S for the Mississippi River at Keokuk, Iowa

MISSISSIPPI RIVER @ HANNIBAL

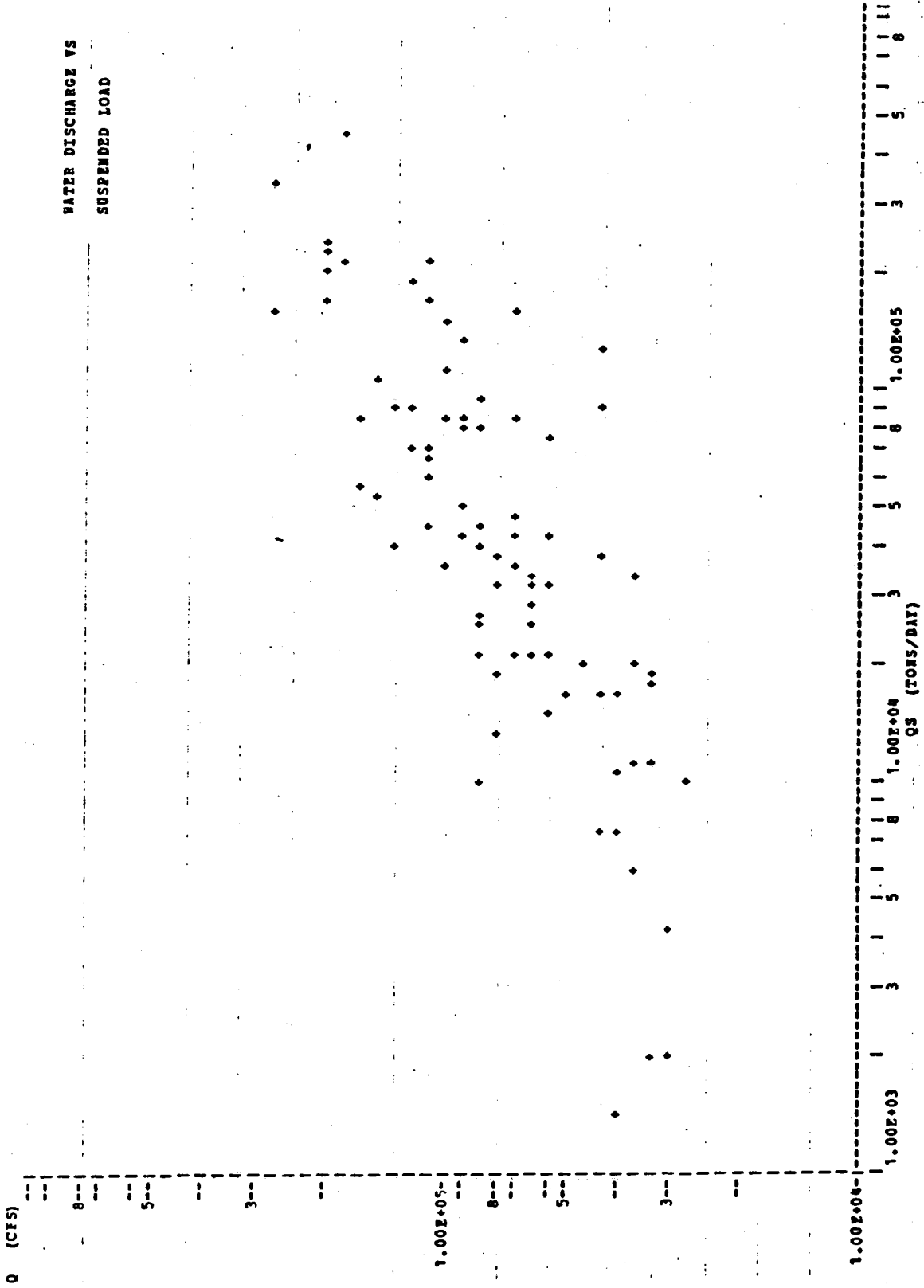


Figure 4. Relationship between Q and Q_s for the Mississippi River at Hannibal, Missouri

WAPSIPINICON RIVER @ DE WITT

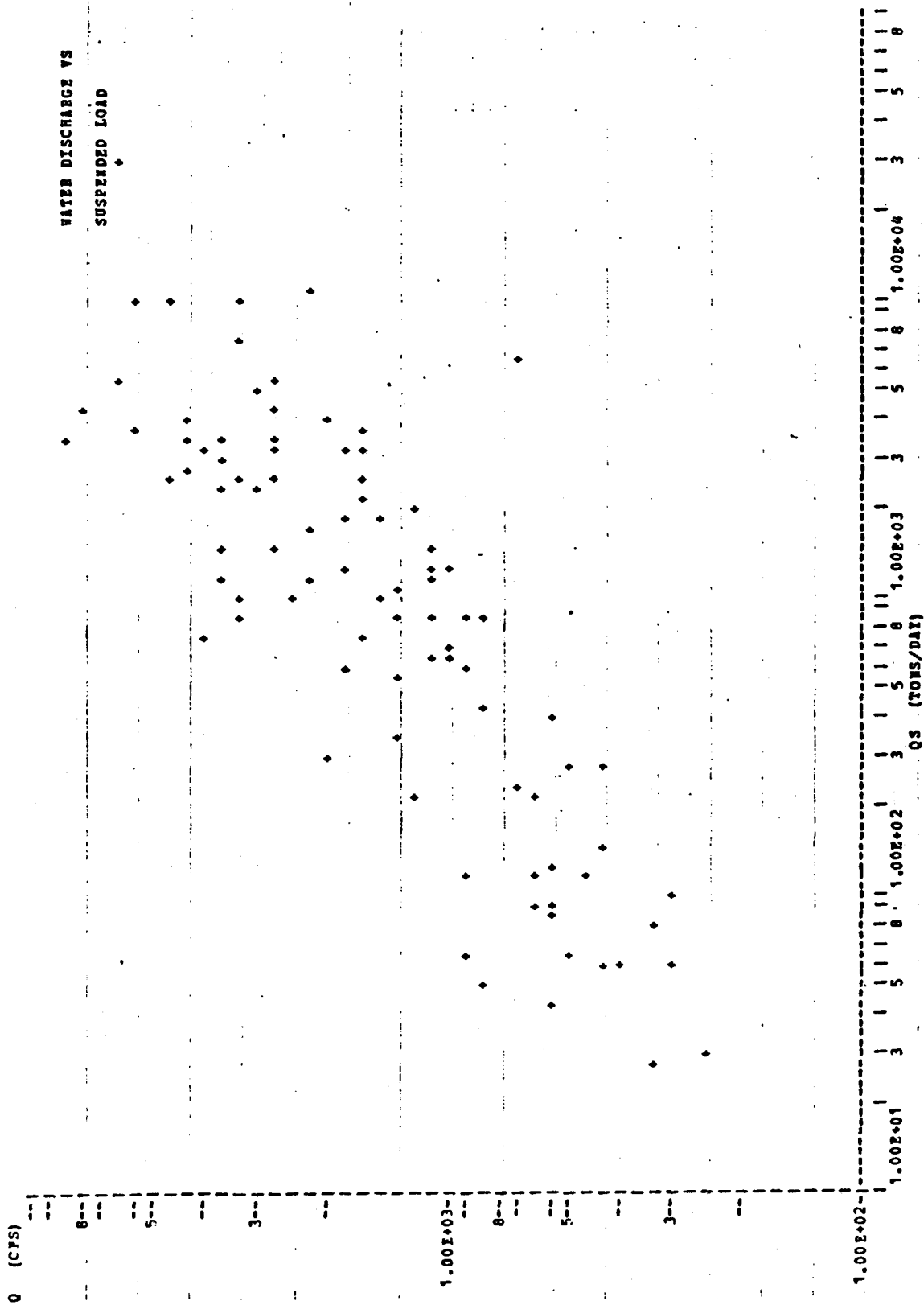


Figure 5. Relationship between Q and Q_s for the Wapsipinicon River at De Witt, Iowa

