An Evaluation of Terrestrial Ecosystem Restoration Options

for the

Northern Ecoregion

of the

Upper Mississippi River System

Prepared for:

U.S. Army Corps of Engineers
St. Paul District
St. Paul, Minnesota

Prepared By:

HDR Engineering
Tony Randazzo, Lead Author

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Contents

Executive Summary

The Northern Ecoregion (NER) reviewed in this evaluation extends from river mile (RM) 866 near Coon Rapids, Minnesota to RM 753 near Alma, Wisconsin. The evaluation uses a hydrogeomorphic modeling (HGM) approach to assess the past, current and potential future characteristics of the river environment. The purpose of this work is to support United States Army Corps of Engineers (USACE) conservation and restoration planning in terrestrial landscapes within the Mississippi River Valley with a focus on returning or maintaining ecosystem processes to more naturally functioning systems in light of current use and projected future uses. HGM analyzes a variety of data, including geology, landscape sediment assemblages, soils, climate and hydrology, vegetation, ecological context, and wildlife in combination with historic and current landuse practices. The combined understanding of these factors provides resource planners with the tools to make informed restoration and conservation decisions in areas affected by past and present river valley landuse practices. The HGM findings of this report are useful to managers in identifying the pre-European settlement conditions, changes in hydrology, plant community structure and distribution, wildlife habitat alterations/opportunities and restoration options within the context of the altered conditions of the terrestrial landscapes.

The following provides a summary of this report.

Geology - The topography of the NER is heavily influenced by the underlying bedrock, which helps shape the landscape. These bedrock units are composed of marine sedimentary rocks that were deposited in a shallow sea during the Early Paleozoic Age (525 to 450 million years ago). These deposits created the consolidated sandstones, limestones, and shales that make up the steep bluffs along the Mississippi River.

Surface Features - The surficial hydrology and stream geomorphology owe their current states to advancing and retreating glaciers, particularly from the Wisconsin Glaciation, which occurred during the period from about 110,000 to 10,000 years BP. The lower pools of the NER lie within what is known as the “driftless” area, which escaped deposits during the Wisconsin Glaciation. The driftless area is characterized by a well defined drainage pattern (coulees) nestled between rounded ridge tops.

Soils - Both surface geology and soils development in the NER are greatly influenced by water movement. Soils in the valley tend to be Inceptisols or Entisols, both of which are more recent in origin. Ongoing fluvial activity continues to shift, bury, and rework the soils in the valley floor. Surface textures are often correlated with landscape position as flooding and water movement affect the sorting and settling of soils carried in the water column.

Geomorphic Surfaces – Landscape Sediment Assemblages (LSAs) developed by Madigan et al. (2001) identify the composition of surficial material as deposited or formed by fluvial action in the Mississippi River Valley and adjacent areas. The glacio-fluvial deposits within the river valley are typically of Holocene origin or are exposed relict features from much older periods (Cambrian). The age and manner of deposition of surficial material has proved to be an effective starting point in evaluating landscape character and the distribution of historic vegetation communities, and, by extension, restorable vegetation communities.

Climate - Average temperatures vary from 12 degrees Fahrenheit (°F) in January to 74 °F in July (Minnesota Climatology Working Group, 2005). Minimum air temperatures are below freezing generally from November to March, and sometimes in April and occasionally in October. Average snowfall depth is 54 inches, mostly accumulating in December to March (Minnesota Climatology Working Group, 2013). On average, about one-fourth to one-third of all years are dry or drought conditions.

Hydrology - In the late 19th century, the average Mississippi River flow at St. Paul was 8.4 million acre-feet per year. The average flow has increased to an average of 11.4 million acre-feet per year at present. The instantaneous peak flow on the river has also trended higher over time. Since measurements were started in 1893 and until 1952, peak flows did not exceed 100,000 cfs. Since 1952, there have been 8 years with peak flows higher than 100,000 cfs. The minimum peak flow was not less than 16,400 cfs from 1952 to 2012, while prior to this, there were 9 years when peak flows were lower.

Cultural Resources - The study area is located in the Southeast Riverine and Central Lakes Deciduous Archaeological Regions of Minnesota. At the time of Euro-American settlement, vegetation of the Southeast Riverine region was varied with patches of oak groves scattered in the prairie (oak barrens) in the west; open prairie in the middle; maple, elm, and basswood on the uplands over the Mississippi River in the east; and elm, ash, and cottonwood in the Mississippi River lowlands. At the time of Euro-American contact, subsistence resources for the Native American residents included bison, white-tailed deer, and elk. Many aquatic mammals, waterfowl, and fish and mussels were plentiful in the bottom lands. There were also edible plants, including cattails and water lilies near water sources, and prairie turnips and acorns in the uplands.

Within the Central Lakes Deciduous Region, vegetation at the time of Euro-American settlement was Big Woods forests (represented by oak, elm, ash, basswood, maple, horn beam, aspen, birch, wild cherry, hickory, butternut, and black walnut) with numerous inclusions of prairie and oak woods, oak woods in the east, and a mixed deciduous-coniferous forest in the north. At the time of Euro-American contact, subsistence resources for the Native American residents included bison, white-tailed deer, elk in the south, and beaver, bear, and moose in the north. Many types of waterfowl and fish were plentiful in the lakes. There were also edible plants, including extensive wild rice beds, cattails, water lilies, and acorns.

Man Made Modifications to the River - Alterations to the river channel began on a large scale as early as 1878, with the 4 ½ foot channel project, continued with the 6 foot channel project in 1907 and culminated with the 9 foot channel project in the 1930s. The following table provides a summary of changes to the river surface as a result of these projects.

Pool	**Project Study Area (acres)**	**1890 Waters Coverage (acres)**	**2000 Waters Coverage (acres)**	**Increase in Open Water (acres)**	**Percentage Increase in Open Water (1890–2000)**
St. Anthony to Coon Rapids	3,339	Not available	Not available	Not available	
Pool 1	3,725	837	844	7	0%
Pool 2	24,286	4,698	11,080	6,382	136%
Pool 3	23,102	4,188	12,832	8,644	206%
Pool 4	71,320	32,632	37,275	4,643	14%
Total analysis area	**125,771**	**42,355**	**62,031**	**19,676**	**46%**

Floodplain Dynamics- The NER ecosystem is defined by millennia of river development and change over time and space. River dynamics are active at broad time scales from the large formative processes to seasonal fluctuations in energy, water levels and movement of nutrients, species and other materials up and down stream and laterally across the river valley. The dynamic nature of the system means that interactions between abiotic and biotic characteristics are subject to change in response to fluctuations over the range of environmental factors. Because of the inherent power of rivers, alterations within the system, either natural or man made, can have profound effects on all other characteristics within the floodplain area.

Ecoregions - The NER lies at the intersection of two major climactic zones and, consequently, two major ecological provinces. To the west of the NER, vast grasslands dominate the Central Plains (Prairie Parkland Province), where distinct wet and dry seasons with precipitation and temperature extremes predominate. To the east, within the Eastern Broadleaf Forest Province, yearly temperatures are similar to those in the western province, but rainfall increases substantially. Western Minnesota along the South Dakota border received 20 to 24 inches of rain annually between 1941 and 1970, whereas, during the same period, rainfall along the Wisconsin border averaged 32 inches per year (Minnesota County Biological Survey, 2007).

Plant communities - The character of plant community types in the NER has changed drastically because of anthropogenic activities including the elimination of fire, channelization, farming, and the introduction of invasive species. These changes affected plant communities by decreasing native vegetation and altering its structure and composition. The landscape has become increasingly fragmented. These altered habitats, however, remain especially important to migratory land birds as stopover sites.

The presence of invasive species also affects the plant community character of Floodplain Forests in the NER. The presence and expansion of species such as reed canary grass (*Phalaris arundinacea*), garlic mustard (*Allariea petiolata*), common buckthorn (*Rhamnus cathartica*), burdock (*Arctium* spp.), and dodder (*Cuscuta* spp.) can change the composition of wildlife species inhabiting the Floodplain Forests of the NER. Kirsch (2009) found that bird assemblage composition is primarily influenced by a lack of ground cover a, high percentage of *reed canary grass* as ground cover, and a low basal area.

The following table provides a summary of the cover type changes that have occurred in the NER.

Landcover Type	**Pre-contact Landcover (acres)**	**1890s Landcover (acres)**	**2000 Landcover (acres)**
Agriculture	NA	12,885	8,011
Developed	NA	3,388	16,594
Dike	NA	79	NA
Forest	41,007	34,356	27,589
Grass/forbs/scattered trees	28,219	17,941	3,738
Marsh/swamp	7,988	7,988	10,442
Open water	42,610	42,531	55,348
Sand/mud	839	839	330
Unclassified	78	735	249
Total	**120,741**	**120,742**	**122,301**

HGM Results – HGM methods rely on a broad range of biotic and abiotic landscape characteristics combined with landuse patterns over time to develop best natural community restoration options. Geomorphic surface, as a reflection of recent surficial landscape processes provides a basis for developing a matrix of features to support the success of valley natural community types. The method uses overlays of flood frequency, soil texture, geomorphic surface and age and landuse coverages, past and present to determine best fits for natural community restoration. The results can be used at the broad scale to determine where and what type of habitat restoration efforts are best to build regional or continental ecological connectivity or at the local level to determine appropriate and self-sustaining projects that improve the health of the river and the valley.

1 Introduction

1.1 Northern Ecoregion in Context

The Northern Ecoregion (NER) extends from River Mile (RM) 866 near Coon Rapids, Minnesota, to RM 753 near Alma, Wisconsin. The river is divided into four reaches, commonly referred to as Pools 1 to 4. Additionally, this evaluation includes analysis of a fifth reach, the Coon Rapids/St. Anthony Pool (Figure 1).

The area analyzed for this evaluation includes the Mississippi River channel, valley floor, and adjacent upland transitions. The total land area reviewed is about 68,000 acres, while the overall watershed area is more than 58 thousand square miles. The NER is within the larger Mississippi River Watershed, which covers 1.25 million square miles, or approximately 40% of the total area of the lower 48 states in the U.S. (Figure 2). The NER is located along the border of Minnesota and Wisconsin at the upper reaches of the impounded river (Figure 3).

The Minnesota River flows into the Mississippi River at RM 845 (Pool 2). Other major tributaries to the Mississippi River are the St. Croix River at RM 812 (Pool 3), the Vermillion River at RM 795 (Pool 4), the Cannon River at RM 794, the Chippewa River at RM 764 (Pool 4), and the Buffalo River at RM 755 (Pool 4). Additionally, there are many small rivers and coulee tributaries.

River hydrology is managed by the United States Army Corps of Engineers' (USACE) lock and dam system in order to provide a suitable navigation/transportation channel. Control structures are present at St. Anthony Falls (Upper and Lower) and at the lower ends of Pools 1 to 4 (Lock and Dam 1 to 4). USACE maintains a 9-foot navigation channel.

Figure 1. NER River Pools

Figure 2. Mississippi River Basin (Source, NPS)

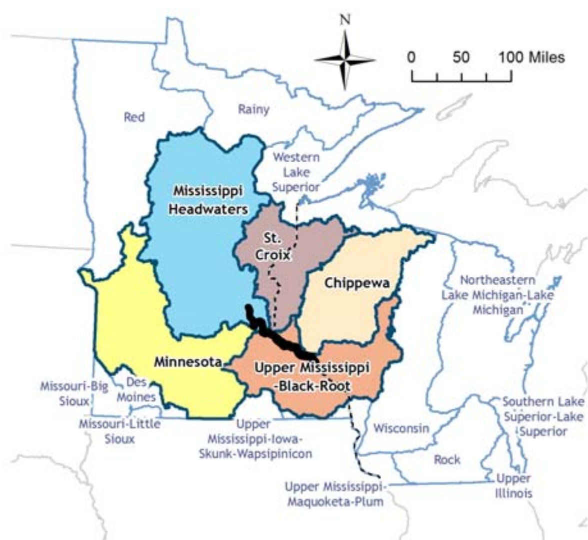


Figure 3. Watersheds of the NER

The ***Coon Rapids/St. Anthony Pool*** is the area located between RM 856.5 and RM 858 upstream of the actively managed navigation channel. It is characterized by a relatively narrow channel within a mostly urban setting. Pool boundaries were designated for this project based on location above the active navigation channel and the variability in pre-project data sets. This segment of the river is not managed for navigation and is not heavily influenced by the lock and dam system. The river channel is well defined, with occasional islands and more expansive floodplains at the north end. The surrounding upland is mostly urban or rural residential land use.

Pool 1 runs through the heart of Minneapolis from RM 858 to 847.5 both above and below St. Anthony Falls. The Pool above Upper St. Anthony Falls Lock is maintained for navigation and is influenced by the Horseshoe dam above St. Anthony Falls. The segment below the falls extends downstream to Lock and Dam 1. The upstream boundary for Pool 1 in this HGM study was defined for this project based on the extent of the navigation channel, and pre-project data availability. The river channel is in a relatively narrow valley that is well defined with steep banks that rise dramatically more than 100 feet above the river.

Pool 2 includes the confluence with the Minnesota River, which contributes nearly the same volume of water as arrives from the Mississippi River above (a greater volume during some years). A wide valley with broad floodplain and intensive agricultural use in the Minnesota River watershed contributes a large amount of nutrients and sediments to the Mississippi River system. The Mississippi River valley widens, narrows briefly through the heart of St. Paul, then widens more dramatically as it nears Lock and Dam 2. This segment of the river is variable. The river channel is generally well–defined in St. Paul and through South St. Paul, but there are some areas of backwaters below the confluence of the Mississippi and Minnesota Rivers, immediately south of the downtown area and in the flooded areas near Grey Cloud Island. These backwaters are relict meanders of the glacial River Warren and the early glacial Mississippi River. The land use also varies considerably, ranging from the highly urban downtown of St. Paul to rural residential to agricultural.

Pool 3 is located adjacent to the Vermillion River floodplain, which supports the “Vermillion Bottoms,” an extensive floodplain environment that borders the southwest side of the Mississippi River for more than 16 miles. These two river floodplains are comprised of contiguous forest and wetland complexes, though the Vermillion River confluence with the Mississippi occurs in Pool 4. The Vermillion Bottoms is “one of the most beautiful and untouched areas of the Mississippi National River and Recreation Area” (NPS http://www.nps.gov/miss/planyourvisit/vermrive.htm).
Within the lower areas of the Vermillion Bottoms, extensive shallow, backwater lakes (North Lake and Sturgeon Lake) were created as a result of flooding forests and emergent wetlands after the construction of the lock and dam system. Two urban areas are adjacent to the river: Hastings, Minnesota, and Prescott, Wisconsin. The upper watershed is largely agricultural with narrow wooded areas in the coulees. The Prairie Island Indian Community is located in the Vermillion Bottoms between these two rivers. The Prairie Island nuclear power facility is immediately adjacent to the Indian Community just upstream of Lock and Dam 3.

Pool 4 contains the large Cannon River tributary delta fan and meander channels near Red Wing, Minnesota, as well as the large Chippewa River delta. Between these river confluences lies Lake Pepin, the widest naturally occurring lake in the Upper Mississippi System. The lake is a result of the sedimented delta of the Chippewa River. This reach includes multiple channels that flow into Lake Pepin, which extends from RM 785 to the confluence with the Chippewa River at RM 764. Extensive bottomland forests (for example, the Nelson-Trevino Bottoms State Natural Area) are located on the Wisconsin side below the confluence with the Chippewa River. On the Minnesota side, parts of the valley have been converted to agriculture. The surrounding watershed is within the "driftless area," which is characterized by steep, well-defined stream channels (coulees) separated by broad ridge tops. The land use is a mix of agriculture and forest lands, with the steep hillsides in forest. The Minnesota cities of Red Wing and Wabasha are located at the upper and lower ends, respectively, of this reach.

1.2 Systemic Forest Stewardship Plan and the HGM

The Mississippi River has been an important navigation corridor since prior to Euro-American settlement. The USACE lock and dam system was developed in the 1930s to provide a consistent navigation channel for barge traffic between St. Anthony Falls in downtown Minneapolis through the Rock Island and St. Louis Districts to Lock and Dam 27 near St. Louis. . The locks and dams create slack-water pools for navigation during low-water levels as well as "steps" up or down from one water level to another. The lock and dam system is not used for flood control (USACE http://www.mvp.usace.army.mil/Missions/Navigation/LocksDams.aspx).

The natural hydrology of the river system has been substantially modified as a result of the lock and dam system. This has changed the river valley's water levels, flood characteristics, stream morphology, plant community, and wildlife habitat. Additionally, the surrounding watersheds have been dramatically altered through urbanization and agricultural practices. These watershed changes have modified nutrient and sediment loads entering the river.

In August 2012, USACE published the *Upper Mississippi River Systemic Forest Stewardship Plan*. The purpose of the plan is "to provide a guide for the sustainable management of Upper Mississippi River System (UMRS) forests, including opportunities for their restoration, and to ensure that the UMRS maintains its recognition as a nationally treasured ecological resource." This plan was compiled by a team of federal and state agency staff, nongovernmental organizations, and other stakeholders (Guyon et al., 2012).

One of the priority actions identified in the Stewardship Plan was to develop a system-wide hydrogeomorphic model (HGM) to be used to assess the past, existing, and potential future conditions of the river environment. This report uses HGM methods to assess the NER between RM 866 near Coon Rapids, Minnesota, and RM 753 near Alma, Wisconsin.

The purpose of this project and the HGM is to assist with and guide large-scale terrestrial ecosystem planning and management in the Upper Mississippi River valley. To the degree possible, this evaluation identifies pre-Euro-American settlement conditions, landscape changes, and the effects of the landscape and landuse changes in order to understand the NER's altered ecological functions and values and provide recommendations for ecosystem restoration.

2 Landscape Setting

2.1 Geology

The NER has been shaped by geologic and geomorphic processes that began millions of years ago. Much of the material that has been transported through the NER consists of sedimentary bedrock of limestone, sandstone, and shale that was formed around 500 million years before present (BP) when the region was covered by shallow seas. The present-day surficial hydrology and stream geomorphology owe their current states to advancing and retreating glaciers, particularly from the Wisconsin Glaciation, which occurred during the period from about 110,000 to 10,000 years BP. The lower pools of the NER lie within what is known as the “driftless area,” which escaped deposits during the Wisconsin Glaciation. The driftless area encompasses southeast Minnesota, southwest and west-central Wisconsin, northeast Iowa, and part of northwest Illinois. This area of the NER, beginning near Hastings, Minnesota, is marked by deeply incised bedrock often covered with varying layers of loess deposits.

2.1.1 Glacial Geology

During the Wisconsin Glaciation, as many as 13 separate ice lobes advanced across Minnesota from the Laurentide Ice Sheet. These lobes alternated from northwestern, northeastern, and east-northeastern sources from ice domes centered to the northwest (Keewatin Dome) and northeast (Labradoran Dome) in Canada. The composition of deposits from each ice lobe indicates the bedrock along its flow path. Lobes from the north and northwest, which originated from the Keewatin Dome, brought deposits containing equal amounts of Paleozoic carbonates and Archean igneous and Archean metamorphic rock and abundant Cretaceous shale fragments. In contrast, deposits from the Labradoran Dome to the northeast are derived from Precambrian igneous and metamorphic rock with variable amounts of carbonates and few if any shale fragments (Morey, 1995). The upper reaches of the NER, located near the Twin Cities metropolitan area, lies in a region covered by glacial sediment from both domains.

The NER began in a river valley carved in Paleozoic bedrock during preglacial times. The river valley was later completely filled with deposits from the Labradoran Superior Lobe when it descended from the north-northeast and reached its glacial maximum in portions of Hennepin, Dakota, and Washington Counties (Meyer, 1989). When the Superior Lobe retreated slightly from this maximum to a more stable position in the north during the Late Wisconsin Glaciation, the St. Croix Moraine was formed. The valley fill in the Upper NER consists of bouldery gravel and sand from the St. Croix Moraine and the Superior Lobe. After the Superior Lobe retreated, the Grantsburg Sublobe (an offshoot of the larger Des Moines Lobe), overrode the St. Croix Moraine and Superior Lobe deposits. The Grantsburg Sublobe advanced northeastward inside the flank of the St. Croix Moraine and stalled.

The meltwater from the sublobe flowed into the St. Croix and Mississippi Rivers (Meyer, 1989). This scoured the valley fill in the main channels of the Upper Mississippi River and deposited Des Moines Lobe outwash over it. Superior Lobe deposits located on the outer margins were then left as terrace deposits along the valley. With the retreat of the Des Moines Lobe, glacial Lake Agassiz formed in parts of northern Minnesota, North Dakota, and Canada. Glacial River Warren (now the Minnesota River), the southern outlet to glacial Lake Agassiz, significantly increased the flow and sediment into the NER, which continued to downcut the river valley through the Superior Lobe deposits (Ojakangas, 1982).

The influence of Pre-Wisconsin Glaciation on the development of the river valley is uncertain due to overprinting of later glacial events (Madigan, 2001). Early glacial events in the NER have been largely obscured by Late Wisconsin and post-glacial events. Glacial deposits older than Late Wisconsin (about 25,000 to 10,000 years BP) are found only at the surface in southwestern and southeastern Minnesota.

Due to the patchy, eroded till displays, the deeply incised river valleys of the glaciated areas north and west of the driftless area have been referred to as the “pseudo-driftless area” (Hobbs, 1999). This area includes all of Pools 3 though the channel remains deeply incised upstream beyond St. Anthony Falls, Minnesota.

2.1.2 Bedrock Geology

The topography of the NER is heavily influenced by the underlying bedrock, which helps shape the landscape. These bedrock units are composed of marine sedimentary rocks that were deposited in a shallow sea during the Early Paleozoic Age (525 to 450 million years ago). These deposits created the consolidated sandstones, limestones, and shales that make up the steep bluffs along the Mississippi River.

The following bedrock units are located at or near the surface along the NER. These units are described based on their stratagraphic position from youngest to oldest.

- **Decorah Shale:** Green, calcareous shale with thin interbeds of fossiliferous limestone.
- **Platteville/Glenwood Formations:** Fine-grained, fossiliferous limestone containing thin shale partings near the top and base, underlain by a very thin layer of green, sandy shale (Glenwood Formation).
- **St. Peter Sandstone:** Upper half to two-thirds is fine- to medium-grained, poorly cemented quartz sandstone that is highly erodible. The lower half contains multicolored beds of mudstone, siltstone, and shale with interbedded very coarse sandstone.
- **Prairie du Chien Group:** Dolostone of the Shakopee Formation makes up the upper two-thirds to half of this group. It is commonly thin bedded and sandy or oolitic and contains thin bed of sandstone and chert. Where the overlying bedrock units have been removed by erosion, the Shakopee Formation can be rubbly. Dolostone in the lower part of the group is commonly massive or thick bedded and is generally not oolitic or sandy except near the transition to the underlying Jordan Sandstone. Both formations are known to be karsted (see karst discussion on page 13) with large amounts of fracturing and enlarged conduits.
- **Jordan Sandstone:** Quartzose sandstone that is carbonate cemented in the upper 10 to 15 feet. Middle portions are coarse grained, and the base is finer grained and can contain minor amounts of shale.
- **St. Lawrence/Franconia Formations:** The St. Lawrence Formation consists of dolomitic siltstone and shale. The Franconia Formation is a fine-grained, glauconitic sandstone and shale that becomes dolomatic in areas. The two units are distinguished from each other by higher glauconite content in the Franconia Formation.
- **Ironton/Galesville Sandstones:** Silty, fine- to coarse-grained quartzose sandstone underlain by fine- to medium-grained sandstone containing interbedded shale.
- **Eau Claire Formation:** Siltstone and shale with minor amounts of very fine to fine sandstone and glauconite.
- **Mt. Simon Sandstone:** Quartzose sandstone containing varying amounts of siltstone and shale in the upper third. The middle part consists of friable medium- to coarse-grained quartzose sandstone. The lower portion is silty and poorly sorted.

Bedrock outcrops can be seen along most of the NER. Multiple units might be exposed along the face of bluffs and cliffs that bracket the river valley.

- **Pool 1:** In the vicinity of Pool 1, the steep bluffs are capped with the Platteville Formation overlain with small pockets of Decorah shale. The river valley lies within the St. Peter Sandstone.
- **Pool 2:** As the Mississippi River moves into downtown St. Paul, Minnesota, the Platteville Formation and St. Peter Sandstone are still exposed along the bluffs and bedrock terraces. Though a thick layer of unconsolidated materials overlays it, the underlying bedrock is Prairie du Chien Group at this location. In the lower half of Pool 2, as the river continues south, the Prairie du Chien Group and Jordan Sandstone can be seen along the river bluffs. The channel here lies within the St. Lawrence/Franconia Formations.
- **Pool 3:** The Mississippi River begins to cut a broader valley through the bedrock south of Prescott, Wisconsin, as it encounters less-resistant bedrock. Bedrock cliffs and steep bluffs border the Wisconsin side of the river, while much of the floodplain and terraces are found along the Minnesota side. St. Lawrence and Franconia Formation bedrock underlay the riverbed, which is covered with nearly 300 feet of Quaternary deposits.
- **Pool 4:** In this area, the bedrock has been deeply cut by the Mississippi River and its tributaries to form blufflands along the river. The areas between the tributaries are made up of resistant bedrock from the Oneota dolomite and Shakopee Formation of the Prairie du Chien Group. Erosion has removed unconsolidated sediments and exposes the bedrock in ravines, bluffs, and cliffs along the river valley. Softer bedrock such as shale and sandstone forms bedrock surfaces in the valley and lower parts of the bluff. Much of river valley consists of up to 350 feet of Quaternary deposits underlain by the Eau Claire Formation and Mt. Simon Sandstone.

Karst features are present in the NER and can be described as sinkholes, springs, caves, disappearing streams, enlarged fractures, and other related features that are created by the slow dissolution of bedrock by acidic groundwater (Alexander E. R., 2001). In the NER, the dissolution of bedrock occurs in carbonate formations, specifically the Prairie du Chien Group. Much of the upland area in southeastern Minnesota that drains into the NER is considered active karst. Active karst is an area that is underlain by carbonate bedrock with less than 50 feet of sediment overlying it (Alexander E. , 2002). The region of the NER from St. Paul Park, Minnesota, south to Alma, Wisconsin, is designated an active karst area, as well as small pockets along the river in Minneapolis and St. Paul.

2.1.3 Fluvial Geomorphology

Rivers played a large part in the movement of water and sediment from retreating glaciers during the Wisconsin Glaciation. For about 3,000 years, high flows were maintained in the NER from overflows from glacial Lake Agassiz through glacial River Warren and glacial Lake Superior through the St. Croix River (Theiling C. , 1999). The meltwater streams responded to changing conditions in volume, load, and gradient. This is clearly documented in the valleys of the Minnesota and Mississippi Rivers near the Twin Cities. The broad valley of the Mississippi River downstream of Fort Snelling in Minnesota, is a sharp contrast to the narrow gorge upstream from that point (Ojakangas, 1982).

The change in the NER near Fort Snelling was brought on by the confluence of glacial River Warren with the Mississippi River. Glacial River Warren, a high-volume outlet to glacial Lake Agassiz, was competent enough to erode a deep valley across the entire state. When glacial River Warren entered the Mississippi River Valley, it cut deeply into the Superior Lobe and Des Moines Lobe outwash deposits and Paleozoic bedrock that were present. The segment of the Mississippi River above Fort Snelling was severely undercut, and a waterfall developed. That waterfall eventually produced a deep gorge through the Twin Cities as the waterfall retreated to its present position upstream as St. Anthony Falls (Ojakangas, 1982).

About 9,000 years ago, the discharge in glacial River Warren was considerably reduced when glacial Lake Agassiz had been drained. Tributaries to the main stream (now the Minnesota and Mississippi Rivers) continued to bring in sediment that could not be carried away due to greatly reduced flows. This caused natural sediment dams where tributaries entered the main channel. Near Alma, Wisconsin, a significant amount of sediment had washed into the NER from the Chippewa River. Ponding of the segment upstream behind this area occurred and formed Lake Pepin. The northern extent of Lake Pepin was once as far upstream as St. Paul, where a delta had formed at the head of the lake. Over time, sediments from the Minnesota and Upper Mississippi Rivers contributed to the advancement of the delta downstream and thus reduced the length of the lake. Material found along the Mississippi River between St. Paul and Red Wing, is primarily made up of deltaic sediments (Ojakangas, 1982).

When the Holocene Epoch began about 9,500 years BP and the NER was no longer receiving meltwater from glacial lakes, the Mississippi River changed from a coarse-grained braided system to an island braided channel system that was dominated by fine-grained sediments (Heitmeyer M. , 2010). Frequent flooding during the early- to mid-Holocene created episodic events that caused widespread erosion and deposition and destabilized channels (Heitmeyer M. , 2010). Around 7,000 years BP, the channel stabilized, leaving a series of abandoned belt channels in the NER. Fine-grained alluvium collected in the floodplains, and natural levees and crevasse splay complexes formed next to channels in wider valleys. Around 2,500 years BP, fan-head trenches developed, and most alluvial fans and colluvial slopes stabilized. Tributary fans also expanded at the confluence with tributary streams (Heitmeyer M. , 2010).

2.2 Landscape Sediment Assemblages

Landform Sediment Assemblages (LSAs) were used to classify the distribution of landforms and sediment within the NER by Thomas Madigan in the report titled: *Geomorphological Mapping and Archaeological Sites of the Upper Mississippi River Valley, Navigation Pools 1-10, Minneapolis, Minnesota to Guttenberg Iowa*. These LSAs were developed by grouping similar landforms and sediments based on similar characteristic such as spatial distribution, physical characteristics, and the geomorphic processes in which they were deposited. The individual LSAs identified in the NER (Pools 1-4) are shown in maps located in Appendices B (LSA Type) and C (LSA Age). These LSAs are further grouped according to geomorphic conditions under which they were developed and described in further detail below.

2.2.1 Glaciofluvial Landform Sediment Assemblages (LSA)

These landform sediment assemblages (LSA) formed during Late Wisconsin Glaciation to the early Holocene Epoch and consist of glacial terraces, glacial stream channels, and glacial stream scarps.

- **Glacial Terrace (High)** deposits are characterized by gently sloping surfaces found between 850 feet above mean sea level (amsl) at St. Anthony Falls to 830 feet amsl at the confluence with the St. Croix Moraine. High terraces are present only in the northern part of the NER in Pools 1 and 2. Sediments here lie high above the highest historical flood stage and consist of sand and gravelly sand. A small amount of loess and colluvial sediment deposited near the end of the Late Wisconsin Glaciation covers the high terrace deposits in Pool 2.
- **Glacial Terrace (Intermediate)** deposits are the most widely distributed LSA in the NER. These deposits also lie above the highest historical flood stage and are about 10 feet below the high terrace deposits near St. Anthony Falls. They have the highest down-valley gradient of any of the

LSAs. The composition of these deposits can vary depending on their location in the NER. In Pool 2 at Inver Grove Heights, Minnesota, terrace sediments consist of more than 30 meters of cross-bedded sand and gravel from the Superior Lobe overlying planar-bedded sand and pebbly sand. In contrast, at St. Paul, terrace sediment consists of a thin, discontinuous accumulation of gravelly sand overlying bedrock surface. On the terrace surface, colluvial sediment has accumulated and alluvial fans have developed locally.

- **Glacial Terrace (Low)** deposits are located below the intermediate deposits and are the lowest level of glaciofluvial outwash deposits present at the surface in the main valley. Many of the terraces are separated from the valley wall by paleochannel systems and form islands within the Mississippi River floodplain (for example, Grey Cloud Island in Pool 2 and Prairie Island in Pool 3). The gradient of the low terrace surface is less than that of the intermediate terrace but is somewhat greater than that of the Holocene floodplain. The deposits are cross-bedded and flat-bedded sand and gravelly sand that is generally less gravely than the intermediate terrace deposits.
- **Glacial Stream Channel (Abandoned)** deposits mark the course of the meltwater drainage through the NER during the Late Wisconsin Glaciation. The deposits vary from coarse sand and gravel channel lag deposits to fine-grained sand and silt deposited as the channel was abandoned. The glacial stream channel deposits are less well drained than the terrace deposits and have small wetlands or lakes within their boundaries.
- **Glacial Stream Scarps** are steep, abrupt slopes bounding the outer margins of the glacial terraces and stream channels in the river valley. This LSA is related to other glacial LSAs in sedimentary characteristics and age but is essentially a glacial stream cut bank formed on the edge of the terrace.

2.2.2 Minor or Inactive Channel LSAs

This LSA group forms low-lying, relatively flat to gently rolling, well to poorly drained, bowed-shaped surfaces on the floodplain. The LSAs mark the position of paleochannels and distributary channels within the early to middle Holocene floodplain.

- **Inactive/Minor Channel Lateral Accretion Meander Scrolls** formed during lateral migration of distributary channels and paleochannels. These deposits appear as series of ridges within intervening swales marking the course of minor or inactive channels. They are common below the confluence of tributary streams entering the Mississippi River valley. Deposits are highly variable depending on location and are generally reworked cross-bedded or planar-bedded sand and gravelly sand with a silt loam cap.
- **Inactive/Minor Channel Vertical Accretion Marshes** are backwater features that appear as flat-lying wetlands that collect sediment due to ponding water upstream of locks and dams.
- **Inactive/Minor Channel Vertical Accretion Lakes** consists of small- to medium-sized open bodies of water formed by abandoned channels in older parts of the floodplain.
- **Inactive/Minor Channel Vertical Accretion Undifferentiated** are strath surfaces covered with a veneer of sediment and areas of the floodplain that are associated with former channels that are periodically flooded by high-stage events. Sediments are silt loam, silt clay loam, and clay interbedded with a mixture of organic material.

2.2.3 Main Channel LSAs

This LSA group consists of low-relief, gently rolling, moderately well to poorly drained surfaces typically located 1 to 3 meters above the level of the active channel. They are associated with fluvial processes operating in the main channel during the Holocene Epoch.

- **Main Channel Lateral Accretions** consist primarily of meander scroll/point bar deposits associated with the current channel. They consists of cross-bedded or planar-bedded sand and gravelly sand.
- **Main Channel Vertical Accretion Crevasses/Splays** are locate-shaped landforms formed when sediment-laden water passes through low spots in the floodplain, spreading out laterally and dropping its load. They are very localized in spatial distribution and are generally more coarse-grained than other types of vertical accretion.
- **Main Channel Vertical Accretion Levees** consist of low ridges of sediment paralleling the present river course and are topographically highest near the active channel before sloping away. These deposits build up over time and protect areas of the floodplain from inundation.
- **Main Channel Vertical Accretion Marshes** are backwater features that appear as flat-lying wetlands that collect sediment due to ponding water upstream of locks and dams. Organic-rich silt and clay typify this LSA.
- **Main Channel Vertical Accretion Lakes** are large, open bodies of water connected to the main channel. Depending on their position, water and sediment flows in these systems can be similar to those in the main channel.
- **Main Channel Vertical Accretions** consist of predominantly fine-grained sand, silt, and clay deposited in areas on the floodplain that are not reworked by the main channel.

2.2.4 Island LSAs

Islands in the NER have formed by different fluvial processes. The majority were formed by a combination of lateral and vertical accretion deposits separated from landforms from the valley wall. Some islands are also erosional remnants of Late Wisconsin Glaciation terraces or bedrock remnants.

- **Main Channel Islands** are influenced by the flow of the active channel and are overtopped during flooding. These landforms appear a teardrop, lobate, or linear to sublinear in shape. Sediments are typically silty clay loam and silt loam in the center of the island grading to sand or gravelly sand on the edges.

2.2.5 Tributary Stream LSAs

Fluvial activity by tributary streams has had a profound effect on the geomorphic development of the floodplain. Tributary streams increase discharges of waters and sediment into the Mississippi River, thereby changing channel configurations, blocking drainages of the river and causing lakes to form, and by extension, developing unique LSAs in and adjacent to the valley.

- **Tributary Alluvial Fans** are gently sloping masses of alluvium deposited by a stream issuing from a narrow canyon or gully onto the valley floor. This unit commonly overlies glaciofluvial terraces, appearing as small cones of sediment grading outward onto the terrace surface.
- **Tributary Alluvial Fan/Deltas** vary in size and shape and form where a tributary stream empties directly into water.

- **Tributary Floodplains** vary in size from 100 meters to several kilometers in width. They are relatively flat-lying with poorly drained surfaces, which form large marshes.
- **Tributary Fan / Deltas** are alluvial fan deposits that prograde into a body of standing water. The mechanism for the formation of fan/delta is similar to alluvial fans, but they differ in that deposition results from reduced stream velocity as the stream flows into a standing body of water. The best-known example along the NER is the Chippewa River delta, which dammed the Mississippi River and is responsible for the formation of Lake Pepin.
- **Tributary Floodplain Terraces** are topographically higher deposits located above the floodplain of the tributary.
- **Tributary Marshes** are water-saturated, poorly drained areas within the floodplain.
- **Tributary Meander Belts**, also called Yazoo systems, are formed by streams entering the valley from another stream and flows parallel to its floodplain. The Vermillion River is the only tributary meander belt in the NER. Deposits consist primarily of silty clay loan and clay loam.

2.2.6 Eolian LSA

The Eolian LSA is mapped only as large complexes covering terrace surfaces. This LSA can include both erosional and depositional landforms. They can consist of thin sheets of sand or loess distributed across the ground surface. There have been several episodes of eolian activity in the Upper Midwest during the Holocene Epoch.

2.2.7 Lacustrine LSA

One of the unique features of the NER is Lake Pepin. The lake has a complex history caused by fluctuations in water levels throughout the Holocene Epoch and gradual infilling by sediment transported into its headwaters by the Mississippi River. Two LSAs are associated with geomorphic processes operating the shoreline. These features are generated by wind currents and motorized craft, which generate waves and transport sediment in this area.

- **Lacustrine Shoreline Beaches** are primary landforms that developed along the shorelines of Lake Pepin as a function of wave and energy currents incident to the shoreline.
- **Lacustrine Shoreline Cusps** are crescentic landforms developed along the upper part of the beach faces and along the outer margins of berms. They are similar to beaches with respect to sedimentary characteristics but differ in their mode of formation.

2.2.7 Mass Wasting/Colluvial Slope LSAs

These LSAs are grouped based on processes that occur in the upland area surrounding the river valley.

- **Upland Hilltops** are comprised of sedimentary derived material occupying the crests of hills with the hills themselves being separated by steep-sided valleys. Mass wasting and sheetwash are the dominant processes operating on this LSA. Sediments are variable but are typically composed of glacial sediment or weather bedrock residuum capped with a veneer of loess.
- **Valley Side Colluvial Slopes** are formed by gravitational redistribution of sediment by mass movement. They are formed by the interaction of infiltration and runoff on slopes. Sedimentary deposits on colluvial slopes tend to be poorly sorted, containing large slabs of weathered bedrock in a matrix of fine-grained silt and silt loam derived from erosion of the upland surface.

