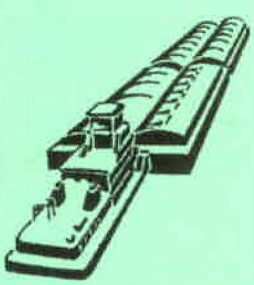
ENV Report 9

Interim Report For The Upper Mississippi River - Illinois Waterway System Navigation Study

Identification of Potential Commercial Navigation Related Bank Erosion Sites



January 1999

Rock Island District
St. Louis District
St. Paul District

US Army Corps of Engineers

IDENTIFICATION OF POTENTIAL COMMERCIAL NAVIGATION RELATED BANK EROSION SITES

I. INTRODUCTION

A. Background. In order to assess the existing bank conditions, the Upper Mississippi Districts of the U.S. Army Corps of Engineers (COE); Rock Island, St. Louis, and St. Paul; conducted an extensive field survey of bank erosion along the Upper Mississippi River (UMR) between St. Paul, Minnesota and Cairo, Illinois, and the Illinois Waterway (IWW) between Joliet, Illinois and Grafton, Illinois during the fall of 1995. A report entitled "Bank Erosion Field Survey Report of the Upper Mississippi River and Illinois Waterway," was published by COE in January 1998 (COE, 1998). The report provides detailed information about site-specific bank and subaqueous conditions existing at the time of the survey.

Upon completion of the field survey, a follow-up study was initiated to utilize the site-specific field observations to assess the relative risk of bank erosion for the existing and future conditions for the study area (a decision point paper describing the overall scope and purpose of the add-on study is contained in Appendix A). This report addresses the effort to achieve this goal. The scope of this study included the construction of a GIS database of information collected during the field survey; the development of a model to identify locations where there is a high, medium, or low risk of navigation contributing to bank erosion; and the system wide implementation of the model. The scope of work for the model development and application is presented in Appendix B. A contract for the development of the bank erosion model was awarded to SENES Oak Ridge Inc., who obtained the services of Dr. Tatsuaki Nakato of the Iowa Institute of Hydraulic Research (IIHR). Dr. Nakato had previously participated in the aforementioned field survey and prepared the UMR portion of the field survey report.

B. Summary of Available Models. At the initiation of the Bank Erosion Study, an extensive literature review of available pertinent data, research, and opinions regarding the process of bank erosion along the UMR and IWW was conducted by the Waterways Experiment Station (CEWES-Technical Report HL-96-10, August 1996). Special emphasis was placed on selecting methodologies which could be used to identify and differentiate between the various mechanisms contributing to bank erosion throughout the system, as well as a means of establishing the relative significance of each mechanism.

The literature search revealed that much of the research conducted has been in reference to navigation effects and bank protection. Research containing actual relationships between navigation processes, or any processes for that matter, and bank erosion were rare and often unverified in the field. Only two articles were identified which presented a shoreline retreat model related to wave energy. One, Grigor'eva (1987), was unverified and showed a conceptual method for bank reworking due to wind waves only. The second, Nanson et al. (1993), was a study conducted on the Gordon River in Australia. The authors measured erosion rates while recreation boats passed a site. A good correlation was found between wave power or wave height and erosion. Based on their observations, they developed a set of maximum wave height thresholds for various soil types and recommended appropriate vessel speed restrictions.

The lack of applicable models and need for further research was expressed in many articles. This nature is best described in an article by Pilarczyk et al. (1989): "*The mechanisms of bank erosion and the stability of protection structures subject to hydraulic loading are complex problems. The understanding of erosion processes and failure mechanisms of structures is still in a rudimentary stage, and it is not yet possible to describe many important phenomena and their interactions by theory*."

At the present time, no computational method exists for linking a commercial vessel with chosen hull shape, traveling at a chosen speed in a channel of chosen depth and chosen cross-sectional area and shape with banks of a chosen height and materials, to a predicted occurrence of erosion. Therefore, there is no existing modeling technique, nor does this paper purport to develop one, that can predict or quantify bench erosion based on physical forces associated with commercial navigation. The model developed by this study is an effort to relate observed erosion, which may or may not be related to navigation, to various parameters associated with navigation through the use of contingency[1] analysis.

II. ASSESSMENT OF DATA

A. Available Data. During the 1995 field survey, data on detailed bank and channel conditions were collected at forty-three erosion sites along the UMR. In addition,

[1] A statistical method of testing the independence of two variables; both of which must be categorical (e.g., minor, moderate, and severe) as opposed to continuous numeric values.

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comparable but less intensive data collections were made at thirty-six observation sites. Along the IWW, detailed data were obtained from twenty-nine erosion sites. The principal information obtained during the field survey are listed in Table 1. During the present investigation, a database for each of the three data groups (UMR, IWW, and UMR observation sites) was developed.

B. Preliminary Assessment of Data. A statistical modeling effort was undertaken to relate the risk of bank erosion to a number of site specific physical parameters. The project was originally envisioned as producing a mathematical model of the severity of bank erosion based upon a number of significant physical parameters taken from the large list of parameters available in the field data sets. This model, based on a limited number of the erosion sites and later validated against the remaining sites, could then be applied to the entire river system. Therefore, the two main phases of the modeling effort undertaken were: (1) significant parameter identification, and (2) model construction based on correlation/regression of these significant parameters related to the perceived bank erosion severity and causative mechanisms. Ideally the resulting model would be based upon a limited number of parameters such that it could be easily applied to the entire UMR and IWW system.

C. Data Assessment Approach. Initial plans called for an exploratory analysis of the field data sets to investigate trends, clustering, and distributions of the data. Outliers and inconsistent data were identified and remedied, and an attempt to verify the analytical approach was made by visualizing the data in scatter plots, histograms, and three-dimensional cluster graphs. Numerical correlation testing was used to identify the numeric site-specific parameters related to bank erosion severity and to use a rank analysis for identifying the significant descriptive parameters. Exploratory scatter plots, cluster analysis, and frequency analysis were made of all parameters, each one considered against the remaining ones. However, no significant results were obtained.

These detailed analyses revealed a bias in the sampling method used during the field survey that made them unfit for use with the standard statistical techniques proposed. This bias resulted in a violation of the normal distribution assumption, which underlies most statistical methods. The selected erosion sites visited during the field survey did not represent a randomly selected set of observations of bank erosion severity as would be required for the proposed modeling effort. The data set represents sites that were exclusively eroded. Therefore, there is no way to produce a numerical model based on these sites capable of predicting the occurrence vs. non-occurrence of bank erosion.

Table 1. Principal Information Obtained During the 1995 Field Study

1	Site Number
2	Date
3	Time
4	River
5	River Mile @ Midpoint
6	UTM X
7	UTM Y
8	Bank Profile Type
9	RDB/LDB (Right Descending Bank/Left Descending Bank)
10	Pool Name
11	Geomorphic Characteristics
12	Bank Type
13	Wing Dams (Present or Not)
14	Archeological Site (Y/N)
15	Surrounding Structures
16	Commercial Traffic Level (Barges per Year)
17	Recreational Traffic Level (Trip-Miles per Year)
18	Estimated Distance to Sailing Line (ft)
19	Land Use on Bank Crest
20	Type of Vegetation on Top of Bank
21	Type of Vegetation at Scarp Face
22	Type of Vegetation at Bench
23	Extent of Tree Root Exposure on Bank Face
24	Overland Drainage
25	Bank Erosion Type (Causitive Mechanisms)
26	Scarp Height (ft)
27	Scarp Slope (V:H)
28	Scarp Soil Type (USCS)
29	Berm Height (ft)
30	Berm Width (ft)
31	Berm Soil Type (USCS)
32	Subaqueous Bench Slope (V:H)
33	Bench Sediment Type
34	Subaqueous Bench Description
35	Channel Top-Width (ft) at Low Flow
36	Degree of Bend Curvature
37	Radius of Bend Curvature (ft)
38	Bench Width (ft)

Note: Parameters No. 35 through No. 37 were determined during the development of the GIS database.

III. ASSESSMENT ANALYSIS

The following section provides an overview of the model development process conducted by the IIHR with assistance from the COE. An attempt was first made to develop a general methodology and model formulation capable of identifying areas subject to erosion, regardless of cause. Once this methodology and general formulation had been established, the model was modified in an attempt to single out those locations potentially affected by commercial navigation.

A. Analysis Methods Investigated. Investigations of alternate ways of using the collected data sets were undertaken. A contingency analysis of the data was used to provide a measure of the dependency between pairs of parameters and to show whether the parameters were statistically independent or interrelated. The contingency analysis yielded a series of contingency tables, comparing one parameter against all other selected parameters. To conduct the contingency analysis, a commercial exploratory statistics package, DataDesk (Data Descriptions, Inc., P.O. Box 4555, Ithaca, NY, 14852) was selected. In order to conduct the contingency analysis, the data had to first be divided into discrete categories such as high, medium, and low (each representing 1/3 of the sampling sites).

A sample contingency table is presented in table 2 for explanation. It relates the variable cDist (distance from the bank to the sailing line) and cCwidth (channel top width). These variables are obviously related, since in narrow channel sections the distance that the tow is operating from the bank also tends to be quite small. Both numeric variables were categorized into LOW (L), MEDIUM (M), and HIGH (H) categories and contingency analysis conducted. The correlation between the variables can be seen from the strong diagonal of counts (H-H of 23, M-M of 18, and L-L of 26) and the weak non-diagonal counts. In addition, the Chi-Square value provides a measure of the significance of the variation in the counts that could be expected by chance with independent parameters.

Table 2. A Sample Contingency Table

Rows are levels of cDist
Columns are levels of cCwidth
108 total cases of which only one is missing

		H	*L*	*M*	*Total*
H	Count	23	0	13	36
	Expected Count	11.7757	11.7757	12.4486	36
L	Count	4	26	6	36
	Expected Count	11.7757	11.7757	12.4486	36
M	Count	8	9	18	35
	Expected Count	11.4486	11.4486	12.1028	35
Total	Count	35	35	37	107
	Expected Count	35	35	37	107

Chi-Square = 52.59 with 4 df (degrees of freedom)
$p <= 0.0001$

Statistics reported by the contingency analysis are:

Count: The number of cases falling into each cell

Chi-Square: The null hypothesis associated with this test for independence states that the two parameters are statistically independent. The probability that a randomly selected case falls in a specified cell depends only upon the probability that the case falls in the specified column and the probability that it falls in the specified row.

Expected value: This is the number of cases expected to be in the given cell were the Chi-Square null hypothesis true. If the null hypothesis is true, then the observed cell counts approximately equal the expected cell counts. If the null hypothesis is false, then the observed cell counts will tend to differ from the expected cell counts.

p: Probability of obtaining a Chi-Square value at least as large as computed, if the two parameters were independent.

1. Analysis No. 1. Since some of the selected erosion sites had data collected at more than one cross section, multiple data sets from the same erosion site were eliminated to avoid bias effects. It was decided to use only the data collected from the midpoint section of each site. Only the UMR site data were considered in this initial analysis, and the list of perceived erosion mechanisms was reduced to the most dominant processes at each site. The parameters considered in this statistical analysis are shown in table 1.

Each quantifiable, numeric parameter was considered individually. A frequency breakdown of the parameter's distribution permitted the continuous numeric parameter to be broken down into a small number of discrete categories. Percentiles were computed for the upper and lower thirds of the distributions and histograms were plotted to verify the computation. Thirty-third and sixty-sixth percentile rankings gave cutoff points by which the original numeric values could be categorized. Values below the thirty-third percentile were categorized as LOW, values above the sixty-sixth percentile were categorized as HIGH, and the remaining values were categorized as MEDIUM.

In order for the model to be implemented on a system wide basis, the model must be limited to those parameters that can be estimated for the approximately 2,000 miles of bankline being considered in this study. Therefore, the number of parameters was reduced to those which were known or which could be readily determined or measured for the entire study area. These remaining parameters were recategorized and the contingency analysis repeated. Data for the forty-three UMR sites were used. Table 3 summarizes numeric ranges that define each of the LOW, MEDIUM, and HIGH categories for each attribute.

Table 3. Categorization of Numeric Variables

Attribute	**LOW value**	**MEDIUM value**	**HIGH value**
Bench width (ft)	< 9 ft	9 ft ~ 17 ft	≥ 17 ft
Channel width (ft)	< 950 m	950 m ~ 1,450 m	≥ 1,450 m
Degree of curvature	< 30°	30° ~ 45°	≥ 45°
Distance to sailing line (ft)	< 500 ft	500 ft ~ 800 ft	≥ 800 ft
Scarp height (ft)	< 1.5 ft	1.5 ft ~ 3.5 ft	≥ 3.5 ft
Scarp slope (V:H)	< 2:1	2:1 ~ 3.5:1	≥ 3.5:1
Subaqueous bench slope (V:H)	< 1:8.7	1:8.7 ~ 1:6.7	≥ 1:6.7

It should be noted that the labels, LOW, MEDIUM, and HIGH, refer only to the relative numerical value of the given parameter at that site, and do *not* refer to the bank erosion risk. For example, a LOW value in the "distance to sailing line" parameter should be seen as a high bank erosion risk. Therefore, a determination was made for each parameter, as to whether the HIGH or LOW values corresponded to a high erosion risk, as shown in table 4.

Table 4. Relationship Between Categorization Value and Risk Value

Measures / Categories	L (Low) High Risk shown in shade	M (Medium)	H (High) High Risk shown in shade
Distance to Sailing Line	L	M	H
Scarp Height	L	M	H
Scarp Slope	L	M	H
Subaqueous Bench Slope	L	M	H
Channel Width	L	M	H
Radius of Curvature	L	M	H
Bench Width	L	M	H

In an attempt to define a relative risk of erosion, a new parameter, Rate of Hit (ROH), was constructed to count the number of parameters (of the seven total per site) that were considered to be in the high erosion risk category. However, the resulting values of ROH failed to provide sufficient resolution between sites or results that were consistent with the field survey observations.

2. Analysis No. 2. A review meeting regarding the initial analysis effort (Analysis No. 1) was held between the IIHR and the COE at the Rock Island District on 25 November 1997. Discussions at the meeting indicated that the general formulation being used in the analytic approach taken by IIHR appeared promising for making limited statements about the relative effects and significance of various parameters on severely eroded sites. It was decided to continue the contingency analysis for the entire UMR and IWW data sets (including the UMR observation sites), as opposed to using just the forty-three UMR sites as in Analysis No. 1.

The analyses continued by investigating a slightly different set of parameters. A new data set with nine parameters (*distance to sailing line, scarp slope, subaqueous bench slope, channel width, radius of curvature of bend, bench width, commercial traffic level, and recreational boat traffic level*) was constructed for the entire UMR and IWW navigation system. Frequency analyses were done and numerical range limits were determined for the LOW, MEDIUM, and HIGH categories for each parameter. Contingency tables for each parameter versus all other parameters were prepared and significant correlations were noted only for parameter pairs related to site geometries, i.e., radius of curvature of bend, degree of curvature of bend, distance to sailing line, and channel width. No significant correlations were observed among other parameters.

Analysis efforts then turned to consideration of the 108 erosion sites observed during the UMR/IWW field surveys. Midpoint sections at each site (forty-three UMR, twenty-nine IWW, and thirty-six UMR observation sites) were extracted for analysis. Frequency analysis resulted in the numeric range limits, and the risk criteria unfavorable to bank-erosion processes were established. The established risk criteria was applied to each site and the numbers of the unfavorable features were counted as before using the Rate of Hit (ROH) measure.

Another approach taken in evaluating the severity of bank-erosion risk factors was to give a numeric value to each of the LOW, MEDIUM, and HIGH values rather than counting the number of occurrences of each erosion risk category. In place of the ROH counting scheme, the categorical weights were increased linearly such as 1, 2, 3, or 1, 3, 5 for the LOW, MEDIUM, and HIGH risk categories. The overall erosion risk measure was then defined as the sum of the resulting weighted-attribute scores. However, simple linear weights did not provide sufficient discrimination among the resulting overall erosion risk categories. Therefore, an exponential categorical weighting scheme, shown in table 5, was devised to provide a better distribution of these categories. A total score from the sum of the weighted values for the nine parameters was then obtained for each site. The resulting frequency distribution of the overall erosion risk scores showed a good distribution; thus, providing the desired discrimination. The histogram of scores is shown in figure 1. The histogram shape approximates a normal distribution, indicating a good discrimination among the erosion site parameters used in this analysis.

Table 5. Exponential Weighting Scheme

Category Value	Weighting Factor
LOW	$2^1 = 2$
MEDIUM	$2^3 = 8$
HIGH	$2^5 = 32$

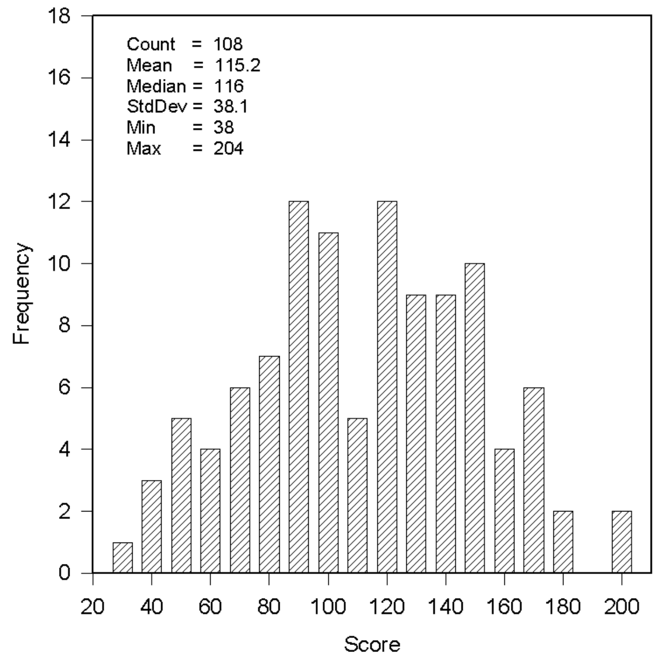

Figure 1. Histogram of overall erosion risk scores using the exponential weighting scheme

It should be noted that all of the sites used in this analysis were diagnosed as severely eroding during the field survey. The risk distribution obtained in this analysis indicated that the proposed exponential weighting scheme could be expanded for further refinement.

3. Analysis No. 3. During discussions between the IIHR and the COE on 31 December 1997, it was decided to continue analyses using the exponential weighting scheme with one adjustment. It was decided to try several different sets of additional weighting factors to be used in conjunction with the exponential weighting used earlier. These weighting factors were to be multiplied by the exponential weights determined according to the erosion risk severity category. The weighting factor represents a combination of the relative importance of the parameter in the overall bank erosion process as well as the interrelated nature of some of the parameters (i.e., if channel width and distance to the sailing line are strongly related, then the weighting factors provide a means to avoid biasing the model result). Hence, the total score for a particular site's attribute would be the product of an attribute-specific weighting factor and a severity-specific exponential value. For example, if "distance to sailing line" had a weighting factor of 8 and the attribute for a particular site was found to be high risk, the resulting attribute score would be: $8 * 2^5 = 256$. The total numeric score for a section of the bank line could then be determined as:

$$Score = w_1 2^{x1} + w_2 2^{x2} + \ldots + w_n 2^{xn}$$

where: $w_1, w_2, \ldots, w_n$ = parameter weighting factors
x1,x2, … , xn = exponents based on the risk categories
n = the number of parameters used in the analysis

Use of this final score provides a method of quantitatively comparing the relative risk of erosion between different sites based on the set of *n* parameters.

B. Selected Method. Using the general model formulation and methodology developed in Analysis No. 3, the model was adjusted to focus on just those available attributes that are, based on judgement, directly related to the potential for commercial navigation induced erosion. The potential for navigation induced erosion relates directly to the water motions that vessels create and that are capable of attacking banks. These include return currents, water level drawdown, short period and transverse stern waves, and propeller wash. In addition, fleeting activities and temporary mooring associated with tows waiting for lockage could have the potential to produce localized impacts.

The potential for significant drawdown and return currents is highly related to the channel blockage ratio (channel area/vessel area) and is most significant in the IWW and upper reaches of the UMR where channel dimensions are smallest. Since the existing bathymetric data are not sufficient to compute the blockage ratio for all sections of the bank in the system, the channel top width (bank to bank) at low flow conditions was used to represent the potential for vessel drawdown and return current related erosion.

The potential for vessels to produce significant wave heights at the bank line is related to the distance the vessels operate relative to the bank, and the speed, size, direction and draft of the vessel. The Economics Workgroup of the UMR/IWW Navigation Study, has identified little variability in the speed at which tows transit the system. In addition, the most frequently occuring tow size operating on the system pools is 1,200 feet in length (three barges wide by five long) with a maximum draft of 9 to 9.5 feet. Since the speed, draft, and maximum size of the tows operating in the pooled reaches of the UMR and IWW are consistent between pools; the distance from the sailing line to the bank line at low water was used as the significant parameter for the risk of wave attack due to commercial vessel movement.

Propeller wash has the potential to produce erosion in small radius bendways, and in narrow channels sections where the transiting tow is forced to perform additional maneuvering. The potential risk for direct prop wash of the bank is represented in the model by the radius of curvature of the bend, as well as the channel top width and distance to the sailing line at low flow conditions.

The areas currently being used for fleeting and temporary mooring by tows waiting for lockage, have been identified as part of the Navigation Study and are considered high risk areas for the potential for commercial navigation induced bank erosion.

Using these three quantitative (distance to sailing line, channel top width, and radius of curvature) and two qualitative parameters (location of fleeting and mooring areas) the system was screened using the general model formulation presented above, with some minor adjustments. First, the risk ranges were increased from 3 levels to 5, allowing for greater resolution of the high risk areas. The risk ranges and corresponding exponents used in this analysis are listed in table 6. Second, the entire UMR and IWW databases were used to develop the cut-offs for the risk ranges (as opposed to just the 72 sampling sites and 36 observation sites). Therefore, the “HIGH RISK” category represents the five percent on the system most susceptible to erosion for that particular parameter. The UMR and IWW were modeled separately and two sets of risk ranges were computed.

Table 6. Five Level Risk Range Categorization

Range Name	Range	Exponent
HIGH RISK	< 5th Percentile Value	5
HIGH/MEDIUM RISK	5th – 20th Percentile Value	4
MEDIUM RISK	20th - 50th Percentile Value	3
MEDIUM-LOW RISK	50th – 75th Percentile Value	2
LOW RISK	> 75th Percentile Value	1

For all three quantitative parameters, a low value represents a high risk for commercial navigation related bank erosion. Tables 7 and 8 summarize the risk range category limits for the UMR and IWW.

Table 7. Risk Range Category Limits – Upper Mississippi River

Breakpoint Location	Channel Top-Width (m)	Distance to Sailing Line (m)	Radius of Curvature (m)
5th Percentile Value	268	97	1306
20th Percentile Value	419	171	2005
50th Value	607	286	3640
75th Value	754	407	6200

Table 8. Risk Range Category Limits – Illinois Waterway

Breakpoint Location	Channel Top-Width (m)	Distance to Sailing Line (m)	Radius of Curvature (m)
5th Percentile Value	151	68	879
20th Percentile Value	181	87	1300
50th Value	230	113	2548
75th Value	292	148	4450

The new overall erosion risk score was then defined as:

$$\textbf{Score} = \underset{\text{(Dist2Sail)}}{8 * 2^{A}} + \underset{\text{(Channel Width)}}{6 * 2^{B}} + \underset{\text{(Radius of Curvature)}}{4 * 2^{C}}$$

where exponential constants A, B, and C are the values associated with the five risk ranges (Table 6), and 8, 6, and 4 are weighting factors for the distance to the sailing line, channel width, and radius of curvature, respectively. The weighting factors used in this analysis were chosen based on the perceived importance and independence of the parameters, as well as the resulting distribution of model scores (i.e., the selected weighting factors produced good dissemination of model scores).

The model was applied to the GIS database and the resulting scores for each section of the bankline were ranked (the main channel border was divided into approximately 10,000 segments in the GIS database). The resulting score represents the relative potential for commercial navigation related bank erosion at a bank section with respect to other sections. The bank sections with the highest score represent the highest potential, and the bank sections with the lowest scores the lowest potential.

Having ranked each segment of the bank, we then sought to define what score would represent a high, medium, or low potential for commercial navigation related bank erosion. One method would be to simply assign one third of the bank sections a value of "high", one-third a value of "medium", and the remaining third a value of "low". However, this would be inconsistent with the findings of the field survey report (COE, 1998) which concluded that approximately 14% of the banks of the UMR and 20% of the banks of the IWW were actively eroding. Based on the site descriptions and observed erosion mechanisms, it was concluded that approximately 1 in 5 (20%) of the selected erosion sites on the UMR showed signs of navigation induced disturbance. Similarly, approximately 24% of the selected erosion sites along the IWW showed signs of navigation induced disturbance.

Assuming that the sites selected during the field survey and the observed erosion mechanisms are representative of the erosion processes occurring at the other actively eroding sections throughout the system, we can conclude that approximately 2.8% (14% * 20%) and 4.8% (20% * 24%) of the UMR and IWW banks, respectively, are actively eroding in areas where forces generated by commercial navigation is a contributing mechanism. Therefore, the "high" potential areas were defined as those areas most susceptible to commercial navigation related bank erosion which are represented by 2.8% (UMR) and 4.8% (IWW) of the system (i.e., the highest score). In addition, areas used for temporary mooring and fleeting were also defined as having a high potential for commercial navigation related bank erosion. The balance of the actively eroding areas was then divided evenly into the medium and low risk categories. Therefore (14%-2.8%)/2 = 5.6% of the UMR and (20%-4.8%)/2 = 7.6% of the IWW were identified as having a medium potential for navigation related bank erosion.

