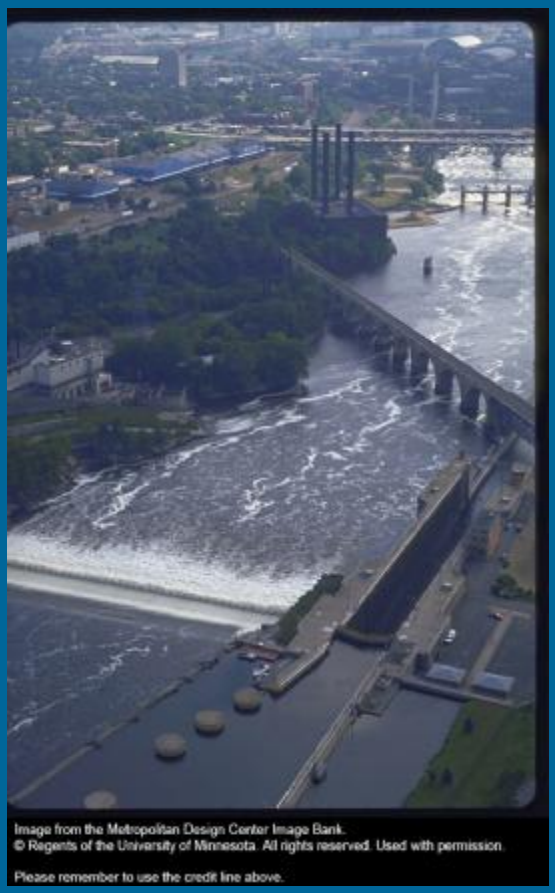
Mississippi River Gorge Restoration Study:

Synthesis of past work and feasibility assessment of restoration actions



Report to the McKnight Foundation's Environment Program

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This document is a summary of more detailed report covering background and feasibility, which will be available online as PDF files at http://environment.umn.edu/riverlife/. Section numbers from the background and feasibility study are referred to throughout this report in brackets.	

Executive Summary

The Twin Cities reach of the Mississippi River has historically been dominated by commercial navigation and hydropower. Yet with increasing recreational usage and evolving economic priorities in the Twin Cities there is growing interest in recreational, aesthetic and ecological uses of the river, particularly within the area known as the Gorge (between St. Anthony Falls and Ford Dam). The City of Minneapolis' "*Above the Falls Master Plan"* proposed closing the upper harbor to barge traffic, creating opportunity for restoration of ecological, historic, aesthetic and recreational features.

The University of Minnesota working with government agency and non profit partners: the National Park Service, Mississippi Watershed Management Organization, Great River Greening, the Minnesota DNR and Minnesota Pollution Control Agency, conducted an assessment of existing restoration and management work and a preliminary investigation into the feasibility of restoration and management actions. The restoration and management of physical, ecological, and socio-economic processes were examined between the Ford Dam and St. Anthony Falls (Pool 1) with consideration given to the adjacent reaches up to Coon Rapids Dam and downstream to the Hastings Dam because of the influence of adjacent river reaches on the Gorge.

The synthesis of existing work showed that restoration and management has focused on upland vegetation and tributary watersheds but not the main channel of the Mississippi. The Navigation and Ecosystem Sustainability Program (NESP) developed by the U.S. Army Corps of Engineers established lofty goals for river management, but in fact, sustainable river management is exceedingly difficult with locks and dams in place.

Feasibility of Gorge restoration alternatives was assessed using the five - factor TELOS framework, a method adopted from computer science, indicating Technical, Economic,

Logistical, Operational and Systems feasibility. An ecological impact category was added for this study. Within the Gorge, most restoration options have economic and /or political (legal) barriers often because of the maintenance of the 9-foot barge channel, hydropower rights and the costs of restoration projects. Yet many restoration and management actions are feasible at the current time or could be within the next decade, including water-level drawdowns, sediment management, island re-creation, fish and mussel habitat improvements, enhanced canoeing and kayaking and establishment of more park areas. However to completely re-establish connectivity of fish and mussel movement and restore the sediment transport regime, removal of Ford Dam would be required.

Recommendations for short-term actions (<5 years) include conducting more detailed analysis of promising areas of restoration and mapping potential parkland gains in the Gorge from water level management and/or removal of Ford Dam. A test drawdown could be done on the Ford Dam within the next few years. Public presentations will continue to be made on the study and additional grant funds pursued to better understand the costs and benefits of restoration actions.

Project purpose and background

Restoration of the Mississippi River Gorge in the Twin Cities metro region is becoming increasingly debated because of changing economics and usage of the river. With the City of Minneapolis's *Above the Falls Master Plan* calling for ending barge traffic above St. Anthony Falls in favor of recreational, ecological and commercial improvements, interest in river restoration has grown in recent years. Despite the growing interest in river restoration little has been done on the river in the Twin Cities. Most work has focused on tributary watersheds and upland vegetation management. River restoration has been framed as an all-or-nothing proposition to either retain maximum industrial usage or remove the dams and restore the entire river ecosystem (Mosely, 2005). In fact, there are numerous restoration and management actions that could be undertaken now and planned for in the near future [1.1]. At this point in time, neither of the extreme ends of the spectrum: no action or total dam removal, are realistic.

The primary goals of this study were to:

- **Provide a current synthesis of existing restoration and management** work done on the Mississippi River between Hastings and Coon Rapids.
- **Identify gaps and opportunities** for improvement in river restoration approaches and types of projects being conducted
- **Examine feasibility of restoration and management actions** within the study area, ranging from total ecosystem restoration via dam removal to partial restoration actions.
- **Recommend next steps,** actionable items that can be undertaken immediately (0-5 year)
- **Recommend ways to improve sustainability** of river management from ecological and economic standpoints (Figure 1).

