National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Mississippi National River and Recreation Area

Natural Resource Report NPS/MISS/NRR—2015/990

ON THE COVER
Daybreak on the Mississippi River through downtown St. Paul, Minnesota
Photograph by Christine Mechenich

Natural Resource Condition Assessment

Mississippi National River and Recreation Area

Natural Resource Report NPS/MISS/NRR—2015/990

George J. Kraft[1], Christine Mechenich[2], David J. Mechenich[3], James E. Cook[4], and Jennifer L. McNelly[5]

[1, 2, 3, 5] Center for Watershed Science and Education
College of Natural Resources
University of Wisconsin – Stevens Point
Stevens Point, Wisconsin 54481

[4]College of Natural Resources
University of Wisconsin – Stevens Point
Stevens Point, Wisconsin 54481

July 2015

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available from Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Kraft, G. J., C. Mechenich, D. J. Mechenich, J. E. Cook, and J. L. McNelly. 2015. Natural resource condition assessment: Mississippi National River and Recreation Area. Natural Resource Report NPS/MISS/NRR—2015/990. National Park Service, Fort Collins, Colorado.

NPS 607/129012, July 2015

Contents

Contents (continued)

Page

Contents (continued)

Figures

Page

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Tables

Page

Tables (continued)

Page

Tables (continued)

Page

Executive Summary

Mississippi National River and Recreation Area (MISS) became a unit of the National Park Service on November 18, 1988 with the passage of Public Law 100-696. Although MISS owns only 26 hectares of land in floodplain islands and the Coldwater Springs unit, it encompasses about 22,000 hectares of public and private land and water in the Twin Cities Metropolitan Area (Minnesota), including 116 kilometers of the Mississippi River and the last 6.4 kilometers of the Minnesota River. In addition to the mission to "protect, preserve and enhance the significant values of the waters and land of the Mississippi River Corridor," the park was also charged with encouraging coordination of governmental programs affecting land and water resources and providing a management framework to assure orderly development in the area.

The Mississippi River within the MISS corridor has three "dramatically different" reaches; the "prairie river" that extends from the cities of Dayton and Ramsey to St. Anthony Falls, the "gorge river" below the falls and down to the confluence with the Minnesota River at St. Paul, and a "large floodplain river" below the Minnesota River, with high bluffs, a broad floodplain, and a valley width of 1.5-3 kilometers.

The NPS Great Lakes Inventory and Monitoring Network (GLKN) has noted that MISS is an essential link through the most important mid-continental migration corridor for waterfowl and other migratory birds in North America, and that this is a critical resource for MISS. The GLKN notes airborne pollutants, noise pollution, toxic waste pollution, invasive or exotic species, diseases spread from domestic animals, land use practices, urban sprawl, industrialization, and complex land ownership as the primary threats to the natural resources in MISS.

This Natural Resource Condition Assessment was undertaken to evaluate current conditions for a subset of natural resources and resource indicators in MISS. Using a framework developed by the Science Advisory Board of the United States Environmental Protection Agency (USEPA 2002), natural resources were evaluated in six categories: natural disturbance regimes, hydrology and geomorphology, landscape condition, biotic condition, chemical and physical characteristics, and ecological processes. A total of 49 resources and indicators were evaluated (Table i) by reviewing existing data from peer-reviewed literature and federal and state agencies. Data were analyzed where possible to provide summaries or new statistical or spatial representations. Of these 49 natural resource condition indicators, eight were in "good" condition, 14 were in condition of "moderate concern," 20 were in condition of "significant concern," and the condition of the remaining seven was "unknown." Only half of the indicators had sufficient information over time to assess trends; for 24 of the 49, the trend was "unknown." Eight were improving, nine were stable, and eight showed a deteriorating trend. Confidence in the assessment was high for 27 indicators, medium for 10, low for five, and unknown for seven.

Resource indicators that are in good condition, with an improving or stable trend at MISS, include levels of mercury in bald eaglet feathers, land cover stability, and dissolved oxygen in river water. The bird and fish communities and two additional water quality parameters (alkalinity and chloride) also appear to be in good condition, although there is insufficient information to assess the trend. Conditions of significant concern and uncertain or deteriorating trend are road density, *E. coli* in surface water, chloride in tributary streams, presence of invasive Asian carp, composition and abundance of fish and macroinvertebrate communities in

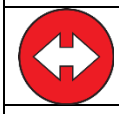
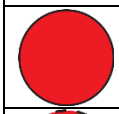
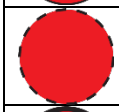
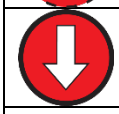
tributaries, mercury and PFOS (perfluoro-1-octanesulfonate, an organic compound) in fish tissue, air quality (overall, visibility, and wet deposition of nitrogen), forest morphology, and impervious surfaces in the watershed. Although the GLKN has collected a significant amount of data on natural resources in MISS in recent years, much of it does not yet have a period of record sufficient to evaluate trends.

Natural resources and resource indicators at MISS are affected by activities and processes at scales ranging from local (e. g., road density, urban sprawl, noise pollution) to global (atmospheric deposition and climate change). Because MISS owns little land, and has no jurisdiction over lock and dam management or point or nonpoint source discharges to the river, its resource managers must rely on its many partnerships to address the environmental issues of both moderate and significant concern.

Table i. Condition and trend of natural resources and resource indicators evaluated for Mississippi National River and Recreation Area.

Condition and Trend		Confidence	Natural Resource or Resource Indicator
	Condition good, improving trend	High	Water quality – dissolved oxygen
	Condition good, stable trend	High	Mercury in eaglet feathers
	Condition good, stable trend	Medium	Current land cover
	Condition good, uncertain trend	High	Water quality – alkalinity and chloride
	Condition good, uncertain trend	Low	Bird community, fish community
	Condition good, deteriorating trend	High	Water quality – specific conductance
	Condition of moderate concern, improving trend	High	DDE and total PCBs in eaglet serum Water quality – total suspended solids
	Condition of moderate concern, stable trend	High	Air quality – ozone Floodplain land cover changes – 1890s to 2000
	Condition of moderate concern, stable trend	Medium	Vegetation relative to presettlement conditions Mussel community
	Condition of moderate concern, uncertain trend	Medium	Air – wet deposition of total sulfur
	Condition of moderate concern, uncertain trend	Low	Macroinvertebrate populations – Mississippi River
	Condition of moderate concern, deteriorating trend	High	Water quality – pH Mean annual discharge – Mississippi River Seasonal and annual variation of flow – Mississippi River
	Condition of moderate concern, deteriorating trend	Low	Terrestrial invasive plants
	Condition of significant concern, improving trend	High	Total PCB in fish tissue Total PFOS in eaglet serum Water quality – total phosphorus and chlorophyll *a*
	Condition of significant concern, stable trend	High	Water quality – total nitrogen and nitrate + nitrite nitrogen

Table i. Condition and trend of natural resources and resource indicators evaluated for Mississippi National River and Recreation Area (continued).

Condition and Trend		Confidence	Natural Resource or Resource Indicator
	Condition of significant concern, stable trend	Medium	Mercury in precipitation
	Condition of significant concern, uncertain trend	High	Road density Composition and abundance of fish and macroinvertebrate communities in tributaries Water quality – *E. coli* Presence of invasive Asian carp
	Condition of significant concern, uncertain trend	Medium	Mercury and total PFOS in fish tissue Air quality – overall, visibility, and wet deposition of nitrogen
	Condition of significant concern, uncertain trend	Low	Forest morphology – core forest area
	Condition of significant concern, deteriorating trend	High	Impervious cover in watershed Water quality – chloride in tributaries
	Condition unknown, unknown trend	n/a	Forest density – dominant to intact forest Lightscape Soundscape DDE in fish tissue Total PBDEs in fish tissue and eaglet serum Flood duration – Mississippi River

Acknowledgments

We gratefully acknowledge the contributions of all those who assisted in the preparation of this report. John Anfinson, Chief of Resource Management (now Superintendent), and Nancy Duncan, Natural Resource Program Manager at MISS, were particularly helpful in scoping the report and providing input into its contents. They and Lark Weller, MISS Water Quality Coordinator (Community Planner), were particularly helpful in reviewing the draft report, as was Brenda Moraska Lafrancois, NPS Midwest Region aquatic ecologist. Ulf Gafvert of the GLKN served as the liaison between UWSP and GLKN; Ulf and Rory Stierler, Planning and GIS Specialist at MISS, shared GIS data. David VanderMeulen of the GLKN shared water quality data and provided helpful suggestions on the analysis. Terrie O'Dea and Kent Johnson helped us acquire Metropolitan Council Environmental Services river water quality monitoring data. Jeff Dimick, Laboratory Supervisor, UWSP Aquatic Biomonitoring Laboratory, assisted with macroinvertebrate data interpretation.

List of Acronyms and Abbreviations

AOA	Area of analysis
BWCAW	Boundary Waters Canoe Area Wilderness
DDE	1,1-bis-(4-chlorophenyl)-2,2-dichloroethene, a metabolite of DDT
DDT	An organochlorine insecticide
DO	Dissolved oxygen
EBF	Eastern broadleaf forest
ECS	Ecological classification systems
GCM	General circulation model
GLKN	NPS Great Lakes Inventory and Monitoring Network
HUC	Hydrologic unit code
IRMA	NPS Integrated Resource Management Applications web portal
ISRO	Isle Royale National Park
MDNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
NPS	National Park Service
NLCD	National Land Cover Database
NRCA	Natural Resource Condition Assessment
NRCS	Natural Resources Conservation Service (USDA)
PBDEs	Polybrominated diphenyl ethers
PCBs	Polychlorinated biphenyls
PFOS	Perfluoro-1-octanesulfonate, a perfluorinated compound
SACN	Saint Croix National Scenic Riverway
TMDL	Total maximum daily load
TN	Total nitrogen
TP	Total phosphorus
UMR	Upper Mississippi River
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency

USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UWSP	University of Wisconsin – Stevens Point
VOYA	Voyageurs National Park
WDNR	Wisconsin Department of Natural Resources
ww	wet weight

1 NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs Strive to Provide…

Credible condition reporting for a subset of important park natural resources and indicators

Useful condition summaries by broader resource categories or topics, and by park areas

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue-and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- are multi-disciplinary in scope;[1]
- employ hierarchical indicator frameworks;[2]
- identify or develop reference conditions/values for comparison against current conditions;[3]
- emphasize spatial evaluation of conditions and GIS (map) products; [4]
- summarize key findings by park areas; and [5]
- follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on

[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-on response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA Success Factors

Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline

Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)

Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and

management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

Over the next several years, the NPS plans to fund a NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information on the NRCA program, visit http://www.nature.nps.gov/water/NRCondition_Assessment_Program/Index.cfm.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations
(near-term operational planning and management)

Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values
(longer-term strategic planning)

Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public
("resource condition status" reporting)

[6] An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

2 Introduction and Resource Setting

2.1 Introduction

2.1.1 *Enabling Legislation*

The 116 kilometer (km) portion of the Mississippi River within the St. Paul-Minneapolis Metropolitan Area, along with the last 6.4 km of the Minnesota River, were designated as the Mississippi National River and Recreation Area (MISS) and became a unit of the NPS with the passage of Public Law 100-696 on November 18, 1988. The purposes of the law were:

> *(1) To protect, preserve and enhance the significant values of the waters and land of the Mississippi River Corridor within the Saint Paul-Minneapolis Metropolitan Area.*
>
> *(2) To encourage adequate coordination of all governmental programs affecting the land and water resources of the Mississippi River Corridor.*
>
> *(3) To provide a management framework to assist the State of Minnesota and its units of local government in the development and implementation of integrated resource management programs for the Mississippi River Corridor in order to assure orderly public and private development in the area consistent with the findings of this subtitle.*

The MISS enabling legislation emphasizes its role as a "coordinator and advisory organization" and instructs it to help develop policies and programs that preserve and enhance environmental values; outdoor recreation opportunities; scenic, historical, cultural, natural, and scientific values; and commercial and economic opportunities within the corridor (Lafrancois et al. 2007).

2.1.2 *Geographic Setting*

MISS is located in eastern Minnesota (MN) (Figure 1) and stretches from just upstream of Anoka, MN, through the Twin Cities (Saint Paul and Minneapolis) Metropolitan Area, to just downstream of the confluence with the St. Croix River near Prescott, Wisconsin (WI). It encompasses about 22,000 hectares (ha) of public and private land and water in the Mississippi River corridor in five MN counties and twenty-five communities (Figure 2) (Lafrancois et al. 2007). Within the corridor, 75.6% of the land is in private ownership and 24.4% in public ownership (Table 1). MISS owns only 26 ha of land, 14 in nine small floodplain islands and 12 in the Coldwater Spring unit, which was acquired in January 2010 (NPS 2013a).

The Mississippi River within the corridor has three "dramatically different" reaches; the first, in which the prairie used to run up to the river, is approximately 300 meters (m) wide and extends from the cities of Dayton and Ramsey to St. Anthony Falls. Below the falls and down to the confluence with the Minnesota River at St. Paul, the river is confined to a gorge approximately 400 m wide whose bottom is almost completely filled by the river. Below the confluence, the bluffs get higher and spread apart. The valley width is 1.5-3 km, and the floodplain becomes broader, reflecting its geologic history as it was sculpted by the glacial River Warren when the Minnesota River was the dominant stream in the Twin Cities area (Figure 3) (Hogberg 1971, Anfinson et al. 2003).

Figure 1. Location of Mississippi National River and Recreation Area.

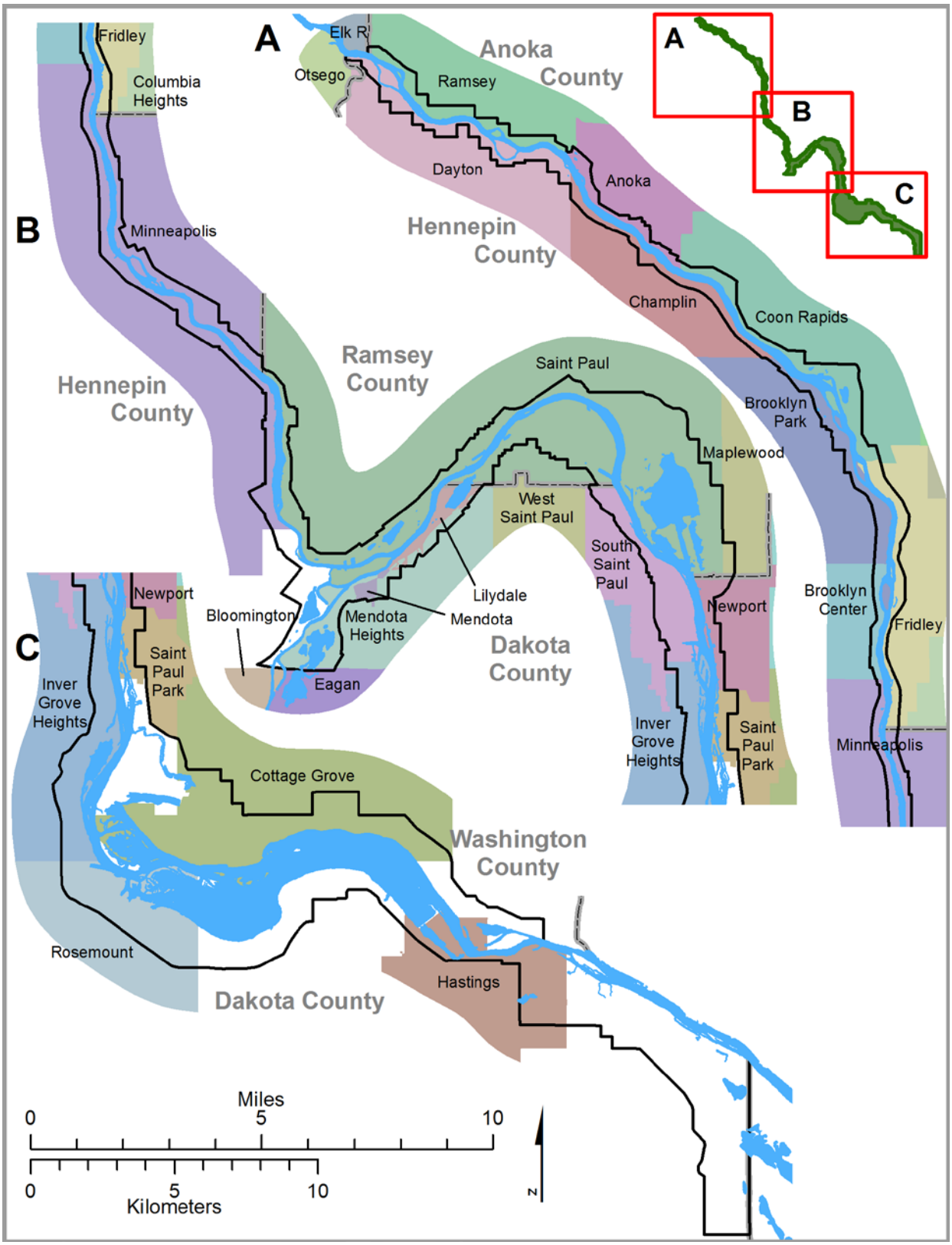


Figure 2. Municipal boundaries within the Mississippi National River and Recreation Area corridor (MDOT 2002).

Table 1. Land ownership in the Mississippi National River and Recreation Area corridor (adapted from Kirschbaum and Gafvert 2013).

Owner	Public	Private	Percent
Other Private		x	72.11
MN DNR	x		9.08
Ramsey County	x		4.55
State of MN	x		2.86
Dakota County	x		2.49
First Trust Co of St. Paul		x	2.17
Army Corps of Engineers	x		2.10
Hennepin County	x		1.29
Anoka County	x		1.26
MN Mining & Manufacturing Company (3M)		x	1.25
City of Anoka	x		0.53
Washington County	x		0.20
Northwestern Refining Company		x	0.11
Total	24.4%	75.6%	

The Mississippi River is impounded by ten dams upstream of MISS and five within the MISS corridor (Figure 4). (Lock and Dam #3 is below the MISS corridor, but does influence the flow of water at the lower end of MISS.) The northernmost dam in the corridor, the Coon Rapids dam, is an abandoned hydropower dam operated mainly for recreation (Lafrancois et al. 2007). In 2012, a rehabilitation project was approved to make the Coon Rapids dam a more effective barrier to the migration of invasive fish species (http://www.dnr.state.mn.us/waters/surfacewater_section/damsafety/coon_rapids_dam.html). The management of this dam is a joint responsibility of the Three Rivers Park District and the MN Department of Natural Resources (MDNR).

The remaining four dams (Upper and Lower St. Anthony Falls and Lock and Dam #1 and #2) are managed at least in part by the US Army Corps of Engineers (USACE) for hydropower generation and navigation. The St. Anthony Falls dams have locks, even though they are above Lock and Dam #1. The pool above Upper St. Anthony Falls has marked the uppermost extent of the Lock and Dam system and commercial navigation on the Upper Mississippi River (UMR) since 1963, but is to be closed in June 2015 to help prevent the spread of invasive Asian carp into MN's northern lakes (USACE 2015). River regulation at these dams is very close to run-of-river (Lafrancois et al. 2007).

2.1.3 *Demographics and Visitation*

MISS is located within the seven-county (Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington Counties) metro area of the Twin Cities, where population has been increasing steadily since 1900 (Figure 5) and was 2.85 million in 2010 (http://www.metrocouncil.org/news/2011/news_700.htm). In addition, the Mississippi River basin is one of the projected areas of fastest population growth in MN from 2000-2035 (Figure 6), with all seven metro counties expected to increase in population. The currently most densely

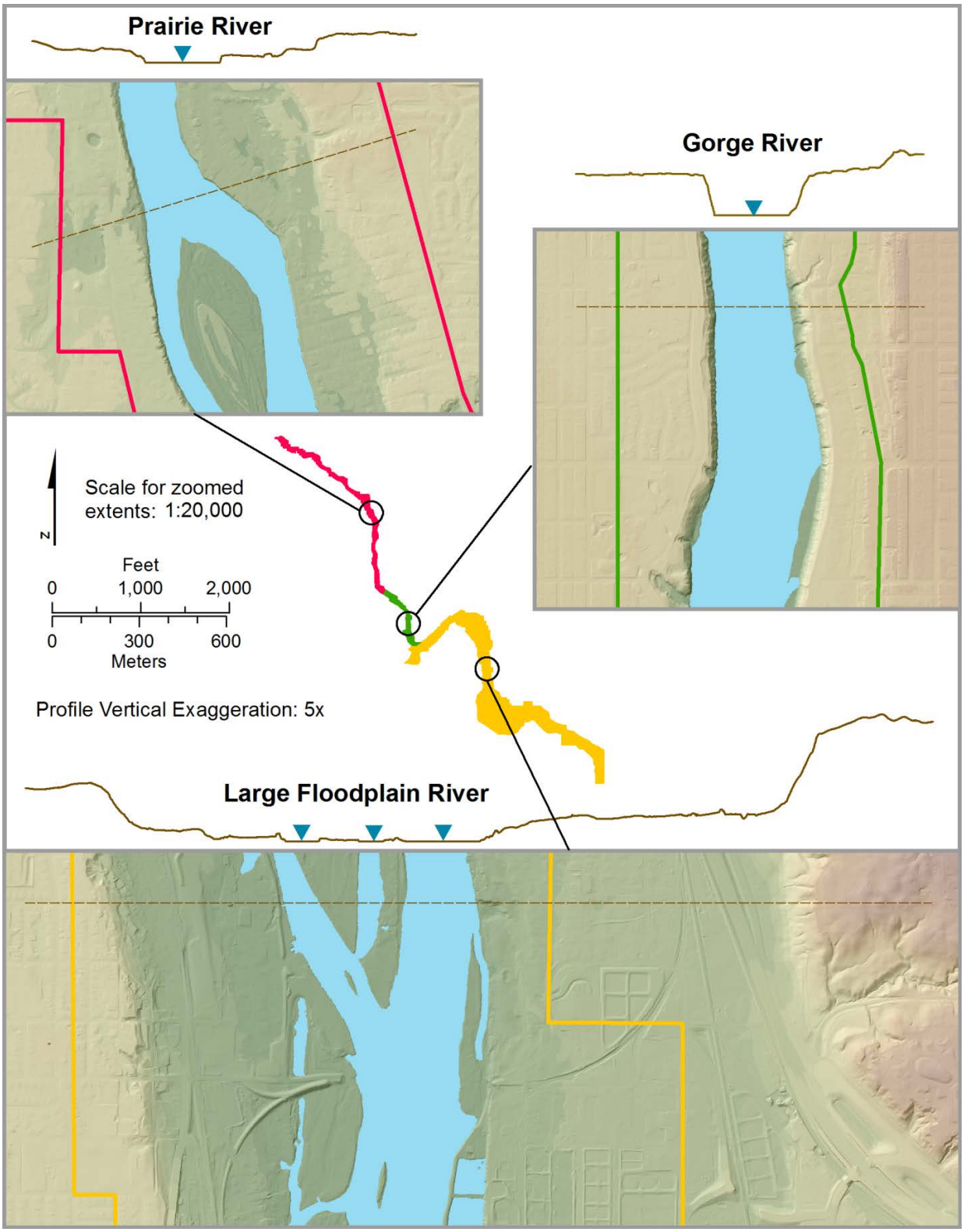


Figure 3. Profiles and cross sections for the three distinct river reaches in Mississippi National River and Recreation Area (MDNR 2012a).

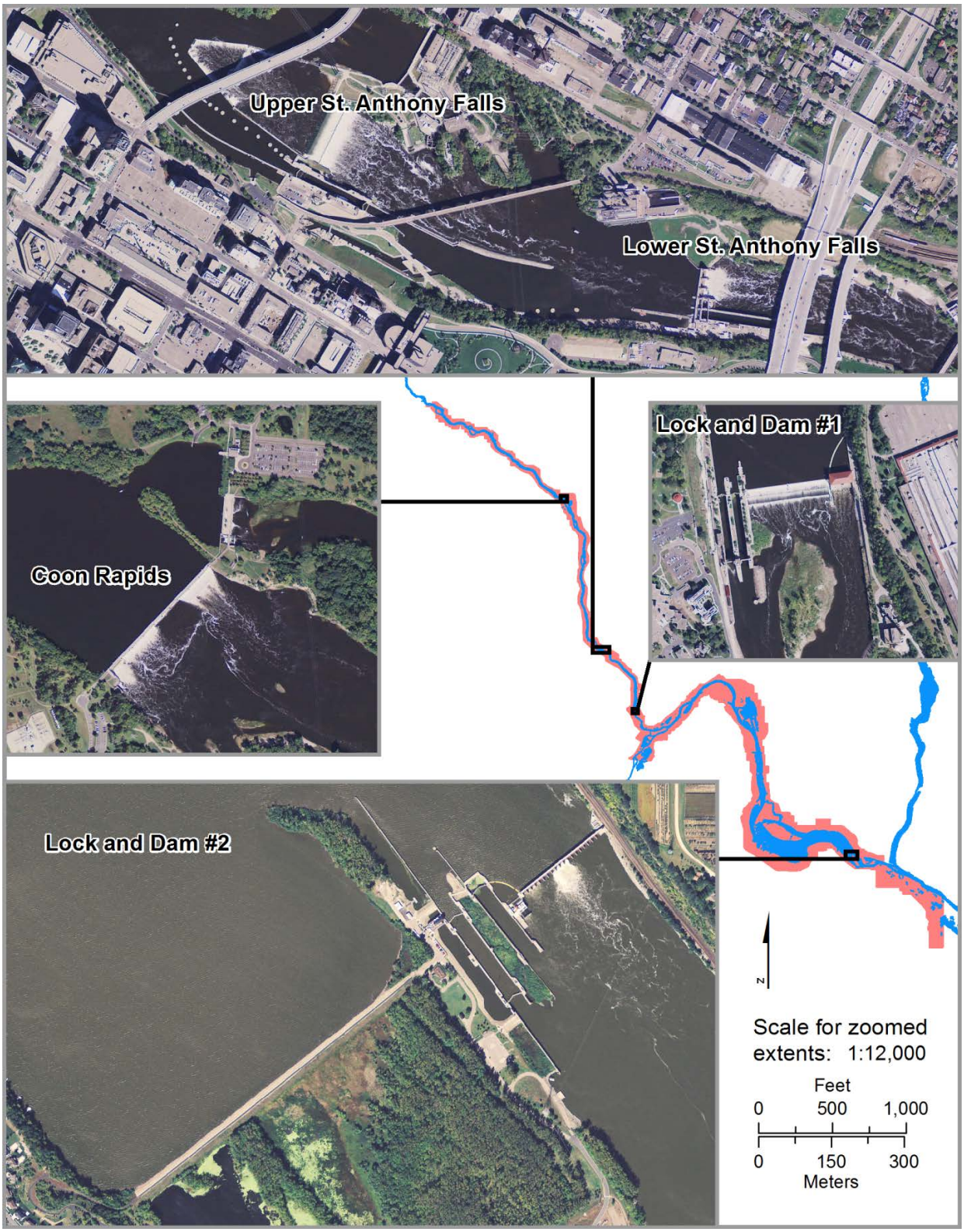


Figure 4. Locations of dams within Mississippi National River and Recreation Area (USDA 2010).

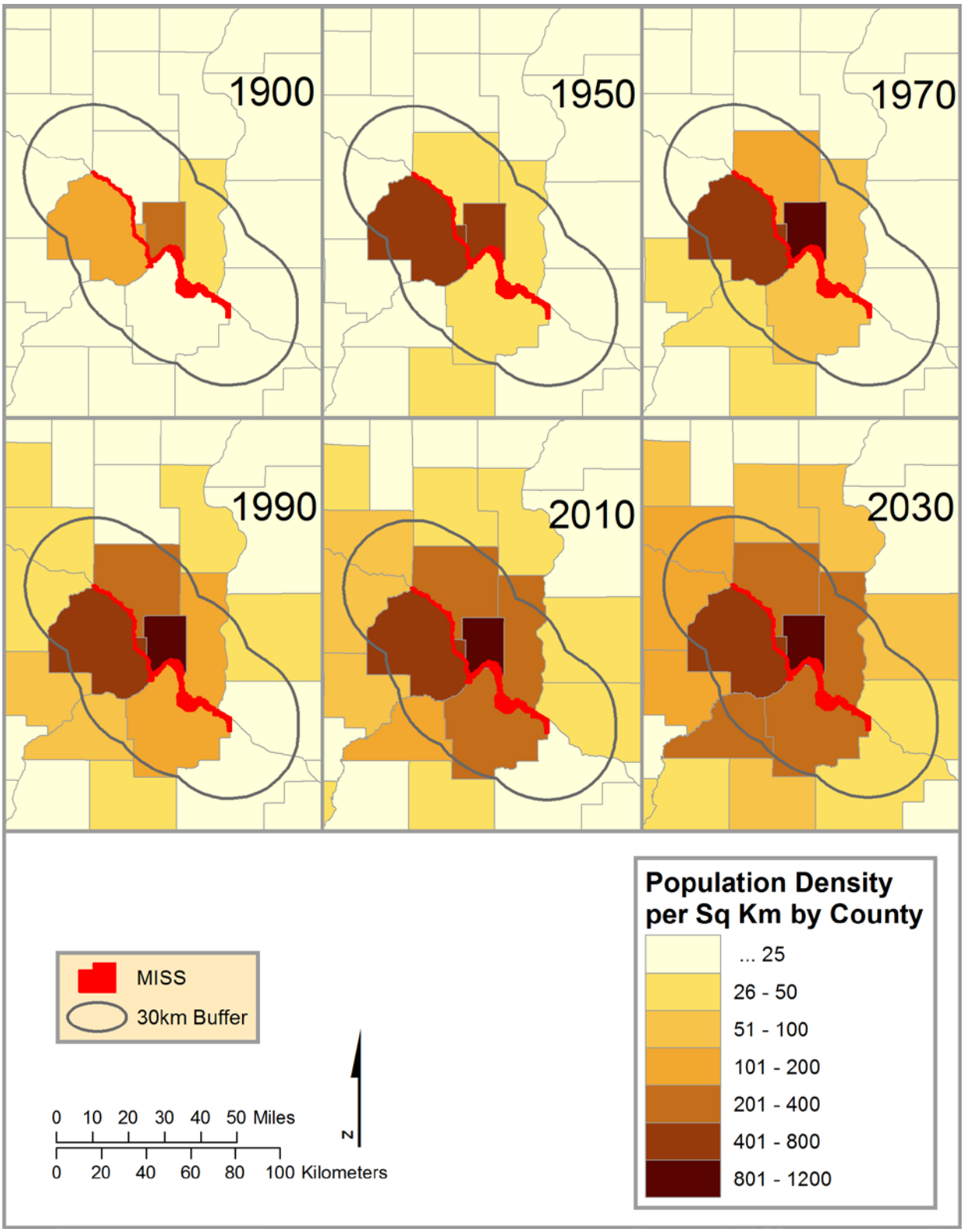


Figure 5. Historical and projected population density per km^2 by county in the Mississippi River basin, 1900-2030 (NPS 2012).

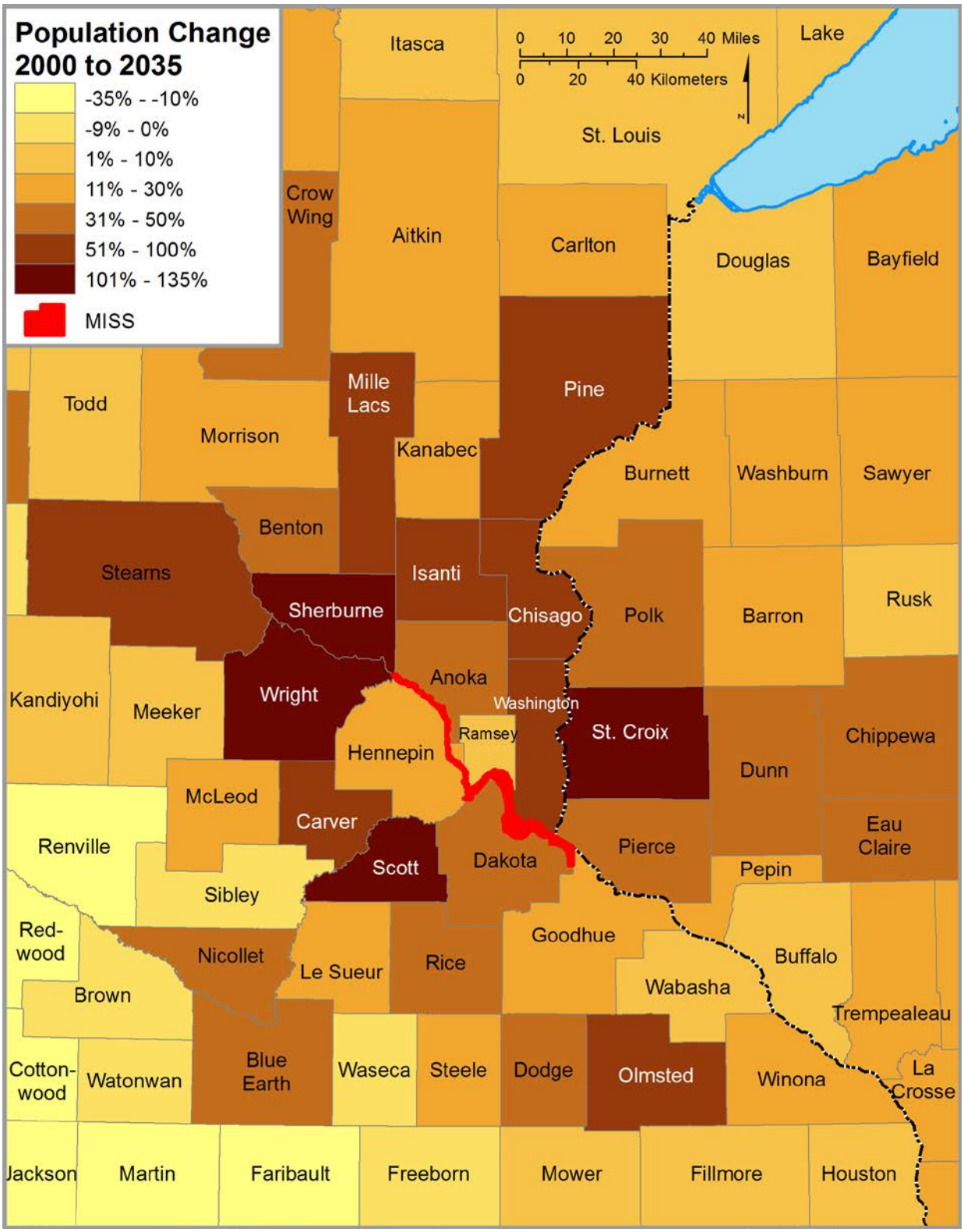


Figure 6. Projected population changes in counties surrounding the Mississippi River basin from 2000 to 2035 (Egan-Robertson et al. 2008, Minnesota State Demographic Center 2012).

populated counties (Ramsey and Hennepin) are expected to grow 7% and 20%, respectively. Scott, Sherburne, and Wright Counties are projected to increase in population by 130%, 116%, and 103%, respectively. Nearby in WI, St. Croix County is expected to increase in population by 134% from 2000-2035.

Official visitation statistics for MISS show 99,398 recreational visitors in 2011, 106,733 in 2012, and 85,204 from January-September 2013 (NPS 2013b), but over 7.9 million visits occur each year through partner parks (NPS 2013a). At the Visitor Center in the Science Museum of Minnesota, attendance has ranged from a high of 112,672 in 2006 to 65,718 in 2012 (NPS 2013a). Participation in NPS-led programs has increased from 24,395 in 2006 to 56,652 in 2012. Tens of thousands of visitors were expected at the Coldwater Springs unit in 2013. Some uncontrolled and unmeasured visitation occurs on the MISS islands (NPS 2013a).

2.2 Natural Resources

2.2.1 *Climate*

The climate of MISS is subhumid continental and has wide and rapid diurnal and seasonal temperature fluctuations (Lafrancois et al. 2007). NPS (2007) analyzed NOAA cooperative weather station data for the Minneapolis-St. Paul Airport (station 215435, years 1948-2007) to characterize climate for the park. The mean annual temperature at MISS was 7.3°C with a range of means of 4.8-10.5°C. Mean annual precipitation was 69.9 cm with a range of annual means of 29.2-102.1 cm (NPS 2007). The mean monthly maximum precipitation (10.9 cm) occurs in August, and the minimum (1.96 cm) occurs in February (NWS 2011). Mean annual snowfall is 137 cm (NWS 2011). The mean annual temperature has increased about 1.1°C for the Minneapolis-St. Paul area since 1895, and all seasonal mean, maximum, and minimum temperatures have also increased, with the greatest increase in winter minimums (1.4°C). Annual average precipitation has also increased slightly since the 1890s (NPS 2013a).

2.2.2 *Ecological Units and Watersheds*

Ecological classification systems (ECS) are intended to create a format to convey basic information on both the biological and physical characteristics of a landscape. Both WI and MN have developed ECS mapping schema based on the National Hierarchical Framework of Ecological Units (MDNR 1999, WDNR 1999, IIC 2011). Provinces, the first level within the ECS, are further divided into sections, subsections, land type associations, land types, and land type phases.

MISS is entirely within the Eastern Broadleaf Forest (EBF) Province (Figure 7), which traverses MN, Iowa, WI, Michigan, Ohio, New York, Illinois, Indiana, Kentucky, Tennessee, Missouri, and Arkansas (MDNR 2012b). The land surfaces of most of the EBF province are largely the product of Pleistocene glacial processes. The EBF Province coincides roughly with the part of MN where precipitation approximately equals evapotranspiration; it seems likely that this aspect of climate has an important influence on plants, as many forest species reach their western range limits and several prairie species reach their eastern range limits within the province (MDNR 2012b). The soil types, presettlement vegetation, and present vegetation of the ECS subsections present at MISS are described in Table 2.

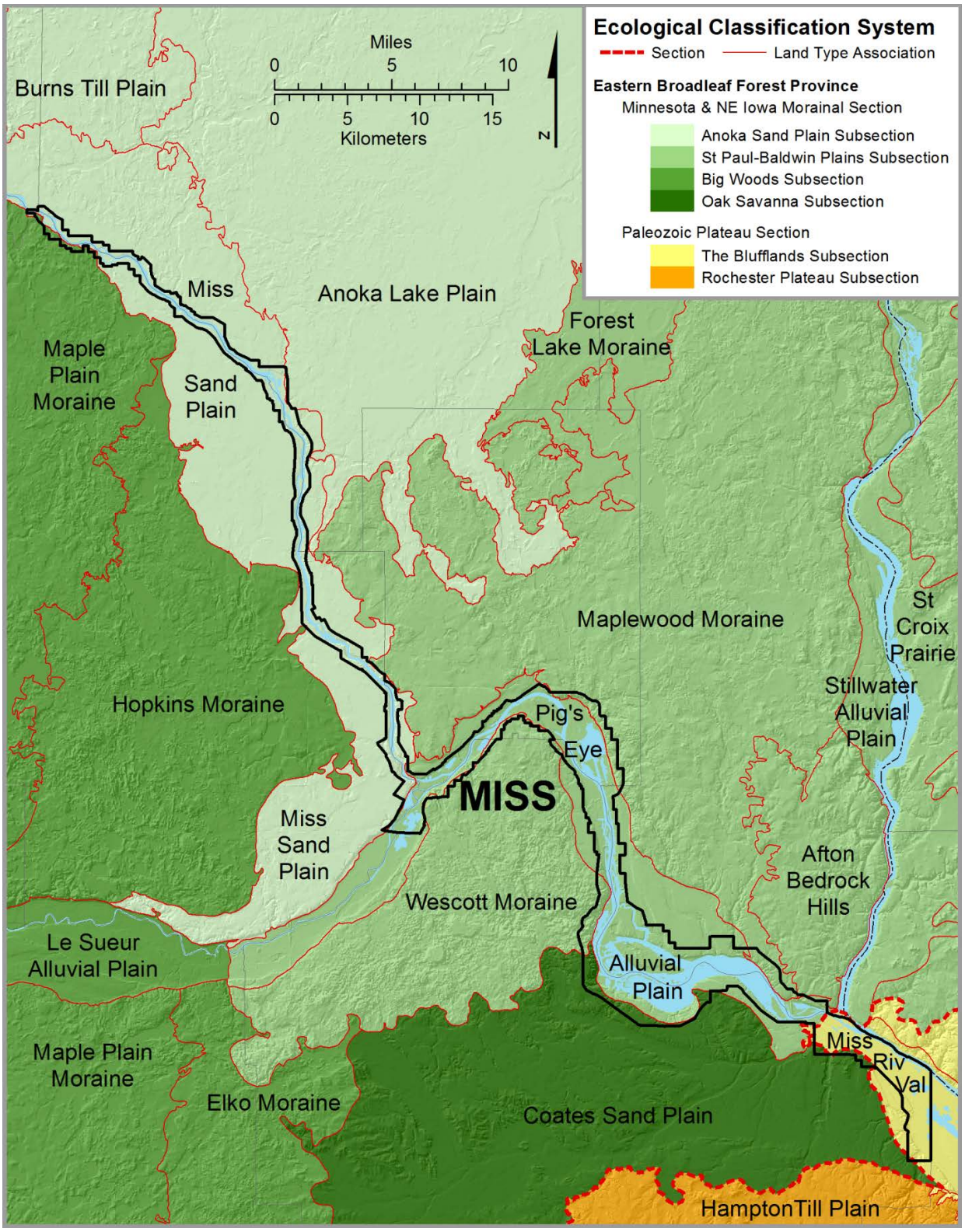


Figure 7. Ecological classification system provinces, sections, and subsections for Mississippi National River and Recreation Area (MDNR 1999, WDNR 1999).

Table 2. Soil and vegetative characteristics of ECS subsections and land type associations in Mississippi National River and Recreation Area (http://www.dnr.state.mn.us/ecs/index.html, table after Lafrancois et al. 2007).

Subsection (general location)	Land Type Associations		Soil Orders and Suborders	Soil Descriptions	Presettlement Vegetation	Present Vegetation
Anoka Sand Plain 222Mc (northern)	Anoka Lake Plain Burns Till Plain Mississippi Sand Plain	222Mc01 222Mc02 222Mc05	Entisols (Psamments) Histosols (Hemists) Mollisols (Aquolls)	Derived from fine sands and include primarily droughty, upland soils (Psamments) with some wet prairie (Aquolls) and organic (Hemists) soils	Oak barrens and openings, brushland on large areas.	Sod and vegetable crops extensively grown but species associated with oak openings and oak barrens abundant on sand plain.
Big Woods 222Mb (western)	Maple Plain Moraine Hopkins Moraine Le Sueur Alluvial Plain Elko Moraine	222Mb03 222Mb04 222Mb05 222Mb06	Alfisols Mollisols	Derived from calcareous glacial till and include primarily soils developed under forests (Alfisols) with some soils developed under grassland (Mollisols) in the west.	Oak woodland and maple-basswood forest were common on the irregular ridges.	Greater than 75% of subsection is cropland with an additional 5-10% pasture; remaining is either upland forest or wetland.
Oak Savanna 222Me (southern)	Coates Sand Plain	222Me09	Alfisols (Aqualfs, Udalfs) Mollisols (Udolls)	Mosaic of Mollisols and Alfisols; common soils include Aquolls, Udolls (well drained prairie soils), Udalfs (well drained forest soils), and Aqualfs (wet forest soils)	Bur oak savanna with areas of tallgrass prairie and maple-basswood forest.	Mostly farmed with some urban development.

Table 2. Soil and vegetative characteristics of ECS subsections and land type associations in Mississippi National River and Recreation Area (continued).

Subsection (general location)	Land Type Associations		Soil Orders and Suborders	Soil Descriptions	Presettlement Vegetation	Present Vegetation
Blufflands 222Lc (southern)	Mississippi River Valley	222Lc08	Alfisols (Udalfs) Entisols (Aquents)	Predominately Udalfs with localized Aquents (wet floodplain soils) along major river floodplains.	Tallgrass prairie and bur oak savanna on ridge tops and dry slopes with red oak-white oak-shagbark hickory-basswood on moister sloped and red oak-basswood-black walnut forests in protected valleys.	About 50% woodland, 30% cropped, and 20% pasture.
	Elba Slopes	222Lc11				
	Eroded pre-Illinoian Ground Moraines	222Lc12				
St. Paul Baldwin Plains 222Md (eastern)	Wescott Moraine	222Md01	Alfisols Mollisols	Derived from mixed parent materials on moraines and sandy parent material on outwash plains and include primarily Alfisols with some Mollisols on outwash plains	Oak and aspen savanna were primary communities, with some tall grass prairie and maple-basswood forest.	Small areas of forest present in eastern portion of unit, but urban development continues.
	Afton Bedrock Hills	222Md02				
	Maplewood and Somerset Moraines	222Md03				
	Forest Lake Moraine	222Md04				
	Pig's Eye Alluvial Plain	222Md05				
	St. Croix Prairie and Stillwater Alluvial Plain	222Md06				
	River Falls Eroded Moraines	222Md10				

MISS is located entirely within the Mississippi River watershed and almost entirely within the Mississippi Headwaters subbasin (United States Geological Survey [USGS] 4-digit hydrologic unit code [HUC] 0701) (Figure 8). It also enters the Minnesota River subbasin (HUC 0702) and Upper Mississippi-Black-Root subbasin (HUC 0704) and is joined by the St. Croix subbasin (HUC 0703). The 8-digit HUCs that most directly connect to MISS are the Twin Cities (07010206), Lower St. Croix (07030005), Rush-Vermillion (07040001), Lower Minnesota (07020012), Crow (07010204), and Rum (07010207) subbasins (Figure 8) (USGS 2012).

2.2.3 *Resource Descriptions*

The NPS Great Lakes Network Inventory and Monitoring Program (GLKN) describes the midcontinental migration corridor for waterfowl and other migratory birds as a critical resource for MISS, and notes that although MISS protects a small portion of the Mississippi River, it is "an essential link through this highly fragmented and industrialized area" (NPS 2007). MISS is also home to federal-endangered mussel species: the Higgins eye mussel (*Lampsilis higginsi*), the winged mapleleaf mussel (*Quadrula fragosa*), the sheepnose (*Plethobasus cyphyus*), the spectaclecase (*Cumberlandia monodonta*), and the snuffbox (*Epioblasma triquetra*) (Minnesota Rare Species Guide [http://www.dnr.state.mn.us/rsg]) (see Section 4.4.8 for details). The State of the Park report (NPS 2013a) lists one federal-endangered plant, prairie bush clover (*Lespedeza leptostachya*).

MISS is also home to many state-listed species. The Minnesota Rare Species Guide (http://www.dnr.state.mn.us/rsg) lists 147 species for the Mississippi River-Twin Cities, Lower Minnesota, and Mississippi River-Lake Pepin watersheds. Unpublished supplemental data to Larson and Larson (2009) from the Minnesota Natural Heritage database includes three mammals of state special concern; two threatened and four special concern birds; one threatened and four special concern fish; seven endangered, seven threatened, and three special concern mussels; a threatened turtle; one threatened and two special concern snakes, and a spider of special concern for MISS (Table 3). The authors also listed five Minnesota endangered, four threatened, and ten special concern plants (Table 4). The State of the Park report lists 41 state-listed rare plant species confirmed present and 25 state-listed rare plant species probably present (NPS 2013a).

Section 2.3.1 lists those resources considered fundamental to MISS as described in the park's Foundation Document (NPS 2014).

2.2.4 *Resource Issues Overview*

The GLKN lists the following issues related to natural resources at MISS: airborne pollutants, noise pollution, waters contaminated with toxic waste, invasive or exotic plants and animals (especially exotic mussels), diseases spread from domestic animals, land use practices within and outside the boundaries, urban sprawl, industrialization, and complex land ownership. It further states that there are 114 hazardous waste sites within or near the MISS boundary; 19 are on the state Superfund list and six are on the national Superfund list (NPS 2007).

Issues discussed as of significance during the initial scoping meeting with MISS resource professionals included invasive species, biodiversity, urban expansion, water quality, recreational overuse, and climate change.

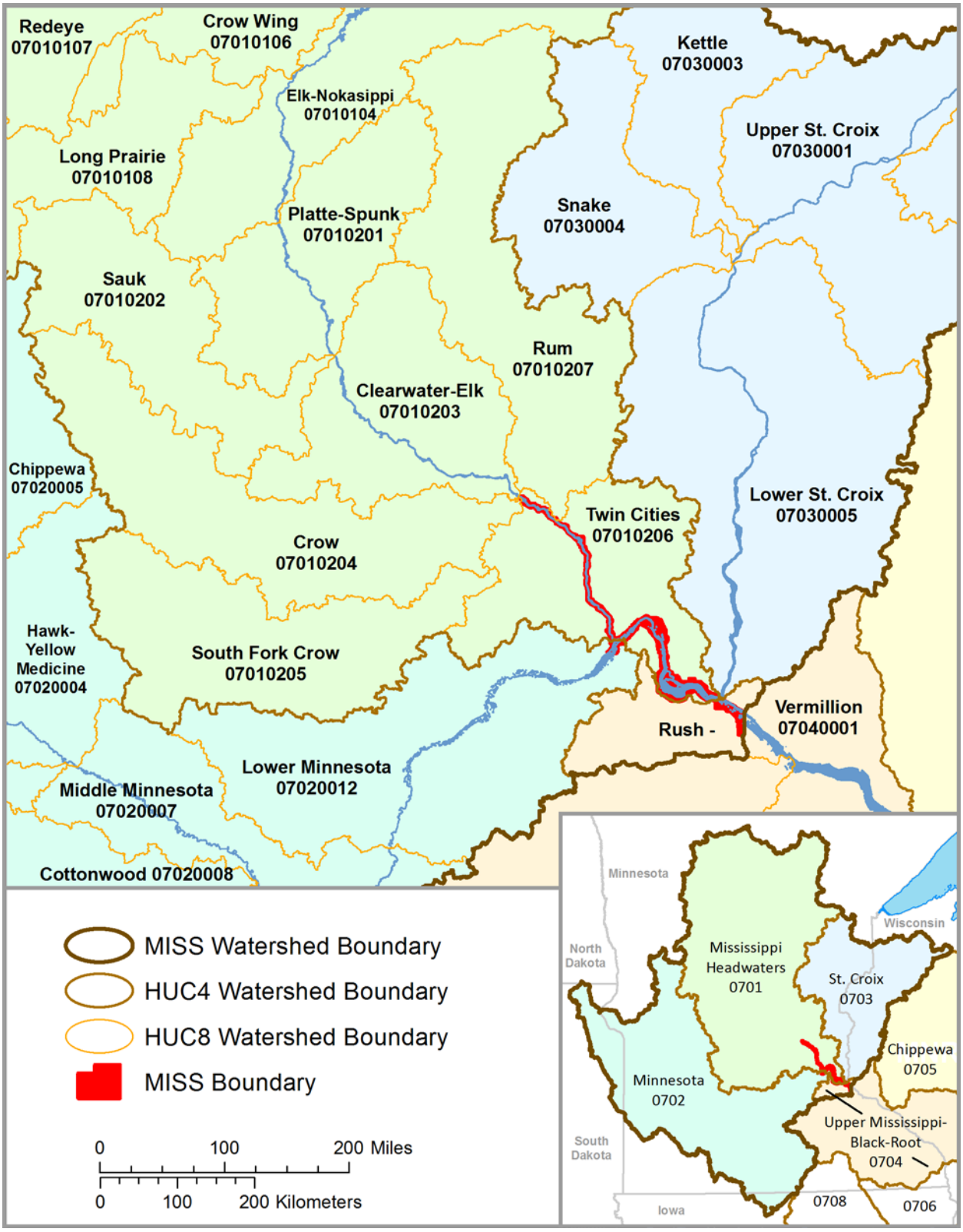


Figure 8. Location of Mississippi National River and Recreation Area in the Upper Mississippi River watersheds and subwatersheds (USGS 2012).

Table 3. Minnesota endangered, threatened, and special concern fauna in Mississippi National River and Recreation Area (Larson and Larson 2009).

Group	Scientific Name	Common Name	Minnesota Status
Mammals	*Microtus ochrogaster*	Prairie vole	Special Concern
	Myotis septentrionalis	Northern myotis	Special Concern
	Pipistrellus subflavus	Eastern pipistrelle	Special Concern
Birds	*Falco peregrinus*	Peregrine falcon	Threatened
	Lanius ludovicianus	Loggerhead shrike	Threatened
	Buteo lineatus	Red-shouldered hawk	Special Concern
	Dendroica cerulea	Cerulean warbler	Special Concern
	Haliaeetus leucocephalus	Bald eagle	Special Concern
	Seiurus motacilla	Louisiana waterthrush	Special Concern
Fish	*Polyodon spathula*	Paddlefish	Threatened
	Acipenser fulvescens	Lake sturgeon	Special Concern
	Cycleptus elongatus	Blue sucker	Special Concern
	Notropis amnis	Pallid shiner	Special Concern
	Notropis anogenus	Pugnose shiner	Special Concern
Mussels	*Lampsilis higginsi*	Higgins eye mussel	Endangered
	Arcidens confragosus	Rock pocketbook mussel	Endangered
	Elliptio crassidens	Elephant-ear mussel	Endangered
	Fusconaia ebena	Ebonyshell mussel	Endangered
	Lampsilis teres	Yellow sandshell mussel	Endangered
	Plethobasus cyphyus	Sheepnose mussel	Endangered
	Quadrula nodulata	Wartyback mussel	Endangered
	Actinonaias ligamentina	Mucket mussel	Threatened
	Cyclonaias tuberculata	Purple wartyback mussel	Threatened
	Ellipsaria lineolata	Butterfly mussel	Threatened
	Megalonaias nervosa	Washboard mussel	Threatened
	Pleurobema coccineum	Round pigtoe mussel	Threatened
	Quadrula metanevra	Monkeyface mussel	Threatened
	Tritogonia verrucosa	Pistolgrip mussel	Threatened
	Elliptio dilatata	Spike mussel	Special Concern
	Ligumia recta	Black sandshell mussel	Special Concern
	Obovaria olivaria	Hickorynut mussel	Special Concern
Herps	*Emydoidea blandingii*	Blanding's turtle	Threatened
	Crotalus horridus	Timber rattlesnake	Threatened
	Coluber constrictor	Racer	Special Concern
	Pituophis catenifer	Gopher snake	Special Concern
Spiders	*Marpissa grata*	A species of jumping spider	Special Concern

Although as noted in chapter 1, climate change is not a primary focus of Natural Resource Condition Assessments such as this, the large predicted impacts make it necessary to address this topic at least briefly. A 2010 report projects that annual temperatures in the Great Lakes region, of which MISS is a part, will increase 1.4 ± 0.6°C from 2010-2039, 2.0 ± 0.7°C to 3.0 ± 1.0°C (depending on emissions levels) by 2069, and 3.0 ± 1.0°C to 5.0 ± 1.2°C by 2099 (Hayhoe et al. 2010).

Table 4. Minnesota endangered, threatened, and special concern flora in Mississippi National River and Recreation Area (Larson and Larson 2009).

Scientific Name	Common Name	Minnesota Status
Carex formosa	Handsome sedge	Endangered
Carex plantaginea	Plantain-leaved sedge	Endangered
Cristatella jamesii	James' polanisia	Endangered
Platanthera flava var. herbiola	Tubercled rein-orchid	Endangered
Scleria triglomerata	Tall nut-rush	Endangered
Besseya bullii	Kitten-tails	Threatened
Carex sterilis	Sterile sedge	Threatened
Huperzia porophila	Rock clubmoss	Threatened
Valeriana edulis var. ciliata	Valerian	Threatened
Aristida tuberculosa	Sea-beach needlegrass	Special Concern
Cirsium hillii	Hill's thistle	Special Concern
Cypripedium candidum	Small white lady's-slipper	Special Concern
Hudsonia tomentosa	Beach-heather	Special Concern
Juniperus horizontalis	Creeping juniper	Special Concern
Orobanche ludoviciana	Louisiana broomrape	Special Concern
Panax quinquefolius	American ginseng	Special Concern
Scirpus clintonii	Clinton's bulrush	Special Concern
Trillium nivale	Snow trillium	Special Concern
Triplasis purpurea	Purple sand-grass	Special Concern

Global air temperatures increased 0.74 ± 0.18°C from 1906-2005, mostly attributable to human activities (IPCC 2007). In addition to creating this general warming, climate change also likely contributes to rises in sea level; changes in wind patterns and extra-tropical storm tracks; increased temperatures on extreme hot nights, cold nights, and cold days; increased risk of heat waves; increased area affected by drought; and greater frequency of heavy precipitation events (IPCC 2007). Signs that climate change is already occurring in the Great Lakes region include increases in average annual temperatures, more frequent severe rainstorms, shorter winters, and decreases in the duration of lake ice cover (Kling et al. 2003a). By the end of the 21st century, winter and summer temperatures in Minnesota may increase 3-6°C and 4-9°C, respectively (Kling et al. 2003b). Annual average precipitation may not change much, but may increase in winter and decrease in summer to the point where soil moisture declines and more droughts occur. The frequency of heavy rainstorms could increase 50-100% (Kling et al. 2003b).

Significant uncertainty accompanies most predictions related to global climate change, not only in the magnitude of changes in physical parameters, but also in their ecological implications. The uncertainty, though, is not in the general trend, but rather in how large the changes will be, the rate at which they occur, and the net effect of all of the indirect and interactive effects. A wide variety of ecological processes (Aber et al. 2001) and species-specific responses (Walther et al. 2002; McKenney et al. 2007) have been, or will be, affected. An additional source of uncertainty is that average climate changes may not be key. The fluctuation in temperature among seasons, the extremes that occur, the timing of certain phenomena, and the duration of a condition could all have more of an impact than the average condition (Morris et al. 2008).

All predictions of future climate are based on one of several General Circulation Models (GCM), which vary in their predictions for the 21st century. Predictions of the ecological impacts of climate change are achieved by taking the predictions of a GCM and plugging them into one or

more other models (see Hansen et al. [2001] and Aber et al. [2001] for the common models used in this way). These, as well as the GCM models, are simplifications of reality and are based on a set of assumptions, creating further uncertainty in the predictions. Furthermore, there is not a single model that can even begin to predict the full range of phenomena that are likely to be affected, their interactions, and the net outcome. Thus, all models focus on a few of the changes and ignore the others. For example, we have limited capacities to predict what biotic disturbances are likely to influence a community if the average temperature increases by 3 or 4°C, or where ice storms are going to be most frequent (Dale et al. 2001). The predictions of models apply to a finite scale, and the majority of ecological models project for a smaller spatial scale than the GCMs. To make these mesh, either the GCM predictions have to be interpolated or the ecological model extrapolated, creating yet another source of uncertainty.

More detailed discussions of climate change are included in the context of stressors to resources assessed in Chapter 4.

2.3 Resource Stewardship

2.3.1 *Management Directives and Planning Guidance*

MISS has a Comprehensive Management Plan, which serves as the general management plan for the park. It was established and issued in 1995 and provides guidance for managing this area for 10-15 years. (http://www.nps.gov/miss/parkmgmt/cmp.htm).

The draft Foundation Document for MISS (NPS 2014) lists the following fundamental resources and values for the park:

- Cultural and historic sites that owe their national or regional significance to their presence along the Mississippi River.
- A Mississippi River that supports the region's economic prosperity and the economies of the communities that lie along the river in the NRRA.
- Collaborative relationships with governments, private sector organizations, non-profits, schools, and individuals that allow the park to achieve its purpose.
- Healthy aquatic ecosystems that provide for a rich and diverse assemblage of fish, mussels, macro-invertebrates and other species.
- Healthy terrestrial ecosystems that provide for a rich and diverse assemblage of plants and animals.
- Birds that rely on the Mississippi River Flyway in the NRRA to provide nesting, resting and feeding habitat.
- Scenic vistas that allow people to experience the nationally and regionally significant landscapes of the NRRA
- Outdoor recreational opportunities that connect visitors with the river and its parks, greenspaces and stories in the NRRA.
- The experience of interacting with nature in the largest metropolitan area on and along the Mississippi River.
- The presence of bluffs, caves, waterfalls and fossil beds that demonstrate the unique geologic character of the Mississippi River in the NRRA.
- The experience of connecting to the Mississippi River as one of the world's most legendary rivers.

- A Mississippi River in the NRRA that is clean, safe, accessible, and inviting.

2.3.2 *Status of Supporting Science*

MISS is one of nine National Park units in the GLKN, one of 32 similar networks across the United States and part of the NPS strategy to improve park management through greater reliance on scientific information. The purpose of the I&M program is to design and implement long-term ecological monitoring and provide results to park managers, science partners, and the public. The intent is to provide periodic assessments of critical resources, to evaluate the integrity of park ecosystems, and to better understand ecosystem processes.

In 2007, GLKN completed its long-term ecological monitoring plan (NPS 2007) which included a list of Vital Signs (select indicators that represent the health of natural resources in the nine parks) (Table 5). Specific GLKN goals for Vital Signs monitoring are:

1. Determine status and trends of selected indicators of the condition of park ecosystems to help managers make better-informed decisions and work more effectively with other agencies and individuals for the benefit of park resources.
2. Provide early warning of abnormal conditions and impairment of selected resources to promote effective mitigation and reduce management costs.
3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
4. Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.
5. Provide a means of measuring progress towards achieving performance goals that are mandated by Government Performance Results Act (GPRA).

From these Vital Signs, GLKN selected eight focal indicators: Climate, Inland Lakes Water Quality, Large Rivers Water Quality, Diatoms, Terrestrial Plants, Amphibians, Land Birds, Persistent Contaminants, and Land Cover and Land Use. Monitoring protocols have been developed for all these except Amphibians, Climate, and Persistent Contaminants in Fish and Dragonflies; those protocols are in development.

Current GLKN activities for MISS are in the areas that have monitoring protocols. A report was provided by Bill Route of the GLKN (email, October 31, 2013); it is summarized below (Table 6).

Table 5. Vital Signs for the Great Lakes Inventory and Monitoring Network (NPS 2007).

National Level[1]		Great Lakes Network[2]									
Level 1	**Level 2**	**Vital Sign name**	**APIS**	**GRPO**	**INDU**	**ISRO**	**MISS**	**PIRO**	**SACN**	**SLBE**	**VOYA**
Air and Climate	Air Quality	Air Quality	•	•	•	•	•	•	•	•	•
		Air Quality (AQRV)	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	Weather	Weather	•	•	•	•	•	•	•	•	•
		Phenology	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Geology and Soils	Geomorphology	Aeolian, Lacustrine Geomorphology	Δ	-	Δ	-	Δ	Δ	Δ	Δ	-
		Geological Processes	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Stream Dynamics	Δ	Δ	Δ	Δ	+	Δ	+	Δ	Δ
	Soil Quality	Soils	+	+	+	+	+	+	+	+	+
		Sediment Analysis	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Water	Hydrology	Water Level Fluctuations	+	+	+	+	+	+	+	+	+
	Water Quality	Core Water Quality Suite	+	+	+	+	+	+	+	+	+
		Advanced Water Quality Suite	+	+	+	+	+	+	+	+	+
		Toxics in Water	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Toxics in Sediments	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Pathogens in Water	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		IBI	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Benthic Inverts	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Freshwater Sponges	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Phytoplankton	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Diatoms	+	-	+	+	+	+	+	+	+
Biological Integrity	Invasive Species	Plant and Animal Exotics	•	•	•	•	•	•	•	•	•
	Infestations and Disease	Terrestrial Pests and Pathogens	+	+	+	+	+	+	+	+	+
	Focal Species or Communities	Aquatic Plant Communities	+	+	+	+	+	+	+	+	+
		Mussels and Snails	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Mammal Communities	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Problem Species (White-tailed deer)	+	+	+	+	+	+	+	+	+
		Special Habitats	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Lichens and Fungi	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Terrestrial Plants	+	+	+	+	+	+	+	+	+
		Fish Communities	+	+	+	+	+	+	+	+	+
		Zooplankton	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Terrestrial Invertebrate Communities	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Amphibians and Reptiles	+	+	+	+	+	+	+	+	+
		Bird Communities	•	•	•	•	•	•	•	•	•
		Biotic Diversity	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	At-risk Biota	Species Health, Growth and Reproductive Success	+	+	+	+	+	+	+	+	+
		Threatened and Endangered Species	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Human Use	Non-point Source Human Effects	Trophic Bioaccumulation	+	+	+	+	+	+	+	+	+
	Consumptive Use	Harvested Species	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	Visitor Use	Land use Fine Scale	+	+	+	+	+	+	+	+	+
Ecosystem Pattern and Processes	Land Use and Cover	Land use Coarse Scale	+	+	+	+	+	+	+	+	+
	Soundscape	Soundscapes and Light Pollution	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	Nutrient Dynamics	Nutrient Dynamics	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Trophic Relations	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	Productivity	Primary Productivity	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		Succession	+	+	+	+	+	+	+	+	+

+ = The Network plans to develop a monitoring protocol or SOP.
• = Park or partner monitoring will continue with Network collaboration.
Δ = Time and funds are currently not available.
– = Not applicable in this park
1 = Level names are from the National Park Service's Vital Signs Ecological Framework.
2 = APIS=Apostle Islands National Lakeshore; GRPO=Grand Portage National Monument; INDU=Indiana Dunes National Lakeshore; ISRO=Isle Royale National Park; MISS= Mississippi National River and Recreation Area; PIRO=Pictured Rocks National Lakeshore; SACN=Saint Croix National Scenic Riverway; SLBE=Sleeping Bear Dunes National Lakeshore; VOYA=Voyageurs National Park.

Table 6. Activities of the Great Lakes Inventory and Monitoring Network at Mississippi National River and Recreation Area, fall, 2013.

Water Quality: Monthly water quality monitoring is conducted by GLKN staff at five sites within MISS every other year. To date, monitoring has taken place in 2006, 2008, 2010, and 2012. Data Summary Reports describing monitoring for those years are available on the GLKN website. In 2013 a NPS Natural Resource Technical Report titled "Water Quality Conditions and Trends in the Mississippi National River and Recreational Area, 1976-2005" was published and is also available on the GLKN website. Additional work by several agencies to include analyses of recent water quality trends and further characterize changes in trends over 35+ years of monitoring is underway.

In 2013 GLKN joined an effort to sample surface waters to assess for pesticides, pharmaceuticals, personal care products, and waste water indicators in National Park Service waters, which included four Mississippi River sites and one groundwater spring site at MISS. This project is a collaborative effort among the United States Environmental Protection Agency, NPS Water Resources Division, and six other NPS I&M Networks. Data analysis and reporting will take place in 2014-2015. Contact: David VanderMeulen

Diatoms: Sediment samples are collected and analyzed for diatoms on a 3-5 year schedule. Diatoms are a major group of algae with unique cell walls made of silica that remain intact in the sediment. They are a popular tool for monitoring environmental conditions, past and present, and are commonly used in studies of water quality. Samples were collected in 2008 and 2011 at three sites in MISS. An NPS Natural Resource Technical Report with analysis of diatom sediment samples collected at MISS and other GLKN parks will be published by December 2013 and available on the GLKN website. Contact: David VanderMeulen

Persistent Contaminants: All known bald eagle nests within the MISS boundary have been mapped during annual occupancy and productivity surveys from 2006 through 2013. Occupancy surveys are done by aircraft during late March/ early April. Productivity surveys are done by either aircraft or ground visits in mid-May. These surveys provide an annual assessment of the health of the bald eagle population. From 2006 through 2011 staff also visited all occupied nests, hand captured nestlings, took standard measures of growth and health, banded them, and took samples of blood and feathers for determining levels of target environmental contaminants. Banding and sampling was done by a GLKN team during a 10 day tour in mid to late May. The GLKN took a two year planned break from field work in 2012 and 2013 and will return to sample nestlings for contaminants in 2014 and 2015. An NPS Data Summary Report, a Natural Resource Technical Report, two journal publications, and several Resource Briefs are available on the GLKN web site. Two additional journal publications are in preparation. Several presentations have been given at public and professional forums. Contact: Bill Route

Vegetation: Vegetation was monitored at MISS in 2011, the first year of implementation there. Training the field crew of five seasonals took place from May 9 - May 31st, 2011 with sampling occurring June 1 - June 30. High water levels during June prevented reaching the target of 50 plots in 2011. The GLKN established 32 plots and will resample them in 2019, at which time they will establish an additional 18 plots. An NPS Natural Resource Technical Report documenting the implementation of the program and providing baseline vegetation data was published in 2012 and is available on the GLKN website. Results were presented at the spring 2012 Mississippi River Forum. Contact: Suzanne Sanders

Land Use/Land Cover: High resolution aerial photography is used to confirm natural or human related disturbances that are identified from a time series of satellite imagery (Landsat). This analysis is conducted for each park in the GLKN on an approximately six-year rotation and was completed at MISS in 2013. A report is available as an NPS Natural Resource Technical Report on the GLKN website. Contact: Ulf Gafvert

Landbirds: Landbird monitoring at MISS takes place in May/June each year and is conducted by a small group of volunteers. MISS is a relatively new partner in the landbird monitoring effort and data gathering and quality is dependent on partner involvement. Cooperators anticipate an assessment of data quality and usefulness in the coming years. Contacts: Ted Gostomski (GLKN) and Nancy Duncan (MISS)

Table 6. Activities of the Great Lakes Inventory and Monitoring Network at Mississippi National River and Recreation Area, fall, 2013. (continued).

Amphibians: Amphibian monitoring began in spring 2013. Three automated listening devices (Song Meters) were placed in wetlands to document the presence/absence of calling frogs and toads. This is a shared program with GLKN supplying the protocol, Song Meters, and data management services. MISS provides field staff to place, check, and pick up the devices. Ninety-nine days of records were successfully gathered at each of 3 wetlands in 2013. The data have been provided to a contractor who will identify species of frogs and toads. In 2014 GLKN hopes to expand the program at MISS to as many as 10 wetlands. Contact: Ulf Gafvert
Species Inventories and Outreach: A species checklist has been published for MISS. This effort was based on records in the NPS species database that were certified by subject experts with review by MISS and GLKN staff. The database is available online at: https://irma.nps.gov/NPSpecies/. The GLKN has participated in three BioBlitzes at MISS, assisting with data collection and bringing information to share with the public. The bird section of the species checklist booklet created by GLKN was distributed by the park to all participants at the 2013 BioBlitz. The GLKN has also commissioned and published inventories at MISS on amphibians and freshwater mussels. These reports are available on the GLKN web site.

Literature Cited

Aber, J, R. P. Neilson, S. McNulty, J. M. Lenihan, D. Bachelet, and R. J. Drapek. 2001. Forest processes and global environmental change: predicting the effects of individual and multiple stressors. *BioScience* 51:735–750.

Anfinson, J. O., T. Madigan, D. M. Forsberg, and P. Nunnally. 2003. River of history: a historic resources study of the Mississippi National River and Recreation Area. United States Army Corps of Engineers. St. Paul District, St. Paul, Minnesota. Available at http://www.nps.gov/miss/historyculture/historic_resources.htm. (accessed June 10, 2013).

Dale, V. H., L. A. Joyce, S. McNulty, R. P. Neilson, M. P. Ayres, M. D. Flannigan, P. J. Hanson, L. C. Irland, A. E. Lugo, C. J. Peterson, and others. 2001. Climate change and forest disturbances. *BioScience* 51:723–734. Available at http://www.srs.fs.usda.gov/pubs/ja/uncaptured/ja_dale003.pdf. (accessed October 28, 2013).

Egan-Robertson, D., D. Harrier, and P. Wells. 2008. Wisconsin Population 2035: A Report on Projected State and County Populations and Households for the Period 2000-2035 and Municipal Populations, 2000-2030. Wisconsin Department of Administration, Madison, Wisconsin. Available at http://www.doa.state.wi.us/docview.asp?locid=9&docid=2108. (accessed December 17, 2012).

Hansen, A. J., R. P. Neilson, V. H. Dale, C. H. Flather, L. R. Iverson, D. J. Currie, S. Shafer, R. Cook, and P. J. Bartlein. 2001. Global change in forests: responses of species, communities and biomes. *BioScience* 51:765–779.

Hayhoe, K., J. VanDorn, T. Croley II, N. Schlegald, and D. Wuebbles. 2010. Regional climate change projections for Chicago and the US Great Lakes. *Journal of Great Lakes Research* 36 (Supplement 2):7–21.

Hogberg, R. K. 1971. Environmental geology of the Twin Cities metropolitan area. Educational Series – 5. Minnesota Geological Survey, University of Minnesota, St. Paul, Minnesota.

Available at http://conservancy.umn.edu/bitstream/57259/1/MGS_ES_5.pdf. (accessed October 1, 2013).

IIC (Interagency Information Cooperative). 2011. ECS overview (webpage). Available at http://iic.gis.umn.edu/finfo/ecs/ecs2.htm. (accessed December 4, 2012).

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007–the physical science basis: contribution of Working Group I to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge, UK. Available at http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm. (accessed January 7, 2013).

Kirschbaum, A. A., and U. B. Gafvert. 2013. Landsat-based monitoring of landscape dynamics at Mississippi National River and Recreation Area, 2005-2010. Natural Resource Technical Report NPS/GLKN/NRTR—2013/745. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2195280. (accessed October 28, 2013).

Kling, G. W., K. Hayhoe, L. B. Johnson, J. J. Magnuson, S. Polasky, S. K. Robinson, B. J. Shuter, M. M. Wander, D. J. Wuebbles, D. R. Zak, and others. 2003a. Confronting climate change in the Great Lakes region: impacts on our communities and ecosystems. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C. Available at http://www.ucsusa.org/greatlakes/glchallengereport.html. (accessed January 7, 2013).

Kling, G. W., L. B. Johnson, and S. Polasky. 2003b. State summary: Minnesota. Findings from Confronting climate change in the Great Lakes region: impacts on our communities and ecosystems. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C. Available at http://www.ucsusa.org/greatlakes/glchallengereport.html. (accessed January 7, 2013).

Lafrancois, B. M., D. L. Vana-Miller, and S. P. Johnson. 2007. Water resources information and issues overview, Mississippi National River and Recreation Area. Natural Resource Technical Report NPS/NRWRD/NRTR—2007/364. National Park Service, Water Resources Division, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/648364. (accessed October 28, 2013).

Larson, J., and D. Larson. 2009. Distribution and abundance of invasive non-indigenous plants and rare plants at two riverine national parks in the Great Lakes Network. Natural Resource Technical Report NPS/GLKN/NRTR—2008/161. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/660996. (accessed August 27, 2013).

McKenney, D. W., J. H. Pedlar, K. Lawrence, K. Campbell, and M. F. Hutchinson. 2007. Potential impacts of climate change on the distribution of North American trees. *BioScience* 57:939–948.

MDNR (Minnesota Department of Natural Resources) Division of Forestry. 1999. Ecological Land Type Associations of Minnesota. MDNR, St. Paul, Minnesota. Available at http://deli.dnr.state.mn.us. (accessed August 30, 2012).

MDNR (Minnesota Department of Natural Resources). 2012a. LiDAR elevation, Twin Cities metro region, Minnesota, 2011. MDNR, St. Paul, Minnesota. Available at http://www.mngeo.state.mn.us/chouse/elevation/lidar.html. (accessed October 24, 2012).

MDNR (Minnesota Department of Natural Resources). 2012b. Ecological classification system: eastern broadleaf forest province (webpage). MDNR, St. Paul, Minnesota. Available at http://www.dnr.state.mn.us/ecs/222/index.html. (accessed December 10, 2012).

