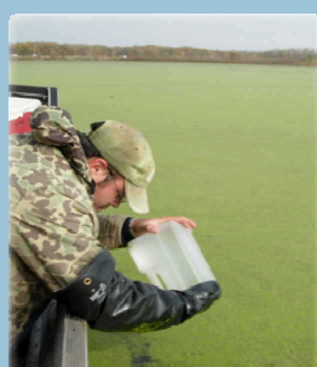
Upper Mississippi River Nutrient Monitoring, Occurrence and Local Impacts

A Clean Water Act Perspective

Upper Mississippi River Basin Association

September 2011



This project was led by the Upper Mississippi River Basin Association's Water Quality Task Force. Illinois, Iowa, Minnesota, Missouri, and Wisconsin jointly funded the project through Section 604(b) of the Clean Water Act, using appropriations from the American Recovery and Reinvestment Act of 2009.

Illinois Environmental Protection Agency

Minnesota Pollution Control Agency

Missouri Department of Natural Resources

Wisconsin Dept. of Natural Resources

Upper Mississippi River Nutrient Monitoring, Occurrence, and Local Impacts: A Clean Water Act Perspective

September 2011

Upper Mississippi River Basin Association
415 Hamm Building, 408 St. Peter Street
St. Paul, Minnesota 55102
651-224-2880
www.umrba.org

This project was led by the Upper Mississippi River Basin Association's Water Quality Task Force. Illinois, Iowa, Minnesota, Missouri, and Wisconsin jointly funded the project through Section 604(b) of the Clean Water Act, using appropriations from the American Recovery and Reinvestment Act of 2009.

Cover Page Photo Credits

Left: U.S. Army Corps of Engineers, St. Louis District

Middle and Right: Wisconsin Department of Natural Resources

Table of Contents

List of Tables, Figures, and Photographs

Tables

Figures

Photographs

Definitions and Acronyms Used in this Report

Definitions

Cyanobacteria	Also known as blue-green algae. Photosynthetic aquatic bacteria, some strains of which may produce chemicals that are toxic to humans, domestic or wild animals, and aquatic life.
Eutrophication	A condition of nutrient enrichment in surface water, characterized by algae growth and low oxygen levels (hypoxia). Eutrophication is measured along a spectrum of trophic states, from oligotrophic (lowest nutrient concentrations), to mesotrophic, to eutrophic, to hypereutrophic (highest concentrations).
Hypoxia	A condition of low dissolved oxygen within a waterbody that is detrimental to aquatic life.
Macrophyte	A multicellular aquatic plant that may be emergent, submersed, or floating.
Mainstem	The interstate Upper Mississippi River, including the main channel, side channels, backwaters, and other aquatic strata. "Mainstem" differentiates the UMR proper from the river basin as a whole, and is distinct from the term "main channel", which refers to just the central flowing water stratum in the mainstem.
Metaphyton	Floating/surficial algal growth, including duckweed and filamentous algae.
Periphyton	Submerged, attached algal growth.
Sestonic Algae	Single-cell, free floating algae. Includes both green algae and blue-green algae (cyanobacteria).
Strata	Distinct aquatic areas on the UMR.

Acronyms

AWQMN	(Illinois) Ambient Water Quality Monitoring Network
CEAP	(USDA) Conservation Effects Assessment Project
Chl-a	Chlorophyll-a
CWA	Clean Water Act
DBPs	Disinfection Byproducts
DNR	Department of Natural Resources
DO	Dissolved Oxygen
ELS	Early Life Stages
EMAP	(US EPA) Environmental Monitoring and Assessment Program
EMP	(USACE) Environmental Management Program
HUC	Hydrologic Unit Code
IL EPA	Illinois Environmental Protection Agency
IA DNR	Iowa Department of Natural Resources
IWL	Izaak Walton League
LTRMP	(USACE EMP) Long Term Resource Monitoring Program
MARB	Mississippi-Atchafalaya River Basin

MCES	(Twin Cities) Metropolitan Council Environmental Services
MCL	Maximum Contaminant Level
MN DNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
MO DNR	Missouri Department of Natural Resources
MO DoC	Missouri Department of Conservation
N	Nitrogen
NASQAN	(USGS) National Stream Quality Accounting Network
NAWQA	(USGS) National Water Quality Assessment Program
NRSA	National Rivers and Streams Assessment
NWIS	(USGS) National Water Information System
P	Phosphorus
SAV	Submersed Aquatic Vegetation
SDWA	Safe Drinking Water Act
SPARROW	SPAtially Referenced Regressions On Watershed attributes model
SRP	Soluble Reactive Phosphorus
SRS	Stratified Random Sample(ing)
STORET	(US EPA) STOrage and RETrieval Data Warehouse
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
VSS	Volatile Suspended Solids
THMs	Trihalomethanes
TMDL	Total Maximum Daily Load
UMR	Upper Mississippi River
UMRBA	Upper Mississippi River Basin Association
UMRCC	Upper Mississippi River Conservation Committee
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
US EPA	United States Environmental Protection Agency
WI DNR	Wisconsin Department of Natural Resources
WQEC	(UMRBA) Water Quality Executive Committee
WQTF	(UMRBA) Water Quality Task Force
WTP	(Drinking) Water Treatment Plant

Executive Summary

Background

Phosphorus and nitrogen, collectively referred to as nutrients, have been an increasingly important water quality issue in the Upper Mississippi River (UMR) Basin. While nutrients are necessary for aquatic life, at concentrations significantly above natural background they can pose a threat to the use of waterbodies by humans and aquatic life, and are often cited as a water quality concern for the UMR (EPA 2008; Johnson & Hagerty, 2008; NRC, 2010; Sullivan et. al., 2002). This concern is most often expressed in terms of nutrients' impact on hypoxia in the Gulf of Mexico which, while a critical national environmental issue, is less central to informing and motivating actions on a state and regional scale than more local water quality impacts, such as algae blooms, fish kills, and effects on drinking water supplies. The states of Illinois, Iowa, Minnesota, Missouri, and Wisconsin, as stewards of the UMR and administrators of the Clean Water Act (CWA), require an understanding of UMR nutrient dynamics and issues, informed by research and monitoring, to best address and resolve nutrient-related water quality problems on the River.

Two Upper Mississippi River Basin Association (UMRBA) work groups, the Water Quality Task Force (WQTF) and the Water Quality Executive Committee (WQEC), work to coordinate CWA programs among the UMR states and US EPA Regions. This nutrient-focused report is part of a project supported by the these work groups to aid the implementation of CWA programs on the UMR, both to achieve greater interstate consistency and to enhance water quality protection.

While this report is a product of the UMRBA, and its WQTF in particular, it has been informed by the input of a diverse project work group, which participated in two work sessions and offered numerous comments and suggestions throughout the project. See *Appendix A: Project Participants* for a list of the work group members. The contributions of these individuals are greatly appreciated.

Report Purpose and Structure

A number of efforts are ongoing to assess the impacts of nutrient loading in the Mississippi River Basin on hypoxia in the Gulf of Mexico. While these efforts can help to elucidate sources and fates of nutrients, they do less to shed light on the effects of nutrients as they pass through and influence local river reaches. State and federal agencies are also working to collect data and analyze the effects of nutrients at much more localized levels, such as the backwaters of individual river reaches. However, there is a need to bring together UMR-specific data and research in a CWA context to better understand localized effects on the River's mainstem (which includes main and side channels, impounded areas, and backwaters), and to apply this understanding to nutrient reduction efforts. Therefore, this report does the following:

1. Describes current CWA approaches to nutrients on the UMR (Chapter 1).
2. Compiles and synthesizes UMR mainstem and tributary information regarding historical and existing nutrient and nutrient-related monitoring (Chapter 2).
3. Discusses trends in nutrient concentrations in the UMR mainstem and tributaries over time (Chapter 3).
4. Compiles and synthesizes reported impacts to aquatic life, recreation, drinking water, and other CWA designated uses on the UMR mainstem (Chapter 4).
5. Identifies areas of emerging interest that, while beyond the scope of this report, merit further investigation (Chapter 5).
6. Makes recommendations related to nutrient monitoring, research, and CWA implementation (Chapter 6).

In summary, by bringing together current research, monitoring data, and reported nutrient impacts on the UMR, this report seeks to aid the states in identifying and prioritizing future directions for monitoring, assessing, and addressing nutrients in the UMR.

Findings and Recommendations

The findings and recommendations in this report are both extensive and ambitious in their scope. As such, the intent of the recommendations is not that each and every one will be implemented, but rather that they provide a set of options that the states, individually or collectively, may choose to pursue. Further, while these recommendations are primarily addressed to the states, many of them will also require collaboration and participation from other agencies – most prominently from US EPA. The UMRBA Water Quality Executive Committee and Water Quality Task Force provide ongoing venues for the states and their partners to discuss, prioritize, and plan for action on these recommendations.

Regarding Monitoring and Data Collection

Findings:

- Extensive monitoring relevant to CWA assessment, including nutrient monitoring, is being conducted on the UMR mainstem and in the UMR basin at federal, state, and local levels.
- Some important differences exist between UMR mainstem monitoring programs, including program designs, parameters sampled, and data reporting and management.
- There are significant spatial gaps in nutrient monitoring on the mainstem UMR.
- There are no standardized, commonly accepted approaches to the measurement of nutrient impacts, including algae blooms and fish kills, on the UMR.

Recommendations:

- Pursue more consistent and comprehensive monitoring protocols among water quality programs, including:
  - identifying a standard, minimum set of nutrient-related parameters to monitor;
  - establishing a minimum sampling frequency for fixed sites;
  - expanding the lateral and longitudinal monitoring of the UMR mainstem to address its full spatial extent (but not at the expense of basinwide nutrient monitoring); and
  - considering how to integrate U.S. Army Corps of Engineers (USACE) Environmental Management Program (EMP) Long Term Resource Monitoring Program (LTRMP) stratified random sampling (SRS) data with existing or proposed monitoring schemes.
- Integrate continuous monitoring for nutrient-related variables into monitoring programs.
- Develop a UMR-wide, CWA-focused monitoring strategy, as this will address many of the needs listed above.
- Harmonize data reporting and sharing; at minimum by documenting data standards and retrieval protocols. Improvements to the US EPA Storage and Retrieval (STORET) data system to facilitate data retrieval on larger spatial scales would also be beneficial.
- Consider establishing a tributary load monitoring network.
- Identify mutually-accepted methods of tracking and reporting algal blooms and fish kills. This may include:
  - expanded chlorophyll-a monitoring to estimate sestonic algae blooms;

- expanded implementation of metaphyton quantification efforts, as initiated by LTRMP and Wisconsin Department of Natural Resources (DNR); and
- more uniform mechanisms for reporting and tracking fish kills, including a water quality sampling protocol to follow when a kill is reported.

Regarding UMR Nutrient Sources, Concentrations, and Trends

Findings:

- UMR nutrient concentrations have increased significantly from pre-settlement levels, but levels have stabilized in many locations over the past twenty years, while rates of increase have slowed at other locations.
- Current concentrations of total nitrogen (TN) and total phosphorus (TP) on the UMR are frequently above existing guidelines and criteria (where applicable) to limit excessive nutrient enrichment.
- Nutrient concentrations vary by location on the UMR.
- Research and modeling indicate that agricultural land use is the primary determinant of nutrient loading in the UMR, followed in importance by the presence of urban areas.
- Agricultural conservation practices have successfully reduced loading in many areas, but important challenges remain, including the loss of nitrogen to surface waters through subsurface flow.

Recommendations:

- Additional research on nutrient levels over time, starting with pre-settlement levels, similar to the core sampling done for Lake Pepin, should be pursued on a broader scale. This is particularly true for phosphorus, as less historical data is available for phosphorus as compared to nitrogen.
- As UMR TN and TP concentrations frequently exceed existing guidelines and criteria related to eutrophication, continued investigation into the occurrence of eutrophication and its impacts on the UMR is warranted.
- As agricultural land use is a dominant factor in UMR basin nutrient loading, successful approaches to preventing nutrient losses to water will need to address agricultural nonpoint source pollution, while also addressing point source contributions. Ideally, each source will be addressed in proportion to its contribution.
- Ongoing collaboration among local, states, federal, private, and other partners is essential in expanding agricultural conservation practices in the basin and in improving their efficiency.

Regarding Impacts to CWA Designated Uses

Findings:

- Both nitrogen and phosphorus appear to contribute to local nutrient impacts on the UMR mainstem.
- Elevated nutrient concentrations do not necessarily lead to eutrophic or hypereutrophic conditions that constitute an impairment of the aquatic life or recreation uses. Rather, nutrient concentrations over certain locally determined thresholds are prerequisites for eutrophication-related aquatic life and/or recreation use impairments but other factors (e.g., water velocity and light penetration) also determine whether, when, and where impacts occur.
- Metaphyton (filamentous algae and duckweed) blooms are likely a regular occurrence in backwaters of the UMR.
- Sestonic (floating) algae blooms appear to be commonplace on the UMR.

- Too few data exist to accurately estimate the extent of cyanobacteria blooms on the UMR.
- There is evidence that the UMR fish community and other aquatic communities are being affected by eutrophication caused by nutrient loading. However, the extent, mechanism, and frequency of impacts are not fully known.
- Using current criteria as a guide, direct toxicity to aquatic organisms from ammonia and to humans from nitrate does not appear to be an issue for the UMR, but some concerns remain and new criteria could affect this characterization.

Recommendations:

- Formalize a metaphyton sampling and quantification protocol, presumably using LTRMP and Wisconsin DNR's methods, and expand existing programs to utilize the new protocol.
- Develop definition(s) of nuisance sestonic algae applicable to the entire UMR.
- Begin recording and reporting N:P ratios, along with chl-a concentrations, as part of UMR monitoring. As cyanobacteria thrive at low N:P ratios, this additional reporting would improve the accuracy of cyanobacteria bloom estimates.
- Conduct additional paired fish/water chemistry monitoring and research to clarify the extent and nature of nutrient impacts on fish. Also, remain attentive to Minnesota's review of aquatic life nitrate toxicity.
- Work with UMR water suppliers to explore issues related to algae growth and total organic carbon (TOC), assemble relevant TOC data, and consider additional and/or expanded monitoring as needed.

Regarding CWA Implementation

Findings:

- Nutrients affect designated uses in a number of locations on the UMR, subject to certain conditions. However, there is currently just one nutrient-related CWA 303(d) impairment listing for the UMR, at Lake Pepin.
- All of the UMR states are working to further address nutrients in their CWA programs, but are taking differing approaches and may be at different points in this process, particularly in regard to numeric nutrient criteria.
- The nutrient parameters monitored in NPDES-permitted point source discharges vary among states.
- Nitrate criteria for drinking water uses are currently consistent between states. At least one state is considering aquatic life criteria for nitrates.
- Ammonia criteria are generally consistent between states, though early life stage (ELS) schedules for aquatic organisms differ.
- It is not clear that the states' current approaches to protecting the drinking water use on the UMR are congruent with UMR water suppliers' needs and goals.

Recommendations:

- The states and US EPA should consider the following in the development of any numeric nutrient criteria applicable to the UMR:
    - Phosphorus and nitrogen may both require target values, potentially varying by river strata, as evidence indicates that TP and TN affect distinct algae and aquatic life communities to differing degrees and differentially among strata.

- While phosphorus and nitrogen are the drivers of eutrophication, concentrations of TP and TN alone cannot always predict its occurrence. Because eutrophication on the UMR is dependent on several factors (e.g., water velocity, light penetration) beyond nutrient concentrations alone, there can be cases where TP and TN are above target values, but eutrophication does not occur. States may wish to consider response variables (e.g., biological parameters, dissolved oxygen, chlorophyll-a, biological oxygen demand) in conjunction with causal variables (TP and TN) in assessing waters. To be successful, such an approach would require, among other things, significant dependency between causal and response variables and protection of downstream uses.
- Numeric nutrient criteria are most likely to be effective as a component of a comprehensive approach to nutrient reduction, including not only CWA tools focused on monitoring, assessment, and impairment listing, but also other CWA approaches (such as permit limits and technology controls for point sources), and non-CWA tools including nonpoint source reduction techniques.
- Interstate considerations are critical. The states may not necessarily employ identical approaches; however, they should work collaboratively and seek congruence in their development of nutrient criteria for the UMR.

▪ Pursue consistent NPDES discharge monitoring requirements for both nitrogen and phosphorus.

▪ Agree upon schedules of ELS presence for all 13 of the UMR assessment reaches.

▪ Pursue further dialog with water suppliers to explore the relationship between CWA programs and water suppliers' needs.