2.3 Soils of the Region

2.3.1 General Soil Characteristics

The Natural Resources Conservation Service (NRCS) uses Major Land Resource Areas (MLRA) to describe soils at the landscape level. The NER is located within the following three MLRAs (NRCS, http://soils.usda.gov/MLRAExplorer):

- **MLRA 91A – Central Minnesota Sandy Outwash.** The upper reaches of the Mississippi River, from the headwaters to central Dakota County, Minnesota, are located within MLRA 91A – Central Minnesota Sandy Outwash. The dominant soil orders in this region are Mollisols, deep soils of the prairie, and Histosols, organic soils of large basins and depressions. The soils have a udic or aquic moisture regime and mixed mineralogy. The surface tends to be loamy, underlain by coarse textured outwash material. Local relief is 10 to 20 feet. Soils on uplands tend to be well drained or excessively drained, while soils in depressions are very poorly drained. In this MLRA, Hapludolls and Argiudolls formed in outwash mantled with loamy material. They are on outwash plains and stream terraces. Hapludolls formed in outwash plains and stream terraces. Haplosaprists formed in organic material in basins and depressions.
- **MLRA 104 – Eastern Iowa and Minnesota Till Prairies.** Southeast Hennepin and north Dakota Counties (Minnesota) and Pierce County (Wisconsin) are located within MLRA 104 – Eastern Iowa and Minnesota Till Prairies. The dominant soil orders are prairie Mollisols and Alfisols, soils that developed under forested conditions. Local relief is 10 to 20 feet. Like the soils in MLRA 91A, they developed under udic or aquic moisture regimes and have mixed mineralogy. These soils, especially the Mollisols, tend to be very deep. They vary from well drained to very poorly drained and tend to have loamy surface textures. In this MLRA, Hapludolls and Hapludalfs formed in loamy sediments over till on uplands. Argiudolls formed in loess over till on uplands. Endoaquaolls formed in loamy and silty sediments over till on uplands.
- **LMRA 105 – Northern Mississippi Valley Loess Hills.** LMRA 105 covers the remaining part of Dakota County (Minnesota) as well as Goodhue and Wabasha Counties (Minnesota) and Buffalo County (Wisconsin). This area is known as the driftless area because it was mostly excluded from the most recent glacial events. The topography consists of gently sloping to rolling summits with steeper valley walls that adjoin small to very large floodplains. Stream valleys tend to be deep, narrow, and V-shaped with irregular slopes and steep cliffs. Local relief is 10 to 20 feet but is as much as 50 to 100 feet on valley walls along major streams and as much as 250 feet on the Mississippi River bluffs above the river valley floor. Alfisols (forest soils) and Entisols, soils that were more recently formed, are predominant. Mollisols are also present, but to a lesser extent. These soils have a udic moisture regime and mixed mineralogy. They are generally moderately deep to very deep, well drained or moderately well drained, and loamy. In this LMRA, Hapludalfs formed in loess or loess over residuum on uplands and benches. Paleudalfs formed in loess over residuum on uplands. Argiudolls formed in loess on uplands and terraces. Udifluvents formed in alluvium on floodplains and alluvial fans. Udisamments formed in glaciofluvial deposits on outwash plains, terraces, and valley trains.

2.3.2 Soils within the NER

The NER study area encompasses about 68,000 acres of land area, excluding surface water. Table 1 summarizes the soil classifications and typical soil descriptions for the predominant soils in each soil great group of the NER land area.

Table 1. Soil Orders, Great Groups, and Predominant Soil Series in the NER Study Area

<table>
<tr><td>Order: Mollisols</td><td colspan="2">Aerial coverage: 51.8%</td></tr>
<tr><td>Great Group: Hapludolls</td><td>Aerial Coverage: 26.3%</td><td>Most Prominent Series: Finchford and Sparta</td></tr>
<tr><td colspan="3">Finchford loamy sand – Very deep, excessively drained soils that formed in coarse textured alluvium or glacial outwash. These soils are on treads and risers on stream terraces in river valleys and valley trains on uplands. Slope ranges from 0% to 14%. The native vegetation is big bluestem, indiangrass, switchgrass, and other grasses of the tall grass prairie.
Sparta loamy fine sand – Very deep, excessively drained soils formed in sandy outwash that has been reworked by wind. These soils are on nearly level to very steep treads and risers on stream terraces in river valleys, outwash terraces, outwash plains, and dune fields. Slope ranges from 0% to 40%. The native vegetation is mixed big bluestem, little bluestem, switchgrass, and other grasses of the tall grass prairie with widely spaced oak and hickory trees.</td></tr>
<tr><td>Great Group: Endoaquolls</td><td>Aerial Coverage: 21.4%</td><td>Most Prominent Series: Calco</td></tr>
<tr><td colspan="3">Calco silty clay loam – Very deep, poorly drained and very poorly drained soils formed in calcareous alluvium. These soils are on floodplains in river valleys. Slope ranges from 0% to 2%. The native vegetation is prairie cordgrass, reedgrass, sedges, big bluestem, little bluestem, and other grasses of the tall grass prairie that tolerate excessive wetness.</td></tr>
<tr><td>Great Group: Argiudolls</td><td>Aerial Coverage: 4.0%</td><td>Most Prominent Series: Dakota and Rasset</td></tr>
<tr><td colspan="3">Dakota loam – Very deep, well-drained soils formed in 50 to 100 centimeters (cm) of loamy alluvium and in the underlying sandy outwash. These soils are on outwash plains, stream terraces, and valley trains. Slope ranges from 0% to 18%. The native vegetation is big bluestem, little bluestem, switchgrass, and other grasses of the tall grass prairie with scattered oak groves.
Rasset sandy loam – Very deep, well-drained soils that formed in 50 to 100 cm of loamy sediments and the underlying sandy and gravelly outwash. These soils are on nearly level to convex slopes on outwash plains, valley trains, and moraines and on treads and risers of strath terraces. Slope ranges from 0% to 40%. The native vegetation is mixed deciduous forest and big bluestem, little bluestem, switchgrass, and other grasses of the tall grass prairie.</td></tr>
<tr><td>Order: Entisols</td><td colspan="2">Aerial Coverage: 38.1%</td></tr>
<tr><td>Great Group: Udipsamments</td><td>Aerial Coverage: 18.1%</td><td>Most Prominent Series: Algansee and Plainfield</td></tr>
<tr><td colspan="3">Algansee loamy find sand – Very deep, somewhat poorly drained soils formed in stratified sandy alluvium. These soils are on floodplains and lake shores. Slope ranges from 0% to 4%. Native vegetation is red maple, swamp white oak, quaking aspen, and white ash.
Plainfield sand – Very deep, excessively drained soils formed in sandy drift on outwash plains, valley trains, glacial lake basins, stream terraces, and moraines and other upland areas. Permeability is rapid or very rapid. Slopes range from 0% to 70%. Native vegetation is mixed deciduous and coniferous forest. Common trees are jack pine, red pine, eastern white pine, and northern pin oak.</td></tr>
<tr><td>Great Group: Udifluvents</td><td>Aerial Coverage: 10.0%</td><td>Most Prominent Series: Sandy alluvial land and Minneiska</td></tr>
<tr><td colspan="3">Sandy alluvial land – No description is available, since this is a general category and not a soil type.
Minneiska fine sandy loam – Very deep, moderately well-drained soils that formed in calcareous alluvium on floodplains. These soils have moderately rapid permeability. They have slopes of 0% to 4%. Mean annual precipitation is about 30 inches. Pre-settlement vegetation was mixed deciduous forest and prairie.</td></tr>
<tr><td>Great Group: Udorthents</td><td>Aerial Coverage: 5.2%</td><td>Most Prominent Series: Not Applicable</td></tr>
</table>

Udorthents – There are no soil series within this soil great group. Udorthents are Entisols on recent erosional surfaces. The erosion can be geologic or might have been induced by cultivation, mining, or other factors. The surface texture is loamy fine sand or finer. The profile lacks diagnostic features. Slopes generally are moderate to steep but are gentle in a few areas. Udorthents commonly occur in areas of very recently exposed regolith, such as loess or till; in areas of weakly cemented rocks, such as shale; or in areas of thin regolith over hard rocks. Many of the gently sloping soils are the result of mining or other earth-moving activities. Some have a sandy-skeletal particle-size class. They do not occur in areas that have aquic conditions such as a high water table. The native vegetation is commonly deciduous forest (USDA Soil Taxonomy 1999).		
Great Group: Fluvaquents	Aerial Coverage: 4.2%	Most Prominent Series: Chaska
Chaska silt loam – Very deep, somewhat poorly drained soils that formed in recent calcareous loamy alluvium on floodplains. These soils have moderate permeability. Their slopes are less than 2%. Native vegetation was marsh grasses, sedges, and deciduous trees such as elm and ash.		
Great Group: Psammaquents	Aerial Coverage: 0.7%	Most Prominent Series: Glendora
Glendora sandy loam – Very deep, poorly drained or very poorly drained soils formed in sandy alluvium. These soils are on nearly level areas or slight depressions, including old drainageways, and on floodplains in river valleys. Slope ranges from 0% to 2%. Native vegetation is American elm, white ash, swamp white oak, and quaking aspen.		
Order: Alfisols	**Aerial Coverage: 4.1%**	
Great Group: Hapludalfs	Aerial Coverage: 4.1%	Most Prominent Series: Meridian
Meridian silt loam – Very deep, well-drained soils that are moderately deep to sandy outwash. They formed dominantly in loamy alluvium underlain by sandy outwash on lake terraces and outwash terraces of valley trains. Permeability is moderate in the loamy alluvium and rapid or very rapid in the sandy outwash. Slopes range from 0% to 20%. Native vegetation is a mixture of deciduous trees and prairie grasses.		
Great Group: Glossudalfs	Aerial Coverage: <0.1%	Most Prominent Series: Brill
Brill silt loam – Very deep, moderately well-drained soils that are moderately deep to stratified sandy outwash. These soils formed mostly in loess or silty alluvium underlain by sandy outwash. Typically they are on outwash plains, valley trains, and stream terraces, but some are on glacial lake basins and moraines. Permeability is moderate in the silty and loamy mantle and rapid or very rapid in the sandy outwash. Slopes range from 0% to 6%. Native vegetation is dominantly deciduous forest with a few conifers in some areas. Common trees are sugar maple, American elm, red maple, white pine, and white spruce.+		
Order: Histisols	**Aerial Coverage: 0.9%**	
Great Group: Haplosaprists	Aerial Coverage: 0.8%	Most Prominent Series: Kerston
Kerston muck – Very deep, very poorly drained soils that formed in 41 to 76 cm (16 to 30 inches) of organic materials overlying alternating layers of organic and mineral materials on floodplains and glacial drainageways. Slope ranges from 0% to 2%. The greater part of this soil is in native vegetation, which consists of marsh grasses, sedges, reeds, and shrubs. Some areas have lowland hardwood forest including American elm, white ash, cottonwood, and red and silver maple.		
Great Group: Haplohemists	Aerial Coverage: 0.1%	Most Prominent Series: Boots
Boots muck – Very deep, very poorly drained soils formed in organic material. These soils have moderate or moderately rapid permeability. Slopes are less than 2%. These soils are primarily in woodland, but in some places the vegetation is chiefly reeds, sedges, and cattails. Principal woodland vegetation is tamarack, dogwood, poison sumac, alder, and willow with ground cover of sphagnum moss, marsh grasses, sedges, reeds, and cattails. Ground cover varies with amount of sunlight and microrelief.		
Order: Inceptisols	**Aerial Coverage: 0.4%**	

Great Group: Dystrudepts	Aerial Coverage: 0.4%	Most Prominent Series: Northbend and Dune Land
Northbend silt loam – Very deep, somewhat poorly drained soils that are moderately deep to sandy alluvium on floodplains. They formed mostly in silty and loamy alluvium underlain by sandy alluvium. Permeability is moderate or moderately rapid in the silty and loamy alluvium and rapid in the sandy alluvium. Slopes range from 0% to 3%. Most areas are in woodland. Common trees are silver maple, red maple, green ash, white ash, white oak, and cottonwood. *Dune land* – No description is available, since this is a general category and not a soil type.		
Great Group: Eutredepts	Aerial Coverage: <0.1%	Most Prominent Series: Timula
Timula silt loam – Very deep, well-drained soils formed in loess on upland hill slopes. Slope ranges from 2% to 60%. Native vegetation is deciduous forest, mainly oak, hickory, and birch.		
Other	**Aerial Coverage: 4.7%**	
Urban Land	Aerial Coverage: <0.1%	Most Prominent Series: Urban Land, Made Land, Cut and Fill, Pits
No description is available, since these are general categories and not soil types.		

Soil description source: USDA-NRCS Soil Survey Division, Official Soil Series Descriptions https://soilseries.sc.egov.usda.gov/osdname.asp

The NER is located in two geologic regions that are defined based on their surface geology. The first region is the driftless area, which includes most of the southern part of the NER. The driftless area did not experience the most recent glacial events (10,000 years ago). Soils in this landscape tend to be older; the drainage pattern is well developed with fewer isolated basins and more streams. The second region, which includes the northern part of the NER, experienced the most recent glaciation and has a landscape surface dominated by glacial features. The soils developed in various types of glacial till materials, depending on the source and direction of glacial movement. Isolated basins are common in this second region.

Both surface geology and soils development in the Mississippi River valley are greatly influenced by water movement. As shown in the Table 1 above, soils in the valley tend to be Inceptisols or Entisols, both of which are more recent in origin. Ongoing fluvial activity continues to shift, bury, and rework the soils in the valley floor. Surface textures are often correlated with landscape position as flooding and water movement affect the sorting and settling of soils carried in the water column. The following quotation from Robert H. Meade describes the typical sorting that occurs due to fluvial activity.

> In the Upper Mississippi River, which has been dammed in order to form a series of lakes to provide depth sufficient for barge navigation (see fig. 10A), the sizes of the particles in both the bed sediments and suspended sediments are distributed differently from those in the unimpounded reaches of the lower river. The examples shown here are data collected from the Mississippi River at Hastings, Minnesota, in the upper end of navigation Pool 3 on October 10, 1991, and from the nonchannel areas of lower Pool 3 on October 11, 1991; and from the Mississippi River near Winfield, Missouri, at the upper end of Pool 26 on July 24, 1991, and from the nonchannel areas of lower-middle Pool 26 on November 1, 1991. In the navigation channels, the bed sediments consist largely of sand, as they do in the channels of the freely flowing lower river. Suspended sediments, however, consist almost entirely of silt and colloidal particles and contain very little sand except during floods. In the shallow nonchannel areas of the navigation pools, which cover the former floodplains of the upper river, the bed sediment is typically intermediate in size-finer than the bed material in the main channels but generally coarser than the bulk of the sediment in suspension. (Meade, 1995)

2.4 Climate and Hydrology

Within the NER, average temperatures vary from 12 degrees Fahrenheit (°F) in January to 74 °F in July (Minnesota Climatology Working Group, 2005). Minimum air temperatures are below freezing generally from November to March, and sometimes in April and occasionally in October. Average snowfall depth is 54 inches, mostly accumulating in December to March (Minnesota Climatology Working Group, 2013). The upper soil freezes starting from early November to early December. The growing season, defined as months in which average air temperatures are 50 °F or higher, is generally between May and October and occasionally as early as April. Annual precipitation is 29 inches per year, with over half occurring from May to August. The annual precipitation ranges from 16 inches during drought conditions to 39 inches during wet conditions. Most storms produce less than 1 inch of rain.

The Mississippi River between RM 760 and 870 has two major tributaries: the Minnesota River and the St. Croix River. The average flow at St. Paul, upstream of these two tributaries, is 15,700 cubic feet per second (cfs). Base flow ranges from 5,000 to 10,000 cfs, with high flows of 35,000 cfs usually occurring in April. The average volume is 11.4 million acre-feet per year. This ranges from 2.7 million acre-feet per year during drought conditions to 26.4 million acre-feet per year during wet conditions. Downstream of the St. Croix River, the average base flow is about 10,000 cfs with a high flow of 43,000 cfs and an overall annual average of 21,700 cfs. Average flow volume at this location is 15.7 million acre-feet per year.

On average, about one-fourth to one-third of all years are dry or drought conditions. Tree-ring reconstruction of paleoclimatology indicated drier conditions over the past 700 years (National Climate Data Center, Ashville, NC, 2004). From 1300 to 1700, roughly 1 in 3 years were dry or drought conditions. About 1 in 10 years were moderate to extreme drought conditions. About half of years were normal precipitation and temperatures. From 1700 to 2000, dry or drought years occurred 1 out of 4 years. The occurrence of moderate to extreme drought remained the same 1 in 10 years. The occurrence of mild drought has lessened and above-average precipitation conditions have increased.

The trend of increased precipitation is also present during the 20th century. The Palmer Drought Severity Index (PDSI) is a measure of agricultural drought that relates soil moisture to a description of drought. Soil moisture is replenished by precipitation and exhausted through evapotranspiration driven by temperature. Through much of the 20th century, the southeast part of Minnesota has cycled between wet conditions and drought based on this index (Figure 5). Significant droughts occurred around 1910, the 1920s, the 1930s (an era known as the Dust Bowl), and the 1950s, 1960s, and 1970s. Most of these droughts culminated in extreme drought conditions.

Post-1970 there was the drought of 1988 to 1992, which was a regionally significant event. However, although this drought progressed over multiple years, it was rated as a moderate drought. Precipitation records (Figure 5) indicate that wetter conditions have predominated in the last 30 years. Annual precipitation has increased by 20% since 1900 (MPCA, 2007), although this trend is less apparent when the latter half of the 19th century is considered.

Temperatures in the Minneapolis–St. Paul area have increased over the past 100 years (Figure 6). Average temperatures overall have increased by 2.5 °F per 100 years. The average maximum temperatures, which occur in summer, have increased by 1.8 °F per 100 years. More so, the minimum temperatures during winter have increased by 5.1 °F per 100 years. These climatic trends are consistent with the future climate change Global Circulatory Models (GCMs) developed by the Intergovernmental Panel on Climate Change (IPCC).

The IPCC studies predicted that overall average global temperatures would rise an additional 2 to 7 °F by 2100. Northern latitudes were predicted to warm more than equatorial or southern areas of the planet. Winter temperatures were predicted to warm more than annual average or summer temperatures. Warmer temperatures increase the capability of the atmosphere to hold and transport water vapor, leading to increased precipitation and storm intensities in certain areas. Vegetation zones migrate northward 60 miles for each 1.8 °F increase in temperature. In 2012, the U.S. Department of Agriculture (USDA) shifted the plant hardiness zones in Minnesota in part due to the last 20 years of temperature data.

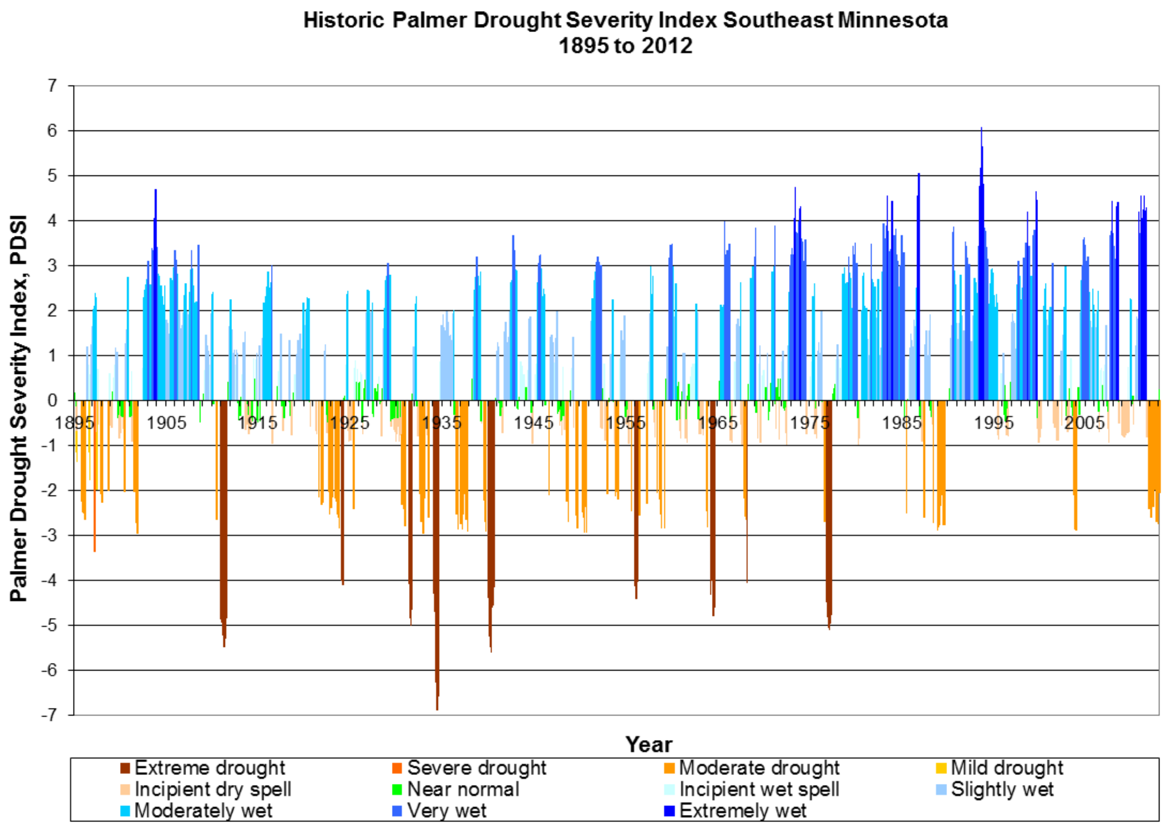


Figure 4. Historic Palmer Drought Severity Index (PDSI)

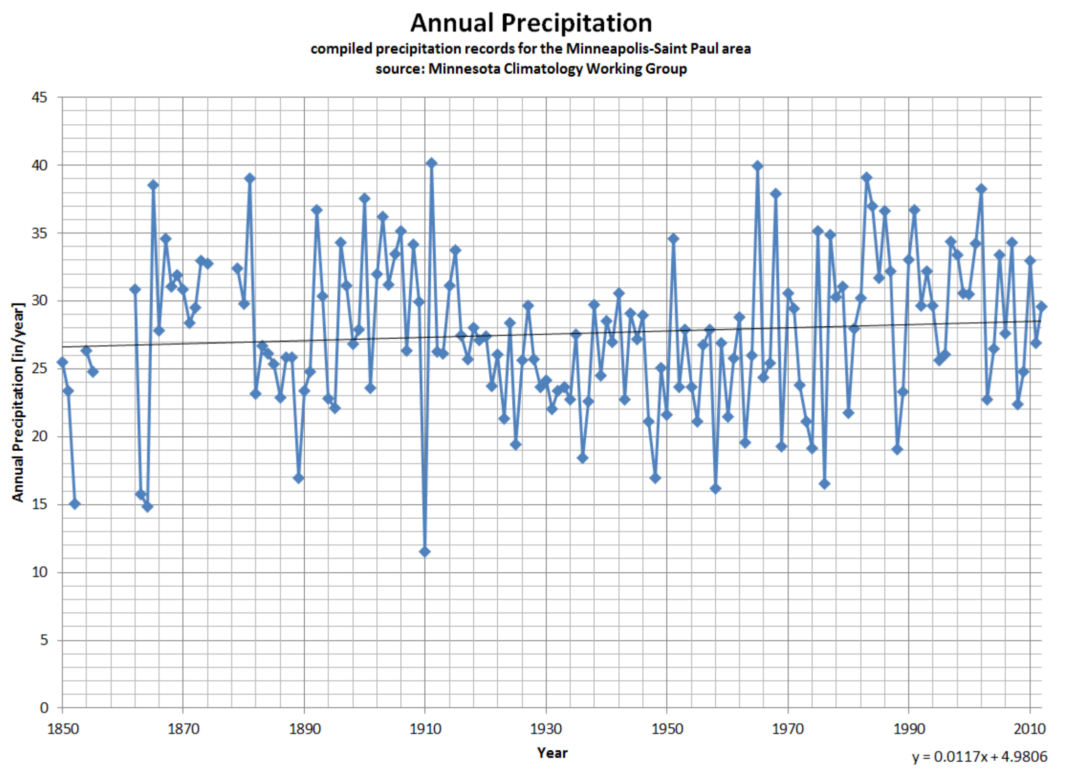


Figure 5. Annual Precipitation in the Minneapolis–St. Paul Area

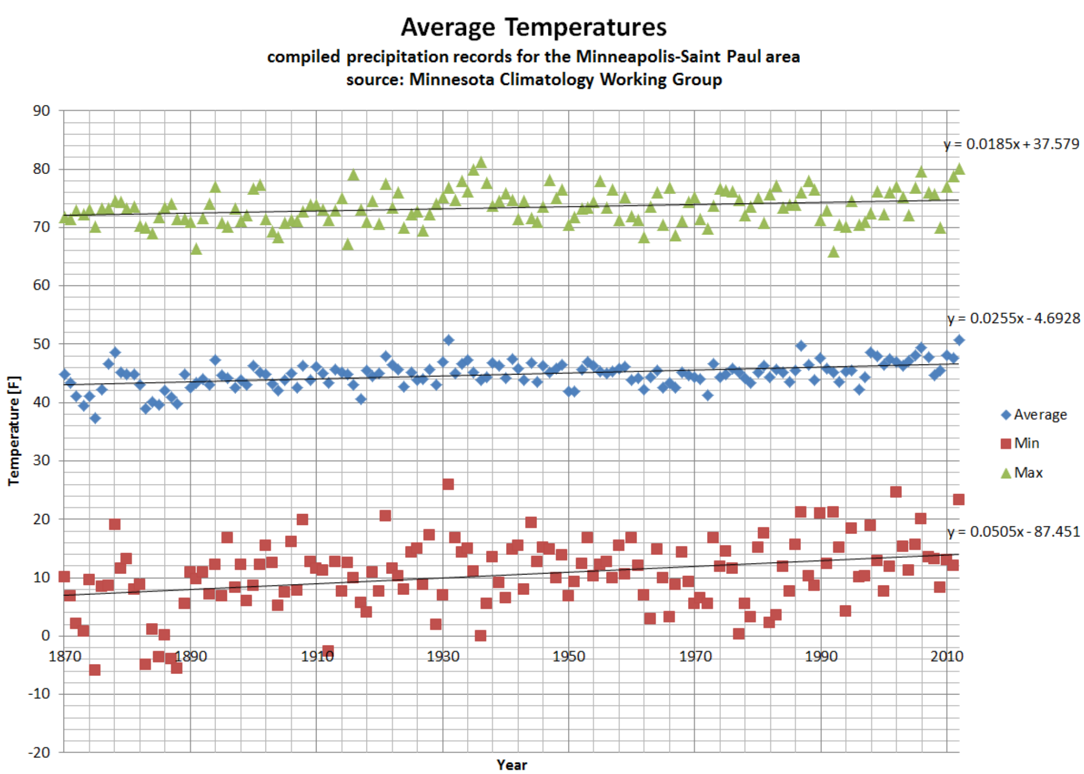


Figure 6. Average Temperatures in the Minneapolis–St. Paul Area

In the late 19th century, the average Mississippi River flow at St. Paul was 8.4 million acre-feet per year. The average flow has increased to an average of 11.4 million acre-feet per year at present (Figure 7).

The instantaneous peak flow on the river has also trended higher over time (Figure 8). Since measurements were started in 1893 and until 1952, peak flows did not exceed 100,000 cfs. Since 1952, there have been 8 years with peak flows higher than 100,000 cfs. The minimum peak flow was not less than 16,400 cfs from 1952 to 2012, while prior to this, there were 9 years when peak flows were lower.

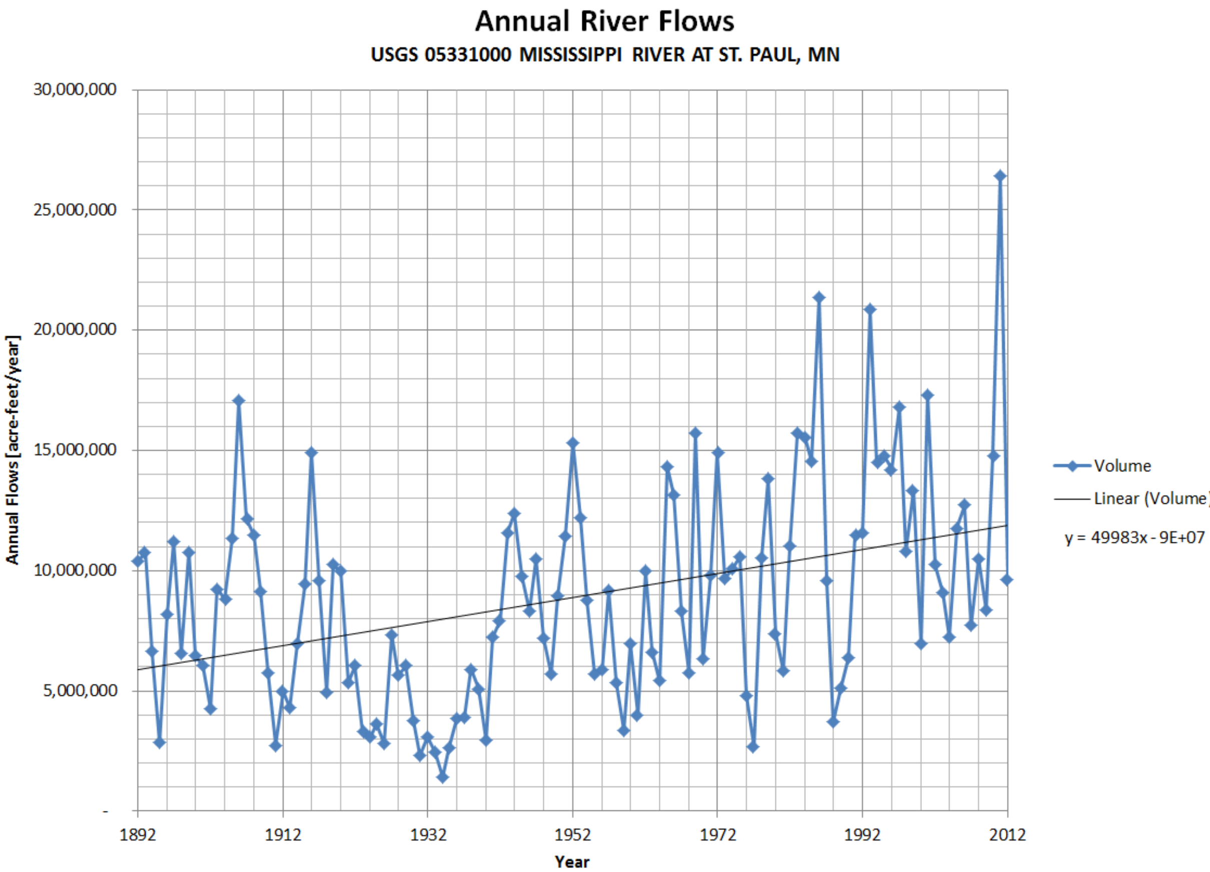


Figure 7. Annual Average River Flows at St. Paul, Minnesota

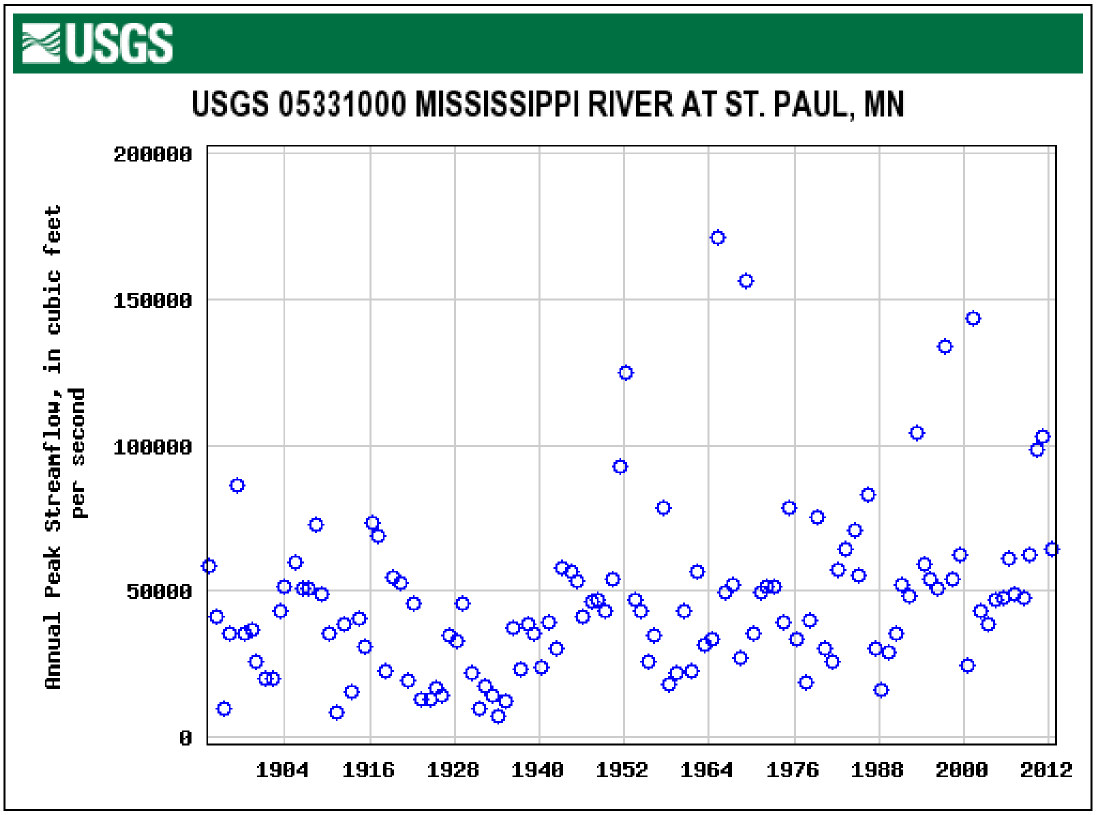


Figure 8. Annual Peak Stream Flows at St. Paul, Minnesota

3 Cultural Background

The study area is located in the Southeast Riverine and Central Lakes Deciduous Archaeological Regions of Minnesota (see). The following environmental history of these regions is based on information in an overview titled *Minnesota's Environment and Native American Culture History* by Gibbon, Johnson, and Hobbs (Gibbon, 2002).

Southeast Riverine Archaeological Region

The topography of the Southeast Riverine Archaeological Region is characterized by terrain that has been extremely dissected by streams. This area was not glaciated during the Late Wisconsin Glaciation, and it has experienced many more years of erosional processes then the land surrounding it. There are no natural lakes in the region's interior, although there are valley bottom lakes. The three major river systems in the region are the Cannon, Zumbro, and Root.

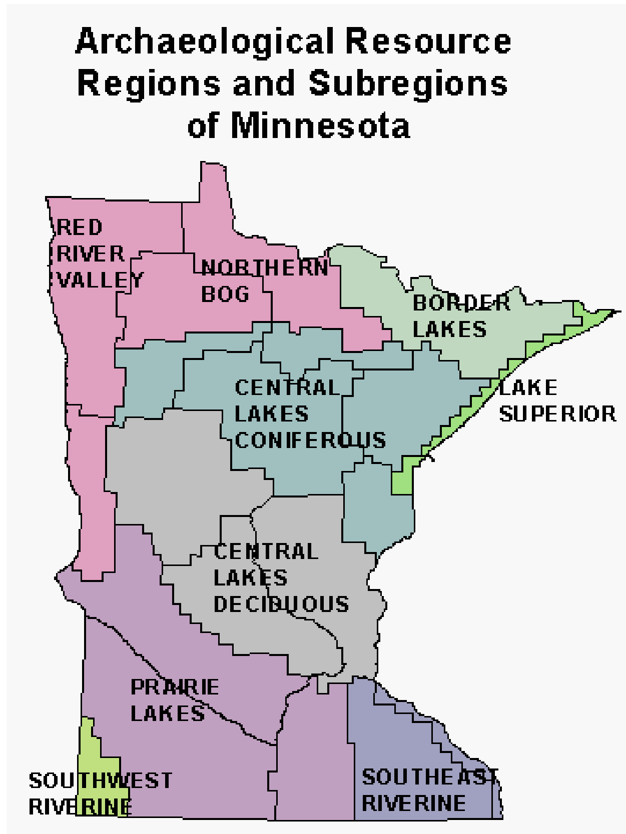


Figure 9. Archaeological Resource Regions of Minnesota (Minnesota Department of Transportation, 1997)

Soil types in this region consist of medium prairie soils, prairie border soils, and fine-textured forest and prairie soils formed over loess deposits. Extensive rock outcrops of high-quality flaking material are present in this region, and there are numerous prehistoric quarry areas. Average annual precipitation ranges from 28 to 30 inches. The average January high temperature is 23 °F, and the average July high temperature is 85 °F. The frost-free season is about 160 days.

At the time of Euro-American settlement, the vegetation of this region was varied with patches of oak groves scattered in the prairie (oak barrens) in the west; open prairie in the middle; maple, elm, and basswood on the uplands over the Mississippi River in the east; and elm, ash, and cottonwood in the Mississippi River lowlands. At the time of Euro-American contact, subsistence resources for the Native American residents included bison, white-tailed deer, and elk. Many aquatic mammals, waterfowl, and fish and mussels were plentiful in the bottom lands. There were also edible plants, including cattails and water lilies near water sources, and prairie turnips and acorns in the uplands.

Central Lakes Deciduous Archaeological Region

The topography of the Central Lakes Deciduous Archaeological Region consists of a patchwork of ground moraines, till plains, and outwash plains. Lake basins in the region vary greatly in size, are numerous, and can reach depths of 100 feet. The Mississippi River flows through the eastern and central parts of this region. The St. Croix River forms its eastern boundary, and the beach ridges of prehistoric glacial Lake Agassiz form its western boundary.

Soil types in this region consist of medium to course textured prairie soils in the west and south, and forest soils in the north and east. Average annual precipitation ranges from 22 to 28 inches. The average range of January high temperature is 12 to 24 °F, and the average range of July high temperatures is 78 to 82 °F. The frost-free season lasts from 140 days in the north to 160 days in the south.

At the time of Euro-American settlement, the vegetation in the southeastern part of the region was Big Woods forests (represented by oak, elm, ash, basswood, maple, horn beam, aspen, birch, wild cherry, hickory, butternut, and black walnut) with numerous inclusions of prairie and oak woods, oak woods in the east, and a mixed deciduous-coniferous forest in the north. At the time of Euro-American contact, subsistence resources for the Native American residents included bison, white-tailed deer, elk in the south, and beaver, bear, and moose in the north. Many types of waterfowl and fish were plentiful in the lakes. There were also edible plants, including extensive wild rice beds, cattails, water lilies, and acorns.

3.1 Pre-contact Cultural Contexts

This section briefly summarizes the cultural contexts relevant to the study area. The summary is based partially on the information in a series of statewide historic contexts developed by the Minnesota State Historic Preservation Office (SHPO) ((Dobbs, Historic Context Outlines: The Contact Period Contexts (ca. 1630 A.D.-1820 A.D.), 1990a); (Dobbs, Historic Context Outlines: The Contact Period Contexts (ca. 1630 A.D.-1820 A.D.), 1990b); (State Historic Preservation Office (SHPO), 1993)) and partially on an overview titled *Minnesota's Environment and Native American Culture History* by Gibbon, Johnson, and Hobbs (Gibbon, 2002).

In addition, specific information pertaining to archeo-botanical data from archaeological evaluations at a few specific sites in the study area is discussed within the appropriate historical timeframe. This information provides insight into the types of plants that were used by cultural groups in the study area at specific times. The data discussed here are compiled from the following sources: *Plant-use Systems and Late Prehistoric Cultural Change in Red Wing Locality* (Schirmer, 2002), *The Diamond Bluff Site Complex: Time and Tradition in the Northern Mississippi Valley* (Rodell, 1997)*, The Late Archaic–Early Woodland Transition in Southeastern Minnesota* (Perkl, The Late Archaic-Early Woodland Transition in Southern Minnesota: A Dissertation to the Faculty of the Graduate School of the University of Minnesota, 2009), *Cucuribita Pepo from King Coulee, Southeastern Minnesota* (Perkl, Cucurbita pepo From King Coulee, Southern Minnesota, 1998), and *Vegetation, Lake Level, and Climate Change in Eastern North America* (Webb, 1993).

3.1.1 Paleoindian Tradition (9500–6000 BC)

The earliest human inhabitants of Minnesota entered the area about 11,000 years ago as the glacial front receded from northern Minnesota. Because of the behavior of this group and because of their group distribution across the landscape, little material evidence of these inhabitants is visible in Minnesota. In many cases, we have no evidence of these inhabitants because of the nature of their cultural materials and the passage of time. Where cultural materials still exist, the materials are often deeply buried under more recent sediment. The current data we have concerning the Paleoindian Tradition suggest that its people were migratory hunter-gatherers specializing in hunting Pleistocene megafauna. Archaeological finds from this period are isolated and can be identified only by the group's distinctive fluted-lance late projectile point style.

During the earliest years of Minnesota's human occupation, the general landscape was similar to that of the North American tundra today. As time progressed, the general landscape gave way to spruce-covered bogs and swamps. Toward the end of the Paleoindian Period, the landscape changed again to open pine and oak forests. Notable vegetation of the time, based on identified pollen types crossed with the prevalence of the type within the sample, was (from most prevalent to least prevalent) spruce, sedge, elm, a variety of forbs, fir, birch, pine, and oak (Webb, Bartlein, Harrison, and Anderson, 1993). It is likely that the inhabitants of this period used a variety of plants for medicinal, utilitarian, and nutritional purposes. Unfortunately, only very limited archeo-botanical site data are available from sources around the United States that can give us any insights into this type of information for this period.