MDOT (Minnesota Department of Transportation). 2002. Municipal boundaries (bdry_munipy3). MDOT, St. Paul, Minnesota. Available at http://deli.dnr.state.mn.us. (accessed November 14, 2012)

Minnesota State Demographic Center. 2012. Minnesota population projections by county, 2015-2040. Minnesota Department of Administration, St. Paul, Minnesota. Available at http://www.demography.state.mn.us/. (accessed October 1, 2013).

Morris, W. F., C. A. Pfister, S. Tuljapurkar, C. V. Haridas, C. L. Boggs, M. S. Boyce, E. M. Bruna, D. R. Church, T. Coulson, D. F. Doak, and others. 2008. Longevity can buffer plant and animal populations against changing climatic variability. *Ecology* 89:19–25.

NPS (National Park Service). 2007. Long-term Ecological Monitoring Plan: Great Lakes Inventory and Monitoring Network. Natural Resource Report NPS/GLKN/NRR-2007/001. National Park Service. Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/645523 (accessed October 28, 2013).

NPS (National Park Service). 2012. NPScape metric GIS data-population. Geospatial Dataset 2184561. NPS Natural Resources Stewardship and Science Inventory and Monitoring Division, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2184561. (accessed September 13, 2012).

NPS (National Park Service). 2013a. State of the park report for Mississippi National River and Recreation Area. State of the Park Series No. 4. National Park Service, Washington, D.C. Available at http://www.nps.gov/stateoftheparks/. (accessed June 11, 2013).

NPS (National Park Service). 2013b. Recreation visitors by month-Mississippi NRRA. NPS Stats Report Viewer (online). Available at https://irma.nps.gov/Stats/SSRSReports/Park Specific Reports/Recreation Visitors by Month (1979 - Last Calendar Year)?Park=MISS. (accessed October 22, 2013).

NPS (National Park Service). 2014. MNNRA foundation document (draft). Mississippi National River and Recreation Area, St. Paul, Minnesota.

NWS (National Weather Service). 2011. New 1981-2010 climate normals (webpage). NWS, Chanhassen, Minnesota. Available at http://www.crh.noaa.gov/mpx/?n=mpxclimatenormals. (accessed October 22, 2013).

USACE (United States Army Corps of Engineers). 2015. Upper St. Anthony Falls lock closure, Upper Mississippi River. Information Paper 44. USACE, St. Paul, Minnesota. Available at http://www.mvp.usace.army.mil/Home/Projects/tabid/18156/Article/571138/upper-st-anthony-falls-lock-closure.aspx. (accessed May 18, 2015).

USDA (United States Department of Agriculture). Farm Service Agency. 2010. National agricultural imagery program (NAIP) digital orthorectified images (DOQ), Minnesota, 2010. Minnesota Geospatial Information Office, St. Paul, Minnesota. Available at http://www.mngeo.state.mn.us/chouse/airphoto/fsa.html. (accessed November 12, 2012).

USGS (United States Geological Survey). 2012. NHD…Flowline/NHD…Area/NHD…Waterbody/WBD_HUC… USGS, Reston, Virginia. Available at http://nhd.usgs.gov/data.html. (accessed June 4, 2012).

Walther, G, E. Post, P. Convey, A. Menzel, C. Parmeson, T. J. Beebee, J. Fromentin, O. Voegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. *Nature* 416:389–395.

WDNR (Wisconsin Department of Natural Resources). 1999. Wisconsin Land Type Associations (LTAs). WDNR, Madison, Wisconsin. Available at ftp://dnrftp01.wi.gov/geodata/. (accessed May 22, 2013).

3 Study Scoping and Design

3.1 Preliminary Scoping

A scoping meeting of MISS resource staff and partners, GLKN representatives, and University of Wisconsin – Stevens Point (UWSP) researchers was held at MISS on September 21, 2011. Topics discussed included the purpose of the NRCA and process for its development; resources and existing protection efforts for MISS; human use as the purpose of the park but also as a potential stressor; other stressors; and success stories to be emphasized. On September 22, park staff gave the UWSP researchers a tour of some significant park resources, including the Coldwater Spring unit.

On January 31, 2012, UWSP researchers attended a meeting at MISS in which the State of the Park Report (SOTP) was discussed and planned. It was agreed that the natural resources in the SOTP would be considered for inclusion in the NRCA, and that to the extent possible, the NRCA would support and give detail to the SOTP.

On August 1, 2013, UWSP researchers and MISS resource staff met to discuss how the NRCA could be meshed with the Foundation Document being developed for MISS. The draft Foundation Document (NPS 2014) laid out the fundamental resources and values of MISS as:

1. Cultural and historic sites that owe their national or regional significance to their presence along the Mississippi River.

2. A Mississippi River that supports the region's economic prosperity and the economies of the communities that lie along the river in the National River and Recreation Area (NRRA).

3. Collaborative relationships with governments, private sector organizations, non-profits, schools, and individuals that allow the park to achieve its purpose.

4. Healthy aquatic ecosystems that provide for a rich and diverse assemblage of fish, mussels, macro-invertebrates and other species.

5. Healthy terrestrial ecosystems that provide for a rich and diverse assemblage of plants and animals.

6. Birds that rely on the Mississippi River Flyway in the NRRA to provide nesting, resting and feeding habitat.

7. Scenic vistas that allow people to experience the nationally and regionally significant landscapes of the NRRA

8. Outdoor recreational opportunities that connect visitors with the river and its parks, greenspaces and stories in the NRRA.

9. The experience of interacting with nature in the largest metropolitan area on and along the Mississippi River.

10. The presence of bluffs, caves, waterfalls and fossil beds that demonstrate the unique geologic character of the Mississippi River in the NRRA.

11. The experience of connecting to the Mississippi River as one of the world's most legendary rivers.

12. A Mississippi River in the NRRA that is clean, safe, accessible, and inviting.

3.2 Study Design

3.2.1 Indicator Framework, Focal Study Resources and Indicators

The MISS NRCA uses the six-category assessment and reporting framework developed by the US Environmental Protection Agency Science Advisory Board (USEPA–SAB) (USEPA 2002). The top reporting categories in this framework are landscape condition; biotic condition; chemical and physical characteristics of water, air, soil, and sediment; ecological processes; hydrology and geomorphology; and natural disturbance regimes. It was chosen because it was developed to build on the strengths of several of the alternative frameworks (such as the Heinz Center or National Research Council frameworks) and the key natural resources for MISS fit well into its categories.

3.2.2 Reference Conditions and Trends

Reference conditions (sometimes called benchmarks, standards, trends, thresholds, desired future conditions, or norms) give a point of reference to which to compare a measurement or statement about an indicator (USFS 2004). A large body of literature has been developed around the development and interpretation of reference conditions. All NRCAs are required to define and apply reference conditions, but NPS has adopted a "pragmatic approach" that requires only that NRCAs apply "logical and clearly documented forms of reference conditions and values" (http://www.nature.nps.gov/water/nrca/conditionsandvalues.cfm).

Stoddard et al. (2006) has suggested that reference conditions fall into four categories, which they name "historic condition," "minimally disturbed condition," "least disturbed condition," and "best attainable condition." We have attempted, where possible, to apply this reference condition scheme as follows:

"Historic condition," in our judgment, is the condition of MISS before European settlement. It assumes the absence of contaminants known to be primarily anthropogenic in origin or the presence of naturally sustainable populations of organisms.

"Minimally disturbed condition" is defined by Stoddard et al. (2006) as "the condition of systems in the absence of significant human disturbance" and we apply this definition.

"Least disturbed condition" is defined by Stoddard et al. (2006) as "the best of today's existing conditions." We apply this reference condition in conjunction with regulatory standards or peer-reviewed guidelines; resources with levels of contaminants that do not exceed standards are deemed to be in "least disturbed condition."

"Best attainable condition" is defined by Stoddard et al. (2006) as "the condition that today's sites might achieve if they were better managed."

We use professional judgment to assess the trend of resource conditions, using statistical methods where appropriate data are available, but many MISS resources do not have consistent measurements or assessments that occur at the same sites and use the same methods over time. We also use professional judgment to give a confidence ranking of high, medium, or low to our assessments; these are based on the amount of data, the age of the data, and the proximity of the sampling locations to MISS. An effort was made to provide consistency between the SOTP and NRCA.

Symbols were developed to provide a graphic representation of the status and trend of resources (Table 7).

Table 7. Key of the Status and Trend symbols used throughout this report. The background color represents the current condition status, the direction of the arrow summarizes the trend in condition, and the thickness of the outside line represents the degree of confidence in the assessment.

Condition Status		**Trend in Condition**		**Confidence in Assessment**	
	Warrants Significant Concern		Condition is Improving		High
	Warrants Moderate Concern		Condition is Unchanging		Medium
	Resource is in Good Condition		Condition is Deteriorating		Low
	An open (uncolored) circle indicates that current condition is unknown or indeterminate; this condition status is typically associated with unknown trend and low confidence				

3.2.3 Reporting Areas

The focus of this report was the natural resource condition of the lands within the MISS corridor under the management of NPS or its partners. Evaluation of condition sometimes required evaluation of conditions at other scales, such as in the watershed or with a 30-km buffer of the park.

3.2.4 General Approach and Methods

As noted in Chapter 1, the primary objective of the MISS NRCA is to report on current natural resource conditions relative to logical forms of reference conditions and values. Emphasis was placed on gathering existing natural resource data about MISS. NPS inventory and monitoring reports and plans, management plans, and study reports by independent researchers were provided by MISS and GLKN staff and taken from the MISS, GLKN, and other NPS websites, including the IRMA web portal.

Data at larger scales were also collected. Many of these data are managed by state and other agencies and fall into the category of grey literature. Agency staff in relevant programs was contacted when clarification or documentation was needed. Past and current peer-reviewed

journals were also extensively reviewed to obtain general background information and appropriate data for reference conditions.

Extensive gathering and analysis of spatial data was conducted to create maps and summary statistics used to evaluate conditions and compare MISS natural resources to those of surrounding areas.

The report was reviewed by Brenda Moraska Lafrancois, NPS Midwest Region aquatic ecologist, and John Anfinson, Nancy Duncan, and Lark Weller of MISS before being submitted to NPS for final approval and publication.

Literature Cited

NPS (National Park Service). 2014. MNNRA foundation document (draft). Mississippi National River and Recreation Area, St. Paul, Minnesota.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

USEPA (United States Environmental Protection Agency) Science Advisory Board. 2002. A framework for assessing and reporting on ecological condition: an SAB report. EPA-SAB-EPEC-02-009. USEPA, Washington, D.C. Available at http://www.epa.gov/sab/pdf/epec02009.pdf. (accessed September 23, 2013).

USFS (United States Forest Service). 2004. Reference values (fact sheet). USFS, Washington, D.C. Available at http://www.fs.fed.us/emc/rig/readingroom/library/Reference_Values_Fact_Sheet_2004.pdf. (accessed July 8, 2012).

4 Natural Resource Conditions

4.1 Natural Disturbance Regimes

The EPA-SAB framework (USEPA 2002) lists natural disturbance regimes as one of its six major categories and states that all ecological systems are dynamic, due in part to discrete and recurrent disturbances that may be physical, chemical, or biological in nature. We have described the natural disturbance regimes of MISS in the categories of flood regime, herbivory, wind and other small-scale disturbances, and moderate to severe disturbances.

4.1.1 *Flood Regime*

The disturbance regime of a river, riparian zone, and associated floodplain is dominated by the hydrologic, or flood, regime of the system. A flood regime consists of the frequency, duration (how long there is standing water), intensity (flow volume or rate), and timing (time of year) of all flow events (Baker and Wiley 2009). To the biota, an important dimension of the flood regime is the duration (Richter and Richter 2000, Gergel et al. 2002) and timing of the annual minimum baseflows (Lenhart et al. 2013). Many plants and invertebrates (and possibly other taxa) common to floodplain ecosystems require a minimal level of moisture during part of the growing season to thrive or become established (Knutson and Klaas 1998, Streng et al. 1989, Boulton et al. 1992, Gorham et al. 2002).

Other, typically small-scale disturbances (e.g., insects, pathogens, wind, and ice) are universally present in the river corridor and have impacts at the scale of a tree to a patch. These small-scale effects interact with the flood regime to influence habitat, biotic interactions, and composition of the riparian area and floodplain. However, both macro- and micro-geomorphic features of the system are largely due to the hydrologic regime (Hughes 1997). The infrequent, major floods (such as the one seen on the Mississippi River in 1993 [Curley and Urich 1993]) produce more prominent and longer lasting geomorphic features as a result of erosion and deposition patterns (Hughes 1997, Parsons et al. 2005). The geomorphic characteristics of a channel and the associated floodplain exert a notable influence over vegetation types and their distributions (Hupp and Osterkamp 1996, Parsons et al. 2005).

One important habitat feature that is intimately linked to the flood regime and riparian vegetation is coarse woody structure (Gurnell et al. 2005). Floods generate this structure and also move it around. Thus, the quantity of this special and important habitat is a function of the recent (i.e., decades) flood regime and the size of the trees along and near the river channel. A flood of any magnitude directly affects moisture conditions, sediment movement and deposition, particle-size organic matter movement and deposition, and intermediate-sized woody debris and movement (Hughes 1997, Baker and Wiley 2009). Floods may have indirect effects on nutrient status, light levels at the forest floor, biotic composition, and mortality and regeneration rates. These indirect effects combine with direct effects to partially determine plant succession of the riparian area and floodplain (Hughes 1997, Knutson and Klaas 1998, Cosgriff et al. 1999, Baker and Wiley 2009). Hence, the long term (decades to centuries) vegetation dynamics of a floodplain are the result of multiple interacting factors and stochastic influences (Hughes 1997, Baker and Wiley 2009).

The complete and cumulative effects of the hydrologic regime are not always obvious. Some of the important effects of the flow regime may be weakly related to magnitude of annual peak flows and strongly linked to duration (Richter and Richter 2000). For a few key ecosystem

processes, such as decomposition and plant regeneration, the *variability* of one or more flood regime components (e.g., frequency or timing) may be as important as intensity (Hupp and Osterkamp 1996, Richter and Richter 2000, Rood et al. 2003). Inter-annual variability is the norm for hydrologic regimes (Richter and Richter 2000, Rood et al. 2003).

The effects of individual floods, and more generally the regime, do not occur in spatial isolation. Landforms and land use in the watershed often have strong influences on regime characteristics and subsequent effects (Allan 2004, Baker and Wiley 2009), including the variability in peak flow and timing (Richter and Richter 2000, Rood et al. 2003). Given the differences noted in Section 4.3.2, land use should be exerting a strong effect on the flood regime throughout the MISS corridor (Burcher et al. 2007). An analysis of the mean annual discharge, timing of floods and inter-annual variability for MISS is provided in section 4.2.

4.1.2 ***Herbivory***

Herbivory is qualitatively like other disturbances; it involves destruction of part or all of a plant, and events occur at different intensities, frequencies, and times of the year (Stiling 1996). The scale of impact is usually small, but insects that reach epidemic levels can defoliate thousands of hectares in a year. All natural communities contain herbivores, and they range in size from very small arthropods to large mammals. These herbivores feed on different plants and different plant parts, and they utilize both below- and above-ground tissues. Due to variation in utilization, timing, and regularity, the different species of herbivores have impacts ranging from negligible to pronounced to catastrophic. Thus, the vast majority of plants have persisted with the native suite of herbivores for many generations. Some species thrive in the presence of herbivore pressure (in the community or landscape) because of traits that provide inherent ability to tolerate the herbivory (Cote et al. 2004). Other species persist by largely escaping any intense herbivory by their phenology, by containing defensive compounds, or by having physical traits that discourage most herbivores (Stiling 1996).

This form of coexistence can be upset if herbivore densities reach very high levels or a novel herbivore enters the system. The situation in the upper Midwest contains both of these threatening elements. In most areas, the population densities of white-tailed deer (WTD) (*Odocoileus virginianus*) are much higher than estimated historical levels (Alverson et al. 1988, Waller et al. 2009). Novel insect herbivores that are currently of grave concern include the gypsy moth (*Lymantria dispar*), which has been present in the Twin Cities since the 1970s, and the emerald ash borer (EAB) (*Agrilus planipennis*, Coleoptera), which entered the Twin Cities in 2009 (http://www.emeraldashborer.info).

<u>WTD Herbivory</u>

There are several extensive reviews of the impacts of WTD from the past 10 years (e.g., Rooney and Waller 2003, Cote et al. 2004, Waller et al. 2009). The impacts can be subtle, moderate, or severe. These reviews list the ecological impacts as: growth reduction, reduced seed production, decreased survival, altered relative abundance, reduced plant cover and richness, shifts in composition of the understory and ultimately other layers, and longer-term impacts on vegetation dynamics. Within this, there can be extirpation of species and major structural change. The indirect impacts extend, in some cases, to invertebrates, songbirds, soil properties, and ecosystem processes. The effects of WTD herbivory are often site- or area-specific, but not always negative. At moderate levels of abundance in a community experiencing low intensity fire and canopy

gaps, the presence of WTD herbivory *increased* herbaceous richness in an upland, mixed hardwood forest (Royo et al. 2010). Even in areas of moderately high densities, the effect of deer browsing can be overestimated if a holistic, long-term view is not taken (Mladenoff and Stearns 1993). A critical factor for placing the current level and extent of WTD impacts in perspective is population density and carrying capacity of the landscape (Alverson et al. 1988, Cote et al. 2004, Waller et al. 2009 and citations therein).

What is largely unknown, however, are the role and impacts of WTD in floodplain ecosystems of the Great Lakes region. The review by Waller et al. (2009) for the region discusses all major facets of the WTD "problem," but it does not include any information about riparian or riverine systems. Studies from the Southeast reinforce the important influence of deer density; forb cover was reduced and many tree species disappeared at 67 deer km^{-2} in three forest types (Rossell et al. 2005). However, low deer densities did not result in any significant effects on the plant community (Castleberry et al. 2000). An experimental study in a bottomland hardwood forest in South Carolina found no effect of deer (no density given) or rabbit herbivory on the growth or survival of planted oak seedlings (Collins 2003). In contrast, Liang and Seagle (2002) documented a 39% increase in seedling mortality, a 42% reduction in recruitment, and a 28% growth reduction due to browsing by WTD in a riparian forest in Maryland. Of special note were the differential impacts among plant species and the indication that browsing would not alter succession in this system.

Emerald Ash Borer Herbivory

Life History

The EAB has a one-year life cycle that begins with adult emergence in early June-early July. The beetles live for about 3 weeks (or longer under constant temperature, [Lyons et al. 2004]), are active during the day, and feed on the edges of ash (*Fraxinus* spp.) leaves. This feeding has effectively no impact on the tree. The beetles will usually take refuge under bark or in bark crevices when the winds are strong, it is rainy, or temperature drops down near 0° Celsius. Females may mate several times and lay 60-90 eggs during their life span. The eggs are deposited in bark crevices on the trunk or large branches. Eggs will mature and hatch in 7-20 days, and the first instar larvae chew through the bark. Cooler than average temperatures approximately double the egg development time (Lyons et al. 2004). These larvae feed on the cambium, phloem, and outer sapwood for several weeks. They meander during this process, creating S-shaped galleries. Each larva will create a gallery ranging from 10-50 cm, which gradually enlarges as the larva grows. Phenological development can be quicker on the upper part of a tree compared to low down on the trunk (Siegert et al. 2005). Feeding ends in autumn, and late-instar larvae overwinter in shallow chambers in the outer sapwood or in the bark. Pupation begins in late April or May. Newly eclosed adults usually remain in the pupal chamber for 1-2 weeks and then emerge head-first; this creates a D-shaped exit hole that is 3-4 mm in diameter (McCullough et al. 2004).

Hosts and Distribution in North America

EAB has fed on all ash species that it has encountered since its introduction in southern Michigan in the 1990s. If it were to spread throughout the US, 16 species would be threatened, as well as many cultivars used for landscaping (Poland and McCullough 2006). Since 2002, the beetle has spread to Ontario and around the southern end of Lake Michigan to Ohio, Indiana, and WI; it reached Minnesota in 2009. The three most common ash species-white (*F. americana*),

green (*F. pensylvanica*), and black (*F. nigra*)-are very susceptible to EAB, and black ash especially so (Poland and McCullough 2006, Rebek et al. 2008, McCullough 2013). However, a less common species of ash, blue ash (*F. quadrangulata*) has some inherent resistance (Poland and McCullough 2006, McCullough 2013) or is not as preferred (Haack et al. 2004). Adult beetles will eat the foliage of a few other shrub and tree species, but their longevity is usually reduced, and when they have a choice, they will avoid most trees but will feed on a few shrubs in the same family [Oleaceae] as the ashes (Haack et al. 2004).

Most adults will not fly more than 0.8 km from the tree they emerge from; however, it has been documented that a few will fly much further. The female appears to be the stronger and probably can fly 4.8 km (McCullough 2013). The spread of the species has been aided by unintentional transport (e.g., in firewood and nursery stock), which has substantially increased its rate of range expansion (Poland and McCullough 2006). Attempts to contain the species have been largely unsuccessful, though they appear to have slowed down the rate of expansion in a few areas.

Symptoms and Impacts

Though the adult feeds on leaves (see Life History section), this effect is very difficult to spot. One form of evidence that is clear at any level of infestation are the 3-4 mm, D-shaped exit holes created by the adults as they emerge from the tree. The larvae create S-shaped galleries under the bark as they feed; this is also easy to diagnose but requires removal of the bark. Increased use by woodpeckers may indicate the presence of EAB, as they readily prey on the larvae. The stress and damage done by the larvae will result in crown deterioration of approximately 30-50% within 2 years, and large trees may die within 3-4 years (McCullough et al. 2004). Of course, this time course is strongly dependent on the density of the borer. The ash borer has been found on trees as small as 2.5 cm diameter, and a tree this size will often die within one year (Poland and McCullough 2006). A short term study (Smith et al. 2005) found that ash mortality was independent of tree density in southeast Michigan.

Outcome

To date, the borer has been able to build up its population to a high level in all forests invaded, and thus the mortality level for ash trees is typically 99% (McCullough 2013). Within one year of being killed, the trees may produce epicormic sprouts on the trunk or root sprouts. Thus, some trees will persist into the next generation. In many forests with ash in the overstory there are also significant numbers of ash seedlings (Smith et al. 2005, Sanders and Grochowski 2012). In MISS in 2011 specifically, the ‘upland forests’ contained 1,700 and 133 seedlings ha^{-1} green and black ash, respectively; the seedling bank of the cottonwood-box elder forest type had 3,720 and 1,533 seedlings ha^{-1} of green and black ash, respectively. The green ash-box elder forest type, in contrast, contained only 619 seedlings ha^{-1} of green ash (Sanders and Grochowski 2012). Despite the ability to sprout and the frequent presence of seedlings, the expectation is for the effects of EAB to convert the forest to another type, as typically is true when susceptible and non-susceptible species are present (Abrams and Scott 1989, Attiwell 1994). The composition of the midstory, if present, and large saplings will generally determine the forest type that will replace the ash. For example, in southern Michigan, Smith et al. (2005) hypothesized that some combination of elm, maple, and cherry (*Prunus* spp.) would become the canopy dominants. The seedling layer may contribute to the next forest if the two other strata are sparse.

The loss of a dominant species can have cascading effects on other organismal groups. This is especially likely if there are other species that are true and strict specialists on the plant species that is lost. A literature-based assessment for arthropods determined that 43 native species, which included arachnids and insects, are known to associate only with ash trees for feeding or breeding purposes (Gandhi and Herms 2010). This provides an indication, for one major taxonomic group, of the potential diversity loss from EAB. Similar assessments were not found for other groups, so the full scope of this possible effect is unknown.

The ecological effects of rapid loss of a canopy dominant due to an insect usually include: a change in forest structure, increased growth (richness, biomass) in the understory layer, increased rates of carbon and nutrient cycling, higher amounts of infiltration, and greater potential for leaching and run-off (Haack and Byler 1993, Jenkins et al. 1999, McCullough 2013). The rate of vegetative regrowth is the prime determinant of how long these effects will persist (Haack and Byler 1993).

4.1.3 *Wind and Other Small-scale Disturbances*

Extensive data from many parts of the eastern US prove the regularity and abundance of small spatial scale disturbances. These are commonly produced by wind events, insects, and/or disease working singly or in combination (Runkle 1982, Clinton et al. 1993). In mature forests in the Great Lakes region, the rate at which the canopy is opened up is 0.5-1.5 % per year (Frelich and Lorimer 1991, Dahir and Lorimer 1996). Younger forests have lower rates, and older forests can have higher rates (up to 4%) (Runkle 1982, 2013; Cho and Boerner 1991, Dahir and Lorimer 1996, Busing 2005). In most systems, larger trees are more likely to die (Busing 2005, Runkle 2013) and hence produce a larger gap (Clebsch and Busing 1989). The potential importance of this disturbance regime component is indicated by the amount (2.5% to 17%) of the forest in an ‘open canopy’ condition at any one time.

The canopy gap formation rate for a small floodplain in central WI was estimated to be 1-2% per year (Cook 2005). The amount of windthrow in a balsam fir-dominated riparian buffer was not affected by tree density or a buffer width range of 20-60 m (Ruel et al. 2001).

Gap formation, and the resulting indirect abiotic effects, can have numerous short term effects on plant cover, herb layer richness, herb layer composition, woody plant abundance and composition, and forest structure. It is not known how widespread these are in riparian and floodplain areas, nor the importance of local conditions. In an East Texas bottomland forest, microtopography affected gap abundance but not area or frequency, and the results suggest that gaps will exert a moderate influence on tree seed germination and seedling survival (Almquist et al. 1999). An experimental study in a bottomland hardwood forest demonstrated that shading and herb-layer competition affected tree regeneration, but these effects waned in large gaps (Collins 2003). Gap formation can occasionally have a much longer-term effect. The tree dynamics and succession of an old-growth floodplain forest in southern Illinois were driven by gap formation processes (Robertson et al. 1978).

4.1.4 *Moderate-to-Severe Disturbances*

In contrast to the patch-scale effects of wind, ice, and biotic agents, these and other agents occasionally reach a high level of severity and impact very large areas. In this region, wind and fire are the most likely sources of a ‘catastrophic’ disturbance. Fire will rarely play this role in

the floodplain, but it may in the watershed. In the region, tornadoes and straight-line winds are the phenomena most like to cause a severe disturbance. This was the type of disturbance that damaged more than five thousand hectares in St. Croix State Park in Minnesota in 2011. A similar blowdown of 150,000+ ha occurred in the Boundary Waters Canoe Area in northern Minnesota in July, 1999 (information about both events can be found at http://www.crh.noaa.gov/dlh/?n=1jul2011_winddamge).

An important ecological question is, "How important are the different types and severities of disturbance?" Based on remotely sensed data, Stueve et al. (2011) estimated that intermediate level wind events had a similar level of impact as severe disturbances. This evaluation was based on the amount of canopy affected by the wind events.

In a river floodplain subjected to hurricane force winds, 22% of trees >4.5 cm diameter at breast height (DBH) were severely damaged. Roughly equal numbers of canopy species had a positive and negative relationship between mortality and DBH. The "intermediate severity" disturbance did not alter the relative dominance of species in the small tree layer, and thus probably will not change the long term succession of the forest (Harcombe et al. 2009).

Tornado damage in an occasionally flooded lowland and frequently flooded swamp was assessed by Peterson and Rebertus (1997). Thirty percent of the individual trees were knocked over, but only 20% died within 14 months. More than half of the damaged trees sprouted in the first year. Species differed significantly in resistance, but large trees of all species had a greater likelihood of damage than small trees. The herbaceous layer exhibited a rapid response to the canopy damage with a surge of shade-intolerant species. This ground layer was a competitive barrier for some tree species, and the authors concluded that the severity of disturbance was acting to both reset and accelerate forest succession (Peterson and Rebertus 1997).

An assessment twelve years after a "moderate" windstorm in an upland *Pinus-Acer* forest in Minnesota (Webb and Scanga 2001) found no differences in vegetative richness, composition, or structure between impacted and non-impacted parts of the forest. The lack of a difference was attributed to limited tree regeneration response to the microtopography created by the wind and to the presence of a windfirm subcanopy. The net effect of the storm will be to accelerate succession to a later stage (Webb and Scanga 2001).

Based on the few direct evaluations that have been performed, the conclusions of Stueve et al. (2011) are questionable. Intermediate severity wind events can have a wide range of effects (including no significant effect), but we do not know what local factors push it one way or another.

Sources of Expertise
James Cook, UWSP

Literature Cited

Abrams, M. D., and M. L. Scott. 1989. Disturbance mediated accelerated succession in two Michigan forest types. *Forest Science* 35:42–49.

Allan, D. J. 2004. Landscapes and riverscales: the influence of land use on stream ecosystems. *Annual Review of Ecological and Evolutionary Systems* 35:257–284.

Almquist, B. E., M. G. Messina, and S. B. Jack. 1999. Micro-topographical effects on treefall gap formation in an East Texas bottomland hardwood forest. Tenth Biennnial Southern Silvicultural Research Conference, Shreveport, Louisiana, February 16-18, 1999:166–174. Available at http://www.srs.fs.usda.gov/pubs/gtr/gtr_srs030.pdf. (accessed September 10, 2013).

Alverson, W. S., D. M. Waller, and S. Solheim. 1988. Forest too deer: edge effects in northern Wisconsin. *Conservation Biology* 2:348–358.

Attiwell, P. M. 1994. The disturbance of forest ecosystems: the ecological basis for conservative management. *Forest Ecology and Management* 63:247–300.

Baker, M. E., and M. J. Wiley. 2009. Multiscale controls of flooding in riparian forests of Lower Michigan. *Ecology* 90:145–159.

Boulton, A. J, C. G. Peterson, N. B. Grimm, and S. G. Fisher. 1992. Stability of an aquatic macroinvertebrate community in a multiyear hydrologic disturbance regime. *Ecology* 73:2192–2207.

Burcher, C. L., H. M. Valett, and E. F. Benfield. 2007. The land-cover cascade: relationships coupling land and water. *Ecology* 88:228–242.

Busing, R. T. 2005. Tree mortality, canopy turnover, and woody detritus in old cove forests of the southern Appalachians. *Ecology* 86:73–84.

Castleberry, S. B., W. M. Ford, K. V. Miller, and W. P. Smith. 2000. Influences of herbivory and canopy opening size on forest regeneration in a southern bottomland hardwood forest. *Forest Ecology and Management* 131:57–64.

Cho, D. S., and R. E. J. Boerner. 1991. Canopy disturbance patterns and regeneration of *Quercus* species in two Ohio old-growth forests. *Vegetatio* 93:9–18.

Clebsch, E. E., and R. T. Busing. 1989. Secondary succession, gap dynamics, and community structure in a Southern Appalachian cove forest. *Ecology* 70:728–735.

Clinton, B. D., L. R. Boring, and W. T. Swank. 1993. Canopy gap characteristics and drought influence in oak forests of the Coweeta Basin. *Ecology* 74:1551–1558.

Collins, B. 2003. Ground layer competition and herbivory effects on cherrybark oak (*Quercus pagoda* Raf.) regeneration in experimental canopy gaps. *Journal of the Torrey Botanical Society* 130:147–157.

Cook, J. E. 2005. Vegetation changes in a central Wisconsin floodplain from pre-settlement to the mid-21st century. *Journal of the Torrey Botanical Society* 132:492–504.

Cosgriff, R. J., J. C. Nelson, and Y. Yin. 1999. Forest response to high duration and intensity flooding along Pool 26 of the Upper Mississippi River. LTRMP Project Status Report 99-01. USGS Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. Available at

http://www.umesc.usgs.gov/reports_publications/psrs/psr_1999_01.html. (accessed September 10, 2013).

Cote, S. D., T. P. Rooney, J. Tremblay, C. Dussault, and D. M. Waller. 2004. Ecological impacts of deer overabundance. *Annual Review of Ecology Evolution and Systematics* 35:113–147.

Curley, A. and R. Urich. 1993. The flood of ’93: an ecological perspective. *Journal of Forestry* 91:28–30.

Dahir, S. E., and C. G. Lorimer. 1996. Variation in canopy gap formation among development stages of northern hardwood stands. *Canadian Journal of Forest Research* 26:1875–1892.

Frelich, L. E., and C. G. Lorimer. 1991. Natural disturbance regimes in hemlock–hardwood forests of the Upper Great Lakes region. *Ecological Monographs* 61:145–164.

Gandhi, K. J. K., and D. A. Herms. 2010. North American arthropods at risk due to widespread *Fraxinus* mortality caused by the alien emerald ash borer. *Biological Invasions* 12:1839–1846.

Gergel, S. E., M. D. Dixon, and M. G. Turner. 2002. Consequences of human-altered floods: levees, floods, and floodplain forests along the Wisconsin River. *Ecological Applications* 12:1755–1770.

Gorham, L. E., S. L. King, B. D. Keelend, and S. Mopper. 2002. Effects of canopy gaps and flooding on homopterans in a bottomland hardwood forest. *Wetlands* 22:541–549.

Gurnell, A., K. Tockner, P. Edwards, and G. Petts. 2005. Effects of deposited wood on biocomplexity of river corridors. *Frontiers in Ecology and the Environment* 3:377–382.

Haack, R. A., and J. W. Byler. 1993. Insects and pathogens – regulators of forest ecosystems. *Journal of Forestry* 91:32–37.

Haack, R. A., T. R. Petrice, D. L. Miller, L. S. Bauer, and N. M. Schiff. 2004. Host range of emerald ash borer. p. 38 *in* V. Mastro and R. Reardon, compilers. EAB Research & Technological Development Meeting 2004, Port Huron, Michigan, September 30-October 1, 2003. USDA Forest Health Enterprise Team. FHTET-2004-02. Available at http://www.fs.fed.us/foresthealth/technology/pdfs/2003EAB.pdf. (accessed February 4, 2014).

Harcombe, P. A., L. E. Mann-Leipzig, and I. S. Elsik. 2009. Effects of Hurricane Rita on three long-term forest study plots in East Texas, USA. *Wetlands* 29:88–100.

Hughes, F. M. R. 1997. Floodplain biogeomorphology. *Progress in Physical Geography* 21:501–529.

Hupp, C. R., and W. R. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic process. *Geomorphology* 14:277–295.

Jenkins, J.C., J. D. Aber, and C. D. Canham. 1999. Hemlock woolly adelgid impacts on community structure and N cycling rates in eastern hemlock forests. *Canadian Journal of Forest Research* 29:630–645.

Knutson, M. G., and E. E. Klaas. 1998. Floodplain forest loss and changes in forest community composition and structure in the Upper Mississippi River: a wildlife habitat at risk. *Natural Areas Journal* 18:138–150.

Lenhart, C. F., M. L. Titov, J. S. Ulrich, J. L. Nieber, and B. J. Suppes. 2013. The role of hydrologic alternation and riparian vegetation dynamics in channel evolution along the Lower Minnesota River. *Transactions of the American Society of Agricultural and Biological Engineers* 56:549–561.

Liang, S.-Y., and S. W. Seagle. 2002. Browsing and microhabitat effects on riparian forest woody seedling demography. *Ecology* 83:212–227.

Lyons, D. B., G. C. Jones, and K. Wainin-Keizer. 2004. The biology and phenology of the emerald ash borer, *Agrilus planipennis*. p. 5 *in* V. Mastro and R. Reardon, compilers. EAB Research & Technological Development Meeting 2004, Port Huron, Michigan, September 30-October 1, 2003. USDA Forest Health Enterprise Team. FHTET-2004-02. Available at http://www.fs.fed.us/foresthealth/technology/pdfs/2003EAB.pdf. (accessed February 4, 2014).

McCullough, D. G. 2013. Will we kiss our ash goodbye? American Forests, Winter 2013. Available at http://www.americanforests.org/magazine/article/will-we-kiss-our-ash-goodbye/. (accessed February 4, 2014).

McCullough, D. G., N. F. Schneeberger, and S. A. Katovich. 2004. Pest alert – emerald ash borer. USDA Forest Service, State and Private Forestry, Northeastern Area. NA-PR-02-04, revised September 2008. Available at http://www.na.fs.fed.us/spfo/pubs/pest_al/eab/eab.pdf. (accessed February 4, 2014).

Mladenoff, D. J., and F. Stearns. 1993. Eastern hemlock regeneration and deer browsing in the northern Great Lakes region: a reexamination and model simulation. *Conservation Biology* 7:889–900.

Parsons, M., C. A. McLoughlin, K. A. Kotschy, K. H. Rogers, and M. W. Rountree. 2005. The effects of extreme floods on the biophysical heterogeneity of river landscapes. *Frontiers in Ecology and the Environment* 3:487–494.

Peterson, C. J., and A. J. Rebertus. 1997. Tornado damage and initial recovery in three adjacent, lowland temperate forests in Missouri. *Journal of Vegetation Science* 8:559–564.

Poland, T.M., and D. G. McCullough. 2006. Emerald ash borer: invasion of the urban forest and the threat to North America's ash resource. *Journal of Forestry* April/May:118–122.

Rebek, E. J., D. A. Herms, and D. R. Smitley. 2008. Interspecific variation in resistance to emerald ash borer (Coleoptera: Buprestidae) among North American and Asian ash (*Fraxinus* spp.). *Environmental Entomology* 37:242–246.

Richter, B. D., and H. E. Richter. 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. *Conservation Biology* 14:1467–1478.

Robertson, P. A., G. T. Weaver, and J. A. Cavanaugh. 1978. Vegetation and tree species patterns near the northern terminus of the southern floodplain forest. *Ecological Monographs* 48:259–267.

Rood, S. B., C. R. Gourly, E. M. Ammon, L. G. Heki, J. R. Klotz, M. L. Morrison, D. Mosley, G. G. Scoppettone, S. Swanson, and P. L. Wagner. 2003. Flows for floodplain forests: a successful riparian restoration. *BioScience* 53:647–655.

Rooney, T. P., and D. M. Waller. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. *Forest Ecology and Management* 181:165–176.

Rossell, Jr., C. R., B. Gorsira, and S. Patch. 2005. Effects of white-tailed deer on vegetation structure and woody seedling composition in three forest types on the Piedmont Plateau. *Forest Ecology and Management* 210:415–424.

Royo, A. A., R. Collins, M. B. Adams, C. Kirschbaum, and W. P. Carson. 2010. Pervasive interactions between ungulate browsers and disturbance regimes promote temperate forest herbaceous diversity. *Ecology* 91:93–105.

Ruel, J. C., D. Pin, and K. Cooper. 2001. Windthrow in riparian buffer strips: effect of wind exposure, thinning and strip width. *Forest Ecology and Management* 143:105–113.

Runkle, J. R. 1982. Patterns of disturbance in some old-growth forests of the eastern United States. *Ecology* 63:1533–1546.

Runkle, J. R. 2013. Thirty-two years of change in an old-growth Ohio beech-maple forest. *Ecology* 94:1165–1175.

Sanders, S., and J. Grochowski. 2012. Implementation of a long-term vegetation monitoring program at the Mississippi National River and Recreation Area. Natural Resource Technical Report NPS/GLKN/NRTR—2012/616. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2188820. (accessed February 4, 2014).

Siegert, N. W., D. G. McCullough, A. M. Liebhold, and F. W. Telewski. 2005. Reconstructing the temporal and spatial dynamics of emerald ash borer in black ash: a case study of an outlier site in Roscommon County, Michigan. p. 21 *in* V. Mastro and R. Reardon, compilers. EAB Research & Technological Development Meeting 2004, Romulus, Michigan, October 5-6, 2004. USDA Forest Health Enterprise Team. FHTET-2005-02. Available at http://www.fs.fed.us/foresthealth/technology/pdfs/2004EAB.pdf. (accessed February 4, 2014).

Smith, A., D. Herms, and R. Long. 2005. Does community structure influence forest susceptibility and response to emerald ash borer? Ecological Society of America Annual Meeting, Montreal, Canada. Published abstracts available at http://abstracts.co.allenpress.com/pweb/esa2005/document/47429. (accessed February 4, 2014).

Stiling, P. D. 1996. Ecology – theories and applications. 2nd edition. Prentice-Hall, Upper Saddle River, New Jersey. 539 pp.

Streng, D. R., J. S. Glitzenstein, and P. A. Harcombe. 1989. Woody seedling dynamics in an East Texas floodplain forest. *Ecological Monographs* 59:177–204.

Stueve, K. M., I. W. Housman, P. L. Zimmerman, M. D. Nelson, J. B. Webb, C. H. Perry, R. A. Chastain, D. D. Gormanson, C. Huang, S. P. Healey, and W. B. Cohen. 2011. Snow-covered Landsat time series stacks improve automated disturbance mapping accuracy in forested landscapes. *Remote Sensing of Environment* 115:3203–3219.

USEPA (United States Environmental Protection Agency) Science Advisory Board. 2002. A framework for assessing and reporting on ecological condition: an SAB report. EPA-SAB-EPEC-02-009. USEPA, Washington, D.C. Available at http://www.epa.gov/sab/pdf/epec02009.pdf. (accessed September 19, 2013).

Waller, D. M., S. Johnson, R. Collins, and E. Williams. 2009. Threats posed by ungulate herbivory to forest structure and plant diversity in the upper Great Lakes region with a review of methods to assess those threats. Natural Resource Report NPS/GLKN/NRR–2009/102. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/661464. (accessed September 10, 2013).

Webb, S. L., and S. E. Scanga. 2001. Windstorm disturbance without patch dynamics: twelve years of change in a Minnesota forest. *Ecology* 82:893–897.

4.2 Hydrology and Geomorphology

The EPA-SAB framework considers hydrology and geomorphology an essential ecological attribute because it reflects "the dynamic interplay of water flow and landforms" (USEPA 2002). Water flow patterns, both natural and human-influenced, and the interactions of water, riverbed, and riparian areas influence the natural diversity of habitats and species. Sediment and other material transport patterns are critical to a variety of underwater, riparian, and wetland habitats.

The Mississippi River channel in MISS has been greatly altered from pre-European settlement conditions. These alterations began in 1866 with dredging, snag removal, and tree clearing by the Corps of Engineers (Anfinson et al. 2003). In 1878, a 1.37 m channel was authorized, and wing dams and closing dams were built to direct the river's flow into its main channel. Channel depths of 1.83 m and 2.75 m were authorized in 1907 and 1930, respectively (Chen and Simons 1986). By 1917, two locks and dams had been built for navigation, and by 1963, the current system of locks and dams seen today had been put into place (Anfinson et al. 2003). The history of these projects is described in detail in *River of History: A Historic Resources Study of the Mississippi National River and Recreation Area* (Anfinson et al. 2003).

The construction of dikes and of locks and dams made permanent changes to the river's physical character, which Chen and Simons (1986) summarized in Table 8. These physical changes resulted in many ecological changes. Sediments became more unconsolidated and flocculent and became less suitable habitats for plants, invertebrates, and mussels. With increased wave energy and wind fetch, turbidity increased and light penetration decreased, resulting in a general loss of aquatic vegetation. An elevated water table favored tree species such as silver maple (*Acer saccharinum*) and reduced the diversity of forest communities. As a result of vegetation changes,

Table 8. Geomorphological response of Upper Mississippi River to construction of dikes and locks and dams (from Chen and Simons 1986).

Features	**River response**	
	Construction of dikes	**Construction of locks and dams**
Stage	Not significantly changed	Low stage was raised to the minimum pool levels for navigation
Discharges	Not significantly changed	Not significantly changed
River position	Not appreciably changed	Not appreciably changed
River surface area	Reduced	Increased above lock and dam (floodplain) and decreased further upstream (islands)
Island area	Increased	Decreased above lock and dam and increased further upstream
Surface width	Reduced	Similar to river surface area change
Number of islands	Increased	Increased
River-bed elevation	Low-flow degradation	Degradation immediately below lock and dam and aggradation immediately above
Velocity	Increased at low flow and about the same at high flow	Decreased at low flow and about the same at high flow
Flood plain and backwater	Sediment deposition	Sediment deposition

habitat suitability and food availability for many fishes, waterfowl and other birds, and mammals was reduced (Fremling 2005 in Johnson et al. 2010). (Silver maple, however, is not regenerating well in MISS; see section 4.4.1).

The USACE, which has responsibility for supporting inland navigation through maintenance of the channel and locks and dams, has worked with partners to develop Environmental Pool plans for the water level management of pools 1-10 of the Mississippi River (USACE 2004b). These plans incorporated nine goals previously identified for the river by the Upper Mississippi River Conservation Commission (UMRCC 2000), which were 1) improve water quality; 2) reduce erosion, sediment, and nutrient impacts; 3) return of natural floodplain to enable more habitat diversity; 4) emulate seasonal flood pulse and periodic low flow conditions; 5) restore backwater/main channel connectivity; 6) manage sediment transport, deposition, and side channels; 7) manage dredging and channel maintenance; 8) sever pathways for exotic species; and 9) provide opportunities for native fish passage at the dams.

Unnaturally high summertime water levels produced by management for navigation limit the ability of annual moist soil plants to germinate, grow, and mature (Busse et al. 1995 in Dugger and Feddersen 2009) and may affect the habitat quality for migratory waterfowl (Dugger and Feddersen 2009). To study these and other ecological effects, poolwide drawdowns have been conducted in pools 5, 8, 24, 25, and 26 (Johnson et al. 2010); these authors summarized the drawdown effects on ecological components in Table 9.

In summary, consistent benefits were mainly seen in increased abundance of aquatic vegetation. The most substantial negative ecological effect was direct mortality of native mussels. The ecological processes modified included hydrodynamics, sediment chemistry changes, plant germination, and plant growth. Diversity of habitats and biota was promoted. The authors cautioned that the experiments were relatively short-term, and longer-term outcomes and interactions remain uncertain. A similar drawdown to restore habitat for migratory waterfowl has been proposed for Pool 3 in MISS (NPS 2014).

4.2.1 *Mean Annual Flow, Peak Flow, and Baseflow*

Description

The natural regimes of seasonal and annual changes in flow and water elevation are important to the physical and biological condition of river ecosystems. Changes in flow affect transport of materials, water depths, total amount of aquatic area, access to floodplains, current velocity, scouring, and water retention time, which in turn affect ecological processes and abundance of biota. Positive effects of high flows include physical habitat creation, insertion of new coarse woody debris, and movement of coarse woody debris (Parsons et al. 2005). Low flow benefits include those mentioned for summer drawdowns in Table 9.

As described in the State of the River Report (Russell and Weller 2012), both high and low flows create risks to the Mississippi River ecosystem. High flows can increase erosion, flooding, and habitat degradation and can carry more pollutants into the river. However, higher flows can also dilute pollutant concentrations. Low flows can contribute to increases in algae populations, which harm other aquatic life and recreational activities.

Table 9. Ecological effects of summertime pool drawdowns in Pools 5, 8, 24, 25, and 26 (Johnson et al. 2010).

Ecological Component	Effect of Summertime Pool Drawdown
Aquatic vegetation	consistent increase directly related to duration of exposure
Fish	no negative effects documented on abundance or diversity
Native mussels	mortality observed but not quantified in Pools 5 and 8
Water quality	exposed sediments with high organic matter content became more consolidated; increased dissolved oxygen but greater diurnal fluctuations; changes in nitrogen transformations but no net reduction in sediment; no changes in overall mean levels of dissolved oxygen, nutrients, turbidity, total suspended solids, or chlorophyll *a* were observed during the drawdown or one year after
Invertebrates	in Pool 25, the abundances of macroinvertebrates and zooplankton were higher in areas with vegetation resulting from the drawdown
Birds	shorebird use increased in exposed areas; waterfowl made greater use of areas where aquatic vegetation had increased; generally improved habitat for migrating waterfowl
Navigation and dredging	minimal effects on commercial and recreational navigation, due mainly to advanced dredging and increases in pool elevation to maintain recreational access when flows were low; dredging needs dropped for two years but increased in the third year
Hydrodynamics	percentage of flow conveyed by the main channel increased due to reduced flow in side channels; water level reduction and its effects were most pronounced in the lower portion of the pool
Water level variability	maximum drawdown could not be continuously maintained due to variation in flows, and in some locations within pools there was no water level reduction during large portions of the summer

Methods and Data

Raw data for Mississippi and Minnesota River flows and some tributary flows are available at the USGS WaterWatch website (http://waterwatch.usgs.gov/index.php). However, we did not conduct original data analyses because of the quantity and quality of reports available.

River flow is characterized over time periods varying from instantaneous to annual and beyond, depending on the purpose of the information. For example, the USACE, tasked with regulating navigation and assessing flood potential in the UMR basin, has analyzed linear trends in annual flood flows (Olsen and Stakhiv 2000). The USGS Upper Midwest Environmental Sciences Center (UMESC) tracks the status and trends of natural resources in the basin and has assessed trends in mean annual discharge and the seasonal cycle of water elevations (Johnson and Hagerty 2008).

The USACE conducted a flow frequency study for the UMR in 2004 (USACE 2004a). Lafrancois et al. (2013) conducted a trend analysis of Mississippi and Minnesota River flow data from 1976-2005. MPCA (2012) reported on trends in Minnesota River flow as part of the determination of the Total Maximum Daily Load (TMDL) for total suspended solids in the South Metro Mississippi River.

Reference Condition

Our chosen reference condition is the historic flow regime for the Mississippi River before the dredging and alterations that began in 1866. This is a "historic condition" (Stoddard et al. 2006).

Condition and Trend

We rank the condition of MISS for mean annual discharge as of moderate concern, with a deteriorating trend. This ranking is based on observed increases in flow in the Mississippi River since 1950 and the Minnesota River since 1976 and has a high degree of confidence.

The dams on the UMR were built mainly to facilitate commercial navigation and have little storage capacity (Johnson and Hagerty 2008). Neither they, nor the dikes along the river, have a significant effect on total discharge (Chen and Simons 1986). The USACE (2004a) modeled the effect of the Mississippi River Headwaters reservoirs and a flood control project in the headwaters of the Minnesota River basin at Lac Qui Parle. The authors found "very little difference" between regulated and simulated unregulated flood peaks at St. Paul from 1949-1995. Thus, no change in mean annual flow or flood peaks has been attributed to the human modifications of the river.

However, in modern times, numerous researchers have reported increasing flow in the UMR or its tributaries. McCabe and Wolock (2002) examined annual minimum, median, and maximum daily streamflow for 400 sites in the conterminous US from 1941-1999. In the eastern US, a step change in annual minimum and median daily streamflow occurred around 1970, coinciding with an increase in precipitation. Similarly, the Upper Impounded Reach of the UMR, which includes MISS, experienced a higher mean and range of annual discharges from 1970-1992 than from 1950-1969 and from 1993-2004 than from 1970-1992 (Johnson and Hagerty 2008). The authors documented this step increase for the station at Winona, MN, 110 km from the southern boundary of MISS (Figure 9). Lafrancois et al. (2013) reported increases in annual median flow of 17% and 20% for two Mississippi River sites in MISS above the Minnesota River confluence and 25-27% for four sites below the confluence.

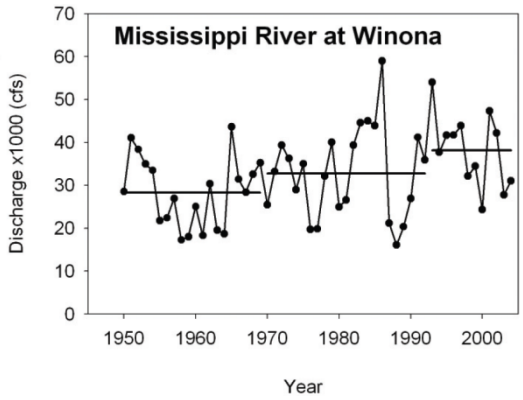


Figure 9. Step increases in mean annual discharge at Winona, MN (graphic from Johnson and Hagerty 2008).

The MPCA (2012) reported that summer (June-September) median flows in the Minnesota River at Jordan, MN have more than doubled, from 86.6 m^3 sec^{-1} from 1937-1977 to 173.8 m^3 sec^{-1} from 1978-2007. River flow as a percentage of rainfall has also more than doubled, increasing from 7% to 20%. Similarly, Lafrancois et al. (2013) reported a 44% increase in annual median flow in the Minnesota River over the period of record from 1976-2005.

Explanations for the increases in flow vary. Novotny and Stefan (2007) found a high correlation between precipitation and flow statistics for Minnesota streams. The authors observed that the Mississippi and Minnesota Rivers were experiencing higher peak flows

associated with rainfall, greater numbers of days of high flows, and increasing baseflows in both summer and winter. Johnson and Hagerty (2008) also attributed the step changes they observed to increases in precipitation. However, Zhang and Schilling (2006) attributed increases in baseflow in the Upper Mississippi River basin since the 1940s to the conversion of perennial vegetation to seasonal row crops, especially soybeans, by reducing evapotranspiration and increasing groundwater recharge. Schottler et al. (2013) found that on average, more than half the change in 21 Minnesota watersheds in the UMR basin was attributable to agricultural drainage, especially through reduction in evapotranspiration losses from depressional areas.

Flow measurements at other volume and time scales have also shown increasing trends. Olsen and Stakhiv (2000) found statistically significant increases in annual flood flows over the period of record for St. Paul, MN (129 years), Jordan, MN (Minnesota River, 63 years), and St. Croix Falls, WI (St. Croix River, 86 years). The State of the River report (Russell and Weller 2012) further states that since the early 20th century, winter and summer low flows, peak flows due to rainfall, and the number of days with high or extreme flow have also increased.

4.2.2 ***Seasonal and Inter-annual Flow Variation***

Description

Plants and animals that live in rivers or on floodplains are adapted to a natural regime of relatively predictable seasonal and annual changes in flow and water elevation. Junk et al. (1989) developed a theory that flood pulses are “the principal driving force responsible for the existence, productivity, and interactions of the major biota in river-floodplain systems.”

The natural hydroperiod of the UMR is characterized by a summer low, but the dams have caused it to be often inverted, with low pool elevations in spring and higher pool levels in summer (Dugger and Feddersen 2009). Changes in the seasonal cycle, including timing of peaks or increases or decreases in ranges of elevations, can affect a variety of ecological functions. These include access to floodplains, timing of reproduction by numerous species in diverse groups, drying of soils, seed germination, and production of plants as food for migrating waterfowl (Rood et al. 2003, Johnson and Hagerty 2008, De Jager et al. 2012).

Though a degree of predictability is required for many ecological processes to function at their maximum, all free-flowing rivers, as well as many impounded ones, show substantial variation at three or more time scales (seasonal, annual, decadal) (Junk et al. 1989, Rood et al. 2003). This variability may be as important as the regularity for some functions.

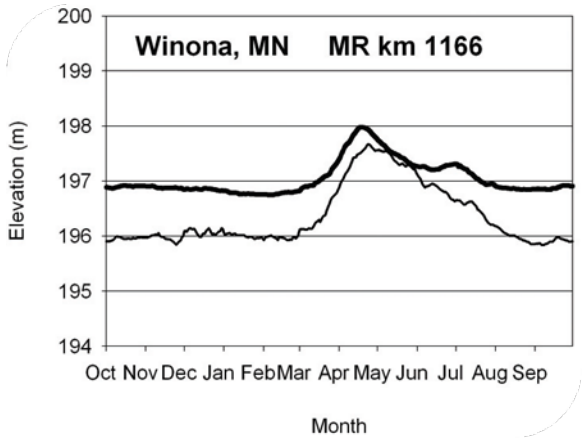


Figure 10. Average annual hydrograph before (thin line) and after (thick line) dam construction, Winona, MN (graphic from Johnson and Hagerty 2008.

Inter-seasonal Variation

At Winona, MN (110 km downstream of MISS), the predam period of 1888-1903 and 1928-1929 was compared to the postdam period of 1940-2004 to determine the effect of dams on seasonal flow (Johnson and Hagerty 2008) (Figure 10). The effect has been to raise water levels by up to

1 m, and to increase low flows for approximately half the year (August to January), but to have little effect on peak flows in spring.

Inter-annual Variation
Novotny and Stefan (2007) observed that streamflow trends in Minnesota exhibit periodicity, and that this is partially linked to precipitation patterns. For some perennial plants, one year or a few years with below-average flow can be essential for new plant establishment (Richter and Richter 2000, Rood et al. 2003).

The Upper Impounded Reach of the UMR, which includes MISS, experienced a greater degree of variation in annual discharges after 1980 than before (Figure 9).

The State of the River Report (Russell and Weller 2012) states that since the early 20th century, the number of days with high or extreme flow have increased, producing wider swings in water level among seasons and years.

Reference Condition
Our chosen reference condition is the historic flow regime for the Mississippi River before the dredging and alterations that began in 1866. This is a "historic condition" (Stoddard et al. 2006).

Condition and Trend
We rank the condition of MISS for seasonal and annual variation as a moderate concern, with a deteriorating trend. This ranking is based on observed changes in the Mississippi River since 1888 and has a high degree of confidence.

4.2.3 ***Flood Duration***

Description
The length of time, within a specific season, that there is standing water or the soils remain completely saturated has a number of important ecological consequences. This dimension of the hydrology of a system is connected to the magnitude of peak flows and seasonality, but can have independent effects (Baker and Wiley 2009). There is a strong link between geomorphology of the floodplain and flood duration, and soil properties play a dominant role in the length of saturation. Hence, a flood of a given intensity can translate into different lengths of inundation due to channel morphology and due to the magnitude of macro- and micro-topography in the floodplain. These linkages can be severed or altered along rivers with dams and levees (Gergel et al. 2002).

It has been noted by numerous authors that obvious effects such as tree mortality, seed dispersal, seed germination, and plant establishment are influenced by flood duration (Cosgriff et al. 1999, Rood et al. 2003, Baker and Wiley 2009, Lenhart et al. 2013); but it has also been documented that key, but often-overlooked processes [e.g., decomposition – Molles et al. 1998) and abundance and composition of groups such as invertebrates (Molles et al. 1998) are also immediately affected.

A key study highlighting several important relationships involving flood duration was conducted in the UMR floodplain (De Jager et al. 2012). These authors examined a hydrologic gradient, based on flood duration, for a 320 km stretch of the UMR. They found that the proportion of fine-textured soil particles, percent organic matter in the soil, overstory diversity, and understory

diversity exhibited trends as flood duration increased from 0% to 40% of the growing season. Several attributes of the system were consistently low at or above 40% flood duration, and the authors suggested 40% may represent a threshold for the system. These associations reflect the flood regime of the recent past, and not a 'natural' regime; nonetheless, they highlight the potential importance of this flood regime component for MISS.

Reference Condition

Our chosen reference condition is the historic flood duration regime for the Mississippi River before the dredging and alterations that began in 1866. This is a "historic condition" (Stoddard et al. 2006).

Condition and Trend

Our understanding of the changes in the flood regime is insufficient to determine a condition or trend for this parameter.

Sources of Expertise

Lafrancois et al. (2013); Christine Mechenich, Dave Mechenich, James Cook, UWSP.

Literature Cited

Anfinson, J. O., T. Madigan, D. M. Forsberg, and P. Nunnally. 2003. River of history: a historic resources study of the Mississippi National River and Recreation Area. United States Army Corps of Engineers. St. Paul District, St. Paul, Minnesota. Available at http://www.nps.gov/miss/historyculture/historic_resources.htm. (accessed June 10, 2013).

Baker, M. E., and M. J. Wiley. 2009. Multiscale control of flooding and riparian-forest composition in Lower Michigan, USA. *Ecology* 90:145–159.

Busse, D., K. Dalrymple, and C. N. Strauser. 1995. Environmental Pool Management. Pages 55-65 *in* Proceedings of the Fifty-first Annual Meeting of the Upper Mississippi River Conservation Committee. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Chen, Y., and D. Simons. 1986. Hydrology, hydraulics, and geomorphology of the Upper Mississippi River system. *Hydrobiologia* 136:5–19.

Cosgriff, R. J., J. C. Nelson, and Y. Yin. 1999. Forest response to high duration and intensity flooding along Pool 26 of the Upper Mississippi River. LTRMP Project Status Report 99-01. USGS Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. Available at http://www.umesc.usgs.gov/reports_publications/psrs/psr_1999_01.html. (accessed September 10, 2013).

De Jager, N. R., M. Thomsen, and Y. Tin. 2012. Threshold effects on flood duration on the vegetation and soil of the Upper Mississippi River floodplain, USA. *Forest Ecology and Management* 270:135–146.

Dugger, B. D., and J. C. Feddersen. 2009. Using river flow management to improve wetland habitat quality for waterfowl on the Mississippi River, USA. *Wildfowl* 59:62–74.

Fremling, C. R. 2005. Immortal River: The Upper Mississippi in Ancient and Modern Times. University of Wisconsin Press, Madison, Wisconsin.

Gergel, S. E., M. D. Dixon, and M. G. Turner. 2002. Consequences of human-altered floods: Levees, floods, and floodplain forests along the Wisconsin River. *Ecological Applications* 12:1755–1770.

Johnson, B. L., and K. H. Hagerty, editors. 2008. Status and trends of selected resources the Upper Mississippi River System. Technical Report LTRMP 2008-T002. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. Available at http://pubs.usgs.gov/mis/LTRMP2008-T002/pdf/LTRMP2008-T002_web.pdf. (accessed November 4, 2013).

Johnson, B. L., J. W. Barko, S. M. Bartell, R. Clevenstine, M. Davis, D. L. Galat, K. S. Lubinski, and J. M. Nestler. 2010. An adaptive management approach for summer water level reductions on the Upper Mississippi River System. Report to U.S. Army Corps of Engineers, Rock Island District, Rock Island, Illinois. Available at http://www2.mvr.usace.army.mil/UMRS/NESP/Documents/Water%20Level%20Management%20Report_Final%2028Oct2010.pdf. (accessed March 28, 2014).

Junk, W. L., P. B. Bayley and R. E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Pages 110–127 *in* D. P. Dodge, editor. Proceedings of the International Large River Symposium, Canadian Special Publication of Fisheries and Aquatic Sciences, volume 106. Honey Harbour, Ontario, Canada, September 14-21, 1986.

Lafrancois, B. M., S. Magdalene, D. K. Johnson, D. VanderMeulen, and D. Engstrom. 2013. Water quality conditions and trends in the Mississippi National River and Recreational Area: 1976-2005. Natural Resource Technical Report NPS/GLKN/NRTR—2013/691. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2193312. (accessed November 11, 2013).

Lenhart, C. F., M. L. Titov, J. S. Ulrich, J. L. Nieber, and B. J. Suppes. 2013. The role of hydrologic alternation and riparian vegetation dynamics in channel evolution along the Lower Minnesota River. *Transactions of the American Society of Agricultural and Biological Engineers* 56:549–561.

McCabe, G. J., and D. M. Wolock. 2002. A step increase in streamflow in the conterminous United States. *Geophysical Research Letters* 29:38.1–38.4.

Molles, M. C., C. S. Crawford, L. M. Ellis, H. M. Valett, and C. N. Dahm. 1998. Managed flooding for riparian ecosystem restoration. *BioScience* 48:749–756.

MPCA (Minnesota Pollution Control Agency). 2012. Minnesota River turbidity total maximum daily load: draft report. Report wq-iw7-32b. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=17108. (accessed November 11, 2013).

Novotny, E. V., and H. G. Stefan. 2007. Stream flow in Minnesota: indicator of climate change. *Journal of Hydrology* 334:319–333.

NPS (National Park Service). 2014. MNNRA foundation document (draft). Mississippi National River and Recreation Area, St. Paul, Minnesota.

Olsen, J. R., and E. Z. Stakhiv. 2000. Flood hydroclimatology in the Upper Mississippi and Missouri River Basins: final draft. USACE, Alexandria, Virginia. Available at http://www.mvr.usace.army.mil/Portals/48/docs/FRM/UpperMissFlowFreq/App. G Report 2.pdf. (accessed November 11, 2013).

Parsons, M., C. A. McLoughlin, K. A. Kotschy, K. H. Rogers, and M. W. Rountree. 2005. The effects of extreme floods on the biophysical heterogeneity of river landscapes. *Frontiers in Ecology and the Environment* 3:487–494.

Richter, B. D., and H. E. Richter. 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. *Conservation Biology* 14:1467–1478.

Rood, S. B., C. G. Gourley, E. M. Ammon, L. G. Heki, J. R. Klotz, M. L. Morrison, D. Mosley, G. G. Scoppettone, S. Swanson, and P. L. Wagner. 2003. Flows for floodplain forests: a successful riparian restoration. *BioScience* 53:647–654.

Russell, T. A., and L. Weller. 2012. State of the river report: water quality and river health in the metro Mississippi River. Friends of the Mississippi River and Mississippi National River and Recreation Area, St. Paul, Minnesota. Available at http://stateoftheriver.com/. (accessed October 29, 2013).

Schottler, S. P., J. Ulrich, P. Belmont, R. Moore, J. W. Lauer, D. R. Engstrom, and J. E. Almendinger. 2013. Twentieth century agricultural drainage creates more erosive rivers. *Hydrological Processes*:1–11 (DOI:10.1002/hyp.9738).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

UMRCC (Upper Mississippi River Conservation Commission). 2000. A river that works and a working river. UMRCC, Rock Island, Illinois. Available at http://www.umrcc.org/Publications.html. (accessed March 25, 2014).

USACE (United States Army Corps of Engineers). 2004a. Upper Mississippi River system flow frequency study: hydrology and hydraulics appendix (Appendix B). USACE St. Paul District, St. Paul, Minnesota. Available at http://www.mvp-wc.usace.army.mil/projects/profiles/AppendixB-MVP-29sep2003.pdf. (accessed November 4, 2013).

USACE (United States Army Corps of Engineers) Fish and Wildlife Work Group. 2004b. Environmental Pool Plans, Mississippi River Pools 1-10. USACE, St. Paul, Minnesota. Available at

http://www.mvp.usace.army.mil/Portals/57/docs/Navigation/River%20Resource%20Forum/EnviroPoolPlansfinal_1.pdf. (accessed April 8, 2014).

USEPA (United States Environmental Protection Agency) Science Advisory Board. 2002. A framework for assessing and reporting on ecological condition: an SAB report. EPA-SAB-EPEC-02-009. USEPA, Washington, D.C. Available at http://www.epa.gov/sab/pdf/epec02009.pdf. (accessed September 19, 2013).

Zhang, Y.-K., and K. E. Schilling. 2006. Increasing streamflow and baseflow in Mississippi River since the 1940s: effect of land use change. *Journal of Hydrology* 324:412–422.

4.3 Landscape Condition

The EPA-SAB framework defines a landscape as "a mosaic of interacting ecosystems or habitat patches" and emphasizes the potential effects of changes in patch size, number, or connectivity on both biotic and abiotic processes. The framework recommends consideration of landscape extent, composition, and pattern and structure with metrics such as perimeter to area ratio, number of habitat types, and longitudinal and lateral connectivity. It identifies managing landscapes, not just individual habitat types, as an important element in insuring the maintenance of native plant and animal diversity (USEPA 2002). Topics considered in this NRCA under Landscape Condition are land cover, historic floodplain changes, impervious surfaces, landscape pattern and structure, road density, lightscapes, and soundscapes. Our primary source of data and methodology is the NPS NPScape landscape dynamics monitoring program (Monahan et al. 2012), which recommends a 30 km buffer around a park as an appropriate-sized area of analysis (AOA) for understanding park condition in a landscape context.

4.3.1 Current Land Cover

Description

The GLKN has identified land use and land cover at the coarse scale as a key Vital Sign across a wide range of ecosystems (ranked 6th of 46 with a score of 3.8 out of 5) (NPS 2007). A significant portion of MISS is located in an urban setting (Figure 11), and the State of the Park report indicates that about 29% of MISS is developed and 71% is classified as natural (the latter category includes 3.5% agriculture) (MLCCS 2011 in NPS 2013). However, in the city, MISS does provide more natural land than its surroundings. The National Land Cover Database (NLCD) shows that the land within MISS is less developed than that in the two concentric 1-km rings that surround it. Within MISS, there is more forest, open water, and wetlands than in rings that begin at the park boundary and extend 1 km outward, or begin at 1 km and extend to 2 km outward (Table 10).Within the broader 30-km AOA, agriculture is the predominant land cover type and is particularly concentrated in the southern third of the AOA. This has consequences for water quality and water flow that will be discussed later.

Table 10. Level 1 NLCD land cover categories for Mississippi National River and Recreation Area and surroundings (USGS 2011).

Level 1 NLCD 2006 Category	MISS	MISS Boundary to 1 km	1 km to 2 km from MISS	MISS 30-km AOA
Open Water	26.1%	13.5%	2.7%	5.6%
Developed	29.0%	48.5%	65.2%	26.9%
Barren	1.3%	0.6%	0.0%	0.1%
Forest	16.9%	12.2%	8.3%	17.3%
Shrub/Scrub	1.6%	1.0%	0.5%	1.0%
Grassland/Herbaceous	1.2%	1.2%	1.2%	3.6%
Agriculture	8.1%	13.9%	18.9%	39.0%
Wetland	15.9%	9.1%	3.2%	6.5%

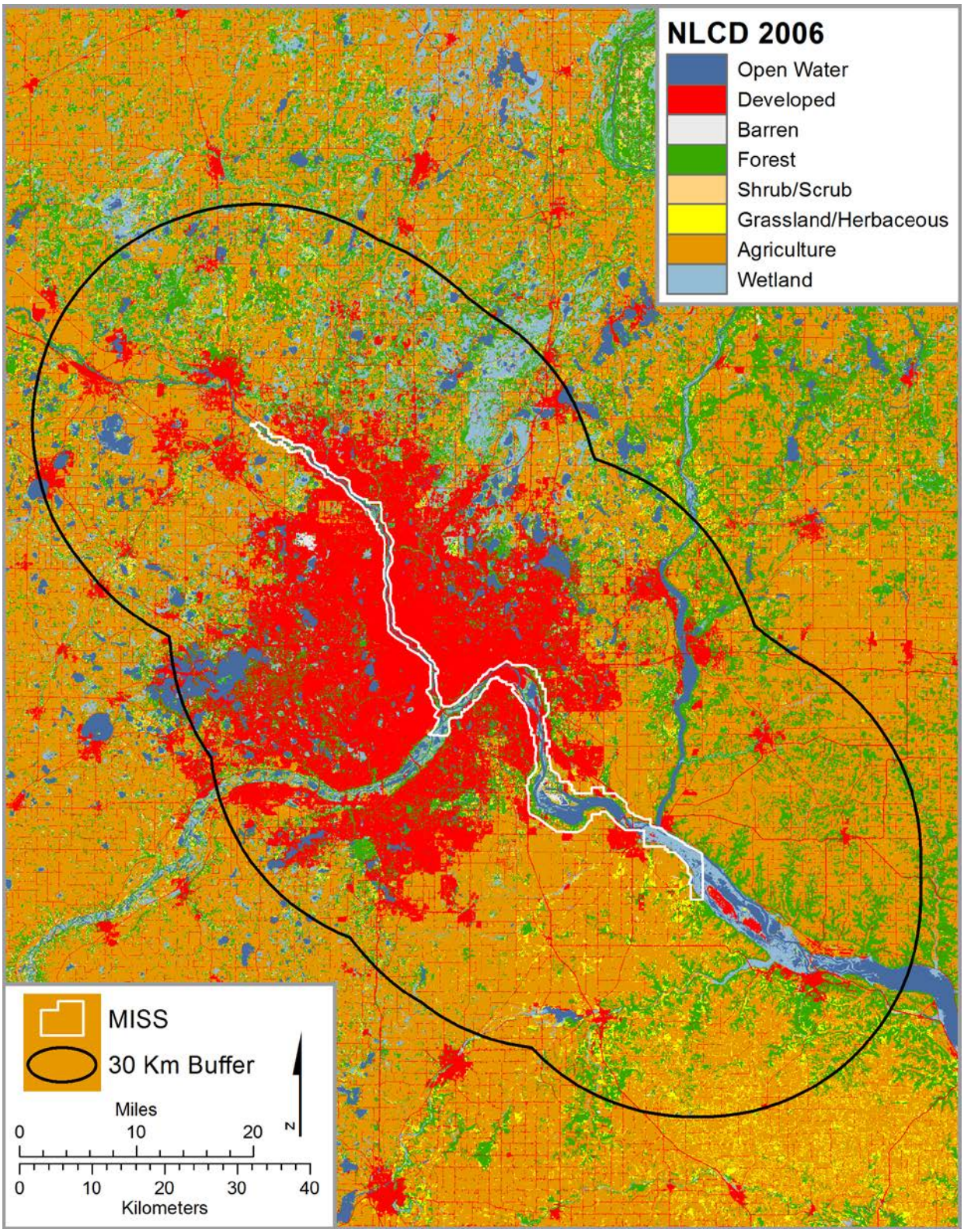


Figure 11. Level 1 NLCD land cover categories for Mississippi National River and Recreation Area and surroundings (USGS 2011).

When open water is excluded, the most common land cover types in MISS are low to high intensity developed land (31.3%), forest (22.8%), and wetland (21.6%) (Table 11). Within the major watersheds that include parts of MISS, the dominant land cover types are agriculture (Mississippi Headwaters, 37.1%; Minnesota River, 80.2%; and Upper Mississippi, 62.0%) and forest (Mississippi Headwaters, 31.5% and St. Croix River, 45.6%) (see Figure 8 for location of these watersheds).

Data and Methods

Land cover data were obtained from the NLCD 2006 (USGS 2011). Change data were obtained from this source and also from Kirschbaum and Gafvert (2013), in which disturbances in and around MISS were delineated for six years (2005-2010) using a combination of Landsat satellite imagery and high resolution aerial photos. Computer algorithms collectively known as LandTrendr were used with Landsat imagery to identify apparent disturbances, which were verified by examination of air photos, to track vegetation changes in and around the park. Kirschbaum and Gafvert (2013) divided their results into MISS (those within the MISS administrative boundary, 12%) and non-MISS (a 300 m buffer around the park and two subwatersheds, 88%). For each validated disturbance, the authors identified the agent of change (fire, forest harvest, agricultural use, development, and blowdowns), the year of occurrence, and the starting and ending vegetation classes.

Reference Condition

Our chosen reference condition for land cover is its stability over five to ten year time frames. Stability should be viewed as the capacity of the landscape to endure chronic stressors and low severity disturbances without undergoing a significant change. No absolute value was found for an "acceptable" rate of land cover change; therefore, a reference condition that compares MISS to a larger, regional land base and to other areas of similar land use has been chosen. The annual land cover change in MISS should not exceed that experienced on lands in the nearby lower Lake Superior basin (0.32% yr^{-1} from 2000-2008) (Stueve et al. 2011) or by other NPS units in the GLKN (<0.1%-0.36% % yr^{-1} from 2002-2010) (Kirschbaum and Gafvert 2013). This represents a "least disturbed condition" or the "best of today's existing conditions" (Stoddard et al. 2006).

Condition and Trend

The rate of land cover change in MISS from 2005-2010 did not exceed that of the lower Lake Superior basin or of other NPS units in the region; thus, we rate the status of MISS for land cover change as good, with a short-term stable trend. This is supported by the analyses of De Jager et al. (2013) who found no statistically significant change in land cover from 1975-2000 for 37% of the UMR floodplain. Our confidence in this assessment is moderate.