Chapter 1:
The Clean Water Act and UMR Nutrients

Regulatory Structure

Setting Standards

A central tool for Upper Mississippi River (UMR) water quality managers is the Clean Water Act (CWA), a national framework designed to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." This goal is advanced by the states in the following way:

1. The state adopts a set of potential "designated uses" for waterbodies.
2. Waterbodies within the state are then assigned one or more of the designated uses. The Mississippi River, for example, is designated for aquatic life and recreation use in all five UMR states. Each state has additional use designations that apply to the UMR.
3. Water quality criteria, narrative and/or numeric, are promulgated by the state to help assess support of the designated uses.

Figure 1-1: The Upper Mississippi River Mainstem, Tributaries, and Basin

Each state is free – with US EPA approval – to create its own framework of designated uses, and assign them to the waters within its jurisdiction. Generally, states will designate all waters for aquatic life and recreation uses unless those uses are proven unattainable. This approach derives from the interim goal stated in CWA §101(a)(2) of "water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water." This interim goal remains in place until the national goal included in CWA §101(a)(1) that "the discharge of pollutants into the navigable waters be eliminated" is achieved. In addition, CWA §303(c)(2)(A) says that water quality standards "…shall be such as to protect the public health or welfare, enhance the quality of water and serve the purposes of this Act" and that other uses including public water supply and navigation need to be considered in setting standards. As a result, the states will often assign several uses to a waterbody in addition to aquatic life and water contact recreation.

In order to give force and effect to these use designations, states must promulgate water quality criteria to protect designated uses. These criteria may be narrative or numeric, but they must be sufficiently stringent that, as long as they are met, the designated uses are fully supported.

Pollutant Monitoring and Reporting

The CWA distinguishes between point and non-point sources of pollutants. For nutrients, point sources can be broadly described as anything with a concentrated flow to a surface water, which generally includes wastewater treatment plants, concentrated animal feeding operations (CAFOs), and municipal storm sewer systems. Non-point sources include all other sources of pollution. Anything driven by precipitation, except municipal stormwater systems, generally fits in this category. Erosion of disturbed land and flow off of manured or fertilized agricultural fields are two primary examples of anthropogenic non-point sources of nutrients; natural phosphorus (P) and nitrogen (N) leaching from terrestrial soils and plants is a non-anthropogenic non-point source.

Whatever the source of the pollutant, states must evaluate and report on the attainment of designated uses by all waterbodies within their boundaries. Every two years each state creates a 305(b) assessment of waters and 303(d) impaired waters list, named for their respective sections in the CWA. These documents, typically compiled into a single “integrated report” for a state, summarize the condition of all waters in the state (305(b) report) and prioritize all of the use impairments in the state (303(d) report). Waters that do not fully meet applicable water quality criteria because of a pollutant are targeted for the development of a Total Maximum Daily Load (TMDL), which establishes how much loading of a particular pollutant a given waterbody can receive and still support its designated use, and often allocates that load between point and non-point sources.

In addition to limits set by TMDLs, point sources are required to obtain permits under the National Pollutant Discharge Elimination System (NPDES), which is also administered by the states in the UMR basin. These permits limit the amount of a pollutant that the source may discharge, and require monitoring of a variety of pollutants.

CWA Implementation on the UMR

Water Quality Standards

Designated Uses

Each UMR state has its own water quality standards that define its set of CWA designated uses. While the language is not identical between the states, they all, at minimum, define broadly similar categories of recreation, aquatic life, and drinking water use. Table 1-1 shows how these uses are applied to the UMR. Although nutrient concentrations over natural background levels can potentially affect many of the UMR's beneficial uses, their impact on these three main uses is of the greatest significance to states. Therefore, Chapter 4’s discussion of impacts to CWA designated uses focuses on these three major designated uses.

Table 1-1: Comparison of Major Designated Uses for the Upper Mississippi River[1]

		Aquatic Life	Contact Recreation[2]	Drinking Water
Illinois	Entire UMR	X	X	X
Iowa[3]	Minnesota Border - Lock and Dam 14	X	X	
	Lock & Dam 14 - Lock & Dam 15	X	X	X
	Lock & Dam 15 - Iowa River	X	X	
	Iowa River - Burlington water intake	X	X	X
	Burlington water intake - Skunk River	X	X	
	Skunk River - Missouri Border	X	X	X
Minnesota	Entire UMR	X	X	
Missouri	Entire UMR	X	X	X
Wisconsin	Entire UMR	X	X	

[1] The designated use descriptions are generalized and thus vary somewhat from the specific language used by states to define uses.

[2] Finalization of the primary contact use in the St. Louis area (28 miles in Missouri) is pending. This use is also not applied in the Sauget, Illinois area due a state approved disinfection exemption.

[3] Iowa assigns its drinking water use only to points of drinking water intake.

Narrative Criteria

The states have adopted narrative criteria that typically apply to all waterbodies statewide (including the UMR) regardless of specific designated uses. Those portions of state narrative criteria most relevant to nutrients are listed in Table 1-2.

Table 1-2: Narrative Water Quality Criteria Related to Nutrients

State	Narrative Criteria	Reference
Illinois	Shall be free from sludge or bottom deposits, floating debris, visible oil, odor, plant or algal growth, color or turbidity of other than natural origin.	Illinois Administrative Code Title 35, Subtitle C, Chapter 1, Part 302.203
Iowa	Shall be free from wastewater/agricultural materials that produce sludge, nuisance conditions, undesirable aesthetic conditions, or undesirable aquatic life.	Iowa Administrative Code Chapter 61, 567-61.3(2)
Minnesota	The aquatic habitat shall not be degraded in any material manner; there shall be no material increase in undesirable slime growths or aquatic plants, including algae; the normal fishery and lower aquatic biota upon which it is dependent and the use thereof shall not be seriously impaired or endangered, the species composition shall not be altered materially, and the propagation or migration of the fish and other biota normally present shall not be prevented or hindered by the discharge of any wastes to the waters.	Minnesota Rule 7050.0150, subpart 3
Missouri	Shall be free from: floating debris; substances that cause undesirable bottom deposits, color, turbidity, or odor, or prevent full maintenance of beneficial uses; and physical, chemical, or hydrologic changes that would impair the natural biological community.	Missouri Code of State Regulations 10 CSR 20-7.031 (3)
Wisconsin	Substances shall not be present that will cause objectionable deposits, color, taste, odor, or unsightliness that interferes with public rights, or are acutely harmful to wild flora & fauna.	Wisconsin Administrative Code NR 102.04

Numeric Criteria

The states also have adopted numeric criteria specific to designated uses. Those numeric criteria related to nutrients are shown in Table 1-3. Of the criteria listed, those for ammonia, dissolved oxygen (DO), and phosphorus are tied to the aquatic life use. The nitrate criterion (identical for all states where it is applied) is a human health-derived standard to protect the drinking water use. The only eutrophication-related criterion currently in place applicable to direct measurements of nutrients in flowing waters is the 100 µg/L concentration for total phosphorus recently adopted by Wisconsin. However, the states' DO criteria are also relevant to eutrophication. Aquatic life criteria for ammonia are focused on toxicity and are not intended to address nutrient enrichment. Because UMR states, for the most part, have not yet developed numeric benchmarks that are specific to eutrophication caused by nutrients, water quality impairments related to eutrophication in the UMR states are most typically interpreted as violations of the states' narrative, rather than numeric, criteria.

Additionally, aside from general references within narrative criteria (Table 1-2), there are no numeric biological criteria in the states' rules or statutes applicable to the UMR. However, biotic condition may still be used to interpret attainment of narrative standards – as in the case of impacts to submersed aquatic vegetation in Lake Pepin associated with elevated turbidity/suspended sediment (John Sullivan, WI DNR, personal communication 01/06/2011).

Finally, it is worth noting that at present the states do not differentiate in the application of water quality standards across strata (i.e., lateral zones, such as the main channel and backwaters) and reaches of the UMR. For example, backwaters are subject to assessment by the same criteria as the main channel throughout the UMR's length in a single state. The UMRBA WQTF is presently working to develop an approach whereby assessment of aquatic life is divided into both lateral and longitudinal strata, allowing for different criteria between areas of the river that are hydraulically, geographically, ecologically, and morphologically distinct. However, the discussion in this report is based upon the current system of assessing the entire length and breadth of the UMR within a state using the same set of criteria.

Table 1-3: Nutrient and Nutrient-Related Numeric Criteria Applied to the UMR

		Illinois			Iowa			Minnesota	Missouri			Wisconsin
Pollutant	**Unit**	**General Use**	**Public & Food Processing Water Supply**	**Secondary Contact and Indigenous Aquatic Life Standards**	**Class A1: Primary Contact Recreation**	**Class B(WW1) Warm Water Aquatic Life**	**Class C: Drinking Water**	**Class 2B: Aquatic Life & Recreation (Cool and warm water fisheries)**	**Aquatic Life**	**Drinking Water Supply**	**VI: Whole-Body Contact Recreation**	**Aquatic Life: Warm Water Fisheries**
Ammonia Nitrogen	mg/L	Acute and chronic criteria vary with temperature, pH and season	--	--	--	Acute and chronic criteria vary with temperature, pH and season	--	--	Acute and chronic criteria vary with temperature, pH, season, presence of salmonids (acute), and fish life stage (chronic)	--	--	Acute and chronic criteria vary with temperature, pH and season
Ammonia Un-ionized	mg/L			0.1 (varies with temperature and pH)	--	--	--	0.04 chronic	--	--	--	--
Dissolved Oxygen	mg/L	5.0 to 3.5 minimum dependent on season and category	--	4.0 minimum	--	5.0 minimum	--	5.0 daily minimum	5.0 minimum	--	--	5.0 minimum
Nitrate-N	mg/L	--	10	--	--	--	10	--	--	10	--	--
(Total) Nitrogen	mg/L	--	--	--	--	--	--	--	--	--	--	--
(Total) Phosphorus	mg/L	--		--	--	--	--	--	--	--	--	0.1
pH	Standard Units	6.5-9.0	--	6.0-9.0	6.5-9.0	6.5-9.0	6.5-9.0	6.5-9.0	6.5-9.0			6.0-9.0
Regulation		*Illinois Pollution Control Board, Title 35, Part 302*			*Iowa Administrative Code 567, Chapter 61*			*Minnesota Administrative Rules, Chapter 7050*	*Missouri Code of State Regulations, Title 10, Division 20, Chapter 7*			*Wisconsin Administrative Rules, DNR, NR 102*

Assessments and Impairment Listing

In its implementation of the CWA, each state compares available data to its water quality criteria to assess attainment of designated uses. In addition to data from their own monitoring efforts, UMR state CWA programs rely on data from a number of other monitoring programs, including other states' CWA programs, state fish tissue monitoring programs, fixed site data from the five UMR state-based field stations of the U.S. Army Corps of Engineers' (USACE) Environmental Management Program (EMP) Long Term Resource Monitoring Program (LTRMP), and the United States Geological Survey's (USGS) National Stream Quality Accounting Network (NASQAN).

One significant point of consistency among the states is their use of a common set of minimum assessment reaches for the UMR (see Figure 1-1). While this does not prevent inconsistencies in assessment and determinations of impairment between states, it at minimum allows for easier comparison between the states' listings.

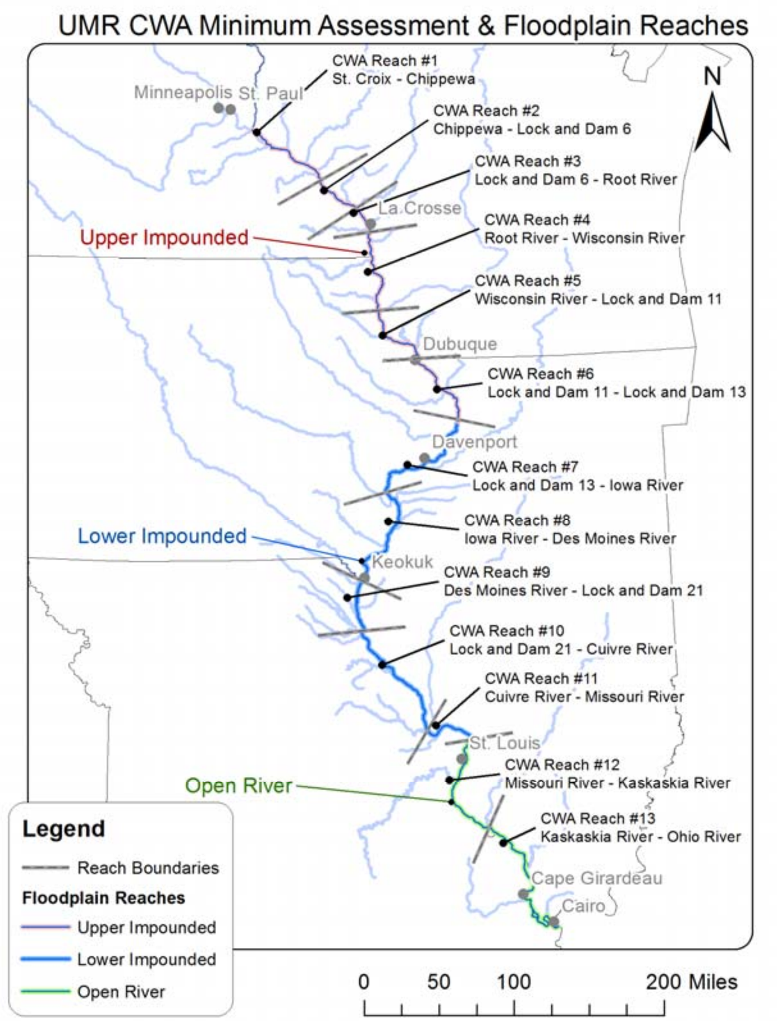


Figure 1-2: Thirteen interstate CWA assessment reaches. Also shown are the UMRs three floodplain reaches.

Table 1-4 shows 2008 and 2010 UMR impairment listings, organized by the 13 assessment reaches. This demonstrates that there are very few current UMR impairments related to nutrients. In fact, the only nutrient-related impairment listed or proposed for the 2008 and 2010 cycles was for a recreation use impairment on Lake Pepin in Minnesota[1].

The relative dearth of CWA impairment listings related to nutrients, as compared to the frequency with which nutrients are referred to as a UMR water quality issue, could be explained by: 1) limited actual effects of nutrients on the UMR mainstem, 2) insufficient nutrient and nutrient-related data to detect impacts, 3) limited understanding of the connection between nutrient concentrations and impacts to designated uses, 4) a lack of nutrient-specific water quality criteria, or 5) a combination of these factors. In its later chapters, this report will examine some of these factors in greater detail.

---

[1] There is also a localized impairment listed in Iowa, which is currently being addressed via a US EPA prepared and approved site-specific TMDL. This impairment is a "slime" or biological growth that originated from water tanks at an industrial operation, and is therefore is not the broad type of nutrient enrichment of surface waters that is the focus of this report.