3.1.2 Archaic Tradition (6000–500 BC)

As the climatic landscape shifted and the Pleistocene megafauna died out, the human inhabitants of the area had to adapt to their changing environment. They developed new tool types and means of subsistence. The Archaic Tradition is distinguished from the Paleoindian Tradition by an increased diversity in tool types, a broader range of raw materials from which the tools were made, and increased exploitation of a larger variety of animals and plants. Typical tools of this period are notched and stemmed projectile points, groundstone tools, stone scrapers, knives, punches, drills, and a variety of copper tools.

As Minnesota became warmer and drier, expanses of prairie began to displace the previously forested land. The melting ice exposed new land surfaces with extensive lakes and large, swift rivers unlike any in present-day Minnesota. Site locations during this period are generally tied to locations near water. Notable vegetation of the time, based on identified pollen types crossed with the prevalence of the type within the sample, was (from most prevalent to least prevalent) elm, pine, a variety of forbs, birch, alder, sedge, oak, and spruce (Webb, 1993).

A few sites in the region provide limited archeo-botanical data about how the peoples of this period used the vegetation in their environment. One of these sites is know as King Coulee (21WB56), which is located at the mouth of King Coulee on the south shore of Lake Pepin. The King Coulee site dates to the Late Archaic Period (3500–500 BP). Excavations at the site have yielded a total of 502 botanical artifacts. Of these botanical artifacts, 21 are of special note since they represent the earliest use and northernmost specimens of domesticated squash (*Cucurbita pepo*) in North America. Other botanical artifacts identified at the site are butternut tree nuts (*Juglans cinerea*), bur cucumber (*Sicyos angulatus*), basswood tree nuts (*Tilia americana*), wild cucumber (*Echinocystis lobata*), oak tree acorn nuts (*Quercus* sp.), and walnut tree nuts (*Juglans nigra*).

3.1.3 Woodland Tradition (500 BC – AD 1650)

Beginning about 3,000 years ago, Minnesota's climate began to resemble the climate that exists today. Woodland-period cultures show evidence of a more sedentary lifestyle. Domestication of plants, ceramic technology, long-term recurring occupation of seasonal village sites, and mound construction emerged in this period. Because the sites are not as deeply buried as sites associated with other traditions, Woodland sites are encountered more often on the landscapes than are any other prehistoric sites. In addition, Woodland sites can also be more definitively defined to specific groups, since ceramics styles and tool types and styles are more distinctive to particular locations on the landscape.

The western part of the state was covered by expanses of prairie. A swath of oak savanna, stretching from the northwest to the southeast, separated the prairie from the pine forests of the north and east. Notable vegetation of the time, based on identified pollen types crossed with the prevalence of the type within the sample, was (from most prevalent to least prevalent) elm, birch, alder, pine, sedge, a variety of forbs, oak, and spruce (Webb, 1993).

A pollen core from Lake Pepin, and few other pollen cores from other locations in this region, provide the best data about the vegetation communities in the Mississippi River Valley at this time. In general, there were four major plant communities—the same communities as today. These communities have likely migrated as climatic changes have over the past few thousand years occurred, but in general these vegetation communities have not shifted since the Archaic Period. The vegetation communities are Prairie, Oak Savanna, Upland Woodland, and Floodplain Forest.

- The Prairie Community consists of tall grass species such as big blue stem, little blue stem, and switchgrass. These species would have been found on upland settings or on high terraces within and above the valley.
- The Oak Savanna Community consists of oak, aspen, hazelnut and other shrubs, located as individuals or in small clumps interspersed with tall grass prairie communities. Historically, this community would have been maintained through natural and human-derived fires. These species would have been found on upland settings or on high terraces within and adjacent to the valley.
- The Upland Woodland Community consists of oak, hickory, walnut, aspen, basswood, maple, and ash. These species would have been found on upland slopes and ridges and high terraces within and adjacent to the valley.
- The Floodplain Forest Community consists of elm, cottonwood, ash, maple, willow, various forbs, ferns, grasses, vines, and shrubs (for example, nettle, wild grape, and poison ivy). These species would have been found on the valley floor but would also grade up the valley walls and small terraces above.

In addition to these communities, the local populations would have carried on practices of horticulture and/or agriculture developed from pervious periods and would have developed new ones. At sites along the Mississippi River Valley such as Belle Creek, Brian, Bartron, Energy Park, Silvernale, Mero/Diamond Bluff, and Adams, paleo-botanists have identified archeo-botanical artifacts such as goosefoot (*Chenopodium berlandieri*), maygrass (*Phalaris caroliniana*), knotweed (*Polygonum erectum*), marsh elder or sumpweed (*Iva annua*), sunflower (*Helianthus annuus*), gourds (*Lagenaria* spp.), and tobacco (*Nicotiana* sp.).

The ethnographic and archaeological evidence suggests that corn hill gardens were developed during this time. This gardening method used cornstalks to support bean and squash vines. While the bean vines fixed nitrogen back into the soil for the corn and squash, the large squash leaves helped keep the soil moist during the summer.

3.1.4 Mississippian/Plains Village/Oneota (AD 1000–1500s)

About 1,000 years ago, a new tradition developed in southern Minnesota. In the western part of the state, this tradition is known as the Plains Village Tradition, and in the eastern part of the state it is known as the Mississippian Tradition. An additional tradition of this period is known as the Oneota Tradition, which, as currently defined, existed sporadically in the southern and eastern parts of the state along the Mississippi River Valley. These traditions are distinguished from Woodland Traditions by an intensification of agriculture, including cultivation of corn, and larger, more complex societies. These influences spread into southwestern Minnesota from the Missouri River and into southeastern

Minnesota from the Mississippi River, and they have possible ties to cultures of the southern United States and possibly even Mexico.

Mississippian/Plains Village/Oneota sites are distinguished by distinct ceramic styles, large village complexes, a greater density of artifacts, and community vegetable storage pits. Effigy mounds in the shapes of animals such as birds and snakes, as well as flat-topped mounds and villages encircled by protective palisades, were constructed during this period.

Notable vegetation of the time, based on identified pollen types crossed with the prevalence of the type within the sample, was (from most prevalent to least prevalent) elm, pine, a variety of forbs, birch, alder, oak, spruce, sedge, and fir (Webb, 1993). These vegetation types and their distribution are generally the same as the current vegetation pattern today.

Although the body of archaeological knowledge for the period encompassing the Mississippian, Plains Village, and Oneota Traditions is increasing, in general these populations were interacting with a vegetative environment that was very similar to that of the Woodland Period. However, specific sites (such as the Diamond Bluff site complex in Wisconsin northwest of Red Wing, Minnesota) can give us more insight into the life-ways of these populations. We know that beans, squash, and sunflowers were already being cultivated, but additional plants were also becoming important food crops. Sometime during the end of the Woodland Period, corn was grown successfully in the region. Sites such as the Diamond Bluff complex reinforce this use of corn as an important food crop, since the number of charred remains of stalks and ears of corn found within the temporal context of the site is astonishing. Ethnographic research suggests that corn hills and ridge fields were used at this time for growing corn and other plants.

3.2 Post-contact Cultural Context

3.2.1 Fur Trade/Contact (1630s–1858)

By the 1620s, the first European goods might have reached the Upper Midwest through trade with the Ottawa and Huron. The first fur trade contact in this area occurred between 1659 and 1660, when two French explorers, Sieur des Groseilliers and Sieur de Radisson, entered present-day Minnesota in search of natural resources, including furs. The subsequent rise in fur trade linked the Northern Plains and western Midwest Woodlands to a worldwide economic and political system (Fremling, 2005).In the 1760s, Minnesota was brought under British rule for approximately the next 50 years. Consequently, this power shift from French to British control changed the distribution of Native Americans in the region. By 1800, the now British-aligned Ojibwa took control of the lakes and forests of northern Minnesota, and the Dakota moved south along the Minnesota River Valley (Fremling, 2005).

After the Treaty of Paris in 1783, the United States gained legal possession of this frontier, fully exerting control over the Minnesota/Wisconsin territory after Zebulon Pike’s expedition from 1805 to 1807. The establishment of Fort Snelling at the junction of the Minnesota and Mississippi Rivers in 1819 was the capstone of this control. It would take only about 40 years for Minnesota to become a state (in 1858) after Fort Snelling was built. This period initiated the politics and policies toward Native American populations in the state that are still in effect today.

During the Fur Trade/Contact Period, Native American populations continued to use the landscape much as they had in the past. In general, the vegetation communities established in the Mississippi River Valley during the periods encompassing the, Mississippian, Plains Village, and Oneota Traditions remained the same. However, the distributions of plant communities in the Mississippi River Valley changed as European beliefs and life-ways altered the vegetative landscape. Because of the technologies, crafts, beliefs, and socio-cultural patterns that Euro-Americans brought with them, some plants and trees were sought out, while others were redistributed or replaced by foreign species. These preferences are notable in the types of trees that Euro-Americans used to build fur trade posts, allowed to grow around their forts, and used for starting and maintaining fires (Fremling, 2005).

3.2.2 Early Agriculture and River Settlement (1840–1870), Early Minnesota Military Activity (1800–1890), and Railroads and Agricultural Development (1870–1940)

Some of the earliest agricultural farming practices in the state occurred in southern Minnesota and along the Mississippi River Valley. Treaties with the Ojibwa and Dakota in the early and middle 19th century allowed European settlement in certain areas west of the Mississippi River. Acts passed in the state in the middle 19th century fostered an influx of settlers to the region from the eastern states and Europe. These initial settlers came by steamboat and followed the major rivers and tributaries into the state. Town sites focused on rivers as a source of transportation and power and often developed according to resource need, according to company/industry need, or via social/ethnic boundaries. Many towns developed into agricultural processing and distribution centers. Industries such as milling and brewing became widespread throughout southern and eastern Minnesota. The initial farming practice of the time was subsistence, but farmers in the state were at the cusp of large-scale farming, such as growing wheat as a cash crop (Fremling, 2005).

Beginning in the middle 19th century, Minnesota territorial representatives appealed to the U.S. Congress to appropriate funds to build and maintain five military roads in the state. The territory representatives argued that these roads were justified on the grounds of frontier defense and would also aid in territorial settlement and commercial development. In July 1850, the territorial representatives secured funding for developing these roads. Over the next decade, territorial representatives and the War Department's Corps of Topographical Engineers oversaw the creation of the five roads, one of which paralleled the Mississippi River Valley (Fremling, 2005).

After 1870, railroads were the single most important factor in the rapid growth of the agriculture industry in Minnesota, since their expansion onto the Great Plains expanded the market for cash crops. The initial railroad lines in Minnesota crossed or followed the Mississippi River Valley. These railroad lines opened up good agricultural land to farmers, reduced dependence on risky water transportation, and allowed goods and services to be transported away from major river transportation corridors. By the 19th century, railroads had become the primary mover of crops within the state and the surrounding region. Railroads helped solidify agriculture as the dominant industry in Minnesota at this time. Two of the most important industrial centers for this period were the milling district in St. Anthony Falls and the meat-packing operation in South St. Paul. Railroads were paramount in supplying unrefined resources to these locations from other parts of Minnesota and the region (Fremling, 2005).

As the influx of people to the region increased, so did the need for a more interconnected transportation systems, infrastructure systems for larger cities and towns, and systems for efficient processing and manufacturing. The need for infrastructure drove the need for additional roads, increased electrical grid capacity, large-scale civic engineering, and manufacturing and processing plants. This boom in regional economic activity established the need for large-scale engineering projects such as those related to Upper St. Anthony Falls Dam for transportation, milling, and hydropower; highway projects throughout the region; and projects related to terraforming the Mississippi River Valley and the surrounding landscapes. This large-scale modification of the area was part of the industrial boom of the middle 20th century (Fremling, 2005).

As with the fur trade, certain types of vegetation in the Mississippi River Valley were selected for, redistributed, or replaced during this time. However, there were two other important factors. The first is the suppression of fire that controlled and maintained vegetation communities, in particular, the oak savanna and prairie. As population in the area increased and European agricultural practices become the dominant way of life, uncontrolled fires would have been disastrous. The second factor is large-scale landscape alterations. As the population increased, prairies were broken and forests were cut down to make way for agricultural fields, roads, railroad lines, and towns. This alteration of the landscape and its vegetative communities dramatically affected the previous vegetation populations and distributions.

3.2.3 Early European Traveler's Accounts and Pre-contact Vegetation

European explorers arrived in the upper Mississippi River Valley in earnest in the 16th century with the intention of establishing colonial dominance in North America. Their written accounts offer valuable descriptions of the general character of the land during that period. In some cases, these authors provide location-specific details, typically where there were unique landscapes (such as extensive areas of prairie, scenic rivers, and prominent geologic features).

The Spanish arrived at the mouth of the Mississippi River in the early 16th century, shortly after their arrival in the Americas. By the 17th century, France, England, and Spain were vying to establish colonial control of the vast interior of North America.

The French successfully established their hold by developing fur trapping and associated posts along the river and by expanding the reach of European influence from the Gulf of Mexico into Canada. French explorers led by Louis Joliet arrived at the Mississippi River following a course from the St. Lawrence River through the Great Lakes and along the Fox and Wisconsin Rivers in 1673, thereby providing the French with their colonial claim to the interior of North America. During this expedition, the name "Misisipi," meaning "Big River," was given to the river by two Miami Indian guides.

Trading and expansion from the north via the St. Lawrence River and the Great Lakes into the Mississippi River Basin provided the French with their colonial foothold as voyageurs, priests, trappers, and traders. In general, the French were interested in trapping and exporting furs and were not intent on subduing the native peoples of the interior of the continent. Rather, they established forts to facilitate trade and established trading posts throughout the region. French trade with Native Americans generally relied on trading manufactured goods for the dried pelts of beaver, otter, mink, fox, marten, fisher, lynx, and other animals (Fremling, 2005).

The French set up outposts along the Mississippi River in the NER around Lake Pepin. The records from these outposts provide insight into the landscape of the region, specifically the descriptions of those areas of "open" landscapes of prairie. This description, from Le Sueur in 1694, supports the naming of Prairie Island:

> At the extremity of the lake (Pepin) you come to the Isle Pelee, so called because there are no trees on it. It is on this island that the French from Canada established their fort and storehouse, and they also winter here, because game is very abundant." (Winchell, 1881)

Colonial possession of the upper Mississippi River changed hands a number of times in the subsequent years. The War for Independence granted to the new United States possession of lands south of the Great Lakes and east to the Mississippi River. In 1803, through the Louisiana Purchase, the French sold the western lands within Mississippi River Basin to the United States, thereby greatly expanding the size of the new nation. In 1804 and 1805, Lewis and Clark made their expedition up the Missouri River to the Pacific Ocean, expanding the breadth of knowledge and understanding of the landscape in the vastly expanding nation.

In 1805, U.S. Army Lieutenant Zebulon Pike led a team up the Mississippi River to the Falls of St. Anthony for the purpose of documenting and acquiring lands for an expanding United States. His accounts from this trip provide a glimpse of the landscape immediately prior to the arrival of large influxes of European-American immigrants. Pike describes Lake Pepin as distinct from all other reaches he had seen downriver with no reach like it "in its whole extent". Immediately upstream of the lake, to the confluence of the Cannon River, the Mississippi River "branched out into many channels, […] its bosom covered with numerous islands." Viewing the river from La Grange (Barn Bluff), "you have one of the most delightful prospects in nature" of

> the river winding in three channels at your feet: on your right the extensive bosom of the lake, bounded by its chain of hills; in front, over the Mississippi, a wide extended prairie; on the left the valley of the Mississippi, open to view quite to the St. Croix; and partly in your rear, the valley through which passes Riviere au Canon.

Travelling upstream to the St. Croix, "navigation [is] less obstructed by islands." North of the Cannon River, "timber is generally ash and maple, except for the cedar of the cliffs." From the St. Croix River to St. Peter River (the Minnesota River), "the navigation is very good," with the east "bounded by river ridges" and the west sometimes by "timbered bottom or prairie. The timber is generally maple, sugar-tree [sugar maple or hackberry] and ash" (Coues, 1895).

Pike describes the gorge between the confluence of St. Peter River (the Minnesota River) and the Falls of St. Anthony as a continual rapid with low waters punctuated by rocks elevated well above water level. This reach of the river was populated by numerous small islands, making navigation difficult. Within this reach, "the shores have many large and beautiful springs issuing forth, which form small cascades as they tumble over the cliffs into the Mississippi." Pike notes the timber as mostly maple, which might have been mixed silver and sugar maple ascending up the slope (Coues, 1895).

Upstream of the Falls, toward Coon Rapids, the land was "almost one continual chain of rapids, with the eddies formed by winding channels. Both sides are prairie, with scarcely any timber but small groves of scrub oak" (Coues, 1895).

Following in the footsteps of Pike, Major Stephen J. Long, Topographical Engineer for the United States Army, took a voyage in a six oared skiff sup the Mississippi River to the Falls of St. Anthony in 1817 for the purpose of providing a topographical settlement and character sketch of the river to identify areas suitable for military sites. Long provided descriptions of the river and landscape character different than he had anticipated. "… I had expected to find on this part of the river, not merely bluffs and knolls five or six hundred feet high, but, also, mountains of vast height and magnitude. On the contrary I now discover that we have long since passed the highest lands of the Mississippi and that we are now moving through a rolling prairie country, where the eye is greeted with the view of extensive undulating plains …" Along the river he came across "two prairies of considerable size at the edge of Lake Pepin" as well as "Chippewa" villages throughout the valley (Long, 1817).

Long described the waters of the Mississippi River above the St. Croix River as "entirely colorless and free from everything that would render it impure, either to the sight or taste. It has a greenish appearance, occasioned by reflections from the bottom." Across the mouth of the St. Croix River, Long identifies the main channel as the side north of a 2-mile-long island. The "small slough" separating the island from the main land is navigable in high water, but would have been easily obstructed by the use of a military "cheveaux de frise," or a portable barrier (Long, 1817). (By the time the 1890 Mississippi River Commission maps were created, this channel had been effectively blocked from navigation by dikes above the island directing the channel to the north side and by a dike crossing the entire channel on the south side.)

Long describes the confluence of the Mississippi and Minnesota Rivers in the context of the island (Pike Island) between the confluence being of "considerable extent" with the main channel less navigable than the slough due to shallow waters of the channel. Immediately above the confluence lay "a flat prairie, extending far up this river and about three hundred fifty yeards [*sic*] along the slough above mentioned. This tract is subject to inundation in time of high water: which is also the case with the flat" (Long, 1817).

His experiences above the confluence of the St. Peter (Minnesota River) were similar to those of Pike, who found that rapids beginning 2 miles above the confluence made passage difficult, and, at 4 miles, the team required ropes ("cordel") to pull the boat upstream.

Long provides the following description of the land and vegetation three-quarters of a mile below the Falls of St. Anthony:

> The banks on both sides of the river are about one hundred feet high, decorated with trees and shrubbery of various kinds. The post oak, hickory, walnut, linden, sugar tree, white birch, and the American box; also various evergreens, such as the pine, cedar, juniper, etc., added their embellishments to the scene. Amongst the shrubbery were the prickly ash, plum, and cherry tree, the gooseberry, the black and red raspberry, the chokeberry, grape vine, etc. There were also various kinds of herbage and flowers, among which were the wild parsley, rue, spikenard, etc., red and white roses, morning glory, and various other handsome flowers. A few yards below us was a beautiful cascade of fine spring water [Fawn's Leap, or Silver Spring Falls], pouring down from a projecting precipice about one hundred feet high. On our left was the Mississippi hurrying through its channel with great velocity, and about three quarters of a mile above us, in plain view, was the majestic cataract of the Falls of St. Anthony." (Long, 1817)

3.2.4 Expansion of Cities, Commerce, and Use of the River

Beginning in the 1850s, with the expansion of steamboat access, the Upper Mississippi River became a magnet for immigrants from the East Coast of the United States and new arrivals from Europe. The signing of Traverse de Sioux Treaty in 1851 gave a "green light" for the expansion of the region and facilitated the rapid growth of the Twin Cities of St. Anthony (later, on the south banks of the river, Minneapolis) and St. Paul, Minnesota. The availability of land for settlers and the ideally suited landscape of mixed savanna/prairie with deep rich soils and forested landscapes rich with timber provided for the rapid expansion of settlement, with the river quickly becoming a natural artery for the movement of goods and people.

Logging

Logging began in earnest with the establishment of a mill near St. Anthony Falls in 1821 in order to provide cut timber for the construction of Fort Snelling (Hogberg, 1971). The study area lies at the southern edge of the great pine forests that extended northward into Canada and at the edge of the vast prairies that extended south and west. The rivers of the region thus became the primary means of moving the product of the first of the great commercial booms of the region. Mature white pine, then red pine, was extensively logged and floated down the Mississippi River and its tributaries to build the growing cities of the treeless prairies. Between 1835 and 1915, virtually all usable trees in northern Minnesota and Wisconsin were felled and transported downstream.

Winter cutting, which was the norm, allowed fallen trees to be dragged (slid) along ice roads. Logs were stacked at landings along the rivers and floated downstream following spring ice thaw. Towns developed along the Mississippi River around the early timber mills and staging ports. During logging's peak, the Upper Mississippi River claimed 80 sawmills along its banks and another 120 along tributary streams (Fremling, 2005). The major tributaries of the Mississippi River in the NER—the Chippewa River, the St. Croix River, and, to a lesser degree, the Minnesota River—were used to transport logs. Logs were floated in rafts of trees lashed together that could be over 1,500 feet long. In the 1890s, floating began to be aided by steam boats, making it possible to move as much as 10 acres of floating logs in a single raft. However, at the time that efficiency techniques were making it possible to move greater quantities of logs, the boom was coming to an end. In 1892, the practice of log floating downriver began to diminish in importance, and, in 1915, the last log raft was floated down the Upper Mississippi River (Fremling, 2005).

Logging the forests of Minnesota and Wisconsin reset the forest ecosystems in the region, since virtually all usable timber was removed from the great forests of the north. Today, within the Mississippi River Valley, there is limited visible evidence of the milling and floating period. Many of the settlements, lumbering camps, and staging areas adjacent to the river have reverted to a natural though altered landscape. As quickly as they developed for lumber, some of the major settlements of the lumber era shifted to grain agriculture, the next great commercial enterprise of the region.

Logging left a lasting effect on the Mississippi River. As the great forests were logged, soils were exposed, both due to the removal of the canopy and increased precipitation and due to the loss of roots binding the soil. This exposure allowed a massive amount of sediment to build up in the river channel, much of it at the back sides of wing dams installed to stabilize the river and maintain the channels.

Agriculture

As logging the great northern forests enabled the construction of homes and cities in the Upper Midwest, the deep and fertile soils of the Great Plains and the Mississippi River Valley supported grain agriculture. Logging boom towns and cities either faded into memory or shifted milling from timber to grain. The continually improving techniques for farming greater swaths of land encouraged farmers to push to the limits the extent of land that was worked. Not yet familiar with conservation techniques to protect soils and slopes, farmers worked the soils of the flattest areas first: river valley floors, hilltops, plateaus above river valleys, and terraces. Next came ravines, hillsides and steeper slopes, with grazing and tillage occurring to the limits of the farmer's and the land's capacity. At the turn of the 20th century, land use practices (logging and agriculture) began to cause flooding and major sedimentation in river valley landscapes as denuded terraces and slopes sloughed into the valley (Fremling, 2005).

Through the logging era and especially during the rise in agriculture, river "improvements" were made to facilitate the movement of commodities for the expanding populations of the Midwest. These early improvements took place in the context of a struggle between riverboat interests (riverboats were the earliest way to move large quantities of goods) and the expanding power of railroads. For a time during early expansion, these interests worked together, providing multiple means of access to the east banks of the Upper Mississippi River. Rail quickly became a dominant connection from the east into Galena, Quincy, and Cairo, Illinois; St. Louis, Missouri; and the Twin Cities in the 1850s, with the first railroad crossing of the river completed by the Chicago and Rock Island Railroad in 1856.

Rail threatened the viability of riverboat traffic but an economic panic of 1857 and the Civil War 3 years later slowed rail's economic growth and briefly kept river transportation economically viable (Anfinson J. , 2003). At least until the complete build-out of the rail system, riverboat movement of grain remained strong. By 1866, 186 barges were working out of St. Paul, moving grain to rail termini on the east bank of the river or farther south to St. Louis or New Orleans. During the period of rapid expansion of agriculture, neither rail nor river could accommodate the needs of farmers moving grain to market. In addition, following the spring melt, the river was clogged with logging rafts moving timber to mills taking advantage of seasonal high water.

In the decades that followed, riverboat interests competed with rail interests to transport goods and people from the south and east. As “dependable” rail networks expanded, riverboat advocates tried to maintain support for a less predictable form of transport using a natural system whose depth could fluctuate dramatically (for example, by up to 41 feet at St. Louis) (Anfinson J. , 2003). To a large degree, riverboat advocates found government support due to a fear in political circles that railroad monopolies were becoming too powerful as the single means of moving goods, thus increasing the railroads’ political grip on power and allowing them to control transportation pricing. In order to retain a counter to such powerful interests, riverboat advocates lobbied the federal government to facilitate improved systems for barge traffic. The federal government spent vast sums of money, primarily through funding Army Corps of Engineers projects, to facilitate transportation on the Mississippi River through a series of appropriations supporting a navigation channel of predictable depth and capacity through the shipping season.

3.3 Physical River Valley Alterations

3.3.1 River Valley Land Use

Transporting goods on the Mississippi River prior to construction of today’s navigation channel was a hazardous affair. Crossing rapids like those at Keokuk, Iowa, and Rock Island, Illinois, and the numerous shallows upstream was difficult and was limited to periods of the year with seasonally high water. Between 1866 and 1883, the Army Corps of Engineers as well as companies and individual landowners embarked on numerous plans to “control” the river to facilitate the movement of goods, during which time Congress approved 16 appropriations for river and harbor projects to improve navigation on the river. Each time an “improvement” was approved, the use, size, and scale of riverboat operations increased, requiring further improvements to facilitate greater capacity through the decades until the completion of the 9-foot channel in the 1930s (Anfinson J. , 2003).

The 4½-Foot Channel Project of 1878

Early efforts by both government and private interests to maintain the Mississippi River navigation channel relied primarily on channel-training structures to direct the flow and continually scour a channel by relying on the power of the river itself. Wing dams encouraged sediment to be deposited behind the structures, thereby limiting buildup from the main channel. As a result, new areas of land formed as sandbars along banks and as permanent islands (Meade, 1995). As early as the 1820s and through the 1920s, wing dams and closing dams were the primary technique used to maintain a defined channel in the Upper Mississippi River. Closing dams were created in between islands and the bank of the river in channels not designated to be the main navigation route (see comparisons in Figure 10-9) in order to direct flows and channel scour to the main channel. Within the NER between St. Anthony Falls and Lock and Dam 4, 470 wing dams and 46 closing dams were installed prior to 1930 ((Mississippi River Commission, 1890) and (Brown, W.N., Inc., 1929, 1930).

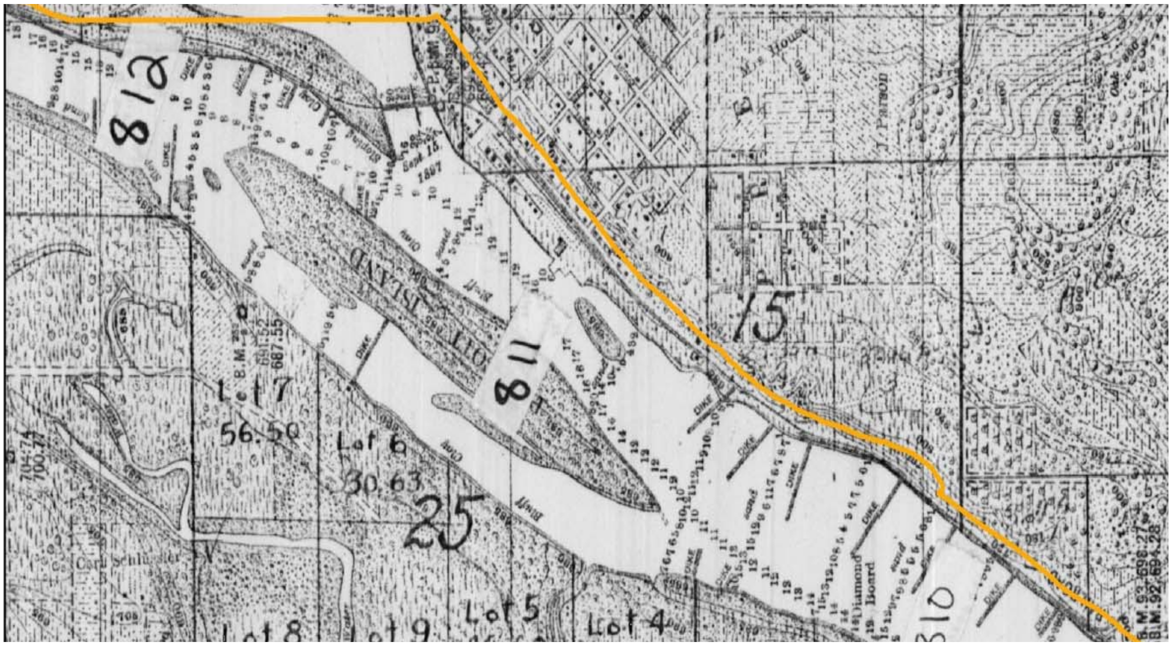


Figure 10. 1890s MRC River Survey, Prescott, Wisconsin. ***This location at the confluence of the St. Croix River and the Mississippi River had two distinct river channels on either side of Prescott Island. By 1890, channel-training structures were in place. Note that the structures on the north side of river are beginning to accumulate sediment at this early stage.***

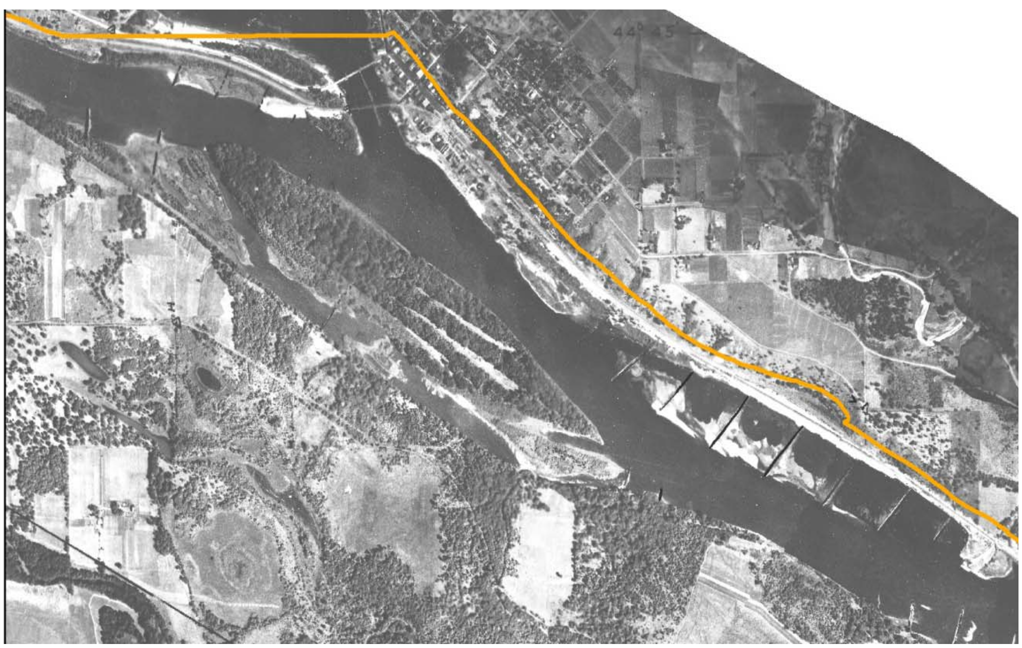


Figure 11. 1930s Aerial Photography of Prescott, Wisconsin. ***Note the sediment buildup behind wing dams and the complete closure of the channel south of Prescott Island.***

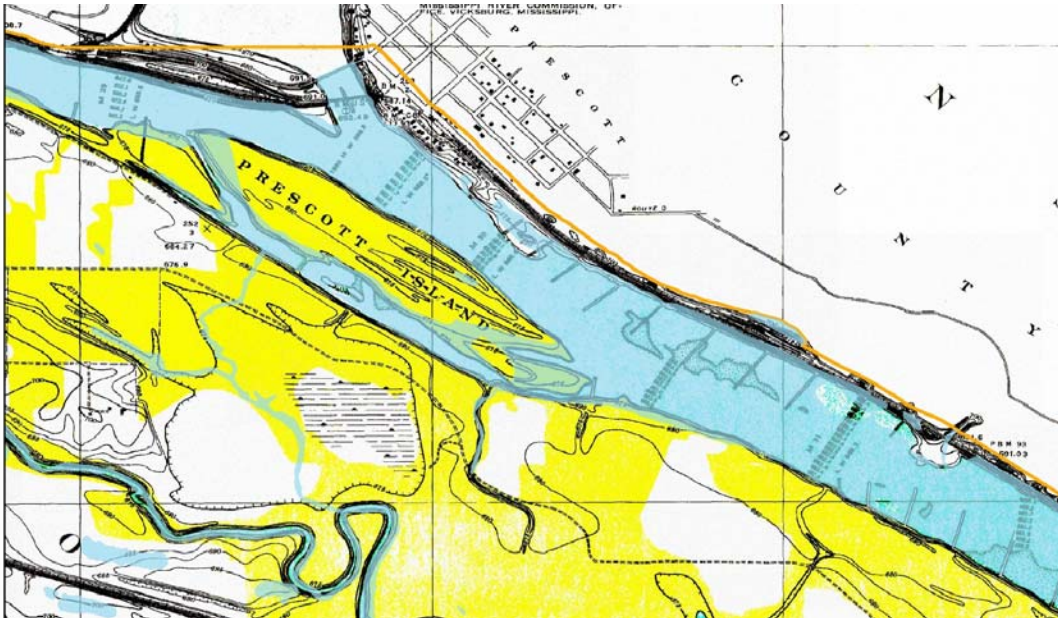


Figure 12. 1930 Brown Survey with 1890s Landcover Waters Coverage. ***Note the effects of the channel-training structures both within the main channel and south of Prescott Island.***

Figure 13. 2011 Aerial Photography Shown beneath 1890s Water Coverage and Wing Dam Locations. ***Note the near channel closure south of Prescott Island and the narrowed channel on the north edge of the river with still-exposed sediment at the surface.***

Wing and closing dams were typically constructed in frozen winter conditions. Crews would haul willow bundles and large boulders quarried from atop river bluff tops onto the ice. After the material was placed, the ice was cut and the material would drop to the river bottom, creating the dam. Once placed, these dams would become solid structures as sediment collected in the pore spaces between the boulders and brush and behind this material as sediment built up (Fremling, 2005).

In addition to these channel-training structures, a variety of bank-protection measures were added to prevent erosion and maintain the shape of the river banks. The techniques used included constructing mass levees to protect increased industrial and urban land uses in the river valley, installing armoring along the river banks (dumping riprap and building concrete and steel embankments), and installing concrete mats. One substantial effect of bank stabilization is that it prevents sediment deposited on floodplains from being remobilized (Meade, 1995). This stabilization of sediments lessens the dynamic state of the river valley setting, reducing meanders and creating generally stable "pools."

The 6-Foot Channel Project

In 1907, recognizing that larger and more powerful boats were plying the Mississippi River with ever-larger payloads, Congress appropriated additional funds to deepen the channel to 6 feet. The expanded program generally relied on the same techniques as the 4½-Foot Channel Project of 1878 and consisted of 2,000 additional wing dams and increased bank armoring. Additional funds were set aside for maintaining the channel through dredging.

Figure 14. Construction of Lock and Dam 1, 1914 (Source: Minnesota Historical Society)

Along with these "improvements," two lock and dam projects were approved, launching a new era in river engineering that would set the stage for changes to come two and a half decades later. The lock and dam at Keokuk, Iowa, was a combination hydropower and navigation dam that would also allow barge traffic to avoid the traffic clogged Des Moines Rapids Channel (opened in 1877) or the river rapids which some operators chose to risk in order to save the time of travelling the channel. The LeClaire Canal and Lock, completed in 1922, allowed boats to bypass 3.6 miles of the Rock Island Rapids.

Figure 15. Construction of Lock and Dam 1, 1914 (Source: Minnesota Historical Society)

The projects were controversial from both ecological and economic standpoints. The Keokuk project effectively removed the potential for ebony shell clams to infiltrate upstream of the dam. From an economic perspective, demand for the electricity produced by the Keokuk dam was low, and the ongoing debate regarding public subsidies for riverboat operators as "pork barrel" remained (Fremling, 2005).

Despite thousands of wing dams, riverbank armor, and regular dredging, the Mississippi River remained only seasonally usable. The 6-foot channel extended the period of time the river was available for shipping, but it relied on a minimum volume of water to achieve the channel depth required by ever larger and deeper barges.

In 1925, the Corps reported that the techniques used to maintain the channel were insufficient for maintaining a navigable channel on the entire river. In 1927, Congress passed the River and Harbors Act, followed in 1930 by a bill approving the 9-foot channel and abandoning the 6-foot channel, thereby opening the way for the lock and dam system that defines river traffic to this day.

The lock and dam system on the Mississippi River was developed to improve and enable navigation (Anfinson J. , 1995). Prior to 1893, St. Paul was an existing port, but Minneapolis was unreachable by steamboats. Original Locks 1 and 2 were intended to extend port access upstream. The initial objective of the locks was purely navigation with the goal of providing a 5-foot channel. Lock and Dam 2 was completed in 1907. As Lock and Dam 1 was nearing completion, Congress directed the Corps to examine hydropower potential at the locks. At this time, the nation's first hydropower electric plants were being constructed, and multiple uses of water-development projects were also becoming a standard consideration.

Lock and Dam 1 and 2 had been designed as low-head structures not compatible with hydropower production. By 1909, Congress authorized the removal of the completed Lock 2 (Meeker Dam) and reconstruction of both locks as higher-head structures. The navigation channel objectives were consequently increased to a 9-foot channel. Lock and Dam 1 and 2 were reconstructed and opened in 1917.

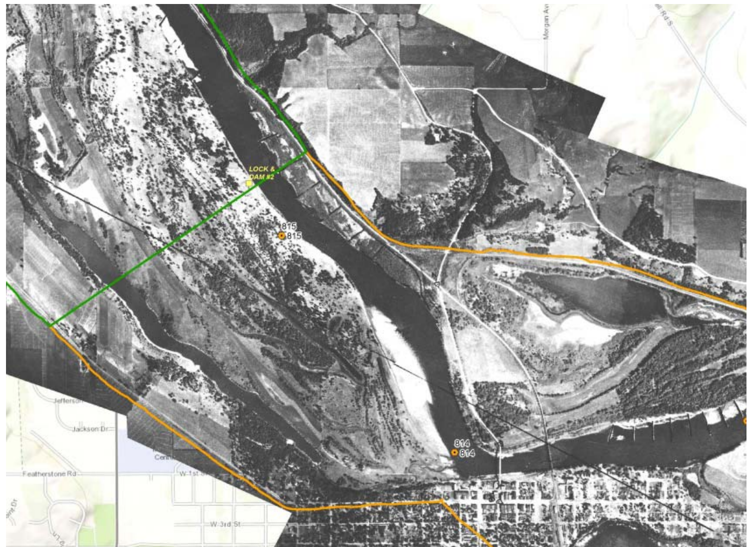
The 9-Foot Channel Project and the Lock and Dam System

The 9-Foot Channel Project became a signature of the New Deal programs of the Franklin D. Roosevelt administration, putting skilled workers back on the job constructing the massive project that extended the 670 miles between Minneapolis and St. Louis. The project allowed large, modern tugboats and barges to travel the 400-foot change in gradient along the entire Mississippi River between Minneapolis and New Orleans (Fremling, 2005) with relative assurance that closures would not disrupt traffic.