IOWA RIVER @ MARENGO

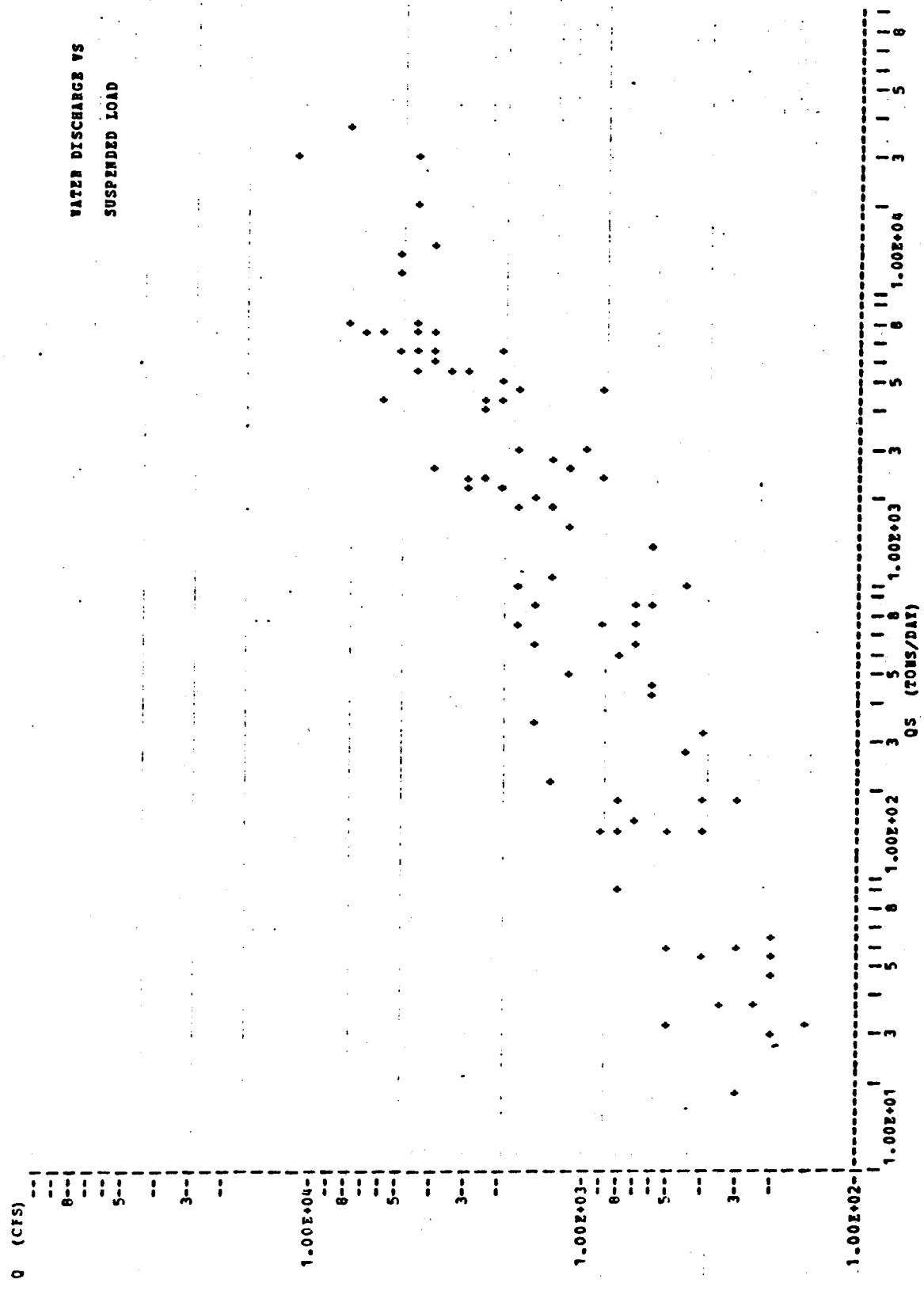


Figure 6. Relationship between Q and Q_s for the Iowa River at Marengo, Iowa

Iowa River @ Coralville Dam

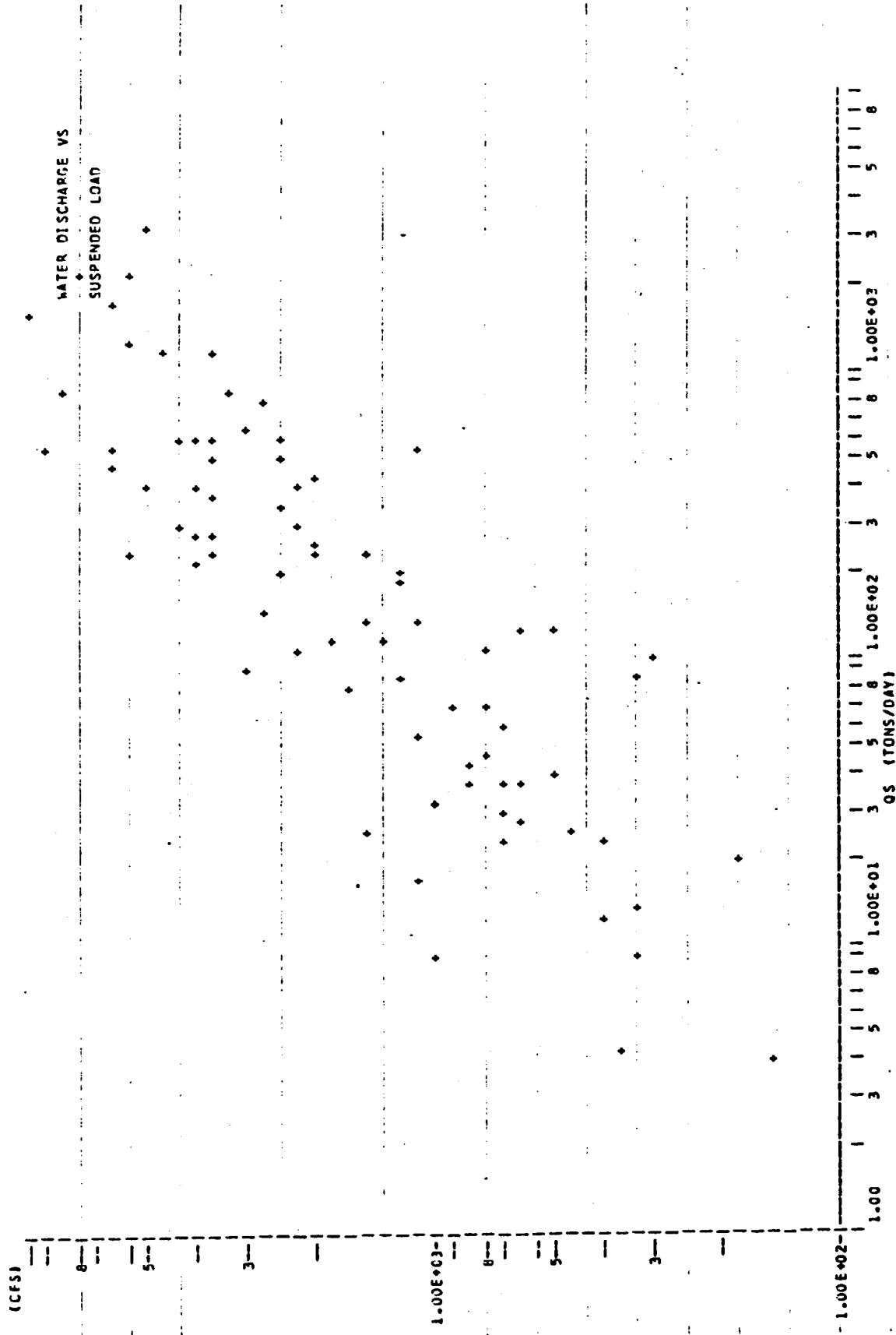


Figure 7. Relationship between Q and Q_s for the Iowa River at Coralville Dam, Iowa

SKUNK RIVER @ AMES

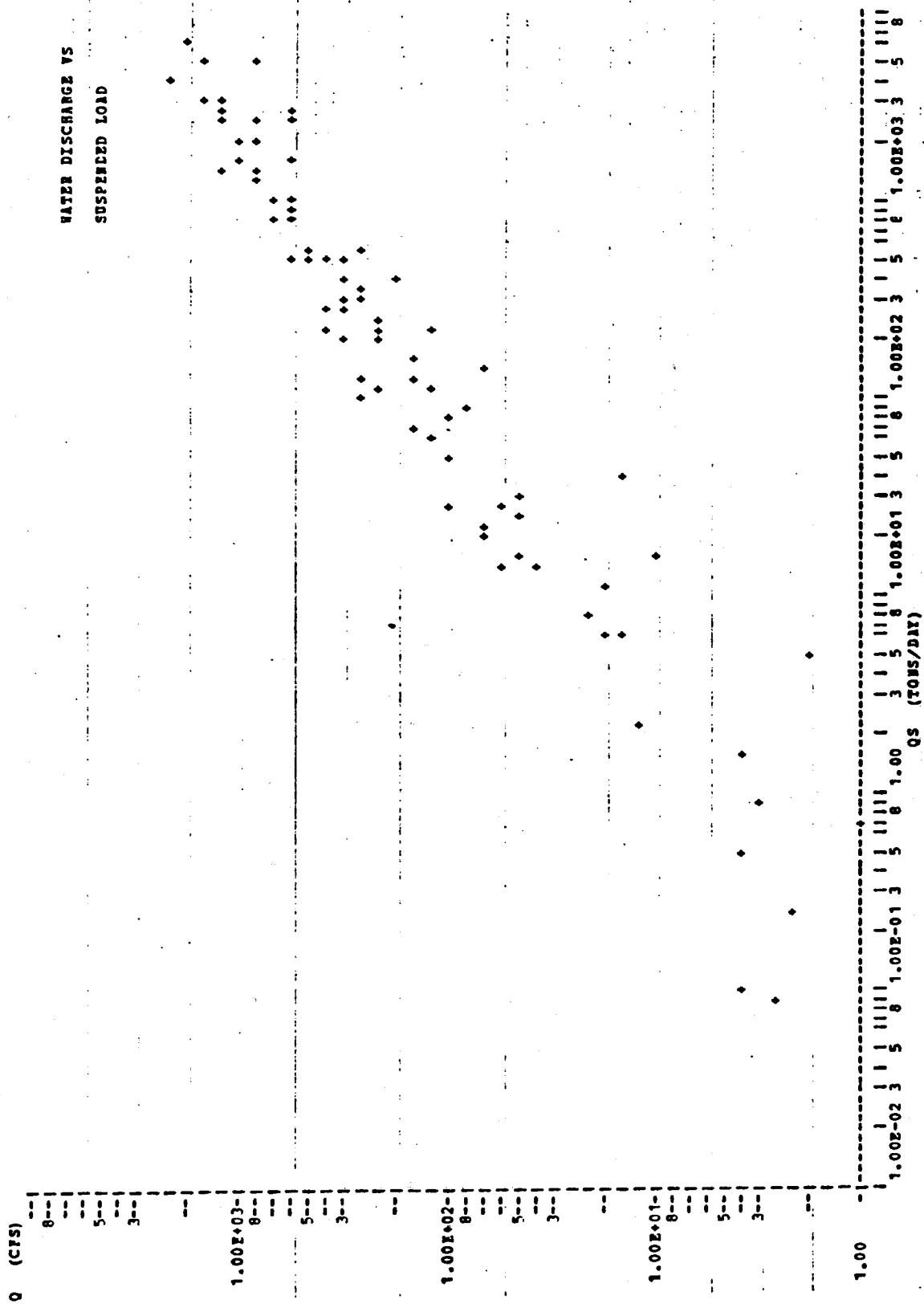


Figure 8. Relationship between Q and Q_S for the Skunk River at Ames, Iowa

SPEED AND A. 218 B. 1955-1960

Des Moines River @ Boone

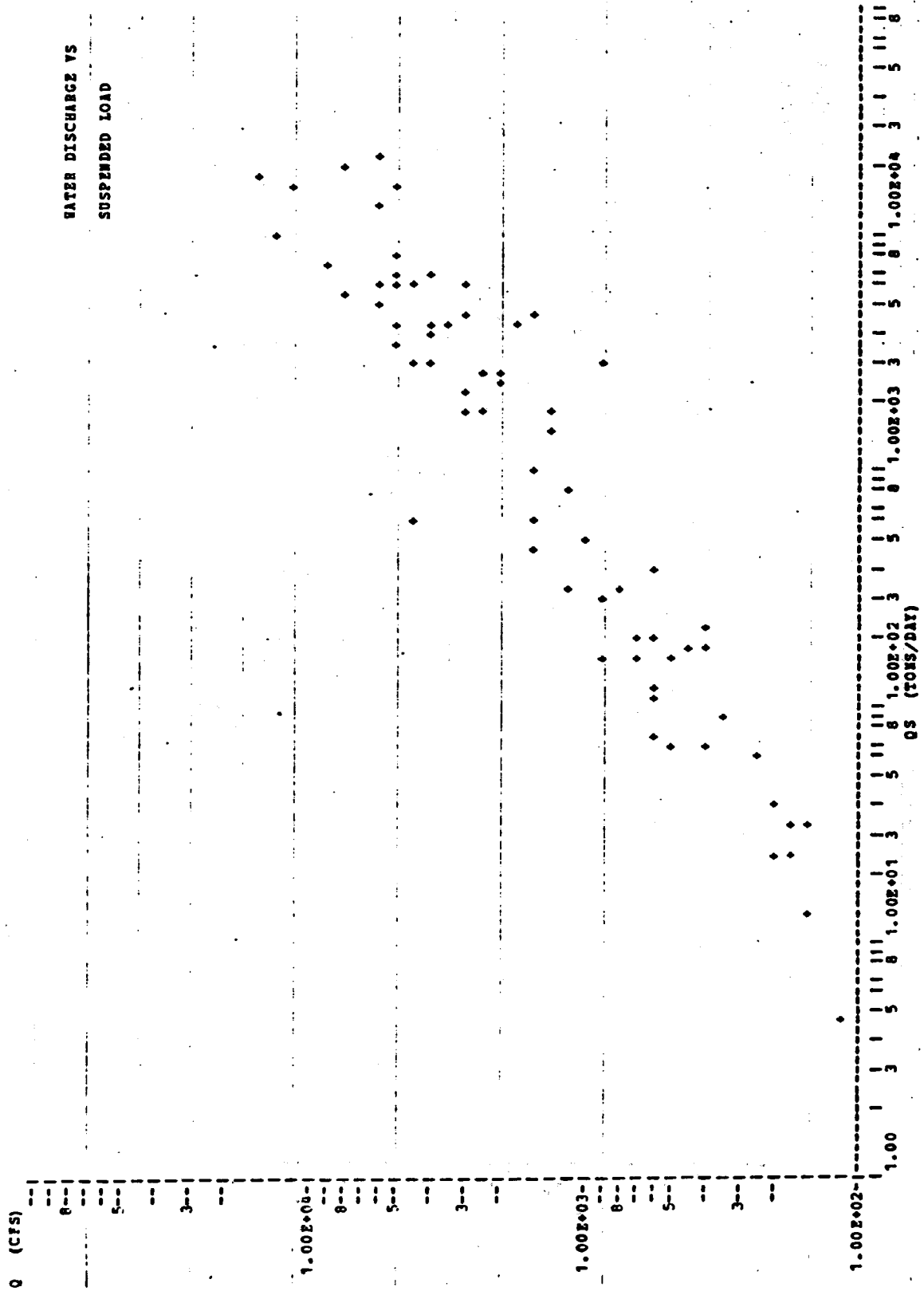


Figure 10. Relationship between Q and Q_s for the Des Moines River at Boone, Iowa