Table 1-4: UMR Impairment Listings for 2008 and 2010

MINNESOTA[1]			WISCONSIN[2]	
2008	**2010**	**St. Croix River**	**2010**	**2008**
PCBs (Fish Tissue)[FC] PFOS (Fish Tissue)[FC] Turbidity[AL] Nutrients (L. Pepin)[AR] *TMDLs approved:* Mercury (Fish Tissue)[FC] Mercury (Water)[FC]	PCBs (Fish Tissue)[FC] PFOS (Fish Tissue)[FC] Turbidity[AL] Nutrients (L. Pepin)[AR] *TMDLs approved:* Mercury (Fish Tissue)[FC] Mercury (Water)[FC]	Reach 1 (48 mi)	PCBs (Fish Tissue)[FC] Mercury (Water)[FC] Suspended Solids[AL] PFOS (Fish Tissue)[FC]	PCBs (Water)[FC] PCBs (Fish Tissue)[FC] Mercury (Water)[FC] Mercury (Fish Tissue)[FC] Suspended Solids[AL] PFOS (Fish Tissue)[FC]
		Chippewa River		
PCBs (Fish Tissue)[FC] *TMDLs approved*: Mercury (Fish Tissue)[FC]	PCBs (Fish Tissue)[FC] *TMDLs approved*: Mercury (Fish Tissue)[FC]	Reach 2 (49 mi)	PCBs (Fish Tissue)[FC] Mercury (Water)[FC] PFOS (Fish Tissue)[FC]	PCBs (Water)[FC] PCBs (Fish Tissue)[FC] Mercury (Water)[FC] Mercury (Fish Tissue)[FC]
		Lock & Dam 6		
PCBs (Fish Tissue)[FC] *TMDLs approved*: Mercury (Fish Tissue)[FC]	PCBs (Fish Tissue)[FC] *TMDLs approved*: Mercury (Fish Tissue)[FC]	Reach 3 (21 mi)	PCBs (Fish Tissue)[FC] Mercury (Water)[FC]	PCBs (Water)[FC] PCBs (Fish Tissue)[FC] Mercury (Water)[FC] Mercury (Fish Tissue)[FC]
		Root River		
PCBs (Fish Tissue)[FC] *TMDLs approved*: Mercury (Fish Tissue)[FC]	PCBs (Fish Tissue)[FC] *TMDLs approved*: Mercury (Fish Tissue)[FC]	Reach 4 (63 mi)	PCBs (Fish Tissue)[FC] Mercury (Water)[FC] - Pool 8 and Pool 10 Mercury (Fish Tissue)[FC] - Pool 9	PCBs (Water)[FC] PCBs (Fish Tissue)[FC] Mercury (Water)[FC] Mercury (Fish Tissue)[FC]
IOWA[3]				
No listing	No listing			
		Wisconsin River		
No listing	Aluminum[AL]	Reach 5 (48 mi)	PCBs (Fish Tissue)[FC] Mercury (Water)[FC]	PCBs (Water)[FC] PCBs (Fish Tissue)[FC] Mercury (Water)[FC] Mercury (Fish Tissue)[FC]
		Lock & Dam 11		
Mercury[FC] (Pool 12)	Mercury[FC] (Pool 12)	Reach 6 (61 mi)	PCBs (Fish Tissue)[FC] Mercury (Water)[FC]	PCBs (Water)[FC] PCBs (Fish Tissue)[FC] Mercury (Water)[FC] Mercury (Fish Tissue)[FC]
			ILLINOIS[4]	
			PCBs (Fish Tissue)[FC] Mercury (Fish Tissue)[FC]	PCBs (Fish Tissue)[FC] Mercury (Fish Tissue)[FC]
		Lock & Dam 13		

<table>
<tr><th>2008</th><th>2010</th><th>Lock & Dam 13</th><th>2010</th><th>2008</th></tr>
<tr><td>Arsenic[DW]
Nutrients (localized)[AL]
Aluminum[AL]</td><td>Arsenic[DW]
Aluminum[AL]
Cadmium[AL]
TMDLs approved:
Nutrients (localized)[AL]</td><td>Reach 7
(89 mi)
Iowa River</td><td>PCBs (Fish Tissue)[FC]
Mercury (Fish Tissue)[FC]
Manganese[DW]</td><td>PCBs (Fish Tissue)[FC]
Mercury (Fish Tissue)[FC]
Manganese[DW]</td></tr>
<tr><td>Arsenic[DW]
Indicator Bacteria[AR]
Aluminum[AL]</td><td>Arsenic[DW]
Bacteria[AR]
Aluminum[AL]
Cadmium[AL]</td><td rowspan="2">Reach 8
(73 mi)
Des Moines River</td><td rowspan="2">PCBs (Fish Tissue)[FC]
Mercury (Fish Tissue)[FC]
Manganese[DW]
Fecal coliform[AR]
Total Dissolved Solids[DW]</td><td rowspan="2">PCBs (Fish Tissue)[FC]
Mercury (Fish Tissue)[FC]
Manganese[DW]
Fecal coliform[AR]</td></tr>
<tr><td colspan="2">MISSOURI[5]</td></tr>
<tr><td rowspan="3">No listing
TMDLs approved:
PCBs[FC]
Chlordane[FC]</td><td rowspan="3">No listing
TMDLs approved:
PCBs[FC]
Chlordane[FC]</td><td>Reach 9
(37 mi)
Lock & Dam 21</td><td>PCBs (Fish Tissue)[FC]
Mercury (Fish Tissue)[FC]
Manganese[DW]</td><td>PCBs (Fish Tissue)[FC]
Mercury (Fish Tissue)[FC]
Manganese[DW]</td></tr>
<tr><td>Reach 10
(88 mi)
Cuivre River</td><td>PCBs (Fish Tissue)[FC]
Mercury (Fish Tissue)[FC]</td><td>PCBs (Fish Tissue)[FC]
Mercury (Fish Tissue)[FC]</td></tr>
<tr><td>Reach 11
(41 mi)
Missouri River</td><td>PCBs (Fish Tissue)[FC]
Mercury (Fish Tissue)[FC]
Manganese[DW]
Fecal coliform[AR]</td><td>PCBs (Fish Tissue)[FC]
Mercury (Fish Tissue)[FC]
Manganese[DW]
Fecal coliform[AR]</td></tr>
</table>

2008	2010		2010	2008
Lead (localized)[AL] Zinc (localized)[AL] *TMDLs approved:* PCBs[FC] Chlordane[FC]	No listing *TMDLs approved:* PCBs[FC] Chlordane[FC] Lead (localized)[AL] Zinc (localized)[AL]	**Missouri River** Reach 12 (78 mi) **Kaskaskia River**	PCBs (Fish Tissue)[FC] Mercury (Fish Tissue)[FC] Manganese[DW] Fecal coliform[AR]	PCBs (Fish Tissue)[FC] Mercury (Fish Tissue)[FC] Manganese[DW] Fecal coliform[AR]
		Reach 13 (118 mi) **Ohio River**	PCBs (Fish Tissue)[FC] Mercury (Fish Tissue)[FC] Manganese[DW] Fecal coliform[AR] Iron[AL] Dissolved Oxygen[AL] pH[AL] Total Suspended Solids[AL]	PCBs (Fish Tissue)[FC] Mercury (Fish Tissue)[FC] Manganese[DW] Fecal coliform[AR] Sulfates[DW]

Table 1-4 Key

Designated Uses:
- FC = Fish consumption
- AL = Aquatic Life
- AR = Aquatic Recreation / Swimming / Primary Contact
- DW = Drinking Water

Note that these are generalized designated use descriptions and may vary somewhat from the specific language used by the states to describe designated uses.

[1] 2008 Minnesota listings are from the final 2008 list as approved by U.S. EPA on June 10, 2008.
2010 Minnesota listings are from the draft list submitted to U.S. EPA in March 2010.

[2] 2008 Wisconsin listings are from the draft 2008 list submitted to U.S.EPA in July 2008.
2010 Wisconsin listings are from the draft list submitted to U.S.EPA in March 2010.

[3] 2008 Iowa listings are from the final 2008 list as approved by U.S. EPA on August 4, 2010.
2010 Iowa listings are preliminary information provided by Iowa DNR staff for September 2010 WQTF meeting.

[4] 2008 Illinois listings are from the final 2008 list as approved by U.S. EPA on October 22, 2008.
2010 Illinois listings are from the draft list produced by the state in April 2010.

[5] 2008 Missouri listings are from the final 2008 list as approved by U.S. EPA on December 16, 2009.
2010 Missouri listings are from the draft list made available for public comment on February 24, 2010.

Discharge Limits/NPDES

The National Pollutant Discharge Elimination System (NPDES) is a permit system for point source dischargers authorized by the CWA. All five UMR states have approved NPDES permit programs, meaning that they are responsible for most aspects of implementation, including review and approval of permits. Point sources permitted by the states include wastewater treatment plants, municipal storm sewer systems, industrial facilities, and concentrated animal feeding operations. Small agricultural operations and fields are considered non-point sources, and are not required to obtain a NPDES permit.

40 CFR 122.21 lays out the federal requirements for a point source discharge permit, including a list of the minimum set of parameters that must be monitored and reported, as follows:

- 5-day Biochemical Oxygen Demand (BOD5)
- Chemical Oxygen Demand
- Total Organic Carbon (TOC)
- Total Suspended Solids (TSS)
- Ammonia as N (NHx)
- Temperature
- pH

All of the parameters listed above potentially have a relationship to nutrients and nutrient impacts. NPDES regulations set limits on discharge of pollutants, including those listed above, based on both available treatment technology and the capacity of the receiving water to assimilate the pollutant.

States that implement NPDES can add additional monitoring requirements to their permits. Among the UMR states:

- Minnesota and Wisconsin require both phosphorus and nitrogen monitoring by NPDES permitees (Bill Franz, US EPA Region 5, personal communication 1/27/2011).
- Illinois requires monitoring of phosphorus and nitrogen for "major" permit holders upon re-issuance of the permit (Gregg Good, IL EPA, personal communication, 5/10/11).
- Iowa requires nitrogen and phosphorus monitoring for continuous discharging municipal or organic discharges (e.g., slaughterhouses) with a treatment plant population equivalent over 3,000 (John Olson, IA DNR, personal communication, 5/13/2011).
- Missouri requires monitoring only in some watersheds, where a TMDL or specific phosphorus effluent limits apply, though some major dischargers monitor voluntarily (Mohsen Dkhili, MO DNR, personal communication, 5/19/2011).

Recent and Emerging Approaches in CWA Implementation Related to UMR Nutrients

This report is intended to both be informed by ongoing efforts and to further the states' work on nutrient criteria development, revision of effluent limitations, and other CWA-based approaches to decrease excessive phosphorus and nitrogen enrichment of surface waters. The following are recent, current, and emerging efforts of note at the state and federal levels in this regard.

National and Regional Approaches

Ammonia Criteria: US EPA has issued guidance to aid states in setting ammonia criteria for aquatic life toxicity. This guidance was most recently updated in 1999. Most UMR states have adopted the criteria from the 1999 update, which includes accounting for the presence of fish early life stages (ELS) and both pH and temperature values (Table 1-3). In 2009, US EPA released a draft update to the 1999 ammonia criteria guidance. The 2009 draft maintains the overall approach of factoring pH and temperature into determining criteria, includes updated science from the past decade regarding the sensitivity of freshwater mussels and snails to ammonia toxicity and may eliminate fish ELS considerations. The updated approach will generally result in lower, more stringent thresholds for CWA aquatic life use attainment.

Biological Criteria: Most states, with the support of US EPA, are moving from basing their assessments of aquatic life use solely on chemical and physical parameters to incorporating measurements of biological condition, though US EPA continues to support exclusively chemical/physical data based assessments where biological measurements are unavailable. While the states are implementing biological assessment on intrastate waters, they currently rely on chemical and physical parameters to determine aquatic life support on the UMR. However, the two examples discussed below demonstrate that initial steps to apply biological assessment to the UMR mainstem are underway:

- Through the UMRBA WQTF, the five UMR states are currently examining the potential for applying biological assessment to the UMR, which should improve the understanding of the biological condition of the Upper Mississippi River and, by extension, help explain the biological response of the UMR to nutrients. This effort is building upon existing UMR biological assessment work, including USACE's LTRMP and US EPA's Environmental Monitoring and Assessment-Great Rivers Ecosystems (EMAP-GRE) programs.
- Additional indications that biological condition is increasingly important for CWA assessment of the UMR are the Minnesota's site-specific TSS standard on assessment reaches 2, 3, and 4 of the UMR (MPCA 2010) and Wisconsin's suspended-solids listing on assessment reach 1, both of which are driven by submersed aquatic vegegation (SAV) condition.

Ecoregion Criteria: In 2000-2001, US EPA released recommended ecoregion-based eutrophication criteria for 1) rivers and streams and 2) lakes and reservoirs as guidance for states and tribes in developing nutrient criteria. Recommended values range between 10 and 76 µg/L for total phosphorus (TP) and between 0.2 and 2.18 mg/L for total nitrogen (TN) within the UMR basin[2]. These criteria are for all rivers and streams within an ecoregion, which may limit their applicability to the UMR specifically. Other approaches to region-based criteria setting have been proposed including Robertson et al. 2006.

The ecoregion criteria, and proposed alternatives, are all related to a broader effort by US EPA to encourage states' movement toward numeric nutrient criteria. Many of the efforts described in the "state approaches" section below are related to the states' work in this regard.

Stressor-Response Framework: The US EPA has recently released a framework for deriving numeric nutrient criteria (US EPA Office of Water Office of Science and Technology 2010). This is a conceptual framework that is designed to guide states through choosing conceptual models of biological responses to nutrients, assembling data, performing analyses to uncover relationships between variables, and deriving criteria on the basis of the discovered relationships.

State Approaches

Illinois recently initiated a series of meetings focused on nutrients, starting with a 2010 summit that was followed by a policy roundtable, with a goal of collaboratively identifying an action plan for addressing nutrients in Illinois waters that can be implemented even before numeric nutrient criteria are in place. Focused nutrient meetings with stakeholder groups continued in 2011, with increased attention paid toward use of narrative (i.e., offensive condition) standards to assess potential nutrient-related causes of designated use impairment.

---

[2] These values come from aggregate ecoregions that drain to the UMR, including regions 6, 7, 8, 9, and 11. They are based on the 25th percentile TN and TP (reported and calculated) concentrations of all streams in the database. Using the individual Level III ecoregion 25% stream criteria, the values range between 6.6 and 118.1 µg/L for TP and between 0.2 and 3.3 mg/L for TN. These maxima and minima are for Level III ecoregions 39, 40, 47, 50, 51, 52, 53, 54, and 72.

In regard to standards specifically, Illinois has had in place for many years a 0.05 mg/L total phosphorus water quality standard for lakes and reservoirs that are greater than 20 acres in size. However, numerous studies and investigations supported by Illinois over the past decade have shown inconsistent and non-definitive relationships between nutrients and biological response.

Iowa is in the process of developing numeric nutrient criteria for lakes and flowing waters. Iowa currently has a recommendation from a panel of science advisors that specifies appropriate numeric criteria for recreational use of lakes (Iowa Nutrient Science Advisors 2008). Proposed lake recreational criteria do not include criteria for N or P, but rather include parameters such as Secchi depth. The work of creating numeric nutrient criteria for aquatic life use in streams is not as far advanced. A Technical Advisory Committee currently convened and considering potential threshold values (Iowa Department of Natural Resources 2010).

Minnesota has established ecoregion-based numeric aquatic recreational use (eutrophication) standards for TP in lakes, and is currently developing flowing water standards. The new standards will also likely use an ecoregion method, and will be applicable to the aquatic life use of the UMR (Heiskary 2008). Minnesota has examined potential targets for nutrient and response variables, and identified preliminary breakpoints for biological response in the UMR at approximately 100 µg/L total phosphorus and 20-35 µg/L chlorophyll-a (Heiskary and Wasley 2010).

Minnesota is also considering a revision of nitrate standards as part of its current triennial standards review, to incorporate aquatic life toxicity concerns in addition to human health (Monson 2010).

Missouri recently established TP and TN numeric criteria for lakes. The process for developing stream criteria for TP is in progress, but this excludes the Missouri and the Mississippi Rivers.

Wisconsin is the only UMR state with numeric nutrient parameter-specific criteria related to eutrophication in flowing waters. These are100 µg/L TP for non-wadeable rivers (including the main channel and side channels of the UMR) and 75 µg/L TP for wadeable streams. These criteria became effective on December 1, 2010, and were approved by the US EPA December 30, 2010. Wisconsin's new numeric phosphorus criteria are part of a comprehensive effort to address nutrient pollution in surface waters, including an overhaul of effluent limitation regulations and an emphasis on an integrated approach addressing both point and non-point nutrient sources (Wisconsin Department of Natural Resources 2011). Work by Robertson, et. al (2008) on biotic response to nutrient concentrations was an important basis for choosing to apply the 100 µg/L concentration uniformly for certain flowing waters, including the UMR.

Summary

The states are required by Congress to set water quality criteria for all interior and border waters, including the UMR, that protect assigned designated uses. The five states have similar, but not identical, use designations and narrative standards that apply to the UMR. All of the UMR states have established numeric criteria for nitrate (drinking water use) and ammonia (aquatic life use), but only Wisconsin has established numeric criteria relating to eutrophication in the form of a 100 µg/L TP standard for non-wadeable rivers and a 75 µg/L TP standard for wadeable streams. There is some monitoring of nutrients in point source discharges via the NPDES system, but it isn't consistent across the UMR basin. There are very few nutrient-related CWA impairments currently listed for the UMR. This may be related to a lack of nutrient criteria, a lack of data or research/understanding of interactions, and/or a lack of actual impacts from nutrients on the mainstem UMR. All of the states are engaged in some nutrient-related work that will affect their CWA programs, though states are at different points and some are not yet addressing large rivers such as the UMR.

Chapter 2:
UMR Nutrient Monitoring

UMR Monitoring Programs

The UMR is monitored by a wide variety of entities at the federal, state, and local levels. Table 2-1 summarizes major ongoing or recent UMR monitoring efforts. Notably, while these various programs produce extensive data for the UMR mainstem and basin, there is currently no unified, mutually recognized, system-wide monitoring program for the UMR mainstem focused on CWA program needs.

