Jonathan H. Goodwin
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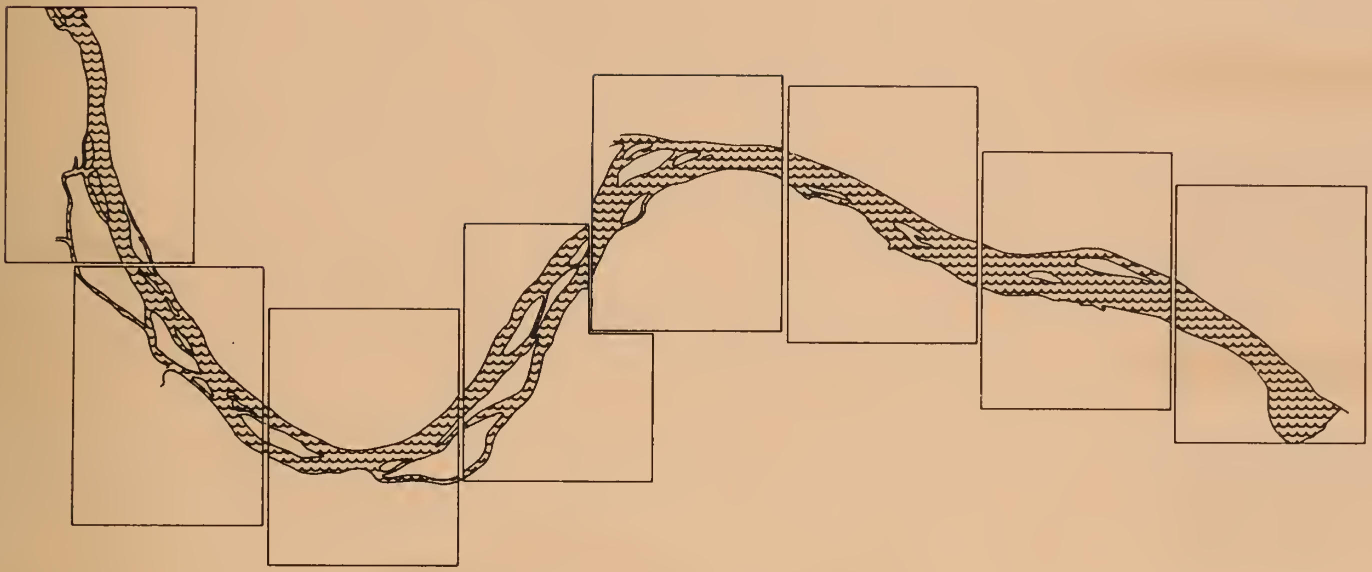

Sedimentology and bathymetry of Pool 26, Mississippi River

Illinois Department of Energy and Natural Resources
STATE GEOLOGICAL SURVEY DIVISION

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February 1983

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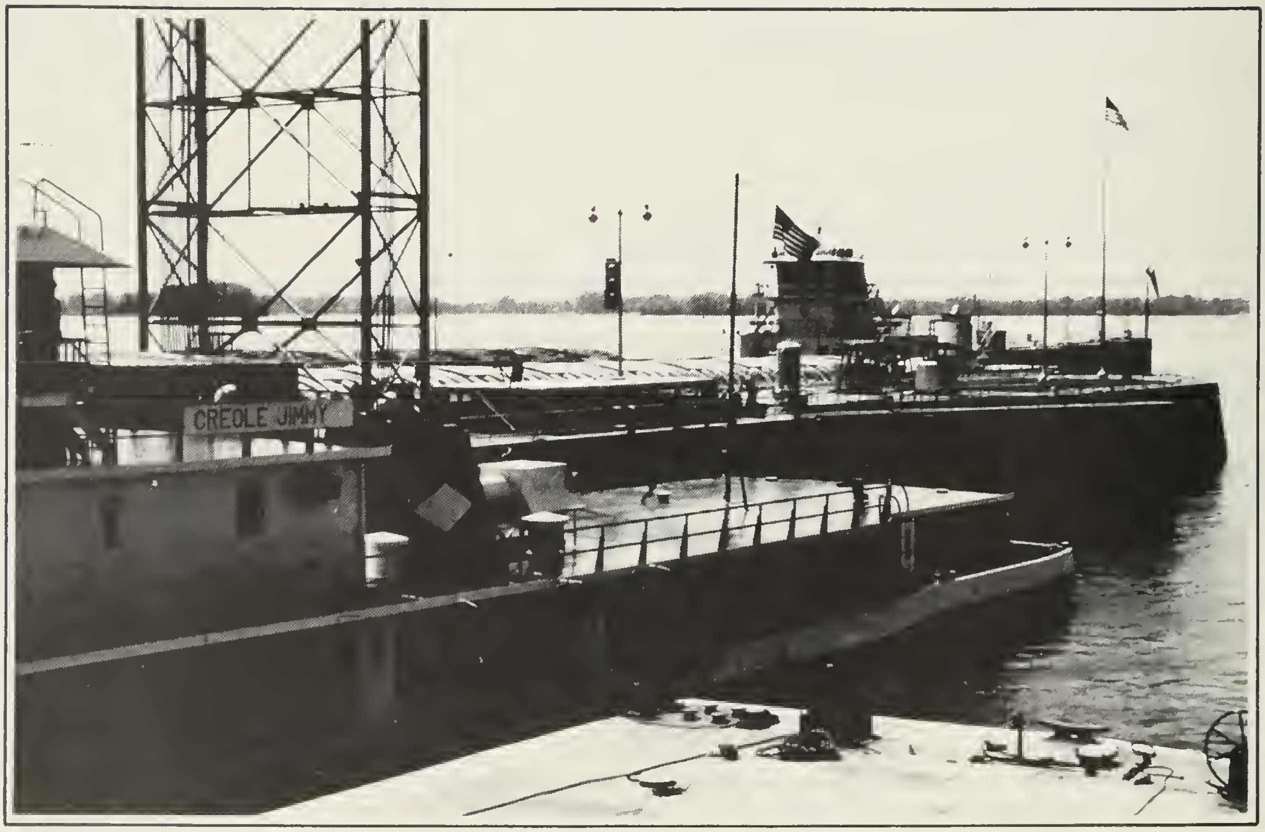


Towboats entering locks at Dam 26, Alton, Illinois.

Sedimentology and bathymetry of Pool 26, Mississippi River

ABSTRACT

During the summer of 1980, the Illinois State Geological Survey (ISGS) undertook an extensive study of Pool 26 of the Mississippi River in cooperation with the Illinois State Natural History and Water Surveys. In 24 working days during July and August, the Geological Survey completed almost 160 kilometers of bathymetric profiling and collected 239 bottom sediment samples in the main channel and selected side channels of the Mississippi River portion of Pool 26 between Alton, Illinois, and Winfield, Missouri.

Particle size analyses of bottom sediments show that the sediments consist of two dominant particle size populations: (1) coarse- to medium-grained, well to moderately sorted sand, and (2) medium- to fine-grained, poorly sorted silt. Above the confluence of the Illinois River in Pool 26, bottom sediments in the main channel consist mostly of moderately to well-sorted, coarse- to medium-grained sand. The coarsest grained and best sorted sediments are confined to the area of the pool that most often requires dredging.

A plot of mean grain size versus skewness of samples discriminates four sediment groups that are distributed within the pool in a manner that can be readily explained in terms of the probable current velocity regime in various parts of the pool. Areal distribution of sediment characteristics within the pool is strongly dependent on positions of current-training structures such as wing dams, closing dams, bank riprap, and the navigation locks and dams.

Maximum water depths between the toe of Dam 25 and the toe of Iowa Island rarely exceed 20 feet (6.1 m). Because of the pooling of the river behind Dam 26 and the extra volume of flow contributed by the confluence of the Illinois River, maximum water depths in the lower part of Pool 26 between the toe of Iowa Island and the head of Dam 26 generally exceed 30 feet (9.1 m).

Extensive fields of sand waves that have amplitudes of up to 6 feet (1.8 m) and wave lengths of up to 50 feet (15 m) are common at intermediate to shallow water depths in the reach of the pool above the confluence of the Illinois River. Although the exact form of these sand waves could not be determined, they are believed to be lunate, like many of those in the lower Mississippi River.

In the uppermost quarter of Pool 26—from the toe of Dam 25 to the head of Turkey Island—the deepest water in the main channel occurs in deep pools spaced about 1.25 km apart and separated by shallows. Locations of the pools form a sinuous pattern that probably follows the course of the strongest current of the river. In the lowermost third of the pool, a similar

pattern of deep pools is present, but the spacing between pools increases to 2 km. In the middle part of the Pool that has been repeatedly dredged, the pattern of alternating pools and shallows is not evident.

The course of the Mississippi River has changed very little since the development of European-American culture in the midwest. Construction of the upper Mississippi River navigation project has further constrained the natural course of the river and preserved and enhanced some pre-existing patterns of sedimentation. Opening and closing of side channels, bank erosion protection, and dredging sites are now largely governed by commercial and recreational needs rather than by natural processes of the river.

INTRODUCTION

The Mississippi River between Alton, Illinois, and Winfield, Missouri, is an area of unusual natural beauty, diversified plant and animal life, and great commercial and recreational activity. The Mississippi and its major tributaries have served as commercial trade routes since prehistoric times, and today hundreds of millions of tons of grain, coal, petroleum, and other commodities annually pass up and down the Mississippi waterway between the industrial and agricultural heartland of the upper midwest and the ocean ports of the Gulf of Mexico.

Since about 1830, the United States government has authorized numerous projects to develop deeper and more stable navigation channels in the nation's waterways. Early efforts in the Mississippi River included removal of snags, construction of wing dikes to constrict the channel, protection of banks to prevent erosion, and construction of levees to protect lowlands from flooding. In the 1930s, construction began on a series of locks and dams intended to increase the navigation channel depth from 6 feet (1.8 m) to 9 feet (2.7 m) (Simons et al., 1975). Locks and Dam 26 at Alton, the first of the projects to be completed, is the gateway to the 9-foot navigation project in the upper Mississippi River basin; all traffic on both the upper Mississippi and Illinois Rivers must pass the locks at Alton.

The dams of the 9-foot navigation project are designed to hold back significant quantities of water only at low flows. At flood stage, the gates on the dams are fully opened to permit virtually unobstructed flow of the river. Despite this design characteristic, significant areas in the lower parts of the navigation pools were flooded when the dams were completed. Recent studies in the Illinois River suggest that these newly flooded wetlands, as well as previously existing wetlands, are being rapidly filled by sediment.

History of study

As an outgrowth of extensive debate in the U.S. Congress on authorization of construction of a new navigation control dam and lock on the Mississippi River at Alton, Illinois, President Carter signed into law on October 21, 1978, an act directing the Upper Mississippi River Basin Commission to prepare a Comprehensive Master Plan for the management of the upper Mississippi River system. The plan was to be drawn up in cooperation with appropriate federal, state and local officials. Among other provisions, the act required the Commission to conduct studies of the system-wide environmental effects of the increase in commercial and recreational boat traffic expected to result from completion of the new lock and dam and the potential construction of an additional navigation lock at Alton. Funds to carry out the mandated studies were appropriated by Congress a year later in October 1979.

In April 1980, a proposal for environmental studies prepared by the Illinois State Geological Survey (ISGS) and other cooperating agencies was accepted by the Basin Commission; preparation for the summer's research program began in May. The work was funded by a contract with the Upper Mississippi River Basin Commission through the Division of Water Resources of the Illinois Department of Transportation. Research by the ISGS was part of a larger program to study the direct effects of boat traffic, channel maintenance, and operational activities on selected environmental parameters of Pools 26 and 9 of the upper Mississippi River waterway. The Illinois Natural History Survey (INHS) and the Illinois State Water Survey (ISWS) cooperated in the studies of Pool 26. Researchers from Winona State College, Winona, Minnesota; Luther College, Decorah, Iowa; River Studies Center of the University of Wisconsin-LaCrosse, LaCrosse, Wisconsin; U.S. Fish and Wildlife Service, Iowa Cooperative Fish and Wildlife Research Units, Iowa State University, Ames, Iowa; and U.S. Fish and Wildlife Service, National Fishing Research Laboratory, LaCrosse, Wisconsin, all worked in Pool 9.

Dr. Richard E. Sparks of the INHS coordinated the combined studies in Pools 26 and 9, and Dr. Kenneth S. Lubinski of the INHS coordinated the studies in Pool 26.

Basis for the study

The major purpose of the environmental studies conducted in Pools 26 and 9 was to determine the effects of varying levels of boat traffic on habitats of the riverine ecosystem. Limited funding and time required that studies of portions of the system be used to provide analogies and models for the complete upper Mississippi River system. Pool 26 was chosen as a study reach because of the divergence of river traffic in the pool at the confluence of the Illinois River (fig. 1). All barge traffic entering and leaving the upper Mississippi River navigation system passes through the locks at Dam 26 at Alton, Illinois. Sixty percent of the barges passing through the locks at Alton travel on the Illinois River and 40 percent on the Mississippi, on the basis of numbers of tows passing the next upstream locks (Corps of Engineers, 1981). Thus, the effects of three different levels of commercial navigation can be studied within a relatively short stretch (reach) of waterway in Pool 26. Pool 9 was selected as a study reach because of the existence of two nearly equivalent channels, only one of which is used by barges; commercial navigation in Pool 9 is about 20 percent of the level in Pool 26.

Focus of ISGS studies

In order to isolate the effects of navigation from all other factors of the riverine environment, it is necessary to select otherwise similar habitats that are subjected to varying traffic levels. To assure such similarity of habitats, it is necessary to determine the physical and chemical characteristics of the habitats to be studied. Additionally, for purposes of the long-term monitoring of the upper Mississippi River system required by the

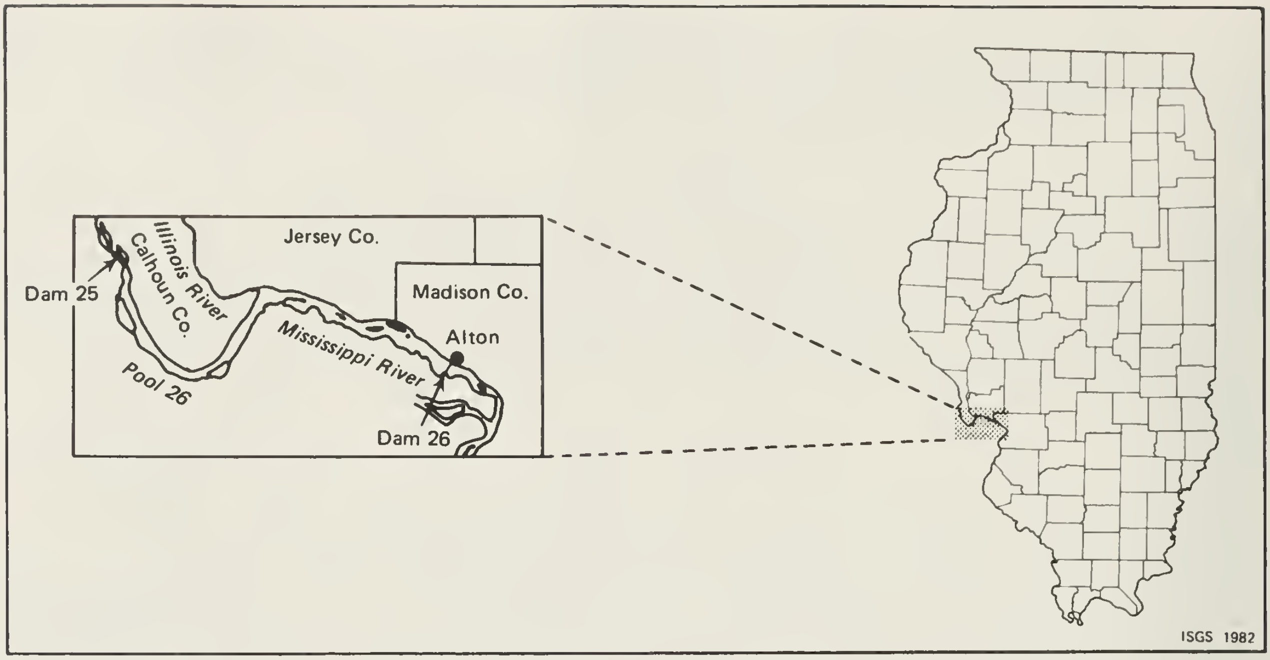


Figure 1. Location of Pool 26 of the Mississippi River in Illinois.

Master Plan, it is necessary to determine the physical and chemical characteristics of the study reaches that will serve as baselines. To assist in these two purposes, the ISGS:

. Completed a detailed bathymetric survey of the main navigation channel and selected side channels along the Mississippi River portion of Pool 26.

. Collected 239 bottom-sediment samples from the main navigation channel and selected side channels along the Mississippi River portion of Pool 26.

. Analyzed the bottom-sediment samples for particle size at 1 Ø size intervals down to a minimum size of 9 Ø (2 μm diameter).

. Analyzed the bottom-sediment samples for moisture content and organic matter content by weight loss on heating.

. Analyzed selected bottom-sediment samples to determine mineral composition by x-ray powder diffraction methods.

SEDIMENTOLOGY

Analytical methods

The detailed analytical methods used in this study are explained in appendix 2 of this report. Researchers at Pools 26 and 9 selected the particular parameters to be measured for this study, and the methods used to determine those parameters were standardized as much as possible.

Locations of sampling sites are shown in figures 2 through 9. Results of the analyses of bottom-sediment samples are reported in appendix 1. Parameters measured and reported include the mean particle size, sorting (standard deviation), and skewness of the particle size distributions of each sample, and two values for the moisture contents and organic matter contents of each sample.

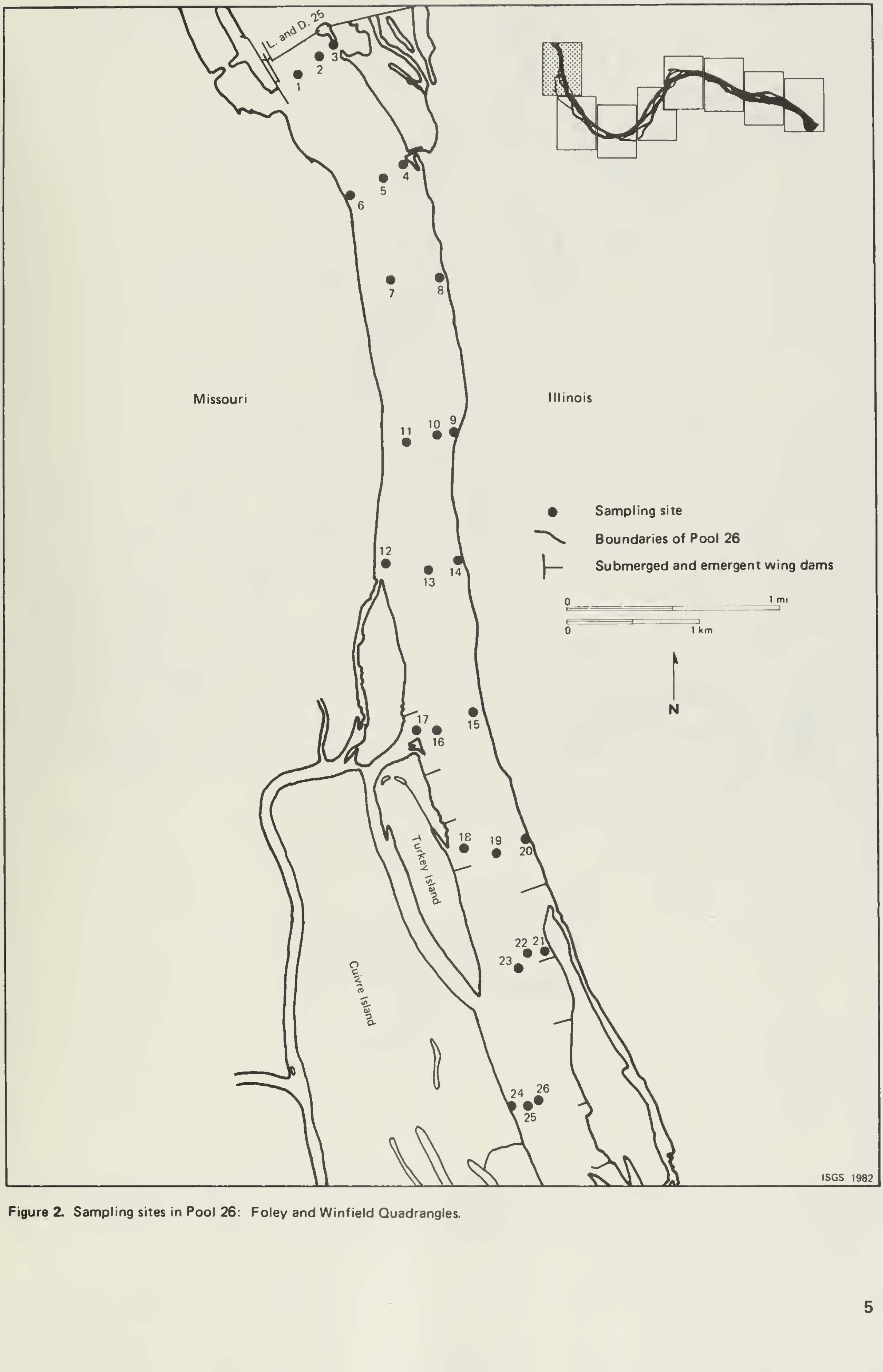


Figure 2. Sampling sites in Pool 26: Foley and Winfield Quadrangles.

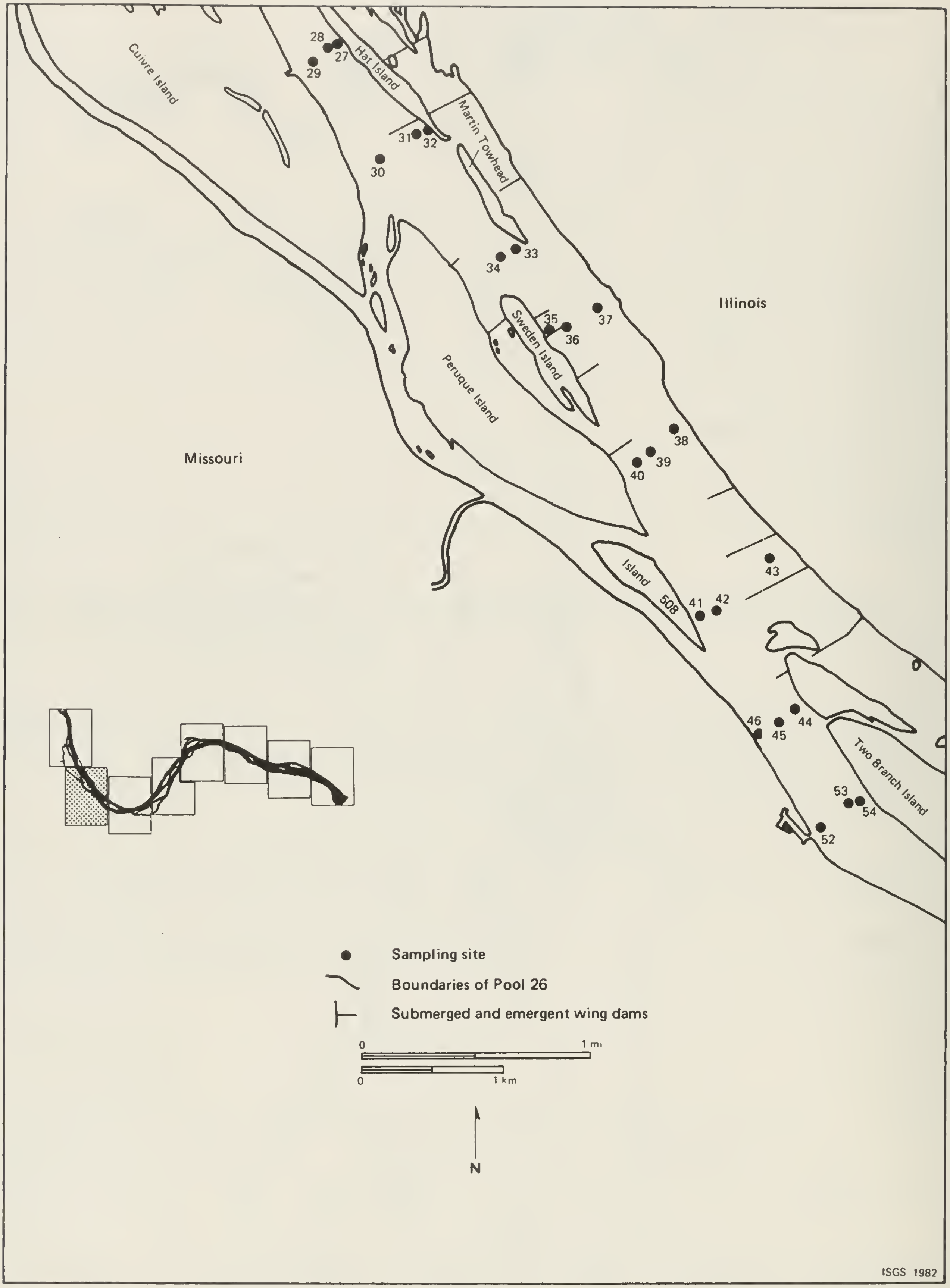


Figure 3. Sampling sites in Pool 26: Winfield and Brussels Quadrangles.

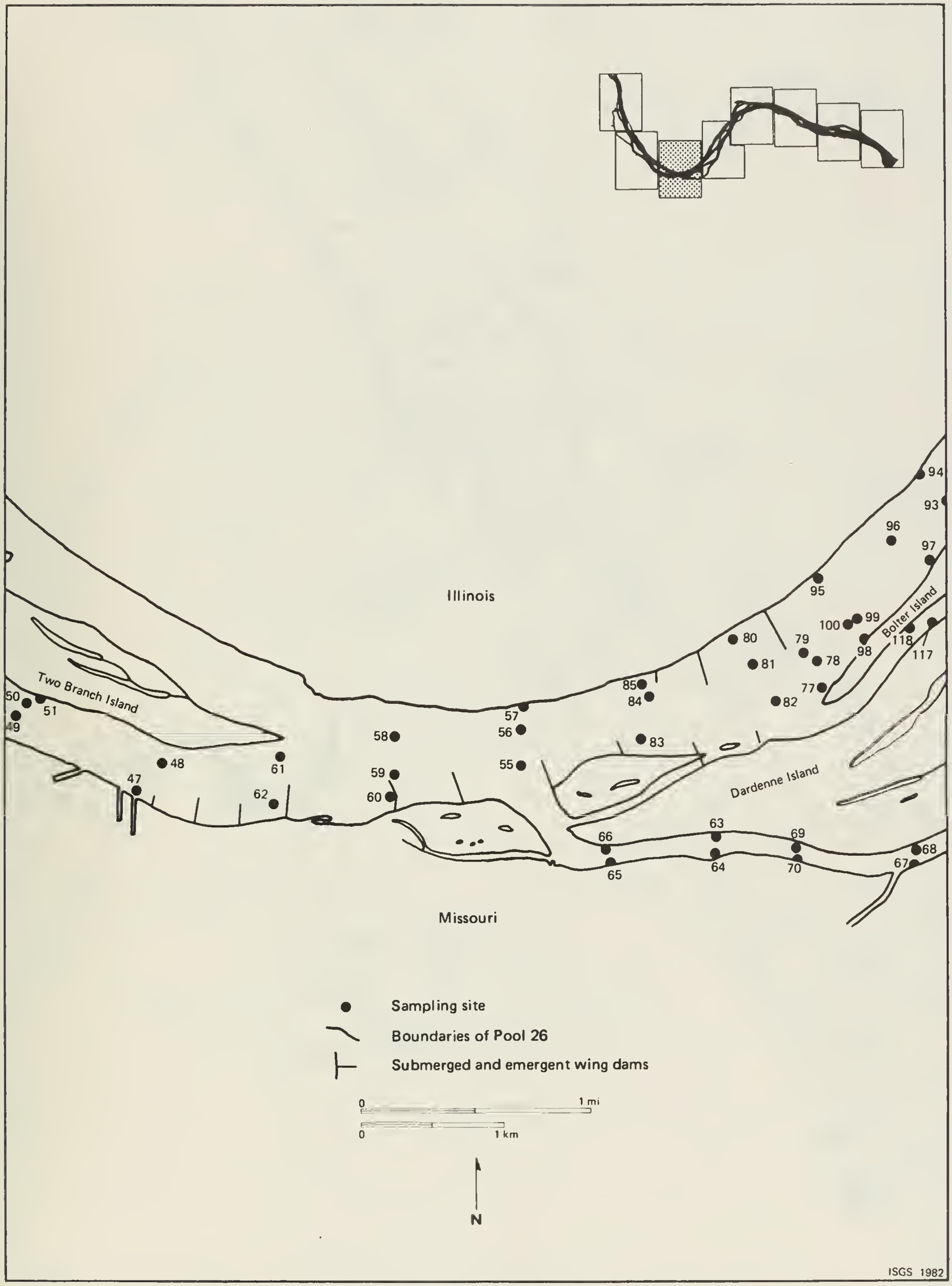


Figure 4. Sampling sites in Pool 26: Kampville and Brussels Quadrangles.

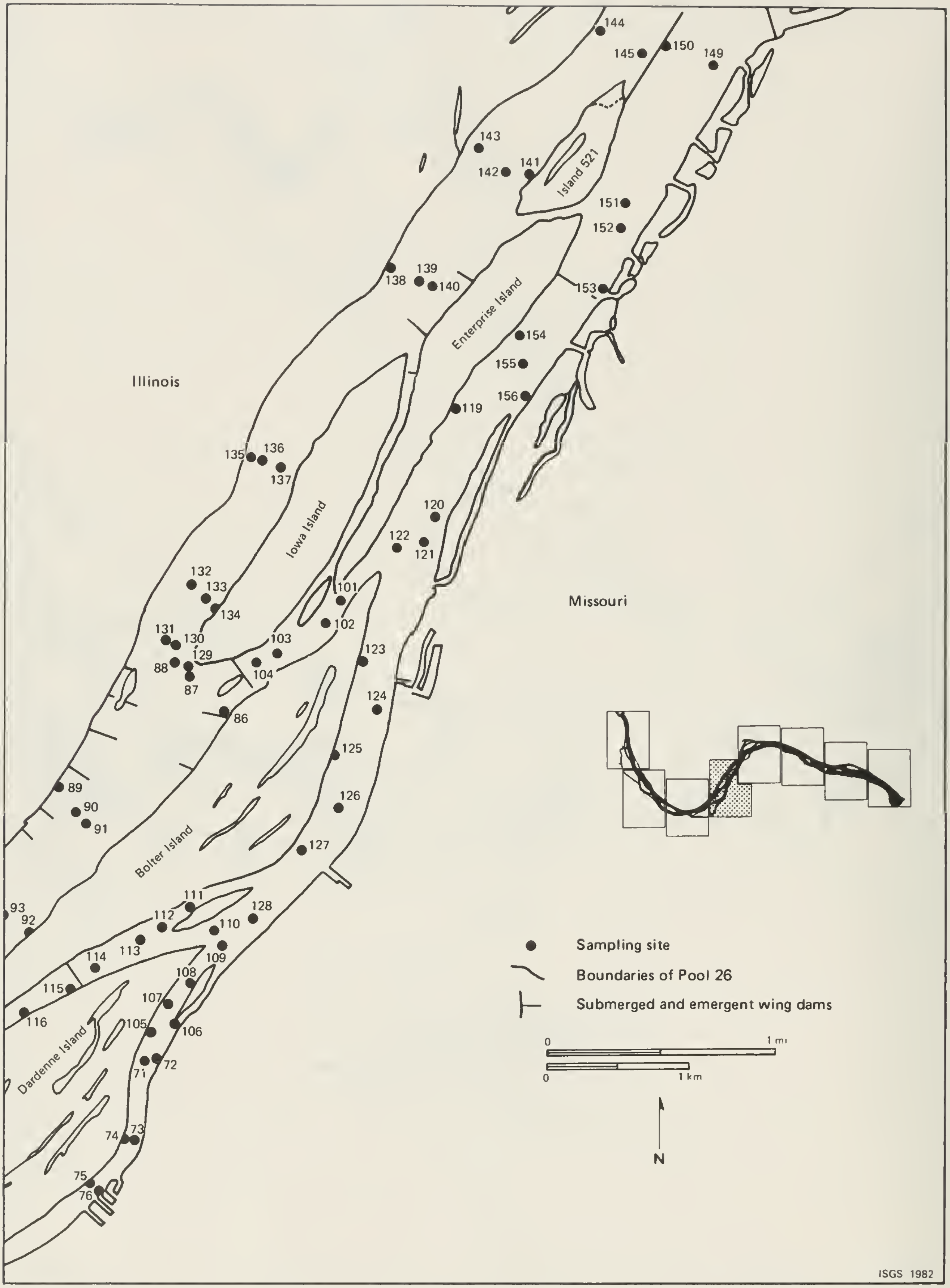


Figure 5. Sampling sites in Pool 26: Kampville, Brussels, and Grafton Quadrangles.

