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The Evolution of the Lower Missouri River: A Discussion of the Geology and a Proposal for Research at Lisbon Bottom

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ABSTRACT

Before 1800, the Missouri River was one of North America's most diverse and dynamic ecosystems. Since 1800, it has been transformed into a navigation system regulated by reservoirs and flood control structures. Flooding in 1993 and 1996 has had a profound effect on the physical and political landscape of the lower Missouri River. The purpose of this research is to determine the spatial and temporal distribution of wetlands at Lisbon Bottom in order to develop a model of the distribution of wetlands along the lower Missouri River. The project focuses on three questions: (1) What is the Quaternary history of the lower Missouri River Valley? (2) Can a general model of the lower Missouri River Valley alluvium be developed? (3) What is the relationship between the valley's alluvial architecture and the hydrogeology of its wetlands? A variety of techniques and technologies will be used to answer these questions. Principal among these will be geographic information and image processing systems, which will be used to analyze and interpret photographic, topographic, and geophysical data.

INTRODUCTION

The Missouri River of the early 1800s was one of North America's most diverse and dynamic ecosystems, with abundant riparian lands, braided channels, chutes, sloughs, islands, sandbars, and backwaters (Laustrup and LeValley, 1998). These river and floodplain habitats were created and maintained by erosion and deposition, which continuously reshaped the channel and the floodplain (Schmudde, 1963; Funk and Robinson, 1974; Nicollet, 1993; Laustrup and LeValley, 1998). Seasonal variation in the river's flow recharged wetlands and backwater habitats in spring. It also exposed nesting habitat and provided slow and shallow aquatic habitat through late summer and fall. Since 1800, the Missouri River has been transformed into a navigation system regulated by reservoirs and flood control structures. These modifications have reduced seasonal flow variability and sediment load, and they have disconnected the river from backwater, off-channel, and flood plain habitats (Funk, 1974; Interagency Floodplain Management Review Committee, 1994; Laustrup and LeValley, 1998).

Flooding along the Lower Missouri River in 1993 and again in 1996 provided the opportunity to study the relationship between biologic and geologic processes in a setting that closely mimics the preregulated Missouri River (Jacobson and others, 1999). Flooding during 1993 broke agricultural levees and created scours on both the upstream and downstream sides of Lisbon Bottom, a loop bottom located approximately 10 miles downstream of Glasgow, Mo. These levee breaks and scours were not repaired, and flooding subsequent to 1993 repeatedly inundated the bottom. Flooding in 1996 connected the upstream and downstream levee breaks and created a chute that crossed the bottom.

Knowledge of surficial geologic characteristics and processes in an alluvial setting like Lisbon Bottom provides a scientific basis for floodplain management. This knowledge is also vital to a complete understanding of riverine habitat disturbance, recovery, and rehabilitation (Interagency Floodplain Management Review Committee, 1994; Winkley and Schumm, 1994; Berg and others, 1999). A critical component of this knowledge is an understanding of the spatial and temporal relationships between riverine habitat dynamics and fundamental geomorphic processes, and the spatial and temporal relationships between groundwater and surface wetlands. Equally important is the contextual framework within which these processes operate. At Lisbon Bottom, as with other sites along the lower Missouri River, that framework includes the geology of the river valley at both the regional and site-specific scales.

Purpose

The purpose of this investigation is to determine the fundamental geologic processes controlling habitat dynamics at Lisbon Bottom. The results of this investigation will include a discussion of the evolution of the river, coupled with a general model of the architecture of the valley. This model will illustrate the interdependence of physical and biological processes, as well as the spatial and temporal relationship between ground and surface water along the lower Missouri River. The results of this investigation will aid in the development of goals for habitat rehabilitation projects and will provide a scientific basis for future flood plain management practices along the lower Missouri River.