The high, medium, or low classification of each section of the bank line was generated and loaded into the GIS database for mapping. The model results, by pool, are mapped in Appendix C and summarized in tables 9 and 10 for the UMR and IWW, respectively. The "Total Bank Length" is the bank length of each pool (both banks) upon which the model was applied. The "High Potential Length" and "Medium Potential Length" are the bank lengths of each pool identified by the model as being high and medium risk for commercial navigation related bank erosion. The "Protected Length" is that portion of the high and medium risk areas that were identified as naturally or artificially protected (rock outcrop, revetment, unerodible rocky bluffs, river wall, riprapped, etc.) during the 1995 field survey. Only the high and medium potential areas are identified on the maps, with the balance of the main channel border having a low potential for commercial navigation related bank erosion. Additionally, the locations of temporary mooring locations and barge facilities are indicated on the maps and are considered high potential areas.

C. Limitation of Approach. The method developed in this study attempts to identify sites where there is a possibility that commercial navigation induced forces contribute, to some undeterminable extent, to bank erosion. It can not predict the magnitude of the contribution or to what extent additional traffic would increase the possibility or extent of erosion. The actual rate of erosion at the identified sites is dependent on the nature of the bank materials and subaqueous conditions, the number (or frequencey) of tow events, as well as the other erosion mechanisms affecting the site. Multiple erosion mechanisms were identified as affecting the stability of the bank sections at all sites visited during the field survey. At many locations along the system the natural erosion and deposition of materials would dominate and may completely mask the effects of commercial navigation.

Table 9. Summary of Results For the Upper Mississippi River.

Pool	Total Bank Length (m)	High Potential Length* (m)	% High Potential	Protected Length (m)	% Protected	Medium Potential Length (m)	% Medium Potential	Protected Length (m)	% Protected
4	139,274	21,754	15.6%	6,342	29.2%	14,693	10.6%	2,846	19.4%
5	37,552	4,650	12.4%	2,292	49.3%	7,596	20.2%	680	9.0%
5a	23,231	3,781	16.3%	1,809	47.8%	4,409	19.0%	536	12.2%
6	41,924	4,496	10.7%	1,956	43.5%	7,226	17.2%	3,985	55.2%
7	33,378	4,284	12.8%	3,942	92.0%	4,155	12.5%	260	6.3%
8	57,512	3,089	5.4%	1,165	37.7%	10,137	17.6%	3,904	38.5%
9	79,341	9,489	12.0%	3,564	37.6%	17,387	21.9%	3,564	20.5%
10	96,030	5,511	5.7%	3,304	60.0%	12,274	12.8%	3,852	31.4%
11	87,371	3,163	3.6%	824	26.0%	1,782	2.0%	0	0.0%
12	75,841	3,313	4.4%	2,109	63.7%	2,077	2.7%	1,092	52.6%
13	82,110	3,062	3.7%	1,210	39.5%	5,663	6.9%	1,564	27.6%
14	84,234	9,843	11.7%	2,104	21.4%	1,488	1.8%	0	0.0%
15	32,716	0	0.0%	0	NA	1,016	3.1%	652	64.2%
16	71,903	4,454	6.2%	0	0.0%	1,630	2.3%	272	16.7%
17	65,790	2,804	4.3%	542	19.3%	3,873	5.9%	660	17.0%
18	79,577	1,041	1.3%	0	0.0%	2,962	3.7%	161	5.4%
19	133,567	4,299	3.2%	1,893	44.0%	2,274	1.7%	0	0.0%
20	69,866	5,169	7.4%	368	7.1%	538	0.8%	538	100.0%
21	51,943	1,221	2.4%	0	0.0%	1,047	2.0%	0	0.0%
22	76,244	579	0.8%	0	0.0%	0	0.0%	0	NA
24	90,008	4,008	4.5%	0	0.0%	4,538	5.0%	1,594	35.1%
25	97,078	0	0.0%	0	NA	720	0.7%	0	0.0%
26	135,066	3,831	2.8%	3,758	98.1%	172	0.1%	0	0.0%
open	675,583	67,147	9.9%	45,382	67.6%	5,113	0.8%	4,876	95.4%
Sum	**2,417,140**	**170,989**	**7.1%**	**82,562**	**48.3%**	**112,770**	**4.7%**	**31,035**	**27.5%**

Unprotected High Length: 88,427 (3.7%) **Unprotected Medium Length: 81,735 (3.4%)**

*** Includes Fleeting Areas**

NOTE: Tables 9 and 10 reflect only the three parameter screening and fleeting areas. Temporary mooring locations and barge facilities, which also represent a high potential for commercial navigation related bank erosion, are shown on the maps in Appendix C.

Table 10. Summary of Results For the Illinois Waterway.

Pool	Total Bank Length (m)	High Potential Length* (m)	% High Potential	Protected Length (m)	% Protected	Medium Potential Length (m)	% Medium Potential	Protected Length (m)	% Protected
Alton	249,763	2,181	0.9%	36	1.7%	4,244	1.7%	837	19.7%
LaGrange	240,935	23,443	9.7%	3,680	15.7%	41,088	17.1%	80	0.2%
Peoria	185,149	18,870	10.2%	1,497	7.9%	4,809	2.6%	0	0.0%
Starved Rock	37,480	3,327	8.9%	1,365	41.0%	2,257	6.0%	634	28.1%
Marseilles	85,376	15,879	18.6%	5,676	35.8%	9,821	11.5%	2,765	28.2%
Dresden Island	50,270	8,025	16.0%	1,999	24.9%	6,568	13.1%	2,416	36.8%
Sum	**848,972**	**71,726**	**8.5%**	**14,253**	**19.9%**	**68,786**	**8.1%**	**6,732**	**9.8%**

Unprotected High Length: 57,473 (6.8%) **Unprotected Medium Length: 62,054 (7.3%)**

*** Includes Fleeting Areas**

IV. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations were derived from the present investigation:

A. Conclusions:

1. Because the 1995 field reconnaissance study on bank conditions for the Upper Mississippi River (UMR) and the Illinois Waterway (IWW) (COE, 1998) included only actively eroding sites, the parameters observed in the field were not suitable for developing a model to predict the occurrence vs. non-occurrence of bank erosion on a system wide basis.

2. A contingency analysis, which provides a measure of dependency between pairs of parameters, was found in this case to produce useful information in conducting risk assessment for bank erosion along the UMR and the IWW. An exponential categorical weighting scheme was introduced to rank each parameter into three risk ranges of low, medium, and high category values. The resulting model was applied system wide to screen the system based upon three important parameters (channel top-width, distance to sailing

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line, and radius of curvature). Based on the field survey estimates of eroding bank and significance of commercial navigation, the model was used to delineate high- and medium-risk areas along the UMR and the IWW.

3. The potential for commercial navigation related bank erosion is greatest in the upper portions of the UMR and along the IWW where channel dimensions are narrowest and where the navigating tow is close to the bank, as well as in localized areas where fleeting and mooring activity are occurring. A significant percentage (48%) of the areas identified as having a high potential for commercial navigation related bank erosion on the UMR were identified as protected during the 1995 field survey.

B. Recommendations:

1. It is recommended that a systematic and statistically based data-sampling scheme be developed for assessing bank conditions and applied in the field to entire pools. New data could be correlated with the 1995 field data.

2. It is recommended that the COE continue to update its system-wide bank erosion GIS database so that significant physical attributes relevant to bank-erosion processes can be included for further analyses as they become available. The priority attributes should be bank soil properties, bench width, subaqueous bench slope, scarp height, wind fetch, and vegetation coverage of the bank.

3. As more information becomes available following *Recommendations 1 and 2* above, the model should be re-calibrated and expanded using additional parameters beyond those used in the present investigation.

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Appendix A

Bank Erosion Study

Decision Point Paper

UPPER MISSISSIPPI RIVER/ILLINOIS WATERWAY
BANK EROSION STUDY
DECISION POINT INFORMATION PAPER

FIELD SURVEY REPORT

The Final Draft Bank Erosion Field Survey Report will be distributed for concurrent review by the previously established Bank Erosion Study Technical Review Group and the Navigation Environmental Coordinating Committee (NECC) in the November/December 1996 time frame. This report will present the results of the field reconnaissance survey conducted by a multi-disciplined study team during the Summer and Fall of 1995. It will document existing bank conditions along the entire Upper Mississippi River and Illinois Waterway and provide detailed information at 72 erosion sites which were determined to be representative erosion sites by the study team. These 72 sites will be classified following a system of classification attributes which can be used in combination with the Aquatic Areas Classification system being developed at WES to extrapolate knowledge gained at the 72 sites to the rest of the UMR/IWW system. Opinions as to the relative significance of bank erosion due to various factors such as hydraulics of flow, floods, waves generated by commercial and/or recreational traffic, mooring and fleeting activities, wind and geotechnical factors will be provided.

DECISION POINT

a. IPMP The decision point as described in the Initial Project Management Plan (IPMP) reads as follows:

"Decision Points: The first two tasks of the bank erosion study are to: (1) search the literature and (2) conduct site inspections of identified erosion sites. The follow-up task then would combine these efforts in determining whether the effects of navigation can be separated from other causative factors of bank erosion and, if so, whether the effects are significant. If the effects of navigation cannot be separated from other causative factors, or if they are concluded to be insignificant, the bank erosion studies will be terminated. Otherwise, the study will continue on to Tasks 4, 5, and 6 as described below.**"**

"Task 4: Predict the Without-Project Future. This task will involve extensive computer modeling of generalized sites along the waterways. Other studies involving physical forces, both physical and numerical sites will represent various configurations typical of the waterways, such as straight reaches and inside and outside of bendways, with navigation close to or far from the bankline. Based on available data, including that accessible through the EMTC database, predictive regression type models will be developed for the various forces causing bank erosion. The predictive equation related to navigation will be a function of the amount of various types of traffic patterns.

This task will quantitatively predict future erosion at generalized sites. These models will be used to simulate conditions anticipated without the navigation improvement projects and to predict the total erosion along the waterways as well as the ranges of site-specific erosion.**"**

"Task 5: Predict With-Project Future. This task is identical to Task 4 with the exception that the study of bank erosion due to navigation will be computed with the traffic patterns which are predicted with the navigation project in place.**"**

b. Discussion

Preliminary results from the 1995 field survey and literature review indicate that it may be possible to conduct field experiments at individual sites which would result in an equation or set of equations which could be applied to that individual site or at an identical site to estimate erosion rates caused by passing navigation traffic. A great deal of field monitoring of each site would be required to determine how navigation induced erosion rates vary with varying antecedent conditions. Secondary effects cannot be properly evaluated unless monitoring is conducted for a sufficient period to include periodic events. This would include making erosion rate measurements over a period of several years at each site so that the varying antecedent conditions could be captured in the equations. Development of a set of equations which could be systematically applied to the entire Upper Mississippi River and Illinois Waterway would require field experiments to be conducted at a large number of sites so that the wide variety of bank conditions which exist on these two rivers are represented in the equations. Variables which would effect the predictability of these empirically derived equations include flood flows, stages, durations, antecedent and subsequent conditions, wetter or dryer than average weather, variation in soil types, variations in soil profiles, back of bank conditions, geologic parameters and ground water conditions at each erosion site. The execution of such a set of field experiments is well beyond the scope of this study. It is estimated that it would take approximately 5 years to conduct such a set of experiments and the cost would be in the millions of dollars.

In the Bank Erosion Field Survey Report, the study team will provide estimates as to the relative significance of navigation use effects in the context of bank erosion processes on the UMR and IWW. Navigation traffic, in a context may be separated from other causative processes. The study team has determined that bank erosion caused by navigation could be significant in mooring and fleeting areas and in narrow channel reaches. Since in some locations it has been proposed that the impacts of navigation traffic may be separated from other causative factors and that in locations where navigation induced bank erosion could be identified it may be significant, the study must proceed to Tasks 4 and 5.

Tasks 4 and 5 of the IPMP discuss development of regression equations which will be used to predict navigation induced erosion for the without- and with- project conditions. Development of such equations has been determined by the field survey report study team to be infeasible for application to large river systems such as the UMR and IWW. Therefore the approach discussed in Tasks 4 and 5 of the IPMP is inappropriate and the correlative approach described in the next section of this information paper is proposed.

PROPOSED STUDY - (Bank Erosion Impacts Assessment Study)

a. Study Summary

1. Task 1 - Assess bank erosion impacts on environmental and cultural resources using the results of the Field Survey Report in combination with the Aquatic Areas Classification Mapping, available data on environmental and cultural resources, and GIS mapping techniques.

2. Task 2 - Develop correlations between apparent navigation induced erosion and physical parameters such as proximity to narrow channel reaches, locks, and mooring/fleeting activities, soil and sediment characteristics, land uses, etc. These correlations will be developed from data collected at the 72 detailed study sites during the 1995 field survey.

3. Task 3 - Using these correlations along with 1995 erosion mapping of both rivers, the Aquatic Areas Classification Mapping and existing resource mapping; predict areas of adverse impacts where measurable increase in navigation induced erosion will likely occur with increases in navigation traffic levels. Bank reaches will be classified as low, medium or high risk areas for naturally occurring and navigation induced erosion.

4. Task 4 - Risk and uncertainty techniques will be applied to the resulting low, medium and high risk areas to develop an impact assessment.

5. Task 5 - To help understand the relative significance of navigation induced waves, a wave study will be performed at approximately 10 sites where storm and flood events and wave effects were observed during the field survey. Wave energies associated with wind will be calculated from existing wind data and predictive equations and compared to wave energies produced by recreation and commercial navigation. Navigation induced waves will be calculated based on present traffic observations and future forecasted traffic volumes using the wave equations developed at WES (Martin).

6. Task 6 - Write a final report which combines the results of the Bank Erosion Field Survey Report and the Bank Erosion Impacts Assessment Study.

b. Study Schedule The study would commence immediately utilizing primarily in-house labor resources and be completed by July, 1997. The final report combining the Bank Erosion Field Survey Report and the Bank Erosion Impacts Assessment Study would be completed by October, 1997.

Appendix B

Scope of Work

Bank Erosion Impact Assessment Study
for the Upper Mississippi River/Illinois Waterway

1. General. The scope of work to be accomplished under this contract consists of developing a model to assess the risk of bank erosion based on site specific field data for existing conditions and future conditions for the Mississippi River and Illinois Waterway system.

2. Data furnished by Government. The government to the contractor will supply the following: Aquatic Areas Classification Mapping, available data on bank erosion field survey, environmental and cultural resources, and GIS mapping/ database.

3. Modeling requirements. Develop correlations between apparent navigation induced erosion and physical parameters such as proximity to narrow channel reaches, locks, and mooring/fleeting activities, soil and sediment characteristics, land uses, etc. These correlations will be developed from data collected at the 72 detailed study sites during the 1995 bank erosion field study. In order to accomplish this task, the contractor will develop a database for relevant physical parameters that were collected during the 1995 field study for both the Illinois Waterway and the Upper Mississippi River. This database is partially available in an EXCEL speedsheet format with the remainder being in ARCINFO GIS format. The government will furnish the GIS data in a format agreed to by the contractor. The contractor will combine these two databases using Microsoft ACCESS so that any correlations between individual variables can be easily sought in a systematic manner. The contractor will seek, beyond 72 detailed sites, additional data from the observation sites, the Navigation Chart Mapping, aerial video descriptions that could help increase the accuracy of the field data. Attributes to be considered for river banks and navigation traffic would include (but are not limited to) the following:

River Attributes:

1. Geomorphic characteristics (inside bend/outside bend/cross over/island) – radius of curvature of bend
2. Channel width
3. Relative location of thalweg sailing line
4. Fetch length and average wind direction within fetch length/river-bank orientation
5. Closeness to flow-control structures
6. Nature of bank (natural/revetment/dredge material/etc.)
7. Bench width
8. Bench slope
9. Bench soil characteristics
10. Subaqueous lateral bed slope
11. Width of vegetation coverage on bench
12. Relative location of water edge on bench at predominant river stage
13. Relative location of erosion site with respect to Lock & Dam
14. Scarp height
15. Scarp slope
16. Bank soil characteristics
17. Bank face coverage (tree roots/vegetation/etc.)
18. Land use (farms/woods/industrial/etc.) and soil characteristics
19. Background features (closeness to lakes/wetlands/etc.)

Traffic Attributes:

1. Locate major industries related to barge traffic (power plant/oil refinery/etc.)
2. Barge/leisure boats traffic records along rivers
3. Mooring activities
4. Traffic during high stages (connect with Item 10 above)
5. Tow/barge size (vary along river reach)

The contractor will develop models to assess the risk of bank erosion, which is directly related to the increase in commercial navigation and recreation traffic. The contractor will determine—based upon the data correlations for the Illinois and Mississippi rivers—if the river systems should be modeled separately or together. This model will be used to model the existing conditions (1992 commercial navigation traffic), the baseline conditions, and the future conditions without project.

Using these correlations along with 1995 erosion mapping of both rivers, the Aquatic Areas Classification Mapping and existing resource mapping, predict areas of adverse impacts where measurable increase in navigation induced erosion will likely occur with increases in navigation traffic levels. Bank reaches will be classified as low, medium, and high risk areas for navigation induced erosion. The contractor and the government will mutually agree upon the criteria for low, medium and high classification. The contractor will identify and characterize the key assumptions and uncertainties associated with the development of the bank erosion model. Considering these assumptions and uncertainties, the contractor will develop the model in a manner consistent with the fundamental concepts and methods of probabilistic risk estimation and assessment.

4. Products to be Furnished by the Contractor. The contractor will provide letter reports to the government for review of progress as the model is developed, calibrated and applied. The contractor will provide the government model software and documentation at the conclusion of the contract. The contractor will provide five copies of the draft report and thirty-five copies of the final report.

Appendix C

Mapping of Potential Commercial Navigation Related Bank Erosion Sites

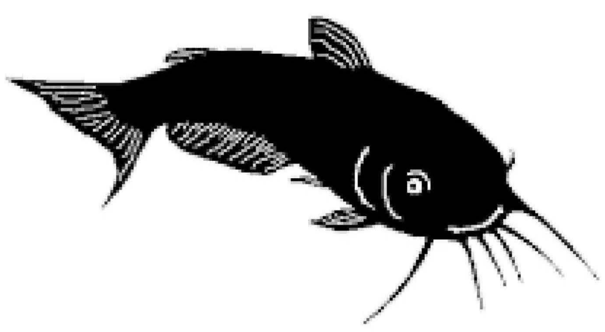
Results of the system screening have been plotted on a series of forty-two, 17" by 22" maps depicting the high and medium risk sites for potential navigation induced bank erosion. The data set used to create the map set consists of 30 ARC/INFO line coverages documenting river bank conditions and physical parameters for the Upper Mississippi River (UMR) and the Illinois Waterway (IWW) as observed during a system-wide field inspection conducted in the months of August, September, and October of 1995. Each coverage in the data set includes data for a single navigation pool associated with a Lock and Dam in the UMR or the IWW. The data set includes the UMR from the confluence with the Ohio River (River Mile 0) to Lock and Dam 3 (RM 797) and the IWW from Grafton, IL (RM 0) to Joilet, IL (RM 286).

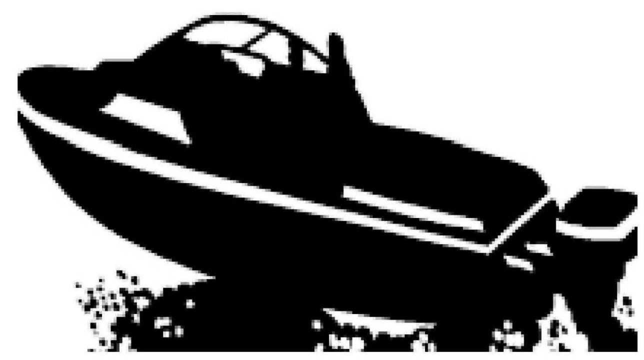
The data were developed by segmenting and attaching attributes characterizing bank condition and physical parameters to an existing line coverage depicting the land-water interface of the UMR and IWW. The land-water interface line used as the base for the UMR coverages was extracted from existing coverages of land use developed from 1989 aerial phototography by the USGS / Biological Resources Division / Environmental Management Technical Center, Onalaska, WI. The land-water interface line used as the base for the IWW coverages was extracted from existing National Wetland Inventory (NWI) data provided by the US Army Engineer District Rock Island. Land use and NWI attributes were carried over from the existing coverages and were attached to the erosion line coverages.

The identified barge facilities were taken from ARC/INFO coverages containing points representing the locations of the barge docking facilities along the Upper Mississippi River and Illinois Waterway. Information for the ARC/INFO Point Attribute Table (PAT) was obtained from the Navigation Data Center and updated with the aide of the 1993 Inland Waterway Guide booklet.

The location of the primary, secondary, and alternate waiting points were provided by the Rock Island and St. Paul District's Operations Divisions, and were augmented with interviews conducted with lockmasters and tow captains. An alternate waiting point can represent either a third waiting point or a waiting point which is only used under certain flow conditions.

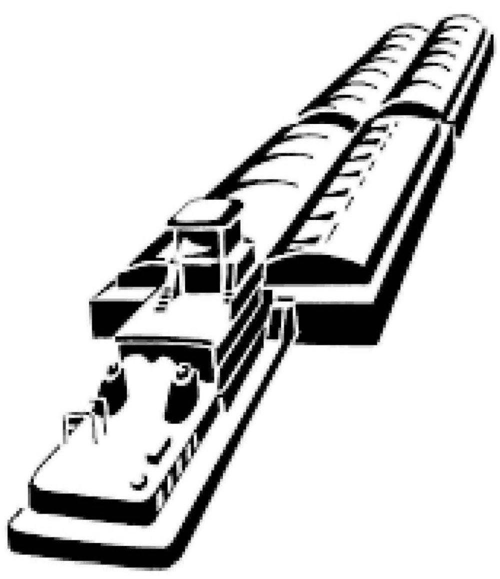
Interim Report For The Upper Mississippi River - Illinois Waterway System Navigation Study