At a broad scale, 98-99% of land cover in the MISS vicinity and 30 km AOA was unchanged from 2001-2006, as determined by comparing NLCD statistics (Table 12). The rate of change was 0.26-0.44% yr^{-1}, meeting the reference condition of 0.32% yr^{-1} at MISS but not in its surrounding area or AOA. It should be noted that this level of stability is not expected for long periods (i.e., many decades), due to the infrequent but natural occurrence of moderate to severe natural disturbances.

Table 11. Number of hectares and percent of land in 2006 NLCD land cover classes (excluding open water) (USGS 2011).

Level 1 NLCD2006 Category	MISS	1 km Ring	30 km Buffer	Mississippi Headwaters	Minnesota River	St. Croix River	Upper Mississippi	Watershed Total
2 Developed-Open Space	1,267	2,353	70,200	195,502	213,058	74,217	6,390	489,167
2 Developed-Low to High Intensity	5,041	14,314	177,251	169,737	84,673	29,359	11,698	295,467
3 Barren	287	2	1,034	5,912	4,633	271	111	10,927
4 Forest	3,673	2,111	159,758	1,501,930	123,860	875,839	8,498	2,510,126
5 Shrub/Scrub	343	124	8,869	133,443	11,178	55,589	724	200,933
7 Grassland/Herbaceous	265	304	33,322	118,685	192,199	38,544	4,170	353,598
8 Agriculture	1,757	4,841	359,742	1,772,655	3,422,325	488,809	56,540	5,740,329
9 Wetland	3,473	817	59,916	877,437	217,331	357,137	3,004	1,454,909
Total:	16,107	24,866	870,093	4,775,301	4,269,256	1,919,764	91,136	11,055,457
Level1 NLCD2006 Category	**MISS**	**1 km Ring**	**30 km Buffer**	**Mississippi Headwaters**	**Minnesota River**	**St. Croix River**	**Upper Mississippi**	**Watershed Total**
2 Developed-Open Space	7.9%	9.5%	8.1%	4.1%	5.0%	3.9%	7.0%	4.4%
2 Developed-Low to High Intensity	31.3%	57.6%	20.4%	3.6%	2.0%	1.5%	12.8%	2.7%
3 Barren	1.8%	0.0%	0.1%	0.1%	0.1%	0.0%	0.1%	0.1%
4 Forest	22.8%	8.5%	18.4%	31.5%	2.9%	45.6%	9.3%	22.7%
5 Shrub/Scrub	2.1%	0.5%	1.0%	2.8%	0.3%	2.9%	0.8%	1.8%
7 Grassland/Herbaceous	1.6%	1.2%	3.8%	2.5%	4.5%	2.0%	4.6%	3.2%
8 Agriculture	10.9%	19.5%	41.3%	37.1%	80.2%	25.5%	62.0%	51.9%
9 Wetland	21.6%	3.3%	6.9%	18.4%	5.1%	18.6%	3.3%	13.2%
Total:	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 12. Land cover changes in the National Land Cover database in the vicinity of Mississippi National River and Recreation Area, 2001-2006 (USGS 2011).

Change Category NLCD 2001 to 2006	MISS	MISS Boundary to 1 km	1 km to 2 km from MISS	MISS 30 km AOA
No Change	98.7%	98.2%	97.8%	97.8%
Natural to Natural	0.4%	0.2%	<0.0%	0.2%
Converted to Natural	0.1%	0.1%	0.1%	0.2%
Natural to Agriculture	0.1%	0.1%	0.1%	<0.1%
Natural to Developed	0.4%	0.5%	0.7%	0.5%
Agriculture to Developed	0.2%	0.7%	1.1%	1.2%
Converted to Converted	0.1%	0.2%	0.3%	0.1%
% change per year, 2001-2006	0.26	0.36	0.44	0.44

For 2005-2010, using a more precise methodology, Kirschbaum and Gafvert (2013) found that the rate of change of MISS land cover was <0.01-0.11% yr^{-1}. All this change was caused by development. For the non-MISS areas (the 300-m buffer and two subwatersheds), the rate of change ranged from 0.01-0.22% yr^{-1}, again mainly due to development but with minor amounts of new agricultural disturbance and forest harvest. Of other NPS units studied in the region (Voyageurs National Park [VOYA], Apostle Islands National Lakeshore [APIS], Isle Royale National Park [ISRO], and Saint Croix National Scenic Riverway [SACN]), MISS had the third-least amount of disturbance within its administrative boundaries and the least amount of disturbance outside the park (Table 13). In part, that is because much of the land cover is already in the "permanent" condition of developed, and some is held in conservation status by various state and local entities. The authors also noted that even small amounts of change around MISS may be accompanied by increases in runoff, fertilizer inputs from lawns, and fragmentation of natural landscapes. In the study period, new development was highest in 2006 and 2007, possibly because of the economic downturn that occurred in 2008. As a corridor park, MISS is affected by the land cover changes that are made by its many neighbors.

Table 13. Disturbance in and around Mississippi National River and Recreation Area compared to other NPS units in the GLKN (Kirschbaum and Gafvert 2013 and citations therein).

NPS Unit (national park, lakeshore, or scenic riverway)	In-park area disturbed (total and yearly range)	Disturbed area in surrounding analysis area (total and yearly range)	Time period
VOYA	0.68% (0.03%-0.26%)	11.4% (0.74%-3.61%)	2002-2007
APIS	<0.1%* (0%-0.02%)	3.94% (0.33%-0.98%)	2004-2009
ISRO	<0.1% (0%-0.02%)	2.66% (0.15%-0.61%)	2003-2008
SACN	1.12% (0.04%-0.36%)	0.85% (0.11%-0.18%)	2005-2010
MISS	0.28% (0%-0.11%)	0.57% (0.01%-0.22%)	2005-2010

*a forest pathogen event which caused defoliation but not mortality was excluded

Sources of Expertise

NLCD (USGS 2011); Kirschbaum and Gafvert 2013; Christine Mechenich, Dave Mechenich, James Cook, UWSP.

Literature Cited

De Jager, N. R., J. J. Rohweder, and J. C. Nelson. 2013. Past and predicted future changes in the land cover of the Upper Mississippi River floodplain, USA. *River Research and Applications* 29:608–618.

Kirschbaum, A. A., and U. B. Gafvert. 2013. Landsat-based monitoring of landscape dynamics at Mississippi National River and Recreation Area, 2005-2010. Natural Resource Technical Report NPS/GLKN/NRTR—2013/745. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2195280. (accessed November 19, 2013).

MLCCS (Minnesota Land Cover Classification System). 2011. Website. MDNR, St. Paul, Minnesota. Available at http://www.dnr.state.mn.us/mlccs/index.html.

Monahan, W. B., J. E. Gross, L. K. Svancara, and T. Philippi. 2012. A guide to interpreting NPScape data and analyses. Natural Resource Technical Report NPS/NRSS/NRTR—2012/578. National Park Service, Fort Collins, Colorado. Available at http://science.nature.nps.gov/im/monitor/npscape/interpguide.cfm. (accessed August 5, 2013).

NPS (National Park Service). 2007. Long-term Ecological Monitoring Plan: Great Lakes Inventory and Monitoring Network. Natural Resource Report NPS/GLKN/NRR-2007/001. National Park Service. Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/645523 (accessed October 28, 2013).

NPS (National Park Service). 2013. State of the park report for Mississippi National River and Recreation Area. State of the Park Series No. 4. National Park Service, Washington, D.C. Available at http://www.nps.gov/stateoftheparks/. (accessed June 11, 2013).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

Stueve, K. M., I. W. Housman, P. L. Zimmerman, M. D. Nelson, J. B. Webb, C. H. Perry, R. A. Chastain, D. D. Gormanson, C. Huang, S. P. Healey, and W. B. Cohen. 2011. Snow-covered Landsat time series stacks improve automated disturbance mapping accuracy in forested landscapes. *Remote Sensing of Environment* 115:3203–3219.

USEPA (United States Environmental Protection Agency) Science Advisory Board. 2002. A framework for assessing and reporting on ecological condition: an SAB report. EPA-SAB-EPEC-02-009. USEPA, Washington, D.C. Available at http://www.epa.gov/sab/pdf/epec02009.pdf. (accessed August 5, 2013).

USGS (United States Geological Survey). 2011. National Land Cover Database 2006. USGS, Sioux Falls, South Dakota. Available at http://www.mrlc.gov/nlcd2006.php. (accessed November 28, 2011).

4.3.2 Floodplain Land Cover Changes – 1890s to 2000

Description

In this section, we compare land cover in the Mississippi River floodplain in MISS in the 1890s to that in the year 2000. From the late 1880s to the early 1900s, the Mississippi River was mapped by the Mississippi River Commission all the way from Minneapolis to Cairo, Illinois (De Jager et al. 2013). The charts we used for Pools 1, 2, and 3 were all created in 1895. Alterations to the Mississippi River channel by the Corps of Engineers, beginning with dredging and clearing of obstacles and progressing to the construction of wing dams and closing dams in what is now MISS began in 1866 (see details in section 4.2). Thus, we have no data for a pre-European settlement Mississippi River, but we do have data that predates the construction of locks and dams, which did not receive construction funding from Congress until 1899 (Anfinson et al. 2003).

Data and Methods

The 1890s Mississippi River Commission charts were automated by the USGS UMESC in the 1990s and made available on its website (http://www.umesc.usgs.gov/data_library/land_cover_use/1890s_lcu_mrc.html). The UMESC also created and made available high-resolution land cover/use data sets for the UMR from 1:24,000-scale color infrared aerial photos collected in 2000 at http://www.umesc.usgs.gov/data_library/land_cover_ use/2000_lcu_umesc.html. We downloaded shape files that included the areas of Pools 1, 2, and 3 and overlaid the MISS boundaries on them for reference. We divided Pools 2 and 3 into Upper and Lower pools at their midpoints. We then generated statistics giving the number of hectares in a compressed list of land cover types and the amount of the overall change in the pool section that was attributable to the change in each land use type. We used the areas of Pools 1, 2, and 3, as defined by UMESC, to discuss changes in and around MISS.

De Jager et al. (2013) determined the extent of seven common land cover types and performed a statistical analysis of land cover change on these two data sets, as well as data sets collected in 1975 and 1989. The authors' area of interest extended from Pool 3, part of which is in MISS, to the end of the UMR at the confluence of the Mississippi and Ohio rivers. They found that land cover in the UMR basin was not significantly different among 1975, 1989, or 2000, but was significantly different in the 1890s ($p < 0.001$).

Knutson and Klaas (1998) randomly chose 56 locations within the floodplain forests with canopy cover >70% in Pool 6 to Pool 10 (a distance of approximately 177 km). At each location, 3-10 sampling points were installed, and trees, shrubs, and snags were sampled. The 1840s data to which they compared their data were from Moore (1988) and consisted of trees recorded at section corners during the General Land Office Survey.

Reference Condition

There have been massive changes in land use and landscape structure of the UMR watershed since the late 1800s. De Jager et al. (2013) estimated that 8% of the floodplain was in agriculture, 1% was developed, and 43% was forested in ~1890. The difference between these numbers and those presented in Table 10 give a general indication of part of the extent of landscape pattern alteration. Knutson and Klaas (1998) compiled information from several sources and estimated that 50-70% of the UMR was forested prior to European settlement. Much of the land currently

developed or in agriculture is not going to change or revert back to natural vegetation. Thus, this precludes the establishment of a reference condition for land cover in the usual sense. The chosen reference condition for this analysis is the condition of the UMR basin ecosystem before the construction of the locks and dams; this is a historic condition (Stoddard et al. 2006).

Condition and Trend

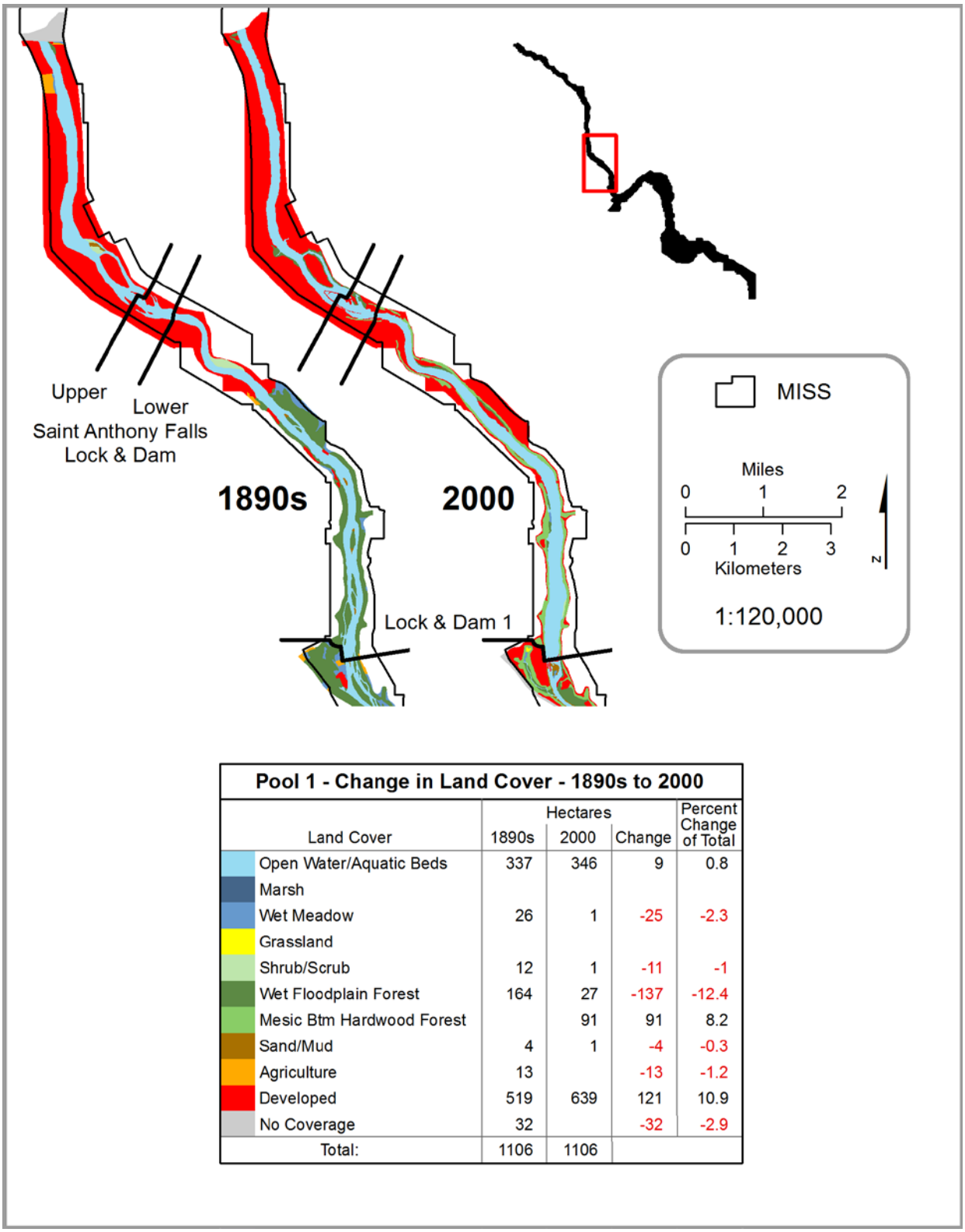
The condition of the floodplain of Pools 1, 2, and 3 is of moderate concern, with a stable trend. Our confidence in this assessment is high. Between the 1890s and 2000, 8,703 ha (41.5%) of the land cover in the floodplain changed. Losses included 3,107 ha of wet floodplain forest (-14.8% of total land cover) and ~1,100-1,500 ha (-5.2-7.3%) each of wet meadow, shrub/scrub, agriculture, and marsh (Table 14). Open water increased by 3,720 ha (17.7%), and developed area increased by 2,781 ha (13.2%).

Table 14. Land cover categories and net change from 1890s-2000 for Pools 1, 2, and 3 within and adjacent to Mississippi National River and Recreation Area.

Land Cover	1890s		2000		Change	
	ha	%	ha	%	ha	%
Decreased from 1890s to 2000						
Wet Floodplain Forest	7,256	34.6%	4,149	19.8%	-3,107	-14.8%
Wet Meadow	2,483	11.8%	946	4.5%	-1,537	-7.3%
Shrub/Scrub	1,561	7.4%	46	0.2%	-1,516	-7.2%
Agriculture	2,526	12.0%	1,093	5.2%	-1,433	-6.8%
Marsh	2,215	10.6%	1,117	5.3%	-1,097	-5.2%
Sand/Mud	89	0.4%	76	0.4%	-14	-0.1%
Increased from 1890s to 2000						
Open Water/Aquatic Beds	3,873	18.5%	7,594	36.2%	3,720	17.7%
Developed	822	3.9%	3,603	17.2%	2,781	13.2%
Grassland		0.0%	792	3.8%	792	3.8%
Mesic Bottomland Hardwood Forest		0.0%	804	3.8%	804	3.8%
No Coverage	164	0.8%	771	3.7%	606	2.9%
Total:	20,989		20,989			

We conducted further analysis for MISS by individual pools. In the UMESC coverage, Pool 1 includes the area impounded by Lock and Dam 1 and extends 6.0 km above Upper St. Anthony Falls (Figure 12). Within this mapped area, 20.9% of the land cover in the floodplain changed from the 1890s to 2000. Wet floodplain forest decreased by 137 ha (-12.4% of total land cover), while mesic bottomland hardwood forest increased by 91 ha (8.2%). Developed land, already 46.9% of the mapped area (519 ha) in the 1890s, increased 10.9% to 57.8% (639 ha) by 2000. Open water and aquatic beds increased only slightly, from 337 ha (30.5%) to 346 ha (31.3%).

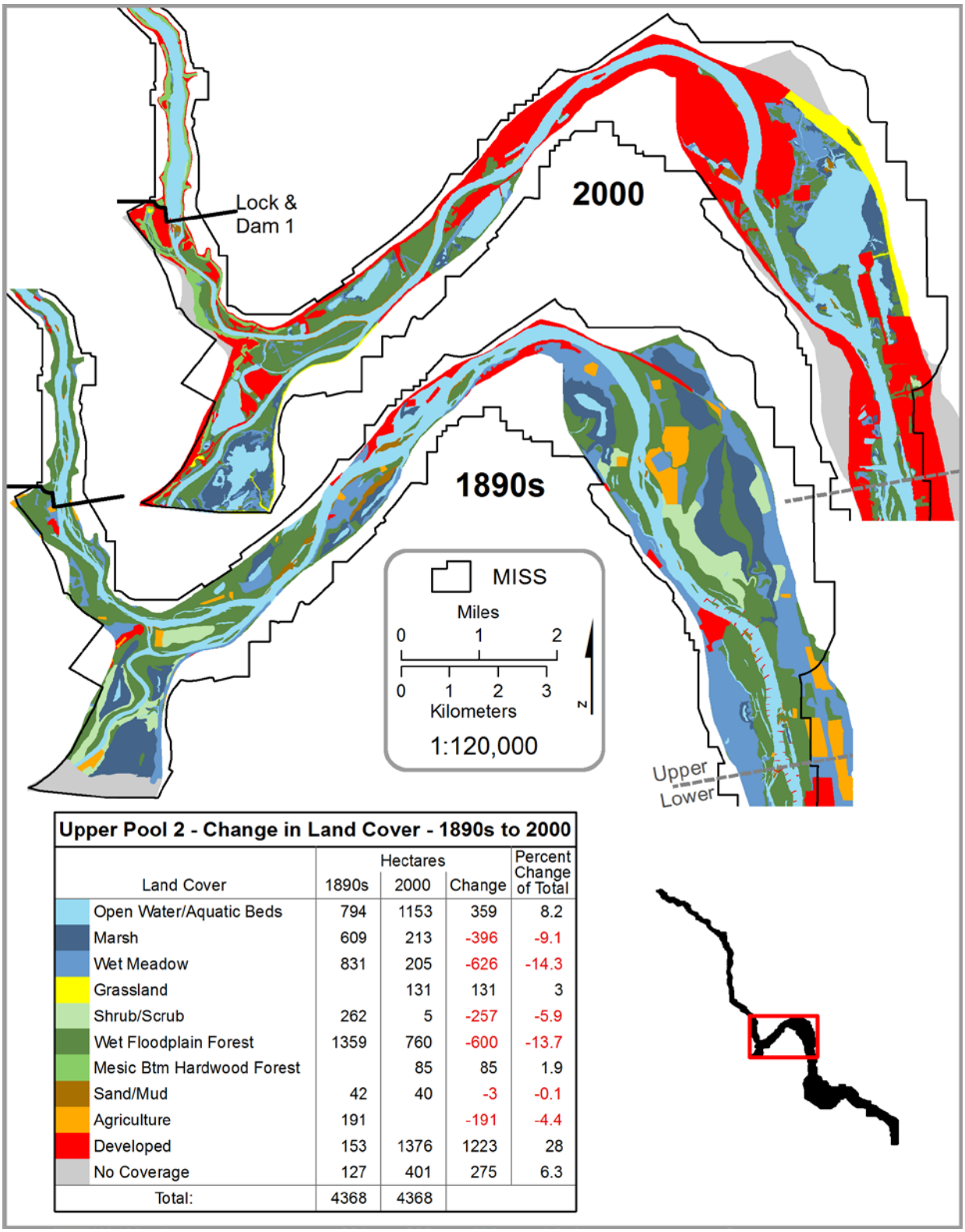
For Upper Pool 2, including the lower part of the Minnesota River, the largest category of land cover in the 1890s was wet floodplain forest at 1,359 ha (31.1%). This had decreased to 760 ha (17.4%) by 2000, resulting in a 44% loss of wet floodplain forest and a decrease of 13.7% in the total area of Upper Pool 2 covered by wet floodplain forest (Figure 13). The area of wet meadow decreased 75.3%, from 831 to 205 ha, resulting in a decrease of 14.3% in the total area of Upper



Pool 1 - Change in Land Cover - 1890s to 2000

Land Cover	Hectares 1890s	Hectares 2000	Hectares Change	Percent Change of Total
Open Water/Aquatic Beds	337	346	9	0.8
Marsh				
Wet Meadow	26	1	-25	-2.3
Grassland				
Shrub/Scrub	12	1	-11	-1
Wet Floodplain Forest	164	27	-137	-12.4
Mesic Btm Hardwood Forest		91	91	8.2
Sand/Mud	4	1	-4	-0.3
Agriculture	13		-13	-1.2
Developed	519	639	121	10.9
No Coverage	32		-32	-2.9
Total:	1106	1106		

Figure 12. Change in land cover from the 1890s-2000 for Pool 1 and the area north of St. Anthony Falls in Mississippi National River and Recreation Area.



Upper Pool 2 - Change in Land Cover - 1890s to 2000

Land Cover	Hectares 1890s	Hectares 2000	Hectares Change	Percent Change of Total
Open Water/Aquatic Beds	794	1153	359	8.2
Marsh	609	213	-396	-9.1
Wet Meadow	831	205	-626	-14.3
Grassland		131	131	3
Shrub/Scrub	262	5	-257	-5.9
Wet Floodplain Forest	1359	760	-600	-13.7
Mesic Btm Hardwood Forest		85	85	1.9
Sand/Mud	42	40	-3	-0.1
Agriculture	191		-191	-4.4
Developed	153	1376	1223	28
No Coverage	127	401	275	6.3
Total:	4368	4368		

Figure 13. Change in land cover from the 1890s-2000 for Upper Pool 2 in Mississippi National River and Recreation Area.

Pool 2 covered by wet meadow. Increases occurred in developed area, from 153 ha (3.5%) to 1,376 ha (31.5%), or a 28% increase in the total developed area of Upper Pool 2. Open water and aquatic beds increased from 794 ha (18.1%) to 1,153 ha (26.4%), increasing the total area of Upper Pool 2 covered by open water and aquatic beds by 8.2%.

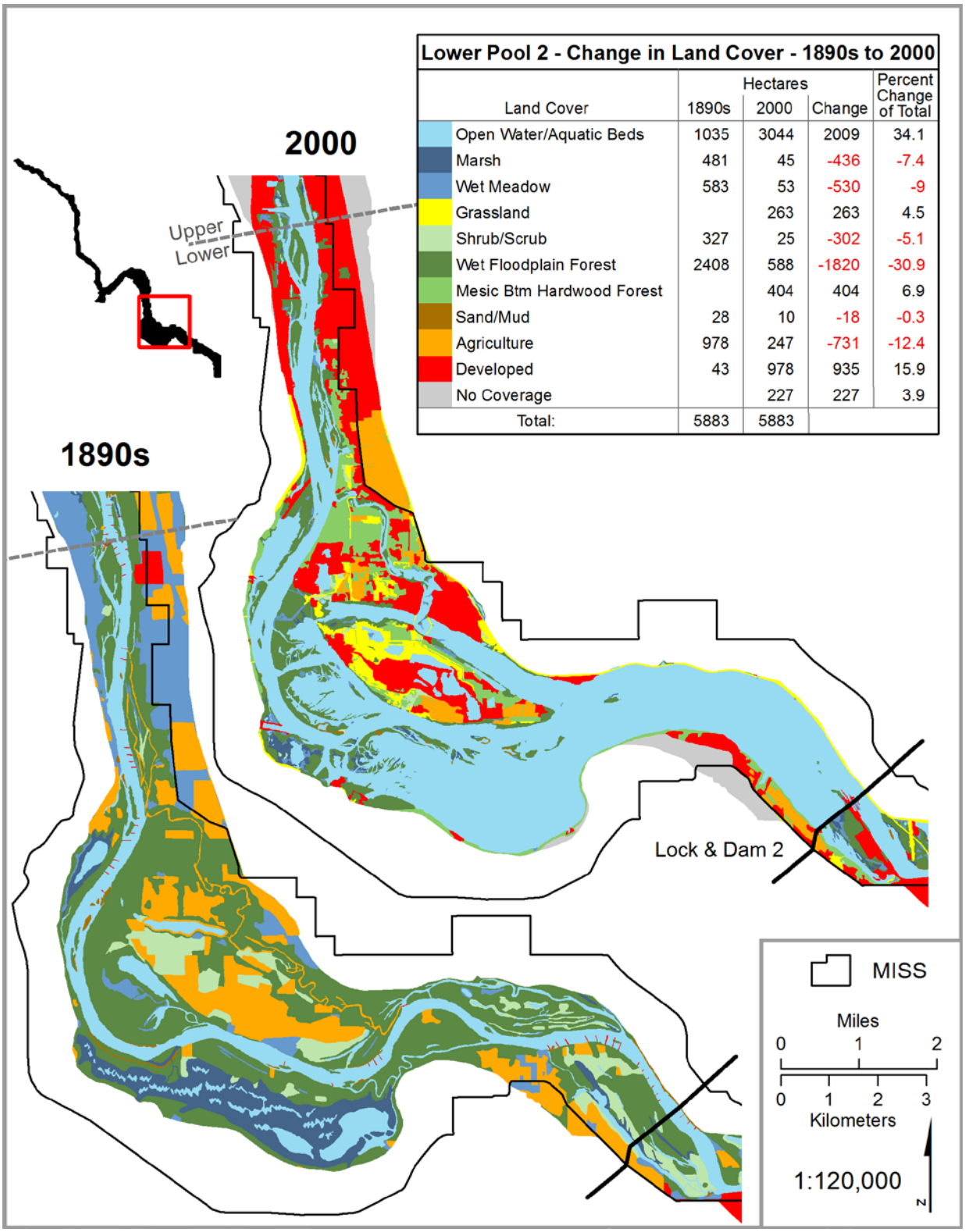
For Lower Pool 2 (that area downstream of the midpoint of Pool 2), the largest category of land cover in the 1890s was also wet floodplain forest at 2,408 ha (40.9%). This had decreased to 588 ha (10.0%) in 2000, resulting in a 75.6% loss of wet floodplain forest and a decrease of 30.9% in the total area of Lower Pool 2 covered by wet floodplain forest (Figure 14). Agriculture decreased from 978 ha (16.6%) to 247 ha (4.2%), a 12.4% decrease in the total area of Lower Pool 2 used for agriculture. Developed area increased from 0.7% to 16.6% of the total land cover of Lower Pool 2. Open water and aquatic beds increased nearly 200%, from 1,035 ha to 3,044 ha, increasing the total area of Lower Pool 2 covered by open water and aquatic beds by 34.1% (from 17.6% to 51.7%).

A more detailed look at the changes in Lower Pool 2 (Table 15) shows that of the 2,005 ha of floodplain forest that was lost between the 1890s and 2000, 60.5% became open water, 14.6% became mesic bottomland hardwood forest, and 15.2% was developed. A smaller area of floodplain forest (185.0 ha) was also gained during that time period; 30.1% from agriculture, 23.5% from wet meadow, and 14-15% each from shrub/scrub, open water, and marsh. Smaller changes may be more related to issues of mapping accuracy than actual land cover change.

Table 15. Land cover changes from floodplain forest to other cover types and to floodplain forest from other cover types in Lower Pool 2, Mississippi River, 1890s-2000.

Land Cover Change 1890s-2000	From Floodplain Forest to:		To Floodplain Forest from:	
	ha	%	ha	%
Open water	1,213.0	60.5%	27.3	14.8%
Marsh	18.7	0.9%	27.9	15.1%
Wet meadow	27.8	1.4%	43.4	23.5%
Grassland	74.6	3.7%	0.0	0.0%
Shrub/scrub	7.1	0.4%	25.4	13.7%
Mesic bottomland hardwood forest	293.4	14.6%	0.0	0.0%
Sand/mud	6.4	0.3%	4.1	2.2%
Agriculture	18.8	0.9%	55.8	30.1%
Developed	305.4	15.2%	1.1	0.6%
No coverage	39.9	2.0%	0.0	0.0%
	2,005.3	100.0%	185.0	100.0%

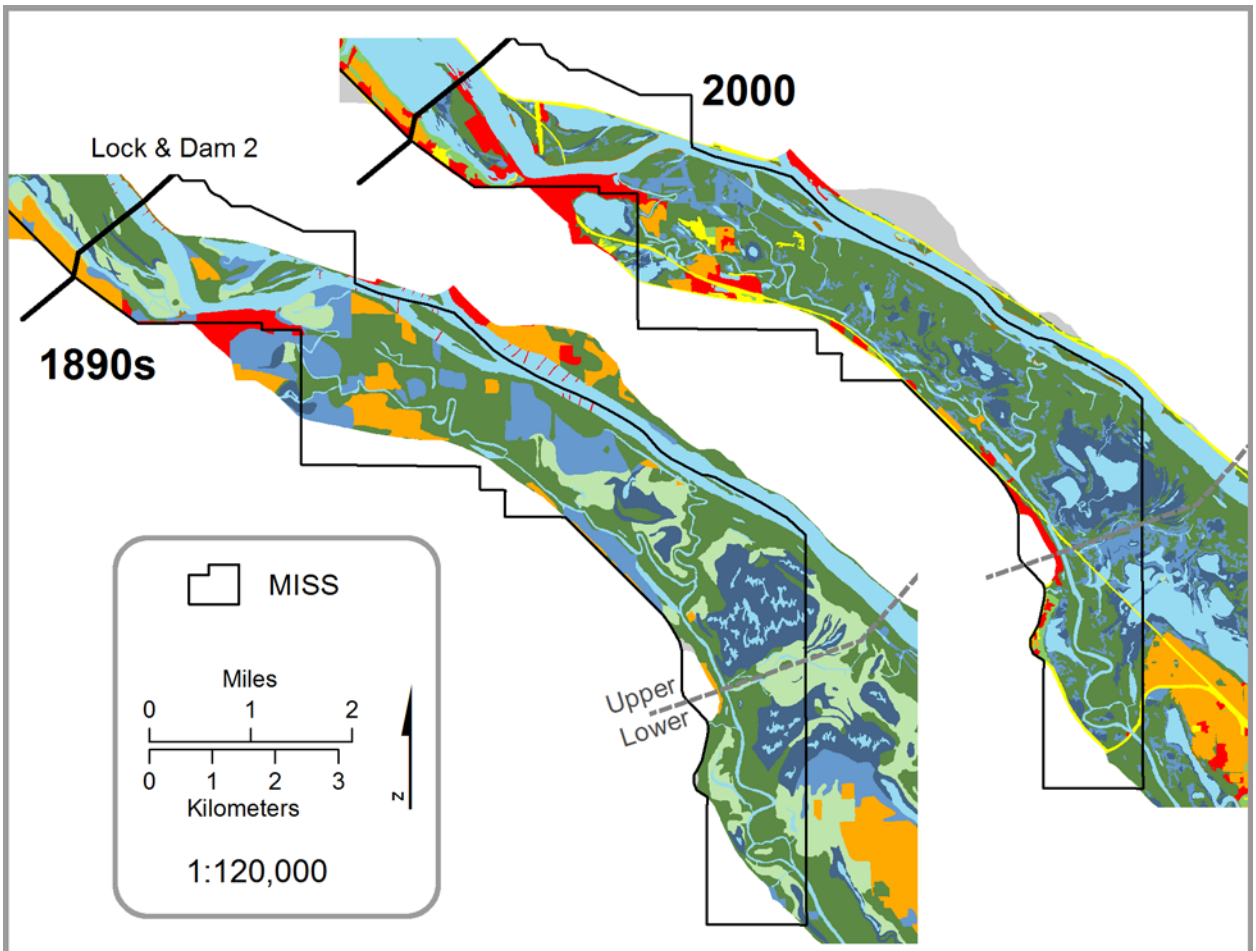
Like Pool 2, the largest category of land cover in Upper Pool 3 in the 1890s was wet floodplain forest (1,034 ha, 34.2%). This had increased to 1,144 ha by 2000, a 10.6% increase that resulted in an increase of 3.6% in the total area of Upper Pool 3 covered by wet floodplain forest (Figure 15). Development covered 3.7% more of the total mapped area of Upper Pool 3 in 2000. Grasslands, not noted in the 1890s maps, covered 4.7% more area, and open water and aquatic beds covered 3.6% more area in 2000 than in the 1890s. Land cover losses in Upper Pool 3 included shrub/scrub, covering 10.1% less of the total area, as well as agriculture and wet meadow (covering 5.8% and 4.4% less of the total area, respectively).



Lower Pool 2 - Change in Land Cover - 1890s to 2000

Land Cover	Hectares 1890s	Hectares 2000	Hectares Change	Percent Change of Total
Open Water/Aquatic Beds	1035	3044	2009	34.1
Marsh	481	45	-436	-7.4
Wet Meadow	583	53	-530	-9
Grassland		263	263	4.5
Shrub/Scrub	327	25	-302	-5.1
Wet Floodplain Forest	2408	588	-1820	-30.9
Mesic Btm Hardwood Forest		404	404	6.9
Sand/Mud	28	10	-18	-0.3
Agriculture	978	247	-731	-12.4
Developed	43	978	935	15.9
No Coverage		227	227	3.9
Total:	5883	5883		

Figure 14. Change in land cover from the 1890s-2000 for Lower Pool 2 in Mississippi National River and Recreation Area.



Upper Pool 3 - Change in Land Cover - 1890s to 2000

Land Cover	Hectares 1890s	Hectares 2000	Hectares Change	Percent Change of Total
Open Water/Aquatic Beds	671	779	109	3.6
Marsh	301	287	-14	-0.5
Wet Meadow	381	246	-134	-4.4
Grassland		142	142	4.7
Shrub/Scrub	307	2	-305	-10.1
Wet Floodplain Forest	1034	1144	110	3.6
Mesic Btm Hardwood Forest		27	27	0.9
Sand/Mud	3	16	13	0.4
Agriculture	230	56	-174	-5.8
Developed	92	204	111	3.7
No Coverage	3	119	116	3.8
Total:	3021	3021		

Figure 15. Change in land cover from the 1890s-2000 for Upper Pool 3 and a small portion of Lower Pool 3 in Mississippi National River and Recreation Area.

Only a very small portion of Lower Pool 3 (below the midpoint of the pool) is included in MISS (487 ha). Of this area, wet floodplain forest was the major land cover type in 2000 and had increased slightly, covering 2.5% more of the total area than in the 1890s. In 2000, 25.7% less was covered by shrub/scrub; wet meadow, open water, and grassland covered 12.5%, 8.9%, and 4.5% more of the total area, respectively.

A broader analysis by De Jager et al. (2013) found that from the 1890s to 2000, Pool 3 shifted from a cluster of pools characterized by a high proportion of forest to one characterized by increased open water, possibly because of changes at the lower end of the pool that are not included in our analysis. A similar conclusion appears possible for Pool 2, although the authors did not include it in their analysis. The authors then used observed changes for 1975 to 1989 to project changes to 2039 and used observed changes for 1989 to 2000 to project changes to 2050. Because the changes in the former period were small, the projection for 2039 was not statistically significant from the land cover in 1975, 1989, or 2000. However, larger land cover changes from 1989 to 2000, driven by a rise in river discharge, led to a statistically significantly different land cover projection for 2050, in which Pool 3 will have an increase in open water and a decrease in natural semi-terrestrial habitat.

Sources of Expertise:
Maps and data at http://www.umesc.usgs.gov/data_library/land_cover_use/1890s_lcu_mrc.html and http://www.umesc.usgs.gov/data_library/land_cover_ use/2000_lcu_umesc.html; Dave Mechenich, Christine Mechenich, James Cook, UWSP.

Literature Cited

Anfinson, J. O., T. Madigan, D. M. Forsberg, and P. Nunnally. 2003. River of history: a historic resources study of the Mississippi National River and Recreation Area. United States Army Corps of Engineers. St. Paul District, St. Paul, Minnesota. Available at http://www.nps.gov/miss/historyculture/historic_resources.htm. (accessed June 10, 2013).

De Jager, N. R., J. J. Rohweder, and J. C. Nelson. 2013. Past and predicted future changes in the land cover of the Upper Mississippi River floodplain, USA. *River Research and Applications* 29:608–618.

Knutson, M. G., and E. E. Klaas. 1998. Floodplain forest loss and changes in forest community composition and structure in the Upper Mississippi River: a wildlife habitat at risk. *Natural Areas Journal* 18:138–150.

Moore, G. F. 1988. Plant communities of Effigy Mounds National Monument and their relationship to presettlement regional vegetation. Thesis. University of Wisconsin, Madison, Wisconsin.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

4.3.3 Impervious Surfaces

Description

Monahan et al. (2012) reviewed literature on the effects of impervious surfaces on ecosystems and reported watershed thresholds of 2-10% for effects on stream geomorphology, 10-15% for effects on fish diversity, and 1-33% for invertebrate diversity. They further reported impacts to "more sensitive species" at 3-5% impervious cover and stated that thresholds vary geographically and with a variety of physical and biotic factors. An impervious cover model created by the Center for Watershed Protection predicts that most stream quality indicators decline when watershed impervious cover exceeds 10%, with severe degradation expected beyond 25% (Schueler 2003).

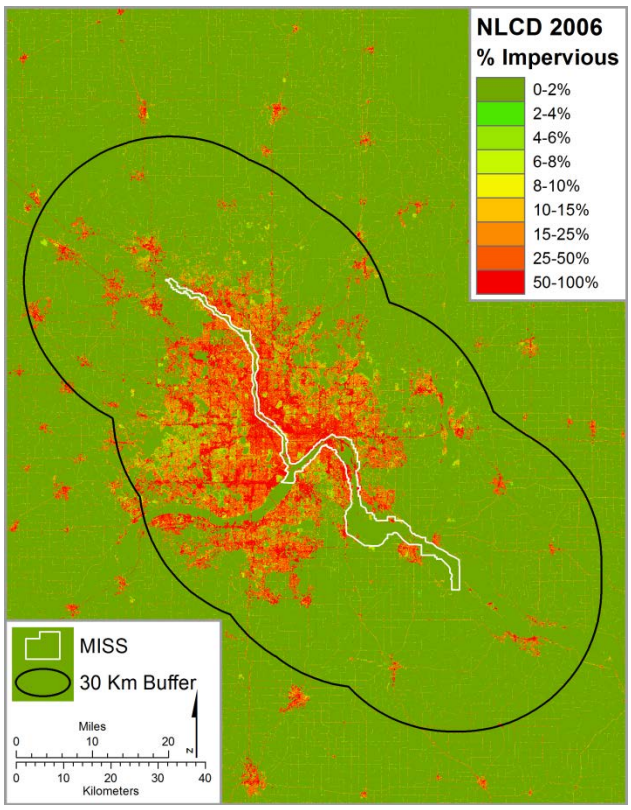


Figure 16. Percent impervious surface in the vicinity of Mississippi National River and Recreation Area (USGS 2011).

Data and Methods

We analyzed percent impervious surface using the NLCD 2006 Percent Developed Imperviousness dataset from the NPScape Metric GIS Data – Land Cover (NPS 2012) for MISS, a 1-km ring outside the MISS boundary, and the 30-km AOA around MISS (Figure 16). In this dataset, 30-m cells have a value for % impervious surface from 0-100 from which the % areal impervious surface in Table 16 is derived. NPScape further places each cell in a category (1-9) according to its percent impervious surface; we combined some categories (see Table 16). We also used 2011 data for MISS from the Minnesota Land Cover Classification System (MLCCS 2011 in NPS 2013).

Reference Condition

Impervious land cover should not exceed 10% within MISS, its subwatershed, or the 30-km AOA for the protection of stream ecosystems. This represents a "least disturbed condition" or "the best of today's existing conditions" (Stoddard et al. 2006).

Condition and Trend

The condition of MISS for impervious cover is of significant concern, with a deteriorating trend. Our level of confidence in this assessment is moderate. Within MISS, 12.8% of the total area and 18.2% of the land area consisted of impervious surfaces in the NLCD 2006 dataset (NPS 2012), exceeding the recommended watershed target of <10%. Impervious cover in MISS increased 1.0% from 2001 to 2006 (NPS 2013). In the 30-km AOA and the UMR subwatershed, impervious surfaces were 9.5% and 6.3% of the total areas, respectively (Table 16).

However, MISS does contain less impervious surface than its immediate surroundings, both in its total area (land + water) and in land area only. Within MISS, 71.3% of the total area (61.2% of the land area) was ≤4% impervious in the 2006 NLCD, but in a 1-km ring outside the park, the value for total area decreased to 36.0%. For the 30-km AOA, the area ≤4% impervious was comparable to MISS at 74.6% (Table 16). For the UMR subwatershed, the area ≤4% impervious was 82.6%. Within MISS, 18.0% of the total area (24.3% of the land area) was 26-100% impervious in the 2006 NLCD, but in a 1-km ring outside the park, the value for total area increased to 45.3%.

For MISS total area, the proportion of land that was 26-100% impervious was slightly higher in MLCCS (2011) data than in NLCD (2006) data (19.5% vs. 18.0%), but the proportion of land that was 4-100% impervious was the same in both datasets (28.7%).

Table 16. Percent impervious surface in Mississippi National River and Recreation Area and its vicinity (MLCCS 2011 in NPS 2013, NPS 2012).

			NLCD 2006			MLCCS 2011
% Impervious	**MISS**	**MISS (land only)**	**MISS Boundary to 1 km**	**Upper Mississippi Watershed**	**MISS 30-km AOA**	**MISS**
0-4%	71.3%	61.2%	36.0%	82.6%	74.6%	-
5-10%	4.9%	6.7%	7.4%	3.5%	4.7%	-
11-15%	2.4%	3.2%	4.2%	1.7%	2.4%	-
16-25%	3.4%	4.6%	7.1%	2.3%	3.5%	-
Total 4%-25%	10.7%	14.4%	18.7%	7.5%	10.6%	9.2%
26-50%	6.6%	8.9%	18.9%	5.1%	7.4%	-
51-100%	11.4%	15.4%	26.4%	4.9%	7.4%	-
Total 26%-100%	18.0%	24.3%	45.3%	9.9%	14.8%	19.5%
Total 4%-100%	28.7%	38.8%	64.0%	17.4%	25.4%	28.7%
% areal impervious*	12.8%	18.2%	29.4%	6.3%	9.5%	-

*derived from values for individual 30-m cells

Sources of Expertise

NPS 2012, 2013; Dave Mechenich, Christine Mechenich, UWSP.

Literature Cited

MLCCS (Minnesota Land Cover Classification System). 2011. Website. MDNR, St. Paul, Minnesota. Available at http://www.dnr.state.mn.us/mlccs/index.html.

Monahan, W. B., J. E. Gross, L. K. Svancara, and T. Philippi. 2012. A guide to interpreting NPScape data and analyses. Natural Resource Technical Report NPS/NRSS/NRTR—2012/578. National Park Service, Fort Collins, Colorado. Available at http://science.nature.nps.gov/im/monitor/npscape/interpguide.cfm. (accessed August 5, 2013).

NPS (National Park Service) Stewardship and Science Inventory and Monitoring Division. 2012. NPScape metric GIS data – land cover. Geospatial Dataset – 2184564. Available at https://irma.nps.gov/App/Reference/Profile/2184564. (accessed September 5, 2012).

NPS (National Park Service). 2013. State of the park report for Mississippi National River and Recreation Area. State of the Park Series No. 4. National Park Service, Washington, D.C. Available at http://www.nps.gov/stateoftheparks/. (accessed June 11, 2013).

Schueler, T. 2003. Impacts of impervious cover on aquatic systems. Center for Watershed Protection, Ellicott City, Maryland. Available at http://clear.uconn.edu/projects/TMDL/library/papers/Schueler_2003.pdf. (accessed November 19, 2013).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

USGS (United States Geological Survey). 2011. NLCD (National Land Cover Database) 2006 percent developed imperviousness. USGS, Sioux Falls, South Dakota. Available at http://www.mrlc.gov/nlcd06_data.php. (accessed September 10, 2012).

4.3.4 Landscape Pattern and Structure

Description

The NPScape project allows for the calculation of metrics for forest density and forest morphology as well as grassland density and morphology; the latter will not be discussed here. Forest density is a measure of area-density which describes a very broad habitat category, and forest morphology is a metric that indicates the amount of core habitat vs. edge in a landscape.

NPScape uses the NLCD definition of "forest" to distinguish forest from nonforest cells (Monahan et al. 2012). A grid cell (30 m wide) is considered "forest" if the proportion of vegetative cover contributed by woody vegetation generally greater than 5 m tall is at least 20% (http://www.mrlc.gov/nlcd06_leg.php). For the forest density metric, a cell is considered "forest dominant" if at least 60% but <90% of the grid cells surrounding it in a 7 x 7 cell window (4.4 ha) meet the definition for forest. This means that a given window could have anywhere from ~12-90% tree cover, and the cell at its center would meet the definition of "forest dominant." The metric does not distinguish between very young forests and mature ones.

In the forest density metric, the categories with the highest area-density are "dominant" (60-90%), "interior" (90-100%), and "intact" (100%). Percolation theory suggests that 60% area-density is a threshold below which a landscape may "flip" from mostly interconnected areas to mostly small, isolated patches (Monahan et al. 2012 and citations therein). Wickham et al. (2007, in Monahan et al. 2012) found area-density to be sensitive to loss in the area of dominant forest, even when patch size distribution was unchanged.

Forest morphology is a metric related to core habitat, which is significant to both biotic and abiotic processes in the landscape (Turner 1989). The narrow, linear shape of MISS substantially limits the amount and proportion of core habitat; it also contributes to a lot of edge due to the large amount of open water, agriculture, and development in the landscape. Edge effects on

vertebrates, especially birds, are well known and may include increased nest predation and parasitism and creation of a biological sink (Ries and Sisk 2004). However, individual species have variable responses (positive, negative, or neutral) to edge (Ries and Sisk 2004).

All sharp edges also alter the micro-environment (temperature, relative humidity, and wind) for an appreciable distance into the taller community type (Matlack 1993, Chen et al. 1995). The spatial extent of these influences, and the corresponding changes in vegetation, vary substantially among studies, which have noted differences by aspect, region or forest type, and edge structure (Matlack 1993, Cadenasso and Pickett 2001, Nelson and Halpern 2005). For forests of eastern North America, the environment modification is consistently 50 m or less. A study in the boreal mixed-wood forest type of Alberta found a distinct aspect effect, with the edge width for shrubs narrowest on the east; shrub and herb abundance varied up to 20 m into the forest (Gignac and Dale 2007). Of particular note is that narrow communities generally contain more alien species, which reached their peak abundance 5-15 m from the forest edge and occurred up to 40 m from the edge (Gignac and Dale 2007). Changes in the size or number of natural habitat patches, or a change in the connectivity between those patches, can lead to loss of diversity of native species, among other effects (Fahrig and Merriam 1985).

Forest morphology is examined with an NPScape SOP that uses Morphological Spatial Pattern Analysis (MSPA). This process uses image segmentation to classify individual grid cells in binary (forest/nonforest) maps into a set of pattern types (Figure 17). In NPScape, the eight basic landscape pattern types are core, islet, perforation, edge, loop, bridge or corridor, branch, and background (Monahan et al. 2012).

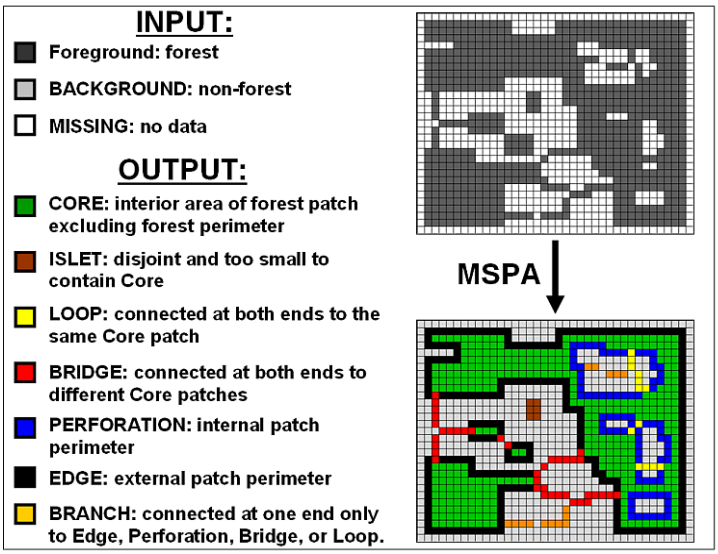


Figure 17. Explanation of Morphological Spatial Pattern Analysis (figure obtained from http://ies.jrc.ec.europa.eu/news/108/354/Highlight-November-2009/d,ies_highlights_details.html).

Data and Methods

The degree to which the current habitat of MISS is intact was assessed using the landscape dynamics monitoring project NPScape to calculate metrics of forest density and forest morphology (NPS 2013a). Forest density and morphology were calculated for MISS, a 1-km ring around it, and its 30-km AOA. Both the 30 m and 150 m edge widths were used for forest morphology. The current version of NPScape data is from the 2006 NLCD.

Reference Condition

It is impossible to establish a precise reference condition for either forest density or morphology due to lack of data. A reasonable goal, given the land cover changes noted above, would be a

modest increase in forest density (forested wetland); this would represent a "least disturbed condition" or "the best of today's existing conditions" (Stoddard et al. 2006).

Condition and Trend – Forest Density

Within MISS, 18.7% of the area consisted of "dominant" to "intact" forest in 2006 (Table 17), a percentage over three times greater than in the 1-km ring around the park. The amount of dominant forest did not change from 2001-2006 (NPS 2013b). MISS provides an oasis of forest and its associated habitat in the city. MISS also had nearly twice the "dominant" to "intact" forest of its 30-km AOA, emphasizing the amount of agricultural land in the region in which it is located.

The distribution of forest within MISS varied by reach. As might be expected, the prairie reach, corresponding roughly to A in Figure 18 (see Figure 3 for more detail), had some interior and intact forest, but forest was mainly "patchy" or "rare," similar to its ring. In the gorge reach (B in Figure 18 north of the Minnesota River confluence), there was little forest in MISS or the ring. In the large floodplain river downstream of the confluence, MISS was clearly more densely forested than its 1-km ring.

Table 17. Forest density metric for Mississippi National River and Recreation Area and the 1-km ring and 30-km AOA around the park (NPS 2013a).

Density Class Name	Area-Density for Forest Cover (p)	Location					
		MISS		MISS Boundary to 1 km		30 km AOA	
		km^2	%	km^2	%	km^2	%
No Focal Landcover	p = 0%	69.4	31.9%	169.5	66.3%	4,282	46.5%
Rare	0% < p < 10%	22.2	10.2%	21.8	8.5%	990	10.7%
Patchy	10% ≤ p < 40%	59.8	27.5%	40.1	15.7%	2,182	23.7%
Transitional	40% ≤ p < 60%	25.6	11.8%	11.0	4.3%	753	8.2%
Dominant	60% ≤ p < 90%	26.3	12.1%	9.4	3.7%	675	7.3%
Interior	90% ≤ p < 100%	7.6	3.5%	2.3	0.9%	176	1.9%
Intact	p = 100%	6.8	3.1%	1.6	0.6%	157	1.7%
Subtotal – Dominant to Intact		40.7	18.7%	13.3	5.2%	1,008	10.9%
Total		217.8	100%	255.7	100%	9,215	100%

Knutson and Klaas (1998) reported a 42% decline in tree density from the mid-1840s (511.9 trees ha^{-1}) to the early 1990s (297.4 trees ha^{-1}) for Pools 6-10. Sanders and Grochowski (2012) found a tree density for the silver maple forest type (310.17 trees ha^{-1}) very close to the 1990s value in Knutson and Klaas (1998). However, Sanders and Grochowski's (2012) two other lowland forest types had densities (502.43 trees ha^{-1} and 576.28 trees ha^{-1}) close to or exceeding the 1840s value. Therefore, we hypothesize that tree density is lower today than in presettlement times for silver maple forests and unknown for others. We tentatively rate the condition of MISS for forest density as uncertain, and our degree of confidence in this assessment is fair-to-poor.

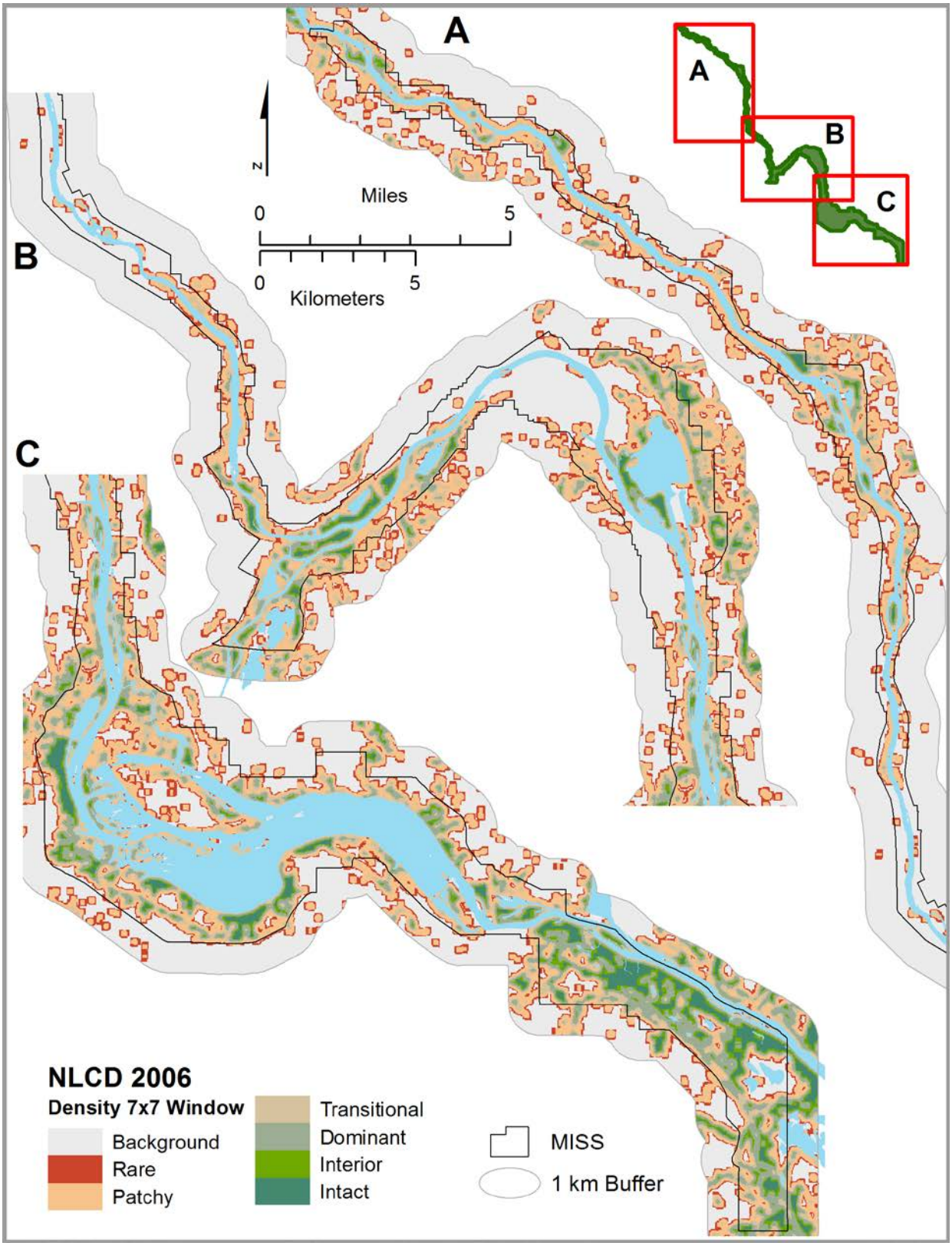


Figure 18. Forest density in the vicinity of Mississippi National River and Recreation Area (NPS 2013a).

Condition and Trend – Forest Morphology

The analysis produced a snapshot of forest morphology in 2006 for the MISS corridor, the surrounding 1-km ring, and the AOA. Using a 30 m edge width, only 12.3% of the area within the MISS corridor was core forest, and 8.4% was edge (Table 18). Nearly seventy-two percent was not forest, and the remaining 7% was in one of five categories (branch, islet, bridge, perforated, or loop) that identified it as an area that was either a type of connector between core forest areas or too small to be core forest. As a percentage, MISS had more core forest than its 1-km ring (3.3%) or its 30-km AOA (7.3%). The very small proportion of the area in bridge, loop, or islet (<4%), shows that very few of the communities were connected to others; i.e., corridors were not common. As with forest density, the core forest morphology type was more dominant in the large floodplain reach of the river (Figure 19). In MISS, 64.5% of core patches were <1 ha; these accounted for 3.8% of the area covered by core forest. Core patches >10 ha were 8.7% of all core patches, but accounted for 76% of the area covered by core forest (NPS 2013a). The patch size distribution in MISS did not change from 2001 to 2006 (NPS 2013b).

Though an edge of 30 m or slightly larger is most likely to represent the situation for MISS forests, this is not certain because all edge-related studies in the East were done in upland landscapes. One or more micro-environmental effects (e.g., relative humidity) may extend more than 50 m into a forest when bordered by open water. In the West, occasionally the edge effects extend 200 m into a forest (Chen et al. 1995). With an edge width of 150 m, there is less core forest and more edge; core forest drops from 12.3% to just 1.0% in MISS (Table 18) and is

Table 18. Forest morphology metrics for Mississippi National River and Recreation Area and the 1-km ring and 30-km AOA (NPS 2013a).

Morphology Class Name	Edge Width	Location					
		MISS		MISS Boundary to 1 km		30-km AOA	
		km^2	%	km^2	%	km^2	%
Background	30 m	156.6	71.9%	230.4	90.1%	7,496	81.3%
Branch	30 m	7.5	3.5%	3.8	1.5%	241	2.6%
Edge	30 m	18.3	8.4%	7.5	2.9%	525	5.7%
Islet	30 m	4.2	1.9%	4.0	1.6%	182	2.0%
Core	30 m	26.9	12.3%	8.5	3.3%	670	7.3%
Bridge	30 m	2.5	1.1%	1.0	0.4%	63	0.7%
Perforated	30 m	0.6	0.3%	0.1	<0.1%	8.5	0.1%
Loop	30 m	1.1	0.5%	0.4	0.2%	29	0.3%
Total		217.8	100.0%	255.7	100.0%	9,215	100.0%
Background	150 m	156.6	71.9%	230.4	90.1%	7,496	81.3%
Branch	150 m	4.5	2.0%	2.1	0.8%	149	1.6%
Edge	150 m	10.8	5.0%	2.5	1.0%	225	2.4%
Islet	150 m	24.0	11.0%	15.1	5.9%	891	9.7%
Core	150 m	2.2	1.0%	0.5	0.2%	55	0.6%
Bridge	150 m	14.2	6.5%	3.9	1.5%	298	3.2%
Perforated	150 m	-	-	-	-	0.2	<0.1%
Loop	150 m	5.5	2.5%	1.2	0.5%	101	1.1%
Total		217.8	100.0%	255.7	100.0%	9,215	100.0%

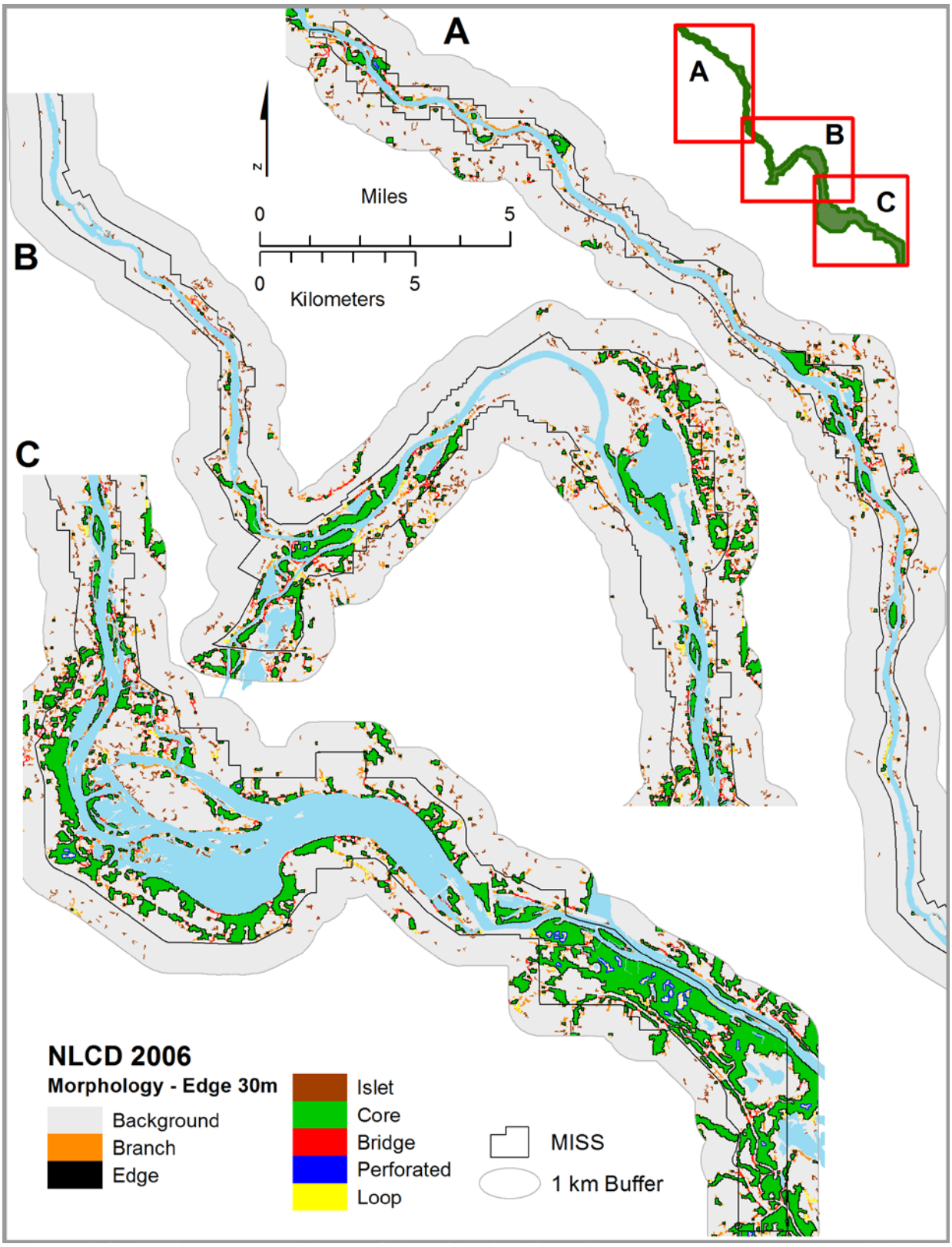


Figure 19. Forest morphology in the vicinity of Mississippi National River and Recreation Area at the 30 m edge width scale (NPS 2013a).

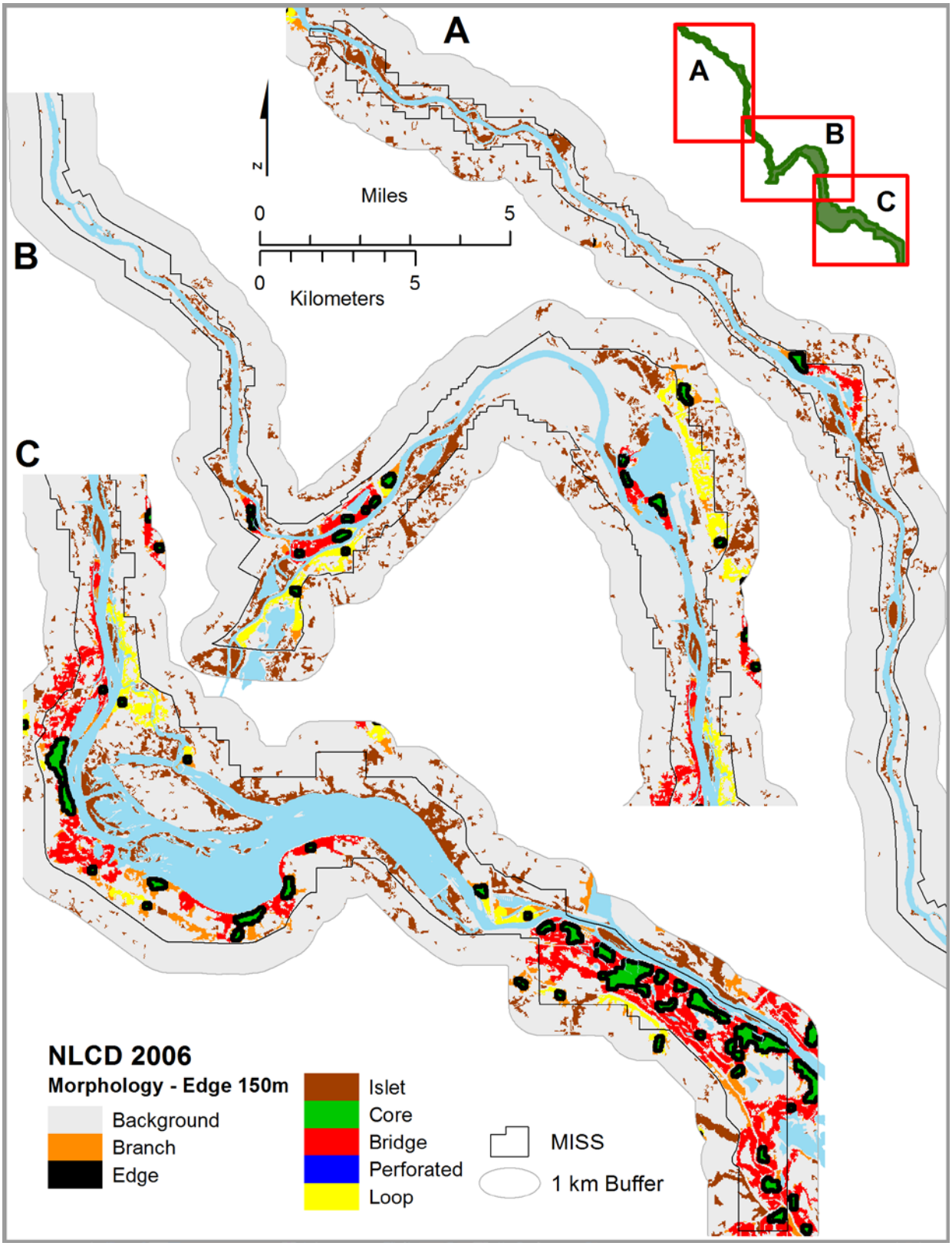


Figure 20. Forest morphology in the vicinity of Mississippi National River and Recreation Area at the 150 m edge width scale (NPS 2013a).

increasingly confined to the southernmost portions of the corridor (Figure 20) (NPS 2013a). At this edge width, 54.1% of core patches were <1 ha; these accounted for 4.4% of the area covered by core forest. Core patches >10 ha were 8.2% of all core patches, but accounted for 55% of the area covered by core forest (NPS 2013a).

Based on the estimates of De Jager et al. (2013) and Knutson and Klaas (1988), the region historically had relatively large expanses of forest, broken up primarily by open water and secondarily by wet meadow type communities. This would have provided, in all likelihood, extensive core habitat and a reasonably well connected set of habitats. We hypothesize that core habitat is less today than in presettlement times for the forests south of the confluence. We tentatively rate the condition of MISS for forest morphology as poor. Our degree of confidence in this assessment is poor.

Sources of Expertise

Monahan et al. (2012); James Cook, Dave Mechenich, Christine Mechenich, UWSP.

Literature Cited

Cadenasso, M. L., and S. T. A. Pickett. 2001. Effect of edge structure on the flux of species into forest interiors. *Conservation Biology* 15:91–97.

Chen, J., J. F. Franklin, and T. A. Spies. 1995. Growing-season microclimatic gradients from clearcut edges into old-growth Douglas-fir forests. *Ecological Applications* 5:74–86.

De Jager, N. R., J. J. Rohweder, and J. C. Nelson. 2013. Past and predicted future changes in the land cover of the Upper Mississippi River floodplain, USA. *River Research and Applications* 29:608–618.

Fahrig, L., and G. Merriam. 1985. Habitat patch connectivity and population survival. *Ecology* 66:1762–1768.

Gignac, L. D., and M. R. T. Dale. 2007. Effects of size, shape, and edge on vegetation in remnants of the upland boreal mixed-wood forest in agro-environments of Alberta, Canada. *Canadian Journal of Botany* 85:273–284.

Knutson, M. G., and E. E. Klaas. 1998. Floodplain forest loss and changes in forest community composition and structure in the Upper Mississippi River: a wildlife habitat at risk. *Natural Areas Journal* 18:138–150.

Matlack, G. R. 1993. Microenvironment variation within and among forest edge sites in the eastern United States. *Biological Conservation* 66:185–194.

Monahan, W. B., J. E. Gross, L. K. Svancara, and T. Philippi. 2012. A guide to interpreting NPScape data and analyses. Natural Resource Technical Report NPS/NRSS/NRTR—2012/578. National Park Service, Fort Collins, Colorado. Available at http://science.nature.nps.gov/im/monitor/npscape/interpguide.cfm. (accessed August 5, 2013).

Nelson, C. R., and C. B. Halpern. 2005. Short-term effects of timber harvest and forest edges on ground-layer mosses and liverworts. *Canadian Journal of Botany* 83:610–620. Available at http://www.cfc.umt.edu/nelsonrestorationlab/files/Pubs/CRNelson%20and%20Halpern_bot63.pdf. (accessed August 5, 2013).

NPS (National Park Service). 2013a. NPS Natural Resource Stewardship and Science Inventory and Monitoring Division. NPScape Metric GIS Data - landscape pattern. Geospatial Dataset-2184565. Available at https://irma.nps.gov/App/Reference/Profile/2184565. (accessed December 11, 2013).

NPS (National Park Service). 2013b. State of the park report for Mississippi National River and Recreation Area. State of the Park Series No. 4. National Park Service, Washington, D.C. Available at http://www.nps.gov/stateoftheparks/. (accessed June 11, 2013).

Ries, L., and T. D. Sisk. 2004. A predictive model of edge effects. *Ecology* 85:2917–2926.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

Turner, M. G. 1989. Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics* 20:171–197.

Wickham, J. D., K. H. Riitters, T. G. Wade, and J. W. Coulston. 2007. Temporal change in forest fragmentation at multiple scales. *Landscape Ecology* 22:481–489.

4.3.5 Road Density

Description

An extensive body of literature has documented the effects of roads on both terrestrial and aquatic environments. Gross et al. (2009) stated that “Even in areas where human population densities are relatively low and landscapes are perceived as natural, the impacts of roads are pervasive and may extend hundreds to thousands of meters from the roadside.”

Roads have a wide variety of ecological effects, including altered hydrology, increased erosion, habitat segregation, migration barriers, and direct mortality (Forman and Alexander 1998). For mammals, noise may be more important than collisions due to its effect on behavior. A full evaluation of the effect of roads must include the ‘road-effect zone,’ not just the road and associated altered habitat (Forman and Alexander 1998). For large mammals in woodland areas, this typically extends 100-200 m out from the road. Physical and biological effects of roads are summarized in Table 19.

Forman and Alexander (1998) stated that large and mid-sized mammals are especially susceptible to two-lane, high-speed roads. Though animals generally stay 500 m or more away from roads, some herbivores may be drawn to the road corridor due to a different vegetative complex, ease of access, phenology of the vegetation, and nutrition; predators may use them due to enhanced prey abundance.

Table 19. Pervasive effects of roads on natural resources and park visitor behavior (adapted from Gross et al. 2009).

Physical Effects	Biological Effects
Alter temperature, humidity, and other weather attributes	Increase mortality
Increase rate and amount of water runoff	Physical barrier to movement
Alter surface and ground water flows	Habitat loss
Alter rates of sediment and nutrient dispersal	Habitat fragmentation
Runoff of chemicals applied to road surface	Behavioral avoidance of disturbances
Alter geological and soil substrates	Corridor for invasive species
Increase production and propagation of noise	Indirect effects like poaching, fire ignition
Alter light	Noise interference with species communication
Increase trash in area	Habitat alteration

Kociolek et al. (2011), in a synthesis of existing studies, examined the effects of roads on bird populations. The direct effects they examined included habitat loss and fragmentation, vehicle-caused mortality, pollution, and poisoning. The indirect effects included noise, artificial light, barriers to movement, and edges associated with roads. The authors concluded that traffic noise appeared to have the greatest potential to reduce population abundance and species richness of birds. Vehicle-induced mortality was a problem for some species, especially near watercourses, and the authors recommended further study in this area. Light and chemical pollution appeared to have "minor effects at the population level."

Fahrig and Rytwinski (2009) reviewed 79 studies on the effects of roads and traffic on animal abundance and distribution, with results for 131 species and 30 species groups. Of reported responses, 114 responses were negative, 22 were positive, and 56 showed no effect. Negative effects were noted for amphibians, reptiles, birds, mid-sized mammals, and large mammals. Positive effects were noted for some small birds, vultures, and small mammals. The authors listed four species types predicted to respond negatively to roads: (i) those attracted to roads and unable to avoid individual cars; (ii) those with large movement ranges, low reproductive rates, and low natural densities; and (iii and iv) small animals whose populations are not limited by road-affected predators and either (a) avoid habitat near roads due to traffic disturbance or (b) show no avoidance of roads or traffic disturbance and are unable to avoid oncoming cars. The two species types predicted to respond positively to roads are those that can avoid cars and are attracted by an important resource such as food, or those that avoid roads but are unaffected by traffic disturbance and whose main predators are negatively affected by roads.

However, the landscape context is pertinent; many factors in addition to range size and reproductive rates affect population abundance. In some landscapes, these additional forces could prevent a 'road effect' from materializing. Also, over time a population may change its tolerance of humans and human-generated habitat features.