Research Questions

This project will address three specific questions regarding the Quaternary geology of the lower Missouri River Valley and the relationship between the geology of the valley and terrestrial habitat along the river:

(1) What is the Quaternary history of the lower Missouri River Valley?

(2) Can a general model of the lower Missouri River Valley alluvium be developed?

(3) What is the relationship between the valley's alluvial architecture and the hydrogeology of its wetlands?

Whether Pleistocene glaciers advanced into or south of the modern Missouri River Valley between Kansas City, Mo. and the confluence near St. Louis has not been satisfactorily resolved. There is evidence that ice did advance south of the modern Missouri River near present day Kansas City, Mo. (Simms, 1975; Colgan, 1992; Kelly and Blevins, 1995). There is also evidence that ice advanced into the Missouri River Valley near present day Miami, Mo. (Baker, 1993). However, there appears to be little or no evidence that ice advanced into or south of the modern valley either between these sites or at any others along the river.

Determining the architecture of the river's alluvium and the relationship between that architecture and the hydrology of the valley's wetlands will provide a more complete understanding of the relationship between the geology of the river valley and the dynamics of its terrestrial habitats. This will lead to a more complete understanding of habitat disturbance, rehabilitation, and restoration along the lower Missouri River.

REVIEW OF LITERATURE

Regional Setting

The Missouri River flows nearly 2,350 miles from the confluence of the Gallatin, Madison, and Jefferson Rivers at Three Forks, Mont., to its confluence with the Mississippi River near St. Louis, Mo. Its basin encompasses more than 500,000 square miles (fig. 1). From its headwaters in southwestern Montana, the Missouri River flows north then east across Montana and into North Dakota, where it turns southeast and crosses South Dakota. Leaving South Dakota, the river turns east and forms part of the boundary between South Dakota and Nebraska before turning south again to form the boundaries between Nebraska and Iowa, Nebraska and Missouri, and Kansas and Missouri. At Kansas City, the river turns east, crosses Missouri, and enters the Mississippi River approximately 20 miles north of St. Louis.

Broadhead (1889) divided the Missouri River Valley into three general areas: the upper or mountain district, the plains, and the lower valley region. Today, the river can still be subdivided into three major sections. However, unlike Broadhead's more geographical classification, today's subdivisions are based on the degree to which each section has been modified by mainstem reservoirs or bank stabilization and flood control structures. These three divisions include the free-flowing upper section, the impounded middle section, and the channelized lower section. The free-flowing upper section extends from the confluence of the Gallatin, Madison, and Jefferson Rivers in southwestern Montana to Fort Peck Lake in central Montana. The impounded middle section extends from Fort Peck Lake to Gavins Point Dam near Yankton, S. Dak., and includes Fort Peck Lake, Lake Sakakawea, Lake Oahe, Lake Sharpe, Lake Francis Case, and Lewis and Clark Lake. The channelized lower section extends from Gavins Point Dam to the confluence near St. Louis. This study is focused generally on the channelized section of the lower Missouri River Valley between Glasgow, Mo. and the confluence with the Mississippi River near St. Louis (fig. 2).

The Missouri River Valley between Glasgow and the confluence is a bedrock trench filled with 60 to 120 feet of alluvium. This alluvium consists of highly permeable basal glacial outwash (sand, gravel, and boulders) overlain by postglacial sand and gravel, which in turn are overlain by postglacial interbedded sand, silt, and clay (Dahl, 1961; Schmudde, 1963; Emmett and Jeffery, 1969; Simms, 1975; Interagency Floodplain Management Review Committee, 1994; Jacobson and others, 1999). This segment of the valley is relatively narrow (less than 3 miles wide) with steep sides. Within this relatively narrow valley, the meandering course of the river frequently approaches the valley sides, partitioning the alluvial surface into separate pieces enclosed by a loop of the river and the side of the valley. These distinct, nearly level partitions of the floodplain are locally referred to as bottoms.