Identification of Potential Commercial Navigation Related Bank Erosion Sites

Appendix C



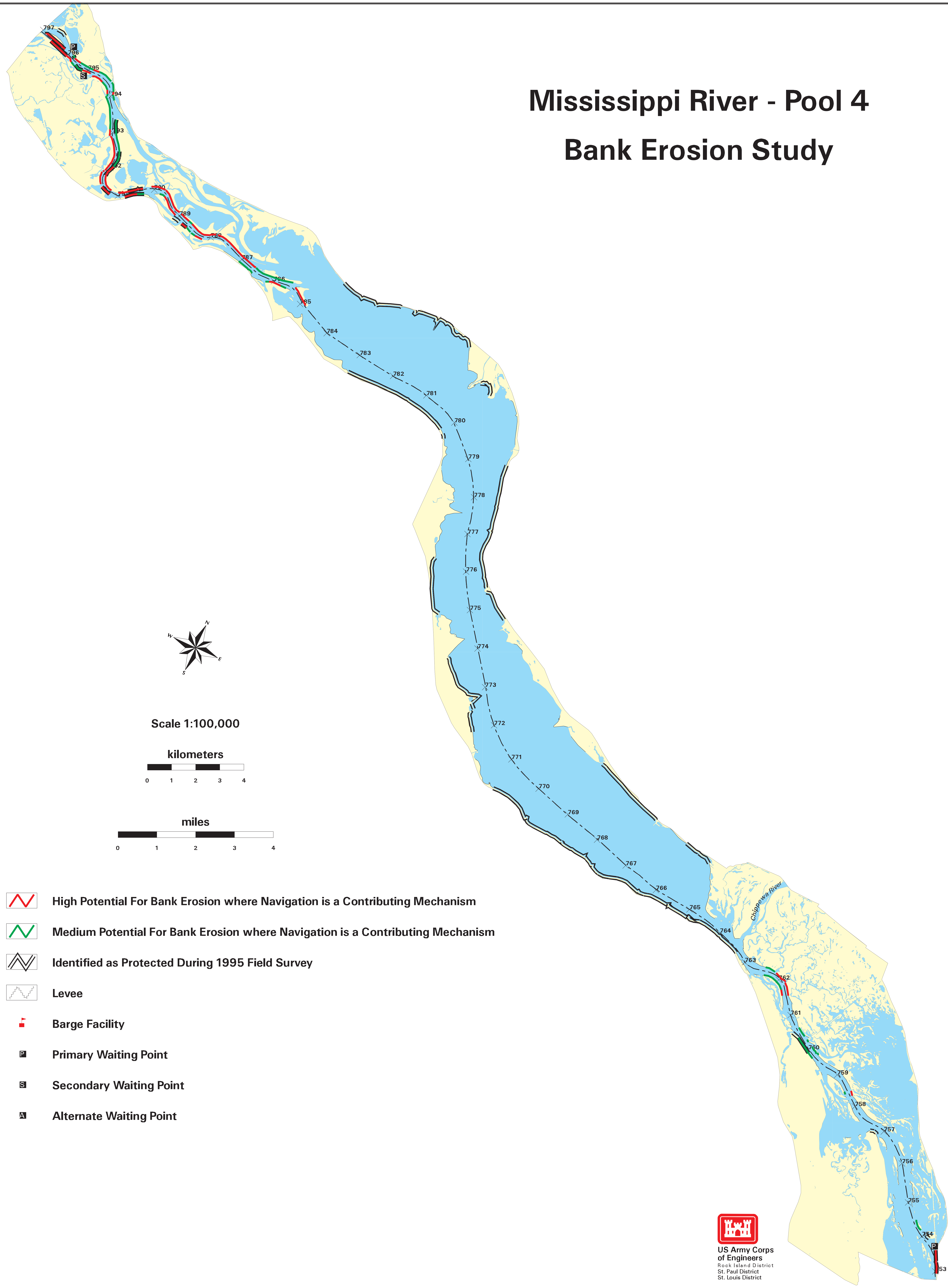
May 1998

US Army Corps of Engineers

St. Paul District
Rock Island District
St. Louis District

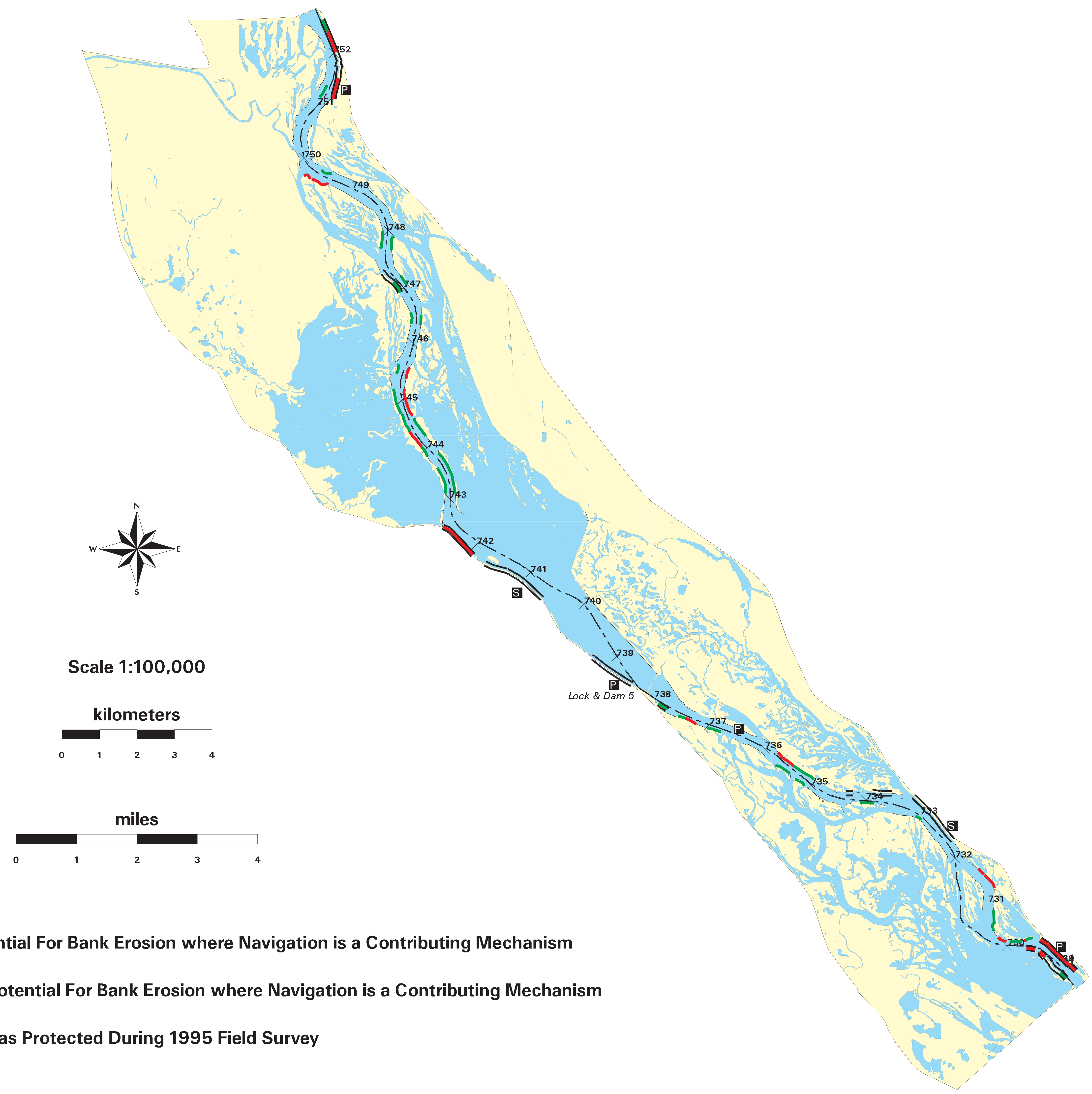
Mississippi River - Pool 4

Bank Erosion Study



Mississippi River - Pools 5 and 5a

Bank Erosion Study



High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

P Primary Waiting Point

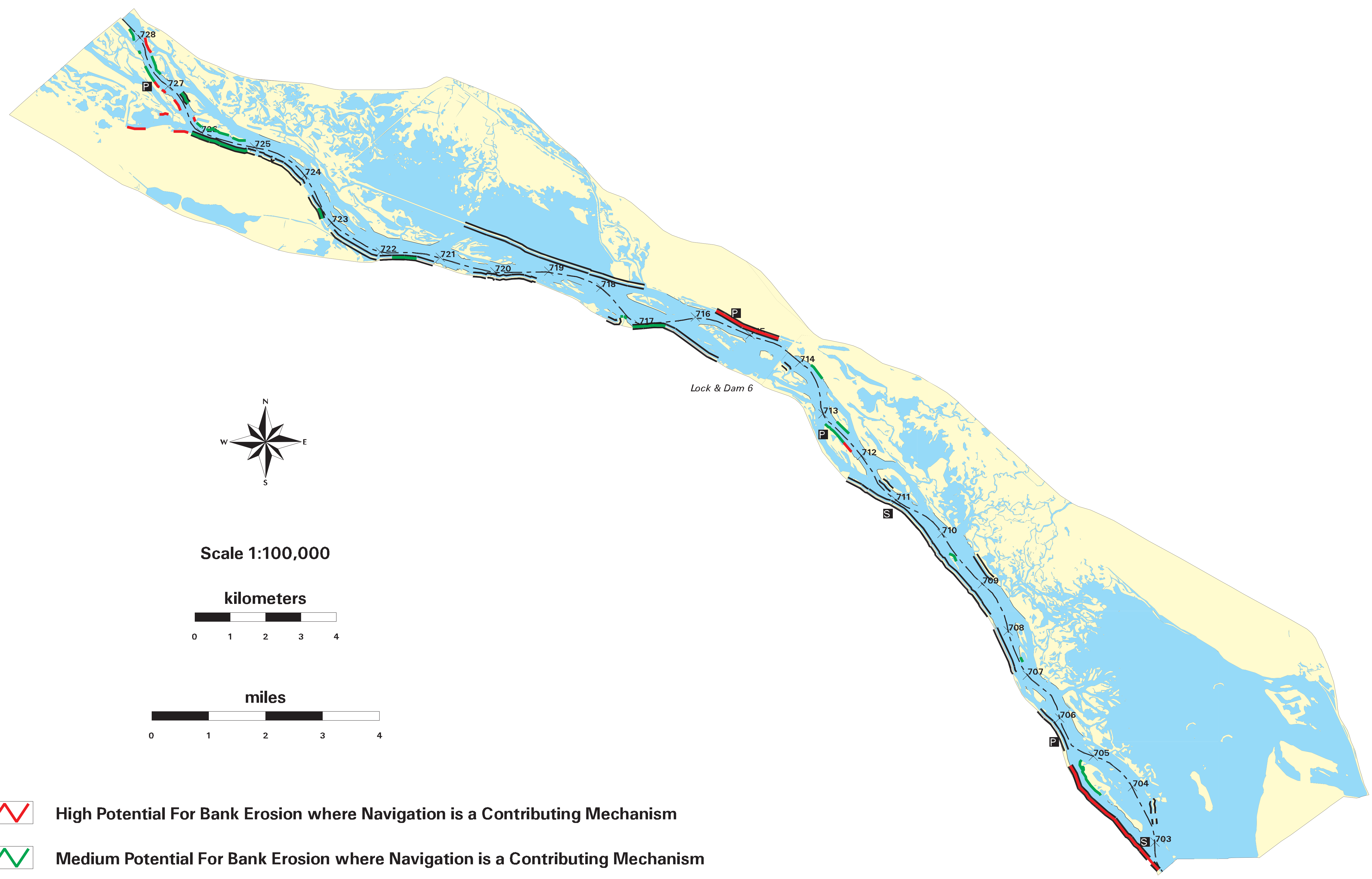
S Secondary Waiting Point

A Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pools 6 and 7

Bank Erosion Study



High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

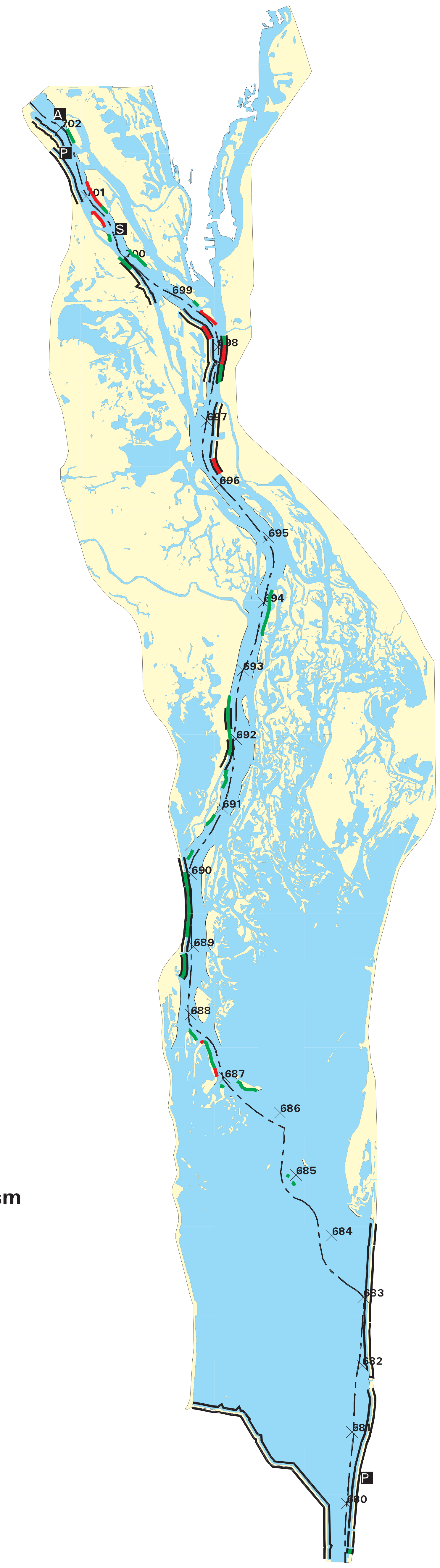
Secondary Waiting Point

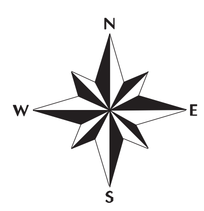
Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 8

Bank Erosion Study





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0 1 2 3 4

miles

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High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

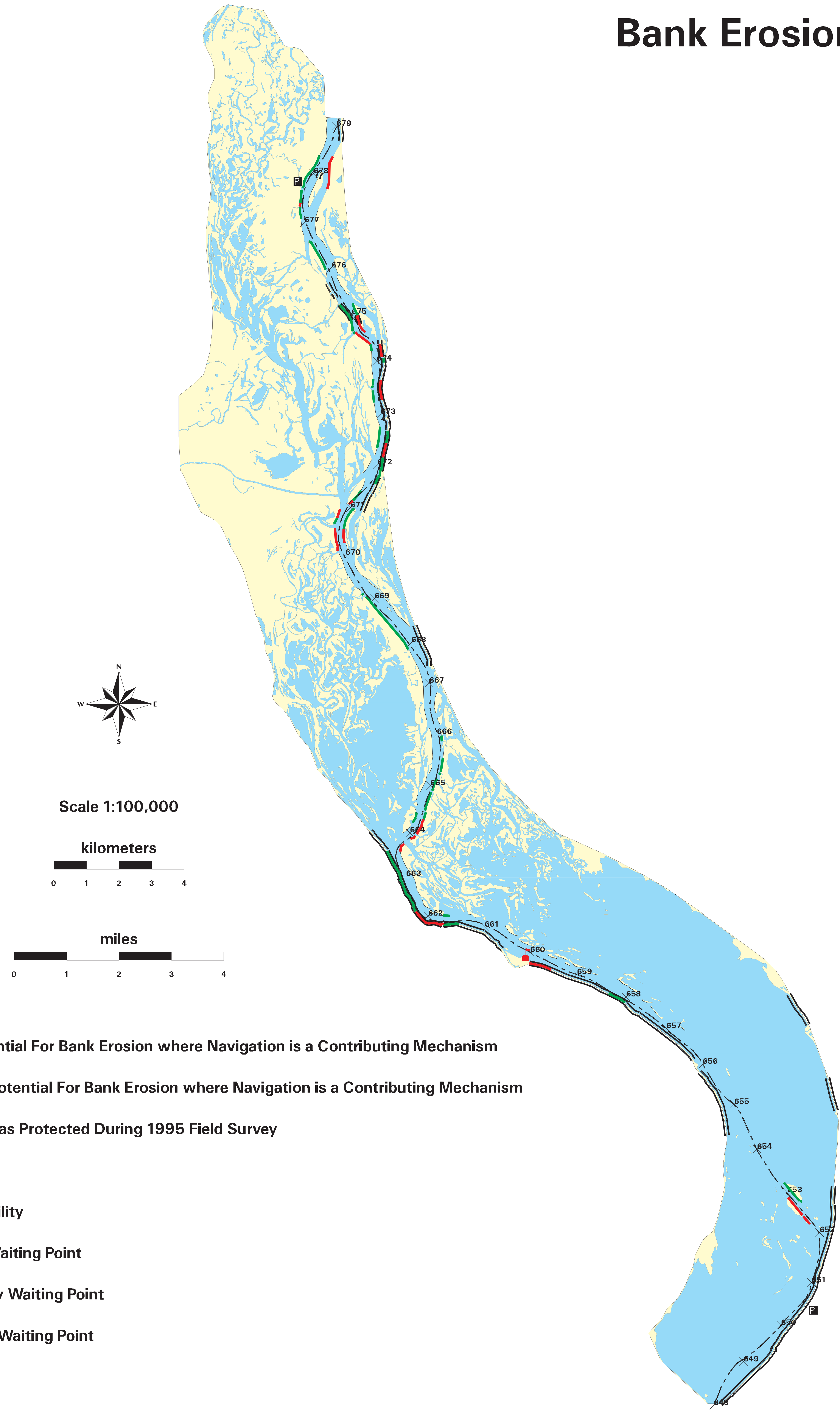
Secondary Waiting Point

Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 9

Bank Erosion Study

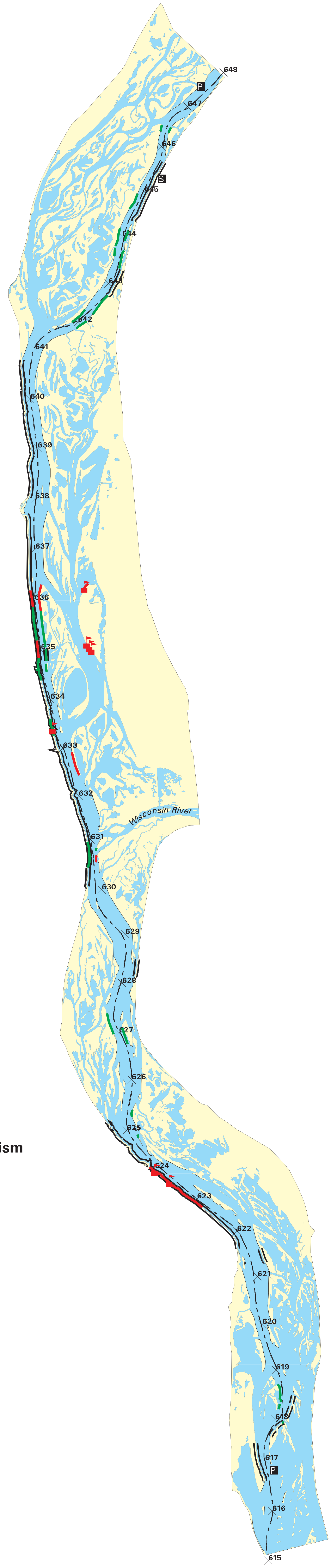


- High Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Identified as Protected During 1995 Field Survey
- Levee
- Barge Facility
- Primary Waiting Point
- Secondary Waiting Point
- Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 10

Bank Erosion Study



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High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

