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Water Resources, Infrastructure Restoration, and Protection of the Upper Mississippi River Basin

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Abstract

The Upper Mississippi River flows approximately 2000 km from Lake Itasca, Minnesota to Cairo, Illinois where it is confluences with the Ohio River to form the Lower Mississippi River. North of the confluence, numerous snags, sand bars, rapids, and other obstructions made the Upper Mississippi River travel difficult. This paper highlights how the geological and landscape resources of the Upper Mississippi River and tributary watershed were responsible for the successful economic development of this historically rich region of North America. Environmental challenges include an attempt to keep invasive species such as the Asian carp out of the rivers and lakes north of the Twin Cities. In an attempt to protect the Mississippi River resource, Environmental and Conservation groups have opposed continued navigation through Minneapolis and St. Paul and the planned Upper Mississippi River navigation infrastructure restoration by the United States Corps of Engineers including the upper and lower St. Anthony locks and dams. These Environmental, Conservation and Save the River groups are attempting to mitigate the historic highest and best use of the Mississippi River and adjacent watershed, navigation, and economic development, by having the urban river restored to the natural state.

Keywords

Falls of St. Anthony, Locks, Dams, Minneapolis, St. Paul, Navigation, Water Pollution

1. Introduction

The Upper Mississippi River originates in Lake Itasca and flows 2000 km into the Lower Mississippi River at the confluence of the Ohio and Mississippi Rivers [1]. The Upper Mississippi River drains 7% of the continental United States (**Figure 1**). The Native Americans used the Upper Mississippi River for travel and trade. As the seasons changed the Native Americans, the Woodland dwellers (CE 700 to CE 1300), used the river to follow their food supply. These Native Americans were mound builders. They buried their dead in mounds (**Figure 2** and **Figure 3**). Further to the south, the Mississippians (CE 900 to CE 1300) built even larger mounds at Cahokia Mounds (**Figure 4**). These Cahokian mounds are located across the river from St. Louis, Missouri. The Mississippians had a diverse food supply which included cultivated maize, fish, wild game and food plants.

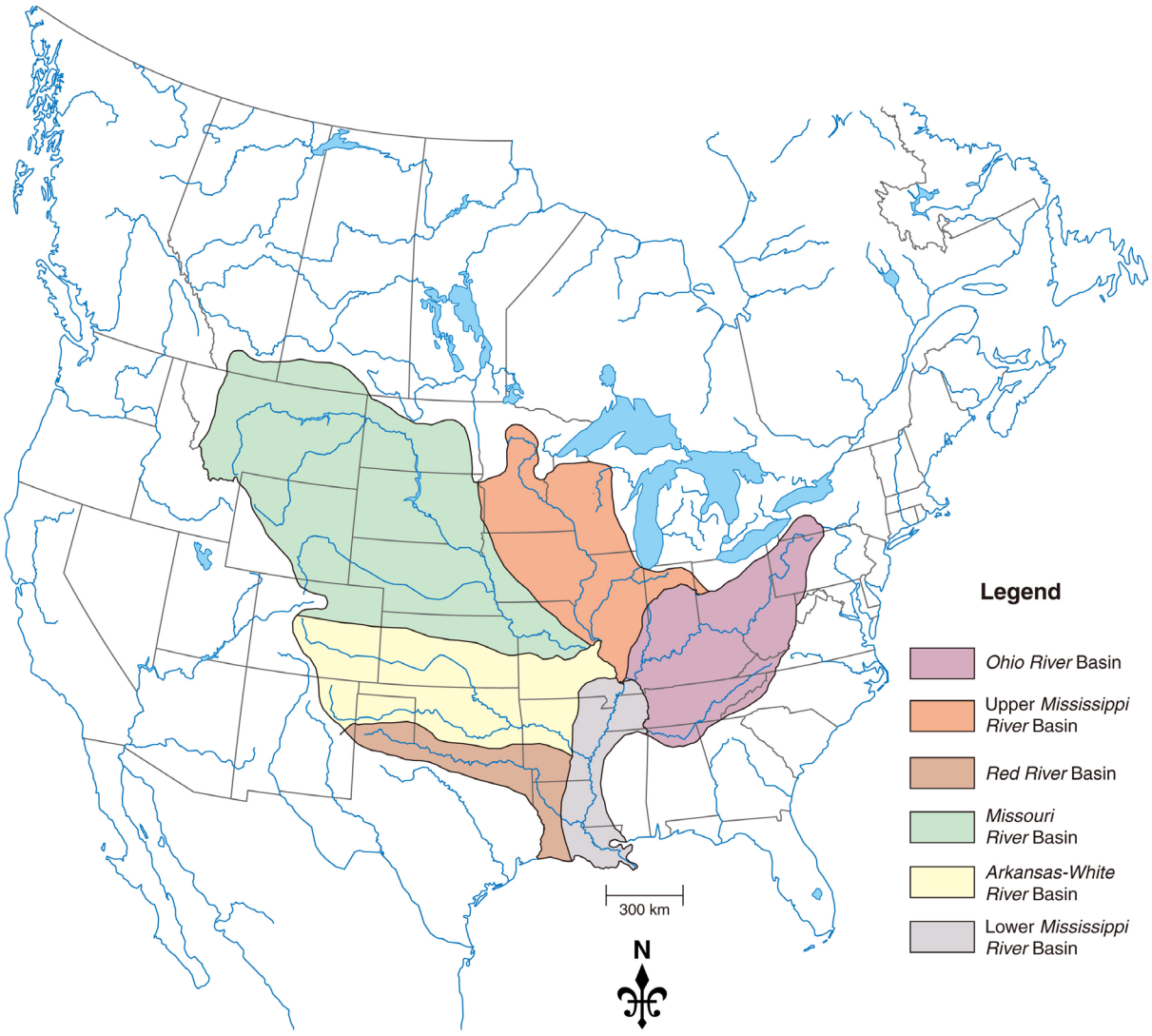

Figure 1. Mississippi river watershed with major rivers identified. Published with copyright permission from the Book Editor of the Soil and Water Conservation Society [1]. Map by Mic Greenberg.

Figure 2. The effigy mounds national park in northeast Iowa along the Upper Mississippi river is a classic example of the American Indian mound builders' culture (1400-750 B.P). Photograph was taken by Lois Wright Morton.

Figure 3. Woodland mounds at Effigy Mounds Park are constructed in shapes of bear, birds, turtle, panther and other animals and are also found from northeast Iowa and southwest Wisconsin and north along the Upper Mississippi River. Photograph was taken by Lois Wright Morton.

Figure 4. One of the best examples of the Mississippian mound builder culture has been found at Cahokia Mounds near Collinsville, Illinois. Here archeologists have discovered temple sites, burial graves, and elaborate configurations that served as solar calendars for planting and harvesting.