A similar synthesis of existing studies examined the effects of highway construction, highway presence, and urbanization on physical habitat, water chemistry, and biota of streams (Wheeler et al. 2005). Channelization, often associated with highway presence, increases channel slope, reduces base flows, increases peak flows, alters substrate composition, and severs links to floodplains. It also reduces habitat diversity by replacing coarse substrates with finer ones,

reducing heterogeneity in velocity and depth, creating more laminar flows, removing cover, and eliminating natural pool-riffle sequences.

Highway surfaces collect a variety of chemical pollutants from automobile traffic and are disproportionate contributors to overall pollutant loads of substances including metals, oil and grease, and deicing chemicals (Wheeler et al. 2005). Accidents that result in spills of toxic contaminants are also a concern and may be especially detrimental to isolated populations of rare species with limited mobility, such as freshwater mussels. Sediments may also be toxic; polycyclic aromatic hydrocarbons (PAHs) in stream sediments may be responsible for the majority of macroinvertebrate toxicity.

Data and Methods

A road density of 3.6 km km^{-2} was calculated for MISS in the State of the Park Report (NPS 2013).

Reference Condition

Numeric reference conditions for specific species likely to be found in the urban setting of MISS were not found. Carnefix and Frissell (2009) suggest that habitat restoration strategies in areas of high aquatic resource value strive to reduce road density to <0.6 km km^{-2}. This is a lower road density than that recommended for gray wolves (*Canis lupus*) (<0.7 km km^{-2}, Potvin et al. 2005). These represent "least disturbed conditions" (Stoddard et al. 2006).

Condition and Trend

The MISS road density of 3.6 km km^{-2} exceeds the chosen reference condition of 0.6 km km^{-2} and is of serious concern. No trend was reported. Our confidence in this assessment is high.

Sources of Expertise

NPS (2013); Christine Mechenich, James Cook, UWSP.

Literature Cited

Carnefix, G., and C. Frissel. 2009. Aquatic and other environmental impacts of roads: the case for road density as indicator of human disturbance and road-density reduction as restoration target; a concise review. Pacific Rivers Council Science Publication 09-001. Pacific Rivers Council, Polson, Montana. Available at http://pacificrivers.org/science-research/resources-publications/road-density-as-indicator. (accessed December 10, 2013).

Fahrig, L., and T. Rytwinski. 2009. Effects of roads on animal abundance: an empirical review and synthesis. *Ecology and Society* 14:21. Available at http://www.ecologyandsociety.org/vol14/iss1/art21/. (accessed December 10, 2013).

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29:207–231.

Gross, J. E., L. K. Svancara, and T. Philippi. 2009. A guide to interpreting NPScape data and analyses. NPS/IMD/NRTR—2009/IMD/XXX. National Park Service, Fort Collins, Colorado. Available at

http://www.cfc.umt.edu/CESU/Reports/NPS/UID/2008/08_09Scott_IM_landscape%20metrics_finalrpt.pdf (accessed August 19, 2013).

Kociolek, A. V., A. P. Clevenger, C. C. St. Clair, and D. S. Proppe. 2011. Effects of road networks on bird populations. *Conservation Biology* 25:241–249.

NPS (National Park Service). 2013. State of the park report for Mississippi National River and Recreation Area. State of the Park Series No. 4. National Park Service, Washington, D.C. Available at http://www.nps.gov/stateoftheparks/. (accessed June 11, 2013).

Potvin, M. J., T. D. Drummer, J. A. Vucetich, D. E. Beyer, Jr., R. O. Peterson, and J. H. Hammill. 2005. Monitoring and habitat analysis for wolves in upper Michigan. *Journal of Wildlife Management* 69:1660–1669.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

Wheeler, A. P., P. L. Angermeier, and A. E. Rosenberger. 2005. Impacts of new highways and subsequent landscape urbanization on stream habitat and biota. *Reviews in Fisheries Science* 13:141–164.

4.3.6 Lightscapes

Description

The NPS uses the term "natural lightscape" for those resources and values that exist in the absence of human-caused light at night (NPS 2013). Through its management policies (NPS 2006), the NPS directs MISS and all other NPS units to preserve, to the greatest extent possible, the natural lightscapes and thus avoid light pollution. The GLKN recognizes the importance of natural lightscapes as a Vital Sign; it received a rank of 2.3 on a 5-point scale (45th of 46 Vital Signs) (NPS 2007).

Longcore and Rich (2004) distinguish between "astronomical light pollution," which affects the ability of people to see the stars and is a degradation of human views of the night sky, and "ecological light pollution," which alters the natural light regimes of terrestrial and aquatic ecosystems. For NPS units, astronomical light pollution may also affect historic and cultural values (NPS 2013). In the broadest terms, ecological light pollution may cause changes for organisms in orientation, disorientation, or misorientation, and attraction or repulsion from the altered light environment. These, in turn, may affect the foraging, reproductive, migrating, and communication behaviors of wildlife (Longcore and Rich 2004).

Data and Methods

No data on lightscapes and light pollution were found for MISS. Albers and Duriscoe (2001) modeled light conditions for National Parks based on 1990 data; their map showed a low Schaaf class (high level of light pollution) in the MISS vicinity, but the authors did not assign a specific score to MISS.

Reference Condition

The reference condition for natural lightscape at MISS is the natural night sky condition, as recommended by the NPS Natural Sounds and Night Skies Division (Chad Moore, NPS Night Skies Team Leader, email, 2/19/2013). This is a historic condition (Stoddard et al. 2006).

Condition and Trend

We rate the condition of MISS for natural lightscape as unknown, but likely of moderate concern, with an unknown trend. As shown in Chapter 2, MISS is located in a densely populated area with a fast-growing population, so chances for human impact on the night sky will likely be increasing.

Sources of Expertise

Chad Moore, NPS Night Skies Team Leader; Albers and Duriscoe (2001); Christine Mechenich, UWSP.

Literature Cited

Albers, S., and D. Duriscoe. 2001. Modeling light pollution from population data and implications for National Park Service lands. *The George Wright Forum* 18:56–68. Available at http://www.georgewright.org/184albers.pdf. (accessed April 29, 2013).

Longcore, T., and C. Rich. 2004. Ecological light pollution. *Frontiers in Ecology and the Environment* 2:191–198.

NPS (National Park Service). 2006. NPS management policies 2006. National Park Service, Washington, D.C. Published Report-2173472. Available at http://www.nps.gov/policy/MP2006.pdf. (accessed April 16, 2013).

NPS (National Park Service). 2007. Long-term ecological monitoring plan: Great Lakes Inventory and Monitoring Network. Natural Resource Report NPS/GLKN/NRR-2007/001. National Park Service. Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/645523. (accessed September 23, 2013).

NPS (National Park Service). 2013. Night sky website. NPS, Fort Collins, Colorado. Available at http://www.nature.nps.gov/night/index.cfm. (accessed April 29, 2013).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

4.3.7 Soundscapes

Description

Soundscape resources encompass all the natural sounds that occur in national parks, including the physical capacity to transmit sounds and interrelationships between natural sounds (NPS 2006). Among visitors to national parks who were surveyed, 91% considered enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting (McDonald et al. 1995 in Lynch 2012). In addition, sound plays a critical role for wildlife and affects intra-species communication, courtship, predation and predator avoidance, and effective use of habitat (Stein 2012 and citations therein).

NPS management policies recognize the importance of monitoring the frequencies, magnitudes, and durations of unnatural sounds as well as preserving those natural sounds that are part of the biological and physical resource components of the park. The policies recognize that in some parks, cultural and historic sounds are also important and appropriate to the purposes and values of the park.

Soundscapes are a Vital Sign for MISS (ranked 45th of 46 with a score of 2.3 on a five-point scale) (NPS 2007).

Data and Methods

No data on soundscapes or sound pollution were found for MISS. MISS staff has noted that on some river segments, such as in the gorge, the ambient noise level is less than one might expect in a dense urban setting.

Reference Condition

NPS Management Policy 8.2.3, Use of Motorized Equipment, provides that the natural ambient sound level is the baseline condition against which current conditions in a soundscape should be measured unless specific significant cultural or historic sounds have been recognized by NPS (NPS 2006). This represents a historic condition (Stoddard et al. 2006).

Condition and Trend

We rate the condition of MISS for natural soundscape as unknown, but likely of moderate concern, with an unknown trend. As shown in Chapter 2, MISS is located in a densely populated area with a fast-growing population, so chances for human impact on the soundscape will likely be increasing.

Sources of Expertise

Christine Mechenich, UWSP.

Literature Cited

Lynch, E. 2012. Saint Croix National Scenic Riverway: Acoustical monitoring 2011. Natural Resource Technical Report NPS/NRSS/NRTR—2012/544. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile?Code=2183395. (accessed April 16, 2013).

McDonald, C. D., Baumgarten, R. M., and Iachan, R. 1995. Aircraft management studies: National Park Service Visitors Survey. HMMH Report No. 290940.12; NPOA Report No. 94-2, National Park Service, U.S. Department of the Interior.

NPS (National Park Service). 2006. NPS management policies 2006. National Park Service, Washington, D.C. Published Report-2173472. Available at http://www.nps.gov/policy/MP2006.pdf. (accessed April 16, 2013).

NPS (National Park Service). 2007. Long-term ecological monitoring plan: Great Lakes Inventory and Monitoring Network. Natural Resource Report NPS/GLKN/NRR-2007/001. National Park Service. Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/645523. (accessed September 23, 2013).

Stein, C. E. 2012. Letter to City of Scandia, May 18, 2012 from Christopher E. Stein, SACN, St. Croix Falls, Wisconsin. Available at http://www.ci.scandia.mn.us/index.asp?Type=B_BASIC&SEC={73C38C5A-8CA7-4F87-8C56-B066C4CF775D}&DE={532BE6C8-E66F-4FDD-92E1-709F07A512A3}. (accessed April 22, 2013).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

4.4 Biotic Condition

In the EPA-SAB framework, biotic condition includes structural and compositional aspects of the biota below the landscape level at the organizational levels of ecosystems or communities, species and populations, individual organisms, and genes (USEPA 2002). We will discuss the biotic condition of the terrestrial and aquatic ecosystems, focusing on the plant, bird, fish, aquatic macroinvertebrate, and mussel communities; tree regeneration; invasive terrestrial and aquatic species; and the presence of mercury and persistent organic contaminants in biota.

4.4.1 *Vegetation*

As noted in Section 2.1.2, there are three very distinct sections of MISS in terms of physiography and hence vegetation that fall within its boundaries. At the very northern end, prairie, barrens, and savanna-type vegetation historically came up to the river's edge (Figure 21), but over half of the land was developed by 1895 (Figure 12). Today, most of this area is developed (Figure 12).

The next section to the south is defined by a very steep gorge, and the current vegetation within the boundaries is largely dry, upland forests. Prior to European settlement, this reach had 'river bottom forest' (wet floodplain forest) adjacent to the river in a few places, but oak openings and barrens dominated the adjacent uplands (Figure 21). In today's landscape, this terrain is largely a mesic oak forest subtype (Figure 13). In the late 1800s in Upper Pool 2, the three dominant land cover types, in descending order, were wet floodplain forest, wet meadow, and open water/aquatic (Figure 13). By 2000, developed areas and open water/aquatic beds had assumed the top two positions.

In the most southern section, south of the confluence of the Minnesota River, the valley becomes much wider, and there is a much greater diversity of plant communities. With the greater valley width, the range of abiotic conditions increases as do flood characteristics (frequency, duration, water depth, etc.) and the extent of sediment build-up. Open water and aquatic beds are the dominant land cover type in Lower Pool 2 today, whereas wet floodplain forest was the most abundant natural community in the 1890s (Figure 14). The vegetation communities range from floating and emergent to herbaceous-dominated, meadow-like communities to floodplain forests. This latter broad community type dominates the narrow strip next to the river bank. The larger islands contain a surprising amount of grassland (Figure 14).

<u>Methods</u>

Because the Park owns only 26 ha, the amount of detailed (survey-based) information on the vegetation within the boundaries of the Park is limited. For this reason, we refer the reader to information that is broader in scope but is likely to provide a reasonably accurate description of the vegetation.

The vegetation as documented by the original land survey in the mid-1800s was obtained from MDNR and the Wisconsin Department of Natural Resources (WDNR) (WDNR 1990, MDNR 1994). The late 1890s and 2000 vegetation were obtained as described in Section 4.3.2.

Minnesota has developed a hierarchical vegetation classification scheme of its own called "Minnesota's Native Plant Community Classification" (Aaseng et al. 2011). This scheme was

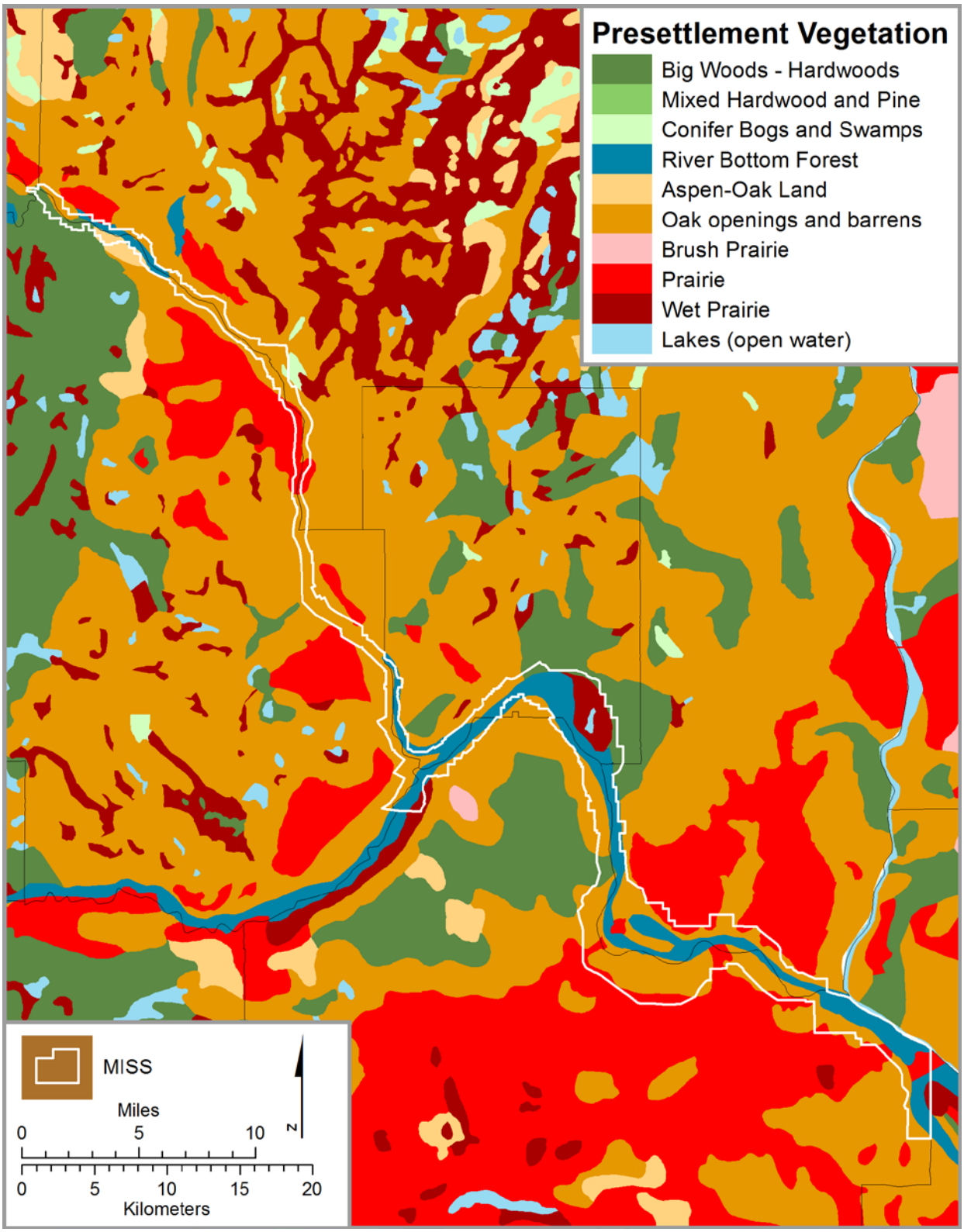


Figure 21. Presettlement vegetation in Minnesota (WDNR 1990, MDNR 1994).

based on a very large number of plots and was structured to parallel the National Hierarchical Framework of Ecological Units by creating keys for native plant communities based on the four ecological provinces in Minnesota. MISS falls within the Eastern Broadleaf Forest province (MDNR 2012, see Figure 7). The 'working units' in this classification are the Native Plant Community (NPC) classes, which are roughly equivalent to habitat types (e.g., Kotar et al. 1988) and which correspond approximately to associations within the National Vegetation Classification Standard (NVCS) (Aaseng et al. 2011). The NPC classes that clearly pertain to MISS are Southern Seepage Meadow/Carr and Southern Wet Prairie. Descriptions of these communities are available in MDNR (2005).

For the barrens-type communities, the descriptions developed by the Natural Heritage Program and the WDNR are the most useful (Epstein et al. 2002a, 2002b).

In summer 2011, Sanders and Grochowski (2012) initiated a long-term vegetation monitoring program for MISS. They established 33 plots in four forest types: i) upland, ii) cottonwood (*Populus deltoides* var. *deltoides*)-box elder (*Acer negundo*), iii) green ash-box elder, and iv) silver maple.

Reference Condition

Floodplain: The vegetation in a naturally-functioning floodplain is quite dynamic at multiple temporal and spatial scales due to weather fluctuation, flooding, and other types of disturbance. The concept of historic range of variability is applicable to this landscape (Landres et al. 1999), as the composition of a single site and the abundance and/or distribution of different community types would have naturally varied over time (Richter and Richter 2000, Baker and Wiley 2009). The long history of lock and dam installation and intensive use of part of the basin has truncated part of this natural variability. These considerations dictate that no single reference condition is warranted and that any reference condition (e.g., presettlement vegetation) incorporate current and anticipated human use. In addition, because the river has been dammed for such a long time, there is scant information about the species composition (other than large trees) of the floodplain prior to this significant alteration of the flood regime (see section 4.3.2).

An appropriate target for floodplain vegetation in MISS is a "best attainable condition" (Stoddard et al. 2006), wherein the impacts of land use on biological systems are minimized. This would entail a small-to-modest increase in natural vegetation and a reduction in open water/aquatic beds. The highest priority vegetation classes would be wet floodplain forest (Pool 1, 2, and Upper Pool 3), marsh and wet meadow (Pool 2), and shrub/scrub (Lower Pool 2).

Uplands: The upland vegetation areas of MISS have undergone drastic changes. Because of the current land use, and because the area has none of the features of a 'properly functioning watershed' (Potyondy and Geier 2011), a reference condition is also not warranted. The presettlement vegetation along the upper 1/3 of the park was predominantly oak opening and barrens, and this is almost completely gone today due to development. The bluff area above the gorge was dominated by a similar community type. In this area, the "best attainable condition" (Stoddard et al. 2006) target might apply, with the general goal to increase the amount of Oak Openings and Barrens. MDNR (2005) provides a suitable benchmark for this community and many of the communities in the MISS corridor. This source provides moderately detailed information on vegetation composition and structure, as well a list of indicator species.

Condition and Trend

We believe the composition and abundance of both floodplain and upland plant communities at MISS are significantly outside their normal range of variation. We rate this condition as a moderate concern, with no discernable trend in recent times (De Jager et al. 2013, see section 4.3.2). Our confidence in this assessment is fair, in part because of presumptions about historic condition, and because of very limited data on non-arboreal community types.

Sanders and Grochowski (2012) provide the most detailed current information about vegetation types within the MISS boundaries. The upland forest type is the most diverse on the basis of tree species (n=24). No species is numerically dominant, but the three most abundant, based on basal area, are bur oak (*Quercus macrocarpa*), bitternut hickory (*Carya cordiformis*), and elm (*Ulmus* spp.). In decreasing order based on density, the most common are elm, hickory, basswood (*Tilia americana*), and hackberry (*Celtis occidentalis*). Most of the tree species are regenerating at a moderate level or above; the species dominating the seedling layer are black cherry (*Prunus serotina*), hackberry, green ash, and hickory. The upland forests have the greatest level of browsing documented, but they have the smallest amount of coarse woody debris (CWD) (36.9 m^3 ha^{-1}).

Some commonality was noted across the three wetland forest types. They all average between 8-11 snags >30 cm DBH ha^{-1}, thus providing approximately the same level of this type of habitat. They also all show a moderately high level of deer browsing, but there is less noted in the green ash-box elder type than the other two. The third common trend is lack of regeneration by cottonwood and silver maple. Sanders and Grochowski (2012) attribute this to river impoundment. The final consistent trend is a high frequency of invasive species; this also is true for the upland plots.

In the cottonwood-box elder community type, the three most abundant overstory species, based on basal area, are cottonwood, silver maple, and box elder. Very large cottonwoods dominate the community, but no small trees are found. The shrub layer is populated by common buckthorn (*Rhamnus cathartica*), Virginia creeper (*Parthenocissus quinquefolia*), and grape (*Vitis* spp.). The species dominating the seedling layer are black ash, green ash, and hackberry. Total seedling density is 8,720 ha^{-1}. This forest type is the most speciose of the three wetland forests, with 46 species documented; this includes 13 woody species. This forest also has the greatest volume of CWD (68.2 m^3 ha^{-1}).

The green ash-box elder type actually contains a greater basal area of silver maple than green ash, which is the second most abundant overstory tree. Box elder makes up the third largest amount of basal area, but it should be noted that this species does not grow as tall as the others and thus does not ever achieve dominant overstory status. The same three shrubs as noted for the cottonwood type are found here, with the only difference being that grape is more common than Virginia creeper. Green ash, elm, and hackberry seedlings dominate this stratum in this forest type, but the total density (1,313 ha^{-1}) is much lower than in the cottonwood-box elder type and barely half the density in the silver maple type. This forest type has an intermediate number (n=29) of vascular plants, but only seven woody species, and an intermediate amount of CWD (50.3 m^3 ha^{-1}) (Sanders and Grochowski 2012).

In the silver maple type, the dominant species are silver maple, cottonwood, and box elder. The difference between the first and second species is much greater in this type than any other. The shrub layer is notably different in this type; the top three species in decreasing order are grape, bristly greenbriar (*Smilax tamnoides*), and moonseed (*Menispermum canadense*). The species dominating the seedling layer are green ash, box elder, hackberry, and black ash. Total density was 2,222 ha^{-1}. This forest type contains the least CWD of the wetland types (39.5 m^3 ha^{-1}) (Sanders and Grochowski 2012).

Sources of Expertise

Sanders and Grochowski (2012); Aaseng et al. (2011); James Cook, UWSP.

Literature Cited

Aaseng, N. E., J. C. Almendinger, R. P. Dana, D. S. Hanson, M. D. Lee, E. R. Rowe, K. A. Rusterholz, and D. S. Wovcha. 2011. Minnesota's native plant community classification: A statewide classification of terrestrial and wetland vegetation based on numerical analysis of plot data. Biological Report 108, Minnesota Biological Survey Program, Ecological Land Classification Program, Natural Heritage and Nongame Research Program, Minnesota Department of Natural Resources, St. Paul, Minnesota. Available at http://files.dnr.state.mn.us/natural_resources/npc/npc_methods_paper.pdf. (accessed August 20, 2013).

Baker, M. E., and M. J. Wiley. 2009. Multiscale control of flooding and riparian forest composition in Lower Michigan, USA. *Ecology* 90:145–159.

De Jager, N. R., J. J. Rohweder, and J. C. Nelson. 2013. Past and predicted future changes in the land cover of the Upper Mississippi River floodplain, USA. *River Research and Applications* 29:608–618.

Epstein, E. J., E. J. Judziewicz, and E. A. Spencer. 2002a. Oak barrens. Wisconsin Natural Community Abstracts. Wisconsin Department of Natural Resources, Bureau of Endangered Resources, Madison, Wisconsin. Available at http://dnr.wi.gov/topic/endangeredresources/communities.asp?mode=detail&code=ctsav002wi. (accessed February 25, 2014).

Epstein, E. J., E. J. Judziewicz, and E. A. Spencer. 2002b. Pine barrens. Wisconsin Natural Community Abstracts. Wisconsin Department of Natural Resources, Bureau of Endangered Resources, Madison, Wisconsin. Available at http://dnr.wi.gov/topic/EndangeredResources/Communities.asp?mode=detail&Code=CTSAV006WI. (accessed March 3, 2014).

Kotar, J., J. A. Kovach, and C. T. Locey. 1988. Field guide to forest habitat types of northern Wisconsin. Department of Forestry, University of Wisconsin-Madison and Wisconsin Department of Natural Resources, Madison, Wisconsin.

Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. *Ecological Applications* 9:1179–1188.

MDNR (Minnesota Department of Natural Resources). 1994. Presettlement vegetation. MDNR Division of Forestry, St. Paul, Minnesota. Available at http://deli.dnr.state.mn.us/. (accessed October 25, 2012).

MDNR (Minnesota Department of Natural Resources). 2005. Field guide to the native plant communities of Minnesota: The Eastern Broadleaf Forest Province. Ecological Land Classification Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program, Minnesota Department of Natural Resources, St. Paul, Minnesota.

MDNR (Minnesota Department of Natural Resources). 2012. Ecological classification system: eastern broadleaf forest province (webpage). MDNR, St. Paul, Minnesota. Available at http://www.dnr.state.mn.us/ecs/222/index.html. (accessed March 3, 2014).

Potyondy, J. P., and T. W. Geier. 2011. Watershed condition classification technical guide. Publication FS-978. USDA Forest Service, Washington, D.C. Available at http://www.fs.fed.us/publications/watershed/watershed_classification_guide.pdf. (accessed August 27, 2013).

Richter, B. D., and H. E. Richter. 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. *Conservation Biology* 14:1467–1478.

Sanders, S., and J. Grochowski. 2012. Implementation of a long-term vegetation monitoring program at the Mississippi National River and Recreation Area. National Park Service Great Lakes Inventory & Monitoring Network Report GLKN/2012/616. GLKN, Ashland, Wisconsin. Available at https://irma.nps.gov/App/Reference/Profile/2188820. (accessed March 3, 2014).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

USEPA (United States Environmental Protection Agency) Science Advisory Board. 2002. A framework for assessing and reporting on ecological condition: an SAB report. EPA-SAB-EPEC-02-009. USEPA, Washington, D.C. Available at http://www.epa.gov/sab/pdf/epec02009.pdf. (accessed August 5, 2013).

WDNR (Wisconsin Department of Natural Resources). 1990. Original vegetation cover of Wisconsin. WDNR, Madison, Wisconsin. Available at ftp://dnrftp01.wi.gov/geodata. (accessed November 28, 2012).

4.4.2 *Tree Regeneration*

In the UMR system, several tree species are currently much less common than they were in pre-European settlement times, and others are more abundant in the overstory but not regenerating well (Knutson and Klaas 1998, Romano 2010). The inventories conducted by the GLKN (Sanders and Grochowski 2012) within the boundaries of MISS found abundant regeneration of ash but very little of silver maple or cottonwood. The lack or limited extent of regeneration may be due to a large number of factors; these include a range of biotic agents and biotic forces. Any

one, or a combination, could have become a reproductive barrier (Cornett et al. 1998) in the past 20-70 years. Consequently, the reproductive capacity and requirements, up to establishment of seedling-size individuals, are reviewed for silver maple and cottonwood.

Silver maple

Seed Production and Dispersal: Flowering of this species may begin very early in the year, compared to its neighbors (February-May). Four different types of trees occur with respect to reproductive function, ranging from all male to all female to hermaphroditic. The seeds/fruits of silver maple develop very rapidly, with swelling of the ovary noted within 24 hours of pollination. Within three weeks, the seeds are mature. Thus, dispersal occurs from early April through June. Along the Wisconsin River, Dixon et al. (2002) documented the dispersal period for silver maple as May 15-June 16 in 1998-99. This should closely approximate the phenology along MISS. The seed of this species is the largest of the genus *Acer* in the US and is dispersed by wind and water. The minimum age of sexual reproduction is generally 11 years (Gabriel 1990). Once the species has reached canopy size, it is a regular and prolific seed producer (Geyer et al. 2010).

Germination and Establishment: The seeds are capable of germination at the time of maturation; i.e., no stratification is necessary. As is typical for riparian species, germination is generally maximized on moist, mineral soils. This is enhanced if the substrate has a moderate level of organic matter (Gabriel 1990). Seedlings require 2,000 to 2,500 hours of chilling to break dormancy. The light (radiation) level required by silver maple is highly variable. It has been classified as very intolerant to shade in the South but expresses a moderately tolerant capacity on productive sites in other parts of its range (Gabriel 1990).

Studies with one-year old seedlings from southern Illinois populations indicated that silver maple can withstand at least 30 days of complete inundation and 60 days with completely saturated soils (Hosner 1960, Hosner and Boyce 1962). A study of the photosynthetic capacity [Ps] of silver maple showed that new seedlings exhibited lower rates after 21 days of root flooding, but only 3 days of submersion were need to curtail photosynthetic rate. The flood effect was greater if the water was turbid. Two-year old seedlings had a greater capacity for Ps than one-year old seedlings. This implies that the flooding impact is temporary (Peterson and Bazzaz 1984). The species has a shallow, fibrous root system and is capable of producing abundant adventitious roots; this is considered an adaptation to flooding (Hosner and Boyce 1962, Loucks 1987). These traits provide an index of the ability of the species to withstand flooding during the growing season and explain why it is commonly rated as ‘tolerant’ of flooding (the highest of three categories) (Loucks 1987).

Site Conditions: Silver maple can be found on sandbars in the river channel, along the river’s edge (riparian zone proper), in the floodplain, and in bottomland forests (Hosner and Boyce 1962, Gabriel 1990, Dixon et al. 2002). The species is most commonly found on alluvial soils in the orders Inceptisols and Mollisols; it is rarely found on soils with a pH below 4.0 (Gabriel 1990).

Eastern cottonwood

Seed Production and Dispersal: This species is dioecious with a sex ratio of approximately 1:1. Floral buds are formed the previous year, and flowering may occur as early as February in the

southern part of its range. In the upper Midwest it is April or later. Flowering time may vary by up to 30 days among the trees in one community, and the male trees flower a few days earlier than females. Seed dispersal occurs approximately 1.5 months after flowering. This species becomes sexually mature at a young age – between ages of 5-10 years, but total seed production increases as tree size increases. The seeds are quite small, and thus a single, open-grown tree may produce as many as 48 million seeds (Bessey 1904 in Cooper 1990). Cottonwood typically has moderate to large amounts of seeds produced each year. In the northern part of its range, seed dispersal is June to mid-July (Cooper 1990). Dissemination occurred May 29–July 1 in 1998, but as late as August 1 in 1999, along the Wisconsin River (Dixon et al. 2002). The small weight of the seed and the cottony hairs attached to the seed enable it to be disseminated a long way from the parent tree (Cooper 1990).

Germination and Establishment: Very moist, bare mineral soil is essentially required for successful germination; the seeds are not hardy and thus must reach a suitable substrate very soon. The new seedlings are also quite susceptible to various mortality agents for the first few weeks; heavy rains, hot days, and damping-off fungi kill many. The seedlings have very little root growth the first few weeks, making them susceptible to dislodgment. After 3-4 weeks, the growth rate accelerates, and hardiness increases; however, the developing seedlings need full sun for a substantial part of the day during this period (Cooper 1990).

Studies with one-year old seedlings from southern Illinois populations indicated that cottonwood suffered close to 50% (7/15) mortality during 30 days of complete inundation, and about 10% mortality after 30 days of completely saturated soils. By 60 days with completely saturated soils, mortality also rose to near 50% (7/15) (Hosner 1960, Hosner and Boyce 1962). This provides an index of the ability of the species to withstand flooding during the growing season and explains why it is typically rated as ‘intermediate’ in flood tolerance (the middle of three categories) (Loucks 1987).

Site Conditions: The species can survive on a range of soil textures, and is most commonly found on Entisols and Inceptisols; i.e., relatively new and not well-developed soils. The conditions most favorable include a moist but not saturated soil with the water table at least 60 cm below the surface (Cooper 1990). In the southern part of its range, it is found in a greater array of topographic positions; in the north, it is restricted to sandbars and the riparian zone.

Studies in the western US with plains cottonwood (*Populus deltoides* var. *occidentalis*) and a closely related species, Fremont cottonwood (*P. fremontii*), have demonstrated that the root growth rate of the seedling and the rate at which the moisture zone (capillary fringe or water table) recedes are the primary determinants of successful seedling establishment (Mahoney and Rood 1991, Rood et al. 2003). It is not known how closely this model applies to eastern cottonwood, but it highlights the importance of the flood regime throughout the growing season and may provide some insight into the lack of successful regeneration in recent decades.

Sources of Expertise
James Cook, UWSP

Literature Cited
Bessey, C. E. 1904. The number and weight of cottonwood seed. *Science* 20:118–119.

Cooper, D. B. 1990. Eastern cottonwood. *In* R. M. Burns and B. H. Honkala, technical coordinators. Silvics of North America, Volume 2 – Hardwoods. USDA Forest Service Northeastern Area Office, Newtown Square, Pennsylvania. Available at http://www.na.fs.fed.us/spfo/pubs/silvics_manual/volume_2/silvics_v2.pdf. (accessed February 24, 2014).

Cornett, M. W., K. J. Puettmann, and P. B. Reich. 1998. Canopy type, forest floor, predation and competition influence conifer seedling emergence and early survival in two Minnesota conifer-deciduous forests. *Canadian Journal of Forest Research* 28:196–205.

Dixon, M. D., M. G. Turner, and C. Jin. 2002. Riparian tree seedling distribution on Wisconsin River sandbars: controls at different spatial scales. *Ecological Monographs* 72:465–485.

Gabriel, W. J. 1990. Silver maple. *In* R. M. Burns and B. H. Honkala, technical coordinators. Silvics of North America, Volume 2 – Hardwoods. USDA Forest Service Northeastern Area Office, Newtown Square, Pennsylvania. Available at http://www.na.fs.fed.us/spfo/pubs/silvics_manual/volume_2/silvics_v2.pdf. (accessed February 24, 2014).

Geyer, W. A., J. Dickerson, and J. M. Row. 2010. Plant guide for silver maple (*Acer saccharinum* L.). USDA Natural Resources Conservation Service, Manhattan Plant Materials Center, Manhattan, Kansas. Available at https://plants.usda.gov/plantguide/pdf/pg_acsa2.pdf. (accessed March 3, 2014).

Hosner, J. F. 1960. Relative tolerance to complete inundation of fourteen bottom land tree species. *Forest Science* 6:246–251.

Hosner, J. F., and S. G. Boyce. 1962. Tolerance to water saturated soil of various bottomland hardwoods. *Forest Science* 8:180–186.

Knutson, M. G., and E. E. Klaas. 1998. Floodplain forest loss and changes in forest community composition and structure in the Upper Mississippi River: a wildlife habitat at risk. *Natural Areas Journal* 18:138–150.

Loucks, W. L. 1987. Flood-tolerant trees. *Journal of Forestry* 85:36–40.

Mahoney, J. M., and S. B. Rood. 1991. A device for studying the influence of declining water table on poplar growth and survival. *Tree Physiology* 8:305–314.

Peterson, D. L., and F. A. Bazzaz. 1984. Photosynthetic and growth responses of silver maple (*Acer saccharinum* L.) seedlings to flooding. *American Midland Naturalist* 112:261–272.

Romano, S. 2010. Our current understanding of the Upper Mississippi River system floodplain forest. *Hydrobiologia* 640:115–124.

Rood, S. B., C. R. Gourley, E. M. Ammon, L. G. Heki, J. R. Klotz, M. L. Morrison, D. Mosley, G. G. Scoppettone, S. Swanson, and P. L. Wagner. 2003. Flow for floodplain forests: a successful riparian restoration. *BioScience* 53:647–656.

Sanders, S., and J. Grochowski. 2012. Implementation of a long-term vegetation monitoring program at the Mississippi National River and Recreation Area. National Park Service Great Lakes Inventory & Monitoring Network Report GLKN/2012/616. GLKN, Ashland, Wisconsin. Available at https://irma.nps.gov/App/Reference/Profile/2188820. (accessed March 3, 2014).

4.4.3 *Invasive Terrestrial Species*

Description

The introduction of terrestrial alien species probably began with the arrival of European settlers (DiTomaso 2000). It was not unusual for immigrants to bring useful plants or seeds with them from their native lands. Collectively, exotic plants represent an important ecological threat (Ehrenfeld 2003, Heneghan et al. 2006). In the recent past, eastern North America has experienced a rapidly increasing number of exotic plant populations. Effects have been widespread and have included, at a minimum, alteration of community structure (Heneghan et al. 2006); reduction of native richness (Woods 1993, Rooney et al. 2004); alteration of ecosystem process such as decomposition, mineralization, and primary productivity (Ehrenfeld 2003, Heneghan et al. 2006); and altered fire regimes (Brooks et al. 2004). Recently, it has been noted that invasive plants have negative effects on vertebrates such as amphibians, although the frequency of these effects is unknown (Maerz et al. 2009). Scientists are also beginning to document invasive species' effects on below-ground conditions and interactions (e.g., Callaway et al. 2011, Klionsky et al. 2011).

However, most exotics do not have any appreciable ecological effects, and among those that do, some have minor impacts. Only a small proportion of non-native species are invasive. The National Invasive Species Council (http://www.invasivespecies.gov/) was established in 1999 by Executive Order 13112, which defines invasive species as "…an alien (or non-native) species whose introduction does, or is likely to cause economic or environmental harm or harm to human health." The breadth of this definition seems appropriate for a park unit such as MISS, where the concerns reach beyond ecological impacts.

Many, although not all, of the problem exotic species are especially adept at invading recently disturbed areas. A study in the Saint Croix National Scenic Riverway found that a high percent of boat landings and campsites in the central portion of the park contained one or more alien species (Larson and Larson 2009). Even a use as seemingly 'low impact' as a canoe portage can function as a route of plant invasion (Dickens et al. 2005). The establishment of a park by no means guards land against further exotic invasion. A study of a small (19 km^2), newly established national park in Quebec found that the proportion of exotics increased from 16 to 25% in just 21 years (1984-2005) (Lavoie and Saint-Louis 2008).

To explain the full breadth of sites more conducive to invasion, the hypothesis of 'fluctuating resources' was proposed (Davis et al. 2000). The authors' hypothesis states that an increase in nutrient availability is the key factor that sets the stage for invasion. This idea has considerable merit in that it captures the change(s) associated with a) disturbance, b) invasion by a nitrogen-fixing species (e.g., black locust [Callaway et al. 2011]), and c) a decline in the native species. What it misses, which is probably quite important for wetland and riverine systems, is a fluctuation in the opposite direction; i.e., a substantial reduction in resource availability. The other key factor is 'propagule pressure' (Davis et al. 2000). This is simply the number and

identity of plant parts (fruits, seeds, or shoot fragments) that are capable of establishing a new individual.

These findings highlight four reasons that MISS has a relatively high invasive risk. First, there is heavy recreational use, and users are a common vector for plants. Second, the river itself serves as a dispersal vector for many floodplain species (Honnay et al. 2001), and thus can readily facilitate spread once a species is established and producing seed. Third, the landscape near the corridor is heavily disturbed (agriculture, roads, right-of-ways, forestry operations) (Gignac and Dale 2007) and thus provides frequent and widespread opportunities for species such as Canada thistle and spotted knapweed to establish (Czarapata 2005). Fourth, alteration of the hydrologic regime can favor an exotic species over a native of the same life form (Mortenson and Weisberg 2010).

Data and Methods

Larson and Larson (2009) installed 68 vegetation plots at MISS over the course of 2003-2004. This was not a random or stratified random design, but rather a general survey and a targeted effort to document a specific group of invasive species (Table 20). The species of special interest to MISS staff were common buckthorn (*Rhamnus cathartica*), black locust (*Robinia pseudoacacia*), tatarian honeysuckle (*Lonicera tatarica*), garlic mustard (*Alliaria petiolata*), and reed canarygrass (*Phalaris arundinacea*).

Table 20. Invasive plants chosen for inventory at Mississippi National River and Recreation Area by Larson and Larson (2009).

Vegetation type	Scientific name	Common name	Number of plots in which species was observed/surveyed
Forbs	*Allaria petiolata*	Garlic mustard	20/33
	Centaurea biebersteinii (now *Centaurea stoebe* ssp. *micranthos)*	Spotted knapweed	2/2
	Carduus nutans	Nodding thistle	1/1
	Cirsium arvense	Canada thistle	3/11
	Salsola collina	Russian thistle	1/2
Grasses	*Bromus inermis*	Smooth brome	2/2
	Phalaris arundinacea	Reed canarygrass	18/52
Woody plants	*Lonicera tatarica*	Tatarian honeysuckle	26/35
	Rhamnus cathartica	Common buckthorn	39/41
	Robinia pseudoacacia	Black locust	3/14

In the survey performed by Sanders and Grochowski (2012) (see section 4.4.1), the authors noted exotic species that fell within their 33 plots. These plots were distributed among four forest types: upland, cottonwood-box elder, green ash-box elder, and silver maple.

The Great Lakes Exotic Plant Management Team (GLEPMT) conducted inventory, treatment, and retreatment activities to manage invasive plants in MISS in each year between 2004 and 2013 except 2006 and 2008. Their annual reports list the species inventoried or treated, the gross area of the infestation, and the area treated, which is calculated by multiplying the gross area by the Daubenmire cover class. Treated (not retreated) areas by year are listed in Table 21 and shown in Figure 22. It should be noted that the GLEPMT also includes native species in their

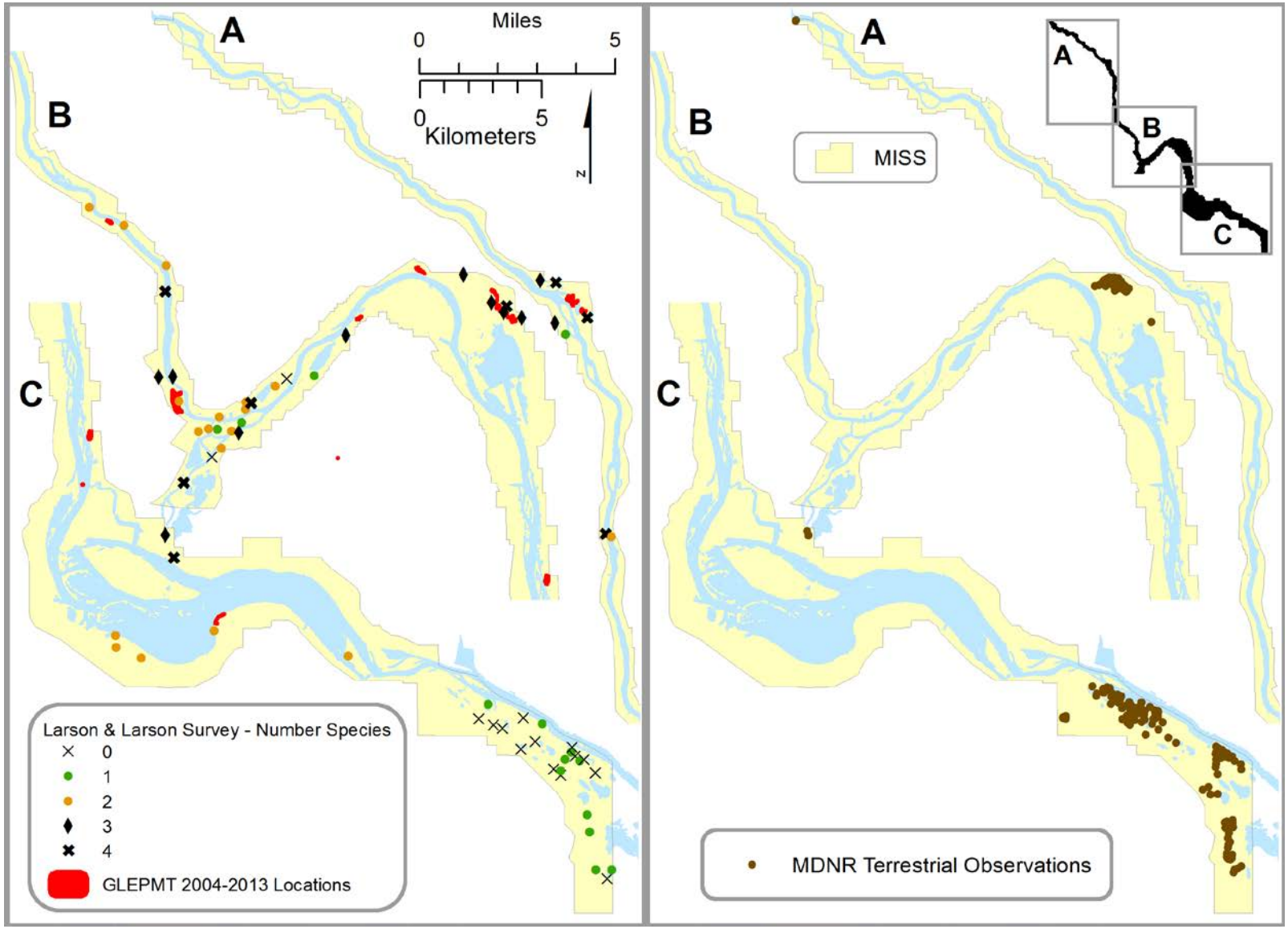


Figure 22. Locations of exotic plants noted by Larson and Larson (2009), MDNR (2005), GLEPMT (2004, 2005, 2007, 2010a, 2010b, 2011, 2012, 2013).

Table 21. Invasive and native plants found and treated at Mississippi National River and Recreation Area by the GLEPMT, 2004-2013 (GLEPMT 2004, 2005, 2007, 2010a, 2010b, 2011, 2012, 2013).

		m^2 Invasive Plants Treated by Year								
Scientific name	**Common name**	**2004**	**2005**	**2007**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
Acer ginnala	Amur maple					11.5	27.6	5.2		**44.3**
**Acer negundo*	Box elder	44.3					4,356.2			**4,400.5**
Alliaria petiolata	Garlic mustard		0.7		565.2		16,039.0	20,191.6		**36,796.5**
Arctium minus	Burdock			38.7			3,129.4	2,182.4		**5,350.4**
Berberis thunbergii	Japanese barberry					0.8				**0.8**
Cardamine impatiens	Narrow-leaf bittercress				750.3		2,794.1	4,828.4		**8,372.8**
Centaurea biebersteinii (now Centaurea stoebe)	Spotted knapweed	247.6		13.7	229.3			124.4		**615.0**
Cirsium	Thistle	7,665.6						65.8		**7,731.4**
Cirsium arvense	Canada thistle			26.8	2,877.3			10,378.4		**13,282.5**
Coronilla varia/ Securigera varia	Crown vetch	35.0		11.7				1,959.2	379.3	**2385.2**
Elaeagnus angustifolia	Russian olive					0.8		10.6		**11.4**
Elaeagnus umbellata	Autumn olive			<0.1						**<0.1**
Euphorbia esula	Leafy spurge								233.4	**233.4**
**Fraxinus pennsylvanica*	Green ash							64.0		**64.0**
Glechoma hederacea	Ground ivy							168.6		**168.6**
Hesperis matronalis	Dame's rocket				509.0					**509.0**
Iris pseudacorus	Yellow iris			12.0						**12.0**
Leonurus cardiaca	Common mothewort							94.6		**94.6**
Linaria genistifolia	Broomleaf toadflax	0.5								**0.5**
Linaria vulgaris	Yellow toadflax							183.1		**183.1**
Lonicera	Honeysuckle				4,302.5	620.7	4,006.4		1,716.5	**10,646.1**
Lonicera tatarica	Tatarian honeysuckle	80.1	756.9					2,085.4	601.7	**3,524.1**
Lythrum salicaria	Purple loosestrife							70.5		**70.5**
Melilotus	Sweet clover							758.4		**758.4**
Melilotus albus	White sweet clover							364.6		**364.6**

*native species, **may be native or exotic

Table 21. Invasive and native plants found and treated at Mississippi National River and Recreation Area by the GLEPMT, 2004-2013 (continued).

		m^2 Invasive Plants Treated by Year								
Scientific name	**Common name**	**2004**	**2005**	**2007**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
***Morus*	Mulberry				3,650.1					**3,650.1**
Morus alba	White mulberry					11.0		18.5		**29.5**
--	Other	3,066.9								**3,066.9**
Phalaris arundinacea	Reed canarygrass			26.9					948.1	**975.0**
***Poaceae*	Grasses							133.8		**133.8**
Polygonum cuspidatum	Japanese knotweed	564.7	87.8		327.7					**980.2**
**Populus deltoides*	Cottonwood	37.5							539.9	**577.4**
Rhamnus cathartica	Common buckthorn	1,902.4	3,265.3	3,164.9	8,720.8	23,476.1	14,087.1	36,937.0	52,910.8	**144,464.4**
Rhamnus frangula	Glossy buckthorn							27.0		**27.0**
**Rhus*	Sumac					1,175.3				**1,175.3**
**Rhus glabra*	Smooth sumac							1,594.1		**1,594.1**
**Rhus hirta*	Staghorn sumac							195.2		**195.2**
Robinia pseudoacacia	Black locust	5,207.3	1,400.3		312.8	15.2		497.1	1,339.8	**8,772.5**
**Solidago*	Goldenrod							213.6		**213.6**
Tanacetum vulgare	Common tansy				11,737.7			28.4		**11,766.1**
**Toxicodendron radicans*	Poison ivy							70.1		**70.1**
Typha angustifolia	Narrow-leaved cattail							29.7		**29.7**
Typha x glauca	Hybrid cattail								948.1	**948.1**
***Ulmus*	Elm							64.7		**64.7**
Ulmus pumila	Siberian elm		1.0			588.8	221.0	746.4	2,400.5	**3,957.7**
Verbascum thapsus	Common mullein						506.4	65.8		**572.2**
**Vitis riparia*	Riverbank grape							2,358.1		**2,358.1**
**Zanthoxylum americanum*	Common prickly ash		0.5							**0.5**
	Total	**18,851.9**	**5,512.5**	**3,294.7**	**33,982.7**	**25,900.3**	**45,167.2**	**86,514.7**	**62,018.1**	**281,242.1**

*native species, **may be native or exotic

surveys. Eight species were noted and treated between 2004 and 2013. Four taxa were listed at the genus level and thus could have included natives, exotics, or species from both groups.

The MDNR has conducted regular surveys since 2003 for invasive species on all state-managed lands. These are primarily road- and trail-side surveys, and the effort has fluctuated among years (Invasive Species Program 2012). A map (MDNR 2005) shows the current status of invasive plant populations and is updated monthly (Figure 22).

Reference Condition

Less than 10% of MISS should be infested with populations of terrestrial invasive species that could necessitate treatment (Potyondy and Geier 2011). This is a "least disturbed condition" or "the best of today's existing conditions" (Stoddard et al. 2006).

Condition and Trend

We rate the condition for terrestrial invasives as of moderate concern, with a worsening trend. This is based on the number of species documented since 2004, and the four risk-related reasons detailed above. Our confidence in the assessment is low due to lack of a rigorous, systematic repeated inventory and an accurate measurement of the percent of the park-owned land occupied by invasives.

Larson and Larson (2009) found one or more exotics in 53 of 68 plots. A total of 10 exotics were documented (Table 20). Common buckthorn was the most common species, though tatarian honeysuckle achieved the greatest level of cover (in dry prairie). Figure 22 suggests that specific reaches have the largest problem (e.g., near the confluence with the Minnesota River). Though the sample size was small, the data suggest that some communities are more susceptible to invasion than others; the 'mesic maple-oak' forest is at greatest risk from buckthorn. The authors noted that most invasives were found among vegetation that did not meet the definition of a known community type. They hypothesized that this is due to greater frequency or magnitude of disturbance in the past, which is consistent with the theoretical framework suggested above. At the other end of the spectrum, the southern floodplain forest had the lowest invasion rate, which they attributed to these sites having the least alteration of their flood regime. Silver maple seedlings and wood nettle (*Laportea candensis*) were the primary ground cover species in this forest type.

Among the exotic species found and treated by GLEPMT, more area was treated for common buckthorn than any other species. Other species that were treated over more than 1 ha (10,000 m^2) included common tansy, honeysuckle, Canada thistle, and garlic mustard (Table 21). The species that exhibit a strong and increasing trend are garlic mustard, burdock, bittercress, Canada thistle, common buckthorn, and Siberian elm (Table 21).

Sanders and Grochowski (2012) determined that buckthorn and honeysuckle were very frequent in the upland plots (9 of 10 locations). Not only were these two invasive taxa common across sites, they dwarfed the cover of the native species in these upland communities. In the floodplain sites (all three other forest types), garlic mustard was present in 10 of 23 locations and reed canarygrass in a little over half (13 of 23). Though the absolute amount of cover was lower, an exotic shrub was the most abundant shrub taxa in two of the three floodplain type of forests. No

honeysuckle was noted in the green ash-box elder or silver maple forest types. This pattern suggests that the wetter sites were less susceptible to invasion by woody invasives.

The MDNR (2005) data indicate that 30 terrestrial invasive species occur within the boundaries of MISS. This includes 19 forbs, four grasses, four trees, and three shrubs. The most frequent invaders, in descending order, are reed canarygrass, common buckthorn, and garlic mustard.

Sources of Expertise
James Cook, UWSP

Literature Cited

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. *BioScience* 54:677–685.

Callaway, R. M., E. J. Bedmar, K. O. Reinhart, C. G. Silvan, and J. Klironomos. 2011. Effects of soil biota from different ranges on *Robinia* invasion: acquiring mutualists and escaping pathogens. *Ecology* 92:1027–1035.

Czarapata, E. J. 2005. Invasive plants of the Upper Midwest – an illustrated guide to their identification and control. University of Wisconsin Press, Madison, Wisconsin.

Davis, M. A., J. P. Grime, and K. Thompson. 2000. Fluctuating resources in plant communities: a general theory of invisibility. *Journal of Ecology* 88:528–534.

Dickens, S. M., F. Gerhardt, and S. K. Collinge. 2005. Recreational portage trails as corridors facilitating non-native plant invasions of the Boundary Waters Canoe Area Wilderness (U.S.A.). *Conservation Biology* 19:1653–1657.

DiTomaso, J. M. 2000. Invasive weeds in rangelands: species, impacts and management. *Weed Science* 48:255–265.

Ehrenfeld, J. G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. *Ecosystems* 6:503–523.

Gignac, L. D., and M. T. Dale. 2007. Effects of size, shape and edge on vegetation in remnants of the upland boreal mixed-wood forest in agro-environments of Alberta, Canada. *Canadian Journal of Botany* 85:273–284.

GLEPMT (Great Lakes Exotic Plant Management Team). 2004. Mississippi National River and Recreation Area Exotic Plant Management Locations, 2004. Vector Dataset-1046710. Available at https://irma.nps.gov/App/Reference/Profile/1046710. (accessed January 17, 2013).

GLEPMT (Great Lakes Exotic Plant Management Team). 2005. Mississippi National River and Recreation Area Exotic Plant Management Locations, 2005. Vector Dataset-1046711. Available at https://irma.nps.gov/App/Reference/Profile/1046711. (accessed January 17, 2013).

GLEPMT (Great Lakes Exotic Plant Management Team). 2007. Mississippi National River and Recreation Area Exotic Plant Management Locations, 2007. Vector Dataset-1045805. Available at https://irma.nps.gov/App/Reference/Profile/1045805. (accessed January 17, 2013).

GLEPMT (Great Lakes Exotic Plant Management Team). 2010a. Mississippi National River and Recreation Area Exotic Plant Management Locations, 2009. Vector Dataset-1048770. Available at https://irma.nps.gov/App/Reference/Profile/1048770. (accessed January 17, 2013).

GLEPMT (Great Lakes Exotic Plant Management Team). 2010b. Mississippi National River and Recreation Area Exotic Plant Management Locations, 2010. Vector Dataset-2165744. Available at https://irma.nps.gov/App/Reference/Profile/2165744. (accessed January 17, 2013).

GLEPMT (Great Lakes Exotic Plant Management Team). 2011. Mississippi National River and Recreation Area Exotic Plant Management Locations, 2011. Vector Dataset-2180591. Available at https://irma.nps.gov/App/Reference/Profile/2180591. (accessed January 17, 2013).

GLEPMT (Great Lakes Exotic Plant Management Team). 2012. Great Lakes Exotic Plant Management Locations, 2012. Geodatabase-2203537. Available at https://irma.nps.gov/App/Reference/Profile/2203537. (accessed January 28, 2014).

GLEPMT (Great Lakes Exotic Plant Management Team). 2013. Great Lakes Exotic Plant Management Locations, 2013. Geodatabase-2203538. Available at https://irma.nps.gov/App/Reference/Profile/2203538. (accessed January 28, 2014).

Heneghan, L., F. Fatemi, L. Umek, K. Grady, K. Fagen, and M. Workman. 2006. The invasive shrub European buckthorn (*Rhamnus cathartica* L.) alters soil properties in Midwestern U.S. woodlands. *Applied Soil Ecology* 32:142–148.

Honnay, O., W. Verhaeghe, and M. Hermy. 2001. Plant community assembly along dendritic networks of small forest streams. *Ecology* 82:1691–1702.

Invasive Species Program. 2012. Invasive species of aquatic plants and wild animals in Minnesota: annual report for 2012. Minnesota Department of Natural Resources, St. Paul, Minnesota. Available at http://files.dnr.state.mn.us/aboutdnr/reports/legislative/2012_invasive_species_annual_report_final.pdf. (accessed February 10, 2014).

Klionsky, S. M., K. L. Amatangelo, and D. M. Waller. 2011. Above- and belowground impacts of European buckthorn (*Rhamnus cathartica*) on four native forbs. *Restoration Ecology* 19:728–737.

Larson, J., and D. Larson. 2009. Distribution and abundance of invasive non-indigenous plants and rare plants at two riverine national parks in the Great Lakes Network. Natural Resource Technical Report NPS/GLKN/NRTR—2008/161. National Park Service, Fort Collins,

Colorado. Available at https://irma.nps.gov/App/Reference/Profile/660996. (accessed August 27, 2013).

Lavoie, C., and A. Saint-Louis. 2008. Can a small park preserve its flora? A historical study of Bic National Park, Quebec. *Botany* 86:26–35.

Maerz, J. C., V. A. Nuzzo, and B. Blossey. 2009. Declines in woodland salamander abundance associated with non-native earthworm and plant invasions. *Conservation Biology* 23:975–981.

MDNR (Minnesota Department of Natural Resources). Division of Ecological Services. 2005. Invasive species – terrestrial observations. MDNR, St. Paul, Minnesota. Available at http://deli.dnr.state.mn.us. (accessed January 28, 2014).

Mortenson, S. G., and P. J. Weisberg. 2010. Does river regulation increase the dominance of invasive woody species in riparian landscapes? *Global Ecology and Biogeography* 19:562–574.

Potyondy, J. P., and T. W. Geier. 2011. Watershed condition classification technical guide. Publication FS-978. USDA Forest Service, Washington, D.C. Available at http://www.fs.fed.us/publications/watershed/watershed_classification_guide.pdf. (accessed August 27, 2013).

Rooney, T. P., S. M. Wiegmann, D. A. Rogers, and D. M. Waller. 2004. Biotic impoverishment and homogenization in unfragmented forest understory communities. *Conservation Biology* 18:787–798.

Sanders, S., and J. Grochowski. 2012. Implementation of a long-term vegetation monitoring program at the Mississippi National River and Recreation Area. Natural Resource Technical Report NPS/GLKN/NRTR—2012/616. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2188820. (accessed February 4, 2014).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

Woods, K. D. 1993. Effects of invasion by *Lonicera tatarica* L. on herbs and tree seedlings in four New England forests. *American Midland Naturalist* 130:62–74.

4.4.4 ***Birds***

Description

MISS is at the core of the northern end of the Mississippi Flyway, one of the four major flyways in North America (Figure 23). Tens of millions of birds and hundreds of species, over half of all found in North America, move up and down the Mississippi Flyway each year (NPS 2014). The bird checklist for MISS includes 264 known species (NPS n.d.). MISS includes all or parts of four of the 54 Important Bird Areas (IBAs) in Minnesota designated by the MDNR Nongame Wildlife Program and Audubon Minnesota. These are 24-Lower Minnesota River Valley, 29-Mississippi River Twin Cities, 31-North Metro Mississippi River, and 51-Vermillion Bottoms-Lower Cannon River (http://mn.audubon.org/important-bird-areas-3). The numbers of documented bird species during specified time periods are 153 for IBA 51 (1980-2005), 157 in the gorge at the upper end of IBA 29 (1988-2004), 207 near Grey Cloud Island at the lower end of IBA 29 (1965-2004), 234 for IBA 31 (1997-2006), and 260 for IBA 24 (n.d.) (National Audubon Society 2013a, 2013b, MDNR 2014a, 2014b). In IBA 29, six MN threatened and special concern species were noted during a 1997 survey (National Audubon Society 2013a).

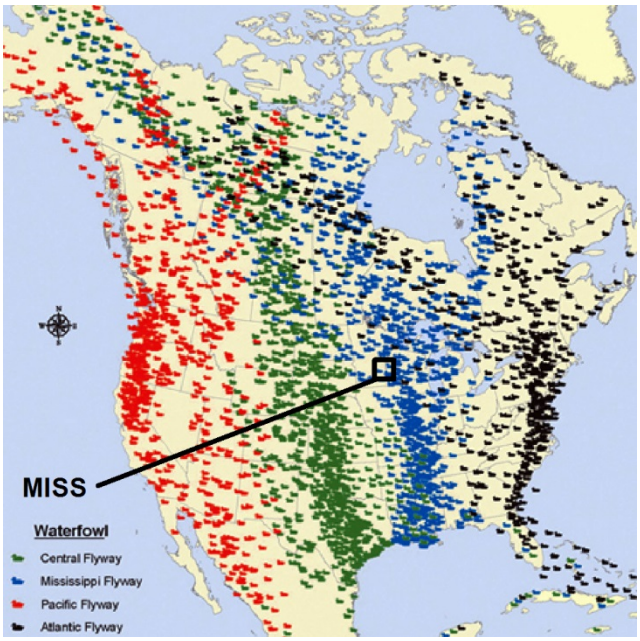


Figure 23. Location of Mississippi National River and Recreation Area on the Mississippi Flyway (original figure from Michael Johnson, North Dakota Game and Fish, at https://www.fws.gov/migratorybirds/NewReportsPublications/flyways.html.)

Point count bird surveys from 1993-1998 in the Upper Mississippi River National Wildlife and Fish Refuge, which is south of MISS, noted 150 species migrating along the Mississippi River (Nelson and Wlosinski 1999). The importance of the Flyway is even greater for waterfowl in general and canvasbacks and mergansers in particular (NPS 2014).

The habitat value within the boundaries of MISS is greater now than in the past due to loss of natural communities over the past 100 years in the watershed (see section 4.4.1) and the fragmentation of the landscape. Fragmentation leads to greater rates of local extinction and year-to-year turnover of area-sensitive bird species (Boulinier et al. 2001) and for migratory songbirds (Parker et al. 2005). Thus, the corridor value increases as the proportion of the adjacent watershed converted to agriculture and urban uses increases (Stauffer and Best 1980, Mossman 1991), since birds must find suitable resting and foraging habitat to successfully complete the migration between their breeding and wintering grounds. The vital importance of the current conditions and uses of the landscape around MISS are corroborated by the 'threat assessment' by the MDNR Nongame Wildlife Program and Audubon Minnesota; they list recreation/tourism and invasive species as the most important threats to the avian community in IBA 29.

The cumulative process of habitat loss has a wide range of direct and indirect effects on bird species (Kociolek et al. 2011), and the indirect may be more important (e.g., Butler et al. 2013). The habitat provided in the corridor is especially important due to the sharp decline in waterfowl (e.g., Vest et al. 2006, Brook et al. 2009) and neo-tropical migrants (Peterjohn et al. 1995, Groom and Grubb 2002) in the 1980s and 1990s. Contrary to popular perception, migratory birds use this habitat in all seasons (Nelson and Wlosinski 1999).

The corridor of vegetation associated with a river performs many ecological functions in the landscape; one of these is to provide avian habitat not presented, or well represented, in the adjacent uplands. Floodplain woodlands often contain greater densities of breeding birds than upland forests (Stauffer and Best 1980, Knutson et al. 1999, Groom and Grubb 2002). The value of the corridor to avian species varies over the course of the year; this is true for the amount of use by residents (Bowen et al. 2007) and due to migrants and occasional visitors. Plant communities within the corridor can provide one or more of the essential habitat needs of a species (breeding, nesting, roosting, rearing young, foraging, or escape cover) and thereby help sustain the avian community. Groom and Grub (2002) found that the presence of bird species in riparian habitat was more strongly correlated with woodland area than the width of the corridor.

The ecological value of a floodplain corridor is partially determined by the uniqueness and suite of features in the corridor relative to the surrounding landscape (Stauffer and Best 1980, Mossman 1991). These features can include vertical structure (general physiognomy, shrub or midstory layer), snags, a particular forage species or group, richness of one or more plant groups, large branched trees for nests, shallow standing water, gaps in the forest canopy, etc. (Stauffer and Best 1980, Grubaugh and Anderson 1988, Gabbe et al. 2002, Bowen et al. 2007). Along the Wisconsin River, the landscape pattern influenced bird use and density, but local habitat features exerted a stronger impact (Miller et al. 2004). In total, it is the structure that the avian community responds to, above all.

Along Pools 6-10, tree density declined, but there was a major shift in dominance toward silver maple from the 1840s to 1992 (Knutson and Klaas 1998). Along other smaller rivers in the region, tree density has increased, but tree size has declined (Bell 1997, Cook 2005). The loss of American elm in the canopy in the latter half of the 20th century altered structure (Romano 2010). These types of canopy structural changes may be important, as many species that show a strong affinity for savanna-type habitat in uplands will commonly use floodplain forests (Knutson et al. 1999).

Frequent, natural scale (~0.5 ha and less) canopy gap creation is probably important to the diversity of the avian community. In a southeastern floodplain forest, richness and abundance increased as gap size increased up to 0.5 ha (Moorman and Guynn 2001). Gaps in these forests were used during all bird-use periods, but more so in the non-breeding season (Bowen et al. 2007). Thus, the habitat feature(s) affecting bird behavior can change among seasons (Bowen et al. 2007). It was noted in a floodplain forest in Illinois that foliage gleaners preferentially selected specific tree species, and that less abundant species (e.g., cerulean warbler [*Dendroica cerulea*]) were more selective than abundant species (Gabbe et al. 2002).

Data and Methods

NPS staff compiled information from in-house surveys, surveys conducted by partners, and grey literature to describe the status of birds in the MISS State of the Park report (NPS 2013). In 2009 and 2010, standard bird surveys were conducted within the boundaries of the park by Minnesota Audubon and provided to NPS. Audubon conducts bird surveys at MISS during the migratory period between April and May and two surveys in early June (Gostomski et al. 2010).

Reference Condition

We suggest that an appropriate reference condition is a "least disturbed condition" or "the best of today's existing conditions" (Stoddard et al. 2006). However, there are major differences among various bird species and guilds; thus, an overall rating reflects only a portion of the situation.

Condition and Trend

We evaluate the current condition of the bird community in MISS as fair-to-good; our confidence in this is low due to lack of multiple surveys (within park boundaries) over an appropriate time frame for some species and groups.

An early draft of the MISS State of the Park report (NPS 2013) cited Martell and Homayoun (2010) to indicate that surveys in 2009 and 2010 survey documented 51 of 83 known migratory species and 17 of 21 known resident songbirds using the park. More years of survey data are needed to verify species and trends (NPS 2013), but migratory songbird populations are generally remaining stable (NPS 2014).

The bald eagle (*Haliaeetus leucocephalus*) population in MISS has been rising rapidly in recent years. The great blue heron (*Ardea herodias*) and great egret (*Ardea alba*) rookeries have remained stable. The number of water bird species in Pool 2 and the upper reaches of Pool 3 has remained stable, and the number of puddle and dabbling ducks in the same reach has increased slightly (NPS 2014).

Species of Concern Among migratory species, the vesper sparrow (*Pooecetes gramineus*), brown thrasher (*Toxostoma rufum*), dickcissel (*Spiza americana*), and field sparrow (*Spizella pusilla*), are 'species of special conservation concern' for MISS (NPS 2013). The North American Breeding Bird Survey (Sauer et al. 2012) shows population declines for these four species in MN from 1966-2011. The GLKN has identified the latter three species as priority bird species for the entire Great Lakes network based on information from the international bird conservation organization Partners in Flight and lists from the states of MN, Michigan, Indiana, and WI (NPS 2011). The Martell and Homayoun (2010) surveys of 2009 and 2010 documented that the dickcissel was rare in MISS and the other three were present in modest numbers. Trends for these species could not be determined (NPS 2013).

Martell and Homayoun (2010), in an early draft of the MISS State of the Park report, additionally listed cedar waxwing (*Bombycilla cedrorum*) and mourning dove (*Zenaida macroura*) as resident songbird 'species of special conservation concern.' Sauer et al. (2012) have similarly noted declines in these species in MN from 1966-2011. Martell and Homayoun (2010) found a decline in the number of cedar waxwings in 2009 and 2010, but the dove population was approximately constant.

Sources of Expertise
NPS 2013, 2014; Martell and Homayoun 2010; James Cook, UWSP.

Literature Cited

Bell, D. T. 1997. Eighteen years of change in an Illinois streamside deciduous forest. *Journal of the Torrey Botanical Society* 124:174–188.

Boulinier, T., J. D. Nichols, J. E. Hines, J. R. Sauer, C. H. Flather, and K. H. Pollock. 2001. Forest fragmentation and bird community dynamics: inference at regional scales. *Ecology* 82:1159–1169.

Bowen, L. T., C. E. Moorman, and J. C. Kilgo. 2007. Seasonal bird use of canopy gaps in a bottomland forest. *Wilson Journal of Ornithology* 119:77–88.

Brook, R. W., R. K. Ross, K. F. Abraham, D. L. Fronczak, and J. C. Davies. 2009. Evidence for black duck winter distribution change. *Journal of Wildlife Management* 73:98–103.

Butler, L. K., L. Ries, I.-A. Bisson, T. J. Hayden, M. M. Wikelski, and L. M. Romero. 2013. Opposite but analogous effects of road density on songbirds with contrasting habitat preferences. *Animal Conservation* 16:77–85.

Cook, J. E. 2005. Vegetation changes in a central Wisconsin floodplain from pre-settlement to the mid-21st century. *Journal of the Torrey Botanical Society* 132:492–504.

Gabbe, A. P., S. K. Robinson, and J. D. Brawn. 2002. Tree-species preferences of foraging insectivorous birds: implications for floodplain forest restoration. *Conservation Biology* 16:462–470.

Gostomski, T., M. Knutson, N. P. Danz, B. Route, and T. W. Sutherland. 2010. Landbird monitoring protocol, Great Lakes Inventory and Monitoring Network. Natural Resource Report NPS/GLKN/NRR—2010/225. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2124862. (accessed February 18, 2014).

Groom, J. D., and T. C. Grubb. 2002. Bird species associated with riparian woodland in fragmented, temperate-deciduous forest. *Conservation Biology* 16:832–836.

Grubaugh, J. W., and R. V. Anderson. 1988. Spatial and temporal availability of floodplain habitat: long-term changes at Pool 19, Mississippi River. *American Midland Naturalist* 119:402–410.

Knutson, M. G., and E. E. Klaas. 1998. Floodplain forest loss and changes in forest community composition and structure in the Upper Mississippi River: a wildlife habitat at risk. *Natural Areas Journal* 18:138–150.

Knutson, M. G., R. K. Hines, C. M. Sveum, T. J. Fox, and C. E. Korschgen. 1999. Floodplain forest songbirds of the Upper Mississippi River. *Passenger Pigeon* 61:307–310.

Kociolek, A. V., A. P. Clevenger, C. C. St. Clair, and D. S. Proppe. 2011. Effects of road networks on bird populations. *Conservation Biology* 25:241–249.

Martell, M., and T. Homayoun. 2010. Unpublished data supplied to the National Park Service, Great Lakes Inventory and Monitoring Network from Minnesota Audubon. On file at the Great Lakes Network office, Ashland, Wisconsin.

MDNR (Minnesota Department of Natural Resources). 2014a. Lower Minnesota River Valley IBA (web page). MDNR, St. Paul, Minnesota. Available at http://www.dnr.state.mn.us/minnesota_river_iba.html. (accessed January 21, 2014).

MDNR (Minnesota Department of Natural Resources). 2014b. North Metro Mississippi River IBA (web page). MDNR, St. Paul, Minnesota. Available at http://www.dnr.state.mn.us/northmetro_iba.html. (accessed January 21, 2014).

Miller, J. R., M. D. Dixon, and M. G. Turner. 2004. Response of avian communities in large-river floodplains to environmental variation at multiple scales. *Ecological Applications* 14:1394–1410.

Moorman, C. E., and D. C. Guynn. 2001. Effects of group-selection opening size on breeding bird habitat use in a bottomland forest. *Ecological Applications* 11:1680–1691.

Mossman, M. J. 1991. Breeding birds of the St. Croix River, Wisconsin and Minnesota. *Passenger Pigeon* 53:39–77.

National Audubon Society. 2013a. Mississippi River Twin Cities IBA (web page). National Audubon Society, New York, New York. Available at http://netapp.audubon.org/iba/Site/2421. (accessed January 21, 2014).

National Audubon Society. 2013b. Vermillion Bottoms-Lower Cannon River IBA (web page). National Audubon Society, New York, New York. Available at http://netapp.audubon.org/IBA/Reports/2922. (accessed January 21, 2014).

Nelson, E. C., and L. B. Wlosinski. 1999. Wetland birds of the Upper Mississippi River National Wildlife and Fish Refuge. *Passenger Pigeon* 61:299–307.

NPS (National Park Service). n.d. Birds of the Mississippi River. Available at http://www.nps.gov/miss/naturescience/birds.htm. (accessed February 18, 2014).

NPS (National Park Service). 2011. Monitoring landbirds in the Great Lakes Network parks. Great Lakes Network Resource Brief. GLKN, Ashland, Wisconsin. Available at https://irma.nps.gov/App/Reference/Profile/2196634. (accessed February 18, 2014).

NPS (National Park Service). 2013. State of the park report for Mississippi National River and Recreation Area. State of the Park Series No. 4. National Park Service, Washington, D.C. Available at http://www.nps.gov/stateoftheparks/. (accessed June 11, 2013).

NPS (National Park Service). 2014. MNNRA foundation document (draft). Mississippi National River and Recreation Area, St. Paul, Minnesota.

Parker, T. H., B. M. Stansberry, C. D. Becker, and P. S. Gipson. 2005. Edge and area effects on the occurrence of migrant forest songbirds. *Conservation Biology* 19:1157–1167.

Peterjohn, B. G., J. R. Sauer, and C. S. Robbins. 1995. Population trends from the North American Breeding Bird Survey. Pages 3–39 *in* T. E. Martin and D. M. Finch, editors. Ecology and management of Neotropical migratory birds: a synthesis and review of critical issues. Oxford University Press, Oxford, United Kingdom.

Romano, S. P. 2010. Our current understanding of the Upper Mississippi River System floodplain forest. *Hydrobiologia* 640:115–124.