P Primary Waiting Point

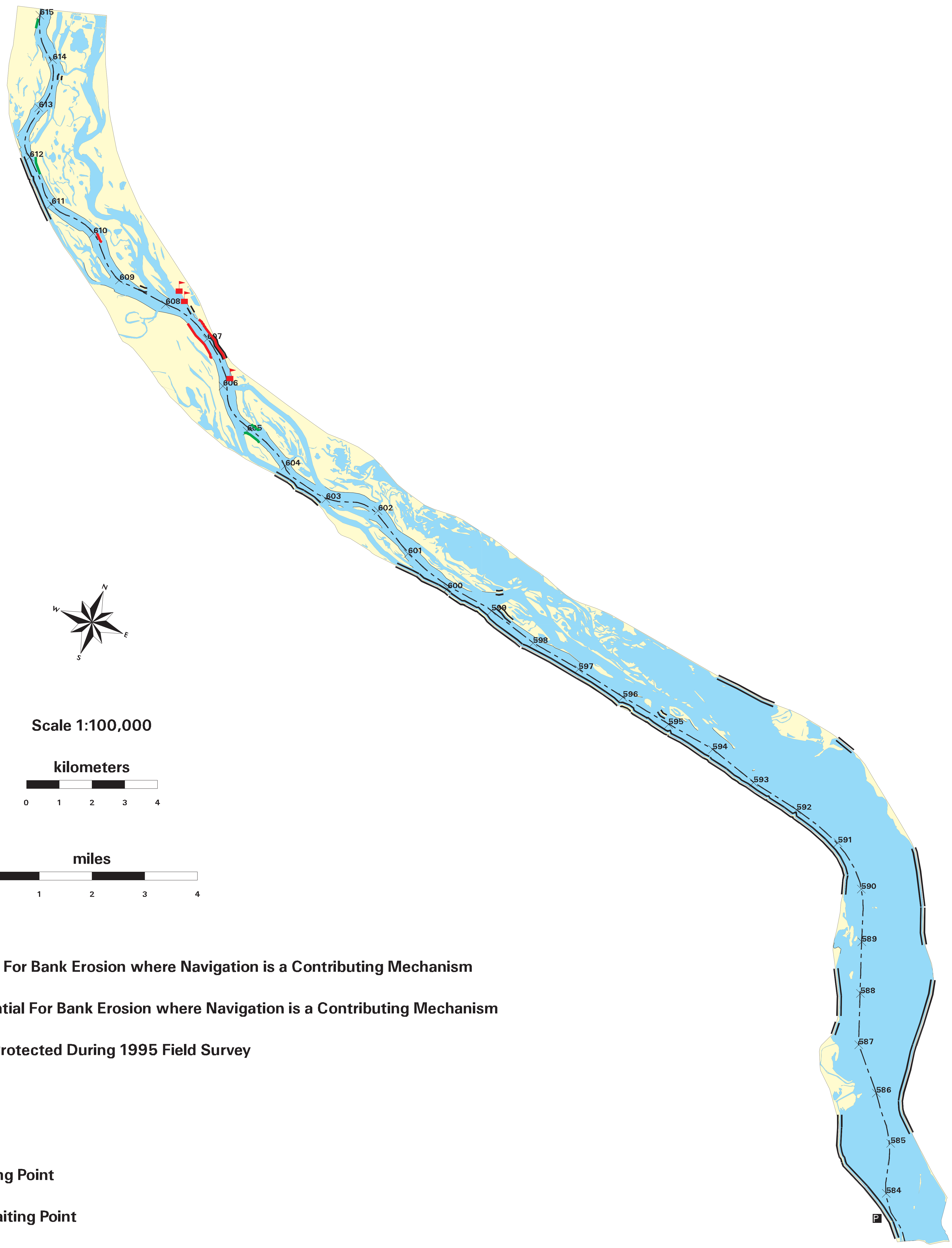
S Secondary Waiting Point

A Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 11

Bank Erosion Study



Scale 1:100,000

kilometers

0 1 2 3 4

miles

0 1 2 3 4

High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

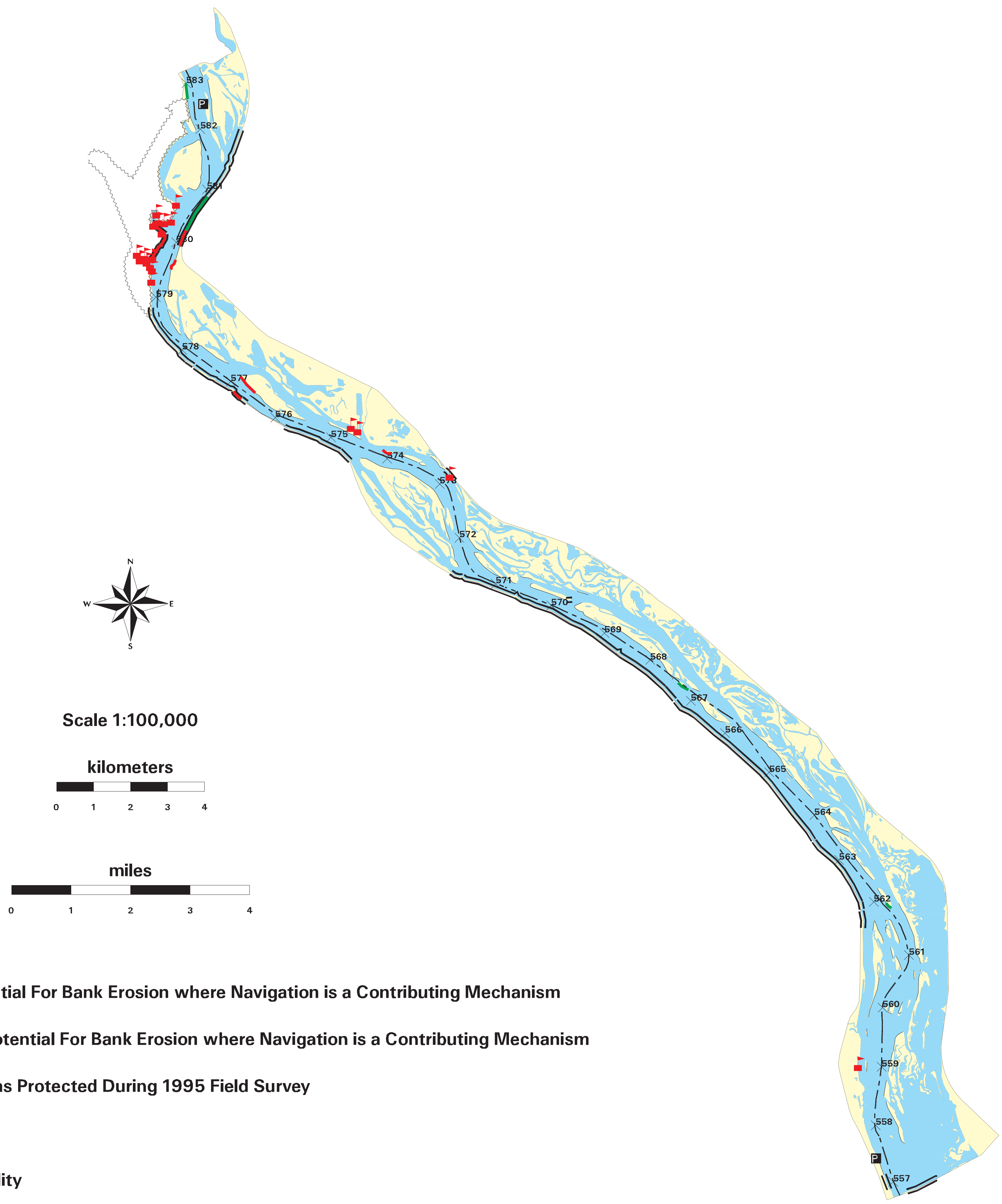
Secondary Waiting Point

Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 12

Bank Erosion Study



High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

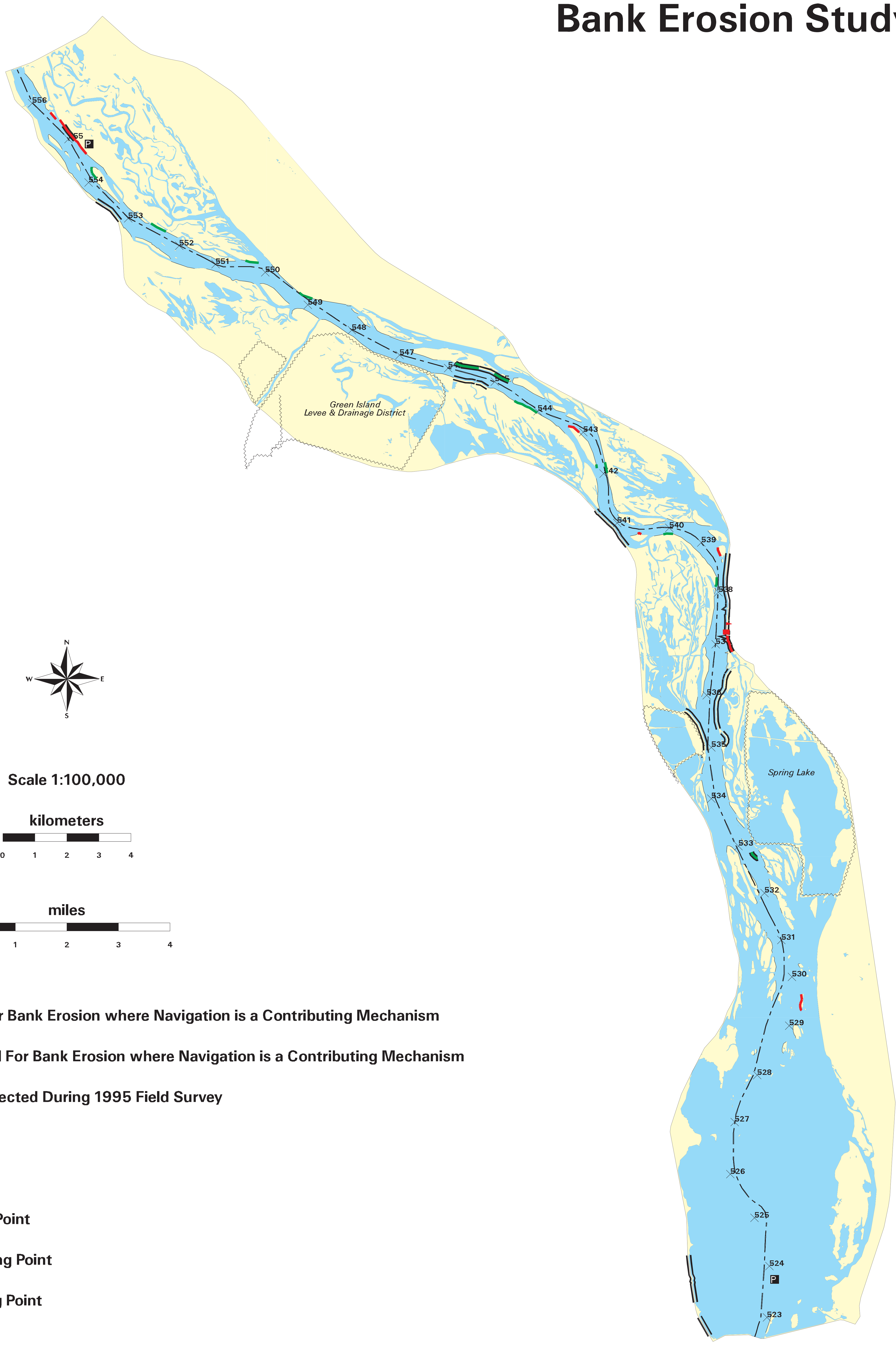
Secondary Waiting Point

Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 13

Bank Erosion Study



Scale 1:100,000

kilometers

0 1 2 3 4

miles

0 1 2 3 4

High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

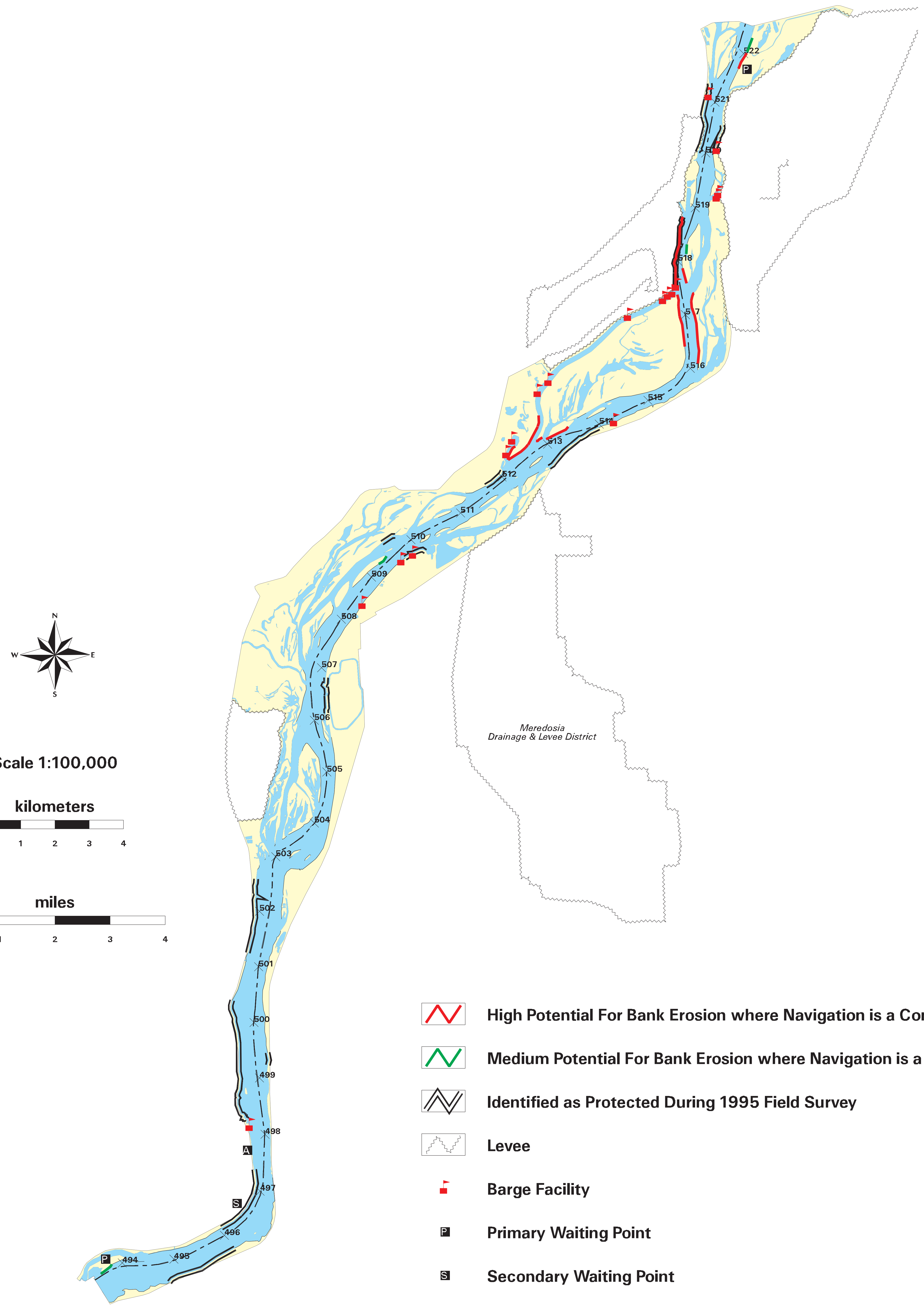
Secondary Waiting Point

Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 14

Bank Erosion Study



Scale 1:100,000

kilometers

0 1 2 3 4

miles

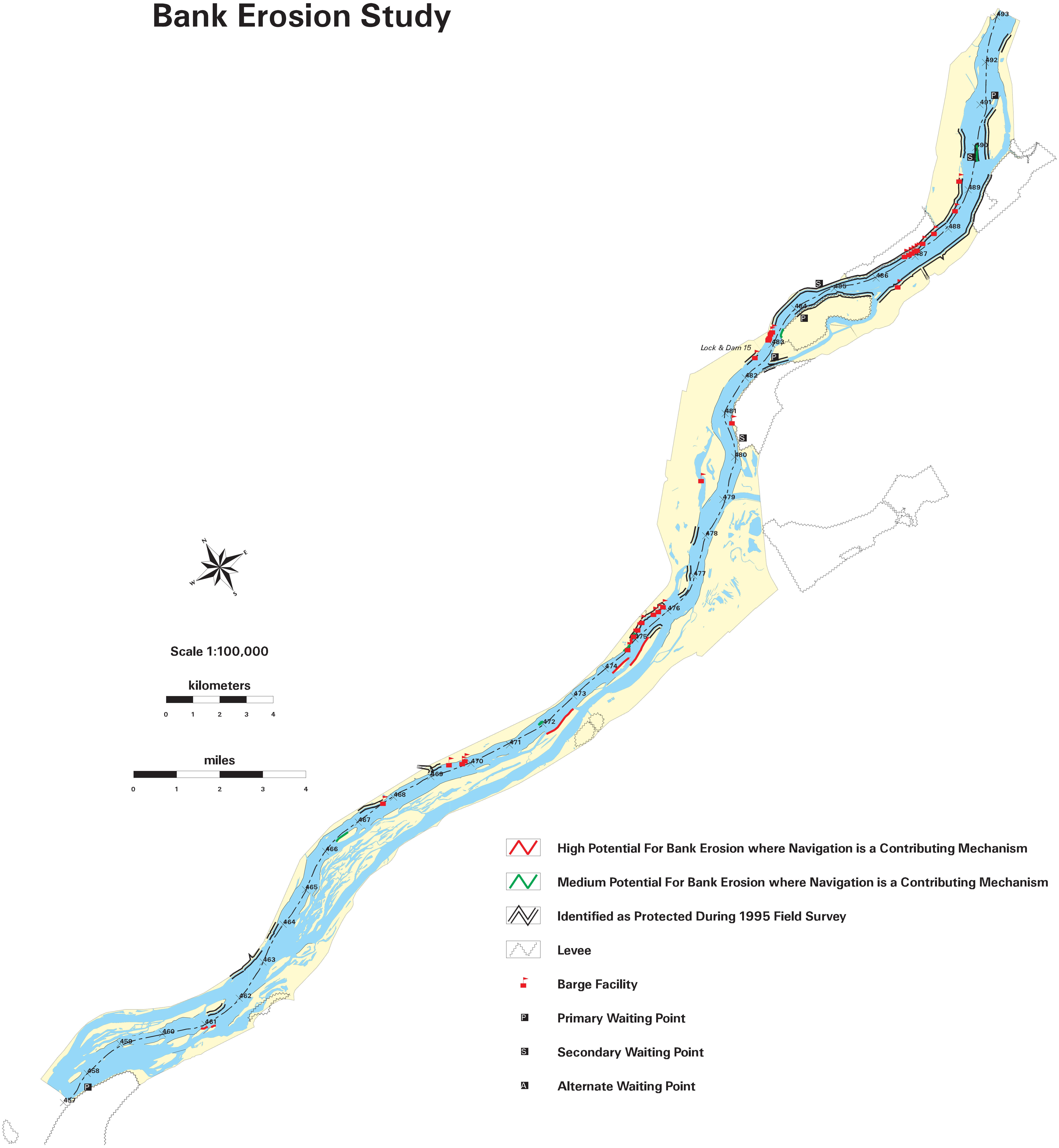
0 1 2 3 4

- High Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Identified as Protected During 1995 Field Survey
- Levee
- Barge Facility
- P Primary Waiting Point
- S Secondary Waiting Point
- A Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pools 15 and 16

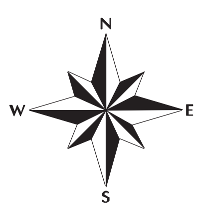
Bank Erosion Study



US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 17

Bank Erosion Study



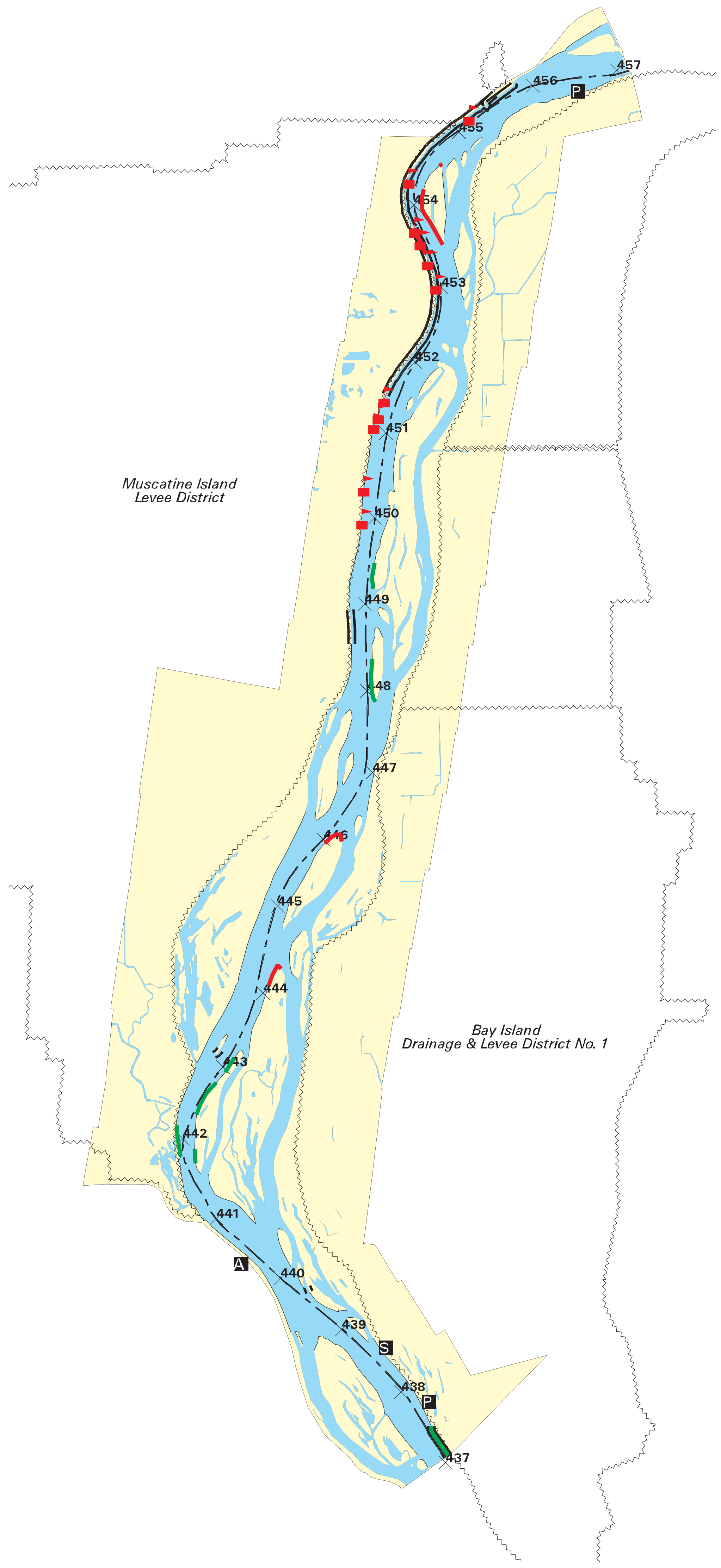
Scale 1:100,000

kilometers

0 1 2 3 4

miles

0 1 2 3 4

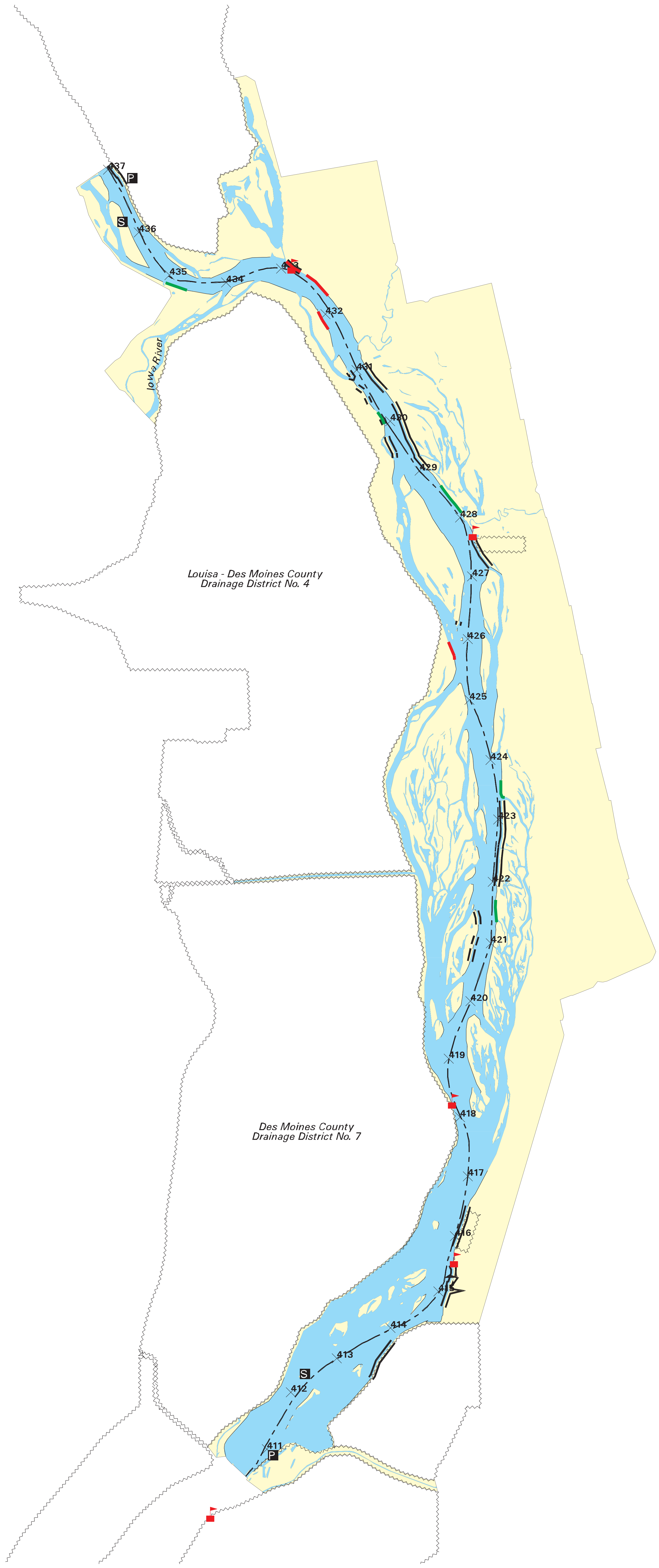


- High Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Identified as Protected During 1995 Field Survey
- Levee
- Barge Facility
- P Primary Waiting Point
- S Secondary Waiting Point
- A Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 18