In the 1830s, the United States Army Corps of Engineers (USACE), began improvements in the interest of navigation and shipping. In 1866, Congress approved the first of four navigation projects [2]. The first project established a 1.22 m deep channel which included removing the worst snags and sand bars and dynamited several rapids on the Upper Mississippi River. The initial channel did little to improve navigation on the river. In 1878, Congress authorized the USACE to establish a 1.36 m deep channel. This was accomplished primarily by constructing canals with navigation locks to bypass the De Moines Rapids near Keokuk, Iowa and the Rock Island Rapids between Rock Island and Moline, Illinois. Riverboat passage was virtually impossible over these rapids, because the river became shallow and the riverbed consisted of rock. In 1907, Congress authorized a 1.83 m deep channel [2]. The Mississippi River became completely navigable from New Orleans to St. Paul, Minnesota with the opening of the Moline Lock that bypassed the Rock Island rapids in 1907. The current 2.74 m deep channel project was completed in 1940 [2].

Navigation locks on the Upper Mississippi River allowed towboats, barges and other vessels to transit the dams. The distance from Mile marker 858 at Minneapolis, Minnesota to Cairo, Illinois is 1350 km. The commercial navigation channel has a depth of 2.75 m. Each lock and dam complex creates an upstream pool (**Figure 5**). There are 29 locks on the Upper Mississippi maintained by the USACE from Upper St. Anthony Falls upstream to Chain of Rocks downstream (**Figure 6**). The locks provide 123 m of lift. The environmental challenges include the settlement of millions of people in the Upper Mississippi Basin, year around navigation, re-building of 3 locks and dams on the Mississippi River in the Twin city area, disposal of treated and untreated industrial and urban wastewater, water pollution, flooding, invasive species and flooding.

Figure 5. The dam in the lock and dam system on the Upper Mississippi River creates an upstream pool of water to ensure sufficient water depth for navigation. The lock, seen in the foreground of this picture, enables boats and barges to move between the pools created by the dams. Photograph was taken by Lois Wright Morton.

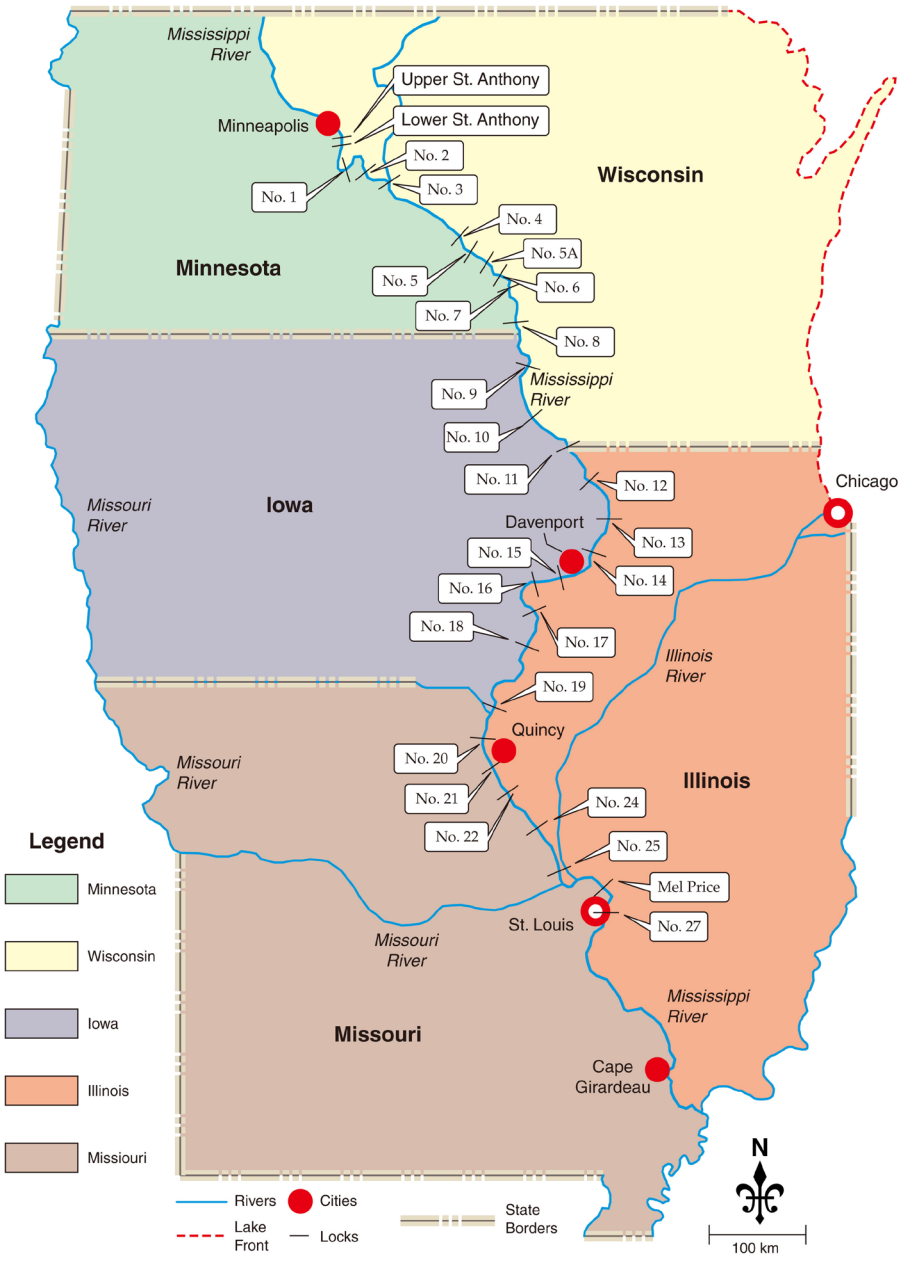

Figure 6. Location of 29 lock and dams on the Upper Mississippi River. Published with copyright permission from the Book Editor of the Soil and Water Conservation Society [1]. Map by Mic Greenberg.

The primary objectives of the paper are: 1) to document how geological and landscape resources of the Upper Mississippi River have contributed to the successful water resource and economic development of a historically rich region in North America and 2) to identify the environmental and natural resource risks to the Upper Mississippi River basin and 3) evaluate the proposed Environmental and Conservation groups attempts change the historic highest and best use, navigation and economic development, of the Upper Mississippi River and watershed to having the urban river restored to the natural state.

2. Study Site Location

2.1. Ancient Mississippi River History and Location

In terms of geologic and hydrographic history, the Upper Mississippi River is a portion of the now-extinct Glacial River Warren which carved the valley of the Minnesota River, permitting the immense Glacial Lake Agassiz (**Figure 7**) to flow into the Gulf of Mexico. The Upper Mississippi River valley likely originated as an ice-marginal stream (**Figure 8**) during what had been referred to as the "Nebraskan" glaciation and is now identified as Pre-Illinoian glaciation. The earliest Pre-Illinoian drift was deposited approximately 2.8 million years before present (YBP) [1]. The Pre-Illinoian drift was covered by more recent glaciations (**Figure 9**) [3].