Schmudde (1963) defined two types of Missouri River bottoms: long and loop. Long bottoms are much longer than they are wide. Long bottoms are terminated where the river cuts diagonally across the valley. Conversely, loop bottoms are relatively small and partly enclosed by a single, curving, meander-like loop of the river. Between Glasgow and the confluence, Schmudde (1963) identified eight long bottoms, five well-formed loop bottoms (where the length and width within the enclosing meander loop are approximately equal), four less well formed loop bottoms, and several bottoms that have shapes and sizes intermediate between long and loop types. This project focuses specifically on Lisbon Bottom, a well-formed loop bottom located 10 miles downstream from Glasgow, Mo. The lower Missouri River Valley at Lisbon Bottom is nearly 2 miles wide and is incised 200 feet into the surrounding terrain. The channel meanders from valley wall to valley wall, enclosing approximately 3 square miles of flood plain (fig. 3).

Although regulated, the modern lower Missouri River is characterized by alternating reaches of high and low sinuosity. Reaches with high sinuosity, such as the Lisbon Bottom reach, can be expected to have greater hydraulic diversity (variations of depth and velocity) compared with low sinuosity reaches because of the stronger secondary currents associated with tighter bends (Jacobson and others, 1999). High-sinuosity meanders typically migrate downstream. Deposition on the convex bank of the bend complements erosion along the concave bank, which, being concentrated on the downstream limb beyond the bend apex, establishes a predominantly downstream component to meander-bend migration. This process results in an irregular surface of ridges and swales, which tend to direct flood flows across the bottom toward the valley wall. Because of this, there is a tendency for loop bottoms to have wetlands along the downstream half of the valley wall (Jacobson and others, 1999). At Lisbon Bottom, small tributary streams entering the bottom from the east provide additional water for these low, wet areas.

<u>Pre-Quaternary Geology of the Missouri River</u>

The pre-Quaternary drainage system of central North America was much different than the system we see today (Bayne and others, 1971; Dreeszen and Burchett, 1971).

During the Oligocene, the Rio Grande was the continent's major drainage system (Galloway and others, 1991). However, a shift during the Miocene, possibly resulting from continental tectonism, reorganized the continent's drainage systems and established the Mississippi as the dominant drainage system (Winker, 1982). By the end of the Tertiary, the Mississippi River drainage was established as the dominant system for the continent and was actively prograding into the Gulf of Mexico, with the Laramide orogeny and subsequent intracontinental uplifts providing significant amounts of sediment.

The continental glaciations of the Pleistocene rearranged the interior drainage systems of the North American continent. Before the Pleistocene, the ancestral rivers of the northern Great Plains (the Missouri, Yellowstone, Little Missouri, and Cheyenne Rivers) drained north then east into Hudson Bay, while the ancestral rivers of the middle Great Plains (the White, Niobrara, Platte, and Kansas Rivers) drained east and southeast into the Gulf of Mexico (Todd, 1914; Fisk, 1944; Meneley and others, 1957; Howard, 1960; Flint, 1971; Wayne and others, 1991; Langer and others, 1994). The ancestral Platte River followed the course of the modern Grand River across northwestern Missouri and joined the ancestral Kansas River near the confluence of the modern Grand and Missouri Rivers (Todd, 1914; Dreeszen and Burchett, 1971; Simms, 1975; Anderson, 1979; Whitfield, 1982; Aber, 1991; Whitfield and others, 1993).

It is generally accepted that the present course of the Missouri River from Kansas City to the confluence near St. Louis is coincident with the pre-Quaternary course of the ancestral Kansas River (Todd, 1914; Greene, 1921; Fisk, 1944; Bretz, 1965; Flint, 1971; Dreeszen and Burchett, 1971; Anderson, 1979; Whitfield, 1982; Whitfield and others, 1993). However, Whitfield and others (1993) provide an alternative, more northern route for the ancestral Kansas River across the eastern half of Missouri. They suggest that rather than following the modern channel, which turns south near Boonville, Mo., the ancestral Kansas River continued east to join the Mississippi River near the present confluence of the modern Missouri River. Although their suggestion of an alternative route is unique, the idea is certainly consistent with the widely held view that the modern Missouri River marks approximately the southern extent of Pleistocene glaciation, which in some areas relocated the channels of existing rivers.