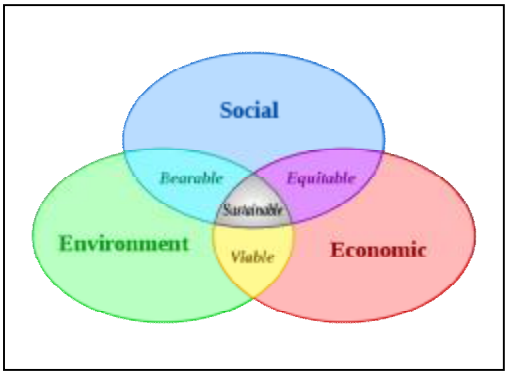

Figure 1: Sustainability is defined by the long-term maintenance of social, environmental and economic values over time (Adams, 2006).

Study Area

The focus of this study is between St. Anthony Falls and Pike Island, (the area known as the Gorge, which is mostly contained within Pool One of the U.S. Army Corps of Engineers Lock and Dam System). However, it was necessary to examine the reaches immediately above and below the Gorge in order to adequately assess the feasibility of restoration and management actions. Therefore the entire study area was defined as the Mississippi River below Coon Rapids Dam downstream to the Hastings Dam which is in Pool Two.

1.0 Review and Synthesis of restoration and management work in the Gorge

We reviewed restoration and management plans for the Mississippi River within the Twin Cities region to characterize the work currently being done and identify gaps in restoration and management actions. The key natural resources management organizations at the federal level include the National Park Service (NPS) and the U.S. Army Corps of Engineers (USACE). At the state level the Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Natural Resources (DNR) have important roles, with the MPCA regulating water quality and the DNR conducting restoration and management activities in the river, including mussel restoration in Pool Two. At the local level, City of St. Paul, City of Minneapolis, the Mississippi Watershed Management Organization and the Minneapolis Parks Board are just a few of the key entities, while Great River Greening and Friends of the Mississippi River are two of the main non-profits working on habitat improvements within the river corridor. A host of other organizations work on broader watershed management and related issues [1.1, Appendix A].

Within a large urban area there is a strong need to balance economic, aesthetic, ecological and recreational services provided by the river. In order to achieve that goal, the USACE's Navigation and Ecosystem Sustainability Program (NESP) was recently developed to establish guidelines for sustainable management to balance ecological restoration and maintenance of the lock and dam system for commercial barge traffic. In NESP, restoration is defined as "*improving the hydrologic, geomorphic and ecological processes to reestablish a river that is more self-regulating and integrated into its ecological, social and economic landscapes.*" We examined whether the ecological goals of NESP were being met and found that they were not for the Gorge area. Fish, mussels and aquatic vegetation have been highly altered and the hydrologic and sediment transport processes changed dramatically since the locks and dams were installed [1.2.1 – 1.2.2]. The alteration to hydrologic and sediment transport regimes with lock and dam system pose fundamental obstacles to ecosystem sustainability; yet that is the challenge that managers must address. Specifically, sediment accumulation in reservoir, alteration of water levels changes affecting plant communities, and blocking fish and mussel migration need to be improved to sustain these components of the ecosystem (Table 1).

In addition to the challenge of balancing ecosystem need with commercial navigation requirements, river restoration and management in urban areas is often constrained by the location of infrastructure such as bridges, roads, dams, and private property. In contrast, most of the restoration done on the upper Mississippi River has been done in fairly undeveloped reaches along the Wisconsin/Minnesota border. In addition to physical constraints, another major urban issue is the large number of visitors increasing the importance of recreation, aesthetic and economic issues. Consequently, the public benefits of such projects may be much greater, even if the projects have less ecological benefit than river restoration projects in less developed areas. They tend to be less ecological in urban areas since parkland and user-friendly areas are in high

demand, calling for a different approach to river restoration projects. All of these challenges make large urban rivers difficult to manage sustainably [1.3, 2.0].

Because of the challenges described above and the legal mandate to maintain the 9 ft barge channel most of the restoration and management work has been done on the uplands of the river valley to restore vegetation and historical, cultural features but little has been done on the main channel itself. Clearly there is a lack of attention paid to in-river restoration from an ecological, recreational, aesthetic and long-term planning standpoint [1.1].

2. Feasibility assessment and review of scientific literature

As a preliminary to the feasibility assessment, relevant scientific research was reviewed on restoration and management of large rivers. Case studies were also examined for similarities to the Upper Mississippi. The Mississippi River is one of the most thoroughly studied rivers in the world, making it a challenge to simply synthesize the existing information. Therefore we focused on research related to restoration and management particularly issues involving large rivers in urban settings. Unfortunately, much of the information concerning river restoration projects is not published in peer-reviewed scientific journals because it is not research-oriented, but practically oriented and therefore is found in unpublished reports or notes. Literature was reviewed for information on physical processes [1.2.1], ecological processes [1.2.2], socio-economic [1.2.3], issue and research related specifically to large river issues [1.2.4], (Table 1).

A preliminary feasibility study of restoration and management actions within the study area was done to identify promising strategies for more detailed analysis and possible future implementation [2.0]. Feasibility assessment also reduces the planning, time and effort needed to carry out future restoration and management actions. Aspects of feasibility were examined using five categories outlined in the **TELOS** framework (*T*echnology, *E*conomic, *L*egal, *O*perational and *S*chedule). While TELOS was developed for computer and business applications, this framework helped to identify more practical issues associates with river restoration often not considered in ecological or economic assessment alone. For example the physical constraints associated with river restoration involving hydrology, geomorphology, and channel alterations fall under the *Technology* category. *Economic* issues include commercial barge and hydropower uses, river recreation, tourism, and aesthetics. *Legal* issues include questions of regulatory power and management authority, such as maintenance of the 9 foot channel which was authorized at the Congressional level. *Operational* issues are practical problems related to doing restoration while operating a lock and dam system, including the logistics of doing water level drawdowns and its impact on barge traffic. *Schedule* issues involve feasibility from a timing standpoint including such issues as the timescale for restoration and management actions, the seasonality of water level variation, and the duration of hydropower licenses among many others. [2.1].