The Driftless Area is a portion of North America demonstrating no evidence of glacial till deposits [1]. The area, left unglaciated at that ice age's height, was not smoothed out or covered over by previous geological processes. Inasmuch as the Wisconsin glaciation formed lobes that met (and blocked) where the ancient Mississippi River once flowed it is projected that huge amounts of glacial meltwater flowed into the Driftless Area. There is no lakebed so it is assumed that there were instances of ice dams bursting. Considering the history of Glacial

Figure 7. Lake Agassiz. Published with copyright permission from the Book Editor of the Soil and Water Conservation Society [1]. Map by Mic Greenberg.

Figure 8. Glacial ice is flowing from land into water. Photograph taken by James M. Lang.

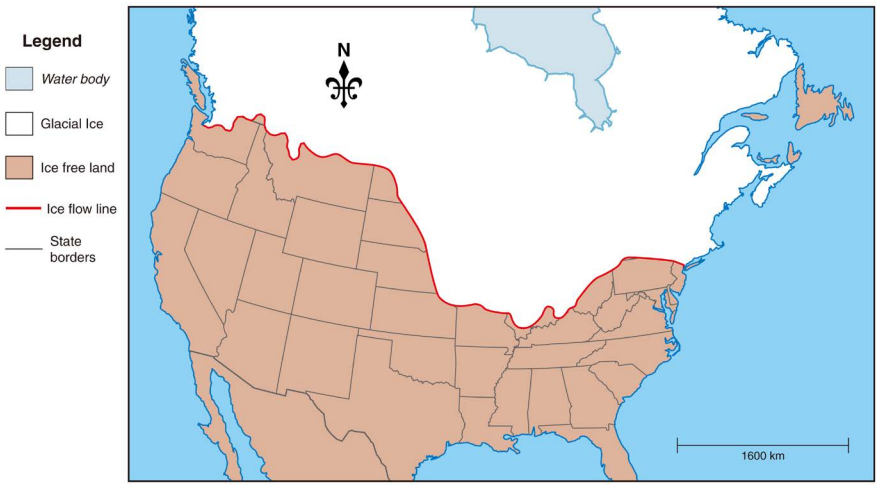

Figure 9. Wisconsin, Illinoian and Pre-Illinoian glacial map. Published with copyright permission from the Book Editor of the Soil and Water Conservation Society [1]. Map by Mic Greenberg.

Lake Missoula a similar episodic event is hypothesized to have occurred in the Driftless Area. The Upper Mississippi from below upper and lower St. Anthony Lock and Dams are in Minneapolis and downstream to St. Paul. The gorge with high limestone bluffs (**Figure 10**) carved by the water flowing over the falls. Upstream from waterfalls the land slopes gently to river's edge. Downstream of St. Paul the river enters a wide pre-glacial valley.

The Mississippi River is the western boundary of Illinois (**Figure 11**). However, before the glacial periods the ancient Mississippi River passed much farther to the east. The ancient Mississippi River was eventually blocked by the Wisconsian glacier and the terminal moraine [4] blocking the drainage with debris about 12,000 to 15,000 years ago. The ancient Mississippi River then moved to

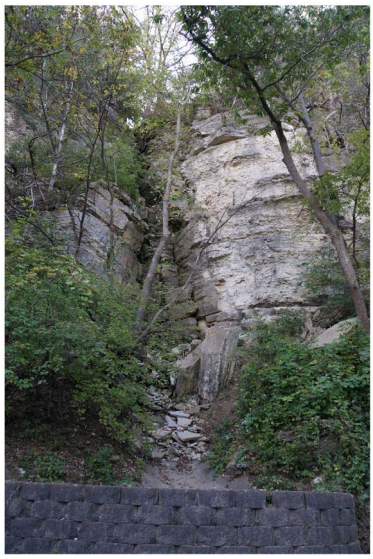

Figure 10. Limestone and sandstone bluffs along the Mississippi River. Photograph was taken by Lois Wright Morton.

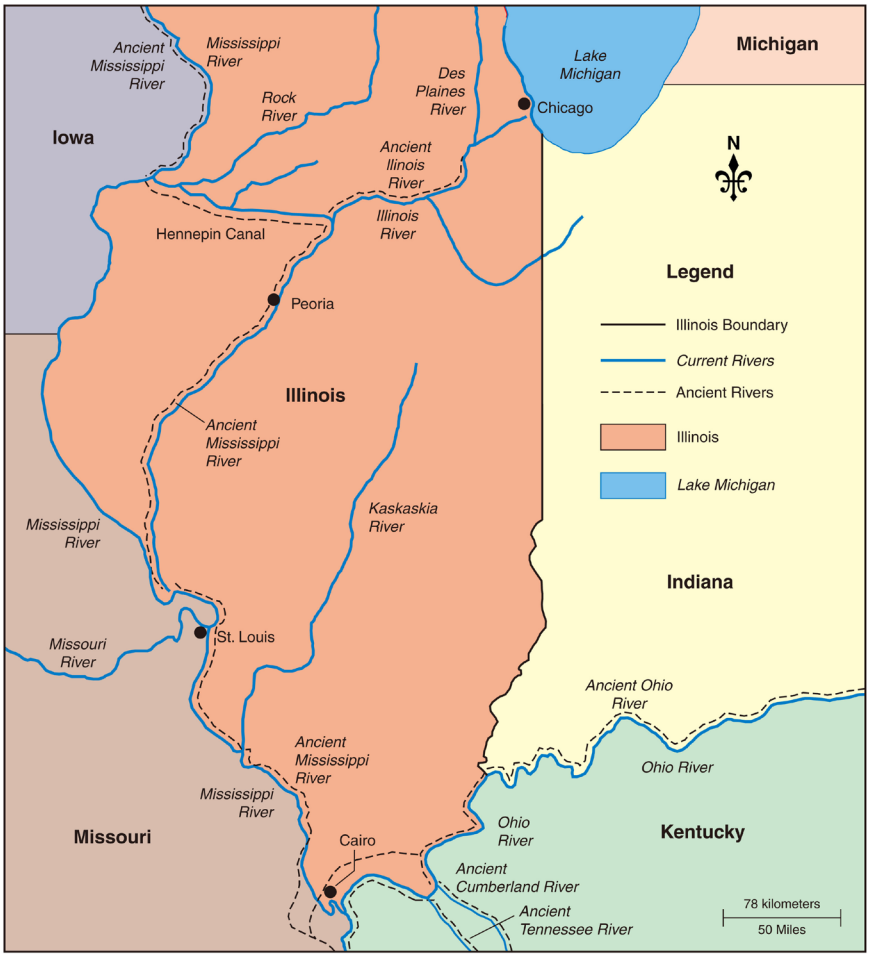

Figure 11. Location of the ancient Mississippi River on western side of Illinois. Published with copyright permission from the Book Editor of the Soil and Water Conservation Society [1]. Map by Mic Greenberg.

its current position which was used as the western border when Illinois became a state in 1818. The land west of the current Mississippi River was controlled by the French and was part of the 1803 Louisiana Purchase [3] [5] by the USA. Later, after Iowa and Missouri became states, they had a border dispute and it was settled by U.S. Supreme court. The border between these two states was set at the 40 degree 35 minute latitude line. If the ancient Mississippi River had not re-aligned [6] and that line had been extended into current Illinois area between the Illinois River and Mississippi River. The 3 million ha would not have been in Illinois. Approximately 1.6 m ha would have eventually belonged to Iowa and 1.4 m ha to Missouri.