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2012. The North American breeding bird survey, results and analysis 1966–2011. Version 07.03.2013. USGS Patuxent Wildlife Research Center, Laurel, Maryland. Available at http://www.mbr-pwrc.usgs.gov/bbs/bbs.html. (accessed January 28, 2014).

Stauffer, D. F., and L. B. Best. 1980. Habitat selection by birds of riparian communities: evaluating effects of habitat alterations. *Journal of Wildlife Management* 44:1–15.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

Vest, J. L., R. M. Kaminski, A. D. Afton, and F. J. Vilella. 2006. Body mass of lesser scaup during fall and winter in the Mississippi flyway. *Journal of Wildlife Management* 70:1789–1795.

4.4.5 ***Fish Community***

Description

Schmidt and Proulx (2009) reported historic fish species numbers of 60 for Pool A (above Coon Rapids Dam), 31 for Pool B (above the historic location of St. Anthony Falls), 44 for Pool 1, 79 for Pool 2, and 77 for Pool 3. In 1996, 72 species were collected in sampling at river sites on the Mississippi, Minnesota, and St. Croix Rivers in and near MISS (Goldstein et al. 1999). The 2004 species checklist for Fishes of Minnesota (Hatch and Schmidt 2004) lists 127 fish species (119 native and eight introduced) for the lower Mississippi River basin in MN. In 2006, over 100 fish species were considered present or likely present within MISS (Lafrancois et al. 2007).

MDNR surveys from 2006-2008 found eight species of greatest conservation concern in the Mississippi River from the Coon Rapids Dam to Lock and Dam #3 (Schmidt and Proulx 2009). In 2013, one species reported to be in or near MISS was MN-endangered, three were MN-threatened, and five were of special concern in MN (MDNR 2013a) (Table 22).

Table 22. Minnesota endangered, threatened, and special concern fish in Mississippi National River and Recreation Area (Lafrancois et al. 2007, Larson and Larson 2009, Schmidt and Proulx 2009, MDNR 2013a).

Scientific Name	Common name	Minnesota status
Hybopsis amnis	Pallid shiner	Endangered
Ictiobus niger	Black buffalo	Threatened
Notropis anogenus	Pugnose shiner	Threatened
Polyodon spathula	Paddlefish	Threatened
Acipenser fulvescens	Lake sturgeon	Special Concern
Anguilla rostrata	American eel	Special Concern
Cycleptus elongatus	Blue sucker	Special Concern
Etheostoma microperca	Least darter	Special Concern
Morone mississippiensis	Yellow bass	Special Concern

Historically, St. Anthony Falls was the major barrier to fish migration in the Mississippi River in MISS. Approximately 60 species were found above the falls and over 100 were found below (Eddy et al. 1963 in Lafrancois et al. 2007). However, lock and dam installation moved the fish migration barrier upstream to the Coon Rapids dam (Russell and Weller 2012). In June 2015, the Upper St. Anthony Falls lock is to be closed, which will help prevent the movement of invasive Asian carp into northern MN waters (USACE 2015).

Fish populations in the metropolitan portion of the Mississippi River declined dramatically following European settlement, but conditions have greatly improved since the passage of the Clean Water Act in 1972 (Russell and Weller 2012).

Goldstein et al. (1999) examined fish community composition in relationship to environmental factors and land use in the part of the UMR basin that includes MISS. The authors noted that beyond the effects of natural barriers, the fish community composition of the Mississippi River changes in and downstream of the Twin Cities metro area because of the lock and dam system, dredging, channelization, increased impervious surface, warmer waters, and nutrient inputs from the Minnesota River basin. The result is a fish community that contains more lentic (lake) species, species with higher thermal tolerance, and an increase in planktivores.

Anglers currently regard the metropolitan portion of the Mississippi River as a world-class fishery (Russell and Weller 2012). Lafrancois et al. (2007) described an “outstanding” catch-and-release trophy fishery for walleye (*Sander vitreus*) and smallmouth bass (*Micropterus dolomieui*) in Pool 2, helped along by special MDNR angling restrictions implemented in the early 1990s. However, downstream of the confluence with the Minnesota River, the decline in water clarity makes Pool 2 suboptimal for smallmouth bass and other game fish that feed by sight (MDNR 2008).

Data and Methods

Fish population surveys were conducted by MDNR for Pool 1 (up to the Coon Rapids Dam) in 2009 (MDNR 2013b, c), Pool 2 in 2008 (MDNR 2008), and Pool 3 in 2014 (MDNR 2014).

MPCA (2012, 2013) conducted watershed monitoring for the Mississippi River–Twin Cities watershed and the Vermillion River watershed and produced assessment reports in 2012 and 2013, respectively. These watersheds cover 88.9% and 5.7%, respectively, of the river km in MISS. The Minnesota River assessment is scheduled for 2014.

The reports included a fish Index of Biological Integrity (IBI), which tries to convey an integrated picture of ecosystem health through a suite of metrics that reflect the taxonomic composition, trophic relationships, abundance, and condition of organisms in an aquatic community (Karr and Yoder 2004 in Dolph et al. 2010). A score for a fish IBI (Niemela and Feist 2002) was calculated for 14 nonchannelized reaches in six subwatersheds of the Twin Cities watershed. Samples were collected only from tributaries, not from the Mississippi River proper. A fish IBI score was calculated for nine nonchannelized reaches in three subwatersheds of the Vermillion River, including tributaries and some headwater areas of the river itself.

Reference Condition

Fish populations in the Mississippi River in MISS should be similar to presettlement fish populations in species richness and fish numbers. This is a historic condition (Stoddard et al. 2006).

The tributaries that contribute to the major rivers within MISS should be fully supporting of aquatic life according to the fish IBI metric, a multimetric index. This is a "least disturbed condition" or "the best of today's existing conditions" (Stoddard et al. 2006).

Condition and Trend

The condition of the fish community in the Mississippi River in MISS is believed to be good, but the trend is unknown, and the ranking has a low degree of confidence. The number of native species reported is similar to the presettlement numbers, and there is a significant sport fishery. However, there are few consistent surveys of aquatic life, and there is inadequate data to adequately manage the river's fishery (Russell and Weller 2012).

The MPCA assessment for fish for two of the three major watersheds in MISS is of significant concern, with an unknown trend. Our confidence in this assessment is high. Of 14 stream segments assessed for the fish IBI in the Mississippi River – Twin Cities watershed, all were rated EXS (exceeds criteria, potentially severe impairment). Eleven were ranked non-supporting of aquatic life, and the ranking of the other three was deferred. In the Vermillion River watershed, three of nine stream segments met the standard for the fish IBI, two were rated EXP (exceeds criteria, potential impairment), and five were rated EXS. Three segments were ranked supporting of aquatic life, five were non-supporting, and one was deferred. No trend could be established, since the MPCA process uses ten year averages to determine its rankings.

Sources of Expertise

Christine Mechenich, UWSP

Literature Cited

Dolph, C. L., A. Y. Sheshukov, C. J. Chizinski, B. Vondracek, and B. Wilson. 2010. The index of biological integrity and the bootstrap: Can random sampling error affect stream impairment decisions? *Ecological Indicators* 10:527–537.

Eddy, S., J. Moyle, and J. Underhill. 1963. The fish fauna of the Mississippi River above St. Anthony Falls as related to the effectiveness of this falls as a migration barrier. *Proceedings of the Minnesota Academy of Science* 30:111–115.

Goldstein, R., K. Lee, P. Talmage, J. Stauffer, and J. Anderson. 1999. Relation of fish community composition to environmental factors and land use in part of the Upper Mississippi River Basin, 1995-1997. Water-Resources Investigations Report 99-4034, US Geological Survey, Mounds View, Minnesota. Available at http://pubs.er.usgs.gov/publication/wri994034. (accessed March 4, 2014).

Hatch, J. T., and K. Schmidt. 2004. Fishes of Minnesota: Distribution in 8 major drainage basins. James Ford Bell Museum of Natural History, University of Minnesota, Minneapolis, Minnesota. Available at http://academics.cehd.umn.edu/hatch/research/fish/fishes/distribution_table.html. (accessed May 12, 2015).

Karr, J. R., and C. O. Yoder. 2004. Biological assessment and criteria improve total maximum daily load decision making. *Journal of Environmental Engineering* 130:594–604.

Lafrancois, B. M., D. L. Vana-Miller, and S. P. Johnson. 2007. Water resources information and issues overview, Mississippi National River and Recreation Area. Natural Resource Technical Report NPS/NRWRD/NRTR—2007/364. National Park Service, Water Resources Division, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/648364. (accessed March 4, 2014).

Larson, J., and D. Larson. 2009. Distribution and abundance of invasive non-indigenous plants and rare plants at two riverine national parks in the Great Lakes Network. Natural Resource Technical Report NPS/GLKN/NRTR—2008/161. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/660996. (accessed August 27, 2013).

MDNR (Minnesota Department of Natural Resources). 2008. Fisheries Lake Survey U.S. Lock & Dam #2 Pool, Survey Date: 07/21/2008. MDNR, St. Paul, Minnesota. Available at http://www.dnr.state.mn.us/lakefind/showreport.html?downum=19000500. (accessed May 4, 2015).

MDNR (Minnesota Department of Natural Resources). 2013a. Minnesota's list of endangered, threatened, and special concern species. MDNR, St. Paul, Minnesota. Available at http://files.dnr.state.mn.us/natural_resources/ets/endlist.pdf. (accessed March 4, 2014).

MDNR (Minnesota Department of Natural Resources). 2013b. Fisheries Management Standard Lake Survey Report, St. Anthony Falls Pool Population Assessment. DOW Number: 27-0033-00 Survey ID Date: 08/11/2009, Standard Lake Survey Report revision: 04/05/2011. Data Date: 07/25/2013. Unpublished report. MDNR, St. Paul, Minnesota.

MDNR (Minnesota Department of Natural Resources). 2013c. Fisheries Management Standard Lake Survey Report, U.S. Lock & Dam #1 Pool Population Assessment. DOW Number: 27-0003-00, Survey ID Date: 08/10/2009, Standard Lake Survey Report revision: 04/05/2011-RJE. Data Date: 07/25/2013. Unpublished report. MDNR, St. Paul, Minnesota.

MDNR (Minnesota Department of Natural Resources). 2014. Fisheries Lake Survey U.S. Lock & Dam #3 Pool, Survey Date: 10/16/2014, Inventory Number: 25001700. MDNR, St. Paul,

Minnesota. Available at http://www.dnr.state.mn.us/lakefind/showreport.html?downum=25001700. (accessed May 12, 2015).

MPCA (Minnesota Pollution Control Agency). 2012. Vermillion River watershed monitoring and assessment report. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=18751. (accessed January 27, 2014).

MPCA (Minnesota Pollution Control Agency). 2013. Mississippi River - Twin Cities watershed monitoring and assessment report. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=20042. (accessed January 27, 2014).

Niemela, S., and M. Feist. 2002. Index of biotic integrity (IBI) guidance for coolwater rivers and streams of the Upper Mississippi River Basin in Minnesota. Minnesota Pollution Control Agency, Biological Monitoring Program, St. Paul, Minnesota.

Russell, T. A., and L. Weller. 2012. State of the river report: water quality and river health in the Metro Mississippi River. Friends of the Mississippi River and National Park Service, St. Paul, Minnesota. Available at http://stateoftheriver.com/. (accessed May 12, 2015).

Schmidt, K., and N. Proulx. 2009. State Wildlife Grant Final Report: Status and critical habitat of rare fish species in the Mississippi River from the Coon Rapids Dam to the Iowa border. Division of Ecological Resources, Minnesota Department of Natural Resources, St. Paul, Minnesota. Available at http://files.dnr.state.mn.us/eco/nongame/projects/consgrant_reports/2009/2009_schmidt_proulx2.pdf. (accessed May 4, 2015).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

USACE (United States Army Corps of Engineers). 2015. Upper St. Anthony Falls lock closure, Upper Mississippi River. Information Paper 44. USACE, St. Paul, Minnesota. Available at http://www.mvp.usace.army.mil/Home/Projects/tabid/18156/Article/571138/upper-st-anthony-falls-lock-closure.aspx. (accessed May 18, 2015).

4.4.6 Aquatic Non-Native and Invasive Species – Asian Carp

Description

Non-native species interact with the environment in unpredictable ways, and at least ten percent of non-native species are considered to be invasive and negatively affect ecosystem health (Environment Canada and USEPA 2009). Invasive species are defined as those whose introduction cause or are likely to cause harm to the environment, human health, or the economy (USEPA 2008). They are the second-leading cause of loss of biodiversity and species extinction in aquatic environments worldwide. Common sources of aquatic invasive species (AIS) include improperly cleaned boats, aquaculture escapes, and accidental and/or intentional introductions (USEPA 2008). Plant and animal exotics ranked first among 46 Vital Signs important to monitor in GLKN parks (NPS 2007).

Species recommended for monitoring at MISS by Quinlan et al. (2007) were rusty crayfish (*Orconectes rusticus*), quagga mussels (*Dreissena bugensis*), and white perch (*Morone americana*). The State of the Park report (NPS 2013) does not mention aquatic invasive species. The draft Foundation Document (NPS 2014) indicates that zebra mussels (*Dreissena polymorpha*) have been found in the MISS corridor, but not at problem levels, and that several invasive plant species (water lettuce, [*Pistia stratiodes*]; water hyacinth [*Eicchornia crassipes*]; and parrot feather [*Myriophyllum aquaticum*]) have been found in Pool 5 (MDNR 2012, USFWS 2013) and are feared to be advancing upriver.

The main AIS focus of concern of MISS resource managers are the various species of Asian carp in the family Cyprinidae (bighead carp [*Aristhythys nobilis*], silver carp [*Hypothalmichthys molitrix*], black carp [*Mylopharyngodon piceus*], and grass carp [*Ctenopharyngodon idella*]). Asian carp are of concern to MISS resource managers because they grow to large sizes (23-50 kg) and eat up to 20-40% of their body weight daily. They could disrupt the natural food web by consuming the plankton needed by smaller fish that feed sport fish. Silver carp can also leap high out of the water and injure people using the water for recreation (http://www.nps.gov/miss/naturescience/ascarpover.htm). They have been advancing upriver; isolated bighead carp were collected from Lake Pepin (Pool 4) (2003, 2007), Pool 5a (2009), and Pool 6 (2012), and a silver carp was collected from Pool 6 (2012) (MDNR 2013). In 2013, they were detected in MISS for the first time.

Data and Methods

A 2007 report (Quinlan et al. 2007) assessed the threat of AIS in GLKN parks, including MISS, and produced a list of species most important to monitor.

The MDNR (2012) reviewed the current state of knowledge of Asian carp in Minnesota in an annual report to the legislature. Amberg et al. (2013) followed up on the detection of Asian carp DNA in the St. Croix River and also sampled part of the Mississippi River in MISS. A Minnesota Invasive Carp Action Plan was developed in 2011 (Ad Hoc Asian Carp Task Force 2011) and updated in 2014 (Invasive Carp Work Group 2014).

Reference Condition

Asian carp should not be present in MISS, since they may be detrimental to recreation or the functioning of natural aquatic ecosystems. This represents a “historic condition” (Stoddard et al. 2006).

Condition and Trend

In 1996, an Asian carp was reported for the first time on the St. Croix River, and bighead carp were caught on the St. Croix near the confluence with the Mississippi in 2011 and 2012 (MDNR 2012). In 2011, testing showed the presence of silver carp DNA in environmental samples on the St. Croix River, but not in Pool 2 (Hickox et al. 2011). However, more refined testing in 2012, as well as electrofishing and netting surveys, did not confirm the presence of bighead or silver carp DNA in the St. Croix River or detect it in the Mississippi River (Amberg et al. 2013).

Invasive Carp are not known to be in MN waters in large numbers (numbers that can be estimated) and no natural reproduction has been documented (Invasive Carp Work Group 2014). Asian carp are not considered to have reproducing populations above Pool 17 in the Mississippi River (MDNR 2012). However, a grass carp was collected by MDNR in Pool 2 in 2013 (http://nas.er.usgs.gov/queries/CollectionInfo.aspx?SpeciesID=514&State=MN). In July 2014, both a silver and bighead carp were collected in Pool 2 (Invasive Carp Work Group 2014), and these contained eggs, suggesting the possibility of natural reproduction (Nancy Duncan, Natural Resource Program Manager, MISS, email August 7, 2014). A bighead carp was also collected in Pool 2 in October 2014 (Invasive Carp Work Group 2014). MDNR describes Asian carp as "an urgent issue for the state, requiring immediate action" (MDNR 2013).

We rate the condition of MISS for Asian carp as of significant concern because of their detection in Pool 2 in 2013 and 2014. The trend is unknown. Our confidence in this assessment is good.

Actions are being taken to prevent the further spread of Asian carp in the Mississippi River. The Ad Hoc Asian Carp Task Force (2011), in its report section on prevention and deterrence, recommended installing deterrent barriers at the mouth of the St. Croix River and at lock chambers at Lock and Dams 1, 2 (both within MISS), 5 (below Lake Pepin), and 19. The task force further recommended a permanent fish barrier at Upper St. Anthony Falls and a back-up barrier at the upstream Coon Rapids Dam. Agreement could not be reached on emergency closure of the locks at Upper St. Anthony Falls or Lock and Dam 1 because the USACE did not then have authority to take such action on the basis of an invasive species. Agreement was reached on asking boaters to voluntarily avoid using the locks; MISS has done this on its website (http://www.nps.gov/miss/naturescience/minimizing-lock-usage.htm). In 2014, the Water Resources Reform and Development Act provided the needed authority and directed the Secretary of the Army to close the Upper St. Anthony Falls lock within one year; closure is to occur in June, 2015 (USACE 2015).

Sources of Expertise

Quinlan et al. 2007; Amberg et al. 2013; Christine Mechenich, UWSP.

Literature Cited

Ad Hoc Asian Carp Task Force. 2011. Asian carp action plan: a plan to assess the threat posed by Asian carp and actions needed to minimize their impact in Minnesota. Minnesota Department of Natural Resources, St. Paul, Minnesota. Available at http://files.dnr.state.mn.us/natural_resources/invasives/aquaticanimals/asiancarp/asiancarpactionplan.pdf. (accessed January 2, 2014).

Amberg, J. J., S. G. McCalla, L. Miller, P. Sorensen, and M. P. Gaikowski. 2013. Detection of environmental DNA of bigheaded carps in samples collected from selected locations in the St. Croix River and in the Mississippi River. United States Geological Survey Open-File Report 2013–1080. USGS, Reston, Virginia. Available at http://www.maisrc.umn.edu/files/2013/04/OFR2013-1080-web-final.pdf. (accessed April 23, 2013).

Environment Canada and USEPA (United States Environmental Protection Agency). 2009. State of the Great Lakes 2009: invasive species. United States Environmental Protection Agency, Chicago, Illinois. Available at http://www.epa.gov/solec/sogl2009/invasivespecies.pdf. (accessed April 23, 2013).

Hickox, T, F-C Hsu, R Wong, and T Brito-Robinson. 2011. eDNA Surveillance of Asian Carp on the St. Croix and Mississippi Rivers. Report to the Minnesota Department of Natural Resources, St. Paul, August 4, 2011. Available at http://files.dnr.state.mn.us/eco/invasives/edna-stcroix-mississippi080411.pdf (accessed January 2, 2014).

Invasive Carp Work Group. 2014. Minnesota invasive carp action plan. Original plan – 11/2/2011, Update 12/15/2014. Available at http://files.dnr.state.mn.us/natural_resources/invasives/carp-action-plan-draft.pdf. (accessed May 14, 2015).

MDNR (Minnesota Department of Natural Resources). 2012. Invasive species of aquatic plants and wild animals in Minnesota: annual report 2012. MDNR, St. Paul, Minnesota. Available at http://archive.leg.state.mn.us/docs/2013/mandated/130421.pdf. (accessed January 2, 2014).

MDNR (Minnesota Department of Natural Resources). 2013. New test results show no DNA evidence of Asian carp, but scientists urge continued action (press release). MDNR, St. Paul, Minnesota. Available at http://news.dnr.state.mn.us/2013/04/04/new-test-results-show-no-dna-evidence-of-asian-carp-but-scientists-urge-continued-action/#more-11678. (accessed January 2, 2014).

NPS (National Park Service). 2007. Long-term Ecological Monitoring Plan: Great Lakes Inventory and Monitoring Network. Natural Resource Report NPS/GLKN/NRR-2007/001. National Park Service. Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/645523. (accessed September 23, 2013).

NPS (National Park Service). 2013. State of the park report for Mississippi National River and Recreation Area. State of the Park Series No. 4. National Park Service, Washington, D.C. Available at http://www.nps.gov/stateoftheparks/. (accessed June 11, 2013).

NPS (National Park Service). 2014. MNNRA foundation document (draft). Mississippi National River and Recreation Area, St. Paul, Minnesota.

Quinlan, H., M. Dryer, G. Czypinski, J. Pyatskowit, and J. Krajniak. 2007. Strategic approach to problem identification and monitoring of aquatic invasive species within Great Lakes Inventory and Monitoring Network Park units. GLKN/2007/08. U.S. Fish and Wildlife

Service, Ashland Fishery Resources Office, Ashland, Wisconsin, for National Park Service, Great Lakes Inventory and Monitoring Network, Ashland, Wisconsin.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

USACE (United States Army Corps of Engineers). 2015. Upper St. Anthony Falls lock closure, Upper Mississippi River. Information Paper 44. USACE, St. Paul, Minnesota. Available at http://www.mvp.usace.army.mil/Home/Projects/tabid/18156/Article/571138/upper-st-anthony-falls-lock-closure.aspx. (accessed May 18, 2015).

USEPA (United States Environmental Protection Agency. 2008. Invasive species website. Available at http://www.epa.gov/owow/invasive_species/. (accessed April 29, 2013).

USFWS (United States Fish and Wildlife Service). 2013. A new exotic threat to the Upper Mississippi River (web page). Available at http://www.fws.gov/midwest/news/571.html. (accessed January 2, 2014).

4.4.7 ***Aquatic Macroinvertebrates***

Description

One of the fundamental resources and values of MISS is "healthy aquatic ecosystems that provide for a rich and diverse assemblage of fish, mussels, macro-invertebrates and other species, as well as the opportunity for scientific study" (NPS 2014). The indicator species and populations of concern to MISS in this ecosystem are rooted aquatic plants, macroinvertebrates, turtles, river otter, frogs, mussels, and birds.

Aquatic macroinvertebrates are an important, if often overlooked, contributing community of most ecosystems. In addition to their obvious role as food sources for fish, herptiles, and birds, aquatic macroinvertebrates are important processors of organic matter. Aquatic macroinvertebrates can be used to infer and monitor the environmental condition of a stream and contributing watershed, provided the ecological requirements of resident taxa are known. This biological monitoring can supplement physical and chemical testing to more adequately assess water resource quality (Stroom and Richards 2000, Brady and Breneman 2008).

Aquatic macroinvertebrates are ideally suited to environmental condition assessments for several reasons. They are common in most streams, easy to collect, relatively immobile, easy to identify, and many taxa have life cycles of a year or greater (Hilsenhoff 1977). Their immobility causes them to be continually exposed to environmental conditions and stressors (Barbour et al. 1999); hence, aquatic macroinvertebrates function as *in situ* environmental barometers. However, aquatic macroinvertebrate studies are infrequently conducted on nonwadeable rivers such as the Mississippi River in MISS because of their more complex hydrology and the greater difficulty of sample collection (McCord and Kuhl 2012 and citations therein).

Limited historic aquatic macroinvertebrate information was found for MISS. Burrowing mayflies (*Hexagenia* spp.) were very scarce in Pools 2 and 3 in the 1960s, but returned in the mid-1980s with improvements in wastewater treatment (USEPA 2000). These are members of the order Ephemeroptera and are sensitive to low dissolved oxygen levels. The Long Term Resource

Monitoring Program report for the UMR (Johnson and Hagerty 2008) reported stable populations and trends for burrowing mayflies and fingernail clams (*Musculium transversum*) from 1993-2004 in Pool 4, downstream of MISS. The State of the Park report (NPS 2013) describes an improving trend for aquatic macroinvertebrates since the 1970s, corresponding to improvements in water quality, with declines during low rainfall years as a result of less dilution of pollutants entering the river.

Data and Methods

MPCA (2012, 2013) conducted watershed monitoring for the Mississippi River–Twin Cities watershed and the Vermillion River watershed and produced assessment reports in 2012 and 2013, respectively. These watersheds cover 88.9% and 5.7%, respectively, of the river km in MISS. The Minnesota River assessment is scheduled for 2014. A score for a macroinvertebrate Index of Biological Integrity (mIBI) (Genet and Chihart 2004) was calculated for six subwatersheds of the Twin Cities watershed. mIBIs were calculated for tributaries, not the Mississippi River itself, because the method is appropriate only for drainage areas <~1,300 km^2 (500 mi^2). A mIBI score was calculated for three subwatersheds of the Vermillion River, including tributaries and some headwater areas of the river itself. A mIBI uses macroinvertebrate metrics to detect human influence by weighting environmental variables among multiple spatial scales to characterize human influence in a way relevant to the biota and quantifying the relative influence of environmental variables among multiple spatial scales (Weigel 2003).

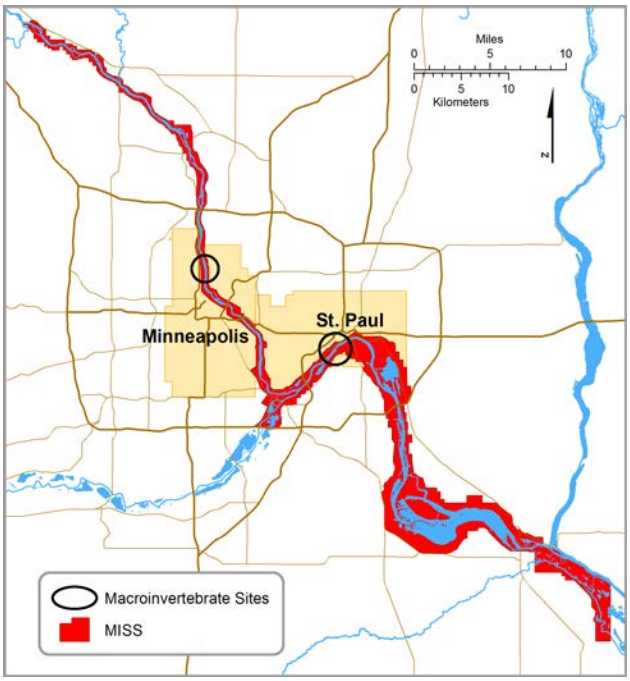


Figure 24. Aquatic macroinvertebrate sampling sites in the Mississippi River, 2007-2009 (McCord and Kuhl 2012).

No systematic aquatic macroinvertebrate sampling data were found for the Mississippi River in MISS. However, McCord and Kuhl (2012) collected macroinvertebrate samples from 2007-2009 at six sites from river km 1377-1379 (near the Riverside Generating Station in Minneapolis, upstream of Upper St. Anthony Falls) and six sites from river km 1350-1353 (near the High Bridge Generating Station in downtown St. Paul, in upper Pool 2) (Figure 24). The authors focused on seasonal variation and found that community metrics consistently differed between study periods (months), but differed only sporadically between study years or sampling depths. The taxonomic composition of the macroinvertebrate assemblage was similar to that reported in other great river studies (the Upper Mississippi near its confluence with the Ohio, the Ohio, and the Lower Missouri Rivers). However, the densities and relative abundances of major groups in this study differed from those in the Upper Mississippi near the Ohio and the Lower Missouri for reasons that may have included the type of sampling equipment, location of samplers, and flow regimes.

Weigel and Dimick (2011) developed a mIBI for nonwadeable rivers of WI, which they suggested was also applicable to border rivers in Minnesota. This index is appropriate for use in MISS (personal communication, Jeff Dimick, 1/27/14).

Reference Condition

Community-level bioassessments should incorporate several classes of metrics, as different metrics describe different aspects of the community and may provide differing insights to the ecological stressors influencing the community. Suites of metrics calculated on a dataset spanning multiple years can provide inference to trends in environmental condition of the streams sampled.

As one reference condition, the tributaries that contribute to the major rivers within MISS should be fully supporting of aquatic life according to the mIBI metric, a multimetric index (Genet and Chihart 2004).

Little aquatic macroinvertebrate data collection has occurred recently in MISS itself (NPS 2014), and data published in McCord and Kuhl (2012) were insufficiently detailed to calculate an mIBI. Therefore, as a second reference condition, we have selected a single index for which limited data are available. The aquatic macroinvertebrate community in the Mississippi, Minnesota, and Vermillion rivers within MISS should be in good condition according to the Ephemeroptera-Plecoptera-Trichoptera (EPT) taxa richness (EPT-T) metric. This metric describes the number of taxa present in these three sensitive groups, and higher values are correlated with higher-quality communities (Barbour et al. 1999).

Acceptable scores on the mIBI and EPT-T are “least disturbed conditions” or “the best of today’s existing conditions” (Stoddard et al. 2006).

Condition and Trend

The MPCA assessment for aquatic macroinvertebrates for two of the three major watersheds in MISS is of significant concern, with an unknown trend. Our confidence in this assessment is high. Of 22 stream segments assessed, only one met standards for aquatic life in MN (Table 23). Ten showed potential impairment, and 11 showed potential severe impairment. Data were collected over a ten-year span, but mainly in the year listed in the table.

We rate the condition of the aquatic macroinvertebrate community at two locations in the Mississippi River in MISS as of moderate concern, with an unknown trend. Our confidence in the assessment is low because of the limited data set. We compared the EPT-T scores calculated by McCord and Kuhl (2012) to the scoring criteria of Weigel and Dimick (2011). Only August scores were used. These mean scores (n=24 samples) were 6.4 for the Minneapolis site and 11.2 for the St. Paul site, earning rankings of “poor” and “fair,” respectively.

Our overall ranking for the aquatic macroinvertebrate community in MISS is of significant concern, with an unknown trend and a low degree of confidence.

Table 23. Assessment summary for stream water quality in the Mississippi River –Twin Cities and Vermillion River watersheds (MPCA 2012, 2013).

Year	HUC 11	Name	Area (km^2)	Stream segments assessed for mIBI	Meets aquatic life standard	Potential impairment	Potential severe impairment
2010	07010206820	Elm Creek	274.8	5	0	3	2
2010	07010206840	Sand Creek	59.8	1	0	0	1
2010	07010206850	Coon Creek	242.7	1	0	1	0
2010	07010206860	Rice Creek	498.3	3	0	1	2
2010	07010206890	Minnehaha Creek	111.1	2	0	1	1
2010	07010206910	St. Paul	563.8	1	0	0	1
2012	07040001055	Vermillion River	448.1	7	1	3	3
2012	07040001035	North Vermillion River	194.2	1	0	1	0
2012	07040001075	Mississippi River (direct)	129.5	1	0	0	1
		Total		22	1	10	11

Sources of Expertise

Jeffrey J. Dimick, Laboratory Supervisor, Aquatic Biomonitoring Laboratory, UWSP; Christine Mechenich, UWSP.

Literature Cited

Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid bioassessment protocols for use in wadeable streams and rivers: periphyton, benthic macroinvertebrates and fish, Second Edition. EPA 841-B-99-002. USEPA Office of Water, Washington, D.C.

Brady, V., and D. Breneman. 2008. Poplar River macroinvertebrate and habitat survey. Natural Resources Research Institute, Technical Report NRRI/TR-2008/27, 46 pp. University of Minnesota-Duluth, Duluth, Minnesota.

Genet, J., and J. Chirhart. 2004. Development of a Macroinvertebrate Index of Biological Integrity (MIBI) for Rivers and Streams of the Upper Mississippi River Basin. Minnesota Pollution Control Agency Biological Monitoring Program, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=6093. (accessed January 27, 2014).

Hilsenhoff, W. L. 1977. Use of arthropods to evaluate water quality of streams. Technical Bulletin (100) 1–15. Wisconsin Department of Natural Resources, Madison, Wisconsin.

Johnson, B. L., and K. H. Hagerty, editors. 2008. Status and trends of selected resources in the Upper Mississippi River System. Technical Report LTRMP 2008-T002. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. Available at http://pubs.usgs.gov/mis/LTRMP2008-T002/. (accessed January 27, 2014).

McCord, S. B., and B. A. Kuhl. 2012. Macroinvertebrate community structure and its seasonal variation in the Upper Mississippi River, USA: A case study. *Journal of Freshwater Ecology* 28:63–78.

MPCA (Minnesota Pollution Control Agency). 2012. Vermillion River watershed monitoring and assessment report. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=18751. (accessed January 27, 2014).

MPCA (Minnesota Pollution Control Agency). 2013. Mississippi River - Twin Cities watershed monitoring and assessment report. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=20042. (accessed January 27, 2014).

NPS (National Park Service). 2013. State of the park report for Mississippi National River and Recreation Area. State of the Park Series No. 4. National Park Service, Washington, D.C. Available at http://www.nps.gov/stateoftheparks/. (accessed June 11, 2013).

NPS (National Park Service). 2014. MNNRA foundation document (draft). Mississippi National River and Recreation Area, St. Paul, Minnesota.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

Stroom, K., and C. Richards. 2000. Development of macroinvertebrate biocriteria for streams of Minnesota's Lake Superior watershed. Natural Resources Research Institute, Technical Report NRRI/TR-2000/19, 44 pp. University of Minnesota Duluth, Duluth, Minnesota.

USEPA (United States Environmental Protection Agency). 2000. Progress in water quality: An evaluation of the national investment in municipal wastewater treatment. EPA 832-R-00-008. U.S. Environmental Protection Agency. Washington, D.C. Available at http://water.epa.gov/polwaste/wastewater/treatment/upload/2002_06_28_wquality_chap12.pdf (accessed January 6, 2014).

Weigel, B. M. 2003. Development of stream macroinvertebrate models that predict watershed and local stressors in Wisconsin. *Journal of the North American Benthological Society* 22:123–142.

Weigel, B. M., and J. J. Dimick. 2011. Development, validation, and application of a macroinvertebrate-based index of biotic integrity for nonwadeable rivers of Wisconsin. *Journal of the North American Benthological Society* 30:665–679.

4.4.8 ***Mussel Community***

Description

The Mississippi River corridor within MISS has historically been home to as many as 41 species of unionid mussels, constituting nearly 90% of mussel species found in MN and including approximately 80% of all mussel species in the UMR drainage (Kelner and Davis 2002 and citations therein). However, as recently as the 1970s, a survey found no live mussels in Pool 1 and only a few scattered mussels from Lock and Dam 1 to Lock and Dam 3 (Fuller 1980 in Kelner and Davis 2002). "Radical improvements" in water quality in the river have allowed the mussel population to recover since then, as documented by field surveys done by MDNR, in cooperation with MISS and GLKN, from 1999-2001. A comprehensive survey has not been done since then.

Kelner (2003) listed the status of mussels in Mississippi River Pools 1-26 and some tributaries. Pool 1 and St. Anthony Falls sites had 17-19 species, both current and historic; from pool 2 downstream, total numbers of mussel species were 38-42 in the river and its tributaries (Table 24). The St. Croix River had the largest number of currently living species (39), while the Minnesota River had the fewest (11).

Table 24. Historic and current abundance of mussel species in the vicinity of Mississippi National River and Recreation Area (Kelner 2003).

	Number of Mussel Species				
	Historic	Current			Total
Location	(not detected in ~25 years)	Rare	Common	Abundant	
Lower Minnesota River	28	9	2	-	39
Lower St. Croix River	3	29	6	4	42
Upper St. Anthony Falls	0	5	4	8	17
Lower St. Anthony Falls	4	12	-	-	16
Pool 1	2	8	4	5	19
Pool 2	11	14	10	3	38
Pool 3	13	16	8	3	40

The Mississippi River in MISS has now become a refugium for endangered native mussels. In 2000, the USFWS determined that the major adverse effect jeopardizing the continued existence of the Higgins eye mussel was the invasive zebra mussel (USFWS 2000). The mechanisms by which they might cause harm include direct physical attachment or smothering, potential food limitation, and ammonia toxicity (Wu et al. 2010). As a result, Higgins eye mussels and several other species of mussel listed for protection in Minnesota were relocated from Pools 11 and 14 of the Mississippi River to MISS in 2000 and 2001 (Kelner and Davis 2002). This effort continues to the present; in 2012, winged mapleleaf mussels were reintroduced after being absent from the Mississippi River for a century. MDNR has also reintroduced the snuffbox and other state-listed species (USFWS 2013).

Today, the MN Rare Species Guide (http://www.dnr.state.mn.us/rsg) lists 24 mussel species with federal or state status in the Mississippi River – Twin Cities watershed, 20 in the Minnesota River watershed, and 20 in the Mississippi River – Lake Pepin watershed. Five of these are

federal-endangered species, 8 are state-endangered, 12 are state-threatened, and 4 are of state special concern (Table 25).

Data and Methods

Kelner and Davis (2002) reported on field surveys conducted in MISS for mussels from 1999-2001. Kelner (2003) also produced a list of historic and current mussel species in Mississippi River pools and selected tributaries. The MN Rare Species Guide (http://www.dnr.state.mn.us/rsg) lists mussel species with federal or state status in MN.

Reference Condition

No numeric reference condition such as an IBI was found for mussel populations. The chosen reference condition for mussels for MISS is the continued presence of native mussels, especially rare species, in appropriate habitats, and the development of appropriate strategies for their protection. This is a "historic condition" (Stoddard et al. 2006).

Table 25. Federal and state-listed mussel species in Minnesota watersheds of Mississippi National River and Recreation Area.

Common name	Scientific name	Federal status	State status	Mississippi River	Lake Pepin	Minnesota River
Black sandshell	*Ligumia recta*	-	special concern	X	X	X
Butterfly	*Ellipsaria lineolata*	-	threatened	X	X	X
Ebonyshell	*Fusconaia ebena*	-	endangered	X	X	X
Elephant-ear	*Elliptio crassidens*	-	endangered	X	X	X
Elktoe	*Alasmidonta marginata*	-	threatened	X	X	X
Ellipse	*Venustaconcha ellipsiformis*	-	threatened	X	-	-
Fluted-shell	*Lasmigona costata*	-	special concern	X	X	X
Hickorynut	*Obovaria olivaria*	-	special concern	X	X	X
Higgins eye	*Lampsilis higginsii*	endangered	endangered	X	X	X
Monkeyface	*Quadrula metanevra*	-	threatened	X	X	X
Mucket	*Actinonaias ligamentina*	-	threatened	X	X	X
Pistolgrip	*Tritogonia verrucosa*	-	threatened	X	X	X
Purple wartyback	*Cyclonaias tuberculata*	-	threatened	X	X	X
Rock pocketbook	*Arcidens confragosus*	-	endangered	X	X	X
Round pigtoe	*Pleurobema sintoxia*	-	threatened	X	X	X
Salamander mussel	*Simpsonaias ambigua*	-	threatened	X	-	-
Sheepnose	*Plethobasus cyphyus*	endangered	endangered	X	X	X
Snuffbox	*Epioblasma triquetra*	endangered	threatened	X	-	-
Spectaclecase	*Cumberlandia monodonta*	endangered	threatened	X	-	-
Spike	*Elliptio dilatata*	-	special concern	X	X	X
Wartyback	*Quadrula nodulata*	-	endangered	X	X	X
Washboard	*Megalonaias nervosa*	-	threatened	X	X	X
Winged mapleleaf	*Quadrula fragosa*	endangered	endangered	X	-	-
Yellow sandshell	*Lampsilis teres*	-	endangered	X	X	X

Condition and Trend

We rank the condition of the mussel community in MISS as of moderate concern, with a stable trend. Many mussel species that were historically present in the corridor are absent today. Reintroduction has been successful for some of the most endangered species, and there is evidence of natural reproduction in the Higgins eye population. No current census or trend data are available (NPS 2013). In the absence of more detailed census data, our confidence in this assessment is fair.

A recent study (Newton et al. 2013) measured surface water and sediment temperatures at known mussel beds in SACN and the UMR south of MISS. Some observed sediment temperatures exceeded those shown to cause mussel mortality in the laboratory. The authors noted that quantitative data on lethal temperatures are available for only about 5% of North American mussel species. They noted that global warming, thermal discharges, water extraction, and/or droughts may adversely affect native mussel assemblages.

Sources of Expertise

Christine Mechenich, UWSP

Literature Cited

Fuller, S. L. H. 1980. Final report: Freshwater mussels (Mollusca: Bivalvia: Unionidae) of the Upper Mississippi River: observations at selected sites within the 9-foot navigation channel project for the St. Paul District, United State Army Corps of Engineers, 1977-1979. Volume 1: Text. Academy of Natural Sciences of Philadelphia, Division of Limnology and Ecology, Philadelphia, Pennsylvania.

Kelner, D. E., and M. Davis. 2002. Final Report: Mussel (Bivalvia: Unionidae) survey of the Mississippi National River and Recreation Area Corridor, 2000-01. Contract report to the National Park Service Mississippi National River and Recreation Area and the Great Lakes Network Inventory and Monitoring Program. Minnesota Department of Natural Resources, Division of Ecological Services, St. Paul, Minnesota. Available at http://www.fws.gov/midwest/mussel/documents/mussel_survey_mississippi_national_river_corridor_2002.pdf. (accessed February 25, 2014).

Kelner, D. 2003. Distribution and relative abundance of Upper Mississippi and Illinois River mussels, 2003. US Army Corps of Engineers, St. Paul, Minnesota. Available at http://www.fws.gov/midwest/mussel/documents/upper_mississippi_illinois_river_mussels_2003.pdf. (accessed February 25, 2013).

Newton, T., J. Sauer, and B. Karns. 2013. Water and sediment temperatures at mussel beds in the Upper Mississippi River Basin. *Walkerana* 16:53–62. Available at http://molluskconservation.org/WALKERANA/Walkerana_Vol16_2.pdf. (accessed June 8, 2015).

NPS (National Park Service). 2013. State of the park report for Mississippi National River and Recreation Area. State of the Park Series No. 4. National Park Service, Washington, D.C. Available at http://www.nps.gov/stateoftheparks/. (accessed June 11, 2013).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

USFWS (United States Fish and Wildlife Service). 2000. Biological opinion for the operation and maintenance of the 9-foot navigation channel on the Upper Mississippi River system. USFWS Midwest Region website. Available at http://www.fws.gov/midwest/mussel/documents/april_2000_biological_opinion.pdf. (accessed February 25, 2014).

USFWS (United States Fish and Wildlife Service). 2013. Endangered Mussels gain ground in Twin Cities (news article). USFWS Midwest Region website. Available at http://www.fws.gov/midwest/news/643.html. (accessed February 25, 2014).

Wu, Y., S. M. Bartell, J. Orr, J. Ragland, and D. Anderson. 2010. A risk-based decision model and risk assessment of invasive mussels. *Ecological Complexity* 7:243–255.

4.4.9 ***Mercury in Precipitation and Biota***

Description

Mercury is a persistent, bioaccumulative toxic pollutant with harmful health consequences for both humans and animals. Although it is naturally occurring, human activities have facilitated its spread throughout the environment. Most of the mercury that is found in MN lakes, rivers, and fish is deposited from the atmosphere (MPCA 2013). An MPCA (2008) report projected that in 2010, 1,191 kg of mercury would be emitted to the atmosphere in MN; 46% from energy production, 32% from taconite production, and 22% from "purposeful use" of mercury. Air emissions within 250 km of MISS are shown in Figure 25; within 50 and 250 km of MISS, 388 and 1,113 kg yr^{-1} of mercury are emitted, respectively, from a total of 1,377 facilities. The three facilities in the 100.1-199.5 kg yr^{-1} category are power plants, and the two in the 50.1-100 kg yr^{-1} category are a power plant and a taconite processing facility. Because mercury can be carried long distances by the wind, about 90% of the mercury deposited from the air in MN comes from other states and countries, and the "vast majority" of MN mercury emissions are deposited on other states and countries (MPCA 2013).

Mercury occurs in three forms in the atmosphere: the gas-phase elemental form (Hg[0]), a gaseous inorganic form (Hg[II]) formed in photochemical reactions, and the particulate form (Hg[P]). Ninety-five percent of the total in the atmosphere is in the elemental form (Grigal 2002), but the inorganic form is more soluble and is the dominant form in precipitation. In aquatic ecosystems, particularly in anaerobic environments such as wetlands and lake sediments, microbes transform deposited inorganic mercury into methylmercury (MeHg), which biomagnifies in food webs, resulting in high concentrations in fish (Drevnick et al. 2007 and citations therein).

Data and Methods

Mercury air emissions data were obtained and mapped from the 2011 National Emissions Inventory (USEPA 2013). Taconite processing emissions were based on MPCA (2008) on the advice of Anne Jackson, (email, Air Assessment section, MPCA, December 16, 2013).

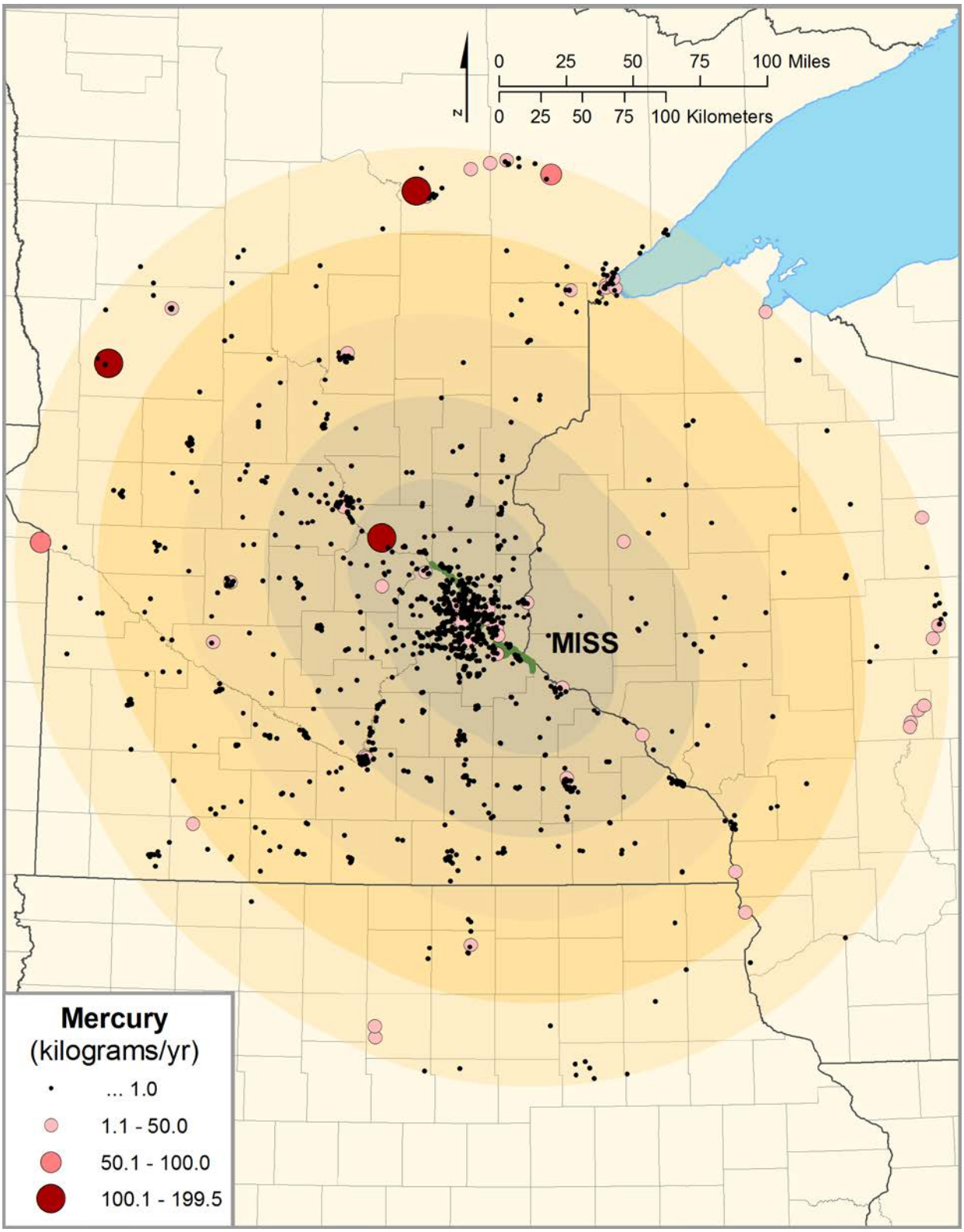


Figure 25. Mercury emissions to the air within 250 km in Mississippi National River and Recreation Area for 2010 (taconite processing facilities) and 2011 (all others) (MPCA 2008, USEPA 2013).

Data for mercury in precipitation at the MDN stations at Blaine, 5 km E of MISS; Camp Ripley, 135 km NW of MISS; and Lamberton, 180 km SW of MISS, were downloaded from the Mercury Deposition Network of the National Atmospheric Deposition Program (NADP) http://nadp.sws.uiuc.edu/ on December 19, 2013.

Most bald eagle data discussed in this section were taken from recent work by the GLKN and its cooperators (Dykstra et al. 2010, Route et al. 2011). Fish contaminant data came from the Minnesota Department of Health (MDH 2008, 2012).

Reference Condition

Precipitation

A modeling study in Sweden indicates that in humic lakes in the boreal ecosystem, the maximum mercury concentration in precipitation to maintain the regional mean mercury concentrations in 1-kg northern pike below 0.5 mg kg^{-1} fresh weight is approximately 2 ng L^{-1} (Meili et al. 2003). The authors also suggested that 2 ng L^{-1} or less may be the global pre-industrial level of mercury in precipitation. Thus, this reference condition represents both a "historic condition" and a "least disturbed condition" (Stoddard et al. 2006).

Fish Tissue

The USEPA (2002) has established a tissue residue criterion for MeHg of 0.30 mg kg^{-1} for fish intended for human consumption, based on a total fish consumption rate of 0.0175 kg day^{-1} (2-3 meals per month [Evers et al 2012]). Accordingly, the Great Lakes Fish Advisory Workshop (2007) has developed fish consumption advisories based on mercury levels in fish, ranging from unlimited consumption at ≤ 0.05 mg kg^{-1} to no consumption at >0.95 mg kg^{-1}. MN has established a statewide fish tissue criterion of 0.2 mg kg^{-1} for mercury and places water bodies in which less than 90% of sampled fish meet this criterion on the impaired waters list (MPCA 2013). This differs slightly from the MDH criterion of 0.22 mg kg^{-1} for protection of sensitive populations, which takes into account consumption of marine as well as freshwater fish (MPCA 2013).

Eaglet Feathers

Route et al. (2011) set a provisional threshold of 7.5 µg g^{-1} wet weight for mercury in eaglet breast feathers, following the proposal of Jagoe et al. (2002).

The reference conditions for both fish tissue and eaglet feathers are "least disturbed conditions," or "the best of today's existing conditions" (Stoddard et al. 2006). Reference conditions for mercury are summarized in Table 26.

Table 26. Reference conditions used in evaluating mercury status at Mississippi National River and Recreation Area.

Medium	Source	Reference condition	Units	Equivalents (ppm)
Precipitation	Meili et al. 2003	2	ng L^{-1}	0.000002
Fish tissue	MPCA 2013	0.2	mg kg^{-1}	0.2
Eaglet feathers	Route et al. 2011	7.5	µg g^{-1}	7.5

Condition and Trend

Precipitation

Mercury concentrations in precipitation at MISS are of significant concern, with a stable trend. Our confidence in this assessment is moderate. Mercury concentrations in precipitation at Blaine, Camp Ripley, and Lamberton, MN consistently exceed the reference condition of 2 ng L^{-1} (Figure 26, Table 27). Of 218 weekly samples for which data were recorded from 2008-2013 at Blaine, the closest MDN station to MISS, only 7 (3.2%) met the reference criterion; 159 (72.9%) were up to an order of magnitude higher, in the 2-20 ng L^{-1} range, and 52 (23.9%) exceeded 20 ng L^{-1}. For Camp Ripley and Lamberton, with 631 and 579 weekly samples collected from 1996-2013, 16 and 3 (2.5% and 0.5%) samples met the reference condition, respectively. We found no trend at any station. Risch et al. (2012), in a study of deposition rates, also found no trend at Camp Ripley or Lamberton from 2002-2008.

Table 27. Data from Mercury Deposition Network for precipitation at Blaine, Camp Ripley, and Lamberton, Minnesota (NADP 2013).

Hg in precipitation ng L^{-1}	Blaine	Camp Ripley	Lamberton
0-2	7 (3.2%)	16 (2.5%)	3 (0.5%)
2.1-20	159 (72.9%)	473 (75.0%)	410 (70.8%)
20.1-200	52 (23.9%)	141 (22.3%)	164 (28.3%)
>200	0	1 (0.2%)	2 (0.3%)
Total number of observations	218	631	579
Date range	2/4/2008-4/23/2013	7/2/1996-4/23/2013	7/2/1996-4/23/2013
Maximum and date	98.7 ng L^{-1}, 6/15/2010	209.11 ng L^{-1}, 4/11/2006	653.18 ng L^{-1}, 5/8/2007

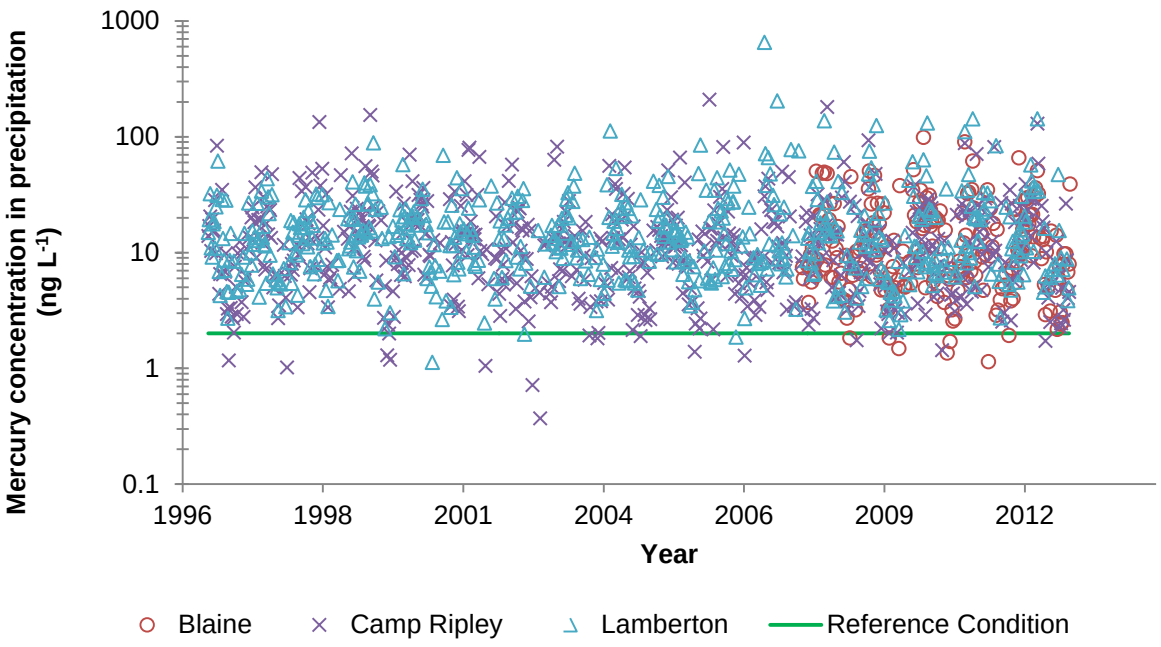


Figure 26. Total mercury in precipitation, weekly sampling, Blaine, Camp Ripley, and Lamberton, Minnesota (NADP 2013) (Note that the data are plotted on a logarithmic scale for ease of viewing. No significant trends were observed.)

Fish Tissue

Mercury concentrations in fish tissue at MISS are of significant concern, with an uncertain trend. Our confidence in this assessment is moderate. The MDH (2008, 2012) has issued six fish consumption advisories that cover parts of MISS (Table 28); these include 13 types of fish (buffalo, common carp, channel catfish, flathead catfish, freshwater drum, northern pike, redhorse sucker, sauger, smallmouth bass, sucker, walleye, white bass, and white sucker) that contain from 0.22-0.95 mg kg^{-1} mercury and should be eaten only once a month by sensitive populations (Table 29). All these exceed the reference condition of 0.2 mg kg^{-1}.

Data summarized by Wiener and Sandheinrich (2010, Figure 2 therein) show that mean mercury concentrations in 38-51 cm walleye declined from the 1970s to the 1990s in Pools 1 and 2, but then increased approximately 1 µg g^{-1} (mg kg^{-1}) in Pool 2 from the 1990s to the 2000s. Similarly, Monson et al. (2011) found a biphasic trend of a downward trend in walleye and northern pike mercury concentrations in lakes in MN from 1982 to the mid-1990s, followed by an upward trend through 2006. The authors noted that researchers in the Canadian arctic have found increasing mercury concentrations in fish and attributed them to a warming climate (Carrie et al. 2010, Kirk et al. 2011 in Monson et al. 2011). They also suggested changes in the aquatic food web caused by invasive species as a possible contributing factor to changing growth rates, and thus, changing mercury concentrations in fish.

Table 28. Fish consumption advisories for mercury >0.22 mg kg^{-1} for segments of the Mississippi and Minnesota Rivers within Mississippi National River and Recreation Area (MDH 2012).

	Buffalo	**Carp**	**Channel Catfish**	**Flathead Catfish**	**Freshwater Drum**	**Northern Pike**	**Redhorse Sucker**	**Smallmouth Bass**	**Sauger**	**Sucker**	**Walleye**	**White Bass**	**White Sucker**
Mississippi River													
St. Cloud Dam to Coon Rapids Dam	-	-	58 cm or longer	-	-	-	All sizes	36 cm or longer	-	All sizes	41 cm or longer	-	All sizes
Coon Rapids Dam to St. Anthony Falls	-	-	51 cm or longer	-	-	-	-	33 cm or longer	-	-	All sizes	-	-
St. Anthony Falls to Ford Dam, Pool 1	-	-	All sizes	-	-	All sizes	-	-	-	-	All sizes	-	-
Ford Dam to Hastings Dam, Pool 2	-	-	56 cm or longer	All sizes	-	-	-	-	-	-	-	All sizes	-
Hastings Dam to Red Wing, Pool 3	-	All sizes	All sizes	-	-	-	-	-	-	-	-	All sizes	-
Minnesota River													
below Minnesota Falls	All sizes	-	-	56 cm or longer	All sizes	-	-	-	All sizes	-	41 cm or longer	All sizes	-
Vermillion River	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 29. Recommended guidelines and criteria for protection of sensitive populations (children and women of childbearing age) who eat wild-caught (noncommercial) fish, in relation to mercury concentrations in fish fillets (Evers et al. 2011).

Consumption guideline	Intake of <7 µg Hg day^{-1} and	Allowable Hg level in raw fish fillet (ppm, mg kg^{-1})
Unrestricted consumption (>225 meals year^{-1})	<140 g fish day^{-1}	≤0.05
Two meals/week(104 meals year^{-1})	<64 g fish day^{-1}	>0.05- 0.11
One meal/week (52 meals year^{-1})	<32 g fish day^{-1}	>0.11- 0.22
One meal/month (12 meals year^{-1})	<7.4 g fish day^{-1}	>0.22- 0.95
No consumption		>0.95

A review of mercury in selected fish species in the Great Lakes region from 2000-2008 (Evers et al. 2011) indicates that in inland waters, predators such as northern pike, largemouth bass, walleye, smallmouth bass, and muskellunge have the highest levels of mercury (Figure 27).

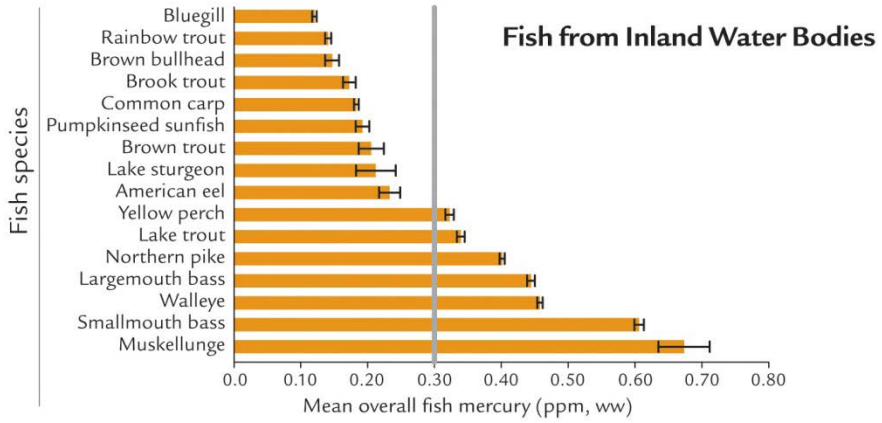


Figure 27. Mercury in selected fish species in inland waters in the Great Lakes region (Evers et al. 2011; graphic obtained at http://www.briloon.org/mercuryconnections/greatlakes/graphics).

Wiener and Sandheinrich (2010 and citations therein) report that in Lake Pepin, a part of Pool 4 downstream of MISS, about half of the mercury deposition from 1800 to the mid-1990s occurred between 1940 and 1970. Point source inputs of mercury other than from air have been largely eliminated, and recent inputs are associated with eroding soils in agricultural and urban watersheds.

Eaglet Feathers

The condition of the bald eagle population for mercury at MISS is good, with a stable trend. Our confidence in this assessment is good and is based on the assessment of the GLKN (Route et al. 2011, NPS 2013). The geometric mean concentration of mercury in eaglet feathers at MISS was 3.12-3.70 µg g^{-1}, below the reference condition of 7.5 µg g^{-1} (Figure 28). This mean was significantly lower than the means at SACN and along the south shore of Lake Superior. The authors noted that eagle nestlings with high mercury levels at those locations were from eagle territories immediately downgradient of extensive wetlands (Route et al. 2011). The authors noted that mercury trend data were mixed, with levels in Lake Superior eaglet feathers declining 3% per year from 1991-2008, but with no declines and even increases in mercury in other biota over similar time periods.

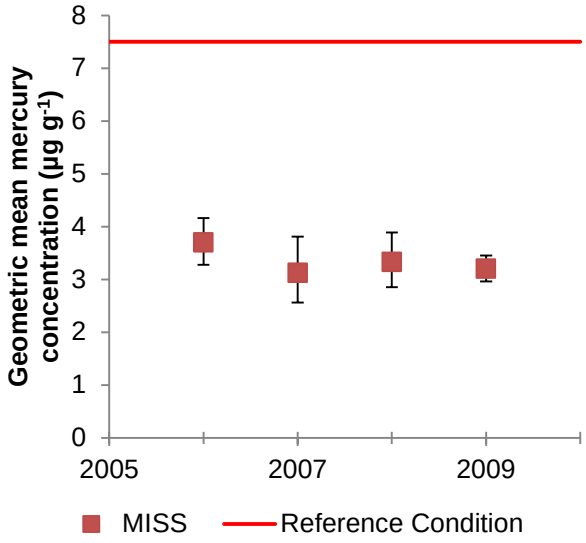


Figure 28. Estimated geometric means and 95% confidence intervals of mercury in feathers from bald eagle nestlings sampled in Mississippi National River and Recreation Area, 2006-2009 (n=11-18).

Sources of Expertise

Route et al. 2011; Christine Mechenich, UWSP.

Literature Cited

Carrie, J., F. Wang, H. Sanei, R. W. Macdonald, P. M. Outridge, and G. A. Stern. 2010. Increasing contaminant burdens in an arctic fish, burbot (*Lota lota*), in a warming climate. *Environmental Science and Technology* 44:316–322 .

Drevnick, P. E., D. E. Canfield, P. R. Gorski, A. C. Shinneman, D. R. Engstrom, D. C. G. Muir, G. R. Smith, P. J. Garrison, L. B. Cleckner, J. P. Hurley, R. B. Noble, R. R. Otter, and J. T. Oris. 2007. Deposition and cycling of sulfur controls mercury accumulation in Isle Royale fish. *Environmental Science and Technology* 41:7266–7272.

Dykstra, C. R., W. T. Route, M. W. Meyer, and P. W. Rasmussen. 2010. Contaminant concentrations in bald eagles nesting on Lake Superior, the Upper Mississippi River, and the St. Croix River. *Journal of Great Lakes Research* 36:561–569.

Evers, D. C., J. G. Wiener, C. T. Driscoll, D. A. Gay, N. Basu, B. A. Monson, K. F. Lambert, H. A. Morrison, J. T. Morgan, K. A. Williams, and A. G. Soehl. 2011. Great Lakes mercury connections: the extent and effects of mercury pollution in the Great Lakes region. BRI report 2011-18. Biodiversity Research Institute, Gorham, Maine. Available at http://www.briloon.org/mercuryconnections. (accessed November 12, 2012).

Evers, D. C., A. K. Jackson, T. H. Tear, and C. E. Osborne. 2012. Hidden risk: mercury in terrestrial ecosystems of the Northeast. BRI report 2012-07. Biodiversity Research Institute, Gorham, Maine. Available at http://www.briloon.org/research/research-centers/center-for-mercury-studies/hg-forest-songbirds. (accessed November 5, 2012).

Great Lakes Fish Advisory Workgroup. 2007. A protocol for mercury-based fish consumption advice: an addendum to the 1993 "Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory." Wisconsin Department of Health Services, Madison, Wisconsin. Available at http://www.dhs.wisconsin.gov/eh/fish/FishFS/2007Hg_Add_Final_05_07.pdf. (accessed February 12, 2013).

Grigal, D. F. 2002. Inputs and outputs of mercury from terrestrial watersheds: a review. *Environmental Reviews* 10:1–39.

Jagoe, C. H., A. L. Bryan, Jr., H. A. Brant, and T. M. Murphy. 2002. Mercury in bald eagle nestlings from South Carolina, USA. *Journal of Wildlife Diseases* 38:706–712.

Kirk, J. L., D. C. M. Muir, D. Antoniades, M. S. V. Douglas, M. S. Evans, T. A. Jackson, H. Kling, S. Lamoureux, D. S. S. Lim, R. Pienitz, J. P. Smol, K. Stewart, X. Wang, and F. Yang. 2011. Climate change and mercury accumulation in Canadian high and subarctic lakes. *Environmental Science and Technology* 45:964–970.

MDH (Minnesota Department of Health). 2008. Meal advice categories based on levels of mercury in fish. Minnesota Department of Health, St. Paul, Minnesota. Available at http://www.health.state.mn.us/divs/eh/fish/eating/mealadvicetables.pdf. (accessed February 18, 2013).

MDH (Minnesota Department of Health). 2012. Fish consumption guidelines for women who are or may become pregnant and children under age 15, rivers. Minnesota Department of Health, St. Paul, Minnesota. Available at http://www.health.state.mn.us/divs/eh/fish/eating/specpoprivers.pdf. (accessed February 18, 2013).

Meili, M., K. Bishop, L. Bringmark, K. Johansson, J. Muthe, H. Sverdrup, and W. de Vries. 2003. Critical levels of atmospheric pollution: Criteria and concepts for operational modelling of mercury in forest and lake ecosystems. *The Science of the Total Environment* 304:83–106.

Monson, B. A., D. F. Staples, S. P. Bhavsar, T. M. Holsen, C. S. Schrank, S. K. Moses, D. J. McGoldrick, S. M. Backus, and K. A. Williams. 2011. Spatiotemporal trends of mercury in walleye and largemouth bass from the Laurentian Great Lakes Region. *Ecotoxicology* 20:1555–1567.

MPCA (Minnesota Pollution Control Agency). 2008. Estimated mercury emissions in Minnesota for 2005 to 2018. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=11652. (accessed December 11, 2012).

MPCA (Minnesota Pollution Control Agency). 2013. Sources of mercury pollution and the methylmercury contamination of fish in Minnesota. p-p2s4-06. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=288. (accessed December 19, 2013).

NADP (National Atmospheric Deposition Program [(NRSP-3]). 2013. NADP Program Office, Illinois State Water Survey, Champaign, Illinois. Available at http://nadp.sws.uiuc.edu/sites/sitemap.asp?net=mdn&state=mn. (accessed December 19, 2013).

NPS (National Park Service). 2013. State of the park report for Mississippi National River and Recreation Area. State of the Park Series No. 4. National Park Service, Washington, D.C. Available at http://www.nps.gov/stateoftheparks/. (accessed June 11, 2013).

Risch, M. R., D. A. Gay, K. K. Fowler, G. J. Keeler, S. M. Backus, P. Blanchard, J. A. Barres, and J. T. Dvonch. 2012. Spatial patterns and temporal trends in mercury concentrations, precipitation depths, and mercury wet deposition in the North American Great Lakes region, 2002-2008. *Environmental Pollution* 161:261–272.

Route, B., P. Rasmussen, R. Key, M. Meyer, and M. Martell. 2011. Spatial patterns of persistent contaminants in bald eagle nestlings at three national parks in the upper Midwest: 2006-2009. Natural Resource Technical Report NPS/GLKN/NRTR—2011/431. National Park Service, Fort Collins, Colorado. Available at http://science.nature.nps.gov/im/units/GLKN/monitorreportpubs.cfm. (accessed February 18, 2013).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

USEPA (United States Environmental Protection Agency). 2002. National recommended water quality criteria. USEPA, Washington, D. C. Available at http://water.epa.gov/scitech/swguidance/standards/current/index.cfm. (accessed March 20, 2012).

USEPA (United States Environmental Protection Agency). 2013. The 2011 national emissions inventory website. Available at http://www.epa.gov/ttn/chief/net/2011inventory.html. (accessed December 10, 2013).

Wiener, J., and M. Sandheinrich. 2010. Contaminants in the Upper Mississippi River: historic trends, responses to regulatory controls, and emerging concerns. *Hydrobiologia* 640:49–70.

4.4.10 ***Persistent Organic Contaminants in Biota***

Description

Human-made organic contaminants released into the environment are often concentrated in the food web, with possible detrimental effects to both wildlife and human consumers. Those evaluated here are DDE (a metabolite of DDT), PCBs, PFCs, and PBDEs.

DDE (dichlorodiphenyldichloroethylene) is a metabolite of DDT (dichlorodiphenyl-trichloroethane), an organochlorine insecticide banned in the U.S. in 1972 (USEPA 2011). The presence of DDE at a site may reflect past DDT use and the slow breakdown of this chemical in the environment; midwestern agricultural soils and urban areas continue to emit significant quantities of DDT (Bidleman et al. 2006). Atmospheric transport related to continuing use in Mexico and Central America is another potential DDT source.

PCBs (polychlorinated biphenyls) are synthetic organic compounds that make good insulating materials because they do not burn easily. They were widely used as coolants and lubricants in transformers, capacitors, and other electrical equipment until their manufacture ceased in the U.S. in 1977 (USEPA 2012a). These also may arrive at MISS via atmospheric transport; Hafner and Hites (2003) reported that the major source of PCBs to a monitoring site at Eagle Harbor, Michigan was the Chicago area.

PFCs (perfluorinated compounds) are synthetic organic compounds with unique properties that make them useful in many consumer products, most notably fire-fighting foam, stain protection, and non-stick surfaces (Chou et al. 2009). They “are globally distributed, environmentally persistent, bioaccumulative, and potentially harmful” (Giesy and Kannan 2002). PFOS (perfluoro-1-octanesulfonate) is the primary PFC found in fish and other biota (Monson et al. 2010). In 2002, PFOS was voluntarily phased-out of production, but its use continues in both the U.S. and Canada because of specific use exemptions (USEPA and Environment Canada 2012).

PBDEs (polybrominated diphenyl ethers) are released into the environment from their manufacture and use as flame retardants in thermoplastics in a wide range of products (WHO 1994). The congeners of PBDE are named according to the number of bromine atoms they contain, which can vary from one to ten. A phase-out of penta- and octaBDEs began in 2004, and decaBDEs were scheduled to be phased out by December 31, 2013 (USEPA and Environment Canada 2012, USEPA 2012b).

Data and Methods

Wiener and Sandheinrich (2010) synthesized historical data on mercury, cadmium, DDT, and PCBs and described emerging concerns about PFCs, PBDEs, and endocrine disruptors.

Route et al. (2011) sampled serum from bald eagle nestlings from 2006-2009 at MISS and other sites in the region for mercury, lead, DDT and its metabolites DDD and DDE, PCBs, PBDEs, and PFCs.

Lee and Anderson (1998) reported on results of fish tissue sampling for PCBs in the Mississippi, Minnesota, and St. Croix Rivers from 1975-1995. Other data on fish contaminants were obtained from the MPCA (2013a) draft 2014 impaired waters list.

Reference Condition

A threshold of 28 ppb (ng g^{-1}) has been set for DDE in eaglet feathers to protect the health of the bald eagle population (Elliott and Harris 2001/2002 in Route et al. 2011).

The threshold for total PCBs in nestling serum to protect the health of the bald eagle population is 190 ppb (ng g^{-1}) (Elliott and Harris 2001/2002 in Route et al. 2011).The target for total PCBs in the Great Lakes Water Quality Agreement (GLWQA) is 100 ng g^{-1} ww (wet weight) in whole fish; this target was established for the protection of birds and animals that consume fish (IJC 1989). The threshold concentration for impairment in MN (triggering a consumption advisory of no more than one meal per month for humans) is 0.22 mg kg^{-1} (220 ng g^{-1}) (MPCA 2013b).

Route et al. (2011) found published values of a toxicity reference value (TRV) of 1,700 µg L^{-1} (ng g^{-1}) (Newsted et al. 2005) and a no observable adverse effects level (NOAEL) of 30,500 µg/L (ng g^{-1}) PFOS in bird serum (Giesy et al. 2006). The threshold concentration in fish tissue for impairment in MN (triggering a consumption advisory of no more than one meal per month for humans) is 0.20 mg kg^{-1} (200 ng g^{-1}) PFOS (MPCA 2013b). PFOS is the main PFC found to accumulate in fish tissue at levels of concern (Monson et al. 2010).

Route et al. (2011) found no data to support establishing a threshold value for PBDEs in bald eagle nestling serum. Environment Canada has determined that three classes of PBDEs (tetra-, penta-, and hexaBDEs) are highly bioaccumulative and has established Federal Environmental Quality Guidelines (FEQGs) of 88, 1.0, and 420 ng g^{-1} ww in fish tissue, respectively, to protect wildlife consumers of fish (Environment Canada 2010).

These reference conditions are summarized in Table 30 and represent “least disturbed conditions” or “the best of today’s existing conditions” (Stoddard et al. 2006). The “historic” condition would be that no residues of these chemicals are found at MISS.

Table 30. Reference conditions for persistent organic contaminants.

Contaminant	**Reference Condition Concentration (ng g^{-1})**	
	Bald eagle nestling serum	**Fish tissue**
DDE	28	--
PCBs	190	100 (birds and animals) 220 (humans)
PFOS	1,700	200 (humans)
PBDEs	--	88 tetraBDEs 1.0 pentaBDEs 420 hexaBDEs (wildlife)

Condition and Trend

DDE

The condition of the bald eagle population at MISS for DDE is of moderate concern, with an improving trend. Our confidence in this assessment is good and is based on the assessment of the GLKN (Route et al. 2011, NPS 2013).