Bank Erosion Study



N
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Scale 1:100,000

kilometers

0 1 2 3 4

miles

0 1 2 3 4

High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

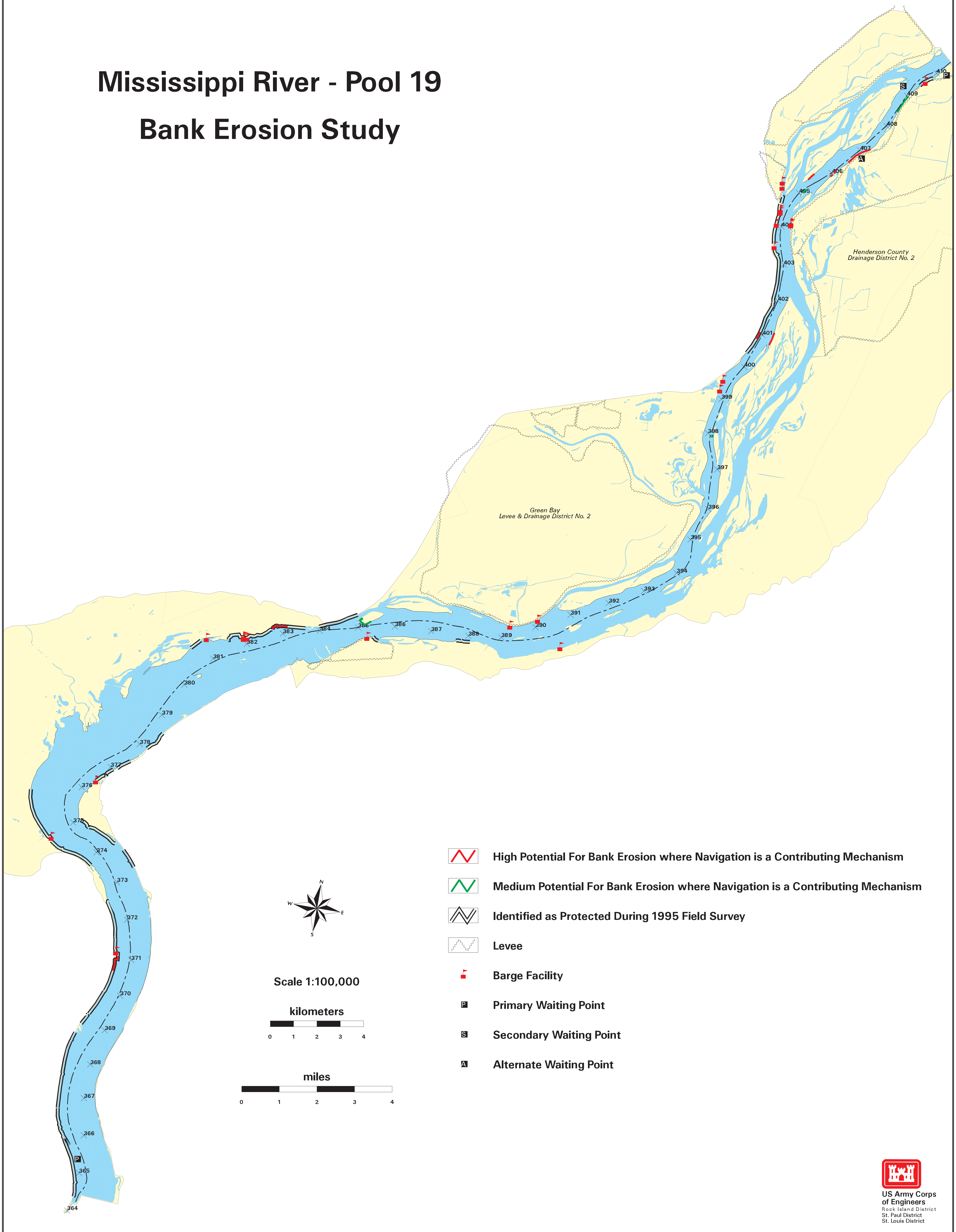
Secondary Waiting Point

Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

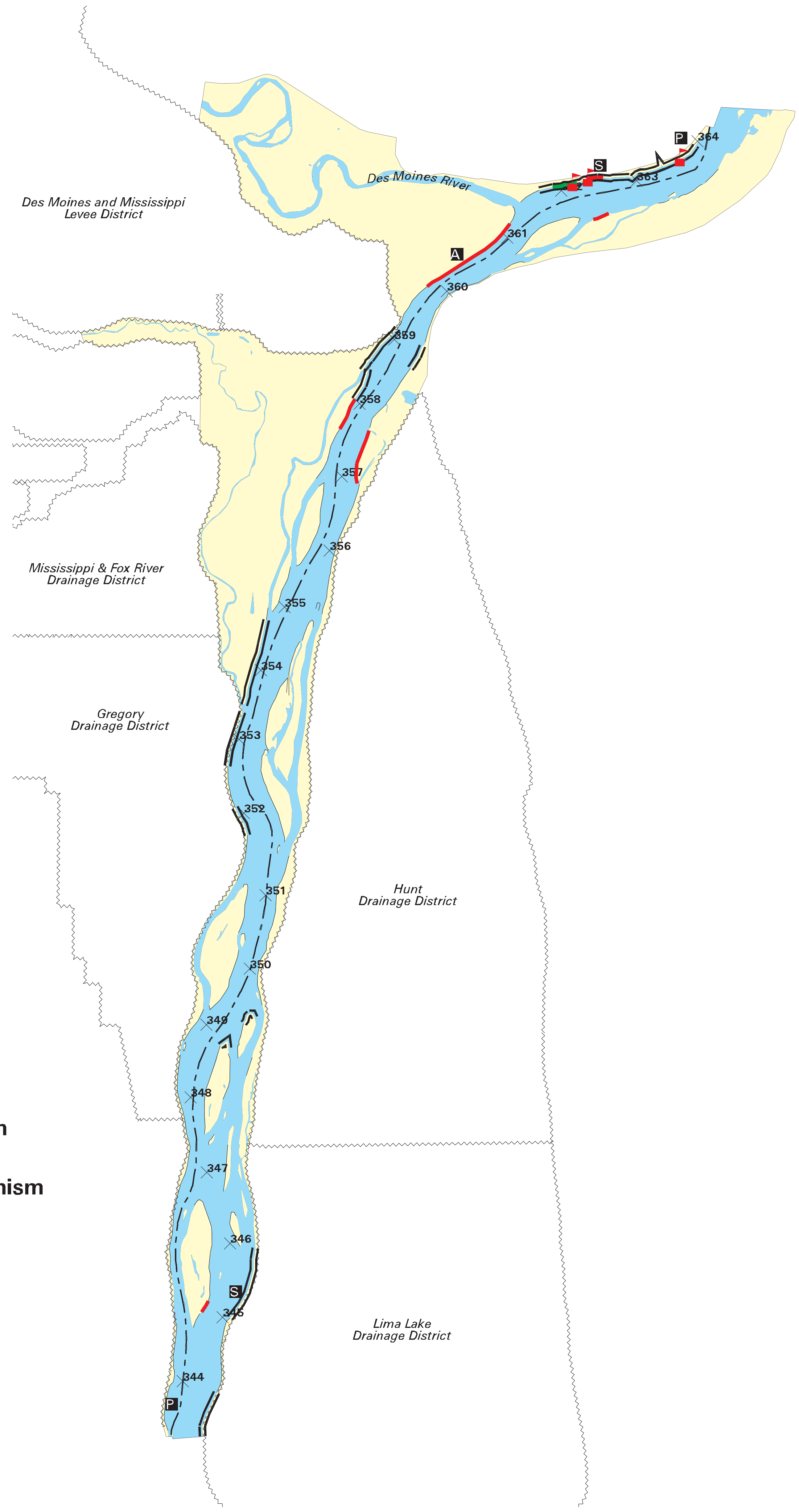
Mississippi River - Pool 19

Bank Erosion Study



Mississippi River - Pool 20

Bank Erosion Study



Scale 1:100,000

kilometers

0 1 2 3 4

miles

0 1 2 3 4

High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

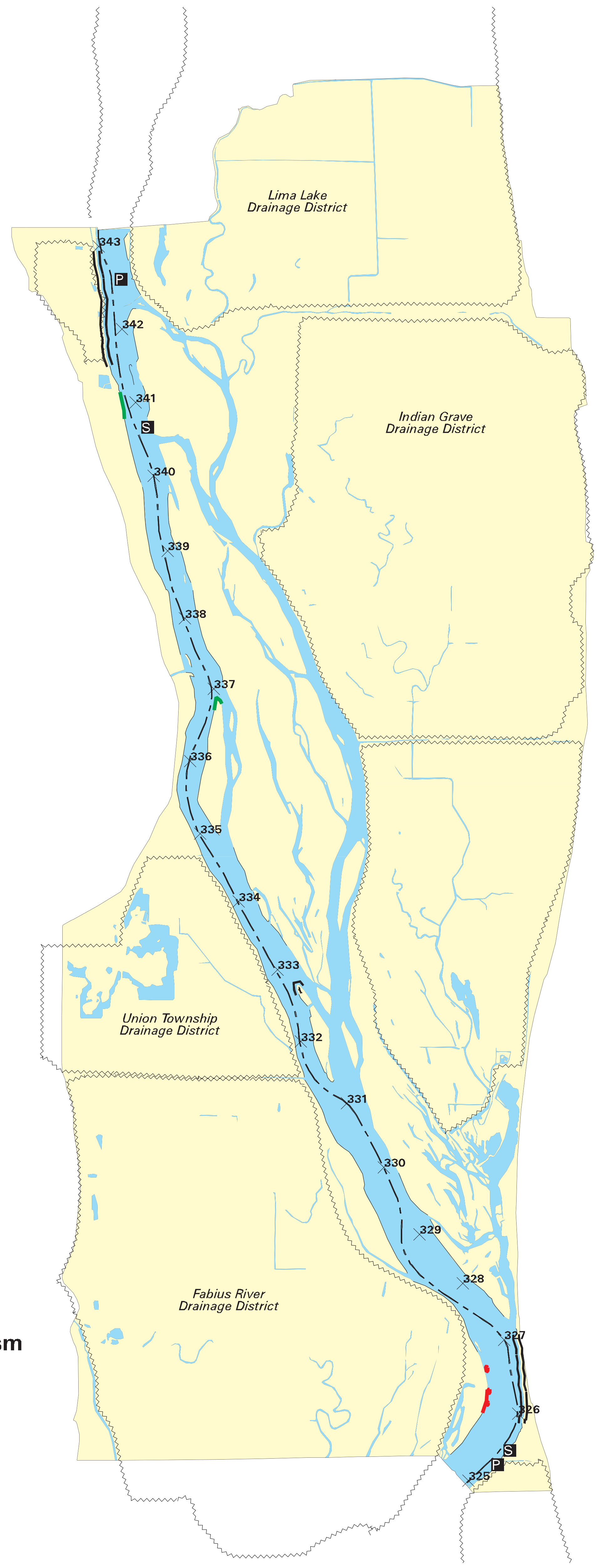
Secondary Waiting Point

Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 21

Bank Erosion Study



N
W E
S

Scale 1:100,000

kilometers

0 1 2 3 4

miles

0 1 2 3 4

High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

P Primary Waiting Point

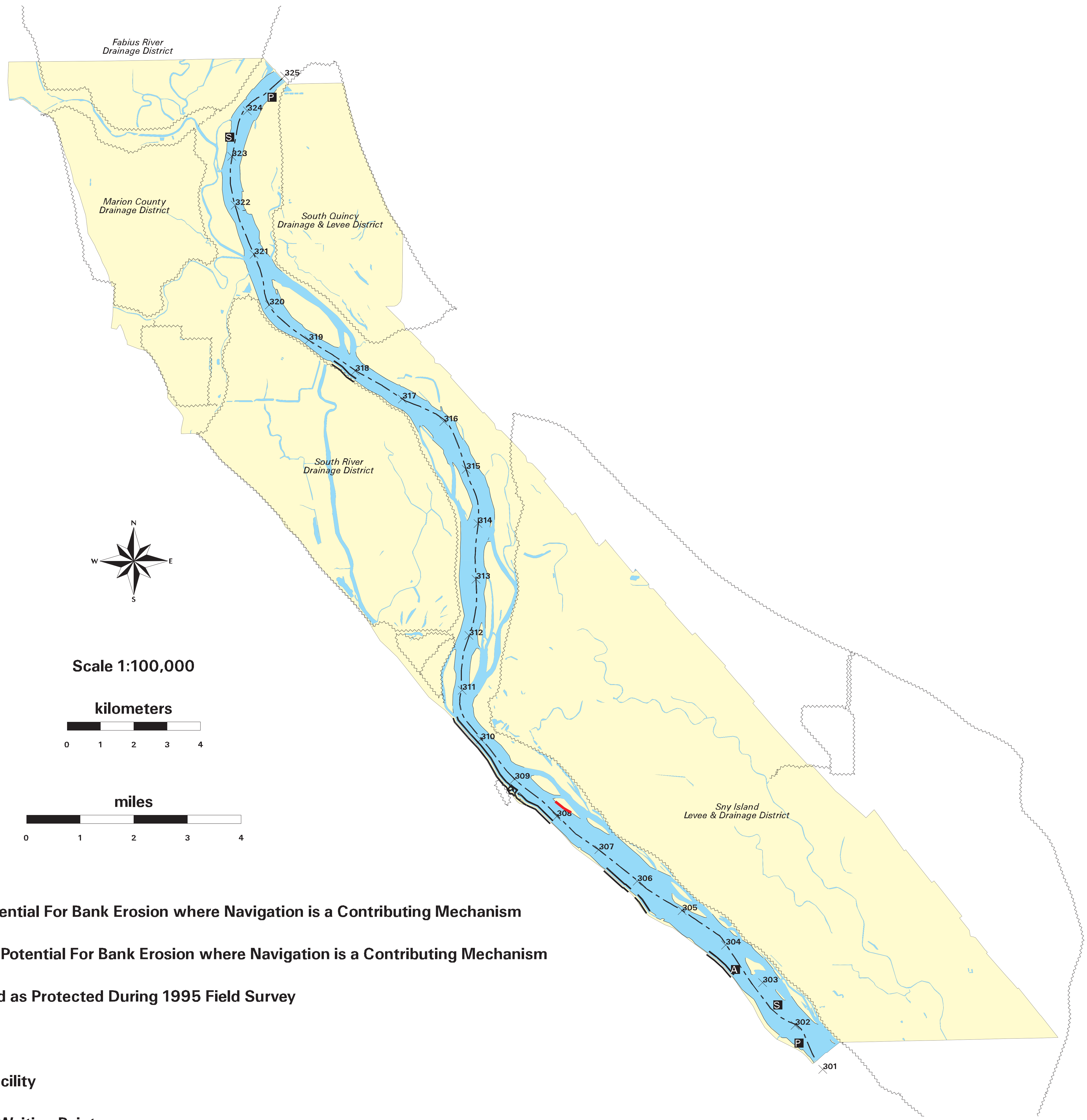
S Secondary Waiting Point

A Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 22

Bank Erosion Study



High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

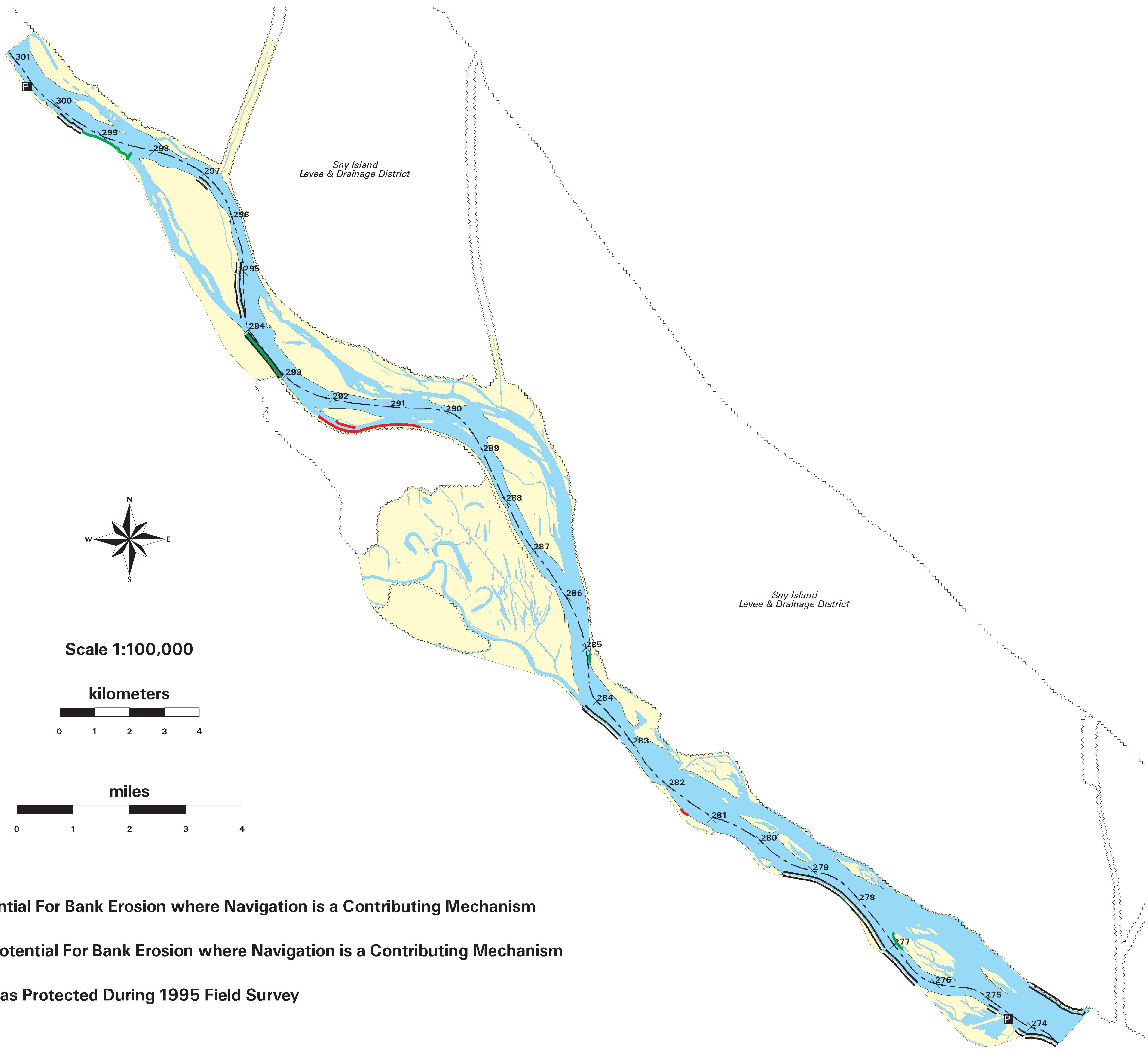
Secondary Waiting Point

Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 24

Bank Erosion Study



High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

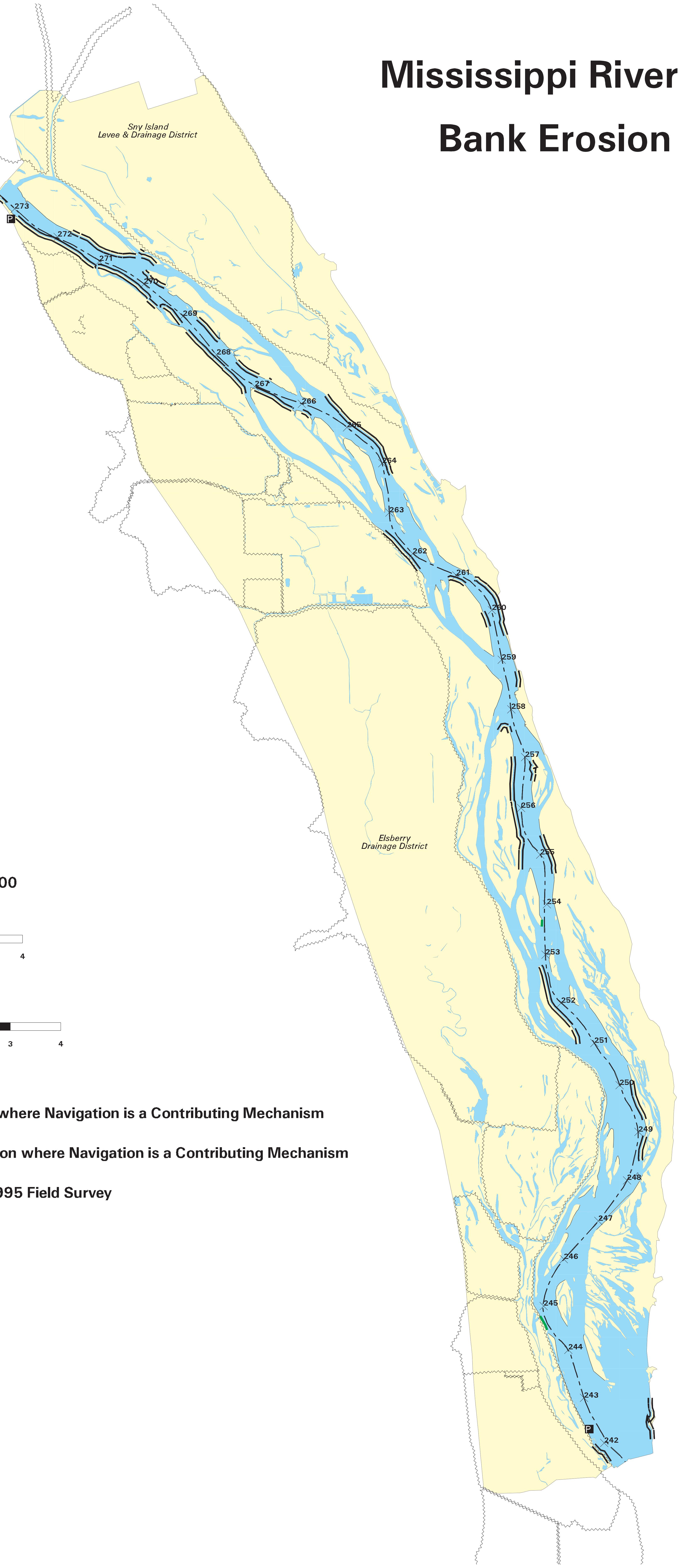
Secondary Waiting Point

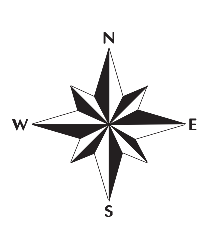
Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 25

Bank Erosion Study





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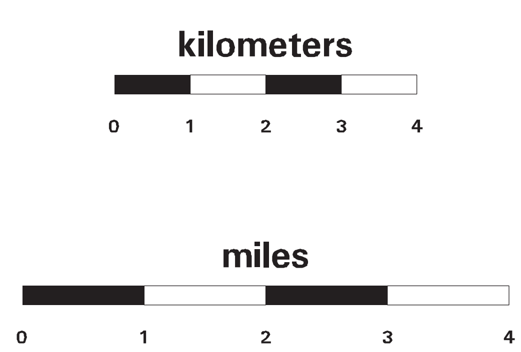


High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

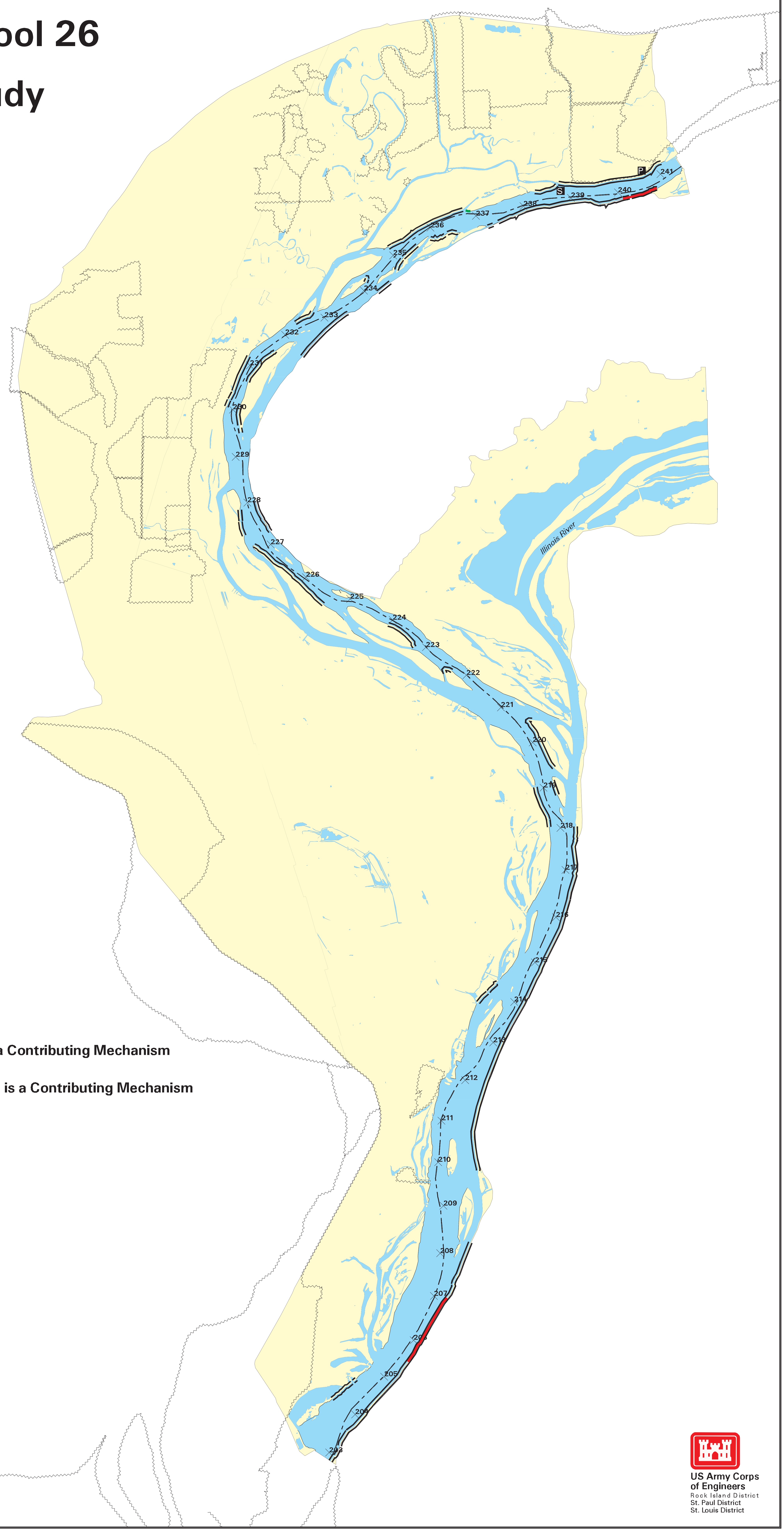
Secondary Waiting Point

Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Mississippi River - Pool 26

Bank Erosion Study



Scale 1:100,000

kilometers

0 1 2 3 4

miles

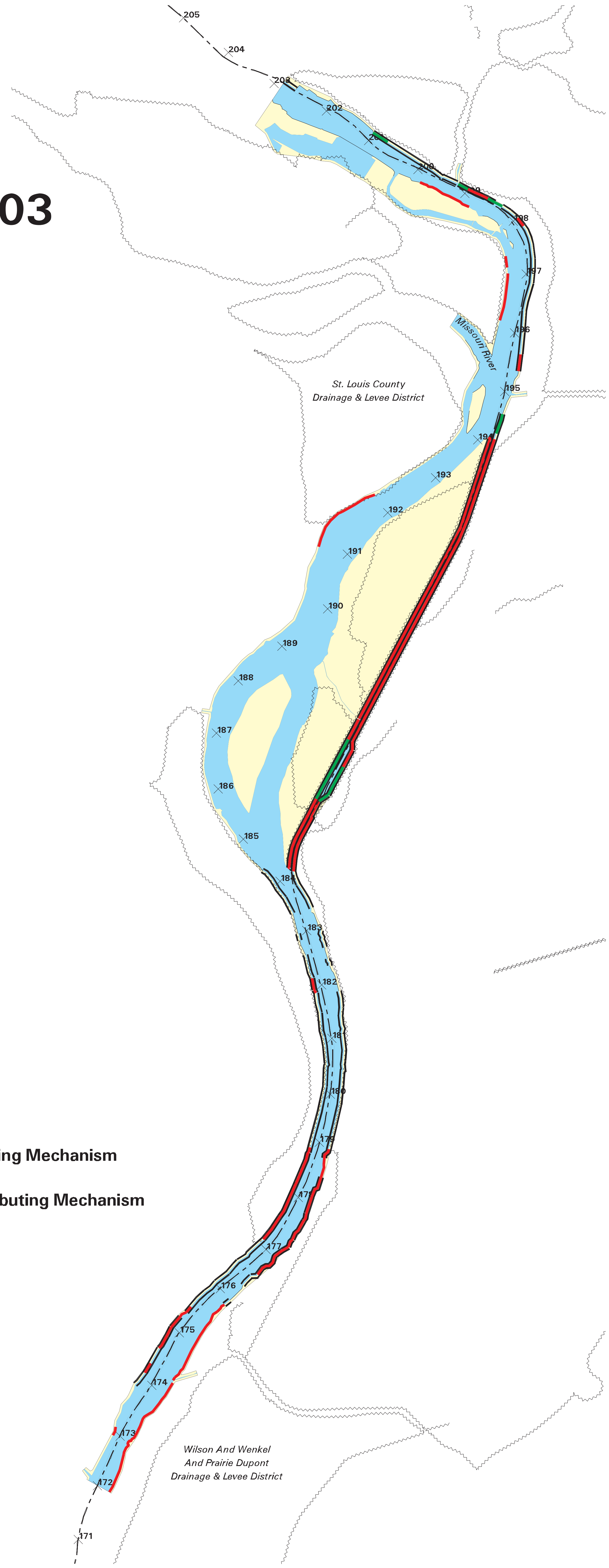
0 1 2 3 4

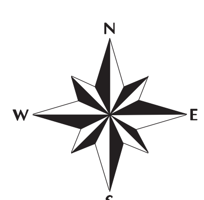
- High Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Identified as Protected During 1995 Field Survey
- Levee
- Barge Facility
- Primary Waiting Point
- Secondary Waiting Point
- Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Open River, Mile 172 to 203

Bank Erosion Study





Scale 1:100,000

kilometers

0 1 2 3 4

miles

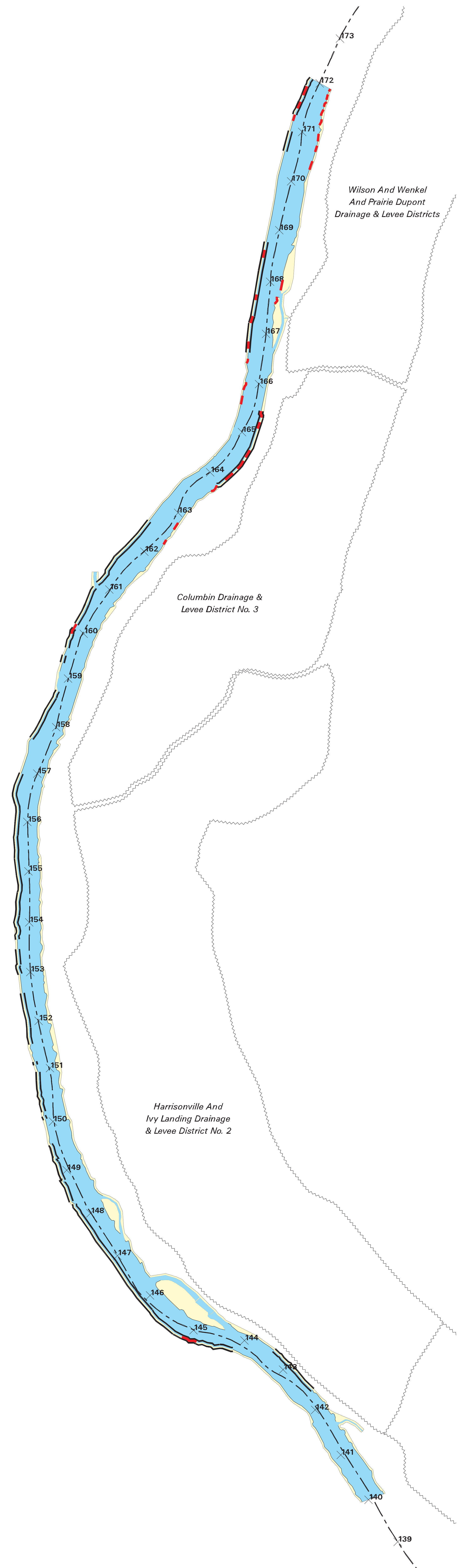
0 1 2 3 4

- High Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Identified as Protected During 1995 Field Survey
- Levee
- Barge Facility
- Primary Waiting Point
- Secondary Waiting Point
- Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Open River, Mile 140 to 172