Table 2-1: Major Monitoring Programs and Agencies on the UMR Mainstem and Tributaries

Level	Agency	Program	UMR Mainstem Sites	Tributary/ Basin Sites	Samples/site/year[1]
Federal	USACE	LTRMP	Fixed: 62 SRS Pools: 5	Fixed: 35 SRS Pools: 1	Fixed: 12-24 SRS: 4 (many samples per sample event)
	US EPA	EMAP-GRE[2]	145	302	1
		NRSA	18	[3]	0.2 (once every 5 years)
	USGS	NASQAN	3	5	12-24
		NAWQA	1	9	12-24
State	Illinois EPA	Ambient Water Quality Monitoring Network	11	202	UMR: 4 Non-UMR: 9
	Iowa DNR	Ambient Monitoring Program	-	62	12-24
	Minnesota PCA	Minnesota Milestone	6	44	10 (2 years out of 5)
		Major Watershed Pollutant Load Monitoring	5	105	~32
	Missouri DNR	USGS/DNR Cooperative Network	1	58	6-12
		DNR Chemical Monitoring	-	90	2-4
	Wisconsin DNR	Long Term Trends Water Quality Monitoring	3	20	4-12
Local	Twin Cities Metropolitan Council	MCES	1	21	24-32

[1]Applies to both mainstem and tributary sites.
[2]EMAP-GRE sampled between 2004 and 2006 only. Most sites were sampled once, with a 20% resample rate.
[3]Not determined for this report.

Table 2-2 compiles nutrient and nutrient-related parameters monitored by the programs listed above. For the purposes of this report, nutrient and nutrient-related parameters are defined as follows:

- Nutrient parameters: total nitrogen (TN), total phosphorus (TP), nitrate + nitrite (NO_x), ammonia (NH_x), total Kjeldahl nitrogen (TKN), and orthophosphate / soluble reactive phosphorus (SRP).
- Nutrient-related parameters: chlorophyll A (chl-a), dissolved oxygen (DO), total suspended solids (TSS), dissolved silica (DSi), acidity (pH), 5-day biochemical oxygen demand (BOD_5), and water turbidity, velocity, and/or flow.

Table 2-2: UMR Monitoring of Nutrient and Nutrient-Related Parameters

	Nutrient Parameters						Related Parameters							
Program	TN[1]	TP	NO_x	NH_x	TKN	SRP	chl-a	DO	TSS	Turbidity	DSi	pH	BOD	Flow
LTRMP	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	N
EMAP-GRE[2]	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y
NRSA	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y
NASQAN	Y	Y	Y	Y	Y	Y	N[3]	Y	Y	Y	Y	Y	N	Y
NAWQA	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	N	N
IL EPA Ambient Water Quality Monitoring Network	C	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y
Minnesota Milestone	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Minnesota Major Watershed Pollutant Load Monitoring	C	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y[4]	Y
MO DNR/USGS Cooperative Network[5]	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y
WI DNR Long Term Trends Water Quality Monitoring	C	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
MCES	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Tributary-Only Monitoring Programs														
IA DNR Ambient Monitoring Program	C	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
MO DNR Chemical Monitoring	Y	Y	Y	Y	Y	Y	N	Y	N	N	N	Y	N	Y

[1] The value 'C' indicates calculated as the sum of NO_x and Kjeldahl nitrogen (TKN), rather than directly measured.

[2] Not ongoing.

[3] Chl-a concentration measurements were apparently suspended at NASQAN sites in 2007.

[4] BOD monitoring in Minnesota Major Watershed Pollutant Load Monitoring program sites appears to be intermittent, based on MPCA Environmental Data Access search results.

[5] MO DNR operates its large river monitoring network in conjunction with the USGS; the one site on the UMR is also in NASQAN.

Other biological or habitat parameters, though important for understanding nutrients on the UMR, are beyond the scope of this chapter. The UMR states have indicated that increased direct assessment of aquatic life, in addition to assessment via surrogate indicators such as chemical parameters, is an important goal. As such, some biological monitoring programs are discussed in Chapter 4.

Federal

USACE

USACE, through its Environmental Management Program, operates the Long Term Resource Monitoring Program (LTRMP), which has been by far the most extensive monitoring program on the UMR since its inception in 1987. LTRMP also conducts research and includes six field stations operated by the five UMR states. USACE, USGS, and state field station staff all participate in implementing LTRMP.

LTRMP monitoring is performed in five pools on the UMR and one pool on the Illinois River, including both fixed site and stratified random sample (SRS) monitoring. SRS sampling involves choosing random sites distributed among the lateral strata of the river. Accordingly, water quality data from stratified random sites present a more complete picture of condition across lateral strata than main channel data alone. LTRMP monitors all major nutrient related parameters except BOD_5 and flow.

The 29 locks and dams on the UMR are operated by USACE, which maintains a record of the elevation and flow of the river at each structure.[3] USACE also carries out a variety of site- and project-specific monitoring, including water quality monitoring at locks and dams and monitoring associated with individual ecosystem restoration projects.

US EPA

From 2004 to 2006, US EPA's Environmental Monitoring and Assessment Program - Great Rivers Ecosystems (EMAP-GRE) included UMR monitoring. EMAP-GRE was a one-time, comprehensive assessment of the midcontinent's Great Rivers – i.e., the UMR, the Missouri, and the Ohio. EMAP-GRE included a focus on biology and was intended to demonstrate a probabilistic approach to Great River monitoring. Sampling was performed using SRS, but with samples chosen from a single stratum (main channel border) along the length of the river. Primarily focused on assessment, EMAP-GRE was not intended to provide an understanding of historical nutrient trends in the UMR. However, the project included monitoring for nutrient and nutrient-related parameters and featured concurrent monitoring of extensive biological, physical, and chemical parameters, which can provide unique insight into nutrient-related mechanisms in the UMR.

A current US EPA monitoring program of relevance for the UMR is the National Rivers and Streams Assessment (NRSA). NRSA is a national program that incorporates elements of the EMAP-GRE design. Sampling took place in 2008-2009, including sites on the UMR, with additional UMR sites likely to be sampled in 2013-2014. The sampling protocol is SRS-based, and is focused on the main channel. As NRSA is intended to be an ongoing monitoring program, it will eventually add to the long-term nutrient record of the UMR. While data from recent NRSA monitoring will soon be available, the relative youth of the program and current lack of UMR data limits its utility for CWA nutrient assessment at present.

---

[3] Data available at www.Rivergages.com.

USGS

In addition to its role in LTRMP, the USGS operates fixed stations on the UMR and other major rivers and streams through the National Stream Quality Accounting Network (NASQAN) program, the National Water-Quality Assessment (NAWQA) program, and in conjunction with partner organizations (primarily state agencies). NAWQA's mission explicitly includes long-term trend analysis and source tracking. The program uses cyclical sampling in select basins, and includes the Upper Mississippi/Minnesota/St. Croix, Eastern Iowa, and Illinois River basins, as well as numerous basins that drain to the Missouri River. NAWQA relies to some degree on existing sites from other programs, including NASQAN.

NASQAN is designed to track pollutants moving through large rivers to coastal waters. With their long periods of record (some extending back nearly 90 years) and extensive sets of chemical and physical parameters monitored, NASQAN sites tend to be very useful for establishing long term patterns and trends. These fixed sites include nearly all nutrient and nutrient related parameters. One key exception is chl-a, which has been intermittently sampled at NASQAN sites and recently discontinued.

State

Four of the five UMR states operate monitoring programs on the UMR – i.e., Illinois, Minnesota, Missouri, and Wisconsin. All five states operate monitoring programs on intrastate streams and rivers, including major and minor tributaries to the UMR. All state sampling on the UMR (and most sampling of other rivers and streams) is performed at fixed sites located in the main channel, often in conjunction with the USGS.

Illinois

The Illinois Environmental Protection Agency (IL EPA) Bureau of Water has operated the Ambient Water Quality Monitoring Network (AWQMN) since 1977. This statewide fixed station chemical monitoring program originally consisted of 213 stations with four sites located on the UMR. In 1999, seven additional sites were added to the UMR. In 2008 the total number of sites on the AWQMN was reduced to 146 and sampling frequency at the 11 UMR sites was reduced to 4-times a year. Most of the network is sampled for all nutrient and nutrient-related parameters. Chlorophyll-a is collected from six of the eleven ambient sites on the UMR.

The IL EPA also runs an Intensive Basin Surveys program in which 33 major river basins are studied for biological communities, water chemistry and stream habitat on a 5-year rotating basis. Twenty-eight of the 33 river basins sampled are tributary to the UMR. Nutrient parameters are the same as for the ambient monitoring program, but include chlorophyll-a at every site.

Iowa

Iowa primarily collects data under its Ambient Monitoring Program, a cooperative venture of the Iowa Department of Natural Resources (IA DNR) and the State Hygienic Laboratory at the University of Iowa. The Ambient Monitoring Program has conducted routine statewide monitoring of water quality since the early 1980s. A stated goal of the program is to provide the capacity to document total loading of nutrients to the UMR and the Missouri River, and as a result major tributaries are regularly monitored for all nutrient and nutrient-related parameters. However, apart from the Bellevue LTRMP field station, Iowa does not conduct any nutrient-related monitoring on the UMR. Border rivers are considered a high priority for monitoring (Iowa Department of Natural Resources 2000) and lack of funding is cited as the primary reason no UMR monitoring is conducted (Iowa Department of Natural Resources 2005). The Ambient Monitoring Program also monitors lakes, wetlands, and wadeable streams.

The volunteer IOWATER program is focused on wadeable streams that are safe for volunteers to assess. That focus, along with QA/QC concerns, makes IOWATER samples less useful than data from large local, state, and federal agencies in understanding nutrients in tributaries to the UMR. There are no IOWATER samples in the UMR mainstem (USEPA Region 7; Iowa Department of Natural Resources 2006).

Minnesota

One direct monitoring activity of the Minnesota Pollution Control Agency (MPCA) is the Minnesota Milestone River Monitoring program, which samples each target area for two years in a five year cycle and has been in continuous operation since 1953. The rivers sampled under this program include major tributaries to the UMR (St. Croix, Minnesota, and non-interstate UMR) as well as six sites on the interstate Mississippi River. This program is focused on trend analysis of chemical parameters, including all nutrient and nutrient-related parameters, but relies on USGS and the Minnesota Department of Natural Resources (MN DNR) sites to provide flow data.

The Milestone program is scheduled to be discontinued as MPCA expands its Major Watershed Pollutant Load Monitoring program. The watershed monitoring effort includes approximately 110 sites, including 5 on the UMR, with monitoring records ranging from a single sample to six decades – i.e., from the 1950s to the present (Minnesota Pollution Control Agency 2010). Sample frequency is variable, depending upon what is required to generate loading information. Samples in this program are analyzed for all nutrient and nutrient related parameters except for ammonia (NH_x). There may be some overlap between stations in this program and those in the Milestone Monitoring program.

In addition to water quality sampling, the MN DNR operates the Minnesota Cooperative Stream Gaging program, which provides flow data on the UMR and some major tributaries, jointly with the MPCA and the USGS.

Minnesota is increasingly relying upon data provided by other entities, including the USGS, the Metropolitan Council, watershed organizations, and volunteer citizens, in its CWA assessments (Minnesota Pollution Control Agency 2004).

Missouri

The Missouri Department of Natural Resources (MO DNR) and USGS cooperatively support a fixed station network for water quality monitoring (Ambient Water Quality Network) with 59 statewide fixed stations, three of which – St. Louis, MO, Chester, IL, and Thebes, IL - are on the UMR (and included in the NASQAN program). Of the three UMR sites, nutrient parameters are regularly monitored only at Thebes. The program’s overall monitoring regime, particularly the parameters studied, is similar to NASQAN. For the Thebes site, all nutrient and nutrient-related parameters are collected, except chl-a and BOD_5.

The MO DNR also conducts a number of special studies each year and cooperates with the Missouri Department of Conservation in a biological monitoring program involving fish and aquatic invertebrate sampling.

Wisconsin

Wisconsin Department of Natural Resources’ (WI DNR) river monitoring is divided into three sections: Biological Integrity, Long Term Trend (ambient water quality), and Flow Gaging (Wisconsin Department of Natural Resources 2008). Each of the three sections is partially driven by CWA objectives. Sampling is conducted more frequently (12/yr) at sites near the mouths of rivers, and less frequently (4/yr) further upstream and at the two UMR sites with nearby USGS stations (Wisconsin Department of Natural Resources 2006). Samples are analyzed for all nutrient and nutrient-related parameters, with the exception of BOD_5.

WI DNR also conducts some unique studies of fish habitat and other water quality related issues. Work has included studies of metaphyton in UMR pools 5-9 and SAV studies (coordinated with EMAP-GRE) in UMR pools 2-11. These state studies are coordinated with and extend the monitoring conducted by the Onalaska LTRMP field station.

Local

Many local entities sample in the UMR basin; fewer sample directly on the UMR mainstem. These entities may include local units of government, such as watershed districts and soil and water conservation districts; nonprofit and volunteer organizations, such as IOWATER; and private corporations that perform monitoring as a condition of a permit to discharge into a public water.

Of these local entities, the only one that appears to be operating a program with sufficient technical rigor and sampling duration to be useful for trend analysis or CWA assessment is the Environmental Monitoring and Assessment Section of Metropolitan Council Environmental Services (MCES), which conducts water quality monitoring of rivers, streams, lakes, and wastewater treatment plant discharges in the Minneapolis-St. Paul seven-county Metropolitan Area. MCES monitoring includes automated, continuous monitoring of a limited set of chemical parameters and conventional weekly or biweekly monitoring of a broader set of parameters. Only one of the MCES monitoring sites located on the interstate UMR.

Spatial Extent of Mainstem Monitoring

Figure 2-1 depicts the current spatial distribution of monitoring stations associated with major, ongoing UMR monitoring programs that include nutrient parameters. Figure 2-2 also depicts major monitoring stations as of 2002, but is not limited to stations monitoring for nutrients. These maps illustrate the following in regard to UMR mainstem monitoring:

- By far the most extensively monitored section of the UMR, presently and in 2002, is the reach that extends from the Twin Cities to the Minnesota boundary. The combination of Wisconsin, Minnesota, and Metropolitan Council ambient monitoring programs, along with two LTRMP study pools, makes this section of the river well monitored, both in terms of water quality generally and for nutrient/nutrient-related parameters in particular. This extensive monitoring may be due in part to the specific attention paid to Lake Pepin over the past two decades.
- By contrast, much of the river along the Illinois, Iowa, and Missouri borders, particularly between LTRMP study pools 13 and 26, has limited significant ongoing monitoring. In this context, Illinois' sampling at its 11 AWQMN sites on the UMR mainstem is particularly important, as it is the only source of consistent, complete, ongoing nutrient data for a 200 mile span of the UMR.
- The most significant change from 2002 to the present appears to be the expansion of Illinois monitoring. The two spans highlighted with significant gaps in Figure 2-2 (the Iowa-Missouri border to the Illinois River, with 1 site in 100 miles; and between the Pool 26 and Open River study reaches of LTRMP, with 0 sites in 80 miles) have each been enhanced with an additional Illinois monitoring station since 2002.

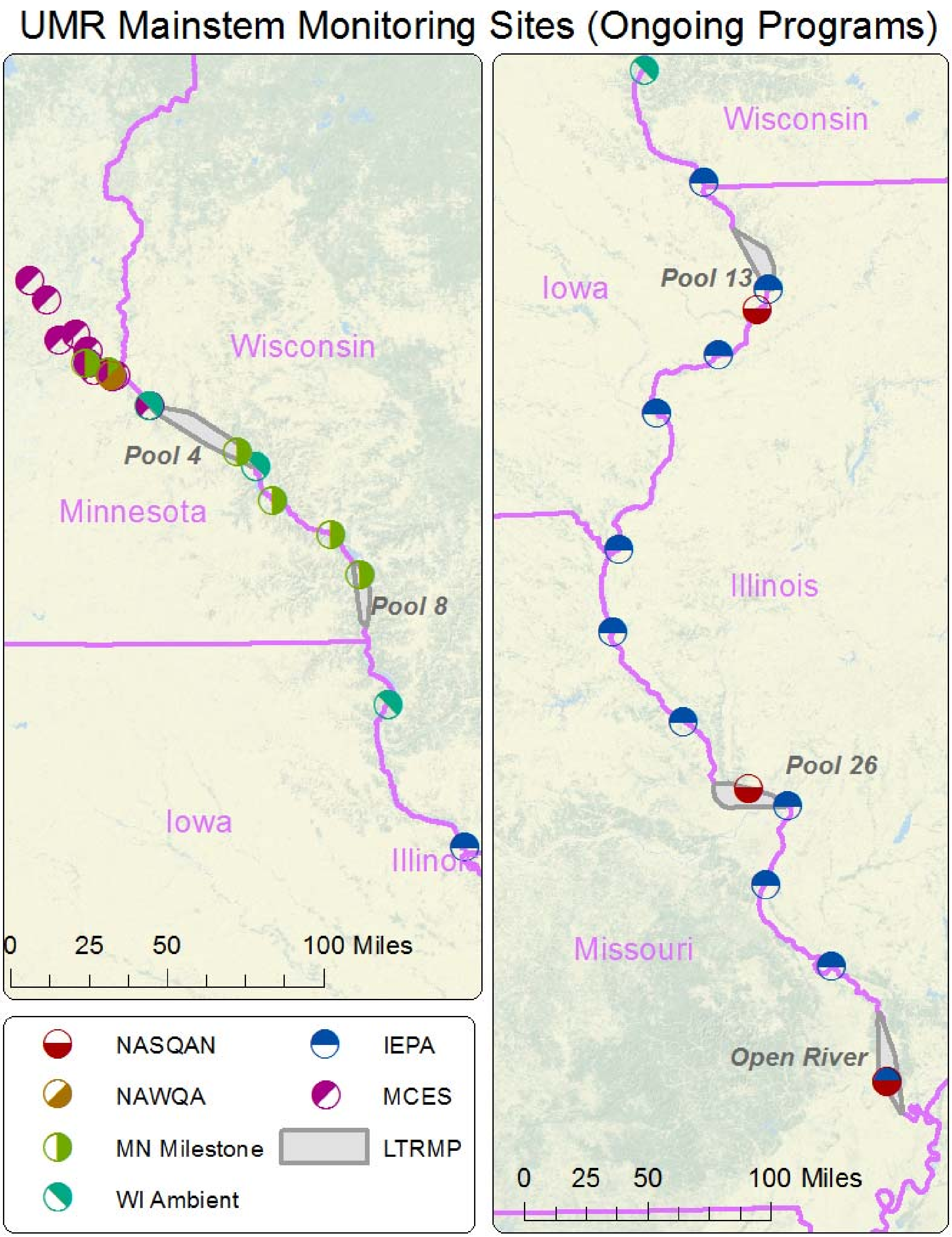


Figure 2-1: Sampling sites of major monitoring programs on the UMR mainstem.