Des Moines River @ Tracy

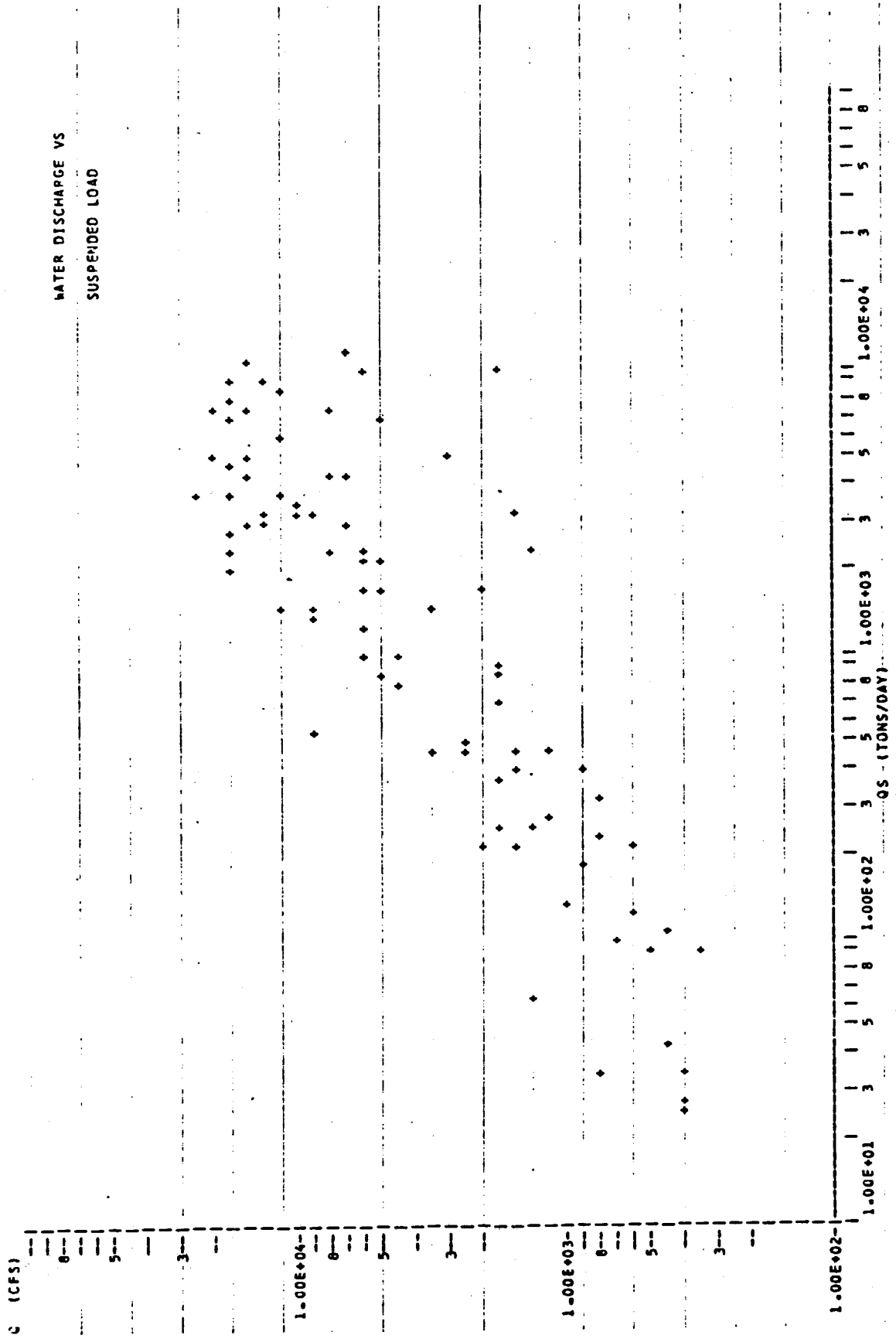


Figure 11. Relationship between Q and Q_s for the Des Moines River at Tracy, Iowa

Raccoon River @ Van Meter

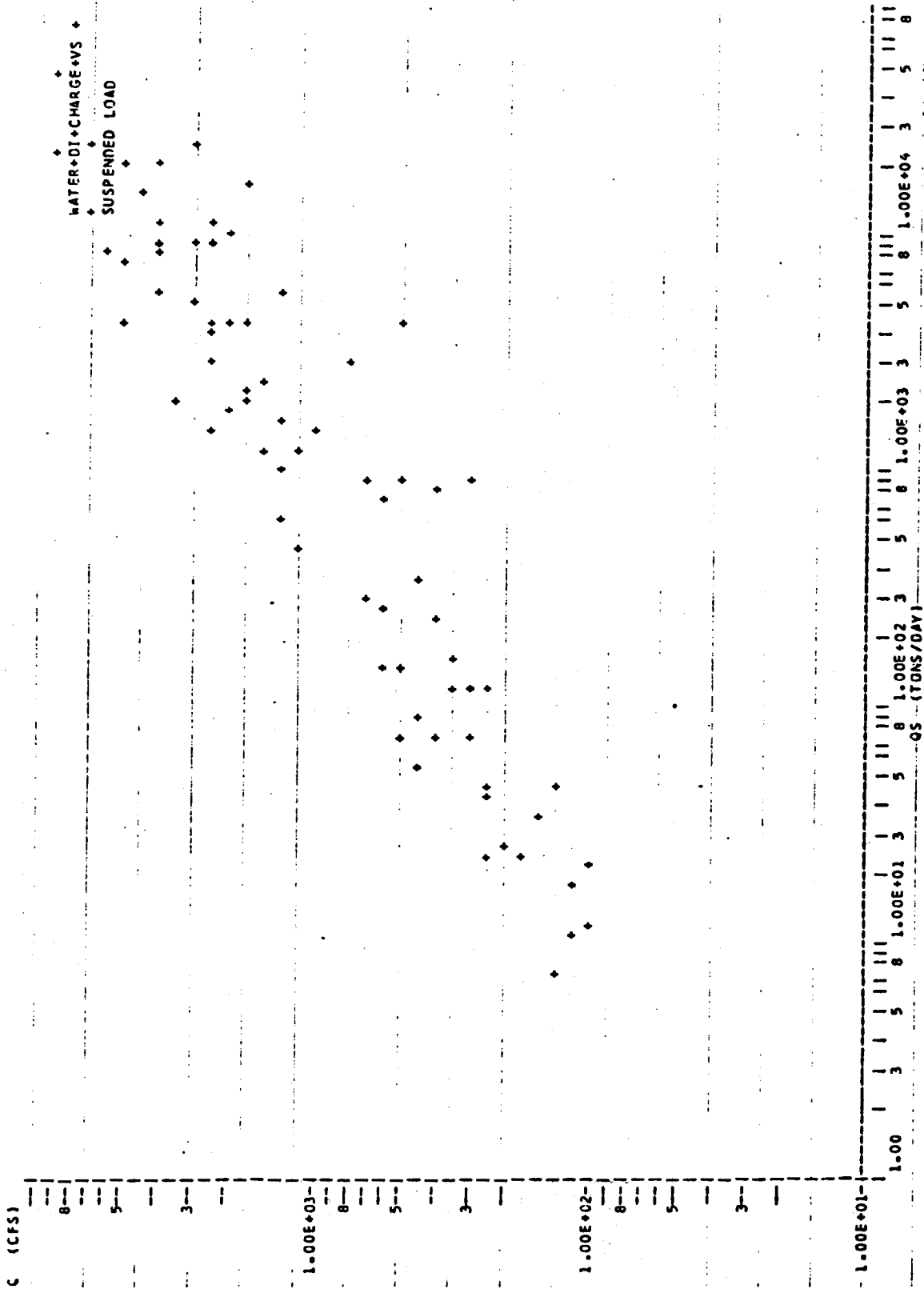


Figure 12. Relationship between Q and Q_s for the Raccoon River at Van Meter, Iowa