Bank Erosion Study



N
W E
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Scale 1:100,000

kilometers

0 1 2 3 4

miles

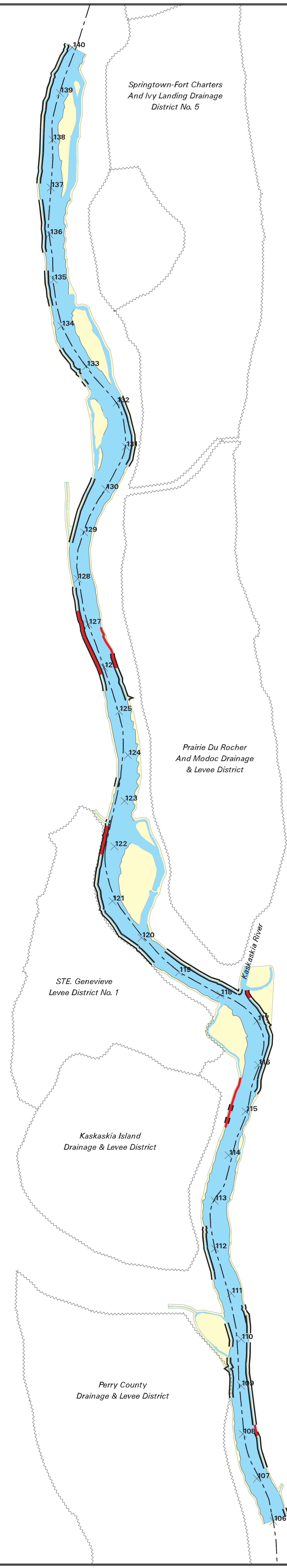
0 1 2 3 4

- **High Potential For Bank Erosion where Navigation is a Contributing Mechanism**
- **Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism**
- **Identified as Protected During 1995 Field Survey**
- **Levee**
- **Barge Facility**
- P **Primary Waiting Point**
- S **Secondary Waiting Point**
- A **Alternate Waiting Point**

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Open River, Mile 106 to 140

Bank Erosion Study



Scale 1:100,000

kilometers

0 1 2 3 4

miles

0 1 2 3 4

High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

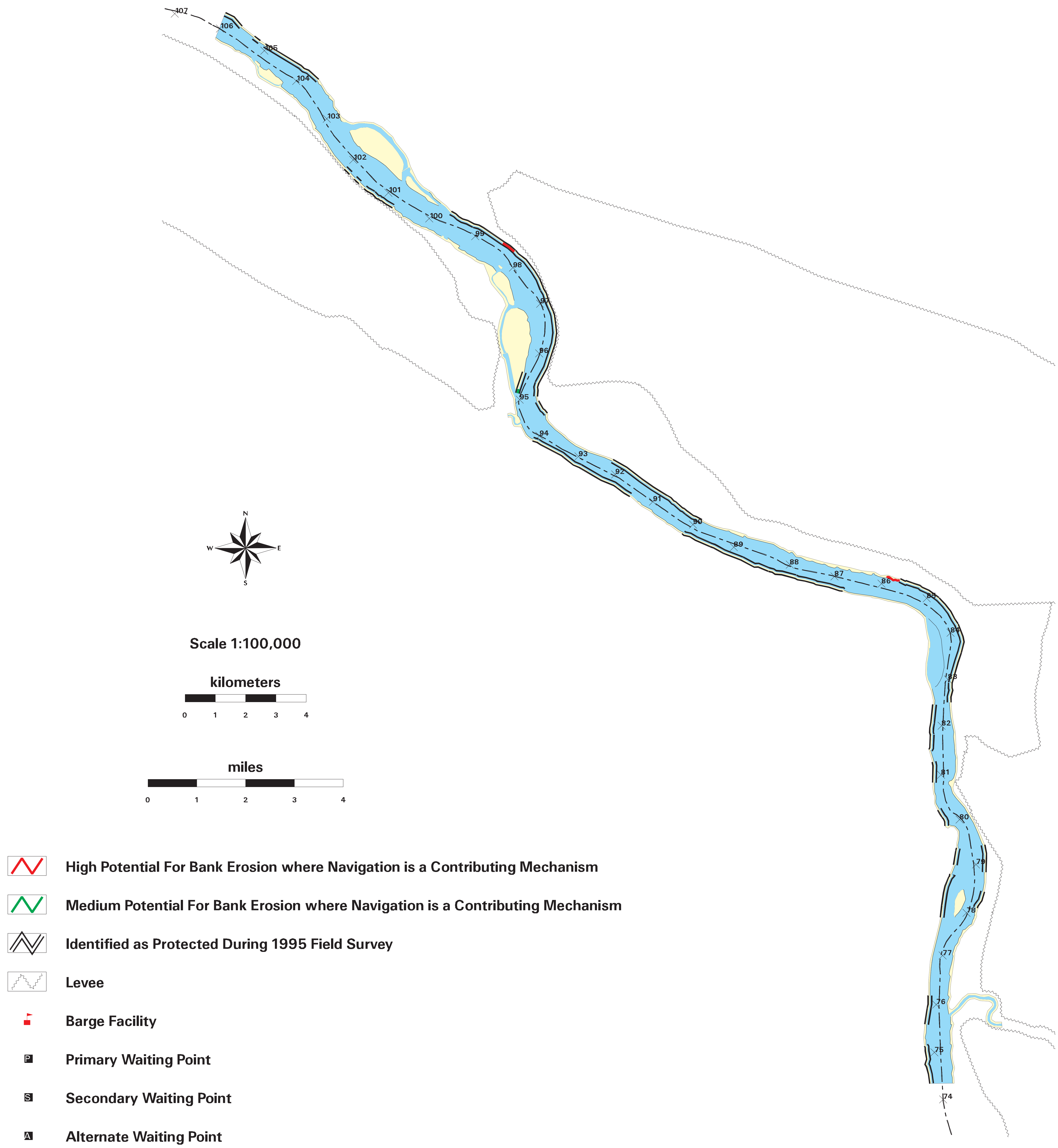
Secondary Waiting Point

Alternate Waiting Point

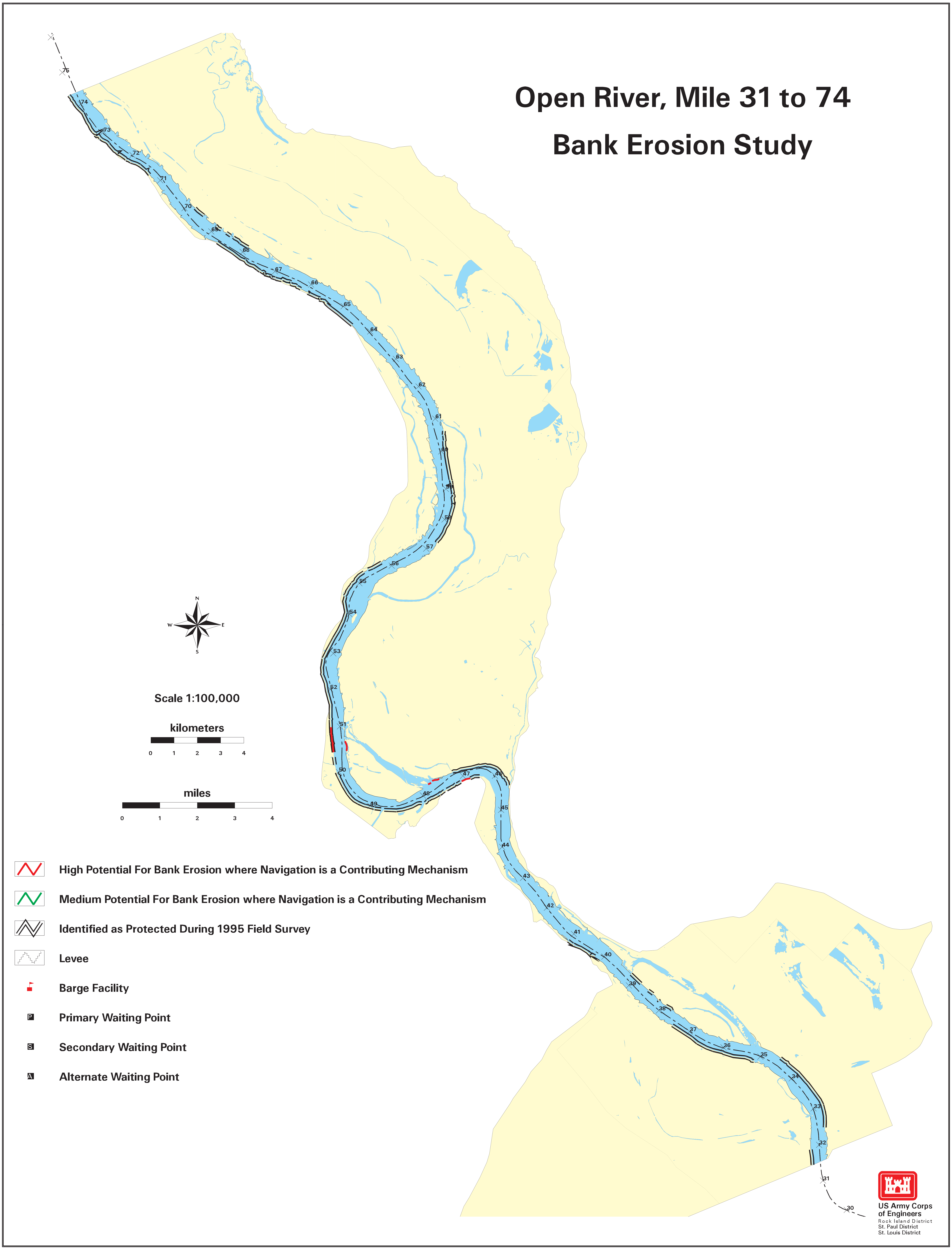
US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Open River, Mile 74 to 106

Bank Erosion Study



US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District


Open River, Mile 31 to 74
Bank Erosion Study
Scale 1:100,000
kilometers
0 1 2 3 4
miles
0 1 2 3 4
N
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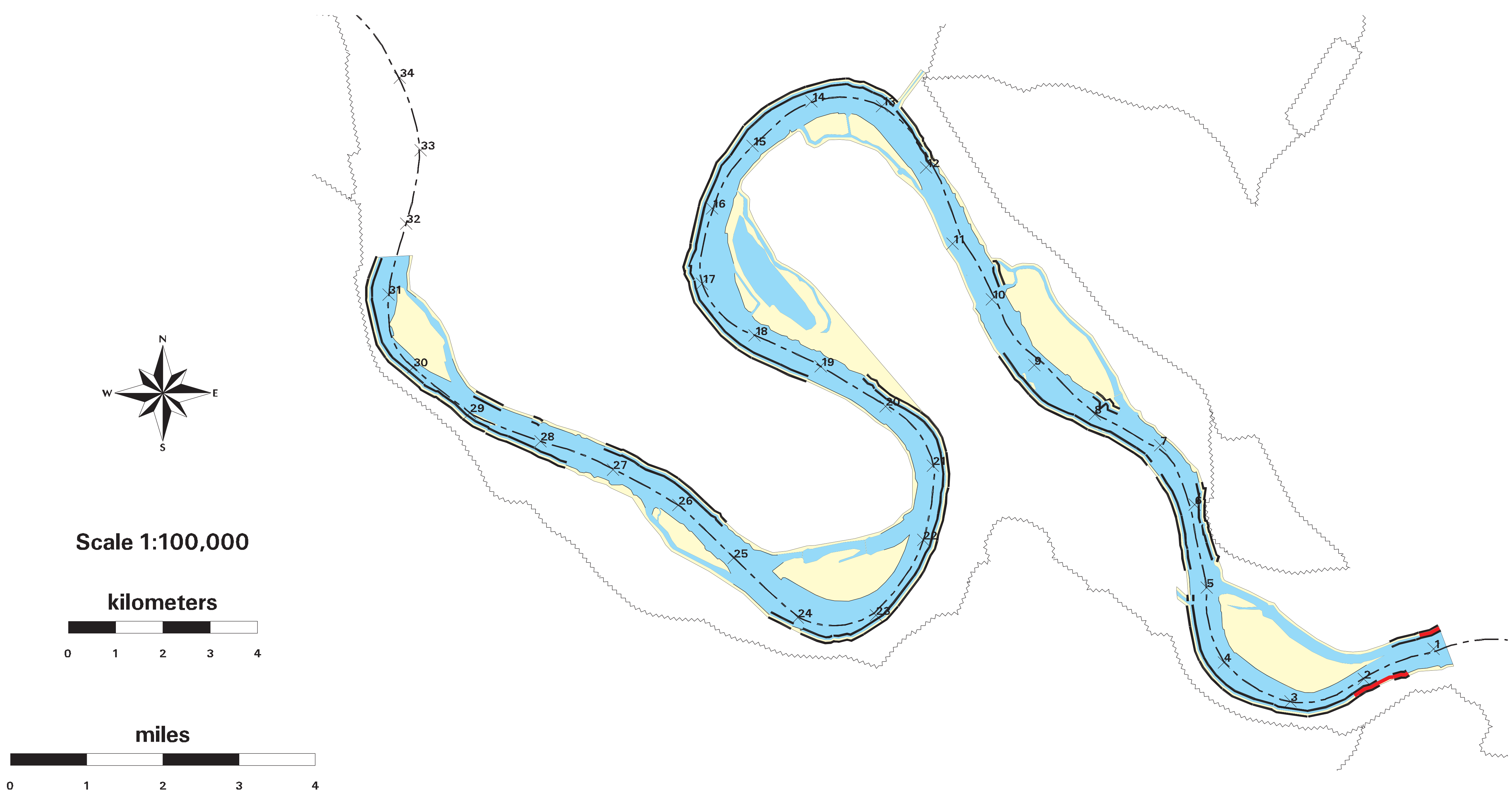
W
High Potential For Bank Erosion where Navigation is a Contributing Mechanism
Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
Identified as Protected During 1995 Field Survey
Levee
Barge Facility
Primary Waiting Point
Secondary Waiting Point
Alternate Waiting Point
US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Open River, Mile 1 to 31

Bank Erosion Study



High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

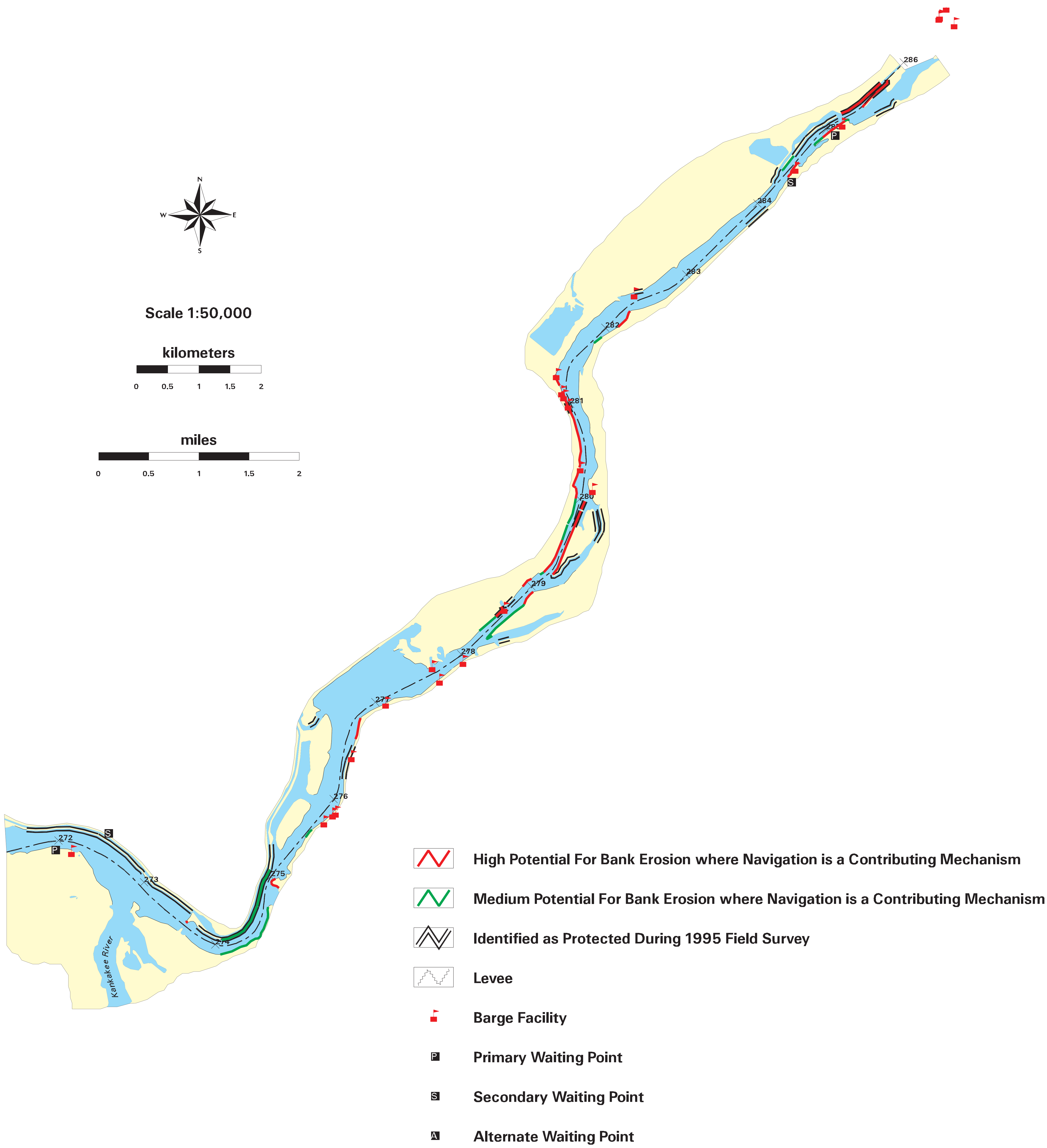
Secondary Waiting Point

Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Illinois River - Dresden Island Pool

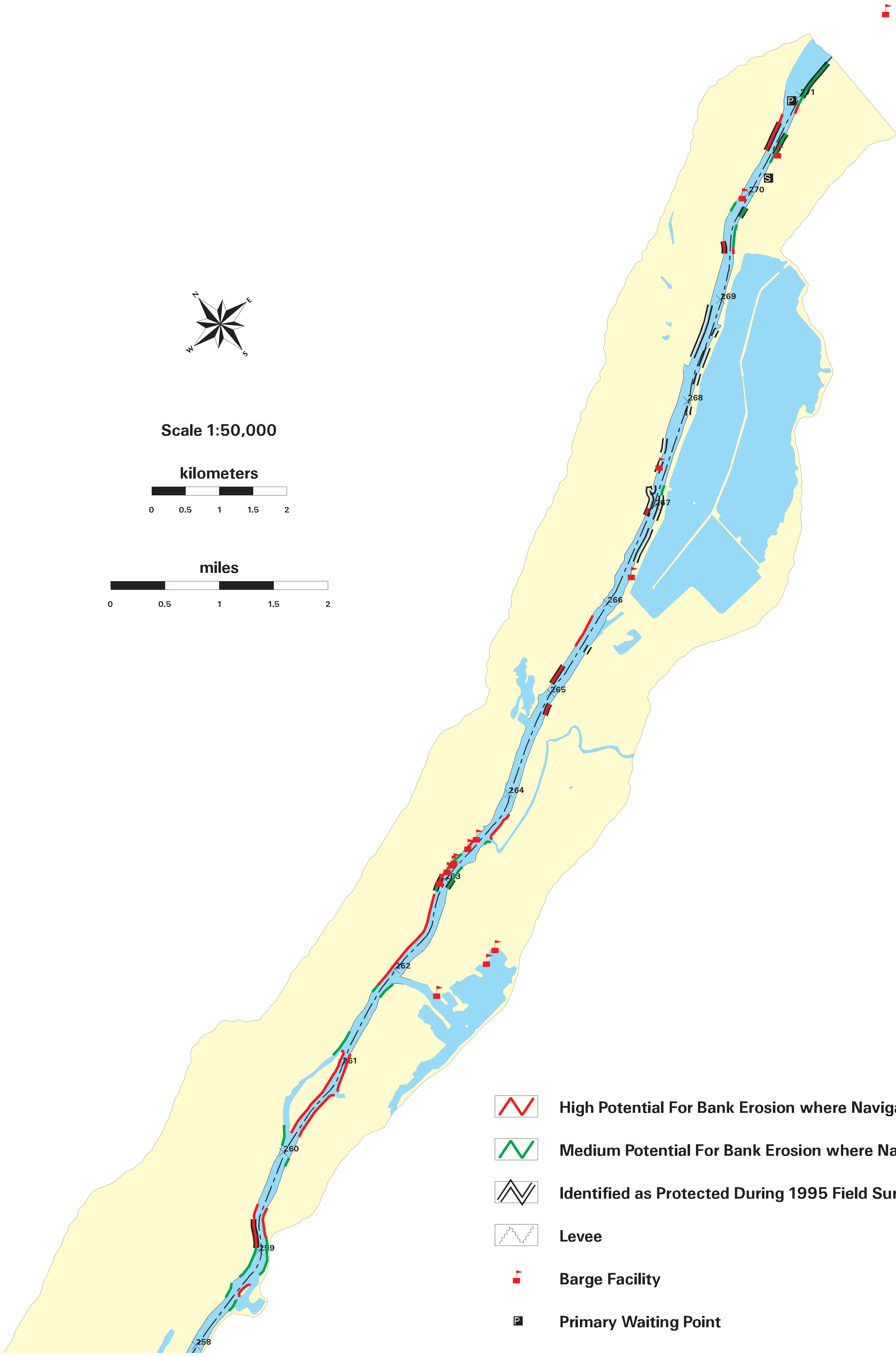
Bank Erosion Study



US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Illinois River - Upper Marseilles Pool

Bank Erosion Study



High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

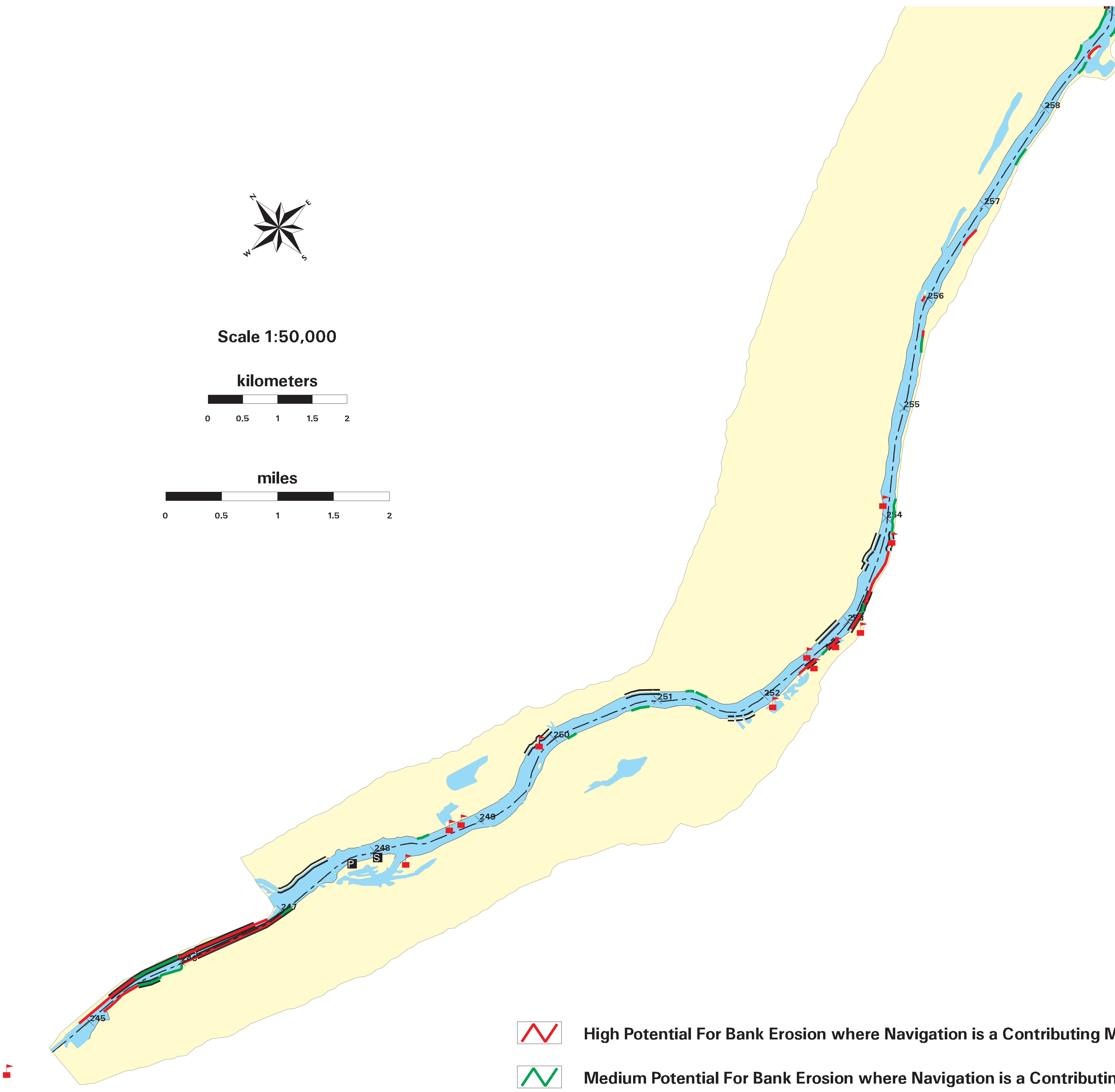
Secondary Waiting Point

Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Illinois River - Lower Marseilles Pool