Sources: http://infotrek.er.usgs.gov/nawqa_map/; Kevin Zidonis, Illinois EPA, personal communication; http://www.dnr.state.wi.us/org/water/swims/; www.metrocouncil.org/environment/RiversLakes/rivers/riverwatermonsitesparameters.htm; http://www.pca.state.mn.us/r0pgaf6 (MPCA).

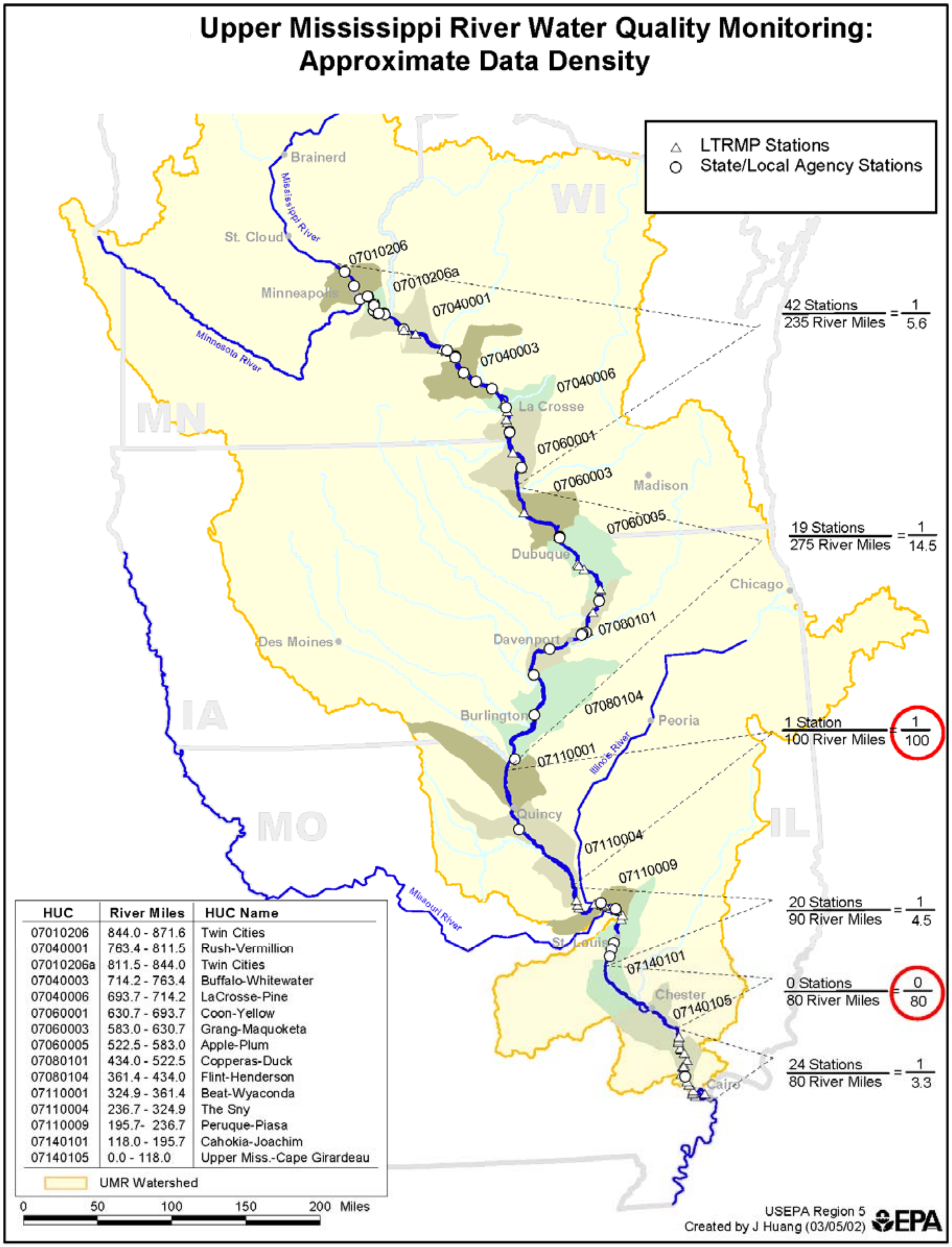


Figure 2-2: Mainstem monitoring sites, 2002. (From Sullivan et al. 2002)

Basin-Wide Monitoring

USGS Monitoring

The National Water Information System (NWIS) database is a long term, comprehensive data set incorporating monitoring performed by USGS. It includes sites in NASQAN, NAWQA, and those jointly maintained with partner organizations. It does not include data from the LTRMP, a USACE program administered by USGS. NWIS data is summarized in Table 2-3 and Figures 2-3 through 2-5.

Table 2-3: NWIS UMR Basin Monitoring Summary

Region	Descriptor	1975	1985	1995	2005
UMR Basin	Number of Sites	451	505	540	268
	Avg. Samples/site/yr	8.5	10.6	15.5	18.7
	Avg. monitoring span, in years	32.4	32.8	30.3	31.9
UMR Mainstem	Number of Sites	21	23	21	18
	Avg. Samples/site/yr	6.6	5.9	6.5	8.2
	Avg. monitoring span, in years	38.6	38.5	39.2	36.8

Lake & stream sampling sites in hydrologic unit 07 with more than 10 water quality samples overall are summarized here.

NWIS data demonstrates that a number of long-term USGS sites on the UMR and throughout the basin have been discontinued within the past ten years. The decline in USGS sites disproportionately affects long term trend tracking, as USGS fixed sites tend to include the extended data sets that are key to analysis of trends in nutrient concentration and loading.

Several additional trends are evident from Table 2-3. The first is that the change in the number of mainstem monitoring sites is less dramatic than the change in the basin overall. While the number of mainstem sites dropped from a high of 23 in 1985 to 18 in 2005, the number of basin sites dropped much more precipitously, from a high of 540 in 1995 to 268 in 2005. Another trend is the significant upswing in per-site sampling frequency in UMR basin sampling between 1975 and 2005, with over twice as many water quality samples per site per year in 2005 than in 1975. The consistency of the average monitoring span (last monitoring year – first monitoring year) is another notable characteristic - it remains fairly constant through the decades for both the basin and the mainstem. This indicates that sites with longer data records are being regularly replaced by new sites, such that in 2005 the average starting date for lake and stream monitoring sites in the UMR basin is approximately 1973, just two years before the first NWIS monitoring snapshot. This continual loss of long-term monitoring sites, combined with the recent sudden decline in the number of monitoring sites, poses a challenge for creating long term trend analyses.

There are two additional differences of note between the NWIS UMR mainstem and basin monitoring data. First, sampling frequency on the mainstem has been consistently lower than frequency in the basin as a whole, and that discrepancy has increased between 1975 and 2005. Second, the average span of monitoring on the UMR mainstem is slightly higher than the span in the basin as a whole, with durations on the mainstem being 5 to 9 years greater than basin durations during the years summarized in Table 2-3.

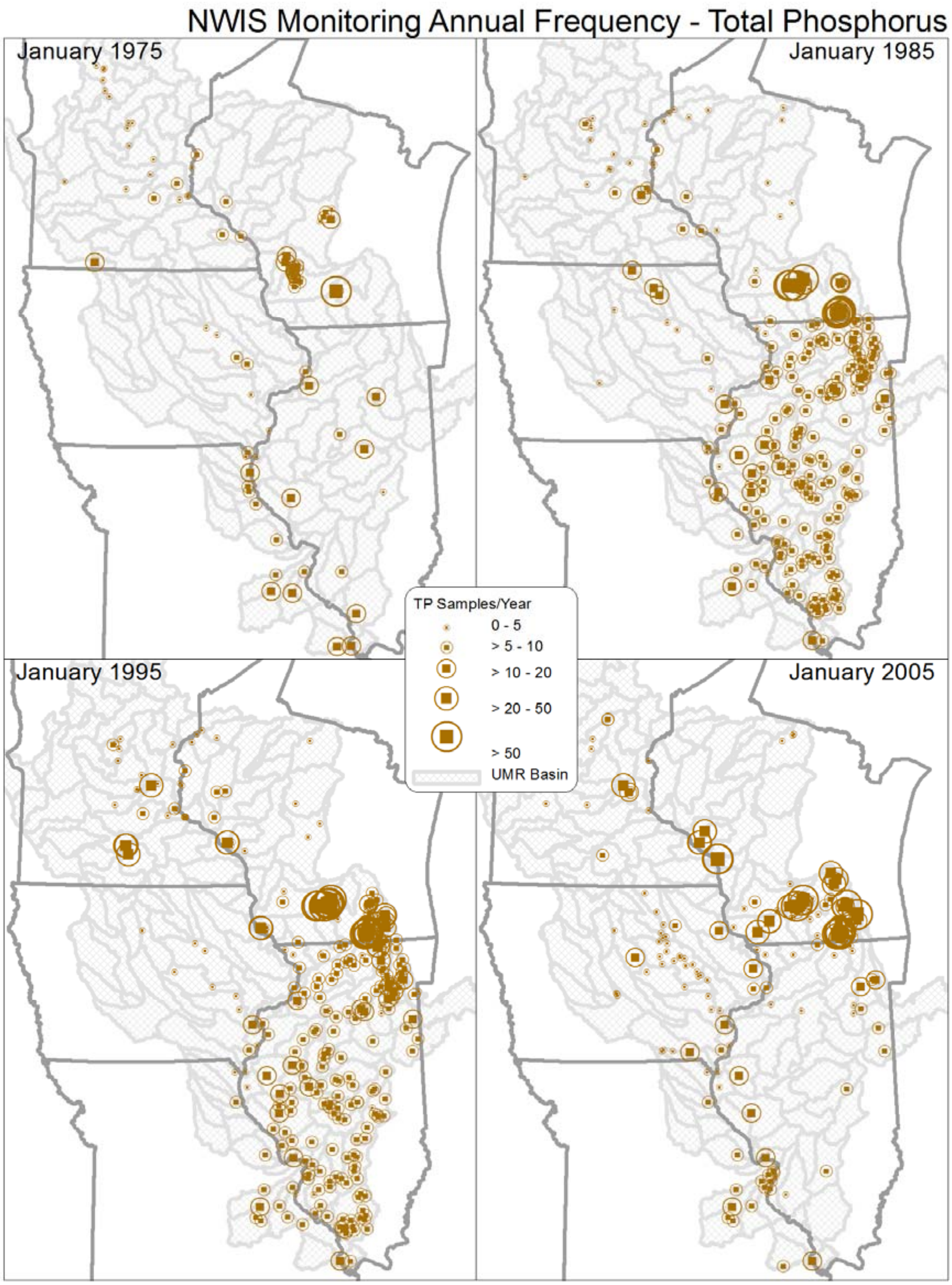


Figure 2-3: NWIS total phosphorus monitoring in the UMR basin; four snapshots, 1975 – 2005 (where "January (Year)" indicates that these stations were active as of the beginning of the given year).

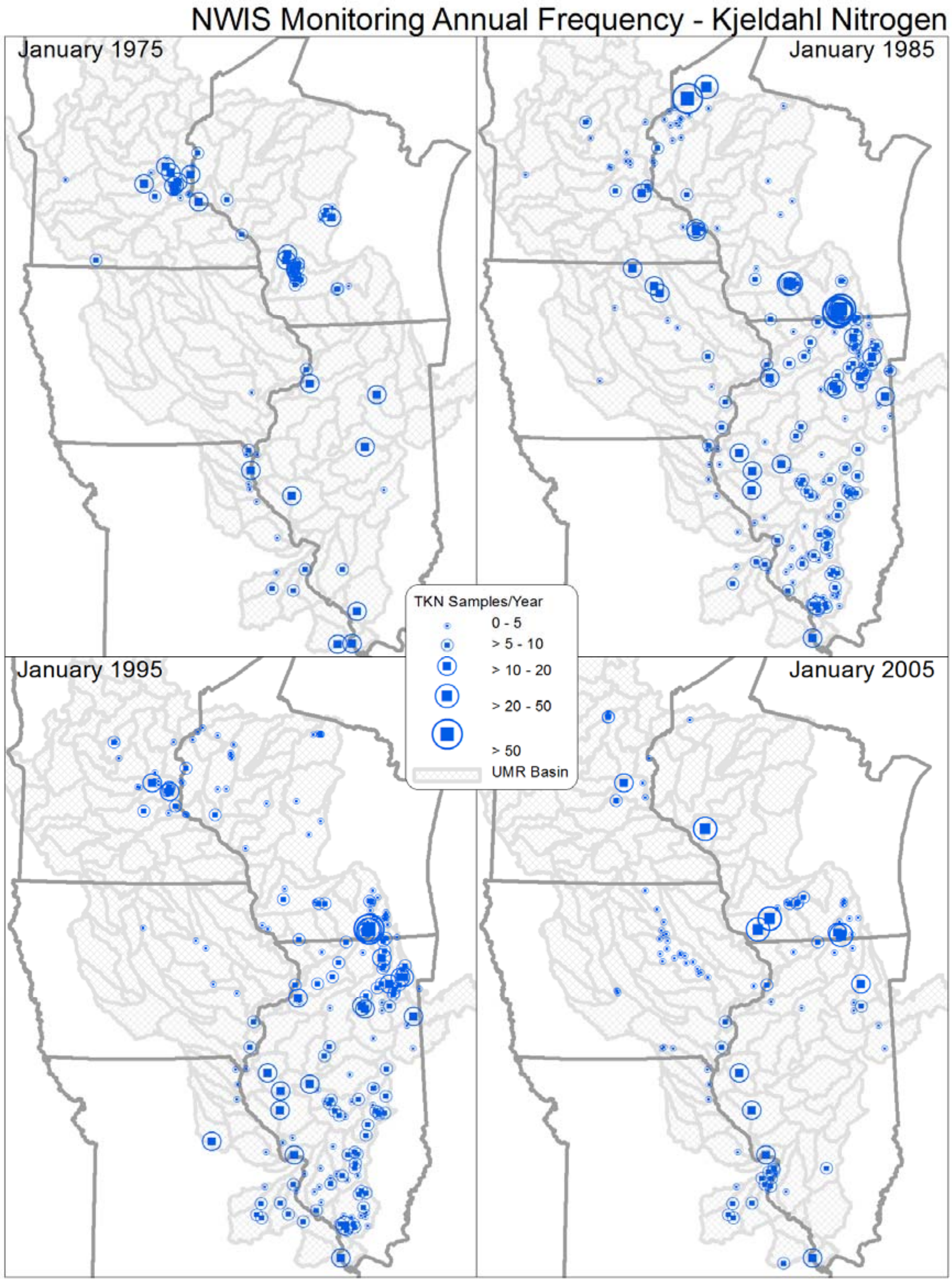


Figure 2-4: NWIS Kjeldahl nitrogen monitoring in the UMR basin; four snapshots, 1975 – 2005 (where "January (Year)" indicates that these stations were active as of the beginning of the given year).