The main stem of the Mississippi Waterway is the Upper Mississippi River which partially runs from Minnesota to Cairo, Illinois. Historically the ancient Mississippi River entered Illinois south of Davenport, Iowa and flowed east into the valley where the Hennepin Canal was later dug (**Figure 11**). Then the ancient Mississippi joined with the ancient Illinois River and then flowed south from near the current city of Peoria and towards St. Louis, Missouri. The Wisconsian end moraine blocked the flow of the ancient Mississippi River through the valley [4] approximately 12,000 to 15,000 years ago. The upper Illinois River headwaters now starts near Chicago, Illinois and outlets to the Mississippi River at Grafton, Illinois [7] (**Figure 12**).

2.2. The Missouri River

The Big Muddy, the Missouri River (**Figure 13**), is a great river and longest tributary of the Upper Mississippi River. The confluence of these two great rivers is located at Spanish Lake and north of the St. Louis, Missouri [1]. The longest (3767 km) named river in North America is the Missouri River which is longer

Figure 12. The Illinois and Mississippi rivers confluence at Grafton, Illinois, a few kilometers north of St. Louis, Missouri. Photograph was taken by Lois Wright Morton.

Figure 13. The Missouri and Mississippi rivers confluence near St. Louis, Missouri. Photograph was taken by Lois Wright Morton.

that the Mississippi River and the Yukon River. The Missouri river flows from the Rocky Mountains of western Montana southeast to the confluence with the Mississippi River and drains a 14.4 million ha semi-arid watershed.

The Missouri River (**Figure 13**) was a big part of the Native American culture and provided social, spiritual, physical and economic resources**.** With the arrival of Europeans the river became a route for trade and adventure. Lewis and Clark traveled the entire length of the Missouri River in search of the Northwest Passage through the Rocky Mountains only to find out later that it did not exist [8]. While Lewis and Clark were at Alton, Illinois winter base camp in 1803 (**Figure 14**) they received word from President Jefferson that he purchased the land which drained into the Missouri River and Lower Mississippi River (Louisiana Purchase) [9]. In the spring of 1804 Louis and Clark left the confluence and traveled northwest via the river to the headwaters of the Missouri River a distance of 3767 km. In spring of 1804 Lewis and Clark reached the confluence with the 1690 km Platte River which was not navigable and President Jefferson insisted they stay on the Missouri River.

The Oregon Trail is located adjacent to the Platte and North Platte rivers (**Figure 14**) and then goes overland to the Snake River. The wooden wheels had a steel covered rims which cut grooves into any exposed bedrock (**Figure 15**) and can still be seen 140 years later. Many American settlers traveled the Oregon Trail using horses and Conestoga wagons**.** The final destination was the Land of Flowing Milk and Honey which was the Williamette valley in Oregon (**Figure 16**) south of the Columbia River and the current city of Portland.

2.3. Discovery of the Upper Mississippi River and Settlement History

The French explorers, Louis Jolliet and Jacques Marquette, left Lake Huron and traveled down the Wisconsin and Upper Mississippi Rivers in May of 1673. They

Figure 14. Lewis and Clark 1803 to 1806 route from Atlantic Ocean to Pacific Ocean. Map by Mic Greenberg.

Figure 15. The wagon tracks from thousands of pioneers traveling west on the Oregon Trail in Nebraska are still visible in the bedrock. Photograph was taken by Lois Wright Morton.

returned to the Great Lakes via the Illinois and Des Plaines rivers with a short portage through Mud Lake to Lake Michigan. France in 1682 expanded territorial claims in North America to include land on west side of Mississippi River [1]. The Upper Mississippi River had a long and colorful history of transporting canoes, guns, armies, settlers, agricultural products and manufactured goods in 1700s and 1800s. French and Indian War erupted in 1754 between France and

Figure 16. The climate and soils of the Willamette Valley south of Portland, Oregon are well suited to growing wine grapes. Photograph was taken by Lois Wright Morton.

Great Britain over North American land disputes. In 1795, the young U.S. and Spain signed Pinckey's Treaty which gave American the rights to navigate the entire Mississippi River [3]. The keelboat, traveling upstream at 13 to 24 km per day, was the primary craft used for navigation until 1823. In that year the steamboat *Virginia* traveled the 1100 kilometers from St. Louis to Fort Snelling in 20 days [2]. The *Virginia* opened a new era of transportation on the Upper Mississippi River.

Meriwether Lewis and William Clark traveled the Upper Mississippi River between the confluence of the Ohio and Mississippi Rivers at Cairo in the fall of 1803 and set up a winter camp at Alton, Illinois across the river from St. Louis, Missouri and just below the confluence of the Mississippi and Missouri Rivers. In the spring of 1804 Lewis and Clark started their trip up the Missouri River, a tributary of the Upper Mississippi River in an attempt to explore the Missouri River and find a water route to the Pacific Ocean [8] [9].

The Lower Mississippi River has no locks or dams. The Upper Mississippi River is a series of pools created by a system of 29 locks and dams (**Figure 6**). These structures were authorized by Congress in the 1930s and most were completed in 1940s [10]. The primary reason for damming the river was to facilitate barge transportation (**Figure 17**). The dams regulate water levels for the Upper Mississippi river and impact the water levels on the Lower Mississippi River. About 60 percent of U.S. grain exports travel down the Mississippi River to terminals in Louisiana where corn and soybeans are loaded onto ocean going ships headed to foreign markets. Goods such as coal, road ice, and cement are moved north to Minnesota by barges.

The lock and dam system built more than 80 years ago is aging and at risk of failure. The USACE repairs locks by draining the lock, repairing the gate or other parts and patching the concrete walls. The failure of just one of the 29 locks and dams (**Figure 6**) can put the entire waterway system at risk. When a lock

and dam is shut down for an extended period of time it can disrupt Mississippi River barge traffic and do serious economic harm. The infrastructure on the Upper Mississippi, Illinois and Ohio rivers are in dire straits [1]. There have been sections of the cement walls slide into the waterways and rivers. Only a few of the 29 locks and dams (**Figure 6**) have an auxiliary chamber to allow barge traffic to continue during gate and wall repairs (**Figure 18**) which often can take more than 6 months to completed.

Figure 17. Arthur Daniels Midland barges carrying agricultural products are being pushed through an Upper Mississippi River lock. Photograph was taken by Lois Wright Morton.