North River @ Norwalk

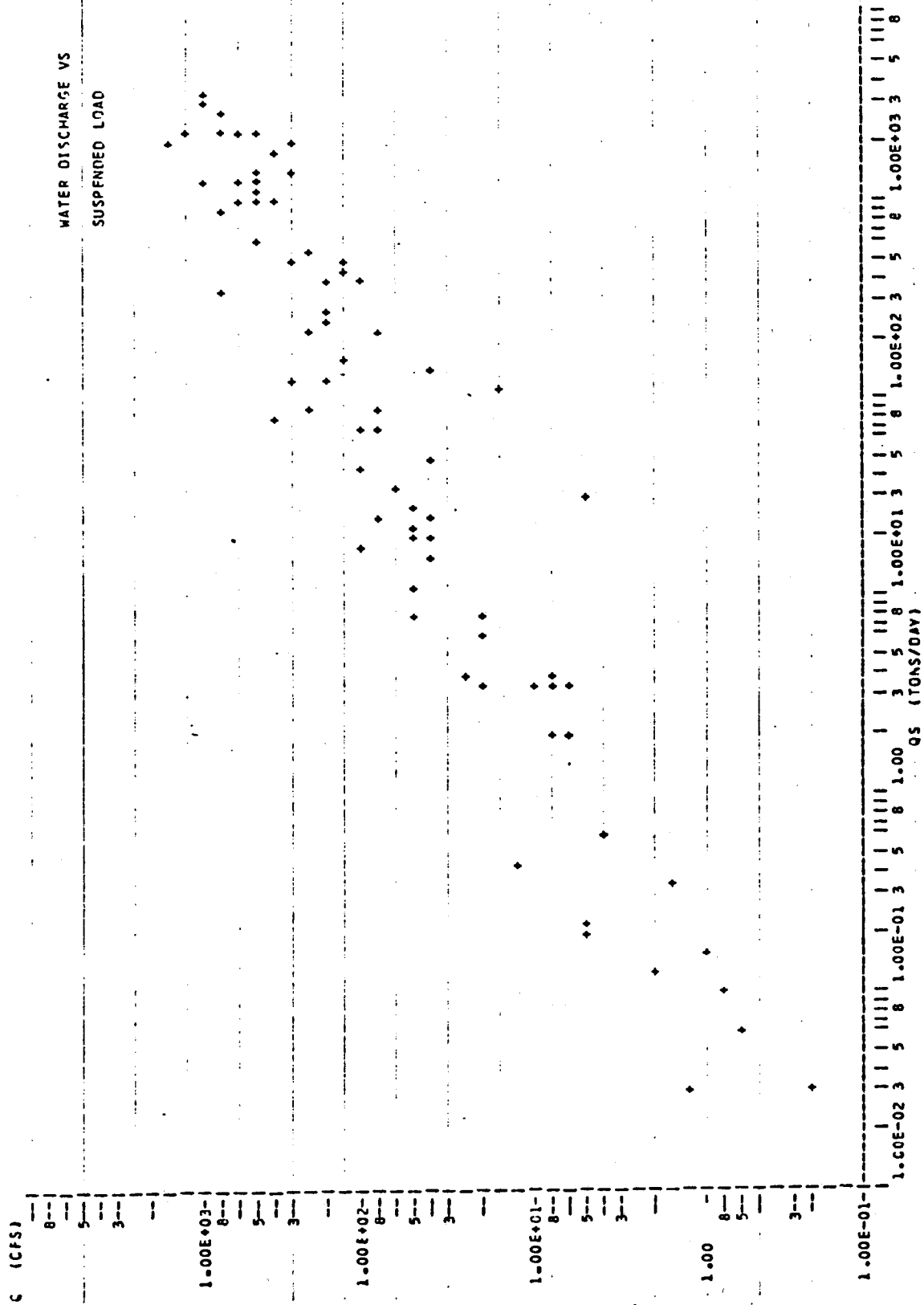


Figure 13. Relationship between Q and Q_s for the North River at Norwalk, Iowa

MIDDLE RIVER @ INDIANOLA

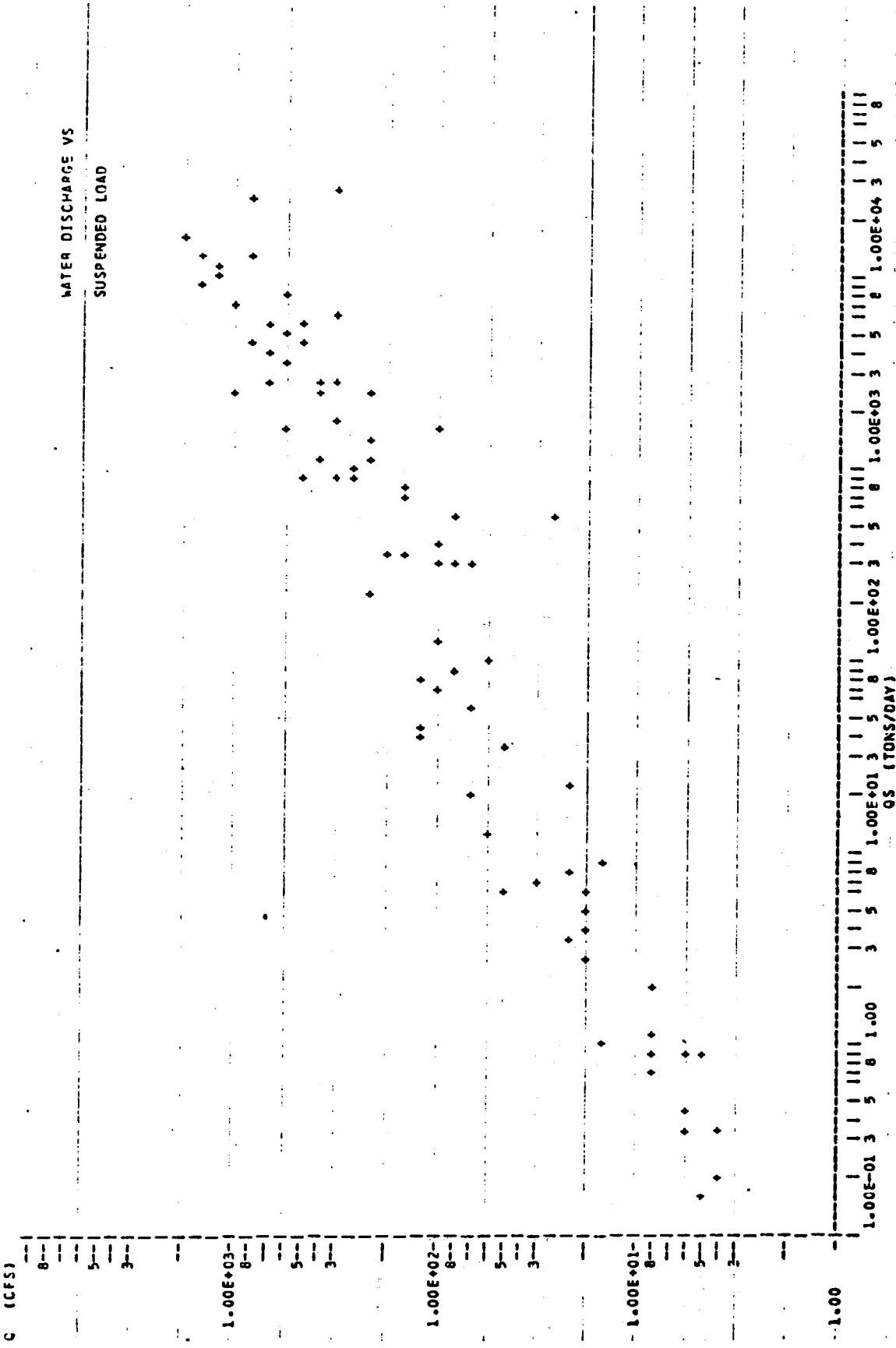


Figure 14. Relationship between Q and Q_S for the Middle River at Indianola, Iowa

South River @ Ackworth

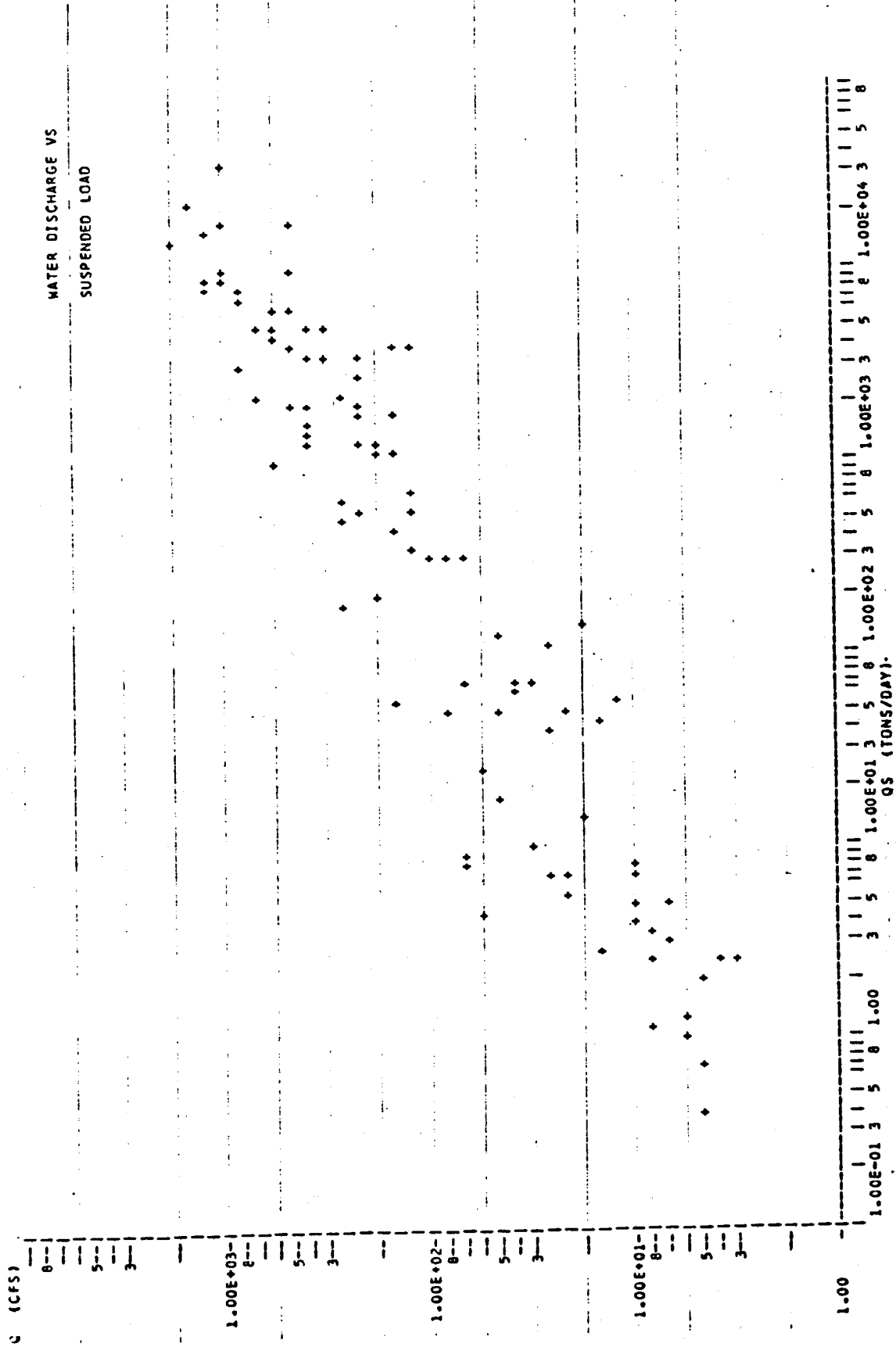


Figure 15. Relationship between Q and Q_s for the South River at Ackworth, Iowa

HADLEY CR. @ KINDERHOOK ILL.

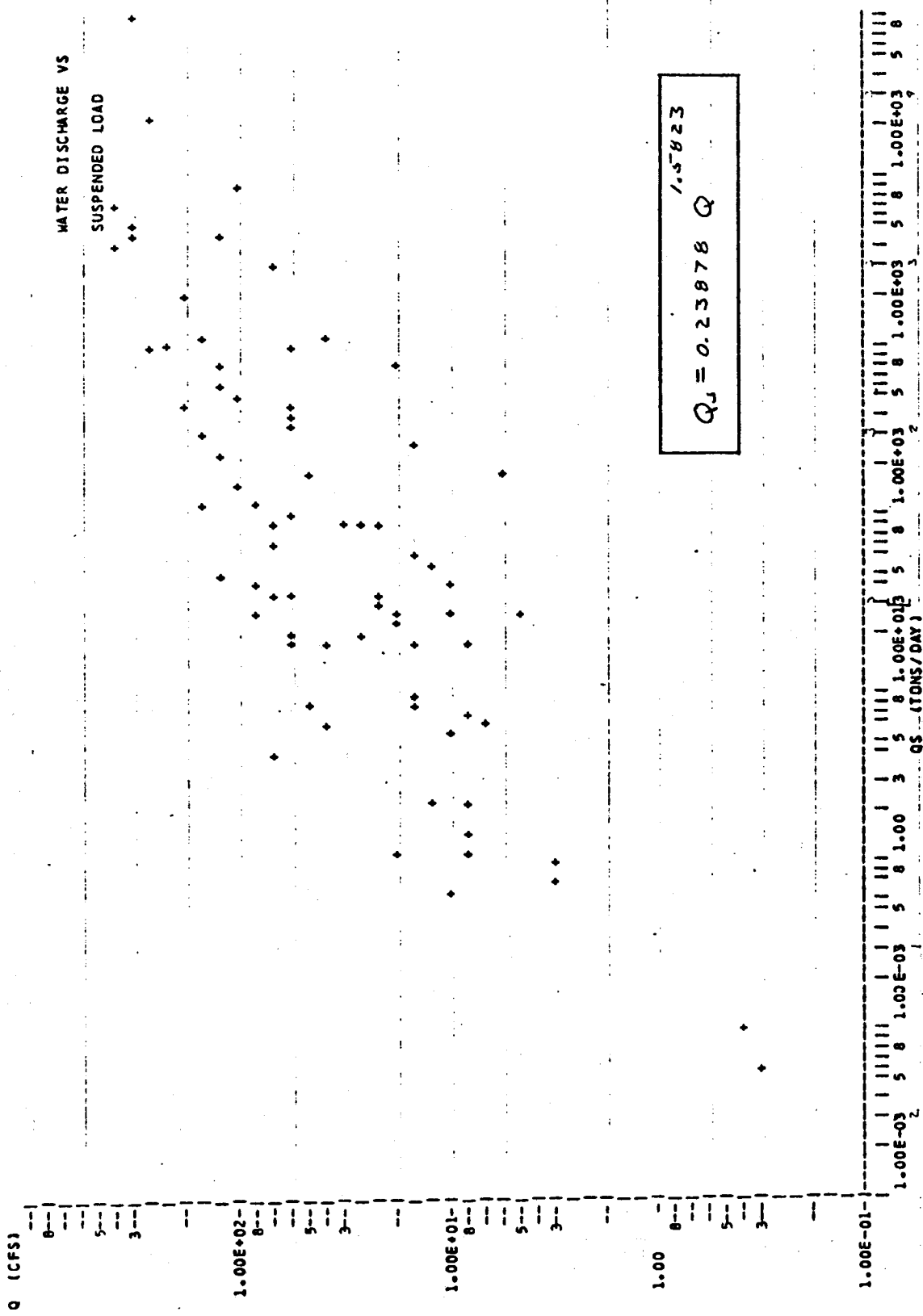


Figure 16. Relationship between Q and Q_s for Hadley Creek at Kinderhook, Illinois

BAY CREEK @ NEBO, ILL.

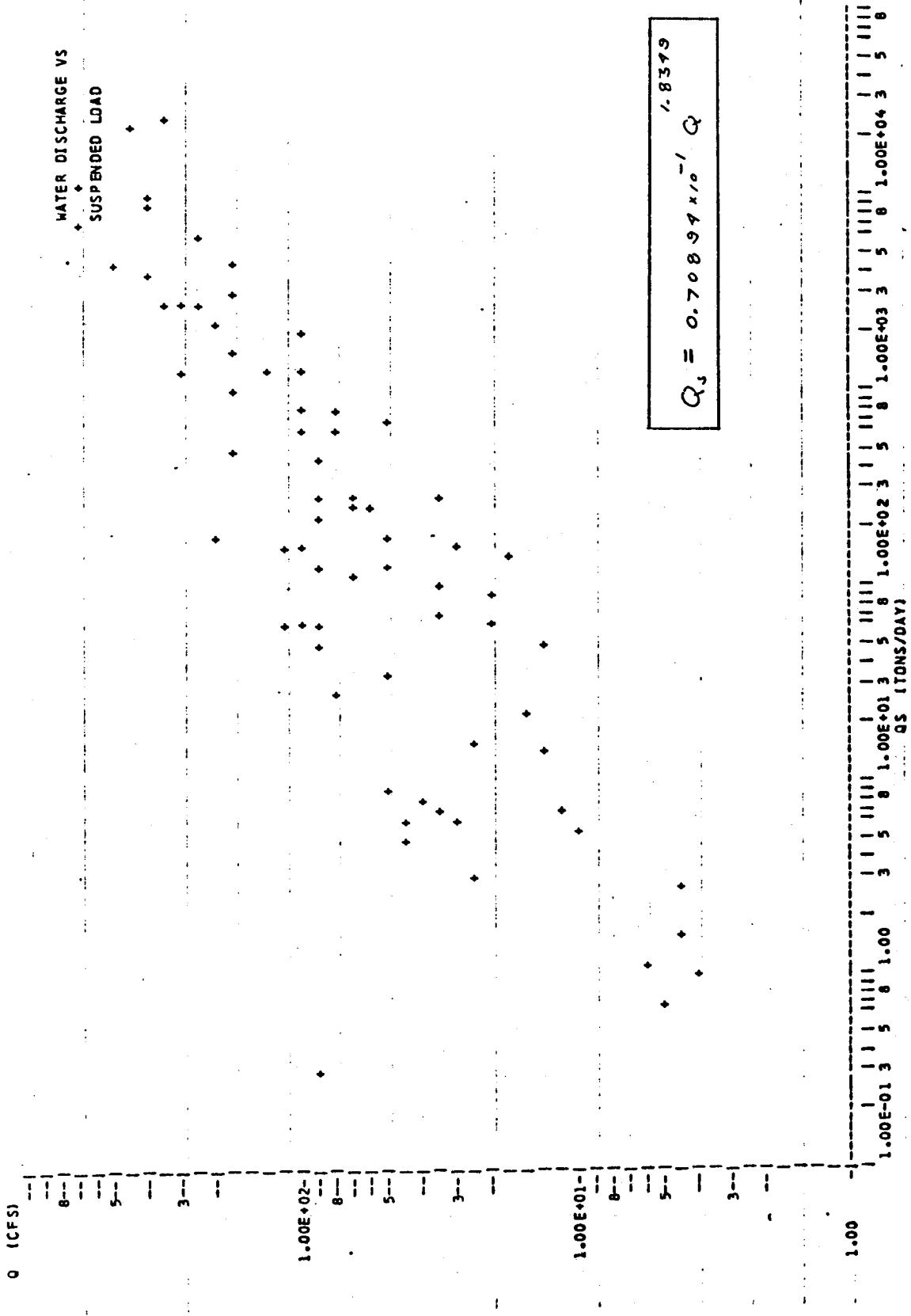


Figure 17. Relationship between Q and Q_s for Bay Creek at Nebo, Illinois

Turkey River @ Garber

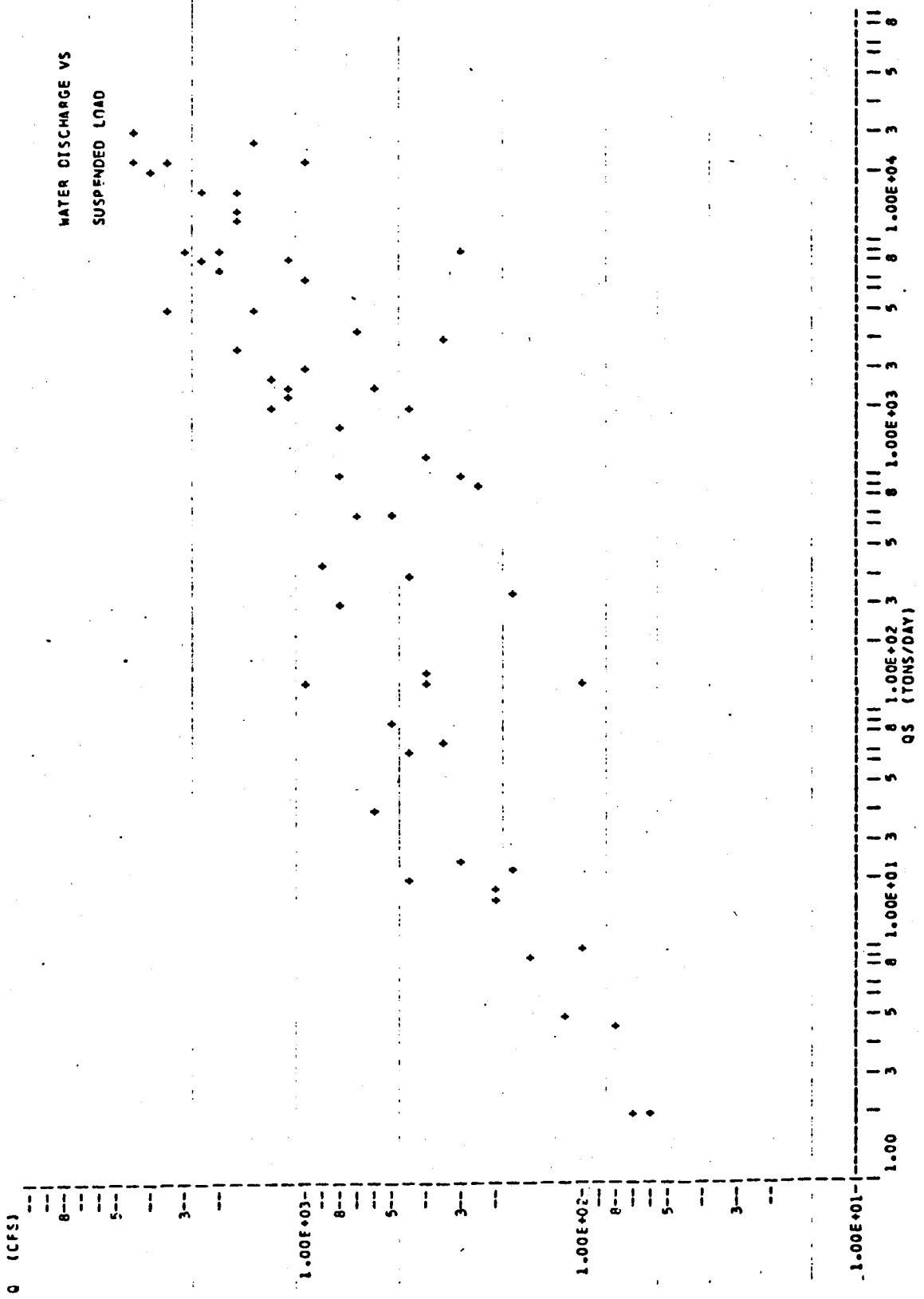


Figure 18. Relationship between Q and Q_s for the Turkey River at Garber, Iowa

WAPSIPINICON RIVER @ INDEPENDENCE

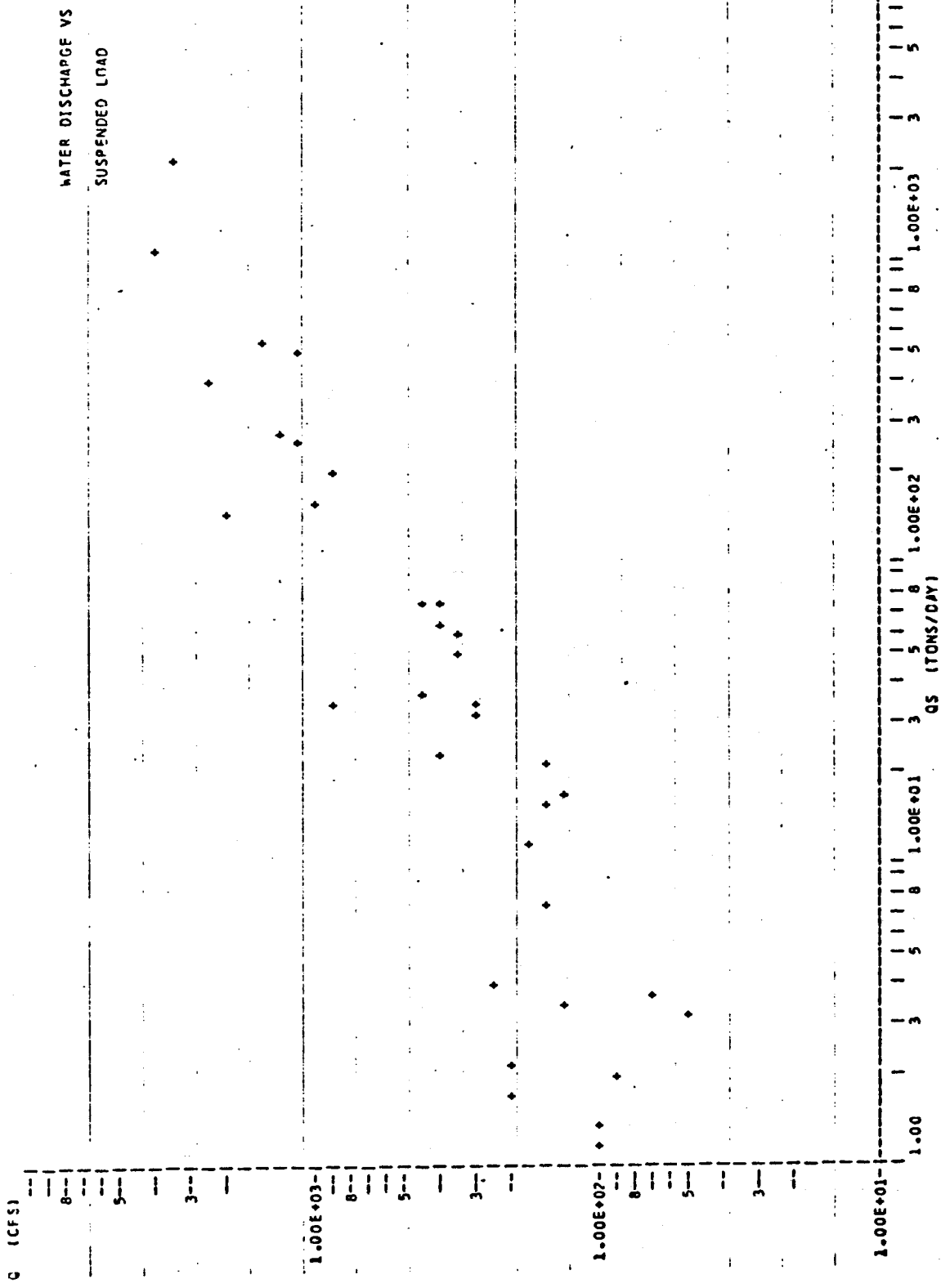


Figure 19. Relationship between Q and Q_s for the Wapsipinicon River at Independence, Iowa

Iowa River @ Iowa City

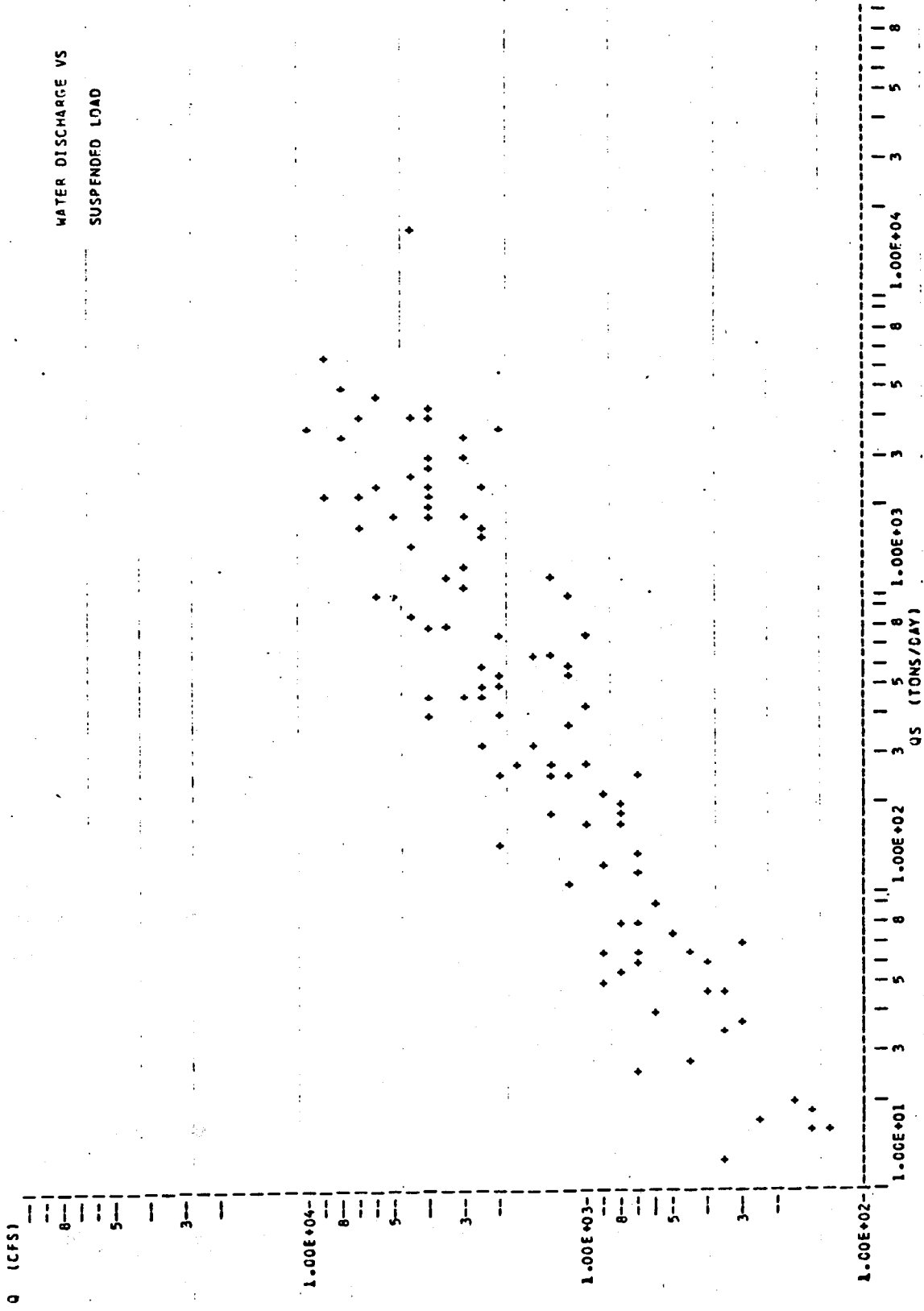


Figure 21. Relationship between Q and Q_s for the Iowa River at Iowa City, Iowa

RALSTON CREEK @ IOWA CITY

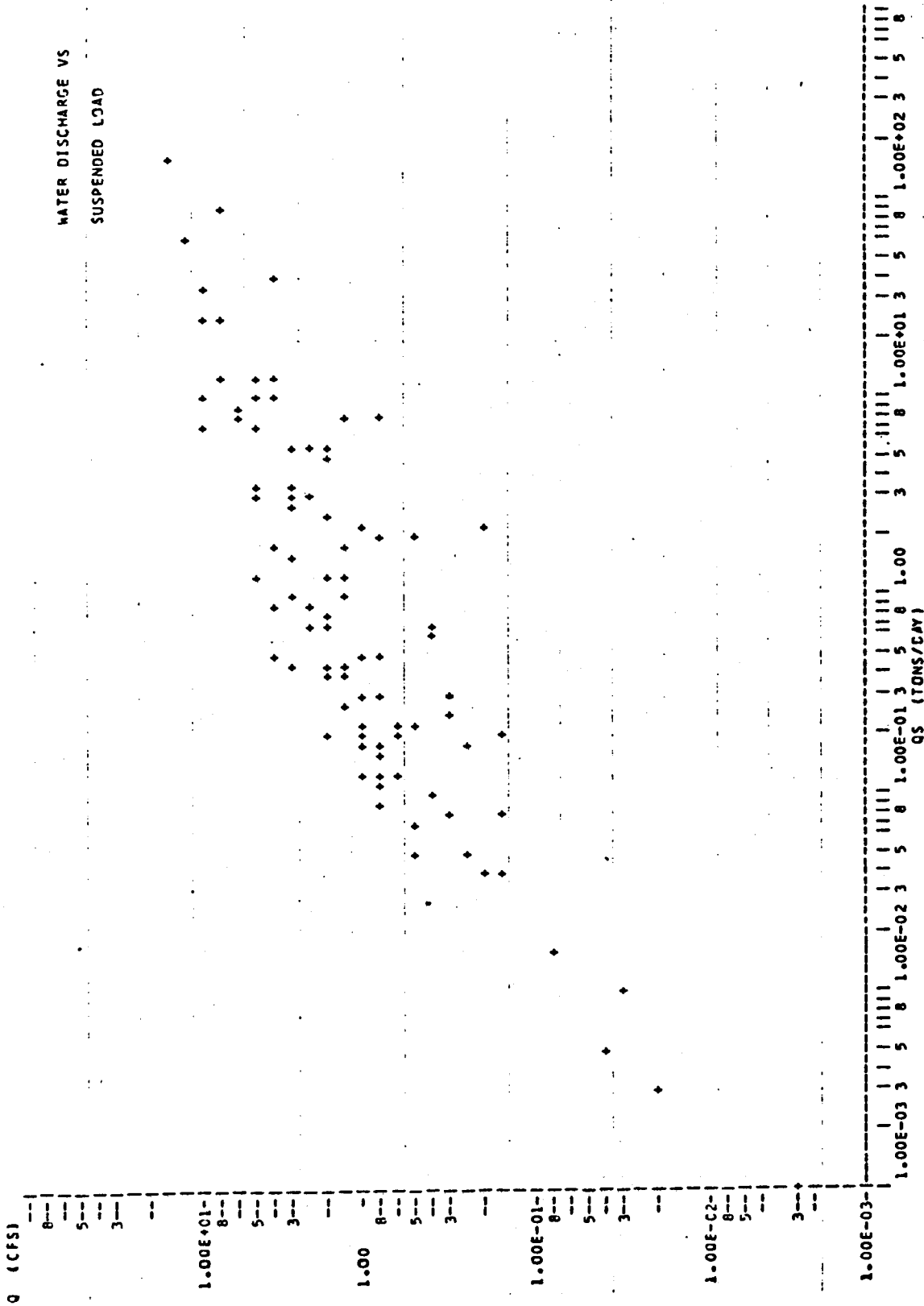


Figure 22. Relationship between Q and Q_S for Ralston Creek at Iowa City, Iowa

FOURMILE CREEK @ LINCOLN

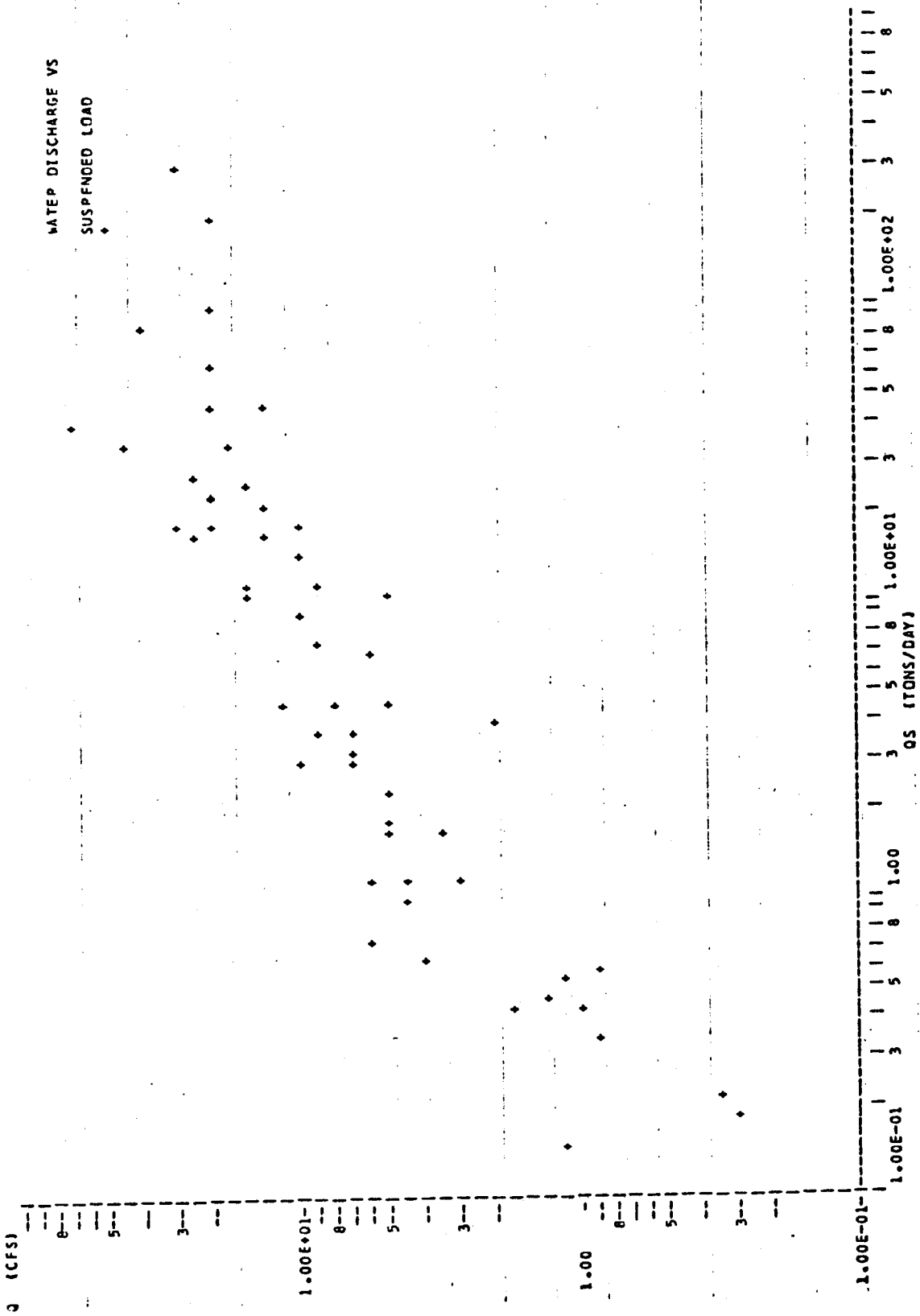


Figure 23. Relationship between Q and Q_s for Fourmile Creek at Lincoln, Iowa

HALF MILE CREEK @ GLADSBROOK

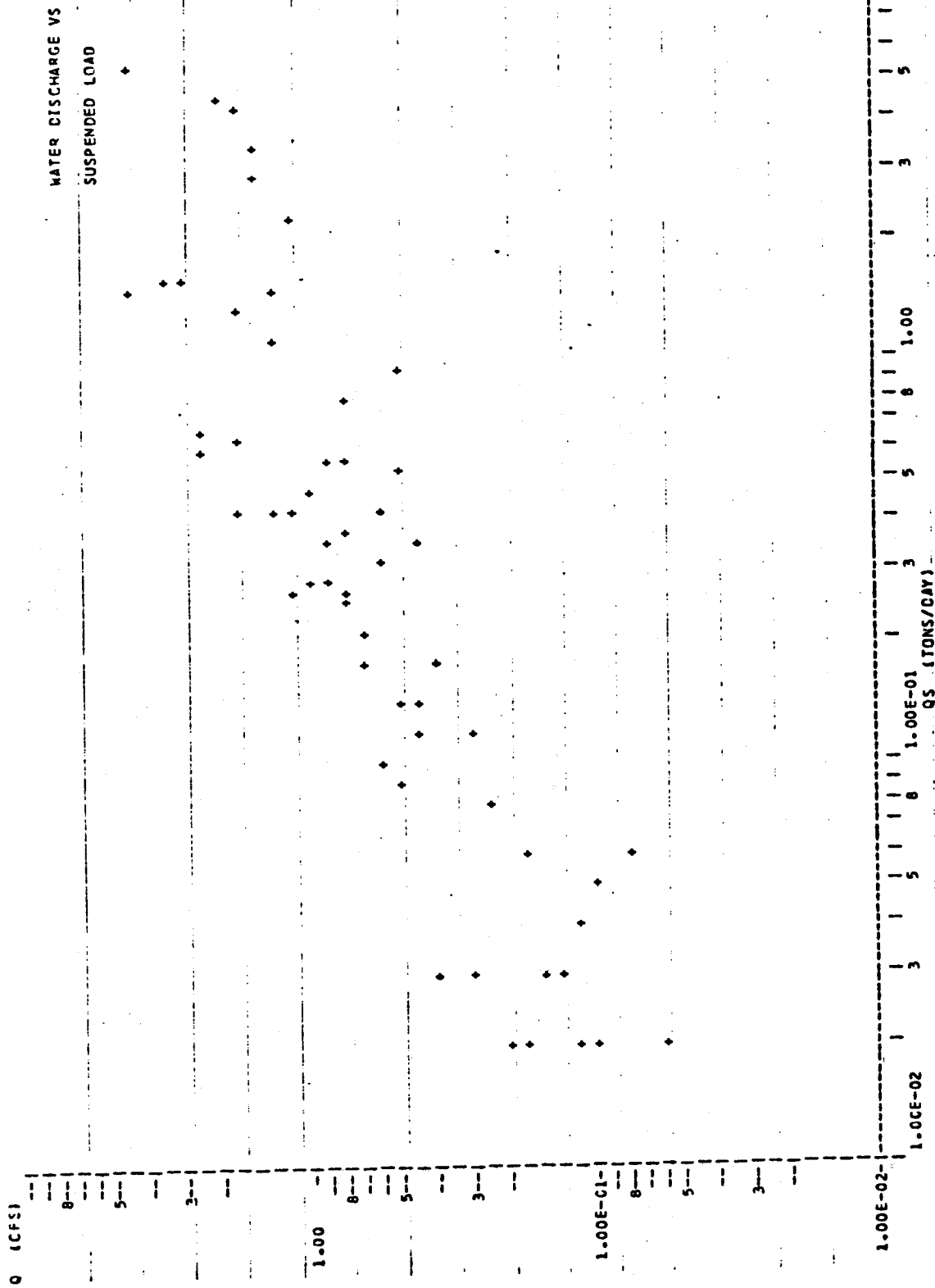


Figure 24. Relationship between Q and Q_s for Half Mile Creek at Gladbrook, Iowa

FOURMILE CREEK @ TRACER

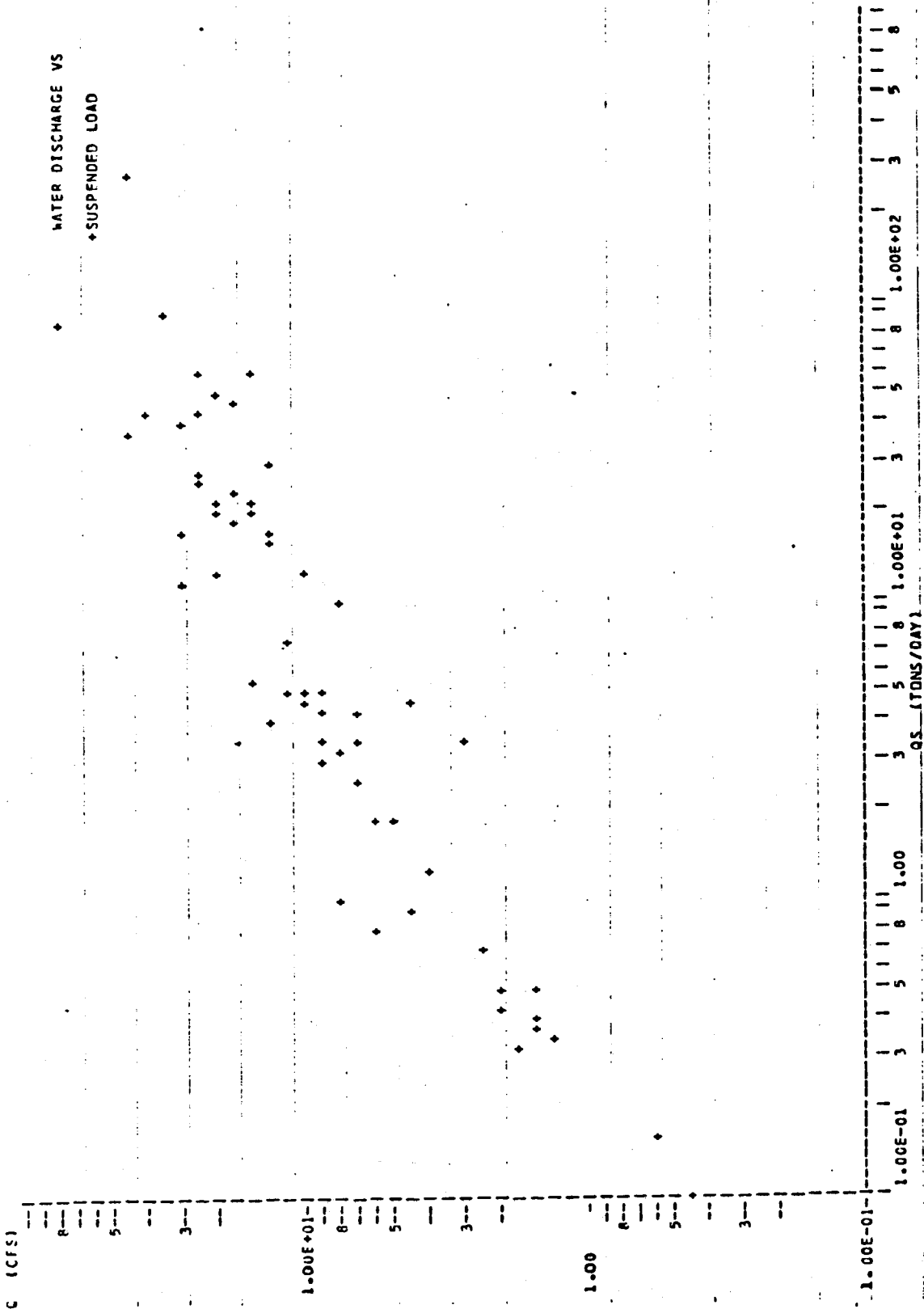


Figure 25. Relationship between Q and Q_s for Fourmile Creek at Tracer, Iowa

CEDAR RIVER @ CEDAR RAPIDS

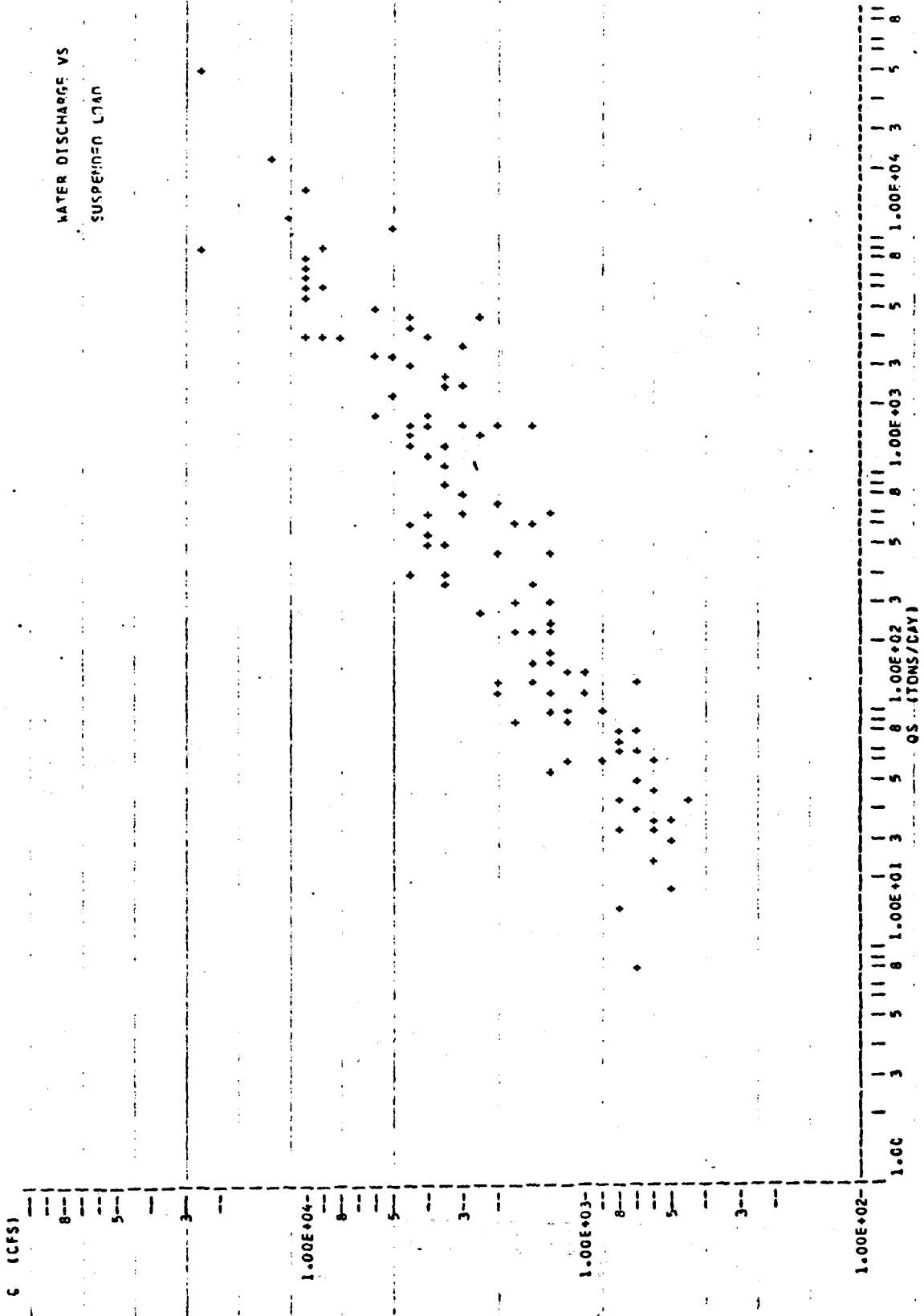


Figure 26. Relationship between Q and Q_S for the Cedar River at Cedar Rapids, Iowa

Des Moines River @ Saylorville

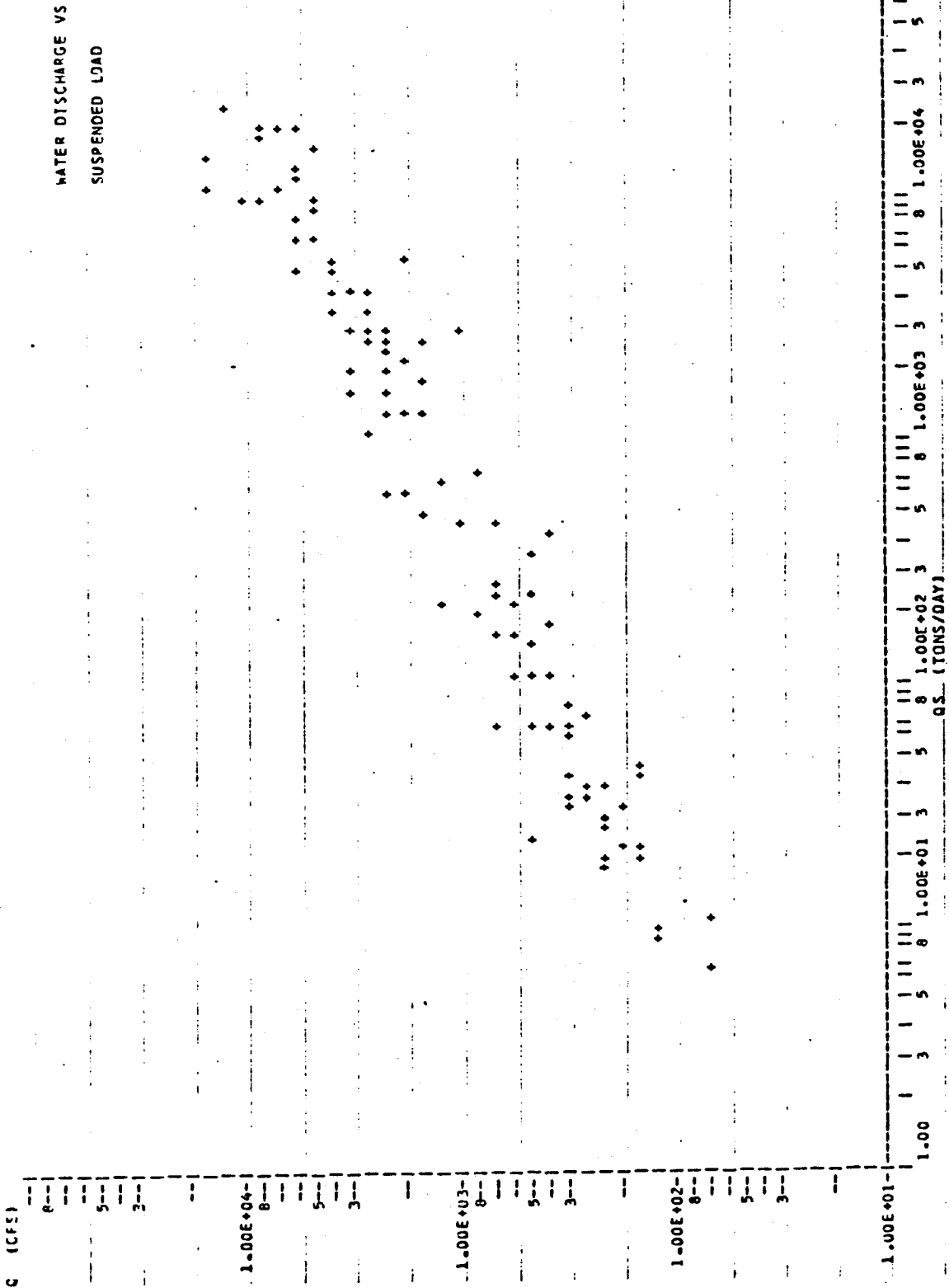


Figure 27. Relationship between Q and Qs for the Des Moines River at Saylorville, Iowa

Des Moines River @ Des Moines

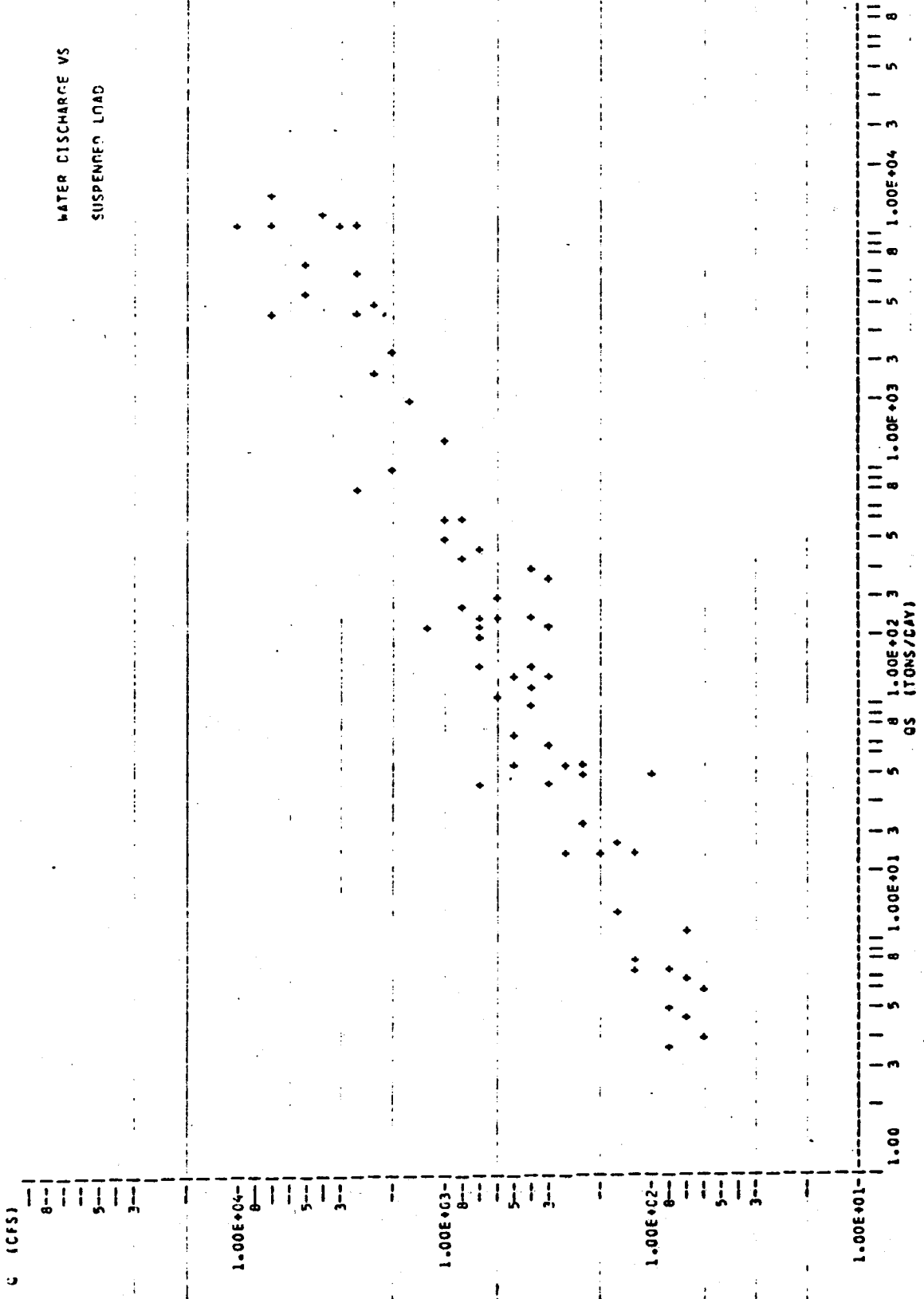


Figure 28. Relationship between Q and Q_s for the Des Moines River at Des Moines, Iowa

Des Moines River / Raccoon R. @ Des Moines

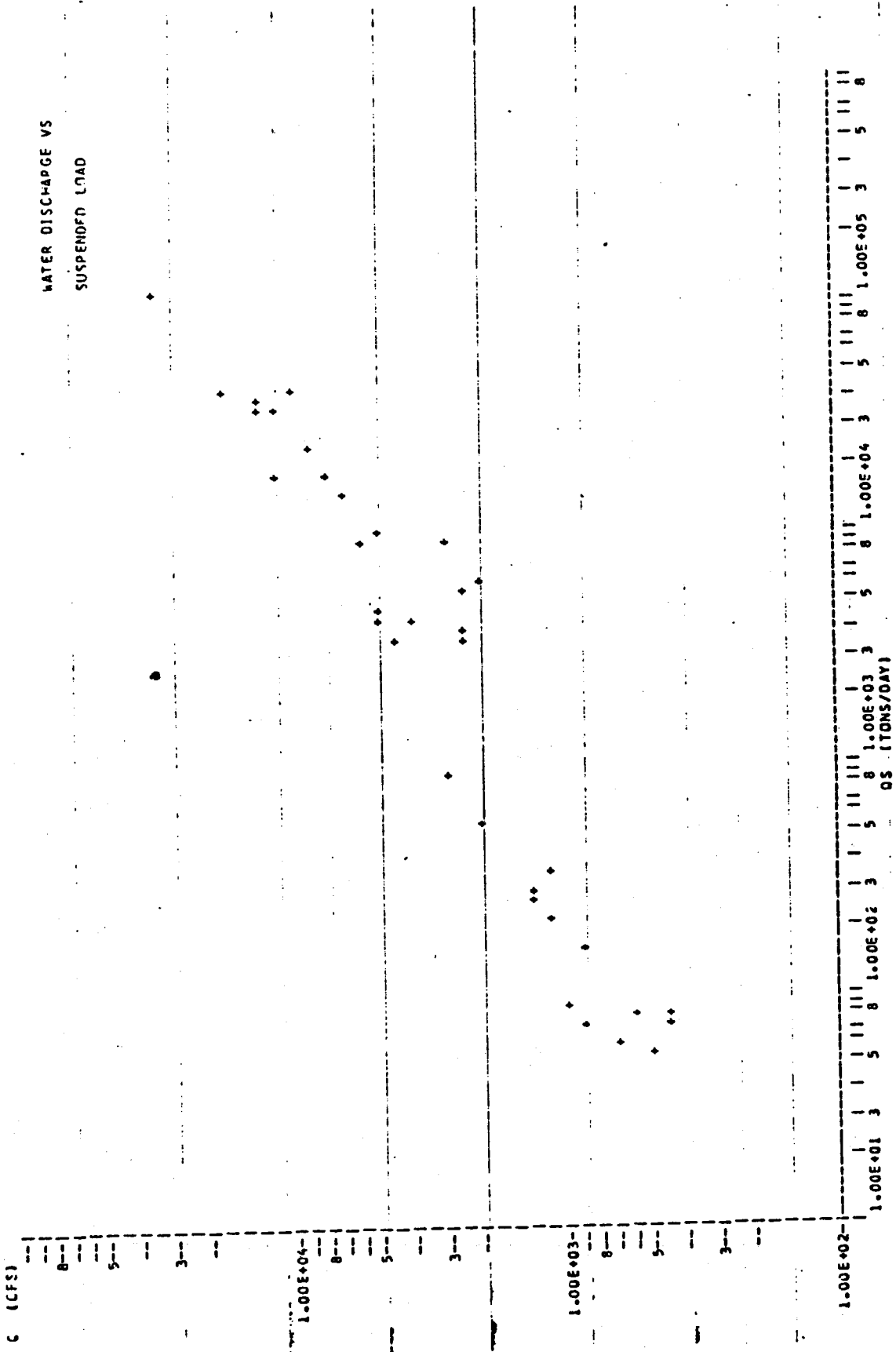


Figure 30. Relationship between Q and Q_s for the Des Moines River at Des Moines (below the Raccoon River), Iowa

WHITE BREAST CREEK @ DALLAS

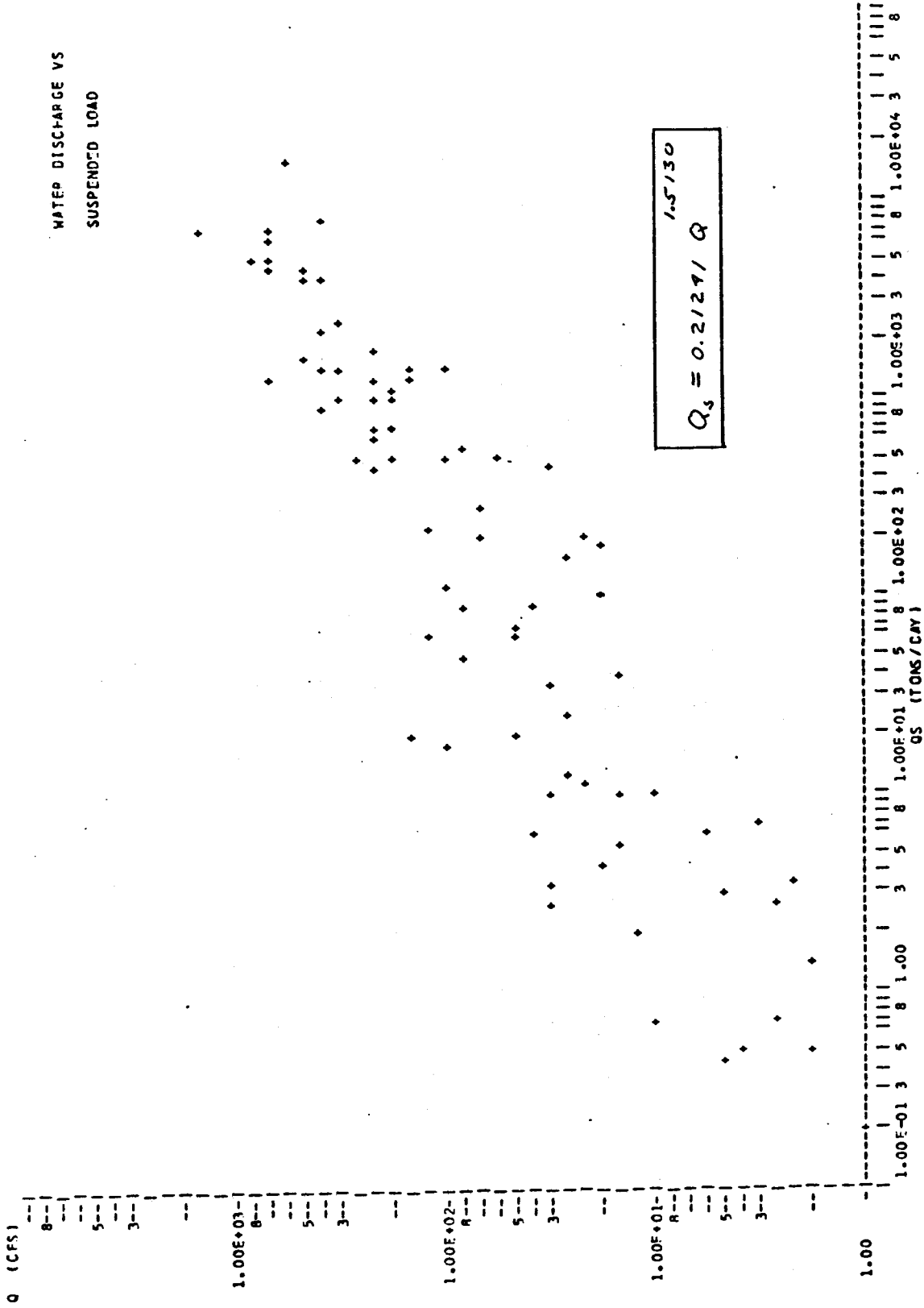


Figure 31. Relationship between Q and Q_s for White Breast Creek at Dallas, Iowa