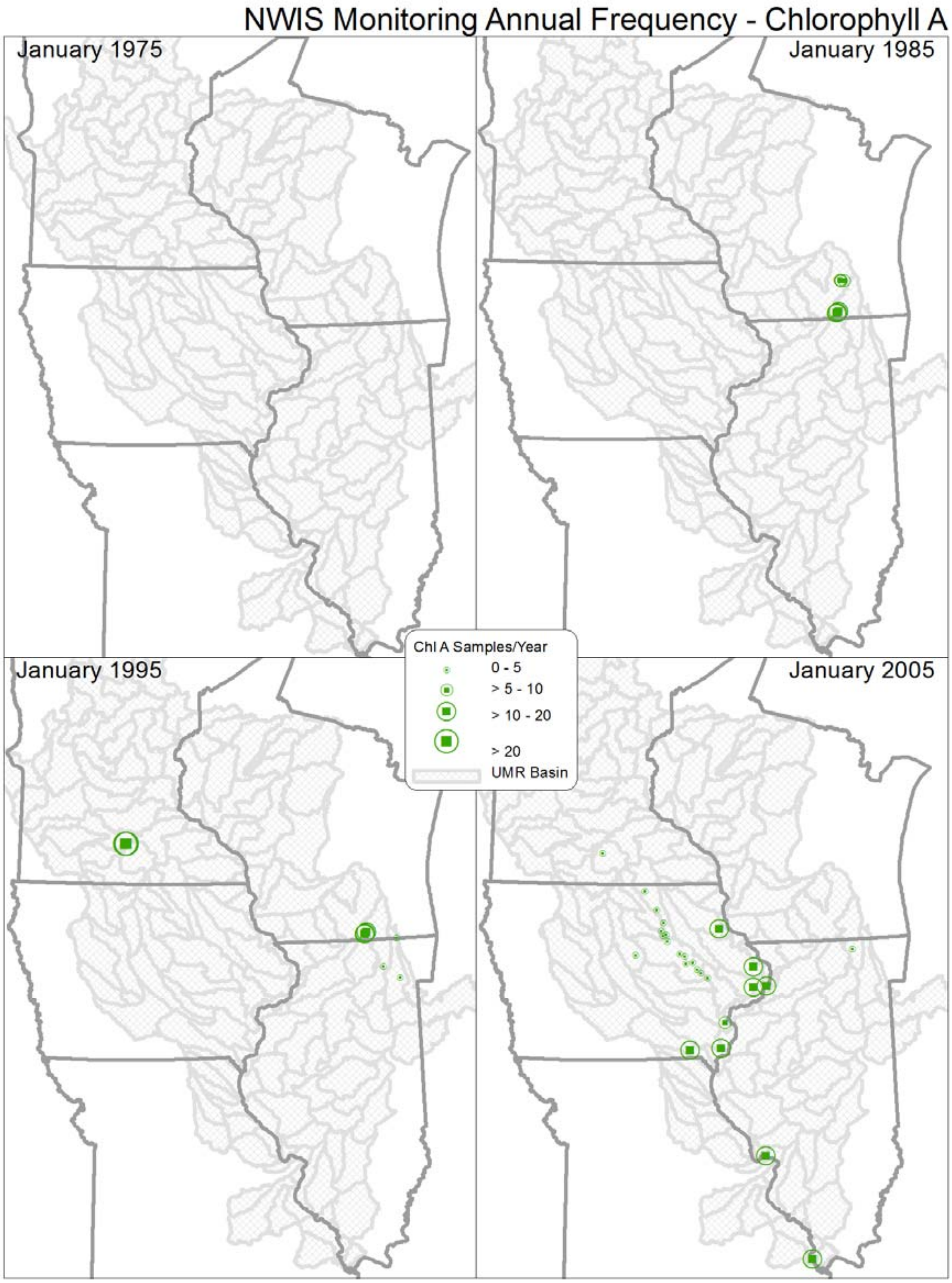


Figure 2-5: NWIS chlorophyll-a monitoring in the UMR basin; four snapshots, 1975 – 2005 (where "January (Year)" indicates that these stations were active as of the beginning of the given year).

Figures 2-3 through 2-5 show USGS active monitoring sites in ten year snapshots, between 1975 and 2005. One immediately obvious pattern is the extensive monitoring network that existed in Illinois in 1985 and 1995, which is virtually missing in 2005. Whether these sites were discontinued or are now maintained by a different agency was not apparent in the research done for this report.

Figure 2-5 also reveals that USGS's chl-a monitoring in the UMR basin has been much more limited than its chemical nutrient parameter monitoring. Missing in the snapshots is the fact that the USGS discontinued chl-a monitoring on several key UMR mainstem sites, including the Clinton, Iowa; Grafton, Illinois; and Thebes, Illinois monitoring stations, in 2007.

Overall, the steady loss of USGS fixed site monitoring is a significant constraint for surface water data collection in the UMR basin, both in general and specifically for nutrients.

State and Local Monitoring

Using Existing Databases to Characterize State and Local Monitoring

State monitoring programs are a significant source of surface water quality data in the UMR basin, as is apparent from the program descriptions earlier in this chapter. There are at least three centralized databases of fixed site nutrient and nutrient-related monitoring in the basin that capture state and local monitoring efforts:

- ***STORET*** is the US EPA's centralized STOrage and RETrieval database for water quality data for the entire nation. Most states synchronize their local water quality databases with STORET.
- ***SPARROW*** is a SPAtially Referenced Regressions On Watershed attributes model developed by the USGS to simulate nutrient yields off of landscapes, taking into account actual in-stream nutrient concentrations and land use. In this report the term "SPARROW" also refers to the effort to apply the SPARROW model to the Mississippi/Atchafalaya River Basin (MARB), an effort which necessarily involved the collection of nutrient monitoring records from a variety of sources across the UMR basin. Summaries of these records were provided to the UMRBA for this report.
- The ***UMRCC*** (Upper Mississippi River Conservation Committee) coordinated with US EPA Region 5 on an effort to characterize water quality on the UMR, which cumulated in both a report (Sullivan et al. 2002) and a compilation of water quality data. Figure 2-2 is an excerpt from this report.

Each of the above data sets has significant drawbacks as a source of data for a basin-wide compilation or summary of nutrient monitoring. The UMRCC-compiled data set, while inclusive of nutrients is focused on the UMR mainstem of the river and thus was not intended to evaluate basin monitoring. The SPARROW data set is not comprehensive, as the modelers' goal was to create a set of monitoring data that spanned a wide variety of basin and hydrologic conditions, and met rigorous quality assurance and quality control standards. For this reason, various important data sets, though entirely valid for research in other contexts, were excluded from the SPARROW data set.

The only potentially comprehensive set of state and local nutrient monitoring data in the UMR basin is the US EPA STORET database. Unfortunately, a variety of technical limitations of the database prevented full characterization of state and local nutrient monitoring, the most important of which are listed below.

- STORET is not designed to be queried for mass quantities of data on a spatial scale larger than an eight-digit Hydrologic Unit Code (HUC-8) watershed. The web query form does not permit users to enter multiple HUCs.
- While there is an interface for scripted querying of the database, which would potentially allow for circumventing of the spatial scale limitation, it is not sufficiently stable for regular use. The water quality exchange (WQX) direct access framework regularly failed to respond to requests for data, making the compilation of a full data set for the UMR basin impossible.

In sum, due to the limitations of existing data sets, a comprehensive portrayal of baseline state and local nutrient monitoring could not be compiled for this report.

Spatial Extent of State Monitoring

While basin-wide data sets could not be used to comprehensively describe state and local monitoring, site data are available from the states directly. The following pages show state monitoring locations for four of the five UMR states. A state monitoring map for Missouri is not included due to both:
1) difficulty in finding either monitoring site data or existing maps of Missouri monitoring locations, and 2) the fact that the major Missouri surface water monitoring efforts are conducted in conjunction with the USGS, and are therefore reflected in the NWIS summary.

Figure 2-6: Illinois Ambient Water Quality Monitoring Network stations, 2007 (From Illinois Environmental Protection Agency 2007)

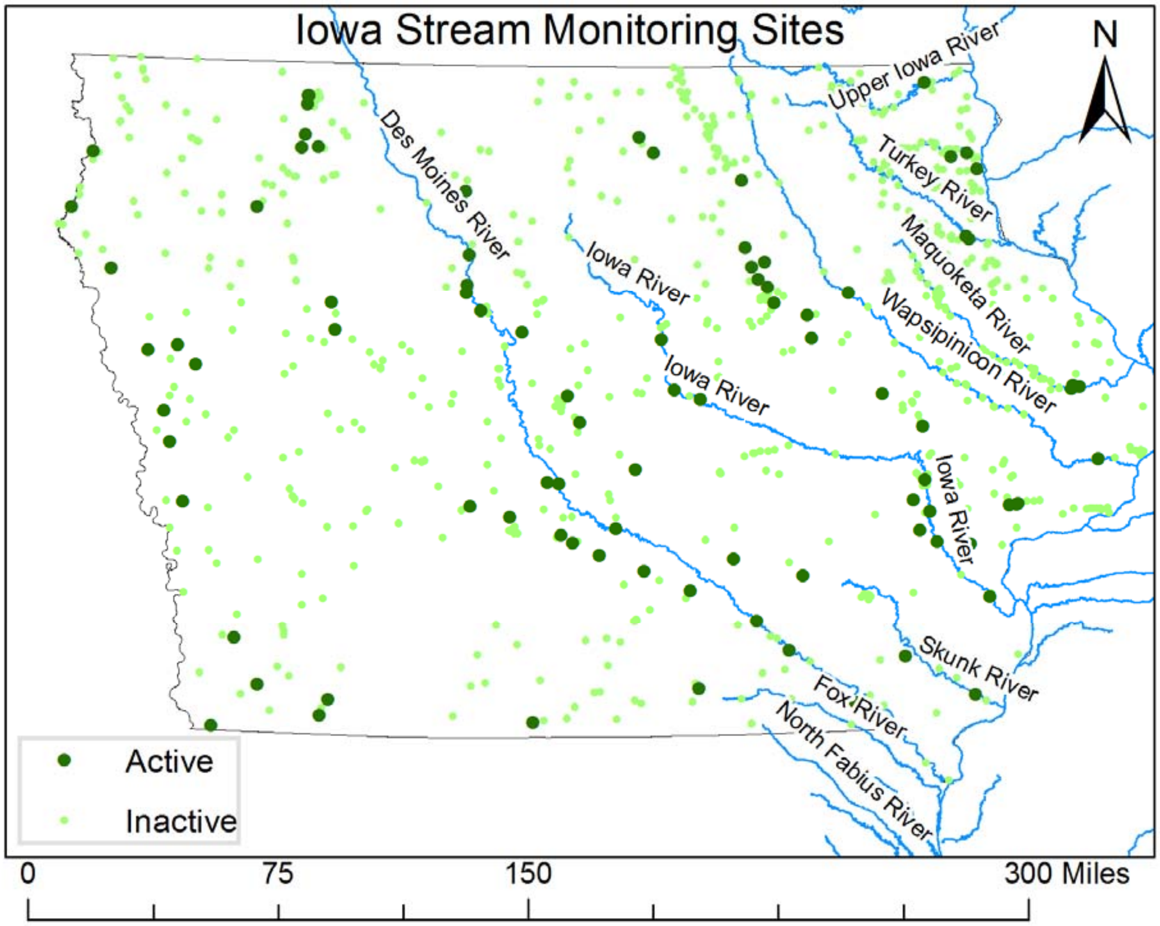


Figure 2-7: Iowa stream monitoring sites containing data in US EPA STORET, 2010. Data via Iowa DNR: ftp://ftp.igsb.uiowa.edu/gis_library/ia_state/hydrologic/surface_waters/STORET_sites.html

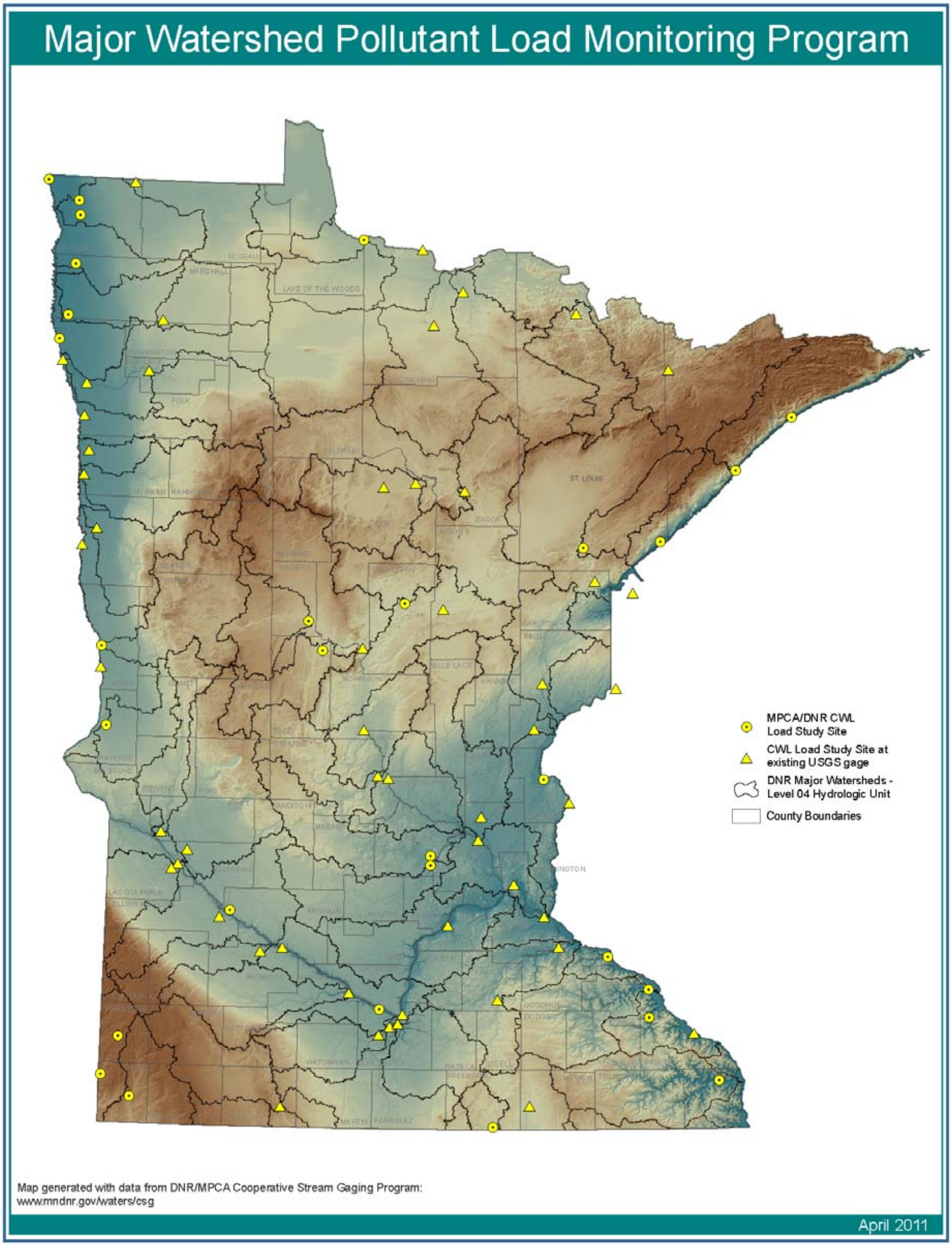


Figure 2-8: Minnesota Clean Water Legacy load monitoring locations, 2011. (MPCA and MN DNR data; Pat Baskerfield, MPCA, personal communication, 3/11/2011)