There are 29 locks and dams between Minneapolis and St. Louis whose primary purpose is to maintain the navigation channel at a depth of 9 feet, deep enough to support the large barge and tugboat traffic of the modern river commerce age. The effect of the lock and dam system on the floodplain is most obvious in its creation of shallow lakes in the lower reaches of the navigation pools, where floodplain natural communities (forest, marsh, meadow, and bottomland lakes) were often previously present. These areas, once flooded during high waters typically during late spring and early summer, are now permanent shallow- to deep-water lakes that capture fine sediments and often contaminants adsorbed into the soil (Meade, 1995). The backwaters also trap a significant amount of sand sized sediments forming deltas where secondary channels enter the backwaters.

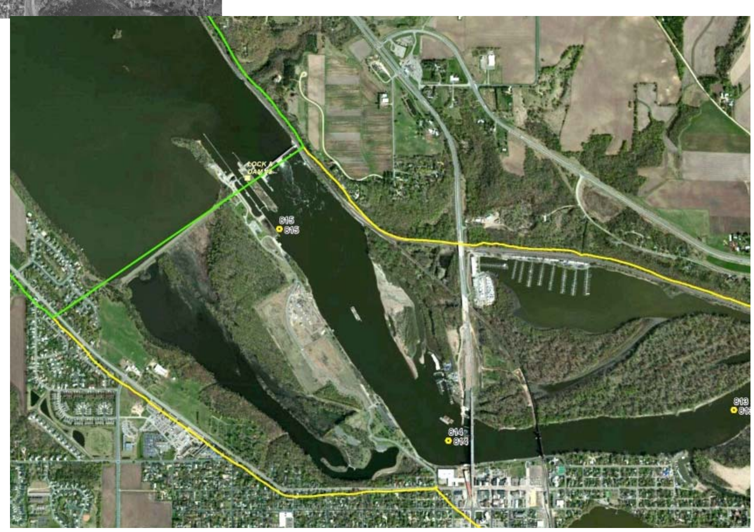
Figures 16, 17 and 18 show changes along the river at Lock and Dam 2 in Hastings, Minnesota.

The 1927 image (Figure 16), taken before construction of the 9-foot navigation channel, shows logged and farmed backwaters as well as Floodplain Forests and back channels. Note that much of the river bottom is farmed. The Mississippi River channel is well defined but has abandoned channels and a vertical accretion ridge and swale to the west.



The 1937 (Figure 17) image shows the lock and dam within a decade of construction. The deep pool above the dam has eliminated all terrestrial communities, and downstream effects of new channel and pool creation, siltation and altered channel configuration are evident. Note in particular the effectiveness of wing dams immediately north of Hastings where entirely new river bank has formed.

The 2012 (Figure 18) air photograph shows reforestation of previously farmed tributary valleys and increased floodplain on the south banks and islands. Conversely, the channel has widened below the lock and dam.



Even with the controls on water flow and the limits on sedimentation provided by the dikes and other engineering practices, the river still requires periodic dredging to maintain the 9-foot channel. In the Upper Mississippi River, the dredged material was typically deposited along the river's banks. In recent decades, the dredge material is placed in designated placement sites or used to create artificial islands along the main navigation channel.

In addition to the navigation channels, river bank composition was altered by urban embankments, quarrying, and river bank fill for lumber and other staging areas. Along much of the river within the NER, particularly in urban areas, material was hauled in from upland sites or from river dredge and was placed above river flood stages, behind armored (stone or concrete) shorelines, or on constructed embankments of wood or steel pilings. In these areas, soils and bank shape are no longer a result of river forces but of the needs of industry (Anfinson J. , 1995).

The effects of dam development on the Mississippi River have primarily been changes in water levels (

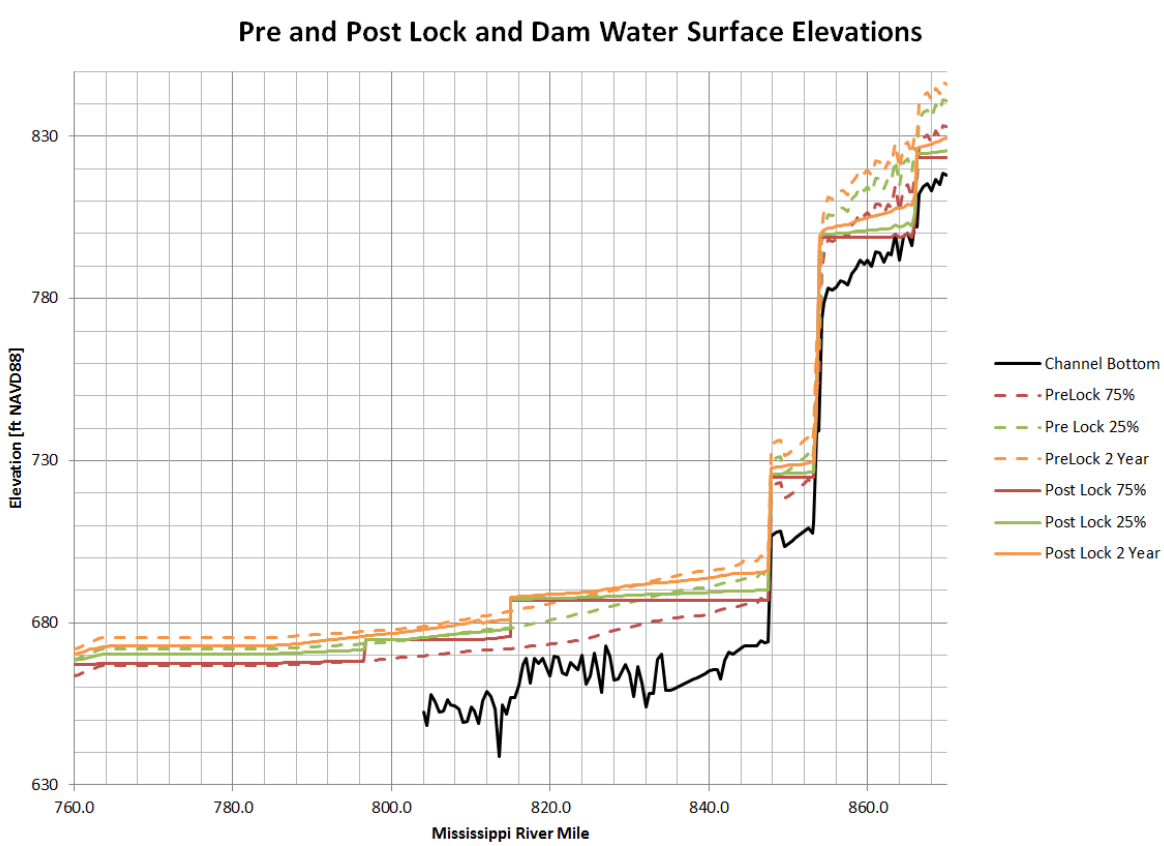


Figure 19. Pre- and Post-Lock and Dam Water Surface Elevations (Source, USACE)

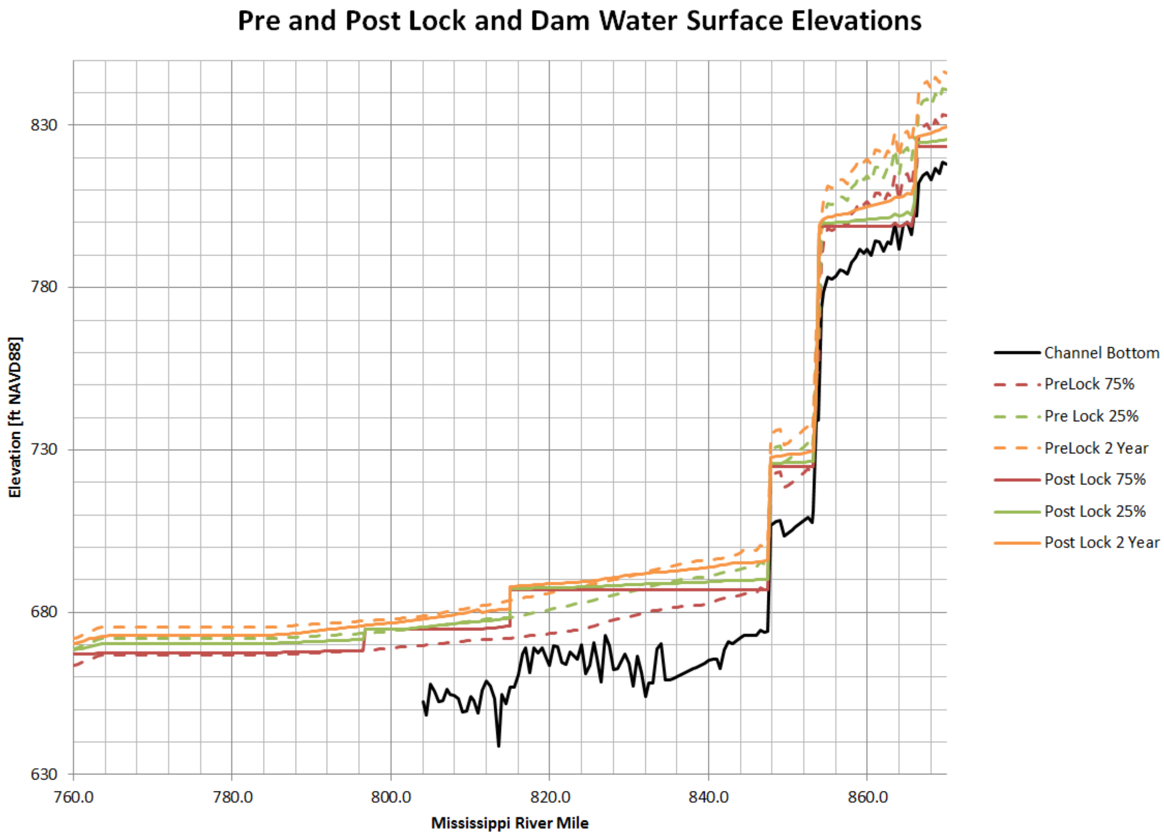


Figure 1). The largest flood-control structures are 400 river miles upstream of St. Paul. Peak flow effects through the study area as a consequence of dam development are negligible (USACE, 2004). The lock and dam system's facilities are on-stream facilities with limited storage. These structures likewise have negligible effects on peak flow rates.

3.3.2 Landscape Changes by River Pools

The most obvious and significant effect on the Mississippi River Valley landscape has been the creation of the 9-foot channel and the associated lock and dam system. The system is designed to maintain a 9-foot-deep channel by maintaining low- and moderate-flow elevations within the channel to maintain a navigable waterway. The system does not typically hold water back during high-flow stages. The effect of removing the low flow elevation changes effects composition of natural communities adapted to the seasonal fluctuations of a dynamic and unfettered river system. In addition, the lock and dam system created a system of pools behind each of the dams, and the though the effects are most evident immediately upstream of dams, in reality, system controls effect the entire the distance to the upstream dam. The most obvious land cover effect is the vastly expanded areas of open water immediately upstream of each dam. Table 2 compares the mapped open water within each pool between 1890 and 2000 as determined by GIS (geographic information systems) software.

Table 2.

Pool	Project Study Area (acres)	1890 Waters Coverage (acres)	2000 Waters Coverage (acres)	Increase in Open Water (acres)	Percentage Increase in Open Water (1890–2000)
St. Anthony to Coon Rapids	3,339	Not available	Not available	Not available	
Pool 1	3,725	837	844	7	0%
Pool 2	24,286	4,698	11,080	6,382	136%
Pool 3	23,102	4,188	12,832	8,644	206%
Pool 4	71,320	32,632	37,275	4,643	14%
Total analysis area	**125,771**	**42,355**	**62,031**	**19,676**	**46%**

The lock and dam system removed much of the natural in-channel meander and island character within the entire NER. Through flooding and level controls, the alterations to natural flows flooded extensive bottomland shallow lakes, eliminated riffles and rapids, river meanders, river islands, and, notably, reduced the potential for river shifting. Specific alterations within each pool are described below.

Coon Rapids to St. Anthony Pool. The river pool between the Coon Rapids Dam (RM 866) to a location about 4 miles upstream of St. Anthony Falls Upper Lock and Dam (RM 858) is less affected by the lock and dam system than are downstream reaches. In areas shown in the 1890s MRC river survey, the river bottom was composed primarily of sand and gravels with sloping banks and clay along the gently sloping banks. Extensive islands, sandbars, dunes, and shallow backwaters have been either inundated or removed through excavation, and the river appears to exhibit less riffle and pool character than during the pre-contact and early settlement periods.

Figure 20. Industrial River's Edge, at Port of Minneapolis, North Minneapolis

In the northern parts of Minneapolis, the levee walls, piers, and urban buildup have fundamentally altered the river banks, and much of the material along the river edge is imported or side cast from river dredge. Side channels, backwater channels, and islands remain scattered above Minneapolis (RM 858) as the most extensive natural floodplain features.

This pool is relatively straight with limited meander. Much of the river shore is privately owned with highly variable vegetation management practices, but owners generally favor the mowed turf of a savanna-type setting. Extensive valley floodplain is limited within this pool to areas east and west of the confluence of Coon Creek, River Park in Brooklyn Park, and Riverview Heights Park in Fridley and the confluence of Rice Creek and Islands of Peace Park.

Pool 1: This pool, 4 miles upstream of the St. Anthony Falls Upper Lock and Dam (RM 858) and Lock and Dam 1 (RM 847.5), is mostly within the deeply entrenched Minneapolis gorge. The limits of the pool are based on the upper edge of the actively managed navigation channel, availability of pre-project MRC and LSA data and past USACE studies that have often extended only as far as the navigation channel at RM 858. Thus, the pool begins at past study boundaries (RM 858).

Changes to the river surface area are represented primarily by the loss of shallow, in-channel riffles; scattered intermittently exposed islands; and rapids, as described by early explorers (See Figure 21). Lock and Dam 1, located within the Minneapolis river gorge, regulates the surface level in this pool.

The St. Anthony Falls lock and dam system was intended to provide navigation for barge traffic to industry near this location at the upstream end of the 9-foot channel system. The lock and dam are located immediately upstream of the Minneapolis gorge. In the part of this pool located above RM 851.5, including St. Anthony Falls Lock and Dam, most of the river banks have been reshaped to accommodate human needs. During the decades of timber mill dominance, logging booms, embankments, and docks were constructed along a river bank built up with railroad tracks and extensive lumber yards. As the shift toward other industries (grain and metal works) occurred, these constructed banks were reinforced with permanent pile-driven embankments to accommodate increased and heavier traffic.

The acquisition of parkland has allowed some river restoration up to RM 855 on both banks and at RM 855.8 on the west bank. Within the urban core of Minneapolis above St. Anthony Falls, mature canopy vegetation is dominated by cottonwoods with very few silver maples present. This could be due to the open character of the channel with limited historic floodplain, the pre-contact prairie setting and sandy soils above the active river channel, the pollution tolerance of the species, and the ability of cottonwoods to survive in the more depauperate soil conditions of the urban landscape.

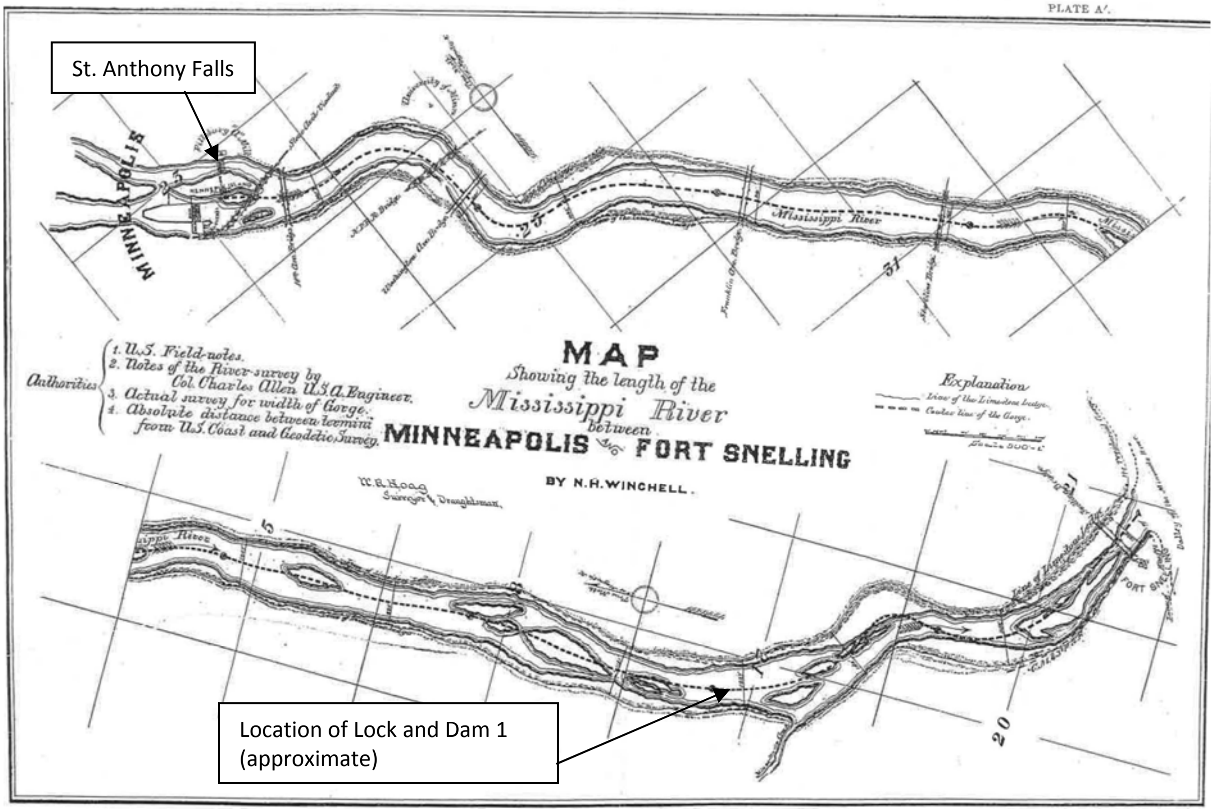


Figure 21. 1877 N.H.Winchell Suvey of the Minneapolis Gorge between St. Anthony Falls and Fort Snelling. Not numerous islands throughout (Source, Hennepin County Historical Society)

Below RM 851.1, the outer extents of the river banks have changed little within this pool as the terrestrial landscape climbs quickly up the steep slopes of the river gorge. Raising the river elevation downstream of the falls flooded numerous small, rocky islands that were present prior to the construction of Lock and Dam 1. Some of these islands were described as a mix of sand/gravel bar islands in the MRC river survey, while others had sufficient topographic relief and size to support Riverfront/Floodplain Forest. River bottom consisted of gravel and boulders throughout the pool between St. Anthony Falls and Lock and Dam 1. As many as 15 islands are shown in the 1890s survey within this stretch of river. The river within the gorge was described by early explorers as having a shallow, poorly defined channel with barely enough depth to support canoe travel. Within this pool, there are no areas of broad, extensive floodplain, though a few lateral bands are present within the gorge.

In 1907, the Army Corps of Engineers completed the first dam within the NER, at about RM 851. This dam extended the head of navigation to the milling district of Minneapolis. Three years later, Congress supported the revamping of the system by approving the construction of a “high” dam at the location of Lock and Dam 1. The high dam greatly improved navigation and allowed hydropower generation, but in essence removed all islands and rapids within the gorge. At present, active floodplain areas are generally confined to areas immediately adjacent to the river channel with the exception of Boom Island in Minneapolis and a small band of forested, active floodplain at RM 851.

Pool 2: River Pool 2 is located between Lock and Dam 1 (RM 847.5), which is 3.5 miles upstream of the confluence of the Mississippi and Minnesota Rivers, and Lock and Dam 2 (RM 815.2), which is immediately upstream of Hastings, Minnesota. The pool is characterized by substantial areas of urban and natural features, which create a highly variable setting. The major characteristics of Pool 2 are (1) the lower gorge from Lock and Dam 1 to the confluence at RM 844 with the Minnesota River, which drops its silt-laden waters into the Mississippi River immediately downstream of Fort Snelling; (2) the urban core of St. Paul and the well-established industrial suburbs south of the city, which are largely protected by 13 miles of continuous constructed levee; and (3) Grey Cloud Island and the nearby created Baldwin and Spring Lakes, which are immediately upstream of Lock and Dam 1.

The lower gorge below Lock and Dam 1 is in a confined floodplain. At its narrowest, the river at normal elevation is 240 feet wide, 120 feet below and 1,250 feet across from bluff top to bluff top. The river is deeply incised, then widens below the prominently placed Fort Snelling. The 5 miles of valley between RM 846 and RM 841 widen sufficiently to support backwater lakes and 1,440 acres of slope and bottomland seminatural terrestrial settings, including floodplain (351 acres) and Riverfront Forest (389 acres of cottonwood and *Salix* communities), lowland forest (116 acres), and open wetlands (307 acres) (Appendix O, Pool 2, Upper), nearly all of which are in city, county, or state park ownership.

These floodplain communities persist within the urban Twin Cities core 2 river miles below Lock and Dam 1 and 30 river miles above Lock and Dam 2. This relative location limits the effects of the downstream lock and dam on natural floodplain communities. There are external pressures on natural communities in the forms of direct stormwater inputs, invasive species from the urban surroundings, park maintenance practices, heavy foot traffic and plant collection, wave action from boat traffic, and past land use practices of tree clearing, plantation plantings, industrial activities, land fill, and other heavy settlement uses.

The Minnesota River is a major tributary of the Mississippi. It drains a basin of 14,830 square miles and includes portions of Iowa, South Dakota, and Minnesota (Musser, 2009). Over the past 30 years, flows from the Minnesota River into the Mississippi River have nearly doubled due to wetland drainage systems and increased rainfalls. The river contributes roughly 75% of the sediment in the Mississippi Valley in the Twin Cities metropolitan area compared to 6% contributed by urban runoff (Russell, 2013).

The Minnesota River Basin is largely agricultural, with 92% of its land in agricultural uses. These agricultural uses load the Minnesota with sediment and associated manure, pesticides, and fertilizers (Fremling, 2005). Much of the sediment dropped into the Mississippi River ends up in Lake Pepin. According to the Friends of the Mississippi (Russell, 2013), the sediment load is roughly 10 times the level before Euro-American settlement. Especially during periods of flooding, sediment loading from the Minnesota River affects the chemical and soil composition and quantity of material deposited in floodplain areas of the Mississippi Valley, particularly by increasing the deposition of pesticides, herbicides, and fertilizer.

Between RM 842 and RM 829, downtown St. Paul and the industrial areas downriver are largely protected by constructed levees. With the exception of the backwater Pig’s Eye Lake between RM 836 and RM 834, much of the natural floodplain is hydrologically disconnected from the river.

Grey Cloud Island is a large upland glacial relict island within the river valley with two distinct geomorphic surfaces. The upper portion of the island consists of a limestone plateau, and the lower island is largely made up of sandy alluvial deposits (The Institute for Minnesota Archaeology, 1999). The entire island has been extensively affected by human uses, both gravel quarrying on the upper island and removal of the alluvial sand and gravel on the lower parts the island. In addition, the island is immediately upstream of Lock and Dam 2 and has experienced extensive flooding, especially in the lower southern and western parts of the island.

The largely created Spring and Baldwin Lakes extend over areas that were flooded by the construction of Lock and Dam 2 and were heavily excavated for sand and gravel. The slackwater behind Hastings was, prior to channel construction, a mix of small backwater lakes and meander channels, meadow and palustrine emergent marsh (PEM), and lowland forest communities [see Appendix G, Pool 2 (lower)]. Within the 11,797 acres contained in the created pool (RM 828 to RM 815), 5,422 acres of terrestrial area (including wetlands) were flooded after the construction of Lock and Dam 2 (), forming open pools that had previously supported wetlands, wet meadows, and Floodplain Forest communities.

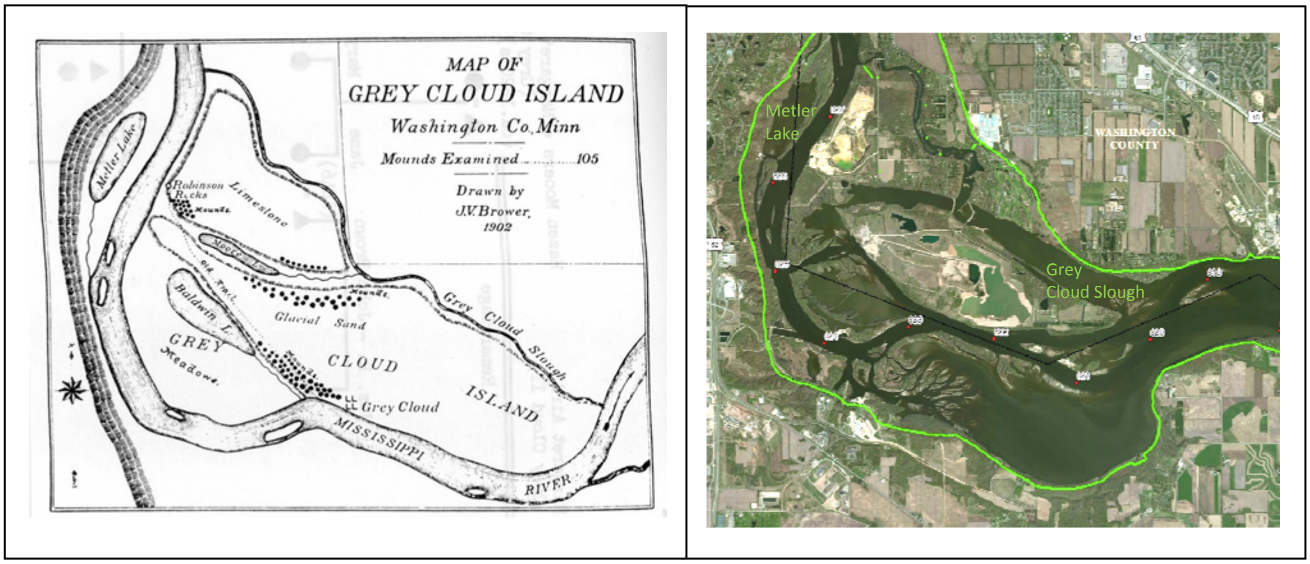


Figure 22. Gray Cloud Island as drawn by J.V. Brower in 1902 (Brower, 1902) and in 2012 Aerial Photography. Though spatially inaccurate, the early map shows locations of historic mounds, meadows, sandy uplands and limestone bedrock. Note combination of flooding and mining operations on the highly disturbed island of today.

The pre-lock and dam topography of Spring Lake has created a series of fundamentally altered islands. The pre-flood levees at the edge of the former channel from RM 825 to RM 819 that once provided a buffer for backwater marshes and Floodplain Forest are now islands within a much-widened pool. These islands are now altered with scattered Riverfront Forest typically located at the upstream (elevated) edge of the former levees and marsh communities persisting at the sheltered back sides of the islands.

Forest expansion is limited by the existing hydrologic conditions. Along the river's edge between RM 829 and RM 824, steep cutbank slopes define the western banks, with mesic and dry oak forests dominating the ravines and prairie savanna remnants along the tops of the bluffs.

Within the terrestrial areas surrounding Pool 2, forested lowland communities are relatively diverse, considering the mostly urban setting. Farther downstream, concerns have been raised regarding the single aged and single species dominance of silver maple in Floodplain Forest communities and that species' ability to fill openings, thus forming near monocultures (Yin Y. , 1999) (Dunevitz-Texler, 2005). Through the urban core, and especially in Pool 2, there are few Floodplain Forests with absolute dominance by silver maple, but rather there are dense pockets of the species in swales and in floodplain flats away from the active river channel. (Note the abundance of willow/*Populus* communities identified on maps in Appendix O in pools 1-2).

The Project Team speculates that the urban conditions and past land uses likely favor the disturbance-adapted Riverfront Forest species with their ability to recolonize disturbed sites, adapt to a wide range of environmental conditions including flooding and drought, the narrowed floodplain with its associated greater flood velocities and greater accessibility to available light with greater edge and less backwater sedimentation in still waters.

Pool 3: River Pool 3 is located between Lock and Dam 2 (RM 815) at Hastings and Lock and Dam 3 (RM797) 6 miles upstream of Red Wing, Minnesota.

The confluence of the Mississippi River with the St. Croix River occurs at about RM 811.5 at Prescott, Wisconsin. The waters of the St. Croix River contribute minor amounts of sediment into the Mississippi River [13 pounds per acre compared to 134 pounds per acre from the Minnesota River (Russell, 2013)], though the sediment delta from the Minnesota River extends to the upper reaches of Lake Pepin. The clean waters of the St. Croix River substantially dilute the nutrients and pollutants contributed upstream by the Minnesota River and the metropolitan Twin Cities (Wasley, 2010). As the St. Croix River enters Lake St. Croix, its relatively clean waters continue to drop out sediment in Lake St. Croix prior to the confluence of these major rivers. The St. Croix River watershed, though heavily logged during the 19th and early 20th centuries, has largely reverted to forested cover.

The Vermillion River enters the valley through a 1–mile-long gorge after falling over a waterfall south of Hastings. The falls powered one of the first flour mills (built in 1857) of the NER area (Ojakangas, 1982). Once in the Mississippi River Valley, the Vermillion River becomes a low-gradient stream extending through a vast backwater floodplain extending 15 miles parallel to the main channel of the Mississippi River. These upstream and downstream channels are connected both above and below Lock and Dam 3 and flow in either direction depending on Mississippi River water levels.

In the Vermillion River bottoms, hydrology is directly connected to the Mississippi River water levels and is regulated through backwater spillways (spot dikes) and channels. The Vermillion River bottoms contain the largest expanse of floodplain in the NER. The bottoms support a mosaic of riverfront and Floodplain Forests, bottomland lakes with floating emergents, emergent wetlands, wet meadow, and extensive mesic and dry prairie/savanna on Prairie Island and adjacent slopes.

Wetlands and uplands were extensively logged and farmed for decades prior to the 1930s, though most lowland farming ceased after the construction of the 9-foot channel, and much of the floodplain wetland communities have rebounded. Because the bottoms are flat lowland close to the normal levels of both the Mississippi and Vermillion Rivers, extensive backwaters with fine silt and clay soils are common. Backwater channels directly connecting the two rivers are common throughout the bottoms and retain the direct hydrological and sedimentation sources for the area. Since many farmed areas were abandoned during the same period (the 1930s), single–aged, 80-year-old stands of dense silver maple are common. Lock and Dam 3 backed water up into Sturgeon and North Lakes, creating open, deep-water lakes in what had previously been backwater lake settings.

Like Grey Cloud Island, Prairie Island is a remnant glacial terrace island from the much wider valley of the post-glacial melt period. Away from the main channel, the Vermillion River meanders through backwater channels. Extensively farmed over the past century and a half, the island was dominated by prairie prior to settlement. The edges of the island were extensively flooded following the construction of the 9-foot channel. Xcel Energy operates the Prairie Island Nuclear Generating Power Plant on the Island. Prairie and savanna have recently been restored on the well-drained soils of the island, and since

1992 the Mdewakanton Sioux community on the island has been managing buffalo on 187 acres of set-aside prairie (Prairie Island Indian Community, 2013).

Along the main channel, ecosystem function is relatively intact, given the nature of natural levees along the main river channel and the regeneration of Riverfront and Floodplain Forest. Water level manipulation at Lock and Dam 2 and 3 create stabilized river levels and have reduced channel migration. However, along the natural levees, the channel has remained relatively stable since the period of Euro-American settlement.

At the river's edge and along elevated levees, silver maple, cottonwood, green ash, and willows are co-dominant with lesser amounts of hackberry and black walnut. Away from the levees, on finer sediment, extensive areas of silver maple dominate with remnant green ash and hackberry present.

Obvious water level changes are most apparent in the backwaters of the Vermillion River between RM 808 and RM 797, seen in the formation or expansion of Sturgeon and North Lakes. The 1890s MRC maps show these areas as extensive backwaters with emergent and submergent communities mixed with lowland forest along river levees and extensive flat bottomlands. Within the 17,678-acre area between RM 808 and RM 797, 2,965 acres were mapped as open water in 1890, whereas 5,241 acres were identified as open water in 2000. These 2,276 acres of additional open water are mostly away from the main channel in created pools. The effects on the shoreline of the main channel are present today in wave action created by extensive recreational boating and in remnant shoreline protection measures, particularly near Lock and Dam 3.

Pool 4: River 4 is located between Lock and Dam 3 (RM 797) and Lock and Dam 4 (RM 753) and includes the Canon River delta at the upper end of the pool, Lake Pepin, the Chippewa River alluvial fan at the lower end. Changes in open water acreages (14% increase) within this pool between 1890 and today are less substantial than the other reaches largely because the banks of Lake Pepin generally rise quickly out of the water surface, thereby limiting the floodplain area within that area of the pool. Additionally, because Lake Pepin lies at the center of this river reach, the effects of the lock and dam system in the upper Canon River part of the pool are minor. Most of the increase in open water has occurred in the lowest 7 miles of the pool on the Wisconsin (east) side of the river in the lower Chippewa River delta area. The increased open water has backed up in areas likely consisting of mixed Floodplain Forest, open marsh, and meadow communities within the valley floor prior to the construction of Lock and Dam 4.

Within the Canon River delta, the Mississippi River channel meanders through extensive Floodplain Forest with abundant pools scattered within the delta. Hydrologically, this is an interconnected floodplain where the Canon River and the Mississippi River valley floor merge. As the Canon River flows perpendicularly into the Mississippi River, natural river levees are less distinct and more irregular along the main channel than upstream in the Vermillion River bottoms. The Canon River bottoms contain extensive backwater emergent wetlands and bottomland lakes, with Floodplain Forest scattered between these open wetlands on former levees and tributary and main channel accretion. Very few wing dams and only one closing dam was placed in this part of the pool. In general, the river configuration in this part of the pool has changed little since the 1890 MRC survey, with the exception of armoring for railroad and industry in Red Wing.

Lake Pepin is characterized by generally steeply sloping banks, though the shore has numerous triangular sand point fans created by tributary streams cutting through the bedrock bluffs along the lake. Notable floodplain tributary fans along the banks of Lake Pepin are Isabelle Creek, Rush River, Gilbert Creek, and Wells Creek. Generally, these deltaic fans are composed of level alluvial material of loamy fine sand to silt loam. These deltas were extensively cleared for agriculture following Euro-

American settlement as early as the 1860s but have largely reverted to mixed floodplain/Riverfront Forests. Within these forests, super-canopy cottonwoods are common, but the species is poorly represented in the shady understory. This suggests either that the trees established after farming were abandoned or that the front edge of the tributary fan has been altered.

The lower part of Pool 4 is characterized by the extensive tributary delta and fan of the Chippewa River on the northern (Wisconsin) side of the main channel. This fan is a mosaic of open water channels, emergent wetlands, and Floodplain Forest. Soils tend toward sand and loamy fine sand along the upstream parts of this delta and silt loam in the more protected downstream [arts. Pockets of open water and multiple channels are scattered throughout the delta fan. Wing dams in combination with channel embankments were used extensively below the mouth of the Chippewa River (RM 764 to RM 753) to maintain the river navigation channel. The Chippewa River delta appears not to have been converted to agriculture, though evidence of logging is apparent in 1930s aerial photographs.

4 Ecological Contexts: Historic and Present

4.1 Floodplain Dynamics

Riverine floodplains are those areas contained within the confines of river valleys that are subject to flooding and are typically made up of alluvial materials (mud, sand, and gravel) deposited as a result of surface water flows. The material deposited in a large floodplain like that of the Mississippi River might have been deposited over hundreds or thousands of years. This definition includes areas from permanently flooded open water within the river channel, permanently or semi-permanently flooded adjacent backwater lakes, areas at the base of valley bluffs where the effects of flooding from a main river channel are limited, or upland areas that do not flood but that have been created by river processes within a river valley (U.S. Geological Survey, April 1999).

Gregory et al. as quoted in Mitsch (1991) define riparian zones as “the interfaces between terrestrial and aquatic ecosystems. As ecotones, they encompass gradients of environmental factors, ecological processes and plant communities. Riparian zones are not easily delineated but are composed of mosaics of landforms, communities, and environments within the larger landscape.” Within this context, riparian zones encompass the widely ranging communities of upland dry prairie/savanna to bottomland lakes. Brinson et al. as quoted in (Mitsch, 2000) define riverine systems as generally linear due to their proximity to streams, having energy and material inputs from surrounding landscapes that converge and pass through the system, and functionally connected to upstream and downstream ecosystems and laterally upslope and downslope.

Most riverine wetlands are open systems receiving overland hydrologic inputs and outputs. Water and nutrients arrive from external sources and are captured and stored, and energy is released in pulses. While they are biologically productive during only parts of the year, temperate riverine wetlands receive and contribute inputs and outputs throughout the year. Occurring at the interface between land and water, riverine marshes and other floodplain plant communities function as sources of organic matter, but also function in a regulatory capacity as recharge areas, rainfall storage zones, and subsequent flood attenuation zones. They might also function as valves or sinks for nutrients from surrounding terrestrial areas (Klopatek, 1978). While providing these functions, these same ecosystems and associated plant communities can suffer adverse effects from excessive inputs of nutrients, pollutants, and altered hydrology. Often, these inputs become trapped, and, in many cases, the increased nutrients favor aggressive and/or non-native invasive species or can cause other detrimental effects on floodplain vegetation.

River floodplains form from the combination of aggradation (deposition) of alluvial material and degradation or downcutting of surface geology. As a river forms and meanders through a landscape, it transports, erodes, and deposits alluvial sediments (Mitsch, 2000). Along the banks of rivers, natural levees form from coarse, deposited materials flowing over channel banks. These levees are typically steeply sloping at the river's edge and are more gently sloped toward the floodplain. The highest areas of natural levees might be above the 20-year floodplain but near the normal river bank. Point bars are located where sedimentation gathers on the convex sides of river curves. In these locations, meander curves increase in radius and migrate downstream as sediments are deposited on these river landforms, which are eventually stabilized as vegetation takes root and becomes a terrestrial vegetated community.

Meander scrolls are typically referred to as ridge and swale landforms, where depressions and ridges form on convex sides of bends in the river. They form from point bars as the stream migrates laterally across the floodplain, leaving bands of elevated ridges interspersed with lowland swales. These areas of highly variable topography tend to contain a mosaic of vegetation types based on topographic position with accompanying soil variation with coarser soils on ridges and finer soils deposited in swales, in addition to hydrologic variation due to groundwater or river elevations.

Bottomland lakes, deepwater wetlands, and emergent wetlands often form under a variety of settings, including oxbows, sloughs, and backswamps. Oxbows are areas of permanently standing water, the result of abandoned meanders cut off from the actively flowing river. These areas are often fringed along a gradient from deep to shallow and by open water lakes, deepwater swamps, freshwater marshes, and emergent wetlands. Sloughs are areas of still water disconnected form active river flows that form in meander scrolls and along valley walls. Deepwater swamps can also form in the permanently flooded sloughs. Backswamps are deposits of fine sediments located between a natural and valley walls or terraces.

Terrace formations are abandoned floodplains formed by a river's alluvial deposits, but they are not hydrological connected to the present river. In the NER, terrace formations are typically formations of the ancient rivers created by glacial meltwater and associated alluvium carried from glacial lakes and outwash plains.

Riparian systems within the active river zone are dynamic. Anaerobic conditions develop rapidly during flood conditions but usually persist for a limited time. Most plants adapted to mesic floodplain conditions cannot tolerate extended periods of anoxic soil conditions (Mitsch, 2000). These highly fluctuating conditions tend to diminish farther from the active river. In these more distant areas, groundwater helps the soil remain moist for extended periods, and wetland plant communities tend to be more similar to the plant communities outside river floodplains.

4.2 Vegetation Communities

The diversity of pre-settlement habitats of the NER reflects the heterogeneity of soils, geology, geomorphology, hydrology, topography, and aspect within the river valley. Pre-settlement vegetation can be a difficult term to define due to dynamic time, space, and climate interactions. The vegetated landscape of much of the NER is a recent condition in geological terms, with final glacial retreats from the region as recently as 11,000 years BP in addition to millennia of fluvio-glacial effects. For this reason, it is important to define a period of pre-settlement condition.