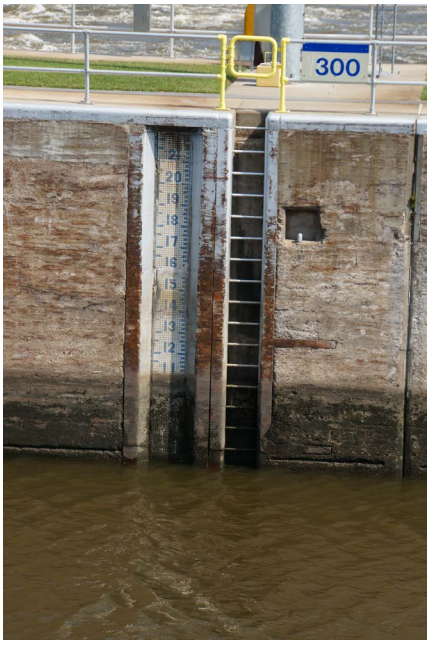

Figure 18. Locks and dams on the Upper Mississippi River were first built in late 1800s and early 1900s by the US Army Corps of Engineers to improve navigation. While they have been modernized over the years, there is a continual need of maintenance and repairs.

Barge companies and agricultural companies have called for the federal government to spend billions in the next 20 years to improve the countries waterway system. As of 2019, there are no funded plans to replace any of the Upper Mississippi River locks and dams but that could change if U.S. congress passes an Infrastructure bill which could include waterway infrastructure in addition to roads, bridges, airports and railroads.

2.4. The Falls of St. Anthony and Settlement of Minneapolis and Saint Paul

Glowing reports of the abundant water and other natural resources in the Upper Mississippi River region led fur traders, early settlers, and military surveyors, transported in keelboats, to follow the river Mississippi River north. The first steamboat, named the *Virginia*, reached St. Paul, Minnesota in 1823 and initiated the golden age of steamboat travel and trade on the Mississippi River. St. Paul was settled in the 1840s and soon became the northernmost destination of steamboat navigation.

With the invention of the electric light, St. Anthony Falls was soon harnessed for electricity to power street lights, street cars, and allowed industries to grow even when they were not located on the banks of the river. A dam and hydroelectric station (**Figure 19**) were constructed in 1887-1898 below the Falls of St. Anthony to capture the gravitational force of the falling water. Hydroelectricity became a leading industry in Minneapolis and one of the new technologies replacing direct drive waterpower for milling (**Figure 20**) in the early Twentieth Century. Today, Northern States Power Company still delivers hydroelectricity to 9000 homes in the city of Minneapolis (**Figure 21**).

Nineteen kilometers upstream, the Falls of St. Anthony provided the waterpower for sawmills that cut the pines of northern Minnesota forests into boards. For a brief six years Minneapolis had the largest sawmill center in the U.S.

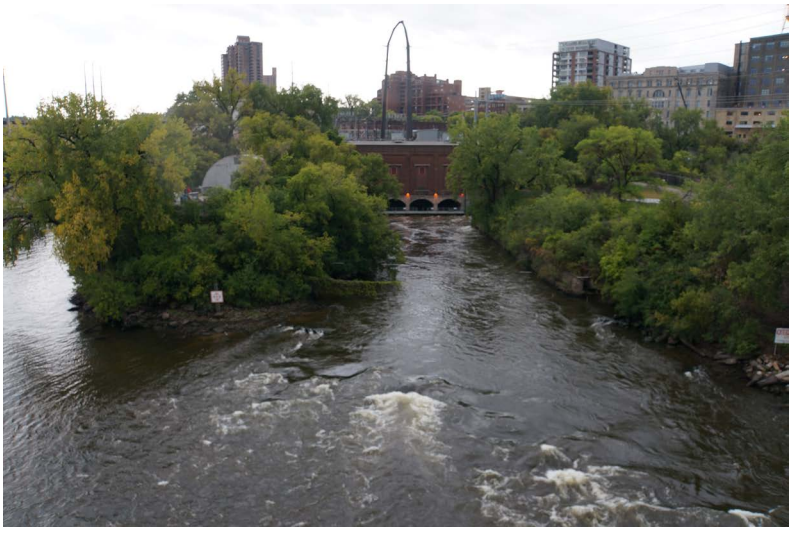

Figure 19. Minnesota hydroelectric power plant on Upper Mississippi River located between the upper and lower St. Anthony locks and dams.

Figure 20. The lock and dam system on the Upper Mississippi River enabled agricultural commodities like wheat and finished products like flour to be produced in Minneapolis and transported throughout the United States. The Gold Medal Flour headquarters founded in 1866 in Minneapolis was located on the Mississippi River near grain elevators. Photograph was taken by Lois Wright Morton.

Figure 21. Minneapolis used the hydropower from the Mississippi River to electrify city businesses and homes. A modern-day electric substation with downtown Minneapolis in the background.

However, by 1910, nearly all the mills had closed as the timber supply of northern forests waned [11]. The agriculture of Minnesota's western prairies soon supplanted the economic importance of sawmills with flour mills (**Figure 22**) making Minneapolis the flour milling capital of the nation (1880-1930). Water was channeled from the Mississippi River into underground raceways to drop into turbine pits. The force of its fall rotated turbines that drove the milling machinery. The Pillsbury A. Mill, completed in 1881 (**Figure 22**), had the largest direct drive waterpower system ever constructed with two Victor turbines each generating 1200 horsepower. At its peak, the Pillsbury A. Mill produced more than 17,000 barrels of flour per day [11].

Natural erosion over many centuries moved the St. Anthony Falls upstream to their present location (Figure 23). Lumbering and milling activities increased the pace of erosion to about 1.2 m a year as logs crashed into the limestone falls and excavation broke off limestone ledges exposing the soft, easily erodible sandstone underneath [11]. A disastrous tunnel project almost destroyed the falls in the 1860s and threatened the economic viability of waterpower-dependent Minneapolis. The USACE built a concrete dike under the river and a wooden apron over the ledge to protect the face of the falls. This apron is now a concrete spillway (Figure 24 and Figure 25). The St. Anthony Falls would be a potential erosion hazard if the river was returned to the natural conditions. Over time result this would result in the retreat of the falls moving farther upstream. The falls had previously moved almost 12 km in the past 15,000 years (Figure 23).

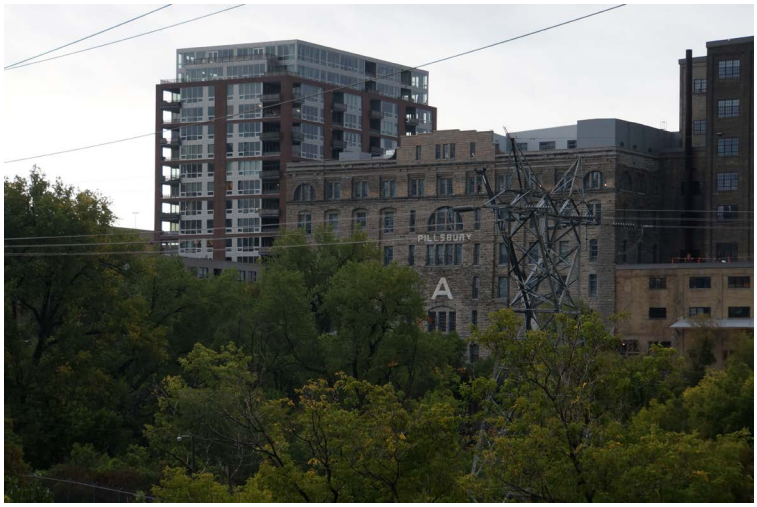

Figure 22. The Pillsbury Mill headquarters along the Mississippi River in Minneapolis used the river for hydropower to mill grains. Photograph was taken by Lois Wright Morton.