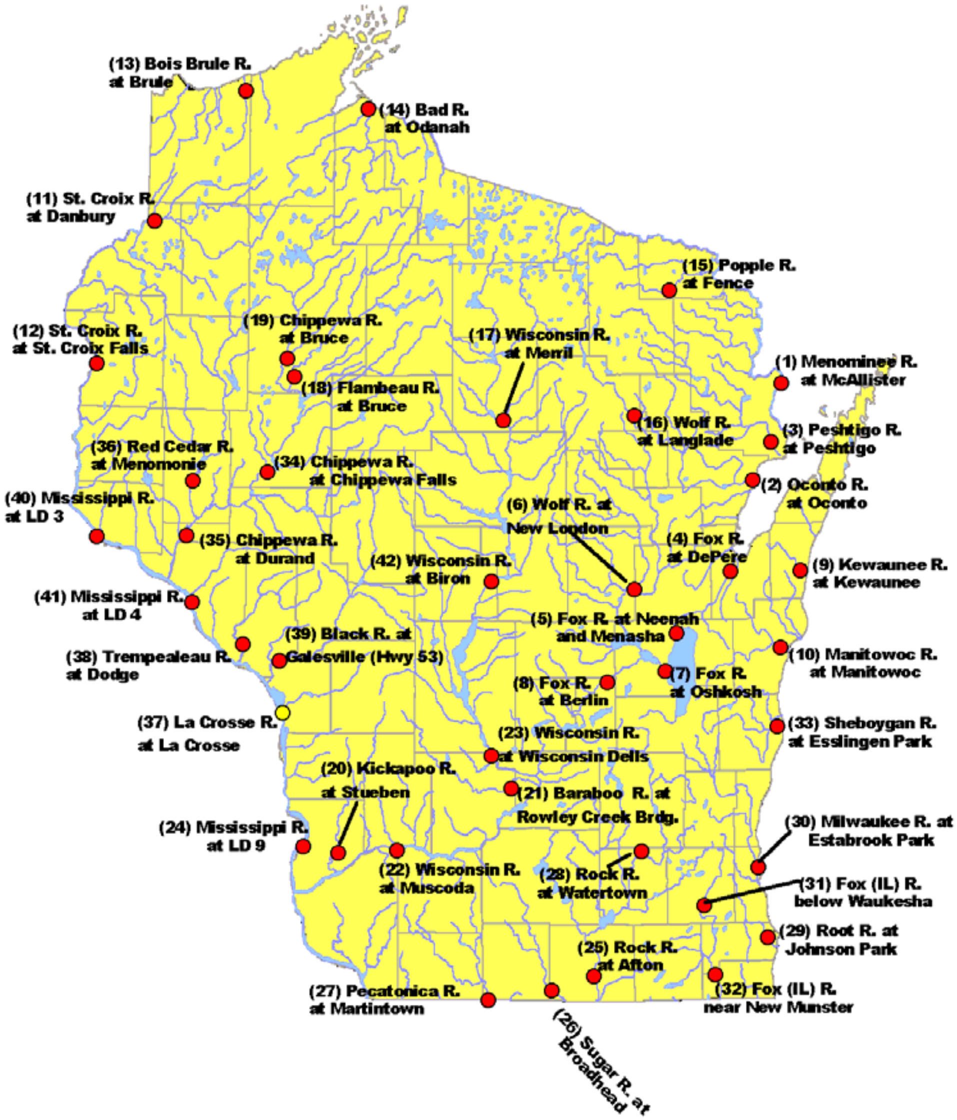


Figure 2-9: Wisconsin Long Term Trend Monitoring Network, 2006. (WDNR Bureau of Watershed Management 2006)

While the monitoring locations displayed in Figures 2-6 through 2-9 are not specific to nutrients, Table 2-2 indicates that many nutrient parameters are sampled at most of these sites. With this in mind, it is clear that most major tributaries to the UMR are sampled as a part of a significant state monitoring effort, often at multiple locations. The Minnesota, St. Croix, Chippewa, Wisconsin, Iowa, Des Moines, Rock, Illinois, and Kaskaskia rivers are all monitored near their respective outlets to the UMR.

Summary

A wide variety of monitoring is being conducted on the UMR mainstem at federal, state, and local levels. However, no monitoring program currently exists that provides a complete picture of nutrients in the river in terms of spatial distribution (lateral and longitudinal), temporal variation, or parameters of interest on the UMR mainstem. Major tributary monitoring is being conducted by both the USGS and states, though USGS monitoring has declined in recent years and there is no easy mechanism for examining state monitoring basinwide.

Specific observations regarding UMR mainstem and tributary monitoring include:

- USACE's LTRMP provides by far the greatest source of current nutrient-related data, and is unique in spanning the entire lateral extent of the UMR (channels, backwaters, impounded areas), but has longitudinal gaps between its study reaches, with the gap Pool 13 and Pool 26 being the most significant.
- US EPA's EMAP-GRE has developed a potentially viable design for extensive longitudinal coverage, but is specific to the main channel border and, as a demonstration program, has ceased sampling operations.
- No state program regularly monitors the UMR mainstem outside the main channel (i.e., off-channel areas are not regularly monitored).
- Fixed monitoring sites, such as those jointly maintained by the USGS and the states, are primarily useful for trend and loading analyses. The utility of fixed sites on the UMR for that purpose is often hindered by multi-year or even decadal gaps in the data record, and such sites are generally established in the main channel of the river, providing little insight into other strata such as side channels and backwaters. USGS sites are also often missing chl-a, and so are less useful for eutrophication-based assessment.
- While all programs monitor most nutrient and nutrient-related parameters, there are two significant exceptions to this as chl-a and BOD_5 are not universally collected. Both of these parameters, particularly chl-a, are essential for understanding the links between nutrient concentrations and aquatic use impacts, so lack of monitoring data for these constituents is a significant problem for CWA purposes.
- Although many monitoring programs are in place on the UMR mainstem, as described in this chapter, there is no comprehensive, CWA-focused monitoring strategy for the mainstem (including its various lateral strata). Lack of such a strategy limits the states' ability to fully and consistently characterize the River's condition in a CWA context.
- USGS monitoring in the UMR basin increased in per-site sample frequency from 1975 to 2005. UMR mainstem monitoring frequency appears to have increased as well, though not as dramatically, and USGS monitoring of the mainstem appears to have been less frequent in all time periods than its basin monitoring.
- The number of USGS sampling locations in the UMR basin increased between 1975 and 1995, but appears to have decreased between 1995 and 2005. The same trend is evident on the mainstem of the UMR, but is much less pronounced. Given the currently available data sets, temporal trends in state monitoring cannot be characterized.

Chapter 3:
UMR Nutrient Sources, Concentrations, and Trends

Sources

Phosphorus

Phosphorus (P) is a nutrient found in fertilizers and human and animal excrement. It readily binds with sediment, and most soils have some naturally occurring phosphorus bound to them.

Generally phosphorus enters surface water through erosion, either natural or artificially accelerated, and point discharges. The relative contribution of P sources to surface waters can vary depending upon flow conditions. At low flow, point sources tend to contribute proportionally more, whereas non-point sources contribute proportionately more during rainy, high-flow periods (Barr Engineering Company 2004).

Phosphorus concentrations in rivers such as the UMR and major tributaries tend to increase during high flow events (Hubbard et al. 2011). UMR mainstem P concentrations demonstrate a longitudinal gradient, increasing from upstream (lowest concentrations) to downstream (highest concentrations) (Houser and Richardson 2010).

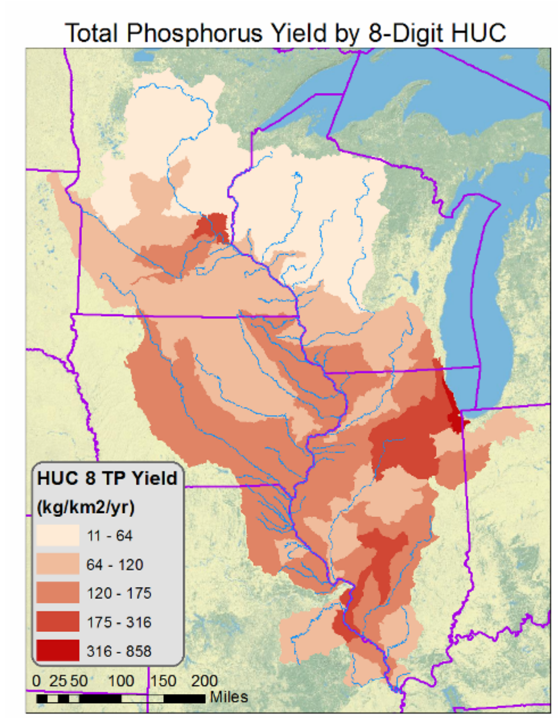


Figure 3-1: Modeled phosphorus yields for HUC 8 watersheds, as calculated by Robertson et al. (2009).

Because phosphorus binds with soil, subsurface flows tend to contribute significantly less phosphorus to waters than surface flows. Another outcome of P's sediment affinity is that river and lake bottoms can act as phosphorus "banks," releasing phosphorus under anoxic conditions and taking in phosphorus under P-enriched conditions. Lake Pepin is an example of a system that takes in particulate phosphorus and releases dissolved phosphorus.

As shown in Figure 3-1, USGS' recent SPARROW modeling effort indicates that UMR sub-basins with highly agricultural watersheds and with rivers that flow through or next to urbanized areas tend to have higher phosphorus concentrations than basins with more natural landcover (Houser and Richardson 2010, Alexander et al. 2008). Other studies have shown that converting more natural landscapes to urban uses tends to increase phosphorus loading more than nitrogen loading due to the conversion of formerly pervious surfaces that infiltrate water to impervious surfaces that encourage surface flow. Activities such as using detergents with phosphate and lawn fertilizers with phosphorus also contribute to an increase of P with urbanization.

It is difficult to tie phosphorus inputs on a landscape, such as fertilizer and manure, to phosphorus outputs to surface water, as measured via in-stream monitoring. There is some evidence that phosphorus export to waters is more closely associated with soil erodability than watershed inputs (Libra et al. 2004). Activities that decrease the bank stability of flowing waters can increase sediment, and therefore phosphorus, inputs into the system. All told, the combined effects of basin and bank erosion, urbanization, and increased phosphorus inputs make human activity a major contributor to phosphorus loading in surface waters.

Nitrogen

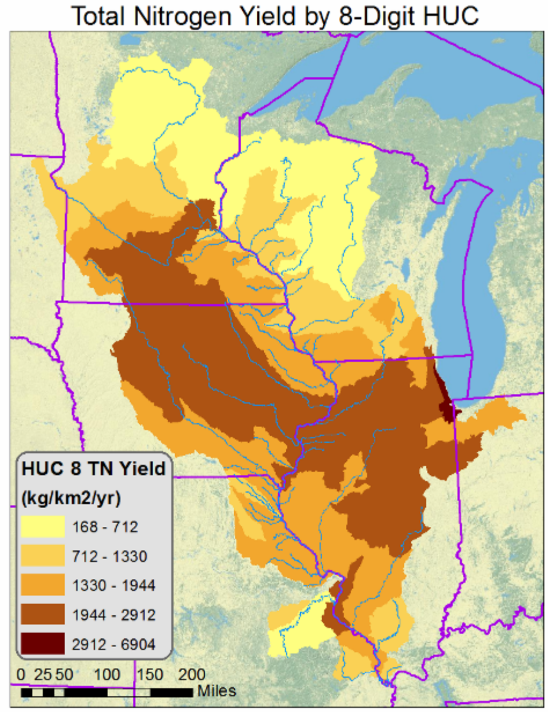


Figure 3-2: Modeled nitrogen yields for HUC 8 watersheds, as calculated by Robertson et. al. (2009).

Nitrogen (N) is a nutrient found in surface water, generally at higher concentrations than P. The major forms of reactive nitrogen in biological cycles are nitrate/nitrite (NO_x), ammonia/ammonium (NH_x), and organic nitrogen. Two important nitrogen-centric reactions in surface waters are nitrification, in which ammonia is converted to nitrate, and denitrification, in which nitrate is converted into non-reactive atmospheric N_2.

As with phosphorus, nitrogen can originate from point and non-point sources. Non-point nitrate sources include natural and agricultural plant growth and fossil fuel combustion; ammonia sources include manure and fertilizer (Bobbink et al. 2010). Plant-driven fixing of nitrogen in soil is an important natural (and agricultural) source, converting some of the nonreactive N_2 in the atmosphere to reactive nitrogen. Nitrate and ammonia are much more likely than phosphorus to deposit in surface water via air, particularly in the past 200 years as anthropogenic sources of nitrogen, such as combustion, mass production of manure, and regular tillage, have increased atmospheric concentrations of reactive nitrogen. Since 1860, atmospheric deposition of N in the UMR basin has increased from approximately 100-700 to approximately 500-1,000 mg/m^2 per year (or kg/km^2 per year, which allows cross-referencing with Figure 3-2) (ibid). Point sources such as CAFOs (and smaller animal feeding operations) and wastewater treatment plants are important sources of nitrogen in surface water as well.

In the UMR basin, elevated nitrogen concentrations are associated with runoff from agricultural watersheds, particularly fertilized row crops, and greater rainfall (Alexander et al. 2008). Nitrogen concentrations in the UMR mainstem remain similar moving downstream until the significant increase observed at Pool 26, which contains the mouth of the Illinois River, a significant tributary that likely contributes excess nitrogen to the UMR (Houser and Richardson 2010, Sullivan et al. 2002). As with phosphorus, human activity is a major driver of nitrogen concentrations, though unlike phosphorus, agriculture appears to have a greater impact than urbanization. This is congruent with SPARROW model results, as seen in Figure 3-2.

Unlike phosphorus, nitrate and total nitrogen (TN) concentrations tend to decrease in rivers and streams during periods of high flow, despite the overall increase in load during such events (Hubbard et al. 2011). Modeling by Donner et al. (2002) indicates that the significant year-over-year variation in nitrate loading to the UMR mainstem and tributaries can be partially explained by nitrate building up in cultivated soils and flushing in years with heavy precipitation. This may be due to the fact that nitrogen has a lower affinity for particles than phosphorus, and unlike phosphorus, both surface and subsurface water flow (such as drain tile and ditches) can contribute significant loading to waters (Alexander et al. 2008).

Effects of Land Cover/Use, Geomorphology, and Hydrology

Several factors affect how nutrients move from sources (as described previously) and are ultimately expressed as surface water concentrations (as described in the following section). These factors include land cover and land use, geomorphology, and hydrology.

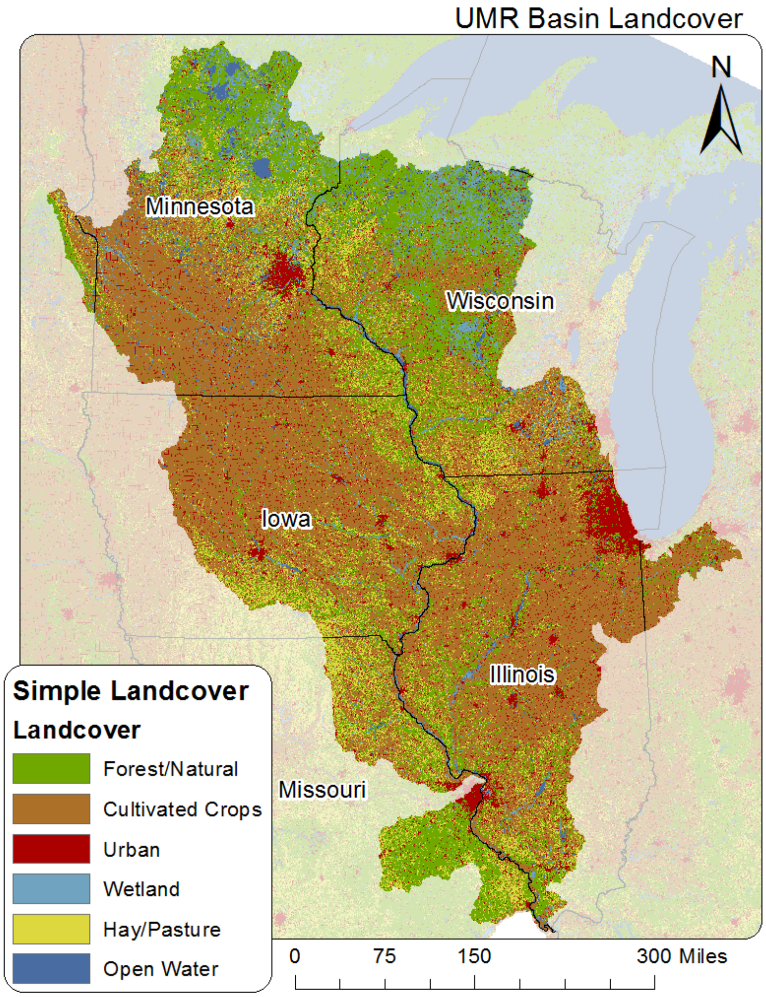


Figure 3-3: Land cover/land use in the UMR, derived from Landsat 7 (National Land Cover Database, USGS).

Landscape

Much of the original prairie and forest of the UMR basin has been cleared for agricultural use, including row and perennial crops and pastures. Urban land has displaced some natural and agricultural land as well, as the population in the region has grown over the past 150 years (Turner and Rabalais 2003).

Many studies have linked nutrient concentrations in surface waters with agricultural and urban land use. Robertson et al. (2008) found that land use characteristics, including percent agricultural and percent urban, were strongly correlated with nutrient concentrations in non-wadeable Wisconsin rivers. USGS SPARROW modeling results also suggest similar correlations with respect to yields, estimating agricultural and urban N and P yields per square kilometer many times higher than yields in forested areas, and re-stating the broader link between high-agriculture watersheds and high nutrient concentration surface waters (Alexander et al. 2004, Robertson et al. 2009). Randall and Mulla (2001) compiled evidence from numerous papers establishing the connection between both agricultural land and fertilizer use and nitrate concentration in UMR waters. As a result of these studies as well as other work, the strong influence of agricultural and urban landscapes on nutrient surface water concentrations, both generally and in the UMR basin, has been widely accepted for decades.