Upon analysis, many restoration and management actions are found to be feasible from technical and operational (practical) standpoints. The major barriers tend to be economic and legal, depending on the action. For example, water level drawdown can physically be done at Lower St. Anthony Falls Dam, but may have unacceptable economic costs to hydropower and barge interests. However, much economic uncertainty exists over ecological, recreational and aesthetic benefits, because of the difficulty in quantifying non-marketable goods or services. If these benefits were adequately quantified by documentation of the value of ecological services, recreational access and tourism usage, the economic feasibility of many projects would improve substantially [2.0-2.4]. Feasibility is likely to change over time as evidenced by the rapid economic changes along the Twin Cities Riverfront just in the past decade.

While a project must have a favorable balance of the feasibility factors previously discussed, there are other factors that may limit the viability of restoration projects, including public acceptance. Public knowledge of restoration and management issues on the river is very limited. However the restoration of parkland and recreational areas along the river fits in with cultural values and priorities of the Twin Cities region, known for its excellent system of urban parks.

2.1 Physical processes: Hydrology and geomorphology [1.2.1]
The variation in water level and discharge seasonally and over years is critical to almost all aspects of river restoration and management. Water level and discharge strongly influence the type of aquatic and riparian vegetation that may grow within the river and flood-prone area. The hydrologic characteristics of the river are key for fish and wildlife, recreation, hydropower and boat navigation. Water level and streamflow characteristics have been greatly altered by the locks and dams, creating large lake-like environments (Pools 1 and 2) where highly variable water levels existed prior to dam construction. The lack of variation in water depth and stream discharge from impoundment is therefore a major impediment to ecological restoration in the UMR [1.2.1].

In recent decades there has been a substantial increase in the volume of stream flow in the Upper Mississippi, creating challenges for water quality and flood control downstream of the Twin Cities. On the other hand, increased stream flow is beneficial to hydropower and some river recreation uses. Economically, the river is important for water supply, supplying the City of Minneapolis and supports several hydropower dams and commercial barge navigation.

Historically, stream flow was more variable in the river, with large areas of sandbars and mudflats exposed due to the lower summer flow which existed without the reservoirs. In addition changes in land-use and climate over the past century have increased mean and low flows in the Mississippi reducing the period of sediment exposure [2.1]. Water level variation promoted growth of a variety of plant community types and in-stream habitats for aquatic organisms.

In contrast with much of the Mississippi downstream of the Gorge, flood control is not a major issue. The dams have little storage volume, so they have little effect on peak flows downstream of them. Furthermore, the river is deeply entrenched within the rock walls of the Gorge between St. Anthony and the Ford Dam, limiting any flood damage from occurring within that area [2.1].

Feasibility of hydrologic restoration
Despite the challenges, options exist for restoring aspects of the hydrologic regime ranging from total ecological restoration to partial reestablishment of water level variation through seasonal drawdown [2.1]. Currently dam removal is not feasible because of the active hydropower and commercial barge usage, but that situation could easily change in the next decade. If Minneapolis' *"Above the Falls Master Plan"* was implemented, barge traffic would end in the Gorge, greatly increasing the demand for ecological restoration, as well as aesthetic and recreational improvements. On the other hand, more limited seasonal drawdown is possible immediately from logistic, ecological and technical standpoints.

Water quality plays a key role in both ecosystem and human health [1.2.1]. The Mississippi River is much cleaner in the Gorge above the merger with the Minnesota River at Ft. Snelling (Figure 2). Consequently, water quality issues are dramatically different in Pools One and Two. Although water quality issues remain, the river between Minneapolis and Hastings is much cleaner than it was prior to the Clean Water Act over 30 years ago allowing for recovery of fish and freshwater mussel communities.

Table 1: Indicators of sustainability in management and restoration of the Mississippi River Gorge considering balance between ecological and economic needs required under NESP.

Category	Processes	Actions needed
Physical	Maintenance of hydrologic regime and geomorphic traits: Sediment transport; Island formation; Water level variation	Water level management; flushing and dredging of reservoir;
Ecological	Maintenance of connectivity and ecological integrity for fish and mussel populations; depth and velocity variation for vegetation and fish	Seasonal drawdown; manual restoration of mussels; fish passage at dams
Socio-Economic	Value of commercial, industrial, ecological services and recreational uses should outweigh costs;	Better valuation of aesthetic, recreational and ecological services; documentation of river use for these purposes
Large River-specific issues	Restoration of ecosystem function over structural projects; integration of ecology and economics	Determine optimal mix of ecological restoration, industrial and recreational uses

Yet challenges remain with high levels of sediment, nutrients and bacteria. Suspended sediment often measured as Total Suspended Solids (TSS) is very high in Pool 2 (above the Hastings Dam) due to inputs from the Minnesota River. Above the merger of the two rivers, the MR is impaired for fecal coliform bacteria in several reaches, posing a potential threat to human health if water is ingested and thus limiting recreational activities to boating and fishing. There is rising concern over emerging contaminants that were not recognized until recently. For example endocrine-disrupting hormones have caused widespread feminization of fishes, in U.S. rivers and were found in the Mississippi River, though much remains unknown concerning these chemicals.

Figure 2. Water quality declines greatly when the Minnesota River empties into the Mississippi River at Fort Snelling in St. Paul, MN. The Minnesota is in the lower left of the photo.

Geomorphology and sediment management

The physical geomorphic characteristics of the river channel and the movement of sediment through the river strongly influence river ecosystem characteristics and the long-term viability and sustainability of the lock and dam system. The geomorphic setting of the Gorge is unique for the Mississippi River as it contains one of the steepest sections on the entire river, dropping over 100 feet from St. Anthony Falls to St. Paul and effectively preventing commercial barge navigation until the SAF lock and dams were completed in the 1960s. The Gorge was created as the downcutting of Glacial River Warren lowered the base elevation of the Minnesota River which in turn caused the Mississippi to downcut 100 feet to the new, lower elevation (Fremling, 2005). Consequently, over centuries the falls migrated upstream from Ft. Snelling to its present day location.