Geometric means for DDE in bald eagle nestling serum were 7.52-11.8 ng g^{-1} for MISS from 2006-2009 (Route et al. 2011), below the reference condition of 28 ppb (Figure 29). DDE levels in nestlings at MISS were significantly lower than at Lake Superior sites and significantly higher than at Upper St. Croix River sites from 2006-2008 (GLKN 2010). The assessment of an improving trend is based on declining levels of DDE in Lake Superior nestlings from 1989-2008 (Dykstra et al. 2010); Route et al. (2011) stated that the literature suggests this trend is regional. It should be noted that at MISS in 2009, Route et al. (2011) found a level of DDT in one nestling higher than any reported in current literature. DDD (dichlorodiphenyldichloroethane), another metabolite of DDT and a chemical used as a pesticide in its own right, was also found consistently in nestlings from MISS (Route et al. 2011).

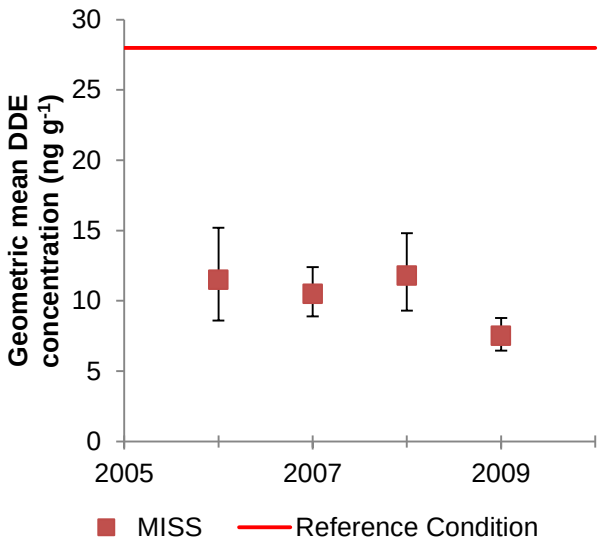


Figure 29. Estimated geometric means and 95% confidence intervals of DDE in plasma from bald eagle nestlings sampled in Mississippi National River and Recreation Area, 2006-2009 (n=10-18).

Levels of DDE in fish at MISS are unknown, but the concentrations of DDT and its metabolites DDD and DDE have continuously declined in top predator fish in Lake Superior since 1972, with median values of 40 and 90 ng g^{-1} ww (Canada and U.S., respectively) in 292 whole fish samples from 2006-2009. The condition of the Great Lakes for DDT and its metabolites in whole fish is rated as good, with an improving trend (USEPA and Environment Canada 2012).

Total PCBs

The condition of the bald eagle population for total PCBs at MISS is of moderate concern, with an improving trend. Our confidence in this assessment is good and is based on the assessment of the GLKN (Route et al. 2011, NPS 2013).

Geometric means for total PCBs in bald eagle nestling serum were 63.1-86.4 ng g^{-1} for MISS from 2006-2009 (Figure 30) (Route et al. 2011), below the reference condition of 190 ng g^{-1}. Total PCB levels in nestlings at MISS are statistically similar to those on the Lower St. Croix River and significantly higher than at Upper St. Croix River and Lake Superior sites (GLKN 2010). The assessment of an improving trend is based on declining levels of PCBs in Lake Superior nestlings from 1989-2008 (Dykstra et al. 2010); Route et al. (2011) stated that the literature suggests this trend is regional.

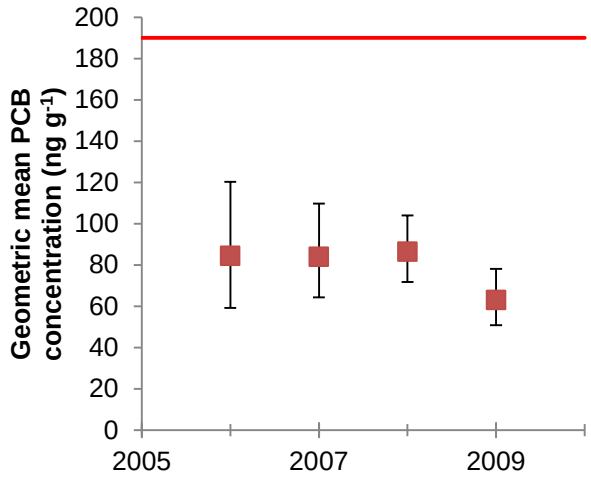


Figure 30. Estimated geometric means and 95% confidence intervals of total PCBs in plasma from bald eagle nestlings sampled in Mississippi National River and Recreation Area, 2006-2009 (n=10-18).

The condition of the fish community at MISS for PCBs is of significant concern, with an improving trend; our confidence in this assessment is good. Wiener and Sandheinrich (2010) reported that in the Upper Mississippi River, PCBs in fillets of common carp (*Cyprinus carpio*) have declined substantially since PCB manufacture was banned in the U.S. in 1977. Of Pools 1-11, Pool 2 had the highest median PCB concentration in carp (151,300 ng g^{-1}) from 1975-1979 (Lee and Anderson 1998, Wiener and Sandheinrich 2010). Lipid-normalized PCB concentrations in sampled carp fell 90% and 93% in carp from Pools 1 and 2, respectively, between 1975-1979 and 1988-1995 (Lee and Anderson 1998).

In the 2000s, the mean concentration of total PCBs in fillets of common carp in the 51-64 cm total length group in Pools 1, 2, and 3 met the reference condition of 100 ng g^{-1} for wildlife protection and 220 ng g^{-1} for human consumption more than once a month (figure 4 in Wiener and Sandheinrich 2010). However, in the lower Minnesota River, Pool 2, Vermillion Slough, and Pool 3, PCB levels in some fish (longer flathead catfish, white bass, carp, and channel catfish) have current fish consumption advisories corresponding to PCB levels in excess of the reference condition of 220 ng g^{-1} (MDH 2012). These waters are on the 2014 draft impaired waters list for PCB in fish tissue (MPCA 2013a, b). These PCB levels exceed, by a factor of two, the reference condition for the protection of birds and animals that consume fish. Trends in PCBs in the Mississippi River in MISS show overall improvement (NPS 2013).

PFOS

The condition of the bald eagle population for PFOS at MISS is of significant concern, with an improving trend. Our confidence in this assessment is good and is based on the assessment of the GLKN (Route et al. 2011, NPS 2013).

Geometric means for total PFOS in bald eagle nestling serum were 541-1,250 ng g^{-1} from 2006-2009 (Route et al. 2011), below the reference condition of 1,700 ng g^{-1} (Figure 31). However, three nestlings at MISS (5.5%) exceeded the reference condition. Concentrations of PFOS in nestling serum at MISS were similar to those in Pools 3 and 4 and significantly higher than those

in Lake Superior or the St. Croix River. Although PFOS is only one of 16 measured PFC congeners, it made up the majority (68%) of PFC volume at MISS. Some PFC congeners (PFNA, PFOA, and PFTrDA) were higher in Lake Superior samples than those at MISS. The concentration of total PFCs in bald eagle nestling serum appears to have declined from 2006-2009 at MISS (Route et al. 2011).

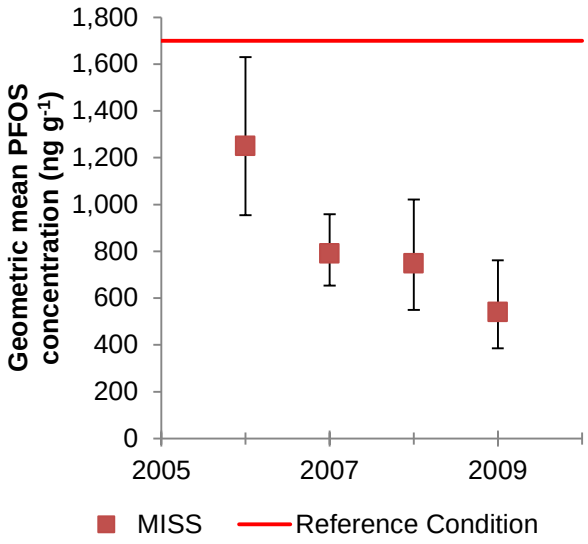


Figure 31. Estimated geometric means and 95% confidence intervals of PFOS in plasma from bald eagle nestlings sampled in Mississippi National River and Recreation Area, 2006-2009 (n=10-18).

The condition of the fish community at MISS for PFOS is of significant concern, with an uncertain trend. Our confidence in this assessment is fair. Pool 2 from the Rock Island railroad bridge to Lock and Dam 2 is on the 2014 draft impaired waters list for PFOS in fish tissue, corresponding to a PFOS concentration >200 ng g^{-1} (MPCA 2013a, b). Wiener and Sandheinrich (2010) reported mean concentrations of PFOS in fillets of bluegill, white bass, carp, and smallmouth bass exceeding 200 ng g^{-1} in Pool 2.

PBDEs

The condition of the bald eagle community for PDBEs is unknown because a threshold value has not been established; the trend is also unknown. Geometric means for total PBDEs in bald eagle nestling serum were 12.5-16.8 ng g^{-1} for MISS from 2006-2009 (Figure 32) (Route et al. 2011). Five of nine PDBE congeners had sufficient data to conduct a statistical analysis; in all cases, levels of those congeners in nestlings at MISS were significantly higher than those on the St. Croix River, and in four of the five cases, levels at MISS were significantly higher than those in Pools 3 and 4.

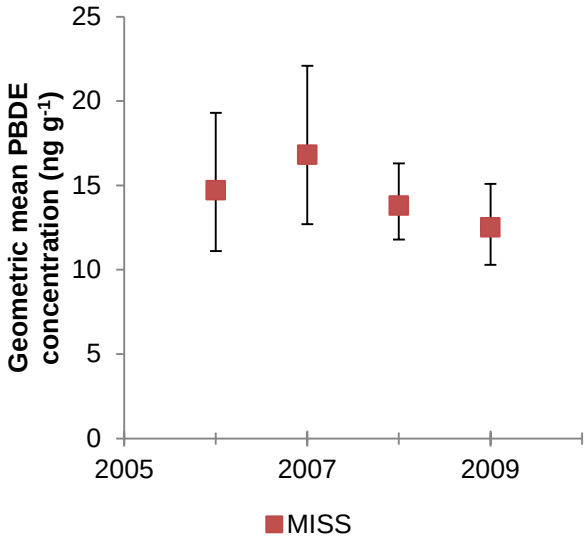


Figure 32. Estimated geometric means and 95% confidence intervals of PBDEs in plasma from bald eagle nestlings sampled in Mississippi National River and Recreation Area, 2006-2009 (n=10-18).

The condition and trend of the fish community for PBDE at MISS is unknown; no data were found. In the region, the majority of tetraBDE concentrations in fish tissue in the Great Lakes are below the FEQG, but all measured

pentaBDE concentrations are "well above" the FEQG. Concentrations of PBDEs in Lake Superior appear to be declining since the early 2000s, but the decline is not statistically significant. The condition of Lake Superior for PBDEs is rated fair, with a stable trend (USEPA and Environment Canada 2012).

Sources of Expertise

Route et al. 2011;Wiener and Sandheinrich 2010; Christine Mechenich, UWSP.

Literature Cited

Bidleman, T. F., F. Wong, C. V. Audette, P. Blanchard, and H. Alegria. 2006. DDT in Great Lakes air: long-range transport or home-grown? Abstracts, International Association for Great Lakes Research, 49th Annual Conference: Great Lakes in a changing environment. University of Windsor, Windsor, Ontario, Canada.

Chou, S., D. Jones, H. R. Pohl, A. Cadore, F. T. Llados, G. L. Diamond, and D. J. Plewak. 2009. Draft toxicological profile for perfluoroalkyls. U.S. Department Of Health And Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, Georgia. Available at http://www.atsdr.cdc.gov/toxprofiles/tp200.pdf. (accessed June 19, 2012).

Dykstra, C. R., W. T. Route, M. W. Meyer, and P. W. Rasmussen. 2010. Contaminant concentrations in bald eagles nesting on Lake Superior, the Upper Mississippi River, and the St. Croix River. *Journal of Great Lakes Research* 36:561–569.

Elliott, J. E., and M. L. Harris. 2001/2002. An ecotoxicological assessment of chlorinated hydrocarbon effects on bald eagle populations. *Reviews in Toxicology* 4:1–60.

Environment Canada. 2010. Risk management strategy for polybrominated diphenyl ethers (PBDEs). Chemicals Sectors Directorate, Environmental Stewardship Branch, Environment Canada, Gatineau, Quebec. Available at http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=34DCDBA9-9C86-4EB2-AA93-81B6755321F9. (accessed July 3, 2012).

Giesy, J. P., and K. Kannan. 2002. Perfluorochemical surfactants in the environment. *Environmental Science and Technology* 36:146A–152A.

Giesy, J. P., S. A. Maybury, J. W. Martin, K. Kannan, P. D. Jones, J. L. Newsted, and K. Coady. 2006. Perfluorinated compounds in the Great Lakes. Pages 391-438 *in* R. A. Hites, editor. The Handbook of Environmental Chemistry: Persistent Organic Pollutants in the Great Lakes. Springer-Verlag, Berlin and Heidelberg, Germany.

GLKN (Great Lakes Inventory and Monitoring Network). 2010. Monitoring persistent contaminants in bald eagles. Resource Brief, 2 pp. Great Lakes Network Inventory and Monitoring Program, Ashland, Wisconsin. Available at https://irma.nps.gov/App/Reference/Profile/2196637. (accessed December 9, 2013).

Hafner, W. D., and R. A. Hites. 2003. Potential sources of pesticides, PCBs, and PAHs to the atmosphere of the Great Lakes. *Environmental Science and Technology* 37:3764–3773.

IJC (International Joint Commission United States and Canada). 1989. Revised Great Lakes water quality agreement of 1978; agreement, with Annexes and Terms of Reference, between the United States and Canada signed at Ottawa November 22, 1978 and Phosphorus Load Reduction Supplement signed October 16, 1983, as amended by Protocol signed November 18, 1987. International Joint Commission, Windsor, Ontario and Detroit, Michigan. Available at http://www.ijc.org/rel/agree/quality.html. (accessed June 25, 2012).

Lee, K. E., and J. P. Anderson. 1998. Water-quality assessment of the Upper Mississippi River basin, Minnesota and Wisconsin – polychlorinated biphenyls in common carp and walleye fillets, 1975-95. Originally published as USGS Water-Resources Investigations Report 98-4126. USGS, Minnesota Water Science Center, Mounds View, Minnesota. Available at http://mn.water.usgs.gov/publications/pubs/pcb/pcb.html. (accessed March 15, 2013).

MDH (Minnesota Department of Health). 2012. Fish consumption guidelines for women who are or may become pregnant and children under age 15, rivers. Minnesota Department of Health, St. Paul, Minnesota. Available at http://www.health.state.mn.us/divs/eh/fish/eating/specpoprivers.pdf. (accessed February 18, 2013).

MPCA (Minnesota Pollution Control Agency). 2013a. 2014 draft impaired waters list (wq-iw1-47). MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/impaired-waters-list.html. (accessed December 10, 2013).

MPCA (Minnesota Pollution Control Agency). 2013b. Guidance manual for assessing the quality of Minnesota surface waters for determination of impairment: 305(b) report and 303(d) list: 2014 assessment cycle (wq-iw1-04). MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/impaired-waters-list.html. (accessed December 10, 2013).

Monson, B., L. Solem, P. Hoff, M. Hora, P. McCann, M. Briggs, J. Stiras, and S. DeLain. 2010. Mississippi River Pool 2 intensive study of perfluorochemicals in fish and water: 2009. Minnesota Pollution Control Agency, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=15527. (accessed June 18, 2012).

Newsted, J. L., P. D. Jones, K. Coady, and J. P. Giesy. 2005. Avian toxicity reference values for perfluorooctane sulfonate. *Environmental Science and Technology* 39:9357–9362.

NPS (National Park Service). 2013. State of the park report for Mississippi National River and Recreation Area. State of the Park Series No. 4. National Park Service, Washington, D.C. Available at http://www.nps.gov/stateoftheparks/. (accessed June 11, 2013).

Route, B., P. Rasmussen, R. Key, M. Meyer, and M. Martell. 2011. Spatial patterns of persistent contaminants in bald eagle nestlings at three national parks in the upper Midwest: 2006-2009. Natural Resource Technical Report NPS/GLKN/NRTR—2011/431. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2168992. (accessed March 11, 2014).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

USEPA (United States Environmental Protection Agency). 2011. DDT (website). Available at http://www.epa.gov/pbt/pubs/ddt.htm (accessed March 11, 2013).

USEPA (United States Environmental Protection Agency). 2012a. PCBs questions and answers (website). USEPA Region 9, Pacific Southwest. Available at http://www.epa.gov/region9/pcbs/faq.html. (accessed March 11, 2013).

USEPA (United States Environmental Protection Agency). 2012b. DecaBDE phase-out initiative (website). Available at http://www.epa.gov/oppt/existingchemicals/pubs/actionplans/deccadbe.html. (accessed December 3, 2013).

USEPA (United States Environmental Protection Agency) and Environment Canada. 2012. Draft indicator reports: Contaminants in whole fish (draft for discussion at State of the Lakes Ecosystem Conference). USEPA, Washington, D.C. Available at http://www.solecregistration.ca/en/indicator_reports.asp. (accessed June 18, 2012).

WHO (World Health Organization). 1994. Brominated diphenyl ethers. International Programme on Chemical Safety Environmental Health Criteria 162. World Health Organization, Geneva, Switzerland. Available at http://www.inchem.org/documents/ehc/ehc/ehc162.htm. (accessed July 3, 2012).

Wiener, J., and M. Sandheinrich. 2010. Contaminants in the Upper Mississippi River: historic trends, responses to regulatory controls, and emerging concerns. *Hydrobiologia* 640:49–70.

4.5 Physical and Chemical Condition

The EPA-SAB framework subdivides chemical and physical characteristics into the categories of nutrient concentrations, trace inorganic and organic chemicals, other chemical parameters, and physical parameters (USEPA 2002). It allows for reporting the categories either separately by environmental medium or displaying integrated information from all environmental compartments (air, water, soil, and sediment). In this section, we describe air and water quality.

4.5.1 *Air Quality*

Description

Air quality is a broad term that includes all compounds, particles, aerosols, gases, and metals in the atmosphere. These substances are considered air pollutants when they enter at rates that clearly exceed the background rates and when they have the potential to affect ecosystem structure, function, or composition. They may originate locally or travel long distances from their sources. Air pollution may affect MISS resources through atmospheric deposition of contaminants, nutrient enrichment, or vegetation damage, and may affect human uses of the park by limiting visibility and harming human health.

MISS is designated as a Class II air quality area. Class I air quality areas, such as ISRO and VOYA, are provided with the highest degree of protection under the USEPA Clean Air Act (CAA) and its amendments. Class II areas have higher ceilings on additional pollution over baseline concentrations, allowing for moderate development. Major new and modified air pollution sources with the potential to affect a Class II area must be analyzed for their impacts on the area's ambient air quality, climate and meteorology, terrain, soils and vegetation, and visibility. NPS managers can participate in reviews of a variety of state, federal, and local activities that might affect air quality in these areas (http://www.nature.nps.gov/air/regs/psd.cfm).

Air Quality and Air Quality Related Values (AQRV) are Vital Signs for MISS and all other parks in the GLKN (NPS 2007). In the prioritized list of Vital Signs for GLKN, air contaminants were ranked 27th of 46 (3.0 on a 5-point scale), and AQRV were ranked 36th of 46 (2.6 on a 5-point scale) (NPS 2007).

The USEPA collects monitoring data and establishes concentration limits for six common air pollutants called criteria pollutants; these are carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), particulate matter (PM), and lead (Pb) (USEPA 2013). In order to track the sources of criteria pollutants, USEPA collects emissions data from regulated facilities for CO, SO_2, PM, and three 'precursor/promoters' of criteria air pollutants: volatile organic compounds (VOC), nitrogen oxides (NO_x), and ammonia (NH_3) (USEPA 2013). USEPA also tracks Pb emissions, but reports them as hazardous air pollutants instead of criteria pollutants (USEPA 2013). Thousands of metric tons of criteria pollutants are emitted from regulated facilities, nonpoint sources, and mobile sources in the vicinity of MISS each year (Figure 33, Table 31).

The NPS Air Resources Division (ARD) assesses the current condition of air quality in NPS units in the categories of O_3; wet deposition of NH_3, nitrate (NO_3^-), and sulfate (SO_4^{2-}); and visibility (as PM), all of which are, or are related to, the USEPA criteria pollutants. Ozone affects human health and harms vegetation. Wet deposition affects ecological health through

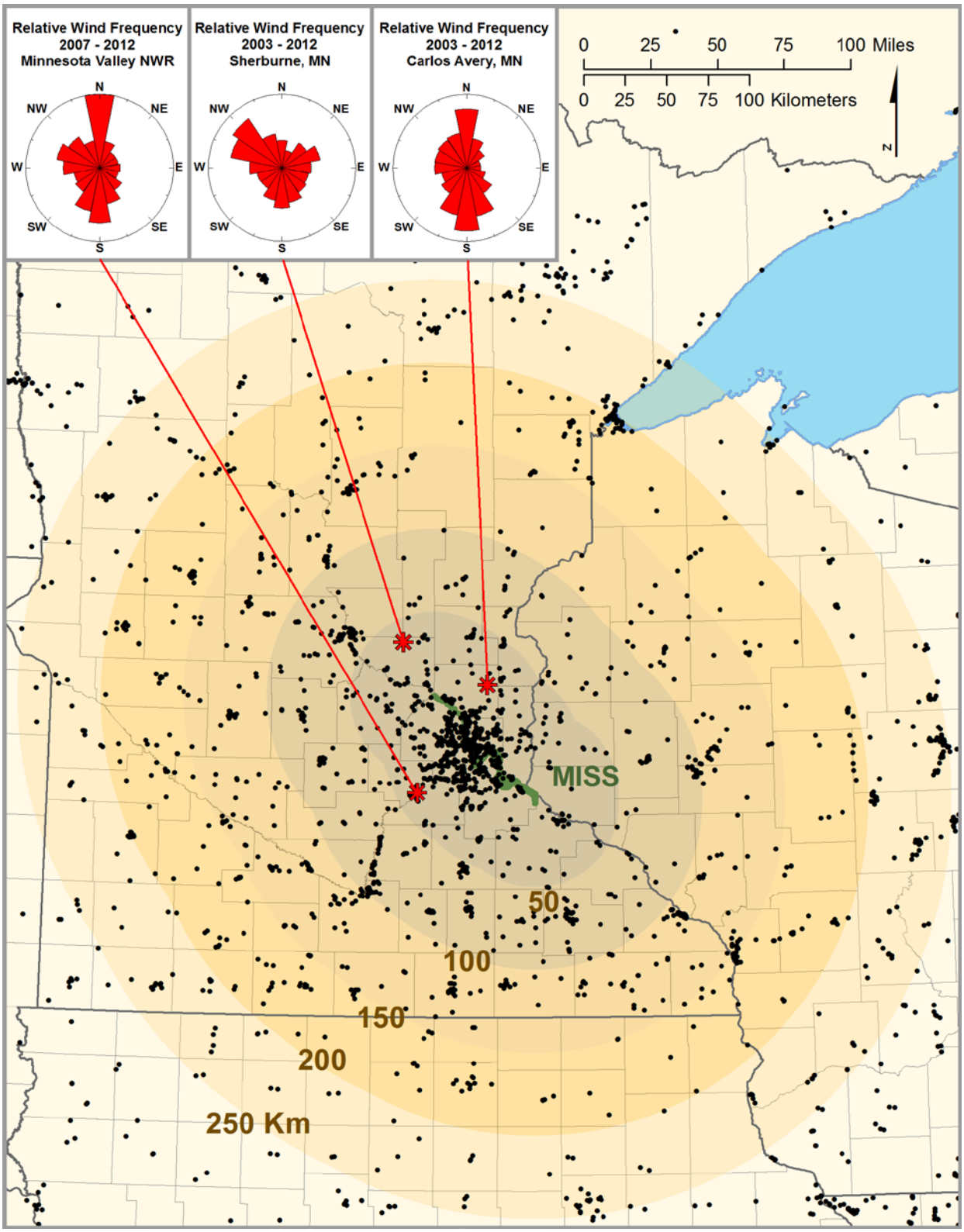


Figure 33. Regulated facilities that emit criteria air pollutants within 250 km of Mississippi National River and Recreation Area and prevailing wind directions (USEPA 2012a).

Table 31. 2008 emissions of criteria air pollutants in metric tons by regulated facilities within a 250 km buffer of Mississippi National River and Recreation Area (USEPA 2012a).

Criteria Pollutant	2008 emissions, MT yr^{-1}
NH_3	1,616
CO	45,078
NO_X	125,256
PM_{10}	20,528
$PM_{2.5}$	10,957
SO_2	156,386
VOC	29,952

acidification and fertilization of soil and surface waters, and visibility affects how well and how far visitors can see (NPS 2013a).

Data and Methods

Data for criteria air pollutant emissions within 250 km of MISS were downloaded from the USEPA 2008 National Emissions Inventory Data website (USEPA 2012a). The 250 km radius, which includes much of MN, western WI, and part of northern Iowa, was chosen to facilitate comparison with an earlier study done for ISRO and VOYA, which are in the same region, by Swackhamer and Hornbuckle (2004). We used data for regulated facilities to map point sources. For nonpoint sources, we included data for counties that were entirely or partially (>50%) within a 50-km radius of any part of MISS; these were the WI counties of Pierce and St. Croix and the MN counties of Anoka, Carver, Dakota, Goodhue, Hennepin, Isanti, Ramsey, Scott, Sherburne, Washington, and Wright (see Figure 6 for county locations).

Air quality data for MISS were acquired from the NPS air quality estimate tables (NPS 2012) as recommended in the *Methods for Determining Air Quality Conditions and Trends for Park Planning and Assessments* (NPS 2013b).

Wind rose climatology was found for the Minnesota Valley National Wildlife Refuge, Sherburne, MN, and Carlos Avery, MN at the Western Regional Climate Center (2012) RAWS USA climate archive. Prevailing winds may give some indication of the importance of a particular emission source for MISS. However, the wind roses on the air monitoring station map reflect the average wind direction for the year and may not match well with emissions if they are timed to certain seasons or times of day.

Numerous air monitoring sites are located in the vicinity of MISS (Figure 34). A National Atmospheric Deposition Program (NADP) National Trends Network (NTN) site (http://nadp.sws.uiuc.edu/) that monitors wet deposition is located at the Anoka Airport, MN, 5 km E of MISS. The other NTN site within 50 km of MISS is located at Cedar Creek, MN, 27 km N. The only NADP Mercury Deposition Network (MDN) site within 50 km of MISS is also located at the Anoka Airport. Dry deposition is monitored by the national Clean Air Status and Trends Network (CASTNet) (http://epa.gov/castnet/javaweb/index.html), with the site nearest MISS at Perkinstown, WI, 177 km E.

Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring sites (http://vista.cira.colostate.edu/improve/Web/MetadataBrowser/MetadataBrowser.aspx) measure fine aerosols, particulate matter less than 10 microns in size (PM_{10}), and light extinction and scattering. The nearest IMPROVE site to MISS is at Winona, MN (Great River Bluffs), 133 km SE. Ozone monitoring sites are scattered throughout the vicinity of MISS, with the closest at the Anoka Airport.

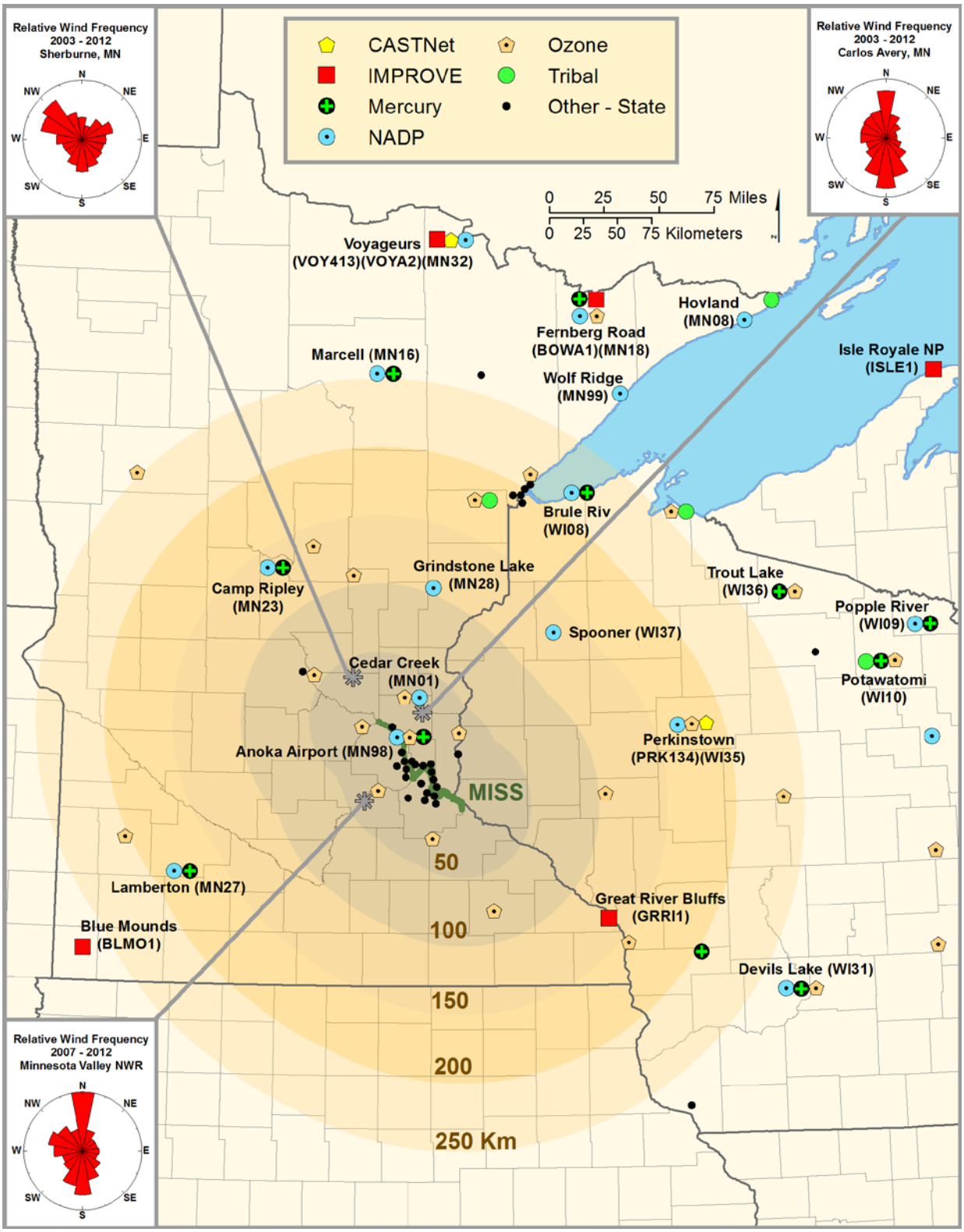


Figure 34. Air monitoring sites operated by state and federal agencies in the vicinity of Mississippi National River and Recreation Area (MPCA 2012, WDNR 2012).

Sullivan et al. (2011a, 2011b, 2011c, 2011d) conducted national-scale risk assessments for nitrogen and sulfur deposition in national parks in NPS Inventory and Monitoring networks. They described their work as "construct(ing) a preliminary overall risk assessment to estimate the relative risk… of nutrient enrichment impacts from atmospheric N deposition" and "provid(ing) a first step" in "compil(ing) available information at the national scale to identify park resources that are known or thought to be sensitive to acidification from atmospheric deposition of acidifying S and N compounds."

Reference Condition

For ozone, the NPS metric is the 5-year average of the annual 4th highest daily maximum 8-hour ozone concentration (The metric used by USEPA is the *3-year average* of the annual 4th highest daily maximum 8-hour ozone concentration). For visibility, the NPS metric is the five-year average of the difference between the mean of the visibility observations falling within the range of the 40th through 60th percentiles and the estimated values that would be observed under natural conditions. This metric is called the 'Group 50 visibility minus natural conditions' and is expressed in deciviews, a unitless measure of light extinction (Malm 1999).

For wet deposition of nitrogen (N) and sulfur (S), the NPS metric is expressed in kilograms per hectare per year. Values that represent 'Good' condition (Table 32) were used as the reference condition as specified in NPS 2013b. Using five-year averages, NPS assigns "good condition" to parks with wet deposition <1 kg ha^{-1} yr^{-1}, "warrants moderate concern" to parks with 1-3 kg ha^{-1} yr^{-1}, and "warrants significant concern" to parks with >3 kg ha^{-1} yr^{-1}. Its rationale is that "Evidence is not currently available indicating that wet deposition amounts less than 1 kg/ha/yr cause ecosystem harm." These reference conditions represent "least disturbed conditions" or "the best of today's existing conditions" (Stoddard et al. 2006).

Condition and Trend

Overall, air quality at MISS is of significant concern, based on the individual scores for wet deposition, ozone, and visibility. Using the NPS weighted calculation method, its overall score is 7.7 for 2001-2010, with >6 being of significant concern (NPS 2013b). Air quality at MISS is of significant concern for wet deposition of total nitrogen and visibility. It is of moderate concern for ozone and wet deposition of total sulfur (Table 32) (NPS 2012, 2013c). Only ozone had sufficient data to assess a trend in MISS; no statistically significant trend was found (NPS 2013a, 2013c). This assessment is based on NPS ARD data and has a moderate level of confidence, since some air monitoring sites are some distance from the park. In the following sections, the significance and sources of ozone, visibility and particulate material, and total sulfur and nitrogen deposition will be further discussed.

Ozone

Ozone is a compound of three oxygen atoms (O_3). In the stratosphere, ozone protects life on Earth from harmful ultraviolet radiation, but at ground level, it is the primary constituent of smog. Breathing ozone can trigger a variety of human health problems such as chest pain, coughing, throat irritation, and congestion, and can worsen bronchitis, emphysema, and asthma (USEPA 2003). Ground-level ozone also damages vegetation and ecosystems (USEPA 2003). Five-year averages of annual 4th highest daily maximum 8-hour ozone concentrations for MISS range from 64.6 ppb for 2006-2010 to 70.8 ppb for 1999-2003 (Table 32).

Table 32. Air quality conditions for ozone, wet deposition, and visibility in Mississippi National River and Recreation Area (NPS 2012).

Parameter	Date Range	Metric/Value	Condition	Condition Range
Ozone		4th highest 8 hr (ppb)*		
	1999-2003	70.8	Moderate Concern	
	2001-2005	68.2	Moderate Concern	
	2003-2007	68.6	Moderate Concern	Significant Concern: ≥ 76
	2004-2008	65.7	Moderate Concern	Moderate Concern: 61-75
	2005-2009	66.9	Moderate Concern	Good: ≤ 60
	2006-2010	64.6	Moderate Concern	
Visibility		Group 50 Visibility minus Natural Conditions (deciviews)		
	2001-2005	7.4	Moderate Concern	
	2003-2007	9.0	Significant Concern	Significant concern:>8
	2004-2008	9.04	Significant Concern	Moderate Concern: 2-8
	2005-2009	8.8	Significant Concern	Good: <2
	2006-2010	8.2	Significant Concern	
Wet Deposition – Total Nitrogen (TN)		Kg/ha/year		
	2001-2005	5.58	Significant Concern	
	2003-2007	5.42	Significant Concern	Significant concern:>3
	2004-2008	5.27	Significant Concern	Moderate Concern: 1-3
	2005-2009	5.4	Significant Concern	Good: <1
	2006-2010	5.1	Significant Concern	
Wet Deposition – Total Sulfur		Kg/ha/year		
	2001-2005	2.69	Moderate Concern	
	2003-2007	2.73	Moderate Concern	Significant concern:>3
	2004-2008	2.52	Moderate Concern	Moderate Concern: 1-3
	2005-2009	2.6	Moderate Concern	Good: <1
	2006-2010	2.2	Moderate Concern	

*In January 2010, EPA proposed but did not ultimately implement a reduction in the ozone standard from 75 ppb to a level within the range of 60–70 ppb; this decision will be reviewed in 2013 (USEPA 2011a).

These values fall within the category of moderate concern (NPS 2013b); our confidence in this assessment is high. An assessment of the risk of foliar injury from ozone in MISS and other GLKN parks listed seventeen plant species sensitive to ozone, but it concluded that MISS was at low risk of foliar injury from ozone because of low exposure levels (GLKN 2004).

Ground-level ozone (hereafter, ozone) is not emitted directly into the air. It is created by chemical reactions between VOC and NO_x in the presence of sunlight. Ozone levels are

generally higher in summer because of the combination of high temperatures and strong sunlight. Industrial emissions, electric utilities emissions, motor vehicle exhausts, gasoline vapors, and chemical solvents are some of the major sources of VOC and NO_x (USEPA 2003).

In the vicinity of MISS in 2008, the largest regulated source of VOC within 250 km is a pulp and paper plant in Wisconsin Rapids (Wood County), WI (1,305 MT yr^{-1}). Large VOC point sources within 50 km include a petroleum refinery and a window and door manufacturer in Washington County, MN (751 and 667 MT yr^{-1}) and a petroleum refinery in Dakota County, MN (449 MT yr^{-1}) (Figure 35). Nonpoint sources of VOC in counties within 50 km of MISS include residential fuel combustion (natural gas, oil, wood, and other fuels) of 4,996 MT yr^{-1}, mobile sources (aircraft, commercial, marine vessels, locomotives, and non-road gasoline and diesel equipment) of 30,633 MT yr^{-1}, and on-road sources (diesel and gasoline-powered vehicles) of 40,881 MT yr^{-1} (Table 33) (USEPA 2012a). Within 50 km of MISS, nonpoint sources account for 89.2% of VOC emissions.

In 2008, the largest sources of NOx within 50 km of MISS were electrical generation facilities located in Becker (Sherburne County), MN (16,073 MT yr^{-1}) and Minneapolis (8,787 MT yr^{-1}) (Figure 36). Other major sources of NO_x within 250 km of MISS included electrical generation facilities in Itasca County, MN (14,030 MT yr^{-1}) and Grant County, MN (12,565 MT yr^{-1}) (Figure 36). Nonpoint sources of NOx included residential fuel combustion of 4,553 MT yr^{-1}, mobile sources of 25,244 MT yr^{-1}, and on-road sources of 81,608 MT yr^{-1} (Table 33) (USEPA 2012a). On-road sources accounted for 52.9% of all NO_x emissions within 50 km of MISS in 2008, and all nonpoint sources accounted for 72.2%.

Visibility

Visibility is a measurement of how well and at what distance visitors to MISS can see the park's natural features. Using the metric called Group 50 visibility minus natural conditions and measured in deciviews, visibility was of moderate concern at MISS in 2001-2005, with a value of 7.4. However, it has become of significant concern from 2003-2007 and beyond, with values ranging from 8.2 in 2006-2010 to 9.04 in 2004-2008 (Table 32). We have a moderate level of confidence in this assessment.

Particulate matter pollution, especially particles with diameters of 2.5 microns or less, ($PM_{2.5}$) is the major cause of reduced visibility, also called haze (Malm 1999, USEPA 2006). The largest source of $PM_{2.5}$ in 2008 within 50 km of MISS was an electrical generation facility in Becker (Sherburne County) MN (1,175 MT yr^{-1}) (Figure 37). Other major sources of $PM_{2.5}$ within 250 km of MISS include electrical generation facilities in Itasca County, MN (916 MT yr^{-1}) and Allamakee County, IA (640 MT yr^{-1}), an ethanol refinery in Faribault County, MN (584 MT yr^{-1}), and a taconite plant in St. Louis County, MN (402 MT yr^{-1}) (Figure 37). Within 50 km of MISS, nonpoint sources of $PM_{2.5}$ in 2008 included residential fuel combustion of 5,577 MT yr^{-1}, mobile sources of 1,894 MT yr^{-1}, and on-road sources of 3,645 MT yr^{-1} and accounted for 73.9% of all $PM_{2.5}$ emissions (Table 33) (USEPA 2012a).

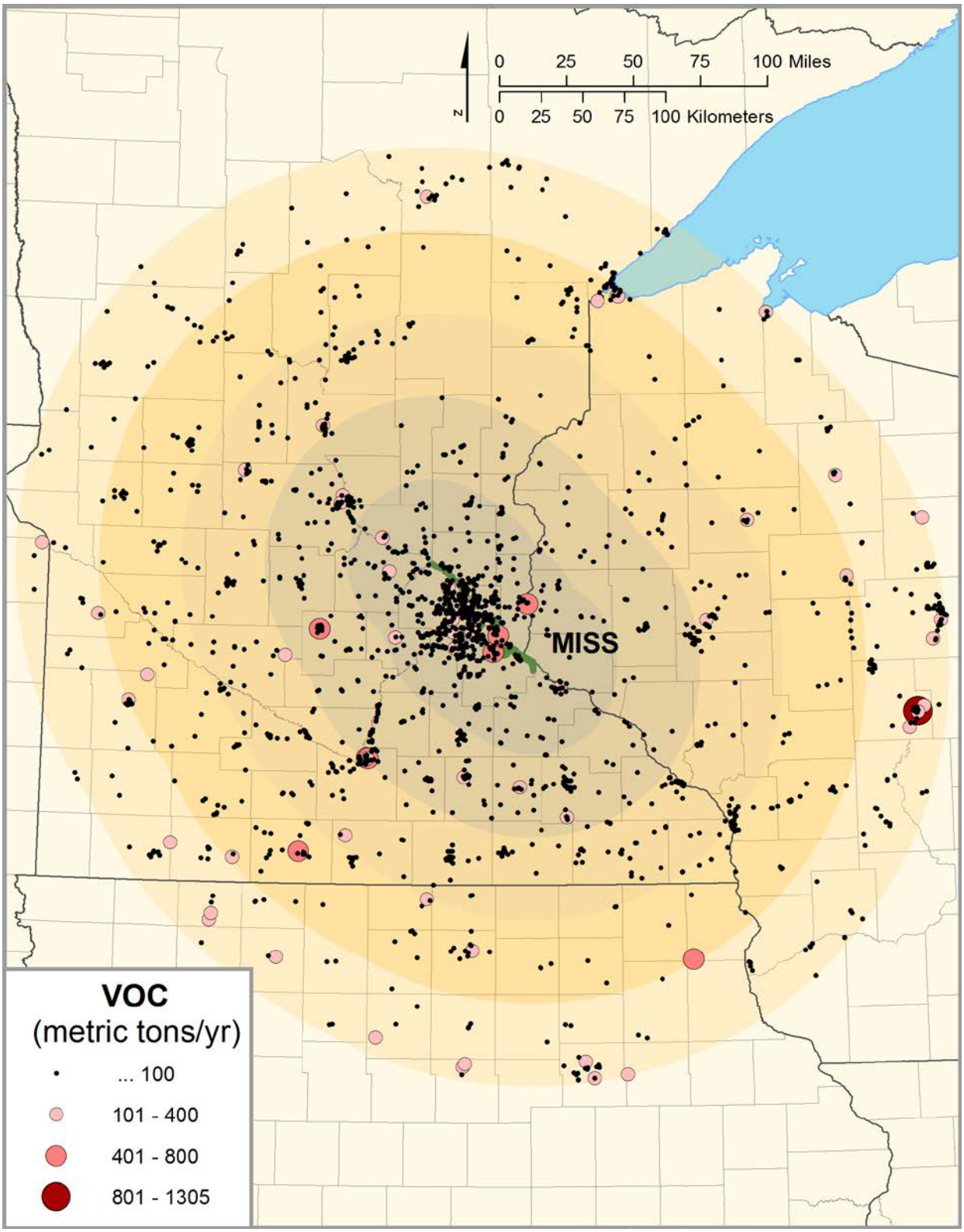


Figure 35. Emissions of volatile organic compounds (VOCs) from regulated facilities within 250 km of Mississippi National River and Recreation Area (USEPA 2012a).

Table 33. 2008 emissions of criteria air pollutants in metric tons for selected nonpoint and point sources within a 50 km buffer of Mississippi National River and Recreation Area (USEPA 2012a).

		2008 emissions in metric tons and % of total													
		CO	**%**	**NH_3**	**%**	**NO_x**	**%**	**PM_{10}**	**%**	**$PM_{2.5}$**	**%**	**SO_2**	**%**	**VOC**	**%**
Selected nonpoint sources															
Residential fuel combustion*		37,331	5.5	1,104	37.3	4,553	3.0	5,586	30.4	5,577	37.1	430	1.0	4,996	5.8
Mobile Sources**		180,471	26.6	23	0.8	25,244	16.4	2,033	11.1	1,894	12.6	571	1.3	30,633	35.7
On-road sources***		446,650	65.9	1,331	44.9	81,608	52.9	4,671	25.4	3,645	24.2	349	0.8	40,881	47.7
	Subtotal	664,452	**98.0**	2,458	**83.0**	111,405	**72.2**	12,290	**66.8**	11,116	**73.9**	1,350	3.1	76,510	**89.2**
Point sources															
Regulated facilities		13,675	2.0	504	17.0	42,789	27.8	6,103	33.2	3,932	26.1	42,025	**96.9**	9,218	10.8
	Total	678,127		2,962		154,194		18,393		15,048		43,375		85,728	

*natural gas, oil, wood, and other fuels
**aircraft, commercial marine vessels, locomotives, and non-road equipment (gasoline and diesel)
***diesel and gasoline-powered vehicles

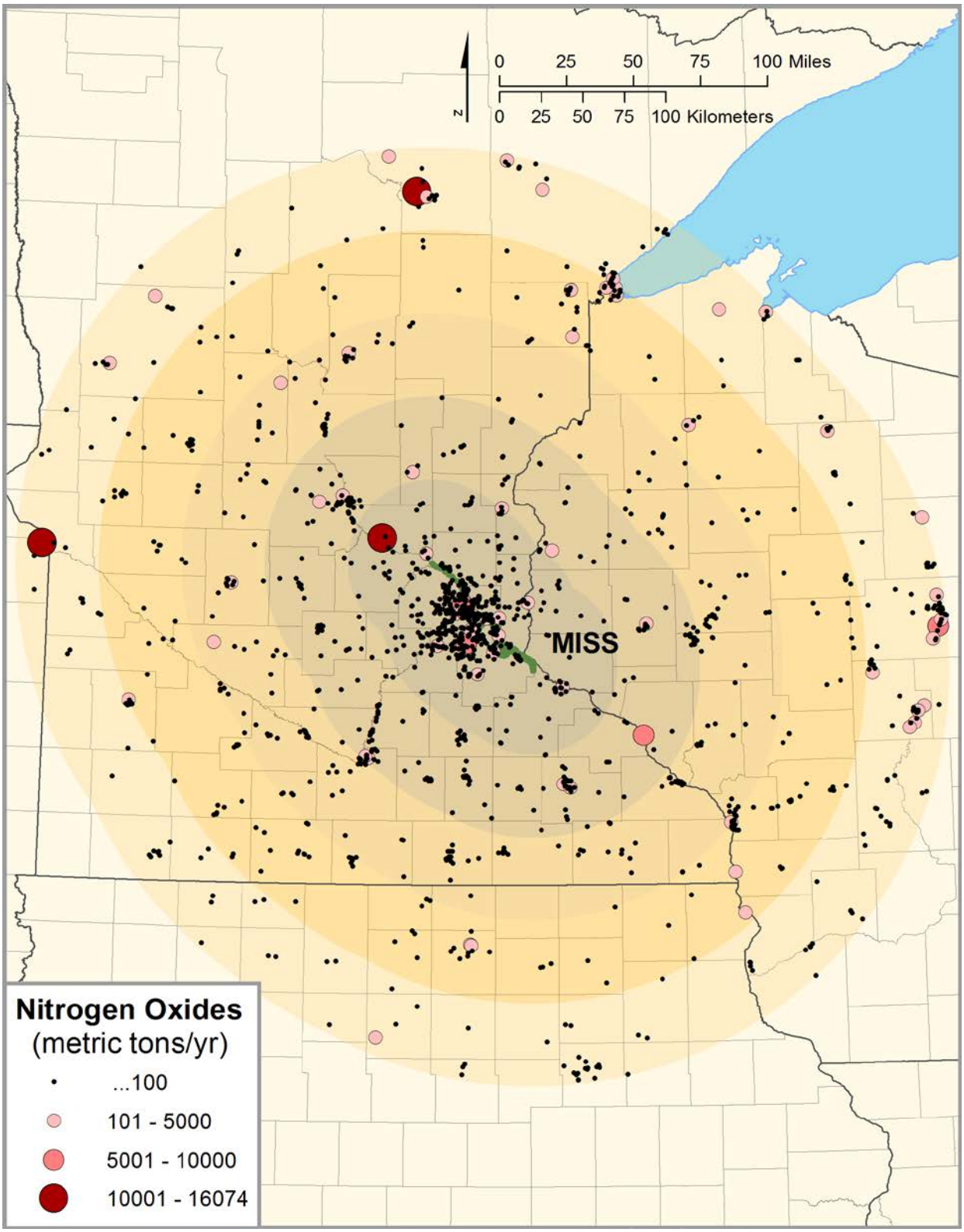


Figure 36. Emissions of nitrogen oxides (NO_x) from regulated facilities within 250 km of Mississippi National River and Recreation Area (USEPA 2012a).

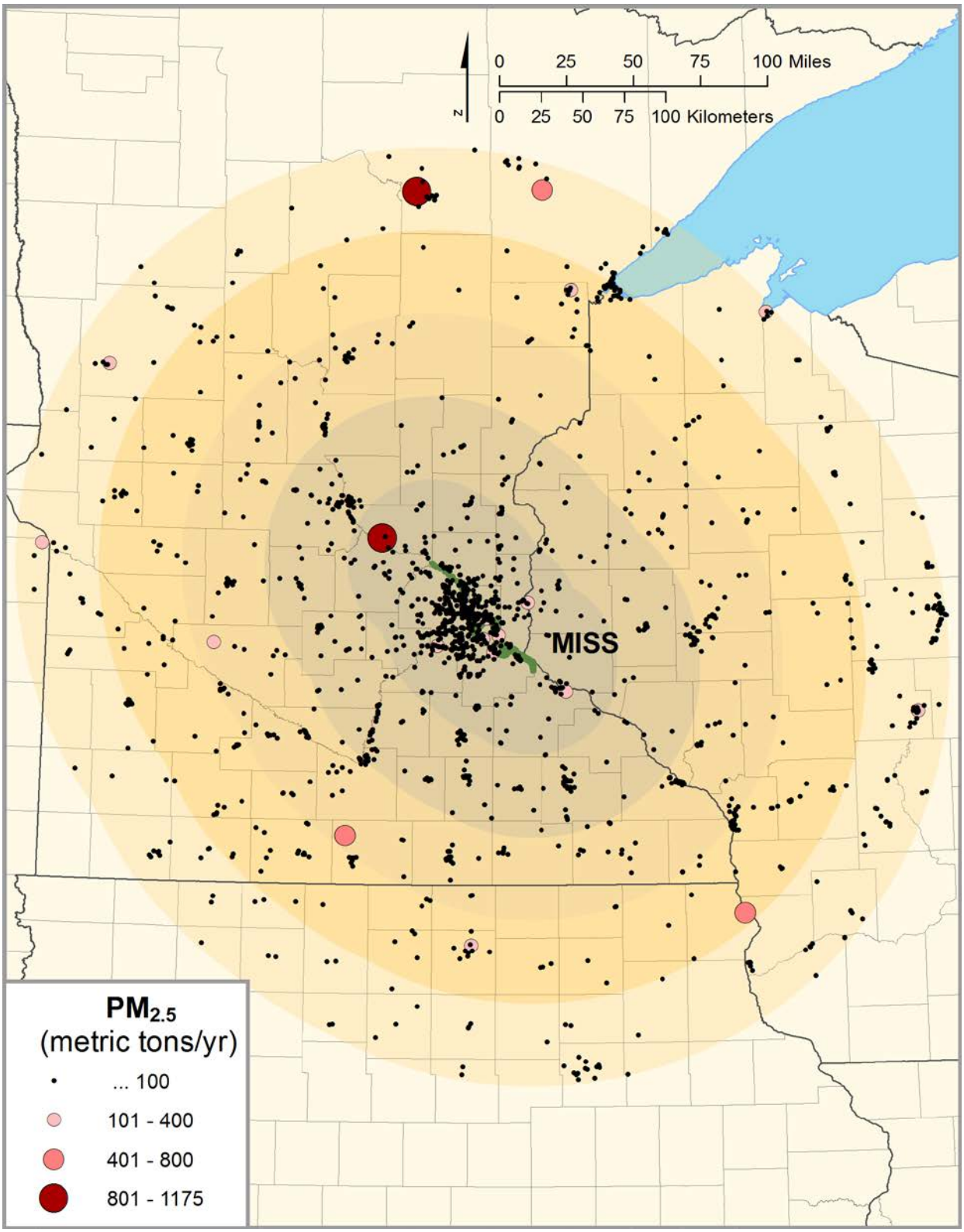
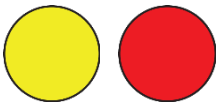


Figure 37. Emissions of particulate matter ($PM_{2.5}$) from regulated facilities within 250 km of Mississippi National River and Recreation Area (USEPA 2012a).

Wet Deposition – Sulfur and Wet Deposition – Nitrogen



Wet deposition of total S is considered by NPS ARD to be moderate for MISS, with a range of 2.2 kg ha^{-1} yr^{-1} from 2006-2010 to 2.73 kg ha^{-1} yr^{-1} for 2003-2007. Wet deposition of total N is considered to be of significant concern for MISS, with values ranging from 5.1 kg ha^{-1} yr^{-1} from 2006-2010 to 5.58 kg ha^{-1} yr^{-1} from 2001-2005 (Table 32) (NPS 2012). We have a moderate level of confidence in this assessment. The potential effects of wet deposition of nitrogen and sulfur include acidification of ecosystems, both aquatic and terrestrial, and addition of nutrients that can lead to eutrophication.

Deposition results from emissions of SO_2 and NO_x, which also have consequences for human health. These gases create a variety of respiratory problems in people, and they react with other components in the atmosphere to create fine particles that create additional respiratory problems (USEPA 2011b, 2011c). Sulfates also contribute greatly to visibility reductions at high relative humidity levels (Malm 1999).

The largest source of SO_2 within 50 km of MISS in 2008 was an electrical generation facility in Becker (Sherburne County), MN (21,247 MT yr^{-1}). Other major sources of SO_2 within 250 km include electrical generation facilities in Itasca County, MN (19,527 MT yr^{-1}) and Buffalo County, WI (16,939 MT yr^{-1}) (USEPA 2012a) (Figure 38). Nonpoint sources of SO_2 within 50 km of MISS include residential fuel combustion of 430 MT yr^{-1}, mobile sources of 571 MT yr^{-1}, and on-road sources of 349 MT yr^{-1} (Table 33). Within 50 km of MISS, regulated facilities accounted for 96.9% of SO_2 emissions in 2008.

Driscoll et al. (2001) reported that a decrease in SO_4^{2-} wet deposition in the eastern US has resulted from the Clean Air Act Amendments (CAAA) of 1990. Atmospheric SO_4^{2-} deposition at ISRO exhibited a downward trend from 1985-2005 (Drevnick et al. 2007). Similarly, in New England, the region with the longest deposition record in North America, a decline in SO_4^{2-} input has been documented since the 1970s (Hedin et al. 1994, Likens et al. 1996). This decline extended as far west as Minnesota.

Sources of nitrogen emissions were described in the previous discussion of ozone. Although the 1990 CAAA decreased sulfur deposition in the eastern US, the same effect was not observed for nitrogen deposition (Driscoll et al. 2001). In addition to the wet deposition of nitrogen considered by NPS ARD, dry deposition of total nitrogen (TN) is also a consideration for MISS. Wet deposition may include HNO_3, NO_3^-, and NH_4^+, while dry deposition includes HNO_3, particulate NO_3^-, particulate NH_4^+, and NH_3 (NAPAP 2005). Of TN deposition at Perkinstown, WI (the closest CASTNet site to MISS) from 2008-2010, 85% was wet deposition and 15% was dry deposition (USEPA 2012b); at VOYA, the proportions were 86% and 14%, respectively (USEPA 2012c).

In the assessment of Sullivan et al. (2011a), a ranking of all national parks by quintile, MISS is considered to be at moderate risk from acidic deposition. This ranking is based on three factors: a high pollutant exposure, moderate ecosystem sensitivity, and a moderate degree of park protection (lack of areas included as Class I or wilderness). The particular ecosystem risk factors for MISS are a) the presence of sugar maple and b) the incidence of surface waters of low alkalinity in the vicinity of MISS (http://water.usgs.gov/owq/alkus.pdf). However, it should be

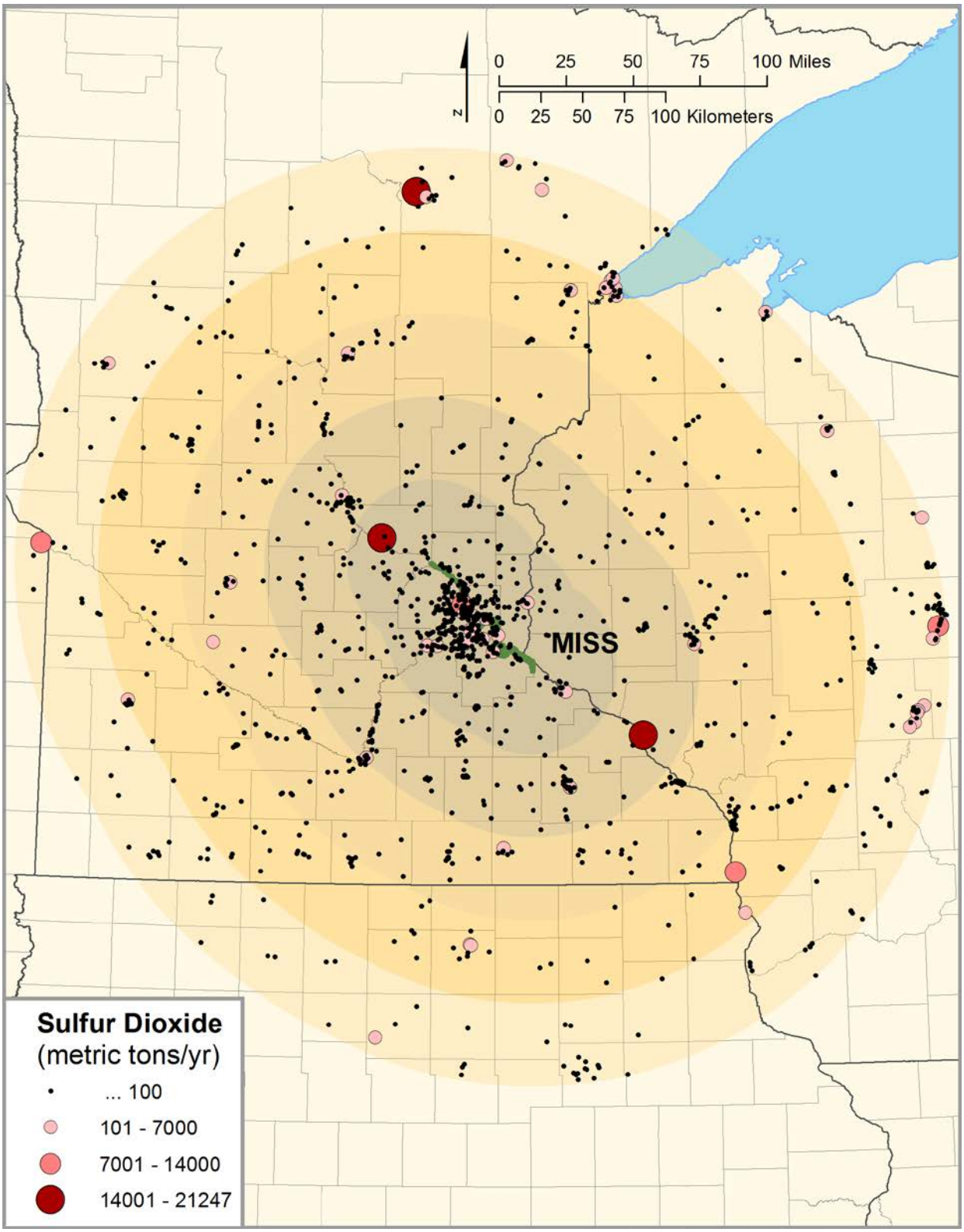


Figure 38. Emissions of sulfur dioxide (SO_2) from regulated facilities within 250 km of Mississippi National River and Recreation Area (USEPA 2012a).

noted that sugar maple is a minor component of the landscape at MISS (section 4.4.1) and that alkalinity values in MISS indicate that surface waters are relatively well-buffered (section 4.5.2); thus, the sensitivity of MISS to acidic deposition may be overstated in this broad-scale analysis.

In a similar ranking performed by Sullivan et al. (2011c), MISS is considered to be at high risk from atmospheric nutrient N enrichment, with a very high pollutant exposure, moderate ecosystem sensitivity, and a moderate degree of park protection. For N enrichment, the particular ecosystem risk factor for MISS is the presence of "sensitive vegetation types" (defined as arctic, alpine, meadow, wetland, arid, and/or semiarid vegetation) (Sullivan et al. 2011d). The authors use USEPA (2008) as a source; this document refers to “more sensitive terrestrial ecosystems” as including “alpine meadows,” which are not found in MISS, but also refers to “grassland ecosystems.” Thus, more site-specific definition of sensitive terrestrial vegetation communities is needed for a thorough evaluation of N enrichment effects at MISS.

Researchers have attempted to define thresholds below which there are no discernible effects of N deposition, called critical loads (CL). Beyond CLs, N saturation can occur. These affect forest ecosystem function by increasing nitrification and NO_3^- leaching, with associated acidification of soils and surface waters; depletion of soil nutrient cations and development of plant nutrient imbalances; and forest decline and changes in species composition (Driscoll et al. 2003).

<u>Acid deposition</u>: Wet deposition of reactive forms of sulfur and nitrogen that form or can form acids when in contact with water is part of the subset of air pollution known as acid deposition. Acid deposition specifically includes gases, particles, rain, snow, clouds, and fog that are composed of sulfuric acid, nitric acid, and ammonium, derived from SO_2, NO_x, and NH_3, respectively.

The effect of acid precipitation on aquatic ecosystems is determined largely by the ability of the water and watershed soil to neutralize the acid deposition they receive. Generally, small watersheds with shallow soils and few alkaline minerals are most sensitive to acidification. Low pH levels and higher aluminum levels that result from acidification hinder fish reproduction and decrease fish sizes and population densities (NAPAP 2005). Watersheds that contain alkaline minerals such as limestone, or those with well-developed riparian zones, generally have a greater capacity to neutralize acids. Although MISS is in a sensitive region (Sullivan et al. 2011a), measured alkalinity values for the Mississippi River exceed the generally accepted threshold value (Sheffy 1984, Shaw et al. 2004) of 25 mg L^{-1} as $CaCO_3$ (see Table 36) and so are not considered particularly vulnerable to acid precipitation.

Recent efforts to assess CLs for atmospheric deposition of TN have not specifically addressed Midwestern lakes or streams. However, Baron et al. (2011a, 2011b) have indicated that for lakes in the eastern US, the CL for the endpoint of acidity is 9 kg ha^{-1} yr^{-1}, within the range derived for forested streams in Europe. Deposition levels at MISS are below that threshold (Table 32).

The effects of acid precipitation on upland and forest ecosystems include direct and indirect impacts on plants, changes in forest floor and/or soil chemistry, and altered rates of mineral and nutrient accumulation and loss (Ohman and Grigal 1990, Aber et al. 1998, 2003). The possible direct effects on plants (e.g., reducing the integrity of the epidermis) are well-known (McLaughlin 1985), and are all negative, with the possible exception of a fertilization effect. The

indirect effects on plants derive largely from changes in chemistry of the system, and include nutritional, toxic, and altered symbiosis effects (Hedin et al. 1994, Aber et al. 1998, Friedland and Miller 1999, Zaccherio and Finzi 2007).

Because N is a common limiting nutrient in temperate forests (Nadelhoffer et al. 1985), N deposition might appear to be beneficial. However, the acidification that accompanies N and S deposition can lead to the loss of cations, which are important nutrients, from the soil. Buffering capacity (the ability to resist acidification) in forest soils is largely a function of four factors: a) surface horizon texture and depth, b) B-horizon texture and depth, c) total cation exchange capacity and base saturation, and d) abundance of fungi and bacteria in the upper soil profile (Johnson et al. 1983, Aber et al. 1998). Generally, buffering capacity is low in systems with coarse, acid soils; soils low in organic matter; and soils that are shallow.

Nutrient deficiency is particularly likely for any upland ecosystem that has low base saturation, which is common on acidic sites. Stottlemyer and Hanson (1989) determined that under conifers, the concentrations of SO_4^{2-} , calcium (Ca^{2+}), and magnesium (Mg^{2+}) were higher in soil solution than in precipitation, and SO_4^{2-} had a flux 2-3 times that of other nutrients. These findings demonstrate how acid deposition could affect a terrestrial system by setting the stage for accelerated loss of cations. The hydrogen ions associated with SO_4^{2-} replace other cations on the soil exchange sites (Tomlinson 2003), and then the cations are leached if water moves down through the soil profile. However, cation loss occurs even on soils with high buffering capacity. The effect is cumulative and continues even after acid deposition is mitigated. In New England, large quantities of Ca^{2+} and Mg^{2+} have been lost from the soil (Likens et al. 1996, Friedland and Miller 1999) even after nitrate and sulfate inputs were reduced and the pH of precipitation increased (Likens et al. 1996).

<u>Nutrient N enrichment:</u> Nitrogen can cause changes in terrestrial plant, fungal, and lichen communities. Among trees, red pine (*Pinus resinosa*), yellow birch (*Betula alleghaniensis*), quaking aspen (*Populus tremuloides*), basswood (*Tilia americana*), and northern white cedar (*Thuja occidentalis*), all present or probably present at MISS (https://irma.nps.gov/NPSpecies), are among the N-'sensitive' species identified by Pardo et al. (2011) and Gilliam et al. (2011). This group shows reduced growth or survivorship at TN deposition rates above 3 kg ha^{-1} yr^{-1}; this level is exceeded at MISS. However, these species are uncommon to rare members of the MISS forest community.

A synthesis by Pardo et al. (2011) for the Northern Forest ecoregion determined that the ectomycorrhizal community and lichen community had the lowest CLs for nutrient N (4-7 kg ha^{-1} yr^{-1}). Similarly, for Eastern Hardwood forests, the lowest CL for nutrient N was observed for lichens (4-8 kg ha^{-1} yr^{-1}) (Gilliam et al. 2011). For wetlands, Greaver et al. (2011 and citations therein) report CLs for TN of 2.7-13 kg ha^{-1} yr^{-1} for peat accumulation and net primary production and 6.8-14 kg ha^{-1} yr^{-1} for pitcher plant community change. The authors did not address the wetland types at MISS, which are parts of open systems and are likely to have higher CL values. TN deposition at MISS exceeds the lower end of the CL range for the ectomycorrhizal and lichen communities.

A second undesirable effect that might manifest from N deposition is simplification of composition. That is, a subset of species is favored under the changed nutrient conditions and is

able to outcompete other species. Simplification has not been documented in forested wetlands or wet meadows, but has been demonstrated in some forest fertilization trials (Rainey et al. 1999).

A recent study (Clark et al. 2013) estimated losses of plant biodiversity in the US from N deposition that occurred from 1985-2010, without distinguishing between acidification and nutrient enrichment effects. The authors concluded that millions of hectares in the US (including 222.1 million ha in the Eastern Forest ecoregion) have N deposition levels exceeding the "common" CL of 10 kg ha^{-1} yr^{-1}. Species losses varied considerably by ecosystem types. They urged greater research in refining CLs and questioned the adequacy of current CL estimates in providing protection to terrestrial plant biodiversity.

Increased nitrate leaching is one of the probable indicators that N saturation has occurred (Aber et al. 2003, Pardo et al. 2011). A compilation of many studies in the eastern hardwood forests of the northeast (Aber et al. 2003) concluded that an increase in nitrate leaching to surface waters is likely to occur if the N deposition rate exceeds approximately 8 kg ha^{-1} yr^{-1} for an extended period of time. Baron et al. (2011a, 2011b) indicated that for lakes in the eastern US, this level of N deposition is a CL for eutrophication.

Because streams and rivers integrate the deposition on land and deposition directly to the aquatic system, the N concentration in water has been suggested as a suitable sentinel of N deposition problems (Williamson et al. 2008). However, the magnitude of nitrate leaching was highly variable among sites; it was hypothesized that this variability is due to the large number of factors (plant composition, soil type, land use, hydrology, and climate) that affect leaching (Pardo et al. 2011). The complexity of the situation is highlighted by the fact that very large differences in nutrient cycling and leaching rates between evergreen and broadleaved species often occur (Stottlemyer and Hanson 1989, Reich et al. 1997, Ollinger et al. 2002), and that N deposition rates are only weakly related to nitrogen cycling processes (Pardo et al. 2011). Other components of the system (such as foliar N concentration or the fungal community discussed above) may change prior to nitrate leaching and thus provide an earlier ‘warning’.

Sources of Expertise

USEPA air quality website (http://www.epa.gov/air); NPS ARD; David Pohlman, NPS; James Cook, Christine Mechenich, Jen McNelly, UWSP.

Literature Cited

Aber, J., W. McDowell, K. Nadelhoffer, A. Magill, G. Berntson, M. Kamakea, S. McNulty, W. Currie, L. Rustad, and I. Fernandez. 1998. Nitrogen saturation in temperate forest ecosystems. *BioScience* 48:921–933.

Aber, J. D., C. L. Goodale, S. V. Ollinger, M. Smith, A. H. Magill, M. E. Martin, R. A. Hallett, and J. L. Stoddard. 2003. Is nitrogen deposition altering the nitrogen status of northeastern forests? *BioScience* 53:375–388.

Baron, J. S., C. T. Driscoll, and J. L. Stoddard. 2011a. Inland surface waters, chapter 18. Pages 209–227 *in* L. H. Pardo, M. J. Robin-Abbott, and C. T. Driscoll, editors. Assessment of nitrogen deposition effects and empirical critical loads of nitrogen for ecoregions of the

United States. General Technical Report NRS-80. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, Pennsylvania. Available at http://treesearch.fs.fed.us/pubs/38129. (accessed July 22, 2013).

Baron, J. S., C. T. Driscoll, J. L. Stoddard, and E. E. Richer. 2011b. Empirical critical loads of atmospheric nitrogen deposition for nutrient enrichment and acidification of sensitive US lakes. *BioScience* 61:602–613.

Clark, C. M., P. E. Morefield, F. S. Gilliam, and L. H. Pardo. 2013. Estimated losses of plant biodiversity in the United States from historical N deposition (1985-2010). *Ecology* 94:1441–1448.

Drevnick, P. E., D. E. Canfield, P. R. Gorski, A. C. Shinneman, D. R. Engstrom, D. C. G. Muir, G. R. Smith, P. J. Garrison, L. B. Cleckner, J. P. Hurley, R. B. Noble, R. R. Otter, and J. T. Oris. 2007. Deposition and cycling of sulfur controls mercury accumulation in Isle Royale fish. *Environmental Science and Technology* 41:7266–7272.

Driscoll, C. T., G. B. Lawrence, A. J. Bulger, T. J. Butler, C. S. Cronan, C. Eagar, K. F. Lambert, G. E. Likens, J. L. Stoddard, and K. C. Weathers. 2001. Acid rain revisited: advances in scientific understanding since the passage of the 1970 and 1990 Clean Air Act Amendments. Science Links™ Publication. Vol. 1, no.1. Hubbard Brook Research Foundation, North Woodstock, New Hampshire. Available at http://hubbardbrookfoundation.org/wp-content/uploads/2010/12/acid-rain-revisited.pdf. (accessed July 22, 2013).

Driscoll, C. T, D. Whitall, J. Aber, E. Boyer, M. Castro, C. Cronan, C. L. Goodale, P. Groffman, C. Hopkinson, K. Lambert, G. Lawrence, and S. Ollinger. 2003. Nitrogen pollution in the northeastern United States: sources, effects, and management options. *BioScience* 53:357–374.

Friedland, A. J., and E. K. Miller. 1999. Major-element cycling in a high-elevation Adirondack forest: patterns and changes, 1986-1996. *Ecological Applications* 9:958–967.

Gilliam, F. S., C. L. Goodale, L. H. Pardo, L. H. Geiser, and E. A. Lilleskov. 2011. Eastern temperate forests, chapter 10. Pages 99–116 *in* L. H. Pardo, M. J. Robin-Abbott, and C. T. Driscoll, editors. Assessment of nitrogen deposition effects and empirical critical loads of nitrogen for ecoregions of the United States. General Technical Report NRS-80. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, Pennsylvania. Available at http://treesearch.fs.fed.us/pubs/38121. (accessed July 22, 2013).

GLKN (Great Lakes Inventory and Monitoring Network). 2004. Assessing the risk of foliar injury from ozone on vegetation in parks in the Great Lakes Network. National Park Service Great Lakes Inventory and Monitoring Network, Ashland, Wisconsin. Available at http://nature.nps.gov/air/Pubs/pdf/03Risk/glknO3RiskOct04.pdf. (accessed July 16, 2013).

Greaver, T. L., L. Liu, and R. Bobbink. 2011. Wetlands, chapter 17. Pages 193–208 *in* L. H. Pardo, M. J. Robin-Abbott, and C. T. Driscoll, editors. Assessment of nitrogen deposition effects and empirical critical loads of nitrogen for ecoregions of the United States. General Technical Report NRS-80. U.S. Department of Agriculture, Forest Service, Northern

Research Station, Newtown Square, Pennsylvania. Available at http://treesearch.fs.fed.us/pubs/38128. (accessed July 22, 2013).

Hedin, L. O., L. Granat, G. E. Likens, T. A. Buishand, J. N. Galloway, T. J. Butler, and H. Rodhe. 1994. Steep declines in atmospheric base cations in regions of Europe and North America. *Nature* 367:351–354.

Johnson, D. W., D. D. Richter, H. Van Miegroet, and D. W. Coles. 1983. Contributions of acid deposition and natural processes to cation leaching from forest soils: a review. *Journal of the Air Pollution Control Association* 33:1036–1041.

Likens, G. E., C. T. Driscoll, and D. C. Buso. 1996. Long-term effects of acid rain: response and recovery of a forest ecosystem. *Science* 272:244–246.

Malm, W. C. 1999. Introduction to visibility. Cooperative Institute for Research in the Atmosphere (CIRA) NPS Visibility Program, Colorado State University, Fort Collins, Colorado. Available at http://www.epa.gov/air/visibility/pdfs/introvis.pdf. (accessed November 29, 2011).

McLaughlin, S. B. 1985. Effects of air pollution on forests. *Journal of the Air Pollution Control Association* 35:512–534.

MPCA (Minnesota Pollution Control Agency). 2012. Annual air monitoring network plan for Minnesota 2013. Document number aq10-07a. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=17855. (accessed July 16, 2013).

Nadelhoffer, K. J., J. D. Aber, and J. M. Melillo. 1985. Fine roots, net primary production and soil nitrogen availability: a new hypothesis. *Ecology* 66:1377–1390.

NAPAP (National Acid Precipitation Assessment Program). 2005. National Acid Precipitation Assessment Program Report to Congress: an integrated assessment. Available at http://www.esrl.noaa.gov/csd/aqrs/reports/napapreport05.pdf. (accessed July 16, 2013).