Quaternary Evolution of the Missouri River Valley

The pre-Illinoian glaciations of the early Pleistocene and, to a lesser extent, the Illinoian and Wisconsin glaciations of the middle and late Pleistocene rearranged the interior drainage systems of the North American continent. The modern Missouri River marks the approximate southern extent of pre-Illinoian glaciers (Todd, 1914; Flint, 1971; Guccione, 1982; Blum and others, 2000). Preglacial rivers that flowed east across the Great Plains were dammed and diverted south while the advancing ice buried earlier systems that drained the northern and central interior of the continent.

Langer and his coauthors (1994) described the Missouri River from Great Falls, Mont., to Kansas City, Mo., as a glacial-margin stream. As the ice advanced, it would dam eastward-flowing streams. Lakes that formed as a result of these dams would eventually spill over into adjacent basins. Following the retreat of the ice, the river would either remain in the new channel or reoccupy its former channel. The Missouri River Valley from Omaha, Neb., to Kansas City, Mo., provides an example of the river remaining in its new channel. Two examples of the Missouri River abandoning glacial bypasses and reoccupying its preglacial channel following the retreat of the ice can be observed near Kansas City, Mo. The Blue (Simms, 1975) and Little Blue Rivers (Kelly and Blevins, 1995) each became temporary diversion channels during pre-Illinoian glacial advances across the ancestral river valley. An additional bypass has been suggested near Miami, Mo., where several authors have suggested that the river was diverted south through the valley of the North Fork of the Salt River, into the Lamine, and on to the Missouri River (Todd, 1914; Whitfield and others, 1993). These diversions of the Missouri River have led some to believe that pre-Illinoian ice advanced south of the modern Missouri River Valley between Kansas City and Jefferson City (Anderson, 1979; Aber, 1991; Whitfield and others, 1993; Soller, 1998; Aber, 1999). Alternatively, others believe that the ice did not advance south of the modern river valley (Bretz, 1965; Hawker, 1992).

Present Geology of the Lower Missouri River Valley

Schumm and Winkley (1994) observed that the character of almost every alluvial river reflects its geologic history, and the modern lower Missouri River is no exception. Its present form has resulted from a sequence of events that included the following:

- incision of the ancestral Kansas River into Pennsylvanian, Mississippian, and Ordovician shale, limestone, and dolomite;
- the accumulation of Pleistocene glacial outwash deposits;
- migration of channels during the Holocene; and
- clearing of the channel and stabilization of its banks by the U.S. Army Corps of Engineers (Schalk and Jacobson, 1997).

The river valley between Glasgow, Mo., and the confluence has been characterized as a bedrock trench filled with 60 to 120 feet of silt and sand with intermixed gravel and boulders near its base (Dahl, 1961; Schmudde,1963; Emmett and Jeffery, 1969; Simms, 1975; Interagency Floodplain Management Review Committee,1994; and Jacobson and others, 1999). The valley is relatively narrow (less than 3 miles wide) with steep sides. It is incised 200 to 400 feet into adjoining Mississippian limestone and dolomite, which are abundantly exposed in bluffs overlooking the floodplain. In many places, these bedrock bluffs rise vertically above the river's surface.