Prior to dredging for barge traffic and lock and dam construction the river bed was lined with coarse bed materials (gravel, cobble, and boulders) that provided excellent fish spawning habitat in the Gorge [1.2.1]. Construction of the St. Anthony and Ford dams induced sediment deposition in Pool 1 burying many of the coarse bed materials in finer sediments, silt and sand. In addition to ecological degradation, reservoir sedimentation reduces the lifespan of the pool for commercial usage by reducing storage, requiring regular dredging and maintenance costs. Sediment accumulation in Pools One and Two is substantial. Approximately half of the volume of Pool One has filled in since 1917.

Sediment could be removed via dredging or flushing, though dredging is very expensive. More sustainable sediment management would be needed to maintain the pools into future decades. Removal of sediment would accomplish the dual purposes of reducing reservoir sedimentation and enhancing aquatic life in the river [1.2.1; 2.1].

Islands were historically an important geomorphic feature of the river with over 20 islands found between Ft. Snelling and St. Anthony Falls in the 1850s. Since then, all have been removed via dredging, merged with the mainland via wing dam construction or submerged under water. Islands create numerous side channels and variation in water depth, velocity and vegetative cover. Mudflats that are often precursors to island formation and sandbars and found in shallow depositional zones also contributed to aquatic habitat heterogeneity. In addition to the ecological benefits of islands, they serve as valuable parklands in urban areas. Several of the most-used parks in the Twin Cities are islands (or were islands before they were merged with the mainland) including Nicollet Island, Boom Island, Harriet Island and Pike Island at Ft. Snelling State Park. [1.2.1; 2.1].

Geomorphic restoration from technical standpoint requires that water level control is possible (unless the Ford Dam were removed). Flushing of sediment by opening the lock gates at high flows can be done, but there are legal, economic and technical barriers because of the requirement to maintain water levels for barge traffic.

Islands can be rebuilt from a technical standpoint, but the geomorphic processes that created them cannot be restored in the Gorge because of the hydrologic and sediment transport alteration by the dams. For that reason and the high number of recreational users, restored islands in the Gorge would have to be more along the lines of an ‘urban park’ with natural features but also containing trails, public access and educational signage.

Another critical geomorphic issue is increasing the exposure of cobble and boulders buried underneath fine sediments for the benefit of fish and mussel species to expand the area of coarse

stream bed materials available for fish spawning and mussel colonization, which would require either dredging or flushing [2.1].

2.2 Ecological processes

The restoration and maintenance of ecological processes are important for ecological health, but also recreation and economics. Ecologically, this study focused on fish and mussel restoration because of the great value of the Gorge for these species, historically. Vegetation restoration and management is also very important from the standpoint of aquatic habitat and providing food chain support for fish and invertebrates. Aquatic, emergent and floodplain vegetation also strongly influence water quality [1.2.2].

Fish and mussel life cycles

The Mississippi River Gorge between Saint Anthony Falls and Ft. Snelling was a prime spawning ground for many fish species and colonization spot for freshwater mussels due to the high gradient and the gravel, cobble/boulder streambed unique for the low-gradient Mississippi River. The Mississippi River is a center for aquatic diversity, supporting 25% of all fish species in North America (MNRRA 2009) with 143 in the Upper Mississippi River (Wilcox et al. 2004), upstream of St. Louis [1.2.2]. As such the river is key to the maintenance of biological diversity across the entire upper Mississippi basin, supporting diversity in the thousands of tributaries connected to the main channel.

After construction of the Ford Dam in 1917 until the 1960s, Pool 1 of the Mississippi River was nearly devoid of aquatic life because raw sewage, stormwater runoff and garbage were dumped into the river untreated, and collected in the stagnant pool created by the dam. Decomposition lowered oxygen levels via biological oxygen demand (BOD). Because of the Clean Water Act, water quality was vastly improved, allowing oxygen levels to rise sufficiently to support aquatic life again. Since that time, many mussel and many fish species returned to the river [1.2.2].

While water quality has recently improved, longitudinal (upstream-downstream) connectivity was greatly reduced by the dams [2.2]. Although lateral connectivity (main channel- floodplain connections) has increased in some cases, as impounded waters flooded adjacent oxbows and side channels, it has decreased where side channels have been cutoff for navigation purposes. Upstream-downstream (longitudinal) connectivity has been greatly decreased by dams, impacting both fish and mussel populations and preventing many fish from reaching the gravel/cobble spawning grounds of the Gorge [BG 1.2.2]. Since mussels are transported in their larval stages by fish, the distribution of both are integrally linked. There are many threatened and endangered mussel species in the Mississippi and the tributary St. Croix River, including the Higgins' Eye mussel. Many of these would benefit from improved connectivity and river restoration actions.

Vegetation could be re-established in back channels, along riparian / shoreline zones, on shallow mudflats and potentially on islands. But without dam removal, restoration of vegetation will depend on creating low flow periods during the late spring and summer when plants can become re-established on sandbars, mudflats or other seasonally exposed surfaces [1.2.2; 2.2]. Several such areas exist in the Gorge and in nearby areas upstream and downstream of the Gorge.

Similarly with re-establishing physical processes, restoring many of the river's ecological functions is technically possible but legal and economic barriers hinder action. Restoration of fish passage through fishways or fish ladders could be accomplished at the Hastings Dam, opening up access to over one hundred miles of the Minnesota River. However the Ford Dam poses serious technical barriers to establishing a fish passageway due to its height (11m).

Alternatively, the locks could be opened at the Ford Dam during periods of fish migration, but due to the age and design of the lock gates, they may not withstand high flow velocities [2.2].

The MN DNR has worked on restoring mussels in Pool Two between the Ford Dam and Ft. Snelling. Pool One offers good habitat for mussels and direct reestablishment of threatened or rare species is very feasible. However, much of the coarse bed material has been buried in finer sediments, greatly reducing the availability of suitable substrate for mussel colonization. Ultimately the most effective way to restore mussel populations is to reestablish longitudinal connectivity of the river so that fish may transport larval mussels upstream [2.2].