NPS (National Park Service). 2007. Long-term ecological monitoring plan: Great Lakes Inventory and Monitoring Network. Natural Resource Report NPS/GLKN/NRR-2007/001. National Park Service. Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/645523 (accessed October 28, 2013).

NPS (National Park Service). 2012. NPS air quality estimate tables. NPS Air Resources Division, Denver, Colorado. Available at http://www.nature.nps.gov/air/Maps/AirAtlas/IM_materials.cfm (accessed April 8, 2013).

NPS (National Park Service), Air Resources Division. 2013a. Air quality in national parks: trends (2000-2009) and conditions (2005-2009). Natural Resource Report NPS/NRSS/ARD/NRR—2013/683. National Park Service, Denver, Colorado. Available at http://www.nature.nps.gov/air/Pubs/pdf/gpra/AQ_Trends_In_Parks_2013.pdf. (accessed November 11, 2013).

NPS (National Park Service). 2013b. Methods for determining air quality conditions and trends for park planning and assessments. NPS Air Resources Division, Natural Resource Program Center, Denver, Colorado. Available at http://www.nature.nps.gov/air/Planning/docs/AQ_ConditionsTrends_Methods_2013.pdf. (accessed November 11, 2013).

NPS (National Park Service). 2013c. Additional trends and conditions information: Air quality in national parks: trends (2000-2009) and conditions (2005-2009). NPS Air Resources Division, Natural Resource Program Center, Denver, Colorado. Available at http://nature.nps.gov/air/Pubs/pdf/gpra/AQ_Trends_In_Parks_2013_508appendix.pdf. (accessed November 11, 2013).

Ohman, L. F., and D. F. Grigal. 1990. Spatial and temporal patterns of sulfur and nitrogen in wood of trees across the north central United States. *Canadian Journal of Forest Research* 20:508–513.

Ollinger, S. V., M. L. Smith, M. E. Martin, R. A. Hallett, C. L. Goodale, and J. D. Aber. 2002. Regional variation in foliar chemistry and N cycling among forests of diverse history and composition. *Ecology* 83:339–355.

Pardo, L. H., C. L. Goodale, E. A. Lilleskov, and L. H. Geiser. 2011. Northern forests, chapter 7. Pages 61–73 *in* L. H. Pardo, M. J. Robin-Abbott, and C. T. Driscoll, editors. Assessment of nitrogen deposition effects and empirical critical loads of nitrogen for ecoregions of the United States. General Technical Report NRS-80. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, Pennsylvania. Available at http://treesearch.fs.fed.us/pubs/38116. (accessed July 22, 2013).

Rainey, S. M, K. J. Nadelhoffer, W. L. Silver, and M. R. Downs. 1999. Effects of chronic nitrogen additions on understory species in a red pine plantation. *Ecological Applications* 9:949–957.

Reich, P. B., D. G. Grigal, J. D. Aber, and S. T. Gower. 1997. Nitrogen mineralization and productivity in 50 hardwood and conifer stands on diverse soils. *Ecology* 78:335–347.

Shaw, B., C. Mechenich, and L. Klessig. 2004. Understanding lake data. Publication G3582. University of Wisconsin-Extension, Madison, Wisconsin. Available at http://www4.uwsp.edu/uwexlakes/understandingLakeData.pdf. (accessed April 9, 2013).

Sheffy, T. 1984. Interpreting acid rain research findings in Wisconsin: what does it all mean? Wisconsin Natural Resource 8:29–32.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

Stottlemyer, R., and D. G. Hanson, Jr. 1989. Atmospheric deposition and ionic concentrations in forest soils of Isle Royale National Park, Michigan. *Soil Science Society of America Journal* 53:270–274.

Sullivan, J. T., G. T. McPherson, T. C. McDonnell, S. D. Mackey, and D. Moore. 2011a. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition: Great Lakes Network (GLKN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/356. National Park Service, Denver, Colorado.

Sullivan, T. J., G. T. McPherson, T. C. McDonnell, S. D. Mackey, and D. Moore. 2011b. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition: main report. Natural Resource Report NPS/NRPC/ARD/NRR—2011/349. National Park Service, Denver, Colorado.

Sullivan, J. T., T. C. McDonnell, G. T. McPherson, S. D. Mackey, and D. Moore. 2011c. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition: Great Lakes Network (GLKN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/309. National Park Service, Denver, Colorado.

Sullivan, T. J., T. C. McDonnell, G. T. McPherson, S. D. Mackey, and D. Moore. 2011d. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition: main report. Natural Resource Report NPS/NRPC/ARD/NRR—2011/313. National Park Service, Denver, Colorado.

Swackhamer, D. L., and K. C. Hornbuckle. 2004. Assessment of air quality and air pollutant impacts in Isle Royale National Park and Voyageurs National Park. National Park Service, Fort Collins, Colorado. Available at http://www.nature.nps.gov/air/Pubs/pdf/SwackHorn20040901.pdf. (accessed November 11, 2013).

Tomlinson, G. H. 2003. Acidic deposition, nutrient leaching and forest growth. *Biogeochemistry* 65:51–81.

USEPA (United States Environmental Protection Agency) Science Advisory Board. 2002. A framework for assessing and reporting on ecological condition: an SAB report. EPA-SAB-EPEC-02-009. USEPA, Washington, D.C. Available at http://www.epa.gov/sab/pdf/epec02009.pdf. (accessed September 19, 2013).

USEPA (United States Environmental Protection Agency). 2003. Ozone – good up high bad nearby. EPA-451/K-03-001. USEPA, Washington, D.C. Available at http://www.epa.gov/airquality/gooduphigh/. (accessed April 9, 2013).

USEPA (United States Environmental Protection Agency). 2006. How air pollution affects the view. EPA-456/F-06-001. USEPA, Research Triangle Park, North Carolina. Available at http://www.epa.gov/air/visibility/pdfs/haze_brochure_20060426.pdf. (accessed April 9, 2013).

USEPA (United States Environmental Protection Agency). 2008. Integrated science assessment for oxides of nitrogen and sulfur — ecological criteria. EPA/600/R-08/082F. National Center for Environmental Assessment, Office of Research and Development, Research Triangle

Park, North Carolina. Available at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485#Download. (accessed February 10, 2014).

USEPA (United States Environmental Protection Agency). 2011a. Ground-level ozone: regulatory actions webpage. http://www.epa.gov/air/ozonepollution/actions.html. (accessed April 8, 2013).

USEPA (United States Environmental Protection Agency). 2011b. Sulfur dioxide webpage. http://www.epa.gov/air/sulfurdioxide/index.html. (accessed April 8, 2013).

USEPA (United States Environmental Protection Agency). 2011c. Nitrogen dioxide – health webpage. http://www.epa.gov/airquality/nitrogenoxides/health.html. (accessed April 8, 2013).

USEPA (United States Environmental Protection Agency). 2012a. 2008 National emissions inventory data. USEPA, Washington, D.C. Available at http://www.epa.gov/ttn/chief/net/2008inventory.html. (accessed October 3, 2012).

USEPA (United States Environmental Protection Agency). 2012b. Composition of N deposition for 2008-2010-PRK134. Webpage. Available at http://www.epa.gov/castnet/javaweb/charts/PRK134_pctn.png. (accessed April 8, 2013).

USEPA (United States Environmental Protection Agency). 2012c. Composition of N deposition for 2008-2010-VOY413. Webpage. Available at http://www.epa.gov/castnet/javaweb/charts/VOY413_pctn.png. (accessed April 8, 2013).

USEPA (United States Environmental Protection Agency). 2013. Basic information – air emission sources webpage. Available at http://www.epa.gov/air/emissions/basic.htm. (accessed November 12, 2013).

WDNR (Wisconsin Department of Natural Resources). 2012. Wisconsin Department of Natural Resources/Air Monitoring Network Plan 2013. WDNR, Madison, Wisconsin. Available at http://dnr.wi.gov/topic/airquality/documents/2013networkplanfinal.pdf. (accessed April 8, 2013).

Western Regional Climate Center. 2012. RAWS (Remote Automatic Weather Stations) USA climate archive website. Available at http://www.raws.dri.edu/. (accessed March 26, 2013).

Williamson, C. E., W. Dodds, T. K. Kratz, and M. A. Palmer. 2008. Lakes and streams as sentinels of environmental change in terrestrial and atmospheric processes. *Frontiers in Ecology and the Environment* 6:247–254.

Zaccherio, M. T., and A. C. Finzi. 2007. Atmospheric deposition may affect northern hardwood forest composition by altering soil nutrient supply. *Ecological Applications* 17:1929–1941.

4.5.2 ***Water Quality***

Description

MISS encompasses the Mississippi River as it flows for 116 km through the Twin Cities Metropolitan Area (from Mississippi River km 1416-1299). MISS is in a highly developed area that includes 25 communities, parts of three major rivers (the Mississippi, St. Croix, and Minnesota Rivers), part of the Vermillion River, and a number of smaller tributaries (Lafrancois et al. 2013).

Water quality in the Mississippi River has long been a concern for both citizens and resource managers. During rapid urbanization and the building of the locks and dams on the river in the early 20th century, the Mississippi River experienced extreme water pollution, oxygen depletion, high levels of bacteria, formation of floating algal mats, and near-extirpation of fish. Since then, the water quality has improved significantly, aquatic life has returned, and the public use of the river has increased. However, development along the river and in the watershed continues to expand and put pressure on the resource. In addition, the Minnesota River carries large loads of sediments, nutrients, and pollutants that adversely affect the water quality of the Mississippi River (Lafrancois et al. 2013).

The water quality of the Mississippi River within the boundaries of MISS is variable and is affected by a number of nonpoint and point sources of pollution, including wastewater treatment plants and the Minnesota River. Within MISS, sections of the Mississippi River are listed on the 303(d) list of impaired waters for MN because they do not meet water quality standards for water clarity, *Escherichia coli* (*E. coli*) bacteria, mercury, PCBs, and PFOS. Additional impairments for excess sediments and nutrients are likely to be designated in the future (VanderMeulen 2011).

The water quality of the Mississippi River has been summarized in numerous agency reports. In 1995, the NPS Water Resources Division and Servicewide Inventory and Monitoring Program conducted a *Baseline Water Quality Data Inventory and Analysis* (NPS 1995). This baseline includes the results of surface water quality data retrievals from six USEPA national databases. This report provides a complete inventory of all retrieved water quality parameter data, stations, and collecting agencies; descriptive statistics and graphical representation of data; comparisons of data to applicable standards; and inventory data evaluation and analysis (IDEA) to determine what servicewide inventory and monitoring program level 1 water quality parameters have been measured within the area.

The GLKN Mississippi River monitoring began in 2006 because water quality was highly ranked as a Vital Sign across Network parks and monitoring was mandated by the NPS Water Resources Division. Elias and Sieracki (2007) summarized the yearly monitoring data collected by the GLKN in 2006. Sampling was conducted monthly in even numbered years at five designated sites from April through November and included a number of different analytes. VanderMeulen continued these yearly summaries of monitoring data collected by GLKN from 2008-2012 (VanderMeulen 2009, 2011, 2013). The sampling schedule and sites remained the same. The 2010 and 2012 annual summaries included a comparison of data collected to applicable water quality standards.

In 2009, an environmental engineering firm, Limnotech, developed a Lake Pepin water quality model (Limnotech 2009). While Lake Pepin falls outside of MISS, chapter 3 of the report focuses on the data sets that were used in the modeling study and the database that was developed for it, which includes stretches of the Mississippi River that flow through MISS. Included in the data sets are the agency that conducted the sampling, the frequency of sampling, the dates of sampling, the location of sampling, and agency contact information.

Heiskary and Wasley (2012) of the MPCA prepared a document outlining the development of Mississippi River, Pool, and Lake Pepin eutrophication criteria. The draft was completed in 2010, and the newest revisions were completed in 2012. The report contains the updated draft and specific criteria for Lake Pepin as part of the TMDL requirements. The criteria are designed to protect aquatic life while also protecting aquatic recreation. The report also summarizes the data and methods used to develop the updated and draft criteria.

Lafrancois et al. (2013) published one of the most comprehensive trend analyses of water quality data on the Mississippi River. Various agencies have monitored the Mississippi River throughout the years. However, comparing data can be difficult because of the various methods used to collect data, how data was analyzed, when data was collected, etc. For these reasons, the authors used data primarily collected by Metropolitan Council Environmental Services (MCES) at eight sites from 1975 through 2005. Core water quality variables, a suite of other nutrient and sediment related variables, and flows from the USGS were all analyzed. Loads were calculated using FLUX32 software for load estimation, longitudinal and seasonal trends were evaluated graphically, and interannual trends were analyzed statistically using the Kendall test for trends.

The Draft Upper Mississippi River Bacteria TMDL study and plan was created in 2014 by Emmons and Olivier Resources, MDH, and MPCA. It describes the reduction in pollutant loading and the implementation activities needed so that upper Mississippi River reaches can meet water quality standards for aquatic recreation for *E. coli*. Outlined in the report are the potential bacteria sources affecting the river, a water quality analysis, including load duration curves, TMDL calculations, and implementation strategies to reach the goals (Emmons and Olivier Resources et al. 2014).

The Draft South Metro Mississippi River total suspended solids (TSS) TMDL report was created by MPCA in 2012. It details the impairment of the river for TSS from the confluence with the Minnesota River through all of MISS and into Lake Pepin downstream (MPCA 2012a). The Minnesota River contributes about 75% of the TSS to the Mississippi River at its confluence; it has a TMDL of its own for turbidity, a measurement related to TSS (MPCA 2012b).

The Draft Chloride Management Plan for the Twin Cities Metropolitan Area was released by MPCA in 2015 (MPCA 2015). It documents 15 streams in the UMR basin that have mean chloride concentrations exceeding the 230 mg/L chronic standard for chloride from 2000-2013.

Data and Methods

For this assessment, we will use four NPS sites (NPS868, NPS862, NPS852, and NPS822) chosen for long-term monthly monitoring (April-November) by the GLKN (Elias and Sieracki 2007) in 2006 and four MCES sites (UM871.6, UM847.7, UM826.7, and UM815.6) that have had monthly monitoring since 1975 and are suitable for long term trend analysis. The chosen

monitoring sites were divided into three different spatial regions based on river morphology (prairie river, gorge river, or floodplain river) (Figure 39, Table 34, Figure 3). The monitoring sites fall within two different USEPA nutrient ecoregions; the western corn belt plains (VI/47) and the northern central hardwood forests (VII/51) (USEPA 2000a, 2000b); the divide occurs at the confluence of the Minnesota River (VanderMeulen 2011). However, for this report we will be following the guidelines used by VanderMeulen (2011) that categorize all MISS monitoring sites into USEPA nutrient ecoregion VII/51.

Table 34. Selected Mississippi National River and Recreational Area water quality monitoring sites (Elias and Sieracki 2007).

Site	Reach	Description
UM871.6	Prairie River	MCES monitoring site
NPS868	Prairie River	In reservoir above Coon Rapids Dam, incorporates upstream point sources
NPS862	Prairie River	Across from municipal water intake for Minneapolis and St. Paul, expands on current monitoring from MCES
NPS852	Gorge River	In Pool 1, incorporates upstream point sources
UM847.7	Gorge River	MCES monitoring site
UM826.7	Large Floodplain	MCES monitoring site
NPS822	Large Floodplain	In Spring Lake, natural riverine impoundment. A historical MCES monitoring site.
UM815.6	Large Floodplain	MCES monitoring site

At each of the NPS sites, water quality sampling was conducted through the open water season in even-numbered years, starting in 2006. Samples were collected at approximately the deepest part of the channel and the centroid of flow whenever it was feasible; details of sample collection are in VanderMeulen (2011). We obtained this data from David VanderMeulen on 05/19/2013; it is also available at http://www.epa.gov/storet/.

At the MCES sites, samples were collected four to five times per month during the open water season and up to two times per month during the remainder of the year (MCES 2012). To minimize seasonal differences in the data and to coincide with NPS data, our use of MCES data was limited to April through November samples. Although MCES sites and sampling frequency do not exactly match those of NPS, the data do allow for a generalized comparison (VanderMeulen 2009), and water quality conditions at NPS sites can be reasonably estimated using water quality data from existing MCES sites (VanderMeulen 2013).

Our analysis at all sites involved averaging sampling data for each year and comparing these yearly means to the chosen reference conditions. A Mann-Kendall test was used to examine temporal trends in all the water quality parameters for each site with enough data, using the method of Helsel and Hirsch (2002). The non-parametric Mann-Kendall test determines whether *y* (water quality) values tend to increase or decrease with time. The test requires at least ten observations for the normal approximation to be appropriate, and only observations from July and August of each sample year were used to eliminate variations due to seasonality. Due to these restrictions, only the MCES sites had enough observations to run the Mann-Kendall test. We referred to older trend testing data (Lafrancois et al. 2013) when available.

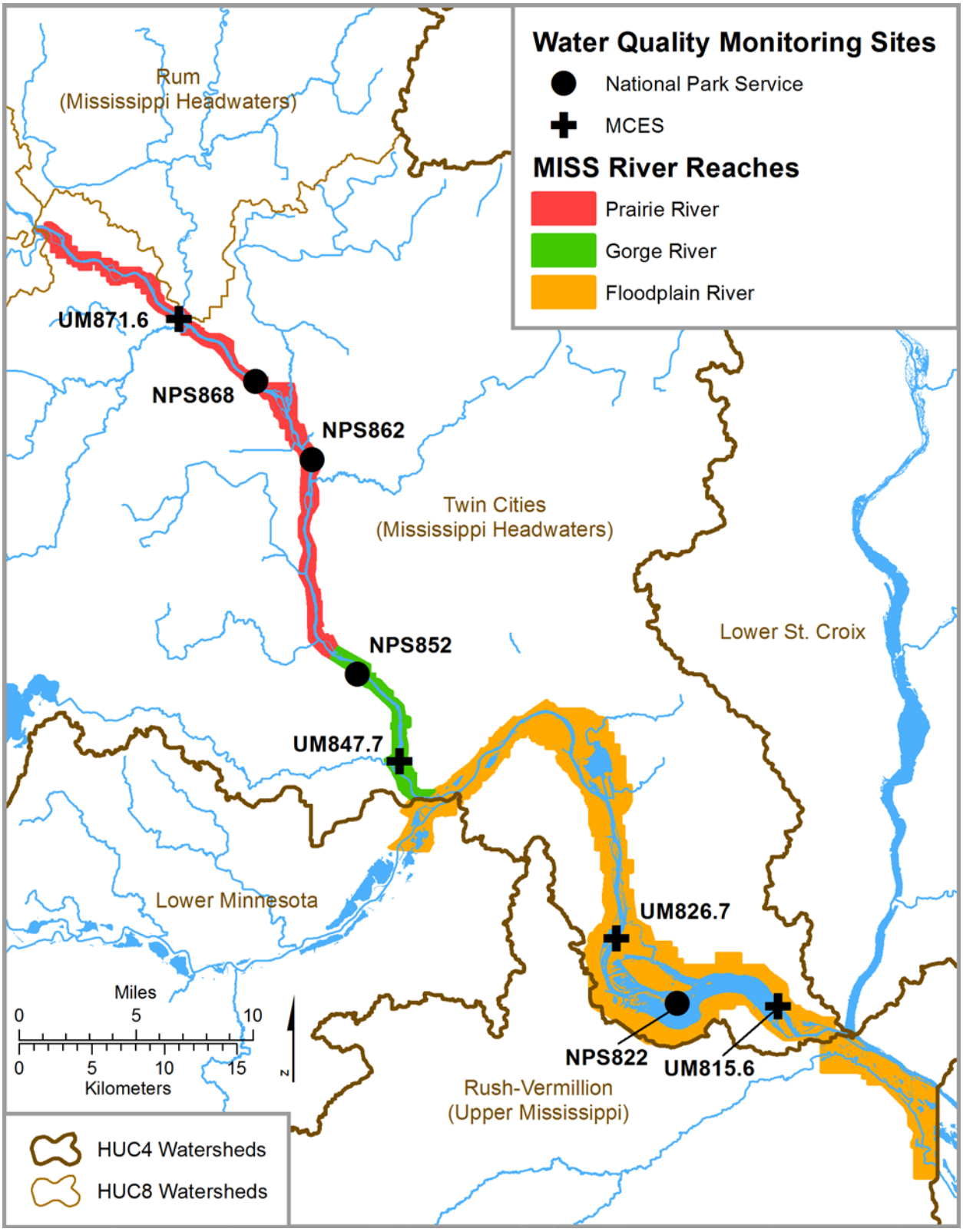


Figure 39. Locations of selected water quality monitoring sites in Mississippi National River and Recreational Area.

Reference Conditions

It is important to define some terms related to water quality conditions. USEPA establishes water quality "criteria," scientific assessments of ecological and human health effects, under the Clean Water Act (e.g., USEPA 1976, 1986, 2006). It recommends these criteria to states and tribes so they can establish water quality "standards," which provide a basis for them to control discharges of pollutants (USEPA 2000a). "Reference conditions" as used by USEPA (2000a, 2000b) refer to a ranking process in which water quality data from water bodies in an ecoregion are ordered in a database; the value representing the 25th percentile is called the "reference condition" and is considered to represent an undisturbed condition for that ecoregion. Therefore, for a parameter whose harmful effects increase with concentration, the value for that parameter would be expected to be less than the reference condition in 25% of the water bodies and more than the reference condition in 75% of the water bodies. Our use of the term "reference condition" may encompass a standard, criterion, or USEPA reference condition, and we specify this in the discussion of each parameter.

The state of MN has assigned seven designated use classes to surface waters of the state; those that pertain to the selected monitoring sites in MISS are in the categories of drinking water (class 1), aquatic life and recreation (class 2), industrial uses (class 3), agricultural and wildlife uses (class 4), aesthetics and navigation (class 5), and other uses and protection of border waters (class 6) (http://www.revisor.leg.state.mn.us/arule/7050/) (MPCA 2013a). The classes and subclasses for each monitoring site are shown in Table 35. The state has established water quality standards for some water quality parameters based on the designated use classes and their subclasses. We use these unless a more stringent federal criterion or draft standard was found.

Table 35. Minnesota designated use classes for surface waters that apply to selected monitoring sites in Mississippi National River and Recreation Area.

Minnesota Designated Use Classification	Definition	GLKN and MCES Sites to Which the Standard Applies							
		UM871.6	NPS868	NPS862	NPS852	UM847.7	UM826.7	NPS822	UM815.6
1C	drinking water with chlorination and other treatment	X	X	X					
2B	cool and warm water fisheries not protected for drinking water				X	X	X	X	X
2Bd	cool and warm water fisheries protected for drinking water	X	X	X					
3C	industrial cooling and materials transport without high degree of treatment	X	X	X	X	X	X	X	X
4A	agriculture and wildlife use – irrigation				X	X	X	X	X
4B	agriculture and wildlife use – livestock and wildlife				X	X	X	X	X
5	aesthetic enjoyment and navigation				X	X	X	X	X
6	other uses and protection of border waters				X	X	X	X	X

Like Lafrancois et al. (2013), we compared annual mean values of selected parameters to current and proposed water quality standards. However, determination of impairment and violation of a standard is often dependent on factors such as seasonality, flow condition, and frequency and duration of exceedence. Therefore, our comparisons simply provide context to the findings and do not constitute an actual determination of violation or impairment.

Condition and Trend for Individual Parameters

Specific Conductance

Specific conductance is the measure of the capacity of water to conduct an electric current. Its magnitude is largely controlled by watershed geology, with the size of the watershed relative to the water body also an important factor (Elias et al. 2008). Waterbodies that have higher concentrations of ions will have higher specific conductance. In MISS, the greatest contributors to specific conductance include the anions chloride and sulfate and the cations calcium, magnesium, sodium, and potassium (Elias and Sieracki 2007). Increases in specific conductance may indicate polluted runoff, which could contain excess nutrients, organic matter, pathogenic microbes, heavy metals, and organic contaminants. If waters are soft, these contaminants can be a major stressor to shoreline and nearshore plants and other aquatic organisms (Elias et al. 2008).

Reference Condition

The MN water quality standard (MnRule 7050.0220) of 1,000 µmhos cm^{-1} for specific conductance applies to designated use classification 4A (MPCA 2013a). This is the chosen reference condition for monitoring sites NPS852, UM847.7, UM826.7, NPS822, and UM815.6, the gorge and large floodplain river sites. This represents a "least disturbed condition" (Stoddard et al. 2006). Sites NPS862, NPS868, and UM871.6, the prairie river sites, do not have a specific conductance standard associated with their water use designations.

Condition and Trend

We rate the condition of the Mississippi River in MISS for specific conductance as good, with a deteriorating trend. Specific conductance has increased over the period of record but remains well below the reference condition. Our confidence in this assessment is good.

All MISS sites covered by the MN water quality standard for specific conductance had annual (April-November 1975-2013 and 2006-2012) means ranging from 303-684 µmhos cm^{-1}, well below the 1,000 µmhos cm^{-1} standard (Table 36). The highest value observed was 950 µmhos cm^{-1} at UM847.7 in 1977. Using July and August data from 1976-2013, an upward trend or statistically significant increase in specific conductance was detected at all MCES sites using the Mann-Kendall trend test (α=0.05). Similarly, Lafrancois et al. (2013) found an increasing trend for specific conductance in all but one MCES Mississippi River site analyzed from 1976-2005.

Spatially, specific conductance in the Mississippi River is higher below the confluence with the Minnesota River (Figure 40), which was also noted by Lafrancois et al. (2013).

Table 36. Minimum and maximum value for annual (April-November) means and individual samples for selected water quality parameters at Mississippi National River and Recreation Area, 1976-2013.

Parameter and Units of Measurement	Minimum Annual Mean	Maximum Annual Mean	Standard Deviation of Annual Means	Minimum Individual Sample, Year, and Location	Maximum Individual Sample, Year, and Location
Specific conductance (µmhos cm^{-1})	303	684	± 103	159 UM871.6, 04-02-1986	950 UM847.7, 11-04-1977
pH (pH units)	7.71	8.55	± 0.19	6.55 UM815.6, 07-02-1986	9.50 UM847.7, 10-15-1980
Dissolved oxygen (mg L^{-1})	5.25	11.43	± 0.79	0.8 UM826.7, 06-08-1976	16 UM847.7, 11-09-1981
Alkalinity (mg L^{-1})	109	202	± 21.7	70 NPS852, 10-03-2008	217 NPS822, 10-08-2010
Chloride (mg L^{-1})	9.4	37.3	±7.6	0.36 NPS862, 04-11-2012	62.8 NPS822, 10-12-2012
Total phosphorus (µg L^{-1})	35	438	± 81.1	10 Multiple sites and years	1,000 UM847.7, 09-21-1981
Nitrate + nitrite nitrogen (µg L^{-1})	616	1,388	± 1,042.3	10 Multiple sites and years	10,180 UM815.6, 05-14-1991
Total nitrogen (µg L^{-1})	665	4,263	± 519.9	110 UM871.6, 11-06-1978	10,250 UM826.7, 05-15-2005
Chlorophyll-*a* (µg L^{-1})	11.25	112	± 15.9	0 UM871.6, 2001-2005	210 UM826.7, 05-17-2006
Total suspended solids (mg L^{-1})	9.4	71.5	± 17.4	1 UM871.6, multiple years	957 UM826.7, 09-12-1979

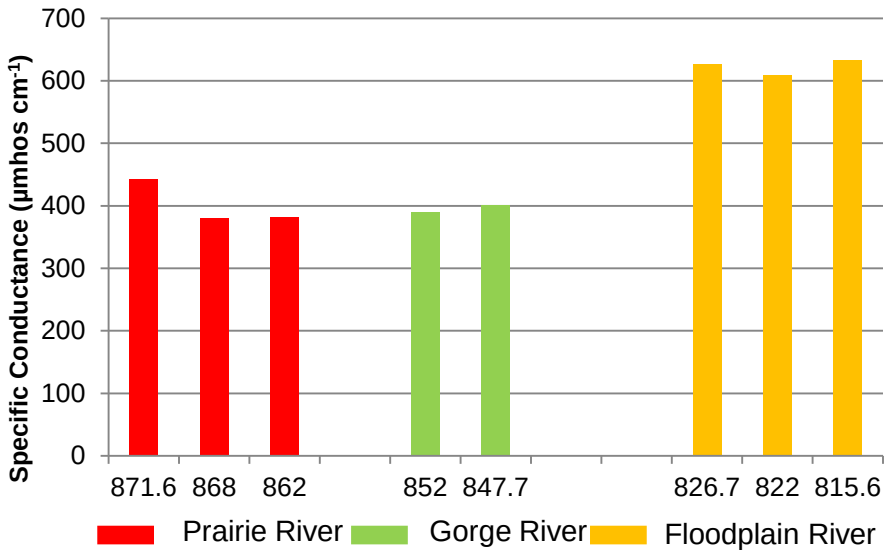


Figure 40. Spatial trends in specific conductance in the Mississippi River in Mississippi National River and Recreation Area, mean of means, 2006-2012.

pH

The pH value is the negative logarithm of the hydrogen ion (H+) activity in the water. It is important as a determinant of the solubility and biological availability of nutrients essential for growth as well as potentially toxic heavy metals (Elias et al. 2008). Aquatic macroinvertebrates and some salmonids can be adversely affected at certain stages of their life cycles when pH is above 9.0 or below 6.5 (Elias et al. 2008).

Reference Condition

The MN water quality standard (MnRule 7050.0220) of a minimum pH of 6.5 pH units applies to designated use classifications 1C and 2B, and a maximum pH of 8.5 applies to classes 1C and 4A (MPCA 2013a). This is the chosen reference condition for all the monitoring sites in this data set and represents a "least disturbed condition" (Stoddard et al. 2006).

Condition and Trend

We rate the condition of the Mississippi River in MISS for pH as of moderate concern, with a deteriorating trend. Our confidence in this assessment is good. The annual means for pH (using samples collected from April-November) were at or slightly above the reference condition at three of nine monitoring sites for at least one year.

Prairie river sites met their reference condition of 6.5-8.5 pH units, based on annual means (Figure 41), and UM871.6 (the only site with sufficient data for trend analysis) did not exhibit a trend from 1976-2013. Sites with annual mean pH values very close to the reference condition were the gorge river sites UM847.7 in 1976 and 1987 (8.54) and NPS852 in 2006 (8.51) (Figure 42). Large floodplain river sites also met their reference condition of 6.5-8.5 pH units (Figure 43). The lowest individual measurement was 6.55 pH units, observed at UM815.6 in 1986, and the highest was 9.50 pH units, observed at UM847.4 in 1980 (Table 36).

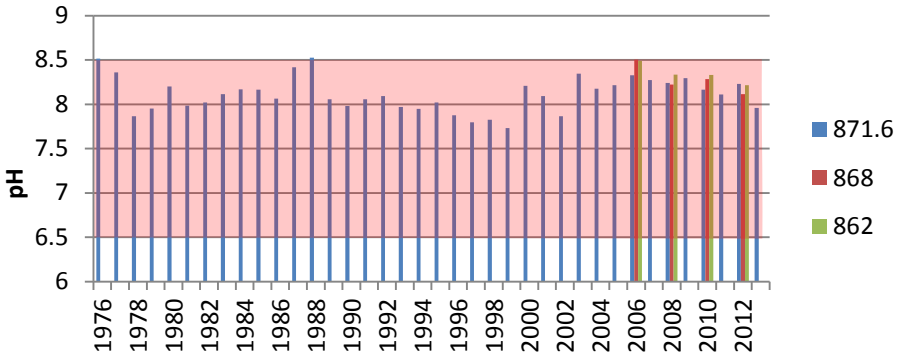


Figure 41. Annual (April-November) mean pH values for Mississippi River prairie river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013 (reference condition 6.5-8.5).

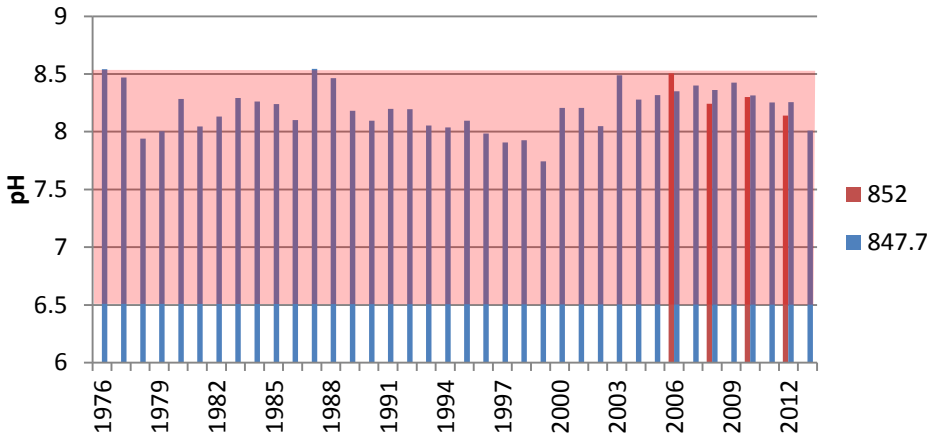


Figure 42. Annual (April-November) mean pH values for Mississippi River gorge river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013 (reference condition 6.5-8.5).

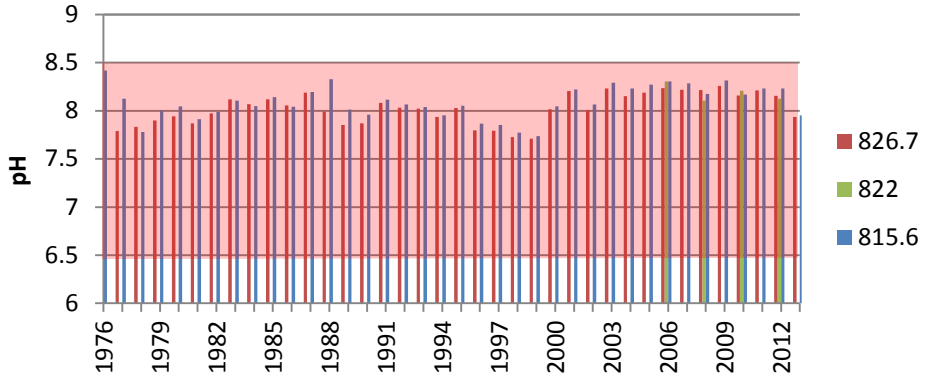


Figure 43. Annual (April-November) mean pH values for Mississippi River large floodplain river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013 (reference condition 6.5-8.5).

VanderMeulen (2009) reported that the summers of 2006 and 2008 were characterized by lower than normal flows which may have resulted in very high algal production and chlorophyll-*a* concentrations. These decrease the amount of carbon dioxide in the water through photosynthesis, which has an overall effect of increasing pH (VanderMeulen 2011). However, pH values outside the range of the standard are not considered exceedences if they are due to "natural causes" (MPCA 2013b).

Using July and August data from 1975-2013, an upward trend or statistically significant increase in pH was detected at large floodplain river site UM826.7 using the Mann-Kendall trend test (α=0.05). No trend was detected at UM871.6 or UM847.7. These trend results agree with the findings of Lafrancois et al. (2013) from 1976-2005. While we detected an upward trend at UM815.6 from 1976-2013, Lafrancois et al. (2013) did not detect such a trend from 1976-2005. Neither we nor Lafrancois et al. (2013) detected a spatial trend in pH.

Dissolved Oxygen

Dissolved oxygen (DO) is a measure of the amount of oxygen in solution in water. The atmosphere is the largest source of DO, although phytoplankton and macrophytes produce DO during photosynthesis. Respiration by animals, plants, and microbes consumes DO (Elias et al. 2008). The MPCA water quality standard for DO is based on the maintenance of a healthy community of fish and associated aquatic life (MPCA 2013a).

Reference Condition

Our chosen reference condition is the MN water quality standard (MnRule 7050.0220) for DO of 5 mg L^{-1} as a daily minimum in designated use classes 2B and 2Bd (MPCA 2013a). This represents a "least disturbed condition" (Stoddard et al. 2006).

Condition and Trend

We rate the condition of the Mississippi River in MISS for DO as good, with an improving trend. Our confidence in this assessment is good.

All monitored sites had annual (April-November 1975-2013 and 2006-2012) DO means ranging from 5.25-11.43 mg L^{-1}, exceeding the minimum standard of 5 mg L^{-1} (Table 36). The lowest individual value was 0.8 mg L^{-1} at UM826.7 in 1976. Using July and August data from 1976-2013, an upward trend or statistically significant increase in DO was detected using the Mann-Kendall trend test (α=0.05) at all UM sites except UM871.6, where no trend was detected. These trend results agree with the findings of Lafrancois et al. (2013) for 1976-2005. Spatially, mean DO values were highest at gorge sites and lowest at floodplain sites from 2006-2012 (Figure 44).

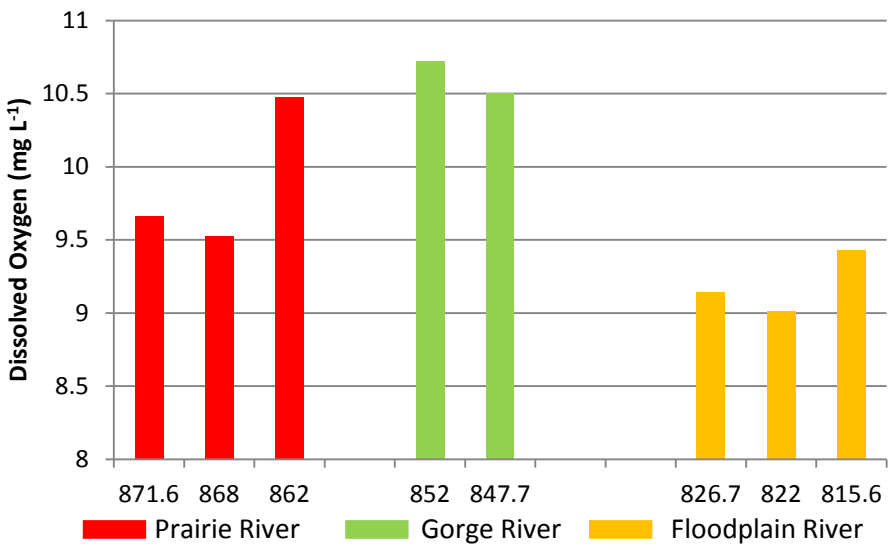


Figure 44. Spatial trends in dissolved oxygen in the Mississippi River in Mississippi National River and Recreation Area, mean of means, 2006-2012.

Alkalinity

Alkalinity is a measure of the ability of a water body to buffer, or resist, a change in pH. It is generally controlled by minerals such as calcium and magnesium carbonate and bicarbonate. Rivers that run through limestone topography generally have high alkalinity, while those that originate in bogs or in lakes in granitic or sandy areas are typically lower in alkalinity (MDNR 2004).

Reference Condition

Our chosen reference condition is the USEPA minimum criterion of 20 mg L^{-1} as calcium carbonate ($CaCO_3$) for the protection of aquatic life "except where natural conditions are less" (USEPA 1986). This represents a "least disturbed condition" (Stoddard et al. 2006).

Condition and Trend

We rate the condition of the Mississippi River in MISS for alkalinity as good. Data were available only for NPS sites from 2006-2012, so trends could not be calculated. Our confidence in this assessment is good. All MISS sites had annual (April-November) means for alkalinity that consistently exceeded 20 mg L^{-1}, with ranges of 107-202 mg L^{-1} and the lowest individual value of 70 mg L^{-1} at NPS852 in 2008, (Table 36), indicating well-buffered waters.

Chloride

Chloride can come from a mixture of natural sources such as the weathering of rocks and soils and human inputs such as fertilizers and runoff from urban and industrial areas. It is often used as a tracer of wastewater plumes and an indicator of road salt runoff into surface waters (Elias et al. 2008). An MPCA draft report (MPCA 2015) lists road salt as the primary source of chloride to both MN surface waters and groundwater. The salt used to regenerate residential water softeners is also a significant source, and the chloride so generated is not removed by either residential or municipal wastewater treatment systems (MPCA 2015).

Reference Condition

Our chosen reference condition for chloride in the Mississippi River and its tributaries is the MN water quality standard (MnRule 7050.0220) of 230 mg L^{-1} for chronic exposure for aquatic life in class 2B and 2Bd waters (MPCA 2013a). This represents a "least disturbed condition" (Stoddard et al. 2006).

Condition and Trend

We rate the condition of the Mississippi River in MISS for chloride as good. Data were available only for NPS sites from 2006-2012, so trends could not be calculated. Our confidence in this assessment is good. All MISS sites had annual (April-November) means far below the standard of 230 mg L^{-1}, with ranges of 9.4-37.3 mg L^{-1} and the highest individual value of 62.8 mg L^{-1} at NPS822 in 2012 (Table 36).

However, contributing water bodies throughout the park's watershed do not meet the chronic chloride standard and are the subject of a pollution prevention and clean-up plan by MPCA (MPCA 2015). Mean chloride concentrations in streams that exceeded 230 mg L^{-1} ranged from 271-1,600 mg L^{-1}. This is a condition of significant concern. In addition, MPCA trend analysis of a limited number of lakes and streams showed that the concentrations were increasing with time. Our confidence in this assessment is good.

In addition, chloride has been unofficially measured within the Coldwater Spring unit at MISS at concentrations that concern park managers, as noted in a study by Dr. E. Calvin Alexander and Sophie Kasahara, UMN (Kasahara 2014). The park needs to better understand Coldwater Spring's contributing ground watershed in order to be able to better address this issue. MPCA is also concerned about chloride levels in a number of wells within the Twin Cities areas. Because it is nearly impossible to remove chloride from water once it is in it, this situation concerns park managers, who will remain engaged as chloride pollution prevention and clean-up efforts proceed in the Twin Cities.

Total Phosphorus (TP)

Nitrogen and phosphorus are the two most important nutrients regulating phytoplankton and aquatic macrophyte growth in lakes and streams. Excessive nutrient inputs can lead to excessive algal growth and eutrophication and are the most important threat to lakes in the upper Midwest (Elias et al. 2008 and citations therein). Nutrients enter bodies of water primarily through surface and subsurface runoff and groundwater. In MN, both nitrogen and phosphorus are considered in the development of eutrophication criteria, but phosphorus is the "primary cause" of eutrophication (MPCA 2010).

Land use in the area surrounding MISS is dominated by urban and suburban development. Major tributaries to the Mississippi River, such as the Rum and Crow Rivers, drain largely agricultural areas. Nonpoint runoff from these land uses can potentially contribute to elevated TP levels in MISS (VanderMeulen 2011). A large portion of the TP and sediment loading to the river occurs at the confluence of the Minnesota River and the Mississippi River (Lafrancois et al. 2013). The Minnesota River is considered to be one of the major contributors of nutrients to the Mississippi River, and in 2006, contributed 52% of the phosphorus load to Lake Pepin downstream of MISS (Russell and Weller 2012).

In order to meet MN goals for the protection of aquatic life and aquatic recreation, eutrophication criteria are in development for rivers in the state. Three regions have been designated, and MISS falls within the Central River Nutrient Region. The draft eutrophication criteria, which have been approved in MN and are awaiting USEPA approval, will help to determine stretches of rivers that may be listed as impaired, and they will be applied in the same fashion as existing lake eutrophication criteria. Water samples are collected 6-8 times per summer for a minimum of two summers. This collected data is combined with all available data for the most recent 10 year period. Means are calculated and compared to the draft criteria. To be listed as impaired, the causative variable (TP) and one or more response variables (sestonic chlorophyll, biological oxygen demand [BOD5], dissolved oxygen flux, and/or pH) must exceed their respective criteria. Such waters will be subject to the future development of a TMDL (Heiskary et al. 2013).

The MN draft nutrient criteria for Pools 1-8 on the Mississippi River were developed in conjunction with a USEPA nation-wide effort to develop nutrient criteria for lakes, rivers, wetlands, and estuaries. When MPCA staff and the Science Advisory Panel (SAP) were developing the Lake Pepin TMDL, it was decided that MPCA needed to develop site specific criteria for the Mississippi River navigation pools and major rivers contributing to water quality in Lake Pepin as well as the lake itself. The proposed criteria are intended to protect the aquatic life in the rivers and pools, while also protecting aquatic recreation and downstream aquatic life (Heiskary and Wasley 2012).

Reference Condition

For the prairie river sites (UM871.6, NPS868, and NPS862), our chosen reference condition is the draft nutrient criterion of 100 $\mu g\ L^{-1}$ for rivers in the Central River Nutrient Region of MN developed by Heiskary et al. (2013) (earlier drafts of which were described by VanderMeulen 2011). The chosen reference condition for the gorge river sites UM847.7 and NPS852 is the MN draft eutrophication criterion of 100 $\mu g\ L^{-1}$ for Pool 1 on the Mississippi River (Heiskary and Wasley 2012). The chosen reference condition for the floodplain river sites UM826.7, NPS822, and UM815.6 is the MN draft eutrophication criterion of 125 $\mu g\ L^{-1}$ for Pool 2 on the Mississippi River (Heiskary and Wasley 2012). These represent a “least disturbed condition” (Stoddard et al. 2006). TP values were also compared to the reference condition for USEPA nutrient ecoregion VII/51 (USEPA 2000b), which represents a “minimally disturbed condition” (Stoddard et al. 2006).

Condition and Trend

We rate the condition of the Mississippi River in MISS for TP as of significant concern, but with an improving trend. Our confidence in this assessment is good.

In the prairie river, annual (April-November) mean TP at NPS868 and NPS862 met the draft nutrient criterion from 2006-2012 (Figure 45). UM871.6 has consistently met this criterion recently but exceeded it in 1990 and 1991. In the gorge river, UM847.7 has exceeded the MN draft eutrophication criterion on numerous occasions, especially in the 1970s and 1980s (Figure 46). UM847.7 also had the highest individual sample in the data set, 1,000 $\mu g\ L^{-1}$ in 1981. Both UM847.7 and NPS852 have met or nearly met their criterion since 2006.

In the large floodplain river, even though the draft eutrophication criterion is higher, few sites have met it since 1976 (Figure 47). This is to be expected, since all of the sites in this reach are

downstream of the confluence with the Minnesota River. The long-term summer average of TP in the Minnesota River from 1993-2009 was 258 μg L^{-1} (VanderMeulen 2011). No monitoring site within MISS met the USEPA reference condition for TP (28.75 μg L^{-1}), indicating that MISS water quality for TP is not within the best 25% of sites in nutrient ecoregion VII/51.

The Mann-Kendall trend test found a downward trend or statistically significant decrease (α=0.05) in TP at UM sites, using data from July and August, 1990-2012. Lafrancois et al. (2013) similarly noted a significant decrease at all UM sites sampled from 1976-2005. However, these authors noted that while TP concentrations decreased, increased flow meant that TP loads had not decreased. As previously noted, the spatial trend is that TP levels are higher in the large floodplain river than in the prairie or gorge river segments (Figure 48).

In addition, it should be noted that the general consensus of scientists studying the river is that the recent decrease is largely attributable to improvements in wastewater treatment at wastewater treatment plants, but further decreases from that source cannot be expected. Thus, a continued decrease in river TP levels will require addressing other TP sources (comment on draft NRCA by Lark Weller, MISS, 8/22/2014).

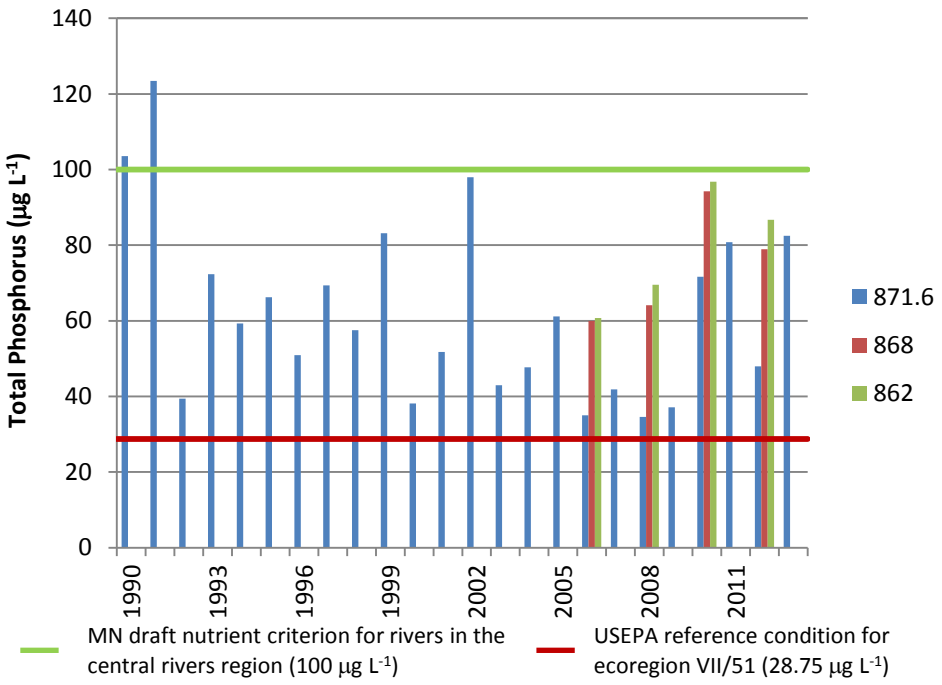


Figure 45. Annual (April-November) mean total phosphorus values for Mississippi River prairie river water quality monitoring sites in Mississippi National River and Recreation Area, 1990-2013.

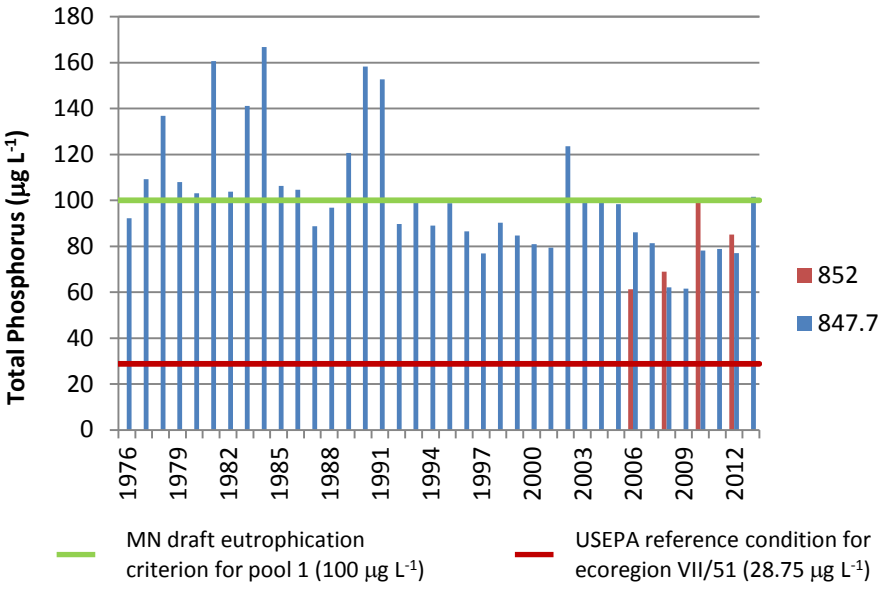


Figure 46. Annual (April-November) mean total phosphorus values for Mississippi River gorge river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013.

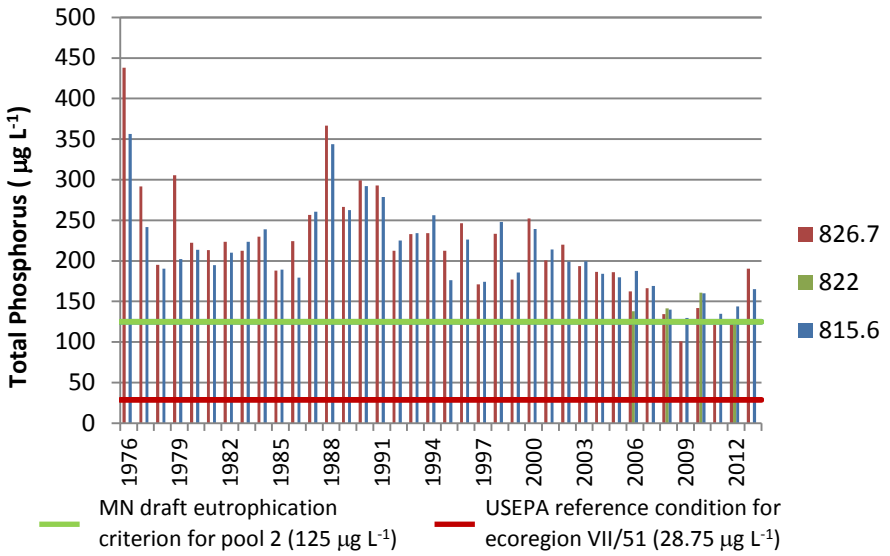


Figure 47. Annual (April-November) mean total phosphorus values for Mississippi River large floodplain river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013.

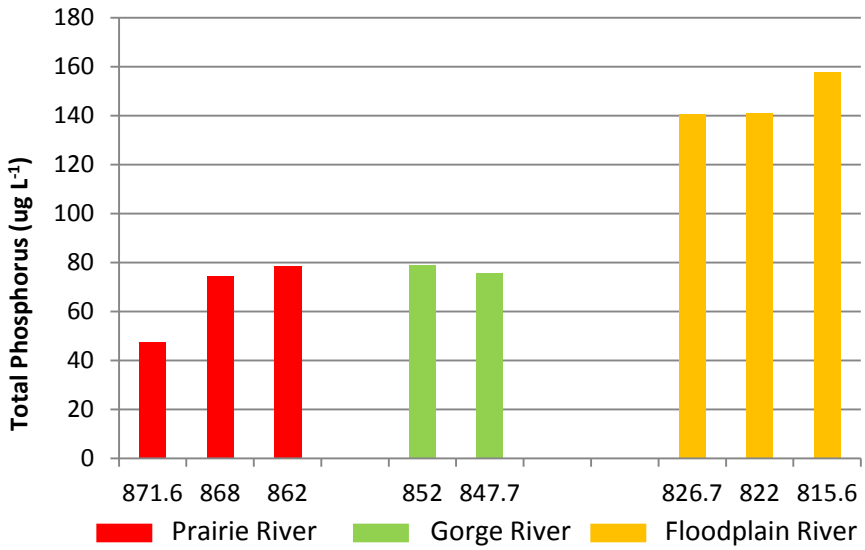


Figure 48. Spatial trends in total phosphorus in the Mississippi River in Mississippi National River and Recreation Area, mean of means, 2006-2012.

Total Nitrogen (TN) and Nitrate and Nitrite Nitrogen (NO_3+NO_2-N)

Approximately 76 million kg of total nitrogen (TN) enters the Twin Cities metro area/MISS in the Upper Mississippi, Minnesota and St. Croix Rivers; only about 6.5 million kg is added by point sources, stormwater runoff, and groundwater discharge within the metro area (MPCA 2013c). Within MISS, 56% of the TN in the Mississippi River at Anoka is in the $NO_{3+}NO_2$-N form (MPCA 2013c). $NO_{3+}NO_2$-N is of concern in MISS for many reasons. It is an essential plant nutrient, it contributes to the low-oxygen "dead zone" in the Gulf of Mexico, it poses health risks to humans who use the river as a source of drinking water, and it is acutely and chronically toxic to aquatic fauna at elevated concentrations. The Minnesota River basin contributes 69% of the total N loads (25% is contributed by the Upper Mississippi River and 6% by the St. Croix River) and 78% of the nitrate loads which arrive at the Twin Cities Metropolitan Area (MPCA 2013c). VanderMeulen (2011) indicated that patterns for total nitrogen and nitrogen species (NO_3+NO_2-N and NH_4-N) are complex within MISS and are influenced by tributaries and site-specific channel morphology.

As noted in the TP section above, criteria are not set for TN as a plant nutrient in MN waters because phosphorus is generally the limiting nutrient. However, nitrogen does become a limiting plant nutrient in the salt water of the Gulf of Mexico. The $NO_{3+}NO_2$-N form of nitrogen also poses a health risk to humans who consume the water, especially infants, pregnant women, and certain other susceptible groups (MDH 2014). The Mississippi River does serve as a source of drinking water in the Twin Cities metro area and meets the USEPA maximum contaminant level of 10 mg L^{-1} (10,000 µg L^{-1}) for human consumption (Russell and Weller 2012, Figure 50).

MPCA is in the process of developing both acute and chronic $NO_{3+}NO_2$-N standards for the protection of aquatic fauna. The draft acute value in class 2 waters is 41 mg L^{-1} for a one-day duration. The chronic value, listed below, forms the basis for our chosen reference condition for $NO_{3+}NO_2$-N.

Reference Condition

The chosen reference condition for TN for the Mississippi River monitoring sites in MISS is the USEPA reference condition for nutrient ecoregion VII/51 (710 μg L^{-1}) (USEPA 2000b), which represents a "minimally disturbed condition" (Stoddard et al. 2006).

The chosen reference condition for $NO_{3+}NO_2$-N in the Mississippi River and its tributaries within MISS is the draft chronic value of 4,900 μg L^{-1} (4.9 mg L^{-1}) for a 4-day duration in class 2B waters (Monson 2010) and is a "least disturbed condition" (Stoddard et al. 2006). $NO_{3+}NO_2$-N values are also compared to the USEPA reference condition for nutrient ecoregion VII/51 (130 μg L^{-1}) (USEPA 2000b), which represents a "minimally disturbed condition" (Stoddard et al. 2006).

Condition and Trend

We rate the condition of the Mississippi River in MISS for TN as of significant concern with a stabilizing trend. Our confidence in this assessment is good. Annual (April-November) mean TN exceeded the USEPA reference condition at every site in every year that monitoring was conducted (Figure 49, Figure 51, and Figure 53), indicating that MISS water quality for TN is not within the best 25% of sites in its nutrient ecoregion. Using July and August data from 1976-2012, a downward trend in TN concentrations was detected at site UM815.6 and an upward trend was detected at UM847.7 using the Mann-Kendall trend test (α=0.05). No trend was detected at UM871.6 or UM826.7. Lafrancois et al. (2013) did not detect a significant trend at any of these four sites from 1976-2005.

We rate the condition of the Mississippi River and its tributaries in MISS for $NO_{3+}NO_2$-N as of significant concern with a stabilizing trend. Our confidence in this assessment is good. The MCES weekly data for April to November from 1976-2013 showed 218 (3.6%) instances in which the chronic value was exceeded at a Mississippi River site on an individual day. No data for four-day periods were found, so the chronic value could not be directly compared. Annual mean $NO_{3+}NO_2$-N concentrations have at times exceeded 80% of the chronic value in the large floodplain river. In the Minnesota River, 29.2% of individual samples exceeded the chronic value (Table 37). In addition, annual (April-November) mean $NO_{3+}NO_2$-N exceeded the USEPA reference condition at every site in almost every year that monitoring was conducted (Figure 50, Figure 52, and Figure 54), indicating that MISS water quality for $NO_{3+}NO_2$-N is not within the best 25% of sites in its nutrient ecoregion.

Table 37. Distribution of nitrate + nitrite-N values in MCES samples collected April to November, 1976-2013 in Mississippi National River and Recreation Area.

	Mississippi River sites in MISS (UM871.6, UM847.7, UM826.7, UM815.6)		**Minnesota River at Fort Snelling**	
Range (μg L^{-1})	**Number**	**%**	**Number**	**%**
≤4,900	5,807	96.4	783	70.8
4,901-7,500	192	3.2	165	14.9
7,501-10,000	25	0.4	99	9.0
10,001-15,000	1	0.0	55	5.0
>15,000			4	0.4
Total	6,025		1,106	

MPCA (2013c) has found generally increasing trends in nitrate concentration in the Mississippi River and its tributaries in the vicinity of MISS since 1976. However, in most cases, the increase is less from the early to mid-2000s to present than it was from 1976 to the early to mid-2000s, indicating that the rate of increase may be slowing (Table 38). Notably, nitrate concentrations in the Minnesota River have decreased in the later time period.

Using July and August data from 1976-2012, an upward trend in $NO_{3+}NO_2$-N concentrations was detected at site UM871.6 using the Mann-Kendall trend test (α=0.05). No trend was detected at sites UM815.6, UM826.7, and UM847.7. Lafrancois et al. (2013) detected a significant upward trend at all these sites from 1976-2005, another indication that nitrate values, although high, may be leveling off.

Table 38. Trends in nitrate concentration in the Mississippi River and tributaries in the vicinity of Mississippi National River and Recreation Area (MPCA 2013c).

Location	River Mile	% Change	Time period	Ending Concentration (mg L^{-1})
Monticello	895	+268%	1976-2010	0.58
Crow River*	879.6	No trend	1976-2010	1.24
Anoka	871.6	+134%	1976-2010	0.88
Rum River*	871.4	+16%	1999-2002	
		-18%	2002-2010	
		+24%	1976-2010	0.21
Fridley	859	+87%	1976-2010	0.49
Minnesota River*	844	+74%	1976-2005	2.2
		-46%	2006-2011	
		-6%	1976-2011	
St. Paul	840	+149%	1975-2010	1.9
Grey Cloud Island	826	+206%	1975-1991	2.4
		No trend	1992-2010	
		+206%	1975-2010	
Lock & Dam #2	815	+172%	1976-1993	2.3
		No trend	1994-2011	
		+172%	1976-2011	
St. Croix River*	811.5	+57%	1976-2000	0.58
		+11%	2001-2009	
		+74%	1976-2009	
Lock & Dam #3	769.9	+117%	1976-1991	2.1
		+24%	1992-2010	
		+168%	1976-2010	

*tributary; others are mainstem sites

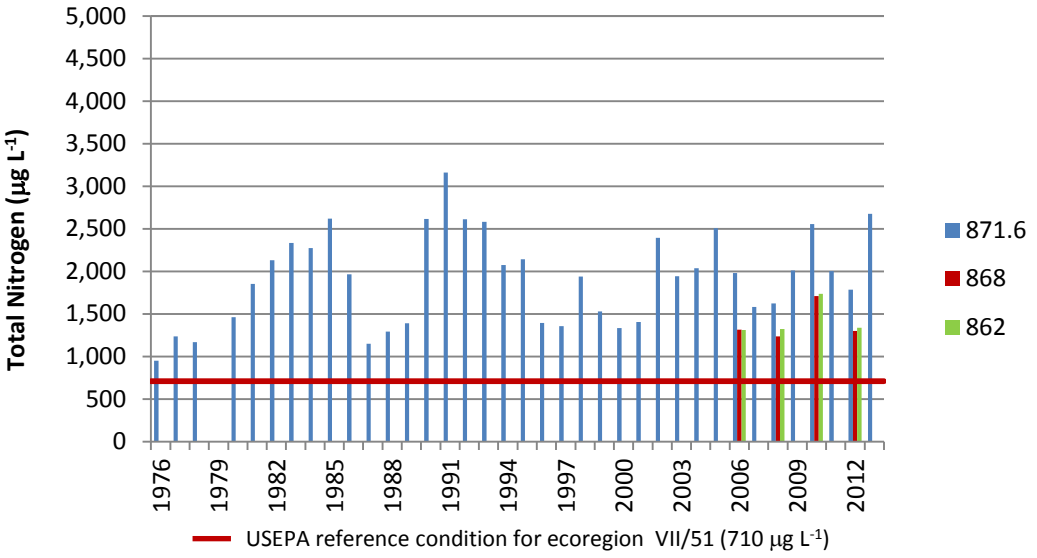


Figure 49. Annual (April-November) mean total nitrogen values for Mississippi River prairie river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013.

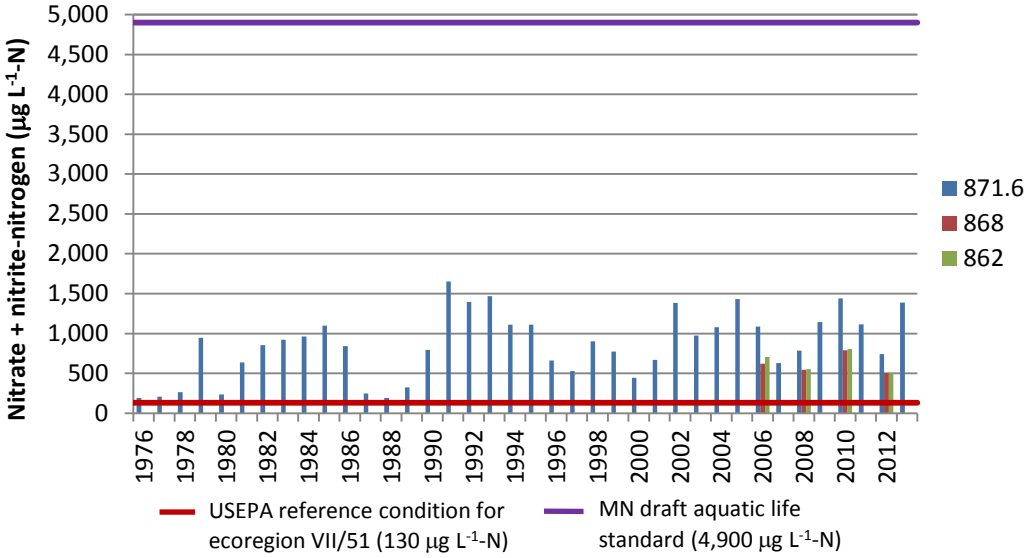


Figure 50. Annual (April-November) mean nitrate + nitrite nitrogen values for Mississippi River prairie river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013.

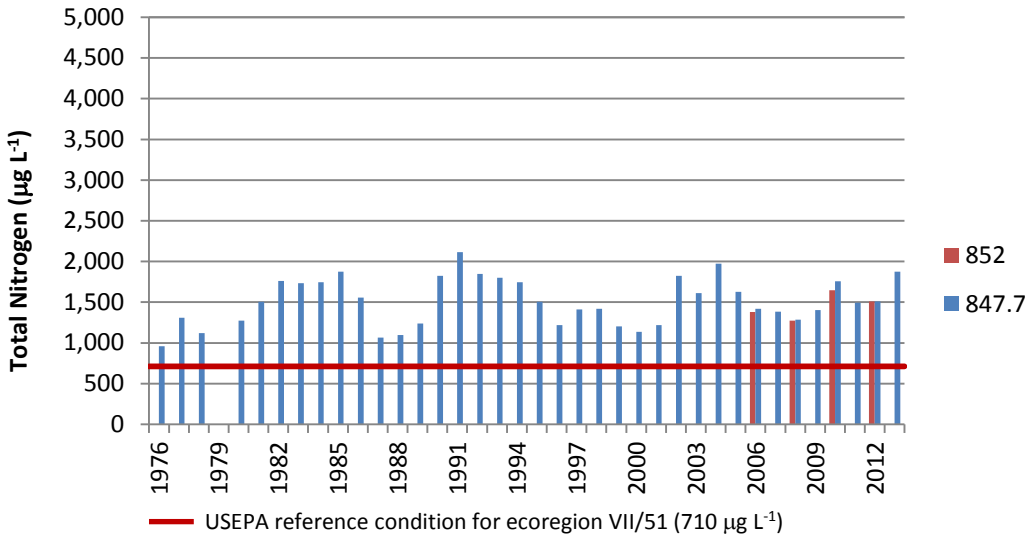


Figure 51. Annual (April-November) mean total nitrogen values for Mississippi River gorge river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013.

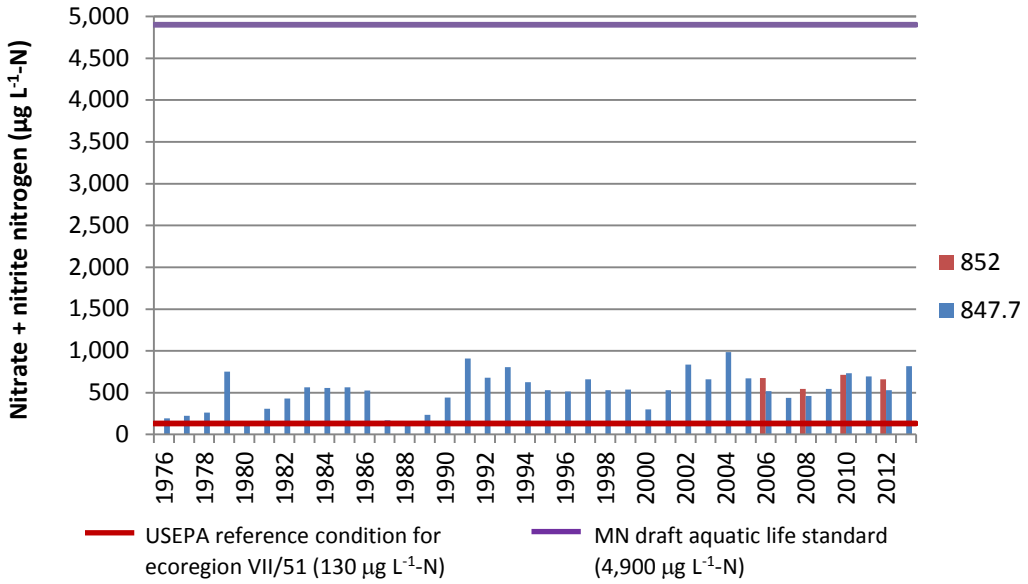


Figure 52. Annual (April-November) mean nitrate + nitrite nitrogen values for Mississippi River gorge river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013.

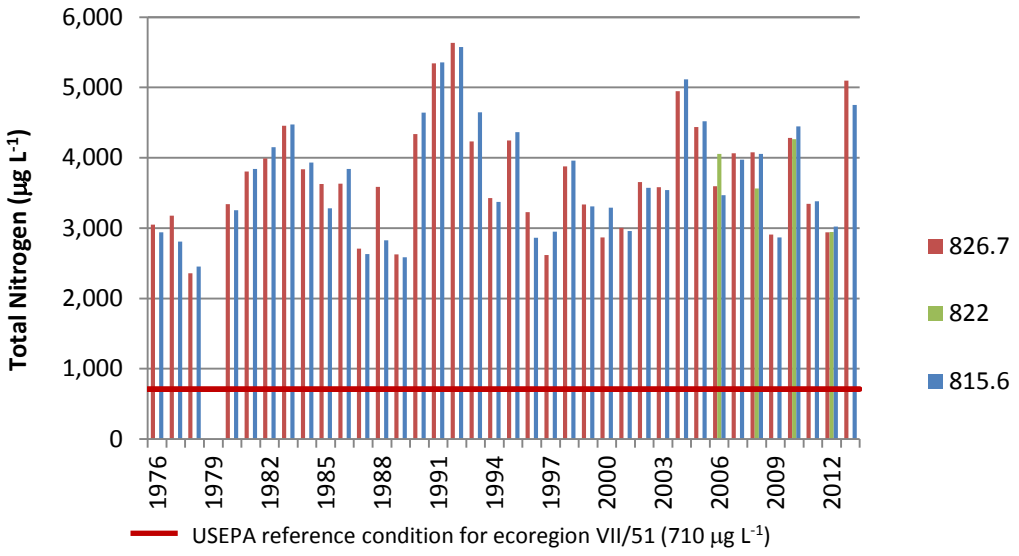


Figure 53. Annual (April-November) mean total nitrogen values for Mississippi River large floodplain river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013.

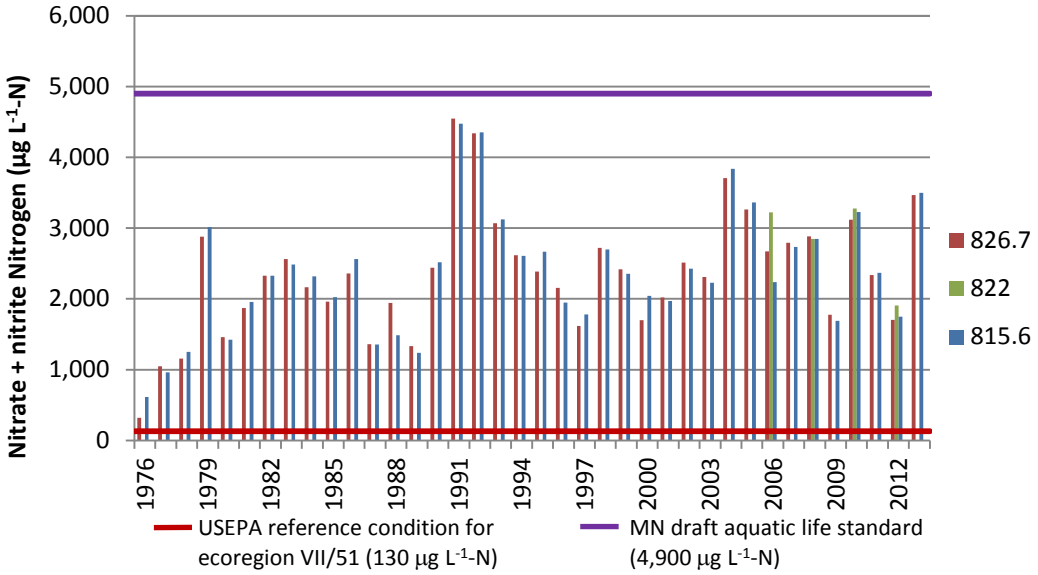


Figure 54. Annual (April-November) mean nitrate + nitrite nitrogen values for Mississippi River large floodplain river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013.

Spatially, both TN and $NO_{3+}NO_2$-N are approximately twice as high in the floodplain river as they are in the prairie or gorge river segments (Figure 55 and Figure 56).

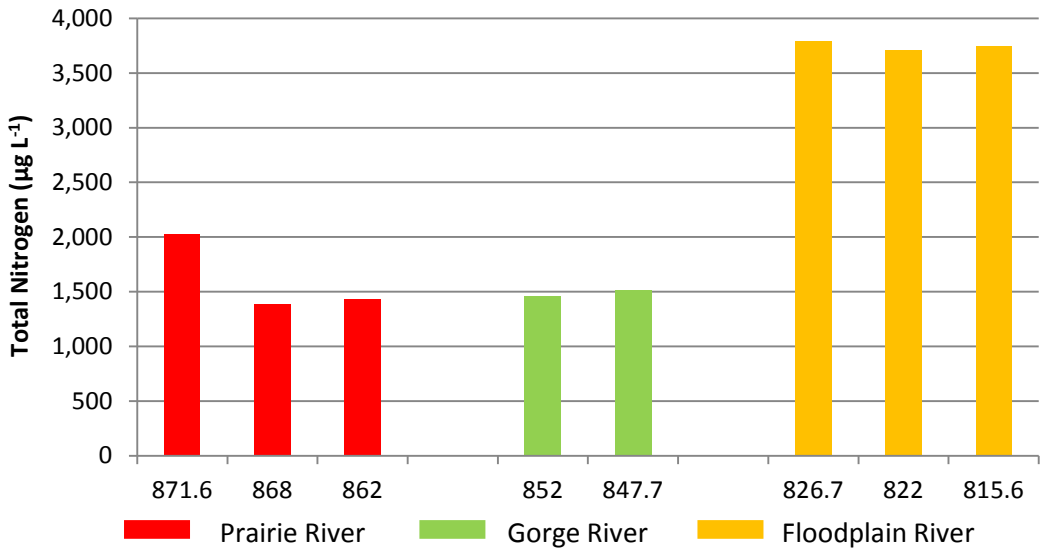


Figure 55. Spatial trends in total nitrogen in the Mississippi River in Mississippi National River and Recreation Area, mean of means, 2006-2012.