Along the lower Missouri River, bedrock lithology is a critical control on valley and channel morphology, as well as the thickness of the alluvial fill (Emmett and Jeffery, 1969; Schalk and Jacobson, 1997). The Missouri River Valley is cut into nearly flat-lying limestone, dolomite, shale, and sandstone. Upstream from Glasgow, the river flows in a wide valley (5 to 10 miles) that has cut into relatively soft Pennsylvanian-aged sedimentary rocks dominated by interbedded limestone and shale. Within this section, the river meanders in broad, sinuous curves. Downstream from Glasgow, the valley is entrenched in harder, more resistant Ordovician and Mississippian sedimentary rocks dominated by limestone and dolomite. Here, the valley narrows to a uniform width that averages 2.2 miles wide, and the river is characterized by alternating reaches of high and low sinuosity.

The lower Missouri River Valley at Lisbon Bottom is nearly 2 miles wide and incised 200 feet into the surrounding terrain. The channel meanders from valley wall to valley wall, enclosing approximately 3 square miles of flood plain. The valley at Lisbon Bottom is filled with approximately 60 feet of material consisting of highly permeable glacial outwash (sand, gravel, and boulders) overlain by postglacial sand and gravel in the lower part, and interbedded sand, silt, and clay in the uppermost part (Dahl, 1961;

Schumde, 1963; Emmett, 1969; Simms, 1975; Grannemann and Sharp, 1979; Interagency Floodplain Management Review Committee, 1994; Kelly and Blevins, 1995; Schaulk and Jacobson, 1997; Jacobson and others, 1999). Emmett and Jeffery (1969) have suggested that irregularities on the surface of the bedrock under Lisbon Bottom control the thickness of the alluvium.

An important characteristic of the preregulated Missouri River was the migration of its channel meanders, resulting in the reworking of its floodplain deposits (Schmudde, 1963; Interagency Floodplain Management Review Committee, 1994; Izenberg and others, 1996). Typically, channel meanders tend to migrate owing to lateral erosion at the upstream or outside margins of meander bends and deposition of sediments on their downstream or inside margins (Leopold, 1997; Knighton, 1998). Along the lower Missouri River, the process of downstream and lateral meander migration has resulted in floodplain surface features that include levees, terraces, abandoned channels, and oxbow lakes. In addition, downstream and lateral channel migrations have resulted in a floodplain stratigraphy that includes point bar, channel fill, and overbank deposits (Schmudde, 1963, Interagency Floodplain Management Review Committee, 1994).

Along the preregulated lower Missouri River, channel avulsions have also been responsible for the relocation of the channel and reworking of floodplain deposits (Izenberg and others, 1996; Schalk and Jacobson, 1997). The term "avulsion" is widely used to describe a relocation of the channel that is achieved by a jump rather than a progressive shift (Smith and others, 1989; Jones and Harper, 1998; Bristow, 1999; Jones and Schumm, 1999). Although it was not specifically suggested, channel avulsions can explain the rapid and frequent relocation of the Missouri River's channel described in historic observations of the river and its behavior. Recently, channel avulsion, like progressive meander migration, has become a rare occurrence along the lower Missouri because of the bank stabilization efforts of the U.S. Army Corps of Engineers. However, the chute across Lisbon Bottom provides an opportunity to study the mechanics of channel avulsion along the lower Missouri River (Jacobson and others, 1999).

Hydrogeology of the Missouri River Valley

Relatively few studies have focused on the hydrogeology of the lower Missouri River Valley. Those that have been conducted have included studies of the alluvial aquifer at Kansas City (Kelly and Blevins, 1995; Kelly, 1996; Kelly, 2000); reconnaissance mapping of the ground-water resources of the lower Missouri River Valley (Emmett and Jeffery, 1968, 1969, and 1970); an overview of the hydrology of the lower Missouri River following the 1993 flood event (Interagency Floodplain Management Review Committee, 1994); and the study of the hydrogeology of the Missouri River Valley near Glasgow, Mo. (Granneman and Sharp, 1979). Granneman and Sharp (1979) concluded that the hydrogeology of the lower Missouri River Valley is considerably more complicated than generally assumed and that the most important influence on that hydrogeology is the river itself.