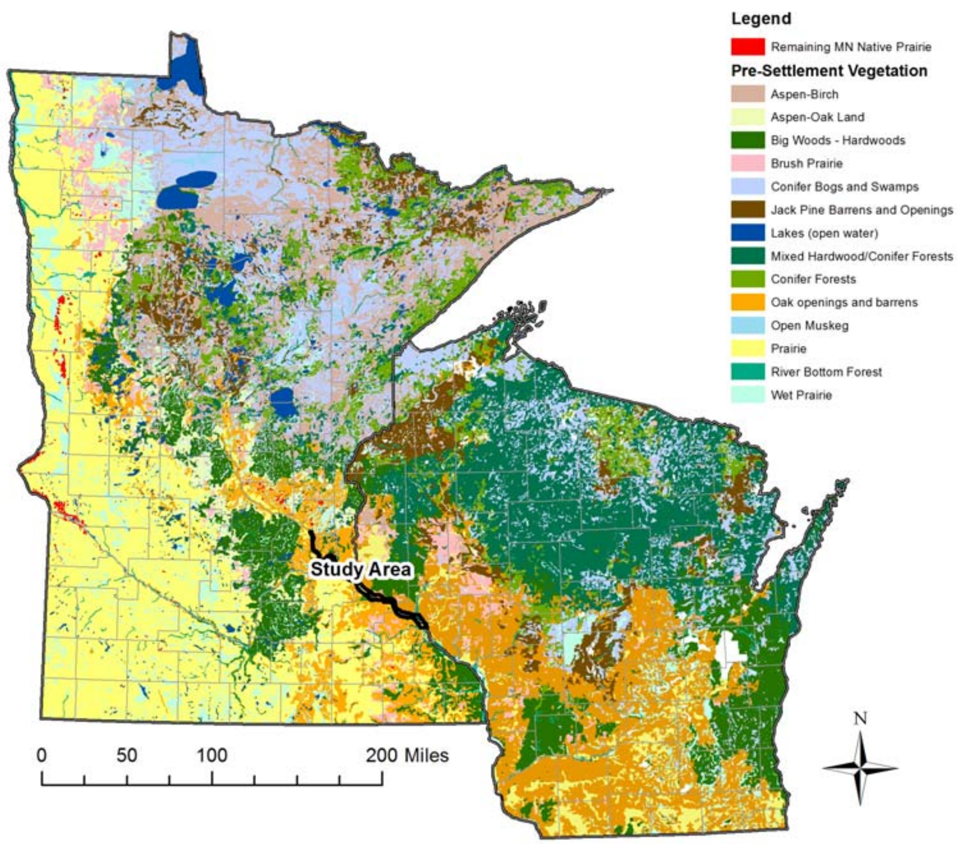


Figure 23. Pre-Settlement Vegetation of Minnesota and Wisconsin (Source: Minnesota DNR and Wisconsin DNR)

For the purpose of this study, pre-settlement vegetation communities are those present in the period immediately before the arrival of Euro-American settlers (in 1800 to 1850). Figure 23 shows the composition of vegetation communities in Minnesota and Wisconsin at the time of Euro-American settlement. Transitions between prairie to the west (yellows), barrens and hardwood forest in the southeast (oranges to greens), mixed hardwoods and conifers in northern Wisconsin (dark teal), and vast conifer swamp and forest (purples and greens) in northern Minnesota show the large landscape patterns of the region. The overall picture shows the study area located within this transition zone between the forests to the east and the prairie to the west.

Vegetation communities within a floodplain are strongly influenced by the flood regime, with the distribution of tree species largely determined by flood frequency, duration, timing, and intensity (Turner, 2004). Diversity in these systems is enhanced by variability in flows, and topographic heterogeneity allows species to occupy different parts of a floodplain depending on the annual and seasonal flood regimes (Turner, 2004).

Prior to Euro-American settlement, several forces acted on the landscape to create a mosaic of natural plant community types. Climate, fire, and hydrology were the strongest forces, but soils and geology, as well as presence and relative location of wetlands, lakes, streams, and rivers, also affected the composition of plant communities. The pre-settlement habitats of the Upper Mississippi River floodplain should be viewed as a snapshot in time when major Euro-American settlement began in earnest.

Biotic assemblages that comprise natural communities are dynamic, influenced by changing climate, shifting of landforms, time scale shifts, and alterations by humans during different periods using shifting land management methods. The dynamic patterns of plant communities are a substantial part of the story of the NER since the glaciers retreated. Most plant community types in the NER are dynamic assemblages that rely on disturbance regimes to persist.

Natural disturbance regimes are not uniform but include fires; the movement of soils due to flooding and flood type; the creation of new landforms; flood frequency, duration, and intensity; and the periodic drawdown of waters. Additionally, communities shift over time and space, and the pace of change is gradual and successional reflecting changing biotic and abiotic conditions. “Climax communities” are those that will, in the absence of catastrophic disturbance, continue to regenerate indefinitely with a similar composition.

The NER lies at the intersection of two major climactic zones and, consequently, two major ecological provinces. To the west of the NER, vast grasslands dominate the Central Plains (Prairie Parkland Province), where distinct wet and dry seasons with precipitation and temperature extremes predominate. To the east, within the Eastern Broadleaf Forest Province, yearly temperatures are similar to those in the western province, but rainfall increases substantially. Western Minnesota along the South Dakota border received 20 to 24 inches of rain annually between 1941 and 1970, whereas, during the same period, rainfall along the Wisconsin border averaged 32 inches per year (Minnesota County Biological Survey, 2007).

Climate affects vegetative patterns as illustrated by the changes in natural community assemblages from southwest to northeast Minnesota. The amount of precipitation and the length of the growing season dictate why there are drought-tolerant plants in the southwest, deciduous forests in the central part of the state, and coniferous species in the northeast part.

Situated between two major ecological provinces, the NER has plant and animal assemblages that are particular to both provinces as well as major community types that are a buffer zone between the two. Drier climatic conditions, coarser soil texture, and regular fires favor and maintain prairie communities to the west, and, conversely, greater moisture, heavier soils, and the absence of fire east of the study area favor the forested communities to the east. In the transition zone along the west of the upper two-thirds of the NER, the Big Woods were a forested region dominated by elm, basswood, sugar maple, ironwood, bitternut hickory, butternut, and ash. Additionally, there was a buffer zone dominated by oaks between the prairie and the Big Woods (Grimm, 1984).

The break between prairie and forest was sometimes abrupt depending on natural fire breaks, but often there was a shift in communities from fire-dependent and -reliant forest types (barrens and oak forest) to Big Woods forests ill-adapted to fire. As a result of Euro-American settlement of the Big Woods area beginning in the 1850s, 98% of the original forests have been lost, mostly due to agriculture and urbanization, with remainder of these forests found in patchy 40- to 80-acre lots (Musser, 2009). Prairie communities and transitional oak barrens communities would probably be absent from the landscape if periodic fires did not clear and prevent woody species encroachment (Grimm, 1984). Situated within this transition zone, the NER was a patchwork of all of these community types, though the top of bluff likely acted as a major firebreak that supported the vast forest in the valley. Early settlers noted that fires burned deep into the valley (Latrobe, in Curtis (1971)) and likely maintained the vast prairie communities at Grey Cloud Island and Prairie Island.

The climatological setting of the NER also drove the composition of vegetative communities in the river valley from Lake Pepin to the Coon Rapids dam. Mast producers such as swamp white oaks (*Quercus bicolor*), butternut (*Juglans cinerea*), and black walnut (*Juglans nigra*) were likely more abundant farther south but were likely a small component of the river terrace forest communities along the NER. Dominant trees in the valley forests in the NER were silver maples (*Acer sacharinum)*, elms (*Ulmus* sp.), cottonwoods (*Populus deltoides*) and green ash (*Fraxinus pennsylvanica*).

Hydrology is another major factor that affected plant community types and composition in the NER prior to Euro-American settlement. Prior to settlement, Floodplain Forests occupied about 50% to 70% of the floodplain (Yin and Nelson, 1995). Soil moisture limited the effects of fire, but periodic flooding associated with the rise and fall of the Mississippi River also directed the development of plant communities in the river floodplain. Annual spring floods select trees that tolerate flooding of the root zone early in the season and that develop leaves and seeds later in the year.

These floods also ensure diversity of structure within the forest. Periodic catastrophic floods alter the floodplain communities by scouring the edges of existing forests, depositing new sediment, clearing new channels, cutting off old channels that would eventually fill in as organic matter is deposited, and scouring existing shorelines. Tree species composition varies in relation to the elevation above the river channel because of flood tolerance. The same flood tolerance drives the composition of shrub and herbaceous species.

Lock and dam construction, agriculture, and urban development throughout the Upper Mississippi River Basin have converted about half of the pre-settlement Floodplain Forests to nonforested habitats (Yin Y. Y., 2009). In the 104 miles between RM 857 and RM 753 in the NER, there are broad changes in habitat types (see Table 3**).** In the NER, the increases in open water are skewed because Lake Pepin has most of the open water with the study area, and its surface area has not changed much since Euro-American settlement.

Table 3.

Landcover Type	Pre-contact Landcover (acres)	1890s Landcover (acres)	2000 Landcover (acres)
Agriculture	NA	12,885	8,011
Developed	NA	3,388	16,594
Dike	NA	79	NA
Forest	41,007	34,356	27,589
Grass/forbs/scattered trees	28,219	17,941	3,738
Marsh/swamp	7,988	7,988	10,442
Open water	42,610	42,531	55,348
Sand/mud	839	839	330
Unclassified	78	735	249
Total	**120,741**	**120,742**	**122,301**

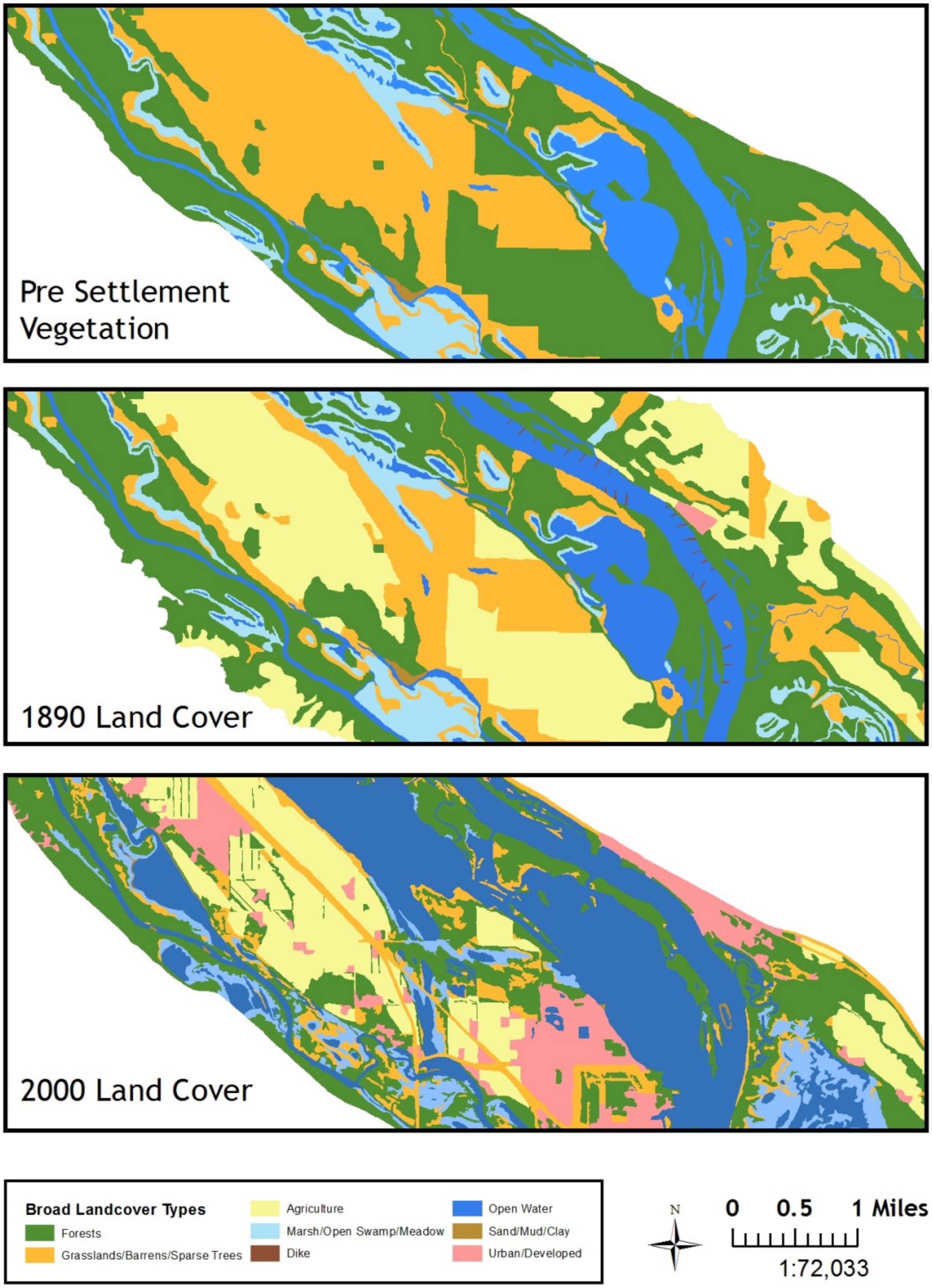


Figure 24. Simplified Landcover types from Pre-Settlement to present day.

Classification systems are valuable tools for understanding the biotic and abiotic characteristics that favor the development of assemblages of plants into a community. In each case, some differences are present based on the degree of specificity between systems, on favoring a certain characteristic over another, and particularly on the scale of the classification. With greater specificity, lines between communities can be blurred and sometimes difficult to define as individual species are often present in multiple classifications. The hydrogeomorphic model (HGM) developed by Heitmeyer (2008) classifies habitats in river valleys into broad types that can be used at the large-scale planning level. The methods developed by Heitmeyer for the Mississippi River floodplain in the Middle Mississippi Ecoregion can be applied to the NER with some alterations for the differences in regional landscapes. For instance, bottomland prairie was likely far more limited in the northern and narrower channel of the NER than in the south. The generally moister climate and fire protection of the bluff landscape would have favored the persistence of forests.

The following plant community descriptions rely heavily on the broad classifications of the HGM developed for previous Mississippi River HGM studies, but use supporting information provided by the much more refined classification systems of the *Field Guide to the Native Plant Communities of Minnesota: The Eastern Broadleaf Forest Province* (Minnesota Department of Natural Resources, 2005), *Vegetation of Wisconsin* (Curtis, 1971), *Distribution and Requirements of Plants on the Upper Mississippi River* (Galatowitsch, 1994), *Recognized Natural Communities – Working Document* (Epstein, Accessed 2013) and the *Wisconsin's Natural Communities* website produced by the *Wisconsin* Department of Natural Resources (WiDNR) (2012). The Curtis and Minnesota Department of Natural Resources (MnDNR) classifications are based on systematic field observations that identify communities in great detail, including hydrologic, soils, geographic, climatic, and other characteristics necessary for community presence and maintenance. In addition, these publications provide assumptions regarding the pre-contact and successional character of plant communities.

Galatowitsch and McAdams (1994) performed literature reviews for the U.S. Fish and Wildlife Service (USFWS) and the Iowa Cooperative Fish and Wildlife Unit specifically examining Mississippi River Valley communities and the effects of flooding and river management on these communities. These and other widely accepted systems have been used in this study to support applying the HGM in the NER.

Table 4 lists the communities that are defined and described by the above authors and agencies that were used to develop the HGM analysis. These classifications and sources are valuable as reference documents for site-specific restoration targets and planning.

Table 4.

HGM Natural Community Types	Author(s) (see sources below)	Associated/Similar Classification(s) and Community Type Descriptions / Naming
Riverfront Forests	CRE HGM	Riverfront Forest
	MnDNR	Southern Terrace Forest (FFs68) Southern Terrace Forest (FFs59)
	WiDNR	Floodplain Forest
	G&M	Cottonwood-Willow Forests
	Curtis	Lowland (Floodplain) Forests
Floodplain Forests	CRE HGM	Floodplain Forest Floodplain Forest-Oak
	MnDNR	Southern Floodplain Forest – Silver Maple Subtype (FFs68) Silver Maple – (Virginia Creeper) Floodplain Forest (FFs68a)
	WiDNR	Floodplain Forest
	G&M	Mixed Softwood Forests
	Curtis	Lowland (Floodplain) Forests

HGM Natural Community Types	Author(s) (see sources below)	Associated/Similar Classification(s) and Community Type Descriptions / Naming
Slope and Mesic Forests	CRE HGM	Slope Forest
	MnDNR	Fire Dependent: Southern Dry-Mesic Oak-Hickory Woodland (FDs38) Mesic Hardwood Forest: Central Mesic Cold-Slope Hardwood-Conifer Forest (MHc38) Central Wet-Mesic Hardwood Forest (MHc47) Southern Mesic Oak-Basswood Forest (MHc38) Southern Mesic Oak-Basswood Forest (MHc39) Southern Wet-Mesic Hardwood Forest (MHs49)
	WiDNR	Southern Dry-Mesic Forest Southern Mesic Forest Southern Dry Forest (uncommon) Pine Relict Oak Woodland
	G&M	Not discussed
	Curtis	Southern Xeric Forest (Mesic Forest to a lesser degree)
Dry/Mesic Prairie and Savanna	CRE HGM	Mesic Prairie/Savanna
	MnDNR	Southern Dry-Mesic Pine-Oak Woodland (FDs27) Southern Dry Prairie (UPs13) Southern Dry Savanna (Ups14)
	WiDNR	Oak Opening Oak Barrens Dry Prairie Sand Prairie Oak Woodland
	G&M	None
	Curtis	Xeric Prairies, Oak Openings, Oak Barrens
Bottomland Prairie	CRE HGM	Bottomland Prairie
	MnDNR	Southern Wet Prairie (WPs54)
	WiDNR	None present in NER
	G&M	Sedge Meadow and Wet Prairie
	Curtis	Lowland Prairies
Wet/Sedge Meadow	CRE HGM	Wet Meadow
	MnDNR	Northern Wet Meadow/Carr (WMn82) Southern Seepage Meadow/Carr (WMs83)
	WiDNR	Southern Sedge Meadow
	G&M	Sedge Meadows and Wet Prairies
	Curtis	Sedge Meadow
Shrub/Carr	CRE HGM	Shrub/Scrub
	MnDNR	Northern Wet Meadow/Carr (WMn82)
	WiDNR	Shrub/Carr
	G&M	Shrub Cars
	Curtis	Southern Shrub Carr
Persistent Emergent	CRE HGM	Persistent Emergent
	MnDNR	Northern Mixed Cattail Marsh (MRn83) Northern Bulrush-Spike rush Marsh (MRn93)
	WiDNR	Emergent Marsh
	G&M	Emergent Marshes
	Curtis	Emergent Aquatic Communities
Open Water: Active River Channels	CRE HGM	Open Water/Aquatic
	MnDNR	Sand/Gravel/Cobble River Shore (RVx32) Rocky River Shore (RVx43)
	WiDNR	Warm water Rivers

HGM Natural Community Types	Author(s) (see sources below)	Associated/Similar Classification(s) and Community Type Descriptions / Naming
	G&M	Submersed Aquatic Communities
	Curtis	River and Flowage Communities
Open Water: Bottomland Lakes and Abandoned Channels	CRE HGM	Open Water/Aquatic
	MnDNR MLCCS	Water Lilly Open Marsh (64110) Northern Water Lily Aquatic Wetland (64113)
	WiDNR	Submergent Marsh
	G&M	Submersed Aquatic Communities and Floating Aquatic Communities
	Curtis	Submerged Aquatic Communities of Lakes

Sources: CRE HGM: (Heitmeyer M. , 2010) / MnDNR: (Minnesota Department of Natural Resources, 2005) / WiDNR: (Wisconsin Department of Natural Resources, 2012) / G&M: (Galatowitsch, 1994) / Curtis: (Curtis, 1971) /MnDNR MLCCS: (Minnesota Department of Natural Resources (Central Region), 2004).

4.2.1 Riverfront Forests

4.2.1.1 Community Description

Historic Riverfront Forests occur on the natural levees created along the Mississippi River's main channel or on braided channels where scouring effects removed canopy species and allowed young cottonwoods and willows to germinate on exposed alluvium. Historic communities in this position on the landscape accumulated the flotsam and jetsam of annual floods.

Riverfront Forests are found along channel margins subjected to frequent inundation and sediment burial as well as summer drought. Coarse soils with little retained soil moisture are the predominant soil type. Areas directly adjacent to the active river channel tend to be a species-poor environment with low species richness near the pool level. The community is dominated by black willows (*Salix nigra*), sandbar willows (*S. interior*), silver maples (*Acer sacharinum*), and cottonwoods (*Populus deltoides*) during the germination period, but willows and cottonwoods typically persist near banks since these species withstand periodic flooding and flood velocities as well as drawdown during dry periods.

Figure 25. Early Succession: Riverfront Forest establishing with willows in foreground and mixed floodplain forest trees dominated by cottonwood at the open forest edge.

Willows and cottonwoods are able to persist on depauperate, low-moisture-holding sandy soils. While willows able to withstand major flooding and cottonwood is less tolerant, this pioneering species is well adapted to substantial fluctuations since it establishes a deep taproot relatively quickly. These two tree species are best adapted to areas with sparse vegetative cover and abundant sunlight. Though a pioneer species, often cottonwood will establish following site stabilization by sandbar willow (FEIS, USDA

Forest Service). Silver maple is less likely to outcompete cottonwood in depauperate, rapidly drained sandy soils, and thus tends to become dominant in the organic soils and shadier setting of the Floodplain Forest. Shrubs such as sandbar willow, heart-leaved willow (*S. eriocephala*), and peach-leaved willow (*S. amygdaloides*) are also common (Galatowitsch, 1994).

Galatowitsch and McAdams (1994) refer to this forest type as cottonwood-willow forests. The distinguishing factor between this and Floodplain Forest is the predominant composition of pioneer tree species, specifically young, early successional cottonwood and black willow. These tree species will establish along the banks of the river and tolerate periods of flooding. This community of pioneering species will establish in areas of frequent flooding, tolerating and outcompeting in openings along recently flooded riverbanks. This community eventually succeeds to mixed softwood forests (HGM Floodplain Forest) as organic matter accumulates and more shade-tolerant species establish. Maintenance of Riverfront Forest in the NER will rely on the presence of shifting riverfront locations, with suitable open habitat and coarse soils to continually re-establish.

Along sand bars, mud flats, and places with recently disturbed soils due to flooding, forest dominants are typically black willow and cottonwood. Succession toward silver maple and American elm (*Ulmus americana*) or Floodplain Forest type community is typical, and these species become the dominants.

Trees typical of the community, except for the willows, are relatively resistant to the effects of ground fires. These trees will survive losing as much as one-half to two-thirds of their bark surface to fire. The tree species in this group all sucker from the base as they senesce, become stressed, or reach the end of life (Curtis, 1971).

MnDNR identifies southern terrace forest (FFs59), recognizing its landscape position along the recently deposited terraces of active river floodplains (Minnesota Department of Natural Resources, 2005), as the community best describing the HGM Riverfront Forest. Shrub and subcanopy layers are sparse to patchy, and canopy is interrupted to continuous. This community is located on complexly stratified silty or fine sandy alluvium. Complexly stratified soils might have layers of organic material underlying surficial layers and soils might be either well or poorly drained, depending on the elevation and the nature of deposited materials.

This community is dominated by species tolerant of extreme river-associated disturbance. For this reason, flood tolerances within this community are varied, with willows tending to persist only where sources of surface water or groundwater remain somewhat persistent. In contrast, cottonwoods, the other dominant tree species, will establish on the same open, coarse soils at the river’s edge but will also persist in the harsh environment of elevated depositional soils of infrequent floods. In these settings, cottonwood trees and shrub willows might grow in areas where flood frequencies range from semi-permanent at river margins to greater than 20 years, typically along levees and upstream depositional portions of the islands. For this reason, the dominant species of this type are often located upslope on alluvium deposited in earlier flood events but lacking the organic and silty deposits of backwater swales.

4.2.1.2 Alteration to the Historic Condition

Riverfront Forests remain along the maintained channel of the Mississippi River but are reduced in scope and area due to greater inundation along the pools. The dynamic quality of channel meanders is reduced, limiting scouring and redirecting the channel, resulting in fewer areas that are colonized by cottonwood and willow. The reduction in area affected by annual floods (in spite of increased inundation overall) has reduced the diversity of tree species and forest types in the NER. River fluctuation is more controlled, so that deposition of sediments and debris is largely episodic and occurs with less frequency than during pre-settlement period. In addition, below the dams, reduced sediment loads may favor the more stable Floodplain Forest types.

Riverfront Forest communities are naturally adapted to major disturbances, and historically shifted over time. After major floods, cottonwood-willow communities tend to increase, forming pioneering communities in the annual floodplain and on higher, recently created open ground. Extreme disturbances will create single-aged forest stands, so future mature forest stands tend to be single aged (Galatowitsch, 1994). As Riverfront Forests tend to succeed to Floodplain Forest types after establishment, limiting the dynamic quality of regular flooding would favor forests dominated by single–aged, shade-tolerant silver maples in seasonally flooded areas. Generally, Floodplain Forests tend toward greater homogeneity than most upland forest types due to the nature of these single events that change the community composition (Galatowitsch, 1994).

The greatest effects on the distribution of Floodplain Forest communities, including Riverfront Forests, in the Mississippi River floodplain over the past 150 years have been from human activities: navigation impoundments, agriculture, and flood control. Logging, road and pipeline construction, recreation, barge fleeting, and levee construction have contributed to fragmentation (Galatowitsch, 1994).

We speculate that this forest type might have increased after wing dams were built and soil was subsequently deposited behind dams. As long as soil deposition remained at an elevation that could support germination of both cottonwoods and willows and remained within the active scour zone of the riverfront, this community type might have benefited from the earlier techniques of channel containment. However, training structures would have reduced the natural action of shifting riverfront soils once they were established and, under controlled conditions, would have declined except after periodic catastrophic events. In areas where wing dams are permanently flooded, these communities have been eliminated.

4.2.1.3 Current Condition

At present, Riverfront Forest communities are limited by the loss of active scour habitat under the controlled river conditions, where low-flow flood-stage elevations are maintained for navigation. In addition, the typical species in this forest type invade and regenerate in the open conditions of riverfront disturbance and require drawdown for deep root development (Jacobson et al., 2010). Control of river levels presumably favors conditions more suitable to the more stable Floodplain Forest communities.

Another threat to regeneration that this community type faces following disturbance is reed canary grass (*Phalaris arundinacea*). This invasive grass species establishes quickly along forest edges and openings and, once established, forms dense monocultures. The density of a well-established plot of reed canary grass precludes establishment of other species (USACE, 2012). Reed canary grass thrives on disturbed soils with seasonal flooding and can withstand both regular flood pulses as well as a permanently high water table. The threat that this species poses to Riverfront Forest communities in the managed river valley is very high because, once it is established, it reduces the availability of habitat for the disturbance-adapted species common to the community type.

4.2.2 Floodplain Forests

4.2.2.1 Community Description

Floodplain forests occur on active floodplains of medium to large rivers over deep, stratified sandy alluvium with a silt cap. Soils are deep and flooding is frequent (Minnesota Department of Natural Resources, 2005). They are identified by the dominance of silver maple, green ash, and elm with lesser amounts of cottonwood, willows, and hackberry. Galatowitsch and McAdams (1994) recognize this forest type as mixed softwood, which follows the establishment of disturbance-tolerant Riverfront Forest type communities. "Mixed softwood forest" communities emerge where organic material accumulates in the protected zones of post-establishment pioneering woody communities. Cottonwoods and willows remain present in this community but tend not to regenerate and decline as dominant silver maple, ash, and (formerly) elm become dominant.

This community is naturally adapted to major floods, though Riverfront Forest species (cottonwood and black willow) tend to be more adapted to constant flooding over a greater period than the maple species (Galatowitsch, 1994). Bottomland hardwood forests are characterized as follows:

> Habitat is inundated or saturated by surface or groundwater periodically during the growing season. Soils within the root zone are periodically saturated to the root zone during the growing season. Dominant woody plants are able to survive, achieve maturity, and reproduce in habitats where the root zones become anaerobic at various times during the growing season due to morphological and or physiological adaptations. (Mitsch, 2000)

Floodplain forest communities are naturally adapted to major disturbance events and historically shifted over time. However, most catastrophic disturbances except for floods were rare in the Floodplain Forest. MnDNR's historic fire frequency surveys indicate that fires were not a factor, and windthrow events averaged more than 300-year intervals. The predominant disturbance was catastrophic floods, which occurred on average every 40 years (Minnesota Department of Natural Resources, 2005).

After major flood events, cottonwood-willow communities tend to increase, forming pioneering communities in the annual floodplain and on higher, recently created open ground. Extreme disturbance events will create single-aged forest stands with the result that future mature forest stands will tend to be single-aged. Generally, Floodplain Forests tend toward greater homogeneity than most upland forest types due to the nature of these single community-composition-changing events.

Riverfront Forest (cottonwood-willow) and floodplain (mixed softwood) forests are distinguished by their flooding regime and the nature of the floods, soil development, and flood frequency. Though Riverfront Forests will tolerate greater flood velocities and periods of inundation, trees of the Floodplain Forest community will, once established, tolerate major floods, especially where they are protected from the effects of debris and scour. In the absence of disturbance, these forests will persist indefinitely.

Silver maple seed establishes away from the main channel during major floods, dropping to the surface as floodwaters recede (Galatowitsch, 1994). Silver maple and cottonwood, while growing at low densities (85 trees per acre typically), represent a large basal area due to the sometimes enormous size of individual trees. The wide canopies, despite the relative low abundance, typically provide closed canopy settings. In the mesic zone, red oak and basswood are sometimes present but never common.

Species typical of these forests downriver (river birch and swamp white oak) become less prevalent in the upper reaches of the Upper Mississippi River (Curtis, 1971).

Within the historic condition, Floodplain Forest types of the NER consisted of a diverse tree community with deciduous trees on seasonally flooded, alluvial soils. The historic Floodplain Forest also had an increased representation of young trees and shrubs, which provided greater vertical structure than current forests of this community type. Forests in this landscape position were likely a silver maple (*Acer saccharinum*)–dominated community type with co-dominants including cottonwoods (*Populus deltoides*) and black willows (*Salix nigra*). Other trees within the canopy included green ash (*Fraxinus pennsylvanica*), elms (*Ulmus* spp.), hackberry (*Celtis occidentalis*), box elders (*Acer negundo*), basswoods

(*Tilia americana*), and occasional mast producers on elevated terraces such as bur oaks (*Quercus macrocarpa*), white oaks (*Q. bicolor*), butternuts (*Juglans cinerea*), and black walnuts (*J. nigra*).

Within the shrub layer, young trees (especially shade-tolerant elm species or green ash) or shrubs are present though discontinuous. Vines are a characteristic feature of the historic Floodplain Forest and include Virginia creeper (*Parthenocissus virginiana*), wild grape (*Vitis riparia*), bur cucumber (*Sicyos angulatus*), and Canada moonseed (*Menispermum canadense*). Herbaceous species consisting of plants adapted to the same annual flooding, erosion, and deposition as trees include wood nettle (*Laportea canadensis*), clearweed (*Pilea* spp.), beggarticks (*Bidens* spp.), sedges (*Carex* spp.), and grasses (*Leersia* spp. and *Elymus* spp.).

Based on field visits in the NER, Floodplain Forest canopy is often entirely dominated by mature silver maples (Acer saccharinum), but commonly these same forests contain scattered super-canopy cottonwoods within fully shaded areas. In many of these locations, these trees are intermixed on similar soil types and in similar topographic settings. The presence of these shade-intolerant trees (cottonwood and black willow) indicates that these Floodplain Forests were openings at one time. The causes of openings in floodplain areas might have been anthropogenic (farming or logging); floods, in particular the great flood of 1965; or, in the case of tributary fan deltas, remnants of the expanding delta where the exposed front edge of soil deposition has shifted outward. Following the 1993 flood, *Acer* lost proportionately more smaller trees than other species, but retained more big trees. In addition, surviving saplings quickly filled “gaps” and through rapid toward the canopy remained the likely dominant canopy tree of Floodplain Forests (Yin Y. Y., 2009)

MnDNR (2005) describes Floodplain Forest and Riverfront Forests as often occurring in similar settings but present during different successional phases. Light availability is a significant limiting factor for trees in the Riverfront Forest community. The southern Floodplain Forest (FFs68) best describes the HGM Floodplain Forest. The MnDNR description defines this forest as the intermediate and climax phase under the following timeframe: formative years (0 to 35 years) dominated by willows and elms, trending toward elms, silver maples, and green ash after establishment (35 to 155 years) and becoming dominated by American elms, silver maples, and green ash at maturity (over 155 years). American elm rarely achieves maturity at present due to Dutch Elm Disease, so it’s presettlement presence as a co-dominant in this and all forest communities is rare today in the NER.

4.2.2.2 Alterations to the Historic Condition

The greatest effects on the distribution of Floodplain Forest communities in the Mississippi River floodplain have been from human activities: navigation impoundments, agriculture, logging, and flood control. Fragmentation due to logging, road and pipeline construction, recreation, barge fleeting, and levee construction remains as a stressor to this community type.

Euro-American settlers harvested Floodplain Forests for timber to construct homes, to heat their homes, as building materials for towns, railroads, and telegraph and telephone poles. This continuous harvest continued through the 1800s and into the 1950s. Large areas of native Floodplain Forest were also converted to farmland and were altered prior to impoundments constructed in the 1930s. The effects of impoundments, wing dams, and channelization also affected the character of the Floodplain Forest community and moved the condition of current-day Floodplain Forests to a more static system consistent of a single-aged silver maple community that is altered only by hydrology or minor windthrow. Large areas of Floodplain Forest have also been destroyed or removed by inundation from dam construction. This effect is most pronounced immediately upstream of where dams are placed. The effect is less pronounced in the upper reaches of dammed pools.

Curtis (1971) suggests that trees of these forests have been relatively well protected from agriculture due to their low topographic position; however, they were and continue to be used for grazing more than for crops. Ground layer vegetation is often subject to adverse effects from overgrazing.

4.2.2.3 Current Condition

Currently, disturbance to the Floodplain Forest community type includes episodic flooding, windthrow, and forest management. The altered river processes, historic logging, and absence of occasional fires have affected the composition and structure of the Floodplain Forest within the NER. The reduction in disturbance and the loss in plant species diversity have contributed to public land managers' concerns over the low tree species diversity compared to historical conditions and low representation of young age class trees (Yin et al., 1997).

Much of the floodplain in this part of the NER consists of single-aged silver maple that resulted from logging of the original Floodplain Forest after dam construction about 80 years ago (Dunevitz-Texler, 2005). It is likely earlier landuses, including grazing and agriculture also contributed to the current forest composition. Silver maple is considered late successional in this forest type, and regeneration of this or other species in the understory is limited due to low light levels. Species richness is lower, and tree density has declined. Cottonwood and Black Willow have declined in importance along with some hardwood species due to the static conditions created by river level and channel controls.

Figure 26. Even Aged Silver Maple Floodplain Forest

Knutson (1995) found that current tree sizes were similar to those in pre-settlement forests, but present forests have fewer trees. Knutson also surmises that the change in forest structure could be due to hydrologic changes or to the continued effects of Dutch elm disease, which eliminates a significant tree component of the community type. Additionally, she found that, although the relative dominance of the three Floodplain Forest co-dominants, silver maple, green ash and American elm, have changed, their combined dominance has changed little in the last 150 years.

Invasive species of concern in these forests include *Ranunculus abortivus*, *Glechoma hederacea*, *Lysimachia nummularia*, *Leonarus cardiac*, *Oxalis stricta*, *O. dillnii*, *Alliaria petiolata*, and *Phalaris arundinacea* (MnDNR, 2005).

Reed canary grass is of greatest concern for land managers, since removing trees can create ideal open conditions for reed canary grass to invade, thereby limiting the restoration potential of this (or any other) community type. It appears as though this species may, in the future, fundamentally alter the "climax community" characteristic of Floodplain Forests. Prior to encroachment by reed canary grass, openings within this community would have been occupied by less aggressive, often annual forb species or sedges until shaded out by Floodplain Forest tree species.   Reed canary grass is so aggressive and once established, precludes establishment by other species, and if established in openings, will likely persist, precluding Floodplain Forest regeneration, leading to an unnatural “Silver Maple Savanna” type (pers. conversations with R. Urich, USACE).

4.2.3 Slope and Mesic Forests

4.2.3.1 Community Description

Slope and mesic forests occur along the upper river terraces and above elevations where periodic catastrophic floods select for more flood-tolerant species. Species developing on rich soils that are protected by fires included a canopy layer dominated by basswoods, black ash, sugar maples, American elms, red elms, green ash, hackberry, box elders, and mast producers such as oaks, butternuts, and black walnuts. The subcanopy is more patchy to continuous than in the Floodplain Forest community and includes species such as chokecherry (*Prunus virginiana*), Missouri gooseberry (*Ribes missouriensis*), and saplings of the canopy trees. The herbaceous layer is a rich community of sedges and forbs.

These forest types are found on terraces above flood stages, on sheltered slopes, on high stream terraces, on middle and upper slopes of bedrock hills, and on loess-covered or drift-covered bluffs (Minnesota Department of Natural Resources, 2005). The geomorphic settings of communities in the Mississippi River Valley include colluvial slopes and colluvial aprons with limited groundwater inputs. Soils are typically mixed erosional soils derived from adjacent upper slopes and bedrock bluffs. Slope forests are often found in a transition zone between floodplain/Riverfront Forest and prairie. Aspect and associated moisture and shelter from fire within valleys in this community type cause variability of the community type.

The HGM designations of slope and mesic forests are a more broadly defined system than other community descriptions. MnDNR (2005) communities describing slope and mesic forests can include central mesic cold-slope hardwood conifer forest (MHc38) on sheltered slopes, stagnation moraines, or till plains; southern mesic oak-basswood forest (MHs38) and southern mesic maple-basswood forest (MHs39) on north-facing middle and upper slopes or stagnation moraines; and southern wet-mesic hardwood forest (MHs49) on modern alluvium in deep tributary valleys of major rivers or in low topographic areas, lake peninsulas, or margins in moraines and till plains. Southern dry mesic oak-hickory woodland (FDs38) might also describe this forest type, which is found on dry slopes and is less protected than the above types.

The presence of groundwater seeps and springs also contributes to the variability of the vegetation community. These community types occupy a range of settings from dry slopes to those areas immediately adjacent to floodplain areas. Thus, canopy composition is highly variable, often contiguous with floodplain or lowland forests. In lower areas, common tree species include basswood, black ash, sugar maples, American elms, red elms, rock elms, green ash, hackberry, box elders, and bur oaks. White pines, yellow birches, balsam firs, butternuts, and black walnuts might be present. Northern red oak is a common component on topographically elevated, drier sites. Ground and shrub layer vegetation on Slope Forests is very diverse and variable. Composition largely depends on slope position and moisture source and availability.

4.2.3.2 Alterations to the Historic Condition

Alterations to Slope Forests have included losses due to construction of roads and railroads, conversion to agriculture, and urbanization. These community types are now limited to narrow bands between floodplain systems (forest and open wetland types) and uplands in highly urbanized or heavily farmed landscapes, especially upstream of Lock and Dam 3 in Hastings. Downstream of Hastings, in the driftless area, these forest types are common on the steeps slopes of the deeply cut tributary valleys where farming did not occur on the steepest of slopes. Erosion from past and present farming practices at the top of the slope continues to contribute sediment to the valley and continues to affect these forests, though conservation farming practices have improved and these forests have shown recovery through regrowth and stabilization. On drier, more-exposed slopes, there has been a loss of diversity due to suppression of regular fires. In all forest types, disease and pests have substantially reduced the numbers of certain tree species.

4.2.3.3 Current Condition

The loess soils of the steeply sloping blufflands of the driftless area are particularly susceptible to erosion. Past land use practices contributed heavy sediment loads to tributaries of and into the Mississippi River. Despite decades of improved farming practices, erosion of Slope Forests remains a concern. Invasive species, especially common buckthorn (*Rhamnus cathartica*) and garlic mustard (*Alliara petiolata*), are serious concerns, since these species displace native plants and in some cases prevent the regeneration of these forest types. Species of concern include a variety of snakes and plant species including kittentails (*Besseya bullii*) and the rare ovate-leaved skullcap (*Scutellaria ovata*).

4.2.4 Prairie and Oak Savannah

4.2.4.1 Community Description

Prairie and oak savannah are fire-dependent communities with well-developed grasses and forbs. The oak savannah or oak barrens is transitional between grass-dominated prairies and forested communities. While fire directed the composition of vegetative communities on the landscape, water-retaining capabilities of certain soil types also interacted with the development of forest on the pre-settlement landscape. Wovcha et al. describe the effects of fire on the landscape in this way (Wovcha, 1995). Forests occurred in areas that have loamy, moisture-retaining soils or strong firebreaks, such as extensive wetlands or rugged hills, and prairies were present on landforms (such as the Mississippi River terraces) that have coarse, droughty soils and few lakes or wetlands. Oak woodlands or savannahs, considered transitional between prairie and forest communities, developed in areas with relatively droughty soils but also where topographic firebreaks limit the intensity of fires.

Figure 27. Prairie and savanna on steep slopes above St. Croix River (Photo: Scott Krych)

These community types are associated with open-canopy oak forest where fire keeps the ground free of woody debris and selects for grasses. They are typically located on more sandy alluvium or glacial outwash where fire keeps woody forest species from encroaching or shading out grasses and forbs. These grass-dominated communities were noted by Henry Schoolcraft, who described extensive mesic prairies along the Mississippi River in 1820 from St. Anthony Falls through Anoka County (Schoolcraft, 1953[1821]). They are also present in southern Washington County and along bluff edges, though these areas tended toward more dry community species composition. In the absence of fire, prairie and savanna communities are likely to succeed to closed forest community types (Grimm, 1984), especially in the NER where forest and savanna are common, thus providing sources for forest encroachment.

MnDNR (2005) dry prairie and savanna communities within the NER include the following types: southern dry prairie (UPs13), dry savanna (Ups14), and dry mesic woodlands (FDs27). With the exception of the areas upstream of St. Anthony Falls, MnDNR's (2005) classifications for mesic prairie (Ups23) and savanna (Ups24) communities in Minnesota occur generally to the west of the NER on glacial moraines and meltwater features with deep rich soils.

Dry prairie and savanna communities are present on shallow soils over limestone and sandstone bedrock and on level terraces in coarse outwash in river valleys on well-drained or excessively well-drained Mollisols, as well as on sand dune areas found above the 20-year flood stage within and above the Mississippi River Valley. Savanna is found along the Mississippi River on deep, sometimes wind-associated stream terrace sands within valleys; on colluvium below sandstone outcrops; and on sand "ramps" created by wind blowing upslope from valley floors. Mesic prairie is a forb- and grass-dominated community found on well-drained loams on glacial till or thin loess over till or in lacustrine sediments and outwash.

Dominant species tend to be grasses including big bluestem, Indian grass, or prairie dropseed on more mesic sites and little bluestem, porcupine grass, side-oats grama, hairy grama, and Junegrass on drier sites. Switchgrass and prairie cordgrass might be common on wetter sites. Forbs tend toward patchy to sparse in these communities but are very diverse and are distributed across a range within the moisture gradient of a site (Minnesota Department of Natural Resources, 2005). On flatlands, prairie sites might grade into savanna, oak woodland, and oak forest very gradually, or, on moister sites, transition slowly to wet prairie and meadow. They also exist as abrupt openings, especially at steep topographic gradients (bluffs) abutting abruptly to oak and other dry forest types (Curtis, 1971).

4.2.4.2 Alterations to the Historic Condition

Alterations to prairie and savannah communities are generally the result of the elimination of periodic fires, removal of grazers, and conversion to cropland. Very few examples of this community type are present in the NER. Pfannmuller and Coffin (1989) estimate that less than 1% of Minnesota's native prairie remains. Fire suppression and subsequent invasion by woody species, invasive species encroachment, and, most significantly, agriculture have eliminated most prairie and savanna from the Upper Midwest. Early farming practices on former prairie sites caused substantial erosion within the river valley, and the effects of these practices remain today in the form of elevated sediment loads from tributary streams. Within the NER, sand and gravel mining have caused a substantial loss of prairie habitat. Additionally, bison and elk grazing was a common disturbance factor that is no longer present.

4.2.4.3 Current Condition

Currently, these communities are largely confined to limited numbers of small fragments scattered throughout the region. Within the Mississippi River Valley, prairie and savanna communities are present on the edges of bluffs and steeply sloping bluff areas that are difficult to access for agriculture and in a few sandy dune areas within the valley. Remnant savannas are often overgrown and have become forested communities.

Primary threats to these communities are the continued conversion of grasslands to active farming or mining. In addition, the suppression of regular fire prevents the sustenance of this community type, allowing either dominance of invasive herbaceous species (such as smooth brome) or encroachment by woody species with subsequent conversion to forest.

Some of the most endangered community types remaining in the region harbor large numbers of rare plant and animal species.

4.2.5 Bottomland Prairie

4.2.5.1 Community Description

In the Middle Mississippi Ecoregion (MME), extensive bottomland prairies occupied vast tracts of land downriver of the NER on older point bar surfaces with 2- to 5-year frequencies. In the MME, these communities were likely maintained by regular fires (Guyon, 2012).

In the NER, fire was likely a less significant factor on a large scale within the relatively protected, narrower Mississippi River Valley floodplain, and the extensive bottomland prairies found farther south were likely less prevalent. This community may have a very similar composition to sedge meadows but be located in a higher topographic setting on poorly drained loam soils. The most significant difference is that bottomland prairie was a fire-maintained community and would have likely been invaded by woody species in the absence of fire. Upland prairies maintained by fire were present within the valley, but typically on dry soils of large islands and are discussed as Prairie and Savanna type communities.

Additionally, wet prairie was generally located adjacent to upland prairie, which burned frequently. The fires in adjacent dry uplands were the source of fire in the wetter prairie, since the wet conditions in this bottomland community would have limited the starting potential for burning (Minnesota Department of Natural Resources, 2005). Extended flooding adversely affects the drier species of wet prairie, though during dry periods these species are expected to rebound.

4.2.5.2 Current Condition

Where present, bottomland prairies would have been considered for agricultural purposes within the valley. These sites were often abandoned on the valley floor due to seasonal inundation, which made these areas inaccessible during some seasons and years. These are typically highly disturbed landscapes, previously used for cattle grazing and row cropping prior to abandonment. These areas typically have a greater proportion of non-native invasive species than their natural counterparts (Galatowitsch, 1994). Reed canary grass will invade areas on wetter sites, and smooth brome (*Bromus inermis*) will invade on more-upland sites with rich soils, both of which species form dense vegetative mats that limit the potential for greater species diversity. Cottonwood, willow, and maple species might invade these sites over time, particularly following heavy flooding and the subsequent ground openings created by such events.

4.2.6 Wet/Sedge Meadow

4.2.6.1 Community Description

Sedge and wet meadows are found on soils with fine textured substrates in areas protected from the active river channel. These communities are often located at the fringes of small lakes and ponds with minimal wave action or are interspersed with bottomland forests. Wet meadows tend to be found in relatively consistent topographic settings that are often too consistently wet for tree species to establish. Grass and grasslike species are typically dominated by big bluestem (*Andropogon gerardii*), prairie chordgrass *(Spartina pectinata)*, reed canary grass *(Phalaris arundinacea)*, Switchgrass *(Panicum virgatum)*, riverbank sedge *(Carex emoryi)*, long-toothed lake sedge *(Carex laeviconica)*, and Canada bluejoint (*Calamagrostis canadensis).* There is high diversity of forbs. Dominants include cardinal flower (*Lobelia cardinalis*), blue flag iris *(Iris virginica)*, water smartweed (*Polygonum amphibium*), spotted joe-pye weed (*Eupatorium maculatum)*, and swamp milkweed (*Asclepias incarnata*)*.* These communities are able to withstand periods of both extended flooding and drought (Galatowitsch, 1994).

MnDNR natural community type WPs54 (2005) occurs as small inclusions in lacustrine sediments. It is mostly found in poorly drained loams with fine textures. It might be found in coarser soils where the water table is high. It is also found on plane or convex surfaces in shallow depressions and drainageways.

Eggers and Reed distinguish between communities dominated by native species (primarily sedges (*Carex* spp.) and Canada bluejoint (*Calamagrostis canadensis*) as sedge meadows (PEM 1B) and those dominated other grasses, typically non-native invasive grasses (reed canary grass and redtop) and generalist forbs (giant goldenrod, giant sunflower, swamp aster, marsh aster, and wild mint) (Eggers, 2013).

4.2.6.2 Alterations to the Historic Condition

The loss of this community has occurred due to permanent impoundment flooding, succession to forest, and conversion to agriculture through the use of drainage and levee systems. In addition, invasive species, in particular reed canary grass (*Phalaris arundinace*) and purple loosestrife (*Lythrum salicaria)*, have invaded and now dominate large areas of the study area though biological controls introduced to control the latter have shown widespread success and reduced the species dominance in wetlands throughout Minnesota. *Phalaris* has the ability to alter its form and reproduction approach to adapt to dry or wet conditions and is likely at its greatest competitive advantage in sedge meadow–type communities (Galatowitsch, 1994).

4.2.7 Shrub/Carr

4.2.7.1 Community Description

Shrub/carr communities are considered an intermediate community between grassland/meadow and lowland hardwood forest. These communities often exist as a band between communities often in a 20- to 30-meter fringe between forest and meadow and sometimes as dominants throughout a basin. Dominance of shrub/carr throughout a basin is often a result of early land use patterns where farming practices cleared wet forest (tamarack) and the remnant shrubs within the forest regrew to form the dominant woody community (Curtis, 1971). Tree invasion in shrub/carr communities can be a slow process (often 20 years or more). Curtis (1971) assumes a minimum life expectancy of shrub/carr communities of 50 years.

Shrub/carr communities are found between emergent wetland communities and alluvial/willow forest communities. They are dominated by willow species (*Salix interior*, *S. nigra*, *Amorpha fruticosa*, *Cornus stolonifera*, *Cornus amomum*, and *Cornus racemosa*)*.* These shrub species can withstand periods of standing water and invading floodplain substrates but not areas of repeated disturbance. This community is often a mosaic of shrubs mixed with species typical of wet/sedge meadow grasses and forbs (*Calamagrostis canadensis* and a mix of *Carex* species with typical forbs of *Ranunculus hispidus*, *Phlox divaricata*, *Galium obtusum*, and *Lobelia cardinalis*) (Galatowitsch, 1994).

Shrub/Carr typically establishes when woody shrub species invade sedge/wet meadow and other wetlands due to alteration (typically a drawdown), fire or other disturbance that allows encroachment by the typical species of the community. Once established, Shrub/Carr can withstand frequent disturbance including extended inundation, though prolonged flooding will kill shrub species and allow for conversion to open wetland. In the absence of flooding, the community will typically convert to forested communities (Kost, 2007).

Wetland shrubs in the NER typically occupy and share a hydrologic zone with wet meadow communities. They occupy a zone too persistently wet for forest establishment. Shrub species of this community are adapted to persistent surface waters, commonly 2 to 3 inches through the growing season, but long–duration, deep flooding can reduce the community during extended periods of high water (historically associated with beaver activity). The shrub species of this community type can withstand periods of extended drought (Minnesota Department of Natural Resources, 2005).

An additional shrub-dominated community type consists of pioneering *Salix inteiror* and *S. eriocephala* found on recently deposited and exposed soils at the edge of the active river channel. These shrubs are known to inhabit regularly flooded areas near active channels, germinating rapidly on newly formed sandbars and mudflats. This assemblage is considered a part of the early successional Riverfront Forest type establishing the setting for cottonwoods, black willows, and other pioneering tree species.

4.2.7.2 Alterations to the Historic Condition

Raised pool elevations within the Mississippi River Valley have eliminated shrub/carr communities at lower elevations. Expansion of the flooded area might have provided some habitat at the somewhat higher elevations than the historic condition, though the relative narrowness of the valley in the NER likely reduced the overall cover of this community type.

4.2.7.3 Current Condition

This community is most threatened by encroachment of invasive species, particularly reed canary grass, which crowds out all other species once it establishes dominance. Shrubs in this community type have difficulty establishing if reed canary grass forms a monotypic stand. The invasive shrub glossy buckthorn (*Rhamnus frangula*) presents a similar threat, forming solid stands, precluding establishment of the shade-intolerant species of this community.

4.2.8 Persistent Emergent

4.2.8.1 Community Description

Persistent emergent (PEM) wetlands dominated by forbs and graminoids are located in areas of standing or slow-flowing water through most of the growing season. These communities are found in flat lowlands within the river floodplain, at the margins of bottomland lakes, in open swales, and in low-flow zones of the river channel.

The maximum sustained depth for these communities is typically 20to 60 inches but can be higher during a flood stage. In communities supplied by groundwater inputs, water levels might remain relatively stable, whereas in communities supplied by river flows, runoff, and precipitation, water levels can be more variable. Water level drawdowns occur predominantly with drought.

Nutrient levels are typically high in marsh communities. Floodwater and seasonal drawdowns allow oxidation of organic material and the release of nutrients. Substrates can range from mineral soils to

Figure 28. Submergent and Emergent Wetland Edge (Photo: S. Krych)

sedimentary peat or peat mats where wave action, river currents, ice scour, or drawdowns are not regular occurrences (Minnesota Department of Natural Resources, 2005).

The dominant perennial plant species typical of floodplain marshes are adapted to persistent elevated water levels, with flowering and vegetative structures extending well above typical water levels. Typical plant species of Mississippi River Valley marshes are dominated by perennial emergent species such as cattails, bulrushes, and arrowheads. The community can fluctuate during periods of drought, favoring annual forb species (beggarticks and smartweeds) occupying exposed substrates and mudflats. Extended periods of elevated water levels favor floating species such as duckweeds and common white water lily. Extended periods of high water levels will cause permanent conversion to shallow open-water communities dominated by floating leaved species (Minnesota Department of Natural Resources, 2005).

Emergent marshes are found in the transition zone between high-water flooded areas and areas that are not persistently flooded. They typically have water at or near the surface throughout the season. They are found away from direct flows in protected bays and sloughs. Water levels fluctuate between 3 feet and complete drawdown. Typical species include cattails (*Typha* spp.), Arrowheads *Sagittaria* spp.), bulrushes *(Scirpus* spp.), spike-rushes (*Eleocharis* spp.), water plantains *(Alisma* spp.), smartweeds (*Polygonum* spp.), cordgrass*(Sparganium* sp.), and docks (*Rumex* spp.). These species often occur as monotypic. Most species are perennials, growing from thick rootstalks. The exception to this is wild rice (*Zizania aquatica*), an annual of persistently flooded areas where water level fluctuations are limited in degree. This species is susceptible to uprooting with rising waters and, as with *Scirpus fluviatalis*, rising waters will limit photosynthesis and respiration, putting these species at a competitive disadvantage (Galatowitsch, 1994)

MnDNR recognizes two types of persistent emergent communities based on distinctions of both landscape position and soil. Northern mixed cattail marshes occur in shallow basins, depressions, and river backwaters. Substrates are muck; shallow, well-decomposed peat; and floating peat mats. Typical vegetation includes *Typha* spp., *Carex lacustris*, *Carex comosa*, and *Saggitaria latifolis.* Variation in communities is due to differences in water depth and substrate. Floating mats are presumed to be relatively stable above changing water levels. Standing, shallow water is present most of the year. This type succeeds to open-water communities if inundation is extended and might succeed to wet meadow during extended low water.

The second type, northern bulrush-spikerush marshes, can occur along stream borders in the northern parts of the NER on mineral soils that are held together by root mats. These communities might be dominated by floating leaved and submergent vegetation including *Polygonum amphibium* var. *stipulaceum*, *Lemna minor*, *Spirodela polyrhiza*, and *Potemageton* spp. Emergent forbs include *Scirpus validus*, *Scirpus fluviatalis*, *Eleocharis palustris*, *Sagitaria latifolis*, and *Sparganium* spp. Grasses and sedges might be common and can include *Scirpus validus*, *S. fluviatalis*, *Eleocharis palustris*, and possibly *Leersia oryzoides.* Forbs can include *Safittaria latifolia*, *Polygonum amphibium*, and *Sparganium* spp. (Minnesota Department of Natural Resources, 2005).

4.2.8.2 Alterations to the Historic Condition

Historically, this community would have occupied large areas of river backwaters in areas of wide extensive floodplain. Maintenance of the community would have relied on persistent or near-persistent surface waters to preclude invasion by woody tree or shrub species. Given the relatively narrow floodplain of the NER, it is unlikely that many new areas of PEM were created after construction of the lock and dam system.

Nutrient inputs have a substantial effect on plant composition, typically favoring highly competitive invasive species such as hybrid cattail (*Typha x glauca*) and reed canary grass (*Phalaris arundinacea*).

Past attempts at farming these areas often failed, and many have reverted back to a natural or seminatural condition.

4.2.8.3 Current Condition

Invasive plant species, hybrid and narrow leaved cattail, common reed (*Phragmites australis*), and reed canary grass are major concerns with this community type. These species are powerful competitors and, once they are fully established as monotype communities, restoration to native plant communities is difficult and often costly. PEM communities can be difficult to manage, since some species require periodic drawdown for seed set and germination, though the same drawdown can favor encroachment by invasives.

Habitat is available for a number of turtle species, and the community provides stopover areas for migratory waterfowl.

4.2.9 Open Water: Active River Channels

4.2.9.1 Community Description

Along the active river channel, vegetation assemblages are found in the zone between normal and high-water settings along active river channels with constant hydrologic flows. These communities are located in the flooded and regularly flooded zone immediately above active stream and river channels or on level or sloping bedrock between normal and high-water settings. They are inundated during periods of high water levels, typically during spring runoff or periods of frequent summer rain. Typical soils along active channels are composed of sands and gravel. Coarse soils might become droughty when exposed to sun during extended drawdown periods (Minnesota Department of Natural Resources, 2005).

MnDNR communities describing this condition include sand/gravel/cobble river shore (RVx32) and rocky river shore (RVx43). Upper zone vegetation can consist of *Salix interior*, *Amorpha fruticosa*, and saplings of *Populus deltoides*, *Acer saccharinum*, and *Salix* spp. In the lower part of active river channels, annual species such as *Eragrostis hypnoides* and *Cyperus squarrosus* dominate during drawdown periods.

In active river channels and in areas affected by wave action, submerged vegetation might establish on fine mineral or sandy mineral soils, boulders, or sedimentary peat. Vegetation typical of these active wave and stream flow areas includes *Eleocharis acicularis*, *Myriopyllum* spp., *Potamogeton amplifolius*, *Potamogeton gramineus*, *Potamogeton praelongus*, *Potamogeton robbinsii*, *Sparganium fluctuans*, and *Utricularia macrorhiza* (The Nature Conservancy, 2012). Single-species dominance is common in these submerged communities.

The variability of vegetation within this assemblage is due to its proximity to the dynamic influences of the river's edge. Fluctuations within this assemblage might shift regularly depending on long-term weather patterns and the ability of the Riverfront Forest species to fully establish, stabilize, and eventually create permanent riverfront habitat.

4.2.9.2 Alterations to the Historic Condition

The boundaries of these communities have shifted substantially after the construction of the Lock and dam system, which affected both the location and character of the shoreline. The active channel vegetation assemblages have been profoundly affected by reductions in flood fluctuations below dams, permanent inundation above dams, and the reduction in active scour and meander. In areas immediately upstream of dams, former active channel edges have taken on the character of lakeshores, where active channel flows have diminished but wave action due to winds on greater areas of open waters and recreational boat have increase wave action. Boat wave action causes severe adverse effects on these communities, particularly on large lakes near islands and shores. Nutrients and pollution are problematic, particularly in those areas where sediment collects in still pools immediately upstream of dams. Channelization through the use of wing dams has altered the historic condition by creating silt accumulation behind these structures and by altering the historic conditions where scour would have retained river banks as coarse sand and gravels.

4.2.9.3 Current Condition

Boat wave action is having severe effects on these communities, particularly on large lakes near islands and shores.

Invasive species are a major concern within this community type, including the wetland plant species narrow-leaved and hybrid cattails and purple loosestrife. Animal species of greatest concern within the NER include zebra mussels, Asian carp, and grass carp, all of which are present and common within this community type.

4.2.10 Open Water: Bottomland Lakes and Abandoned Channels

4.2.10.1 Community Description

Bottomland lakes and abandoned channels occur away from the active river setting in abandoned channels and between natural levees and the bases of bluffs. Vegetation community variation within this classification is largely determined by water depths and duration of flooding. In bottomland lake and abandoned channel settings, vegetation communities can range (from wettest to driest) from submerged aquatics to emergent wetlands to sedge meadows and shrub/scrub at the margins of open water. Vegetation communities associated specifically with these assemblages include floating aquatic and submerged aquatic communities.

In the deeper parts, submerged aquatic vegetation is found on sedimentary peat, often in single-species stands of common hornwort (*Ceratophyllum demersum*), common water-weed *(Elodea canadensis*), duckweeds (*Lemna* spp.), common water-milfoil (*Myriophyllum sibiricum*), whorled water-milfoil *(Myriophyllum verticillatum)*, floating pondweed *(Potamogeton natans)*, sago-pondweed (*Stuckenia pectinata)*, clasping-leaved pondweed *(Potamogeton richardsonii)*, flatstem-pondweed *(Potamogeton zosteriformis)*, white water-crowfoot *(Ranunculus aquatilis)*, common bladderwort (*Utricularia macrorhiza*), and tape-grass (*Vallisneria americana*). The typical species of this community can also be present in protected bays away from the active channel (The Nature Conservancy, 2012). Water clarity combined with depth affects the ability of root-submerged vegetation to persist.

Figure 29. Rooted macrophytes at the edge of North Lake, away from active river channel in an area flooded during much of the year.

Rooted floating aquatic communities occur in areas of intermediate depth between and interspersed with submersed and emergent vegetation. Typical dominants include American lotus-lily (*Nelumbo lutea*), bullhead lily (*Nuphar variegatum*), and white water-lily (*Nymphaea tuberosa*) (MnDNR, 2004). Species typical of both submersed aquatic and emergent communities are commonly found among floating aquatic species. Duckweeds can be common as a dominant or interspersed with the above species in stagnant waters (Galatowitsch, 1994).

Where drawdowns occur at the margins of bottomland lakes and ponds, mudflats can be present. These intermittently exposed surfaces cab become vegetated with a mix of perennial or annual vegetation in diverse or single-species-dominated assemblages. Annual vegetation tends to establish on newer mudflat areas, and, as rooted perennial vegetation becomes fully established, the area can shift toward rooted floating, emergent, or floodplain/Riverfront Forest community types depending on the hydrologic regime. Typical mudflat annual plant species of the NER are awned flatsedge (*Cyperus* *squarrosus*), rusty flatsedge *(C. Odoratus)*, red-root flatsedge (*C. Erythrorhizos*), false nutsedge (*C. Strigosus*), yerba-de-tajo (*Eclipta prostrata*), false pimpernel (*Lindernia dubia*), smartweeds (*Polygonum* spp.) and saltmarsh cockspur-grass (*Echinochloa walteri*) (Galatowitsch, 1994). Spikerushes (*Eleocharis* spp.), rushes (*Juncus* spp.), bulrushes (*Scirpus* spp.), smartweeds (*Polygonum* spp.), plantains (*Plantago* spp.), goosefoots (*Chenopodium* spp.), beggarsticks (*Bidens* spp.), arrowheads (*Sagittaria* spp.), giant bur reed (*Sparganium eurycarpum*), and golden dock (*Rumex maritimus*) can be prevalent late in the season (Minnesota Department of Natural Resources, 2005).

4.2.10.2 Alterations to the Historic Condition

Bottomland lakes and abandoned channels settings were flooded in large areas immediately upstream of dams constructed in the 1930s. Most affected were still waters immediately adjacent and hydrologically connected to the Mississippi River water levels. Notably, the large backwater lakes hydrologically connected to the river (such as Spring Lake at Hastings) are largely flooded and no longer exist as a complex of backwater lakes, emergent wetland, wet meadows, and floodplain type forests, but rather exist as either active channel shorelines. In those areas disconnected from river hydrology, backwater lakes persist (including Crosby Lake at St. Paul and Pickerel Lake at Mendota Heights, Minnesota).

Submerged aquatic vegetation suffered substantial losses during the extended droughts of the late 1980s in the NER but has recovered as river elevations have returned to pre drought levels. (U.S. Geological Survey, April 1999).

4.2.10.3 Current Condition

Boat wave action causes severe adverse effects on shoreline and submerged communities, particularly on large lakes near islands and shores. The adverse effects from wave action due to boating are greatest on those species adapted to the still waters of bottomland lake settings, typically located in protected bays and backwaters not historically affected by moving waters.

Invasive aquatic species are a major concern within this community type, including mussels, fish and plants. Many of the aquatic species of concern are adaptable to a wide range of conditions including those typical of eutrophic, shallow warm waters of bottomland lakes. Grass Carp is of particular concern as this large herbivore consumes large quantities of aquatic emergent vegetation and can substantially increase phosphorous levels.

Highly invasive *Typha x glauca* and *T. angustifolia* will invade temporary mudflats, germinating on open soils while exposed, persisting in these areas following flooding.

4.2.11 Groundwater-Influenced Lowland Communities

4.2.11.1 Community Description

There are a number of groundwater-fed and -influenced lowland communities in the Mississippi River Valley. These communities are difficult to identify using the HGM, which relies heavily on flood frequency to identify the community type. Because these communities often lie at the base of or even on the lower slopes of bluffs, their flood frequencies based on river elevation are often outside even the 20-year flood zone. MnDNR communities likely within the NER are southern wet ash swamp (WFs57), southern seepage meadow/carr (WMs83) and prairie extremely rich fen (OPp93) (Minnesota County Biological Survey, 2007).

Southern wet ash swamp is present on seepage areas on alluvial terraces below steep slopes with exposed bedrock aquifers or on glacial till drift where groundwater seeps through highly permeable aquifers, emerging at the ground surface. Soils are poorly to very poorly drained silty alluvium or colluvium under a thin layer of mucky peat (Minnesota Department of Natural Resources, 2005).

Southern seepage meadow/carr groundwater (WMs83) is located on seepages at the bases of river terrace or level wetlands fed by groundwater discharge. While these can be located within the river level flood zone, their identification through the HGM is limited. Soils can be mineral or muck/sapric peat. This community is semipermanently flooded, either during flood stages with a mix of waters derived from Mississippi River floodwaters (in lowland areas) or later in the season fed by constant groundwater discharge (Minnesota Department of Natural Resources, 2005).

Prairie extremely rich fens (OPp93) are rare communities found on locations with uninterrupted diffuse discharges of mineral-rich groundwater. They are not ponded and are located where surface water inputs are minor. Soils are peat with marl or tufa of carbonates. Fens within the Mississippi and Minnesota River Valleys are found on side slopes of large erosional features. Groundwater has a very high calcium concentration due to its origin flowing through calcareous glacial drift of bedrock. The flow of cold, anoxic waters creates ideal conditions for peat formation.

The plants that develop in these conditions (calciphiles) in Minnesota are plants adapted to the mineral-rich and perpetually flooded conditions. Some plant species found in calcareous fens in Minnesota are found only in these communities. These plants include sterile sedge (*Carex sterilis*), hair-like beak-rush (*Rhynchospora capillacea*), marsh arrowgrass (*Triglochin palustris*), and whorled nutrush (*Scleria verticillata*) (Minnesota Department of Natural Resources, 2005). There are four known occurrences of this community within or adjacent to the NER, though two are in the Minnesota River Valley and two are outside the River Reach boundary (Minnesota Natural Heritage Information System Database, 2013).

4.3 Wildlife

4.3.1 Historic Context

Historically, the landscape of the NER was less fragmented than it is today, and its habitat community characteristics reflected natural disturbances such as floods and fire. Schoolcraft (1953 [1821]) reported large ungulates grazing on the grasslands and prairies along the Mississippi River before Euro-American settlement. Some reports from Father Louis Hennepin, Henry Schoolcraft, and eastern Dakota tribes indicate that, although bison (*Bison bison*)were not as common as in the western prairies, they were abundant in the vicinity of the river for many miles above and below St. Anthony Falls and in the river terrace prairies (Hennepin, 1683 (1938)) (Schoolcraft, Narrative Journal of Travels Through the Northwestern Regions of the United States, extending from Detroit Through the Great American Chain of Lakes to the Sources of the Mississippi River, in the Year 1820, 1953[1821]) (Johnson, 1985).

Elk (*Cervis canadensis*) were also present on the prairie during the summer and in woodland habitats during the winter along the Mississippi River Valley near Elk River. Populations of these large deer declined in prairie habitats and in southcentral Minnesota after the 1830s (Schoolcraft, Narrative Journal of Travels Through the Northwestern Regions of the United States, extending from Detroit Through the Great American Chain of Lakes to the Sources of the Mississippi River, in the Year 1820, 1953[1821]).

White-tailed deer (*Odocoileus virginianus*) use a variety of habitat types in the NER but generally favor relatively open wooded cover, avoiding both dense woods and expanses of open prairie (Hazard, 1982). However, within the context of the river floodplain, historic plant communities included a mosaic of numerous forest/brush/grassland interfaces that provided abundant available habitat for this species.

4.3.2 Current Condition

The changes brought on by anthropogenic disturbance have altered species richness and abundance within the NER. Today, wildlife richness in habitats associated with the NER varies according to habitat characteristics that contribute to breeding sites, forage availability, food preferences, and cover availability for species occupying these vegetative communities. Each of the habitat characteristics also varies depending on the time of year and the need of each species using NER habitats. Some species will never leave the habitats in the NER during their entire lifecycle, as is the case with many invertebrates and some turtles, while others might use these habitats for only short periods, such as migration.

The absence of fire; the loss of mast-producing trees such as oaks, walnuts, and hickories; and the loss of invertebrate fauna associated with these communities can adversely affect both mammals that use the masts for forage and long-distance migrants (Rodewald, 2002).

Currently, white-tailed deer are abundant in the plant community types in the NER and can be negatively affecting plant communities due to overgrazing. These current population levels are primarily due to the lack of predatory species (primarily gray wolves (*Canis lupus*), and, to the west, grizzly bears (*Ursus arctos*)). These predators keep white-tailed deer populations low enough to minimize effects on plants and communities. Predators that prey on these large herbivores are now limited, and human hunting is the primary means used to control their populations.

4.3.3 Breeding Importance

The importance of habitats to wildlife and rare species that breed in the NER was summarized in *An Evaluation of Ecological Significance of the Vermillion Bottoms and the Lower Cannon Area* (Dunevitz-Texler, 2005). Dunevitz-Texler describes the areas in the NER as containing one of the largest expanses of floodplain native plant communities in southeast Minnesota.

Figure 30. Blandings Turtle (Photo: S. Krych)

These habitats contain one of the top four sites in the state for rare forest birds such as red-shouldered hawks (*Buteo lineatus*) and cerulean warblers (*Setophaga cerulea*). Rare or declining reptiles are just as reliant on the open water/active river channel, open water/bottomland lakes/abandoned channels, persistent emergent, and wet/sedge meadow community types.

Several rare turtles that occupy these habitat types include Blanding's (*Emydoidea blandingii*), wood turtles (*Glyptemys insculpta*), and smooth softshell (*Apalone mutica*) turtles. The water-dependent community types in combination with adjacent Floodplain Forest are critical to these species. These species can occupy home ranges of less than 10 acres and might use only habitats less than 500 feet from a nearby river (Minnesota DNR).

4.3.4 Area Sensitivity

Some species occupying forested habitats in the NER can be limited to large blocks of contiguous forest. These species are considered area sensitive and are generally thought to use forested habitats consisting of large core blocks of mature forest with low edge-to-area ratios. However, some studies indicate that small-scale changes in plant community structure and composition can have a larger effect on bird abundance than landscape-scale community factors (Knutson M. , 1995) (Kirsch, 2009). Species identified as area sensitive in the NER include yellow-billed cuckoos (*Coccyzus americanus*), ruby-throated hummingbirds (*Archilochus colubris*), red-bellied woodpeckers (*Melanerpes carolinus*), hairy woodpeckers (*Picoides villosus*), white-breasted nuthatches (*Sitta carolinensis*), brown creepers (*Certhia americana*), yellow-bellied sapsuckers (*Sphyrapicus varius*), and chimney swifts (*Chaetura pelagica*) (Knutson M. L., 2005) (Lebrun, 2008).

Many members of the bird community are heavily dependent on the present tall-canopied forests for breeding and feeding. These birds would be adversely affected by a large-scale change toward a small-stature forest, especially upper-canopy nesters and feeders and cavity-nesting birds. Other changes in forest composition, structure, and height could have corresponding effects on Floodplain Forest birds.

Several authors describe the importance of forest structure on avian communities such as those described by Morse (1989). These structural changes to the NER Floodplain Forest structure could affect the presence and abundance of species of management concern, such as cerulean warblers and bald eagles (*Halieaeetus leucocephalus*). Many avian species that are present in the NER include great blue herons (*Ardea herodias*), great egrets (*A. alba*), green herons (*Butorides virescens*), bald eagles, red-shouldered hawks, great horned owls (*Bubo virginianus*), eastern wood-pewees (*Contopus virens*), Acadian flycatchers (*Empidonax virescens*), least flycatchers (*E. minimus*), eastern phoebes (*Sayornis phoebe*), great crested flycatchers (*Myiarchus crinitus*), eastern kingbirds (*Tyrannus tyrannus*), blue-gray gnatcatchers (*Polioptila caerulea*), yellow-throated vireos (*Vireo flavifrons*), warbling vireos (*V. gilvus*), red-eyed vireos (*V. olivaceus*), cerulean warblers, and Baltimore orioles (*Icterus galbula*) (Knutson M. , 1995).

4.3.5 Fragmentation

Fragmentation of large, forested habitat is often cited as a reason for the decline in the richness of the avian community in the current Riverfront Forest, Floodplain Forest, and Slope Forests. Some researchers suggest that this could affect Floodplain Forest community types less than their upland forest counterparts. Knutson (1995) explains it this way:

> In uplands, croplands, pastures, and urban areas are adjacent to forests. These forest edges support high predator and cowbird populations that can negatively affect reproductive success of songbirds (Brittingham, 1983), (Paton, 1994), (Askins, 1995). In addition, upland forest patches are often separated by long distances (several km). When a species is lost from a patch, re-colonization may not occur, depending upon reproductive success in adjacent habitats and the distance between patches. Island biogeography theory predicts small patches, long distances from source patches, have low colonization rates (MacArthur, 1967). In the floodplain, the distance between patches is not great, in some cases only 5–100 m. Floodplain forests tend to be sinuous and interconnected, and adjacent to open water or marsh, quite different habitats from those that support predators and cowbirds in upland habitats.

In addition to large contiguous forests comprised of Floodplain Forest, Slope Forest, and Riverfront Forest providing habitat for sensitive or declining species, some species rely on habitat characteristics provided only in the UMR.

Floodplain forests, Riverfront Forests, and Slope Forests provide breeding-season habitat for avian habitat specialists, cavity nesters, neotropical migrants, some area-sensitive nesting species, and bark-gleaners. Researchers have found few Floodplain Forest specialists. However, one species that uses Floodplain Forests to the exclusion of other habitat types for breeding is the prothonotary warbler (*Protonotaria citrea*) (Petit, Breeding Biology of prothonotary warblers in reverine habitat in Tennessee, 1989). Some authors include red-shouldered hawks and bald eagles as Floodplain Forest specialists, but these species frequently nest in Floodplain forests, Riverfront Forests, and Slope Forests. They are also found in large blocks of upland forest, in the case of red-shouldered hawks, and in numerous other habitat types, in the case of bald eagles.

Figure 31. Prothonotary Warbler (Photo: S. Krych)

4.3.6 Migration and Migratory Importance

Each spring and fall, the Mississippi River and its associated forest, brush, grassland, and marsh habitats provide stopover habitat for migratory birds and some mammals. The river is also one of North America's major migration corridors for numerous species of waterfowl, raptors, shorebirds, songbirds, and bats. The region that includes the NER has a high species richness for breeding birds and provides important stopover sites for migrating land birds of all types (Ewert D. a., 1996) (Knutson M. L., 2005).

The ability of a migrating land bird to stop in high-quality habitats (that is, habitats with abundant food, low risk of predation, and minimum environmental stress) determines whether it reaches the breeding and wintering grounds in good physiological condition. Pre-settlement landscapes in the Midwest were dominated by a mosaic of forests, wetlands, and grasslands. Habitat loss, loss of species diversity, and fragmentation have drastically altered the landscape.

Within the fragmented landscape, many factors determine which habitats are selected by migrants. Macroscale effects can affect where a migrant first settles. Microscale effects, such as food availability, interspecific and intraspecific competition, shelter, and predation, will determine how a migrant fares at a particular site.

Food availability might be a primary factor in microhabitat selection within a habitat (Moore, 1993). Forests that consist of certain tree species and structure might be especially attractive to migrants. Some tree species support large populations of foliage insects and are therefore attractive to migrants after these trees have leafed out. Oaks (*Quercus* spp.), yellow birches (*Betula allegheniensis*), hackberry

(*Celtis* spp.), and others are examples of important food sources to foliage-gleaning species. Other tree species might be avoided as foraging sites by some species and not others (Robinson and Holmes 1984). Sugar maples and American beeches are examples of these.

Areas near water might be especially important to insectivorous migrants. Petit (1991) and Weisbrod (1993) found that many migrants and newly arriving summer residents concentrate near water. Aquatic habitats that produce large numbers of emerging insects might be particularly important early in spring migration, especially in northern areas where there might be less overlap between migration and the emergence of leaves. These habitats might also be important to breeding birds as sources of emergent insects in some areas (Busby, 1979), (Biermann, 1982) (Guinan, 1987). Some studies indicate that forested sites within 0.5 mile of major water bodies have the highest concentrations and species richness of migrants during spring migration.

Large concentrations of waterfowl also use marshes and open-water habitats to sustain their fat reserves during migration. Habitat selection by migrant species is largely driven by food availability and shelter, and varies seasonally and geographically (Ewert D. M., 1996). The NER is used by 40% of all waterfowl that migrate through the United States. Raptors such as bald eagles and golden eagles (*Aquila chrysaetos*) also follow the migrating waterfowl and overwinter along the Mississippi River between the Coon Rapids dam in Anoka County and Read's Landing in Wabasha County.

Figure 32. The Mississippi River valley provides important waterfowl habitat throughout (Photo: S.

The NER provides important food and shelter resources for a broad range of species including some species designated as species of conservation need. Sensitive species or species of high conservation concern breed within habitats present along the Mississippi River and its adjacent habitats. Species such as Henslow's sparrows, cerulean warblers (*Ammodramus henslowii*), prothonotary warblers, black-billed cuckoos (*Coccyzus erythropthalmus*), and Eastern whip-poor wills (*Antrostomus vociferous*) rely on habitats provided by plant communities in the NER.

The character of plant community types in the NER has changed drastically because of anthropogenic activities including the elimination of fire, channelization, farming, and the introduction of invasive species. These changes affected plant communities by decreasing native vegetation and altering its structure and composition. The landscape has become increasingly fragmented. These altered habitats, however, remain especially important to migratory land birds as stopover sites.

4.3.7 Flooding

Some bird species show evidence of lowered abundance in years of flooding. Blue jays (*Cyanocitta cristata*), house wrens (*Troglodytes aedon*), yellow warblers (*Setophaga petechia*), common yellowthroats (*Geothlypis trichas*), brown-headed cowbirds (*Molothrus ater*), and American goldfinches (*Spinus tristis*) show population reductions during years with flooding. Species showing increases in abundance during flooding include cerulean warblers and white-breasted nuthatches (Knutson M. L., 2005).

Flooding can be detrimental or beneficial for mammals that occupy these habitats. Terrestrial mammals that occupy forested parts of the floodplain are driven from areas when flooding occurs or are left stranded on the land with the highest elevations. Other species such as beavers (*Castor canadensis*), otters (*Lontra canadensis*), or muskrats (*Ondatra zibethicus*) might use the flooded forest during periods of high water.

The presence of invasive species also affects the plant community character of Floodplain Forests in the NER. The presence and expansion of species such as reed canary grass (*Phalaris arundinacea*), garlic mustard (*Allariea petiolata*), common buckthorn (*Rhamnus cathartica*), burdock (*Arctium* spp.), and dodder (*Cuscuta* spp.) can change the composition of wildlife species inhabiting the Floodplain Forests of the NER. Kirsch (2009) found that bird assemblage composition is primarily influenced by a lack of ground cover a, high percentage of reed canary grass as ground cover, and a low basal area.

5 HGM and Ecosystem Restoration Options

5.1 HGM Use and Applicability

The purpose of restoration efforts in the NER ecosystems as developed in the *Upper Mississippi River System – Ecosystem Restoration Objectives* (U.S. Army Corps of Engineers Rock Island District, 2009) is to focus on returning or maintaining ecosystem processes to more naturally functioning systems in light of current use and projected future uses. The following broadly defined objectives are assigned to meet this general purpose:

- Restoring stage variation to mimic natural discharge variability to benefit shallow littoral and wetland habitats
- Restoring or mimicking natural hydrologic connectivity where possible
- Reducing constituent transport (that is, sediment and nutrients to improve aquatic habitats)
- Creating or encouraging, through system management or reconstruction, greater structural geomorphic diversity
- Converting crops to native plant communities and having plans in place so that flood buyouts, budget surpluses, or stimulus spending opportunities can be acted on in a timely fashion
- Encouraging mixed-use floodplain management plans within the existing levee and drainage district framework
- Restoring secondary channel habitat
- Continuing to develop site-specific plans for sensitive tributary confluences (deltas and channelized tributaries)
- Identifying restoration subareas important to meeting the goals of Geomorphic Reach objectives
- Increasing plant community and structural diversity in fragmented and monotypic systems

Within the context of the above objectives, the primary focus of ecosystem restoration is restoring ecological processes. These processes are defined as "dynamic biogeochemical interactions that occur among and between biotic and abiotic components of the biosphere" (U.S. Geological Survey, 2013) and ecosystem function. In a large river system, this ecosystem function can include a focus on "transport of sediment, carbon, or nutrients from land to the sea or on broad relationships between fish and such characteristics as floodplain size" (Sparks, 1990). Ecological structure and function are inherently difficult to define due to the dynamic nature of these systems. However, preparing restoration goals allows managers to work toward a more fully functioning system within the confines of what is currently known about these systems and the dynamic forces such as invasive species or climate change that affect these systems (Stokstad, 2010).

Within the context of the human-altered environment of the NER, restoration planning must account for the historic reduction in the total area of natural communities present, alterations to ecological processes, and the shape and size of remnant habitats as they relate to overall landscape objectives. At the landscape scale, especially in a transitional ecotone such as the NER, which is located between multiple continental ecosystems, a variety of habitats (heterogeneity) would seem to be a reasonable goal. However, with the reductions in the total area available, landscape heterogeneity might be less desirable when planning for target species that need large patches of particular habitat types. For instance, large interior forest habitat can suffer substantial edge effects where small openings or corridors are opened up to edge species (see Section 4.3.5).

Ecological restoration should consider the pre-settlement patterns of natural communities as a starting point for restoration planning and, where possible, should seek to restore the NER to those pre-settlement habitats. However, it is important for restoration planners to consider whether major landscape alterations mimic natural processes, and, if they do not, how that affects restoration planning. For example, it might be better to restore Floodplain Forest types due to the historic loss of this type of forest rather than restore the grasslands that were actually present at the time of Euro-American settlement.

5.2 Methods

5.2.1 HGM Methodology

Hydrogeomorphic modeling has been applied in the Upper and Lower Mississippi River basins using detailed landscape assemblage, hydrogology, and soils data to develop maps of potential plant community distributions. Geomorphology data are effective at capturing "spatially complex but predictable patterns of primary forest succession" (Robertson, 1999). Using geomorphology as the foundational layer for HGM combined with other data sets has been valuable in large-scale restoration and management planning in the Upper Mississippi River Basin. Baseline abiotic data can be correlated to the likely plant community composition of the pre-settlement period and thereby guide restoration in the NER.

Previously, the model has been applied in the Middle Mississippi River Regional Corridor (Heitmeyer M. , 2008), the Chippewa River Ecoregion ((Heitmeyer M. , 2010), and the Mississippi Alluvial Valley (Lower Mississippi) (Klimas, 2009). The model as developed by Heitmeyer and Theiling for the Upper Mississippi River bottomlands provides guidance particular to the Upper Mississippi River Valley and Illinois River Valleys (Theiling C. E., 2012). Each ecoregion contains specific abiotic and biotic conditions distinct from other ecoregions. Abiotic differences are manifested in climatic conditions, river gradients and velocities, geological and geomorphic settings, water chemistry, and sediment loads. Biotic conditions in each large river reach are largely determined by these abiotic factors. In the NER, for instance, many species of southern oaks and hickories disappear as climates grow colder. The HGM incorporates project-specific parameters by applying what is known about pre-settlement vegetation communities at the regional and local levels, past and present land use patterns, river alterations, and current vegetation patterns.

Hydrology is the primary driver of large river floodplain landscapes. Hydrology and hydraulics are strongly influenced by geomorphic setting, which is itself the product of past river and glacial action. The HGM relies on Landscape Sediment Assemblages (LSAs) to classify the distribution of landforms and sediment in the NER. These LSAs were developed by Thomas Madigan in *Geomorphological Mapping and Archaeological Sites of the Upper Mississippi River Valley, Navigation Pools 1–10, Minneapolis, Minnesota, to Guttenberg, Iowa*. LSAs represent unique fluvial geomorphology features created by river actions and/or with an influence on the river valley (for example, upland hilltops and colluvial slopes). LSAs form the foundation of map overlays for identifying restoration potential. Soils and hydrological characteristics in the active river valley are overlain on LSA features to develop the predictive model that identifies the restoration potential of an area.

The NER study team used historic and current vegetation patterns relative to the four primary parameters of hydrology, geomorphic setting, soil texture, and vegetation (historic, present, and change over time) to corroborate what is known through literature reviews and best professional judgments about vegetation patterns and disturbance responses. This information was used to develop a first (internal and field) draft of the restorability of the natural communities in the NER. Vegetation patterns were overlain on LSA, hydrology, and soils maps to corroborate the team's assumptions regarding abiotic factors that influence the distribution of natural communities. The team took these draft maps into the field to verify presumed patterns, and looked at a range of settings from areas adjacent to flooded pools to settings in river backwaters substantially upstream of the areas most affected by the lock and dam system.

The following sections describe the development of hydrologic modeling, soil interpretation, geomorphology and vegetation patterns, and parameters used as overlays in developing HGM outcomes.

5.2.2 Hydrologic Modeling

Hydrogeomorphic modeling and analysis incorporates areas inundated at various flood flow frequencies. The flood flow frequencies used are the 2-year return occurrence (Q2 or 50% annual exceedance probability), the 5-year return occurrence (Q5 or 20% annual exceedance probability), the 10-year return occurrence (Q10 or 10% annual exceedance probability), the 20-year return occurrence (Q20 or 5% annual exceedance probability), and flood areas above the 20-year return occurrence. Additionally, the HGM methodology references several flow frequencies that are defined only in the context of this particular methodology. These are permanent, semipermanent, spring-summer, and 1-year flood flow frequencies.

Previous application of HGM to the NER floodplain has relied on the U.S. Army Corps of Engineers Upper Mississippi River System Flood Frequency Study (UMRSFFS). The UMRSFSS estimated river profiles for the 2-year to 500-year return occurrences. Additionally, USACE provided data for higher-frequency events of a 25% daily flow exceedance (P25) and a 75% daily flow exceedance (P75). These profiles are lower than the 2-year profile. However, in the current study area between Mississippi River miles RM 763 and RM 866 (103 river miles), the UMRSFSS provides only partial information. The UMRSFSS largely ends its analysis at RM 811, leaving a potential gap of 55 river miles. While the data on higher-frequency events provided by USACE might extend farther upstream to RM 845, there are conflicts between these elevations and the known lock and dam pool elevations as well as issues with regard to tying in assumed profiles.

The NER study team extended the hydraulic analysis area between RM 760 to RM 870 to ensure that flood polygons are completely defined in the study area. Elevations were converted as needed to the NAVD 1988 datum (North American Vertical Datum of 1988) by adding 0.16 foot to NGVD 29 (National Geodetic Vertical Datum of 1929) elevations. The actual datum differences range from 0.10 foot to 0.20 foot.

5.2.2.1 Post-settlement Flood-Stage Frequencies

Post-settlement flood areas reflect current hydrology and the impacts of the Mississippi River lock and dam systems and associated mainstem dams. Several areas are located behind levees, which were removed from the flooded areas. The levee areas, or areas outside the 500-year (Q500) floodplain, are:

- Wabasha, Minnesota, levee
- Lake City, Minnesota, levee

- Inver Grove Heights, Minnesota, levee
- Newport, Minnesota, levee
- South St. Paul, Minnesota, LFPP
- An industrial park on the east bank of the Mississippi River and south of Pigs Eye Lake, denoted as Zone X in the Ramsey County Flood Insurance Study (FIS)
- An open space area on the west bank north of Summit Park and south of the Gulf of Minneapolis port, denoted as Zone X in the Dakota County FIS
- The Metro Saint Paul Waste Water Treatment Facility, denoted as Zone X (Protected by Levee) in the Ramsey County FIS
- St. Paul Minnesota LFPP, with some additional areas on the east denoted as Zone X (Protected by Levee) in the Ramsey County FIS

The Mississippi River in the study area has a main navigation channel that is maintained by a series of locks and dams. Table 5 lists these dams, their locations, and the pool elevation ("Pool") created by each. Generally, the listed pool elevation is maintained during low flows. During less-frequent floods, where the dams might influence upstream flooding, the locks are operated at a reduced pool elevation. For the flood areas being considered for the HGM methodology, the listed pool elevations were used and formed a minimum flooded area for the study reach.

Table 5. Dam Tailwater Locations and Pool Elevations

Dam	Tailwater River Mile	Pool Elevation	
		Feet NGVD 29	Feet NAVD 88
Upper St. Anthony Falls	853.85	798.7	798.87
Lower St. Anthony Falls	853.23	749.5	749.67
Lock and Dam 1	847.50	724.6	724.77
Lock and Dam 2	815.05	686.7	686.87
Lock and Dam 3	796.80	674.5	674.67
Lock and Dam 4	752.60	666.5	666.67

Between RM 760 and RM 811, the UMRSFFS provides flood flow frequency elevations between the 2-year and 500-year recurrence intervals. The 20-year interval (Q20) was not provided in this reference. The 20-year interval elevation was linearly interpolated between the provided 10-year and 25-year intervals. USACE separately provided the 25% and 75% daily flow exceedance elevations. Profile elevations were further interpolated between each 0.5 river mile. Profile elevations were also estimated at the immediate upstream and downstream face of each dam.

There are limited existing profiles available from the USACE sources upstream of RM 811 (the confluence with the St. Croix River). To fill this data gap, information from various county Flood Insurance Studies (FIS) was added. The FIS provides flood profiles for the 10-, 50-, 100-, and 500-year intervals. The FIS that were used are:

- Preliminary Anoka County, Minnesota, and Incorporated Areas Flood Insurance Study Number 27003CV001A, 2011
- Effective Dakota County, Minnesota, and Incorporated Areas Flood Insurance Study Number 27037CV001A, June 18, 2010

- Effective Goodhue County, Minnesota, and Incorporated Areas Flood Insurance Study Number 27049CV000A, September 25, 2009
- Effective Hennepin County, Minnesota, and All Jurisdictions Flood Insurance Study Number 27053CV001A, revised December 31, 2005
- Effective Ramsey County, Minnesota, and All Jurisdictions Flood Insurance Study Number 27123CV000A, June 4, 2010
- Effective Washington County, Minnesota, and Incorporated Areas Flood Insurance Study Number 27163CV000A, February 3, 2010

To fill the missing intervals not included in the FIS profiles, the NER study team developed relationships from the USACE data in the reach between RM 804 and RM 811. The USACE profiles are shown in Figure 13. Two types of relationships were examined. One estimated the high-frequency events as ratios between the channel bottom and the 10-year interval. The second approach developed ratios between the dam pool elevation and the 10-year interval. After examining the flooded areas from each approach, the study team selected the second approach because it produced flood areas more consistent with aerial photographs and existing vegetation types.

The relationships used to fill profile data gaps are:

P75 = Pool
P25 = 0.16 × (Q10 – Pool) + Pool
Q2 = 0.46 × (Q10 – Pool) + Pool
Q5 = 0.82 × (Q10 – Pool) + Pool
Q25 = 0.53 × (Q50 – Q10) + Q10
Q200 = 0.40 × (Q500 – Q100) + Q100

Where:

Pool: the pool elevation

P75: 75% daily flow exceedance elevation

P25: 25% daily flow exceedance elevation

Q2: 2-year interval elevation (50% chance annual exceedance)

Q5: 5-year interval elevation (10% chance annual exceedance)

Q10: 10-year interval elevation (5% chance annual exceedance)

Q25: 25-year interval elevation (4% chance annual exceedance)

Q50: 50-year interval elevation (2% chance annual exceedance)

Q100: 100-year interval elevation (1% chance annual exceedance)

Q500: 500-year interval elevation (0.2% chance annual exceedance)

-

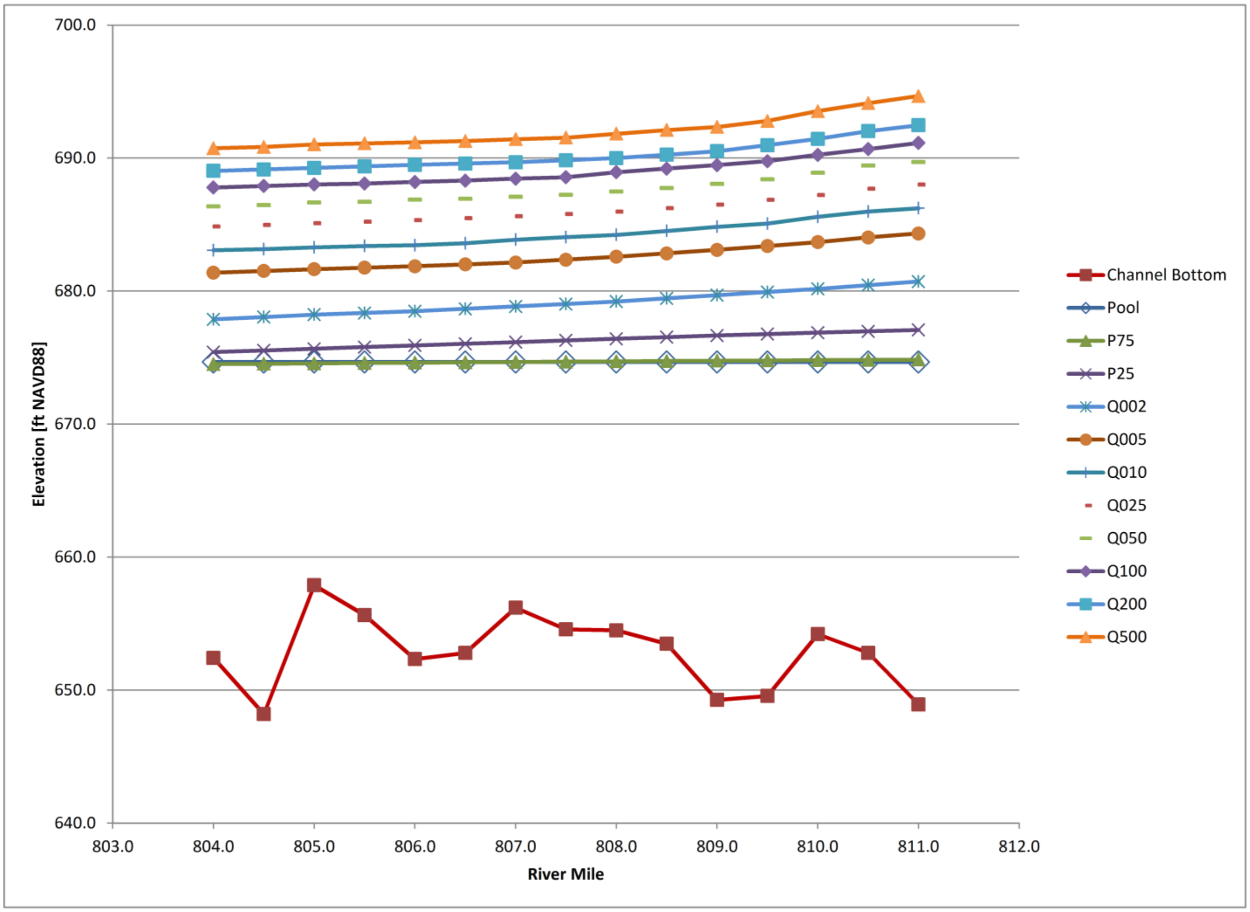


Figure 33. USACE UMRSFSS Profiles between RM 804 and RM 811

Some of the higher-frequency profiles were provided by USACE upstream of RM 811. The Q2 interval was provided up to RM 844. The P75 and P25 were provided up to RM 845.5. Above RM 845.5, no profile data were provided by USACE. Some issues were identified by the study team when using the available USACE profiles versus the assumed relationships above RM 811. For the Q2 profile, the USACE profile is between 0 and 1.5 feet below the assumed Q2 profile from RM 811.5 to RM 833 and 0 to 1.5 feet above the assumed Q2 profile from RM 833 to RM 845. At Lock and Dam 2, the P75 and P25 profiles are less than the pool elevation.

Figure 14 shows the differences between the USACE-provided profiles and the assumed profiles. To develop a consistent dataset, the study team applied the assumed profiles starting at Lock and Dam 2 (RM 815.05) and moving upstream. Alternately, the assumed profiles could have been applied starting at RM 845, although replacing P75 and P25 at the Lock and Dam 2 location corrects for the elevations below the dam pool.

5.2.2.2 Elevation and Bathymetry

Elevation was derived primarily from a LIDAR dataset with some small areas in Wisconsin compiled from the U.S. Geological Survey's (USGS) 10-meter NED. The elevation datum was adjusted for consistency with NAVD 88. The elevation data were resampled to a 3-meter cell size, which provided adequate detail with reasonable computer processing times in delineating flooded areas. The LIDAR dataset does not provide elevation information in water areas. Bathymetric information was needed in order to identify the high-frequency flood area. LIDAR slopes were computed, and slopes shallower than 0.1 foot/foot were identified as water. A combination of USACE bathymetric soundings and assumed water depth was used to lower the water surface elevation in these areas.

Where available, the study team compiled USACE bathymetric soundings of the main and side channels. The available USACE bathymetric information is listed below.

- RM 760 to RM 797
- RM 797 to RM 797.5
- RM 799 to RM 800.5
- RM 801.5 to RM 803
- RM 804 to RM 806
- RM 814 to RM 815
- RM 818 to RM 821.5
- RM 823.5 to RM 825
- RM 826 to RM 828
- RM 830.3 to RM 830.4
- RM 836.6 to RM 837.6
- RM 847.8 to RM 851.4
- RM 851.8 to RM 852.4

In some areas, the full river channel had bathymetric soundings, while in other areas only the main navigation channel was surveyed. Outside this area, the study team made assumptions about water depth. Along the main navigation channel, breaklines were used to connect the gaps between the USACE bathymetric soundings. The shoreline was used as zero water depth, and a TIN was used to create a channel between the shoreline and the navigation channel centerline. In areas with limited USACE bathymetric data, the main navigation channel was generally assumed to be 11 feet deep, and side channels were assumed to be 6 feet deep. Ponds detached from the river were assumed to be uniformly 6 feet deep.

5.2.2.3 HGM Methodology Flood-Stage Frequency and Approach

Flood frequency profile data were compiled at 0.5-river-mile intervals. At each lock and dam location, the profiles immediately downstream and upstream of the dam face were included. A TIN was developed between cross-sections to linearly change flood frequency profiles. ArcGIS, a type of GIS mapping and analysis software, was used to determine elevation cells lower than each flood profile in order to develop inundation polygons. Table 6 shows how the HGM hydraulic classifications were derived from the flood frequency areas.

Table 6. HGM Hydraulic Classifications

HGM Classification	Data Source
Permanent	Water surface defined by UMESC 2000 Land Cover Waters polygons
Semipermanent	Difference between the UMESC water and the P75 areas
Spring-summer	Difference between the P75 and P25 areas
1- to 2-year	Difference between the Q2 and UMESC Water areas
2- to 5-year	Difference between the Q5 and the Q2 areas
5- to 10-year	Difference between the Q10 and Q5 areas
10- to 20-year	Difference between Q20 and Q10 areas
20- to 500-year	Difference between the Q500 and Q20 areas

The HGM assumes that hydrological effects are river stage driven rather than derived from either localized runoff or groundwater systems. In the NER, especially in areas where the valley narrows and river gradients are greater, wetlands and even lakes within the valley have surface water elevations substantially above ordinary river levels. Crosby Lake in St. Paul is an example, where ordinary water is normally isolated from the main channel about 12 feet above the ordinary river level but is flooded most years and ringed by emergent wetland (personal observation, A. Randazzo). This setting and others like it (see Section 5.2.6), which are fed by groundwater and local surface water sources, are not readily identified by the hydrological modeling. In many areas in the NER, hydrological connectivity is fully integrated, as is the case at the Rookery in St. Paul, or in the Vermillion Bottoms where backwaters are fed by both the Mississippi River and tributaries. Some of the hydrologically isolated areas are largely identifiable in soils data, National Wetlands Inventory (NWI) maps, Federal Emergency Management Agency (FEMA) flood map elevations, aerial photographs, topographic maps, and marsh and lake LSAs. The NER study team used its best professional judgment to identify groundwater fed marsh and meadows and, where open water is mapped in UMERC and NWI maps, these locations are identified accordingly. Numerous locations were field verified to ensure accuracy.

5.2.4 LSA Interpretation

LSAs (Madigan, 2001)are mapped units representing discrete geomorphological patterns within the Mississippi River Valley. The mapped units were slightly modified by Theiling and Heitmeyer (2012) and were updated by the study team where errors were clearly apparent during analysis. LSA maps are provided in Appendix B (Landscape Sediment Assemblage Type) and Appendix C (Age Class). Theiling and Heitmeyer identified nine general classes of LSAs with similar characteristics (Paleo Floodplain – Well Drained is not present in the St. Paul District and is not discussed here). These classes, discussed below, helped the team sort the more refined LSA types into more broadly defined classes. The Theiling and Heitmeyer descriptions are divided into the LSA categories below:

- **Modern Aquatic Classes** include classes of open water, either (1) within the historic channel and lakes or in backwater lakes or (2) in backwater lakes created by the lock and dam system. This designation includes Waters (W).
- **Active Floodplain – Poorly Drained** is low-lying floodplain of vertical accretion origin historically flooded and presently flooded in most years. Soils tend to be fine textured over coarser material. These often lie in tributary confluences or river backwaters or sometimes behind levee walls, isolated from the main channel. These areas are flooded in the lower portions of dammed pools. Landforms include Main Channel Vertical Accretion Marshes (MVM) and Undifferentiated Vertical Accretion (MVU), Tributary Floodplain (TF) and Tributary Fan Delta (TF), and Tributary Meander Belts (TY).
- **Active Floodplain – Well Drained** is areas of lateral accretion with coarse soils that, despite variable and often frequent flooding, do not retain water. Landforms are found on Main Channel Islands (MCI) and Main Channel Lateral Accretion (MLB) with coarse soils, Vertical Accretion Splays and Crevasses (GSS) and Main Channel Vertical Accretion Levees (MVL).
- **Paleo Floodplain – Poorly Drained** is poorly drained vertical accretion areas located at high-elevation flood stages or above the elevation of active river hydrology. Typically on poorly drained soils, these areas form lakes and backwater sloughs. Above these zones, these areas function as overflow channels. Landforms include Inactive Channel Lakes (IVS) and Inactive Channel Vertical Accretion (IVU).
- **Natural Levees** occur as elevated, well drained areas paralleling relatively stable channels or as crevasse splays extending from channels cut into natural levees and spreading into adjacent low-lying areas. In the St. Paul District, flood frequency ranges from Semi-Permanently flooded to more than 20 years; however, typical flood frequency is less than 5 years. These are typically stratified soils containing loam, sand, silt, and clay. The landform feature is Main Channel Vertical Accretion Levee (MVL).
- **Alluvial/Colluvial Aprons** are found at the bases of bluffs that consist of mixed material deposited from adjacent slopes and tributary valley walls. These areas are generally dry to mesic

and are generally well above flood stage except where steep slopes meet the river's edge. The landform feature is Valley Colluvial Slopes (VCS)

- **Sandy Terraces** are derived from the period of Wisconsin Glaciation or Holocene Era and found above the 20-year flood stage. These areas include Glacial Terraces (GTL, GTM, or GTH), Eolian Dunes (EDT), and elevated Stream Scarps (GSS).

The existing LSA data set coverage as provided by USACE ends about 10.5 miles short of the northern limits of the study area. The scope of work for this project includes the Mississippi River extending upstream of Lock and Dam 1 to the Coon Rapids Dam located north (upstream) of St. Anthony Falls. Since the study team determined that the Minnesota Department of Transportation (MnDOT) had completed a separate Logistics for System Analysis (LfSA) model for the Mississippi and Minnesota River floodplains, the USACE requested a review of the feasibility of using MnDOT LfSA data for use within the current scope of work. It was agreed that the study team should continue as planned with the upper Mississippi River segment and should use the available MnDOT LSA data to correlate and assimilate into the existing LSA model.

The methodology used to convert the MnDOT LfSA data into the existing St. Paul District LSA classifications included evaluating the landform types along the Mississippi River floodplain for the study area using ArcView (a computer program for visualizing GIS data) for both the existing St. Paul District LSA data and the MnDOT LfSA data layers to initially develop a list of observed landforms in the study area for further evaluation. A comparison table was developed for the observed landform types that included a listing of habitat characteristics, LSA codes, and landform types for both the St. Paul District LSA and the MnDOT LfSA classifications. Based on available aerial photographs, topographic maps, and soil survey information, the study team correlated the MnDOT LfSA polygons that represented each landform type north of the existing St. Paul District data and assigned corresponding St. Paul District LSA codes in order to maintain a similar classification system throughout the study area. The landform polygons adjacent to the transition boundary between the St. Paul District LSA data and the MnDOT LfSA data were interpolated and edge-matched for mapping continuity.

Since the Mississippi River floodplain north of St. Anthony Falls is relatively narrow and linear with limited floodplain habitat and landform diversity, the conversion accuracy was generally predictable. Several polygon areas that presented slight differences in the habitat characteristics were "ground–truthed" in order to increase the level of interpretation accuracy and model consistency.

5.2.3 Soil Interpretation

Soils data were gathered on a countywide basis using SSURRGO and STATTSGO soils maps and associated metadata, combined with soil texture information gathered from Official Soil Series Descriptions provided by the USDA-NRCS (https://soilseries.sc.egov.usda.gov/osdname.asp). Soils information was reduced to the official series name, and textures were defined at this level. In GIS software, the study team consulted county soils data from Anoka, Hennepin, Ramsey, Dakota, Goodhue, and Wabasha Counties in Minnesota and from Pierce, Pepin, and Buffalo Counties in Wisconsin. Individual county shapefiles were unioned into a single coverage in which simplified soil texture attributes were added to all soil polygons. This simplified texture map was used as the HGM layer as the criteria for soil texture.

Generally, soils data are at a higher resolution than LSA polygons, and the study team observed that, within LSA, soil patterns can at times identify more subtle distinctions between natural communities. For example, soil data often identify vertical accretion levees more narrowly than LSA types, and thus clay and silt soils behind natural levees, where one would expect a transition to Floodplain Forest from Riverfront Forest, are often not readily identified. Additionally, bottomland lakes and PEM community types are typically indicated in soils data as open water, or very fine soils at a more-refined scale than in LSA data.

At the site scale, county soils data are valuable at the planning level to identify with greater specificity more subtle distinctions in natural area restoration. In final restoration potential maps, certain areas, particularly those with highly variable natural community types on the ground and with highly variable soils information contained with LSA boundaries, are identified as multiple natural community restorability types (for example, FF/PEM and Tributary Fan/Delta).

5.2.2 Vegetation Mapping and Field Sampling

The study team determined the composition of historic vegetation communities by examining historic accounts of the early post-contact landscape using a variety of narrative sources that described general landscape characteristics just prior to and early in the period of U.S. westward expansion ((Dobbs, Historic Context Outlines: The Contact Period Contexts (ca. 1630 A.D.-1820 A.D.), 1990a) (Dobbs, Historic Context Outlines: The Contact Period Contexts (ca. 1630 A.D.-1820 A.D.), 1990b) (Dobbs, Outline of Historic Contexts for the Prehistoric Period (ca. 12,000-A.D. 1700), 1990c) (Schoolcraft, Narrative Journal of Travels Through the Northwestern Regions of the United States, extending from Detroit Through the Great American Chain of Lakes to the Sources of the Mississippi River, in the Year 1820, 1953[1821]) (Winchell, 1881) (Allen, 1870), (Mississippi River Commission, 1890) (Coues, 1895) (Schoolcraft, 1832) (Long, 1817) (Flint, 1828)) and the Marschner Pre-Settlement Vegetation Map of Minnesota (Marshner, 1930) and Finley's Original Vegetation of Wisconsin (Finley, 1976). The study team determined that it was important to rely on data sources that focused on the NER and its particular regional disposition as transitional ecotone rather than seeking broader resource descriptions that are not necessarily applicable to the narrowed floodplain valley and colder climates of the NER.

Public lands survey (PLS) notes and maps completed in the 1840s and 1850s provide valuable information on historic vegetation patterns, tree species, and landscape character by using replicable survey techniques to establish land ownership, governance, and legal boundaries. These surveys, which were initiated under a 1785 Act of Congress titled "An Ordinance for Ascertaining the Mode of Disposing of Lands in the Western Territory," were intended to facilitate the sale of public land. The PLS established a Township-Range-Section system on an approximately 1-mile grid across the American West. As georeference points, surveyors identified the closest "bearing tree" and recorded its species and size. In addition, line notes also describe the general landscape character (bottomland forest, prairie, water, swamp, etc.), vegetation value (often for the purpose of identifying usable timber), significant trees, geological changes, soil characteristics, structures, streams, rivers, and vegetation breaks.

These surveys were known for errors, including fraudulent misstatements , honest misidentifications of tree species, or lack of specificity in tree identification (Almendinger, 1996). Misapplication of these data is a risk due to the surveys' occasional misidentification of species, but, if the PLS data are used at a broad scale and/or if the landscape descriptions are used, they are an invaluable tool for recreating vegetation patterns. In addition, Minnesota digitized versions of the data identify only section corner locations, making the information valuable at a broad scale but not within sections. The Minnesota and Wisconsin DNRs have each digitized PLS data into GIS shapefiles that allow digital analysis and overlays.

Using the digital PLS (MnDNR and WiDNR) and digitized 1890s landcover (USMEC), the study team created an approximate pre-contact vegetation map using 1890s polygons and PLS points to loosely identify prairie/barrens, wetlands, agricultural and water polygons (see Appendix L). The landcover polygons digitized by UMESC identified broadly defined grasslands, barrens, forests, wetlands and waters, and urban areas. The openings and barrens identified in the 1890s coverages correspond very closely with 1840s and 1850s bearing tree species typical of barrens (bur and red oak) and surveyor landscape descriptions in the bearing tree data, including those areas considered treeless (shown as "_" on bearing tree points in Appendix L maps).

The study team assumed that barrens and openings in the 1890s landcover were likely to have been those areas with least tree cover prior to Euro-American settlement based on the ease of tree clearing, and these areas were typically those shown as agriculture or grassland in the 1890s landcover. It is likely that the map is skewed toward openings, as by 1890 agriculture was firmly entrenched and forests were being or had been cleared for farming. Conversely, fire suppression might have favored some forest encroachment into previously open lands and barrens. The resulting maps (see Appendix L) correspond very closely with LSA, soil, and flood frequency parameters as well as with historic descriptions of areas identified as openings (for example, Prairie Island and Grey Clouds Island).

Current accounts of remnant vegetation communities also provide valuable source information for understanding the pre-contact natural communities. Using rare species inventory data and remnant natural community data sets from Minnesota and Wisconsin, the study team targeted remnant patches for field inspections. Remnant patches offer insights into biological composition and associated abiotic interactions, edge effects, invasive species impacts and controls, and species-specific adaptations.

The documents and GIS data sets produced by MnDNR (2005), WiDNR (2013), and Curtis (1971) are largely drawn from field data collected at remnant plant communities in Wisconsin and Minnesota and provide valuable insight into ecological process, succession, plant species adaptation, landscape setting, and subtle distinctions between community type and subtype. Galatowitsch and McAdams (1994) performed extensive literature reviews specific to the Upper Mississippi Region detailing natural community site requirements, disturbance responses, succession, and species composition. All of these documents examined current threats and presumptions regarding historic settings and the presumed effects of land use alterations.

Considerable literature is available documenting both historic and present vegetation patterns of the landscape in the NER and the relationships between plant species and landscape features. Botanical species distribution is well understood as a response to site-specific characteristics, with overall community composition the result of individual species' ability to inhabit specific soil, hydrological, climatic, chemical, and disturbance traits of a site on a time and space scale. The landscape setting, disturbance, and abiotic conditions suitable for the species that comprise typical vegetation assemblages are well documented. In addition, the distribution of habitat types related to geomorphic patterns has been well documented and is fundamental to the primary literature used to develop the HGM matrix (Galatowitsch, 1994) (Minnesota Department of Natural Resources, 2005) (Wisconsin Department of Natural Resources, 2012) (Curtis, 1971). The study team overlaid geomorphic setting, soils, and hydrology on multiple time period landcover data sets in order to develop the HGM matrix for restoration potential (see Table 7).

The hydrogeomorphic matrix (see Table 7) is the result of the following sequence of investigation, with the study team revisiting earlier steps in the sequence when questions arose:

- Historic land use and landcover GIS data and narrative sources were collected and reviewed in order to document land use changes and river alterations as background source data for HGM development and decision-making. Historic maps and narratives provided the team with valuable source information regarding river training structures, land use development in the NER, and the potential implications of historic and current alterations on natural communities.
- Historic landcover sources (PLS notes, bearing tree data, and MRC maps) were used to develop the landcover of the 19th century prior to Euro-American settlement (Appendix L) including the

distribution of major natural community types (forest, bottomlands, barrens, brush and thicket, prairies and openings, wetlands, and water).

- MRC maps provided data about the distribution of natural communities about 50 years after Euro-American settlement (Appendices G and M).
- The above data sets were overlain on geomorphology (Appendices B and C), flood frequency, (Appendix P), and soil texture (Appendices D) maps to corroborate the affinity of natural communities for these abiotic features based on the literature cited above (Galatowitsch, 1994) (Minnesota Department of Natural Resources, 2005) (Wisconsin Department of Natural Resources, 2012) (Curtis, 1971). Analyzing these data sets required substantial manual interpretation, since the resolution of spatial information is either interpreted at different scales or is created under different circumstances (field created versus remotely created). The team's later field verification focused on those areas where inconsistencies were most apparent.
- Point data coverages were created for all major input layers (landcover sets, flood frequency, soils, and LSA types) to make it easier to cross-reference input data with LSA/HGM polygon assumptions.
- Using current aerial photographs, state DNR landcover, natural features data, threatened and endangered species data, federal agency ownership information, and local and county public land coverages, the team identified higher quality public lands and higher quality remnant natural communities for field investigation.
- A draft HGM matrix was created using the above overlays, previous HGM studies, and literature review for use during the field verification. The team visited remnant natural sites, restored areas, and disturbed settings in all five study reaches in order to corroborate the findings of the draft HGM matrix at remnant sites and to assess the impact of landscape changes. The findings from the field visits were used to refine and/or redefine the HGM matrix based on parameters seen in the field.
- The draft HGM matrix was finalized following field visits, where uncertainties in abiotic factor composition in the mapping were corroborated with remnant natural communities to determine actual field verification.
- Where data were unavailable (for example, St. Anthony/Coon Rapids Pool pre-settlement vegetation or urban soils data), the final HGM matrix was extrapolated to determine restoration potential.

The HGM relies on a broad set of data coverages to determine best options for restoration. None of the data sets alone offers a clear indication of best restoration options. The study team found that cross-referencing each of the abiotic features with what is known about pre-settlement conditions and botanical responses to environmental factors was borne out during the field verification. In general, geomorphic surface was the strongest predictor of pre-settlement communities, but the scale of the data, especially in the NER, lacks some of the specificity that will be required when planning at the site level.

Certain geomorphic classes correspond very strongly with the patterns of pre-settlement vegetation communities; in particular, upland prairie and savanna type communities occupied most of the Glacial Terrace and Scarp settings. Generally, valley colluvial slopes were occupied by mesic forest largely due to the fire-break character of the steeply sloping bluffs of the NER, though we know that goat/bluff prairies were and remain present on shallow bedrock bluff faces. Likewise, geomorphic surfaces within the river bottoms tended to provide strong indications of historic and expected forest community types, though these communities do occur on a dynamic time scale. Generally, floodplain and Riverfront Forests are found on Main Channel Vertical Accretion and Main Channel Lateral Accretion surfaces, as expected given associated soil types associated with LSAs and vegetation community types. Flood frequencies and soil texture tended to bear out this distinction. Within the NER and its relatively narrow valley, time and space shifting of abiotic and biotic features occur naturally over time through flooding and deposition or catastrophic disturbance. Management practices may mimic these patterns to simulate natural processes.

Soils and hydrology specificity were the driving determinants of some pre-settlement vegetation types in the final HGM matrix. On Main Channel Islands, the coarseness of LSA polygons was not detailed enough for the team to distinguish between different parts of each island. These settings often contain both Riverfront and Floodplain Forest types, with the former located at the upper edge and sides and the latter on more-settled lowlands in the center and lower parts of teardrop-shaped islands. The HGM sorted these islands based on soil type, where islands mapped with finer soils were designated as Floodplain Forest and sandier islands were designated as Riverfront Forest.

5.2.4 Results: HGM Application (Restoration Potential)

Using the basic principles of the HGM approach as applied in other reaches of the Mississippi and Illinois River Basins, this project evaluated restoration potential at the landscape-scale level in the NER. The HGM outcomes can aid in restoration planning at scales ranging from the broad ecoregion to site–specific, projects. The information compiled in this evaluation and associated maps and datasets can be used to identify pre-settlement vegetation communities and to identify which landscape characteristics (biotic and abiotic) are associated with those communities. Users of the information can identify which historic community types associated with abiotic landscape features are appropriate for future restoration approaches considering historic changes to the landscape and present and future uses. Based on landscape and land use changes, the information provided can aid in restoration decision-making while accounting for landscape alterations and their impact on natural community processes. By extension, USACE and partner agencies can use the HGM results to develop planning approaches to other land use and management decisions to aid in restoration of ecological health (such as river drawdown, land development plans, and so on).

Accompanying this evaluation is a set of appendices that are available to agencies and conservation organizations to assist them in planning for future river valley restoration in the NER. The maps in the appendices and GIS data can be used to identify physical features, ecological processes, and landscape changes across scales from site to ecoregion. Site-based efforts will require further study of microtopography, microclimate, and finer-scale soil and hydrologic conditions, but the baseline data available will assist in regional decision-making. Restoration potential should take into consideration a range of factors in order to determine the likelihood of success. These considerations should include:

- Historic community types.
- Historic physical and biological composition as well as factors of ecological relationships prior to large-scale landscape alterations.
- Changes to the landscape that affect natural community sustainability and maintenance. This step will require greater detailed study at the site level.
- Expected natural community responses to landscape alterations. This is an essential step in the planning process, particularly considering alterations to the hydrologic regimes of the NER. Natural communities developed in concert with soils and geomorphological conditions, and with the navigation channel and associated flooding of riverfront areas are, in many cases, presently located in areas above historic riverine formation.
- Future planning within the river valley or landscape and global changes that could affect project outcomes (such as changes to navigation channel management, land management changes,

global climate change, and so on). This evaluation and GIS can be used to assist in directing other management efforts as they relate to ecological restoration initiatives.

Table 7. HGM Matrix of Restoration Potential

Habitat Type	Geomorphic Surface	Soil Types	Flood Frequency	Notes
Riverfront Forest	Main Channel Islands (MCI) and Main Channel Lateral Accretion (MLB)	Loamy Sand, Alluvium	Variable (Semi-Permanent to >20 years)	
	Main Channel Vertical Accretion Crevasses/Splay (MVC)	Loamy Fine Sand	1–2 Year	
	Main Channel Vertical Accretion Levees (MVL)	All soil types	Variable (Semi-Permanent to >20 years)	Coarse LSA types do not capture clay soils deposited behind levees (Floodplain Forest).
	Lacustrine Shoreline Beaches/Cusps	Sandy Loam	1–5 Years	All instances are found as tributary fans of small streams at edge of Lake Pepin on sandy substrate at lake/river's edge. Soil, FF, and wave action support RF.
Floodplain Forest	Tributary Fans/Delta (mosaic with PEM/WM), Inactive/Minor Channel Vertical Accretion Undifferentiated (IVU) and Main Channel Vertical Accretion (MVU) Main Channel Islands (MCI)	Silt Loams	1–2 years	Largely determined by soil type with finer-grained soils supporting species of this natural community.
Floodplain Forest/Wet Meadow or PEM Mosaic	Tributary Floodplain (TF) and Tributary Meander Belt (TY)	Silty Clay Loams	Permanent to 1–2 years	Often identified by air photo signatures of banded oxbows and backwater lakes.
Slope Forest, Dry Forest, Mesic Forest	Valley Colluvial Slopes (VCS)	Rocky Lands, Coarse Sands to Silt Loams	>20 years	
	Tributary Floodplains (TFT)	Sands and Loams	>20 years	Found in V-shaped valleys of small streams with narrow floodplain and sandy soils.
Prairie/Savanna	Glacial Terraces (GTL, GTM, GTH) Glacial Stream Scarps (GSS) Eolian Dunes (EDT)	Well Drained Loams and Sands	>20 years	
Persistent Emergent (PEM)	Main Channel and Inactive Channel/Minor Channel Vertical Accretion Marshes (IVM and MVM) Tributary Marshes (TM) and Abandoned Glacial Stream Channels (GSC)	Silt Loams and Silty Clay Loams	NA (see notes)	Many of these communities in the NER lie above normal river level stages, with mixed groundwater and river flooding sources. Project team best professional judgment.
Wet/Sedge Meadow	Abandoned Glacial Stream Channels (GSC)	Fine Sandy Loam and Loam	Seasonal	

Habitat Type	Geomorphic Surface	Soil Types	Flood Frequency	Notes
	Main Channel Vertical Accretion Marshes (MVM)	Silt Loam	See PEM notes above	Many of WS/M are located up slope of normal river stages.
Shrub/Carr	Margins of Tributary Channels, Side Channels, Sloughs/Lakes/River Channels	Silts and Clays	1–2 years	Natural occurrences are found at transition between lowland forest and meadow/PEM.
Active Channels	Margins of Active Channels	Water	Semi-permanent to permanent	
Bottomland Lakes and Abandoned Channels	Main Channel Vertical Accretion Lakes (MVS) and Inactive/Minor Channel Vertical Accretion Lakes (IVS)	Silt and Clay Loams	Semi-permanent to permanent	

5.3 Results: Vegetation Communities Restoration Potential

The vegetation communities discussed in Chapter 4 were identified in the HGM based on their adaptations to replicable parameters applicable on a large scale using remote data sources. These communities show proclivity to soils, geomorphology, flood frequency, and land use patterns across a broad landscape scale. At the more refined level, and for the purposes of restoration and conservation planning "on the ground," these communities share certain aspects across more broadly defined types that lend themselves to a discussion of their shared challenges and improvement potential for ecological functions, values, and sustainability. Shared characteristics in many cases include hydrologic regime; disturbance factors, particularly invasive species management; and control and interactions between types.

The following recommendations are intended to provide general guidance for planning successful river valley restoration of ecological process and function.

5.3.1 Wet Forest Communities

Floodplain and Riverfront Forests

Riverfront Forests HGM: Riverfront Forests are found on LSA types Main Channel Islands (MCI) and Main Channel Lateral Accretion (MLB), where flooding impacts include high velocities with associated flotsam and deposition as well as complete drawdown of river levels at higher elevations at riverfront locations. Riverfront Forests on MCI sites are associated with Loamy Sand and Alluvium with a variable flood frequency ranging from seasonally flooded to greater than 20 (typically 1 to 5) years.

On the interior parts of islands away from the impacts of active river flows and velocities, Floodplain Forest establishes on heavier soils, though these might not be evident at the scale of LSAs. On Main Channel Vertical Accretion Crevasses/Splay (MVC), Riverfront Forest is expected on Loamy Fine Sand with flooding typically in the 1- to 2-year frequency range. All Main Channel Vertical Accretion Levees (MVL) are identified as potential Riverfront Forest, located directly at river's edge with flood deposited alluvium. The LSA polygons are in many cases too coarse to identify backwaters immediately behind the riverfront levees, so, in come cases, finer soils are present, and these areas are often dominated by trees of the Floodplain Forest community.

Along the exposed shores of Lake Pepin, where soil sorting due to wave action and regular flooding with sometimes steep topography produces Lacustrine Shoreline Beaches (LSB) and Shoreline Cusps (LSC) with regular flooding, Riverfront Forest is expected. Soils in these LSAs tend to be Loamy Sands with typical flood frequencies ranging from seasonal to 5 years. LSA type Valley Colluvial Slope (VCS) also contain habitat for this community where the VCS is located immediately adjacent to the main channel.

Floodplain Forest HGM: Floodplain forests occur on LSA Tributary Fans/Delta (TFD) in a mosaic with emergent wetlands and on Main Channel Vertical Accretion (MVU). In these settings, soils tend toward Silt Loams on settings that are generally flat and within a flooding range of 1 to 2 years. In Tributary Fan settings, hydrology appears to determine whether an area is treed (slightly elevated settings) or emergent wetland (semi-permanent to permanently flooded). Main Channel Vertical Accretion settings are typically protected from scour and debris, both behind natural river levees and parallel to the main channel where damaging velocities are greatest.

Mixed Floodplain Forest Types

Ridge and Swale: Adjacent to active river channels and lakeshores, ridge and swale settings develop due to successive flooding events or wind action creating beach ridges. Vegetation composition in ridge and swale settings can be sorted on a gradient of time of establishment, frequency of and timing of previous disturbance (flooding), soils, and topographic position. Within the NER, this setting can be a mix of Floodplain Forest in protected and sedimented lowland flats, Riverfront Forest at the river's edge, and persisting on coarser soils away from the river or open wetlands where ordinarily high water persists. Shrub scrub can also be present at the interface between Open Wetlands and Floodplain Forest.

These communities can be identified using soil, LSA, and hydrological parameters of the HGM and are pulled out into the component communities described above in Floodplain and Riverfront Forest Sections. However, in many cases, they are at a finer scale than the three primary input datasets. Ridge and Swale settings are typically located in areas of lateral accretion and cab be identified in aerial photographs as banded signatures in broad floodplain areas. Within these banded zones, coarse soils are typical of ridge tops and sides, and finer soils in swales. Riverfront Forest species will tolerate soil conditions of ridges but are likely to regenerate unless light at the ground layer is made available through forest openings. Identifying these banded locations can offer an opportunity to encourage diverse Floodplain Forests and away from single-species and single-aged monotypic forests.

Ridge locations are appropriate for species less tolerant of frequent flooding but with deeper taproots and the ability to withstand river drawdown. Appropriate species for ridge plantings can include shade-tolerant elm, hackberry, green ash, and walnut, whereas swales are more appropriate locations for silver maple. These communities are not identified in the HGM modeling but are identifiable on a site basis or through photo interpretation.

Floodplain Forest/Open Wetland Mix HGM:

Mixed Floodplain Forest and Wet Meadows are found on predominantly silty clay soils on Tributary Floodplains with variable flood frequency of between permanently inundated to 5 years. High variability in flood frequency is due to dynamic landscape position in small stream meanders found in wide tributary valleys. Wide valley tributaries provide for the development of fine depositional soils, light, and variable floodplain conditions on flat valley floors. In wetter areas, Wet Meadow and Shrub Carr can develop where extended periods of high water preclude the establishment of forest. In narrower valleys with a V-shaped profile, the development of these conditions is less prevalent, and Slope Forest is more commonly present.

Mixed Floodplain Forest and Open Wetlands also occur in Tributary Meander Belts and Tributary Fans/Deltas on Silt Loams and Loams. These settings tend to be highly variable, supporting in equal parts mosaics of PEM and Floodplain Forest and should be considered and managed as such.

Riverfront Forest Management

Management of this community type should include aspects of restoring disturbance characteristics that selected for more shrubby riverfront species (primarily early successional willows) and a diverse mature forest community. Restoration might require active management including clearing and planting banks and shores to prevent or arrest the advance of invasive species such as reed canary grass.

USACE has been testing alternate techniques for establishing Riverfront Forest species by doing heavy direct seeding in appropriate locations and planting dense seedlings on prepared soils to crowd out weed species prior to establishment. Additional approaches can include identifying freshly disturbed sites following a flood, fire, or windthrow and heavy seeding with favored species (elm, cottonwood, ash, willow, hackberry, or others, depending on the flooding regime). This approach might require early collection of seeds or establishing nursery sites for reforestation.

Seeding understory forbs and grasses native to riverfront settings can help slow the encroachment of weed species, particularly reed canary grass. Specifically, sedge and bulrush species (*Carex emoryi*, *C. haydenii*, *C. stricta*, *C. vulpinoidea*, *Scirpus cyperinus*) that can withstand the variability of the landscape setting and can quickly spread through seeds or rhizomes might help suppress reed canary grass. Essential to success is preventing weeds from establishing before full infestation occurs.

Riverfront Forest is a community that is difficult to maintain as static. Since the community requires periodic flooding, exposed alluvial soils, and openings for germination of the dominant species, it is necessary to reintroduce processes that mimic historic disturbances. The erosive action of waves created by recreational boating creates scour along the banks of the river, but this scour does not sufficiently mimic natural scour and has limited development of Riverfront Forest. In scoured areas at river and lake edges, temporary protective barriers left in place until establishment might provide an opportunity for this community to form.

Developing a more-diverse forest edge in terms of structure and species will provide increased stopover habitat for migratory avian species. An effective eradication of invasive grasses would provide suitable nesting sites or basking sites for turtles. Planting other species such as elm, ash, and cottonwood along cleared areas will increase the forest diversity and forest structure that are essential to avian use during the migration and breeding seasons.

Floodplain Forest Management

Managing this community type should include aspects of restoring an uneven age character to ensure replacing a forest canopy, preserving canopy closure of a minimum 70% during management, preserving decadent trees for cavity nesters, and controlling the advance of invasive species such as glossy buckthorn, garlic mustard, and reed canary grass in the understory. To replace the canopy, selective cuts and small patch cutting will mimic blow-downs and tree fall gaps.

Management decisions can have serious adverse implications and should be carefully considered. Of greatest concern is invasive species encroaching into openings. Before any management decision that involves opening forest canopy, land managers should plan for removing and controlling open area-invasive species. In addition, adaptive management and monitoring to address infestations early is essential. These parameters should be integral to all restoration efforts, and land managers should not overextend their efforts to the extent that infestations cannot be addressed.

Plantings to augment Floodplain Forest should encourage more diverse canopy species, though two primary trees of the community type have been or might soon be devastated by disease or insects. Elm species were a significant component of historic Floodplain Forests, but seldom achieve adulthood due to infestation by Dutch elm disease. USACE has been testing disease-tolerant plantings of American elm.

Green ash is another major component of NER Floodplain Forests. This species is threatened by the invasion of emerald ash borers into the region, and, currently, most state and local agencies assume that this pest will cause a serious die-off of green ash throughout the region. Replacing these trees and any other plantings intended to restore Floodplain Forest should include a diverse mix of species.

Maintaining the forest canopy preserves habitats used by sensitive species such as cerulean warblers and red-shouldered hawks. The goal for selective cutting should be to create small openings in Floodplain Forest community types to preserve large contiguous tracts of closed canopy. Several researchers have found that managing a forest for 70% canopy closure might prevent displacing red-shouldered hawks with more common species such as red-tailed hawks. Maintaining a more mature forest structure (that is, taller trees with >70% crown closure, open wetlands consisting of <3% of the basal area, and an abundance of appropriately shaped nest trees) (Ebbers, 1989)protects habitats for species requiring contiguous tracts of forest, such as cerulean warblers. The closed canopy condition also limits the advance of reed canary grass.

Preserving decadent trees within selectively cut areas provides nest habitat required by cavity-nesting species such as prothonotary warblers. Planting other species such as elm, ash, and cottonwood in the cleared areas will increase forest diversity and forest structure. Limiting cutting to small patches or selective cutting also limits the advance of reed canary grass or makes the affected areas more manageable for controlling it.

5.3.2 Upland Forests

Slope Forest, Dry and Mesic Upland Forests

HGM: Slope Forests located on all LSA Valley Colluvial Slopes (VCS) locations, with mixed soils from Rocky Lands to Silt Loam, Loam, and Loamy Sand. On Tributary Floodplain Terraces (TFT), this community is located on loams and sands where the terrace is elevated and on narrow V-shaped Tributary Floodplains (TF) on sands and loams where limited bottomland sedimentation does not support the conditions typical of the Floodplain Forest community. This community type is located adjacent to the river or well above the 20-year flood frequencies. Those VCS areas immediately adjacent to the main channel of the Mississippi River made of steep slopes rising directly from the flood zone are likely to have a rapid shift in Slope Forest type ranging from riverfront species to dry upland forest species.

Slope Forest Management

As with the Floodplain Forest community type, managing this community type should include aspects of restoring an uneven age character to ensure replacing a forest canopy, preserving canopy closure of 70% during management, preserving decadent trees for cavity nesters, and controlling the advance of invasive species such as glossy buckthorn, common buckthorn, and garlic mustard in the understory. To replace the canopy, selective cuts and small patch cutting will mimic blow-downs and tree fall gaps. The goal for selective cutting should be to create small openings in the Slope Forest community types to preserve large, contiguous tracts of closed canopy. Management operations in shaded forests on steep slopes can create serious erosion problems, so having an erosion control and revegetation plan and practices in place before any management activities is required.

Maintaining the forest canopy preserves habitats used by sensitive species such temperate migrants and neotropical migrants and declining species such as cerulean warblers and red-shouldered hawks. The goal of diverse structure and composition should be implemented to provide high-quality migratory corridors used by temperate and neotropical migrants. Developing a complement of mast-producing species increase the foraging value to long-distance migrants (Ewert D. a., 1995).

Maintaining this community type, especially when it occurs adjacent to large Floodplain Forest tracts, increases the value of the forest for species requiring large, contiguous tracts of forest, such as cerulean warblers. Planting trees that increase the structure and diversity of the forest will provide additional value to species using these forests for breeding and brood-rearing. Selective cutting and patch cutting, brush removing, and using controlled, low-intensity fires might help establish or maintain mast-producing species such as oaks. Augmentation plantings of, butternut, walnut, or hickory might be a suitable substitute.

5.3.3 Prairie/Savanna

Prairies (Dry and Mesic) and Savannas HGM: Very few of these communities remain in the NER. They are located on Low, Intermediate, and High Glacial Terraces (GTL, GTM, and GTH), Glacial Stream Scarps, and Eolian Dunes over terraces. The relative narrowness of the Mississippi River Valley in the NER likely provided some protection from the fires that are typical of the prairie landscape and would have sustained the forested communities currently common in the river valley. Soils are well-drained loams to sands with flood frequencies greater than 20 years. All of the LSAs described here are located well above river flood stages. Within the river valley, these communities are found on post-glacial islands derived from the period of the Wisconsin glaciations, on steep bluffs, or above the river valley setting. Generally, these communities are located above the hydrological (natural or manipulated) influences of the present Mississippi River.

Bottomland Prairie: This community was not likely common in the NER and was not clearly identified in the HGM analysis for the NER. The natural fire breaks of the steeply sloped confined valley of the NER would have limited fires running freely from dry bluff prairies into the valley bottom. Where prairies maintained by fire were present in the valley, they would have been on larger upland sites on well-drained coarser soils. The community type is a transitional community between Wet Meadow and Mesic Prairie that shares the species and ecological attributes of each. It is likely that this community occurred very near the boundaries of the NER on Minnesota River Valley flatlands and within the MME downstream on the Mississippi River. Because many of the known prairies of the NER valley setting rise quickly from the river bottom, this community would have likely been a very small, transitional component. A basic distinction between this community and wet/sedge meadows is that woody encroachment in the former is maintained and sustained by fire and in the latter by hydrology.

Prairie Oak Savanna Management

Historically, this was a fire-dependent community type. Fires were the major source of development and maintenance that triggered seed dispersal, increased the amount of light reaching the ground, stimulated propagules, and released nutrients. Fires also facilitated the removal of dead plant matter and assisted in the cycling of nutrients. Restoring, establishing, and managing this community type should include a goal to create a diverse character of herbaceous and forest components. To achieve an understory with native grasses and forbs, clearing, seeding, cutting of invasive shrubs or mature trees, raking, and using maintenance fires would need to be implemented in areas conducive to this type of management. Restoring this community type would require active management, herbicide application, and episodic fires to eliminate and delay the development of species that would shade lower-stature grasses and forbs. Clearing buckthorn or overgrown woody species will be necessary to allow native prairie grasses and forbs to germinate, but additional broadcasting of native seeds might be necessary to restore some of the historic character of this community type.

Developing a complex savannah structure provides openings used by sensitive snakes, turtles, plants, and mammals. The higher soil temperatures present in large openings with shorter-stature trees provide conditions that allow reptile eggs to develop and also provide habitat used by invertebrates and ground-nesting birds.

5.3.5 Open Wetlands

Persistent Emergent Wetlands: HGM: Persistent Emergent Wetlands (PEM) are located on semi-permanently flooded silt loam and silty Clay Loam Soils or are often mapped as waters in NRCS surveys. These assemblages are located on Main Channel and Inactive/Minor Channel Vertical Accretion Marshes (IVM and MVM), Tributary Marshes(TM), and Abandoned Glacial Stream Channels (GSC) where they are mixed with wet meadows at the margins. These communities are known to exist within the NER with their sources of hydrology not dependent on river levels. In these cases, the study team's best professional judgments were used to determine flood frequency relative to other parameters.

Wet/Sedge Meadow HGM: Sedge and Wet Meadows are found in seasonally flooded areas. LSA locations are Abandoned Glacial Stream Channels (GSC) mixed with PEM on Fine Sand Loam and Loam Soils, and Main Channel Vertical Accretion Marshes with Silt Loam.

Shrub/Carr HGM: Shrub/Carr communities are located on silty or clayey soils at the margins of Tributary Channels, Side Channels, and Sloughs/Lakes/River Channels. Flooding would likely fall into a 1- to 2-year frequency with surface water often present through the growing season. In many cases, sources of hydrology are disconnected from river level fluctuations but are often groundwater-fed systems.

Open Wetlands Management

These community types are maintained by hydrological conditions where extended inundation or shallow groundwater precludes encroachment by tree species. The PEM community type requires periodic drawdown and maintenance of water levels to retain the character of the plant community. Manipulating water levels is often the best tool for preserving these community types, thereby tying the timing of drawdowns or planned flooding to the periods for the best seed setting of desired species. Unfortunately, drawdown can favor invasive species, which in some cases rely on the same disturbance regime (exposed mudflat) as do desirable native species.

Wet meadows are typically located away from the main channel or behind natural levees with only seasonally flooded or saturated mineral soils. PEM species sometimes move into drier areas occupied by Sedge Meadows during wet periods but typically do not persist under normal, drier conditions. Controlling invasive species through best management practices is essential, since removing the primary invader, reed canary grass, is difficult after it is established.

Shrub/Carr communities are transitional between open wetlands and forested wetlands, and their ground layer vegetation is similar in composition to that in sedge/wet meadows. In the Upper Midwest, Shrub/Carr is sometimes considered an invasive community type, because it can displace wet meadow and associated rare species of open wetlands (Kost, 2007). It is often managed with herbicides and with cutting and/or mowing. Maintenance for retaining this community can consist of removing trees, applying herbicides, and manipulating water using prolonged flooding to set back the woody component of the community.

Nutrient loading from river and upland sources can contribute to invasions of invasive species since most PEM and wet meadow species of concern respond vigorously to high nutrient loads. Invasive species such as giant reed grass (*Phragmites australis*), reed canary grass, and purple loosestrife might require specific management or eradication techniques that can include herbicide application, bio-controls, mechanical removal, or a combination of all three. Woody invaders to Shrub/Carr include common and glossy buckthorn.

The maintenance of a healthy submergent plant community will benefit turtles and provide forage for migrant waterfowl and waterbirds. Sedge Meadows provide habitat for numerous threatened and endangered plant species in the NER.

5.3.4 Vegetation Communities of Open Water Areas

Active Channels HGM: This assemblage is located at the margins of Water in areas permanently or semi-permanently flooded. Soils are typically identified as water but will typically occur on soils of active channels and will tend toward coarser-grained sands and gravels with finer material present.

Bottomland Lakes and Abandoned Channels HGM: Bottomland Lakes and Abandoned Channels occur on the permanent margins of open water not affected by severe wave action or river currents. Vegetation might be present across the entire surface of shallow lakes or channels during dry periods. This assemblage is found at the margins of or over entire shallow Main Channel Vertical Accretion Lakes (MVS) and Inactive/Minor Channel Vertical Accretion Lakes (IVS) on finer Silt and Clay Loams. The flood frequency is permanent to semi-permanent.

Open Wetlands Management

These community types are strongly influenced by river level manipulations. The initial construction of the lock and dam system severely reduced these communities where deep water eliminated access to light and oxygen for submergent and aquatic vegetation. Some of these natural communities have re-established at the margins of flooded lakes and backwaters where shallow, flat-bottomed lakes are maintained (Sturgeon and North Lakes).

The greatest threats to these natural communities are encroachment by both aquatic and terrestrial invasive species, waves caused by boat traffic, dredging, and nutrient and sediment loading. Invasive concerns include grass carp, which is a voracious herbivore that can cause a severe loss of emerging vegetative matter. The presence of zebra mussels can alter the chemical composition of water and can increase the submergent vegetation in turbid nutrient rich waters.

Plant species of concern are aquatic Eurasian water-milfoil (*Myriophyllum spicatum*) and emergent species (invasive cattails and purple loosestrife) at the margins, which can establish during drawdowns and persist in shallow waters for extended periods.

Watercraft use is a cause of many of the above threats, including transporting invasive species on boats moving between pools and lakes throughout the region. In addition, wave action from watercraft and barge traffic causes severe bank erosion and disturbs the substrates of submergent communities.

Managing the above threats includes imposing strict rules regarding moving watercraft between pools and throughout the region and imposing speed and spatial limits where bank protection might prevent further degradation. Placing islands and setting boating limits behind protective islands might also help protect these communities. Upland practices that limit nutrient and sediment inputs into backwater lakes and main channel will help maintain healthy substrates that support submergent vegetation (Kost, 2007).

5.3.6 Habitat Types Potentially Identifiable by Other Means

The following habitat types were identified during the course of this study. Some of them have been discussed above but were not specifically shown in HGM maps. In the NER, these communities were not identifiable using the HGM, either because landscape heterogeneity was at a finer scale than the base geomorphic data set, leaving smaller but important natural community types unrecognized, or because hydrological information based on river gauge information neglects to capture groundwater-fed systems.

Shrub/Carr: Shrub/Carr communities are typically located at the interface of PEM or Sedge/Wet Meadow communities and forested cover types on a gradient from wetter to drier. They are a transitional community in both time and space. On a time scale, natural occurrences average 50 years before either being overtaken by trees or being reset to herbaceous/Open Wetland community types (Curtis, 1971). Flood events can reset the community and retain Shrub/Carr for a long period as long as drawdown following flooding is sufficient to allow shrub recovery. Likewise, if water levels remain stable, tree species adapted to wet conditions will tend to encroach into shrub-dominated areas, causing a transition to forested community types.

The geomorphic surface itself will not indicate the likely presence or restorability of this community type. However, finer-resolution modeling can identify appropriate restoration areas at the interface between forested and open wetlands. At these interfaces, the topographic edge is not abrupt and shrub species, occupying an intermediate location between the communities, are likely to occur and thrive. This can be done in GIS by buffering inward the edges of Vertical and Lateral Accretion Marshes.

Lowland Hardwood Forest: Lowland Hardwood Forest communities are present in the NER and to a greater degree in the nearby Minnesota River Valley floodplain at the base of colluvial slopes where groundwater is available. The MnDNR Southern Wet Ash Swamp (WFs57) is a community type (Minnesota Department of Natural Resources, 2005) found where there are upwelling springs and seepage areas on alluvial terraces below steep slopes. The species typical of the community, black ash (*Fraxinus nigra*) with lesser numbers of basswood and sugar maple, rely on cold groundwater inputs but do not tolerate extended periods river flooding. This community type is located in the NER at the base of slopes, but outside of ordinary effects of river flooding.

It might be possible to remotely identify groundwater fed lowland hardwood forests by applying more detailed groundwater map data combined with topographic information and landcover. The study team explored whether it would be possible to use soils information where silty alluvium or peat were present above the effects of river flooding. The study team found that the resolution of the NRCS soils data was to low to pinpoint these locations. Mapped groundwater modeling and spring information, combined with landcover data that identify lowlands in forested areas and high-resolution LIDAR, might be resources for identifying these forest types. These are unique communities in the valley and should be considered important communities for conservation and restoration (particularly protecting groundwater sources, minimizing potential flood impacts, and controlling invasive species).

Ridge and Swale: Ridge and Swale features in the NER are common in the alluvial bottomland in remnant abandoned and shifting river meanders. In Tributary Meander Belts, these features are often not identified in the geomorphic surface layers and will require site-based identification during restoration planning. In Main Channel Vertical and Lateral Accretion surfaces, these features sometimes are apparent and distinguished as Levees with a banded ridge signature interspersed typically with Undifferentiated Accretion swale signatures. Meander Belt Ridge and Swale areas are typically identifiable in aerial photographs and LIDAR coverages as parallel signatures of either alternating tree species or alternating patterns of forest and openings.

Tributary Fan: This geomorphic surface found at the mouths of small streams and rivers emptying into the Mississippi River tends to be made up of relatively flat but undulating surfaces of tributary deposition. At the edges of these fans, main channel forces and geomorphic processes resemble lateral accretion areas when flooding and velocities from the main channel act to reshape and inform a site. Within the Tributary Fans of the NER, Floodplain Forest is common, but, generally, low areas tend to be mix of ephemeral pools with shaded or open wetlands (submergent, emergent, and wet/sedge meadow) where patch openings are large enough to allow light to penetrate.

5.4 Potential Restoration Sites and Opportunities

In the NER, more than 32,000 acres are publicly owned. Lands in public ownership offer the potential to develop agency partnerships, share resources, and partner in planning efforts to best address habitat requirements for a broad range of species and natural community types. Planning across ownership boundaries can help expand large habitat blocks and corridors and could help limit habitat fragmentation by joining habitats across boundaries.

Table 8 lists the total land areas in the NER in federal, state, county and tribal ownership. Figure 16 shows these total public lands areas in the NER. In addition, city parks offer opportunities for partnerships.

Table 8. Federal, State, County and Tribal Land Areas in the NER

Type of Public Land	Acres
Bureau of Land Management	297
Minnesota Wildlife Management Areas	142
Tribal Natural Areas	1,771
Wisconsin DNR Wildlife Areas	5,770
Wisconsin DNR Natural Areas	1,429
Minnesota State Parks	11,654
USACE Managed Lands	2,219
USFWS National Wildlife Refuge	9,922
Minnesota Regional Parks	3,372
Wisconsin DNR Lands (other)	544
Total Public Lands within Reach Boundaries	**37,120**

In the NER, USACE identified 11 subarea priorities for restoration activities in the Navigation and Ecosystem Sustainability Program (NESP) (USACE, 2010). These areas are the Minnesota Valley, Lower Pool 2, Vermillion Bottoms, North and Sturgeon Lakes, Cannon River delta, Pierce Islands, Lake Pepin deltas, Chippewa River deltas, Big Lake, and Zumbro River delta. Each of these areas is discussed in this evaluation and, in some cases, extensive review, planning, and implementation is underway. In particular, managing the larger areas listed above is a regular and ongoing effort of each of the agencies listed in Table 8. Agencies are working together in most of these areas to develop integrated plans to build on habitat and corridor improvements. Rapids restoration in Pool 2 was identified in the NESP planning effort, but is not currently under consideration.

Partnerships with Cities, Counties, nongovernmental organizations, and watershed planning organizations might offer additional opportunities to improve habitat in the river corridor. In particular, city and county parks in the NER are common above Lower Pool 2 in Dakota, Ramsey, Hennepin, and Anoka Counties in Minnesota and in city and county parks on tributary fans along Lake Pepin.

In the more urban settings, park users' needs and ecological restoration needs are sometimes at odds, but often, integrating park planning into the larger NER seems to have been a simple oversight. As Cities embrace waterfront planning, watershed management organizations and communities are embracing park and brownfield redevelopment along the river. USACE, NPS, and DNRs should engage with recreational and water planning organizations to integrate NER objectives into local projects. Urban park districts (Three Rivers Parks, Ramsey and Dakota Counties), Cities (with public parks from Coon Rapids Dam to Lower Pool 2), and NGOs (The Nature Conservancy, Isaac Walton League, Audubon Society, Great River Greening, and Friends of the Mississippi River, among many others) are all active in river restoration and planning.

Parkland, conservation, and restoration efforts by Cities and Counties are taking place along the entire NER, and furthering partnerships with these local agencies could greatly improve regional efforts in corridor and habitat planning. Regional parks from north to south where federal funding and agency cooperation could provide valuable assistance include Coon Rapids Dam Regional Park (Anoka County Parks), River Park (Brooklyn Park), Islands of Peace Regional Park (Anoka County Parks), North Mississippi Park (City of Minneapolis), Boom Island and the Minneapolis Waterfront Redevelopment (City of Minneapolis), Minnehaha Park (City of Minneapolis), Crosby Lake Regional Park (City of St. Paul), Pickerel Lake (City of Lilydale and City of St. Paul), Koposia Landing (South St. Paul), Riverside Park (St. Paul Park), Spring Lake Regional Park (Scott County), Hok-Si-La Park (Lake City, Minneapolis), and County Park (Bay City, Wisconsin). These and other local and county parks could provide ecological benefit to the greater NER habitat plans as well as receive benefits from federal and state interests to improve on-site habitat, floodplain, hydrology, and overall ecosystem values.

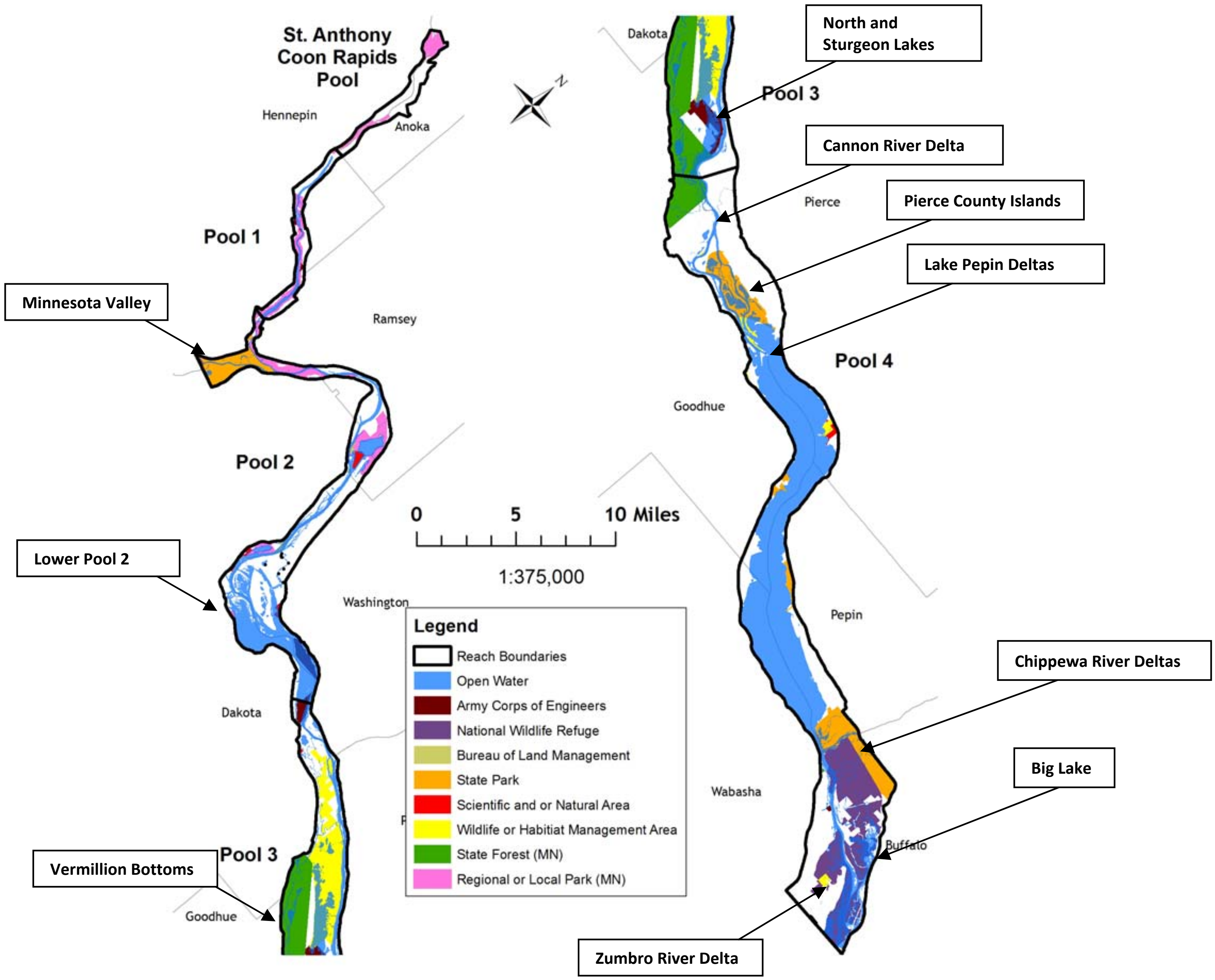


Figure 34. Public Ownership and USACE Subarea

5.5 Management, Monitoring, Evaluation, and Future Trends

Expanding the HGM to Include Groundwater-Fed Communities. The HGM relies primarily on three abiotic features along with analyzing the correlations between vegetation community types and these features. Hydrology becomes a limiting parameter, since it is tied to river gauge data to determine frequency of inundation. For this reason, the hydrology parameter is not effective at identifying groundwater and local surface water inputs, especially where topographically elevated wetlands on valley bottom terraces are hydrologically isolated from river stages during normal years.

Groundwater-fed natural communities are some of the rarest types of communities (for example, calcareous fens) as well as communities that harbor rare species found only in the community (such as bog bluegrass [*Poa paludigena*] and American water pennywort [*Hydrocotyle americana*] in black ash seepage swamps). Identifying these communities and biophysical characteristics is essential to prevent the potential adverse effects of floodplain management (that is, flooding).

Climate Change Adaptations. Global climate change poses substantial challenges to landscape managers. The effects of warming over the past century and the projected trends are well documented and widely accepted. Natural resource managers need to adapt plans and actions on the ground to address changes in community type and composition. The effects of climate change include changes in the composition of natural areas on the continental, regional, and local levels. At the local level in the NER, the following effects will need to be considered:

- Warming water temperatures affect the distribution and composition of fish species, with a general trend favoring the northward movement and predominance of warm-water fish.
- Reduced periods and extents of ice cover on water bodies alter community composition as plant and animal species have adapted to patterns of winter disturbance over millennia.
- Migration patterns and timing of numerous bird species and guilds will be altered (Stokstad, 2010).

At the regional level, these changes are causing natural community shifts. As regional climate shifts geographically, the distributions of populations of plants and animals are expected to shift in response. Resource managers should consider how these changes affect planning and implementing ecosystem restoration.

In particular, plant species are moving with shifting climate and have done so during shifting climatic patterns in past epochs. The pace of climate change today might be more rapid than the dispersal capabilities of some plant species, particularly large-seeded species with low dispersal. Natural resource agencies might want to consider restoration efforts that account for shifts in climate.

In particular, both before and after Euro-American settlement, the NER has not had more than scattered occurrences (or none) of the following tree species: black maple (*Acer nigra*), river birch (*Betula nigra*), red mulberry (*Morus rubra*), and swamp white oak (*Quercus bicolor*) in floodplain areas and shagbark hickory (*Carya ovata*), chinkapin oak (*Quercus muhlengerbii*), and black oak (*Quercus velutina*) in upland oak forests and savannas. These species could become more suited to a northward shift over time, and landscape planners might want to consider expanding their ranges northward in response to shifting climates. This strategy runs counter to strict restoration of pre-settlement conditions but acknowledges changing realities. When expanding ranges, restoration planners should take care to use stock from the directly adjacent areas rather than obtain nursery stock from distant sources.

GIS Photo Analysis, Modeling, and Interpretation in Support of Adaptive Management. Each year, the quality and frequency of updates to true-color, multispectral images (images containing true color and infrared reflectance data) and hyperspectral aerial photographs and satellite images improve. Improvements in resolution, general availability, and embedded data might allow large-scale monitoring of ecosystem patterns, disturbances and invasive species infestations using remote-sourced data. Using multispectral analysis and texture recognition, it might be possible to perform long-term monitoring of whole river reaches by comparing images across spatial and time scales.

Multispectral analysis has become a standard tool for remotely delineating specific vegetative communities. It can be used to identify high-quality mesic and dry prairies suitable for a range of threatened and endangered species. Using these same tools, identification of forest community types may also be possible.

Infrared photography is a well-established practice for recognizing tree species. If USACE were interested in pursuing a color recognition or multi-spectral approach to monitoring bottomland forests, the agency might be able to work with sister agencies to identify how data from existing remote-sensing programs (such as NAIP aerials and Landsat) can be used or modified for these purposes.

In the NER, color, infrared, and texture recognition of aerial photographs or satellite images might be possible to perform ongoing monitoring and assessment of community changes. Photographic and infrared signatures of some invasive species can be diagnostic. Of interest in the NER, reed canary grass could be monitored through analyzing multitemporal images (that is, comparing images taken at different times during the growing season). If it is possible to respond rapidly to encroaching species, the previous year's invasions could be reviewed during the winter and addressed during the following growing season.

Texture and multispectral data could also be used to identify and classify forest age, forest class, and age evenness. Field investigations that identify the precise locations of particular forest conditions could be tied to photo signatures. Using these signatures, it might be possible to create standards for texture (smooth vs. coarse), color (ranges of colors along gradients of green or infrared light), and tree height (using LIDAR data) that allow remote sensing of the forest composition. Monitored over time, the annual results could be tied to disturbance events, shifts in hydrology, effects of encroaching invasive species, or specific management prescriptions.

Adaptive Management. Managing the NER in the context of the entire Mississippi River Basin has been the focus of uncountable studies and heated debate for more than a century and a half. Controls placed on the river for navigation purposes have had a profound impact on floodplain functions for two centuries, and the debate regarding the costs and benefits of the navigation system continues. Adaptive management that includes input from all stakeholders—government, advocacy groups, businesses, and citizens—is essential. However, it is important to recognize the implications of future management activities in response to fundamentally altered landscapes; removing one or more aspects of the constructed system does not necessarily equal a simple reset to pre-settlement conditions.

As this evaluation has discussed, all parties need to carefully consider invasive species, sedimentation, and the fundamentally altered composition of existing communities and the possible effects of each major change in river management. Invasive species (in particular, reed canary grass), climate change, sedimentation, and existing hydrologic conditions should be addressed through active planning and forecasting. Decisions occur within the context of economic and environmental debates that will continue in the political realm. Through sound planning and forecasting, ecosystem processes and functions should be brought to the discussion. This HGM plan provides for planning across scales from site to region. Most importantly, resource managers in the field must have the tools to address specific concerns on the ground. The HGM should be used as a tool not only to understand future planning but also to inform quick actions where urgent responses are needed.

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