Currently there are little or no aquatic plant communities, wetland-side channel habitat or sandbar shrub communities within the Gorge, though considerable work has been done on restoring the uplands of the Gorge by government and non-profit groups. Enhancement of aquatic vegetation coverage and heterogeneity of habitats would be beneficial for fish and wildlife within the Gorge. In fact, vegetation enhancement is highly feasible if water level manipulation can be done [2.2].

2.3 Socio-Economic issues

On large urban rivers heavily used for commerce and recreation, socio-economic issues take on increasing importance. The inter-related issues of recreation, aesthetics and economics were examined related to the re-establishment of parkland, seasonal whitewater runs and aesthetic improvements to the Gorge and St. Anthony Falls.

Recreation is very important in the Gorge area, including boating, bird-watching, hiking, fishing and site-seeing. The reestablishment of a seasonal whitewater run in the spring would be beneficial to whitewater kayakers and canoers. Whitewater sports have proven to be important economically on many other rivers including the New River, West Virginia; the Colorado River in the Utah and Arizona and Boulder Creek in Boulder, Colorado. One of the main barriers to river recreation is the lack of access in the Gorge, or simple stopping points within the river for small motor boats and canoes. Re-establishment of small islands or simple canoe launches and trails would improve the usability of the Gorge for recreationists [1.2.3 and 2.3].

The aesthetics value of river corridors has been much neglected in river management but is very important to river-users particularly in highly-used urban areas. Recent research on aesthetics of the Gorge, as a key aspect of the Mississippi National River Recreation Area showed that protection of the '*viewshed*' is important to the public and should be a higher management priority (Mullan, 2009). The St. Croix National Wild and Scenic River and the Wisconsin State Riverway both provide examples of established aesthetic guidelines that could provide insight into management of the Gorge.

St. Anthony Falls is perhaps the most-visited aesthetic resource in the Gorge with thousands of visitors viewing it each year from the Stone Arch Bridge, Mill City Museum, St. Anthony Main and Guthrie Theater. Protection of flow over St. Anthony Falls is important for maintaining the scenic appeal of the falls. Research has shown that aesthetics of waterfalls is an important factor for tourism, with visitors preferring larger amounts of water overflowing the falls. In addition to maintenance of flow, naturalization of St. Anthony Falls would be a huge aesthetic improvement and could be accomplished without dam removal or significant alteration of existing infrastructure, however little is known about the feasibility of such a project. Rebuilding Spirit Island or some portion of it would be a high priority for Native Americans, as this was a major spiritual site for the Dakota tribe [1.2.3 and 2.3].

Economic benefits are typically attributed mostly to hydropower and commercial navigation. These industrial uses have benefitted from cost-benefit analysis that are able to place direct values on marketable goods and services but are unable to sufficiently quantify the economic benefits of ecological services such as flood control, clean water protection or fish habitat. More accurate and holistic valuation of ecological services is needed to establish a more even balance of industrial, ecological, recreational and aesthetic benefits in the Gorge area. The concept of ecological services is increasingly being used to integrate ecology and economics into a common value system. Quantification of ecological and aesthetic benefits will allow them to compete more equally against marketable goods, making it more likely that river will be restored or managed to maximize the non-marketable benefits provided by the river. With the redevelopment of the Minneapolis and St. Paul riverfronts in the 1990s – 2000s, the economic value of parkland, bike trails and aesthetically attractive river views have increased in importance considerably [1.2.3 and 2.3].

Feasibility of socioeconomic enhancement and rehabilitation

The long-term economic health of the Twin Cities relies on many factors, but the maintenance of healthy, attractive parkland and recreation corridors is critical to its vitality. Restoration of Gorge features and river functions are important for maintaining the ecological integrity and quality of recreational and aesthetic experiences. However the economic benefits of ecological services provided by the Gorge are not well documented. More research is needed to establish the economic benefits related to ecological services, recreation, aesthetics and non-consumptive use of river resources [2.3]. For example quantifying the amount of human use for passive recreation along the Gorge corridor would be a first step in this direction.

The aesthetics of the Gorge area could be enhanced through active *viewshed* management (Figure 3), particularly in the St. Anthony Falls area. For example aesthetic guidelines could be established along the Mississippi River National Recreation Area, as they have been for the St.Croix River, a Wild and Scenic River. The guidelines could be straightforward but may be politically challenging, with the myriad uses of the river corridor.

Figure 3: Management of the "viewshed" is an important component of Gorge management for the aesthetics of recreational users of the river.

On the far upstream end of the Gorge, aesthetic restoration of the St. Anthony Falls may be possible, technically and politically. Re-establishment of Spirit Island is also important aesthetically and as a sacred site to the Dakota Indians. More research is needed in this area, as there are few precedents for aesthetic restoration of falls altered by dams, except for efforts to maintain flow over the falls [2.3].

Many recreational improvements to enhance recreation along the river are possible, including the establishment of a seasonal whitewater run, establishing public small boat landings and generally improving access to the Gorge are all feasible. A seasonal whitewater run could be established by drawing down Lower St. Anthony Falls Dam, as occurred in February 2008. More research is needed into the feasibility of seasonal whitewater runs; primarily in terms of legal and economic barriers. The establishment of islands for outdoor recreation (in addition to the ecological benefits), would facilitate many of the objectives related to enhancing outdoor recreation and providing education on the history of the Gorge. A more detailed and focused GIS analysis of parkland gained from incremental water level drawdown is needed to pinpoint areas of potential land gain within the Gorge area [2.3].

2.4 *Synthesis of large urban river restoration issues*

As a large urban river, the restoration of the Mississippi River poses unique challenges. Most practical stream restoration experiences have come from small streams, not large rivers because of inherent difficulties in scale that arise. Large rivers require a focus on restoration of processes and functions over structures (See Box 1). This is because it is more difficult to physically manipulate the shape, pattern and riparian vegetation of big rivers given the great hydraulic forces involved. Therefore the restoration of physical and ecological processes such as floodplain connectivity should be prioritized over short-term "construction projects", such as the installation of fish habitat structures commonly used in small streams (Galat et al. 2007). A fish habitat structure may be washed out in the next flood, while reconnection of a cut-off side channel provides a long-term restoration of stream function. Although large rivers call for the restoration of stream processes over structural installations, in urban areas like the Twin Cities the limitations created by infrastructure and other human uses often require that the river be "locked in place" via river control structures such as rip-rap and levees. For these reasons, urban river restoration and management practices tend to be less sustainable than similar projects in natural areas, because of the need for structures that tend to have higher costs and limited life-spans.

On the other hand, large urban rivers support multiple ecological, recreational and economic functions (Mcguinness, 2000), which calls for an increased management focus on recreation and other human uses. The increased human usage creates greater potential for economic and social benefit, providing justification for the extra construction and maintenance costs of more structural restoration projects. For example, Fort Snelling State Park, located on the Mississippi River is the most visited state park in Minnesota

<u>Precedents for Mississippi River restoration [1.3]</u>

Precedents of river restoration and management were investigated to identify lessons learned applicable to restoration of the Mississippi River Gorge. A wide spectrum of restoration project were examined ranging from total river restoration via dam removal to partial restoration through individual river "enhancement" projects, such as island reconstruction.

Projects were selected that represent a range of gradients that occur along the river restoration and management spectrum: large vs. small rivers; urban vs. natural settings, and functional vs. structural restoration (Box 1). Large rivers have greater complexity, floodplain interaction and socioeconomic importance compared to smaller streams. The following projects were examined

to gain further insight into restoration and management issues relevant to the Mississippi River. Case studies were selected for similarity in restoration projects or management issues, not because of their similarity to the Gorge in bio-physical conditions.

Box 1: Defining the range of alternatives in large, urban river restoration

Structural vs. Functional Restoration– Traditionally structural restoration in rivers has involved constructing structures to control the flow of water and sediment, such as levees, rock vanes, dams and fish ladders; in contrast functional restoration seeks to reestablish physical and ecological river processes that have been altered or impaired through human activities such as floodplain connectivity, transport of sediment and migration of fish and mussels. In large rivers such as the Mississippi functional restoration is vital to success.

Small vs. Large River– small rivers [<1000 mi^2 drainage area] differ in ecological and geomorphic processes, particularly the extent and importance of floodplain connectivity. The vast majority of stream restoration projects have been carried out on small rivers. Small stream restoration frequently involves re-configuring the channel and installing fish habitat structures, approaches that are problematic on large rivers such as the Mississippi.

Urban vs. Natural - Urban watersheds have a high degree of imperviousness creating very flashy hydrographs; they tend to have confined floodplain and channels from the placement of infrastructure: houses, bridges, levees, roads, etc; limiting the extent of ecological restoration attainable. Although the Gorge is urban, the entire flood-prone area is deeply entrenched within the river valley, limiting urban encroachment. Finally, urban streams tend to have higher rates of human use than remote natural areas, demanding more of a focus on education, recreation and aesthetics.

Sustainability– Sustainability requires the maintenance of key economic, environmental and social processes over decades or centuries. In the Mississippi River one key question is whether ecological and economic "*goods and services*" can be balanced in a lock-and-dam dominated river system over the long-term.

Case studies:

- The Edwards Dam removal in Maine in 1999 demonstrated that removal of large dams is possible. Today, large runs of migratory herring and other fish have re-established.
- The New River, West Virginia and Colorado River in Arizona served as case studies for controlled water releases from dams to support whitewater recreation
- The Rhine River, Germany was a precedent for large, highly altered rivers in developed areas where significant restoration work has been done.
- Boulder Creek, Colorado served as an example of restoration for urban whitewater recreation, aesthetics and channel stability in a small urban stream.
- The Colorado River in Arizona and Utah below the Glen Canyon Dam provided a model for adaptive management through controlled water releases. Adaptive management provides opportunities for doing experiments with management actions, while learning from the test cases and then adapting future management plans.
- The Mississippi River, Pools 4 to 8 demonstrated the possibilities and challenges of recreating islands and restoring side-channel vegetation by water level drawdown

- The St. Croix River and Wisconsin River Corridors served as examples of rivers with aesthetic guidelines for the riparian corridor, regulating the design and appearance of structures within the protected zone.
- The Cuyahoga in Ohio was a prime example of the restoration of a highly urban, industrial river that had been recovered from a degraded condition to serve as a highly valued National Park in the large Cleveland metro area
- The Blue Earth River at Rapidan, Minnesota illustrates the costs of aging infrastructure and sedimentation on reservoirs

Review of case studies provided numerous insights into different aspects of Mississippi River restoration from rivers across a whole range of physical, ecological and socio-cultural settings as described in the background report [1.3]. Although some of the rivers are very different geologically and ecologically than the Mississippi River, such as Boulder Creek Colorado, they all had some aspects that were highly relevant to the Mississippi River (Figure 4].

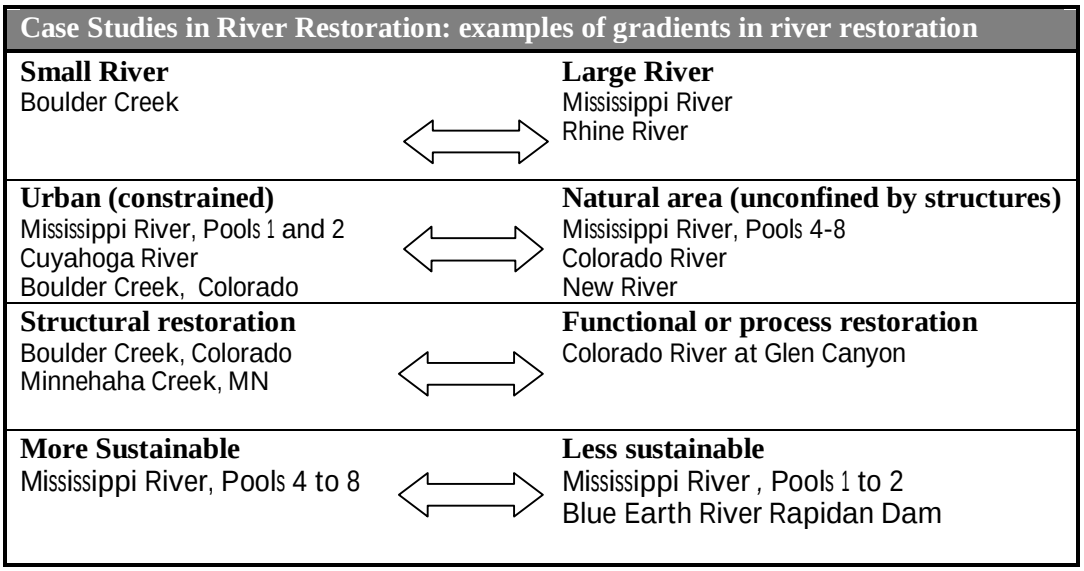

Figure 4: Key dichotomies or gradients of issues for river restoration. Projects representing examples of each type are listed within each box.

Partial restoration vs. dam removal: What is achievable?

Dam removal is clearly the most effective way to restore ecosystem functions and physical channel processes. In fact it may be the only way to effectively re-establish fish and mussel connectivity in the Gorge due to difficulties with fish ladder installation and opening of the lock gates at Ford Dam during high flow. There are some benefits that could only be achieved with dam removal, particularly re-establishing connectivity and restoring the sediment transport regime. In fact, ecological restoration is likely to be cheapest with dam removal in the long-term because temporary structural restoration projects have limited lifespans.

Although total restoration to pre-European settlement conditions is not possible, **taking more active steps to restore portions of the river's ecological functions, aesthetic attributes and recreational opportunities is certainly possible, with or without dam removal**. There are many projects on the river designed to restore one specific habitat feature or recreational use, such as fish habitat structure or island reconstruction. However in large rivers serving diverse

interests, multi-purpose, functional restoration projects are more practical and beneficial. In addition, projects in urban settings in particular require more attention to the social, recreational and aesthetic issues due to the heavy human usage. In this multi-use setting where human uses are balanced with ecological ones, the concept of ecosystem services provides a useful framework for unifying the multi-purpose interests under the ecological services paradigm since all services provided by the river, such as transportation, hydropower, flood control, maintenance of fish habitat, provision of recreation, etc. are counted up in the same balance sheet. Quantifying ecological services should be a major focus area of future restoration assessment in the Gorge

In future decades, the benefits of dam removal will only increase as the cost of maintenance goes up, the reservoirs continue to accumulate sediment and ecological impacts continue. As the lock and dam infrastructure inevitably ages and deteriorates, the cost-benefit ratio of maintaining them increases, making removal more attractive as demonstrated in hundreds of small dam removal projects occurring around the country.

3. Recommendations and Conclusions

While much work has been done around the edges of the Gorge and adjacent Mississippi River reaches, little has been done within the river itself. Given the great importance of the Gorge ecologically, economically, and culturally, there is great interest by many local government agencies and non-profit groups in doing more to restore the Gorge. With the shifting economics of the Twin Cities favoring recreational, aesthetic, ecological and commercial uses, actions which can be done immediately should be undertaken. Despite the challenges outlined in the background and feasibility reports, there are a number of actions which could be done immediately or in the near future as outlined in Table 2.

Table 2: Short-term restoration, management and planning actions for the Gorge (0-3 years)*

Category/ Process	Action	Possible Organizations involved
Nest steps to conclude this study	Hold Mississippi River Restoration symposium to solicit comments on this report and develop a consensus on research needs (2010)	U of M
Nest steps to conclude this study	Meet with river stakeholders and present findings (January-May 2010)	U of M, major government orgs and non-profits
Nest steps to conclude this study	Develop consensus for action on next steps (winter 2010)	U of M with study partners
Nest steps to conclude this study	Expand information available on the internet from this study (January 2010) www.bbe.umn.edu; http://environment.umn.edu/riverlife/	U of M, Dept of BBE and River Life
Physical	Do test drawdown of Lower St. Anthony Falls to identify bed materials: limestone cap, boulders, refuse	USACE, MNDNR, MPCA, U of M, NPS
Physical	Dredge additional sediment from streambed of Pool 1to expose bedrock/cobble/gravel fish and mussel habitat	USACE, MNDNR, MPCA, U of M, NPS
Physical	Conduct ravine, bluff and streambank erosion study on the the Gorge to identify hydrologic and geomorphic processes and locations prone to mass-wasting	UM, Cities of St. Paul, Minneapolis, MWMO, NPS
Ecological	Continue freshwater mussel restoration activities	MN DNR, USACE, USFWS
Ecological	Investigate hydrologic and aesthetic potential for side waterfall restoration	Cities, NPS, MWMO, GRG, DNR

Socio-economic	Establish more educational signage on natural and human history of Gorge and other reaches in TC	NPS, MWMO, GRG, others
Socio-economic	Identify locations for parkland and canoe stopover points	MSP and St. Paul Parks and Rec; U of M, NPS, MWMO, GRG
Socio-economic	Establish canoe landings at feasible locations	MSP and St. Paul Parks and Rec; U of M
Socio-economic	Do user river survey; to document and quantify economic value of ecological, recreational and aesthetic factors; as behavior is linked to economics via spending	U of M, NPS, MWMO, GRG, others
Large urban river issues	Increase awareness of Large Urban River issues- aesthetics of falls, Gorge; recreation; valuation of ecological services	U of M; BBE and River Life
*For a comprehensive list, see the background report.		
List of organization acronyms: **GRG**-Great River Greening, **MWMO**-Mississippi Watershed Management Organization, **USACE**-US Army Corps of Engineers, **MNDNR** – Minnesota Department of Natural Resources, **MPCA** – Minnesota Pollution Control Agency, **MSP and St. Paul Parks and Rec.** – Minneapolis and St. Paul Departments of Parks and Recreation, **NPS**-National Park Service, **USFWS**-United States Fish and Wildlife Service, **U of M**-University of Minnesota, **BBE** - Bioproducts and Biosystems Engineering, **River Life** – River Life Program		

While many improvements could be made through partial restoration and water level management, clearly some ecological and geomorphic gains can only be achieved via removal of the Ford Dam. Fish and freshwater mussel passage would be so costly and challenging at Ford Dam that dam removal may be the only practical alternative to achieve that goal. Restoration of the sediment transport regime and exposure of most of the cobble / gravel substratum is only practically possible via dam removal.

Information needed to move forward with restoration

A major goal of this feasibility study was to identify areas for future action that can be carried out immediately or in the short term future. However many specific restoration actions need further detailed assessment before they can be practically carried out (see Table 3). Some of the needs are very practical or technical in nature, such as identifying costs of temporary drawdowns, while others are more academic, such as improving the valuation of ecological services.

In the future more needs to be done to ensure the sustainability of the combined river/navigation/commercial ecosystem over the long term. Longer-term indicators of sustainability are listed in Table 1. Sustainability is often defined by the long-term maintenance of social, economic and environmental processes simultaneously (Figure 1). But, how is sustainability achieved on a multi-use lock and dam system on a large river? Sustainability will require increased management and restoration in the Gorge in upcoming decades to prevent decline of the ecosystem, maintain the quality of life for local residents and minimize filling of the pool with sediment (Figure 4). More specifically the following will need to be accomplished:

- Maintenance of physical processes - increased variability of water levels; reduced sedimentation of reservoir through flushing, dredging of other methods
- Maintenance of ecological processes– maintain ecological integrity of river; improve connectivity for aquatic life
- Maintenance of economic cost/benefit balance – reduce costs for lock and dam maintenance and other cost inputs; increase benefits from recreation, tourism, fishing and other ecological services

Table 3: Additional information needed to carry out restoration projects in the Gorge	
Project type	*Information needed or research actions needed before proceeding with restoration*
Physical, ecological, socio-economic	Determine cost of re-constructing islands in an urban setting such as Pool 1
Physical, ecological, socio-economic	Determine exact locations of potential island projects in Pools 1 and 2 from geomorphic, ecological, recreation and economic standpoints
Physical	Investigate evolving water quality and quantity issues in upcoming decades related to climate change, land-use change and newly identified contaminants
Physical, ecological	Determine how increased stream flow in the Minnesota and Mississippi Rivers in recent decades effects water quality and ecological health of the Gorge and TC Mississippi River?
Physical	Model stage-discharge and sediment transport that would occur with different dam removal scenarios.
Ecological	Identify vegetation areas that could be re-established or restored through active management with water level drawdown/management.
Physical, ecological	Determine how sediment deposits in pools may be managed more sustainably, both for reservoir life-span and reduced impact on fish habitat
Physical, ecological	Quantify costs of dredging additional sediment to expose gravel/ cobble habitat for fish in the upstream end of the Pool 1 sediment deposit
Physical, ecological	Find cost and specific implementation issues with relocating boulder and limestone cap back into the main channel for fish habitat, boat recreation and aesthetics in Pool 1?
Physical	Determine how dam operations could be modified to improve water quality both within and downstream of Pools 1 and 2, as well as Lake Pepin.
Physical, ecological	Investigate hydrologic, sediment transport and practical issues associated with temporary drawdown and dam removal at Ford Dam and LSAF.
Fisheries	Investigate specific ecological benefit that could be achieved via improved fish and mussel passage; e.g. which species. Etc.
Socio-economic - Recreation	Do study of potential parkland expansion in river corridor including island re-creation and floodplain exposed from drawdown
Socio-economic-Aesthetics	Conduct further aesthetic studies of the Gorge, expanding on previous work by Mullan (2008) and the MN DNR to develop guidelines and plans for management of "*viewshed*"
Socio-economic	Improve valuation of ecological services to better document their value
Socio-economic	Determine quantities of hydropower energy lost in a drawdown
Socio-economic	Determine impacts on barge shipping in terms of costs and time increases

Dams become less sustainable over time, as any piece of human infrastructure has a limited life span. Maintenance costs increase and continued sedimentation of the reservoir requires constant dredging, both high costs for maintaining barge access to Minneapolis. In a 1998 sediment survey of Pool 1, (behind Ford Dam) was found to be roughly half full of sediment. A 2008 survey shows continued aggradation in the lower to middle pool. At some point in upcoming decades, the costs of the dam may well exceed its benefits especially given the low level of commercial barge traffic in Pool 1 and the value of the habitat for increasingly rare fish and mussel species.

Next Steps Identified by Steering Committee

- Study feasibility of gorge restoration alternatives in more detail. Develop an interdisciplinary University of Minnesota team of hydrologists, landscape architects, geomorphologists, environmental economists, aquatic ecologists and others if funding is available.
- Investigate and map potential parkland and public open space gains within the Gorge of the Twin Cities under various water level management and/or Ford Dam removal scenarios.
- Define role of project partners in moving restoration actions forward.
- Continue public education on the issue. Presentations will continue to be given by Chris Lenhart, (University of Minnesota, Department of Bioproducts and Biosystems Engineering), Mike Davis, (Minnesota DNR) and Pat Nunnally, (University of Minnesota, River Life program). The following presentation was recently given at the *Upper Midwest Stream Restoration Symposium* http://www.nced.umn.edu/content/upper-midwest-stream-restoration-symposium-0
- Further investigate possibility of restoration/ dam removal at Coon Rapids Dam, upstream of the Gorge because of greater potential for action in the near future.

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(see background report for a complete list of references)

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