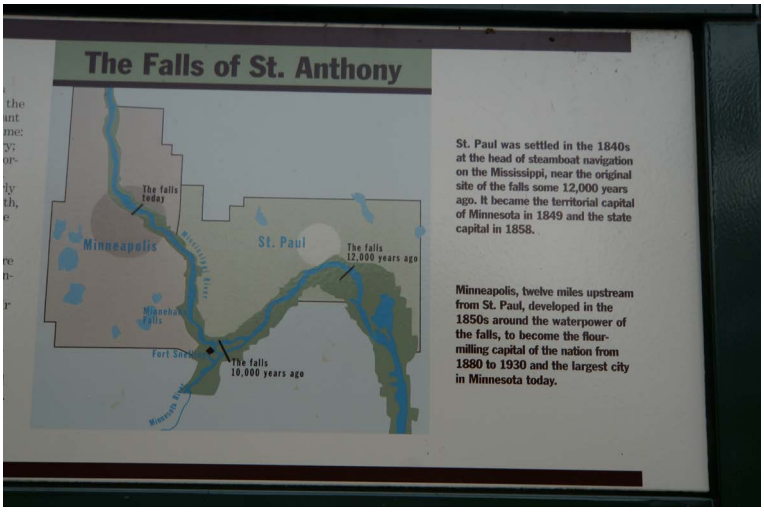

Figure 23. A river plaque shows how the location of the St. Anthony Falls has moved during geologic time.

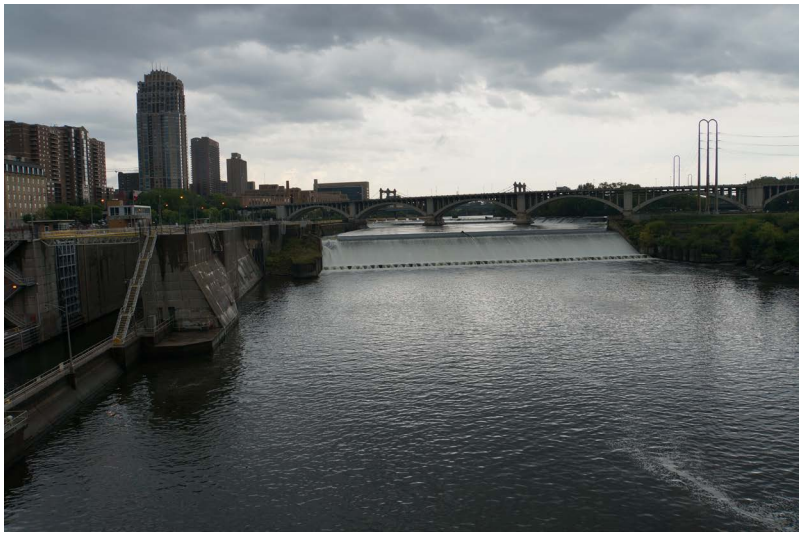

Figure 24. The St. Anthony falls and upper St. Anthony lock and dam are some of the most scenic sights in the Minneapolis-St Paul and draw thousands of visitors annually. Photograph was taken by Lois Wright Morton.

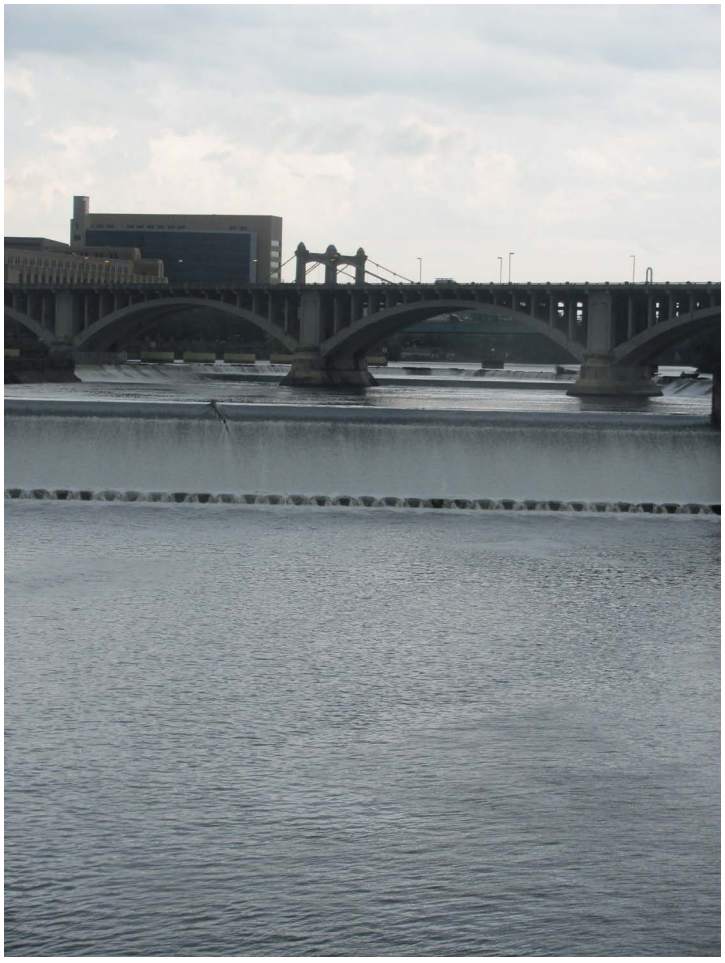

Figure 25. Close-up of St. Anthony falls with a cement cover to slow river erosion and a bridge crossing the Mississippi River in Minneapolis connect the commerce on both sides of the river. Photograph was taken by Lois Wright Morton.

2.5. Dam Removal from North American Great Rivers

Various environmental groups have suggested that the dams and the locks and dam systems, used to provide year around navigation on the Upper Mississippi River, are not economical. Removing major dams isn't a new idea. Nationally, approximately 185 dams have been removed since 2013 including the Glines Canyon and Elwha dams in Washington. Lessons learned from these dam removal projects could help guide future Upper Mississippi River dam removal projects. Removing the Washington dams took 20 years of lobbying, planning, researching and negotiating and at a cost of $26.9 million. The questions asked before and after dam removal included what would happen to the sediments that were previously trapped in the reservoir? How would native fish species respond? Would local water supplies be affected?

Using plans formulated by USACE St. Anthony Falls Laboratory in Minneapolis these two Washington dams were dissembled, sediment was released gradually, water treatment plants were constructed section by section as the Elwha river was returned to its natural state. It is estimated the Elwha River restoration project will cost around $324.7 million [12]. While initially costly, dam removal results in reduced maintenance costs, safety repair costs, staffing costs associated with fish and wildlife protection rather than the Mississippi River navigation related costs (historically navigation was the best and highest use of the river). Economic benefits can occur from recreational opportunities such as fishing, kayaking, rafting and associate businesses.

2.6. Shipping Channel and Fate of Upper Mississippi Locks and Dams

In 1907 a 1.8 m deep channel was authorize, the increased depth being obtained by building hundreds of wing and closing dams. Built close together, wing dams are wood and stone structures extending from the river bank towards the channel, usually at a 90 degree angle. Made of similar materials closing dams were used to block the connections between the main channel and the backwaters and side channels of the floodplains. These original structures are still a common feature on the Upper Mississippi River. However, with the rise of the use of railroads, and the demise of steam trade, the commercial aspects of river transportation became uneconomical and the industry began to die off. Congressional authorization in the 1930s to improve navigation on the Upper Mississippi River led to the construction of an upper lock that bypasses the Falls of St. Anthony (**Figure 24**) and enabled navigation on the Mississippi River above Minneapolis.

The USACE, by law, has to determine the "best and highest use" of a river or waterway. The St. Anthony lock was closed (**Figure 25**) but not removed in 2015 in part to protect Minnesota's northern lakes from Asian carp invasion. There are currently many proposals for the Mississippi River waterway in Minneapolis and St. Paul. These include: 1) removing the upper and lower St. Anthony and Lock no. 1 dams (**Figure 6**) and restoring the river's wild ride through a gorge

and 2) making St. Anthony lock and dams a $45 million national visitor and interpretive center. Resurrecting the rapids would not be easy. Instead of a 9 m of sediment and flooded riverbeds, there could be flowing rapids, waterfalls and parkland. Perhaps native species could be returned along with outdoor enthusiasts in an urban environment.

The Xcel Energy Corporation operates the hydro-electric power dams on the Upper St. Anthony Lock and Dam (**Figure 19**). There were many reasons for the closure in 2015 including repairs (**Figure 18**) and Asian carp migration [5]. It could, however, be the first step in restoring the St. Anthony Falls and Mississippi River gorge. This effort would also require the removal of Lower St. Anthony Lock and Dam and Lock and Dam no. 1 (**Figure 6**). Environmental and Conservation groups are studying the potential economic benefits of the dam removals. It is anticipated that the number of visitors, size of the waterfalls, river flow data, and visual appeal of a natural river in an urban setting could bring $900 million to Twin Cities annually. In addition, the Mississippi River gorge is in need of restoration to re-create the Mississippi River of 1820s. Before the dredging, damming, and re-arranging the rivers' elevation dropped 33 m from St. Anthony Falls to the Hidden Falls Regional Park. Congress will have the final say in closing Lock and Dam No. 1 and the lower St. Anthony, as it did with the closing of the upper St. Anthony Lock and Dam. However, the public holds the real power and everything that happens on the Upper Mississippi River is because people advocate to make change happen.

2.7. Upper Mississippi River Navigation

A number of advancements in the late 20th Century would bring the river transportation industry back to life. New ideas in lock and dam construction, particularly the roller-gate dam, were tested and proven. Diesel powered river vessels became capable of pushing large numbers of heavily laden steel barges (**Figure 17**). A dependable 2.7 m deep channel was needed for the Upper Mississippi River that could accommodate the new towboats and barges being used on the Ohio River and Lower Mississippi River. The creation of this new channel in central United States would form an integrated transportation system.

In 1930 Congress authorized the 2.7 m channel navigation project on the Upper Mississippi River from Minneapolis to the confluence with the Missouri River (**Figure 6**) north of St. Louis. This system created what is commonly called a "Stairway of Water" as the Mississippi falls 127 m from the Falls of St. Anthony in Minnesota to Lock and Dam no. 27 in Granite City, Illinois [3]. Slack water pools are created behind the dams allowing towboats, barges and other river vessels to be raised and lowered as they proceed from one pool to the next. This legislation provides for a 121 m wide navigation channel to be constructed in the 1930s and 1940s with a series of locks and dams. Construction resulted in a total of 29 locks and dams on the Upper Mississippi River (**Figure 6**). On June 9, 2015 the USACE officially closed the lock at upper St. Anthony Falls (**Figure 24** and **Figure 25**), the northernmost (together with the one at the lower St. Anthony

Falls) of the Mississippi River system's 29 locks [12]. The primary reason for the lock closure was the spread of Asian carp into Minnesota [1]; however, others state it was the lock and dam deterioration (**Figure 18**) while still others suggested it related to the desire to change the land use (urban development) adjacent to the lock and dam.

The barge transportation and agriculture industries have lobbied in the late 20th and early 21st centuries for a multi-billion dollar project to upgrade the aging lock and dam system (**Figure 18**). Environmental and conservation groups, advocates of budgetary restraint and railroad groups argued that the project lacks economic justification. The effective management of commercial navigation on the Mississippi River has had important economic impacts on the port cities of the Upper and Lower Mississippi and tributaries. The Port of South Louisiana at the Gulf of Mexico was the lead U.S. port in 2011, carrying 224 million metric tons. The domestic total was 114 million metric tons and foreign cargo was 110 million metric tons [13]. This was a 4.3% increase from the prior year. That same year, the port at St. Louis, Missouri was ranked 18th with a total of 33 million metric tons, an 18.6% increase from 2010. Ports on the Upper Mississippi from Minneapolis, Minnesota to the mouth of the Missouri River recorded a 1.8% increase in ton river-kilometers representing the transport of 56 million metric tons along 1061 river kilometers in 2011. During that same period, there was a 3.9% increase in ton-river kilometers of cargo moving from the mouth of the Missouri River to the mouth of the Ohio River, totaling 97 million metric tons [10]. The agricultural companies get their products to market by trucks, rail and barges but prefer a mixture of all three modes of transportation in part to maintain healthy competition and keep shipping costs down.

2.8. Public Lands, River Ecology, and Recreation

Management of water resources and navigation on the Upper Mississippi River today continues to provide vital social, economic, and environmental benefits to the people of this region and the U.S. Much of the upper river is a series of pools created by a system of 29 locks and dams (**Figure 6**) unlike the Lower Mississippi River. A primary reason for these locks and dams on the river is to facilitate barge transportation (**Figure 26**) which moves raw agricultural commodities, fertilizer, forest products, petroleum, sand, gravel and stone, food and manufactured products from the upper Midwest to ports in the south for domestic and export markets. The dams regulate water levels for the Upper Mississippi River, and also play a major part in regulating levels on the lower Mississippi River.

The locks and dams on the Upper Mississippi River have created lakes (**Figure 5**) and extensive marshes, open sloughs, backwater sloughs and swamps that provide natural habitats for a wide variety of wildlife. More than 30 species of freshwater mussels and 125 species of fish live in the reaches of the Upper Mississippi River. The Upper Mississippi River National Wildlife and Fish Refuge running from Alma, Wisconsin, downstream to Rock Island, Illinois is part of the Mississippi Flyway. Sandstone and limestone bluffs (**Figure 10**) high above

Figure 26. Tug boat and barges locking through Melvin Price Lock and Dam on the lower Mississippi River near St. Louis.

the river overlook backwaters, marshes, bottomland forests, sloughs, and forested islands.

Private and public marinas and recreational areas offer facilities for boat launching, camping, swimming, picnicking, and bird watching. Year-round fishing, waterfowl hunting, water sports, and island camping present unique opportunities to observe waterfowl nesting and hatching. The riparian floodplain forest at the National Audubon Field Station (**Figure 27**) above Melvin Price Lock and Dam across the river from Alton, Illinois is also a good site to view local and migratory birds.

The Upper Mississippi River topography, vegetation, and water surfaces are particularly scenic (**Figure 28**) and several states have set aside public lands for preservation, ecological protection, and recreational uses. Limestone bluffs and gorges carved from the rapids and waterfalls from St. Anthony Falls (Minneapolis, Minnesota) downstream to St. Paul, Minnesota are visible from park overlooks, walking trails, and a wonderfully preserved stone bridge that crosses the Mississippi River just below St. Anthony lock and dam. Below downtown St. Paul the river passes through a wide pre-glacial valley which extends southward for many miles. Minnesota, Wisconsin, Illinois, Missouri, and Iowa, have wildlife refuges and three National Park Service sites. One park, the Mississippi National River and Recreation Area in Minnesota encompasses 21,853 ha and 116 river kilometers. A second National Park Service site at Harper's Ferry, Iowa is the Effigy Mounds National Monument (**Figure 2**) with a visitor's center and trails to observe the animal shaped mounds (**Figure 3**) constructed by Native Americans. Lastly, the Jefferson National Expansion Memorial offers a birds-eye view of the Mississippi River from the Gateway Arch (**Figure 29**) in downtown St. Louis [3].

Figure 27. The wetland areas along the Mississippi River are habitats protected by Riverlands Migratory Bird Sanctuary in Missouri near St. Louis. Photograph was taken by Lois Wright Morton.

Figure 28. Panoramic view of the Mississippi River Valley from an outlook at the Palisades State Park, Illinois.

Figure 29. A common sight, a tugboat pushes a convoy of barges on the Mississippi River. The picture was taken from downtown St. Louis hotel.

2.9. Health of the Upper Mississippi River

The health of the river and its water quality continue to be a deep concern along the entire length of the river. Runoff, soil erosion and river sedimentation, off field and off farm nitrogen and phosphorous losses from cultivated crops as well as agricultural and industrial chemicals are threats to the river ecosystem. There is a general agreement that nutrient impairment is occurring not just in the main stem river but also in off-channel streams suggesting that the entire Upper Mississippi River basin land uses and practices need re-examined [14]. These nutrients accelerate the growth of algae and duckweed and reduce light penetration to underwater aquatic vegetation that fish and aquatic life including waterfowl feed on. Pharmaceuticals and endocrine-disrupting chemicals in river water are new sources of concern. Minnesota, Wisconsin, Iowa, Illinois, and Missouri are working together to find solutions to water impairments that impact local waters and downstream Gulf of Mexico hypoxia conditions. Pool 4 which includes Lake Pepin, Minnesota, a large natural lake is experiencing eutrophication from agricultural runoff.

2.10. Flooding on the Upper Mississippi River

From late May of 2008 and mid-June of 2008, approximately 20 to 30 cm of rain fell on the Upper Mississippi River basin [15]. Most of the national news coverage focused on Iowa where the Cedar and Iowa Rivers flooded the towns of Cedar Rapids and Iowa City. Later the Upper Mississippi River flooded farmland and not protected by the levees and where levees broke during the next few weeks as the floodwater peaked down river. The Upper Mississippi River peaked at St. Louis, Missouri on July 1, 2008 but at a lower height than during the record 1993 flood. There were no levee breaks on the Upper Mississippi River south of St. Louis in 2008. But there was flooding of local roads and agricultural lands (**Figure 30**) [15]. The peak floodwater on the Upper Mississippi River and caused evacuation of residents in the towns of Winfield, Missouri, Keithburg,

Figure 30. When Upper Mississippi River tributaries east of Cape Girardeau, Missouri overflow the river banks, major flooding occurs on local roads in Illinois.

Illinois and Meyers, Illinois. The Flood of 2008 closed many local roads and bridges and flooded adjacent agricultural lands. On the floodplains without levees, the floodwaters resulted in 100% crop loss and the flood plain soils often received thin silt, sand or clay deposits [15]. This sediment could be mixed with tillage equipment into the topsoil prior to the planting of the 2009 crop and the soils were degraded by rapidly flowing floodwaters that created blow out holes, gullies and crater lakes with sand deltas. Floodplains with levees that held usually had little 2008 crop loss, except where tributary streams ponded water behind the levees [15].

2.11. Invasive Species

The silver carp (*Hypophthalmichthys molitrix*) known as flying carp [1] were introduced in 1970 in Arkansas catfish farms in 1970 to control algae. Silver carp have since escaped into the Mississippi River system and migrated into the tributaries and streams. These large carp jump above the water to make their way up stream. As an invasive species, the Asian carp threaten adjacent lakes and the Upper Mississippi River species of filter feeding fish by voraciously consuming the bottom of the food chain [5].

3. Conclusions

Agricultural runoff, including sediment and excessive nutrients (nitrogen and phosphorus) and chemicals from agricultural and industrial sources continue to threaten the river resources. New threats include pharmaceuticals and endocrine-disrupting chemicals. Wisconsin, Minnesota, Iowa, Illinois and Missouri are working together to address the water quality issues.

To address the failing lock and dam system on the Upper Mississippi River and Missouri River, the country as a whole, will need to look at this investment. There is need for systematic investments in routine maintenance and repairs as well as close monitoring and assessment of locks and dams to pre-empt future failure (**Figure 31**). Close monitoring, channel dredging and maintenance of channel control structures such as wing dams, closing dams and bank revetments, snag removal, and accurate channel marking are essential to keep the system operating at peak efficiency. Many of these expenses, shared by USACE, private shipping companies and local port authorities, require substantial public investments and congressional authorization. The public investment for water and waterway improvements is being considered in the current congressional infrastructure bill.

Managing for resilience can best prepare the great river systems to be adapted to future unknown risks and catastrophes [1]. Resilience management can improve capacities to adapt and adjust to system disruptions and change. Contested views make managing river landscapes difficult. People differ in their social values and what they consider the best functional uses of rivers and their floodplains. Managing river landscapes bases on engineering and bio-geophysical

Figure 31. Hydroelectric dam built on top of the Missouri falls on the Missouri River near Idaho falls, Montana provided electricity for economic development of the region. Photograph was taken by Lois Wright Morton.

sciences alone will fail to reduce vulnerability and unforeseen risks. The diversity of social values, land use preferences, and human relationships with rivers and their floodplains must be better understood and made part of the management processes. A comprehensive Upper Mississippi plan similar to the plan for the Lower Mississippi River with an increase resiliency is needed to address climatic extremes.

The landscape and geological resources of the Upper Mississippi River have contributed to the successful water resource and economic development of a historically rich region in North America since the 1830s. We attempted to identify the natural resource and environmental risks to the Upper Mississippi River basin and to evaluate the proposed outline the Environmental and Conservation attempts change the historic highest and best use, navigation and economic development of the Upper Mississippi River and watershed, to having the urban river restored to the natural state.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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