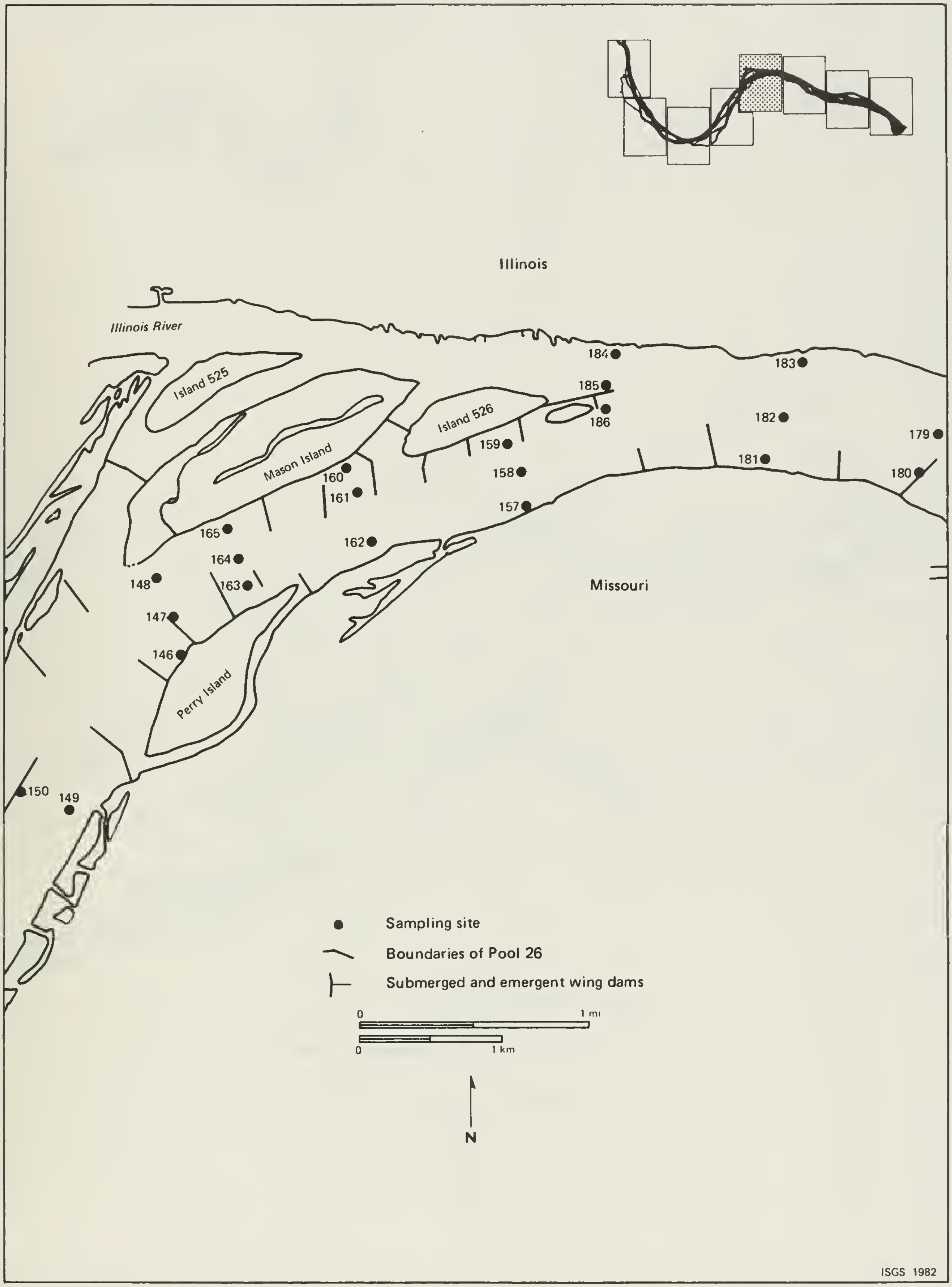


Figure 6. Sampling sites in Pool 26: Grafton Quadrangle.

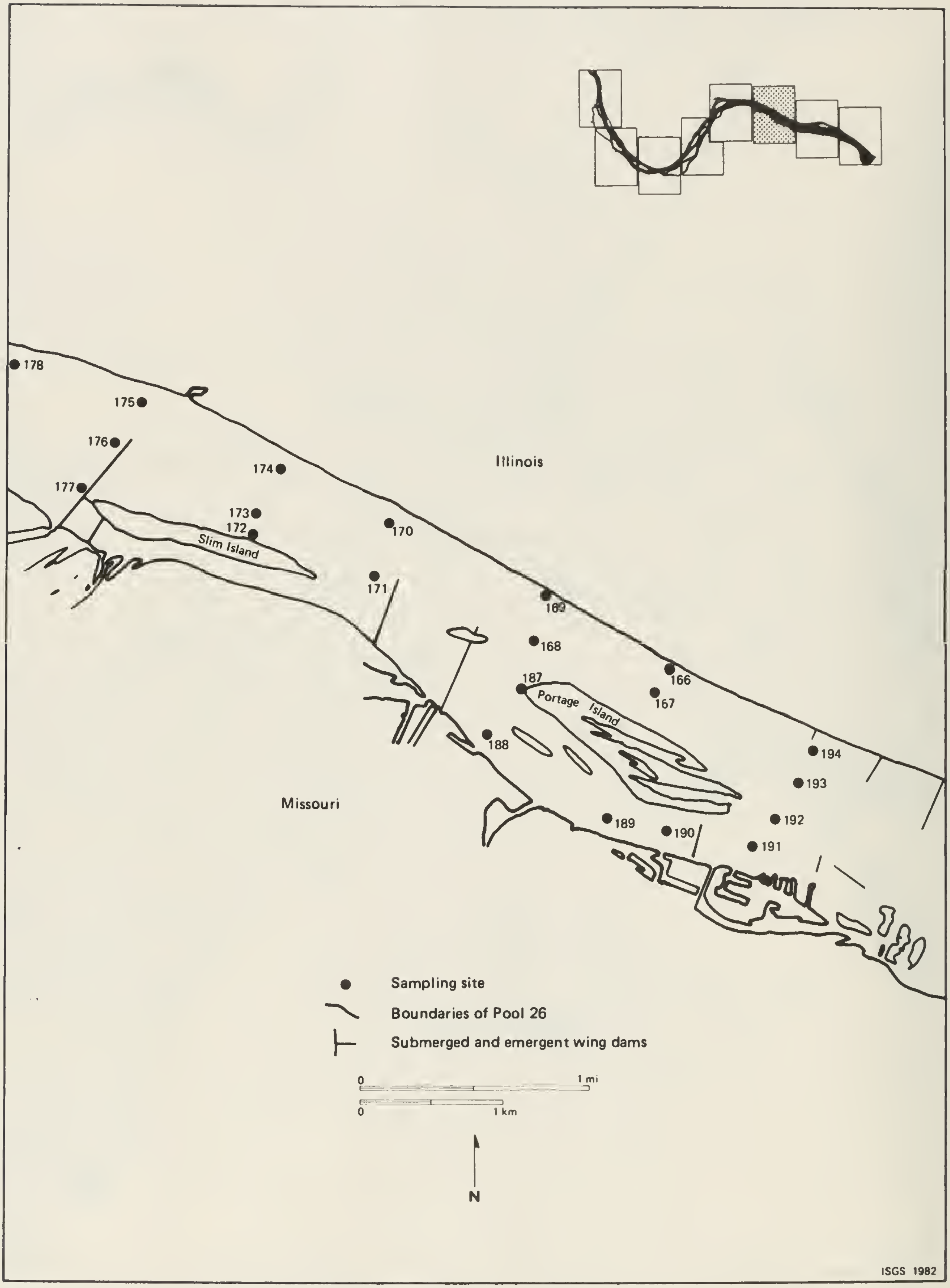


Figure 7. Sampling sites in Pool 26: Grafton and Elsah Quadrangles.

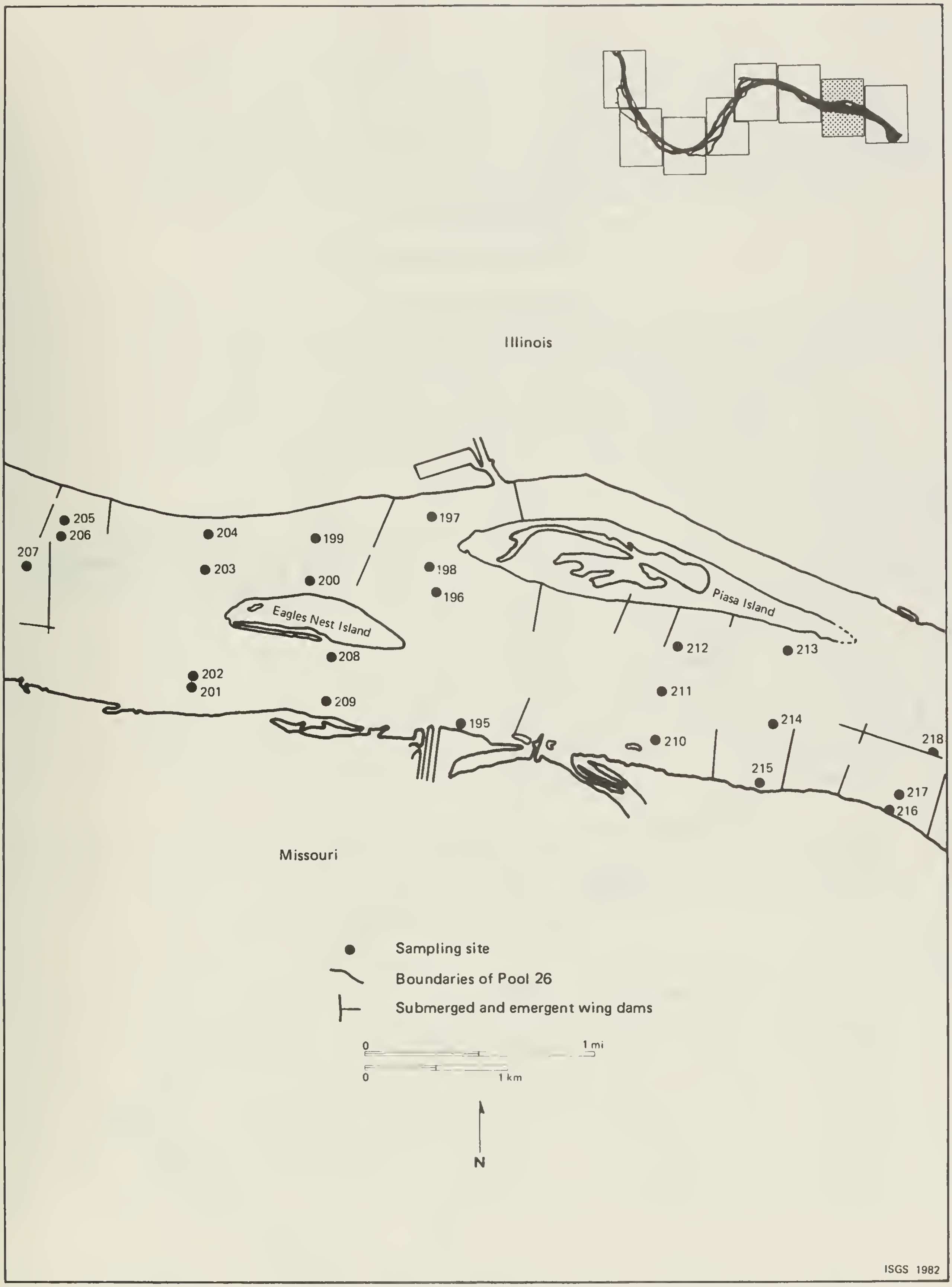


Figure 8. Sampling sites in Pool 26: Elsah Quadrangle.

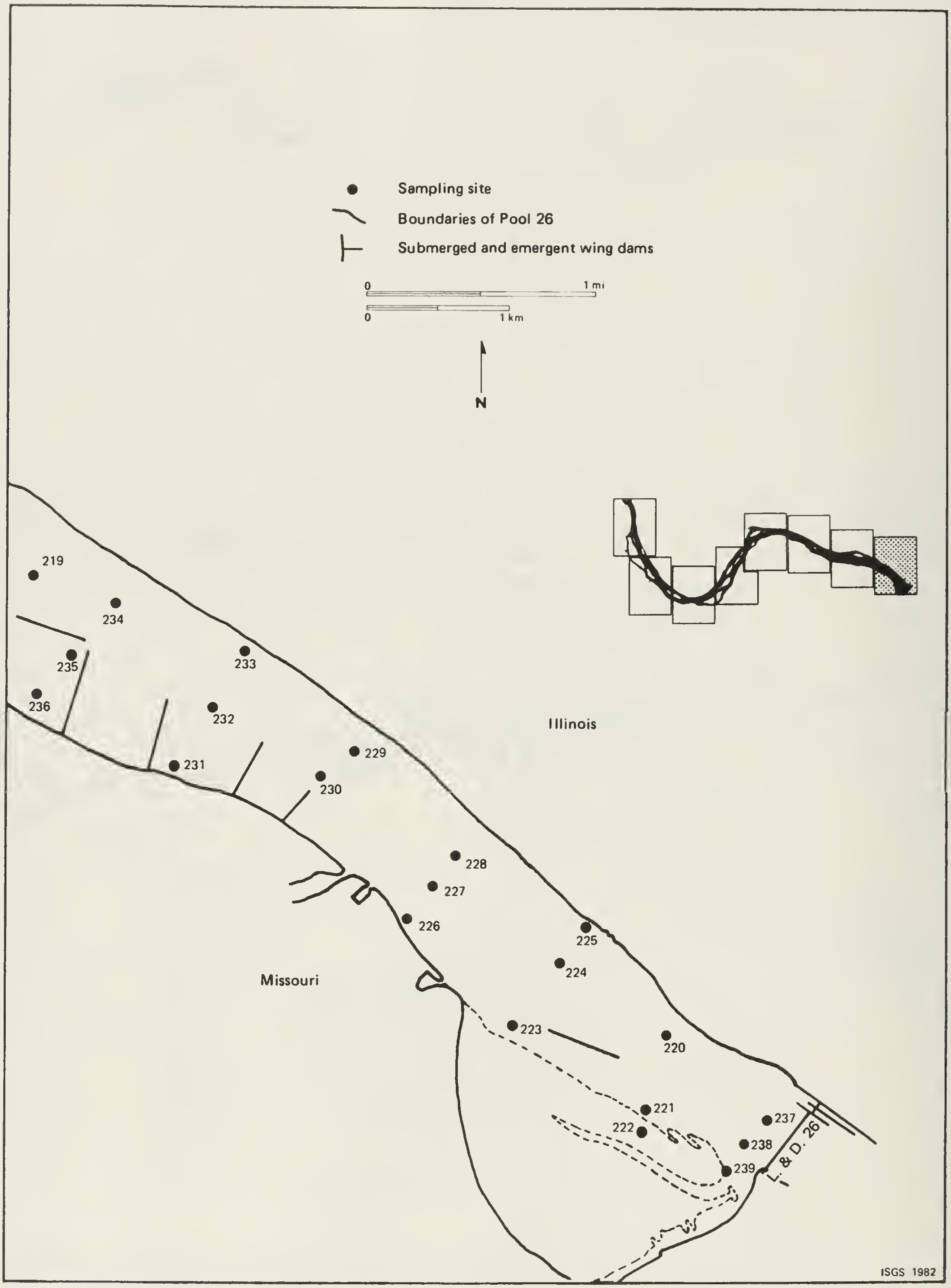


Figure 9. Sampling sites in Pool 26: Alton Quadrangle.

As noted in appendix 2, the SEDSTAT computer program written by C. Brian Trask of the Illinois State Geological Survey was used to calculate the statistical parameters of the particle size distributions that were measured by standard sieving and pipetting techniques. This program computes the statistical parameters by using both the method of moments (Krumbein and Graybill, 1965) and the graphical approximations of Folk and Ward (1957). Only the moment values are reported in appendix 1.

Particle size statistics

Limitations of statistical parameters. Calculated statistical parameters of particle size—such as the mean, sorting (standard deviation), and skewness—are used to describe the characteristics of a unimodal, standard normal statistical distribution. As will be shown, many particle size distributions of sediments from the Mississippi River are bimodal or polymodal and therefore not statistically normal. For polymodal distributions, the mean and sorting (standard deviation) are relatively insensitive to the parts of the distribution far from the center of the normal frequency curve. For example, a calculated mean of a polymodal distribution may fall at a value between major modes. Measures such as skewness that are more sensitive to the tails of the particle size distribution than the mean may more nearly reflect the characteristics of these polymodal sediments. The samples from the Mississippi River all come from the same basic depositional environment and all have similar source materials. With these variables controlled, the calculated statistical parameters of the particle size distributions of these sediments provide a valuable tool for making comparisons among various parts of the river. It should be evident, however, that no single calculated parameter or group of parameters can fully describe the complexity of a polymodal frequency distribution. The final test must be the similar forms of the frequency curves themselves.

Modal particle size. For partical size data grouped according to a series of particle size ranges, the modal particle size classes are defined as the one or more size classes that occur most frequently in a particle size distribution. They are the classes that appear as peaks on a histogram of modal size class versus weight percent frequency.

Modal particle sizes and the frequency curves from which they are determined may be the most informative data regarding size distributions of polymodal sediments because the modal particle sizes probably represent the mean particle sizes of individual, statistically normal particle populations within the overall sample. Because such data are largely pictorial, they cannot be readily used to make comparisons among large numbers of samples. Figure 10 is a frequency histogram of dominant modal particle size classes of the Mississippi River sediments determined by counting dominant modes of the individual frequency curves plotted by SEDSTAT. The dominant mode of the Pool 26 sediments occurs between 0 Ø and 2 Ø, and the most frequent size class in this range is 1 to 1.5 Ø, corresponding to "medium sand" in the Wentworth grade scale (Wentworth, 1922).

Of the 223 samples plotted in figure 10, 86 percent had modal particle sizes in the range of 0 Ø to 2 Ø and more than 57 percent of the samples had a modal particle size in the 1 Ø to 1.5 Ø range. A secondary mode in figure 10 occurs at 4.0 to 6.5 Ø, corresponding to coarse- to medium-silt sizes.

The two dominant modal size classes of bottom sediments in Pool 26 of the Mississippi River clearly define two populations of sediment particles in the bed load of the river. The coarser of the two dominant modes is derived entirely from samples taken in the main channel and main-channel border areas. The finer mode is derived from samples taken where silt- and clay-size particles are abundant—in side channels or in the main channel of the Mississippi near Lock and Dam 26 below the confluence of the Illinois River.

Mean particle size. Mean particle size is the calculated particle size that is at the center of the normal frequency curve for the sample (that is, 50 percent of the area under the normal frequency curve occurs at particle sizes coarser than the mean value and 50 percent at finer sizes). Figure 11 shows a frequency histogram of mean particle sizes of bottom sediments of the Mississippi River study reach. This histogram was determined by arranging the calculated mean particle size values listed in appendix 1 in 1/2 Ø size classes and counting the number of values in each class. Note that the dominant mode in this histogram is in the range from 0.0 Ø to 2.0 Ø. A secondary mode occurs in the range from 5.0 Ø to 8.5 Ø.

Comparison of figures 10 and 11 shows clearly that mean particle sizes of Pool 26 bottom sediments are strongly controlled by the dominant modal particle sizes of the samples. The absence of samples having mean particle sizes between 4.5 Ø and 5.0 Ø in figure 11 further demonstrates the separation of the two populations of particles shown by figure 10. The moderately abundant samples having mean particle sizes between 2.0 and 4.5 Ø almost certainly result from mixing of these two populations of particles.

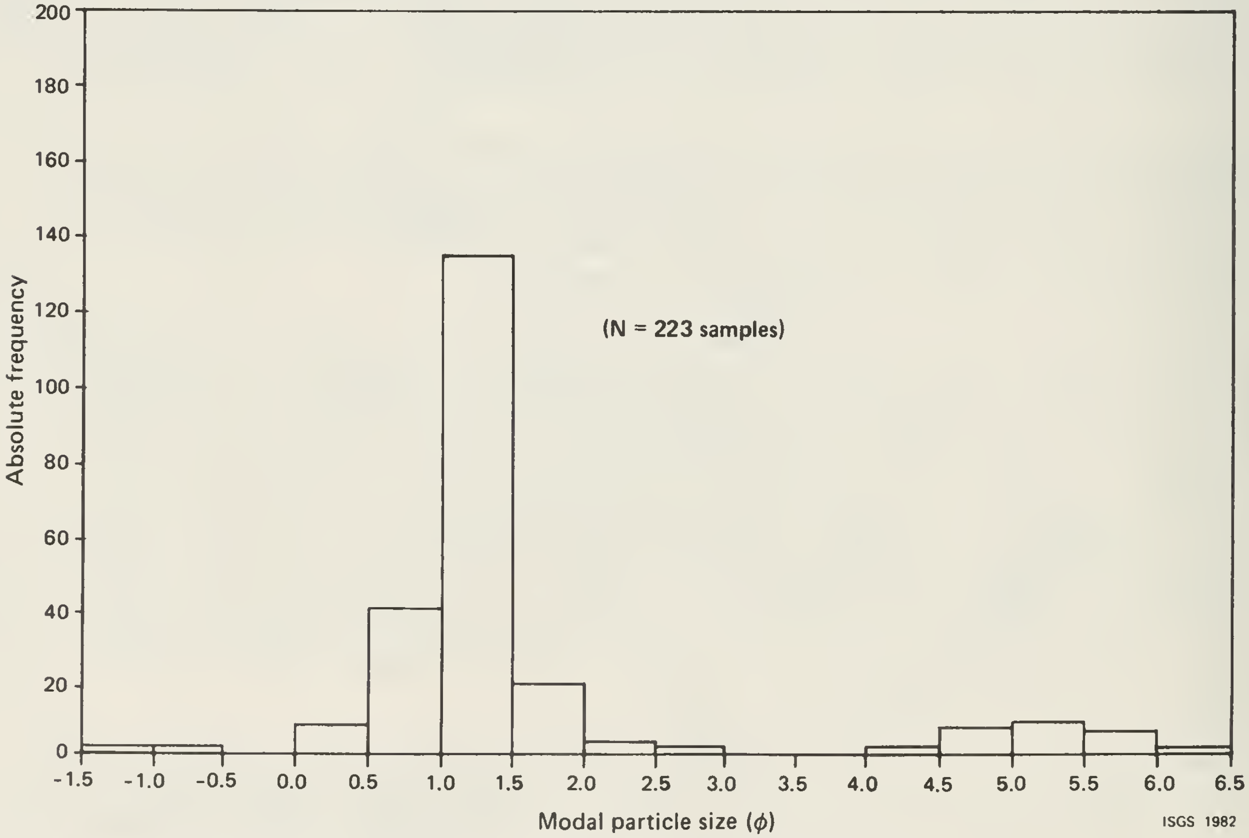


Figure 10. Frequency histogram of modal particle sizes of bottom sediment samples, Pool 26.

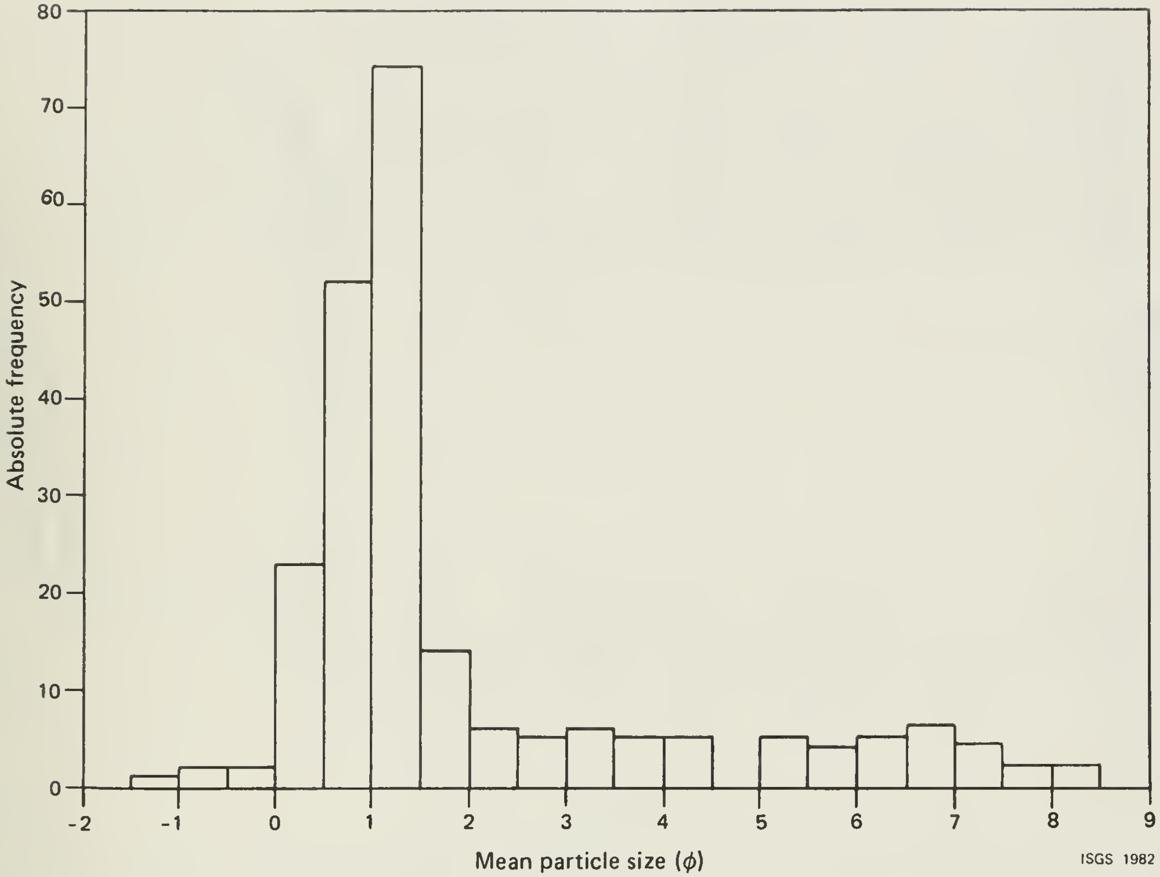


Figure 11. Frequency histogram of mean particle sizes of bottom sediment samples, Pool 26.

Figure 12 shows the relationship between mean particle sizes of samples collected in the deepest water in the main channel and their distance downstream from Dam 25. Between Dam 25 and the mouth of the Illinois River, mean particle sizes range from -0.5 Ø to 1.5 Ø and there is no obvious trend toward a downstream decrease in mean particle size. Below the Illinois River's mouth (km 38), the range of mean particle sizes increases drastically, and there is an obvious downstream trend toward a decrease of the mean particle size. Within the latter area, as the mean particle size decreases, the range among mean particle sizes of individual samples also decreases. This suggests that the downstream trend toward decreasing mean particle size primarily results from increased mixing of finer grained silt- and clay-sized particles delivered by the Illinois River with the coarser sand delivered by the Mississippi. The proportion of sand derived from the Mississippi decreases as the proportion of silt and clay from the Illinois increases and thus the difference between the mean particle size of samples decreases as mixing of the two populations becomes more complete. Within the 62 km length of Pool 26, variations among mean particle sizes of samples are caused either by mixing of sediments from different sources, or by varying strengths of currents in different parts of the river. Any real decrease of particle size caused by abrasion probably is insignificant within Pool 26 and, in any case, would be masked by the much greater effects of varying hydraulic conditions and sediment sources.

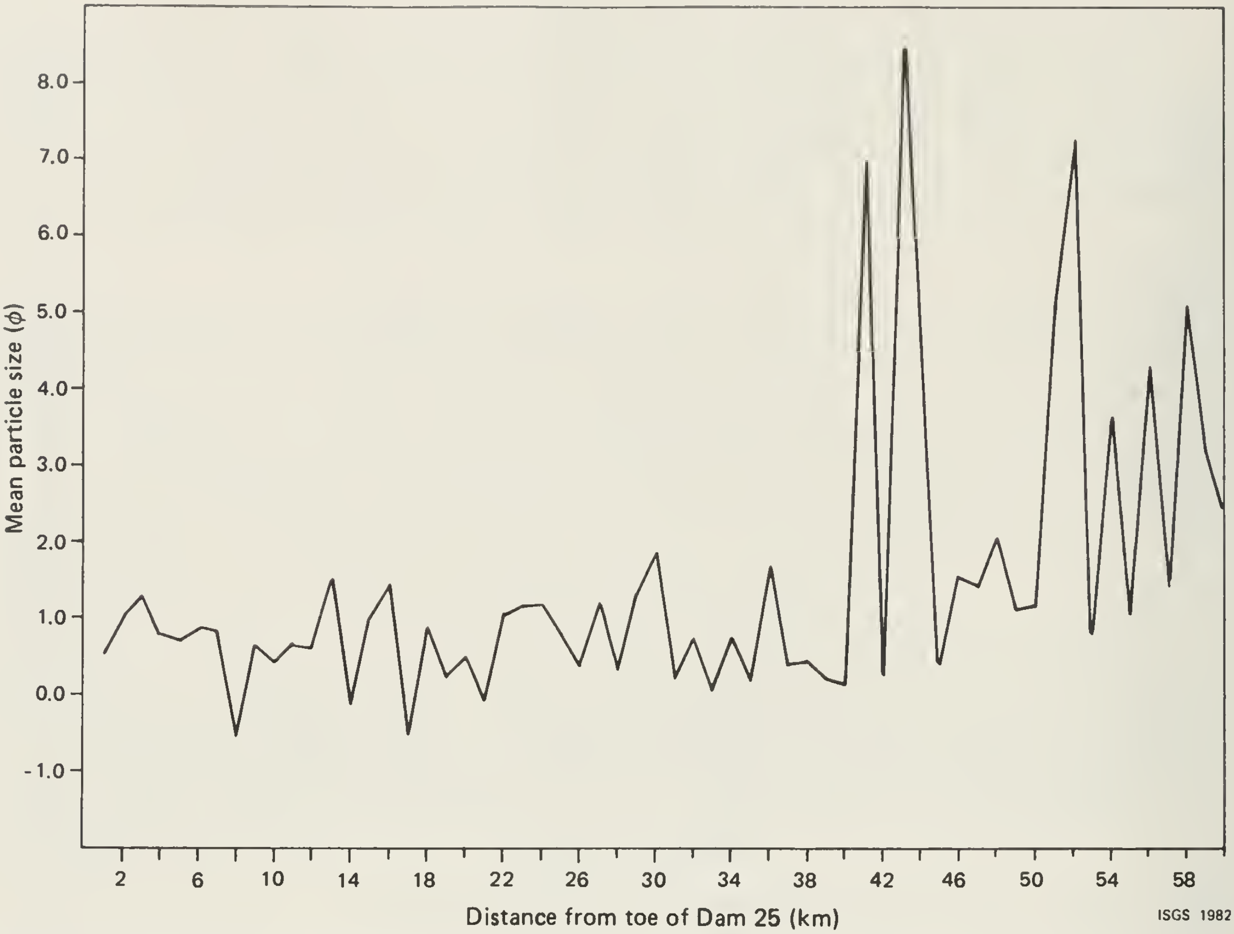


Figure 12. Relationship between mean particle sizes of samples from deepest water in main channel of Mississippi River and distance downstream from toe of Dam 25 in Pool 26.

Sorting. Sorting is equivalent to the statistical parameter known as standard deviation; it is a measure of the degree that the particle size distribution of a sediment sample varies around the mean value. Thus, the sorting value expressed in phi units shows the range of phi units on either side of the mean particle size that would contain 68.27 percent of the area under the frequency versus particle-size curve of the sample distribution. A sample having a mean particle size of 1 ∅ and sorting value of 0.75 ∅ would contain 68.27 percent of the area under its frequency curve between 0.25 ∅ and 1.75 ∅.

Although geologists often use qualitative terms such as "moderately sorted" to describe sediments, there is no general agreement on the correspondence between numerical values of sorting (standard deviation) and descriptive terms. For purposes of describing the sediments of Pool 26, we have selected the following arbitrary scale, modified slightly from Folk and Ward (1957):

∅ Sorting value	Descriptive term
<0.75 ∅	Well sorted
0.75 ∅ to 1.50 ∅	Moderately sorted
>1.50 ∅	Poorly sorted

Figure 13 is a scatter diagram showing the relationship between sorting value and mean particle size of Pool 26 bottom sediments. The diagram shows that, in general, finer-grained samples are more poorly sorted. However, many samples that have mean particle sizes between 0 Ø and 2 Ø also have sorting values greater than 1.5 Ø. A curve having an approximately sinusoidal form has been drawn through the approximate center of gravity of points plotted in figure 13. Folk and Ward (1957) plotted a similar curve in their study of particle size parameters in a Brazos River bar. No

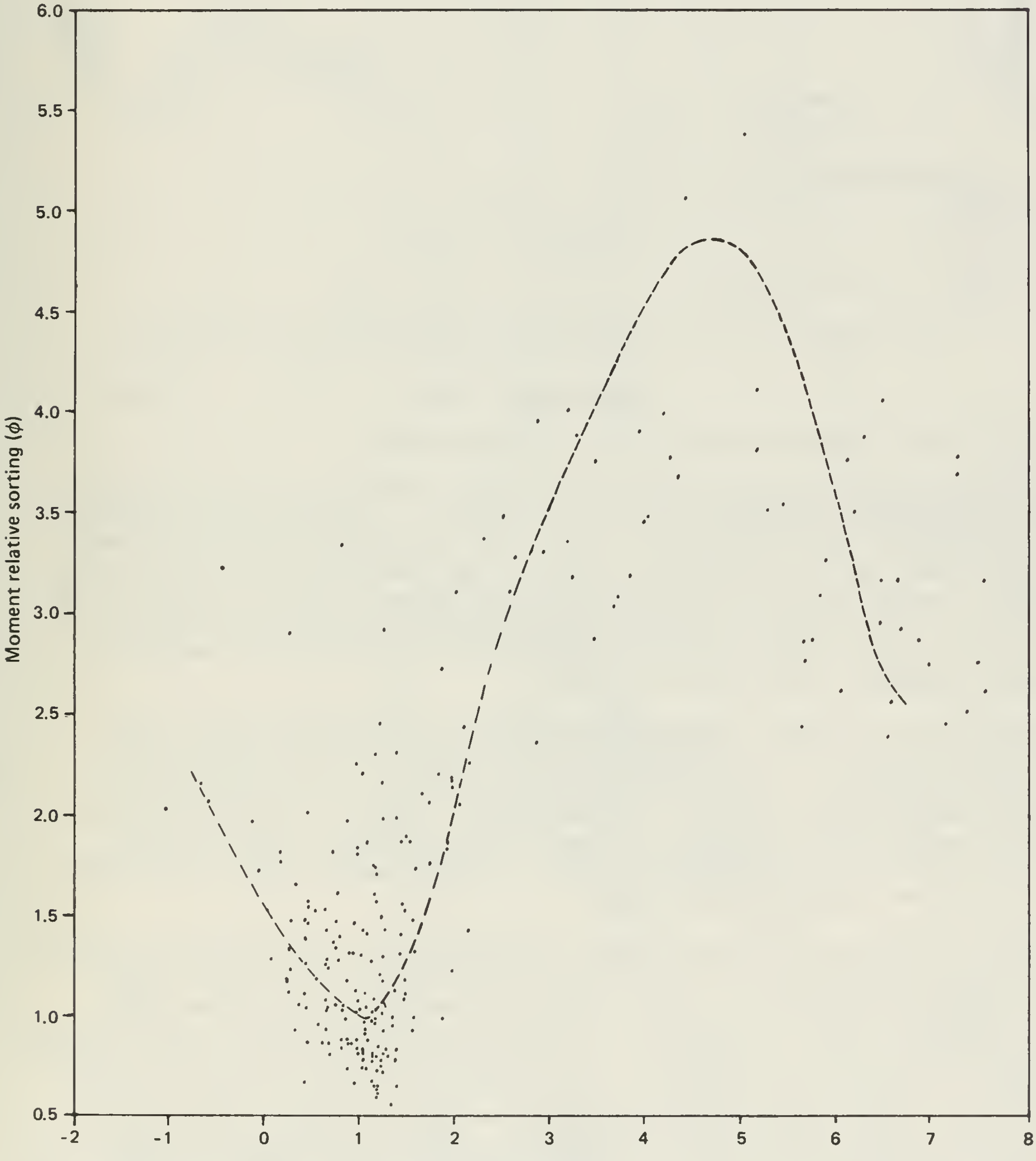


Figure 13. Scatter diagram showing relationship between mean particle size and sorting value of bottom sediment samples, Pool 26.

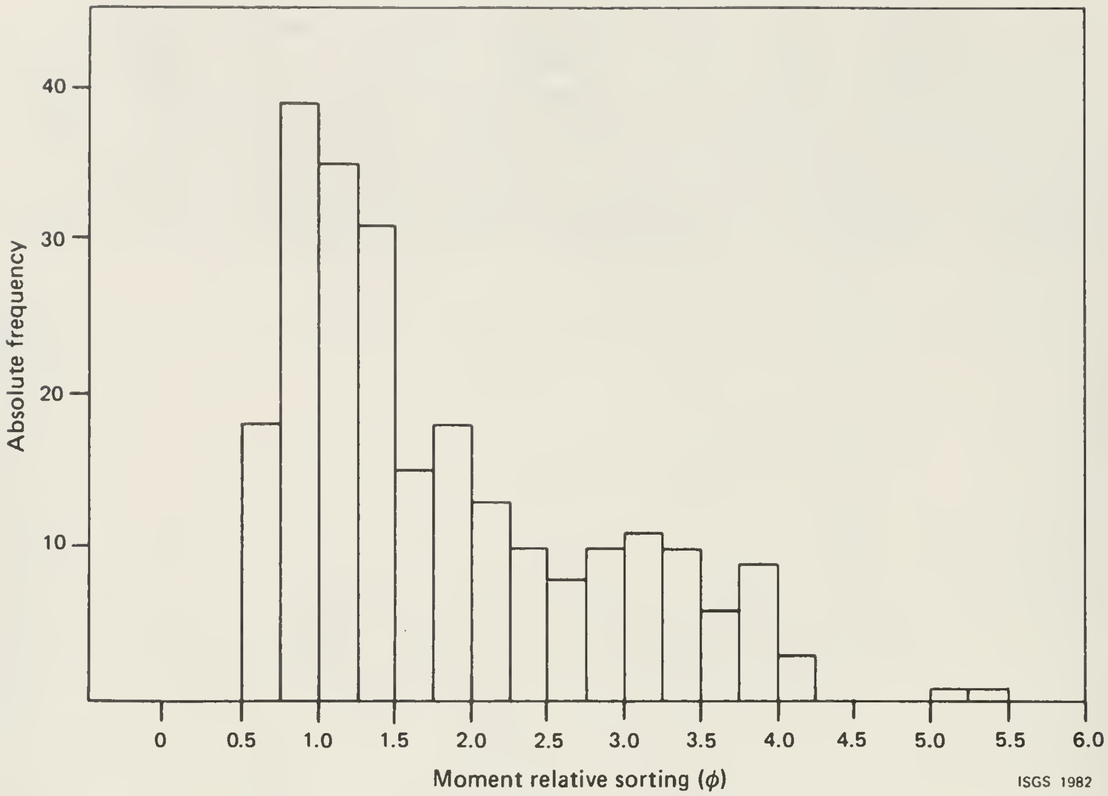


Figure 14. Frequency histogram of sorting values of bottom sediment samples, Pool 26.

physical explanation has ever been offered for the form of this curve, but some interesting inferences may be made from it. A comparison of figures 11 and 13 shows that the best sorting values are associated with the most frequent mean particle size class and that the poorest sorting values occur nearest the mean particle size class that is entirely absent in the Pool 26 samples. Sorting again improves near the silt-size modal class shown in figure 10. Thus, figure 13 also demonstrates the existence of two populations of sediment particles in Pool 26.

Figure 14 is a frequency histogram determined by counting sorting values compiled in table 1. Of the 238 samples included in the histogram, 44.1 percent have values in the moderately sorted range and an additional 7.6 percent have values in the well-sorted range. Thus, 51.7 percent of the bottom sediment samples are considered to be moderately to well sorted. Virtually all of these moderately to well sorted samples come from the main channel or main-channel border area.

Figures 15 through 22 are maps showing the variation of sorting values along the Pool 26 study reach. It is evident from inspection of these figures that bottom sediments in the main channel of the Mississippi River above the confluence of the Illinois River generally are moderately to well sorted. Figure 15 shows two zones of more poorly sorted sediments in areas where the channel is somewhat restricted. Water depths in these areas are not significantly different from other areas where sorting is better. The cause of the poorer sorting is unknown. In general, above the confluence of the Illinois, sorting of sediments is poorer adjacent to the shore in areas where weaker currents might allow deposition of silty and clayey sediments derived from bank erosion or floods.

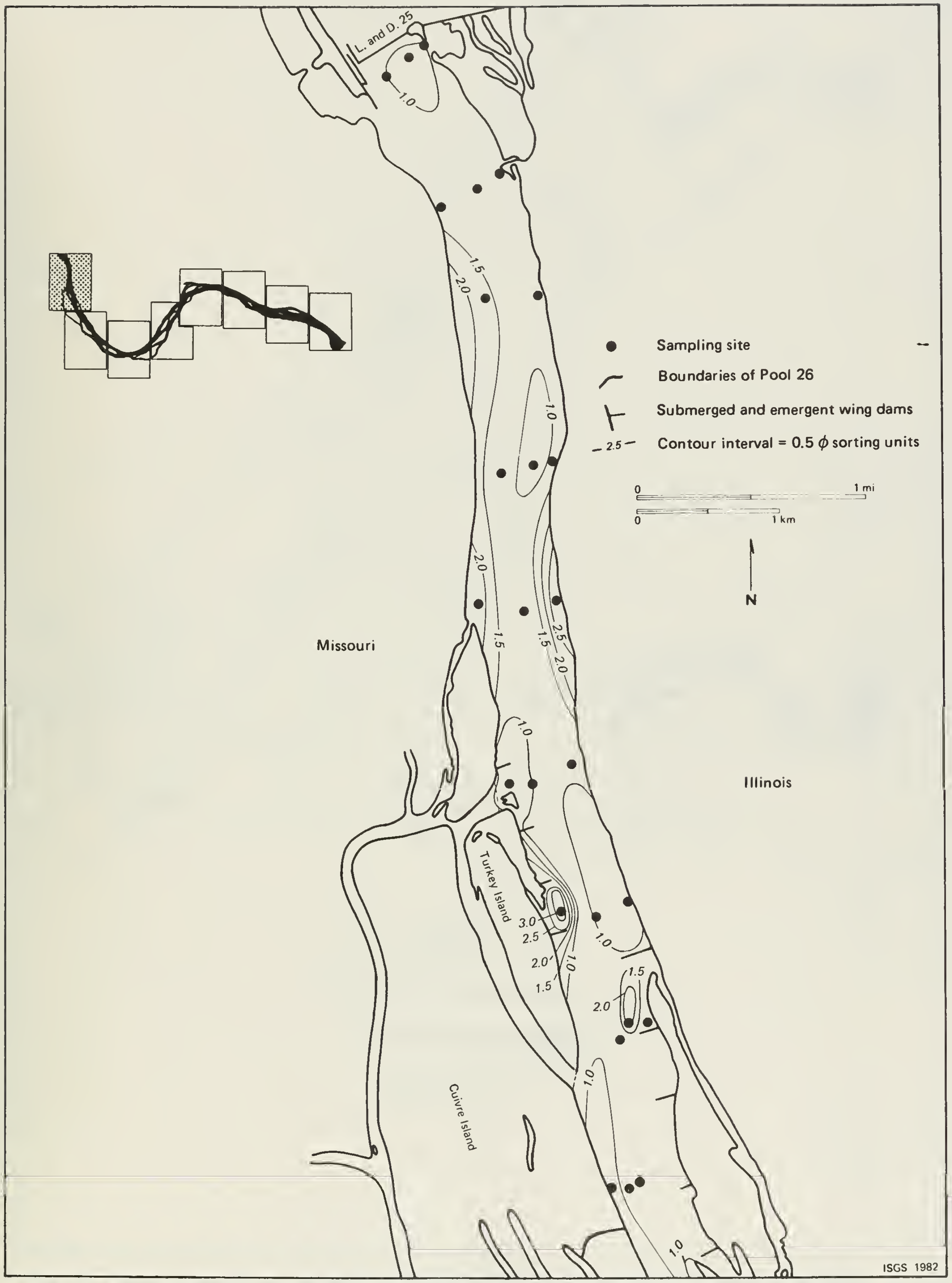


Figure 15. Distribution of sorting values of bottom sediments of Mississippi River: Foley and Winfield Quadrangles.

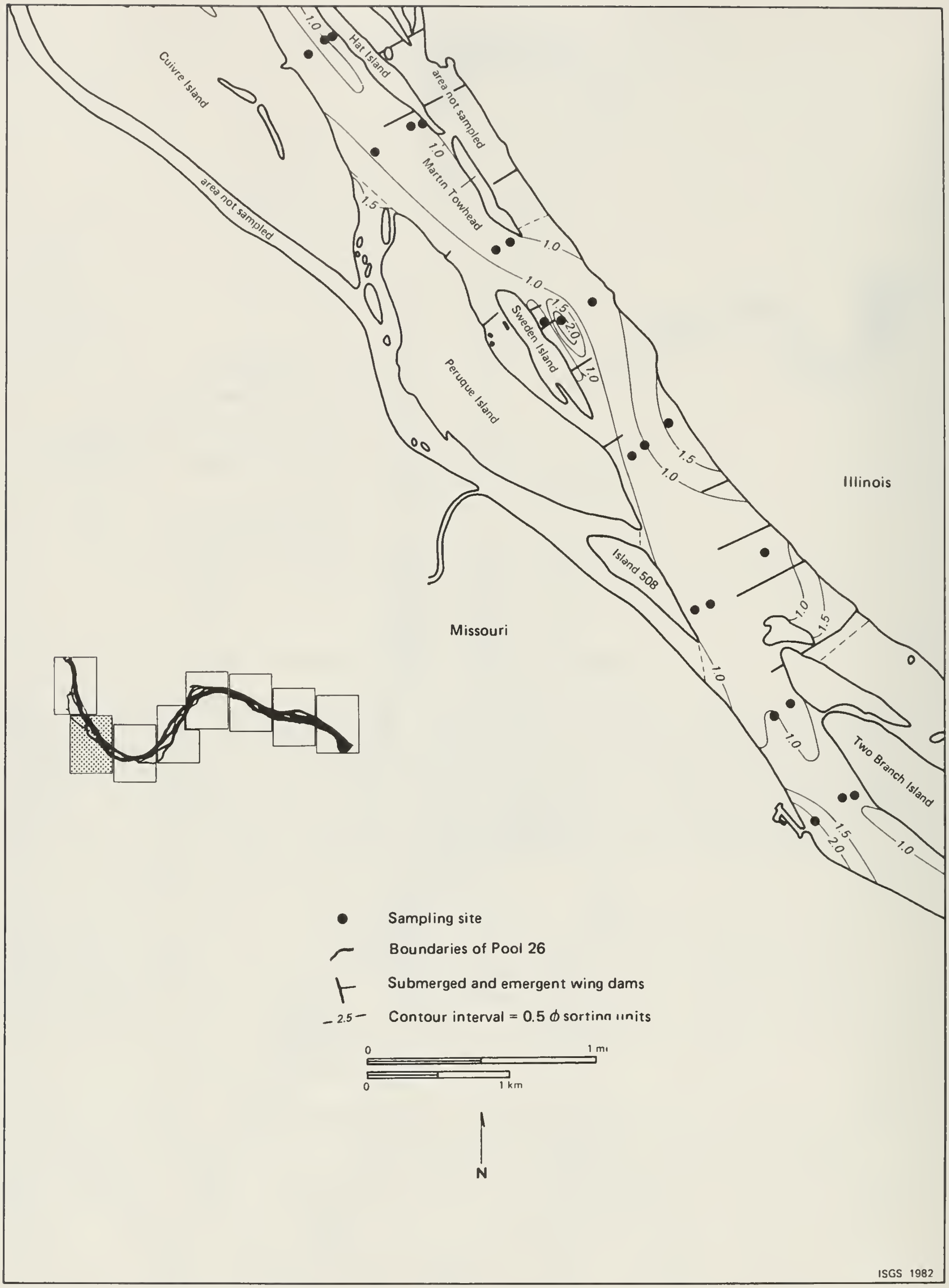


Figure 16. Distribution of sorting values of bottom sediments of Mississippi River: Winfield and Brussels Quadrangles.

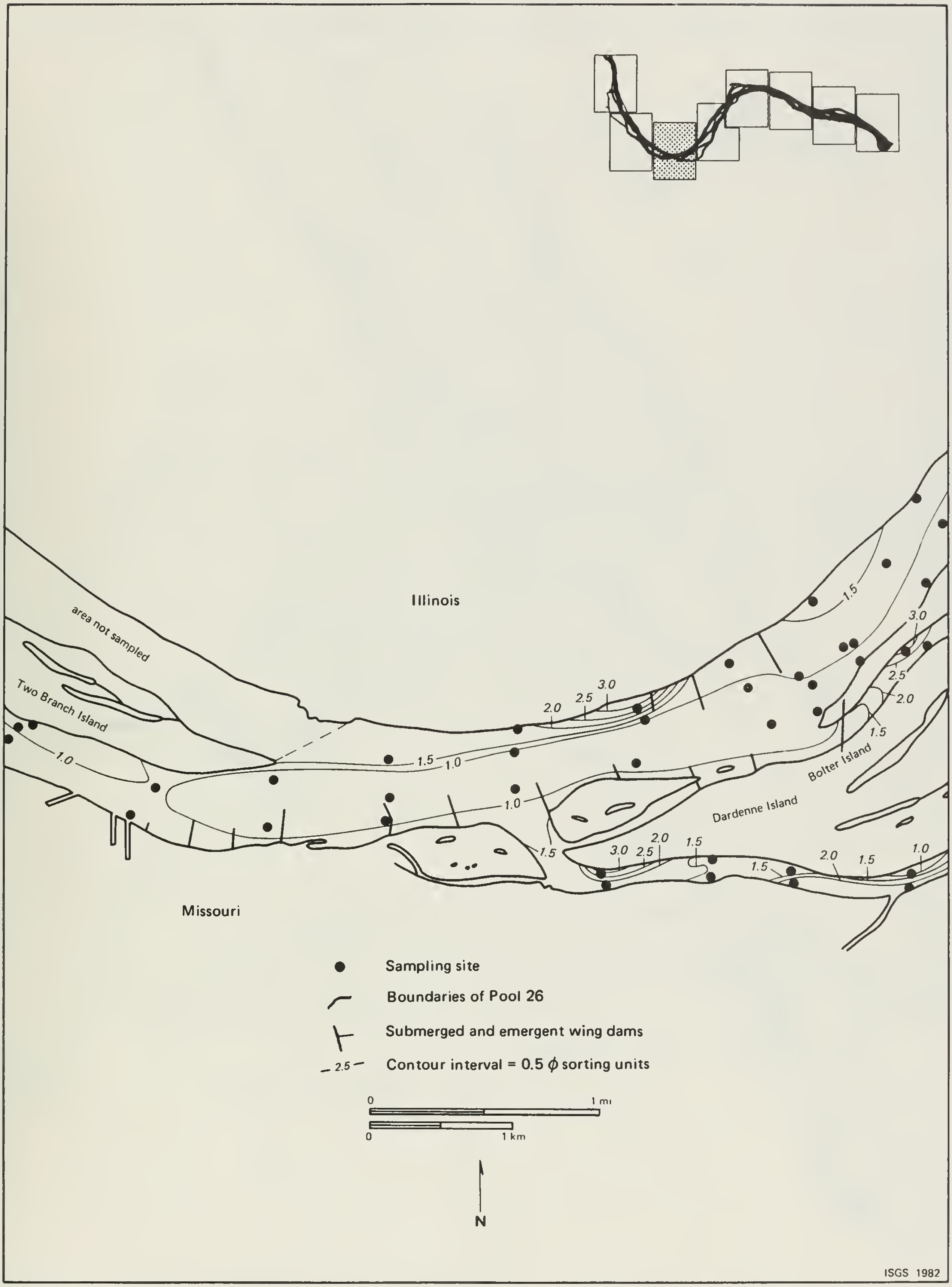


Figure 17. Distribution of sorting values of bottom sediments of Mississippi River: Kampville and Brussels Quadrangles.

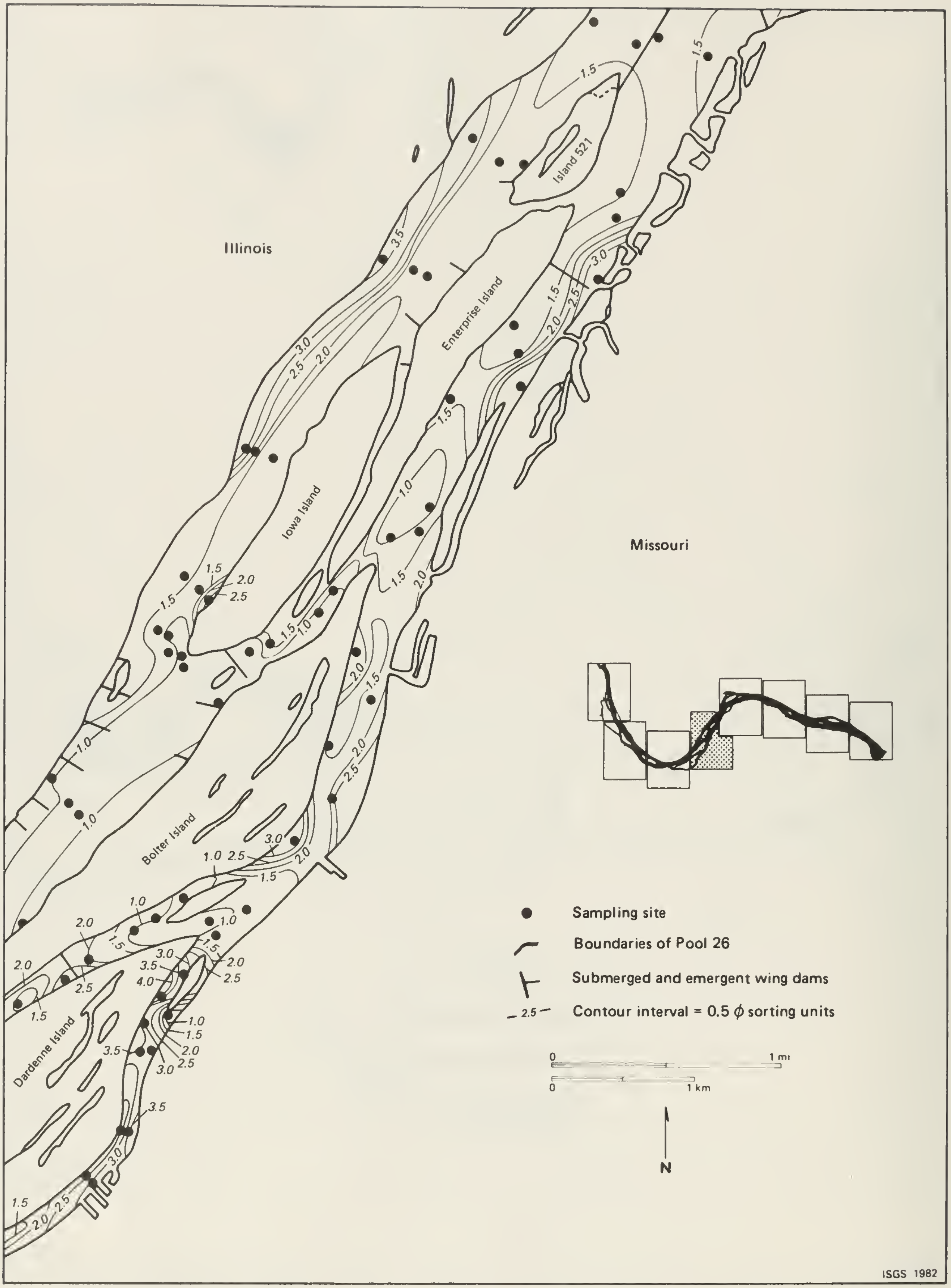


Figure 18. Distribution of sorting values of bottom sediments of Mississippi River: Kampville, Brussels, and Grafton Quadrangles.

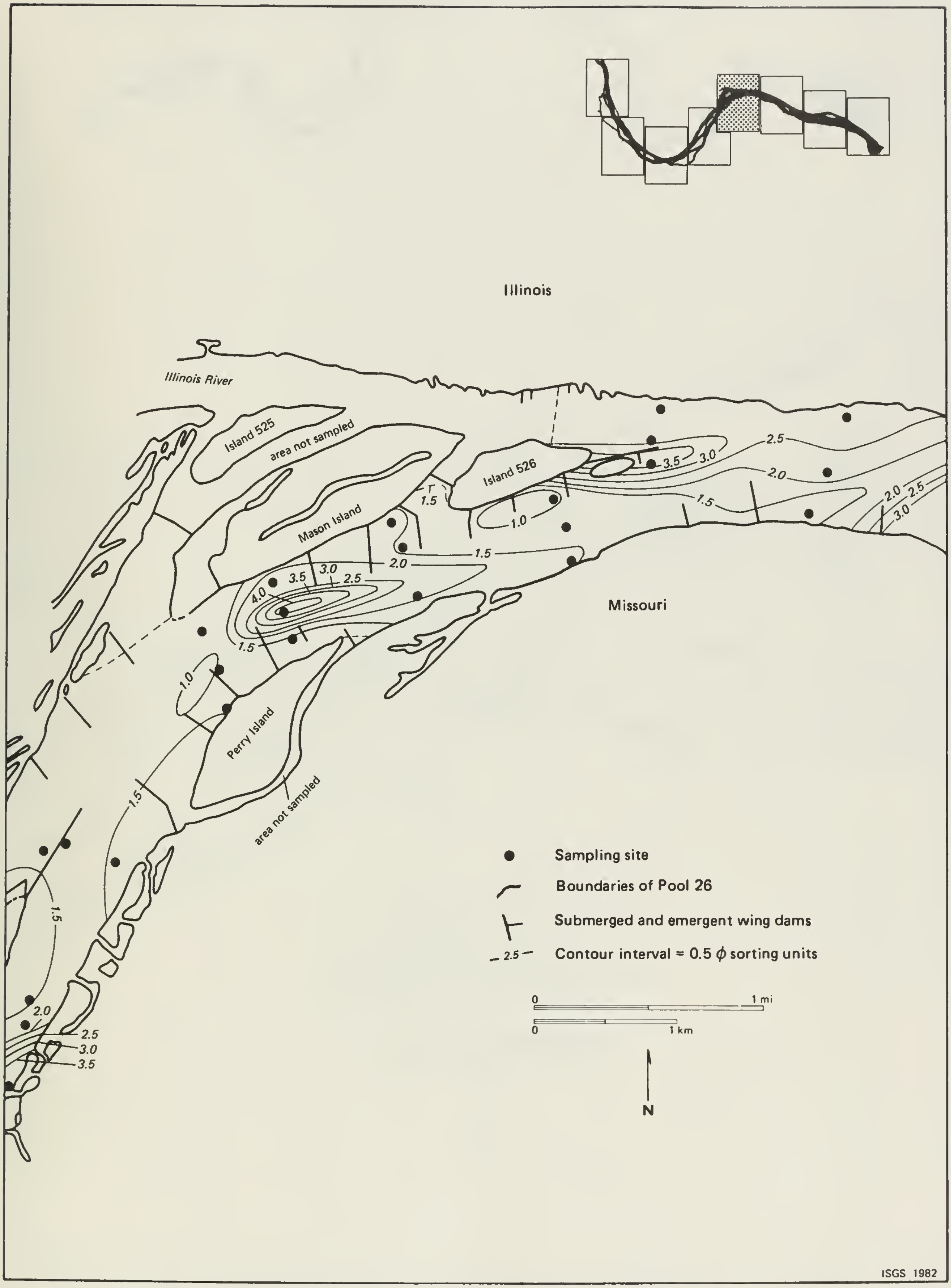


Figure 19. Distribution of sorting values of bottom sediments of Mississippi River: Grafton Quadrangle .

Figure 20. Distribution of sorting values of bottom sediments of Mississippi River: Grafton and Elsah Quadrangles.

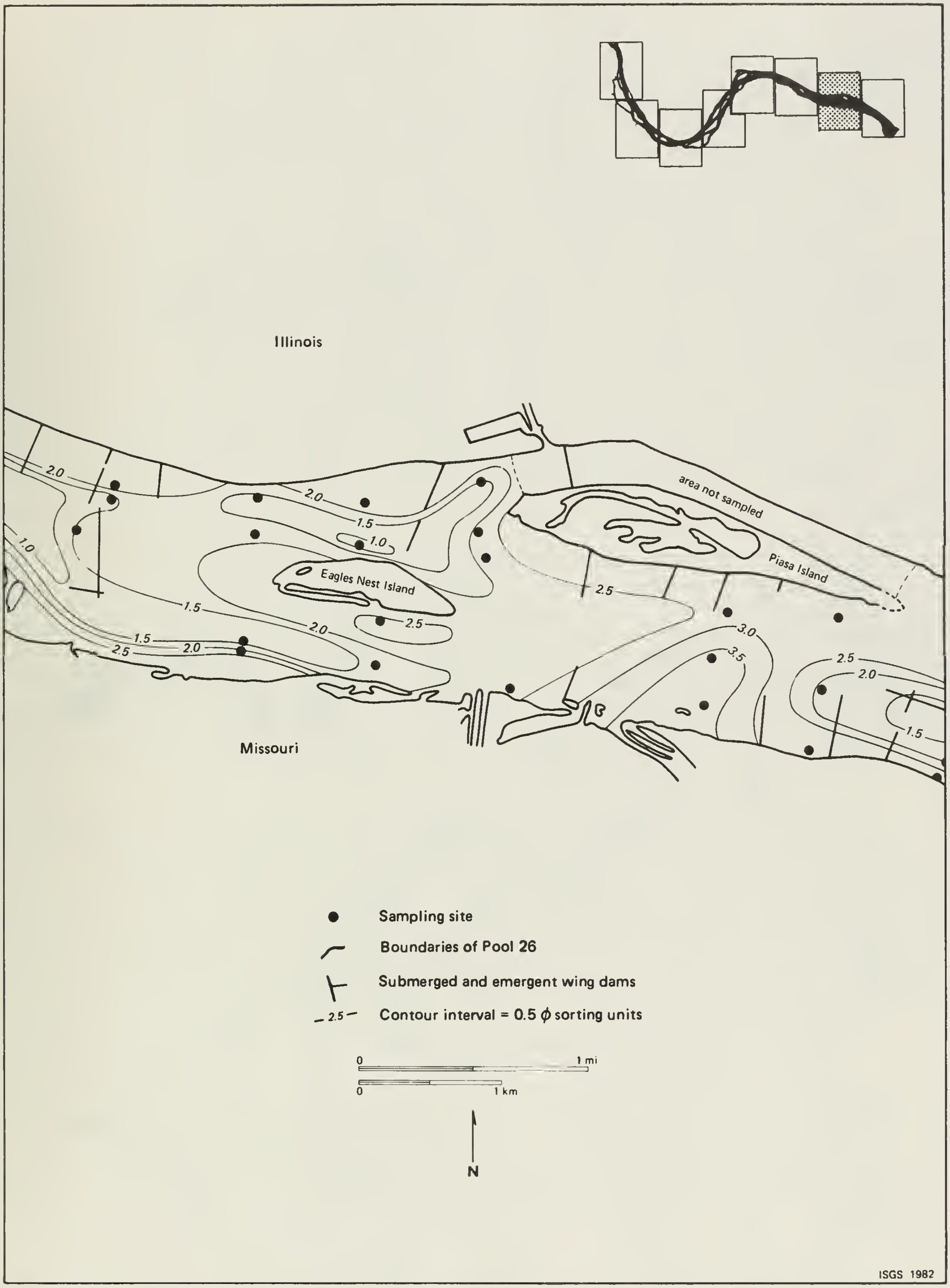


Figure 21. Distribution of sorting values of bottom sediments of Mississippi River: Elsah Quadrangle.

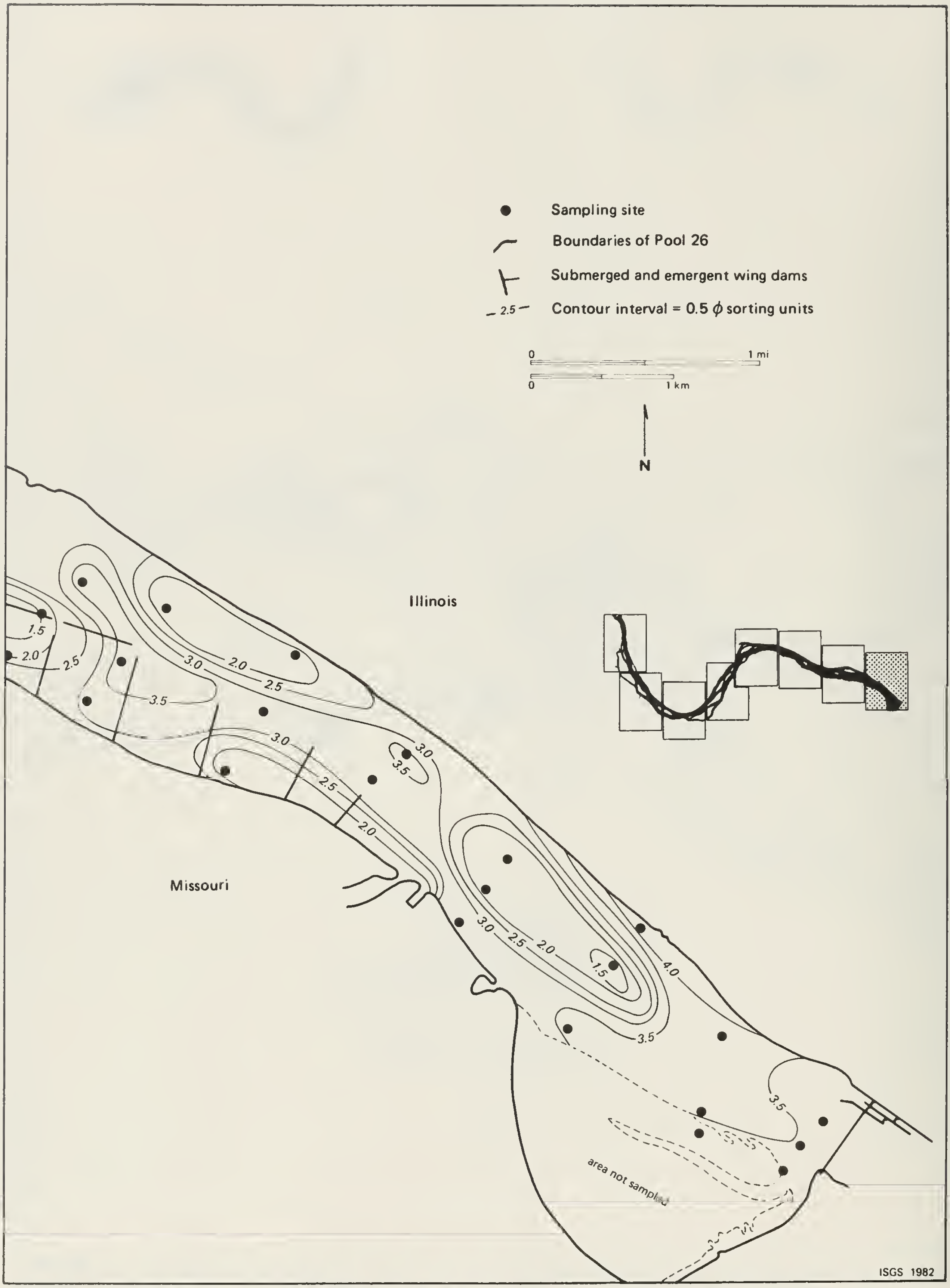


Figure 22. Distribution of sorting values of bottom sediments of Mississippi River: Alton Quadrangle.

In side channels such as those behind Dardenne, Iowa, and Enterprise Islands, sorting values are variable (figs. 17 and 18), but side-channel sediments generally are poorly sorted. These poor sorting values probably result from the mixing of sediment populations by deposition of coarser sediments in backwaters during periods of high river discharge, and subsequent deposition of finer-grained sediments during the waning of floods and during periods of lower discharge. An alternative explanation would be that these poorly sorted sediments represent samples of older sediments exposed by scouring during floods. In several places, sorting of bottom sediments in side channels appears to have been degraded downstream from dredged boat harbors and marinas (figs. 17 and 18). Tributaries such as the Cuivre River (fig. 15) and Dardenne Creek (fig. 17) commonly flow into side channels behind islands. Such small tributaries probably contribute significant amounts of fine silt and clay eroded from the extensive farmlands in the broad floodplain of the Mississippi River on the Missouri shore. These volumes of silt and clay affect the sorting of sediments in side channels where the normal river currents are much lower in velocity than in the main channel. The islands that separate these tributaries from the main channel probably formed because of the extra, localized sediment loads delivered to the main stream by the tributaries.

Sorting of bottom sediments in the Mississippi River generally is poor below the mouth of the Illinois River at Grafton. At the mouth of the Illinois (fig. 19) sorting values range from 2.5 Ø to 3.0 Ø. The currents from the Mississippi and Illinois Rivers impart to the areal distribution of sorting values a sinuous form that approximately follows the position of the deepest channels (figs. 19 and 20). Downstream from the mouth of the Illinois, the wavelike pattern gradually disappears as the finer grained sediment contributed by the Illinois becomes more uniformly mixed with the coarser sediment brought down the Mississippi (Figs. 21 and 22).

Controls on sorting. The three principal controls on the sorting of any sediment are: (1) sorting of source materials or relative quantities of various sizes of particles supplied to the system; (2) average current velocity in the area being considered; and (3) persistence of the current velocity (Pettijohn, 1957; Blatt et al., 1972). The two principal sources of sediment in the Mississippi River portion of Pool 26 are material passed through Dam 25, and the Illinois River. Tributaries within the pool, such as the Cuivre River, Dardenne Creek, Elsah Creek, and Piasa Creek, probably are relatively insignificant sediment sources except in local areas. Major floods due to seasonal spring runoff are relatively rare in the upper Mississippi River (Simons et al., 1975), but there are substantial annual increases of silt- and clay-size sediment loads during spring runoffs. However, the absence of significant amounts of silt- and clay-size sediment in main channel samples indicates that most of this silt and clay remains in the suspended load and bypasses Pool 26. As long as present climatic conditions and erosion rates remain constant within the drainage basin, supplies of sediment to Pool 26 may be considered essentially infinite and continuous. Despite the relative rarity of major floods, current velocities probably vary considerably because of changes in discharge used to control the pool stage. Over much of the length of the pool, however, differences in current velocity across a particular channel transect, from shallow near-shore areas to the thalweg, are probably greater than the normal seasonal variations of current velocity in the thalweg at the particular transect.

Over much of the length of Pool 26, the distribution of sediment sorting values shown in figures 15 through 22, probably is controlled mostly by the average current velocity in the area and the persistence of the current velocity. Even below the mouth of the Illinois River, where average sorting values are significantly higher, the distribution of sorting values within the boundaries of the river still seems to be largely controlled by the probable distribution of current velocities.

In some areas of Pool 26, the Ponar grab sampler may have collected samples from more than one sediment layer. For example, finer-grained sediments may have been deposited on top of coarser-grained sediments and the sampler will have grabbed parts of both sediments. Such a mixed sample could only be processed as a single sample having a sorting value much higher than the probable sorting value of either of the separate sediment layers.

Skewness. The skewness parameter measures the direction and amount by which the mean particle size of a sediment size distribution deviates from the median particle size (50th percentile value of the distribution). A sample whose mean particle size is coarser than the median particle size has a negative value for relative moment skewness, and has a non-normal concentration of coarse grains in the sample distribution. A sample whose mean particle size is finer than the median value will have a positive skewness value. A statistically normal population has zero skewness and the mean and median sizes coincide. Relative moment skewness utilizes values from the entire measured distribution of particle sizes and is therefore strongly influenced by the coarse and fine tails of the frequency curves of the samples. Values for skewness are dimensionless numbers.

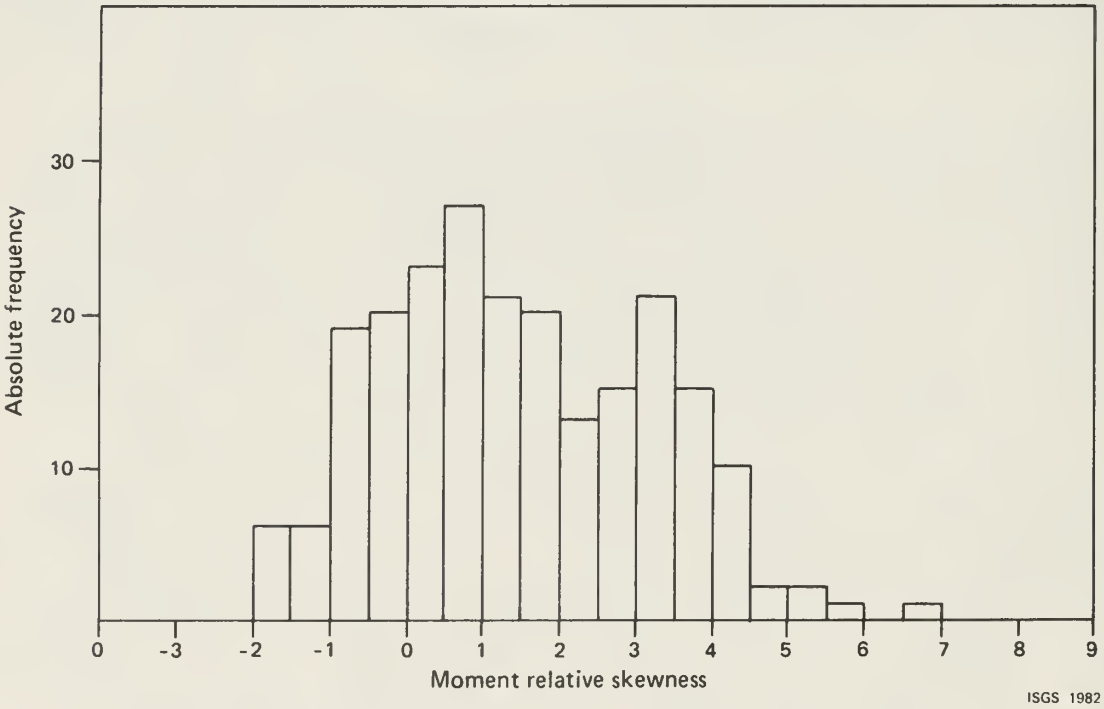


Figure 23. Frequency histogram of relative moment skewness of bottom sediment samples, Pool 26.

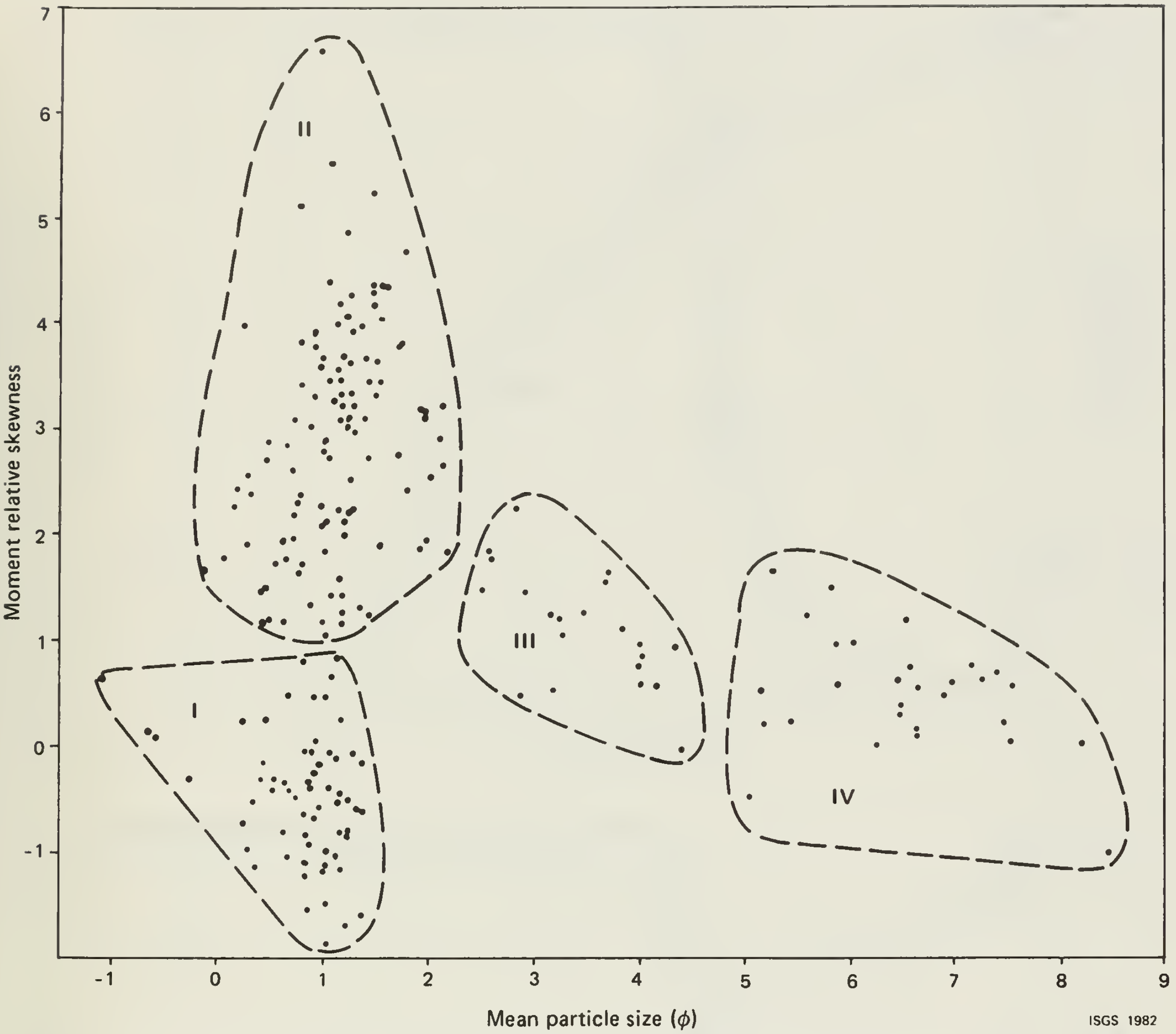
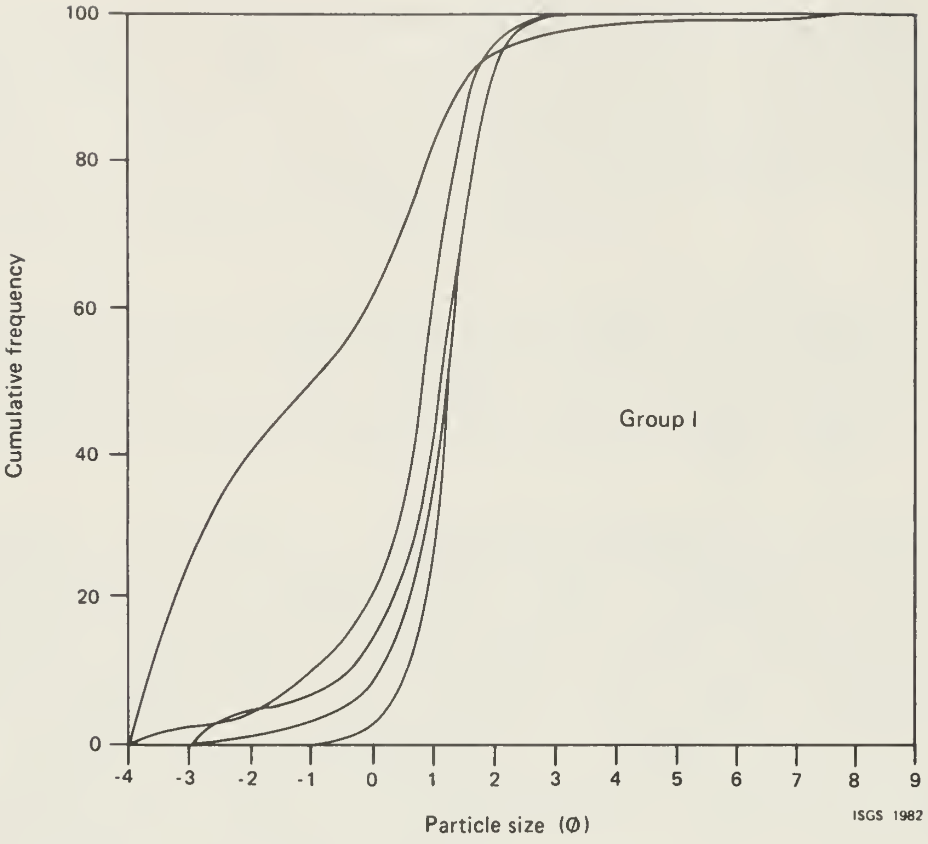


Figure 24. Scatter diagram showing relationship between mean particle size and relative moment skewness, and the four sediment groups, Pool 26.

Figure 23 is a frequency histogram of relative moment skewness values of 222 bottom sediment samples from Pool 26. Of the 222 samples, almost 50 percent have skewness values between -1 and +1. Values for skewness have a broad range, but 77 percent of the samples are positively skewed and therefore have significant fine tails in their distributions.

Sediment Groups. A scatter diagram (fig. 24) plotting mean particle size against skewness values for the Pool 26 sediments separates the samples into four groups. Figures 25 and 26 show examples of cumulative frequency curves for the particle-size distributions in each of the four groups. Group I samples (figs. 24 and 25) have mean particle sizes coarser than about 1.5 ∅ and skewness values less than 1. Group I sediments commonly are unimodal, but may have a slight coarse tail in the gravel sizes. Group II sediments (figs. 24 and 25) have mean particle sizes ranging from finer than 2 ∅ to slightly coarser than 0 ∅ and have skewness values ranging from 1 to about 6.5. Most of these sediments are bimodal or polymodal. They have a major



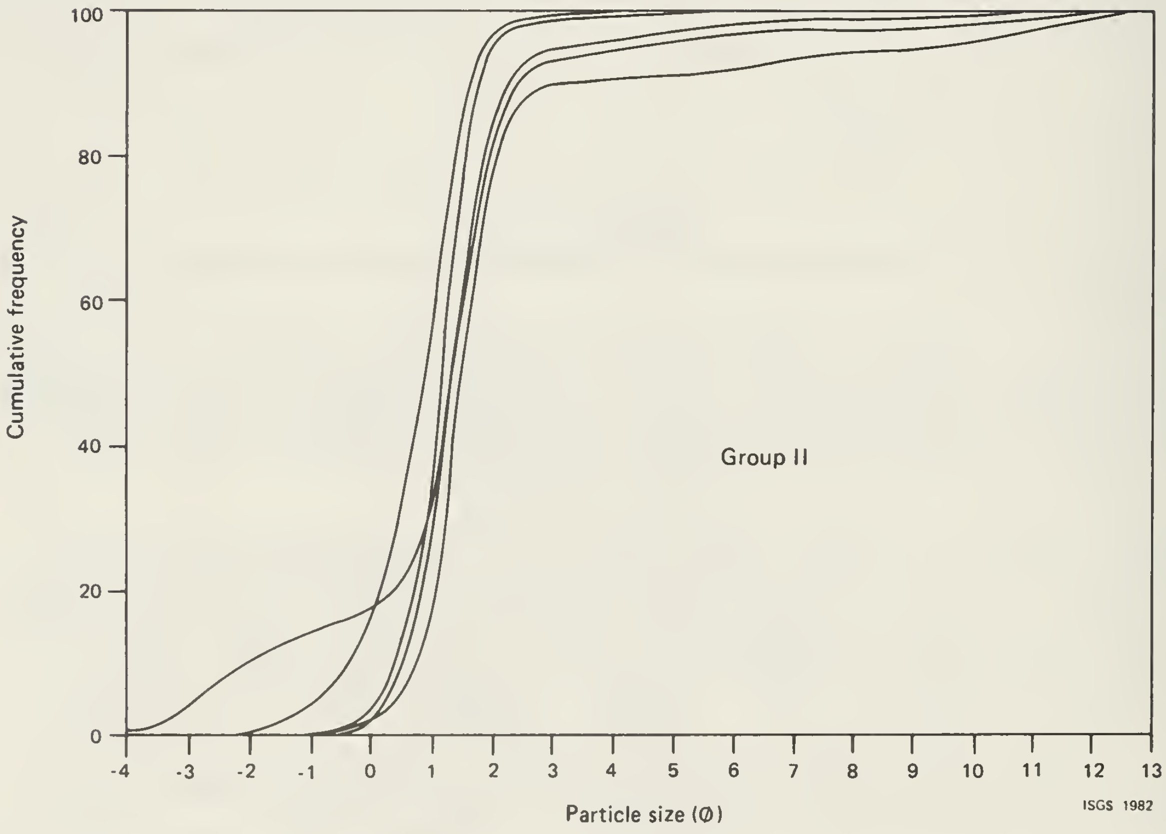
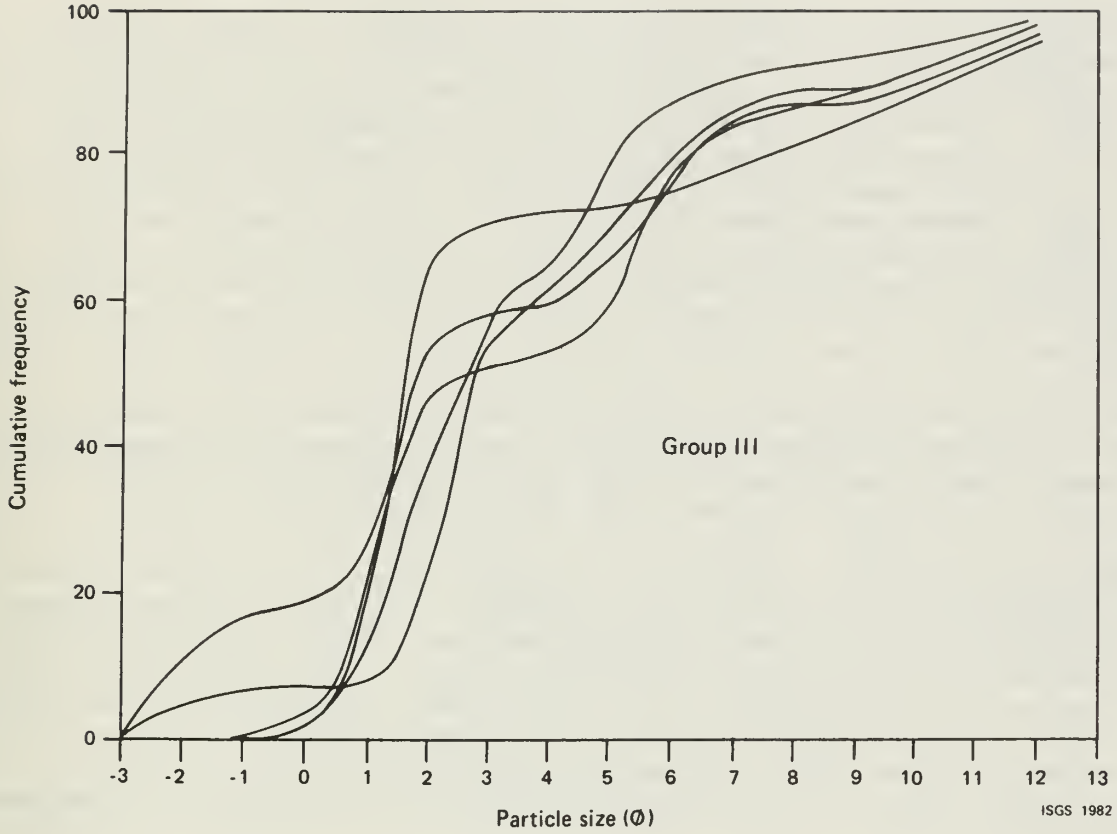


Figure 25. Representative cumulative frequency curves of selected samples from Group I and Group II sediments of Pool 26.



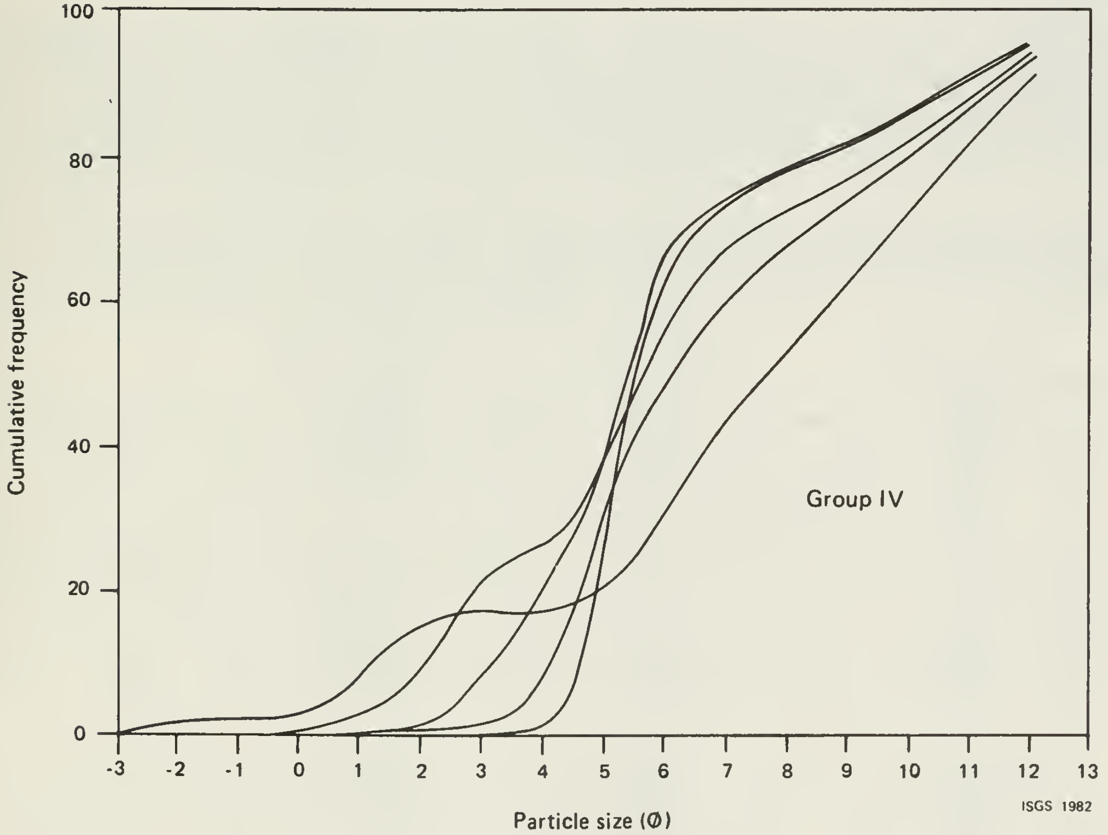


Figure 26. Representative cumulative frequency curves of selected samples from Group III and Group IV sediments of Pool 26.

medium- to coarse-sand component that largely controls the mean particle size, but significant amounts of silt- and clay-size particles impart fine tails to their distributions. Group III sediments (figs. 24 and 26) have mean particle sizes ranging from 2 Ø to 4.5 Ø and skewness values ranging from 0 to +2. Group III sediments commonly are polymodal and consist of mixtures of nearly equal amounts of sand-, silt-, and clay-size particles that impart a near-normal skewness to their distribution. Mean particle-size values for these distributions generally are poor indicators of the actual particle size of the major mode of the distribution. The generally positive skewness values indicate that fine particles are somewhat more common than coarser sizes in these samples. Group IV sediments (fig. 24 and 26) have mean particle size values ranging from about 5 Ø to 8.5 Ø and skewness values ranging from -1 to +1.8. Particle size distributions of Group IV sediments are either unimodal or bimodal. They consist mostly of silt- and clay-size particles, but may have significant admixtures of fine sand that impart a negative skewness to their distributions.

Figures 27 through 34 are maps of the areal distribution of sediment skewness groups along the Pool 26 study reach. As shown in figure 27, Group II sediments predominate in the reach of the main channel of the Mississippi from the toe of Dam 25 downstream to the head of Turkey Island. From there down to the head of Iowa Island (figs. 27 to 30), Group I sediments dominate the main channel. Group II sediments are again dominant in the main channel from the head of Iowa Island down to the vicinity of the head of Piasa Island below the mouth of the Illinois River (figs. 30 to 33). From the head of Piasa Island down to the head of Dam 26, Group IV and Group III sediments predominate (figs. 33 and 34).

This downstream variation of sediment groups may be explained in a unified way by considering the effects of stream gradient in the pool and sediment sources. Table 1 shows the measured stages of Pool 26 at three gauges during the period from July 10 to August 9, 1980. The table shows that during this period the pool stages at the toe of Dam 25 fluctuated between

TABLE 1. Pool stages (ft above mean sea level) at three gauging stations, Pool 26, July 10 to August 9, 1980. Data supplied by St. Louis District, U.S. Army Corps of Engineers.

Date	Dam 25 River mile 242	Grafton River mile 218	Dam 26 River mile 203
7/10	420.8	419.2	418.8
7/11	419.8	419.0	418.8
7/12	420.1	419.1	418.9
7/13	419.9	419.2	418.9
7/14	420.4	419.3	419.0
7/15	420.2	419.1	418.8
7/16	420.8	419.1	418.9
7/22	419.8	419.0	419.0
7/24	420.8	419.2	418.9
7/25	420.9	419.0	418.9
7/31	420.2	419.1	419.0
8/4	419.6	418.8	418.8
8/5	419.8	419.1	419.0
8/6	419.8	418.8	419.1
8/7	421.0	419.2	419.1
8/8	420.5	419.0	418.8
8/9	420.2	419.1	418.8

421.0 and 419.6 feet, a 1.4-foot range about a mean pool stage of 420.25 feet above mean sea level. At the Grafton guage, 24 river miles (28.6 km) below the toe of Dam 25, pool stage elevations ranged between 418.8 and 419.1 feet, a 0.3-foot range about a mean pool stage of 418.9 feet. Using these average pool stages, the average gradient of the Mississippi River between Dam 25 and Grafton is 0.049 feet per mile (0.009 m/km) and the average gradient from Grafton to Dam 26 is only 0.011 feet per mile (0.002 m/km). Thus, the gradient of the Mississippi River in Pool 26 above the confluence of the Illinois River was about 4.5 times greater than the gradient below the Illinois during this period of relatively low discharge in the summer of 1980.

The pool behind Dam 25 has an extensive area of shallow water wetlands in the Batchtown State Management Area and Mark Twain National Wildlife Refuge. Bottom sediments passing into the upper parts of Pool 26 must pass through Dam 25. Large amounts of fine sediment may be contributed to the sediment load from the wetlands and from scour of fine sediment deposited at low flow in the pooled river reach upstream of Lock and Dam 25. The river reach downstream from the toe of Dam 25 is subjected to significant fluctuations of current velocity caused by the varying discharges passed through the dam to control the stage of Pool 25. The combination of large supplies of fine sediment and rapid fluctuations of current velocities could allow large amounts of fine sediment to become entrapped in inter-grain spaces of coarser sediment. These fine tails cause the large skewness values observed in the Group II sediments in the reach from Dam 25 to the head of Turkey Island (fig. 27).

Farther downstream, between Turkey Island and the head of Iowa Island (figs. 27 to 30), current velocities are probably somewhat slower, but more constant, than near Dam 25. Most fine sediments are winnowed out and bypass the main channel in this reach of the river, but coarser sediments commonly are deposited. Parts of this reach of the river have been dredged several times in the last 25 years. According to Simons et al. (1975), river miles 235 to 237 near the head of Turkey Island were dredged nine times in the 25 years from 1949 to 1974; the entire reach from river mile 227 near the head of Iowa Island to mile 237 near the head of Turkey Island is the most troublesome area in Pool 26 in terms of dredging needs.

Simons et al. (1975) also report that the upper quarter of Pool 26, corresponding approximately with the reach from the toe of Dam 25 to the head of Turkey Island, has been eroded substantially since the construction of the dams. Average elevation of the riverbed is now 3 feet (1 m) lower in this reach of the river than it was in 1929 before the dam was completed. It seems evident that much of the sediment eroded from this reach has been deposited somewhere farther downstream. According to Simons et al. (1975) the average riverbed elevation of the middle third of Pool 26 that includes much of the heavily dredged reach has increased by only 0.1 feet from 1949 to 1974. Such a small amount of aggradation could hardly account for the amount of sediment apparently removed from the upper quarter of the pool.

Annual fluctuations of discharge may be sufficient to keep the aggrading reach cleared of navigation obstructions in most years. Perhaps only in years when spring runoff is exceptionally low, such as in 1980, does deposition in this reach become a problem. Dredging was required upstream of and along Iowa Island during late July and August 1980.

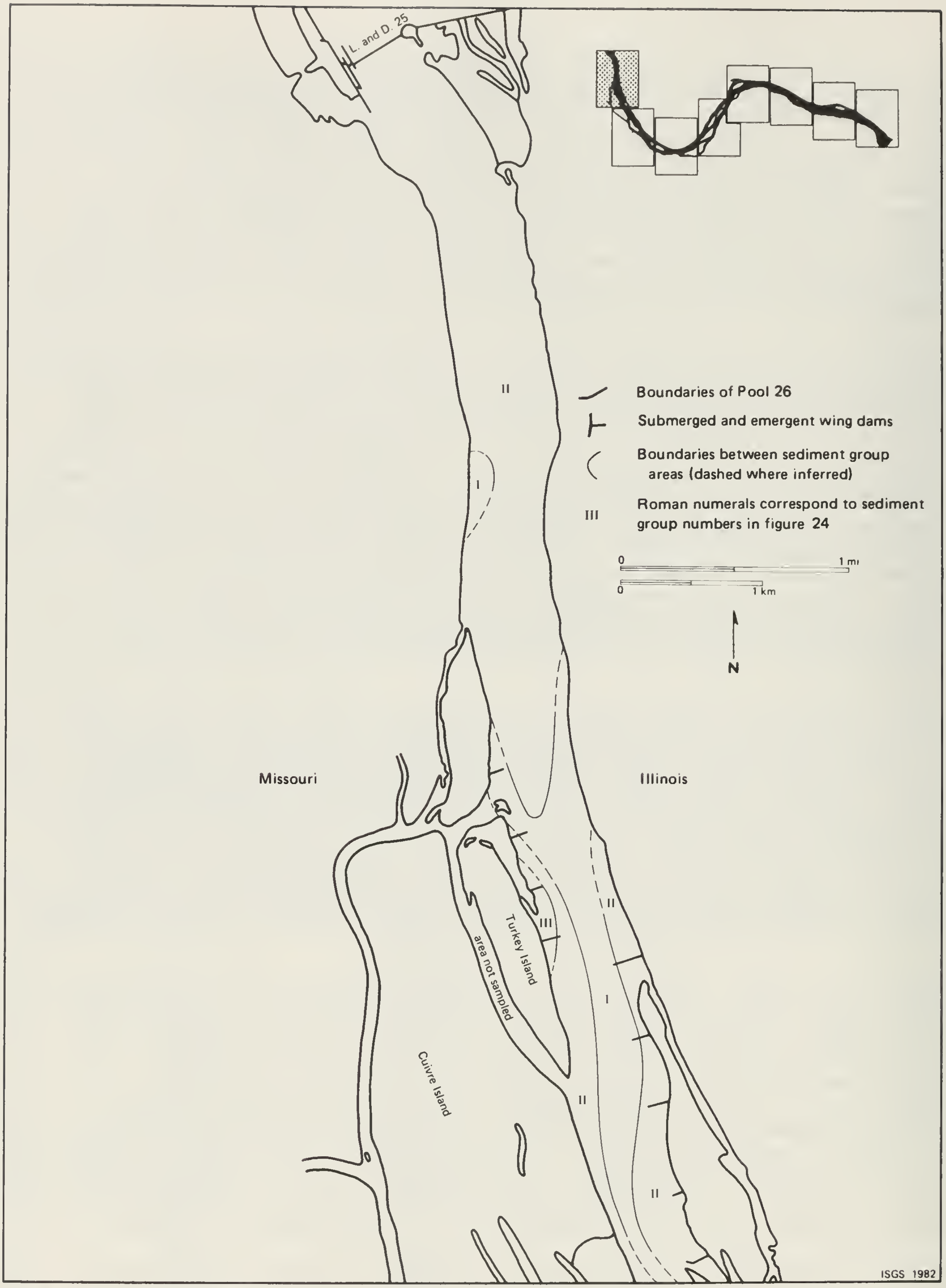


Figure 27. Distribution of sediment groups in Pool 26: Foley and Winfield Quadrangles.

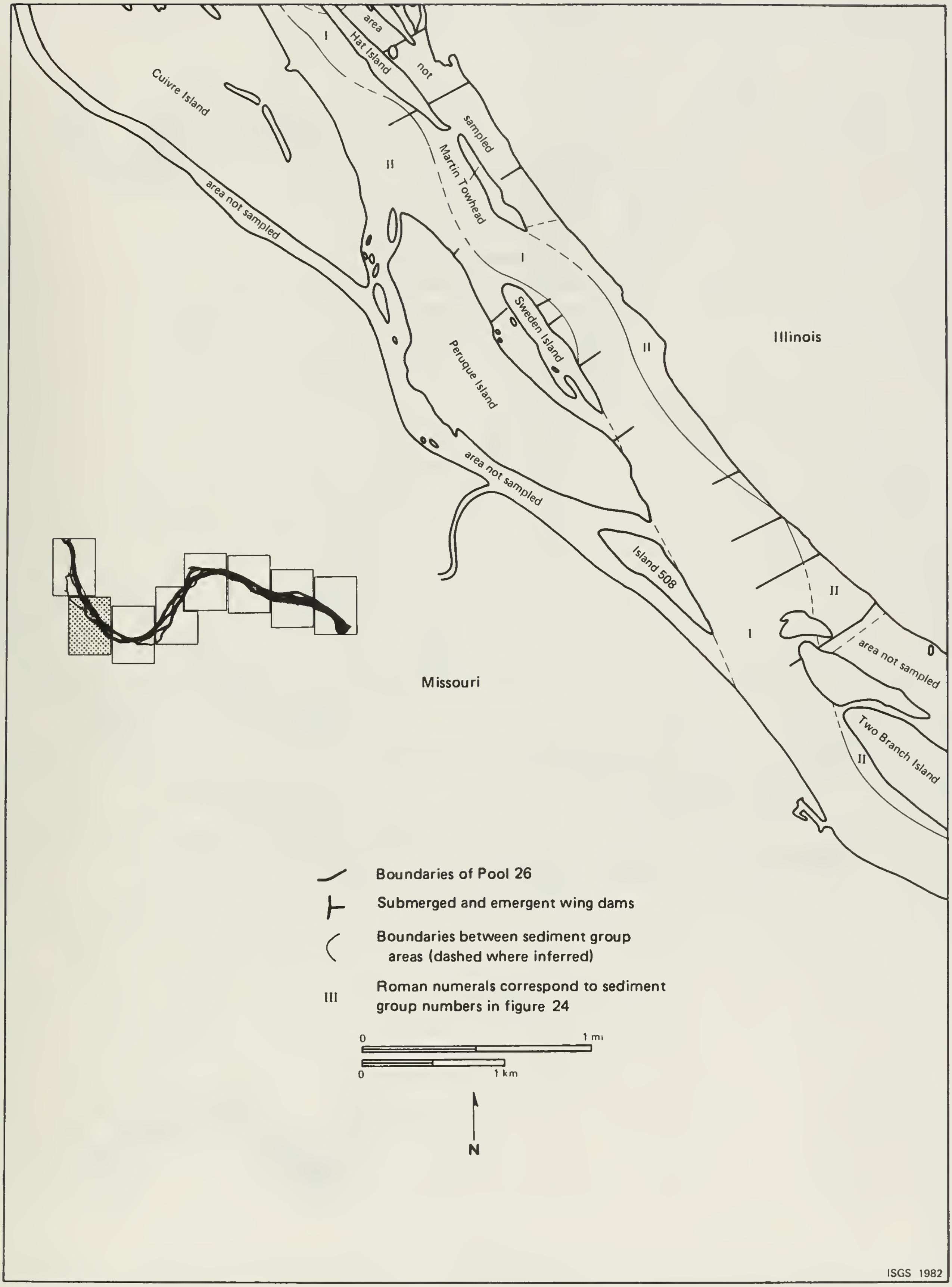


Figure 28. Distribution of sediment groups in Pool 26: Winfield and Brussels Quadrangles.

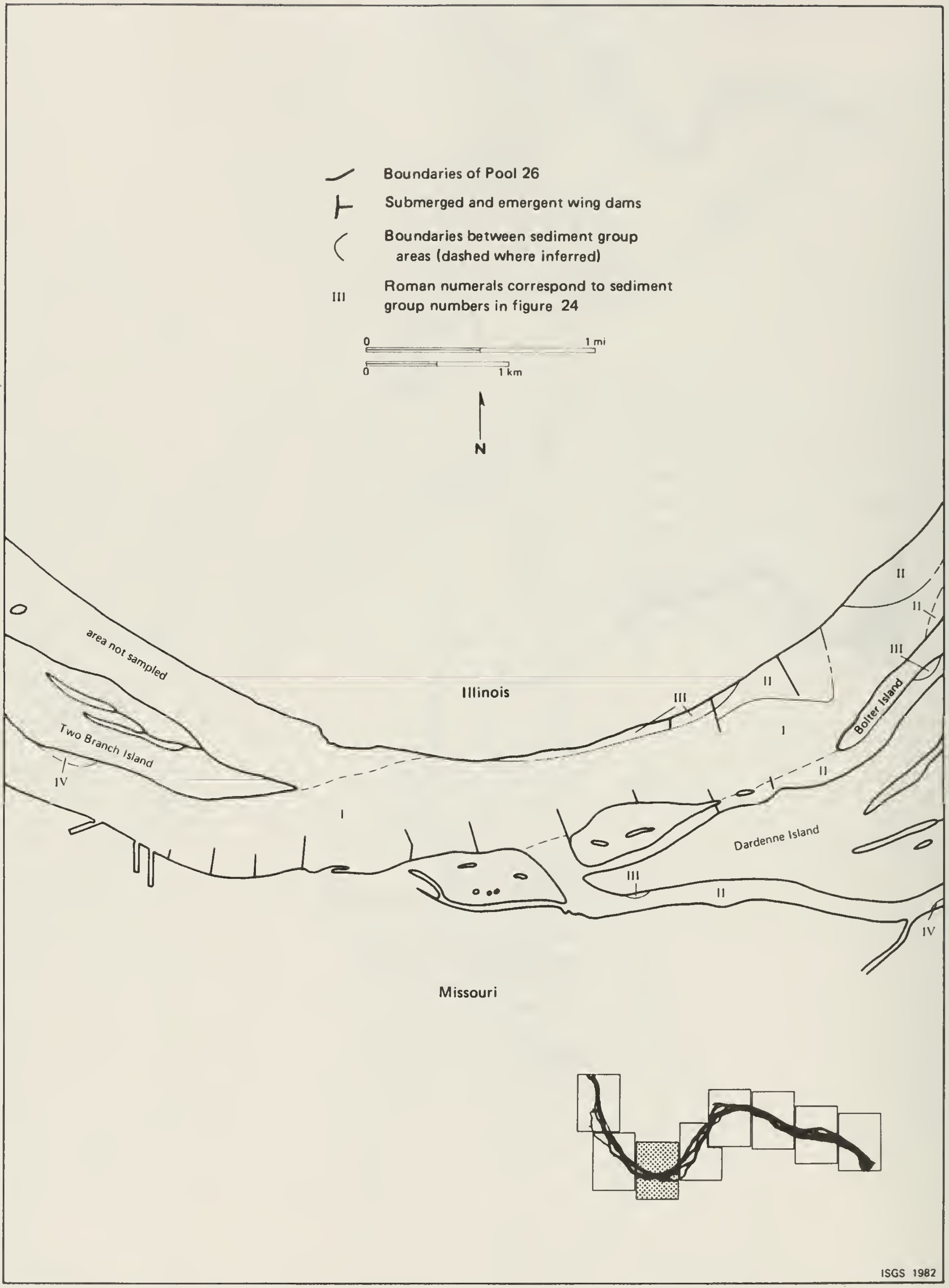


Figure 29. Distribution of sediment groups in Pool 26: Kampville and Brussels Quadrangles.

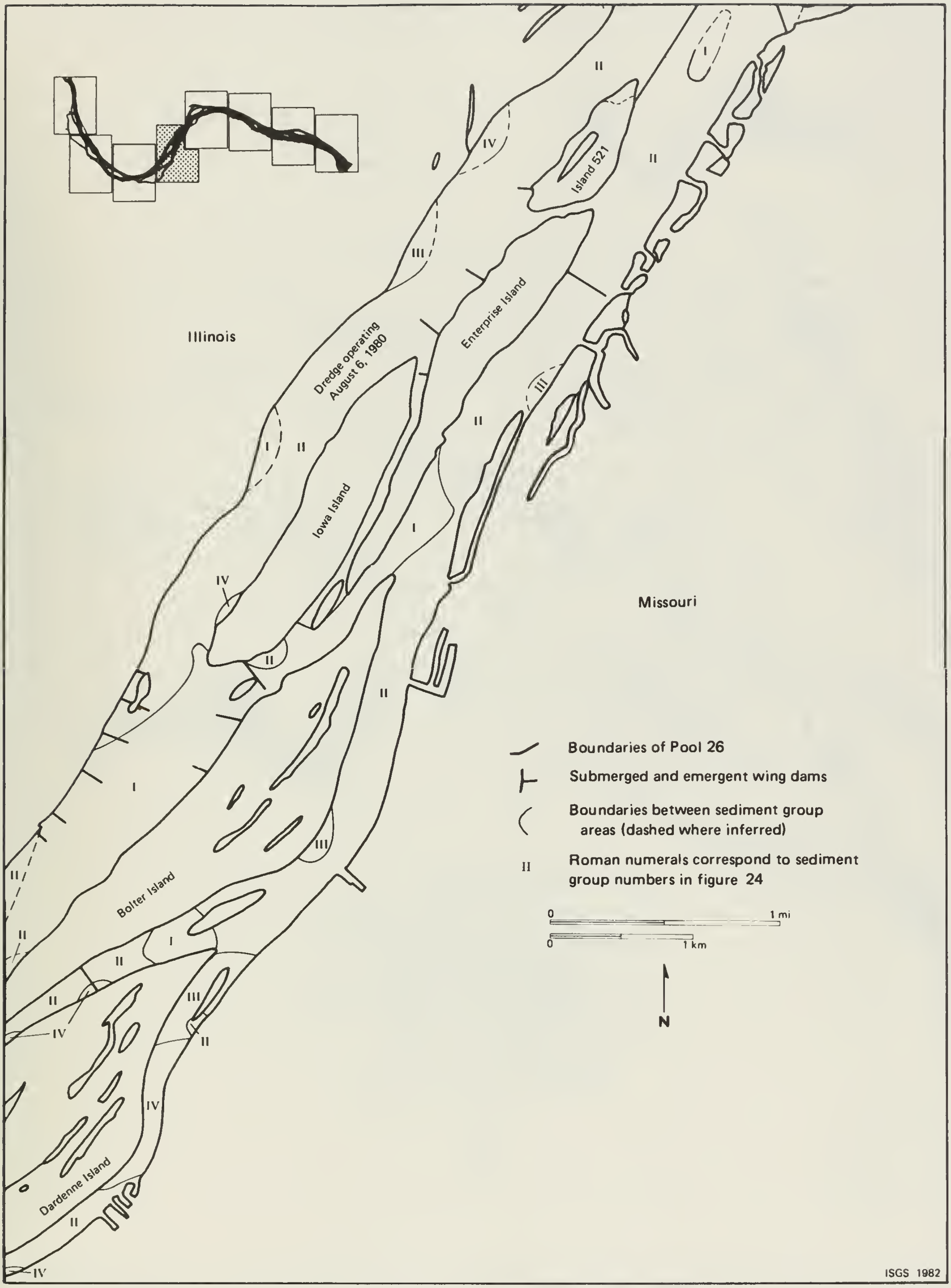


Figure 30. Distribution of sediment groups in Pool 26: Kampville, Brussels, and Grafton Quadrangles.

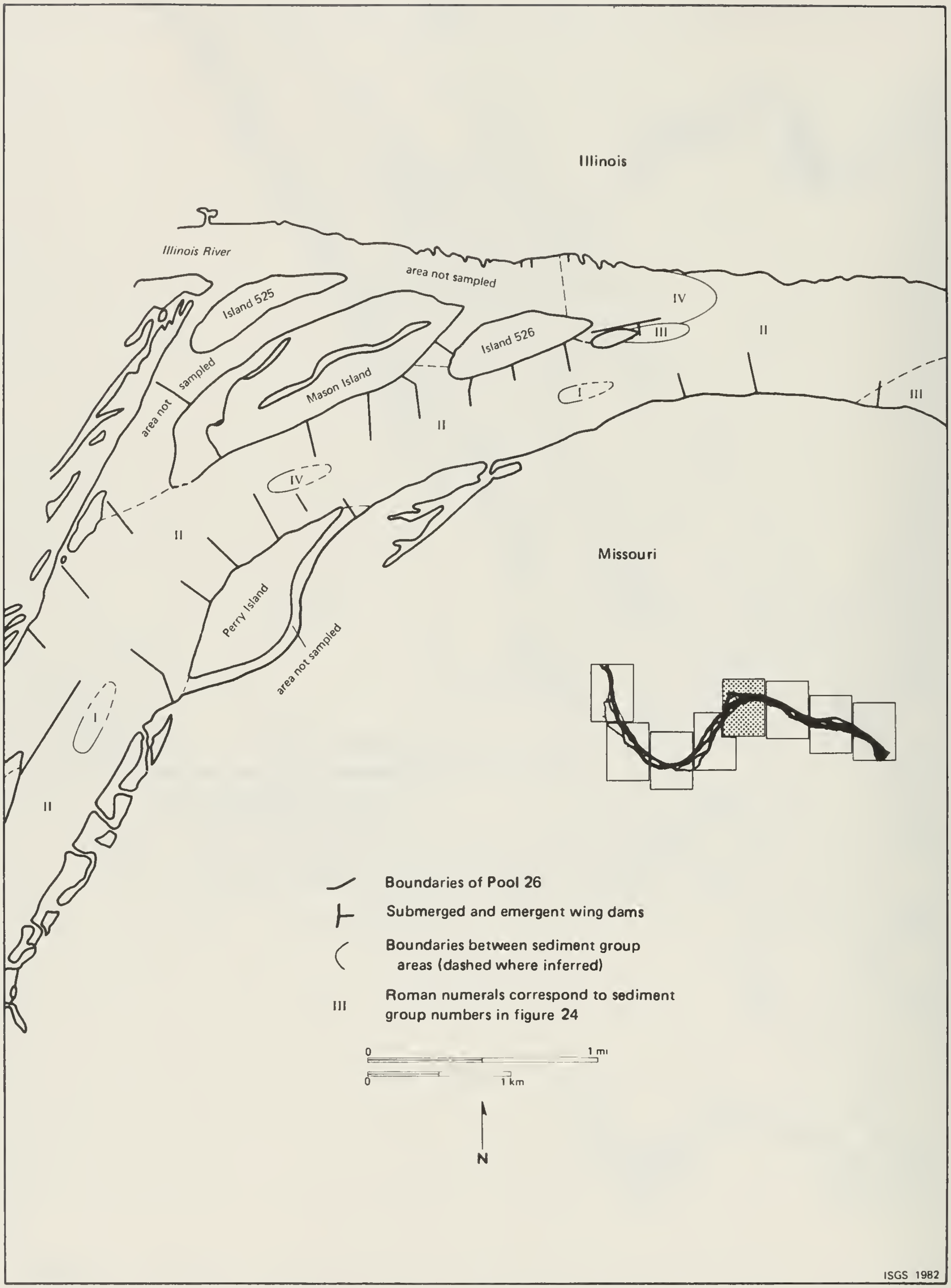


Figure 31. Distribution of sediment groups in Pool 26: Grafton Quadrangle.

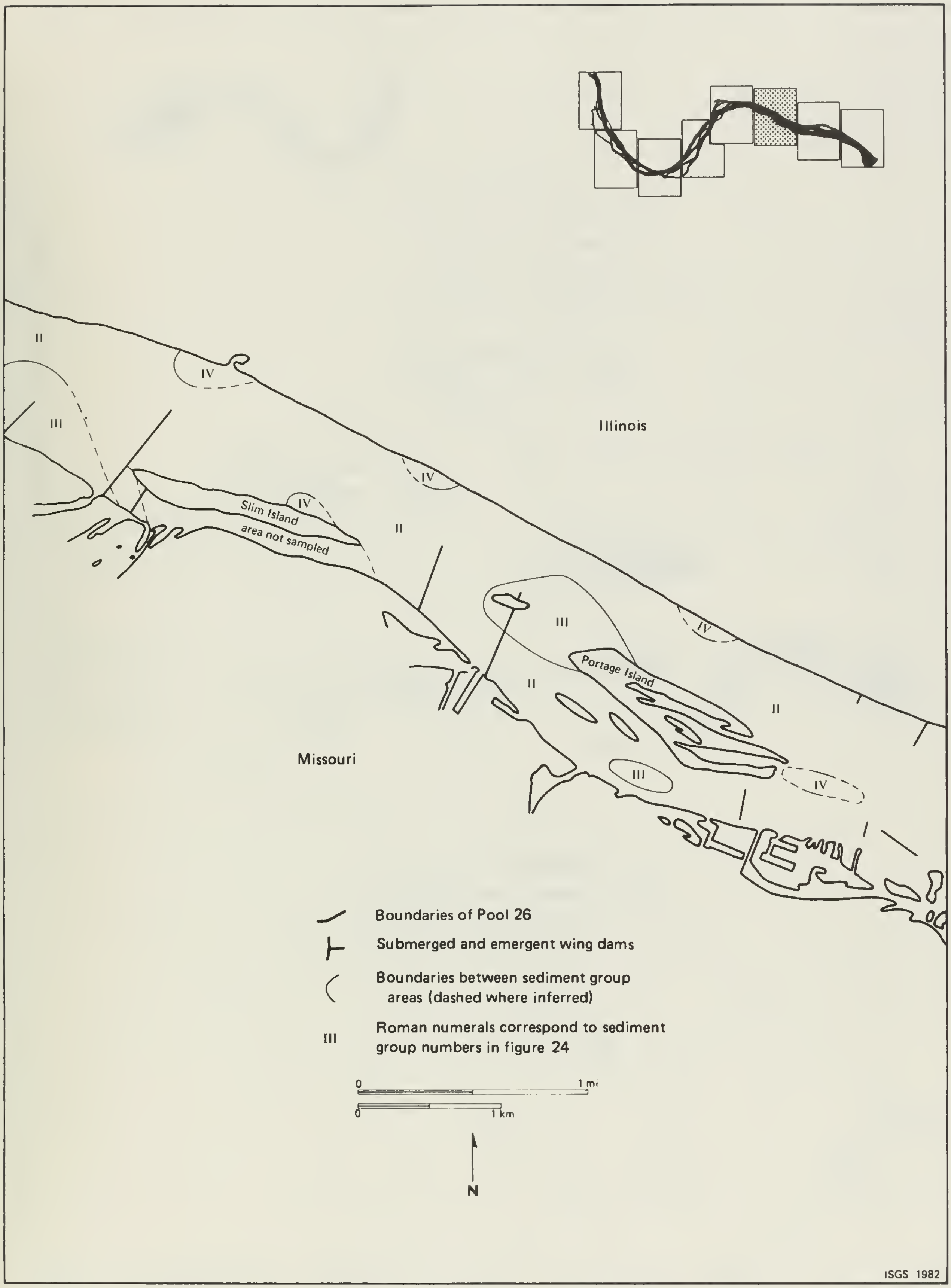


Figure 32. Distribution of sediment groups in Pool 26: Grafton and Elsah Quadrangles.

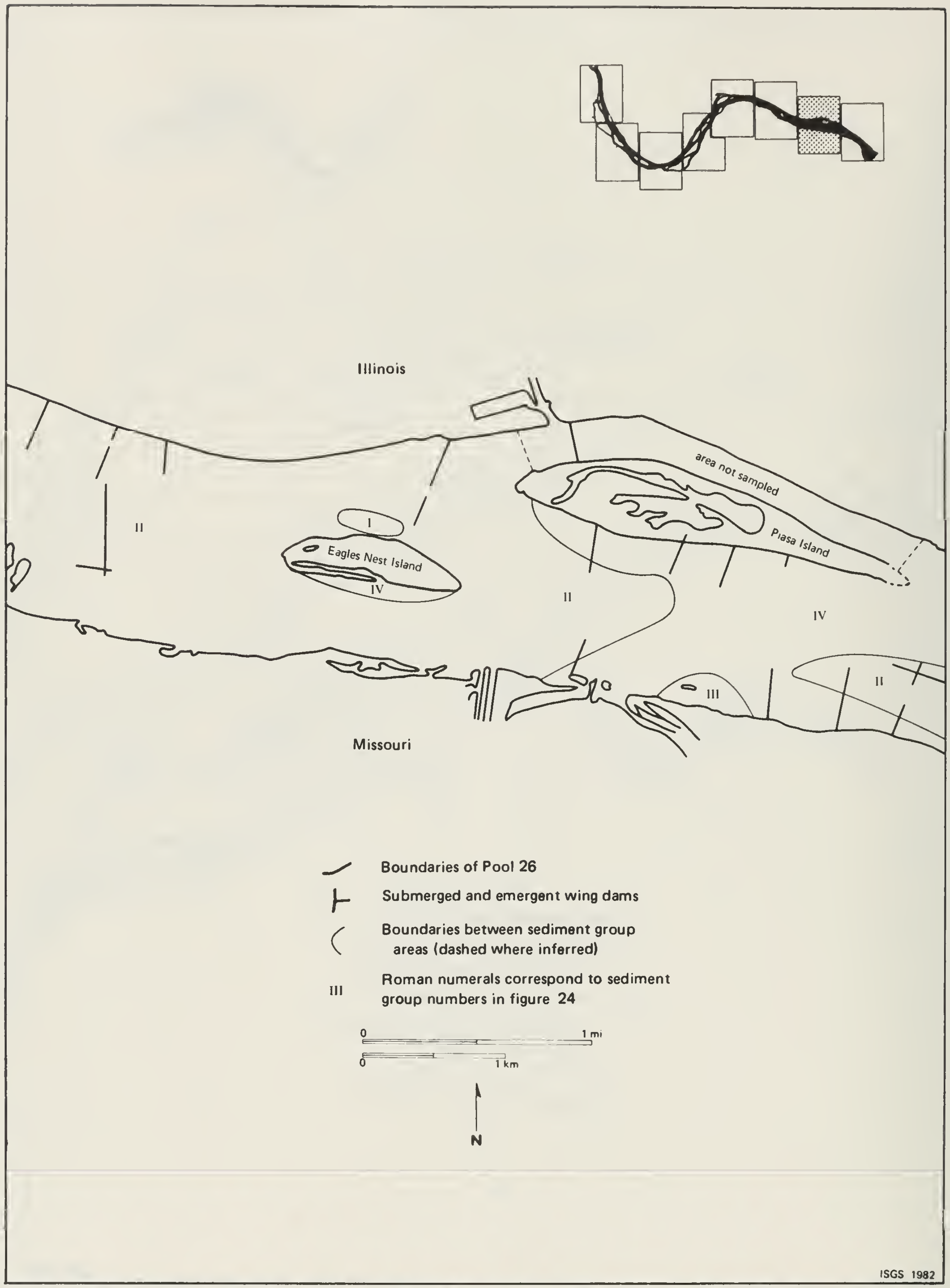


Figure 33. Distribution of sediment groups in Pool 26: Elsah Quadrangle.

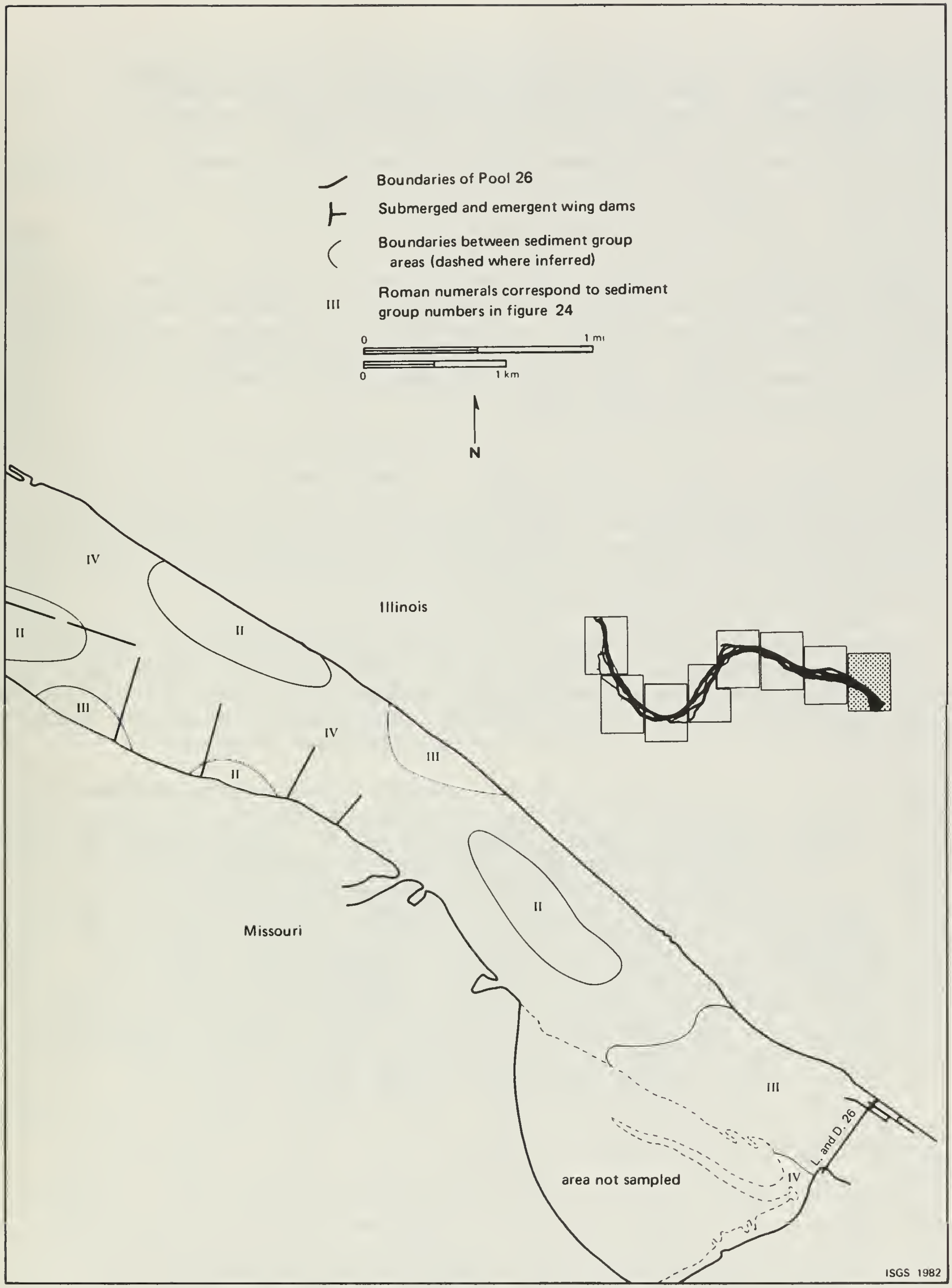


Figure 34. Distribution of sediment groups in Pool 26: Alton Quadrangle.

Figures 27 to 30 show that the only extensive area of Group I sediments corresponds almost exactly with the reach of the river that regularly requires dredging. Figures 15 to 18 show that the Group I sediments in the main channel of this reach have sorting values less than 1, in addition to their low skewness and coarse mean particle size. In this reach, fine silt- and clay-sized particles winnowed from bottom sediments in the main channel may either be deposited in side channels and near-shore areas or carried downstream to be deposited in the pooled reach of the river.

In the reach of the river from Iowa Island to Piasa Island (figs. 30 to 33), current velocities apparently decline as the river is affected by the pooling behind Dam 26. Fine sediments that bypass upstream reaches are deposited in this reach along with coarser sand to form Group II sediments. Current velocities are no longer great enough to winnow out finer particles that become entrapped in inter-grain spaces.

Throughout most of the study reach, Group III sediments generally are confined to channel border areas near shore. In these areas, coarser-grained sediments derived from the main channel may become mixed with fine-grained silt and clay eroded from the shore. Some Group III sediments may be an artifact of the Ponar sampler. If sediments of one mean particle size are overlain by a thin layer of sediments of another mean particle size, the sampler will mix these sediments together.

On the basis of data shown in figure 12, it would be expected that, because of hydraulic sorting, finer-grained sediments would occur downstream from coarser-grained sediments. Thus, the area of Group III sediments in the main channel just upstream from Dam 26 (fig. 34) is unusual because it lies downstream from an extensive area of fine-grained Group IV sediments.

Samples 220, 221, 237, and 238 (fig. 9; appendix 1) define this anomalous Group III area. Sample 220, collected in 19 feet (5.8 m) of water, has a mean particle size of 2.88 Ø and a skewness of 0.471. This sampling site lies directly under the recommended sailing line for commercial barge traffic. The site is also adjacent to the riprapped north bank of the river, just offshore from an area where tows commonly tie up to await their turn in Lock 26. The fact that the sample has an unusual coarse tail in its distribution may indicate that a coarse lag gravel deposit has been formed by the relatively persistent propeller wash and current velocity disturbance from tows accelerating away from Lock 26 or maneuvering in the fleeting area near the sample site. The gravel lag is a minor component of the sample and may also have been derived from material washed out of the fill and riprap used to construct McAdams Highway on the river bank.

Samples 221, 237, and 238 in this Group III area (fig. 9; appendix 1) all were collected from water depths exceeding 30 feet (9 m) in locations far from the normal sailing line of commercial traffic. These samples lack the gravel tail of sample 220, but have significant modes in the 1 Ø to 2 Ø size range and moderately abundant fine tails that give skewness values ranging from 1.24 to 1.85. All these sample sites are relatively close to Dam 26 and may be subject to extensive current scour during seasonal high runoff. This scour would tend to winnow out fine-grained sediments and leave a coarser lag. During low runoff, when the control gates of Dam 26 permit only low discharge from Pool 26, finer-grained sediments could settle out atop the coarse-grained lag. When sampled by our Ponar dredge, these two layers could become mixed into a single Group III type sample. Bathymetric data discussed later in this report indicate extensive scour in the area (fig. 44). A commercial dredge extracts sand from the river bottom in this area, also. Its operations may have altered the natural particle size distribution in the area.

Group IV sediments are rare in all areas except the reach from the head of Piasa Island down to about river mile 204 (figs. 33 and 34). Several streams flow from the north bank into the Mississippi in this area, and these creeks, especially Piasa Creek, may supply extra silt to the reach from thick upland loess deposits. Our preferred interpretation is that the effects of the decreased gradient and pooling behind Dam 26 may reduce average current velocities in this area sufficiently to allow large volumes of the abundant fine sediment supplied by the Illinois River to be deposited. Coarser sediments would already have been deposited upstream as the average current velocity declined.

The distribution of sediment groups in Pool 26 shown in figures 27 to 34 probably changes during periods of high discharge. Spring floods are known to cause scouring of the channel in some areas and deposition in others. Simons et al. (1975) note that the locks and dams create a natural, annual cycle of erosion during spring high discharge and deposition during periods of low and intermediate flow when the dams restrict the discharge of the river to control pool stages for navigation purposes. Areas in which deposition occurs at low and intermediate flows are partly cleaned out during periods of high flow, but the amount of deposition tends to exceed the amount of erosion and net aggradation results (Simons et al., 1975, p. 67).

Organic matter and moisture content

Weight percents of organic matter and moisture in bottom sediment samples from Pool 26 were determined by the methods described in appendix 2 of this report. Results of these analyses are compiled in appendix 1. Figures 35 and 36 are scatter diagrams showing the relationships of organic matter and moisture contents, respectively, to mean particle sizes of the samples. As would be expected, both parameters are directly related to the mean particle sizes of the samples. Because of their much greater surface area per unit volume, fine-grained sediments can retain more interstitial moisture than can sands and gravels. Organic matter in sediments occurs both as discrete particles and as organic molecules adsorbed on the surface of clay minerals. Fairly large particles of organic matter normally accumulate with much smaller mineral grains; because the specific gravity of organic matter is much lower than that of minerals, large organic particles have settling velocities in water similar to those for fine mineral particles.

Table 2 lists the mean contents of organic matter and moisture for the sediment sample groups shown in figure 24 and mapped in figures 27 to 34. Comparison of figure 24 and table 2 shows that samples in Groups I and II have virtually the same mean particle size and also have statistically indistinguishable values for moisture and organic contents. By contrast, Groups III and IV have different mean particle size ranges (fig. 24) and distinctly different organic matter and moisture contents (table 2). Thus, the maps of the areal distribution of sediment groups in Pool 26 (figs. 27 to 34) may

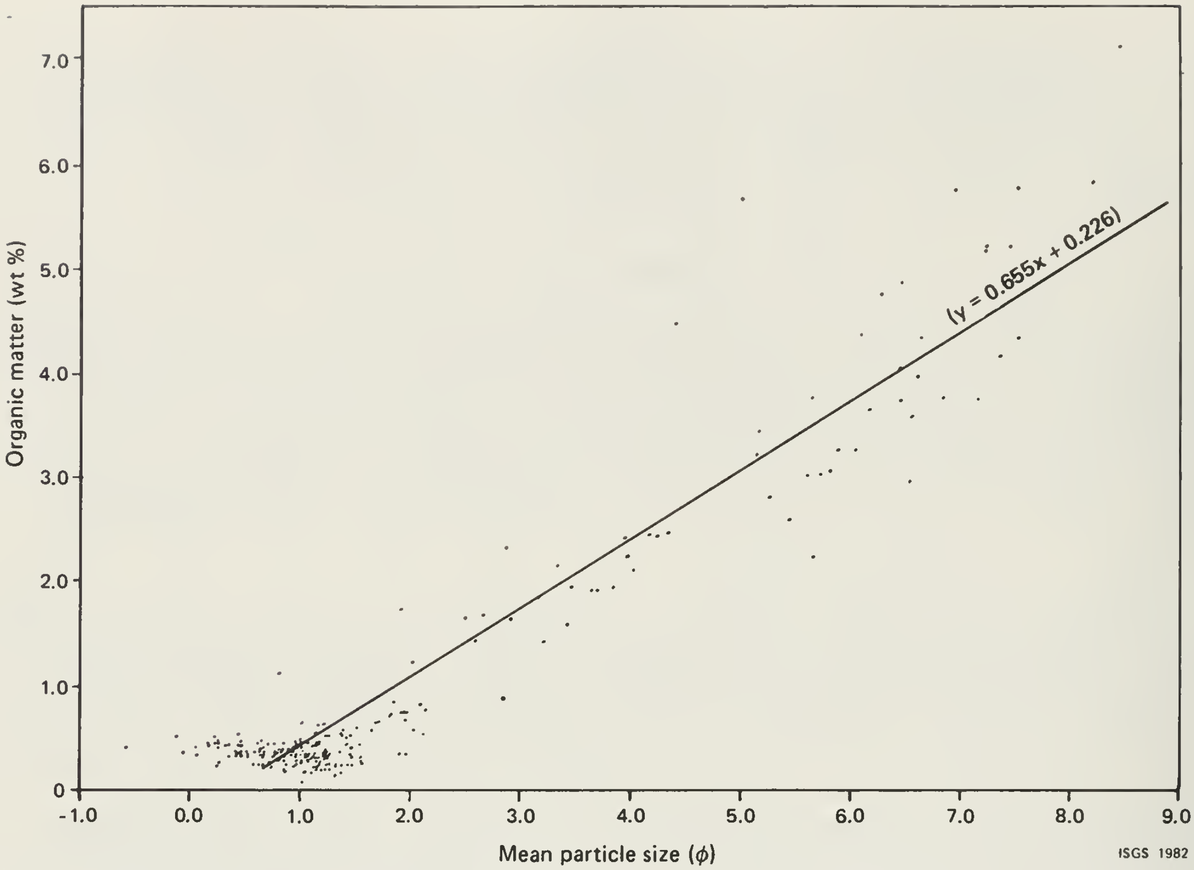


Figure 35. Scatter diagram showing relationship between content of organic matter and mean particle size of bottom sediments, Pool 26.

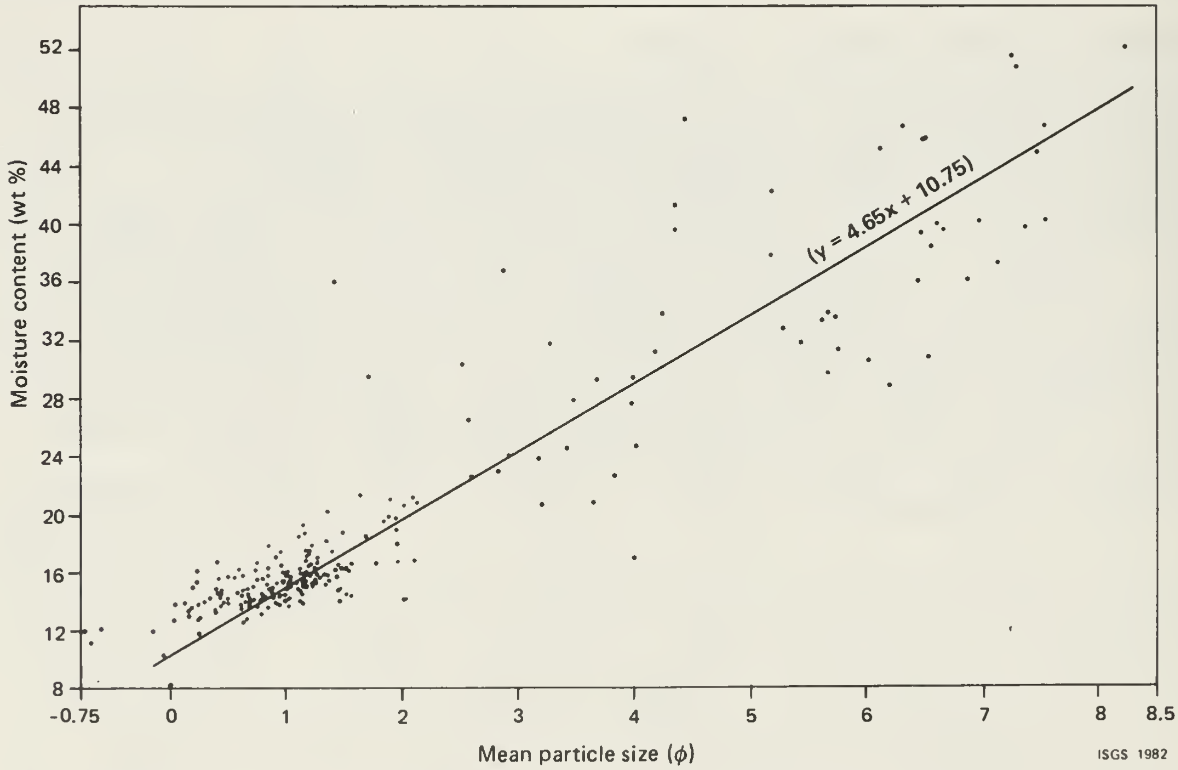


Figure 36. Scatter diagram showing relationship between moisture content and mean particle size of bottom sediments, Pool 26.

TABLE 2. Mean weight percent of organic matter and moisture in samples of bottom sediments.

	Sediment groups			
	I	II	III	IV
ORGANIC MATTER				
Mean	0.35	0.46	2.20	4.15
Standard Deviation	0.19	0.22	0.80	1.16
MOISTURE				
Mean	14.63	16.08	29.05	40.57
Standard Deviation	1.42	2.30	6.70	8.35

also be used to roughly locate areas where bottom sediments will be richer in organic matter and moisture. Areas containing Group IV sediments will have the highest values for organic matter and moisture content; areas of Group III sediments somewhat lower values; and areas of Group I and II sediments the lowest values.

X-ray mineralogy

X-ray powder diffraction analyses of selected samples are compiled in table 3. The x-ray diffraction methods used probably cannot detect minerals present in the samples in amounts less than about 5 percent by volume. Relative amounts of minerals in the samples were estimated by inspection of relative peak heights in the x-ray diffractograms. X-ray peak heights may be affected by factors not related to amounts of minerals in a sample. For example, differential compaction and preferred orientation of the minerals in the powder pack and overlap of diffraction peaks of different minerals can result in unsuspected enhancement of peak heights in the diffractogram. The abundance estimates are probably valid only for the most abundant minerals.

Table 3 shows that quartz is the major mineral in all samples, and that plagioclase and potash feldspar are fairly abundant in all samples. Peak

TABLE 3. Major minerals in selected samples of bottom sediments.

Sample number	Sample site number	Mineral content*
7-23-1B	13	Q, P, K, Cl, M, A
7-23-1C	14	Q, K, P, M, A, Cl
7-26-1A	55	Q, P, K, Cl, M, A
7-30-3A	67	Q, P, K, Cl, M, D, C, A
7-30-4A	69	Q, P, K, M, Cl, A
8-7-3A	163	Q, P, K, A, M, Cl
8-7-3B	164	Q, P, K, Cl, M
8-7-8A	175	Q, P, K, Cl, M
8-7-8B	176	Q, P, K, Cl, M, A
8-7-11A	184	Q, K, P, Cl, M, A
8-7-11B	185	Q, P, K, Cl, M, A
8-9-7B	227	Q, P, K, M, A, Cl
8-9-7C	228	Q, P, K, Cl, M, A

*Mineral content determined by x-ray powder diffraction. Minerals listed in approximate order of decreasing abundance in sample, on basis of inspection of relative peak heights in diffractograms. Key to symbols: Q=quartz; P=plagioclase feldspar; K=potassium feldspar; Cl=chlorite; M=nonspecific mica; A=nonspecific amphibole; C=calcite; D=dolomite.

heights generally indicate that plagioclase is more abundant than potash feldspar. Chlorite, a mica, and an unspecified amphibole are present in nearly all samples. Relative abundance estimates for these three minerals are probably not very reliable.

Within the limits of the analytical methods used, no systematic variation of mineralogy was observed. It is possible that careful analysis of the <2 µm size fraction of the sediments might show dissimilar clay mineral suites in samples taken above and below the confluence of the Illinois River.

BATHYMETRY

Introduction

Figures 37 to 44 show the depth of water in Pool 26 of the Mississippi River. Water depths have been normalized to an average pool stage of 419.0 feet (128 m) above mean sea level. Data points used to construct the contours are shown by lines of dots on the maps. These lines of dots also depict the path of the boat during bathymetric profiling. Water depths determined at the sites at which bottom sediment samples were collected have been used to supplement the profiling data. Sampling sites are shown by larger dots on figures 37 to 44. The methods used to prepare these maps are discussed in appendix 2 of this report.

Discussion

General trends in Pool 26. As shown in figures 37 to 44, average water depth in Pool 26 increases in the downstream direction. Over most of the area of the pool, from Lock and Dam 25 (fig. 37) downstream to the toe of Iowa Island (fig. 40), maximum water depths rarely exceed 20 feet (6.1 m) in the main channel or side channels. Beginning near the head of Perry Island (fig. 41) and continuing downstream to Locks and Dam 26 at Alton (fig. 44) maximum water depths commonly exceed 30 feet in the main channel.

This difference in maximum water depth was noted previously in this report and cited as partly responsible for differences between the characteristics of bottom sediments in the two reaches of the river. As noted there, the average water surface gradient of the Mississippi River is much lower between Grafton and Locks and Dam 26 than between Lock and Dam 25 and Grafton. The pooling effect of the dam at Alton, combined with the substantial additional water volume contributed to the Mississippi by the confluence of the Illinois River, causes the substantial increase in maximum water depths and river width in this lower part of Pool 26.

The main channel of the Mississippi River throughout the length of Pool 26 does not have a continuous, deep thalweg. Instead, relatively narrow, deep channels alternate with broader, shallower areas. Deeps generally are spaced about 1.25 km apart near the upstream end of Pool 26 above Turkey Island. Near the downstream end of the pool, the spacing between deeps increases to approximately 2 km. In addition to the downstream alternation of deeps and shallows, the deeps occupy a sinuous course that generally swings back and forth from one bank to the other. In the middle third of

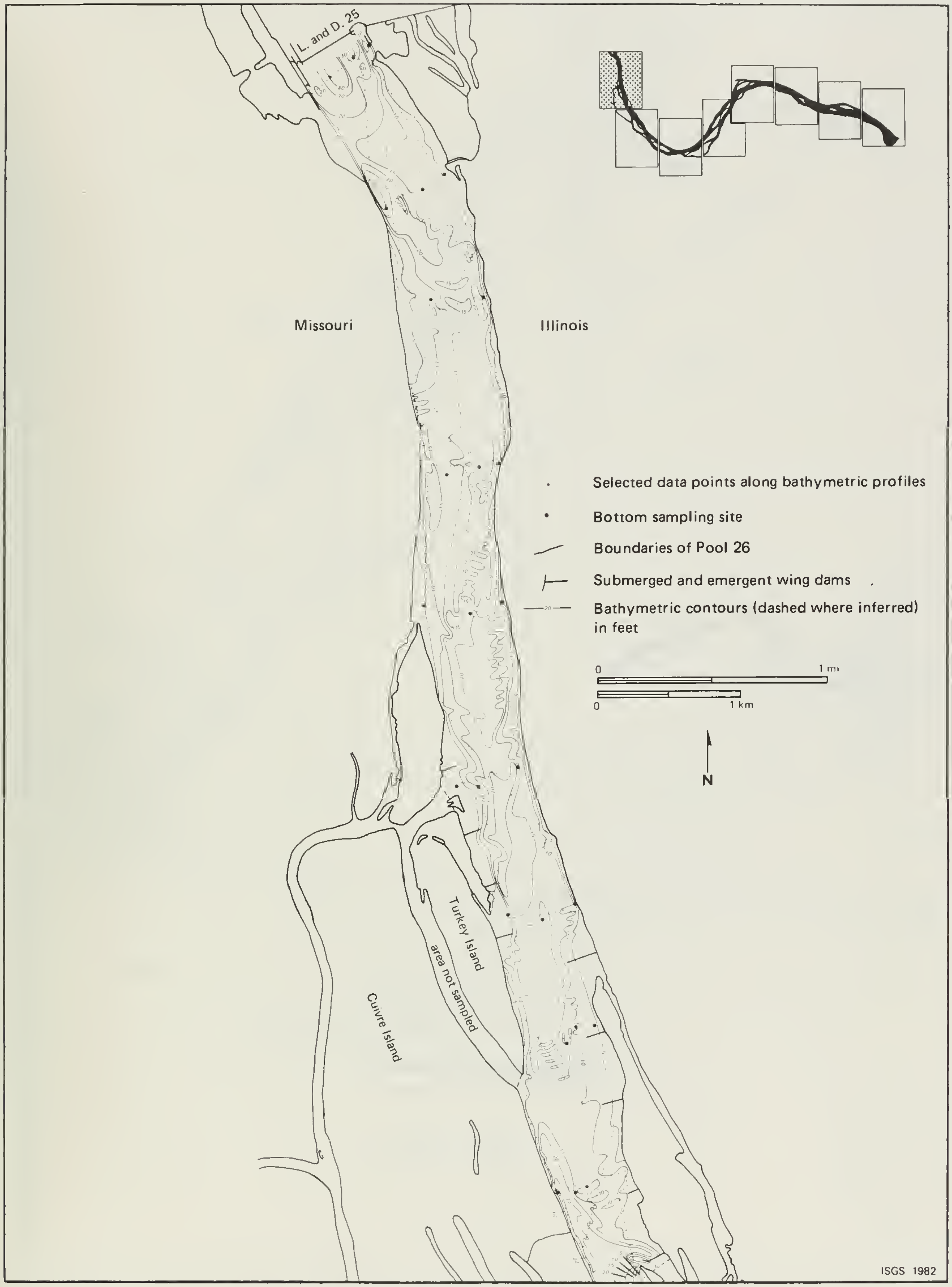


Figure 37. Water depth in Mississippi River: Foley and Winfield Quadrangles.

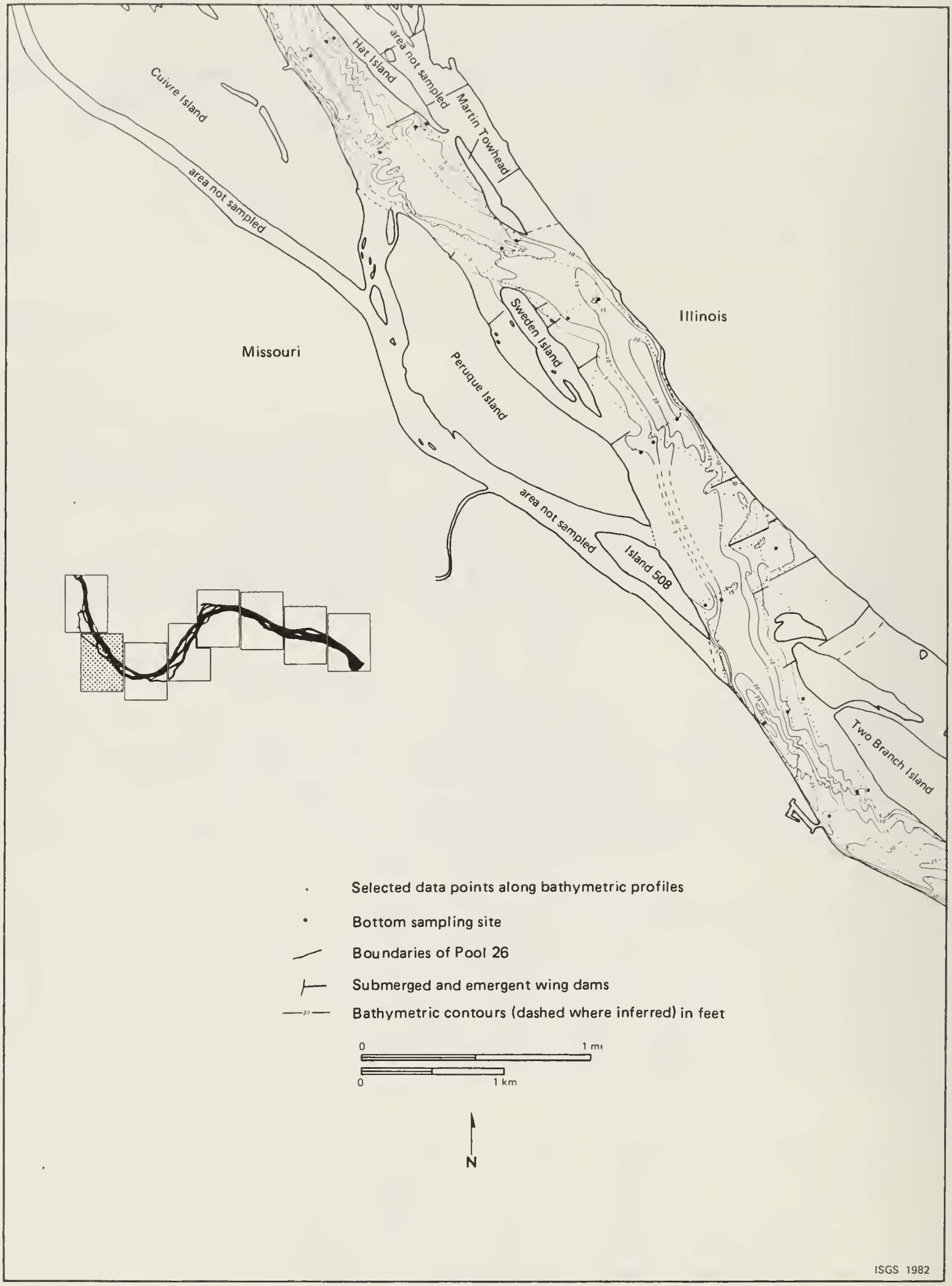


Figure 38. Water depth in Mississippi River: Winfield and Brussels Quadrangles.

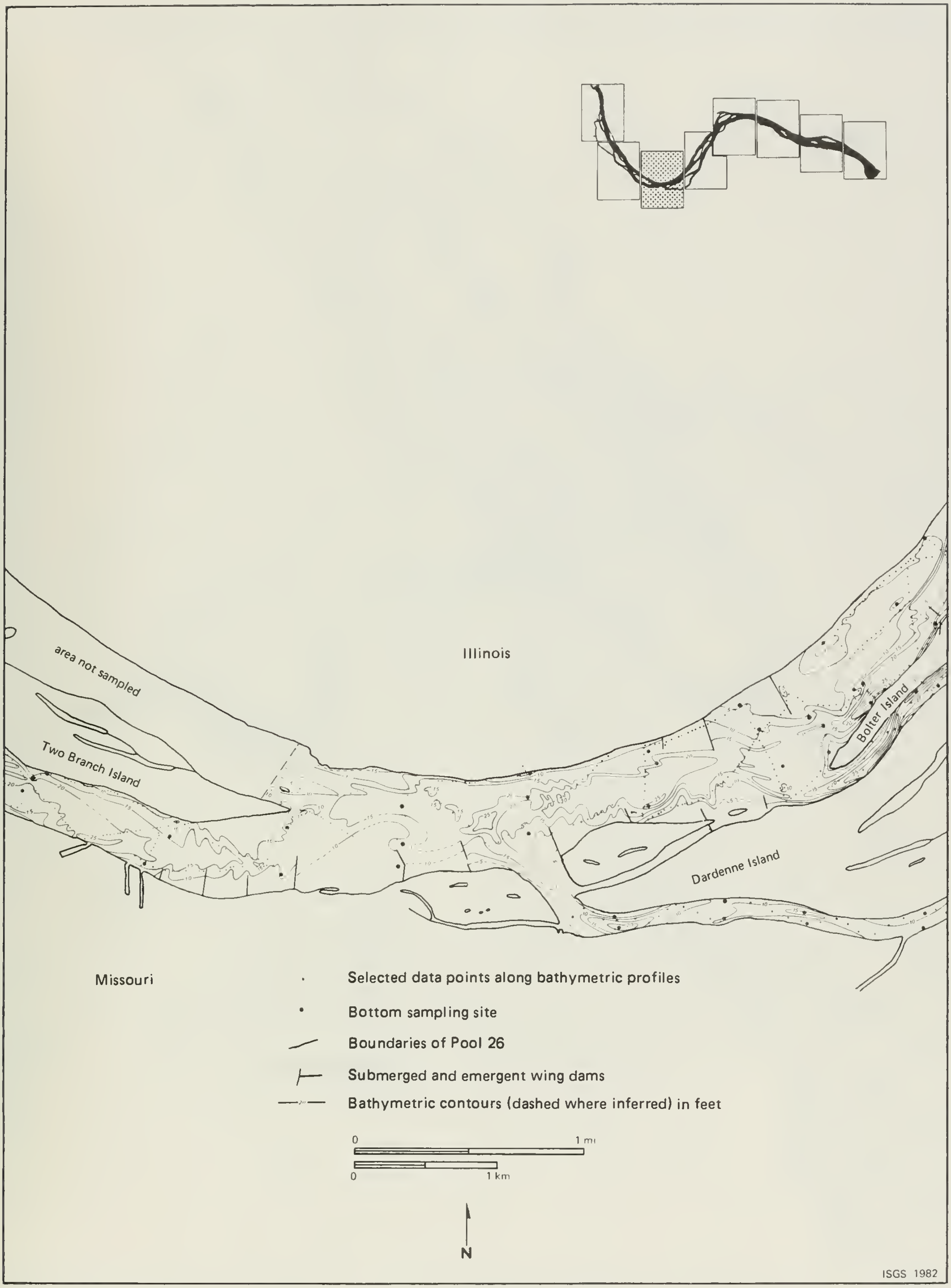


Figure 39. Water depth in Mississippi River: Brussels and Kampville Quadrangles.

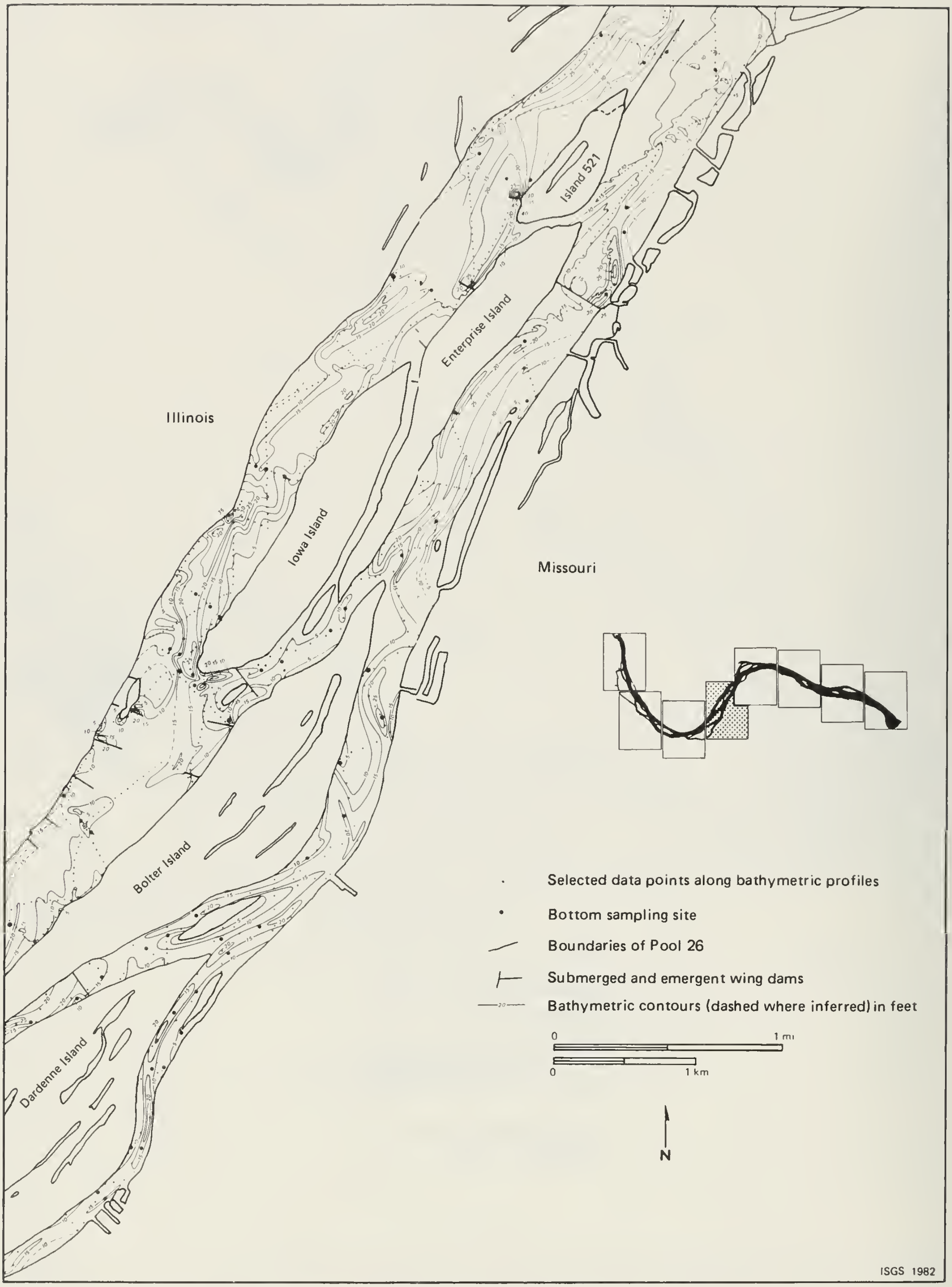


Figure 40. Water depth in Mississippi River: Kampville, Brussels, and Grafton Quadrangles.

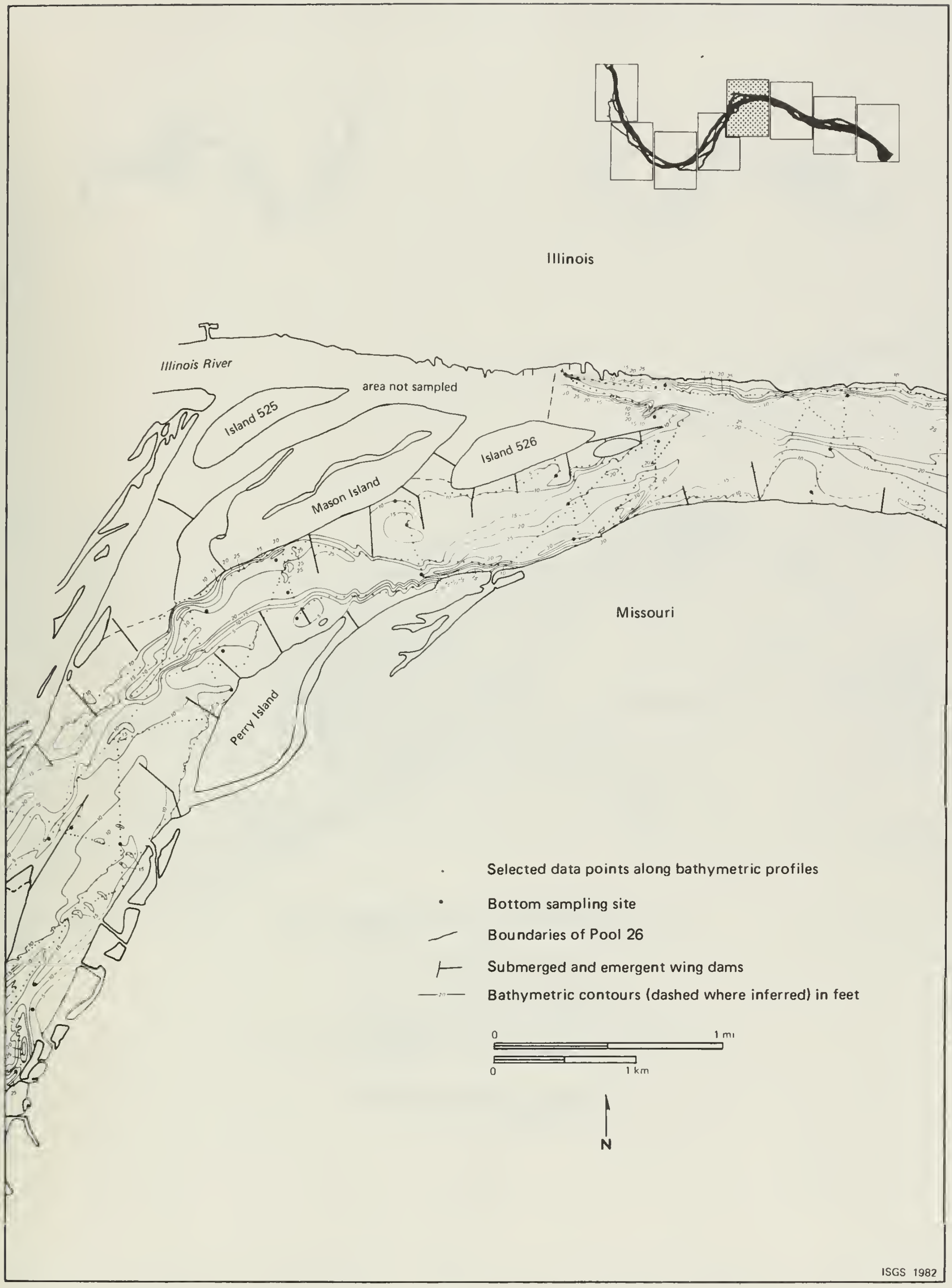


Figure 41. Water depth in Mississippi River: Grafton Quadrangle.

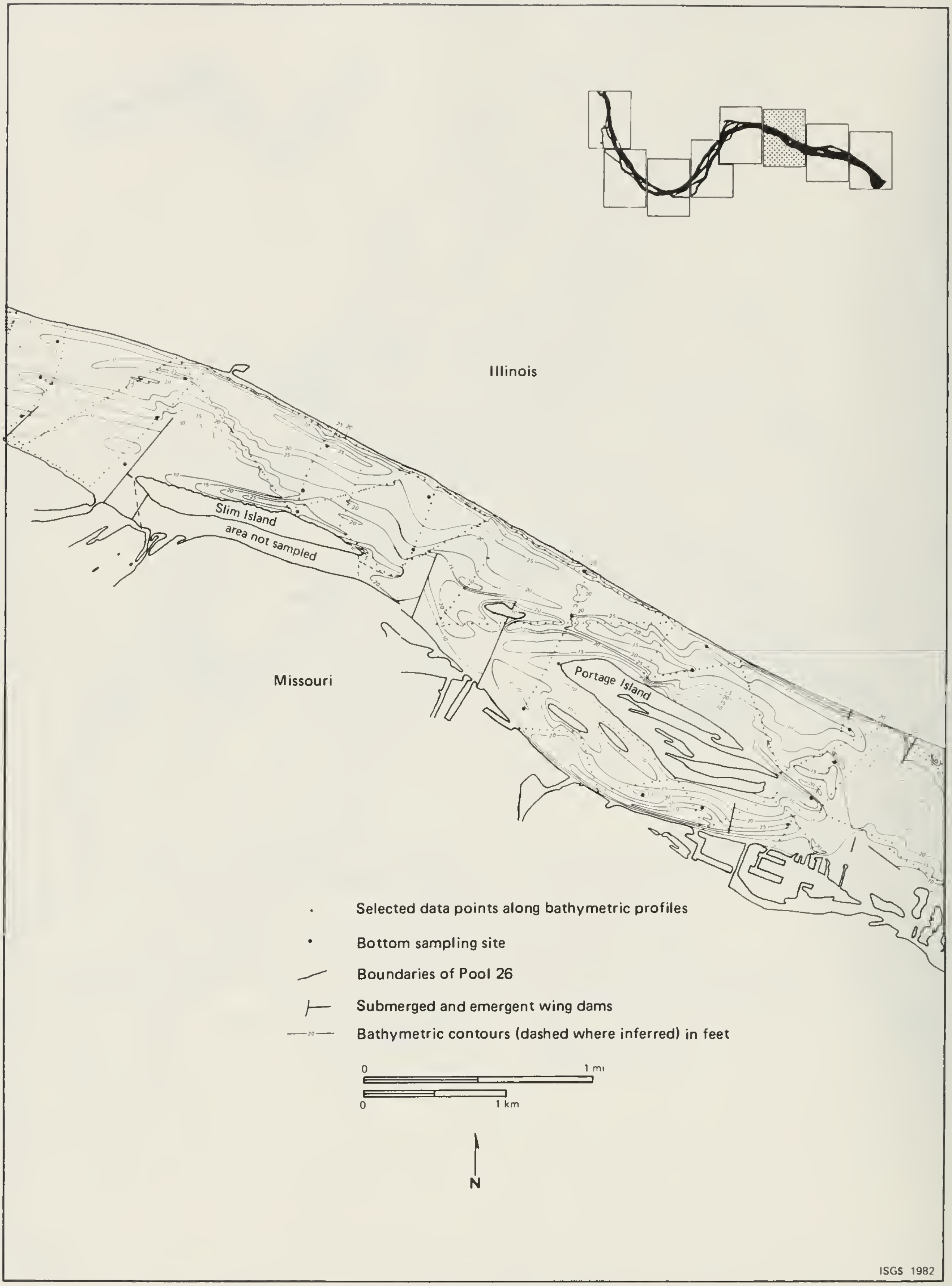


Figure 42. Water depth in Mississippi River: Grafton and Elsah Quadrangles.

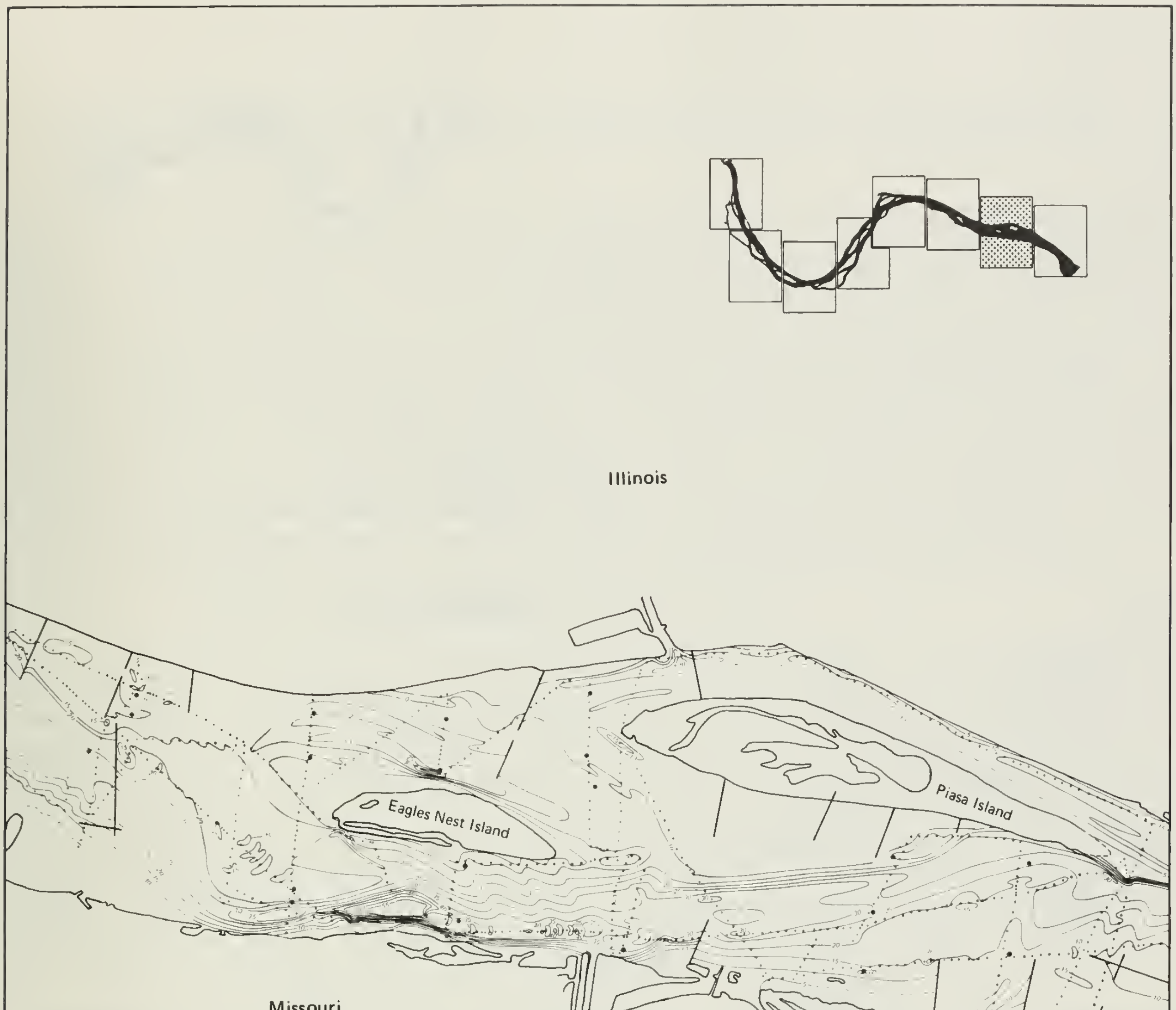


Figure 43. Water depth in Mississippi River: Elsah Quadrangle.

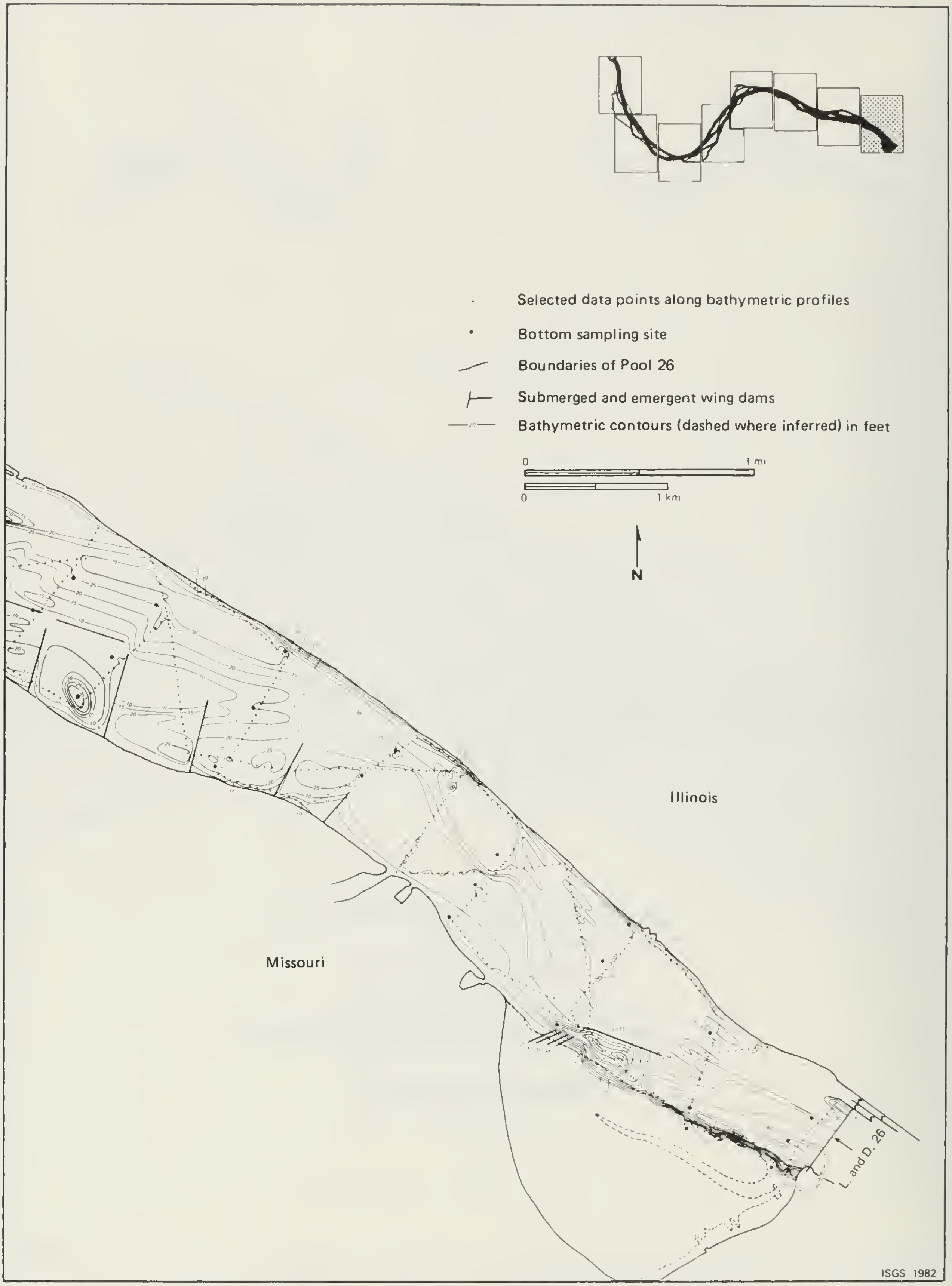


Figure 44. Water depth in Mississippi River: Alton Quadrangle.

the pool from the head of Turkey Island to the head of Iowa Island (figs. 37-40), where dredging is commonly required, this alternating pattern of deeps and shallows is not apparent.

Although the bed load in Pool 26 is sand, the river banks and islands generally consist either of a cohesive mixture of sand, silt, and clay, or bedrock. Extensive vegetative cover commonly stabilizes banks where riprap or revetment have not been applied to prevent erosion. These relatively stable bank conditions contribute to the generally nonmeandering plan of the Mississippi River in Pool 26. Over the 150 years of extensive development of European-American culture in the Pool 26 area, the course of the Mississippi River has changed very little. For the past 100 years, current training structures such as wing dams and bank riprap, removal of snags, and finally, the construction of the navigation dams, have further confined the course of the river and the path of the main current within the banks of the river. It seems probable that the wing dams and bank stabilization structures of the modern river have served only to accentuate and stabilize the natural, alternating pattern of deeps and shallows.

Bed forms. Sand waves are common bed forms at all ranges of water depths in Pool 26. Such sand waves are analogous to sand dunes in the subaerial environment. They are a natural consequence of the interaction of river currents and the unconsolidated bottom sediments in all river systems (Allen, 1965). Sand waves seem to be most numerous, closest spaced, and best developed upstream from the Illinois River at intermediate to shallow depths in the main channel. Allen (1965) notes that, all other factors such as current velocity and particle size being equal, the amplitude of sand waves is proportional to water depth and varies between 10 percent and 20 percent of the water depth over the crest of the bed form. Figure 45 shows a portion of a depth record from a profile near the Missouri shore of the

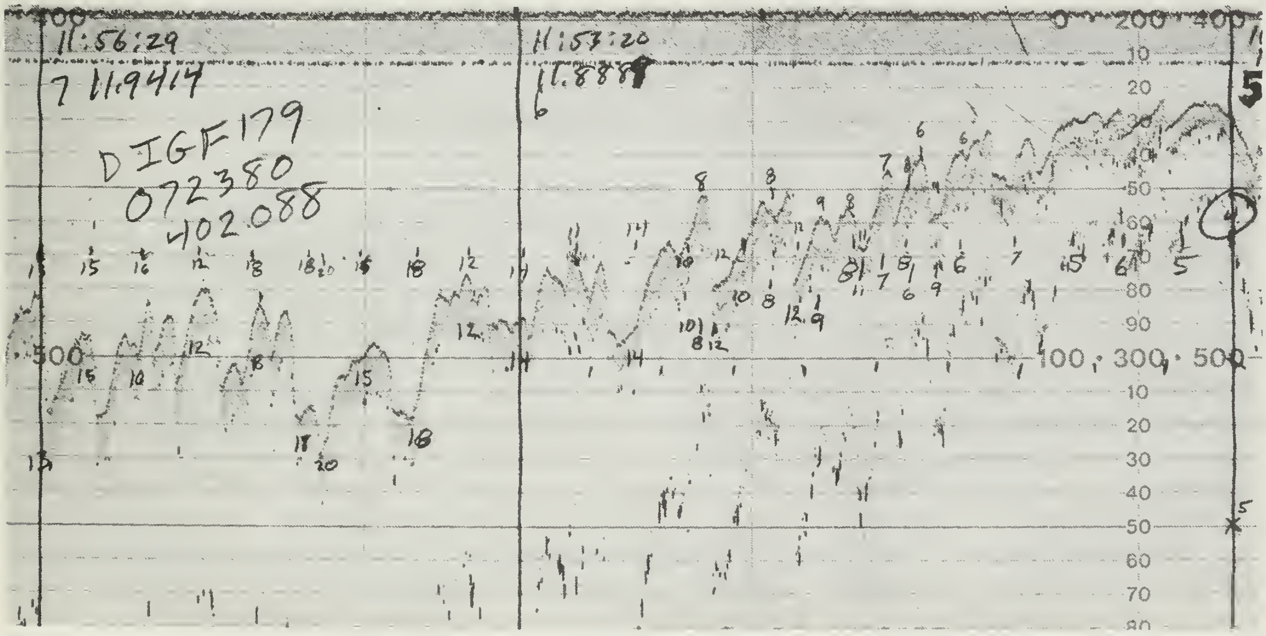


Figure 45. Bathymetric profile of portion of Mississippi River near Turkey Island, Missouri, Pool 26. Vertical scale is 1.5 ft per line. Handwritten depths include corrections for pool stage and submergence of transducer. Horizontal scale is about 1 km for area shown.

river above the head of Turkey Island (fig. 37). Amplitudes of the sand waves shown in figure 45 vary from about 3 feet (where water depths are near 6 feet) to almost 6 feet (where water depths are as great as 16 feet above the crest of the sand waves).

The exact shape of these numerous large bed forms was not determined during this regional bathymetric survey. Data points and profiling lines were not spaced closely enough to accurately determine this. Studies in the lower Mississippi River indicate that sand waves there are either straight transverse sand waves or lunate forms similar to crescent-shaped subaerial sand dunes (Allen, 1965). We have shown sand wave forms in Pool 26 as slightly lunate in shape where amplitudes of the waves and the contour interval of the maps are sufficient to suggest their shape (see fig. 37 near toe of Turkey Island). In many areas of the river bed sand waves are present, but their amplitudes are less than the 5-foot bathymetric contour interval and the bed forms cannot be shown.

Movement of bed forms. The rate of movement of bed forms in Pool 26 has not been determined in this study. Kukal (1971) has indicated that sand bars and bed forms may have an average rate of movement ranging from 30 meters per day in the high gradient of the Brahmaputra River of mountainous Assam to as low as 0.1 meters per day in the Luga River of northwestern Russia in the coastal lowlands near Leningrad. He suggests an average rate of movement, excluding major floods, of about 1 meter per day (Kukal, 1971). If this average rate holds for Pool 26, then a sand wave would require 170 years to travel the full 62 kilometer length of Pool 26. If the rate of travel were as great as 30 m/day, only about 56 years would be required. In the partially controlled reach of Pool 26, rates closer to the average of 1 m/day seem much more likely. Thus, a bed form that was located near Lock and Dam 25 at the time of construction might not yet have traveled the full length of Pool 26 to pass through the weirs at Dam 26. At an average rate of travel of 1 m/day, a bed form that started at the toe of Dam 25 would have moved downstream just to the head of the heavily dredged area in the 40 years since completion of the dam. Ivens et al. (1981) showed that a large sand wave in the Kankakee River moved at an average rate of 1.5 to 2.0 feet (0.45 to 0.6 m) per day during low flow in the summer of 1979.

Island erosion. At several places in Pool 26, areas shown as land in 1974 photorevised editions of U.S. Geological Survey topographic maps were found to be under water in 1980. Erosion areas of special interest include the head of Mason Island (fig. 41), the toe of Piasa Island (figs. 43 and 44) and the large bay southwest of Locks and Dam 26 (fig. 44). At Mason Island several tens of feet apparently have been eroded from the upstream head of the island, destroying a Corps of Engineers permanent mark and leaving behind a shallow shelf less than 5 feet (1.5 m) deep. To control this erosion, the shore has been riprapped.

At the downstream tip of Piasa Island, an extensive stump field under less than 5 feet of water extends almost 1 km downstream from the end of the presently vegetated island. The area is marked as a shoal and stump field on Corps of Engineers navigation charts for the area and may represent a part of the island drowned by the pooling behind Locks and Dam 26. A significant part of this drowned area is shown as land in the 1974 topographic maps.

The large embayment southwest of Locks and Dam 26 is a broad flat cut by two irregular drainage channels. The area probably is a low floodplain area that was drowned by the pooling behind Dam 26 and was either filled in by dredge spoils or by natural accumulation of sediment in this slack-water area. Bathymetric profiling shows that the riverward edge of the area is bounded by a steep escarpment extending down to the greatest water depths in the pool. This escarpment may have formed as the result of erosion. The maximum water depth found (58 ft; 17.7 m) (fig. 44) occurs in a deep hole south of and downcurrent from a wing dam. In Corps of Engineers navigation charts (1978, chart 35), this wing dam is shown to extend diagonally on a nearly east-west trend from the upstream end of the embayment to within 1/8 mile (200 m) from the upstream end of Dam 26. Only a small portion of this wing dam was detected during profiling, although several profile lines cross the area where the wing dam should have been (fig. 44). If this wing dam was constructed after Lock and Dam 26 and after drowning of the embayment, the presence of the wing dam may have cut off supplies of sediment downstream of the wing dam and caused erosion of the escarpment of the bay.

Another exceptional deep is located in the main channel south of Eagle's Nest Island (fig. 43). This deep also is bounded by a steep escarpment on the south shore of the river. Fields of wing dikes and shore protection keep the strong current of the main channel flowing through this area and this continuous flow apparently keeps this deep area scoured out.

The riverward edge of the drowned stump field at the downstream end of Piasa Island also is marked by a steep escarpment that is probably formed by erosion (figs. 43 and 44). Wing dams line the riverward edge of Piasa Island. Other wing dams upstream of Piasa Island direct the main flow of the Mississippi River in such a way that a fairly strong current sweeps past the area of the stump field. Sediment passing through the channel between Eagle's Nest and Piasa Islands probably once migrated downstream along Piasa Island and supplied material for continued downstream growth of the island. Shallow water in the inter-island channel and redirecting of the main current flow by wing dams may have cut off this sediment supply, allowing erosion of the downstream tip of the island.

At Mason Island, as at Piasa Island, wing dams and other current-training structures may have contributed to the recent erosion (fig. 41). Although current-training structures may have been present for long periods of time, erosion may have taken some time to affect surface areas of the island. As in other areas of erosion, the riverward edge of Mason Island has a steep erosional escarpment reaching depths as great as 30 feet (9 m) very near shore.

Backwaters and side channels. Within the currently inundated portion of Pool 26 in the Mississippi River there are few, if any, backwater lakes having only one inlet into the main channel. In other pools of the Mississippi and along the Illinois River in Pool 25 there are numerous such backwater areas. A particularly striking example is Swan Lake, just above Grafton on the Illinois River. In the Mississippi River portion of Pool 26, numerous side channels have been formed by islands in the river. Most of the minor tributaries flowing into Pool 26, including the Cuivre River, Dardenne Creek and Piasa Creek, flow into the river behind islands (figs. 37, 39, and 43). Indeed, the development of Cuivre, Dardenne and Piasa Islands probably was induced by the influx of sediment brought in by their respective tributaries.

Time limitations and problems of vessel draft prevented a full bathymetric survey of all side channels of the Mississippi River portion of Pool 26. During this study, side channels behind Dardenne, Bolter, Iowa, and Enterprise Islands were surveyed. These side channels, for the most part, remain deep and relatively sediment free (figs. 39 and 40). However, the upstream end of the chute behind Dardenne Island (fig. 39) is in danger of becoming sediment-choked. We are uncertain whether this influx of sediment is a continuing problem, but considering the continuing extensive dredging that has been necessary in this area of the main channel, it seems likely that movement of sediment into the upstream end of Dardenne chute is inevitable. The present configuration of wing dams east and west of the mouth of Dardenne chute probably contributes to the movement of sediment into the chute (fig. 39).

The chutes between Dardenne and Bolter Islands and between Bolter and Iowa Islands are blocked by closing dams (fig. 40). The effect on water depths above and below these dams is evident. The tops of these closing dams are rather deeply submerged below the water surface. Although there may be sufficient free-flowing water above them to keep sediment moving and prevent an extensive sediment buildup downstream, the presence of the closing dams makes these channels highly susceptible to rapid infilling with sediment.

Bathymetric profiling was attempted in the chute on the Illinois side of Two Branch Island (figs. 38 and 39), but the water was generally found to be too shallow to be traversed by the R/V OMI. It was possible to travel upstream in a relatively deep channel that parallels the shore of Two Branch Island, but this channel ended in shallow water about two-thirds of the way up the length of the island. The Two Branch Island chute has almost completely filled with sand. If vegetation becomes established here, Two Branch Island will eventually be attached to the Illinois shore.

The growth and destruction of islands, development of oxbow lakes, and the attendant abandonment of old channels and occupation of new ones are inevitable during the course of the history of a free-flowing river. In the modern Mississippi River system, such natural modifications are confined by the works of man. Pooling behind navigation locks and dams affects rates of bank erosion and sedimentation in backwater lakes and side channels. Current-training structures (riprap and revetment, wing dams, and closing dams) and dredging operations control which backwaters and side channels will remain open and which filled in with sediment. Conscious choices are made based on human commerical and recreational needs and wants.

CONCLUSIONS

During the period from June 10 to August 9, 1980, when fieldwork was conducted in Pool 26 by the Geological Survey, discharge of the Missisisppi River was low. Most of the drainage basin had been under drought conditions for the previous 8 to 9 months or longer. Fall and winter precipitation in most of the area of the upper midwest had been exceptionally low. Through most of June and July in the area of Pool 26, daytime temperatures were far above normal, and precipitation far below normal.

Such conditions cannot be considered typical or "average" for Pool 26. Therefore, results of research during this one atypical year must be considered carefully before being extended to apply to other conditions. We have tried to generalize our conclusions as much as possible, so that they will be applicable in all years and may be used as a basis for continued monitoring. Long-term studies may indicate that some of our present conclusions will later need to be modified.

Because the Mississippi and Illinois Rivers are profoundly different in their bathymetric and sedimentologic characteristics, research results reported for this study of the Mississippi River should not be considered directly applicable to conditions in the Illinois River. Specific research has been conducted for the Illinois River by the Illinois State Water Survey (Schnepper et al., 1981) and reported elsewhere.

Sedimentology

- Sediments in Pool 26 consist of two basic populations of particles. Sediments in the main channel of Pool 26 above the confluence of the Illinois River consist predominantly of particles ranging from 0 Ø to 2 Ø (1.0 to 0.25 mm). Below the confluence of the Illinois River, and in main channel border areas and side channels throughout the pool, sediments consist primarily of particles ranging from 4.0 to 6.5 Ø (0.0625 to 0.011 mm).

- Mean grain sizes of sediment samples are controlled primarily by the dominant modal particle size of the sediment. Mixing of coarse-grained and fine-grained sediments results in bimodal or polymodal sediments that have mean grain sizes far from the modal size ranges of the dominant two sediment particle populations.

- Coarser-grained sediment samples tend to be better sorted than finer-grained samples. Of 238 sediment samples, 51.7 percent had sorting values between 0.5 Ø and 1.5 Ø. Sediments having mean particle sizes far from the modes of the two dominant particle populations are the poorest sorted.

- Well-sorted to moderately sorted sediments are confined to the main channel in the reach of Pool 26 from the head of Turkey Island down to the head of Iowa Island. This reach corresponds almost exactly with the reach of Pool 26, where dredging is needed most often.

- Sorting of sediments in Pool 26 is controlled primarily by the average current velocity and persistence of current velocities in the river. Sorting is best where current velocities are fairly high for long periods of time. Sorting is degraded near the locks and dams, where current velocities fluctuate widely because of the opening and closing of the control gates in the dams.

- Most sediments in Pool 26 are positively skewed and therefore have significant fine tails in their particle size distributions.

- Pool 26 sediments fall into four distinct groups determined by a scatter plot of skewness versus mean particle size values of sediment samples. Group I and II sediments have virtually the same mean particle sizes, but Group II sediments are more positively skewed than Group I sediments. Group III and Group IV sediments have nearly identical skewness values, but Group IV sediments are much finer grained than Group III sediments.

. Areal distribution of sediment groups in Pool 26 appears to be largely controlled by the same factors that control the distribution of sorting values. Areas of fairly strong, persistent current velocities commonly have Group I sediment and areas of fluctuating current velocities commonly have more positively skewed, finer-grained Group II sediments. The area of Group I sediments in Pool 26 coincides with the area from the head of Turkey Island to the head of Iowa Island where dredging is needed most often.

. Organic matter and moisture contents of sediment samples are related to the mean particle size of sediments. As particle size decreases, weight percent values for organic matter and moisture content tend to increase. The distribution of sediment groups may be used to differentiate zones where moisture and organic matter contents of sediment samples are high or low. Where Group I and Group II sediments occur, values for organic matter and moisture content tend to be low. Where Group III or IV sediments occur, organic matter and moisture contents are higher.

. Distributions of sediment parameters in Pool 26 may shift, depending on flow conditions in the river. However, because of the extensive current-training structures in Pool 26, the basic pattern in main channel areas probably does not change significantly except under the most severe flood discharges and the basic pattern is probably reestablished within weeks after the waning of a severe flood.

Bathymetry

. Maximum water depths in the upper two-thirds of Pool 26 from the toe of Iowa Island to the tail race of Dam 25 rarely exceed 20 feet (6.1 m) whereas maximum water depths in the lower third of Pool 26 commonly exceed 30 feet (9.1 m). This difference is caused by the pooling of the Mississippi River behind Dam 26 and the added volume of water supplied to the lower part of the pool by the confluence of the Illinois River.

. The main channel has alternating deep and shallow areas except in the reach from Turkey Island to Iowa Island, where dredging is common. In the upper part of Pool 26 above Turkey Island, deeps are commonly spaced about 1.25 km apart. In the lower pool, this spacing increases to about 2 km. In addition to this alternation of deeps and shallows, the locations of the deep pools form a sinuous pattern that probably follows the course of the strongest current of the river. Wing dikes and bank stabilization have confined this pattern, and significant alteration of the pattern seems unlikely without further human intervention.

. Sand waves are common bed forms at all ranges of water depths in Pool 26. The exact shape of these dunes is uncertain, but they are believed to be crescentic. They are best developed and most numerous in areas of intermediate to shallow depths upstream from the Illinois River.

. Bed forms probably move relatively slowly along the length of Pool 26, except during highest discharges. Excluding periods of high discharge, when the bed forms may be completely eradicated, rates of movement probably are in the range of 1 to 10 meters per day. At a rate of 1 m per day, a bed form would require about 170 years to move from the toe of Dam 25 to the head of Dam 26.

. Side channels behind islands in Pool 26 show little sign of infilling with sediment except where wing dams and closing dams direct sediment flows into, or block, the upstream ends of side channels. The choice of which side channels will be closed and which left open now seems to be primarily determined by human commercial and recreational needs and wants.

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APPENDIX 1. Summary of sediment sample data from Pool 26.

Sample site number	Sample number	Water depth (ft)	Moisture content (Wt %)	Moisture content (Wt %)	Organic matter (Wt %)	Organic matter (Wt %)	Moment mean (Ø)	Moment S.D. (Ø)	Moment skewness
1	7-22-1A	40	15.33	15.22	0.36	0.29	0.455	1.045	1.192
2	7-22-1B	38	16.73	16.25	—	0.29	0.985	0.817	3.673
3	7-22-1C	11	19.60	17.23	0.24	0.23	1.135	0.993	5.545
4	7-22-2A	3	16.66	16.55	0.0 *	0.29	1.580	1.336	4.667
5	7-22-2B	12	14.16	14.14	0.27	0.27	0.710	1.368	1.980
6	7-22-2C	30	15.94	15.45	0.39	0.43	1.014	1.303	2.730
7	7-22-3A	12	14.60	15.33	0.33	0.43	0.523	1.537	1.728
8	7-22-3B	20	16.46	17.17	0.25	0.0 *	1.273	1.048	3.948
9	7-22-4A	22	16.11	16.22	0.30	0.34	0.761	1.053	2.323
10	7-22-4B	17	15.72	15.45	0.26	0.25	0.888	0.991	1.337
11	7-22-4C	12	14.78	13.50	0.23	1.50*	0.744	1.455	-0.488
12	7-23-1A	4	16.15	14.91	0.47	0.82*	1.025	2.203	2.118
13	7-23-1B	19	15.12	14.72	0.32	0.21	0.734	1.344	2.198
14	7-23-1C	6	—	24.60	—	1.59	3.443	2.885	0.810
15	7-23-2A	17	18.09	17.50	0.35	0.31	0.868	1.172	-0.059
16	7-23-2B	11	16.56	16.10	0.31	—	1.168	1.087	1.268
17	7-23-2C	5	16.89	16.50	0.19	0.29	1.183	0.629	-0.454
18	7-23-3A	9	23.84	23.99	1.87	1.84	3.179	3.357	1.247
19	7-23-3B	18	15.11	15.21	0.27	0.29	0.861	0.885	-1.208
20	7-23-3C	12	17.20	17.20	0.25	0.28	1.193	0.725	1.183
21	7-23-4A	7	13.42	13.54	0.37	0.35	0.423	1.391	1.167
22	7-23-4B	15	11.65	12.52	0.87*	0.42	-0.592	2.072	0.074
23	7-23-4C	13	13.47	15.12	0.30	0.35	0.536	1.191	-0.418
24	7-24-1A	22	15.99	16.36	0.37	0.0 *	0.638	0.885	1.153
25	7-24-1B	14	13.05	12.57	0.23	0.29	0.668	1.284	-0.937
26	7-24-1C	10	14.45	15.00	—	0.35	1.019	1.127	1.051
27	7-24-2A	4	14.76	14.93	0.27	0.36	1.130	0.780	0.815
28	7-24-2B	13	15.32	14.47	0.37	0.31	0.422	1.256	-0.339
29	7-24-2C	29	16.81	16.59	0.33	0.38	0.427	0.659	1.459
30	7-24-3A	18	15.89	15.34	0.40	0.56	0.647	0.924	1.616
31	7-24-3B	9	15.78	16.13	0.23	0.29	1.022	0.814	2.883
32	7-24-3C	5	16.65	16.71	0.22	0.19	1.271	0.633	-0.328
33	7-24-4A	12	16.86	16.98	0.22	0.25	0.943	0.651	-0.282
34	7-24-4B	14	15.66	15.85	0.30	0.46	0.600	0.870	-0.830
35	7-24-5A	5	16.72	17.14	0.27	0.27	1.182	0.848	3.676
36	7-24-5B	13	—	—	—	—	-1.019	2.040	0.557
37	7-24-5C	19	11.20	11.20	0.34	0.31	1.244	0.817	-0.500
38	7-24-6A	21	11.80	12.40	0.52	0.55	-0.113	1.974	1.655
39	7-24-6B	10	13.61	13.94	0.42	0.41	0.946	1.023	0.044
40	7-24-6C	5	13.45	14.04	0.47	0.34	0.973	0.837	-0.603

* Anomalous value, probably caused by weighing error.

† Anomalous value, probably caused by contamination of sample.

— Sample not analyzed because of inadequate supply, or spilled before being weighed.

APPENDIX 1. *(Continued)*

Sample site number	Sample number	Water depth (ft)	Moisture content (Wt %)	Moisture content (Wt %)	Organic matter (Wt %)	Organic matter (Wt %)	Moment mean (Ø)	Moment S.D. (Ø)	Moment skewness
41	7-25-1A	4	14.04	14.59	0.31	0.32	1.156	0.591	-0.538
42	7-25-1B	16	14.70	15.24	0.58	0.41	1.022	0.822	-1.502
43	7-25-1C	7	14.15	15.62	0.44	0.36	0.913	0.861	0.448
44	7-25-2A	4	15.11	14.85	0.40	0.34	0.888	0.737	-0.341
45	7-25-2B	11	12.86	12.81	0.45	0.42	0.265	1.115	-0.338
46	7-25-2C	28	15.66	14.78	0.36	0.38	1.378	0.786	-0.156
47	7-25-3A	19	9.69*	13.81	8.33*	0.28	0.275	1.474	-0.984
48	7-25-3B	15	13.86	14.34	0.27	0.32	0.814	1.049	-0.060
49	7-25-4A	17	14.03	14.36	0.33	0.0 *	0.371	1.050	-1.166
50	7-25-4B	19	17.70*	14.44	0.12*	0.23	0.875	0.864	-1.582
51	7-25-4C	16	45.99	46.15	1.80†	4.29			
52	7-25-5A	19	11.50	10.98	11.48†	0.0 *	-0.664	2.157	0.135
53	7-25-5B	8	13.87	13.59	0.0 *	0.0 *	1.038	1.069	-0.965
54	7-25-5C	5	14.57	14.67	0.32	0.04*	1.552	1.445	1.894
55	7-26-1A	16	14.02	13.27	0.23	0.14	0.884	0.996	-0.396
56	7-26-1B	20	14.94	15.60	0.0 *	0.18	1.050	0.965	-1.862
57	7-26-1C	3	28.59	27.97	3.08	2.64†			
58	7-26-2A	19	9.87	11.95	0.36	1.14†	-0.057	1.722	-0.230
59	7-26-2B	14	14.87	14.63	0.07	0.12	1.002	0.748	-0.907
60	7-26-2C	8	14.40	14.33	0.24	0.29	0.695	0.816	-0.403
61	7-26-3A	12	15.35	15.43	0.0 †	0.20	1.206	0.642	-0.843
62	7-26-3B	13	13.90	13.91	0.35	0.34	0.534	0.951	-0.309
63	7-30-1A	9	13.97	13.97	0.38	0.37	0.692	1.247	2.600
64	7-30-1B	9	13.96	13.29	0.40	0.40	0.653	1.427	2.841
65	7-30-2A	24	14.04	13.68	0.52	0.38	0.183	1.760	2.422
66	7-30-2B	4	16.91	17.03	0.47	0.50	4.016	3.324	0.599
67	7-30-3A	13	30.82	30.76	2.95	2.94	6.527	2.399	1.182
68	7-30-3B	8	22.04*	10.19*	0.0 *	6.79*	1.223	1.001	3.093
69	7-30-4A	15	13.87	13.99	0.42	0.41	1.486	1.115	3.642
70	7-30-4B	8	16.84	16.44	0.68	0.71	1.808	2.201	2.405
71	7-30-5A	14	32.70	32.96	2.77	2.63	5.264	3.520	0.616
72	7-30-5B	8	31.48	31.32	3.03	3.08	5.819	3.096	0.486
73	7-30-6A	19	31.66	31.89	2.79	2.42	5.433	3.549	0.228
74	7-30-6B	8	39.82	39.93	4.19	4.14	7.357	2.518	0.673
75	7-30-7A	14	37.52	37.44	3.74	3.75	7.146	2.457	0.731
76	7-30-7B	15	19.35*	12.92	1.16	1.12	0.804	3.349	1.682
77	7-31-1A	4	15.70	15.81	0.25	0.26	1.384	0.737	-1.628
78	7-31-1B	14	14.63	14.65	0.37	0.39	0.820	0.882	-0.889
79	7-31-1C	6	—	—	—	—	0.981	1.087	1.166
80	7-31-2A	4	14.49	14.01	0.33	0.34	1.054	1.115	3.469
81	7-31-2B	10	14.82	12.71	—	0.34	1.149	0.797	-1.172
82	7-31-2C	13	15.15	15.64	0.32	0.31	1.132	0.678	-1.043
83	7-31-3A	26	15.48	15.31	0.34	0.27	1.170	0.645	-0.815
84	7-31-3B	17	19.36*	10.51*	0.35	0.34	1.055	0.745	-0.378
85	7-31-3C	12	—	—	—	—	2.377	3.365	0.771
86	7-31-4A	8	16.00	15.89	0.32	0.31	1.195	0.607	-0.807
87	7-31-4B	13	15.06	15.05	0.30	0.36	1.223	0.783	-1.726
88	7-31-4C	18	16.74	16.92	0.52	0.57	2.128	1.423	3.235

APPENDIX 1. *(Continued)*

Sample site number	Sample number	Water depth (ft)	Moisture content (Wt %)	Moisture content (Wt %)	Organic matter (Wt %)	Organic matter (Wt %)	Moment mean (Ø)	Moment S.D. (Ø)	Moment skewness
89	7-31-5A	6	14.94	15.05	0.19*	0.32*	1.066	0.915	0.634
90	7-31-5B	9	14.47	15.27	0.39	0.31	0.678	0.859	-1.003
91	7-31-5C	13	14.08	14.12	0.52	0.39	0.332	0.926	-0.732
92	7-31-6A	14	14.09	13.72	0.39	0.64	0.230	1.199	-0.732
93	7-31-6B	19	15.67	16.01	0.32	0.31	1.230	0.714	-0.881
94	7-31-6C	5	16.25	16.06	0.35	0.36	1.468	1.157	4.180
95	7-31-7A	10	15.07	15.34	0.34	0.35	1.092	0.886	-0.077
96	7-31-7B	5	14.44	15.63	0.34	0.36	1.237	1.300	3.049
97	7-31-7D	15	14.74	15.72	0.36	0.30	1.144	0.794	1.585
98	7-31-8A	32	14.71	14.09	0.44	0.42	0.448	0.866	0.219
99	7-31-8B	18	14.72	14.43	0.39	0.29	0.927	1.045	-0.696
100	7-31-8C	11	14.67	14.29	0.37	0.39	0.829	1.290	-2.384
101	7-31-9A	10	14.18	13.99	0.39	0.37	0.812	1.023	-0.669
102	7-31-9B	6	14.65	14.89	0.52	0.36	1.135	0.807	-0.117
103	7-31-9C	9	14.82	14.26	0.44	0.43	0.464	1.540	-0.162
104	7-31-9D	4	16.00	16.08	0.30	0.25	1.560	0.995	4.353
105	8-4-1A	20	23.21	23.12	0.87	0.92	2.843	2.355	2.220
106	8-4-1B	3	15.85	15.73	0.34	0.33	1.296	0.794	2.997
107	8-4-1C	16	—	—	—	—	3.183	4.005	0.531
108	8-4-1D	9	20.76	20.68	1.41	1.42	3.211	3.183	1.199
109	8-4-1E	12	15.20	15.26	0.40	0.36	1.235	1.181	4.880
110	8-4-1F	13	17.72	17.76	0.26	0.27	1.240	0.924	3.605
111	8-4-2A	17	16.13	15.83	0.27	0.25	1.201	0.749	1.970
112	8-4-2B	8	12.49	12.66	0.26	0.35	0.669	1.073	0.451
113	8-4-2C	12	14.95	14.92	0.23	0.24	1.159	0.958	0.229
114	8-4-2D	18	28.34	30.56	0.77	0.57	1.722	1.776	3.796
115	8-4-2F	8	33.61	33.75	3.58	3.92	5.656	2.857	0.966
116	8-4-2G	20	17.40	17.42	0.33	0.36	1.208	1.204	4.054
117	8-4-2H	10	33.53	33.56	3.03	3.03	5.603	2.441	1.230
118	8-4-2I	29	20.76	20.84	1.88	1.93	3.653	3.035	1.541
119	8-5-1A	25	14.87	14.62	0.46	0.50	0.623	1.535	1.776
120	8-5-1B	17	15.46	15.62	0.38	0.39	0.809	0.848	0.796
121	8-5-1C	21	17.46	17.30	0.51	0.52	1.430	1.400	2.708
122	8-5-1D	9	14.50	14.40	0.43	0.41	0.662	1.039	-0.382
123	8-5-1E	11	18.84	19.14	0.74	0.75	1.976	2.191	3.044
124	8-5-1F	26	15.35	15.35	0.47	0.45	0.984	1.837	2.544
125	8-5-1G	3	16.30	16.40	0.43	0.44	1.557	1.470	4.042
126	8-5-1H	20	9.87*	18.01*	0.98*	1.14*	1.246	2.919	1.438
127	8-5-1I	7	27.43	27.86	2.21	2.32	3.993	3.459	0.935
128	8-5-1J	15	15.77	15.15	0.45	0.45	0.437	1.111	2.021
129	8-5-2A	26	15.62	15.65	0.16	0.15	1.321	0.553	-0.612
130	8-5-2B	14	14.20	15.68	0.28	0.28	1.034	0.781	0.452
131	8-5-2C	5	13.60	13.96	0.35	0.35	0.071	1.287	1.433
132	8-5-3A	22	21.00	20.78	1.59	1.87	1.917	1.851	3.178
133	8-5-3B	14	15.89	15.72	0.27	0.27	1.374	1.124	3.995
134	8-5-3C	4	39.40	39.25	4.07	4.01	6.450	2.949	0.613

APPENDIX 1. *(Continued)*

Sample site number	Sample number	Water depth (ft)	Moisture content (Wt %)	Moisture content (Wt %)	Organic matter (Wt %)	Organic matter (Wt %)	Moment mean (0)	Moment S.D. (0)	Moment skewness
135	8-6-1A	11	18.14	—	2.51	—	-0.438	3.225	0.889
136	8-6-1B	13	15.37	14.94	0.45	0.48	0.232	1.191	3.961
137	8-6-1C	13	16.76	16.38	0.26	0.45	1.994	1.223	4.605
138	8-6-2A	7	30.84	31.81	2.31	2.63	4.172	3.997	0.562
139	8-6-2B	18	12.67	14.59	0.55	0.35	0.767	1.609	1.654
140	8-6-2C	13	16.74	16.25	0.55	0.70	1.193	1.566	3.489
141	8-6-3A	8	14.17	14.50	0.12†	0.28	1.584	1.734	4.353
142	8-6-3B	23	12.90	12.53	0.39	0.43	0.066	1.517	1.789
143	8-6-3C	5	39.94	40.53	6.14	5.33	6.946	2.749	0.574
144	8-6-4A	21	15.47	15.54	0.33	0.37	0.794	1.396	3.807
145	8-6-4B	7	14.56	14.80	0.38	0.39	0.642	1.023	1.943
146	8-6-5A	9	14.56	14.24	0.36	0.36	1.229	1.495	3.342
147	8-6-5B	5	15.84	15.76	0.21	0.30	1.348	0.946	1.292
148	8-6-5C	25	13.66	14.04	0.49	0.42	0.265	1.238	1.914
149	8-6-6A	14	18.15	18.84	0.46	0.48	1.175	1.744	3.324
150	8-6-6AA	4	13.61	13.76	0.36	0.31	0.980	1.026	-0.178
151	8-6-6B	14	15.80	15.56	0.44	0.48	1.143	1.741	3.957
152	8-6-6C	5	14.56	14.33	0.34	0.32	0.955	1.125	3.584
153	8-6-6D	29	20.85	20.17	1.22	1.21	2.018	3.105	1.846
154	8-6-6E	20	14.69	13.90	0.32	0.26	1.121	1.272	3.543
155	8-6-6F	9	14.20	14.19	0.32	0.37	0.925	1.319	3.871
156	8-6-6G	7	24.60	24.69	2.27	2.01	4.011	3.480	0.877
157	8-7-1A	29	14.74	14.22	0.47	0.25	0.455	1.562	2.897
158	8-7-1B	21	15.11	15.48	0.27	0.23	0.254	1.339	0.243
159	8-7-1C	4	14.62	14.39	0.22	0.22	1.158	0.978	3.091
160	8-7-2A	9	15.35	15.52	0.57	0.56	1.399	1.982	3.673
161	8-7-2B	14	13.68	13.23	0.39	—	0.432	1.473	1.486
162	8-7-2C	20	21.22	21.15	0.55	0.62	1.651	2.100	3.387
163	8-7-3A	3	14.91	14.89	0.41	0.39	0.915	1.309	3.280
164	8-7-3B	21	45.88	45.50	4.75	5.02	6.488	4.054	-0.305
165	8-7-3C	27	18.43	18.46	0.65	0.66	1.713	2.055	2.746
166	8-7-4A	24	64.36	64.16	5.65	5.71	4.010	5.382	-0.497
167	8-7-4B	38	14.46	13.32	0.56	0.53	0.466	2.004	2.701
168	8-7-5A	21	47.84	46.26	4.63	4.31	4.416	5.061	-0.047
169	8-7-5B	20	16.42	16.13	0.21	0.32	1.268	1.423	4.253
170	8-7-6A	27	56.40	56.56	6.96	7.27	8.448	2.824	-1.037
171	8-7-6B	16	14.89	15.48	0.37	0.41	0.938	1.453	3.820
172	8-7-7A	25	45.06	45.33	4.34	4.42	6.108	3.750	0.133
173	8-7-7B	15	17.63	18.15	0.69	0.70	1.985	2.142	3.124
174	8-7-7C	33	13.66	14.29	0.42	0.45	0.329	1.651	2.370
175	8-7-8A	33	51.29	51.80	5.08	5.27	7.251	3.776	-0.613
176	8-7-8B	16	19.40	18.97	0.45	0.43	1.175	1.700	3.228
177	8-7-8C	5	15.43	15.20	0.32	0.32	1.261	1.057	2.501
178	8-7-9A	26	13.42	13.30	0.37	0.52	0.188	1.816	2.280
179	8-7-9B	16	33.77	33.84	2.51	2.37	4.254	3.777	0.594
180	8-7-9C	10	21.89	23.42	4.17*	1.43	2.604	3.276	1.722
181	8-7-10A	7	16.56	16.60	0.40	0.37	0.793	1.279	5.100
182	8-7-10B	14	16.52	15.70	0.63	0.51	1.162	2.303	1.424
183	8-7-10C	32	16.19	15.82	1.03	0.98	0.262	2.902	2.588
184	8-7-11A	28	45.00	44.98	5.20	5.21	7.461	2.756	0.204
185	8-7-11B	7	33.47	33.77	3.02	3.08	5.726	2.852	0.932
186	8-7-11C	17	31.47	32.33	2.12	2.19	3.277	3.882	1.051

APPENDIX 1. *(Continued)*

Sample site number	Sample number	Water depth (ft)	Moisture content (Wt %)	Moisture content (Wt %)	Organic matter (Wt %)	Organic matter (Wt %)	Moment mean (Ø)	Moment S.D. (Ø)	Moment skewness
187	8-8-1A	5	22.41	23.13	1.86	2.06	3.836	3.190	1.099
188	8-8-1B	18	19.28	20.15	0.71	0.75	1.951	2.178	3.147
189	8-8-1C	10	24.24	23.87	1.63	1.69	2.921	3.319	1.408
190	8-8-1D	28	19.39	19.63	0.87	0.85	1.857	2.724	1.875
191	8-8-2A	25	13.87	13.51	0.43	0.46	0.717	1.818	3.087
192	8-8-2B	4	38.44	38.65	3.51	3.65	6.559	2.559	0.742
193	8-8-2C	16	15.74	16.69	0.24	0.27	0.966	0.888	6.573
194	8-8-2D	30	20.10	20.47	0.68	0.67	1.396	2.308	3.089
195	8-8-3A	30	17.61	17.46	0.71	0.60	1.211	2.454	2.120
196	8-8-3C	12	14.20	14.31	0.61	0.57	2.034	2.063	2.514
197	8-8-3D	6	14.69	14.28	0.37	0.37	1.021	1.431	1.825
198	8-8-3E	8	21.04	20.36	0.84	0.74	2.144	2.263	2.655
199	8-8-4A	12	15.83	16.01	0.62	0.63	1.243	2.167	2.217
200	8-8-4B	20	18.24	18.19	0.56	0.57	1.374	0.835	-0.624
201	8-8-5A	24	21.44	20.84	0.81	0.83	2.100	2.440	2.906
202	8-8-5B	16	14.77	15.05	—	0.31	1.151	1.023	2.249
203	8-8-5C	9	18.60	18.46	0.62	0.59	1.513	1.861	3.454
204	8-8-5D	18	14.76	14.77	—	0.23	1.457	1.306	4.342
205	8-8-6A	13	16.03	16.76	0.53	0.96*	0.977	2.253	2.267
206	8-8-6B	8	15.95	15.48	0.22	0.38	1.070	1.416	4.384
207	8-8-6C	26	16.26	16.31	0.37	0.36	1.477	1.528	4.315
208	8-9-1A	7	39.78	39.64	4.24	4.41	6.641	2.921	0.530
209	8-9-1B	36	14.97	14.88	0.44	0.44	1.168	1.610	4.193
210	8-9-2A	16	31.43	31.34	2.49	2.33	3.959	3.910	0.747
211	8-9-2B	27	37.85	37.79	3.28	3.16	5.148	3.811	0.521
212	8-9-2C	4	40.35	40.37	4.39	4.27	7.530	2.614	0.551
213	8-9-3A	25	52.08	51.93	5.50	6.10	8.206	2.589	0.023
214	8-9-3B	15	19.55	19.81	0.35	0.34	1.901	1.881	1.895
215	8-9-3C	4	29.80	29.52	2.24	2.24	5.660	2.763	0.682
216	8-9-4A	3	36.17	36.11	3.73	3.84	6.856	2.864	0.452
217	8-9-4B	17	16.40	16.33	0.48	0.47	0.873	1.970	3.030
218	8-9-4C	7	15.67	15.59	0.26	0.26	1.464	1.075	5.201
219	8-9-4D	28	50.44	50.96	5.40	5.01	7.268	3.699	-0.524
220	8-9-5A	19	—	36.64	—	2.33	2.882	3.951	0.471
221	8-9-5B	40	27.99	27.91	1.96	1.96	3.473	3.751	1.243
222	8-9-5C	3	36.08	36.13	3.73	3.74	6.467	3.158	0.360
223	8-9-6A	26	46.50	46.43	4.86	4.62	6.291	3.880	-0.070
224	8-9-6B	21	14.43	14.67	0.38	0.39	0.463	1.461	3.250
225	8-9-6C	25	42.32	42.05	3.45	3.45	5.177	4.112	0.200
226	8-9-7A	9	35.94	35.53	3.28	3.22	5.891	3.253	0.569
227	8-9-7B	17	15.87	16.24	0.40	0.46	1.432	1.855	3.426
228	8-9-7C	35	15.06	17.76	0.50	0.52	1.476	1.889	3.306
229	8-9-8A	36	41.83	40.67	2.40	2.54	4.329	3.685	0.928
230	8-9-8B	23	39.62	39.96	3.90	4.02	6.610	3.165	0.120
231	8-9-9A	21	17.73	14.69	0.51	0.52	1.258	1.972	3.202
232	8-9-9B	14	46.66	46.72	5.72	5.84	7.524	3.153	0.019
233	8-9-9C	30	15.43	15.29	0.47	0.48	1.090	1.869	3.266
234	8-9-10A	24	17.00	17.76	0.45	0.45	0.995	1.805	2.774
235	8-9-10B	4	29.08	29.00	3.68	3.61	6.198	3.504	0.097
236	8-9-10C	30	29.51	29.37	2.05	1.78	3.700	3.089	1.627
237	8-9-11A	32	26.72	26.32	1.72	1.67	2.584	3.108	1.853
238	8-9-11B	44	30.22	30.55	1.65	1.65	2.503	3.489	1.478
239	8-9-11C	4	30.60	30.77	3.30	3.27	6.038	2.606	0.953

METHODS

Research vessel

Field operations during July and August 1980 on the Mississippi River utilized the State of Illinois' research vessel R/V OMI. The R/V OMI is a 26-foot, diesel-powered, aluminum-hulled work boat that has a draft of about 3 feet (1 m), measured to the bottom of the skeg of the outboard stern drive unit. This relatively deep draft allowed access only to areas where water depth exceeded 3 feet (1 m).

Ship tracks

The path of the R/V OMI during bathymetric profiling was designed to provide a series of cross-channel profiles at approximately 1 km intervals along the river. Diagonal profiles returning to the starting point provided additional data with minimum overlap of previously profiled areas. Figure 46 shows a typical path of the R/V OMI during bathymetric profiling.

Depth sounder

The R/V OMI was equipped with an Aquameter Model 390 echo sounder and strip chart recorder. Precision and accuracy of this echo sounding equipment is dependent on the range setting of the strip chart recorder. For most profiling, a setting giving a full-scale reading of 30 feet on the strip chart recorder was used. At this range, depths can be read from the chart record with an accuracy of ± 0.75 feet. In deeper water, the full-scale range of 60 feet was required and reading accuracy declined to ± 1 foot at this setting.

Depth correction

The transducer for the echo sounder was mounted on the stern of the R/V OMI at one foot below the water level. All depths have been corrected by adding one foot to the observed depth on the strip chart. Between Lock and Dam 25 at Winfield, Missouri, and river mile 218 at Grafton, differences in pool stage were as great as 3 feet, but averaged about 1.5 feet during the period from July 10 to August 10, when profiling was completed (see table 2). Data on pool stage were used to determine depth values corrected to a normal pool stage of 419 feet elevation above mean sea level. For example, on July 23, pool stage in the tail water at Lock and Dam 25 at 8 a.m. was 420.8 feet, 1.8 feet above mean pool stage. To correct to 419.0 feet, 1.8 feet must be subtracted from each depth reading. Since one foot must also be added to account for submergence of the transducer, the net correction is a subtrac-

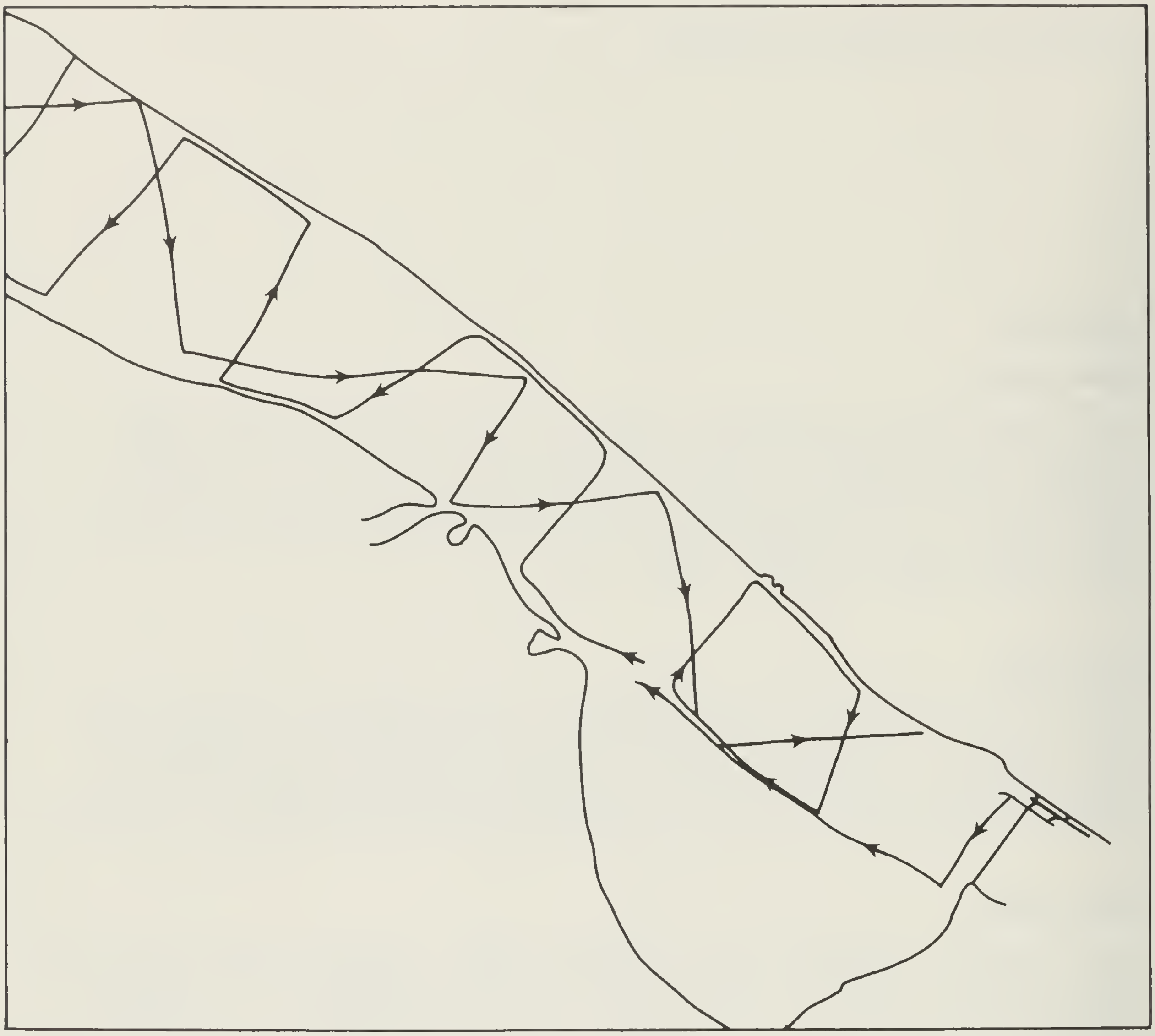

Figure 46. Ship tracks of R/V OMI during bathymetric profiling near Lock and Dam 26. Tracks are traced from data points shown in figure 44.

tion of 0.8 feet from the observed depth on the strip chart to correct to a pool stage of 419.0 feet above mean sea level. Corrections were rounded off to the nearest whole foot. Between Grafton and Alton (Locks and Dam 26) the depth gauge difference was always less than 0.5 foot. Thus the only correction required was that for the submergence of the transducer.

Radar navigation

The R/V OMI was equipped with a Motorola "Miniranger III" radar navigation system. This instrument provides a printed paper tape listing the time of day and the distance in meters to two radar transponders placed at known shore locations. At the slowest operating rate, the instrument provides a printed location approximately every 6 seconds. The printed distances are averages of 5 range determinations from each shore transponder.

Operational accuracy and precision. Under optimum operating conditions, the Miniranger III range locator is capable of an accuracy of location of ± 3 m on each range over a distance of 10 kilometers. Location accuracy is dependent on the relationship between the length of the base line between the transponders at known points and the distances from each transponder to the master unit at the unknown point. Accuracy of the instrument is significantly degraded when the length of the baseline is very small relative to the distance to the unknown point, or when the unknown point is very close to the base line between the transponders. In the latter case, the geometry can produce a non-unique solution in which the unknown point can be at one of two points on either side of the base line between the transponders. In some cases, the known geographic arrangement of points does not limit the choice between the two sides of the base line.

The radio frequency of the Miniranger system limits operation to the line of sight. The radar signals will not penetrate vegetation. Thus, islands or promontories that obstruct the view between the transponders and the master console interrupt the signal. It was also found that under some conditions, radio signals apparently bounced off the water, or the land, and gave spurious ranges. In many cases such spurious signals gave range values that were obviously absurd when compared to preceding and following range values. In some instances, however, such spurious values were not detected in the data until attempts were made to convert the ranges into geographic locations.

Location of transponders. In the relatively remote areas of Pool 26 the logistics of moving the transponders from one location to another were formidable. Only the bridge at Alton and the ferry at Winfield, at opposite ends of the pool, connected the Illinois and Missouri shores for land transportation. The Golden Eagle Ferry, near the middle of the pool, did not operate for most of the field season. In most areas, the most efficient means of moving the transponders was by boat, but such operations commonly consumed at least two hours. To minimize the number of transponder relocations and maximize the amount of time available for surveying from each pair of locations, transponder sites were chosen to give the longest possible view of the river. Because of the curving course of the river and the many islands, pairs of transponder sites commonly had either short base lines relative to the ranges to be determined, or long base lines that extended into or across the river. Optimal transponder siting for maximum navigation accuracy was rarely possible. Navigation accuracy was sacrificed for the sake of maximum speed and efficiency of surveying operations.

Where possible, transponders for the navigation system were placed near permanent marks. Most of these marks were initially surveyed and placed by the U.S. Army Corps of Engineers before or during construction of Locks and Dams 25 and 26. Transponder sites not immediately adjacent to such previously surveyed marks were located by standard cadastral surveying techniques. Thus, accuracy of the location of transponder sites varies from one site to another and is a major source of error in the navigation system. Where transponders are sited adjacent to a permanent mark, the location is probably accurate to ± 5 feet (1.52 m) or less. Where a transponder site was surveyed from landmarks located on a 1:24,000 scale topographic map, the transponder site might be anywhere within a circle with a radius of up to 100 feet (32.8 m).

Computer processing of data

Information necessary to prepare bathymetric maps was collected in three forms. The Miniranger navigation data consisted of a printed paper tape listing the time of day to the nearest second and the ranges to the two transponders at that time. The depth sounder data consisted of a graphical chart of water depth plotted on the vertical axis of the strip chart and time of day on the horizontal axis. Thus, "time of day" was the common factor necessary to combine the depth data with the water depth data to prepare a map of location versus water depth. Three computer files were constructed. File 1 listed the two transponder ranges and time of day for every point determined by the Miniranger. This file consisted of about 100,000 individual location points each requiring manual entry of up to 16 digits. File 2 consisted of the time of day and water depth. This file was constructed using a digitizer to convert the analog strip chart from the echo sounder into a digital log of time versus water depth in feet. The digitizing program included the daily correction factors to convert the water depths from the daily strip charts to the corrected depths for a constant pool stage. File 3 contained the latitude and longitude of every transponder site and the date and times of day of its operation.

As the first step in data analysis, a program utilized the data in files 1 and 3 to convert the ranges in file 1 into coordinates for map sites. Output from this program consisted of a file (file 4) giving map coordinates versus time of day for each pair of ranges in file 1. The trains of map locations in file 4 were plotted by the computer to show the calculated path of the boat within the boundaries of the river. This plot showed areas where the navigation data were inaccurate. If one of the radar ranges was too short, the two range arcs did not intersect and no map location was defined. If one of the ranges was too long, the plotted point fell outside the known boundaries of the river.

Editing of these navigation errors was done in the original entry file (file 1) and the edited version of file 1 was used to create a new file 4 that was then plotted to test the editing. The final, edited version of file 4 was then combined with file 2. The output of this program (file 5) was a master file giving water depth versus map location points. The original intent had been to use file 5 to produce a computer-contoured map of water depths. However, the additional steps necessary to "force" the contouring to stay within the known river boundaries were considered to be too time-consuming to be worthwhile. As an alternative, the computer was programmed to plot locations of water depths at selected sites (trains of data on figs. 37 to 44). These data points were then used to hand plot the bathymetric contour maps shown in figures 37 to 44.

Preparation of bathymetric maps

The computer at the Illinois State Geological Survey plotted the general outline of the river and selected data points on polyester film base maps.

Additional water depth data were transferred to these base maps by hand plotting methods.

Because of a lack of sophistication in the computer plotting program, water depth data plotted by the computer often were illegible. Water depth values for data points were always placed directly above the data points by the computer. Where data points were closely spaced, printing commonly overlapped and became unreadable. In such cases, data plotted by the computer had to be reconstructed by hand plotting methods.

Hand plotting of depth data involved the following steps:

1. Reconstructing the path of the boat on the base map by plotting the intersections of selected transponder ranges that defined the end points and selected intermediate points along the boat path.

2. Measuring the length of the reconstructed boat path and subdividing the line on the map into segments approximately 50 meters long. The points marked on the line are water depth data points spaced approximately 50 meters apart.

3. Marking an equal number of data points (using spacing dividers) on the portion of the echo sounder strip chart corresponding to the plotted boat path. Corrected water depths at these points were transferred from this strip chart to the corresponding data site on the base map.

The hand plotting method assumes that both the profiling vessel and the strip chart recorder operated at constant speed during the profiling of the segment plotted. The profiling vessel always ran at an engine speed of 1,000 to 1,200 rpm during profiling. This meant that profiles made in the upstream direction against the current flow were run at slower velocity than those in the downstream direction. This does not affect the spacing of data points on the plotted boat path since longer paths have correspondingly more points spaced at 50-meter intervals. Data points on the echo sounder strip charts of profiles run at higher velocities have data points spaced closer together because travel time was shorter for the same distance travelled on the earth's surface. Bottom features such as wing dams have distinctive signatures on strip chart records. Where such features were present, they were commonly used to define segments of the strip chart record that corresponded to specific segments of the boat path and the spacing of data points was adjusted accordingly.

All data were first plotted on polyester film base maps drawn by computer at a scale of 1:12,000. Bathymetric contours were then drawn by hand on these base maps, using the original strip charts from the echo sounder as a guide to interpretation of data. U.S. Geological Survey quadrangle topographic maps for the entire area were photographically enlarged to a scale of 1:12,000 and the boundaries, islands, wing dams, and other physical features of the river were traced from these enlargements onto polyester drafting film to make a more accurate blank base for final map preparation. The blank bases were overlain on the computer-drawn base maps and the bathymetric contours and data points were traced onto the new, clean base maps. These clean contour maps were then photographically reduced to a scale of

1:24,000 and final lettering was applied. The 1:24,000 scale bathymetric contour maps then were photographically reduced to publication size.

Sediment samples

Navigation data for bottom sediment sampling. Navigation data for bottom sediment sampling sites were plotted by hand on 1:24,000 scale U.S. Geological Survey topographic maps. As plotted on these maps (figs. 2 to 6), the sites are believed to be accurate within a radius of about 10 m.

Site selection. Sites for sampling of bottom sediments were selected from the bathymetric profiles to represent shallowest, intermediate, and maximum water depths on each cross-channel profile. Where significant midchannel shoals were crossed, additional sampling sites were selected. In narrow side channels where only diagonal profile tracks were made, sampling sites were selected along the diagonal tracks in a similar manner.

Sampling procedures. Bottom sediment samples were collected with a Ponar clamshell-type grab sampler operated from the deck of the R/V OMI. The Ponar sampler had previously been modified to install trap doors on the top surfaces of the sample buckets. These doors are held closed by water resistance during retrieval and help to prevent washout of fine particles as the sampler rises through the water to the surface. Samples from the Ponar sampler were dumped into a plastic washtub and immediately transferred to 1-quart (0.95 l) plastic bottles. Most samples had an initial volume of about 2 quarts (1.9 l). Excess sample was washed overboard and the sampling equipment rinsed in river water before proceeding to the next sampling site. Samples taken in the tail race of Dam 25 (sample sites 1, 2, and 3) (fig. 2) were obtained with a Shipek sampler because the Ponar was found to be too light in weight to reach the bottom in the strong currents below the dam.

Sample preparation

Bottom sediment samples were returned to the laboratories of the Illinois State Geological Survey in Champaign, Illinois at the end of the field season on August 10, 1980. The first samples had been collected on July 22, 1980. Upon delivery in Champaign, samples were stored in a lighted room at ordinary temperatures for about 40 days until analysis could begin. During storage, some samples developed a discoloration probably caused by bacterial or algal growth within the translucent sample bottles. Such biological activity is believed to have been largely confined to a thin layer of sample in contact with the outside of the sample bottles. Discoloration was not observed to extend throughout the samples. To minimize the effects of this biological activity on analyses, the insides of the bottles were not scraped out or washed when sediments were dumped out of them.

Analytical procedures for particle size analysis for this study follow the outline in Guy (1969). Analyses for moisture content and organic matter content follow procedures 208A and 208E in American Public Health Association (1976).

Samples were prepared for analysis by first pouring off excess water from the sample bottle. Wet sediment then was dumped from the bottle onto a plastic sheet, thoroughly stirred, and piled into a mound. The mound was cut into quarters with a large spatula and two opposite quarters placed in beakers and dried at 105°C in a convection oven. The remaining two quarters were mixed together, mounded and split by repeated quartering until 2 or 3 samples, each weighing about 30 grams, were obtained. These 30-gram splits were placed in disposable aluminum oven dishes and were used to determine moisture content and organic matter content.

Moisture and organic matter analysis. The wet, 30-gram sample splits were weighed on a Mettler electronic balance, accurate to ± 0.0005 gm, and dried in a convection oven at 105°C for 24 hours. After cooling in a desiccator jar, the dried samples were weighed and the weight loss was calculated as the weight percent moisture of the sample. The dried and weighed samples were then placed in a muffle furnace and heated to 550°C for 1 hour. Baked samples were transferred to a desiccator jar and weighed while still warm to determine additional weight loss. The high temperature weight loss was calculated as the percent by weight of organic matter in the sample. At least two splits of each sample were analyzed separately for moisture and organic matter contents. Every tenth sample had a third split analyzed in the same manner in order to provide a further check on the reproducibility of the data. Duplicate and triplicate samples commonly were heated at the same time, but no special effort was made to keep pairs or triplets together.

The method used to determine the organic matter content of the sediments probably provides only an approximation of the real organic content, especially for sediments rich in clay minerals. Heating to 550°C not only induces combustion of the organic matter in the sediment, but also drives interlayer water out of clay minerals. At temperatures near and above 550°C, the hydroxyl is also driven out of the structure of many clay minerals. Thus, although clay-rich sediments do tend to contain more organic matter, the de-watering of clay minerals probably will cause an extra weight loss that will indicate the presence of greater amounts of organic matter than the true amount. It follows that as the amount of clay in the sediment increases, the discrepancy between the measured and real content of organic matter will increase.

Particle-size analyses

Laboratory procedures. Sample splits, previously dried in beakers, were dumped into an enamel pan and disaggregated by gentle tapping with a hammer. Samples judged to be sandy were split in a Jones-type riffle splitter to a weight of about 100 grams. Samples with large amounts of silt and clay were split to a weight of about 50 grams. All samples were sent to the Sedimentology Laboratory of the Illinois State Geological Survey for analysis of the -230 mesh particle-size fractions.

Splits received at the Sedimentology Laboratory were transferred to sample bottles, wetted with distilled water and a known volume of dispersing agent, and placed on a shaker table for 8 hours to disperse and suspend all clays. After shaking, the samples and suspensions were transferred to 1,000 ml settling tubes and the -230 mesh particles analyzed for particle size distribution at 1 Ø intervals by standard methods for pipette analysis (Guy, 1969). Sample fractions coarser than 230 mesh were dried and returned to the laboratories of the Industrial Minerals Section of the Survey where they were sieved at 1 Ø intervals to determine the particle-size distribution. Consistency of sieving was monitored by repeated sieving of splits of a standard sand of known particle-size distribution after every twentieth Mississippi River sample. No significant deviation of these standard samples was observed through 12 sievings.

Statistical analysis of data. Weights of sediment retained in each sieve and pipette fraction were entered on computer cards and the data analyzed with the SEDSTAT computer program written by C. Brian Trask of the Illinois State Geological Survey. SEDSTAT computes the 5th, 16th, 25th, 50th, 75th, 84th, and 95th percentiles of the distribution from the arithmetic cumulative frequency curve, and calculates the graphic approximations of the statistical mean, sorting, skewness, and kurtosis of the distribution using the formulas of Folk and Ward (1957). The Folk-Ward parameters are not determined if the first sieve on which particles were retained held more than 5 weight percent of the sample, because in this case the 5th percentile is indeterminate for the sieving interval used. Time limitation did not allow reanalysis of indeterminate samples.

SEDSTAT also utilizes all available particle-size data to calculate the mean, variance, sorting, absolute and relative skewness, and absolute and relative kurtosis using modifications of the moment statistics of Krumbein and Graybill (1965) and Griffiths (1967). SEDSTAT also computes and plots an approximate frequency curve for the distribution of each sample by calculating a numerical approximation of the first derivative of the arithmetic cumulative frequency curve. These plots of particle size versus weight percent per .05 phi units locate the modal particle size classes within the limits of accuracy of the 1 Ø sieving interval. Computer program printouts and plots of frequency curves for all samples are on open file and available for inspection at the Illinois Geological Survey, or the Upper Mississippi River Basin Commission, Minneapolis, Minnesota.

The phi scale used to represent particle size values in this report was devised by Krumbein (1938). Natural sediments commonly have a very broad range of particle sizes, often encompassing up to three orders of magnitude or more when the particle size is expressed in millimeters. Such broad size ranges can be plotted on graphs having logarithmic scales, but such scales are not as convenient to use as are linear scales. Krumbein observed that a scale based on the logarithm of the base 2 provided a convenient linear scale for describing sediments having a broad size range. In the Ø scale of Krumbein (1938),

$$\text{where } \emptyset = -\log_2 d_{(mm)},$$

$d_{(mm)}$ is the diameter of the particle in millimeters. Because the logarithm of a number less than 1 has a negative value, Ø units for particle sizes greater than 1 mm have negative Ø values, and particle sizes less than 1 mm have positive Ø values. Each successive whole Ø unit value is half the next larger Ø value when converted to millimeters. Thus when $\emptyset = 0$, $d_{(mm)} = 1$ mm; when $\emptyset = 1$, $d_{(mm)} = 0.5$ mm, and so on.