Bank Erosion Study



High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

Primary Waiting Point

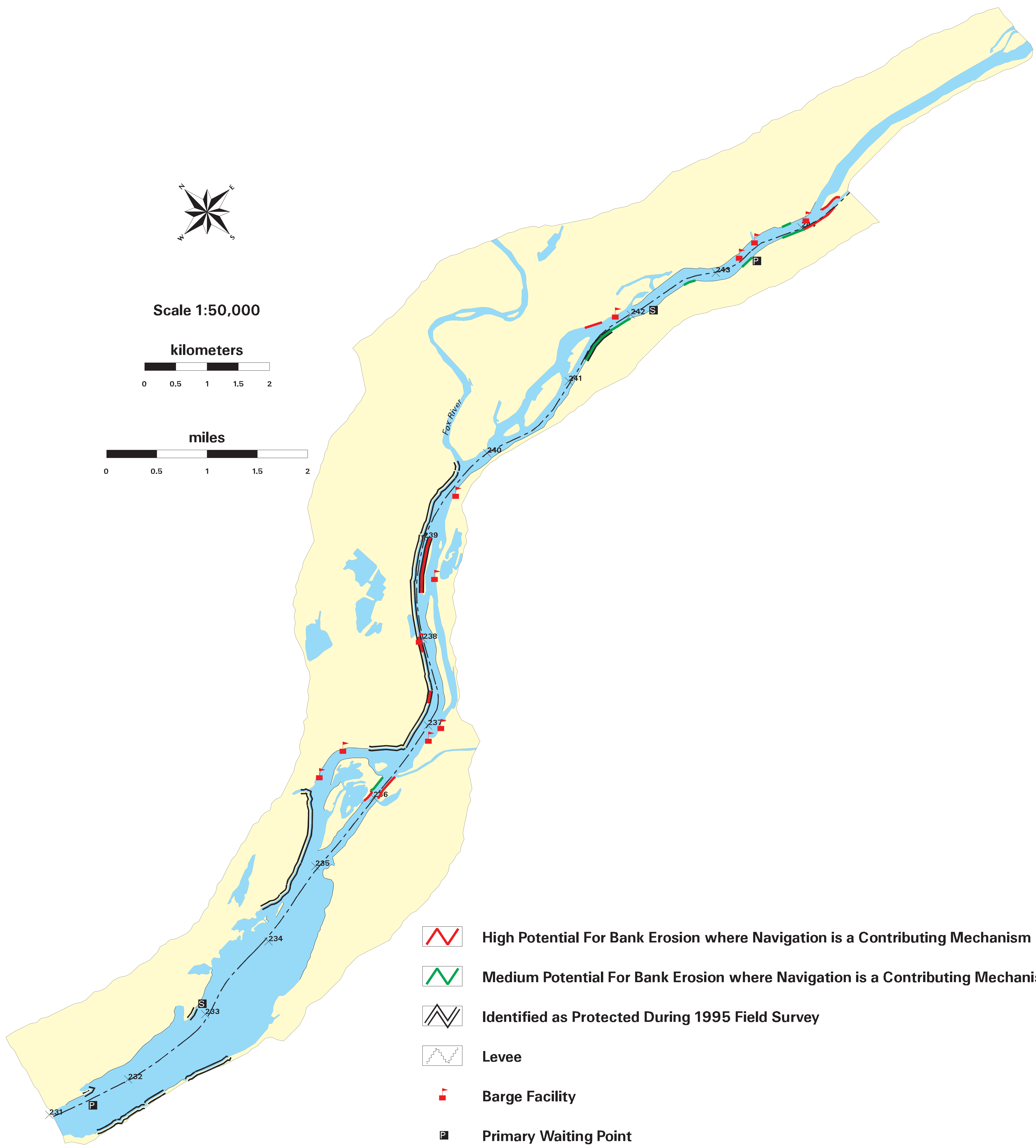
Secondary Waiting Point

Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Illinois River - Starved Rock Pool

Bank Erosion Study



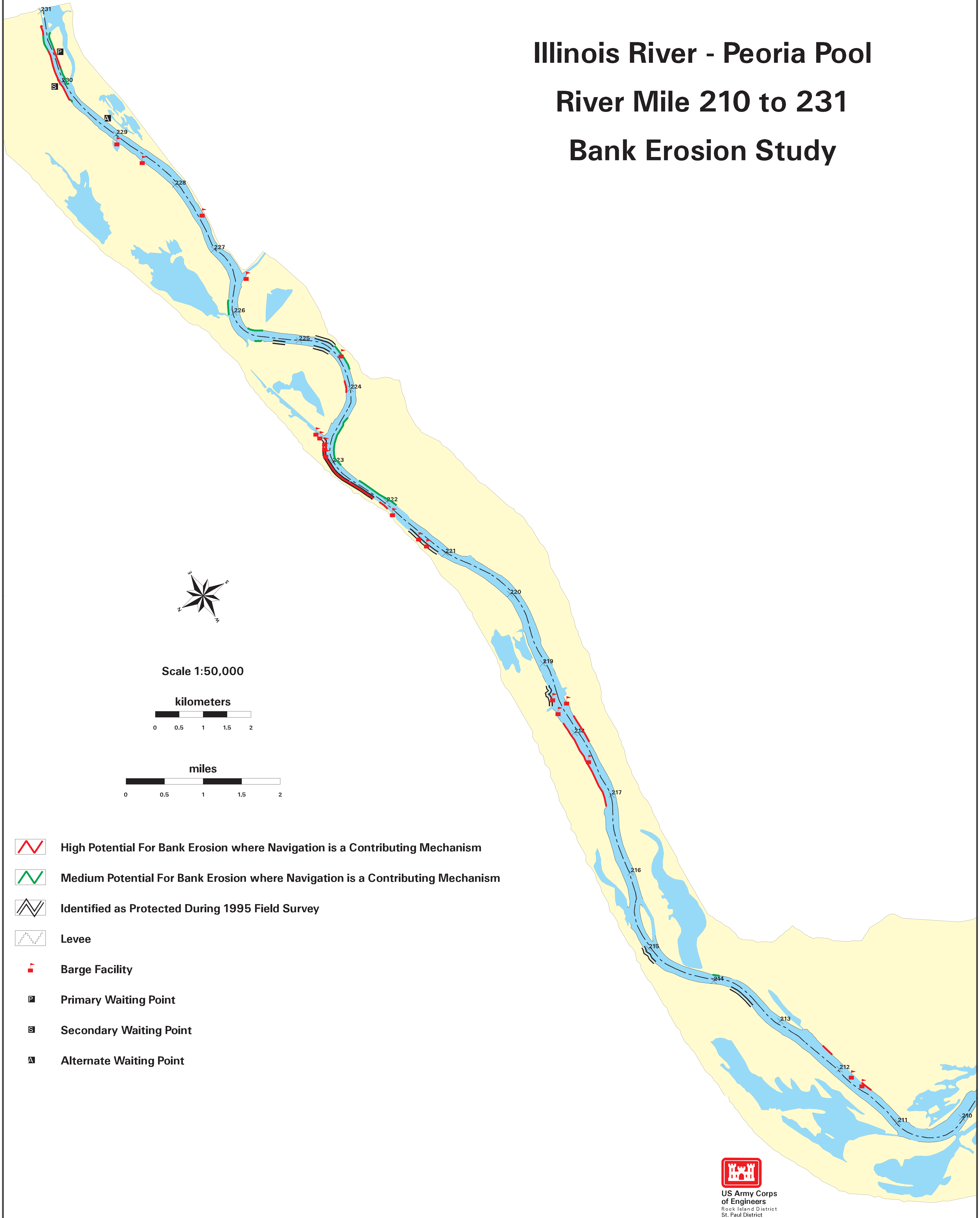
- High Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Identified as Protected During 1995 Field Survey
- Levee
- Barge Facility
- P Primary Waiting Point
- S Secondary Waiting Point
- A Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Illinois River - Peoria Pool

River Mile 210 to 231

Bank Erosion Study



Scale 1:50,000

kilometers

0 0.5 1 1.5 2

miles

0 0.5 1 1.5 2

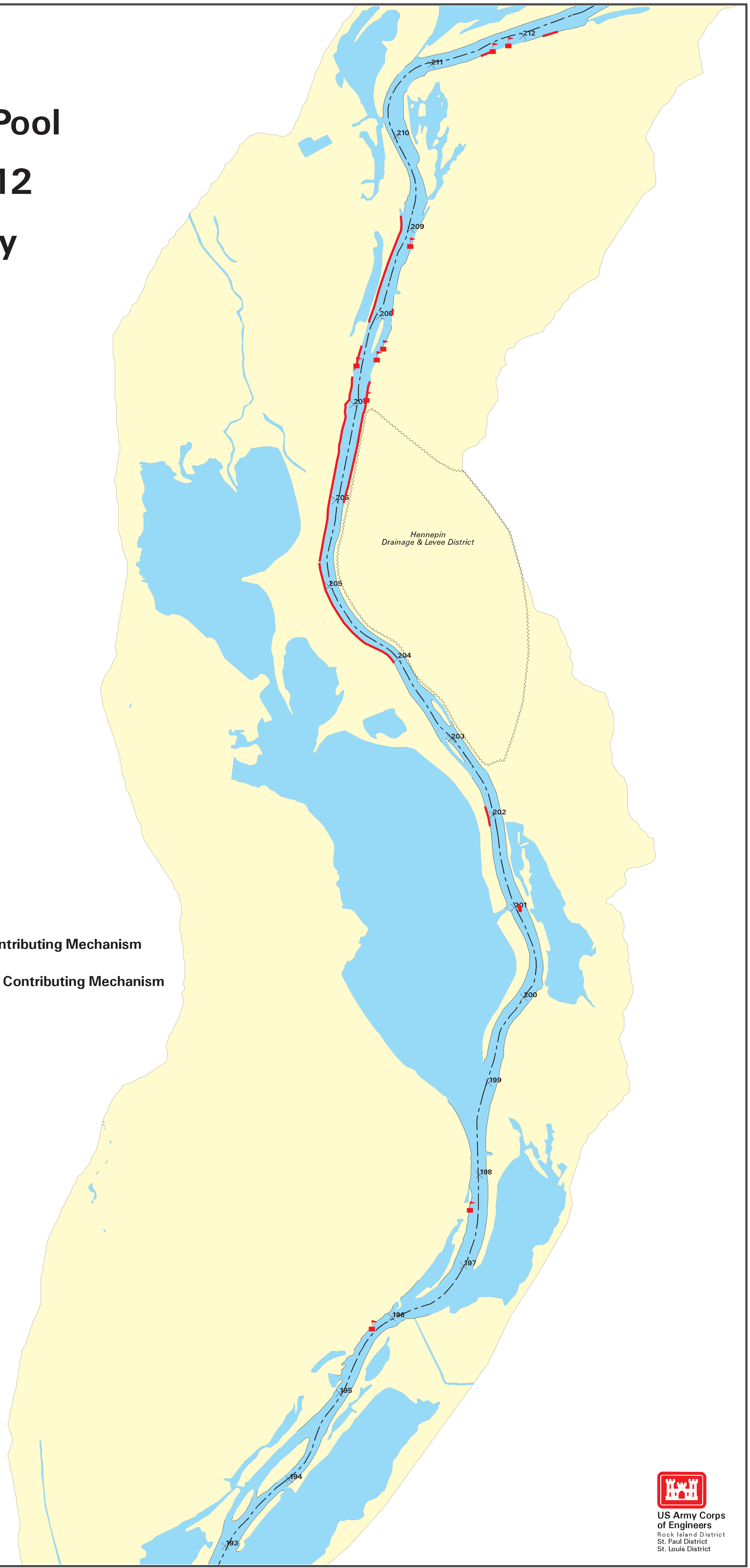
- High Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Identified as Protected During 1995 Field Survey
- Levee
- Barge Facility
- P Primary Waiting Point
- S Secondary Waiting Point
- A Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Illinois River - Peoria Pool

River Mile 193 to 212

Bank Erosion Study



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Scale 1:50,000

kilometers

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miles

0 0.5 1 1.5 2

High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

P **Primary Waiting Point**

S **Secondary Waiting Point**

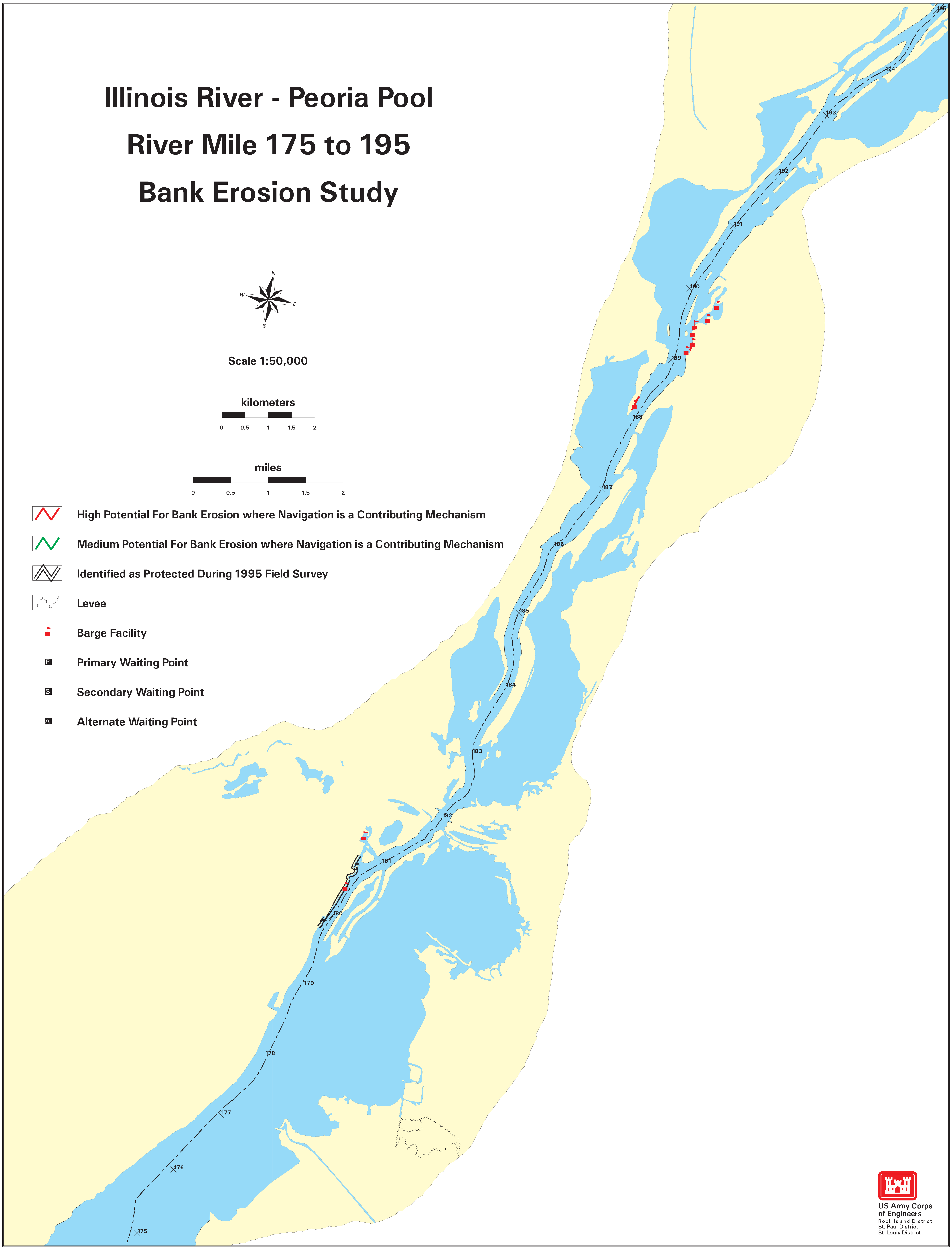
A **Alternate Waiting Point**

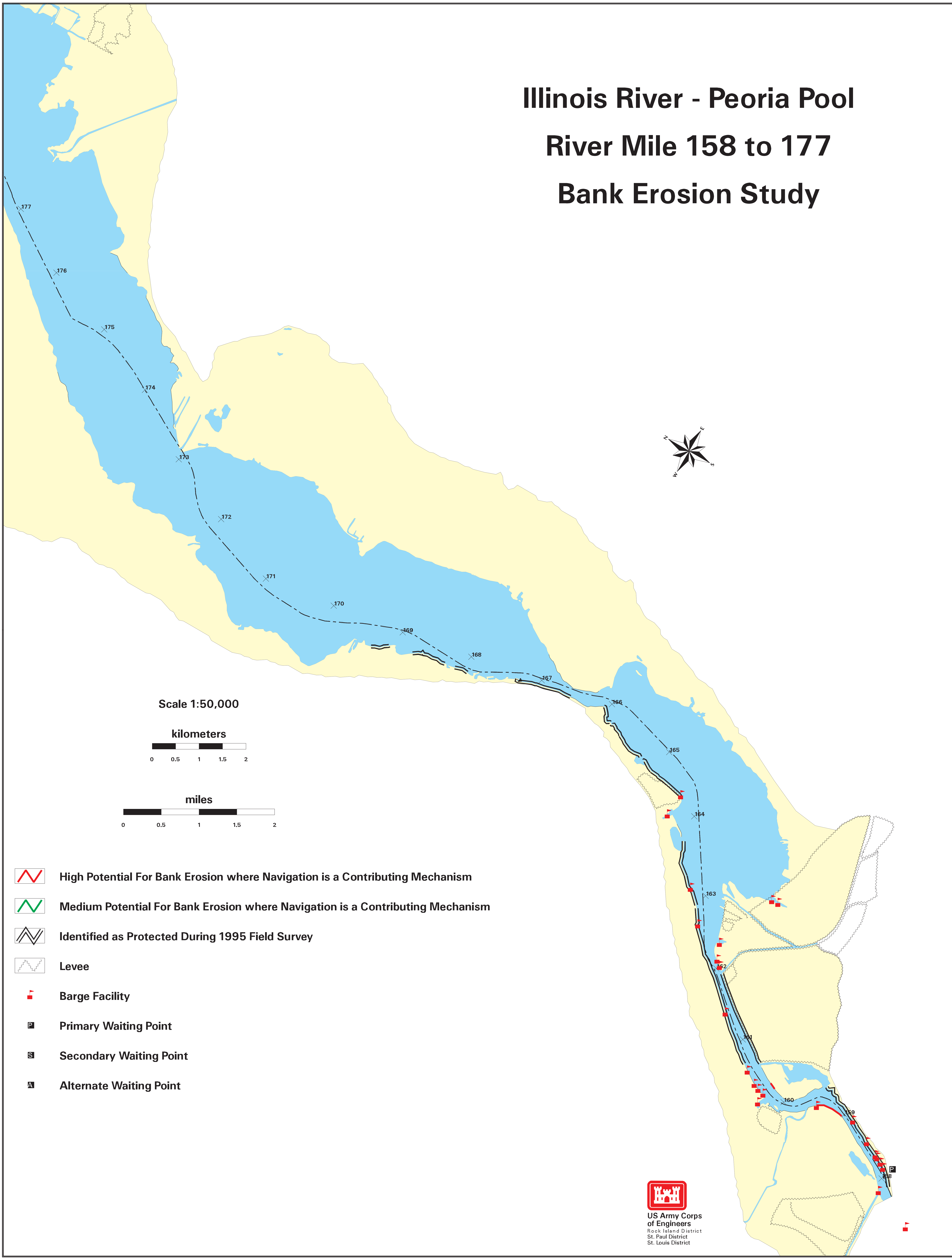
US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Illinois River - Peoria Pool

River Mile 175 to 195

Bank Erosion Study




Illinois River - Peoria Pool
River Mile 158 to 177
Bank Erosion Study
177
176
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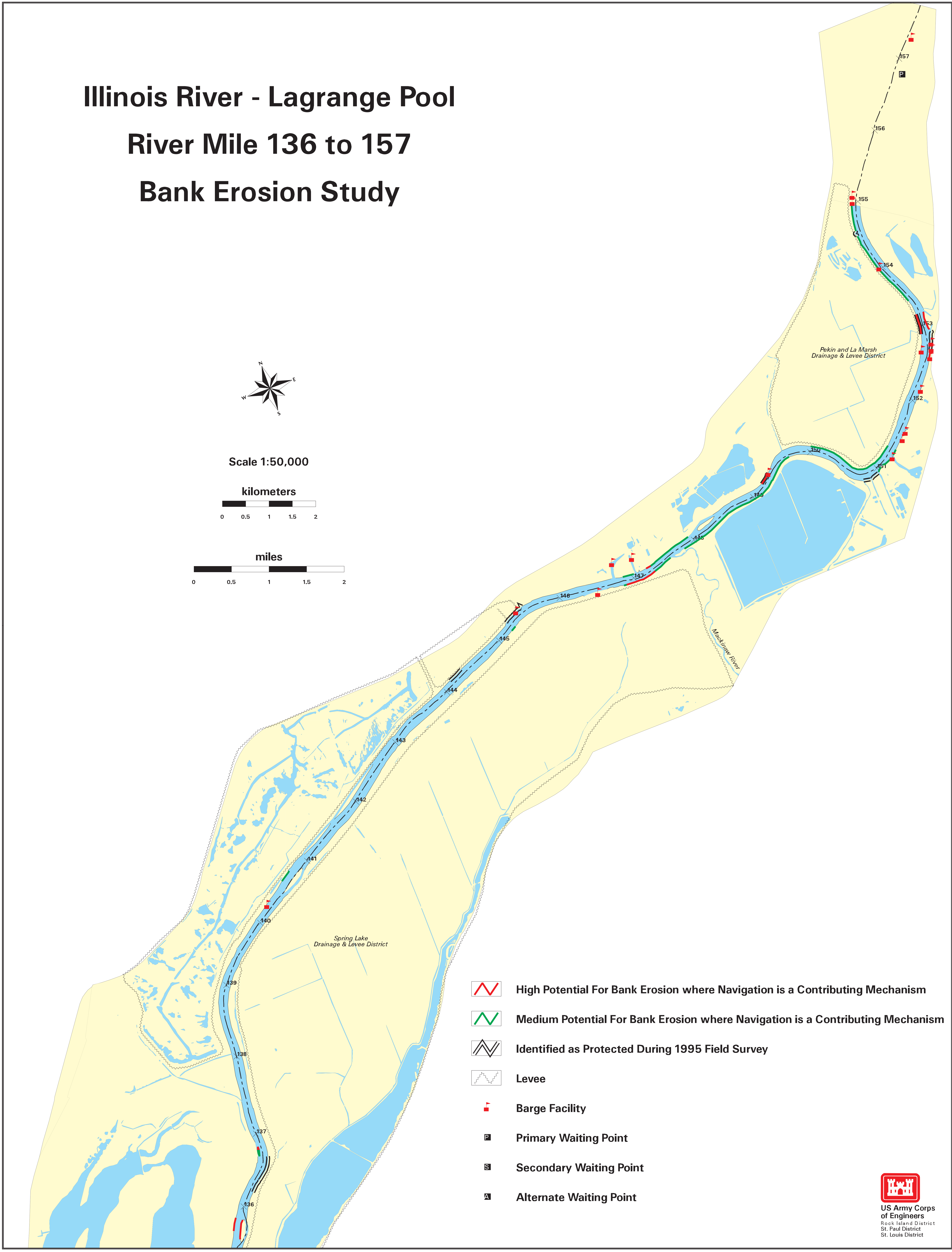
Scale 1:50,000
kilometers
0 0.5 1 1.5 2
miles
0 0.5 1 1.5 2
High Potential For Bank Erosion where Navigation is a Contributing Mechanism
Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
Identified as Protected During 1995 Field Survey
Levee
Barge Facility
Primary Waiting Point
Secondary Waiting Point
Alternate Waiting Point
US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Illinois River - Lagrange Pool

River Mile 136 to 157

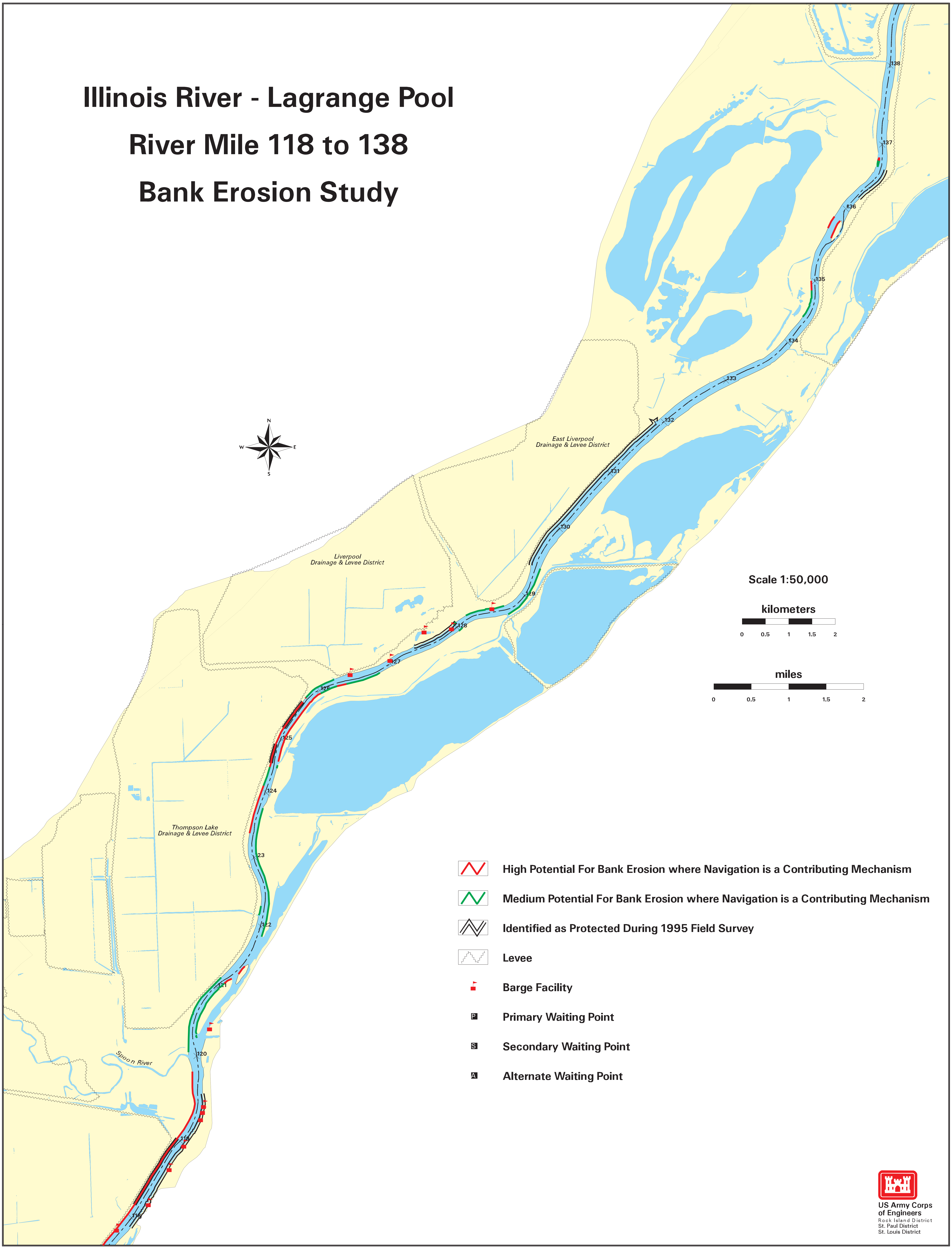
Bank Erosion Study



Illinois River - Lagrange Pool

River Mile 118 to 138

Bank Erosion Study



Scale 1:50,000

kilometers

0 0.5 1 1.5 2

miles

0 0.5 1 1.5 2

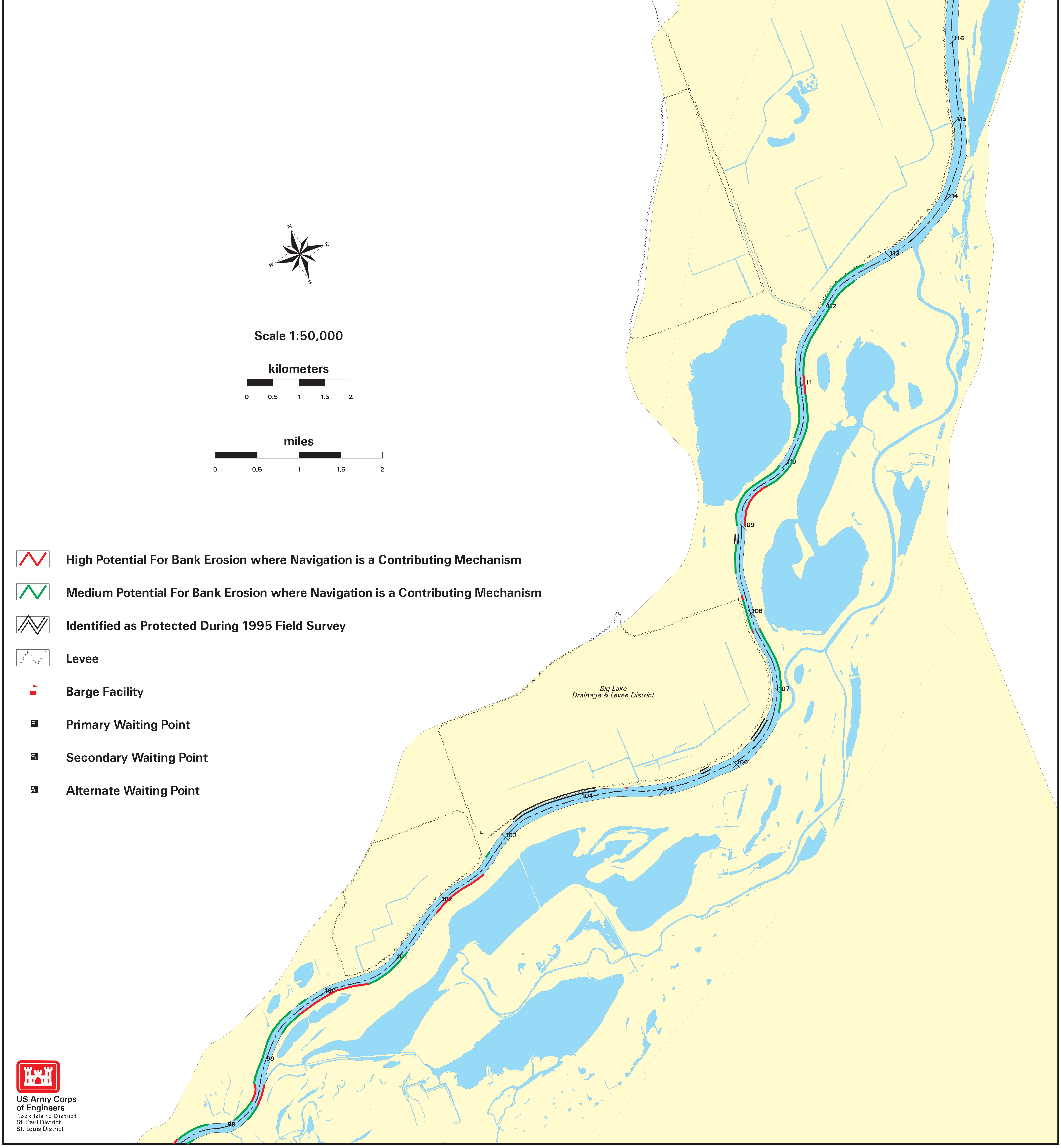
- High Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Identified as Protected During 1995 Field Survey
- Levee
- Barge Facility
- P Primary Waiting Point
- S Secondary Waiting Point
- A Alternate Waiting Point

US Army Corps of Engineers
Rock Island District
St. Paul District
St. Louis District

Illinois River - Lagrange Pool

River Mile 98 to 119

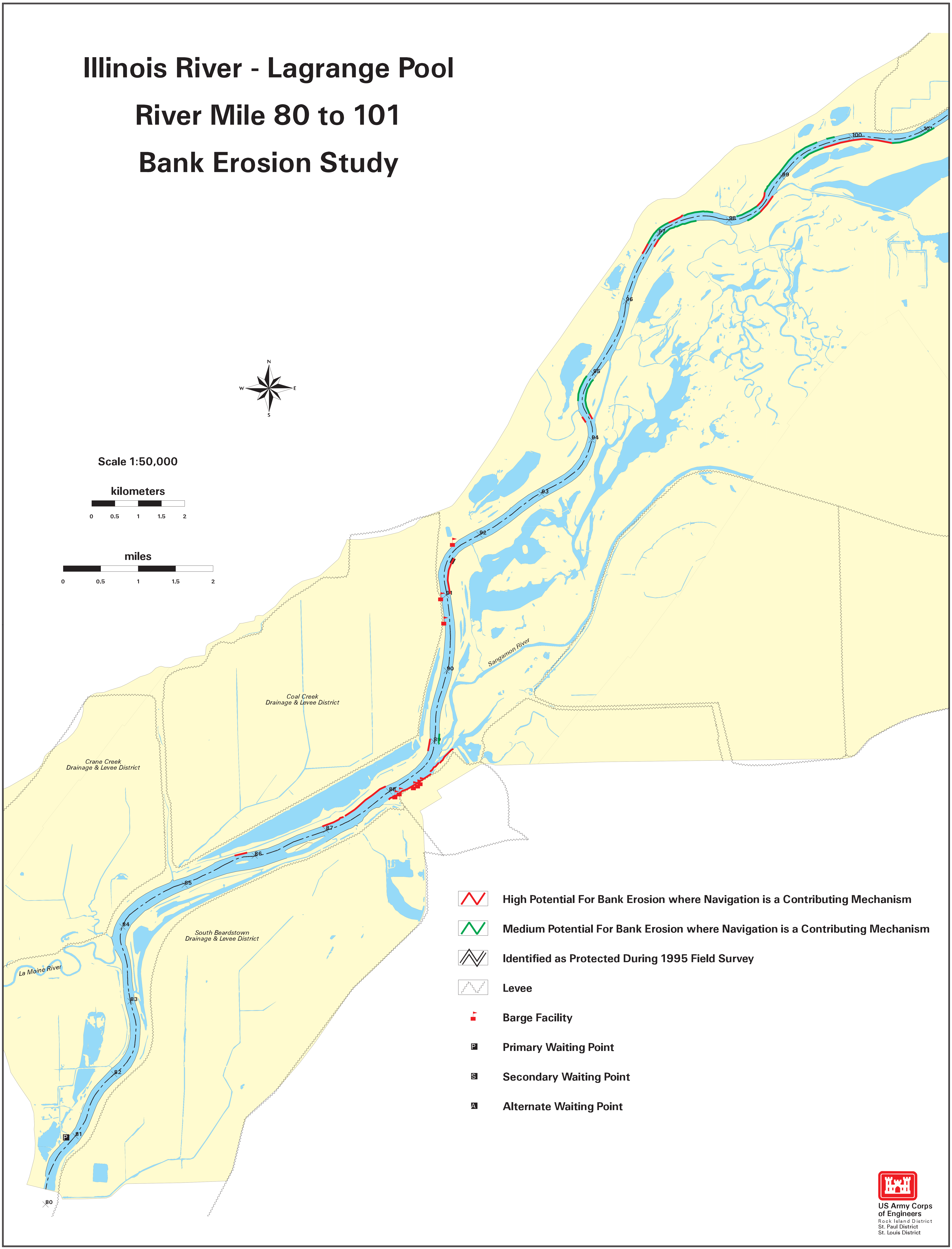
Bank Erosion Study



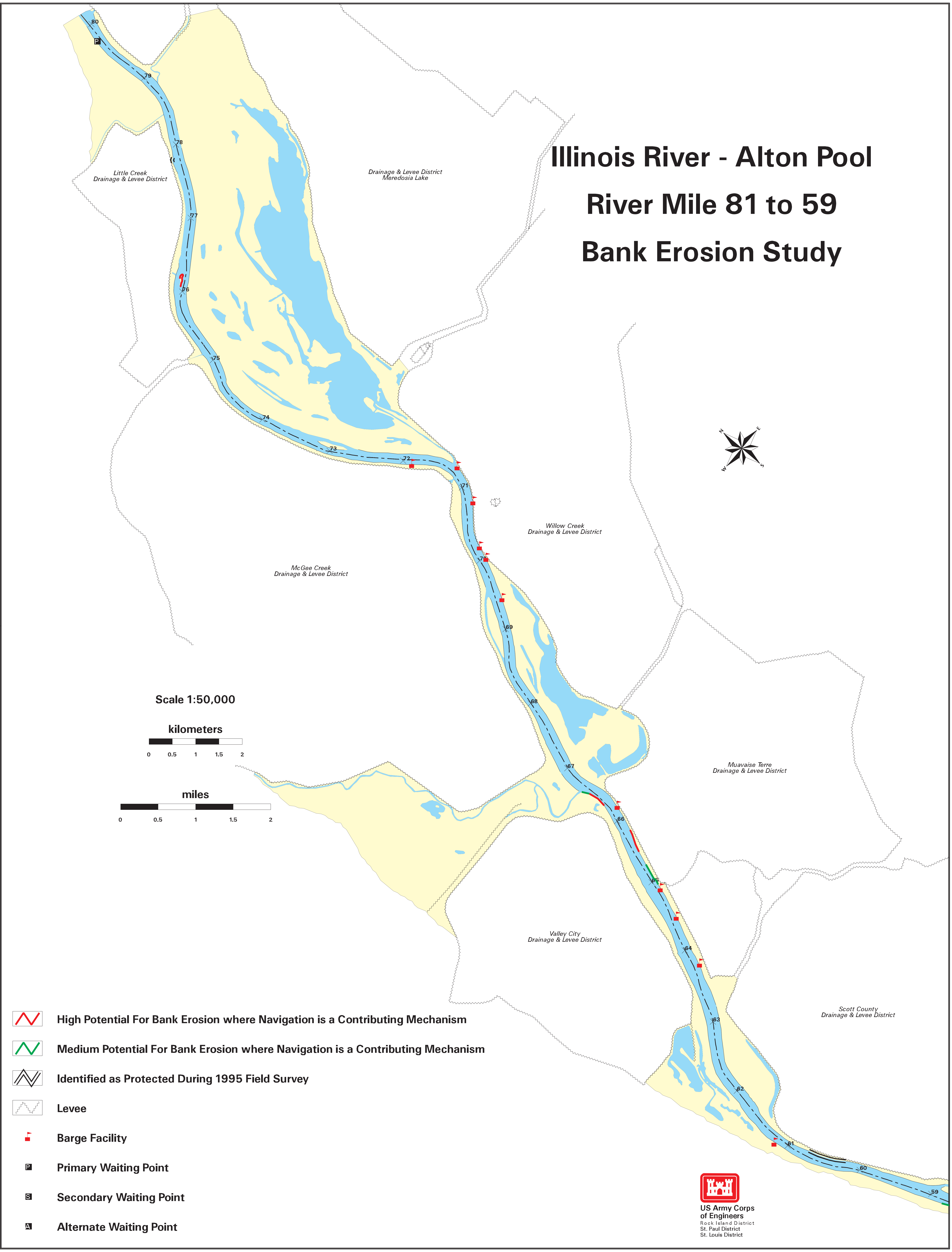
Illinois River - Lagrange Pool

River Mile 80 to 101

Bank Erosion Study



Illinois River - Alton Pool
River Mile 81 to 59
Bank Erosion Study



High Potential For Bank Erosion where Navigation is a Contributing Mechanism

Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism

Identified as Protected During 1995 Field Survey

Levee

Barge Facility

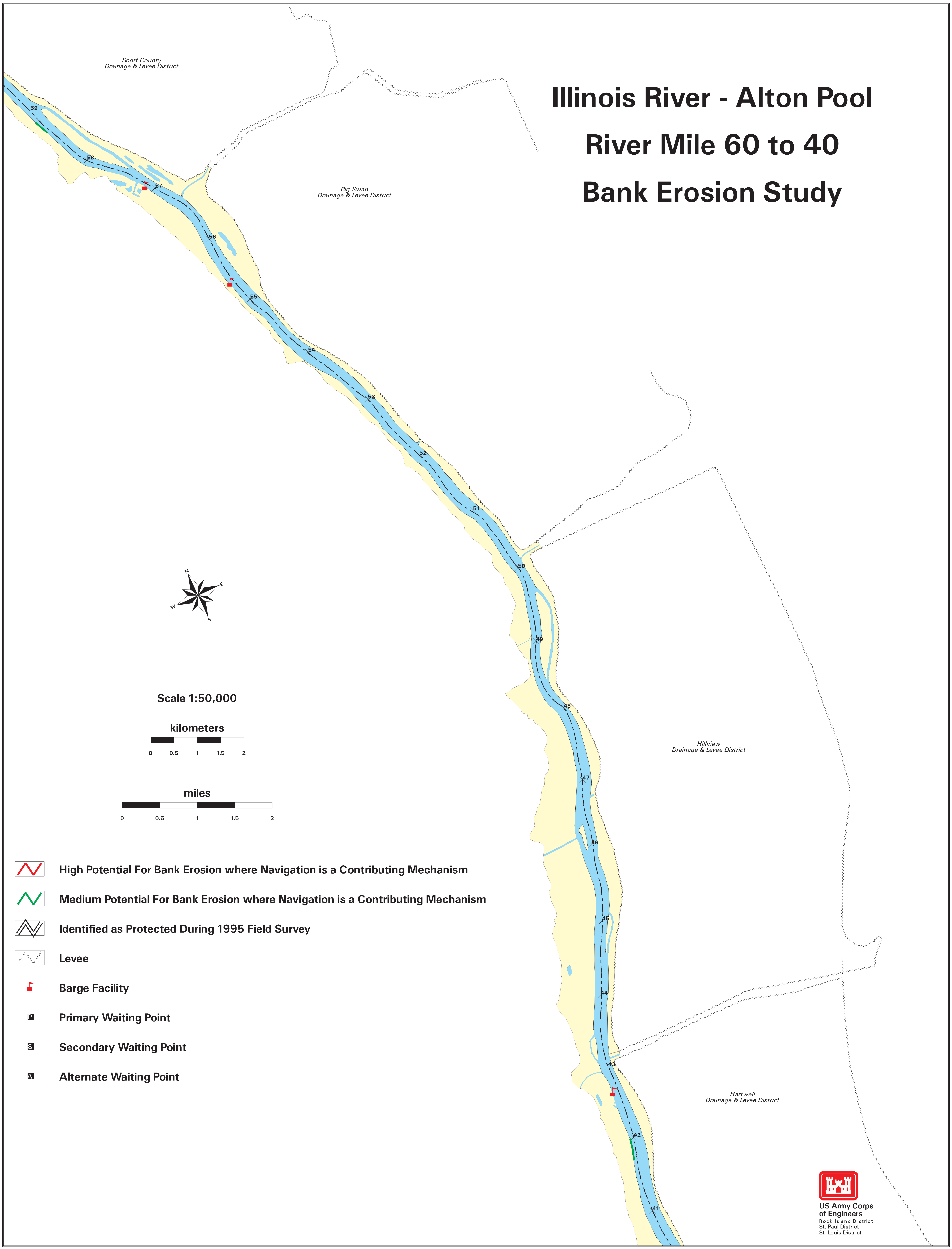
Primary Waiting Point

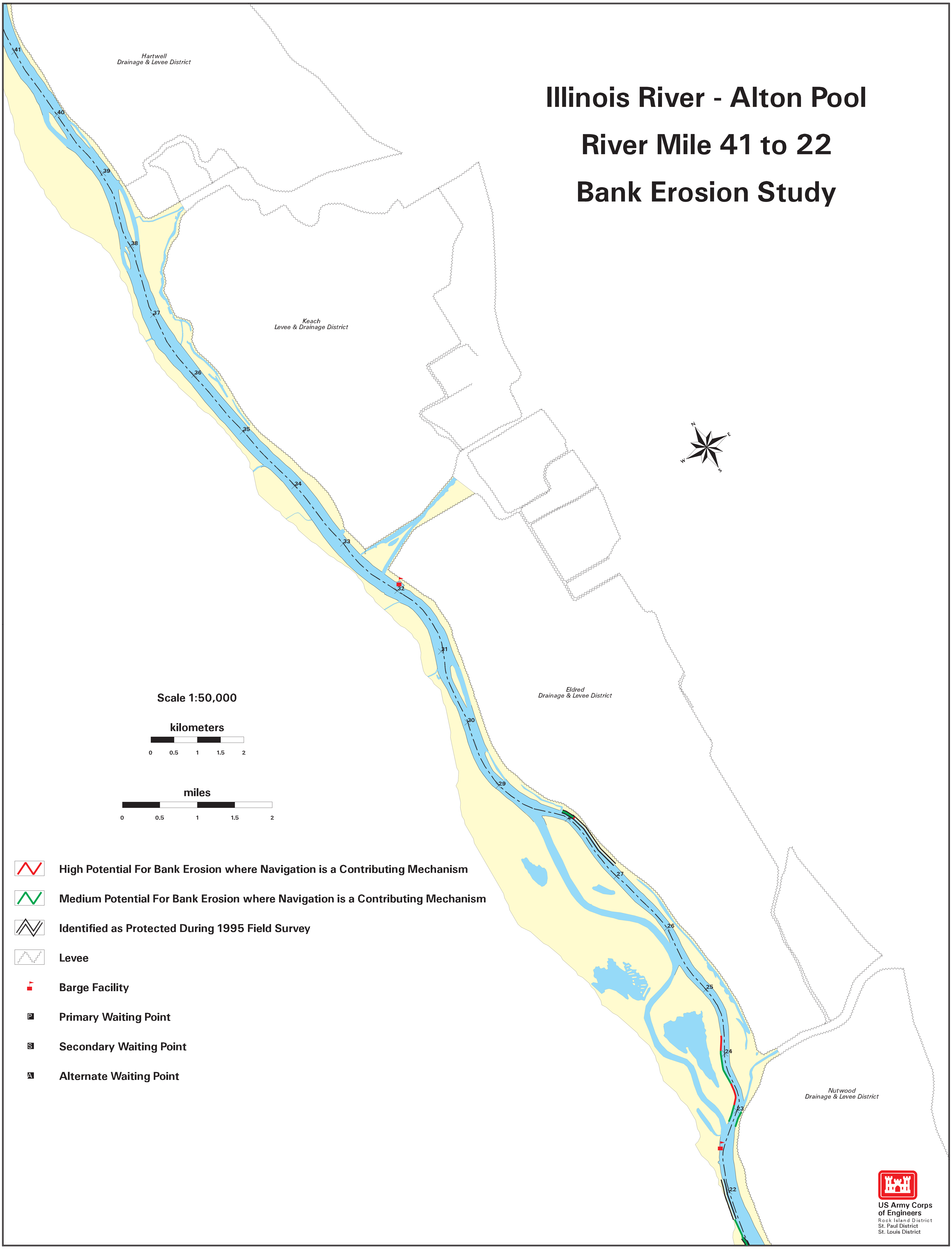
Secondary Waiting Point

Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Illinois River - Alton Pool
River Mile 60 to 40
Bank Erosion Study




Illinois River - Alton Pool
River Mile 41 to 22
Bank Erosion Study
Hartwell
Drainage & Levee District
Keach
Levee & Drainage District
Eldred
Drainage & Levee District
Nutwood
Drainage & Levee District
41
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27
26
25
24
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22
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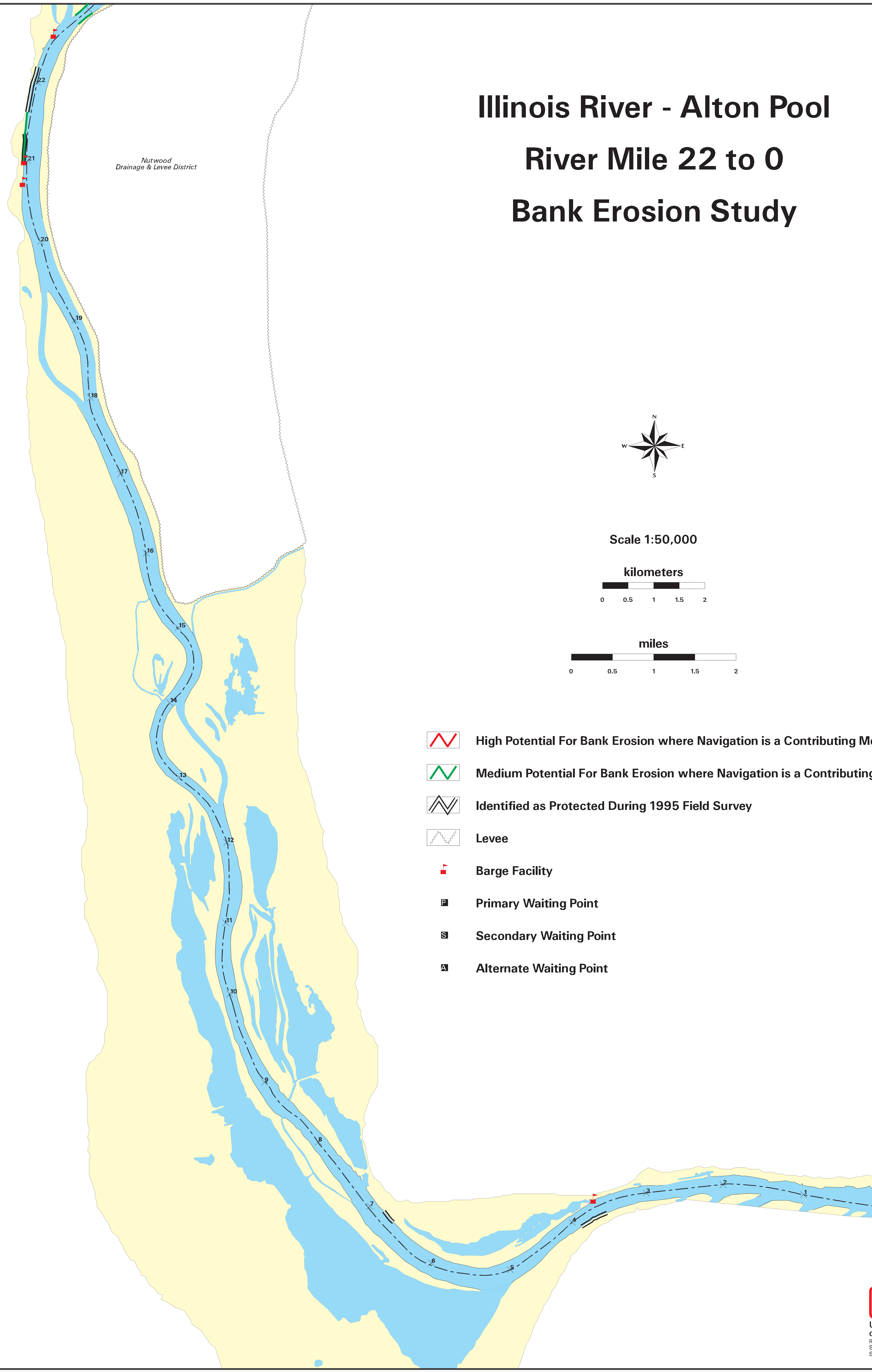
S
W
Scale 1:50,000
kilometers
0 0.5 1 1.5 2
miles
0 0.5 1 1.5 2
High Potential For Bank Erosion where Navigation is a Contributing Mechanism
Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
Identified as Protected During 1995 Field Survey
Levee
Barge Facility
Primary Waiting Point
Secondary Waiting Point
Alternate Waiting Point
US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District

Illinois River - Alton Pool

River Mile 22 to 0

Bank Erosion Study



Scale 1:50,000

kilometers

0 0.5 1 1.5 2

miles

0 0.5 1 1.5 2

- High Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Medium Potential For Bank Erosion where Navigation is a Contributing Mechanism
- Identified as Protected During 1995 Field Survey
- Levee
- Barge Facility
- P Primary Waiting Point
- S Secondary Waiting Point
- A Alternate Waiting Point

US Army Corps
of Engineers
Rock Island District
St. Paul District
St. Louis District