As noted earlier, the alluvial deposits of the lower Missouri River consist of highly permeable boulders, cobbles, gravel, and sand, which are overlain by interbedded sand, silt, and clay. This characteristic distribution of sediment creates an exponential increase in hydraulic conductivity with depth. With the relatively high permeability of the deepest parts of the alluvium, the possibility exists for an upper flow system (primarily influenced by river stage, tributary streams, and local precipitation) superimposed on a deep down-valley flow system. Granneman and Sharp (1979) dismiss this hypothesis through analytical modeling and conclude that only one flow system exists in the alluvium.

Generally, ground water flows away from the valley walls toward the Missouri River and down the valley (Emmett and Jeffery, 1969, 1970; Granneman and Sharp, 1979; Kelly and Blevins, 1995). Granneman and Sharp (1979) determined that ground-water flow direction in the Missouri River Valley is influenced by the stage of the river, distance from the river, geometry of the river meanders and valley walls, and existence and character of tributary streams. They conclude that it is the interdependence of these factors that determines the flow direction of ground water within the valley. For example, during periods of sustained high river stages, seepage through the river's bed and banks keeps ground-water levels high. As river levels fall, the flow direction is reversed, and ground water flows predominantly toward the river (Granneman and Sharp, 1979; Kelly and Blevins, 1995).

The hydrogeology of Lisbon Bottom results from a combination of characteristic alluvial stratigraphy, the geometry of the valley and river meander, and the influence of a small perennial stream (Buster Branch) that enters the valley from the east at the center of the meander and infiltrates the surface before reaching the Missouri River. Ground water flows predominantly from the east valley wall toward the river, except in a narrow corridor along the river, which is influenced by the river's stage (Granneman and Sharp, 1979). Historically, the existence of wetlands on Lisbon Bottom resulted from a combination of overbank flooding and elevated ground-water levels associated with sustained high river stages, perennially elevated ground-water levels near the east valley wall, influent streams, and floodplain geomorphology (Granneman and Sharp, 1979, Jacobson and others, 1999).

Habitat Dynamics Along the Lower Missouri River

The natural features of the Missouri River have been progressively altered since the early 1800s. Before 1800, the Missouri River was one of North America's most diverse and dynamic ecosystems, with abundant braided channels, chutes, sloughs, islands, sandbars, riparian lands, and backwaters (Funk and Robinson, 1974; Nicollet, 1993; Laustrup and LeValley, 1998). These river and floodplain habitats were created and maintained by erosion and deposition, which continuously reshaped the channel and the floodplain (Schmudde, 1963; Laustrup and LeValley, 1998). Seasonal variation in the river's flow recharged wetlands and backwater habitats in spring. It also exposed nesting habitat and provided slow and shallow aquatic habitat through late summer and fall.

Beginning with the congressionally mandated removal of snags and clearing of its channel in 1838, the Missouri River has been transformed into a navigation system that is regulated by reservoirs and by bank stabilization and flood control structures. These modifications have reduced seasonal flow variability and sediment load, and have disconnected the river from backwater, off-channel, and flood plain habitats (Funk and Robinson, 1974; Interagency Floodplain Management Review Committee, 1994; Laustrup and LeValley, 1998).

Funk and Robinson (1974) noted an alarming reduction in the quantity (spatial extent) and quality (species diversity) of both terrestrial and aquatic habitats along the lower Missouri River. They compared U.S. Army Corps of Engineer maps compiled from surveys of the river and its valley conducted in 1879 with maps compiled from surveys conducted in 1954. From this comparison they concluded that the river had lost 8 percent of its length, 27 percent of its width, 50 percent of its original surface area, and 98 percent of its islands. The loss of islands represented a loss of chutes and sloughs between the islands and shore, which meant lost slow and shallow aquatic habitat. These changes, coupled with reduced sediment loads resulting from the construction of mainstem reservoirs, provided Funk and Robinson with circumstantial evidence of a direct relationship between decreased availability and diversity of habitat and decreased diversity in fish populations. They also noted that these changes had an equally devastating effect on the diversity of terrestrial communities as riparian habitats were lost or cleared for agricultural use.