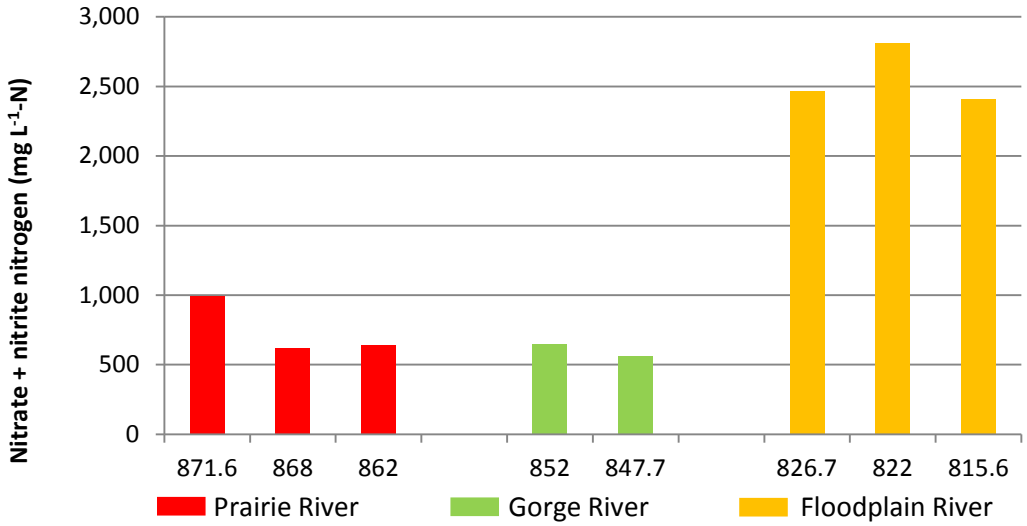


Figure 56. Spatial trends in nitrate + nitrite nitrogen in the Mississippi River in Mississippi National River and Recreation Area, mean of means, 2006-2012.

Chlorophyll-a (Chl-a)

Chlorophyll-*a* is the primary photosynthetic pigment in all green plants, including phytoplankton, and is nearly universally accepted as a measure of algal biomass in the open waters of lakes (VanderMeulen 2011). However, some inaccuracy arises because different algal groups have different proportions of chl-*a* versus other pigments, and the mix of species may affect management decisions for lakes (Elias et al. 2008). Consistent and directional trends in chl-*a* concentrations are good indicators of change in a lake's trophic status (Elias et al. 2008 and citations therein).

Reference Condition

For the prairie river sites (UM871.6, NPS868, and NPS862), our chosen reference condition for chl-*a* is the draft criterion of 18 µg L^{-1} for rivers in the Central River Nutrient Region of MN developed by Heiskary et al. (2013). The chosen reference condition for the gorge river sites UM847.7 and NPS852 and the floodplain river sites UM826.7, NPS822, and UM815.6 is the MN draft eutrophication criterion of 35 µg L^{-1} for pools on the Mississippi River (Heiskary and Wasley 2012). These represent a "least disturbed condition" (Stoddard et al. 2006). Chl-*a* values were also compared to the reference condition for USEPA nutrient ecoregion VII/51 (8.76 µg L^{-1}) (USEPA 2000b), which represents a "minimally disturbed condition" (Stoddard et al. 2006).

Condition and Trend

We rate the condition of the Mississippi River in MISS for chl-*a* as of significant concern, but with an improving trend. Our confidence in this assessment is good. At least some annual (April-November) chl-*a* means for 2001-2013 were above the draft nutrient or eutrophication criterion at all sites except NPS852 and NPS822 (Figure 57, Figure 58, and Figure 59). All sites exceeded the USEPA nutrient reference condition. The maximum individual measurement in the data set was 210 µg L^{-1} at UM826.7 in 2006. Using July and August data from 2001-2012, a downward trend in chl-*a* concentrations was detected at prairie river site UM871.6, gorge river site UM847.7, and large floodplain river site UM815.6 using the Mann-Kendall trend test (α=0.05). No trend was detected at large floodplain river site UM826.7. Lafrancois et al. (2013) found an upward trend at UM826.7 and no significant trend at UM871.6, UM847.7, or UM815.6 from 1976-2005.

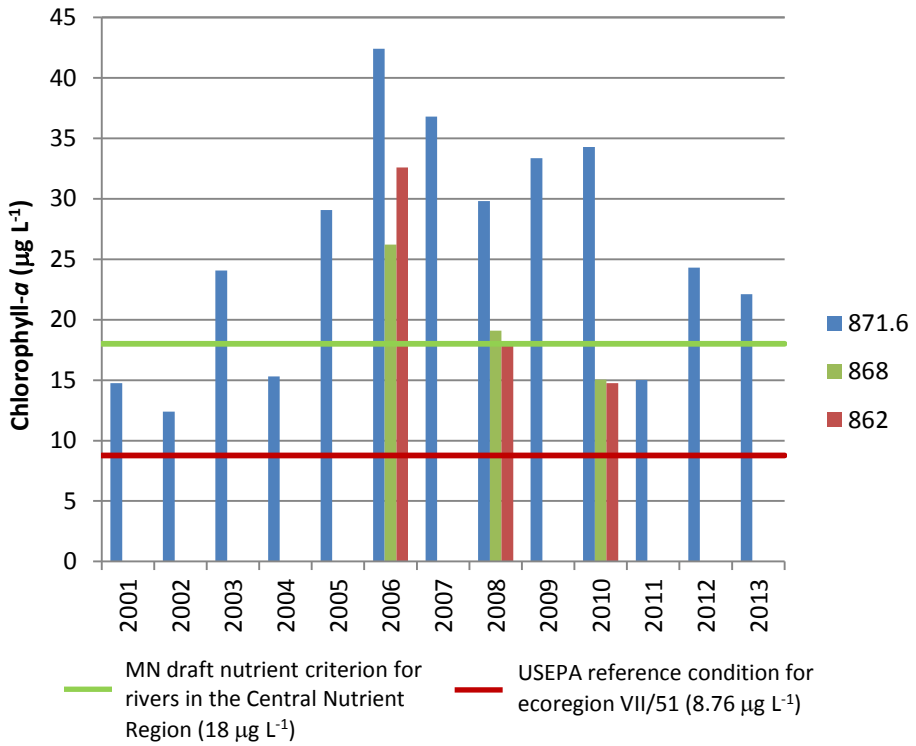


Figure 57. Annual (April-November) mean chlorophyll-*a* values for Mississippi River prairie river water quality monitoring sites in Mississippi National River and Recreation Area, 2001-2013.

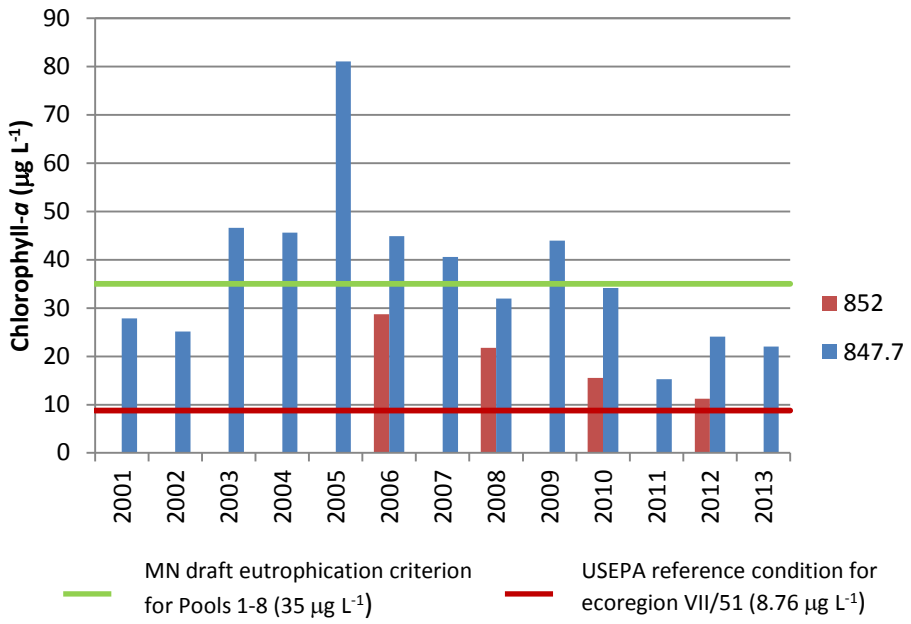


Figure 58. Annual (April-November) mean chlorophyll-*a* values for Mississippi River gorge river water quality monitoring sites in Mississippi National River and Recreation Area, 2001-2013.

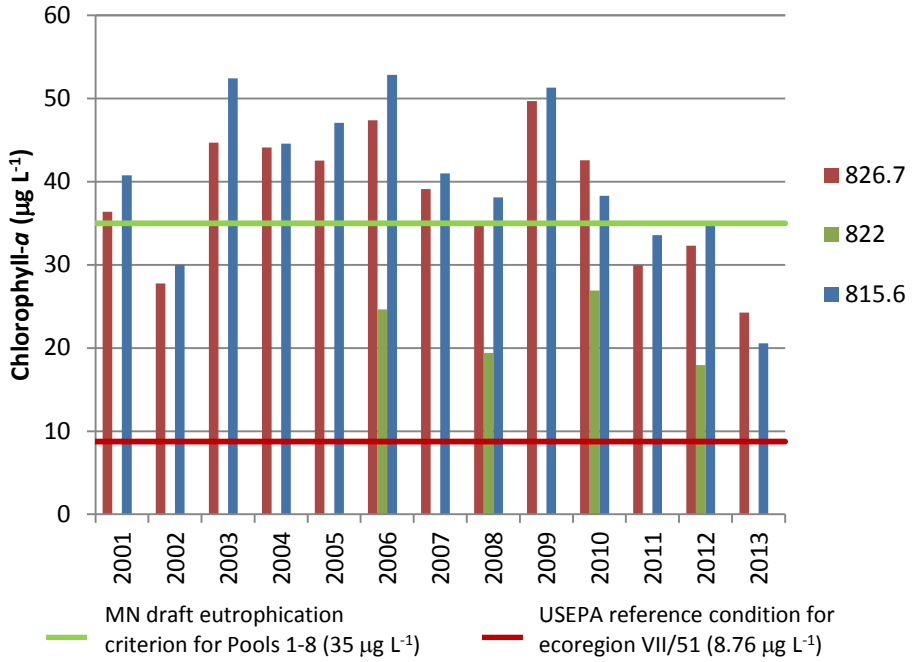


Figure 59. Annual (April-November) mean chlorophyll-*a* values for Mississippi River large floodplain river water quality monitoring sites in Mississippi National River and Recreation Area, 2001-2013.

Lafrancois et al. (2013), working with UM site data from 1976-2005, noted a spatial pattern for chl-*a* that generally increased downstream. A similar pattern can be seen for the UM sites (UM871.6, UM847.7, UM826.7, and UM815.6) in 2006, 2008, and 2010, and at a lower level in the NPS sites for the same time period (Figure 60). The authors also found that most UM sites met the draft nutrient or eutrophication criterion, using a single median value from 1976-2005. They observed that light conditions, nutrients, water temperature, and hydrology all affect algal growth within MISS.

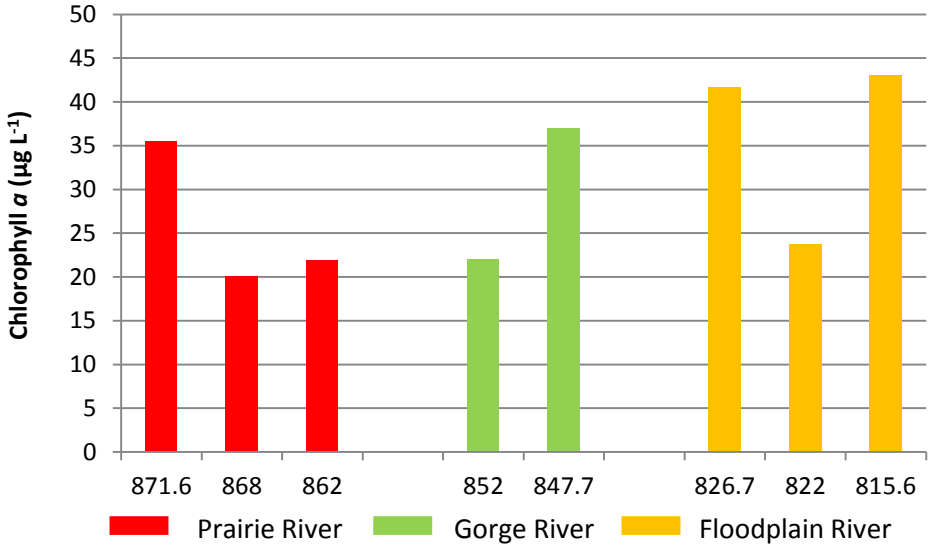


Figure 60. Spatial trends in chlorophyll-*a* in the Mississippi River in Mississippi National River and Recreation Area, mean of means, 2006-2010.

Total Suspended Solids (TSS)

Total suspended solids (also referred to as total suspended sediments) are tiny particles of soil and organic matter. Excess sediment can make the water cloudy, or "turbid," which can negatively impact water quality, aquatic plants, and habitat for fish and wildlife. Other pollutants, such as phosphorus, can also attach to the sediment and be carried downstream. Excess sediment in the Mississippi River comes from a variety of sources. Approximately 75% of the sediment load flowing into the southern metropolitan section of the river can be attributed to the Minnesota River basin, where river banks, ravines, bluffs, and farm fields are primary sources of sediment. The upper Mississippi River contributes 16%, with the remainder attributable to the Cannon, Vermillion, and St. Croix Rivers, minor tributaries, and urban areas (MPCA 2012a).

<u>Reference Condition</u>

The draft regional TSS standard of 30 mg L^{-1} (VanderMeulen 2013 and citations therein) was chosen as the reference condition for sites UM871.6, UM847.7, NPS868, NPS862, and NPS852. The TSS criterion of 32 mg L^{-1} for the Mississippi River TMDL from Lock and Dam 1 to Lock and Dam 4 was chosen as the reference condition for sites UM826.7, UM815.6, and NPS822. These reference conditions represent "least disturbed conditions" (Stoddard et al. 2006).

Condition and Trend

We rate the condition of the river in MISS for TSS as of significant concern, but with an improving trend. Our confidence in this assessment is good. All annual (April-November) TSS means for MISS sites above the Minnesota River (prairie river and gorge river sites NPS868, NPS862, NPS852, UM871.6, and UM847.7) and covered by the draft regional TSS standard (30 mg L^{-1}) were well below the chosen maximum standard from 1979-2013 (Figure 61, Figure 62). Sites in the large floodplain river below the Minnesota River (NPS822, UM826.7, and UM815.6) covered by the TSS TMDL (32 mg L^{-1}) were often above the chosen maximum standard (Figure 63). The maximum individual measurement in the data set was 957 μg L^{-1} at UM826.7 in 1979. Using July and August data from 1976-2012, a downward trend or statistically significant decrease in TSS was detected at UM871.6, UM847.7, and UM826.7 using the Mann-Kendall trend test (α=0.05). Lafrancois et al. (2013) detected a downward trend at all four UM sites from 1976-2005.

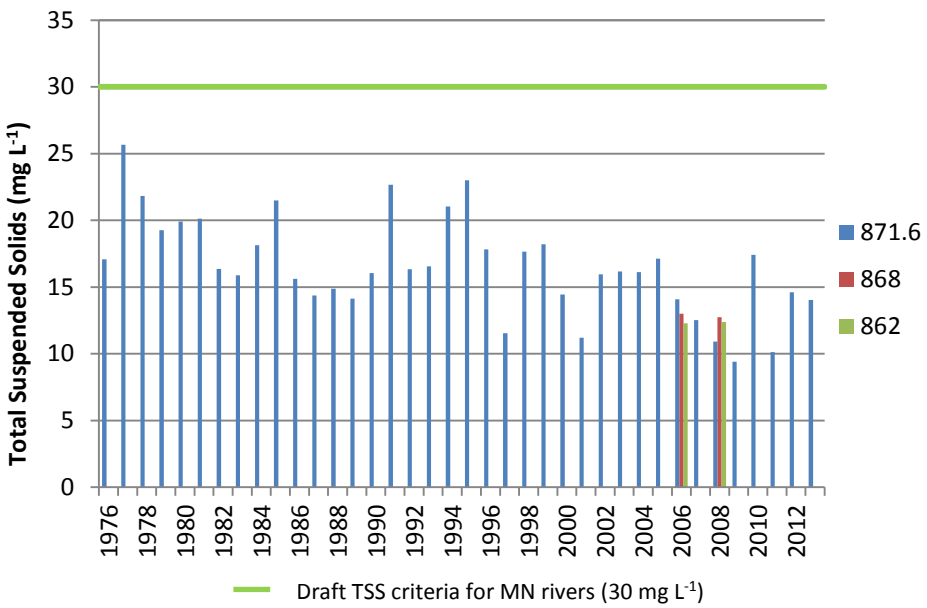


Figure 61. Annual (April-November) mean total suspended solids values for Mississippi River prairie river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013.

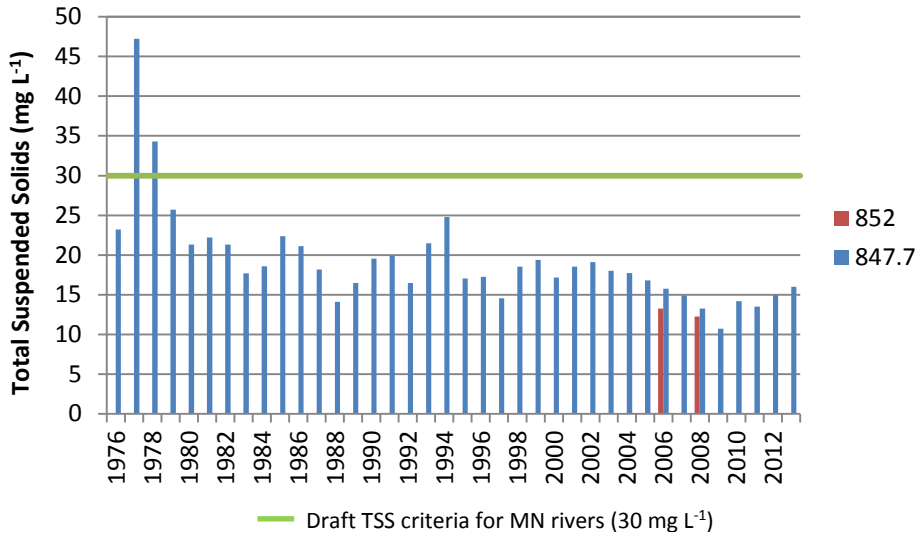


Figure 62. Annual (April-November) mean total suspended solids values for Mississippi River gorge river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013.

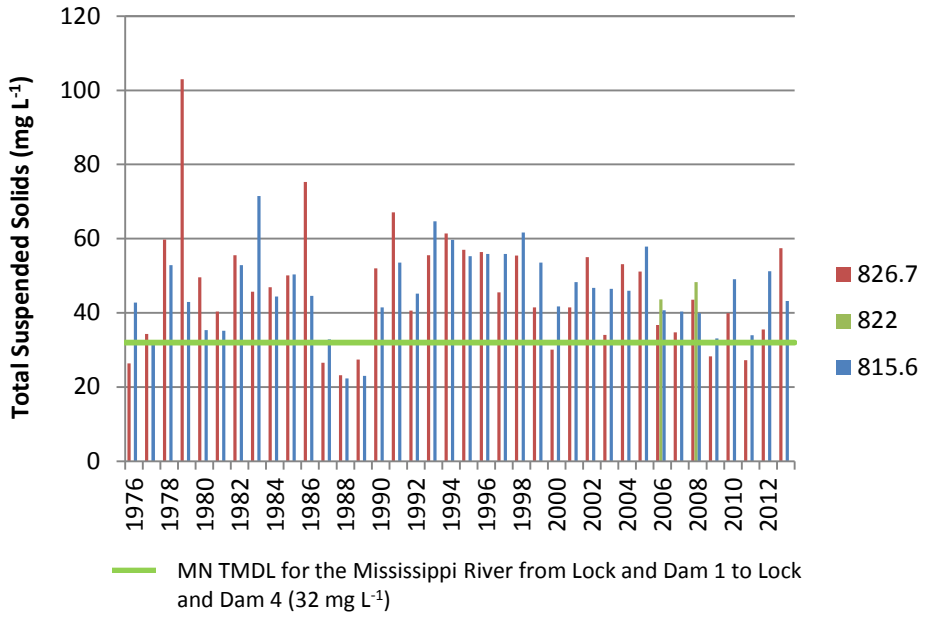


Figure 63. Annual (April-November) mean total suspended solids values for Mississippi River large floodplain river water quality monitoring sites in Mississippi National River and Recreation Area, 1976-2013.

Escherichia coli (E. coli)

Escherichia coli (*E. coli*) is a bacterium typically found in human or animal fecal matter. Its presence in water indicates the potential presence of harmful waterborne pathogens that also originate in the intestines of living creatures and can affect human health. There are multiple sources of bacteria. Human sources can include septic systems, combined storm and sanitary

sewer overflows, and leaking sanitary sewers. Livestock sources can include feedlots, grazing livestock, and field-applied manure. Pets and wildlife can also be contributing sources. In additional to traveling in water, it has been shown that fecal matter can survive in sediment. Areas with stirred-up sediment may also be affected by high bacteria concentrations.

The Mississippi River is a significant recreational resource. Contact with water that has high bacteria concentrations can make users sick. To reduce the risk of users getting sick from these pathogens, Minnesota has set standards for *E. coli* concentrations in water (Russell and Weller 2012).

Reference Condition

Bacteria levels can vary greatly over time, even at the same site. Our chosen reference condition for *E. coli* is the MN water quality standard of a maximum geometric mean, based on five or more samples in a calendar month, of 126 colony-forming units (cfu)/100 mL of water, or a maximum of 1,260 cfu in 10% or more of samples in a calendar month (MPCA 2013b). An impairment in a water body for *E. coli* is determined by aggregating data by individual month over a full ten year period for the April 1 through Oct. 31 season. At least five values for each month is ideal, however a minimum of five values for at least three months (preferably June through September) is required. If the mean of the aggregated monthly values for one or more months exceeds 126 cfu/100 mL, the site is considered to be impaired. The site is also considered impaired if >10% of the individual values over the 10-year data set exceed 1,260 cfu/100 mL (MPCA 2013b).

Condition and Trend

We rate the condition of the Mississippi River in MISS for *E. coli* as of significant concern, but we had insufficient data to calculate a trend. Our confidence in this assessment is good. Three reaches of the Mississippi River that flow through the Twin Cities area are considered impaired; these are from Coon Creek to Upper St. Anthony Falls, from Lower St Anthony Falls to Lock and Dam 1, and from the Minnesota River to the Metro Wastewater Treatment Plant (Figure 64) (MPCA 2014).

The MPCA and MDH, with numerous partners, developed a bacteria TMDL for the Mississippi River from Royalton, MN to Hastings, MN in 2013. The TMDL not only focuses directly on the Mississippi River, but also portions of three major watersheds that have streams and rivers that contribute to the Mississippi River and subwatersheds that were chosen to support the protection of the Mississippi River. TMDLs were developed for 22 reaches on tributaries to the Mississippi River and for five impaired reaches on the Mississippi River. This TMDL excluded any impaired reaches that are currently being or are planned on being addressed in another project. The five Mississippi River reached (three in MISS) that were deemed impaired have had their TMDLs deferred because the modeling process used found that a 0% load reduction was required to meet the TMDL, and further study and analysis was deemed necessary (Emmons and Olivier Resources et al. 2014).

In addition to the recommended reductions, the TMDL plan outlines a variety of implementation strategies to reach the goals of the TMDL. The plan also includes monitoring approaches that will continue to monitor the effectiveness of the TMDL and implementation strategies (Emmons and Olivier Resources et al. 2014).

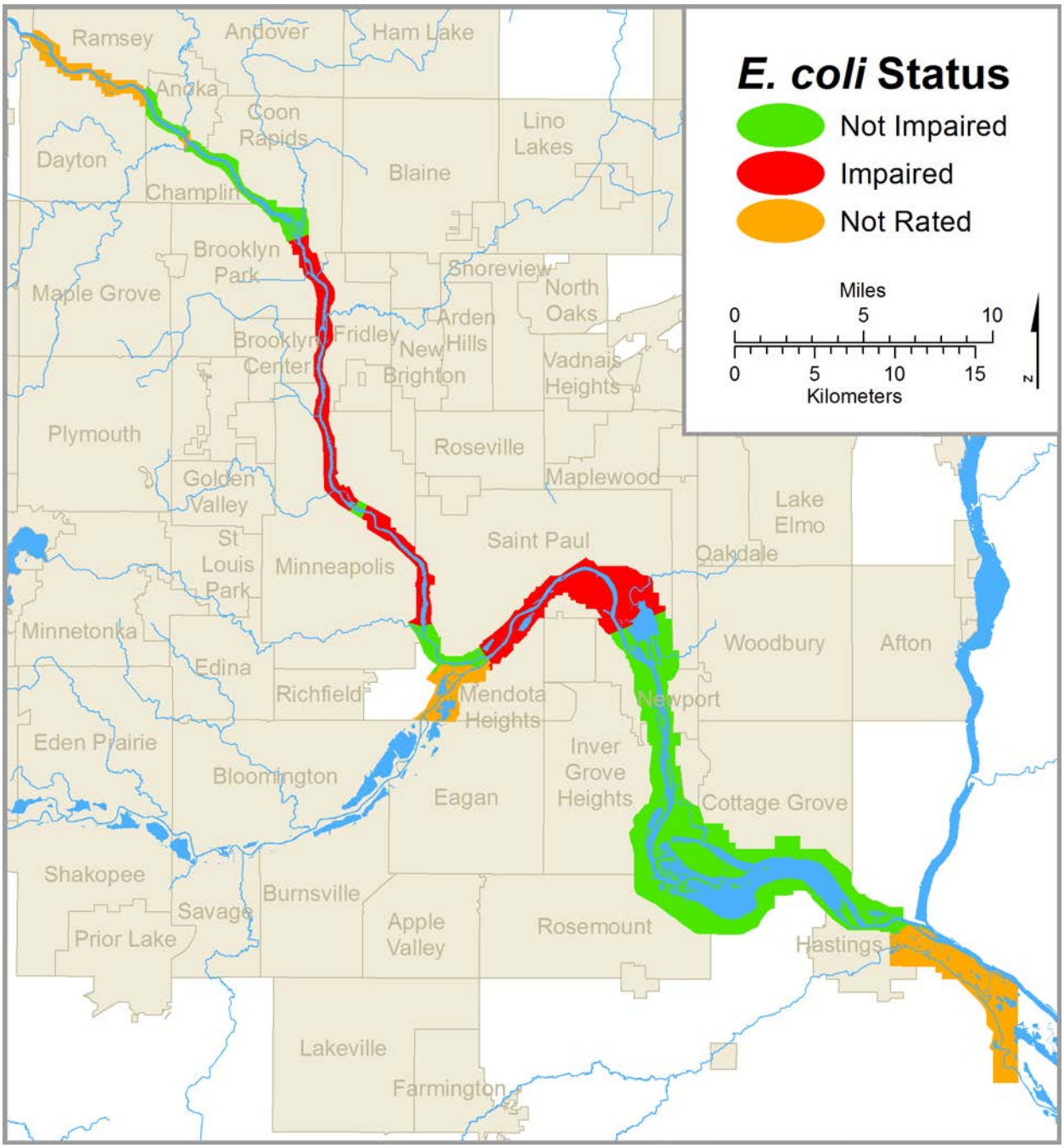


Figure 64. Reaches of the Mississippi River impaired for *E. coli* in Mississippi National River and Recreation Area (Emmons and Olivier Resources et al. 2014).

Sources of Expertise

Lafrancois et al. 2013; Elias and Sieracki 2007; VanderMeulen 2009, 2011, 2013; Elias et al. 2008; Dr. Katherine Clancy, Jen McNelly; Christine Mechenich, UWSP.

Literature Cited

Elias, J. E., and J. L. Sieracki. 2007. Report on 2006 water quality sampling at Mississippi National River and Recreation Area. Great Lakes Inventory and Monitoring Network Annual Monitoring Report GLKN/2007/07. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/660547. (accessed February 21, 2014).

Elias, J. E, R. Axler, and E. Ruzycki. 2008. Water quality monitoring protocol for inland lakes. Version 1.0. National Park Service, Great Lakes Inventory and Monitoring Network. Natural Resources Technical Report NPS/GLKN/NRTR—2008/109. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/653784. (accessed April 15, 2014).

Emmons and Olivier Resources, Inc., Minnesota Pollution Control Agency, and Minnesota Department of Health. 2014. Upper Mississippi River Bacteria TMDL Study and Protection Plan. Draft. Available from the Minnesota Pollution Control Agency, St. Paul, Minnesota and at http://www.pca.state.mn.us/index.php/view-document.html?gid=19121. (accessed March 24, 2014).

Heiskary, S., R. W. Bouchard Jr., and H. Markus. 2013. Minnesota nutrient criteria for rivers (draft). Minnesota Pollution Control Agency, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=14947. (accessed February 19, 2014).

Heiskary, S., and D. Wasley. 2012. Mississippi River Pools 1 through 8: Developing river, pool and Lake Pepin eutrophication criteria. Minnesota Pollution Control Agency, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=14927. (accessed February 19, 2014).

Helsel, D. R., and R. M. Hirsch. 2002. Statistical methods in water resources techniques of water resources investigations, book 4, chapter A3. U.S. Geological Survey, Reston, Virginia. Available at http://pubs.usgs.gov/twri/twri4a3/. (accessed October 2, 2012).

Kasahara, S. M. 2014. Chloride monitoring at Coldwater Spring. Faculty advisor, Professor E. Calvin Alexander, Jr. Proceedings of the National Conference on Undergraduate Research (NCUR) 2014, University of Kentucky, Lexington, Kentucky, April 3-5, 2014. Available at http://www.ncurproceedings.org/ojs/index.php/NCUR2014/article/view/1019/506. (accessed May 21, 2015).

Lafrancois, B. M., S. Magdalene, D. K. Johnson, D. VanderMeulen, and D. Engstrom. 2013. Water quality conditions and trends in the Mississippi National River and Recreational Area: 1976-2005. Natural Resource Technical Report NPS/GLKN/NRTR—2013/691. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2193312. (accessed February 17, 2014).

LimnoTech. 2009. Upper Mississippi River – Lake Pepin water quality model. Report to Minnesota Pollution Control Agency, 304 pp. LimnoTech, Ann Arbor, Michigan.

MCES (Metropolitan Council Environmental Services). 2012. 2012 river water quality summary for the Twin Cities metropolitan area. MCES, St. Paul, Minnesota. Available at http://www.metrocouncil.org/getattachment/d234aed6-015d-4961-b391-8cc8c3d3f826/.aspx. (accessed April 15, 2014).

MDH (Minnesota Department of Health). 2014. Nitrate in well water. MDH, St. Paul, Minnesota. Available at http://www.health.state.mn.us/divs/eh/wells/waterquality/nitrate.pdf. (accessed June 2, 2015).

MDNR (Minnesota Department of Natural Resources). 2004. Healthy rivers: a water course. MDNR, St. Paul, Minnesota. Available at http://www.dnr.state.mn.us/healthyrivers/index.html. (accessed March 25, 2013).

Monson, P. 2010. Aquatic life water quality standards technical support document for nitrate. Triennial water quality standard amendments to Minn. R. chs. 7050 and 7052. Draft for external review, November 12, 2010. Minnesota Pollution Control Agency, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=14949. (accessed June 2, 2015).

MPCA (Minnesota Pollution Control Agency). 2012a. South metro Mississippi River total suspended solids total maximum daily load. Draft. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=15794. (accessed March 28, 2014).

MPCA (Minnesota Pollution Control Agency). 2012b. Minnesota River turbidity total maximum daily load. Draft report. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=17108. (accessed March 28, 2014).

MPCA (Minnesota Pollution Control Agency). 2013a. Waters of the state: water quality standards for protection of waters of the state. Minnesota Administrative Rules Chapter 7050. MPCA, St. Paul, Minnesota. Available at https://www.revisor.mn.gov/rules/?id=7050&version=2014-01-18T07:06:14-06:00&format=pdf. (accessed February 11, 2014).

MPCA (Minnesota Pollution Control Agency). 2013b. Guidance manual for assessing the quality of Minnesota surface waters for determination of impairment: 305(b) report and 303(d) list, 2014 assessment cycle. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=16988. (accessed February 17, 2014).

MPCA (Minnesota Pollution Control Agency). 2013c. Nitrogen in Minnesota surface waters: conditions, trends, sources, and reductions. Report in collaboration with the University of Minnesota and U.S. Geological Survey. MPCA, St. Paul, Minnesota. Available at

http://www.pca.state.mn.us/index.php/about-mpca/mpca-news/featured-stories/report-on-nitrogen-in-surface-water.html. (accessed June 2, 2015).

MPCA (Minnesota Pollution Control Agency). 2014. Draft impaired waters list. Minnesota Pollution Control Agency, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/impaired-waters-list.html. (accessed March 24, 2014).

MPCA (Minnesota Pollution Control Agency). 2015. Twin Cities Metropolitan Area chloride management plan, draft, April 2015. MPCA, St. Paul, Minnesota. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=22754. (accessed May 21, 2015).

NPS (National Park Service). 1995. Baseline Water Quality Inventory, Mississippi National River and Recreation Areas National River. Project-2173807. NPS, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/GroupedProducts?parentReferenceCode=2173807. (accessed February 11, 2014).

Russell, T. A., and L. Weller. 2012. State of the river report: water quality and river health in the Metro Mississippi River. Friends of the Mississippi River and National Park Service, St. Paul, Minnesota. Available at http://stateoftheriver.com/. (accessed February 17, 2014).

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16:1267–1276.

USEPA (United States Environmental Protection Agency). 1976. Quality criteria for water, 1976. EPA 440-9-76-023, Environmental Protection Agency, Office of Water Regulations and Standards, Washington, D.C.

USEPA (United States Environmental Protection Agency). 1986. Quality criteria for water, 1986. EPA 440/5-86-001, Environmental Protection Agency, Office of Water Regulations and Standards, Washington, D.C.

USEPA (United States Environmental Protection Agency). 2000a. Ambient water quality criteria recommendations: Information supporting the development of state and tribal nutrient criteria for rivers and streams in nutrient ecoregion VI. EPA-822-B-00-017. U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology, Health and Ecological Criteria Division, Washington, D.C. Available at http://water.epa.gov/scitech/swguidance/standards/upload/2007_09_27_criteria_nutrient_ecoregions_rivers_rivers_6.pdf. (accessed February 11, 2014).

USEPA (United States Environmental Protection Agency). 2000b. Ambient water quality criteria recommendations: Information supporting the development of state and tribal nutrient criteria for rivers and streams in nutrient ecoregion VII. EPA-822-B-00-018. U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology, Health and Ecological Criteria Division, Washington, D.C. Available at

http://water.epa.gov/scitech/swguidance/standards/upload/2007_09_27_criteria_nutrient_ecoregions_rivers_rivers_7.pdf. (accessed February 11, 2014).

USEPA (United States Environmental Protection Agency). 2006. National recommended water quality criteria. Environmental Protection Agency, Office of Science and Technology, Washington, D.C. Available at http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1003R9X.txt. (accessed March 25, 2013).

VanderMeulen, D. 2009. Monitoring water quality of large rivers, 2008: Annual summary report. National Park Service, Great Lakes Inventory and Monitoring Network Report GLKN/2009/03. GLKN, Ashland, Wisconsin. Available at https://irma.nps.gov/App/Reference/Profile/2188791. (accessed February 11, 2014).

VanderMeulen, D. 2011. Large rivers water quality monitoring: 2009 and 2010 summary report. Natural Resource Data Series NPS/GLKN/NRDS—2011/164. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2170875. (accessed February 11, 2014).

VanderMeulen, D. 2013. Water quality monitoring at Mississippi National River and Recreation Area: 2012 summary report. Natural Resource Data Series. NPS/GLKN/NRDS—2013/577. National Park Service. Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2204426. (accessed February 11, 2014).

4.6 Ecosystem Processes

The EPA-SAB framework lists energy flow and material flow as the two primary subdivisions of ecological processes (USEPA 2002). If these two aspects of ecosystem function and their respective subcategories are tracked over time, they may indicate the trajectory of the ecosystem and provide an indication of proximity to an unimpaired, healthy state.

Primary production and food web structure are the common attributes and indicators of energy flow (e.g., Megonigal et al. 1997, Valett et al. 2005, Cross et al. 2006, Hoeinghaus et al. 2007). Primary production is divided into gross [GPP] and net [NPP]; the latter is defined as GPP minus the energy used up in respiration and for cell maintenance. The energy base of 'riverine' systems is either organic input from upstream (usually plants in the riparian or floodplain zones), algae (phytoplankton) in the system, or aquatic vascular plants rooted in the stream channel, along the river bank (riparian), or in the floodplain (Zeug and Winemiller 2008). For an intermediate-sized river in Texas, it was determined that macrophytes in the riparian zone (but not floodplain) supported a strong majority of the consumers in the main channel and many consumers in side channels and oxbow lakes. In contrast, smaller-bodied consumers in the oxbow lakes relied primarily on algae (Zeug and Winemiller 2008). This high level of importance of riparian vegetation contradicts the previously-held theory that algal carbon was the dominant source of energy in the main channel (e.g., Thorp and Delong 1994). The relative importance of algae and macrophytes as carbon sources is altered by flood duration, with the algal and floodplain contributions increasing as flood duration goes up (Hoeinghaus et al. 2007, Zeug and Winemiller 2008). Rates of GPP and NPP vary among hydrologic regimes and climatic regions (Benke et al. 2000, Hoeinghaus et al. 2007). Disturbance, in the form of floods, nutrient and sediment subsidy, and local topographic/edaphic factors, leads to differences among streams and rivers within a region (Day et al. 1988, Benke et al. 2000, Hoeinghaus et al. 2007). The degree of disruption in hydrologic regime by human activity is a key factor; changes in flood frequency, timing, and extent have strong effects on the level of production (Valett et al. 2005, Zeug and Winemiller 2008), as does nitrogen and phosphorus input from the watershed (Slavik et al. 2004, Craig et al. 2008, Greaver et al. 2012).

Given the natural variation at broad and local scales, and the length of time the UMR has been disrupted by locks and dams, it is difficult to determine its function in an "unimpaired, healthy state" from productivity or food web measures. Furthermore, the information needed to put together an energy flow budget is extensive, time consuming to collect, and quite costly to obtain (Cain et al. 2008; see discussion in Zeug and Winemiller 2008). To use such ecosystem characteristics to gauge 'health' would require detailed, highly accurate, site specific measurements over an extended period of time. Thus, it is highly unlikely that such an investment would produce information, or an indicator, that is better than others that are more readily obtainable. Despite these difficulties, food web studies are being conducted at both MISS and SACN by USGS and Northland College; these should be helpful in understanding energy flow, especially in the lower river (written communication, Brenda Moraska Lafrancois, NPS Midwest Region Aquatic Ecologist, 12/30/2014).

The flow of nutrients (nitrogen, and other essential minerals) into, through, and out of a system is more complex and less well understood than primary production. Input of carbon is internal and external, and the same is true for essential nutrients. Nutrient sources include the atmosphere, the stream bed, groundwater, organic matter breakdown, and overland flow; these sources vary in

importance among different aquatic systems and regions. In the upper Midwest, important external sources of nitrogen and sulfur include the atmosphere, agricultural run-off, and wastewater effluent (Greaver et al. 2012). See section 4.5.1 for the estimated levels of nitrogen and sulfur atmospheric deposition at MISS. Though the depositional rates for sulfur have decreased for several decades, the rate for nitrogen has not.

The processes carried out by specific trophic levels (or functional groups) of a system are reasonably well known, but how long a molecule of a nutrient stays in a trophic level is quite variable and not easy to determine. It is difficult to measure processes accurately *in situ* because the decomposition process occurs over a considerable length of the river, and important drivers such as radiation and oxygen change over short distances, as well as seasonally (Helton et al. 2011, Greaver et al. 2012). It is even more challenging to determine the composition and density of organisms involved in decomposition (Cain et al. 2008). Thus, the situation for nutrient flow is virtually identical to energy flow – a useful assessment would require a large commitment of time and money to produce the level of accuracy and sensitivity needed. There are situations where the 'flow' of nutrients into and/or out of a system (atmosphere, groundwater, and/or overland flow) has a positive fertilization effect, but commonly it is a source of impairment (Greaver et al. 2012). This can lead to the well-known and widespread problem of eutrophication of aquatic systems. Concurrently, there can be reduced productivity, altered species assemblages, and reduced biodiversity; i.e., almost all components that contribute to the functioning of system can be altered. Furthermore, the acidifying effects have continued in some systems even though the pH of precipitation has gone down (Greaver et al. 2012).

The GLKN has identified four monitoring categories related to ecosystem processes (NPS 2007). These are succession, trophic relations, nutrient dynamics, and primary productivity. They are 22nd, 26th, 39th, and 42nd, respectively, in the list of 46 vital signs (see Table 5). Only succession is currently scheduled for the development of a monitoring protocol.

Sources of Expertise
James Cook, UWSP

Literature Cited

Benke, A. C., I. Chaubey, G. M. Ward, and E. L. Dunn. 2000. Flood pulse dynamics of an unregulated river floodplain in the southeastern U.S. coastal plain. *Ecology* 81:2730–2741.

Cain, M. L., W. D. Bowman, and S. D. Hacker. 2008. Ecology. Sinauer Associates, Sunderland, Massachusetts. 544 pp.

Craig, L. S., M. A. Palmer, D. C. Richardson, S. Filoso, E. S. Bernhardt, B. P. Bledsoe, M. W. Doyle, P. M. Groffman, B. A. Hassett, S. S. Kaushal, P. M. Mayer, S. M. Smith, and P. R. Wilcock. 2008. Stream restoration strategies for reducing river nitrogen loads. *Frontiers in Ecology and the Environment* 6:529–538.

Cross, W. F., J. B. Wallace, A. D. Rosemond, and S. L. Eggert. 2006. Whole-system nutrient enrichment increases secondary production in a detritus-based ecosystem. *Ecology* 87:1556–1565.

Day, R. T., P. A. Keddy, J. McNeill, and T. Carleton. 1988. Fertility and disturbance gradients: A summary model for riverine marsh vegetation. *Ecology* 69:1044–1054.

Greaver, T. L., T. J. Sullivan, J. D. Herrick, M. C. Barber, J. S. Baron, B. J. Cosby, M. E. Deerhake, R. L. Dennis, J.-J. B. Dubois, C. L. Goodale, A. T. Herlihy, G. B. Lawrence, L. Liu, J. A. Lynch, and K. J. Novak. 2012. Ecological effects of nitrogen and sulfur air pollution in the US: what do we know? *Frontiers in Ecology and the Environment* 10:365–372.

Helton, A. M., G. C. Poole, J. L. Meyer, W. M. Wollheim, B. J. Peterson, P. J. Mulholland, E. S. Bernhardt, J. A. Stanford, C. Arango, L. R. Ashkenas, L. W. Cooper, W. K. Dodds, S. V. Gregory, R. O. Hall, S. K. Hamilton, S. L. Johnson, W. H. McDowell, J. D. Potter, J. L. Tank, S. M. Thomas, H. M. Valett, J. R. Webster, and L. Zeglin. 2011. Thinking outside the channel: modeling nitrogen cycling in networked river ecosystems. *Frontiers in Ecology and the Environment* 9:229–238.

Hoeinghaus, D. J., K. O. Winemiller, and A. A. Agostinho. 2007. Landscape-scale hydrologic characteristics differentiate patterns of carbon flow in large-river food webs. *Ecosystems* 10:1019–1033.

Megonigal, J. P., W. H. Conner, S. Kroeger, and R. R. Sharitz. 1997. Aboveground production in southeastern floodplain forests: a test of the subsidy-stress hypothesis. *Ecology* 78:370–384.

NPS (National Park Service). 2007. Long-term Ecological Monitoring Plan: Great Lakes Inventory and Monitoring Network. Natural Resource Report NPS/GLKN/NRR-2007/001. National Park Service. Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/645523 (accessed October 28, 2013).

Slavik, K., B. J. Peterson, L. A. Deegan, W. B. Bowden, A. E. Hershey, and J. E. Hobbie. 2004. Long-term responses of the Kuparuk River ecosystem to phosphorus fertilization. *Ecology* 85:939–954.

Thorp, J. H., and M. D. Delong. 1994. The riverine productivity model: an heuristic view of carbon sources and organic processing in large river ecosystems. *Oikos* 70:305–308.

USEPA (United States Environmental Protection Agency) Science Advisory Board. 2002. A framework for assessing and reporting on ecological condition: an SAB report. EPA-SAB-EPEC-02-009. USEPA, Washington, D.C. Available at http://www.epa.gov/sab/pdf/epec02009.pdf. (accessed August 5, 2013).

Valett, H. M., M. A. Baker, J. A. Morrice, C. S. Crawford, M. C. Molles, Jr., C. N. Dahm, D. L. Moyer, J. R. Thibault, and L. M. Ellis. 2005. Biogeochemical and metabolic responses to the flood pulse in a semiarid floodplain. *Ecology* 86:220–234.

Zeug, S. C., and K. O. Winemiller. 2008. Evidence supporting the importance of terrestrial carbon in a large-river food web. *Ecology* 89:1733–1743.

5 Discussion

5.1 Natural Disturbance Regime

The dominant component of the natural disturbance regime at MISS is the flood regime. Of secondary importance are low-severity wind, herbivory, and other small-scale disturbances. There are also occasional-to-very infrequent moderate-to-severe disturbances; most commonly these are wind events. Reference conditions were not established for these. The gypsy moth and emerald ash borer are herbivores that present significant threats to the trees in MISS. Kirschbaum and Gafvert (2013) found that all of the disturbance they documented in MISS from 2005-2010 was caused by development and not natural causes, but this is not typical of all periods.

5.2 Hydrology and Geomorphology

The Mississippi River channel in MISS has been greatly altered from pre-European settlement conditions (Anfinson et al. 2003). The construction of locks and dams and of dikes, while not significantly changing river position or discharge, has changed other physical characteristics such as river surface area, island area, and sediment deposition in floodplains and backwaters (Chen and Simons 1986). These physical changes have greatly affected plant communities and habitat suitability for a variety of fauna (Johnson et al. 2010). Summertime drawdowns to simulate natural conditions have been successful in restoring aquatic vegetation and increasing habitat for migrating waterfowl in some UMR pools and are worth further investigation and possible implementation on the pools within MISS.

Both annual and peak flows have been increasing in both the Minnesota and Mississippi Rivers in MISS; causes include increased rainfall (Novotny and Stefan 2007) and changes in agricultural practices (Zhang and Schilling 2006, Schottler et al. 2013). Increased streamflow may increase flooding and erosion but may decrease concentrations of contaminants in the water by dilution.

5.3 Landscape Condition

Landscape condition for MISS was assessed in the categories of land cover, historic floodplain changes, impervious surfaces, landscape pattern and structure, road density, lightscapes, and soundscapes. Land cover was in good condition and stable, as defined by the low percentage of land use changes documented from 2001-2006 (USGS 2011) and 2005-2010 (Kirschbaum and Gafvert 2013). The condition of the floodplain in MISS is of moderate concern, with a stable trend. Between the 1890s and 2000, the cover of 41.5% of the land in the floodplain changed. The largest increases were in open water and developed area, while the largest decreases were in wet floodplain forest, wet meadow, shrub/scrub, agriculture, and marsh.

MISS is in a condition of significant concern for impervious surfaces, with a deteriorating trend. In 2006, 12.8% of the total area and 18.2% of the land area was >10% impervious, exceeding the target for watershed protection of 10% (NPS 2012). However, MISS has less impervious surface than the urban area surrounding it.

The condition of the landscape in MISS for forest density is uncertain. Tree density in the silver maple forest is less than in presettlement times but is comparable in the other two lowland forest types at MISS (Knutson and Klaas 1998, Sanders and Grochowski 2012). For forest morphology,

we hypothesize that there is less core forest habitat and more fragmentation than in presettlement times. We recommend a goal of a modest increase in forested wetland and wet meadow.

The condition of the landscape for road density is judged to be of significant concern based on targets for restoration of habitat in areas of high aquatic resource value (Carnefix and Frissell 2009). Available data are insufficient to assess the condition of the MISS landscape for lightscapes and soundscapes.

The GLKN program to analyze natural or human-related disturbances using aerial photography and satellite images should help analyze and track landscape condition and should be continued.

5.4 Biotic Condition

The composition and abundance of both upland and floodplain plant communities at MISS are significantly outside their normal range of variation and are of moderate concern. Appropriate goals include increasing the amount of oak openings and barrens in the uplands; wet floodplain forest in Pools 1, 2, and upper Pool 3; marsh and wet meadow in Pool 2; and shrub/scrub in lower Pool 2.

In lowland forests, tree regeneration is of concern for silver maple and cottonwood. Green ash is regenerating well, but the trees are vulnerable to infestation by the emerald ash borer once they reach suitable size for egg laying. Terrestrial invasive plants are of moderate concern and appear to be increasing in number and area, creating a deteriorating trend. In all MISS plant communities, thirty-four exotic and eight native plant species have received treatment by the GLEPMT from 2004-2013, along with four taxa that include both native and exotic species.

For animals and animal communities, the condition is fair to good for birds and fish, of moderate concern for mussels, and of significant concern for fish in tributaries and for aquatic macroinvertebrates. Trends for mussels appear stable, but are unknown for birds, fish, and aquatic macroinvertebrates because of a lack of recent survey data. A condition of significant concern exists for the aquatic non-native and invasive Asian carp. Bighead, grass, and silver carp, types of Asian carp, were caught in Pool 2 in 2013 and 2014. MDNR considers Asian carp an “urgent issue” requiring “immediate action” in MN.

Eaglets and fish in the MISS watershed have been assessed for mercury and a variety of organic chemical contaminants. A significant concern exists for mercury, total PCBs, and PFOS in fish tissue and for PFOS in eaglet serum. The trends for mercury and PFOS in fish tissue are uncertain, but improving trends are seen for total PCBs in fish tissue and PFOS in eaglet serum. A condition of moderate concern, but with an improving trend, exists for both DDE and total PCBs in eaglet serum. The condition for mercury in eaglet feathers is good and stable. For PBDEs, the condition is unknown for eaglets because no reference condition has been established. For fish, no data were found for PBDEs or DDE. Mercury in precipitation is of significant concern, with a stable trend.

5.5 Chemical and Physical Characteristics

Overall, air quality at MISS is of significant concern, based on the individual assessments of significant concern for wet deposition of total nitrogen and visibility and moderate concern for ozone and wet deposition of total sulfur (NPS 2013). Only ozone had sufficient data to assess a

trend in MISS, and no statistically significant trend was found. This assessment is based on NPS ARD data and has a moderate level of confidence, since some air monitoring sites are some distance from the park.

Water quality, as measured by specific conductance, dissolved oxygen, alkalinity, and chloride, is good in MISS, although chloride is of concern in tributary streams. A deteriorating trend in specific conductance and an improving trend in dissolved oxygen were observed. Total suspended solids and pH are in condition of moderate concern, with an improving trend for total suspended solids and a deteriorating trend, caused by rising values, in pH.

The concentrations of the major nutrients nitrogen and phosphorus are of significant concern, but the trends are improving for phosphorus and stabilizing for nitrogen. Chlorophyll-*a*, a measure of algal growth closely related to nutrient availability, is likewise of significant concern with an improving trend. *E. coli* bacteria are of significant concern, with an uncertain trend; three reaches of the Mississippi River are impaired for this contaminant.

A large portion of the load of total phosphorus, total and nitrate + nitrite nitrogen, and total suspended solids in the Mississippi River in MISS is contributed by the Minnesota River. Total maximum daily loads are under development for total suspended solids on the south metro Mississippi River, turbidity on the Minnesota River, bacteria on the Upper Mississippi River, and nutrients in Lake Pepin on the Mississippi River downstream of MISS.

5.6 Ecosystem Processes

Energy flow and material flow, the two primary categories of ecological processes, are of great importance in ecosystems but are costly and time consuming to measure. No specific assessments were found for these in MISS, although food web studies are currently underway. The GLKN lists four monitoring categories related to ecosystem processes (succession, trophic relations, nutrient dynamics, and primary productivity), but only succession is currently scheduled for the development of a monitoring protocol.

Of the 49 natural resource condition indicators evaluated for MISS, eight were in “good” condition, 14 were in condition of “moderate concern,” 20 were in condition of “significant concern,” and the condition of the remaining seven was “unknown.” Only half of the indicators had sufficient information over time to assess trends; for 24 of the 49, the trend was “unknown.” Eight were improving, nine were stable, and eight showed a deteriorating trend. Confidence in the assessment was high for 27 indicators, medium for 10, low for five, and unknown for seven.

A summary of the condition of the resources we evaluated at MISS is included as Table 39.

Literature Cited

Amberg, J. J., S. G. McCalla, L. Miller, P. Sorensen, and M. P. Gaikowski. 2013. Detection of environmental DNA of bigheaded carps in samples collected from selected locations in the St. Croix River and in the Mississippi River. United States Geological Survey Open-File Report 2013–1080. USGS, Reston, Virginia. Available at http://www.maisrc.umn.edu/files/2013/04/OFR2013-1080-web-final.pdf. (accessed April 23, 2013).

Anfinson, J. O., T. Madigan, D. M. Forsberg, and P. Nunnally. 2003. River of history: a historic resources study of the Mississippi National River and Recreation Area. United States Army Corps of Engineers. St. Paul District, St. Paul, Minnesota. Available at http://www.nps.gov/miss/historyculture/historic_resources.htm. (accessed June 10, 2013).

Carnefix, G., and C. Frissel. 2009. Aquatic and other environmental impacts of roads: the case for road density as indicator of human disturbance and road-density reduction as restoration target; a concise review. Pacific Rivers Council Science Publication 09-001. Pacific Rivers Council, Polson, Montana. Available at http://pacificrivers.org/science-research/resources-publications/road-density-as-indicator. (accessed December 10, 2013).

Chen, Y., and D. Simons. 1986. Hydrology, hydraulics, and geomorphology of the Upper Mississippi River system. *Hydrobiologia* 136:5–19.

Johnson, B. L., J. W. Barko, S. M. Bartell, R. Clevenstine, M. Davis, D. L. Galat, K. S. Lubinski, and J. M. Nestler. 2010. An adaptive management approach for summer water level reductions on the Upper Mississippi River System. Report to U.S. Army Corps of Engineers, Rock Island District, Rock Island, Illinois. Available at http://www2.mvr.usace.army.mil/UMRS/NESP/Documents/Water%20Level%20Management%20Report_Final%2028Oct2010.pdf. (accessed March 28, 2014).

Kirschbaum, A. A., and U. B. Gafvert. 2013. Landsat-based monitoring of landscape dynamics at Mississippi National River and Recreation Area, 2005-2010. Natural Resource Technical Report NPS/GLKN/NRTR—2013/745. National Park Service, Fort Collins, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2195280. (accessed October 28, 2013).

Knutson, M. G., and E. E. Klaas. 1998. Floodplain forest loss and changes in forest community composition and structure in the Upper Mississippi River: a wildlife habitat at risk. *Natural Areas Journal* 18:138–150.

Novotny, E. V., and H. G. Stefan. 2007. Stream flow in Minnesota: indicator of climate change. *Journal of Hydrology* 334:319–333.

NPS (National Park Service) Stewardship and Science Inventory and Monitoring Division. 2012. NPScape metric GIS data – land cover. Geospatial Dataset – 2184564. Available at https://irma.nps.gov/App/Reference/Profile/2184564. (accessed September 5, 2012).

NPS (National Park Service), Air Resources Division. 2013. Air quality in national parks: trends (2000-2009) and conditions (2005-2009). Natural Resource Report NPS/NRSS/ARD/NRR—2013/683. National Park Service, Denver, Colorado. Available at http://www.nature.nps.gov/air/Pubs/pdf/gpra/AQ_Trends_In_Parks_2013.pdf. (accessed November 11, 2013).

Sanders, S., and J. Grochowski. 2012. Implementation of a long-term vegetation monitoring program at the Mississippi National River and Recreation Area. Natural Resource Technical Report NPS/GLKN/NRTR—2012/616. National Park Service, Fort Collins, Colorado.

Available at https://irma.nps.gov/App/Reference/Profile/2188820. (accessed February 4, 2014).

Schottler, S. P., J. Ulrich, P. Belmont, R. Moore, J. W. Lauer, D. R. Engstrom, and J. E. Almendinger. 2013. Twentieth century agricultural drainage creates more erosive rivers. *Hydrological Processes*:1–11 (DOI:10.1002/hyp.9738).

USGS (United States Geological Survey). 2011. National Land Cover Database 2006. USGS, Sioux Falls, South Dakota. Available at http://www.mrlc.gov/nlcd2006.php. (accessed November 28, 2011).

Zhang, Y.-K., and K. E. Schilling. 2006. Increasing streamflow and baseflow in Mississippi River since the 1940s: effect of land use change. *Journal of Hydrology* 324:412–422.

Table 39. Natural Resource Condition Assessment summary table.

Priority Resource or Value	Indicator of Condition	Specific Measures	Condition Status/Trend	Rationale
Hydrology and Geomorphology				
Mean Annual Discharge	Historic condition pre-1866	Change in annual flow		Flow has increased in the Mississippi River since 1950 (Johnson and Hagerty 2008) and in the Minnesota River since 1976 (MPCA 2012, Lafrancois et al. 2013).
Seasonal and Annual Flow Variation	Historic condition pre-1866	Change in seasonal flow regime		Low flows have increased for the August to January period as a result of dam construction (Johnson and Hagerty 2008).
Flood Duration	Historic condition pre-1866	Change in flood duration		Insufficient data were found to quantify this condition or trend.
Landscape Condition				
Current Land Cover	Stability over 5-10 year timeframes, comparison to rate of change in Lake Superior basin (0.32% yr^{-1}, Stueve et al. 2011).	Rate of change per year, 2001-2006 and 2005-2010		The rate of change from 2001-2006 was 0.26-0.44% yr^{-1} (USGS 2011), meeting the reference condition at MISS but not in its surrounding area or AOA. The rate of change from 2005-2010 was <0.01-0.11% yr^{-1} in MISS and 0.01-0.22% yr^{-1} in a 300-m buffer and two subwatersheds (Kirschbaum and Gafvert 2013)
Floodplain Land Cover Changes – 1890s to 2000	Historic condition pre-lock and dam construction	% change in land cover 1890s-2000		Between the 1890s and 2000, 41.5% of the land cover in the floodplain changed. Losses included 3,107 ha of wet floodplain forest (-14.8% of total land cover) and ~1,100-1,500 ha (-5.2-7.3%) each of wet meadow, shrub/scrub, agriculture, and marsh (Table 4). Open water increased by 3,720 ha (17.7%), and developed area increased by 2,781 ha (13.2%) (data from www.umesc.usgs.gov).
Landscape Pattern and Structure	Impervious surfaces	% impervious cover in watershed		Within MISS, 12.8% of the total area and 18.2% of the land area consisted of impervious surfaces in the NLCD 2006 dataset (NPS 2012), exceeding the recommended watershed target of 10%. Impervious cover in MISS increased 1.0% from 2001 to 2006 (NPS 2013).
	Forest density	% area with dominant to intact forest		Within MISS, 18.7% of the land area was dominant to intact forest, a percentage over three times greater than in the 1-km ring surrounding the park. No data were available to establish a reference condition.

Table 39. Natural Resource Condition Assessment summary table.

Priority Resource or Value	Indicator of Condition	Specific Measures	Condition Status/Trend	Rationale
Landscape Pattern and Structure (continued)	Forest morphology	% area with core forest		Only 12% of the MISS corridor was core forest, but this was approximately four times greater than in the 1-km ring around the park. No data were available to establish a reference condition.
	Road density	Road density in km km^{-2}		Road density in MISS was 3.6 km km^{-2}, exceeding the chosen reference condition of 0.6 km km^{-2} for the protection of high aquatic resource value habitats
Lightscapes	Natural night sky condition			No data were found, but MISS likely experiences light pollution from its urban surroundings.
Soundscapes	Natural ambient sound levels			No data were found, but MISS likely experiences sound pollution from its urban surroundings. Staff has noted that on some river segments, such as the gorge, the ambient noise level is lower than might be expected.
Biotic Condition				
Vegetation	Natural range of variation	Presettlement terrestrial vegetation		The distribution of major vegetation types are outside their historic natural range of variation. Appropriate targets would be to increase Wet Floodplain Forest (Pool 1, 2, and Upper Pool 3), Marsh and Wet Meadow (Pool 2), Shrub/scrub (Lower Pool 2), and Oak Openings and Barrens (uplands).
	Presence of terrestrial invasive plants	% of land requiring treatment for invasives		MISS is at high risk for terrestrial invasive plant establishment; annual eradication efforts are performed but a systematic survey has not been completed.
Bird Communities	Presence of resident and migratory birds in appropriate habitats			Recent surveys (2009 and 2010) have shown fair to good numbers of bird species, but further surveys are required to verify presence and trends.
Aquatic Macroinvertebrates	Composition and abundance of macroinvertebrate community in tributaries	mIBI		Only one of 22 contributing waters to the Mississippi River in MISS met aquatic life standards for macroinvertebrates from 2010-2012.

Table 39. Natural Resource Condition Assessment summary table.

Priority Resource or Value	Indicator of Condition	Specific Measures	Condition Status/Trend	Rationale
Aquatic Macroinvertebrates (continued)	Composition of macroinvertebrate populations in main channel	EPT metric		A limited data set showed poor condition for the sensitive insect orders Ephemeroptera, Plecoptera, and Trichoptera at a Minneapolis site and fair condition at a St. Paul site on the Mississippi River in 2007-2009.
Fish Community	Composition and abundance of fish community in main channel	Fish surveys		The number of native species reported is similar to the presettlement numbers, but data for management is reportedly inadequate.
	Composition and abundance of fish communities in tributaries	Fish IBI		Of fourteen assessed stream segments in the Mississippi River-Twin Cities watershed, none met the fish IBI standard. Of nine assessed stream segments in the Vermillion River watershed, three met the fish IBI standard. The Minnesota River will be assessed in 2014.
	Invasive Asian carp	Presence		Bighead, grass, and silver carp, types of Asian carp, were caught in Pool 2 in 2013 and 2014.
Mussel Community	Rare mussels	Presence in appropriate habitats		Many mussel species that were historically present in the corridor are absent today. Reintroduction has been successful for some of the most endangered species, and there is evidence of natural reproduction in the Higgins eye population. No current census or trend data are available.
Health of Biota	Mercury	Mercury in precipitation		Mercury concentrations in precipitation at Blaine, Camp Ripley, and Lamberton, MN consistently exceed 2 ng L^{-1}. Only 0.5-3.2% meet the reference condition. No trend was found at any station.
		Mercury in eaglet feathers		The geometric mean concentration of mercury in eaglet feathers at MISS was 3.12-3.70 µg g^{-1}, below the reference condition of 7.5 µg g^{-1}. This mean was significantly lower than the means at SACN and along the south shore of Lake Superior.
		Mercury in fish tissue		Six fish consumption advisories for 13 fish species cover parts of MISS; these fish should be eaten only once a month by sensitive populations.

Table 39. Natural Resource Condition Assessment summary table.

Priority Resource or Value	Indicator of Condition	Specific Measures	Condition Status/Trend	Rationale
Health of Biota (continued)	DDE	DDE in eaglet serum		Geometric means for DDE in bald eagle nestling serum were 7.52-11.8 ng g^{-1} for MISS from 2006-2009, below the reference condition of 28 ppb. However, in 2009, one nestling had a DDT (the parent compound of DDE) level higher than any reported in current literature.
		DDE in fish tissue		No data were found.
	PCBs	Total PCBs in eaglet serum		Geometric means for total PCBs in bald eagle nestling serum were 63.1-86.4 ng g^{-1} for MISS from 2006-2009, below the reference condition of 190 ng g^{-1}. Results from Lake Superior suggest an improving regional trend.
		Total PCB in fish tissue		The lower Minnesota River, Pool 2, Vermillion Slough, and Pool 3 are on the Minnesota 2014 draft impaired waters list for PCB in fish tissue. PCB levels exceed, by a factor of two, the reference condition for the protection of birds and animals that consume fish. Trends in PCBs in the Mississippi River in MISS show overall improvement.
	PFOS	Total PFOS in eaglet serum		Geometric means for total PFOS in bald eagle nestling serum were 541-1,250 ng g^{-1} from 2006-2009, below the reference condition of 1,700 ng g^{-1}. However, three nestlings at MISS (5.5%) exceeded the reference condition.
		Total PFOS in fish tissue		Pool 2 from the Rock Island railroad bridge to Lock and Dam 2 is on the Minnesota 2014 draft impaired waters list for PFOS in fish tissue, corresponding to a PFOS concentration >200 ng g^{-1}.
	PBDEs	Total PBDEs in eaglet serum		Geometric means for total PBDEs in bald eagle nestling serum were 12.5-16.8 ng g^{-1} for MISS from 2006-2009, but a threshold value has not been established.
		Total PBDEs in fish tissue		No data were found.

Table 39. Natural Resource Condition Assessment summary table.

Priority Resource or Value	Indicator of Condition	Specific Measures	Condition Status/Trend	Rationale
Physical and Chemical Condition				
Air Quality	Overall	Weighted calculation		Overall, air quality at MISS is of significant concern, based on the individual scores for wet deposition, ozone, and visibility. Using the NPS weighted calculation method, its overall score is 7.7 for 2001-2010, with >6 being of significant concern (NPS 2013b).
	Ozone	Annual 4th highest daily maximum 8-hour ozone concentration		Five-year averages of annual 4th highest daily maximum 8-hour ozone concentrations for MISS range from 64.6 ppb for 2006-2010 to 70.8 ppb for 1999-2003. These are below the level of significant concern, 76 ppb.
	Visibility	Deciviews		Five-year averages for visibility were of moderate concern at MISS in 2001-2005, with a value of 7.4 deciviews. However, visibility has exceeded the significant concern level of 8 deciviews from 2003-2010, with values ranging from 8.2 in 2006-2010 to 9.04 in 2004-2008.
	Wet deposition of nitrogen	Kilograms N per hectare per year		Five-year averages for wet deposition of total N exceeded the level of significant concern of 3 kg ha^{-1} yr^{-1} at MISS, with values ranging from 5.1 kg ha^{-1} yr^{-1} from 2006-2010 to 5.58 kg ha^{-1} yr^{-1} from 2001-2005. Nitrogen deposition may cause acidification of both aquatic and terrestrial ecosystems and adds nutrients that can lead to eutrophication.
	Wet deposition of sulfur	Kilograms S per hectare per year		Five-year averages of wet deposition of total S ranged from 2.2 kg ha^{-1} yr^{-1} from 2006-2010 to 2.73 kg ha^{-1} yr^{-1} for 2003-2007, below the level of significant concern of 3 kg ha^{-1} yr^{-1}. Like nitrogen deposition, sulfur deposition may cause acidification of ecosystems.
Water Quality	Specific conductance	µmhos cm^{-1}		Annual (1975-2013 and 2006-2012) means for specific conductance ranged from 303-684 µmhos cm^{-1}, well below the 1,000 µmhos cm^{-1} maximum standard, but an increasing trend was detected from 1976-2013. Specific conductance is higher below the confluence of the Minnesota River.

Table 39. Natural Resource Condition Assessment summary table.

Priority Resource or Value	Indicator of Condition	Specific Measures	Condition Status/Trend	Rationale
Water Quality (continued)	pH	pH units		Prairie river sites met their reference condition of 6.5-9 pH units, based on annual means. Some gorge and large floodplain river sites had pH values very close to exceeding the reference condition; it is possible that these elevated values are the result of algae growth in the river. pH is increasing over time at some sites, but there is no clear spatial trend.
	Dissolved oxygen	mg L^{-1}		Annual (1975-2013 and 2006-2012) DO means ranged from 5.25-11.43 mg L^{-1}, exceeding the minimum standard of 5 mg L^{-1}, and an increasing trend was detected from 1975-2013. Spatially, mean DO values were highest at gorge sites and lowest at floodplain river sites from 2006-2012.
	Alkalinity	mg L^{-1} as calcium carbonate		All sites had annual (2006-2012) means for alkalinity that consistently exceeded the minimum standard of 20 mg L^{-1}, with ranges of 107-202 mg L^{-1}, indicating well-buffered waters. Data were insufficient to calculate a trend.
	Chloride	mg L^{-1}		Annual means for chloride were far below the maximum standard of 230 mg L^{-1}, with ranges of 9.4-37.3 mg L^{-1}. Data were insufficient to calculate a trend.
	Chloride in tributaries	mg L^{-1}		Some tributaries to the Mississippi River in MISS do not meet the chronic chloride standard, with mean chloride concentrations in streams that exceeded 230 mg L-1 ranging from 271-1,600 mg L^{-1}.
	Total phosphorus	µg L^{-1}		Annual means for TP generally met or nearly met their nutrient maximum criteria from 2006-2012 at prairie river and gorge river sites. In the large floodplain river, even though the draft eutrophication criterion is higher, few sites have met it since 1976 as a result of the influence of the Minnesota River. However, there has been a downward trend in TP concentration from 1990-2013.
	Total nitrogen	µg L^{-1}		Annual mean TN exceeded the USEPA reference condition at every site in almost every year that monitoring was conducted, indicating that MISS water quality for TN is not within the best 25% of sites in its nutrient ecoregion. Of four monitored sites one showed a downward trend, one showed an upward trend, and two showed no trend in TN concentration from 1976-2012. Spatial patterns are complex.

Table 39. Natural Resource Condition Assessment summary table.

Priority Resource or Value	Indicator of Condition	Specific Measures	Condition Status/Trend	Rationale
Water Quality (continued)	Nitrate nitrogen	µg L^{-1}		Annual mean nitrate + nitrite concentrations at times exceed 80% of the draft chronic standard for aquatic life at sites in the large floodplain river. However, the rate of increase in nitrate concentrations appears to be slowing, and conditions in the Minnesota River, the largest source in MISS, are improving.
	Chlorophyll *a*	µg L^{-1}		At least some annual chl-*a* means for 2001-2013 were above the draft nutrient or eutrophication maximum criterion at most sites. A downward trend not detected in 1976-2005 data was detected in 2001-2013 data at three of four monitored sites. Spatially, chl-*a* levels increase downstream when NPS and MCES sites are considered independently.
	Total Suspended Solids	mg L^{-1}		All MISS sites above the Minnesota River met the TSS standard, while those below often exceeded the standard. However, two of the sites below the Minnesota River had a downward trend for TSS from 1976-2005, and one continued this trend through to 2013.
	E. coli bacteria	colony-forming units/100 mL		Three reaches of the Mississippi River in MISS are considered impaired for aquatic recreation because of *E. coli*; data were insufficient to determine a trend.

Appendix A. GIS Layers, Datasets for Base Maps, and Summary/Analysis Files

All maps and associated geoprocessing were done with the ArcGIS 10.2 software by Environmental Systems Research Institute, Inc., Redlands, CA (2013). Map layouts and source data layers are generally in the NAD 1983 UTM Zone 15N coordinate system (NLCD and NPScape metric source layers, including forest density and morphology, population, and areas of analysis, are Albers Conical Equal Area). Spatial data obtained in other datums or coordinate systems were reprojected using ArcGIS.

All GIS datasets are contained in the MISS.gdb geodatabase along with associated metadata. The geodatabase, map document files, layer definition files, and png/pdf versions of the report figures were packaged on a DVD submitted with the report. Map documents use relative pathnames to data sources and therefore should open properly if kept in the same directory as the geodatabase.

References for specific map content are included in the map caption or are described in the report text that refers to the figure. All base map layers and metadata are included in the geodatabase but are generally not referenced in the report. These layers include:

Mississippi National River and Recreation Area (MISS) Park boundary:
National Park Service Midwest Field Area. 1996. MISS LANDS Boundary. Mississippi National River and Recreation Area, St. Paul, Minnesota (received November 5, 2012).

Elevation layers (and related hillshading created with ArcGIS):
U.S. Geological Survey. 2009. 1-Arc Second National Elevation Dataset. Available at http://nationalmap.gov/viewer.html. (accessed at http://seamless.usgs.gov June 4, 2012).

MDNR (Minnesota Department of Natural Resources). 2012. LiDAR elevation, Twin Cities metro region, Minnesota, 2011. MDNR, St. Paul, Minnesota. Available at http://www.mngeo.state.mn.us/chouse/elevation/lidar.html. (accessed October 24, 2012).

Highways:
Metropolitan Council. 2011. Major Highways. Available at http://www.datafinder.org/catalog/index.asp (accessed 10/17/2012).

Surface water features (NHDs) and watershed boundary datasets (WBDs):
U.S. Geological Survey. 2012. NHD…Flowline/NHD…Area/NHD…Waterbody/WBD_HUC... Available at http://nhd.usgs.gov/data.html (accessed June 4, 2012).

Counties and States basemap layers – created in ArcGIS from:
Environmental Systems Research Institute, Inc. (ESRI). 2002. Canada Provinces, U.S. Detailed County Boundaries. ESRI Data & Maps 2002 CD.

Minnesota Municipalities:
Minnesota Department of Transportation (MnDOT). 2002. Municipal Boundaries. Available at http://deli.dnr.state.mn.us/ (accessed 11/14/2012).

Minnesota Point Features:
Minnesota DNR – MIS Bureau. 2000. Geographic Names. Available at http://deli.dnr.state.mn.us/ (accessed 3/14/2013).

Various background/work layers were created in ArcGIS (see metadata for details), including air emission buffers, various areas of analysis (AOAs) for NPScape metrics, Mississippi River pool reaches, and park zones or reaches along with associated profiles.

The DVD also includes a subdirectory with these Excel spreadsheets that summarize various GIS analyses or provide source information.

Climate Data (MISS HUC 07010206 climate data.xlsx)

Heritage Data (MN_Nat_Heritage_data_within_MISS2.xlsx)

Population (MN_population_projections.xlsx)

Land Type Associations (Land_Type_Associations.xlsx)

NLCD Land Cover (Land_Cover_NLCD.xlsx)

Land Cover Change (Land_Cover_1890_2000.xlsx)

MLCCS Land Cover Summary (Land_Cover_MLCCS_MISS_Summary.xlsx)

Forest Metrics (Forest_Pattern_Metrics_NLCD2006_Dec2013.xlsx)

Exotic Plant Management Team (GLEPMT_cm.xlsx)

Mercury Emissions (Air_Mercury_250km.xlsx)

Air Monitoring Sites (Air_Monitoring_Sites.xlsx)

US Air Point Emissions within 250 km (Air_Point_Facilities_250km.xlsx)

Air Point Emissions Summary (Air_Point_Source_Summary.xlsx)

Water Quality Data
- Water_Quality_Prairie_River.xlsx
- Water_Quality_Trends_Prairie_River.xlsx
- Water_Quality_Gorge_River.xlsx
- Water_Quality_Trends_Gorge_River.xlsx
- Water_Quality_Floodplain_River.xlsx
- Water_Quality_Trends_Floodplain_River.xlsx
- Water_Quality_Spatial_Trends.xlsx
- Water_Quality_Total_Nitrogen.xlsx

NPS 607/129012, July 2015

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov