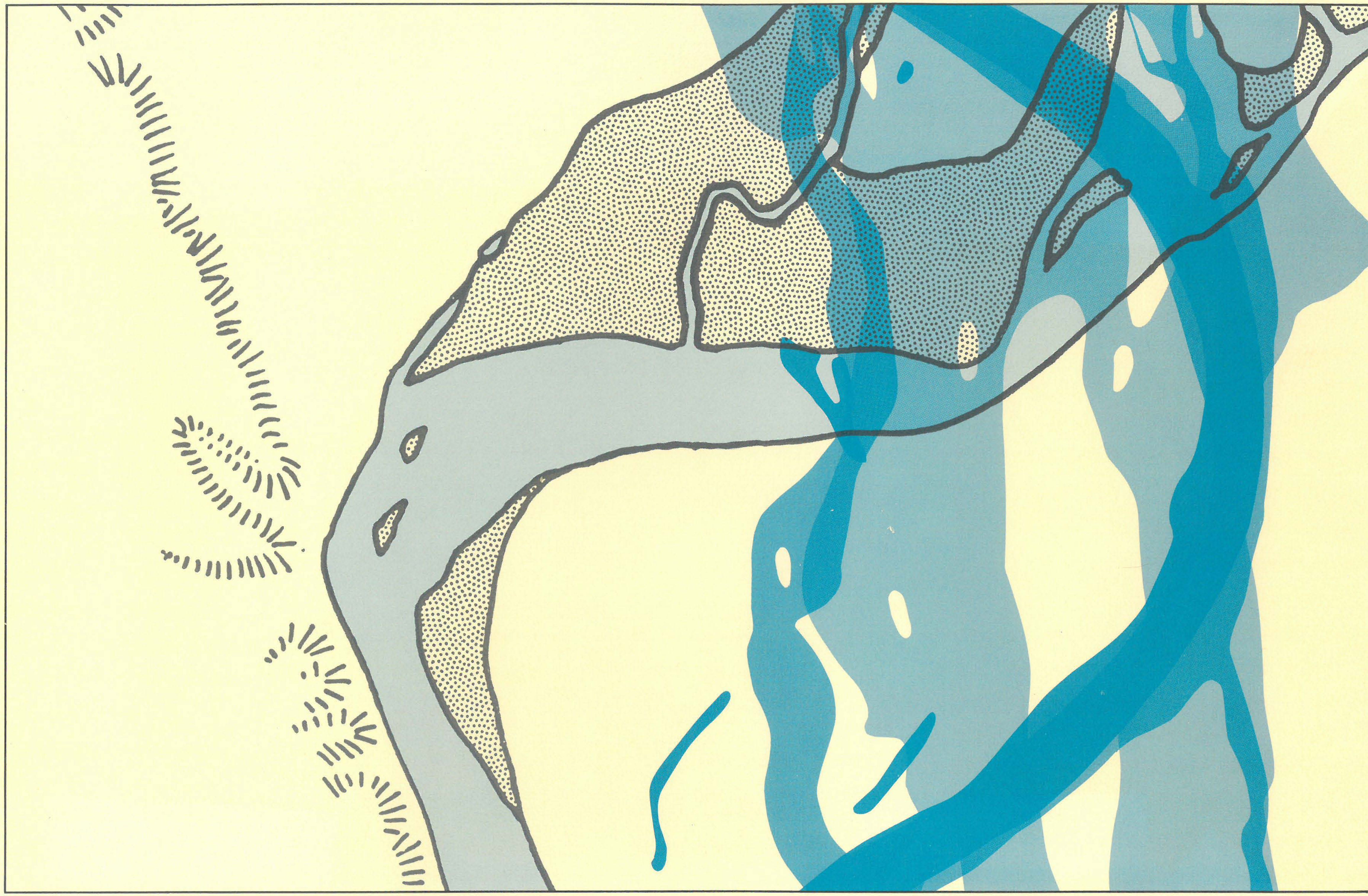
Iowa Geological Survey
Special Report Series Number 1
1979



CHANGES IN THE CHANNEL AREA OF THE MISSOURI RIVER IN IOWA, 1879 - 1976

(Prepared for the Iowa Conservation Commission)

by George R. Hallberg
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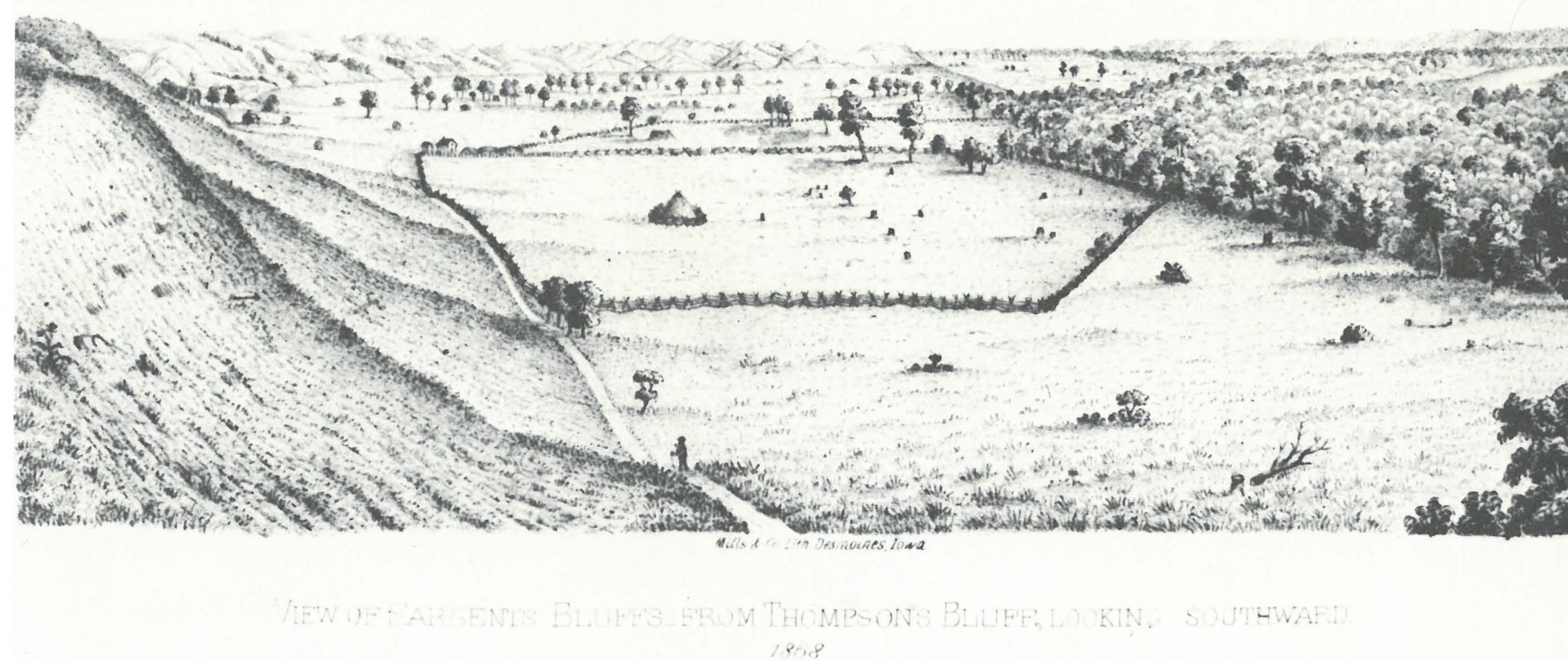

Field sketch—Orestes St. John
1868

Tables in Appendix

Maps in Appendix

Photograph—Carolyn Milligan
1978

These views of the Missouri River valley were both observed from a point on the loess bluffs south of Sioux City, known as "First Bride's Bluff" near Ravine Park. The view is to the south toward the projecting hills of Sergeant's Bluff. These contrasting scenes document 110 years of change in the area, from a pastoral scene of grassy slopes and woods, and a few fences and farmsteads, to occupation by interstate highways, sewage treatment plants, an airport, and electric lines and towers. The drawing on the left was pencil sketched in 1868 by Orestes St. John, Assistant Geologist with the Iowa Geological Survey, and it was published as a lithograph in the 1870 *Report of the Geological Survey of the State of Iowa.* The photograph on the right was taken in 1978 by Carolyn Milligan, an artist, who is working with Jean Prior, of the Iowa Geological Survey, on a special project to relocate the sites of the original St. John sketches.

List of Figures

From "The Missouri, Its Habits and Eccentricities Described by a Personal Friend"

"There is only one river that goes traveling sidewise, that interferes in politics, that rearranges geography and dabbles in real estate; a river that plays hide-and-seek with you today, and tomorrow follows you around like a pet dog with a dynamite cracker tied to his tail. That river is the Missouri."

George Fitch, April, 1907, *American Magazine,* vol. LXII, no. 6

EXECUTIVE SUMMARY

Using maps, aerial photographs, and hydrologic data the natural and man-made changes in the channel of the Missouri River were quantitatively evaluated from 1879, 1890, 1923, 1947, and to 1976. For quantitative comparison and documentation the river mileage, sinuosity, channel area, and the water, island, and bar area within the channel were measured. These parameters are the only features that can be consistently defined and measured over this time span because of the limited coverage of the older surveys.

The early history of the Missouri River was also evaluated. Between 1804 and the late-1800s the regime of the Missouri River, particularly north of the Platte River, changed radically from a meandering stream, with a single sinuous channel, to a semi-braided stream with numerous multi-channel reaches. This trend continued into the 1900s until the channel was artificially altered. This transformation of the river was caused by a long period of frequent recurrence of high-flood flows which were related to climatic conditions which did not occur in the 1900s until the past two decades—a period which has also been marked by frequent recurrence of high-flood flows. These recent climatic-hydrologic changes have contributed to many problems in the management of surface water resources in the Midwest. Hopefully, our growing understanding of these natural phenomena will aid in the resolution of present and future problems.

Even though dramatic natural changes took place in the Missouri River a natural balance also occurred. Between 1890 and 1923 the channel decreased in length by about 14 miles (7%), but the channel area increased by 7% from about 72,000 to 77,000 acres. This is in marked contrast to the artificial changes in the river.

The man-induced changes of the Missouri River were equally as dramatic as the natural changes. The Missouri was altered, by Congressional mandate, in two stages; first by construction of the 6-foot navigation channel, and later by the realignment and construction of the present 9-foot design channel. Between 1923 and 1976 the river was shortened about 18 miles in Iowa. Unlike in the natural river the channel area was also severely altered.

The intent of the design channel was to eliminate the broad natural channel area. From 1923 to 1976 the Missouri was changed from a broad semi-braided stream, to a narrow, single, smooth channel, with a series of gentle bends, with a well stabilized bank. The channel area was reduced by 80%, or about 62,000 acres (96 square miles), between 1923 and 1976. About 35,000 acres of this reduction occurred in Iowa. The surface area of water in the channel area was reduced by 66% or 30,228 acres (55 square miles). This is equal to the water surface area, at normal pool elevations, of the Coralville, Saylorville, Red Rock, and Rathbun reservoirs *combined.* Bars and islands have been essentially eliminated; a loss of over 30,000 acres since 1923.

Often all of these changes are attributed to the construction of the present design channel. However, as shown by the 1947 data, if the first design channel had been allowed to stabilize, this would have accounted for 95% of the losses in channel area and 99% of the loss of water area. As of 1978 the construction of the design channel was considered only 92% complete.

The stabilization and flood control of the Missouri River has provided benefits, particularly by providing thousands of acres of land for agriculture and development on the alluvial plain. However, this has been accomplished at the expense and sacrifice of the river's natural riparian right-of-way. The natural channel area of the Missouri River formed a continuous and diverse area of habitat for fish and wildlife and for other recreational uses. The areal losses, as here documented, are sizeable—but even these are minimal figures. There are other changes which took place in response to the stabilization and control of the river which cannot readily be quantified over time. These include such things as accelerated clearing of timber, draining of poorly drained areas, and encroachment of developments or agriculture on the remaining natural areas.

INTRODUCTION

"The Missouri River as it now exists is the result of extensive, mandated regulation and stabilization works which were designed and constructed to meet the historic objectives of river management: bank stabilization, flood control, land reclamation, power generation, and formation and maintenance of a navigation-channel. Installation of these works was ordered by the Congress of the United States, starting in the 1930s. By any reasonable standards, the Corps has been very successful in achieving these historical goals. Many significant benefits have accrued to the installation and operation of the controls, and it is fair to say that they have resulted in major improvements over natural conditions for some uses. However, the river-control works also have caused other problems, which now must be addressed. The recent emphasis placed on recreation and environmental conservation as high priority objectives of river management needs to be reconciled with the traditional objectives, to develop a more comprehensive approach to river planning, management, and utilization." (Sayre and Kennedy, 1978, p. 4)

This quote from the proceedings of a workshop dealing with the present problems of the Missouri River serves as an appropriate introduction to this report. As the Missouri River was tamed from a natural river into its present highly controlled state, as a navigable waterway, there have been dramatic changes and losses of natural areas along the river. These natural areas, consisting of wetlands, bars, islands, overflow lands, and adjacent timbered areas, represent important fish and wildlife habitats, potential recreation areas, and other conservation resources. It is generally agreed that these changes and losses have been significant. However, in general, these changes have only been qualitatively evaluated.

The purpose of this report is to quantitatively document the magnitude of the changes in land and water areas of the Missouri River bordering Iowa. Hopefully, the quantification of these changes will provide some perspective for future planning and discussion of conservation resources along the Missouri River. This report only addresses the quantitative measurements of these physical changes, but not the assessment of their full impact on conservation resources.

This project was undertaken at the request of the Iowa Conservation Commission, and was funded, in large part, through a contract from the Commission to the Iowa Geological Survey. The project has been guided and assisted through all phases by Mr. Gerald F. Schnepf and other personnel of the Iowa Conservation Commission.

Some of the information presented was derived from materials provided the authors by the U.S. Army, Corps of Engineers. This will be cited as (C.O.E., unpub.), for Corps of Engineers, unpublished documents. Some of these materials are also discussed in Sayre and Kennedy (1978). Assistance was also provided by Mr. Oscar Lara and Ivan Burmeister, U.S. Geological Survey, Water Resources Division, Iowa City. The authors also, gratefully acknowledge Mr. Dean Thompson, Mr. Robert McKay, Mr. John Coughlin, Mr. Peter Kollasch, Mr. Richard Talcott, and Mr. M. Patrick McAdams, all of the Iowa Geological Survey, and Mr. Paul Waite, State Climatologist, for their assistance in various phases of the project. Most notably the work of Mr. John Knecht and Ms. Edith Couchman is acknowledged; they prepared all the maps, artwork, and illustrations, and designed the final publication.

AVAILABILITY AND SELECTION OF DATA

To quantitiatively document these changes, measurements of various land and water features were compiled from historical maps and aerial photographs of the Missouri River. The methóds used are similar to that used by Funk and Robinson (1974) in a comparable study of changes of the Missouri River in Missouri. They compiled measurements of physical features in and along the river channel for the years 1879 and 1954. In the present study, measurements were taken for the years 1879, 1890, 1923, 1947 (1944 and 1945), and 1976. The following sections describe the rationale and methodology used to select source maps and to make the measurements.

Selection of Time Periods

The choice of base maps and time periods was of course constrained by the limited number and quality of historical maps and photographs available. From the available base maps the five particular periods were selected on the basis of the following criteria: 1. the maps show the river conditions before and after major periods of construction of design channels and control structures; 2. the maps were compiled in as short a time span as possible; 3. they provide complete and detailed coverage of land and water features at least in the immediate area of the channel; 4. for the early periods in particular, data to determine the location of the thalweg are available; 5. the maps depict the river at "typical," moderately low-flow conditions. The following sections describe the significance of the criteria and how they have been met for the selected time periods, except 1879. The 1879 map series was the first detailed survey of the river. However, the maps were compiled, in part, during flood conditions or at least higher than normal discharges. The 1879 data are included primarily for the comparison with the study of Funk and Robinson (1974) in Missouri.

Construction History

The chronology of channelization, stabilization, and regulation of the Missouri River was a principal factor in determining the time periods to analyze. To trace the effects that artificial controls have had on the river, pre-control baseline conditions must be established as well as conditions after major periods of construction.

Prior to 1930, the Missouri River in Iowa was in a natural, uncontrolled state. Only small, local structural controls, such as short flood levees, had been placed around bridges and towns. In the mid 1930s, the first major period of channel realignment began. The many braided reaches were channelized into a single, sinuous channel, eventually established as the 1941 design channel.

Little further construction or maintenance work could be done until after WW II. However, before many structures could be repaired or constructed, the highest flood of modern record occurred in 1952 (some estimates of the historical 1881 flood are considerably higher). Some control works were destroyed. New channels were established along several reaches where training works were breached.

In 1954, construction of the new 9-foot design channel was initiated. Between 1954 and 1967 thousands of structures were installed along the river. In a 100-mile reach between Sioux

City and Omaha the number of structures increased from about 400 in 1950 to over 1,000 in 1970. Construction of the present channel was essentially complete in 1967 and work since then has consisted primarily of maintenance of the control structures. As of June 1978 the project was considered 92% complete (C.O.E., 1978).

Another important aspect of the construction history is the chronology of dam closure on the upper Missouri River (Table 1). In particular, with the completion of Fort Randall, Garrison, and Gavin's Point dams between 1953 and 1955, the flow of the Missouri River adjacent to Iowa became highly regulated, dependent on the amount of water released from the upstream reservoirs. The dam closure also had a significant impact on the sediment discharge as well (Sayre and Kennedy, 1978; COE unpub.).

Based on the history of man-made controls of the river, three general periods were first identified for evaluation:

1. pre-1930, prior to any major construction activity;
2. 1941-1952, after the first major period of construction but before the 1952 flood;
3. post-1964, after essential completion of the present channel and closure of upstream dams.

Base maps were then selected to represent river conditions during these three periods. The availability and completeness of the maps and the flow conditions at the time they were originally prepared were considered in the selection of maps and are discussed in the next two sections.

Maps and Aerial Photography

Maps and reports of the Missouri River in the early and mid-1800s provide some information about the river in its natural state, but are not complete or accurate enough for detailed measurements required for this study. The earliest maps and records of the Missouri River are the reports of the Lewis and Clark expedition of 1804. Although these explorers recorded very descriptive observations of the river, they did not conduct an accurate, detailed land survey. During the 1850s and 1860s several General Land Office surveys and steamboat surveys were conducted along the Missouri River. The Land Office surveys were accurate but only covered limited portions of the river, and usually only one side of the river. The steamboat surveys, as implied, were done from steamboats. They covered the entire river but they are not very accurate, in large part having been sketched from the boat.

Table 1. Missouri River Dam Chronology[1]

Completion Date	Dam and Location	Storage Capacity acre-feet of water
1940	Fort Peck near Glasgow, Montana	18,900,000
1953	Fort Randall near Lake Andres, S. Dakota	5,700,000
1955	Garrison Dam near Garrison, N. Dakota	24,200,000
1955	Gavins Point near Yankton, S. Dakota	520,000
1962	Oahe Dam near Pierre, S. Dakota	23,500,000
1964	Big Bend Dam near Chamberlain, S. Dakota	1,910,000

1. COE, unpub.

The first complete, detailed map series of the entire Missouri River was compiled by the Missouri River Commission in 1879 (later published in 1881). The maps show in great detail the water, land, and vegetation features of the channel and adjacent lands. Less detail is shown for areas away from the channel.

The maps also include depth soundings of the river so the location of the thalweg (the deepest part of the channel) could be delineated. This is an important criterion for selection of maps because until the 1940s, the Iowa-Nebraska state border was defined as the thalweg of the river. Consequently, the thalweg location is necessary to divide the measurements of water and land areas into their Iowa and Nebraska components. After the 1940s, the state border, known as the 1943 Compact Line, was established by legislative and later court action as the center of the 1943 design channel.

The Missouri River Commission resurveyed the river from Sioux City to the mouth in 1890-91. These maps were published in 1893 and show detail and coverage comparable to the 1879 maps. However, several changes in the configuration of the river channel had occurred by natural processes since the previous mapping. Justification for resurveying the river was given by the Missouri River Commission: "Since the topographical survey of 1878 and 1879 was made, numerous and important changes in shore line have occurred, so that the published maps of that survey have become quite unreliable as to the present shore line (Suter, 1891, p. 3735)."

The next detailed survey which covered the entire length of the river and included soundings to determine the thalweg was the 1923 series of maps prepared by the U.S. Army, Corps of Engineers. Then beginning in 1927, with the authorization of the 6-foot navigation channel from Kansas City, Missouri, to Sioux City, Iowa (Bondurant, 1963), the Corps of Engineers prepared detailed work maps of the river from aerial surveys, almost yearly into the 1940s. Although accurate and detailed, the maps do not show the location of the thalweg. Construction of the new channel and preparation of the work maps ended in the mid-1940s.

The Corps of Engineers published a later series of maps which are commonly referred to as the 1947 tri-color topographic maps. These detailed topographic maps cover the entire width of the Missouri River floodplain. They were prepared from aerial photography and ground surveys during the fall and winter of 1944-1945. The data derived from these maps will be referred to as 1947 data, however, because the map series is well known as the 1947 tri-colors. These maps do not show the location of the thalweg. However, the center line of the narrow, confined 6-foot navigation channel that was present is a close approximation of the thalweg, and of the Iowa-Nebraska state border.

In 1945 the present 9-foot navigation channel was authorized for construction, but little engineering work was done until the 1950s. Aerial photography was acquired and work maps were prepared intermittently by the Corps of Engineers during the 1950s. Detailed 7½-minute topographic maps covering the Missouri River valley were also prepared by the U.S. Geological Survey in the 1960s. However, because the last upstream reservoir (Big Bend near Chamberlain, SD) was not completed until 1964, a more recent record was required to represent post-1964 river conditions.

Recent aerial photography was selected to prepare the most current base map. Low-altitude color photography was acquired on November 11, 1976, by the Iowa Geological Survey, Remote Sensing Laboratory, for the Iowa Conservation Commission. Unlike other available photography, this set was taken at one time and specifically covers the entire length of the river in Iowa. Since few river modifications have been made since the late 1960s, it depicts the completed modern design channel.

Flow Conditions

The hydrologic regime, particularly the stage of the river, at the time a map is made or photograph is taken is another criterion for the selection of base maps and evaluation of the measurements made for this study. Obviously the area of water and other channel features measured would be much different at flood stage than at low-water stage. It would not be valid to consider the difference in measurements taken at extremely different stages to be solely a function of engineering controls or of natural, long-term changes of the river.

Perhaps an example will illustrate the significance of river flow conditions on the measurement of land and water areas along the river. The Siouxland Interstate Metropolitan Planning Council recently completed a detailed study of land-use changes along part of the Missouri River from 1956 to 1975 (SIMPCO, 1978). Although the study is quite thorough, some of the measurements are problematical. For example, the study shows a substantial increase in wetlands during a time when most observers agree the area of wetlands have declined. For the SIMPCO study land-use measurements were made from 1956 aerial photography taken when the discharge of the Missouri River at Sioux City was about 31,400 cfs, a moderate discharge that is equalled or exceeded about 40% of the time. The 1956 measurements were compared with similar measurements from 1975 aerial photographs taken when river discharge was 60,000 cfs, a relatively high discharge equalled or exceeded only 5% of the time. The difference in the magnitude of these discharges is apparent in figure 3 (compare October 1975 to February-March 1976).

The SIMPCO report points out: "It should be noted that, since the river was at a high level during this year [1975], acreage figures for the river and wetland will most likely be inflated" (p. 5); and "A substantial amount of this wetland increase is due to the high water level evident in August of 1975" (p. 11). Figures compiled in such a manner must be interpreted with care. It would be ideal to compare the features of the river at some "typical" or normal discharge for all time periods. This is an impossible task, in part because there is a limited number of maps and photographs to use. Also, it is nearly impossible to define a discharge value that is "typical" for the last hundred years. Discharge is a measure of the volume of water and is related to the width and stage (elevation of the water surface) of the river. As the river channel changes in width and depth, naturally or otherwise, the relations between stage and discharge may change dramatically. For example, in many places the bottom of the channel has been progressively lowered so that a given discharge now occurs at a lower stage than in previous years.

Since discharge and stage measurements for various years since 1879 can not be compared directly, streamflow duration

Table 2. Monthly flow duration data for Sioux City, Iowa, during the period of river mapping in 1879 and 1890.

Time Period	Mean Discharge (cfs)*	% Time Equalled or Exceeded	Gage Height (ft)	Standard High Water (ft)	Below** SHW (ft)	Standard Low Water (ft)	Above**** SLW (ft)
1879—SIOUX CITY							
June	141,900	4.0	676.5	679.4	−2.9	669.0	+7.5
July	111,400	10.5	674.8	679.4	−4.6	669.0	+5.8
August	44,500	44.0	670.3	679.4	−9.1	669.0	+1.3
1890—SIOUX CITY							
January	26,400	74	668.1	679.4	−11.3	669.0	−0.9
February	34,400	57	669.3	679.4	−10.1	669.0	+0.3
March	39,000	51	669.7	679.4	−9.7	669.0	+0.7
April	48,800	39	670.6	679.4	−8.8	669.0	+1.6
May	49,600	39	670.7	679.4	−8.7	669.0	+1.7
June	102,300	7	674.4	679.4	−5.0	669.0	+5.4
July	87,600	19	673.5	679.4	−5.9	669.0	+4.5
August	47,500	41	670.5	679.4	−8.9	669.0	+1.5
September	32,200	60	669.0	679.4	−10.4	669.0	0.0
October	24,600	74	668.1	679.4	−11.3	669.0	−0.9
November	25,200	72	668.2	679.4	−11.2	669.0	−0.8
December	21,900	80	667.8	679.4	−11.6	669.0	−1.2

* cfs—cubic feet per second
** Feet below standard high water gage height
***Feet above standard low water gage height

curves were used to evaluate the relative frequency and magnitude of flows. A flow duration curve is a graph showing the percent of time, or frequency, that a given discharge is equalled or exceeded. Since low flows are equalled or exceeded more frequently than high flows, the values for the percent of time vary inversely with discharge; the higher the percent value, the lower the discharge. As an example, protected low flow in Iowa streams is defined as the 84% duration flow, whereas flood flows are equalled or exceeded only a few percent to less than 1 percent of the time.

A duration curve is constructed by listing from highest value to lowest the discharge measured at a stream gaging station. From this ranked listing the percentage of time is calculated (e.g., number of days divided by total number of days, if daily data are used) that specific discharges have been equalled or exceeded. The duration curve is then drawn by plotting the discharge values vs. the corresponding percentage of time and fitting a smooth curve to the plotted points. The frequency of occurrence, as percentage of time equalled or exceeded, can then be read from the curve for any given discharge (see figure 1).

Flow duration data were calculated from available discharge records of gaging stations along the Iowa reach of the Missouri River. The earliest data available are mean monthly discharge estimates for Sioux City from January, 1879, through December, 1890 (Suter, 1891, p. 3827). The duration data and gage height information (COE, unpub.) are used to assess the relative magnitudes of flows for the 1879 and 1890 map series.

The earliest discharge data available after 1890 are mean monthly values for Sioux City beginning in October, 1897 (U.S. Geological Survey, 1958). The duration data used in conjunction with the 1923 map series was calculated from monthly means from October, 1897, through October, 1937. The cutoff date was selected because river flows have been partially regulated by upstream dams since November, 1937. The height of flood stage at Sioux City was taken from the National Weather Service (1923) and gage heights for monthly discharges were obtained from unpublished rating curves of the U.S. Geological Survey.

Recording of daily discharge data did not begin along this reach of the river until 1928. Duration values calculated from daily records are compiled in Lara (in press). The values from 1937 to 1976 were used to prepare duration curves for Sioux City, Omaha, and Nebraska City. Curves for 1931-1937, 1938-1957, and for 1958-1976 for Nebraska City were prepared from data provided by the U.S. Geological Survey (figure 1). Flood stages in 1944-45 and 1976 for the 3 stations were taken from the National Weather Service (1944, 1945) and from Lara (1976). Gage heights were obtained from unpublished rating curves of the U.S. Geological Survey.

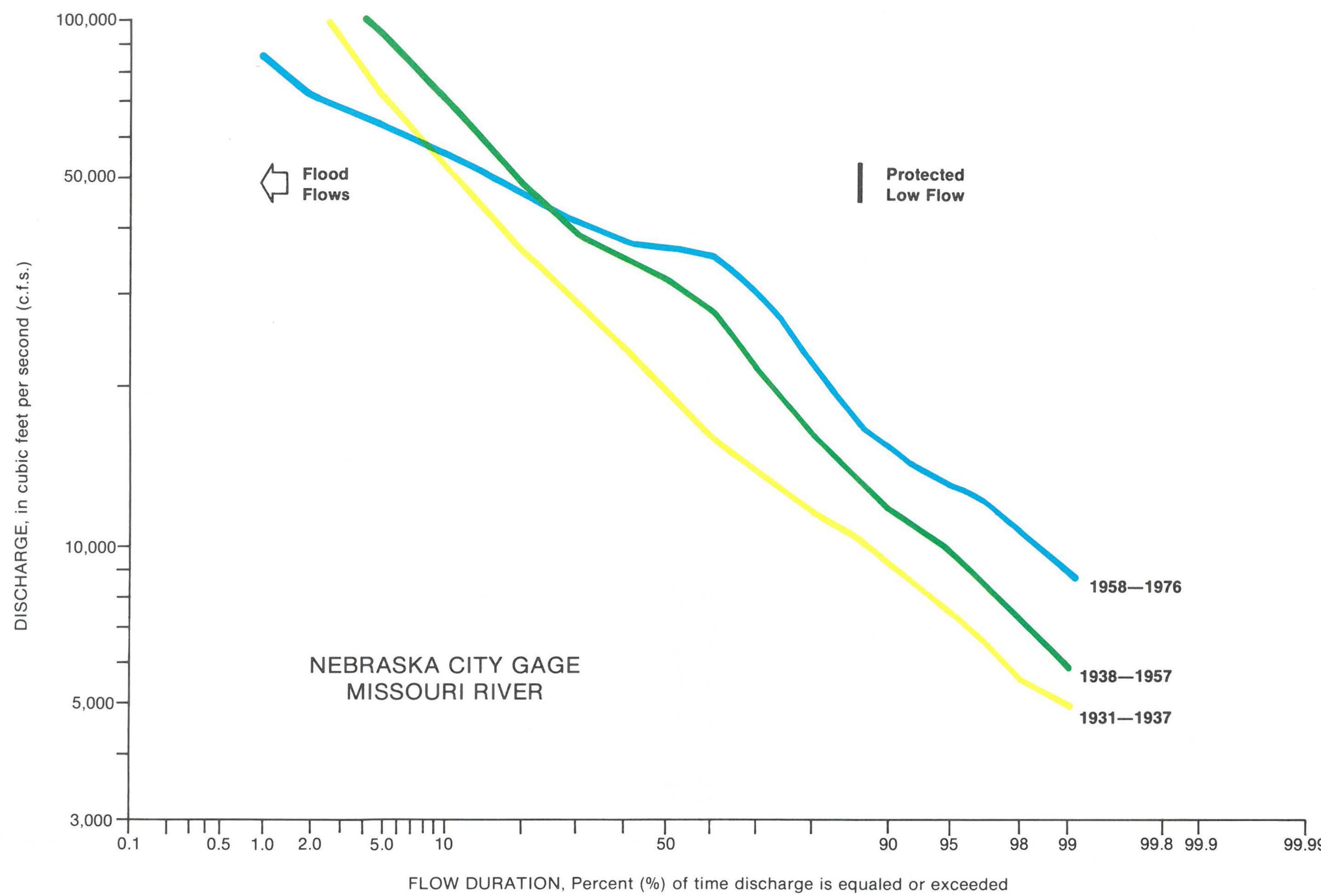

Figure 1. Flow duration curves for the Missouri River, prepared from daily discharge data from the Nebraska City gaging station. Three curves are shown; 1. For the period 1931-1937 when the river was in a natural flow condition; 2. 1938-1957, when the flow was partially regulated; and 3. 1958-1976 when the flow of the river was highly regulated by dams (data, in part, from Lara, in press).

1879

Field mapping for the 1879 map series from Sioux City to the Iowa-Missouri border was done between June 5 and September 3, 1979. Mean monthly discharges during this period are relatively high, being equal to the 4, 10.5, and 44% duration flows for June, July, and August, respectively (Table 2). Mean daily and instantaneous peak discharges during these months, especially June and July, were undoubtedly much greater than the monthly averages. Since there were no significant river control structures to confine high flows, the water and land areas mapped during part of this time represent the width and configuration of the river channel and backwater areas under infrequent high-flow or flood conditions. On each original map sheet a rating of flow conditions is given, and many of these ratings indicate "high water" or minor flood conditions. The 1879 maps, in particular those areas mapped in June and early July, do not represent a fair basis for comparison with the later controlled flow period. However, the 1879 data is included because it is used in the similar study by Funk and Robinson (1974) in Missouri, and therefore will allow some comparisons with their results.

1890

Field mapping for this map series was conducted during 1890, except for Fremont County, which was done in 1891, a year for which there are no discharge estimates. The flow duration and gage height data for 1890 indicate that flow conditions were lower than those during the mapping period in 1879 (Table 2). Except for June and July, the gage heights for the mean discharges were either below or less than two feet above the Standard Low Water stage and had flow duration values greater than 39%. (Table 2). Thus, the water areas shown on the 1890 maps more closely represent more typical flow conditions.

1923

The 1923 maps are based on field surveys conducted during May to the first week in June, and August 27 to October 5, 1923. The intent of the mapping was to survey the river at relatively normal conditions. No major floods were recorded during this period. Mean monthly discharge for May through September appear relatively high, with a 6-7% duration flows for June and July (Table 3). However, gage heights corresponding to the mean monthly discharges are generally less than half flood stage. This suggests that, on the average, river stage was less than half bankfull during most of this period.

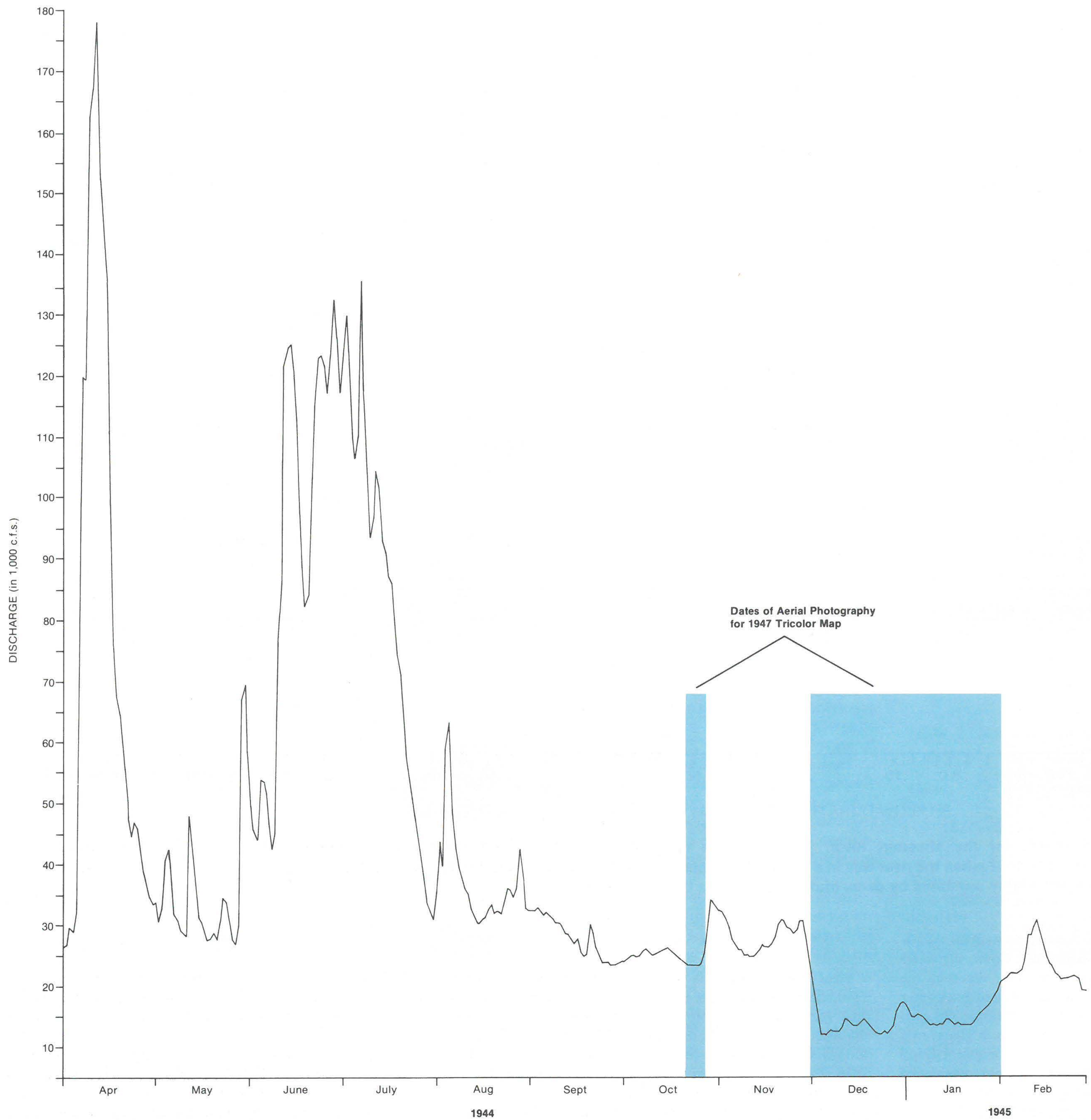

Figure 2. Daily hydrograph for the Missouri River at Sioux City, Iowa; April 1944 through February 1945.

Table 3. Monthly flow duration data for Sioux City, Iowa, during the period of river mapping in 1923.

Time Period	Mean Discharge (cfs)	% Time Equalled or exceeded (1837-1937)	Gage Height (ft)	Flood Stage (ft)	% Time Equalled or Exceeded (1879-1890)
May, 1923	43,900	30.0	7.05	17	42.5
June, 1923	87,400	6.3	8.98	17	19.0
July, 1923	84,600	7.0	8.87	17	20.0
August, 1923	60,200	16.5	7.90	17	30.5
September, 1923	26,900	47.0	5.72	17	69.0

The high duration values illustrate some of the limitations the early discharge records impose on duration curves. The data for 1897-1937 are biased toward lower flow conditions by the extended period of low flows during the 1930s. Consequently, higher durations are assigned to moderate and low discharges than would be the case using the 1879-1890 data. For example, the percent of time the 1923 flows were equalled or exceeded based on the 1879-1890 records are included in Table 3. What appears to be a high duration value of 6.3% for June, 1923, is only a 19% duration flow by the 1879-1890 standard. Compared another way, the 6.3% duration flow for June, 1923, equalled a discharge of 87,400 cubic feet per second (cfs), but a 6.3% flow for 1879-1890 was about 130,000 cfs. These differences result primarily from the nature of the flow regimes. As will be discussed later, 1879-1890 was characterized by relatively high discharges, whereas the early 1900s were marked by relatively lower flow conditions. (See Figure 11 for graph of mean annual discharge since 1879.) Despite these limitations, however, it is apparent that the river was not at high water stage when the 1923 maps were prepared.

1947

The aerial photography from which the 1947 map series was prepared was obtained during October 21-27, 1944, and during December, 1944, and January, 1945. Late fall and winter is normally the period of low flows on the Missouri River because of reduced precipitation, freezing temperatures, and low runoff in the river basin. High discharges, stages, and overbank flooding are infrequent and usually associated with backwater flooding from ice jams or the release of upstream water during rapid breakup of ice. The daily discharge records for Sioux City, Omaha, and Nebraska City show relatively low water conditions during the periods the photography was taken (U.S. Geological Survey, 1958). The monthly averages and daily maximum discharges at all stations are less than the 62% duration flow (Table 4). Gage heights show that river stages at Sioux City and Omaha are less than ⅓ bankfull and at Nebraska City, approximate or are less than ½ bankfull.

Figure 2 shows the daily discharge hydrograph for the Missouri River at Sioux City during this time period. The flow of the Missouri River was only partially regulated by Fort Peck Dam, and the 1943 design channel had been completed. The daily discharges at the time the aerial photography was acquired can be compared with the flood discharges during April and June-July of 1944. It is apparent that the 1947 maps and the measurements taken from them depict the river at relatively low-flow conditions.

1976

The 1976 maps have been compiled from aerial photography taken November 11, 1976. Mean daily discharges for Sioux City, Omaha, and Nebraska City range between 27 and 30% duration flow (Table 4). Although this suggests relatively higher flow conditions than, for example, during 1944-45, the relationship of gage heights to flood stages indicates that the river stage on this day was only ⅓ to ½ bankfull.

Again some changes in the flow regime and river conditions result in problems in comparing these values over time. By 1976 the Missouri River is a fully controlled stream; its channel geometry is wholly different than in the past and its flows are highly regulated by upstream dams. This is apparent by inspection of figure 3, the daily hydrograph for Sioux City during part of 1975 and all of 1976. It is obvious that the discharge of the river at the time the photography was taken (37,300 cfs) approximates the typical controlled flow of the river for much of 1976. This discharge is also considerably lower than the controlled flow in late 1975.

A comparison of figures 2 and 3 shows some of the effects of flow regulation. The most obvious effects are the reduction in peak discharges and smaller fluctuations in the sustained, controlled flows. The three duration curves in figure 1 also show the progressive regime changes with added regulation from natural conditions (1931-1937) to partial regulation (1938-1957) to current conditions of fully regulated flow (1958-1976). Moderate discharges in the 30%-70% duration range were much lower in the natural regime. The median or 50% duration flow was 20,000 cfs in 1931-1937, but was 37,000 cfs in 1958-1976. This regulated flow would have been about an 18% duration flow in the natural regime. Another unique feature is the very flat portion of the 1958-1976 curve between 30% and 60%. This is very unnatural and is the result of sustained, moderate discharges maintained for navigation purposes.

Extreme discharges have also been moderated by river controls. Low flows are now maintained at higher levels for navigation purposes. For example, a 99% flow for 1931-1937 was about 5,000 cfs, but for 1958-1976 was 9,000 cfs. At the other end of the curves the high discharges are much reduced, as shown by the crossing of the duration curves at about a 10% flow. In fact, major floods have essentially been eliminated on this part of the Missouri.

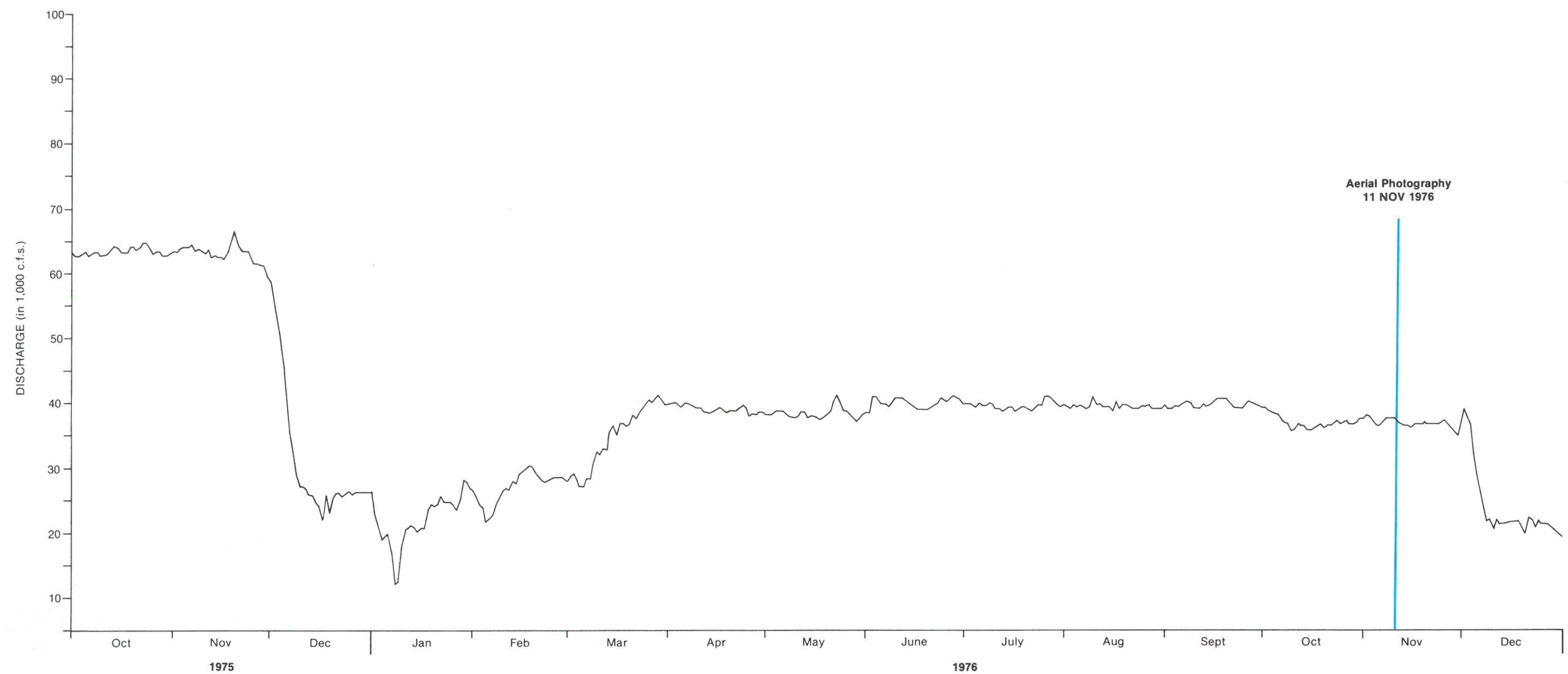

Figure 3. Daily hydrograph for the Missouri River at Sioux City, Iowa; October 1975 through December 1976.

Table 4. Flow duration data during acquisition of aerial photography for 1947 and 1976 map series.

Time Period	SIOUX CITY Mean Discharge (cfs)	%Time Equalled or Exceeded	Gage Height (ft)	Flood Stage (ft)	OMAHA Mean Discharge (cfs)	%Time Equalled or Exceeded	Gage Height (ft)	Flood Stage (ft)	NEBRASKA CITY Mean Discharge (cfs)	%Time Equalled or Exceeded	Gage Height (ft)	Flood Stage (ft)
Oct. 21-27, 1944	23,900	62	2.2	19	23,300	67	5.58	19	26,200	70	6.73	15
Dec., 1944	14,020	79	2.21(ice)	19	13,590	82	2.65	19	15,650	86	8.46	15
(Dec. Max)	23,400	63	2.01	19	24,000	66	4.56	19	28,000	67	9.22(ice)	15
Jan., 1945	14,850	78	4.7 (ice)	19	15,130	79	4.00	19	19,210	80	5.51	15
(Jan. Max)	19,200	71	6.18(ice)	19	17,000	77	6.07(ice)	19	23,000	74	5.98	15
Nov. 11, 1976	37,300	27	19.4	36	38,600	28	6.15	19	40,800	30	8.91	18

METHODS USED

It was necessary to define land and water features that could be consistently identified and measured on all selected historical base maps. On most of the older maps, only the features immediately adjacent to the river channel were surveyed in detail. Channelization and stabilization works prompted many land-use changes on nonadjacent bottomlands. However, the limited coverage of the older surveys does not allow consistent measurement of these changes, nor can they be entirely attributed to the training of the river. Consequently, the areal measurements used to trace the river changes through time are restricted to readily identified natural features of the immediate channel area. This area also approximates, but is not wholly inclusive of, the areas along the river that would come under the jurisdiction of the State of Iowa, namely, the lands below "ordinary high water."

All of the land and water features measured are defined in Table 5. These features were delineated on the base maps and the acreage or mileage of each was measured with an electronic planimeter. The first area outlined is the channel area since it marks the boundaries of all other areas. The channel area includes the main channel plus the minor chutes and sand bars, islands, and backwater areas that separate them from the main channel. In general, it is the area that is most unstable and changing, for it experiences inundation and high discharge flows at least every few years. The channel area is rather clearly shown on the base maps by natural features as channel bars, meander point bars, and braided chutes and channels. In some places the limit of the channel area is easily defined, as it is directly against the bluff line of the Missouri River valley or is clearly outlined by prominent high banks. Cultural features, such as towns, roads, rail lines, or cultivated fields, often occupy the high banks and these features reinforce the interpretation of the channel boundaries. In some portions of the river the outline of the channel area is marked only by map symbols representing timbered areas. These stands of cottonwood, box elder, elm, and other riparian trees indicate relatively stable bank areas which are not flooded frequently any longer. Obviously there are complex transition zones where stands of willows may grade to barren bar sands. In these cases some judgements must be made as to the location of the channel boundary.

In many cases the surveyors who produced the early maps along the river made these judgments during their field inspections. They often delineated the channel area of the river with a solid line which simplified the task of defining some unclear boundary areas. Figure 4 shows an example taken from the 1890 Missouri River Commission maps which will help illustrate how the channel features were identified. The area in color (blue = water; yellow = sand bars; green = islands) is

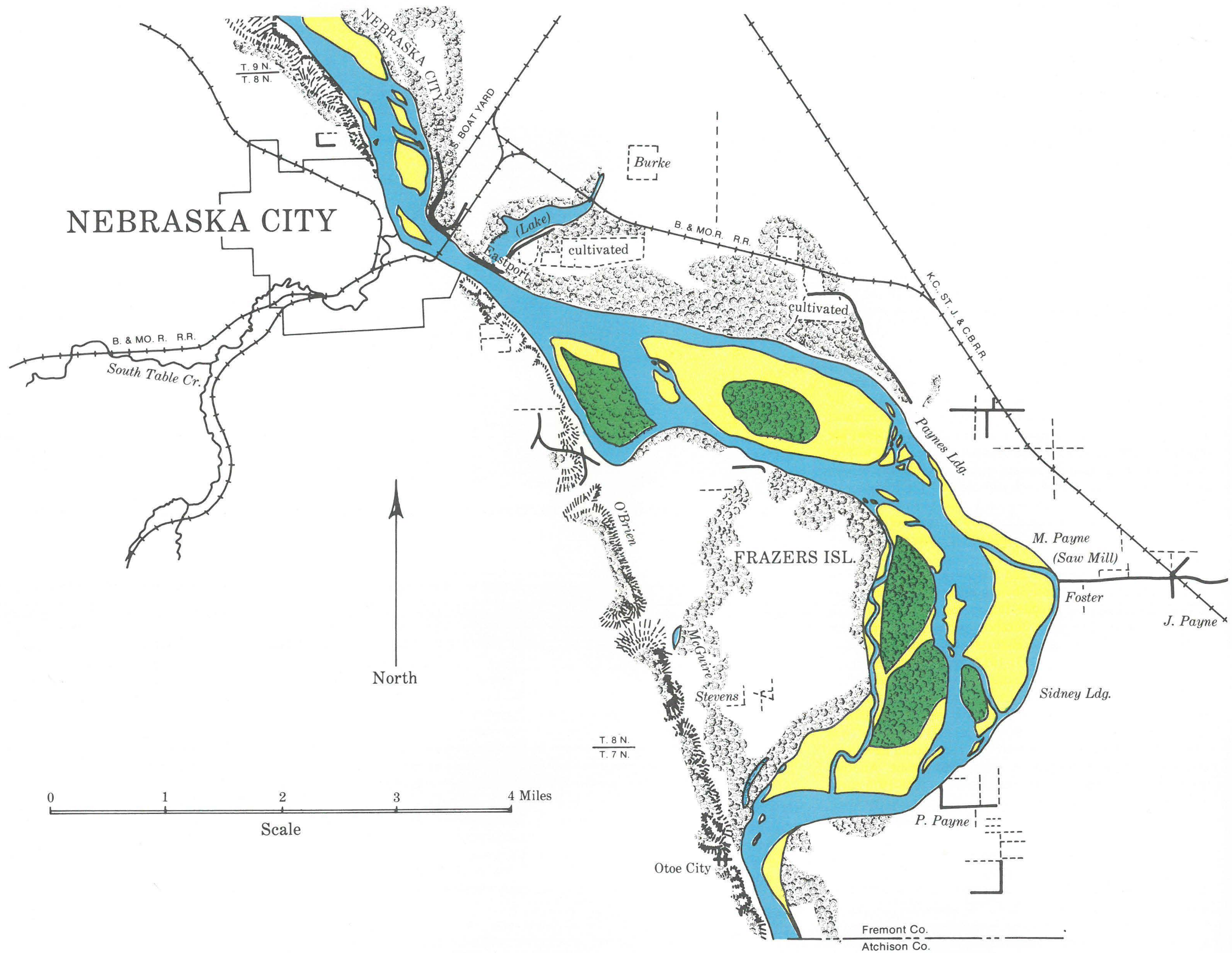

Figure 4. Portion of the 1890 Missouri River Commission map sheet 21. The channel area is shown in color; blue = water; yellow = sand bars; green = islands.

Table 5. Definition of Missouri River Channel features measured.

CHANNEL AREA	portion of the flood plain occupied by the main channel of the river, as well as minor channels and chutes, includes features such as open sand bars and islands, point bars, and cutoff channels. The land features within this area are for the most part unvegetated and unstable, indicating they are still frequently overflowed by the river.
WATER AREA	area of water surface contained in the channel area.
BAR AREA	areas within channel area shown as emergent sand or alluvium with relatively little permanent vegetation.
ISLAND AREA	area of alluvium, with well established vegetation such as willows or timber, within channel area.
RIVER MILES	horizontal distance, measured along thalweg of river. For convenience of reference, river miles are marked on the Appendix maps every 10 miles, numbered consecutively from the southern border of the state of Iowa.
LINEAR MILES	horizontal straight line distance through channel area.
SINUOSITY RATIO	river miles divided by linear miles; a measure of river meandering.
"TOTAL" CHANNEL AREA*	only used in 1947 data; this area is analagous to the channel area in appearance, but it is not directly comparable because it represents the extensive water and bar areas that were artificially cut off by the construction of the design channel, but which had not filled in with sediment or become stabilized and occupied by timber or cultural features by 1947. Includes "active" channel area of 1947.
"ACTIVE" CHANNEL AREA*	only used in 1947 data; this area represents the artifically controlled design channel as of 1947.
BACKWATER AREA*	measured only on 1976 maps; this area represents the few remaining open slack-water areas in 1976, which were artificially cut-off by construction of the design channel.
"POLITICAL" ISLAND AREAS*	measured only on 1976 maps; this area represents tracts of land between the 1943 compact line and the center of the 1976 channel.

*Special measurements (these features were only measured on the 1947 or 1976 maps.)

the portion marked on the map as the channel area. Note some of the features which delineate the channel boundary. In small stretches the river bank is immediately against the bluffs or the town of Nebraska City. In other areas the boundary of the channel area is bordered by stable, timbered tracts. In others, man-made developments such as houses, roads, or plat and field boundaries, are shown coming right to the bank, again indicating some stability.

In the area of Frazer's Island, a large, complex point bar, judgement must be used as to how much of this shore area to include in the channel area measurements. In this case, the field surveyors line was followed. The area on the south and east side of Frazer's Island is shown as an active sand bar (in yellow), which contained some areas with willows on it (shown in green, included as an island), and a minor chute or bar swale with water in it (shown in blue). This area is obviously part of the channel area. The remainder of Frazer's Island was not included because it is much more stable land, as shown by the cover of timber as well as the permanent cultural features. Certainly this area was occasionally flooded, but not often enough to hinder the growth of mature timber and man-made developments.

After the boundaries of the channel, bar, and island areas were outlined on the base maps, the thalweg and/or the 1943 compact Line was outlined as the state boundary. The areas of the land and water features were measured for the entire channel area and for the portions in Iowa and in Nebraska. The data was also summarized into six river reaches which coincide with the boundaries of the six Iowa counties which border the river. The data is tabulated in the Appendix along with summary maps for each of the periods showing the areal changes in the river.

CHANNEL CHANGES

Dramatic changes in the area, length, and configuration of the Missouri River channel have occurred over the past century. The most graphic illustrations of the changes are the maps of the river for 1890, 1923, 1947, and 1976 included in the Appendix. The maps show the reduction in channel area and river miles and the trend from a complex to a simplified, narrow, gently curving channel. All of the area and mileage measurements are compiled in several tables and figures in the Appendix.

The following sections describe the changes in detail. The first sections deal with characteristics of the river before any major construction of river control works. Natural changes that occurred between 1879 and 1890 and 1923 are compared for the entire Iowa reach, for the six county segments, and for the reaches north and south of the Platte River. The discussion of natural changes and their possible causes provide a background for the later discussion of channel changes brought about by construction of the navigation channel and river control structures.

The Natural River—pre-1930

The Missouri River channel before the 1930s was a continually changing natural feature. The river continually adjusted channel width, depth, and length in an attempt to balance the factors that controlled the channel geometry, particularly the sediment load and the water discharge (the sediment transport capacity). If the major controls are nearly balanced (in quasi-equilibrium), channel changes will be minor. However, various hydrologic factors, such as climatic controls on discharge, undergo continuous changes and as pointed out by Schumm (1971, p. 5-4):

> When changes of channel width and depth as well as of sinuosity and meander wavelength are required to compensate for a hydrologic change, then a long period of channel instability can be envisioned with considerable bank erosion and lateral shifting of the channel occurring before stability is restored.

The extent of natural changes and adjustments that occurred in the Missouri River is reflected in the changes of channel features from 1879 to 1890 and from 1890 to 1923. These changes are summarized in table 6 and figure 5.

Although portions of the 1879 maps were surveyed when the river was at high stage, they are used as a starting point from which to review natural changes. From 1879 to 1890, the length of the channel (river mileage) and sinuosity increased slightly. Sinuosity increases as river mileage increases, indicating a less straight, more meandering river. Both the channel area and the water area decrease during this time by -11% and -37%, respectively. The area of islands sharply decreased by -41% but the area of open sand bars nearly doubled. These channel changes are related in part to the high flow conditions in 1879. High flows would tend to straighten the channel, increase the apparent channel and water areas, and scour or flood over shifting sand bars.

Unlike the 1879 to 1890 period, flow conditions in 1890 and 1923 were more comparable with moderate to low flows during most of the mapping periods. However, the magnitudes of the changes between 1890 and 1923 are similar to those from 1879 to 1890, indicating the continuous nature of channel changes, and adjustments in the natural regime. The significant difference is that all of the changes are in the opposite direction from the 1879-1890 changes. River mileage and sinuosity decreased by -7% but channel and water areas increased by 7% and 25%, respectively. The total area of islands and bars was about the same in 1923 as in 1890, but their contributing areas were reversed; bar deposits decreased -32% but island area nearly doubled, increasing by 98%.

This points out the balance that tends to occur in the natural river regime. Over time, changes in channel features are both positive and negative; some features increase in area while others decrease. Channel changes between 1879 and 1890 and between 1890 and 1923 reflect alterations and subsequent adjustment to hydrologic changes, namely the high flow events in the 1880s followed by a period of low flows and continued change to a more braided stream pattern.

Table 6. Summary of changes in Missouri River channel features; 1879 to 1923

Time Period	River Miles		Sinuosity		Channel Area		Water Area		Island Area		Bar Area	
	Miles	% Diff.	Ratio	% Diff.	Acres	% Diff.	Acres	% Diff.	Acres	% Diff.	Acres	% Diff.
1879-1890	+ 3.7	+ 2%	1.50 – 1.52	+ 1%	– 9,086	– 11%	– 21,140	– 37%	– 3,986	– 41%	+ 14,671	+ 99%
1890-1923	– 14.3	– 7%	1.52 – 1.42	– 7%	+ 5,240	+ 7%	+ 9,031	+ 25%	+ 5,075	+ 98%	– 9,496	– 32%

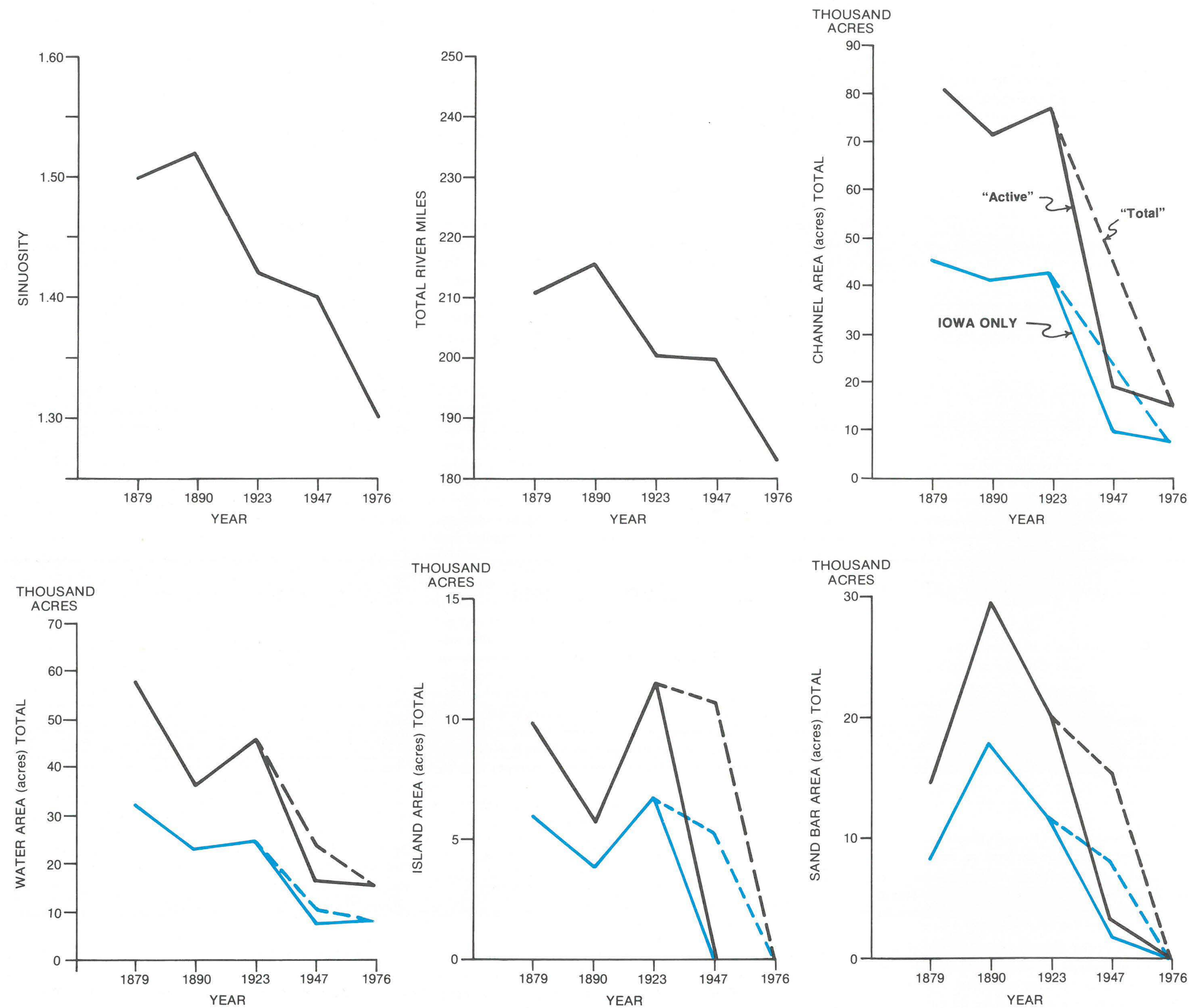

Figure 5. Summary graphs showing changes in the Missouri River channel features adjacent to Iowa, 1879-1976. From 1923 to 1976 the dashed and solid lines show "Active" and "Total" channel categories for 1947 (as defined in Table 4). The lower blue line shows the trends for the Iowa portion alone.

The impact of hydrologic changes on the natural channel may be illustrated by the balance between bars and islands. In 1881 a large magnitude flood occurred on this portion of the Missouri River. Although the instantaneous discharge was not accurately recorded it is estimated by some to be considerably higher than the 100-year flood of 441,000 cfs that occurred in 1952. Major floods tend to alter many channel characteristics by bank erosion and bed scour, sometimes causing significant channel movements, destroying bars and islands, and generally depositing a large volume of alluvial sediments. The flood of 1881 and other high discharge events in 1884, 1887, and 1888 (see Figure 11) undoubtedly reworked the sediments in the channel area. Without sufficient time between floods for vegetation to stabilize the sediments, the result would be an increase in bar area at the expense of island area as occurred between 1879 and 1890.

During the period from 1890 to 1923, particularly after 1910, flood flows were markedly lower than previously. This would have allowed the stabilization of bars into vegetated islands.

The lower discharge also induced other changes to adjust the channel shape to the sediment load present in the channel. Through the late 1800s up to the beginning of the construction of the design channel, the Missouri River changed from a meandering pattern to a more braided stream pattern. (This will be discussed in more detail in later sections.) Braided stream channels are less sinuous and tend to be wider and more shallow than meandering channels. Between 1890 and 1923 the Missouri River decreased its length by 14 miles, adjacent to Iowa, and decreased its sinuosity by 7%. As the river decreased its length, the channel adjusted by widening the average channel area from 334 acres/river mile in 1890 to 384 acres/river mile in 1923.

This discussion points out that while major changes in channel features occur naturally, there tends to be an overall natural balance in the channel. Changes resulting from different natural processes may be out of phase from one time period to the next, such as the overall channel lengthening from 1879 to 1890 versus the channel shortening from 1890 to 1923. However, in the natural setting, the channel accommodates this by increasing the average channel width, or area, between 1890 and 1923. This is in marked contrast to the changes that have taken place because of the artificial control of the channel. As shown in figure 5, all the channel features change in the same direction after 1923; river mileage, sinuosity, channel area, water area and bars and islands all decline.

The natural balance in channel changes can also be shown for shorter reaches, although the extent and timing of changes are more complex. Figures 6 and 7 show the river mileage and channel area changes summarized by Iowa county segments. Overall, river mileage increased between 1879 and 1890. Comparison of county data however, shows that the river in the northern three counties, Woodbury, Monona, and Harrison, increased in length, while in the southern three counties, Pottawattamie, Mills, and Fremont length decreased. Between 1890 and 1923 the situation is more complicated. Though overall Missouri River mileage decreased during this time, the mileage in Woodbury and Monona Counties decreased sharply, but in Pottawattamie decreased less; mileage increased in Harrison and Mills, but only slightly increased in Fremont County.

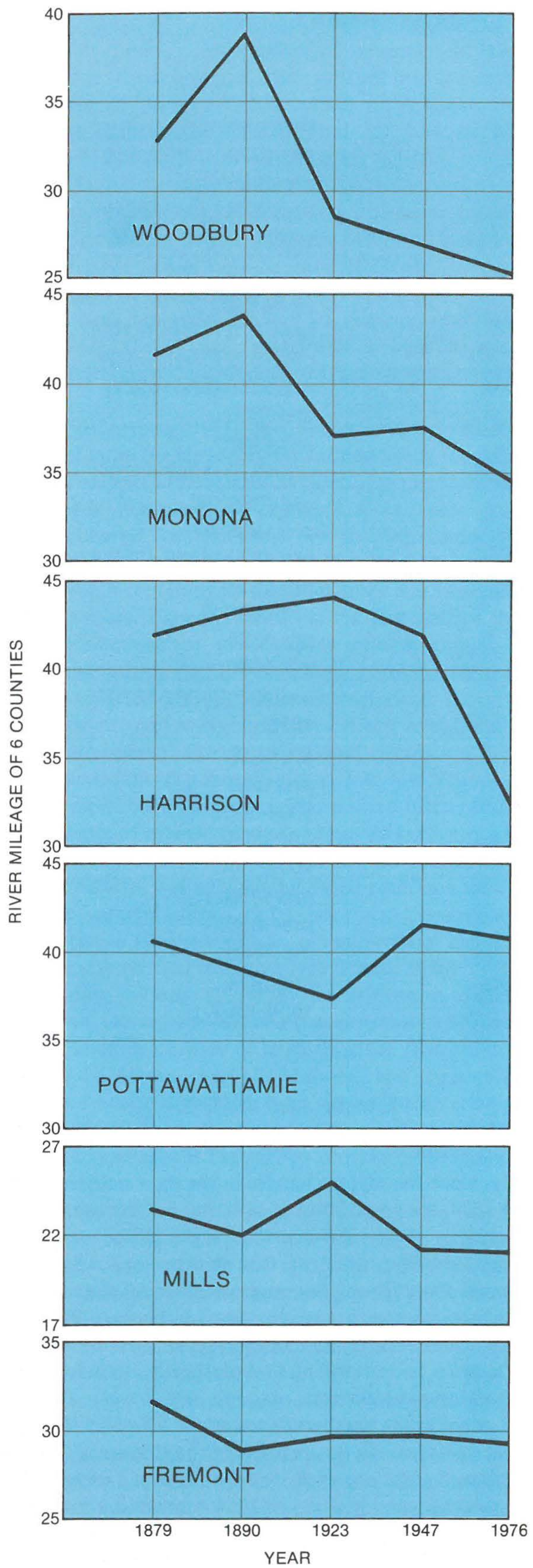

Figure 6. Summary graphs showing Missouri River mileage changes in Iowa counties from 1879 to 1976.

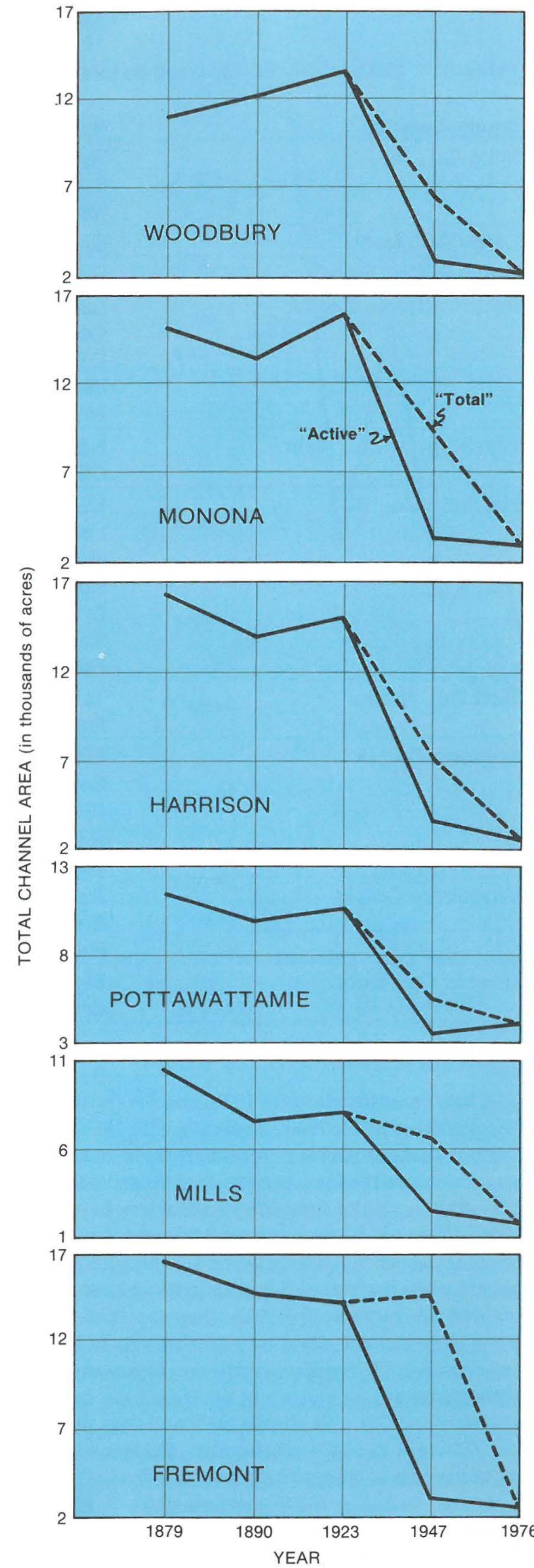

Figure 7. Summary graphs showing Missouri River channel area changes in and adjacent to Iowa counties from 1879 to 1976.

Changes in channel area also illustrate the local impacts and adjustments to hydrologic changes. Channel area increased in Woodbury County from 1879 to 1890, but decreased in all the other counties, in spite of their differences in stream length changes. Again from 1890 to 1923 the channel area in Fremont County decreases slightly, but all other counties increase.

Even during the same time period, changes in channel form in one reach may be countered by opposite changes in another adjacent reach. Again these natural changes may be compared with the aritficial changes between 1923 and 1976. With construction of the design channel, river mileage in all counties but Pottawattamie decreased and channel area in all counties sharply decreased.

The Natural River—Northern and Southern Reaches

The out-of-phase relations in the changes in 1879-1890 river mileage between the northern and southern counties is not unexpected. The natural regime of the northern and southern portions of the Missouri River adjacent to Iowa were much different. Even at the present time these reaches of the controlled river pose very different management problems.

The change in regimen of the Missouri occurs at the junction with the Platte River and many differences have been pointed out by others (U.S. Army Corps of Engineers, 1935; Whipple, 1942; Glenn, 1960; Dahl, 1961; Ruhe, Fenton, and Ledesma, 1975; Sayre and Kennedy, 1978). As reported by the U.S. Army Corps of Engineers (1935, p. 1042) ". . . there is less tendency for the Missouri River to follow a serpentine course below the Plate; the channel is broader, choked with sand bars, and shows a considerable evidence of heavy bed load", typical characteristics of a more braided river. North of the Platte, the Missouri River was more meadering with a narrower, more sinuous channel, a lower gradient, and fewer bars and islands.

Although individual features of the channel area changed over time in each of the reaches, the basic northern meandering versus southern braided distinctions were maintained. The sinuosities of the two reaches are shown in figure 8 for the time span studied. Taking 1.50 as the sinuosity of a true meander (Leopold and Wolman, 1957) it is apparent that the northern reach before 1923 was more meandering with a range of sinuosity from 1.46 to 1.69. By contrast the sinuosity of the lower reach varied only between 1.21 and 1.32. It is interesting that by 1976 after construction of the navigation channel the two reaches have nearly the same sinuosities: 1.23 in the northern reach compared to 1.20 in the southern.

The average channel width or area of the natural river also varied. In the northern reach the channel area averaged 368 acres/river-mile in 1879 and 317 acres/river-mile in 1890. By contrast, the channel area in the southern reach averaged 489 and 440 acres/river-mile for the same periods. As previously mentioned, the Missouri took on a more braided character even in the northern reach by 1923. The average channel areas were essentially equal at this time, being 410 acres/river-mile in the northern reach and 409 acres/river-mile in the southern.

The average area of sand bars and islands in 1879 and 1890 also shows the more braided nature of the Missouri south of the Platte River. In the northern reach the river averaged 96

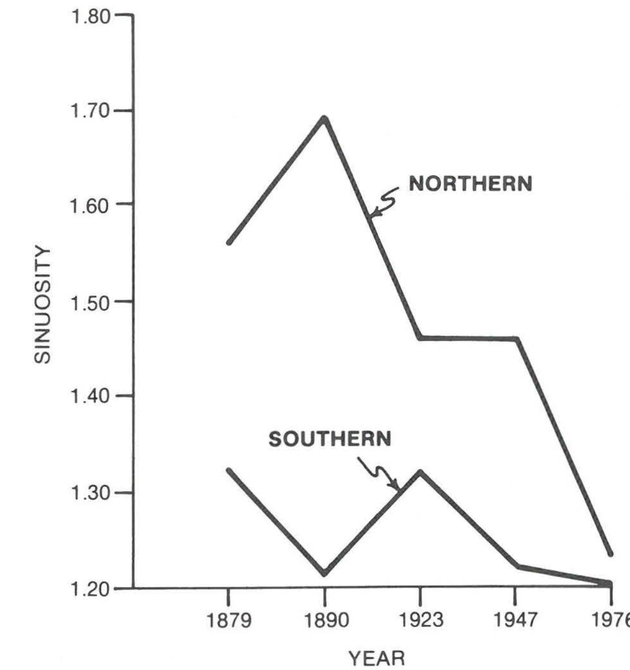

Figure 8. Sinuosities versus time for the northern (Woodbury, Monona, and Harrison Counties), and southern (Mills and Fremont Counties) reaches of the Missouri River in Iowa, 1879-1976.

and 136 acres of bars and islands per river-mile in 1879 and 1890, while the southern reach averaged 194 and 264 acres/river-mile, averaging more than 100 acres of bars and islands per river-mile more than in the north. However, with the changes that took place in the river by 1923, the areas in the northern reach increased to about 204 acres/river-mile, but decreased in the southern reach to its lowest value of 125 acres/river-mile.

Other properties of the river also change at the confluence with the Platte River. One important feature is that the low-water slope of the river increases markedly downstream. In 1890 the surface slope was 0.8 feet/mile from Sioux City to Plattsmouth and then increased to 1.23 feet/mile from Plattsmouth to Nebraska City (C.O.E., 1935). In 1930, the slope for 31 miles north of the mouth of the Platte was 0.74 feet/mile but 1.24 feet/mile for 44 miles below the Platte (Whipple, 1942).

The principal reason for all these changes in the character of the Missouri River is the sediment discharge of the Platte River. The Platte often contributes more sediment load to the Missouri than the Missouri can transport (C.O.E., 1935). "The first evident effect . . . is the building of the mound or alluvial fan in the Missouri River Valley at the mouth of the Platte (Ruhe, Fenton, and Ledesma, 1975, p. 746)." Data compiled in the 1920s and 1930s (C.O.E., 1935) shows that the Platte contributed 60% more suspended sediment, and 60-90% more bed load than is already in transport in the Missouri River (Ruhe, Fenton, and Ledesma, 1975). In addition, the bed load contriubted by the Platte is coarser (larger particle sizes) than the normal bed load of the Missouri. With this dramatic change in sediment load, the natural Missouri River changed its overall channel form to compensate.

There are several other unique aspects to these northern and southern reaches of the Missouri River in Iowa. North of the confluence of the Platte River another major change occurs in the Missouri Valley. North from about the town of Crescent, Iowa, the width of the Missouri River valley or alluvial plain (from bluff to bluff) is two to three times wider than that to the south of this area. This is related to the prevalence of Cretaceous sandstones and shales in the north and of Pennsylvanian limestones in the south. The more resistant Pennsylvanian rocks prevented the development of as wide a valley as found to the north. In places in this southern reach the Missouri River flows on or near the top of the bedrock. This would have prevented any rapid channel degradation in these areas. It is not clear what role these changes in bedrock have played, or might continue to play, in the evolution of the river.

The northern reach is also marked by a hydrologic anomaly. U.S. Geological Survey low-flow data indicate that the Missouri River is losing water through this area (Sulo Wiitala, pers. comm.). The apparent explanation is that the river loses water by seepage to the ground water system.

The northern reach of river has also been subject to larger than average reductions in channel length. The reach from Ponca to Plattsmouth constitutes about 25% of the river mileage to the mouth of the Missouri at St. Louis. Yet between 1890 and 1941, 50% of the channel shortening on the entire river took place in this reach by both natural and artificial channel changes. From 1941 to 1960, 53% of all the artificial channel shortening that took place occurred in this reach. Between 1890 and 1960 the average rate of channel shortening was three times that for the reach extending from Plattsmouth to St. Louis.

This northern reach, with all its unique characteristics and more extreme alterations, is also the stretch of the river where degradation and other river management problems are most acute (Sayre and Kennedy, 1978).

In this regard it is interesting that these northern and southern reaches which were strikingly different in their natural regime are now so much alike in the geometry of the controlled and stabilized navigation channel (for example, see figure 8). The questions still remain: what role have these natural differences played in creating the present river management problems and what role might they play in the solution to such problems as channel degradation?

The Natural Metamorphosis of the Missouri River

Some significant natural changes in the Missouri River have been discussed in the preceding sections. However, during the 1800s the Missouri River in Iowa, and in particular the northern reach, underwent an even more dramatic transformation. Reconstructions of the Lewis and Clark expedition have shown that in 1804 several oxbow lakes, such as Blue Lake and Badger Lake, were part of the main channel of the Missouri River (see Towl, 1935; Coues, 1965; Shimek, 1909). After 1804 these meander loops were cut off and left as oxbow lakes. The morphology of these lakes and related landforms (of this age or older, in particular) are that of classic meander scars and point bar deposits. They indicate that early in the 1800s the Missouri River was more of a classical meandering stream, with a single, coherent, meandering channel. This is in sharp contrast with the semi-braided nature of the Missouri River that is apparent even by the 1879 maps. The morphology of floodplain deposits, particularly after 1879, are those of a semi-braided stream. As discussed in the preceding section this metamorphosis to a straighter, shorter, wider, and more braided channel continued into the 1920s and 1930s.

This change in regime also was accompanied by degradation of the floodplain. Younger channel scars, and semi-braided stream deposits are clearly inset below the older meandering stream deposits. In places, the lower semi-braided channel floodplain surfaces are separated from the older meandering channel surface by a 10 to 12 foot scarp (Lohnes, et al., 1977).

This change in the Missouri River is called "a startling example of change", by Schumm (1971) in relating Towl's 1935 report. Towl (1935) estimated a 40% reduction in river mileage in the northern reach of the river, between 1804 and 1935. Shimek (1909) estimates a 40 mile reduction in the length of the Missouri in Harrison and Monona Counties alone, between 1804 and 1890.

Towl attributed most of the transformation of the river to the clearing of timber on the floodplain and the great flood of 1881. He stated that since that time no cutoffs had occurred, and most of the mileage reduction took place before 1890.

Using available maps and documents* such as the Lewis and Clark reconstruction of 1804, and the later land office survey maps of 1852 and 1858, and the less accurate steamboat reconnaissance surveys of Lt. Warren in 1856, and Col. McComb in 1867, in addition to the 1879 and 1890 maps, it is possible to date many of the changes along the Missouri River. Table 7 shows a compilation from a brief survey of the major apparent natural meander cutoffs and their age. In some cases it is not possible to definitely state a date because of inaccuracies in reconnaissance maps. Also, a few of the features listed may not be meander cutoffs, but may be larger, minor channel remnants resulting from channel migration or semi-braided channel changes. However, the major features such as Lake Manawa, Carter Lake, Horseshoe Lake, Lake Quinnebaugh, Blue Lake, Badger Lake, and Crystal Lake, are all classic meander cutoffs and are well dated. Again, in relation to the 1881 flood, all but **one** of these cutoffs date from before 1879. Only one major cutoff, Lake Manawa, occurred between 1879 and 1890, and might be attributable to the flood of 1881. Obviously, the most significant changes in the Missouri River took place prior to this time. Most of the dramatic shortening of the channel took place between 1804 and 1870.

Towl's contention that the 1881 flood made numerous cutoffs to shorten the river is incorrect. The detailed analysis of historic maps and documents shows that two of the principal cutoffs considered, Blue Lake and Badger Lake were cut off prior to the 1852 General Land Office Survey.

The changes from a meandering stream to semi-braided and to a braided stream are transitional in nature. A rule-of-thumb sometimes used for defining meandering streams or reaches is that the sinuosity ratio is greater than 1.5. As stated by Leopold and Wolman (1957, p. 60), "This value is an arbitrary one but in our experience where the sinuosity is 1.5 or greater, one would readily agree that the stream is a true meander."

The transformation of the Missouri River can also be documented by examining its sinuosity through time. Figure 9 shows the sinuosities for Monona County from 1804 (the Lewis and Clark reconstruction) to 1976, and for the northern and southern reaches of the river, beginning with 1856 (the Lt. Warren reconnaissance survey). Although these older maps are not as accurate as the later surveys they do provide a very reasonable estimate of the sinuosity of the river. In 1804 the sinuosity in Monona County was over 2.10, and then it fluctuated but distinctly declined to between 1.50 and 1.60 in 1879 to 1890 period when the Missouri had already begun to take on a semi-braided appearance. By 1923 when the semi-braided nature of the river was well-developed the sinuosity in Monona County was only 1.33. Similar trends are apparent for the whole northern reach.

The southern reach is also shown on figure 9 to point out again how different the two reaches are. Besides the much lower sinuosities, the southern reach does not fluctuate nearly as much as the northern reach through time. It is not as seriously effected by the changes of the river. As noted previously the sinuosities (and thus river mileage) for the northern and southern reaches are out of phase. This suggests that as the northern reach decreased in sinuosity, straightening and shortening its channel, and thus increasing its gradient, the southern reach may have increased its sinuosity to compensate.

Table 7. Chronology of apparent natural meander cutoffs.

County Location	Name	Date of cutoff
Mills Co., IA	Haynie Slough	pre-1879
	South of Pacific Jnc.	pre-1856
	Mosquito Creek	pre-1879 (pre-1856?)
Sarpy Co., Nebr.	Clark Lake	1879
Douglas Co., Nebr.	Florence Lake	pre-1879
Pottawattamie Co., IA	Lake Manawa	1879-1890
	Carter Lake	pre-1879 (1856-1879?)
	Old Boyer Lake Bed	pre-1879 (1867-1879?)
	Old Honey Creek Lake	pre-1879 (pre-1852?)
	Hills Lake	pre-1856
Washington Co., Nebr.	Horseshoe Lake	pre-1867?
	Calhoun Lake	pre-1879 (1867-1879?)
Harrison Co., IA	Nobles Lake	pre-1856
	Lone Tree Lake	pre-1856
	Horseshoe Lake	pre-1879 (1856-1867?)
	Soldier Lake	pre-1856
	Dry Lake	pre-1867
	Kerr Lake	pre-1856
	Round Lake	pre-1856
Burt Co., Nebr.	Tekamah Slough	pre-1879 (1867-1879?)
	Lake Quinnebaugh	1875
Monona Co., IA	Fletcher Lake	pre-1856
	Guard Lake	pre-1856
	Blue Lake	1804-1852
	Silver Lake	pre-1804
	Badger Lake	1804-1852
Woodbury Co., IA	Sand-Hill Lake	pre-1879
	Brown's Lake	pre-1856
	Brower's Lake	pre-1856
Dakota Co., Nebr.	Blyburg or Omadi Lake	pre-1879
	Crystal Lake	1856-1867

Cause and Effect

Clearly, since the major changes in the river occurred prior to about 1870, the great flood of 1881 was not the cause of the metamorphosis of the Missouri as Towl (1935) presumed. What then was the cause of this change, and what is its significance? Only through an understanding of the causes of such changes in stream regimen can we hope to fully appreciate and understand the modern regime of our rivers and thereby gain an understanding and perspective to help resolve current and future problems.

The changes in the northern reach of the Missouri River are somewhat analagous to the changes of the Cimarron River in southwestern Kansas reported by Schumm and Lichty (1963). They report that a large flood in 1914 converted a previously stable, narrow, deep, and meandering stream into a wide, shallow, braided channel system. Nearly any large flood has the potential to disrupt a stream system in this manner. However, a stream may soon return to its stable configuration if another significant flood does not soon follow (Knox, 1976).

The Cimarron River did not immediately recover its pre-flood form because the next 30 years following 1914 were

*These maps and documents are available from the National Archives, Washington, D.C.

marked by frequent recurrences of large floods. These frequent large floods between 1914 and 1942 nearly destroyed the floodplain of the river. After 1942 until about 1954, the Cimarron River was characterized by low to moderate magnitude floods. Schumm and Lichty (1963) report that this resulted in the termination of floodplain destruction and the beginning of channel narrowing and floodplain construction. As summarized by Knox (1976) the relatively frequent recurrence of large floods may be particularly devastating to the maintenance of morphologic stability in channel systems. This has also been supported by Stevens, Simons, and Richardson (1975) who showed that streams with a wide range of peak-flood discharges are susceptible to frequent changes of channel form.

Knox and others (1975) have shown that the recurrence intervals of large floods are highly influenced by the patterns of large scale upper atmospheric circulation regimes. One of their examples is illustrated by the annual flood series (maximum daily discharge for the year) for the Mississippi River at Keokuk, Iowa, shown in figure 10. The flood series shows that large floods were relatively common in the late 1800s and again in recent years. However, most of the first half of the 1900s was characterized by moderate to low magnitude floods. Knox, and others (1975; and Knox, 1976) found that these high-flood flow periods were characterized by upper atmospheric circulation regimes with a strong meridional (north-south) component. Strong meridional circulation allows the deep penetration of polar air masses into low latitudes and of tropical air into high latitudes. This pattern often results in the development of intense frontal systems and storms, which are often the immediate cause of large floods. The upper air circulation patterns not only produce the conditions conducive to excessive precipitation, but they also influence flood characteristics through effects on antecedent conditions of moisture storage and surface cover (Knox, 1976).

According to Lamb (1974) this intensification of meridional circulation, during the last two decades, has been responsible for the increased number of large floods in many mid-latitude areas, in California, the U.S. Midwest, and parts of Europe. This trend is also associated with a world-wide cooling trend (Lamb, 1969; Mitchell, 1961, 1963) which Leopold (1976) related to reversals in the arroyo erosion cycle in the southwestern U.S.

Conversely, Knox and others (1975) also note that the low-flood flow period (figure 10) was marked by a strong zonal (west-east) component to the upper atmospheric circulation. The strong westerly component of zonal circulation regimes reduces the potential for development of intense storms and the Midwest tends to become drier and experience fewer large floods.

The record of the Missouri River shows some striking similarities. Figure 11 shows the annual flood series for the Missouri River at Sioux City, Iowa. In the late 1800s and early 1900s records were not kept as well on the Missouri River as on the Mississippi. As a consequence the highest monthly mean discharge (rather than daily) for a given year has been used to represent the flood series. Although the use of monthly means reduces the magnitude of the maximum discharge, a comparison of data in years with daily records shows that the same year-to-year trends are present. On figure 11, the same trend as on the Mississippi River is apparent. The late 1800s are marked by a period of frequent high-flood flows. The magnitude of the annual flood series fluctuates but steadily declines to a period of very low-flood flows in the 1930s. In the late 1940s the discharge of the floods on the Missouri begins to rise, as on the Mississippi. This trend peaks on the Missouri with the very large discharge 1952 flood. After this time the flow of the Missouri was regulated by dams (see Table 1) and the graph is less meaningful for the present purposes. This trend did continue, however. As discussed by Bondurant (1963), above normal flood discharges (of both water and sediment) in the late 1950s and early 1960s created serious problems in the management of the Missouri River for navigation.

The Missouri River, like the Mississippi River apparently exhibits a non-random pattern in the frequency of recurrence of high magnitude floods. This pattern, in turn, is related to cycles of climatic change reflected by changes in large scale circulation patterns. This has created conceptual problems for some, because the shorter term, and well-known, "20-year" drought cycle (see Thompson, 1973, 1975; Hallberg, 1976) is superimposed on this longer-term discharge-circulation pattern cycle, with less apparent affect than some would expect. The longer-term pattern of high-flood flows to low-flood flow periods, and back to high-flood flows spans many "20-year" drought intervals. The drought years of the 1950s, 1930s, late 1900s—early 1910s, late 1880s—early 1890s, tend to appear as periods of low-flood flows, in relation to adjacent time periods. Except for the 1930s, these periods are not clearly expressed, however.

This should not really be surprising. The general period of major floods (see months of peak discharges on figures 10 and 11) is during the spring and early summer, coincident with snow-melt and the early season rains. In contrast, the cyclic droughts are principally a growing season phenomenon (Thompson, 1973). The drought cycle is weakly reflected in mean annual precipitation in Iowa (figure 12). It is much more strongly expressed in the growing season, June through August (figure 13), in both the actual data and the 11-year running mean which helps to generalize these trends. As pointed out by Thompson (1973) July-August temperatures also correlate strongly with the drought cycle.

These growing season phenomena have little impact on spring floods, except for their influence on antecedent moisture conditions prior to winter precipitation. An analysis of winter precipitation presents a very different picture. Figure 14 shows October through May, and figure 15 shows January through March precipitation trends, from 1873 to 1978. The general trends of winter precipitation, as shown by the 11-year running means, show a fluctuating but uniform trend in the late 1800s to about 1920. Then there is a general decline in winter precipitation in the 1920s and 30s, which is followed by a sharp rise in the 1940s. The 1940s are followed by a period of extreme fluctuations, particularly in the January through March record. The general trend of the running mean is to decrease from the 1940s level, and to fluctuate around the pre-1920 levels.

There appears to be little long-term resemblance between the winter season and growing season precipitation trends. There is, at best, a vague resemblance in the general winter trends to the discharge-circulation patterns discussed previously. However, if the trends of the highest values for the winter precipitation are viewed there is a stronger similarity. For ex-

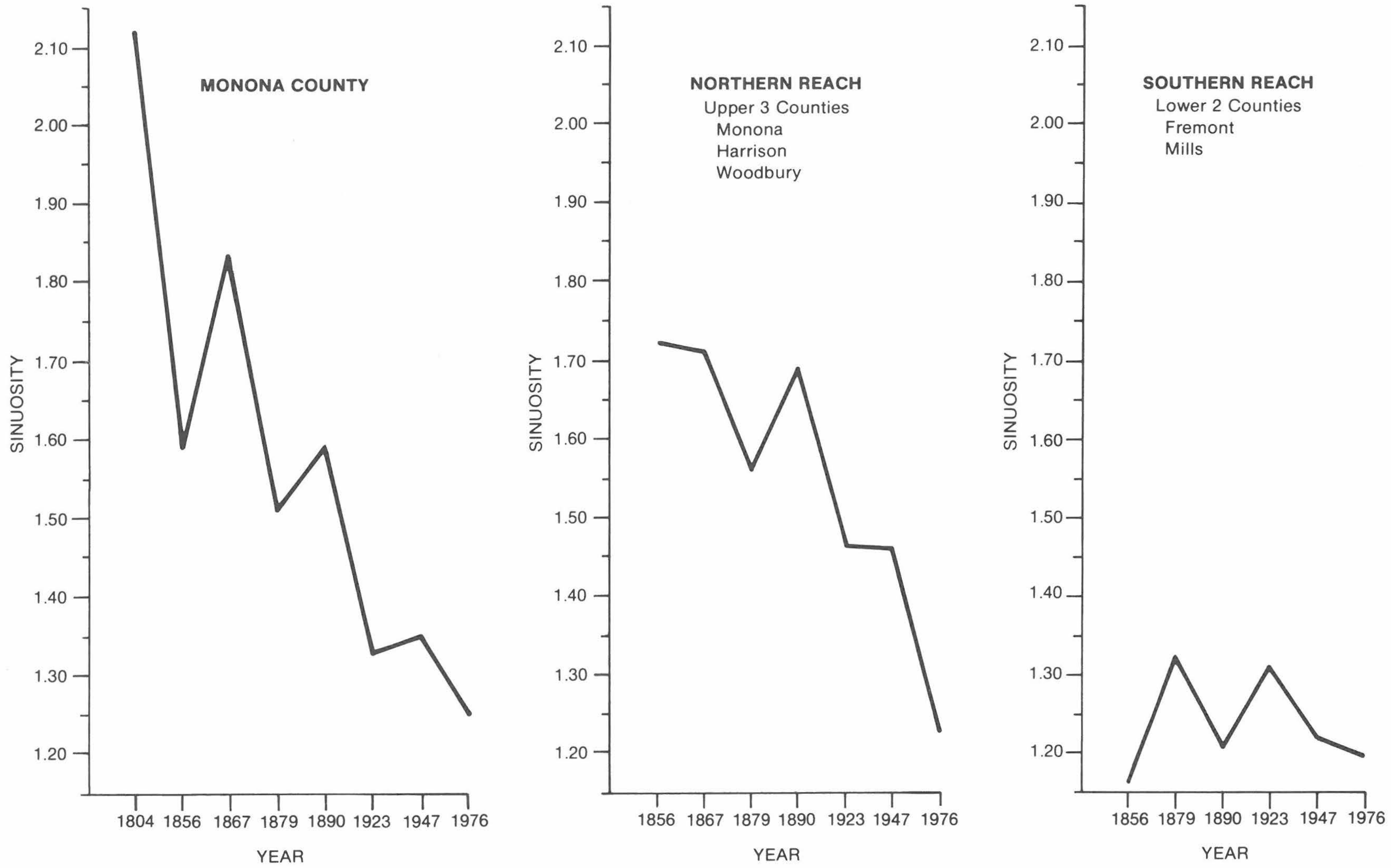

Figure 9. Sinuosities of the Missouri River for Monona County, 1804-1976, and the northern and southern reaches, 1856-1976.

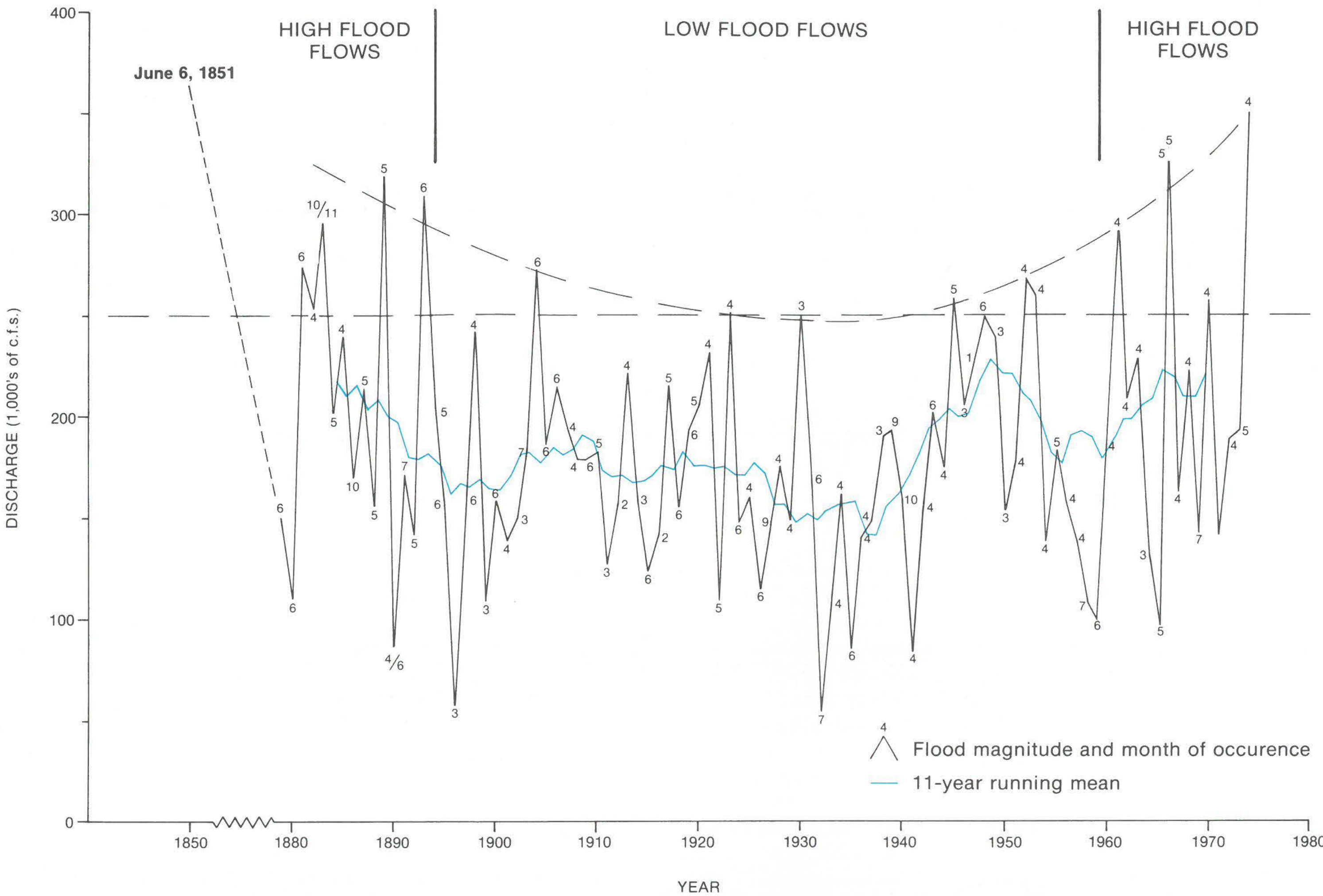

Figure 10. Recurrence characteristics of floods (highest daily peak discharge per year) on the upper Mississippi River at Keokuk, Iowa. The short-term relative variability of the magnitude of annual floods was large in the late 1800s and again since about 1950, but was relatively small during much of the first half of the twentieth century. The non-random pattern of the flood series is strongly related to clamatic variations (after Knox, et al., 1975).

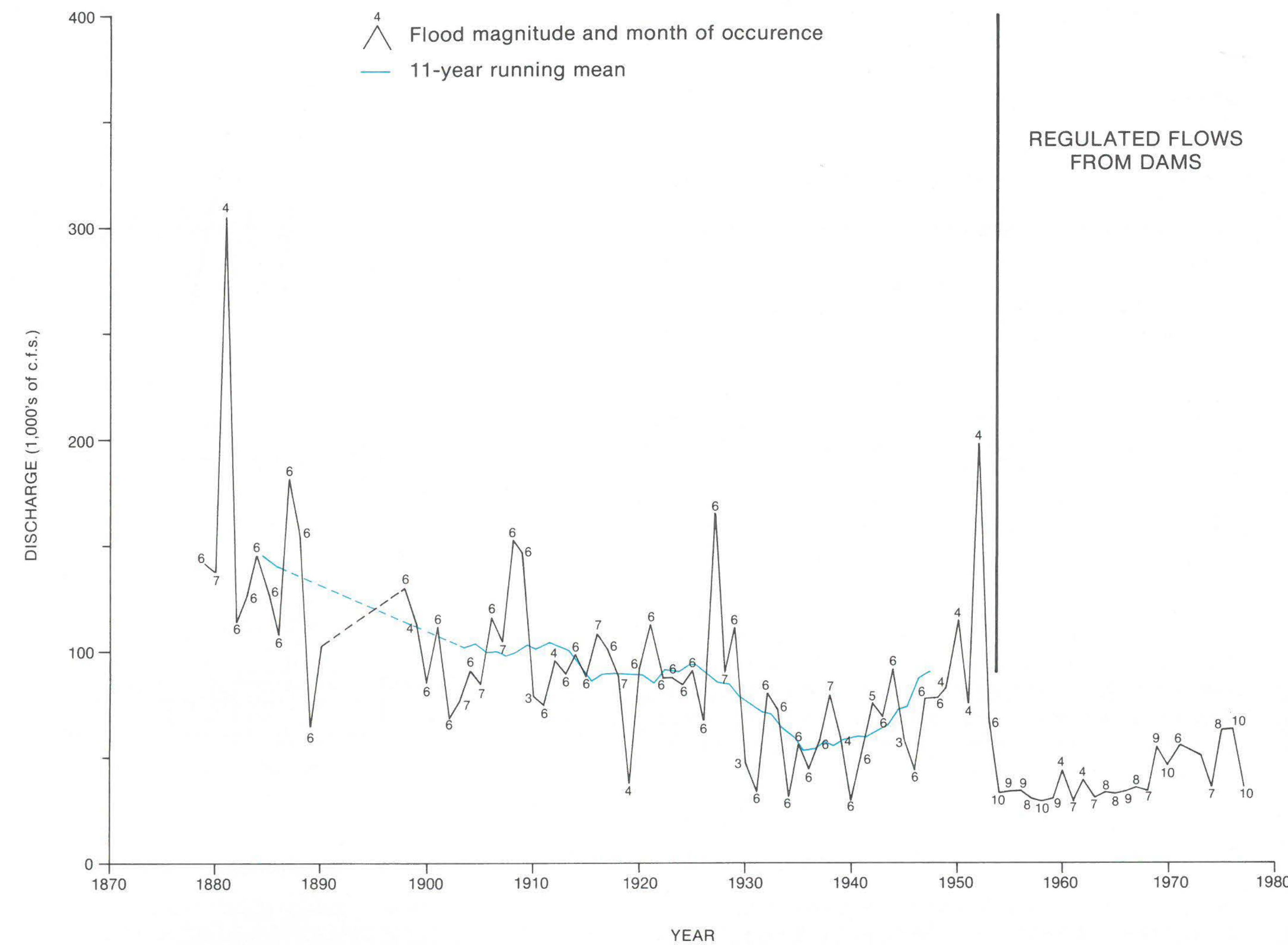

Figure 11. Recurrence characteristics of floods (highest mean monthly discharge per year) on the Missouri River at Sioux City, Iowa. The 11-year running mean is not continued into recent years because the discharge was regulated by dams. See figure 10, and the text for comparison and discussion.

ample, during the early high-flood flow period, 1873-1899, 23% of these years show January through March precipitation, in excess of 5 inches. From 1900-1944, the low-flood flow period, only 7% of the years show greater than 5 inches of January through March precipitation. In contrast, the 1945 to 1978 period shows 33% of the years in excess of 5 inches; again this is a high flood-flow period. Many of the years of high winter precipitation are also the years of high spring flood flows on the Missouri or Mississippi Rivers.

Unfortunately, there are little direct data on discharge, circulation regimes, or precipitation in the Missouri River area prior to the 1870s when so much of the transformation of the river took place. However, as inferred in the discussion above, other forms of "proxy" data may be used to provide insights into the early part of the 1800s. The principal features of the large scale circulation patterns can be inferred from the regional distribution of temperature and precipitation. Maps of these parameters for various decades of the 1800s, prepared by Wahl (1968) and Wahl and Lawson (1970), show climatic patterns which suggest strong meridional circulation patterns for the Midwest (Knox, 1976). In similar fashion, Lamb (1966) suggests that the climatic pattern of the past two decades was similar to those which prevailed for longer periods prior to the 1890s.

As previously noted, the trends in circulation pattern and changes in stream regimen are also coincident with trends in mean annual temperatures. Mitchell (1961; 1963) and Lamb (1969) have shown that global temperatures increased from the late 1800s through the 1930s, and that a cooling trend began in the 1940s. This same trend is apparent in Iowa and has been discussed by Waite (1968). The mean annual temperature trends for Iowa are shown on figure 16. The 11-year running mean clearly depicts the long-term temperature trend. Relating this to the other variables that have been discussed, the relatively cool period of the late 1800s was also marked by an increase in the frequency of large amounts of winter precipitation, which is a function of strong meridional circulation. These factors, have in turn, promoted the frequent recurrence of high-flood flows during this period.

Using these relations with the temperature trends we can extend our record back to the early 1800s. The mean annual temperature for St. Paul, Minnesota (after Mathias, 1974) is also shown on figure 16. This record extends back until about 1820. The average annual temperature, during this time, "has systematically risen and fallen, somewhat in the form of a sine wave," (Knox, et al., 1975). If the portion of the St. Paul data from 1873 on is compared with the data for Iowa, it is apparent that, except for the absolute value of the temperature, the trends in the data are nearly identical. The same is true for mean annual temperature for South Dakota, for 1890 to 1978 (pers. commun. and data from W.F. Lytle, Assoc. Prof., Agric. Eng., S.D. State Univ.). Essentially every major rise and fall in the data are coincident. Thus, we can feel relatively safe in using the St. Paul data to extrapolate our story into the immediate past. Also, with various lengths of recorded data Oltman and Tracy (1951) document this trend throughout the

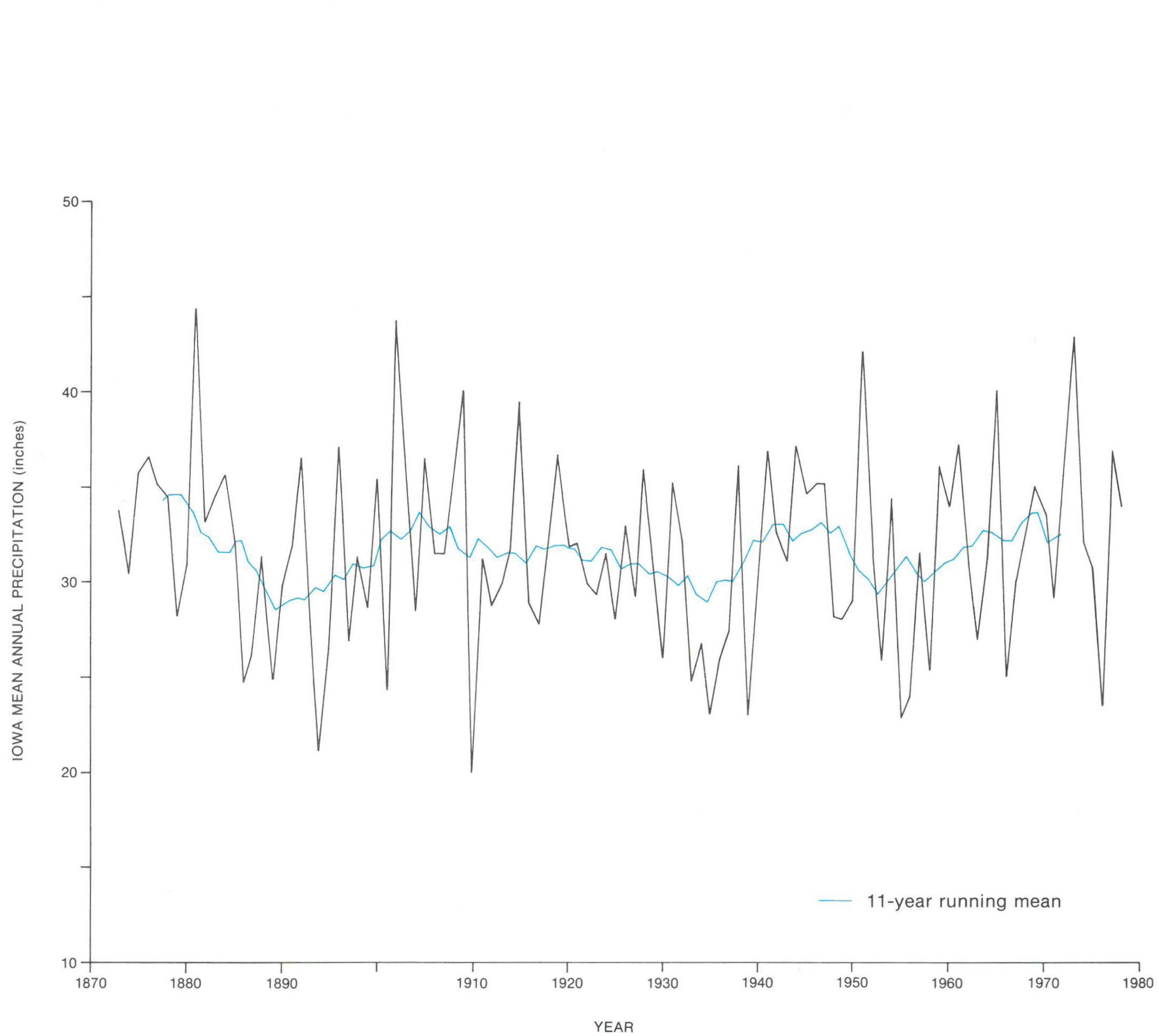

Figure 12. Mean annual precipitation for Iowa (1873-1978), and 11-year running mean.

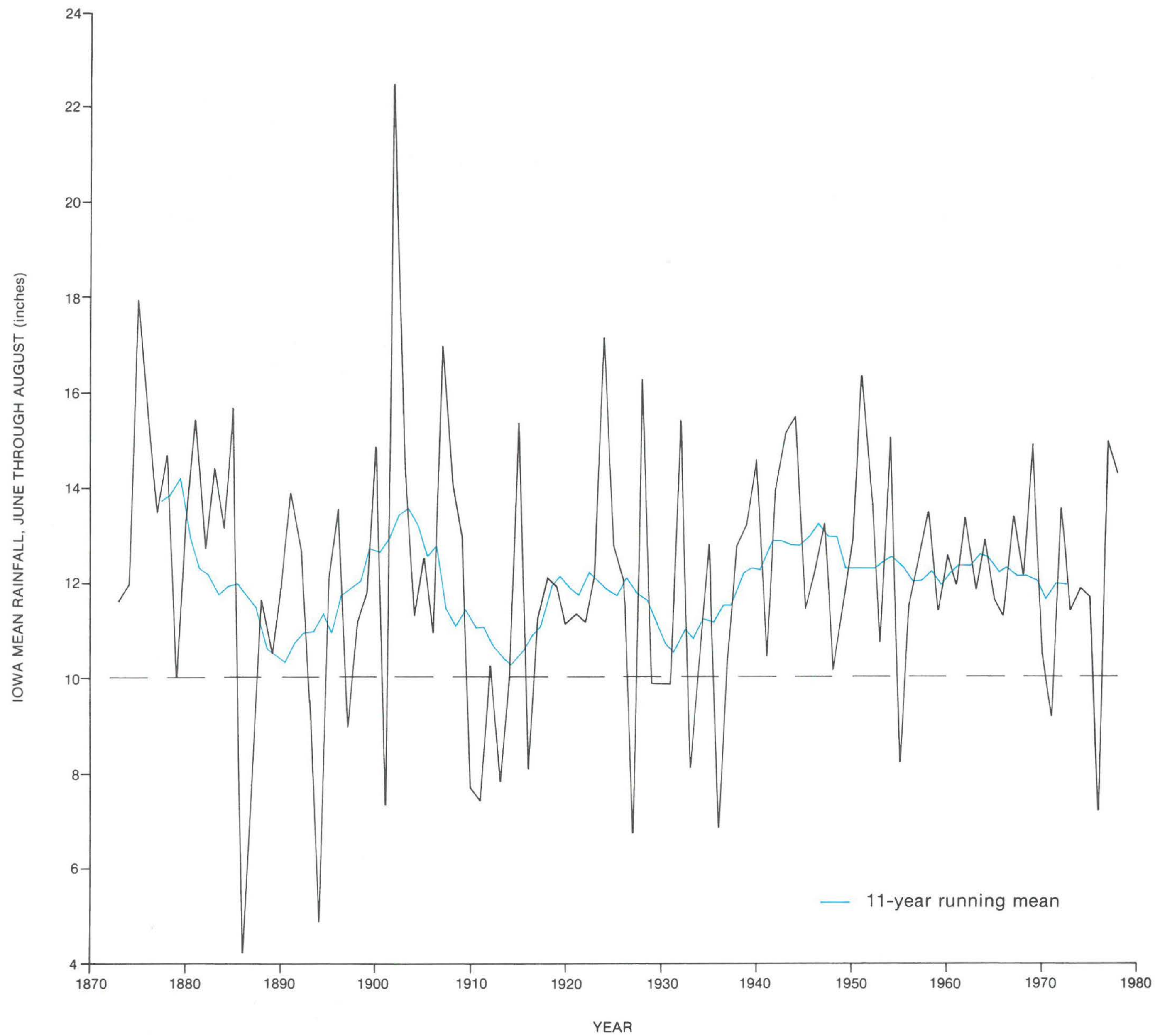

Figure 13. Mean June through August precipitation for Iowa (1873-1978) and 11-year running mean.

Missouri River Basin. They also found that the generalized trend of mean annual precipitation within the basin declined over the period from the mid-to-late 1800s to about 1940.

If the trend of the 11-year running mean (figure 16) is followed, the record begins with a warm period, around 1830. At least from a temperature standpoint the period is analogous to the warm peak of the 1930s. At this same time drought periods were recorded in Nebraska (Thompson, 1973), also analogous to the 1930s. This period is followed by a cooling trend which continues into the 1860s. With a slight high around 1880, the trend is a gradual warming from 1860 to 1930. By analogy the cooling trend following 1830 should have been similar to the last two decades, which as discussed, were marked by strong meridional circulation and frequent high-flood flows. The warming trend but still generally cool period which followed was still marked by meridional circulation and high-flood flows, as established previously, until about 1900.

This lengthy discussion has attempted to illustrate that the available data indicates that the middle 1800s would have been a long time period marked by frequent recurrence of high-flood flows. These are the conditions that must have prevailed to cause the dramatic transformation of the Missouri River from a meandering river in 1804 to the semi-braided conditions of the 1870s. The frequent high-floods (particularly in the early stages of this period, as indicated by the early dates of cutoffs in Table 7) were destructive on the floodplain, producing numerous cutoffs, shortening and straightening the channel, causing the sharp decrease in sinuosity between 1804 and the 1850s (figure 9), and undoubtedly increasing the channel width. These processes continued during the high-flood flow period as indicated by the discharge data and the few additional cutoffs which took place in the 1870s and 1880s. In general, the greatest alterations of the Missouri occurred before this time, and it is interesting to note that the flood of 1881, perhaps the most severe **on record**, had remarkably little impact on the channel.

After this time the regime of the Missouri changed to a period of low-flood flows. Unlike many other river examples, such as the Cimarron (see Schumm 1971; Knox, 1976; Stevens, Simons, and Richardson, 1975), the Missouri River did not recover its meandering form during the low-flood flow period. In fact, in the early 1900s it became more braided and straighter, as evidenced by the changes between 1890 and 1923 (figure 5). There are several likely reasons for this. First, the alterations of the river were so severe that it would have taken a relatively long time to recover. Second, the high flood flow not only increased the water discharge but surely increased the sediment load of the river as well. An increase in the bed load must have occurred, as the channel widened and increased its gradient as a consequence of the straightening and braiding. Perhaps, the increase in bed load was significant enough that the Missouri did not have time to recover. A third variable, which has been inferred already, is that there was not enough time during the low-flood flow period for the channel to recover prior to the 1930s when construction of the initial design channel began. The upper reach of the Missouri River

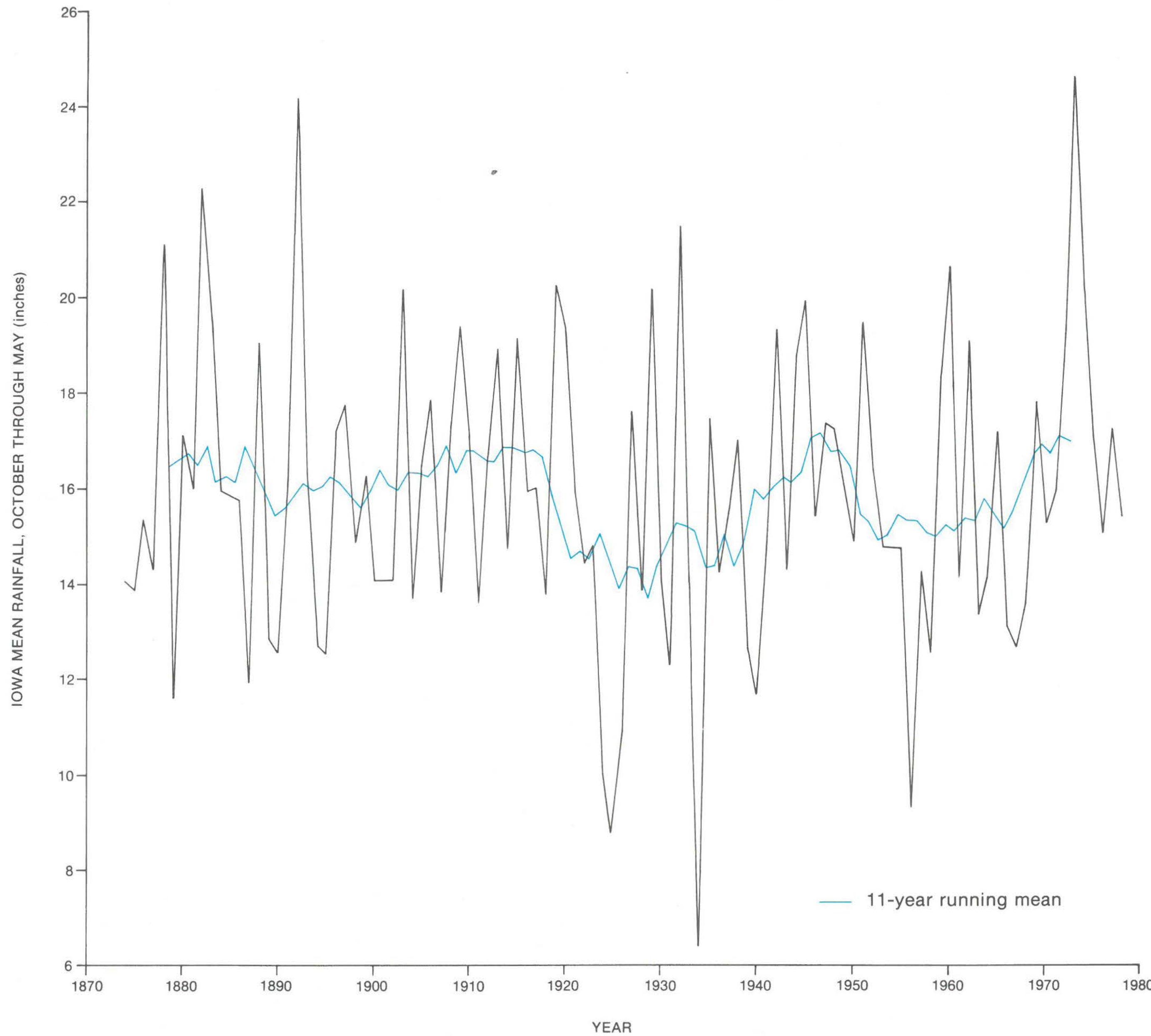

Figure 14. Mean October through May (water-equivalent) precipitation for Iowa (1874-1977) and 11-year running mean.

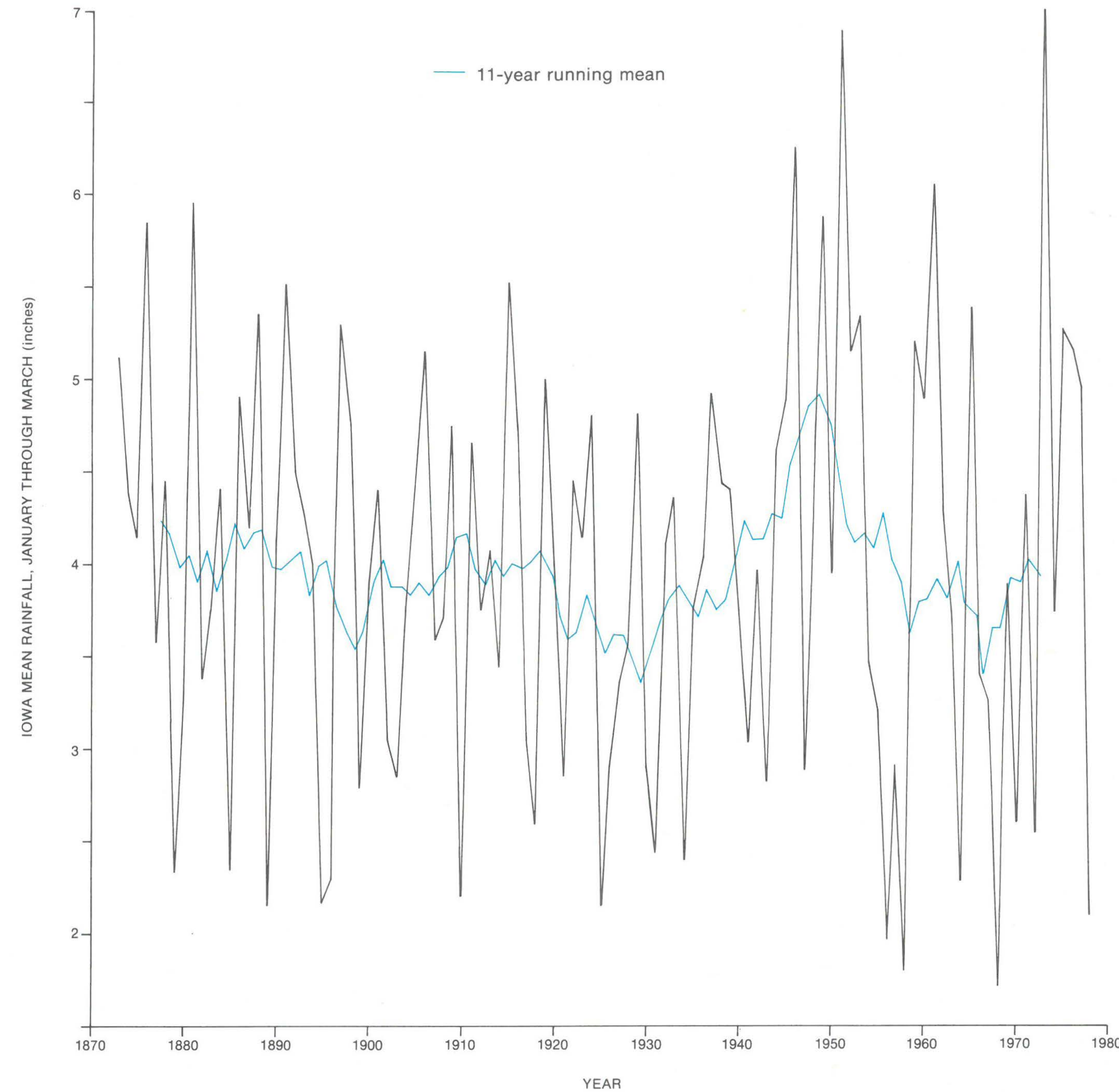

Figure 15. Mean January through March (water-equivalent) precipitation for Iowa (1873-1978) and 11-year running mean.

seems to exhibit, over time, the "non-equilibrium form" of Stevens, Simons, and Richardson (1975).

The aim of this discussion of the natural regime of the Missouri River is to point out that it is becoming increasingly apparent that the distribution or change of many stream characteristics over time is non-random. Many aspects of the fluvial system can still only be dealt with stochastically; especially short term phenomena. As discussed here, and elsewhere (Knox, et al., 1975; Knox, 1976) the distribution of periods marked by frequent recurrence of high-flood flows is not random, but appears to be related to systematic variations in climate. it is these extreme hydrologic events, both floods and prolonged low-flows, which create problems for man in dealing with stream systems.

The tools are not yet available to predict with any certainty, the short-term climatic regime or its hydrologic impact. However, the knowledge of these longer term phenomena can place our present data base and level of understanding into their proper perspective. Most of our hydrologic records and climatic data are from this century, and it is important to realize that the atmospheric circulation and climatic patterns of the last two decades were previously unknown to the twentieth century (Lamb, 1966). Many scientists now question the reliability of the first half of the twentieth century as being representative of longer term climatic and hydrologic averages (Knox, et al., 1975). The prior discussion of climatic and hydrologic changes should make the reason for this apparent.

As an example, most of the data and observations available to guide the design of the training of the Missouri River were obtained during the early 1900s. At least some of the channel maintenance problems of the 1950s and 1960s can be attributed to frequent recurrence of high water and sediment discharges into the Missouri (Bondurant, 1963). Has the return to a high-flood flow period in the last two decades also contributed to the channel degradation problems in the northern reach of the Missouri in Iowa, and to the channel aggradation problems downstream (see Sayre and Kennedy, 1978)? Many of the problems related to the management of other river control works in the 1960s and 1970s are also attributable to this frequent recurrence of high flows.

In this context Knox, and others (1975, p. 6) state:

> Failure to adjust hydrologic records to account for the character of the related prevailing climate regime can lead to serious miscalculations regarding the magnitude and frequency of expected events. It is particularly disturbing that many land use plans and physical structures, such as dams and reservoirs, are designed and implemented on the basis of short term hydrologic records that have not been calibrated to reflect climatic regimes within which they are contained.

It is easy to point out these problems in retrospect. For many of the problems in Iowa which have been mentioned, it

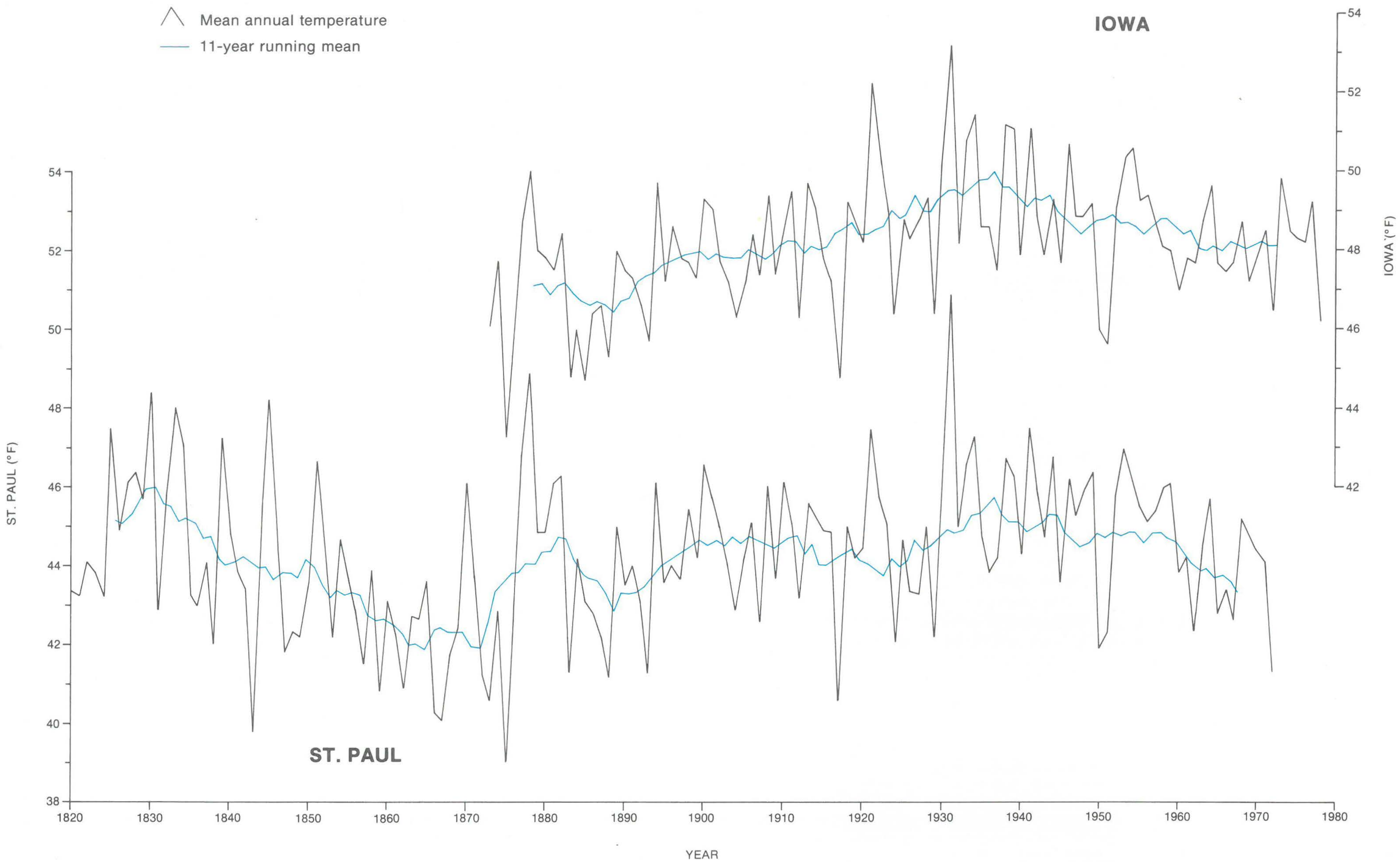

Figure 16. Mean annual temperatures and 11-year running means: 1) upper chart for Iowa 1873-1978, updated from Waite, 1968. 2) lower chart for St. Paul, Minnesota, 1820 to 1972, after Mathias, 1974.

was not possible to consider some of these temporal variations in hydrologic regime, as only now are we becoming aware of them. The question now becomes, can we use this growing perspective to resolve our current and future problems? As pointed out by Hallberg (1978) the design of water management plans or structures for water use, must be based on the extremes of prolonged or recurrent low-flow conditions during short-term drought periods, not on the basis of long-term averages. On the other hand the design of other types of water management plans and structures, such as for flood control, should take into account the high-flood flow periods, when large magnitude discharge events recur frequently.

The Design Period—After 1923

In its natural state the Missouri River underwent some dramatic changes in channel form. Throughout these changes a natural balance was maintained between the channel length and area (or width). After 1923 an equally dramatic change occurred, but principally in the channel area. The reasons are, of course, more obvious as compared with the natural system. The changes to be documented between 1923 and 1976 are man-induced, from the construction and stabilization of the navigation design channel.

Some of the most common structures used to restrain or control the Missouri River have been rock dikes or rock-filled pile dikes, and a variety of revetments. The dredging of pilot channels and disposal of dredge spoil in areas where natural channels were cut off also facilitated the artificial relocation of the channel. More detailed descriptions of the river control structures and their functions are given in C.O.E. (1946), Bondurant (1963), Manning (1964), Lindner (1969), and also in Funk and Robinson (1974).

Basically, dikes are set en echelon at an angle with the existing bank to deflect the channel into its design alignment. The type of dikes used on the Missouri promote rapid sedimentation behind them causing the artificially cut off channel to fill with sediment, merging the channel and its bars and islands into a single land mass, which then joins the natural bank by this artificial accretion. Revetments are used to stabilize the bank of the design channel, to constrain it in place and prevent the new channel from eroding the banks.

The end result was to produce a smooth channel alignment — a curved trace, consisting generally of a series of bends 3 to 5 miles long (C.O.E., 1946), without bank irregularities, lunate bends, or other irregularities (Bondurant, 1963). Also, the process was designed to produce stabilized banks—high banks, protected from erosion, which confines all the water in a single channel (C.O.E., 1946).

Perhaps the most dramatic evidence of the accomplishment of the project is found in the comparison of the maps in the Appendix, which pictorially show the changes in the river from its natural state in 1890 to its controlled condition in 1976. As outlined in the Construction History, the implementation of the navigation and stabilization works took place in two phases. First, was the implementation of the 6-foot navigation project in the 1930s and 1940s, and second, the development of the current 9-foot channel during the 1950s and 1960s. The impact of these two phases of construction will be discussed separately by reviewing the condition of the river in 1947 and 1976. Table 8 summarizes the changes in the Missouri River between 1923, 1947, and 1976; table 16, in the Appendix summarizes all the measurements for the river adjacent to Iowa.

Between 1923 and 1947 the length of the Missouri River adjacent to Iowa was only shortened by about 3 miles, and the sinuosity was decreased from 1.42 to 1.40. A minor change, such as this, in the natural system would not have produced much change in the channel area or its features. However, the purpose of the design channel was to alter the channel area, and the resultant changes are dramatic (see figure 5).

Two figures have been calculated from the 1947 measurements (see Table 4) which are referred to as the 1947 "total" and "active" channel area. The "active" channel area constitutes the actual artificially controlled design navigation channel as it appears in 1947. This is the only area that was an integral part of the controlled river at this time. In 1947 the controlled channel still included a few sand bars and islands, principally because much of the artificially cut off channel area had not yet filled in with sediment. This was, in part, a function of the amount of time available for sedimentation, and, in part, because in the early construction many permeable pile dikes were used. These were later reinforced with rock, or replaced with rock dikes which prompted more rapid and complete sedimentation. These areas still exhibited open water and bar areas in 1947, and are analagous to the areas included in the natural channel area measurements from 1879 to 1923. Thus, for consitency the "total" channel area for 1947 was measured, and included these artificially cut off areas and the "active" channel area.

The measurements were separated into the two categories because the "total" channel area of 1947, while analagous in appearance to the natural channel area, is not really comparable to it. Given enough time these artificially cut off areas would fill in with sediment and stabilize, becoming part of the bank (or non-channel area). Thus, the final result from the first round of construction on the river would have been the 1947 "active" channel area, even if no further work on the river had taken place. Thus, in the following discussion only the 1947 "active" channel will be referred to.

The channel area of the river was reduced by -76% from

Table 8. Summary of the changes in Missouri River channel features; 1923 to 1976

	River Miles			Sinuosity		Channel Area			Water Area			Island Area			Bar Area		
Time Period	% of Change	River Miles	% Diff	Ratio	% Diff	% of Change	Acres	% Diff	% of Change	Acres	% Diff	% of Change	Acres	% Diff	% of Change	Acres	% Diff
1923-1976	100	– 18	– 9	1.42 to 1.30	– 8	100	– 61,652	– 80	100	– 30,228	– 66	100	– 11,513	– 99.9	100	– 19,911	– 9.9
1923-1947 1	17	– 3	– 2	1.42 to 1.40	– 1	95	– 58,337	– 76	99	– 29,977	– 66	99.9	– 11,506	– 99	85	– 16,855	– 84
1923-1947 (2)	(17)	(– 3)	(– 2)	(1.42 to 1.40)	(– 1)	(44)	(– 27,646)	(– 36)	(74)	(– 22,353)	(– 49)	(8)	(– 881)	(– 8)	(22)	(– 4,412)	(– 22)
1947-1976 1	83	– 15	– 8	1.40 to 1.30	– 7	5	– 3,315	– 18	1	– 251	– 2	0	– 7	– 0	15	– 3,056	– 98
1947-1976 (2)	(83)	(– 15)	(– 8)	(1.40 to 1.30)	(– 7)	(56)	(– 34,006)	(– 69)	(26)	(– 7,875)	(– 34)	(92)	(– 10,632)	(– 99.9)	(78)	(– 15,499)	(– 99.9)

1 Calculated on "active" channel basis for 1947

(2) Calculated on "total" channel area for 1947; e.g.—includes 1947, "active" channel area and the artifically cut off channels, bars, etc., which have not yet filled in with sediment.

1923 to the 1947 "active" channel, from over 77,000 acres in 1923 to less than 19,000 acres in 1947. This was a reduction of about 58,000 acres (see Tables 8 and 16). Within the channel the water surface area was reduced by -66%, or about 29,980 acres, the area of sand bars was reduced by -84%, or about 16,900 acres, and the area of islands was reduced by -99%, or about 11,500 acres. Even if the "total" channel area for 1947 is considered, the water area was decreased by -49%, or 22,350 acres.

Between 1947 and 1976 the current 9-foot navigation channel was constructed. This involved the cutting or realignment of a new design channel in many areas in the northern reach of the Missouri. This resulted in an additional 15 mile decrease in river mileage, and a further reduction in sinuosity from 1.40 to 1.30.

By 1976 the river appears as its design intended—as a single smooth channel, a curved trace, with a series of gentle bends with stabilized banks. In 1978 the project was considered 92% complete (C.O.E., 1978). The channel area was reduced to the area of the design channel, a further reduction from the 1947 "active" channel of -18% or an additional 3,315 acres (Table 8). The water area was slightly reduced (by -2%) by about 250 acres, but bars and islands were essentially eliminated; only about 57 acres of bar and island area remain in the channel area.

Two other categories of measurements are shown in the data tabulation for 1976. The 1976 "backwater" areas, which are the few remaining water bodies in the artificial cutoff areas. These areas are within the well-stabilized bank areas in 1976 and, thus, are not an integral part of the channel area as we have consistently defined it over time. There are about 2,000 acres of backwater area. The largest of these areas is the DeSoto Bend National Wildlife Refuge. Many backwater areas are intermittent and the acreage of these features fluctuates seasonally and with river stage.

The second category is called "political islands". these are the land areas that are between the present river channel and the Iowa-Nebraska state line. The state line is based on the 1943 compact, and follows the center of the 1943 design channel. With the realignment of the present design channel some former Iowa land now occurs on the Nebraska side of the channel and vice versa. The state line could only be approximated on the maps used in the project, thus the figures are only approximate as well. Also, the area around the DeSoto Bend National Refuge and Carter Lake were not included. The figures (Table 16) do show the proper apportionment, in that there is about 3 to 4 times as much Nebraska land on the Iowa side of the river, as vice versa.

Summary: 1923-1976

The Missouri River adjacent to Iowa, was artificially shortened by 18 miles between 1923 and 1976. With the development of the stabilized navigation channel the channel area of the river was decreased by nearly 62,000 acres, about 96 square miles, or -80% of the 1923 channel area. The channel area on the Iowa side of the river was decreased by -82%, a little over 35,000 acres (55 square miles).

The water surface area in the channel was reduced by -66% during this time, a reduction of about 30,228 acres. To put this in perspective, this is equivalent to the 30,350 acres of water surface area, at normal pool elevation, of the Coralville, Saylorville, Red Rock, and Rathbun reservoirs *combined.* There was a -69% reduction in water area on the Iowa side of the river, amounting to slightly over 17,000 acres. Bars and islands in the channel were essentially eliminated; their combined surface area of over 30,000 acres in 1923, were reduced to about 60 acres in 1976.

As a matter of perspective Table 8 also records the changes in channel features from 1923 to 1947, and from 1947 to 1976 in relation to the total change between 1923 and 1976. This is recorded as the percentage of change, with the difference between 1923 and 1976 being 100%. Often, all the losses in land, water, and fish and wildlife habitats that have occurred along the Missouri are attributed to the installation of the present design channel. Although many changes have been made from the configuration of the original 6-foot navigation channel (see maps in the Appendix), in the perspective of the total areal changes these alterations are minimal. If the design channel as shown in 1947 had been allowed to stabilize, the resultant channel measurements would have been essentially the "active" channel figures for 1947. As presented in Table 8, 95% of the total acreage decrease in channel area was accomplished by 1947, or in the first navigation channel project. In the construction of the present design channel, only an additional 5% of the channel area (on the basis of total acreage) was lost. Within this area 99% of the loss of water area occurred by 1947 also. These are figures which should be considered in future studies, plans, or discussions of mitigation.

A Perspective on the Artificial Channel Changes and Loss of Natural Areas

As pointed out in the introduction to this report, the taming and stabilization of the Missouri River was mandated by the Congress of the United States. The U.S. Army Corps of Engineers has been very successful at carrying out this mandate and providing a highly controlled, navigable waterway. This has provided significant benefits, particularly for the development of the Missouri River alluvial plain. Controlling the river has not only promoted navigation but has provided thousands of acres of new land for agriculture and development by the filling of the old channel area, and through bank stabilization and flood control. Agriculture and other developments already have spread across many portions of the artificially accreted land created by the stabilization of the river banks.

However, with alteration of any natural system there are costs as well as benefits. The navigable waterway has been developed at the expense and sacrifice of the natural riparian right-of-way. The broad natural channel area of the Missouri River with its slackwater areas, bars and islands, provided some of the most continuous and diverse riparian fauna and flora and recreation potential in the Midwest.

These losses of natural areas are reflected in the losses of land and water areas since artificial control of the river was begun.

As noted, the channel area of the Missouri River adjacent to Iowa was decreased by about 96 square miles between 1923 and 1976. These changes can also be put into a regional perspective by combining the figures for Iowa with those for Missouri prepared by Funk and Robinson (1974) for 1879 to 1972. These are minimal figures because Funk and Robinson did not compile data on the Rulo to Kansas City reach. Also, their channel area figures are calculated as of 1954, and additional losses have taken place since then. These combined figures provide at least some perspective on the change in the Missouri over nearly the past 100 years.

Compared to a century ago the channel area of the Missouri River between Sioux City, Iowa, and the mouth at St. Louis, has been decreased by more than 132,000 acres—over 206 square miles—about a -40% reduction from 1879. Even more striking is that over 103,000 acres—161 square miles—of water area have been lost, over -57% of the 1879 water area.

In terms of the loss of state lands and various conservaiton resources, these figures must be considered as minimal. There are many other changes which took place on the Missouri River alluvial plain which are related to bank stabilization and flood control. Increased clearing of floodplain forest and brush areas has occurred along with control of the Missouri and other rivers (Bragg and Tatschi, 1977; Best, Varland, and Dahlgren, 1978). Many poorly-drained areas outside of the channel area have been drained and/or filled and put into agricultural production. The encroachment of agriculture and other development around the few remaining wetland and conservation areas also creates serious changes in the habitat potential. These kinds of concurrent changes are difficult to quantify and cannot be consistently measured over time as have the channel area features described in this report.

These losses are also minimal estimates in other respects. For example, the loss of water and channel areas is not just a reduction in habitat; it is an alteration in habitat as well. The measurement of the natural water areas includes thousands of acres of minor channels and backwater areas which provided diverse, calm habitat for aquatic life. The 15,500 acres of water area remaining in the channel area comprise the single navigation channel of the river. This remaining water area is entirely a swift and turbid stream which has altered the habitat available and, in turn, radically changed the fish population of the river (Funk and Robinson, 1974). The few thousand acres of "backwater" measured in 1976, are no longer connected to the river, which also alters their potential.

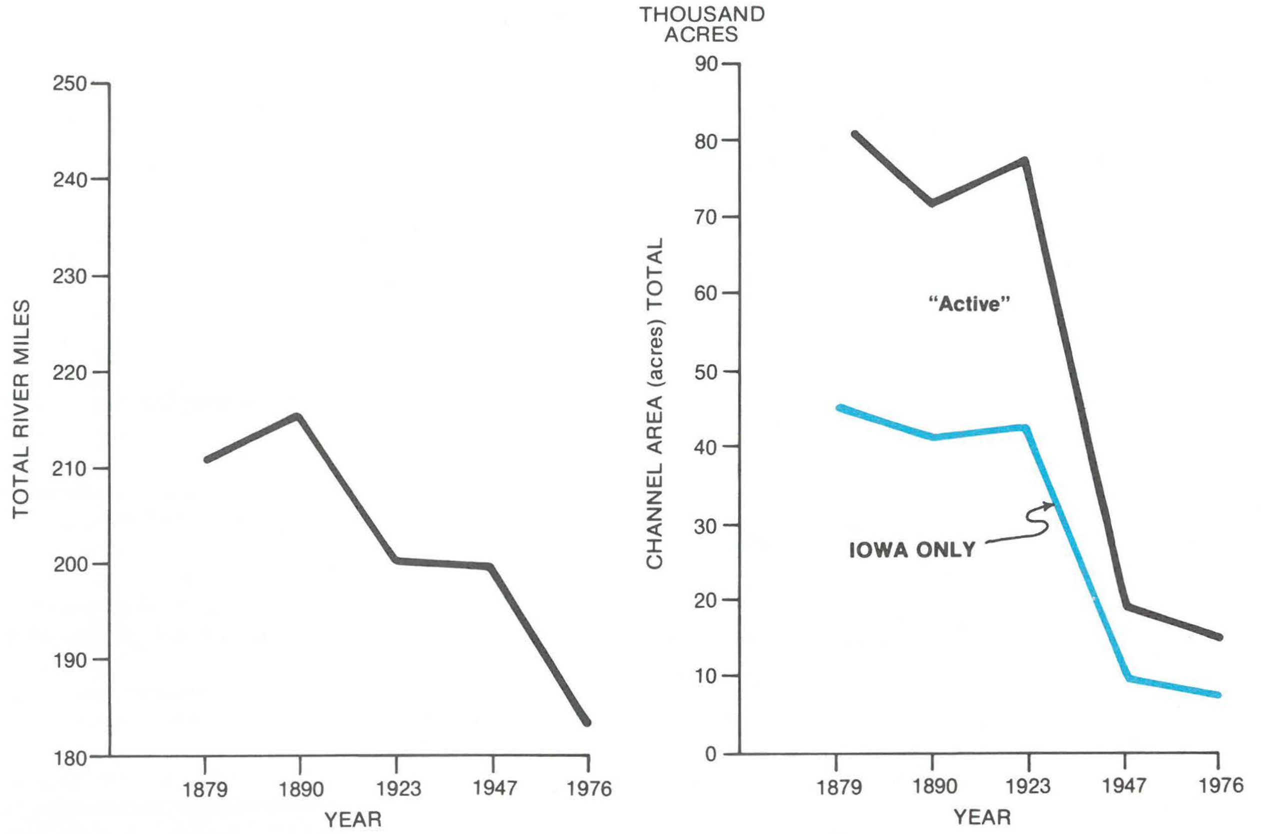

Figure 17. Summary graphs showing changes in Missouri River mileage and channel area, 1879-1976.

SUMMARY

Using maps and aerial photographs from 1879, 1890, 1923, 1947, and 1976 the natural and man-made changes in the channel of the Missouri River were quantitatively evaluated. For all of these time periods the base maps used provided detailed, accurate, and total coverage of the Missouri River channel. Except for the 1879 series, all of the base maps depict the river at moderately low-flow conditions. For quantitative comparison and documentation the river mileage, sinuosity, channel area, and the water, island, and bar area within the channel were measured. The measurements and the changes between the time periods analyzed are summarized spatially for the entire reach of the river adjacent to Iowa, and by the six Iowa counties along the river. The data is also subdivided into its Iowa and Nebraska components.

The early history of the Missouri River was also evaluated. Between 1804 and the late 1800s the regime of the Missouri River, in particular north of the Platte River, changed radically from a meandering stream, with apparently a single, sinuous channel to a semi-braided stream, with numerous split or multi channel reaches. This trend continued into the 1900s until the channel was artificially altered. During this natural transformation the river was shortened, decreased its sinuosity, and increased its gradient. But as the channel length (river mileage) decreased it also increased in width. Between 1890 and 1923 the channel decreased in length by about 14 miles, but the channel area increased by 7% from about 72,000 to about 77,000 acres. Even though there were dramatic natural changes in the Missouri River, a natural balance also occurs between the channel length and the channel area.

This transformation of the river from a meandering to a semi-braided stream was likely caused by a long period of frequent recurrence of high flood flows in the mid and late 1800s. This was caused, in turn, by changes in climate, that were much different than most of the present century. The period was marked by more meridional circulation which promotes more intense storms and cyclones. These climatic conditions did not occur in the 1900s until the past two decades—a period which has also been marked by frequent recurrence of large floods in the Missouri and Mississippi river basins. These recent climatic-hydrologic changes have contributed to many problems in the management of surface water resources in the Midwest.

In its natural state the Missouri River was divided into two very different reaches, north and south of the Platte River. Even at the present time, the management of these reaches present different problems. It is hoped that our growing understanding of these natural phenomena will aid in the resolution of present and future problems.

The man-induced changes of the Missouri River are equally as dramatic as the natural changes. The Missouri was altered in two stages by Congressional Mandate: first by the construction of the 6 foot navigation channnel in the 1930s and 1940s; later by the realignment and construction of the present design channel. In doing so the river was shortened by an additional 18 miles in Iowa, between 1923 and 1976. Unlike in the natural river the channel area was also severely altered, as reviewed graphically, in figure 17.

The intent of the design channel was to eliminate the broad natural channel area. From 1923 to 1976 the channel was altered from a broad semibraided stream, to a narrow single, smooth channel with a series of gentle bends and well stabilized banks. The natural channel areas were artificially cut off and structures were designed to promote sedimentation in the cut off areas. Most of the former channels and sloughs, bars and islands have now by accretion, become part of the stabilized bank. The channel area of the river was reduced by about 62,000 acres—about 96 square miles or -80%—between 1923 and 1976. About 35,000 acres of this reduction occurred in Iowa.

The surface area of water in the channel area was reduced by 66% or 30,228 acres (55 square miles). This is equal to the water surface area, at normal pool elevation, of the Coralville, Saylorville, Red Rock, and Rathbun reservoirs **combined.** Besides the swift flowing navigation channel itself, only a few thousand acres of slackwater areas remain in the artificially cut off areas.

Bars and islands have been essentially eliminated. In 1923 there were about 11,500 acres of islands and nearly 20,000 acres of bars which have been lost. Much of this area has been filled with sediment and now is part of the bank of the navigation channel.

Often all of these changes are attributed to the construction of the present design channel. However, as shown by the 1947 data, if the first design channel had been allowed to stabilize, this would have accounted for 95% of the losses in channel area, and 99% of the loss of water area. As of 1978 the project was considered 92% complete.

The stabilization and flood control of the Missouri River has provided benefits, particularly by providing thousands of acres of land for agriculture and other development on the alluvial plain. However, this has been accomplished at the expense and sacrifice of the river's natural riparian right-of-way. The natural channel area of the Missouri River formed a continuous and diverse area of habitat for fish and wildlife and for other recreational uses. The areal losses, as here documented, are sizeable—but even these are minimal figures. There are other changes which took place in response to the stabilization and control of the river which cannot readily be quantified over time. These include such things as accelerated clearing of timber, draining of poorly drained areas, and encroachment of developments or agriculture on the remaining natural areas.

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APPENDIX

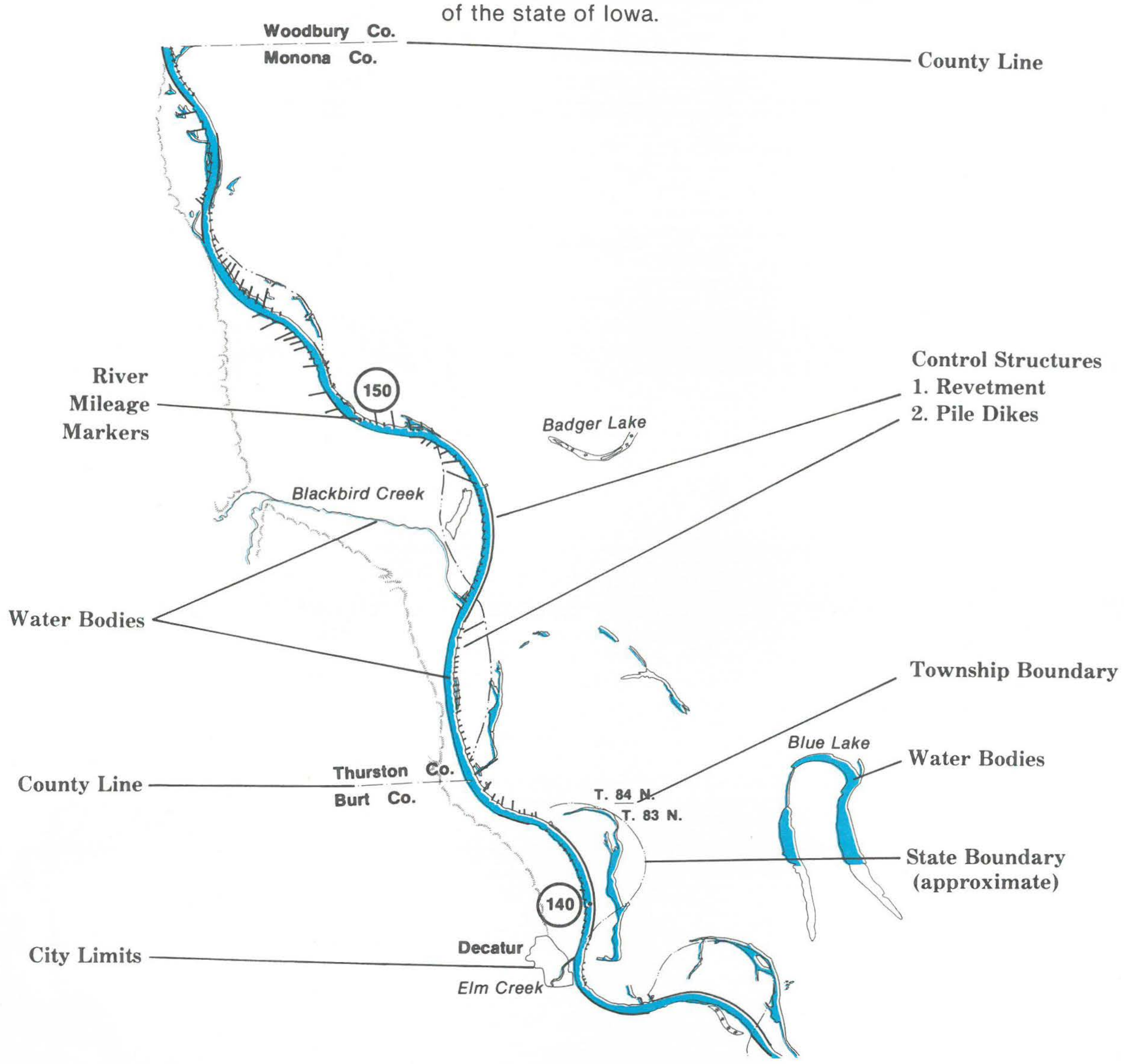
Although the figures and graphs presented describe the changes that have taken place in the Missouri River perhaps the most dramatic impact is to see the changes first hand on maps. This appendix was prepared to record the raw data from this project, and to present the maps which depict these changes. For convenience, table 9 repeats the definitions of the categories measured which were presented in table 5. Figure 18 provides an explanation of symbols used on the maps. Table 16 is a summary of all the measurements for the Missouri River adjacent to Iowa.

The Appendix also presents 6 series of maps and tables, one series for each Iowa county adjacent to the river. For each county series, maps of 1890, 1923, 1947, and 1976 are presented. Presented with the county maps are tables which summarize the data by each Iowa county. All of these tables are subdivided into two parts. The upper part gives the actual values measured for channel area, etc. in acres. For each area category a total value for that reach and time period are shown, as well as the areas for the Iowa and Nebraska portions of the reach. The lower portion of the table shows the differences in each category between the various time periods indicated. The actual difference, in acres or miles, is shown as well as the percentage change. All these values are calculated in reference to the older time period.

Table 9. Definition of Missouri River Channel features measured.

CHANNEL AREA	portion of the flood plain occupied by the main channel of the river, as well as minor channels and chutes, includes features such as open sand bars and islands, point bars, and cutoff channels. The land features within this area are for the most part unvegetated and unstable, indicating they are still frequently overflowed by the river.
WATER AREA	area of water surface contained in the channel area.
BAR AREA	areas within channel area shown as emergent sand or alluvium with relatively little permanent vegetation.
ISLAND AREA	area of alluvium, with well established vegetation such as willows or timber, within channel area.
RIVER MILES	horizontal distance, measured along thalweg of river. For convenience of reference, river miles are marked on the Appendix maps every 10 miles, numbered consecutively from the southern border of the state of Iowa.
LINEAR MILES	horizontal straight line distance through channel area.
SINUOSITY RATIO	river miles divided by linear miles; a measure of river meandering.
"TOTAL" CHANNEL AREA*	only used in 1947 data; this area is analagous to the channel area in appearance, but it is not directly comparable because it represents the extensive water and bar areas that were artificially cut off by the construction of the design channel, but which had not filled in with sediment or become stabilized and occupied by timber or cultural features by 1947. Includes "active" channel area of 1947.
"ACTIVE" CHANNEL AREA*	only used in 1947 data; this area represents the artifically controlled design channel as of 1947.
BACKWATER AREA*	measured only on 1976 maps; this area represents the few remaining open slack-water areas in 1976, which were artificially cut-off by construction of the design channel.
"POLITICAL" ISLAND AREAS*	measured only on 1976 maps; this area represents tracts of land between the 1943 compact line and the center of the 1976 channel.

*Special measurements (these features were only measured on the 1947 or 1976 maps.)



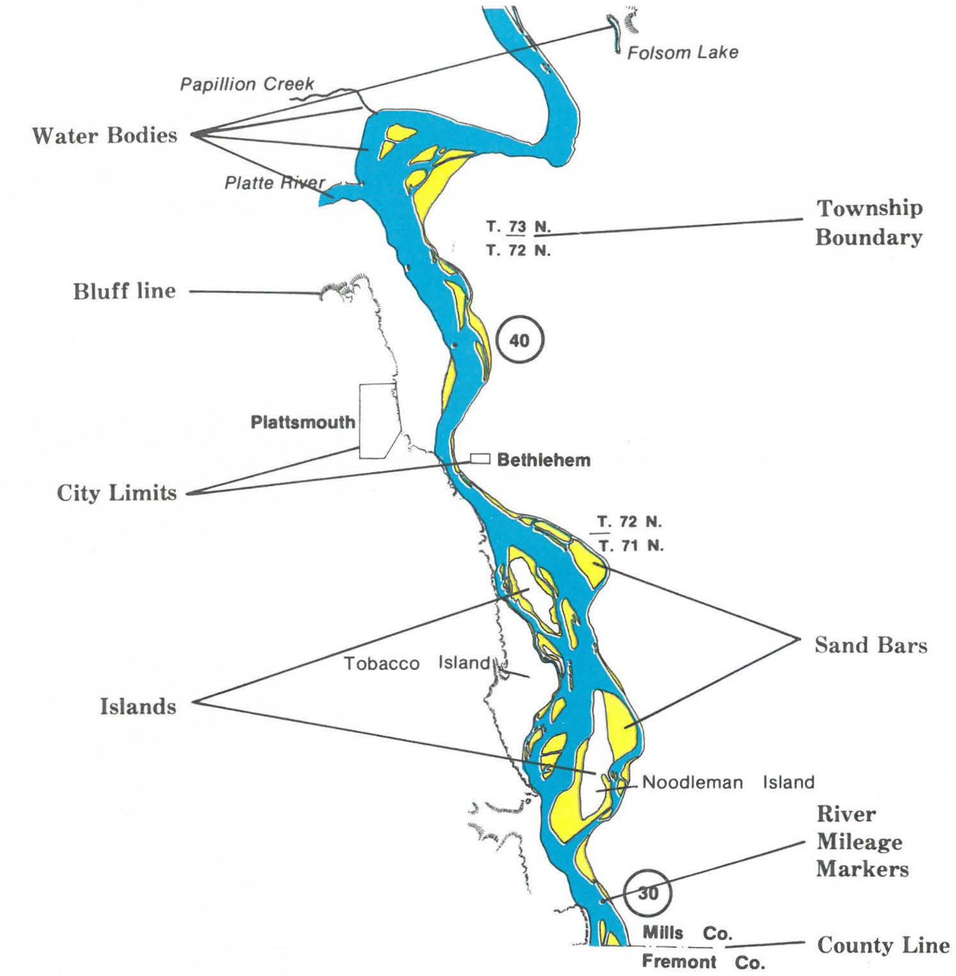


Figure 18. Explanation of symbols on county maps.

FREMONT COUNTY

Table 10. Summary of Changes in Missouri River Channel Features in FREMONT COUNTY

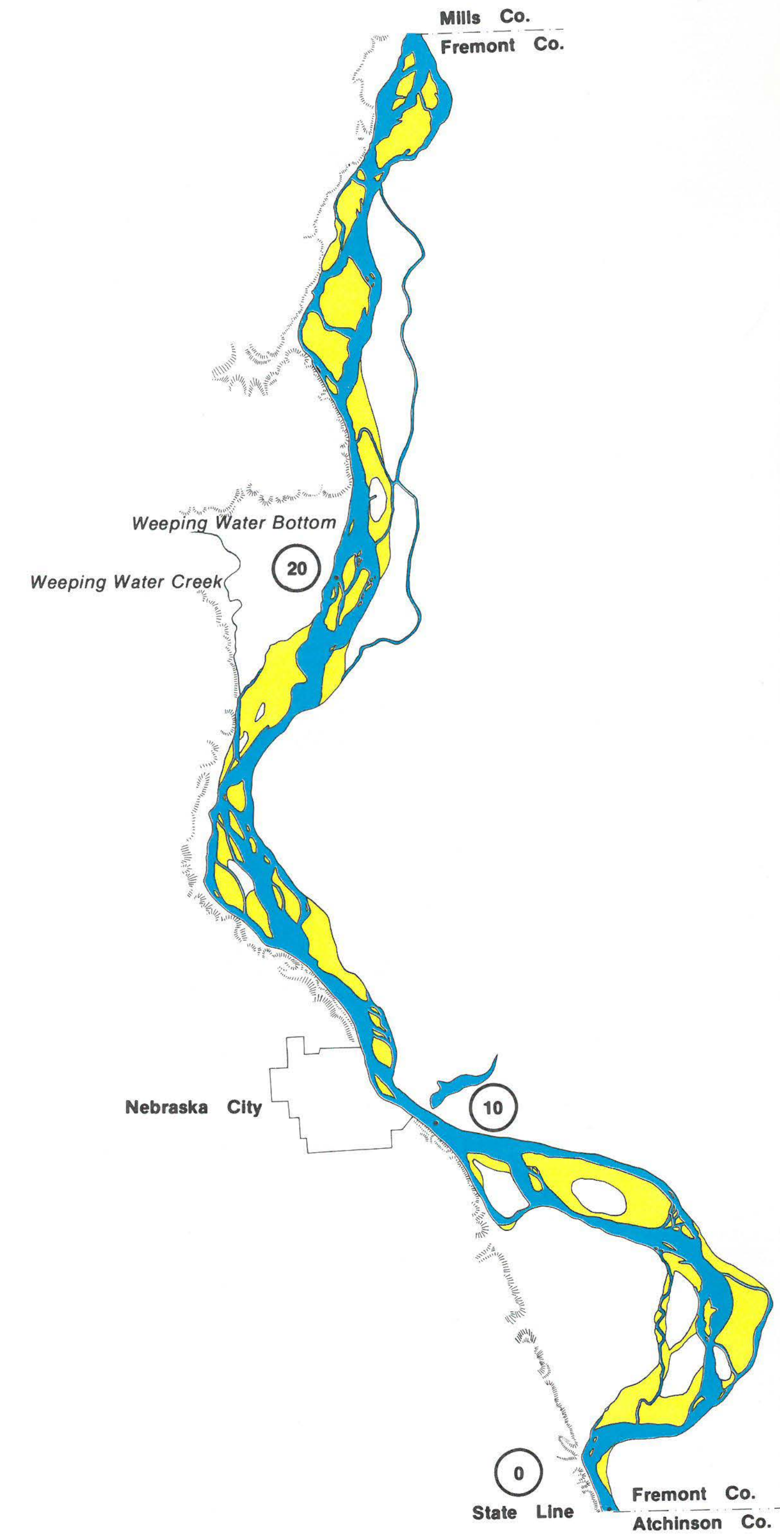
Measured Values

Year	River Miles	Sinuosity	Channel Area (acres) Total	Channel Area (acres) Iowa (Nebr.)	Water Area (acres) Total	Water Area (acres) Iowa (Nebr.)	Island Area (acres) Total	Island Area (acres) Iowa (Nebr.)	Bar Area (acres) Total	Bar Area (acres) Iowa (Nebr.)
1879	31.6	1.33	16,476	9,720 (6,756)	11,432	7,392 (4,040)	3,033	2,328 (705)	3,379	1,368 (2,011)
1890	28.7	1.21	14,693	9,351 (5,343)	5,740	3,377 (2,363)	2,807	2,106 (701)	6,146	3,867 (2,279)
1923	29.5	1.25	14,212	6,840 (7,372)	10,149	5,214 (4,935)	1,742	615 (1,126)	2,321	1,011 (1,310)
1947 ("TOTAL")	29.4	1.24	12,953	5,143 (7,810)	6,019	2,552 (3,467)	4,060	1,427 (2,632)	2,875	1,164 (1,711)
1947 ("ACTIVE")	29.4	1.24	3,065	1,410 (1,656)	2,775	1,258 (1,516)	10	10 (0)	281	141 (140)
1976	29.1	1.23	2,487	1,226 (1,261)	2,484	1,223 (1,261)	3	3 (0)	0	0 (0)
1976 (Backwater)										

Difference Between Indicated Time Periods

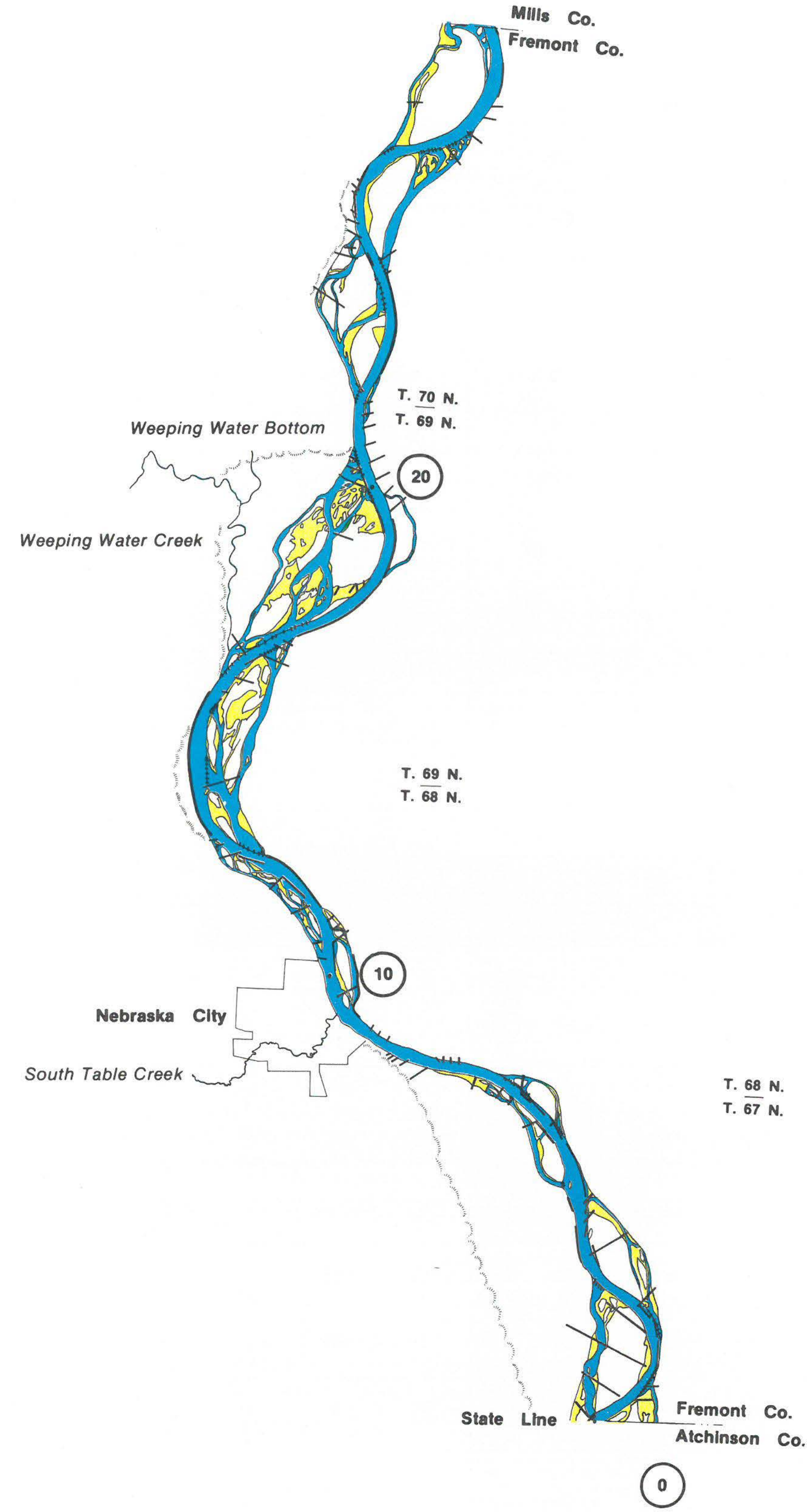
Years Time Period	River Miles %	River Miles Miles	Sinuosity %	Sinuosity Diff.	Channel Area Total %	Channel Area Total Acres	Channel Area Iowa (Nebr.) %	Channel Area Iowa (Nebr.) Acres	Water Area Total %	Water Area Total Acres	Water Area Iowa (Nebr.) %	Water Area Iowa (Nebr.) Acres	Island Area Total %	Island Area Total Acres	Island Area Iowa (Nebr.) %	Island Area Iowa (Nebr.) Acres	Bar Area Total %	Bar Area Total Acres	Bar Area Iowa (Nebr.) %	Bar Area Iowa (Nebr.) Acres
1879-1890	−9	−2.9	−9	−0.12	−11	−1,783	−4 (−21)	−369 (−1,414)	−50	−5,692	−54 (−42)	−4,015 (−1,677)	−7	−226	−10 (−1)	−222 (−4)	+82	+2,767	+183 (+13)	+2,499 (+268)
1890-1923	+3	+0.8	+3	+0.04	−3	−482	−27 (+38)	−2,511 (+2,029)	+77	+4,409	+54 (+109)	+1,837 (+2,572)	−38	−1,066	−71 (+61)	−1,491 (+426)	−62	−3,825	−74 (−43)	−2,857 (−969)
1923-1947 ("TOTAL")	−.01	−0.1	−1	−0.01	−9	−1,258	−25 (+6)	−1,697 (+438)	−41	−4,130	−51 (−30)	−2,662 (−1,469)	+133	+2,318	+132 (+134)	+812 (+1,506)	+24	+554	+15 (+31)	+153 (+401)
1923-1947 ("ACTIVE")	−.01	−0.1	−1	−0.01	−78	−11,146	−79 (−78)	−5,430 (−5,716)	−73	−7,375	−76 (−69)	−3,956 (−3,419)	−99	−1,731	−98 (−100)	−605 (−1,126)	−88	−2,040	−86 (−89)	−870 (−1,171)
1923-1976	−1	−0.4	−2	−0.02	−82	−11,724	−82 (−83)	−5,614 (−6,111)	−76	−7,665	−77 (−74)	−3,991 (−3,674)	−100	−1,739	−100 (−100)	−612 (−1,126)	−100	−2,321	−100 (−100)	−1,011 (−1,310)
1890-1976	+1	+0.4	+2	+0.02	−83	−12,206	−87 (−76)	−8,125 (−4,081)	−57	−3,256	−64 (−47)	−2,154 (−1,102)	−100	−2,804	−100 (−100)	−2,104 (−707)	0	0	0	0 (0)
1947 ("TOTAL")-1976	−1	−0.3	−1	−0.01	−81	−10,466	−76 (−84)	−3,917 (−6,549)	−59	−3,535	−52 (−64)	−1,329 (−2,206)	−100	−4,057	−100 (−100)	−1,424 (−2,632)	−100	−2,875	−100 (−100)	−1,164 (−1,711)
1947 ("ACTIVE")-1976	−1	−0.3	−1	−0.01	−19	−578	−13 (−24)	−184 (−395)	−10	−291	−3 (−17)	−35 (−255)	−72	−7	−72 (−100)	−7 (−10)	−100	−281	−100 (−100)	−141 (−140)

1890

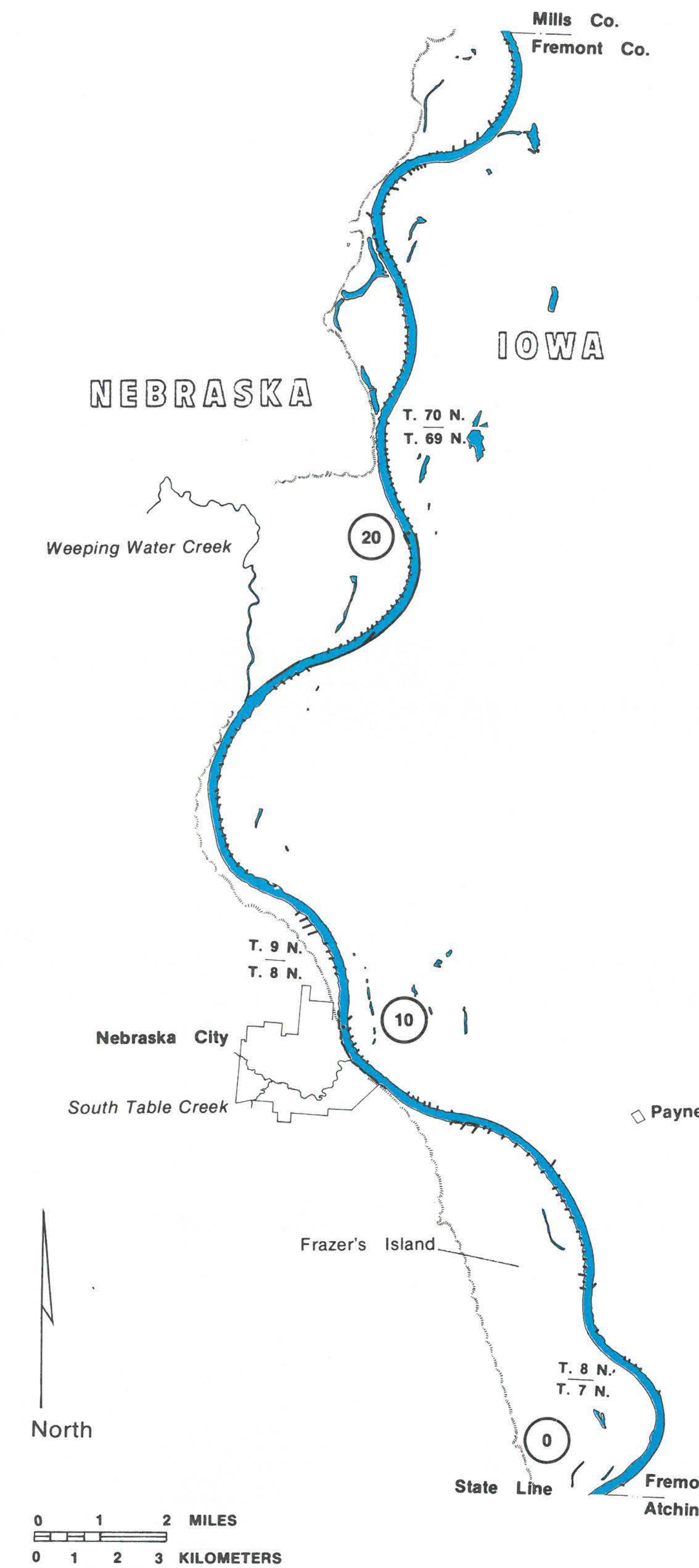


1923

1947



1976



MILLS COUNTY

Table 11. Summary of Changes in Missouri River Channel Features in MILLS COUNTY

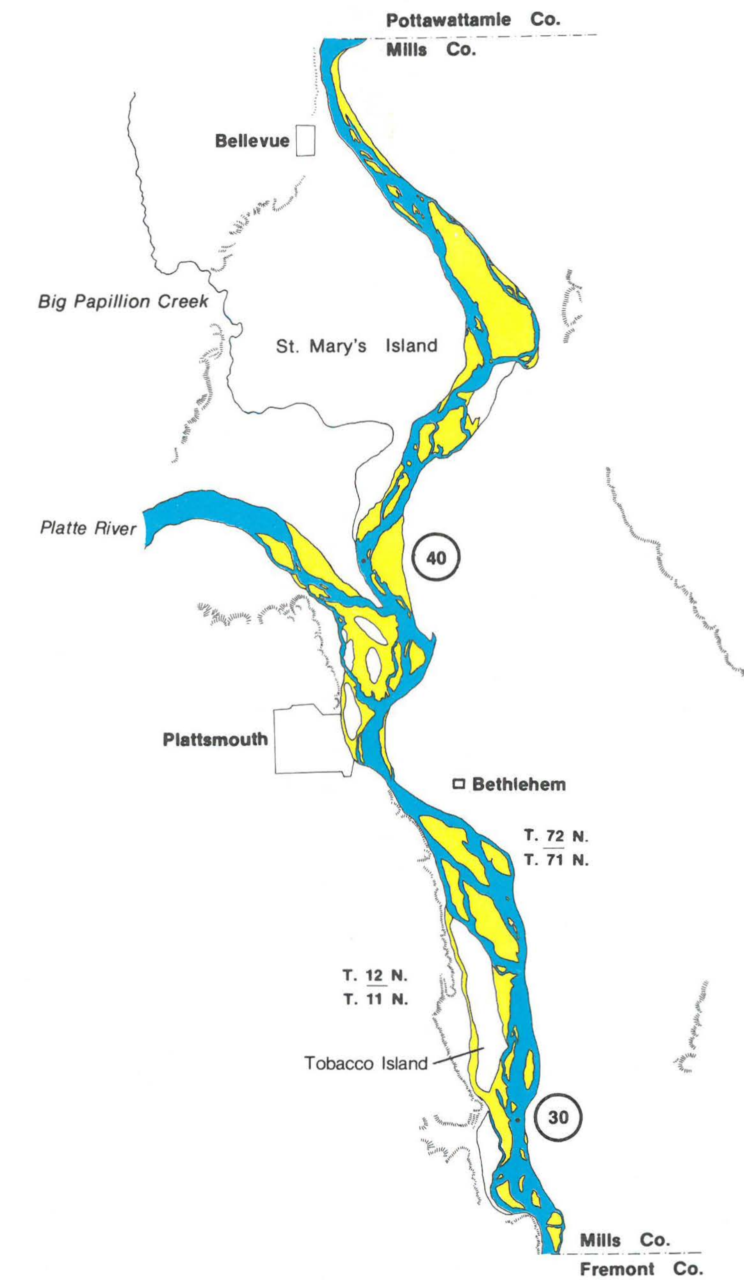
Measured Values

Year	River Miles	Sinuosity	Channel Area (acres) Total	Channel Area (acres) Iowa (Nebr.)	Water Area (acres) Total	Water Area (acres) Iowa (Nebr.)	Island Area (acres) Total	Island Area (acres) Iowa (Nebr.)	Bar Area (acres) Total	Bar Area (acres) Iowa (Nebr.)
1879	23.4	1.30	10,444	6,077 (4,367)	6,162	3,158 (3,004)	1,601	1,143 (458)	2,681	1,776 (905)
1890	22.0	1.22	7,607	3,875 (3,732)	3,173	1,619 (1,554)	579	0 (579)	3,856	2,256 (1,600)
1923	25.0	1.38	8,069	5,915 (2,154)	5,461	3,478 (1,983)	524	506 (18)	2,803	1,931 (153)
1947 ("TOTAL")	21.3	1.18	6,451	3,124 (3,327)	2,869	1,302 (1,567)	2,657	1,451 (1,201)	931	371 (560)
1947 "(ACTIVE)"	21.3	1.18	2,335	1,108 (1,227)	2,059	967 (1,092)	0	0 (0)	276	141 (135)
1976	21.1	1.17	1,582	671 (911)	1,582	671 (911)	0	0 (0)	0	0 (0)
1976 (Backwater)										

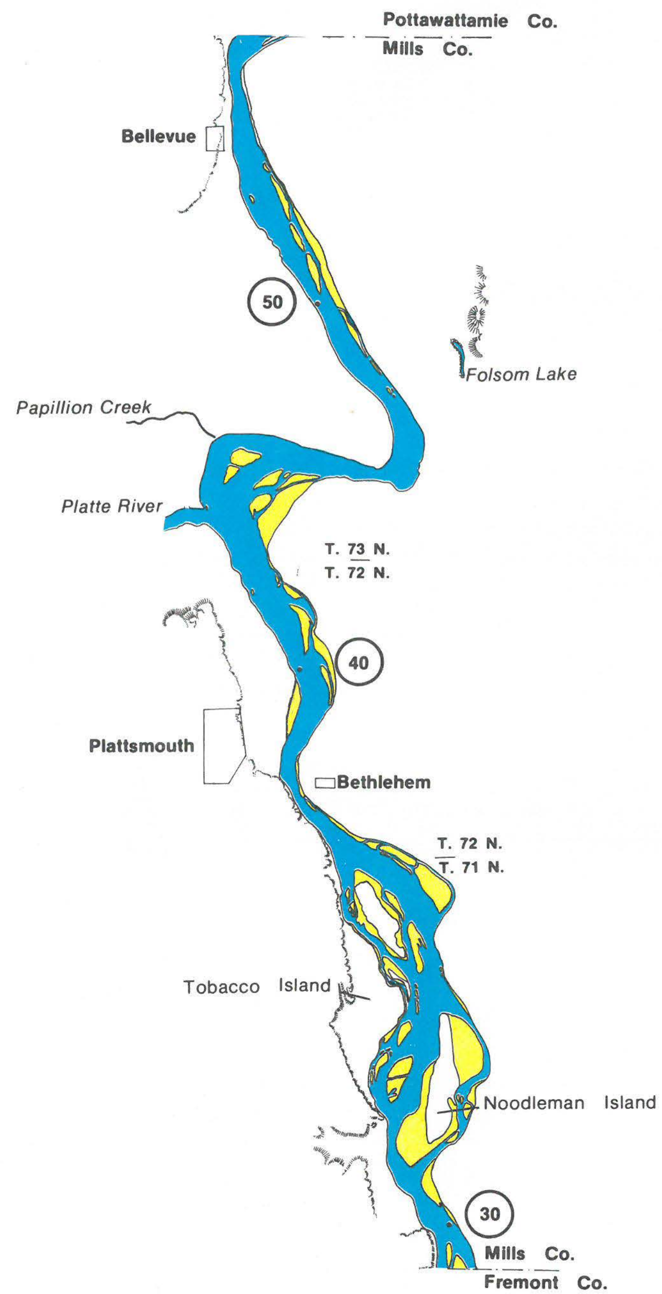
Difference Between Indicated Time Periods

Years Time Period	River Miles %	River Miles Miles	Sinuosity %	Sinuosity Diff.	Channel Area Total %	Channel Area Total Acres	Channel Area Iowa (Nebr.) %	Channel Area Iowa (Nebr.) Acres	Water Area Total %	Water Area Total Acres	Water Area Iowa (Nebr.) %	Water Area Iowa (Nebr.) Acres	Island Area Total %	Island Area Total Acres	Island Area Iowa (Nebr.) %	Island Area Iowa (Nebr.) Acres	Bar Area Total %	Bar Area Total Acres	Bar Area Iowa (Nebr.) %	Bar Area Iowa (Nebr.) Acres
1879-1890	−6	−1.4	−6	−0.08	−27	−2,837	−36 (−15)	−2,202 (−635)	−49	−2,990	−49 (−48)	−1,539 (−1,450)	−64	−1,022	−100 (+26)	−1,143 (+121)	+44	+1,175	+27 (+77)	+480 (+695)
1890-1923	+14	+3.0	+13	+0.16	+6	+461	+53 (−42)	+2,040 (−1,578)	+72	+2,288	+115 (+28)	+1,859 (+429)	−9	−55	— (−97)	+506 (−560)	−46	−1,773	−14 (−90)	−326 (−1,447)
1923-1947 ("TOTAL")	−15	−3.7	−14	−0.20	−20	−1,618	−47 (+54)	−2,791 (+1,173)	−47	−2,592	−63 (−21)	−2,176 (−416)	+406	+2,128	+187 (+6,427)	+945 (+1,182)	−55	−1,153	−81 (+267)	−1,560 (+407)
1923-1947 ("ACTIVE")	−15	−3.7	−14	−0.20	−71	−5,734	−81 (−43)	−4,807 (−927)	−62	−3,402	−72 (−45)	−2,512 (−890)	−100	−524	−100 (−100)	−506 (−18)	−87	−1,807	−93 (−12)	−1,789 (−18)
1923-1976	−16	−3.9	−15	−0.21	−80	−6,487	−89 (−58)	−5,244 (−1,243)	−71	−3,879	−81 (−54)	−2,807 (−1,072)	−100	−524	−100 (−100)	−506 (−18)	−100	−2,083	−100 (−100)	−1,931 (−153)
1890-1976	−4	−0.9	−4	−0.05	−79	−6,026	−83 (−76)	−3,204 (−2,821)	−50	−1,591	−59 (−41)	−948 (−643)	−100	−579	0 (−100)	0 (−579)	−100	−3,856	−100 (−100)	−2,256 (−1,600)
1947 ("TOTAL")- 1976	−1	−0.2	−1	−0.01	−75	−4,869	−79 (−73)	−2,453 (−2,416)	−45	−1,298	−48 (−42)	−631 (−656)	−100	−2,652	−100 (−100)	−1,452 (−1,201)	−100	−931	−100 (−100)	−371 (−560)
1947 ("ACTIVE")- 1976	−1	−0.2	−1	−0.01	−32	−753	−39 (−26)	−437 (−316)	−23	−477	−31 (−17)	−296 (−181)	0	0	0 (0)	0 (0)	−100	−276	−100 (−100)	−141 (−135)

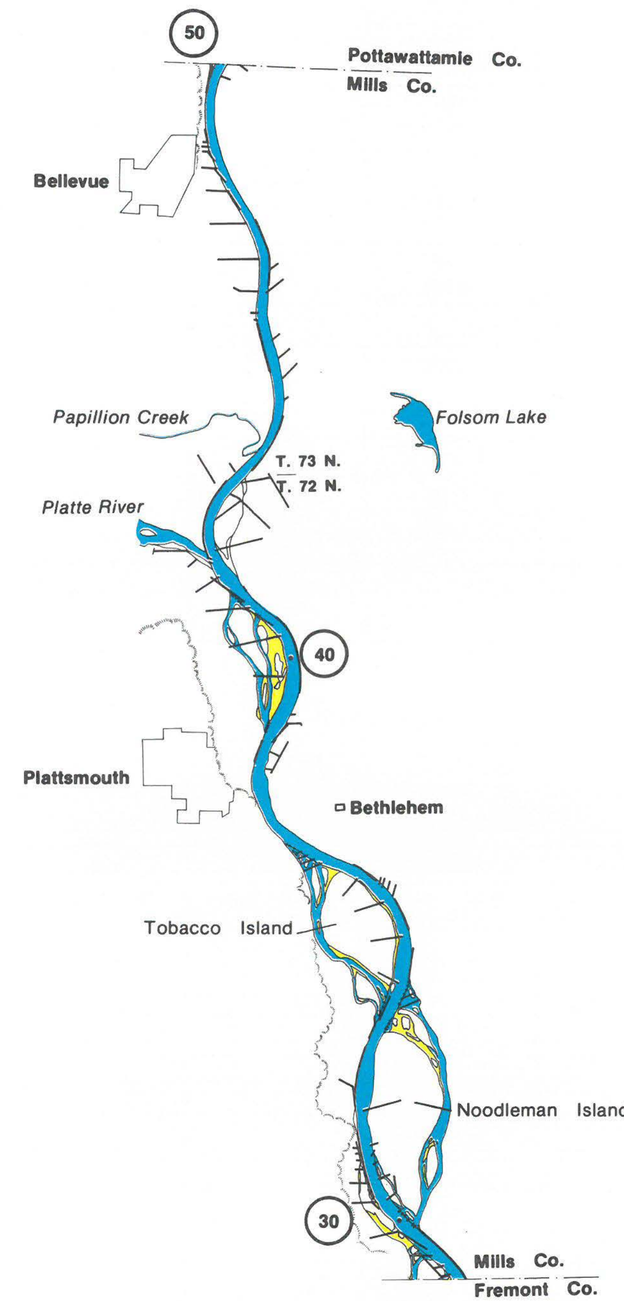
1890



1923



1947



1976

POTTAWATTAMIE COUNTY

Table 12. Summary of Changes in Missouri River Channel Features in POTTAWATTAMIE COUNTY

Measured Values

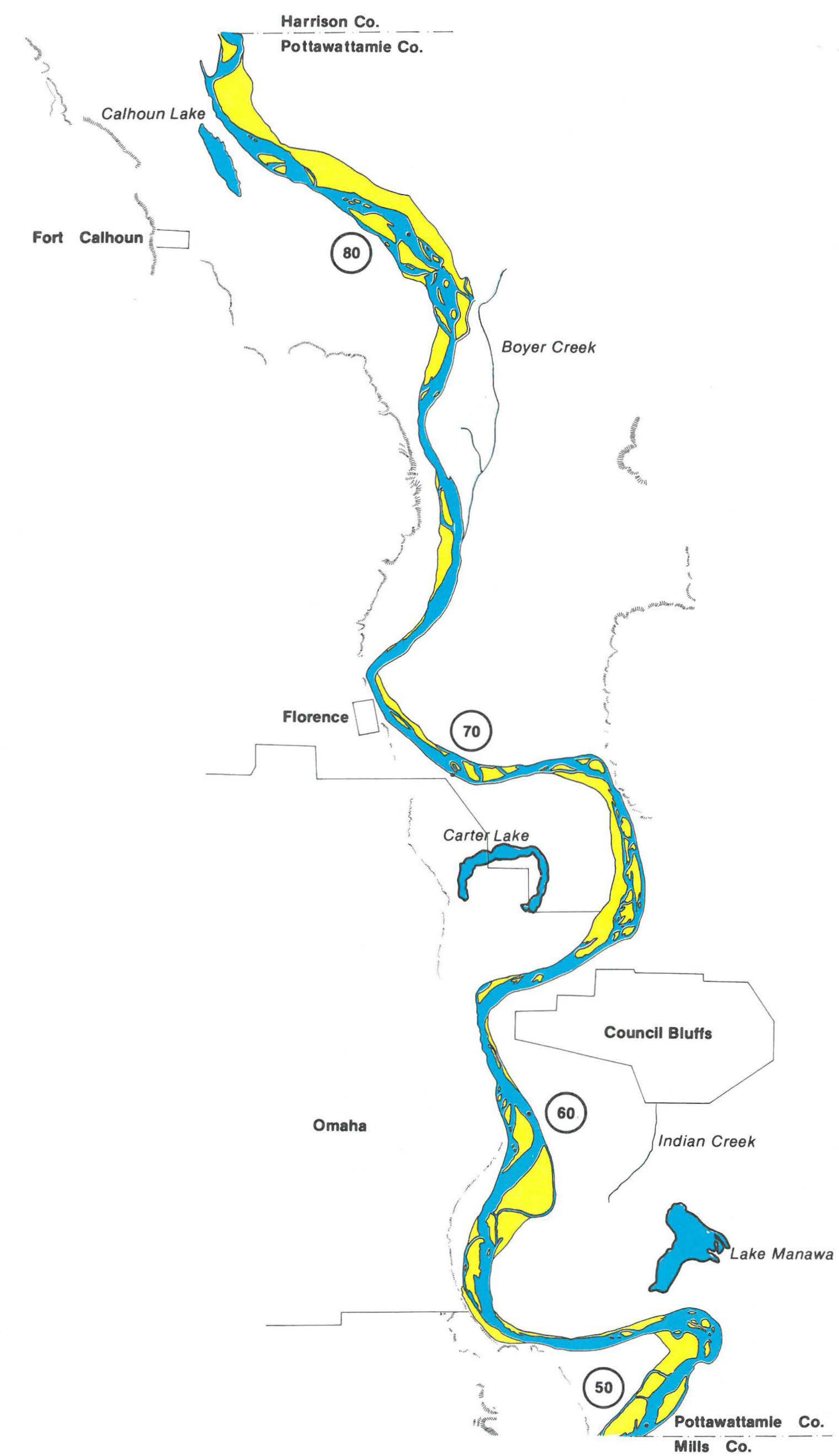
Year	River Miles	Sinuosity	Channel Area (acres)		Water Area (acres)		Island Area (acres)**		Bar Area (acres)*	
			Total	Iowa (Nebr.)	Total	Iowa (Nebr.)	Total	Iowa (Nebr.)	Total	Iowa (Nebr.)
1879	40.5	1.63	11,442	5,737 (5,705)	8,698	4,192 (4,506)	916	469 (477)	1,828	1,076 (752)
1890	38.8	1.56	9,860	4,768 (5,092)	5,032	2,099 (2,933)	0	0 (0)	4,828	2,669 (2,159)
1923	37.3	1.50	10,160	5,931 (4,229)	7,644	4,438 (3,206)	578	49 (528)	1,939	1,443 (495)
1947 ("TOTAL")	41.2	1.66	5,320	2,853 (2,467)	3,944	1,774 (2,170)	596	521 (76)	780	559 (221)
1947 ("ACTIVE")	41.2	1.66	3,464	2,008 (1,456)	2,826	1,566 (1,260)	0	0 (0)	638	442 (196)
1976	40.5	1.63	3,092	1,928 (1,974)	8,899	1,925 (1,974)	**0	**(0) (0)	*3	*3 (0)
1976 (BACKWATER)					63	54 (9)				

*Island Area and Bar Area combined in 1976 and listed under Bar Area.
**"Political Island", areas for 1976 only, listed in ( ) under Island Area.

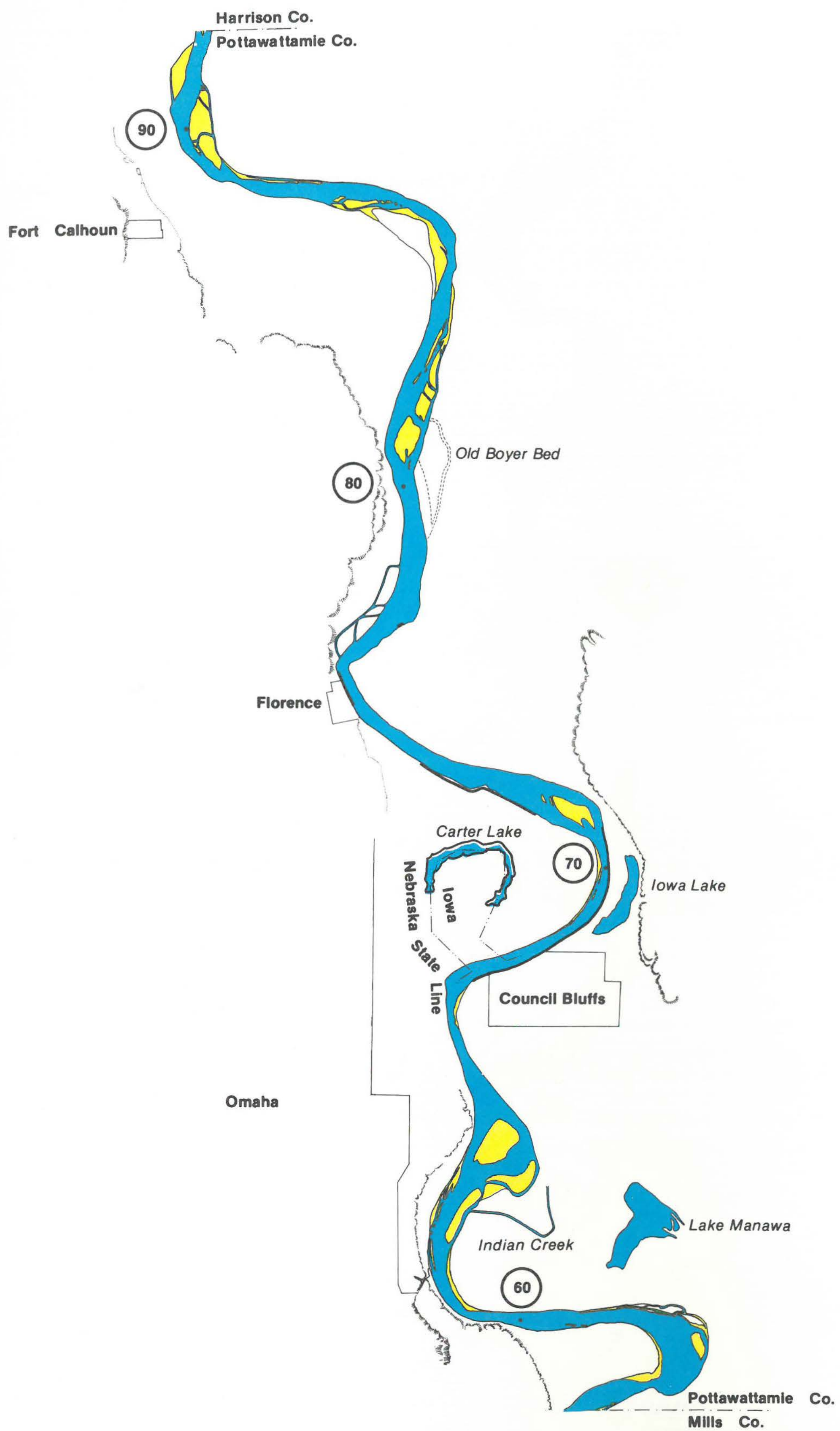
Difference Between Indicated Time Periods

Years	River Miles		Sinuosity		Channel Area				Water Area				Island Area				Bar Area			
					Total		Iowa (Nebr.)		Total		Iowa (Nebr.)		Total		Iowa (Nebr.)		Total		Iowa (Nebr.)	
Time Period	%	Miles	%	Diff.	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
1879-1890	− 4	− 1.7	− 4	− 0.07	− 14	− 1,583	− 17 (− 11)	− 969 (− 613)	− 42	− 3,666	− 50 (− 35)	− 2,093 (− 1,573)	− 100	− 916	− 100 (− 100)	− 469 (− 447)	+ 164	+ 3,000	+ 148 (+ 187)	+ 1,593 (+ 1,407)
1890-1923	− 4	− 1.55	− 4	− 0.06	+ 3	+ 300	+ 24 (− 17)	+ 1,163 (− 863)	+ 52	+ 2,612	+ 111 (+ 9)	+ 2,339 (+ 273)		+ 578		+ 49 (+ 528)	− 60	− 2,890	− 46 (− 77)	− 1,225 (− 1,664)
1923-1947 ("TOTAL")	+ 11	+ 3.95	+ 11	+ 0.16	− 48	− 4,841	− 52 (− 42)	− 3,078 (− 1,763)	− 48	− 3,700	− 60 (− 32)	− 2,664 (− 1,036)	+ 3	+ 18	+ 954 (− 86)	+ 471 (− 453)	− 60	− 1,159	− 61 (− 55)	− 885 (− 274)
1923-1947 ("ACTIVE")	+ 11	+ 3.95	− 11	+ 0.16	− 66	− 6,696	− 66 (− 66)	− 3,923 (− 2,773)	− 65	− 2,872	− 65 (− 61)	− 2,872 (− 1,946)	− 100	− 578	− 100 (− 100)	− 49 (− 528)	− 67	− 1,301	− 69 (− 60)	− 1,002 (− 299)
1923-1976	+ 9	+ 3.25	+ 9	+ 0.13	− 62	− 6,258	− 67 (− 53)	− 4,003 (− 2,255)	− 49	− 3,745	− 57 (− 38)	− 2,513 (− 1,232)	− 100	− 578	− 100 (− 100)	− 49 (− 528)	− 100	− 1,936	− 100 (− 100)	− 1,441 (− 495)
1890-1976	+ 4	+ 1.7	+ 4	+ 0.07	− 60	− 5,958	− 60 (− 61)	− 2,840 (− 3,118)	− 23	− 1,133	− 8 (− 33)	− 174 (− 959)	0	0	0 0	0 (0)	− 100	− 4,825	− 100 (− 100)	− 2,666 (− 2,159)
1947 ("TOTAL")-1976	− 2	− 0.7	− 2	− 0.03	− 27	− 1,418	− 32 (− 20)	− 925 (− 493)	− 1	− 45	+ 9 (− 9)	+ 151 (− 196)	− 100	− 596	− 100 (− 100)	− 521 (− 76)	− 100	− 777	− 100 (− 100)	− 556 (− 221)
1947 ("ACTIVE")-1976	− 2	− 0.7	− 2	− 0.03	+ 13	+ 438	− 4 (+ 36)	− 80 (+ 518)	+ 38	+ 1,073	+ 23 (+ 57)	+ 359 (+ 714)	0	0	0 0	0 (0)	− 100	− 635	− 99 (− 100)	− 439 (− 196)

1890



1923



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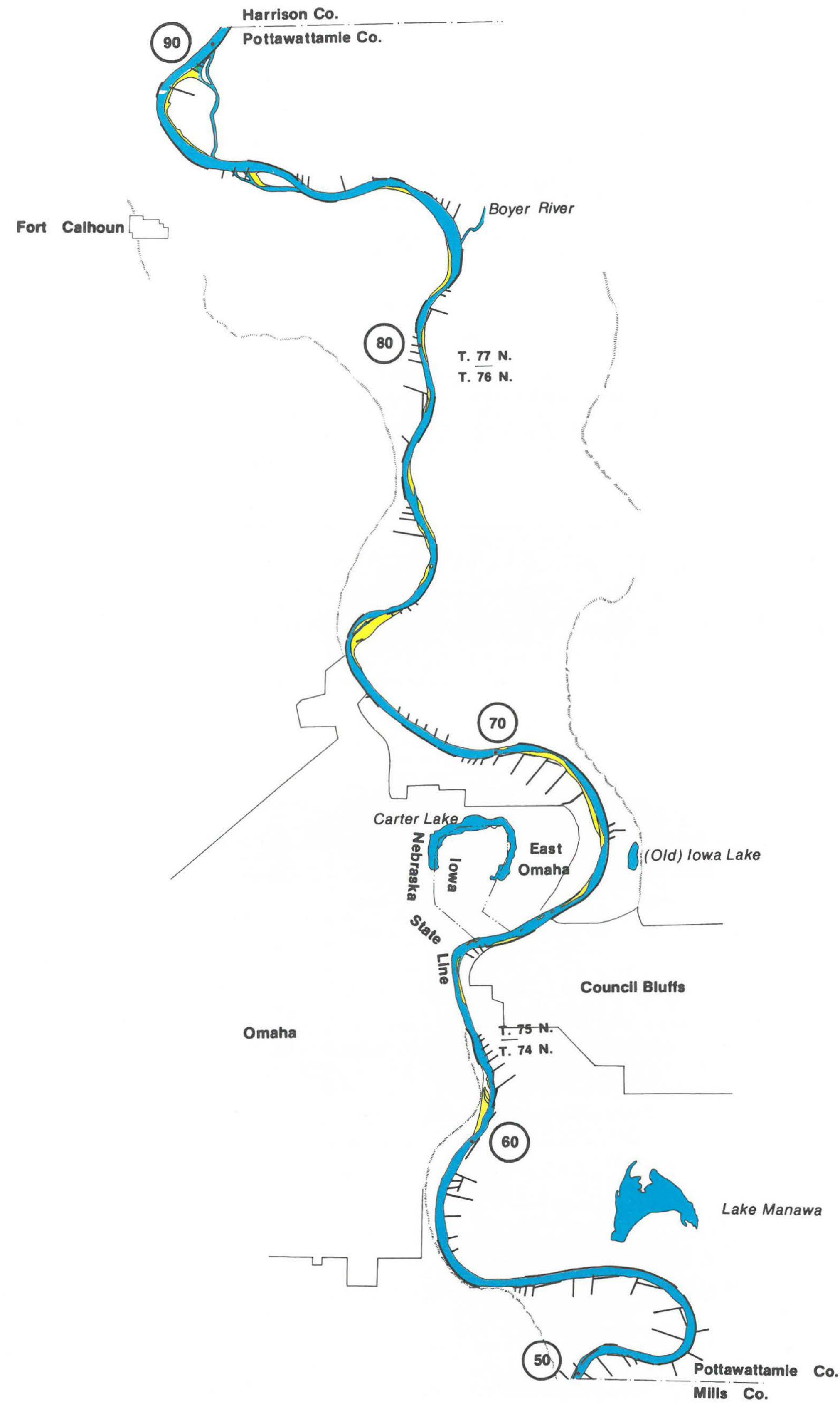
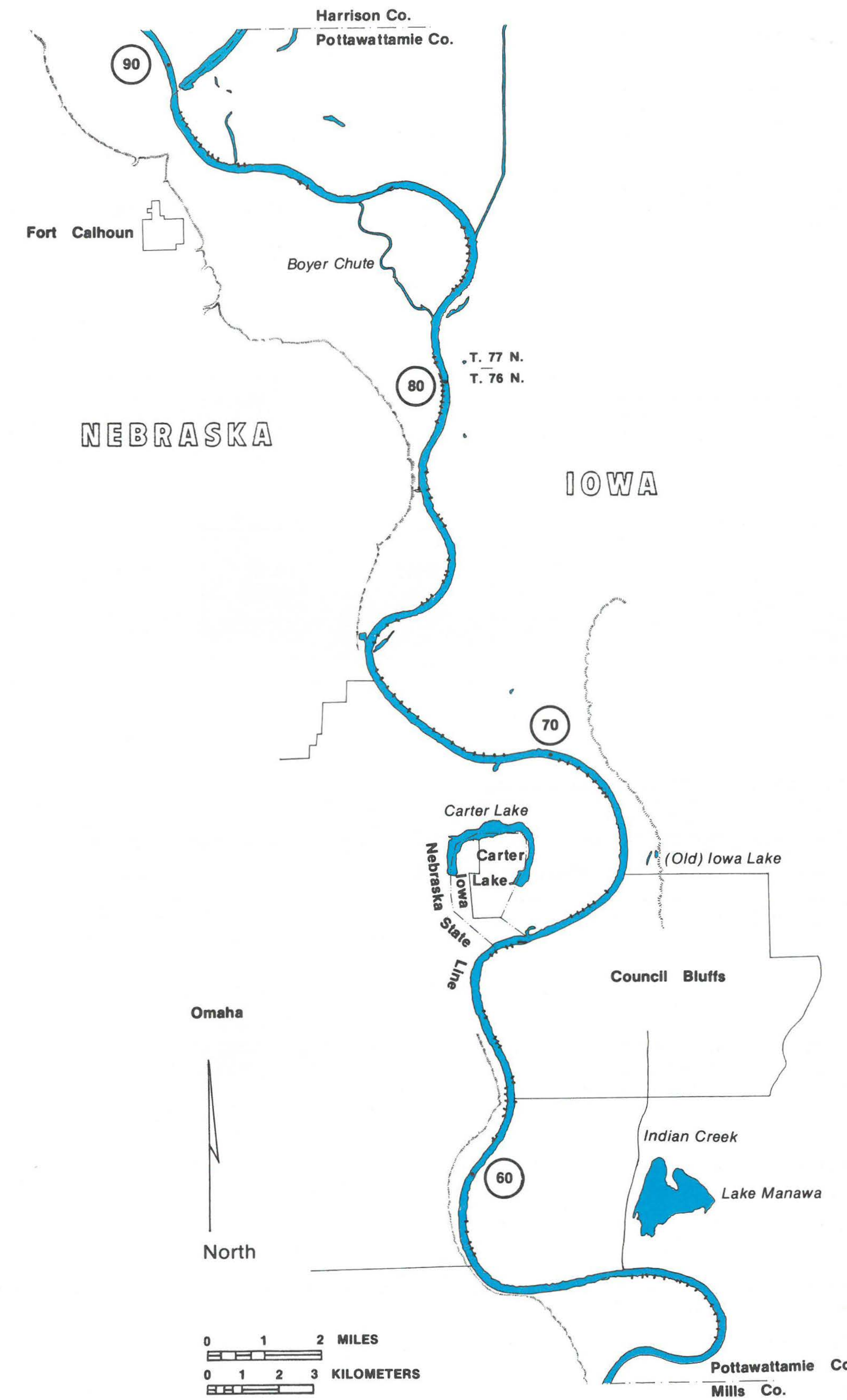


1976



HARRISON COUNTY

Table 13. Summary of Changes in Missouri River Channel Features in HARRISON COUNTY

Measured Values

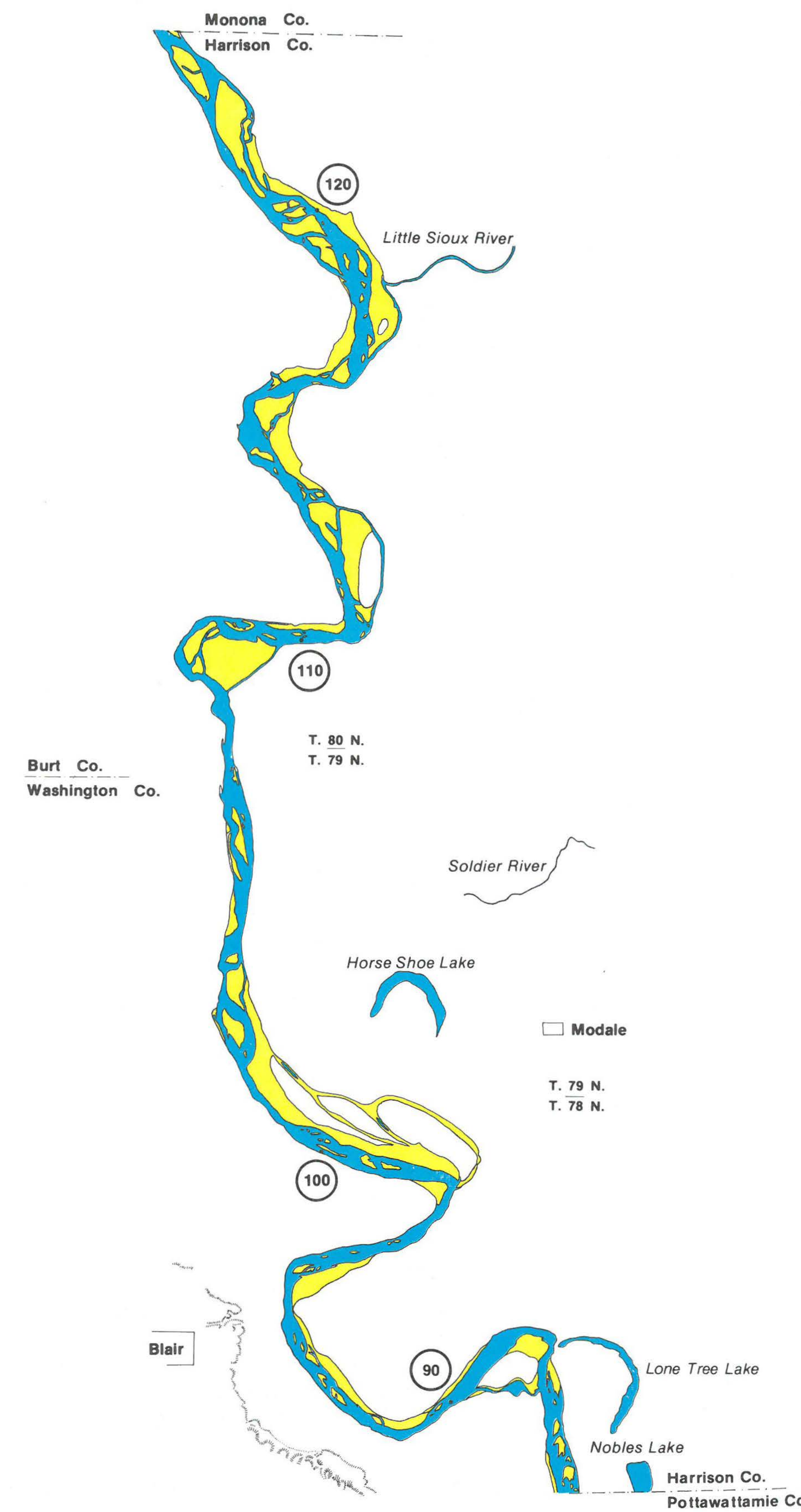
Year	River Miles	Sinuosity	Channel Area (acres)		Water Area (acres)		Island Area (acres)**		Bar Area (acres)*	
			Total	Iowa (Nebr.)	Total	Iowa (Nebr.)	Total	Iowa (Nebr.)	Total	Iowa (Nebr.)
1879	42.5	1.58	16,400	8,704 (7,696)	12,213	6,278 (5,935)	1,930	1,131 7998)	2,257	1,295 (962)
1890	43.8	1.63	14,103	9,131 (4,972)	9,280	5,956 (3,324)	491	277 (214)	4,332	2,898 (1,434)
1923	44.7	1.66	15,148	7,354 (7,794)	9,094	5,006 (4,088)	1,887	431 (1,456)	4,167	1,917 (2,250)
1947 ("TOTAL")	42.5	1.58	9,155	5,287 (3,868)	3,774	1,840 (1,934)	1,434	912 (522)	3,947	2,536 (1,411)
1947 ("ACTIVE")	42.5	1.58	3,721	1,787 (1,934)	3,098	1,439 (1,659)	0	0 (0)	624	348 (276)
1976	32.9	1.22	2,669	1,576 (1,093)	2,620	1,539 (1,081)	*0	0 (0)	*49	*37 (12)
1976 (BACKWATER)					1,188	1,054 (134)				

*Island Area and Bar Area combined in 1976 and listed under Bar Area.
**"Political Island", areas for 1976 only, listed in ( ) under Island Area.

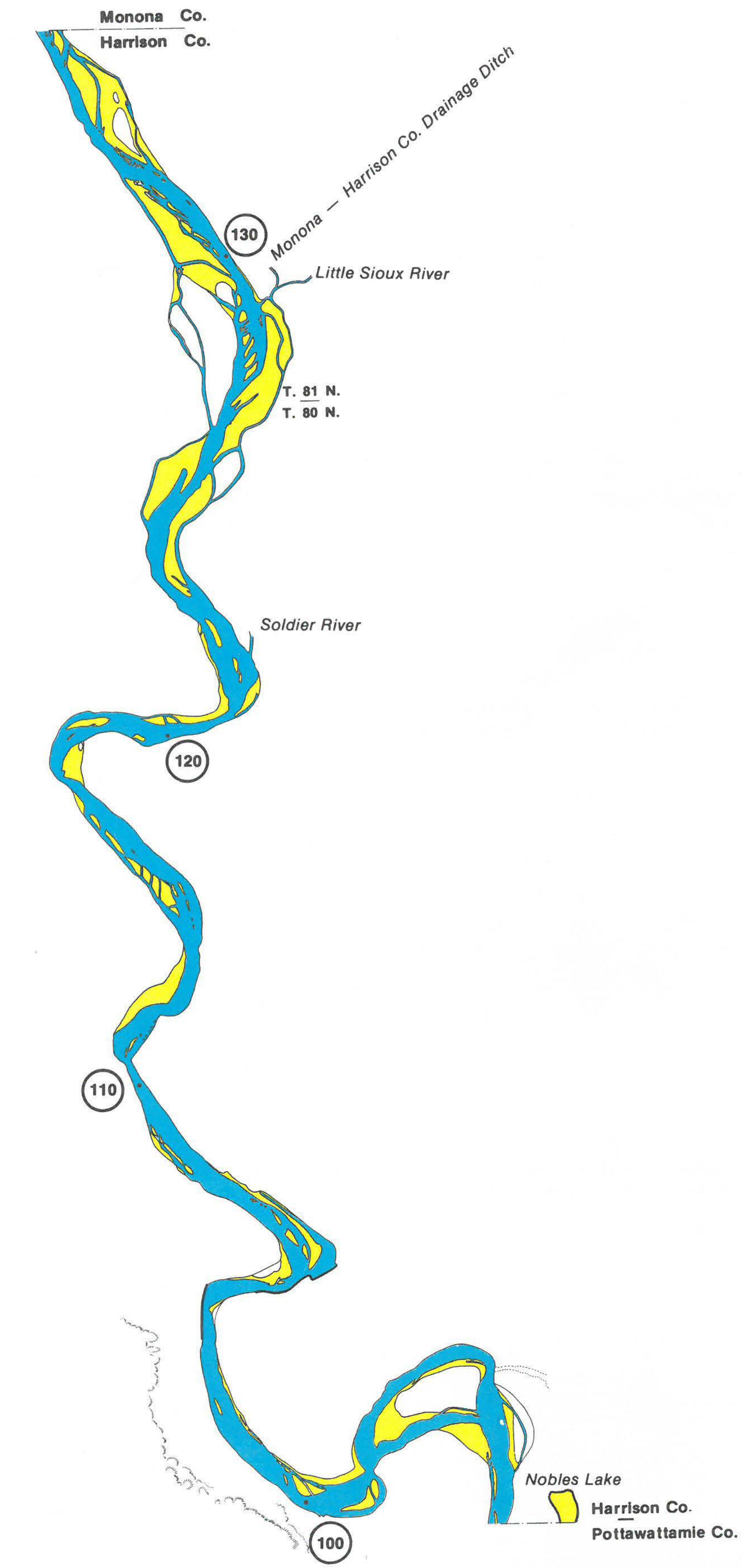
Difference Between Indicated Time Periods

Years Time Period	River Miles %	River Miles Miles	Sinuosity %	Sinuosity Diff.	Channel Area Total %	Channel Area Total Acres	Channel Area Iowa (Nebr.) %	Channel Area Iowa (Nebr.) Acres	Water Area Total %	Water Area Total Acres	Water Area Iowa (Nebr.) %	Water Area Iowa (Nebr.) Acres	Island Area Total %	Island Area Total Acres	Island Area Iowa (Nebr.) %	Island Area Iowa (Nebr.) Acres	Bar Area Total %	Bar Area Total Acres	Bar Area Iowa (Nebr.) %	Bar Area Iowa (Nebr.) Acres
1879-1890	+ 3	+ 1.3	+ 3	+ 0.05	– 14	– 2,297	+ 5 (– 35)	+ 427 (– 2,724)	– 24	– 2,933	– 5 (– 44)	– 322 (– 2,611)	+ 75	+ 1,439	– 75 (– 73)	– 854 (– 586)	+ 92	+ 2,075	+ 124 (+ 49)	+ 1,603 (+ 472)
1890-1923	+ 2	+ 0.9	+ 2	+ 0.03	+ 7	+ 1,046	– 19 (+ 57)	– 1,777 (+ 2,822)	– 2	– 186	– 16 (+ 23)	– 950 (+ 764)	+ 284	+ 1,396	+ 56 (+ 582)	+ 154 (+ 1,242)	– 4	– 165	– 34 (+ 57)	– 981 (+ 816)
1923-1947 ("TOTAL")	– 5	– 2.2	– 5	– 0.08	– 40	– 5,993	– 28 (– 50)	+ 2,067 (– 3,926)	– 58	– 5,320	– 63 (– 53)	– 3,166 (– 2,154)	– 24	– 453	+ 111 (– 64)	+ 480 (– 933)	– 5	– 220	+ 32 (– 37)	+ 618 (– 839)
1923-1947 ("ACTIVE")	– 5	– 2.2	– 5	– 0.08	– 75	– 11,427	– 76 (– 75)	– 5,567 (– 5,860)	– 66	– 5,997	– 71 (– 59)	– 3,567 (– 2,430)	– 100	– 1,887	– 100 (– 100)	– 431 (– 1,456)	– 85	– 3,544	– 82 (– 88)	– 1,569 (– 1,974)
1923-1976	– 26	– 11.8	– 26	– 0.44	– 82	– 12,479	– 79 (– 86)	– 5,778 (– 6,701)	– 71	– 6,474	– 69 (– 74)	– 3,467 (– 3,007)	– 100	– 1,887	– 100 (– 100)	– 432 (– 1,456)	– 99	– 4,118	– 98 (– 99)	– 1,180 (– 2,238)
1890-1976	– 25	– 10.9	– 25	– 0.41	– 81	– 11,434	– 83 (– 78)	– 7,555 (– 3,879)	– 72	– 6,660	– 74 (– 67)	– 4,417 (– 2,243)	– 100	– 491	– 100 (– 100)	– 277 (– 214)	– 99	– 4,283	– 99 (– 99)	– 2,861 (– 1,422)
1947 ("TOTAL")-1976	– 23	– 9.6	– 23	– 0.36	– 71	– 6,486	– 70 (– 72)	– 3,711 (– 2,775)	– 31	– 1,154	– 16 (– 44)	– 301 (– 854)	– 100	– 1,434	– 100 (– 100)	– 912 (– 522)	– 99	– 3,898	– 99 (– 99)	– 2,499 (– 1,399)
1947 ("ACTIVE")-1976	– 23	– 9.6	– 23	– 0.36	– 28	– 1,052	– 9 (– 43)	– 694 (– 841)	– 15	– 478	+ 7 (– 35)	+ 100 (– 578)	0	0	0 (0)	0 (0)	– 92	– 575	– 97 (– 96)	– 336 (– 264)

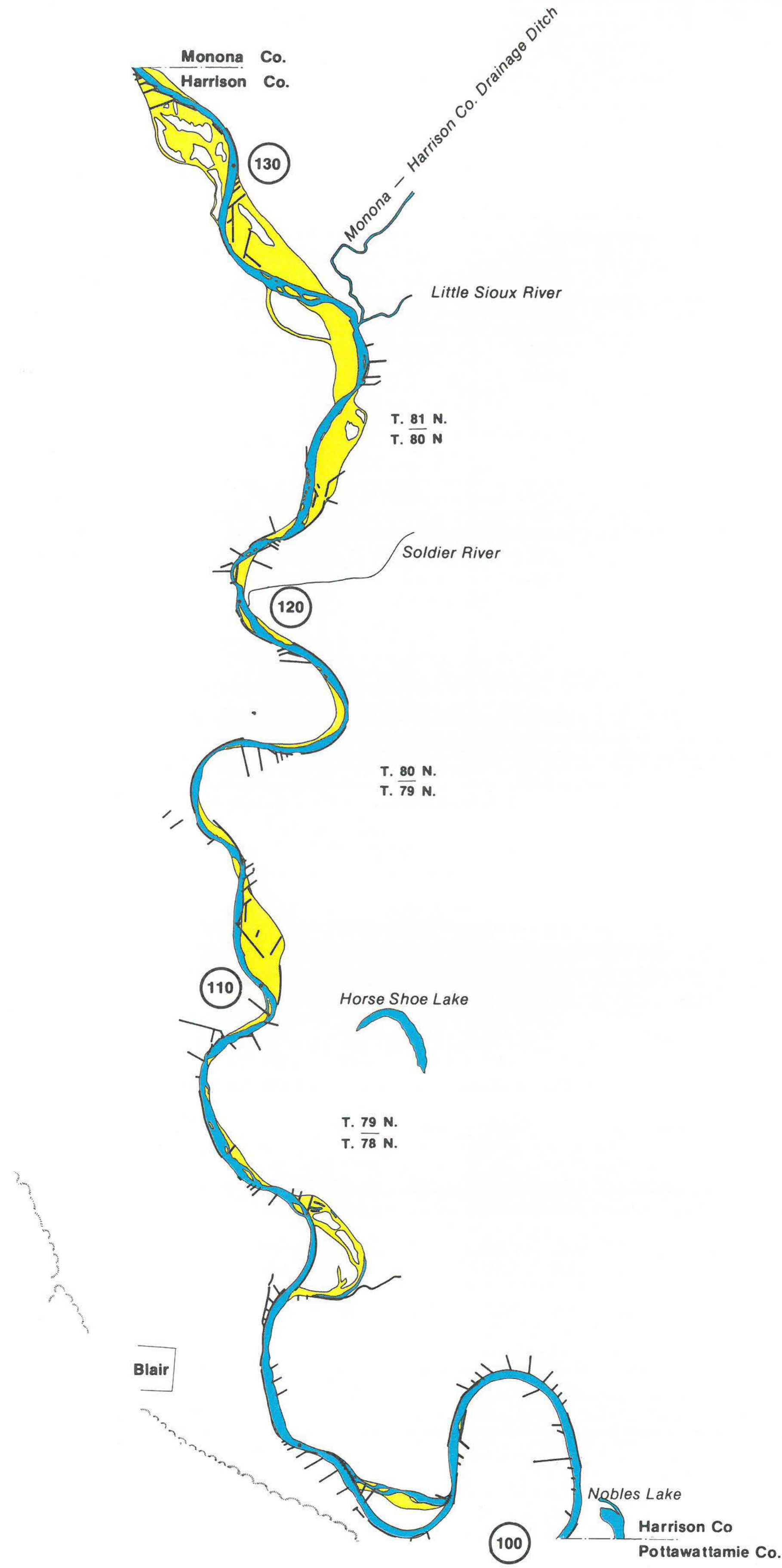
1890



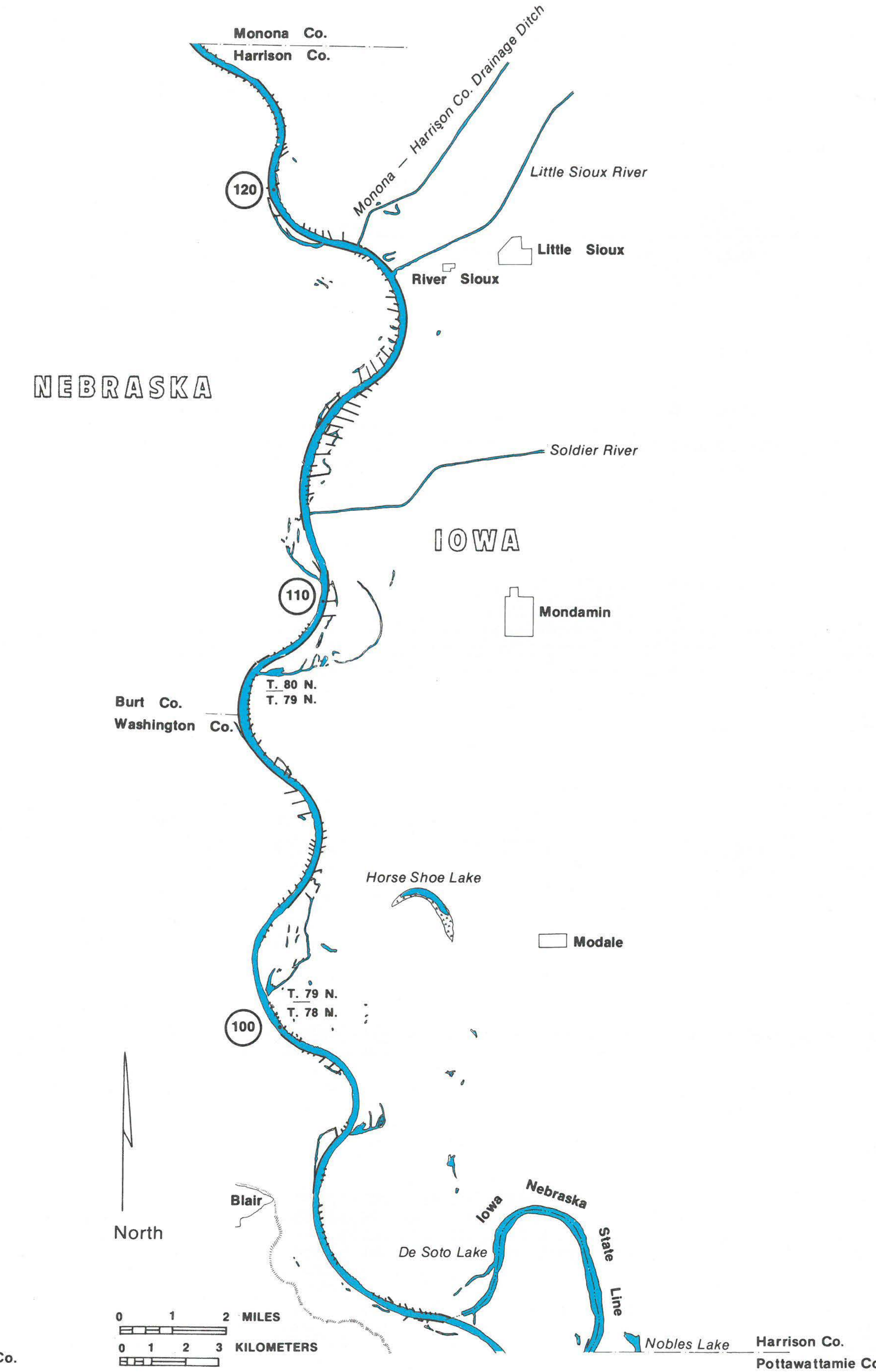
1923



1947



1976



MONONA COUNTY

Table 14. Summary of Changes in Missouri River Channel Features in MONONA COUNTY

Measured Values

Year	River Miles	Sinuosity	Channel Area (acres) Total	Channel Area (acres) Iowa (Nebr.)	Water Area (acres) Total	Water Area (acres) Iowa (Nebr.)	Island Area (acres)** Total	Island Area (acres)** Iowa (Nebr.)	Bar Area (acres)* Total	Bar Area (acres)* Iowa (Nebr.)
1879	40.5	1.51	15,109	8,785 (6,324)	11,674	6,887 (4,787)	819	511 (308)	2,616	1,387 (1,229)
1890	42.7	1.59	13,497	7,945 (5,552)	7,387	4,274 (3,113)	78	0 (78)	6,032	3,671 (2,631)
1923	35.8	1.33	15,937	8,969 (6,968)	6,882	3,494 (3,388)	3,701	2,683 (1,018)	5,354	2,792 (2,562)
1947 ("TOTAL")	36.4	1.35	9,156	3,606 (5,550)	3,365	1,359 (2,006)	925	196 (730)	4,866	2,051 (2,814)
1947 ("ACTIVE")	36.4	1.35	3,298	1,650 (1,648)	2,556	1,275 (1,281)	0	0 (0)	742	375 (336)
1976	33.5	1.25	2,724	1,111 (1,613)	2,723	1,111 (1,612)	*0	0 (0)	*1	*0 (1)
1976 (BACKWATER)					302	133 (169)	**(3,041)	**(333) (2,708)		

*Island Area and Bar Area combined in 1976 and listed under Bar Area.

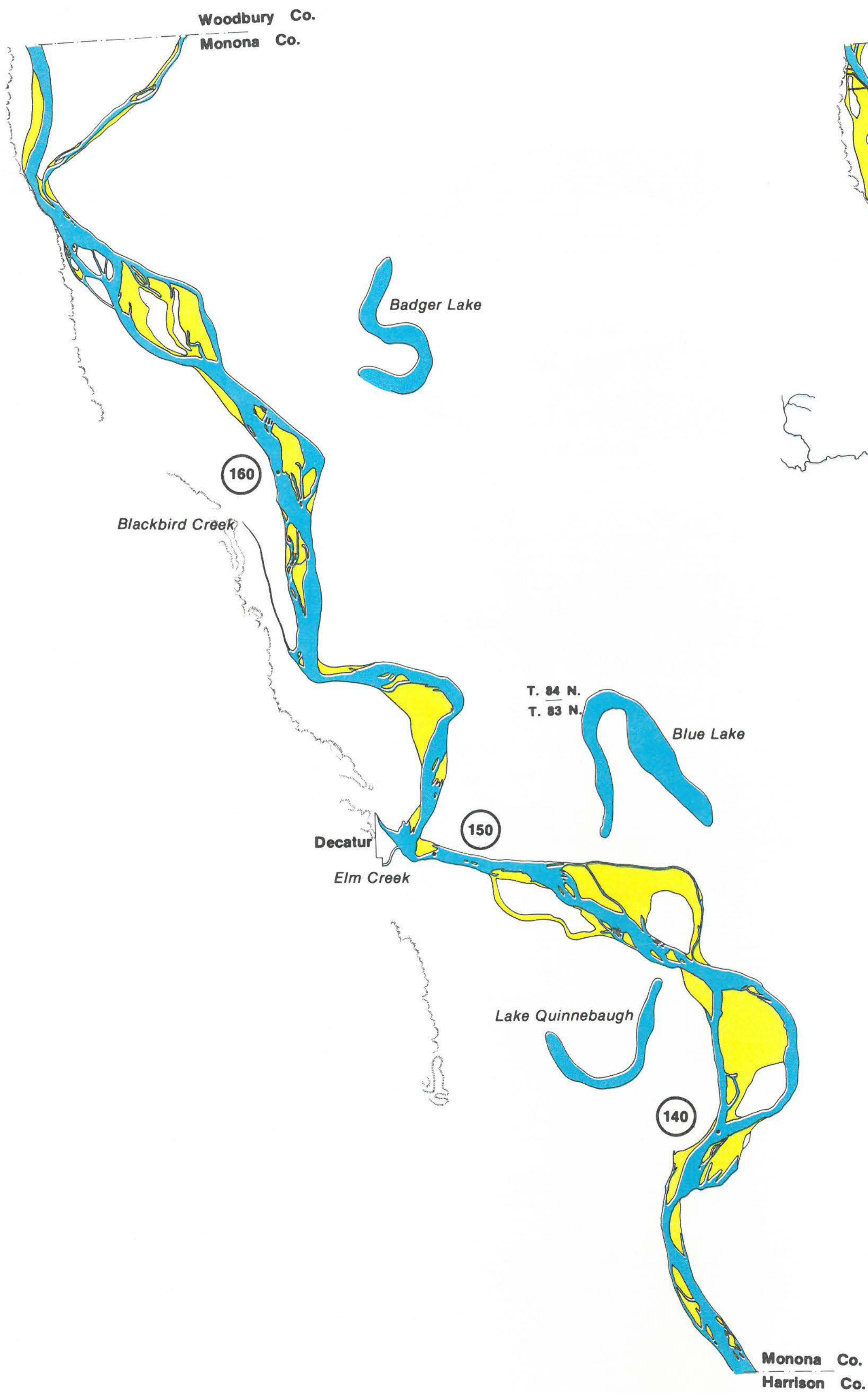
**"Political Island", areas for 1976 only, listed in ( ) under Island Area.

Difference Between Indicated Time Periods

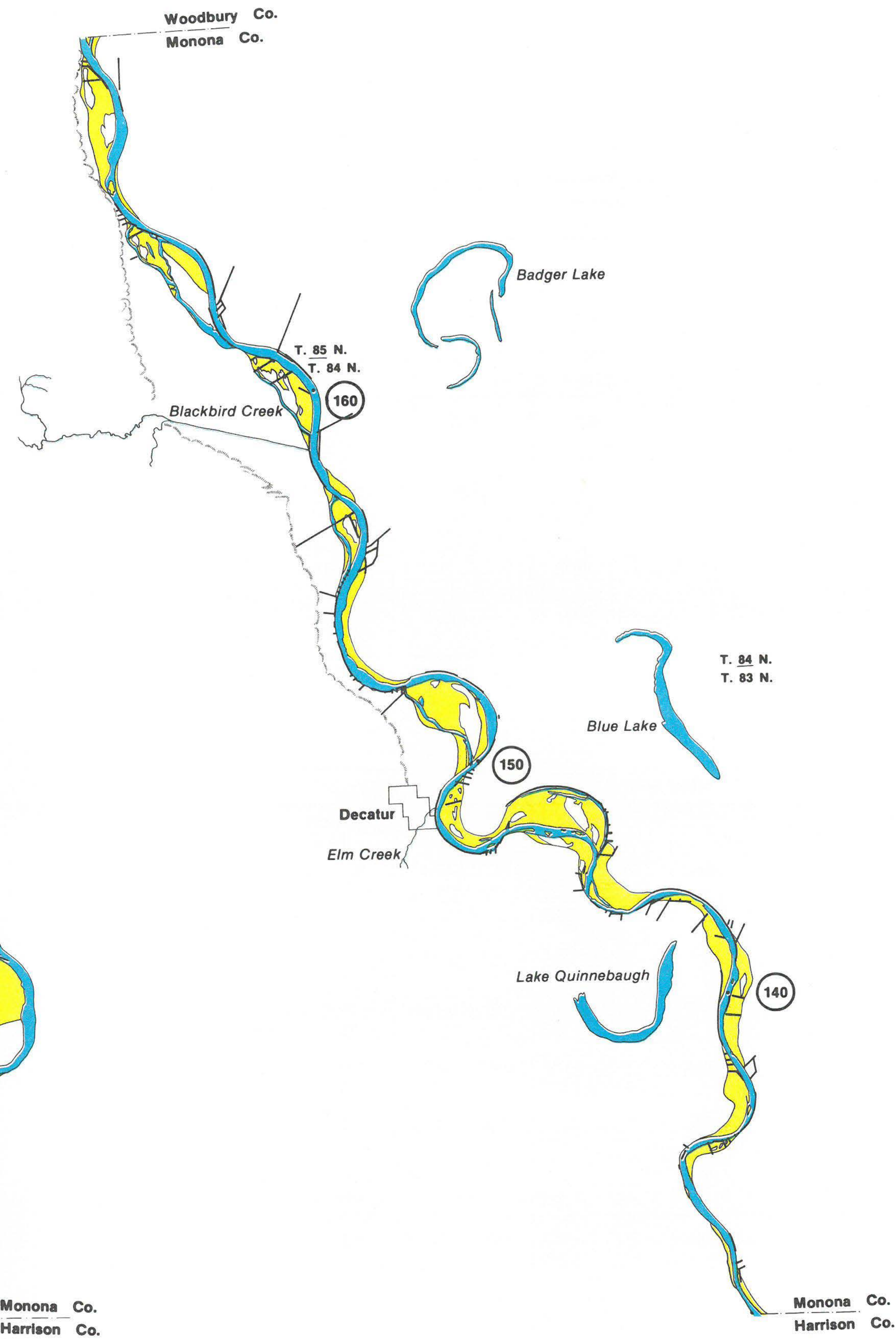
Years Time Period	River Miles %	River Miles Miles	Sinuosity %	Sinuosity Diff.	Channel Area Total %	Channel Area Total Acres	Channel Area Iowa (Nebr.) %	Channel Area Iowa (Nebr.) Acres	Water Area Total %	Water Area Total Acres	Water Area Iowa (Nebr.) %	Water Area Iowa (Nebr.) Acres	Island Area Total %	Island Area Total Acres	Island Area Iowa (Nebr.) %	Island Area Iowa (Nebr.) Acres	Bar Area Total %	Bar Area Total Acres	Bar Area Iowa (Nebr.) %	Bar Area Iowa (Nebr.) Acres
1879-1890	+ 5	+ 2.2	+ 5	+ 0.08	– 11	– 1,612	– 10 (– 12)	– 840 (– 772)	– 37	– 4,287	– 38 (– 35)	– 2,613 (– 1,674)	– 90	– 741	– 100 (– 75)	– 511 (– 230)	+ 131	+ 3,416	+ 165 (+ 92)	+ 2,284 (+ 1,132)
1890-1923	– 16	– 6.95	– 16	– 0.26	+ 18	+ 2,440	+ 13 (+ 25)	+ 1,024 (+ 1,416)	– 7	– 505	– 18 (+ 9)	+ 1,024 (+ 275)	+ 4,627	+ 3,623	 (+ 1,200)	+ 2,683 (+ 940)	– 11	– 678	– 24 (+ 9)	– 880 (+ 202)
1923 -1947 ("TOTAL")	+ 2	+ 0.65	+ 1.5	+ 0.02	– 43	– 6,781	– 60 (– 20)	– 5,363 (– 1,418)	– 51	– 3,517	– 61 (– 40)	– 2,135 (– 1,382)	– 75	– 2,776	– 93 (– 28)	– 2,487 (– 288)	– 9	– 488	– 27 (+ 10)	– 740 (+ 252)
1923-1947 ("ACTIVE")	+ 2	+ 0.65	+ 1.5	+ 0.02	– 79	– 12,640	– 82 (– 76)	– 7,319 (– 5,320)	– 63	– 4,326	– 64 (– 60)	– 2,220 (– 2,107)	– 100	– 3,701	– 100 (– 100)	– 2,683 (– 1,018)	– 86	– 4,613	– 87 (– 86)	– 2,417 (– 2,196)
1923-1976	– 6	+ 2.25	– 6	– 0.08	– 83	– 13,213	– 88 (– 77)	– 7,858 (– 5,355)	– 60	– 4,159	– 68 (– 52)	– 2,383 (– 1,776)	– 100	– 3,701	– 100 (– 100)	– 2,683 (– 1,018)	– 100	– 5,353	– 100 (– 100)	– 2,792 (– 2,561)
1890-1976	– 22	– 9.2	– 21	– 0.34	– 80	– 10,773	– 86 (– 71)	– 6,834 (– 3,939)	– 63	– 4,664	– 74 (– 48)	– 3,163 (+ 1,501)	– 100	– 78	0 (– 100)	– 1 (– 78)	– 100	– 6,031	– 100 (– 100)	– 3,671 (– 2,360)
1947 ("TOTAL")- 1976	– 8	– 2.9	– 7	– 0.10	– 70	– 6,432	– 69 (– 71)	– 2,495 (– 3,937)	– 19	– 642	– 18 (– 19)	– 248 (– 394)	– 100	– 925	– 100 (– 100)	– 196 (– 730)	– 100	– 4,865	– 100 (– 100)	– 2,051 (– 2,813)
1947 "(ACTIVE")- 1976	– 8	– 2.9	– 7	– 0.10	– 17	– 574	– 33 (– 2)	– 539 (– 35)	+ 6	+ 167	– 13 (+ 26)	– 164 (+ 331)	0	0	0 (0)	0 (0)	– 100	– 741	– 100 (– 100)	– 375 (– 365)

1890

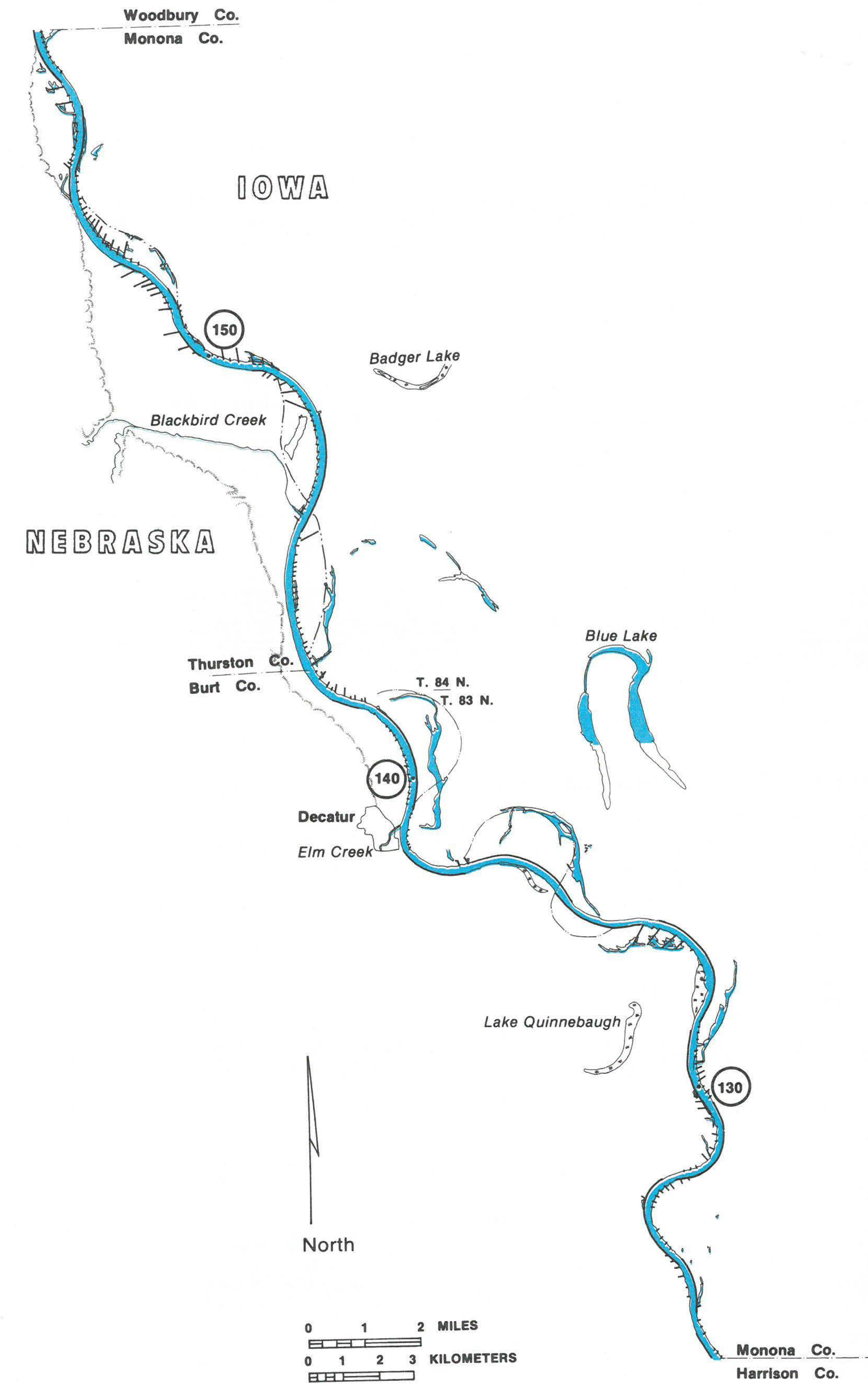
1923



1947



1976



WOODBURY COUNTY

Table 15. Summary of Changes in Missouri River Channel Features in WOODBURY COUNTY

Measured Values

Year	River Miles	Sinuosity	Channel Area (acres) Total	Channel Area (acres) Iowa (Nebr.)	Water Area (acres) Total	Water Area (acres) Iowa (Nebr.)	Island Area (acres)** Total	Island Area (acres)** Iowa (Nebr.)	Bar Area (acres)* Total	Bar Area (acres)* Iowa (Nebr.)
1879	32.8	1.59	11,104	6,081 (5,023)	7,577	4,372 (3,205)	1,498	397 (1,101)	2,029	1,312 (717)
1890	38.9	1.89	12,219	6,668 (5,461)	6,005	2,963 (3,042)	1,856	1,507 (349)	4,267	2,198 (2,070)
1923	28.5	1.38	13,603	7,782 (5,822)	6,417	3,109 (3,308)	3,085	2,470 (614)	4,102	2,202 (1,899)
1947 ("TOTAL")	26.9	1.30	6,448	3,689 (2,759)	3,324	1,715 (1,609)	969	663 (306)	2,156	1,311 (845)
1947 ("ACTIVE")	26.9	1.30	2,908	1,345 (1,564)	2,358	1,107 (1,250)	0	0 (0)	551	237 (313)
1976	25.3	1.23	2,113	1,160 (953)	2,112	1,160 (952)	*0	0 (0)	*1	*0 *(1)
1976 (BACKWATER)					454	242 (212)	**(4,083)	**(1,032) **(3,051)		

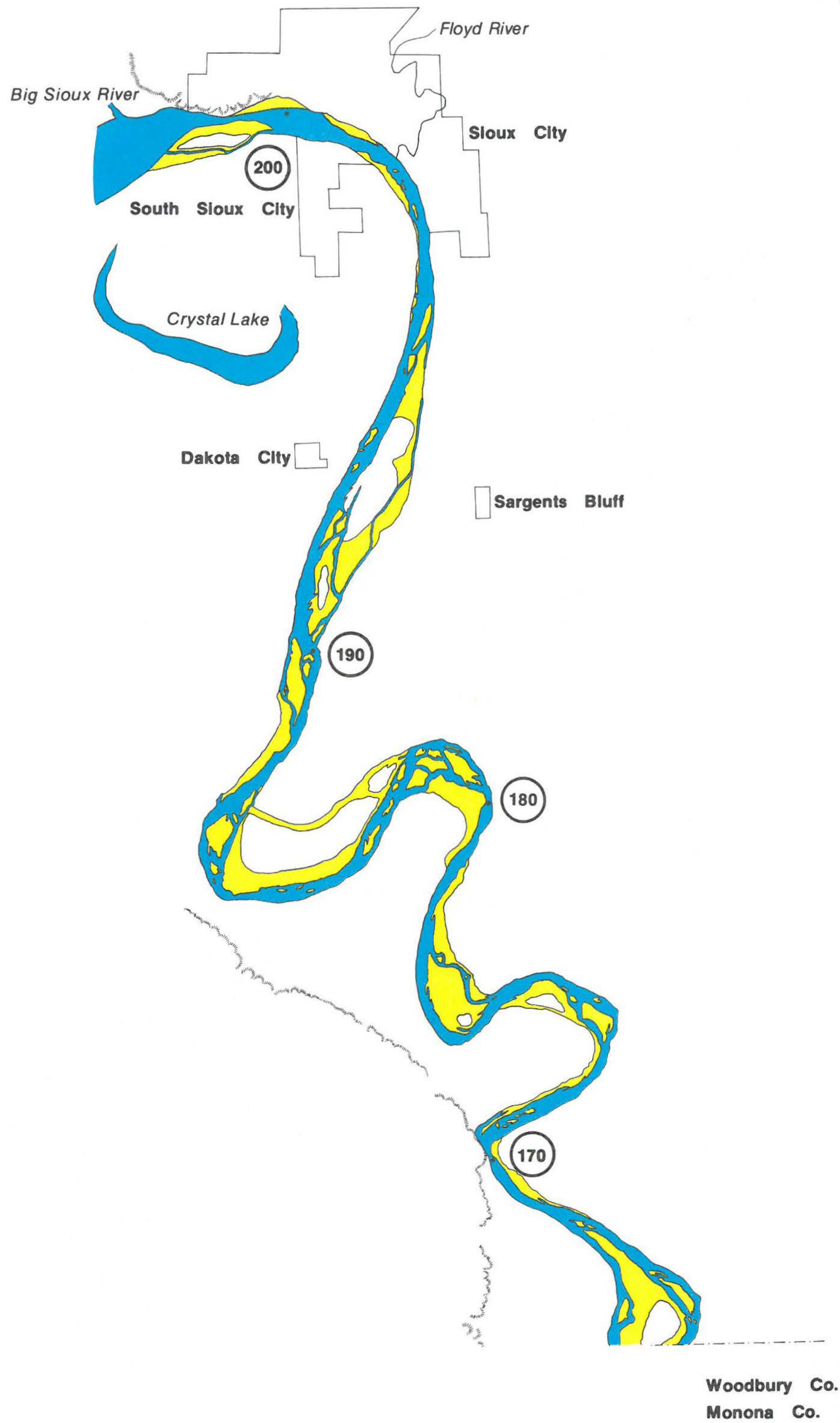
*Island Area and Bar Area combined in 1976 and listed under Bar Area.

**"Political Island", areas for 1976 only, listed in ( ) under Island Area.

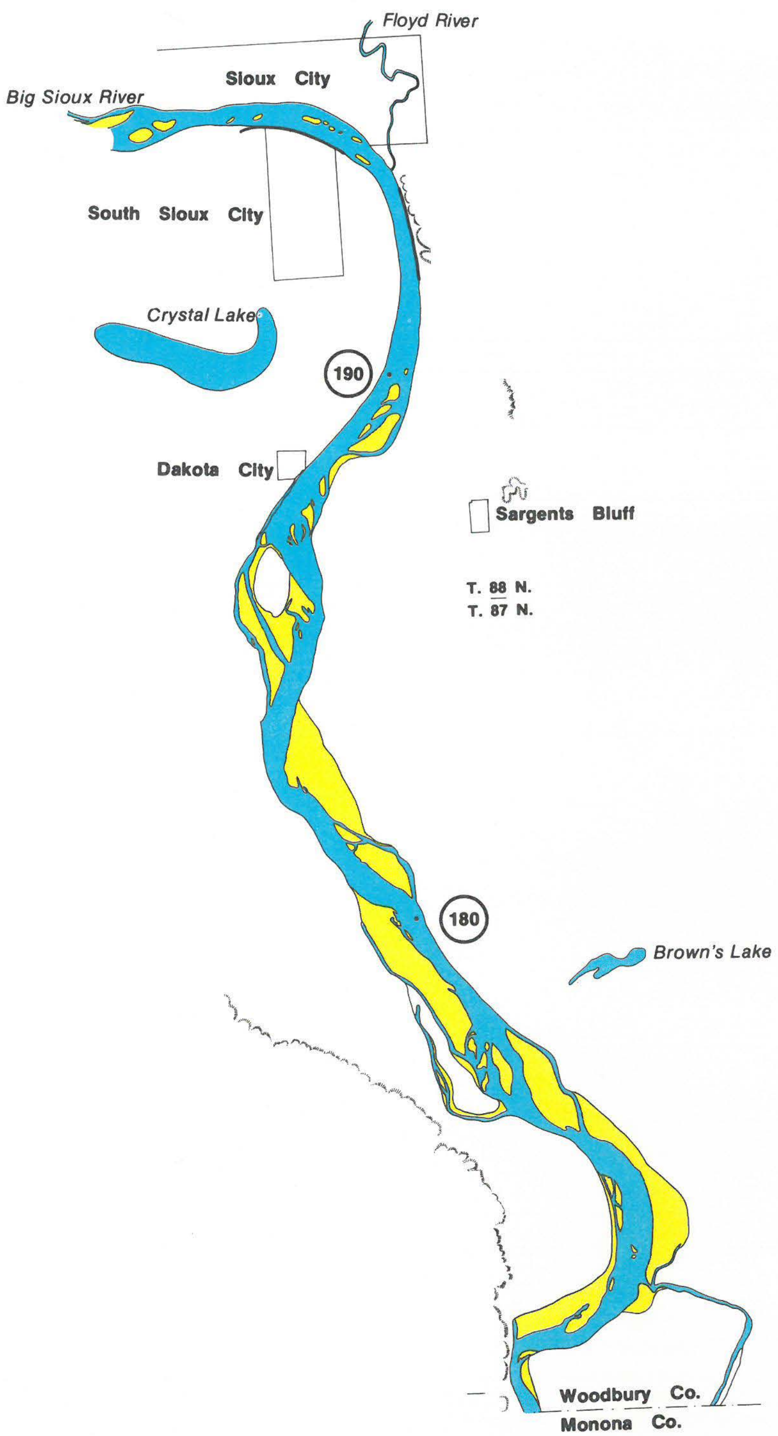
Difference Between Indicated Time Periods

Years Time Period	River Miles %	River Miles Miles	Sinuosity %	Sinuosity Diff.	Channel Area Total %	Channel Area Total Acres	Channel Area Iowa (Nebr.) %	Channel Area Iowa (Nebr.) Acres	Water Area Total %	Water Area Total Acres	Water Area Iowa (Nebr.) %	Water Area Iowa (Nebr.) Acres	Island Area Total %	Island Area Total Acres	Island Area Iowa (Nebr.) %	Island Area Iowa (Nebr.) Acres	Bar Area Total %	Bar Area Total Acres	Bar Area Iowa (Nebr.) %	Bar Area Iowa (Nebr.) Acres
1879-1890	+ 19	+ 6.15	+ 18	+ 0.3	+ 9	+ 1,025	+ 10 (+ 9)	+ 587 (+ 438)	− 21	− 1,572	− 32 (− 5)	− 1,409 (− 163)	+ 24	+ 358	+ 280 (− 68)	+ 1,110 (− 752)	+ 110	+ 2,238	+ 68 (+ 189)	+ 886 (+ 1,353)
1890-1923	− 27	− 10.45	− 27	− 0.51	+ 12	+ 1,475	+ 17 (+ 7)	+ 1,114 (+ 361)	+ 7	+ 412	+ 5 (+ 9)	+ 146 (+ 266)	+ 66	+ 1,228	+ 64 (+ 76)	+ 963 (+ 265)	− 4	− 166	+ 0.2 (− 8)	+ 4 (− 170)
1923-1947 ("TOTAL")	− 6	− 1.6	− 6	− 0.08	− 53	− 7,155	− 53 (− 53)	− 4,093 (− 3,063)	− 48	− 3,039	− 45 (− 51)	− 1,394 (− 1,699)	− 69	− 2,116	− 73 (− 50)	− 1,807 (− 309)	− 47	− 1,946	− 40 (− 56)	− 892 (− 1,054)
1923-1947 ("ACTIVE")	− 6	− 1.6	− 6	− 0.08	− 79	− 10,695	− 83 (− 73)	− 6,437 (− 4,258)	− 63	− 4,060	− 64 (− 62)	− 2,002 (− 2,058)	− 100	− 969	− 100 (− 100)	− 663 (− 306)	− 87	− 3,551	− 89 (− 83)	− 1,965 (− 1,585)
1923-1976	− 11	− 3.2	− 11	− 0.15	− 84	− 11,490	− 85 (− 88)	− 6,621 (− 4,868)	− 67	− 4,305	− 53 (− 71)	− 1,949 (− 2,355)	− 100	− 3,084	− 100 (− 100)	− 2,470 (− 614)	− 100	− 4,100	− 100 (− 100)	− 2,202 (− 1,898)
1890-1976	− 35	− 13.65	− 35	− 0.66	− 83	− 10,015	− 83 (− 83)	− 5,508 (− 4,507)	− 65	− 3,893	− 61 (− 69)	− 1,803 (− 2,089)	− 100	− 1,856	− 100 (− 100)	− 1,507 (− 349)	− 100	− 4,266	− 100 (− 100)	− 2197 (− 2,068)
1947 ("TOTAL")- 1976	− 6	− 1.6	− 5	− 0.07	− 67	− 4,335	− 69 (− 65)	− 2,529 (− 1,806)	− 36	− 1,211	− 32 (− 41)	− 555 (− 656)	− 100	− 968	− 100 (− 100)	− 663 (− 306)	− 100	− 2,154	− 100 (− 100)	− 1310 (− 843)
1947 ("ACTIVE")- 1976	− 6	− 1.6	− 5	− 0.07	− 27	− 795	− 14 (− 39)	− 184 (− 610)	− 10	− 245	+ 5 (− 24)	+ 53 (− 298)	0	0	0 (0)	0 (0)	− 100	− 549	− 100 (− 100)	+ 237 (− 312)

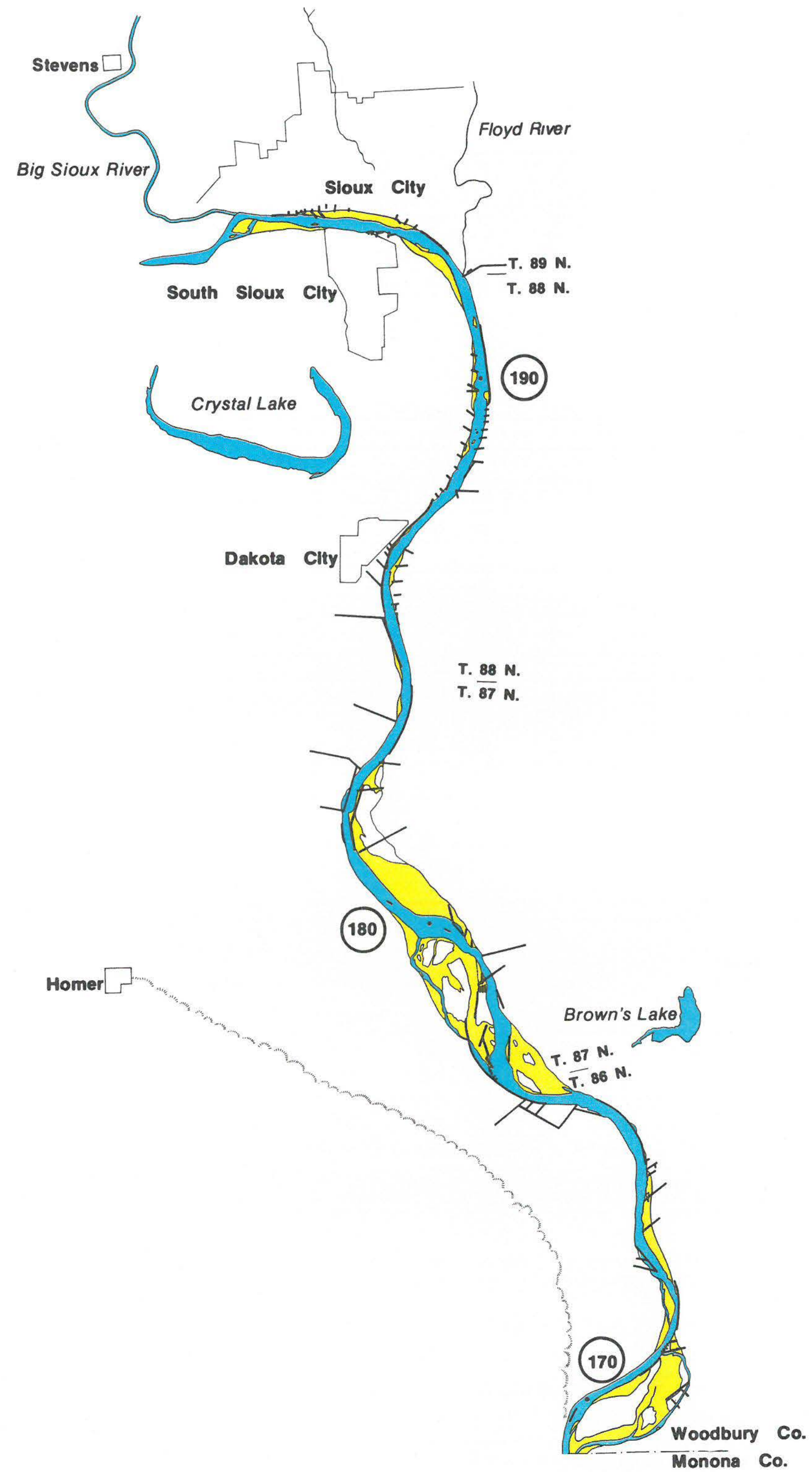
1890



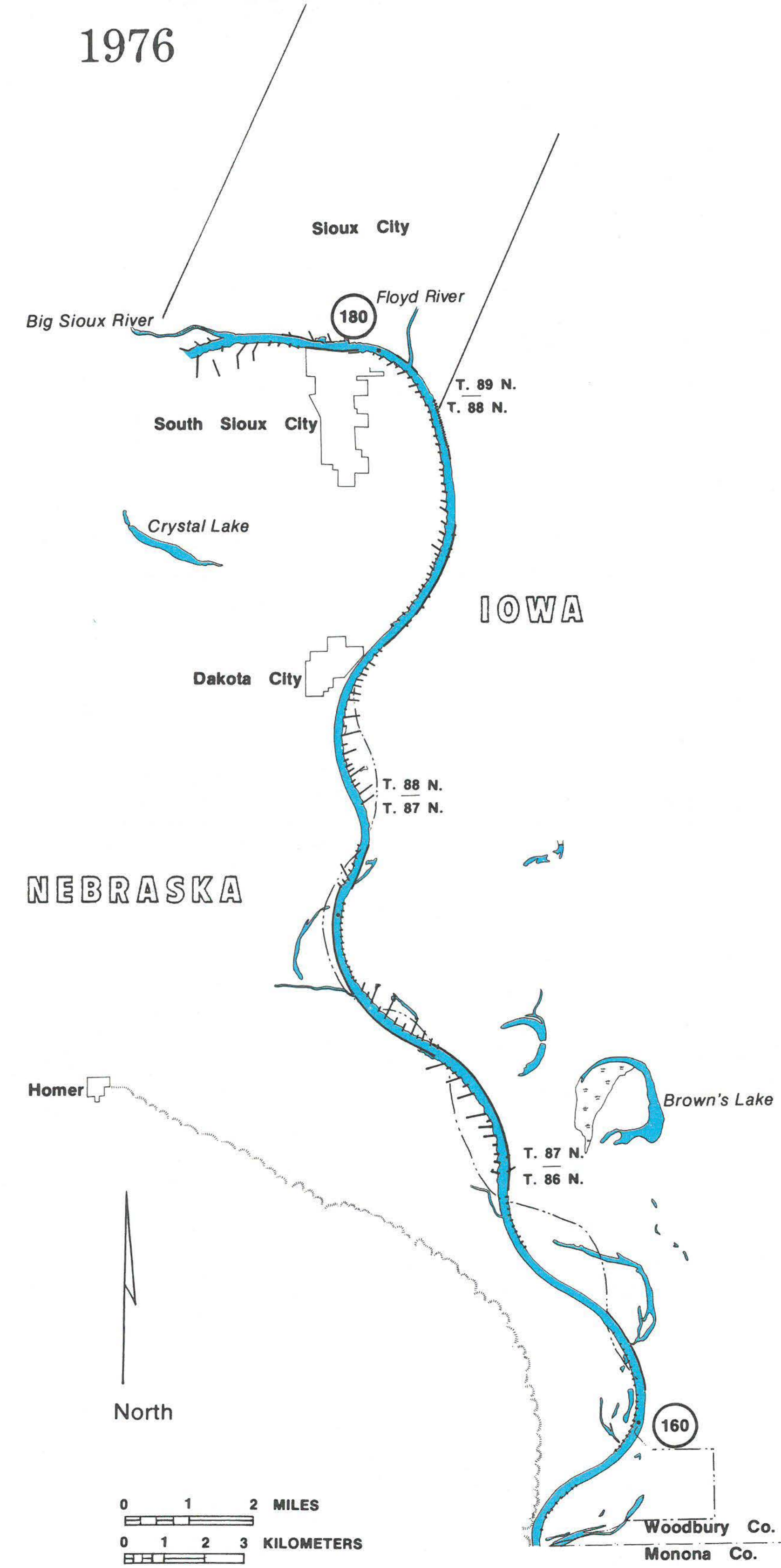
1923



1947



1976



MISSOURI RIVER ADJACENT TO IOWA

Table 16. Summary of Changes in Missouri River Channel Features in 1879-1976

Measured Values

Year	River Miles	Sinuosity	Channel Area (acres)		Water Area (acres)		Island Area (acres)**		Bar Area (acres)*	
			Total	Iowa (Nebr.)	Total	Iowa (Nebr.)	Total	Iowa (Nebr.)	Total	Iowa (Nebr.)
1879	211.3	1.50	80,975	45,104 (35,871)	57,756	32,279 (25,477)	9,757	5,979 (3,818)	14,790	8,214 (6,576)
1890	214.9	1.52	71,889	41,737 (30,152)	36,617	20,288 (16,329)	5,811	3,891 (1,920)	29,461	17,559 (11,902)
1923	200.7	1.42	77,129	42,790 (34,338)	45,647	24,739 (20,908)	11,516	6,755 (4,761)	19,965	11,296 (8,669)
1947 ("TOTAL")	197.7	1.40	49,483	23,702 (25,781)	23,295	10,542 (12,752)	10,635	5,169 (5,466)	15,553	7,991 (7,562)
1947 ("ACTIVE")	197.7	1.40	18,791	9,307 (9,484)	15,671	7,612 (8,059)	10	10 (0)	3,110	1,685 (1,425)
1976	182.7	1.30	15,477	7,672 (7,806)	15,420	7,629 (7,791)	*0	0 (0)	*57	*43 (14)
1976 (BACKWATER)					2,007	1,483 (524)	**(7,124)	**(1,365) **(5,759)		

*Island Area and Bar Area combined in 1976 and listed under Bar Area.

**"Political Island", areas for 1976 only, listed in ( ) under Island Area.

Difference Between Indicated Time Periods

Years	River Miles		Sinuosity		Channel Area				Water Area				Island Area				Bar Area			
					Total		Iowa (Nebr.)		Total		Iowa (Nebr.)		Total		Iowa (Nebr.)		Total		Iowa (Nebr.)	
Time Period	%	Miles	%	Diff.	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
1879-1890	+ 2	+ 3.65	+ 1	+ 0.02	− 11	− 9,086	− 7 (− 16)	− 3,367 (− 5,720)	− 37	− 21,140	− 37 (− 36)	− 11,992 (− 9,148)	− 41	− 3,986	− 35 (− 50)	− 2,088 (− 1,898)	+ 99	+ 14,671	+ 114 (+ 81)	+ 9,345 (+ 5,326)
1890-1923	− 7	− 14.25	− 7	− 0.1	+ 7	+ 5,240	+ 3 (+ 14)	+ 1,053 (+ 4,187)	+ 25	+ 9,031	+ 22 (+ 28)	+ 4,452 (+ 4,579)	+ 98	+ 5,705	+ 74 (+ 148)	+ 2,864 (+ 2,841)	− 32	− 9,496	− 36 (− 27)	− 6,263 (− 3,233)
1923-1947 ("TOTAL")	− 1	− 3.00	− 1	− 0.02	− 36	− 27,646	− 45 (− 25)	− 19,088 (− 8,558)	− 49	− 22,353	− 57 (− 39)	− 14,197 (− 8,146)	− 8	− 881	− 23 (+ 15)	− 1,586 (+ 705)	− 22	− 4,412	− 29 (− 13)	− 3,305 (− 1,107)
1923-1947 ("ACTIVE")	− 1	− 3.00	− 1	− 0.02	− 76	− 58,337	− 78 (− 72)	− 33,483 (− 24,854)	− 66	− 29,977	− 69 (− 61)	− 17,127 (− 12,850)	− 99	− 11,506	− 99 (− 100)	− 6,745 (− 4,761)	− 84	− 16,855	− 85 (− 84)	− 9,611 (− 7,244)
1923-1976	− 9	− 18.00	− 8	− 0.12	− 80	− 61,652	− 82 (− 77)	− 35,119 (− 26,533)	− 66	− 30,228	− 69 (− 63)	− 17,110 (− 13,117)	− 100	− 11,513	− 100 (− 100)	− 6,752 (− 4,761)	− 100	− 19,911	− 100 (− 100)	− 11,256 (− 8,655)
1890-1976	− 15	− 32.25	− 14	− 0.22	− 78	− 56,412	− 82 (− 74)	− 34,066 (− 22,346)	− 58	− 21,197	− 62 (− 52)	− 12,659 (− 8,538)	− 100	− 5,809	− 100 (− 100)	− 3,888 (− 1,920)	− 99	− 29,407	− 99 (− 100)	− 17,519 (− 11,888)
1947 ("TOTAL")- 1976	− 8	− 15.00	− 7	− 0.10	− 69	− 34,006	− 68 (− 70)	− 16,030 (− 17,976)	− 34	− 7,875	− 28 (− 39)	− 2,914 (− 4,961)	− 100	− 10,632	− 100 (− 100)	− 5,166 (− 5,466)	− 100	− 15,499	− 99 (− 100)	− 7,941 (− 7,538)
1947 ("ACTIVE")- 1976	− 8	− 15.00	− 7	− 0.10	− 18	− 3,315	− 18 (− 18)	− 1,636 (− 1,679)	− 2	− 251	+ 2 (− 3)	+ 17 (− 268)	− 72	− 7	− 72 (− 100)	− 7 (− 10)	− 98	− 3,056	− 99 (− 99)	− 1,671 (− 1,411)

IOWA GEOLOGICAL SURVEY
Research and Service 1855-1858 1866-1869 1892- Water—Minerals—Environment