Mazourek and others (1999) examined the succession of floodplain vegetation on Lisbon Bottom following the flood events of 1993 and 1996. They determined that the presence of early successional species, namely cottonwood and willows, was consistent with the historical (preregulated) behavior of these plants along the river. More important, they concluded that continued maintenance of the river's channel and regulation of its flow would most likely prevent transitional or terminal forest communities from developing near the river. They reasoned that these communities were dependent initially upon the erosion and redeposition of sand and silt, followed by the colonization of pioneer species that were not subjected to frequent flooding. Conversely, seasonal flooding and sustained high ground-water levels are critical for the development and maintenance of wetlands. This suggests that spatial as well as temporal flow variability is necessary to maintain habitat diversity along the river (Funk and Robinson, 1974; Interagency Floodplain Management Review Committee, 1994; Jacobson and others, 1999).

PROCEDURE

Determination of the Quaternary History

Geomorphic processes and resultant biologic responses are dependent upon the geologic context within which they operate. Consequently, the initial focus of this investigation will be generally on the geologic evolution of the valley and specifically on Quaternary events. An important question that will be answered involves determining the southern extent of Pleistocene glaciation. Identifying and mapping the southern limits of Pleistocene glacial advances between Kansas City and St. Louis Mo., is a necessary for a complete understanding of the valley's evolution. If continental glaciers advanced south of the modern Missouri River, then physical evidence, such as glacial landforms, till deposits, or abandoned channels of the pre-Pleistocene ancestral Missouri River, should still exist. Identifying and interpreting these features will be accomplished through the analysis of well logs, field observations, and mapping.

Field observations will be supplemented with the analysis of high-resolution digital elevation data. Image processing and geographic information systems will be used to display high-resolution digital elevation data in order to make a visual inspection of the entire region. In addition to visually inspecting the data, we will do numeric searches for potential abandoned channels or other landforms, such as terraces. The results of these analyses may indicate Pleistocene alternatives to the modern course of the Missouri River.

Model Development

The second focal point of this investigation will be to develop a general model that demonstrates the spatial and temporal relationships between geologic processes and riverine habitat dynamics at Lisbon Bottom. These relationships will be dependent upon the architecture of the valley-filling alluvium. This architecture will be determined and modeled through the analysis and interpretation of well logs; field reconnaissance; a review of bridge, levee, and channel management engineering diagrams; and the analysis of ground-penetrating radar and acoustic streambed data. Hydrogeology will be determined through the analysis of local well-pumping test data, combined with the model of the alluvium. The relationship between the architecture of the valley-filling alluvium and the hydrology of the valley's wetlands will be based on the interpretation of the valley's architecture, its hydrogeology, and the spatial and temporal distribution of wetlands at Lisbon Bottom.

Large-scale maps of physical habitat on Lisbon Bottom will be prepared using historical aerial photographs, historical cartographic data, and high-resolution digital elevation data. These maps will delineate historical channels, wetlands, sand bodies, woodlands, and nonwoodland vegetation. The maps will be compiled using image processing and geographic information systems. Historical aerial photographs will be acquired, digitized, and georeferenced to map control points. Photographs from the late 1930s through 2000 will be used to develop a retrospective image archive. In addition, historical river charts will be acquired, digitized, and coregistered with the aerial photographs.

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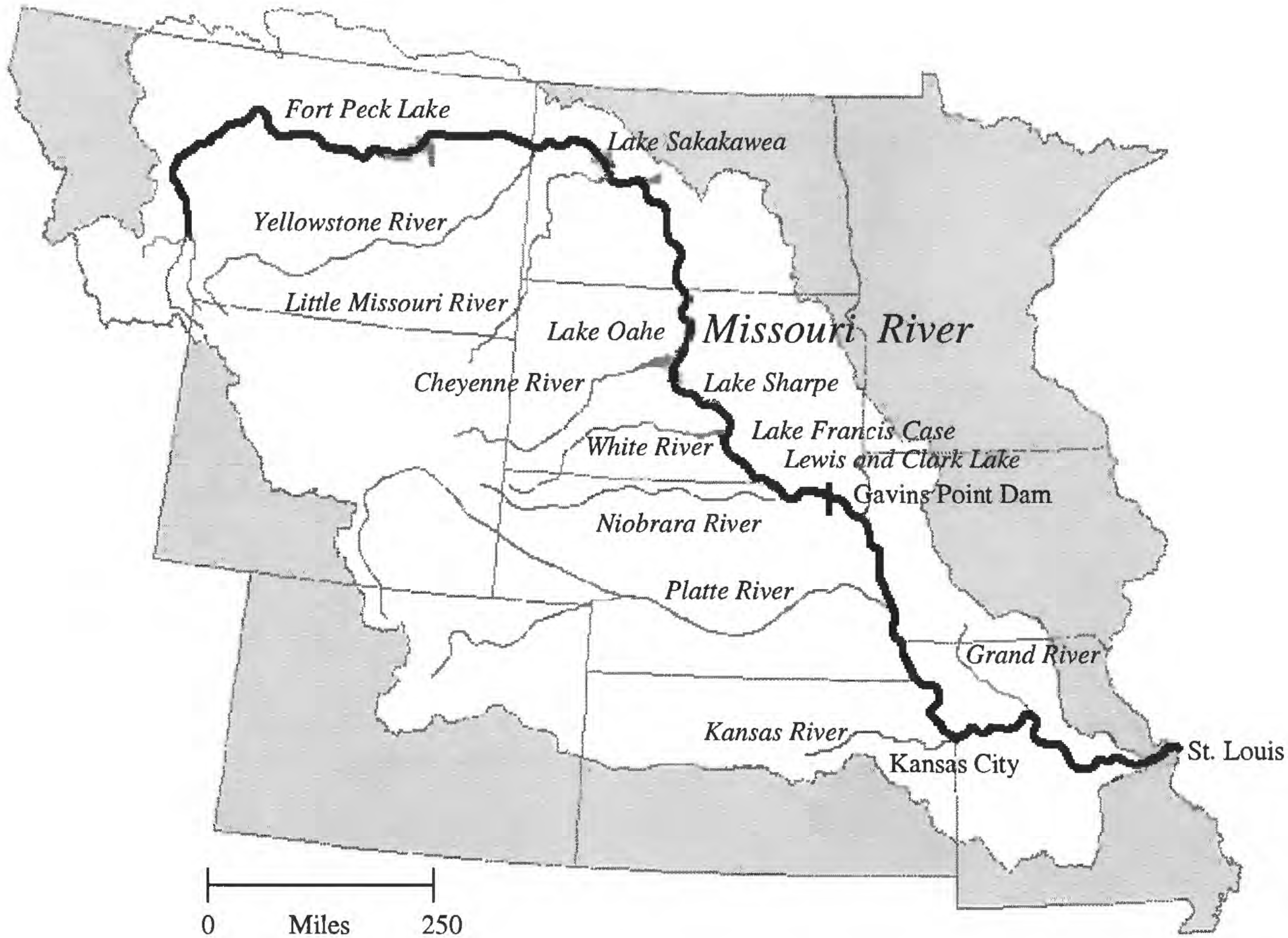

Figure 1. The drainage basin, mainstem reservoirs, and major tributaries of the Missouri River.

Figure 2. Diagram illustrating the general location of Lisbon Bottom.

Figure 3. Lisbon Bottom occupies the floodplain of the Missouri River enclosed by the upper meander bend located near the center of the figure. The Missouri River flows south from the top of the page