Comparing the land use in Figure 3-3 to the nutrient yields in Figure 3-1 and in Figure 3-2, it appears that predominately natural areas, such as northern Wisconsin and Minnesota, contribute relatively little to overall phosphorus and nitrogen. The yields differ in more human-dominated landscapes, with phosphorus yields more concentrated around urban areas (the Twin Cities, Chicago, and St. Louis metropolitan regions in particular stand out) and nitrogen yields apparently driven by both urbanization and cultivated crops.

Conservation Successes, Challenges, and Ongoing Efforts

Although much of the preceding discussion has focused on the contribution of agricultural land use to UMR nutrient loading, agricultural conservation practices have been implemented basinwide and have resulted in significant reductions in nutrient loading. The USDA NRCS Conservation Effects Assessment Project (CEAP) report *Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Upper Mississippi River Basin* (USDA 2010) found that current agricultural conservation practices do significantly reduce nutrient loading to the UMR and that further conservation practices could lead to additional reductions. Specifically, the report stated that existing conservation practices reduce overall loads of nitrogen and phosphorus in the UMR mainstem by about 21 percent and 40 percent respectively (USDA 2010). The report further notes that additional reductions of up to 43 percent for phosphorus and 51 percent for nitrogen could potentially by applying soil conservation and nutrient management practices to 36 million under-treated acres throughout the basin (USDA 2010).

Despite the successes from conservation practices, agricultural land use is a predominant contributor to UMR nutrient levels, as discussed earlier in this chapter. The CEAP report describes areas where conservation can be improved, including an emphasis on the importance of complete and consistent nutrient management as well as a suite of practices to address both soil erosion and nutrient management simultaneously (USDA 2010). The CEAP report notes that the most critical conservation concern in the region is the loss of nitrogen through leaching and that about 51 percent of cropped areas require additional nutrient management to address excessive levels of nitrogen loss in subsurface flow pathways, including tile drainage systems (USDA 2010). Other authors, including Houser and Richardson (2010), have also discussed additional and alternative agricultural practices that could significantly reduce P and N loading to theUMR and the Gulf of Mexico.

A number of ongoing conservation efforts are being pursued to both address the challenges posed by nutrients in the UMR basin and to build on past successes. These efforts include, but are not limited to the following:

- ***Mississippi River Basin Health Watersheds Initiative:*** Beginning in federal fiscal year 2010, The USDA Natural Resource Conservation Service (NRCS) initiated the Mississippi River Basin Healthy Watersheds Initiative (MRBI) to work with conservation partners and build on the past efforts of agricultural producers in a 13-state area within the basin. In this program, NRCS is working with producers using a conservation systems approach to manage and optimize nitrogen and phosphorus within fields to minimize runoff and reduce downstream nutrient loading utilizing programs including Environmental Quality Incentives Program (EQIP) and Wetlands Reserve Program (WRP). Participating states include UMR basin include, Illinois, Indiana, Iowa, Minnesota, Missouri, Ohio, South Dakota, and Wisconsin.
- ***NRCS Drainage Water Management Team:*** In 2011, NRCS formed a national team to assist states in the voluntary conservation efforts to reduce nitrates leaving the intensively drained farmlands in the Upper Mississippi River Basin. This team will work in close collaboration with partners to develop and implement an action plan that helps producers voluntarily apply nutrient and water management practices to reduce nitrate loading into the small watersheds in the Upper Mississippi River Basin.
- ***Discovery Farms:*** This is an on-farm systems research, evaluation, and demonstration program that collects information on operating farms. The Discovery Farms program brings together producers, agricultural organizations, university researchers, and government agencies to develop an approach to production agriculture that results in environmentally compatible and economically sustainable farms. Among UMR basin states, Minnesota, North Dakota, and Wisconsin have Discovery Farm programs.
- ***Ongoing Technical Assistance*:** The existing network of local Soil and Water Conservation Districts (SWCD) and NRCS offices provides critical assistance to landowners that are implementing agricultural BMPs and constructing conservation structures. This system has been in place for decades and local SWCD/NRCS offices work closely with other local, state and federal agency

partners as well as various non-governmental entities such as Pheasants Forever, Ducks Unlimited, The Nature Conservancy and others to meet water quality, conservation and fish and wildlife habitat goals. A number of programs and initiatives exist to promote and encourage landowners and farmers to adopt and implement best management practices (BMPs) on the landscape.

In addition to the programmatic approaches described above, scientific and technological advancements have allowed for improvements in the areas of precision farming and targeting of key watersheds in limiting nutrient loss from agricultural landscapes.

Geomorphology: Effects of Tributaries and Impoundment

Rivers such as the UMR mainstem and major tributaries can be viewed as linear systems with gradual changes in hydrology, chemistry, and biology along their length, punctuated by geomorphic phenomena such as mouths of tributaries or dams that cause sudden alterations (Houser et al. 2010).

On the UMR mainstem, the majority of discharge and nutrient load comes from a few major tributaries, such as the Iowa, the Des Moines, the Illinois, the Minnesota, and the Missouri Rivers, with minor tributaries making up just a small fraction of the total delivered water, nitrogen, and phosphorus – approximately 5-15%, depending on the parameter and reach (Meade 1996; Short 1999).

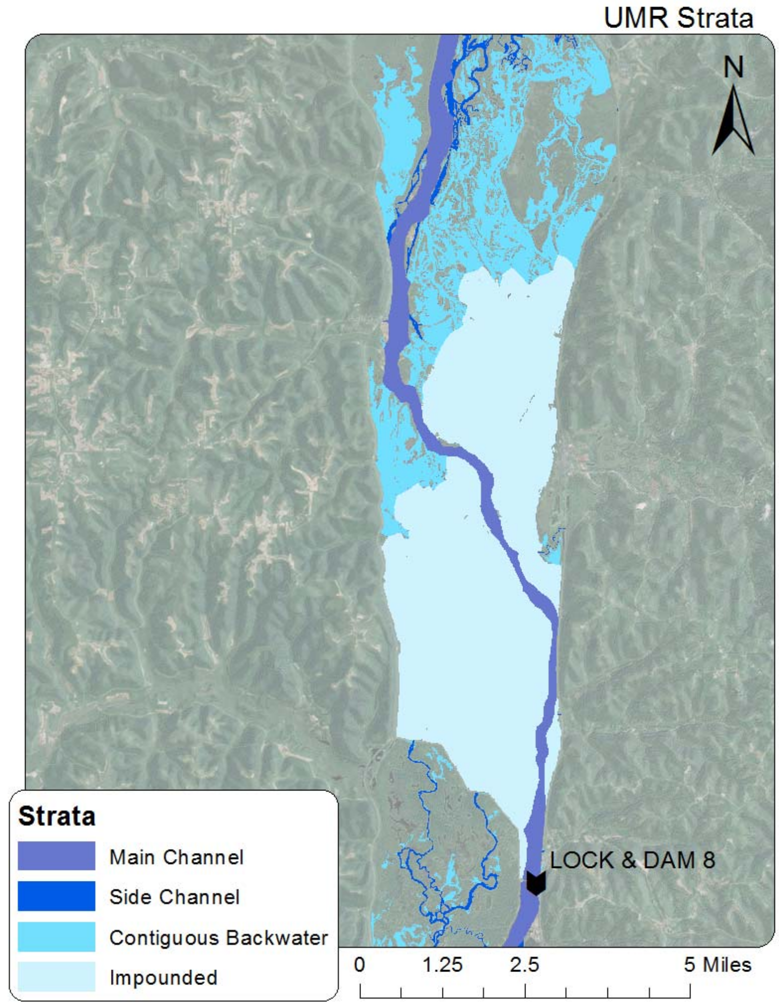


Figure 3-4: Simplified strata on a section of CWA Assessment Reach #4 (Root River to Wisconsin River). A dam creates an impounded area in this reach, creating a lake-like system and inundating previously dry or periodically flooded land.

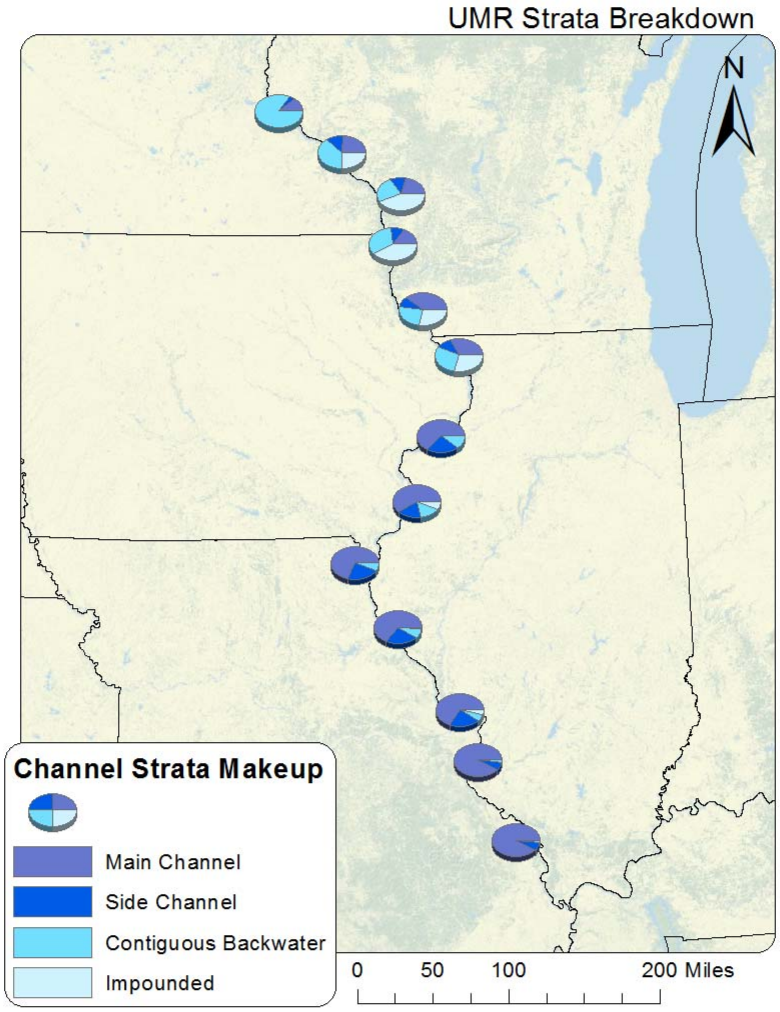


Figure 3-5: Relative proportion of channel strata in the UMR mainstem. Impounded and backwater strata decline markedly after the Wisconsin/Illinois border. The main channel is the dominant strata from St. Louis southward. This has implications for nutrients, and sediment transport specifically.

On the impounded portion of the UMR, flow is affected by a series of navigational locks and dams. The impounded water behind these dams differs significantly in hydrologic regime from the more complex and natural braided channel/floodplain structure observed in the upper portions of the impounded pools.

The combined effect of dams and naturally occurring river features in the impounded reaches of the UMR results in a complex structure, particularly in the upper impounded reach (through Pool 13). This structure includes the main channel, side channels, backwaters and impounded areas (see Figure 3-4). Habitat and water quality characteristics can vary substantially among these aquatic areas.

Moreover, in regard to nutrients specifically, the accumulation and cycling of nutrients, and the expression of nutrient impacts, can vary greatly by strata. For example, velocity varies significantly between the main and side channel and backwaters and affects the formation and persistence of algal blooms, as discussed further in Chapter 4. In the unimpounded reach (below the confluence with the Missouri River), structure is less complex, though some side channels and backwaters do exist (see Figure 3-5).

Hydrology and Hydrologic Regime

As described in the preceding section, precipitation and flow rates can affect ambient concentrations of P and N. The following discussion provides more detail regarding the hydrology and hydraulic regime of the UMR. This background information is important for the discussion of nutrient trends later in this chapter.

Historically, the UMR system has maintained a cyclical hydrologic regime. In the spring, rainfall and snowmelt increase the volume of water in the system and decrease the residence time. Generally the volume of water gradually decreases during the summer, with lowest discharges occurring in the fall and winter due to the lack of rainfall and therefore runoff (Figure 3-6).

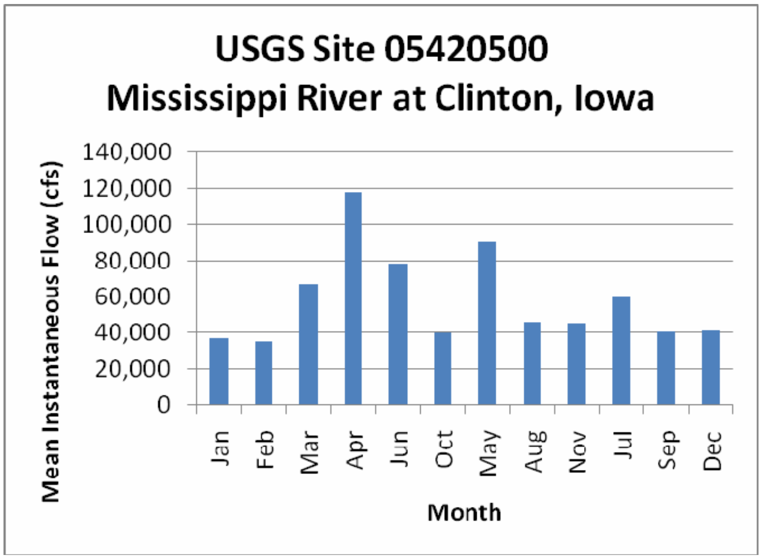


Figure 3-6: Monthly averages of instantaneous discharge of the UMR at Clinton, Iowa. For the period of 1953 to 2010.

Under different hydrologic conditions, a specific area may have varied characteristics, as higher water inundates areas that are usually dry or swampy and connects diverse areas to one another, decreasing chemical and physical distinctions between strata. In regions that maintain the braided channel structure, areas may alternate between side channel, contiguous (connected to flowing water) backwater, and isolated backwater strata. Impounded (artificial or natural) regions tend to remain continually submerged, and have more consistent rates of discharge and residence times throughout the year.

Discharge in the UMR varies with the amount of rainfall received by the basin, as with any other river system. Figure 3-7 shows precipitation at Minneapolis, with a broad "v" trend in the graph, where rainfall amounts decreased to a low in the Dustbowl years around 1930, then generally increased (albeit inconsistently) to the present. Houser et al. (2005) saw this same trend for the entire UMR. Data summarized by LTRMP data indicate that discharge has been stable to slightly increasing in the UMR mainstem between 1993-2008 (Johnson and Hagerty 2008). Overall, this information suggest an upward trend in precipitation and discharge since approximately 1940, which has likely contributed to increased runoff and erosion in the UMR basin, carrying with it more phosphorus and nitrogen into surface water.

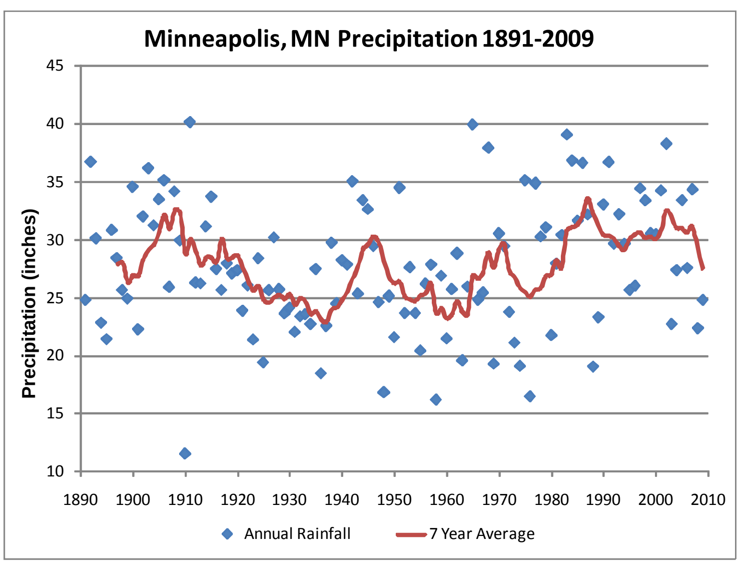


Figure 3-7: Precipitation measured at Minneapolis, Minnesota (from the NOAA Western Regional Climate Center).

Table 3-1: UMR Tributary Flow Characteristics

River	Low Flow ($m^3 s^{-1}$)	High Flow ($m^3 s^{-1}$)	Drainage (km^2)
Minnesota	11.4	416.3	43,631
Mississippi	51.5	331.3	51,317
St. Croix	53.5	291.7	20,002
Vermillion	0.6	3.5	676
Cannon	7.8	60.6	3,749
Chippewa	96.3	416.3	24,622
Zumbro	8.5	46.7	3,662
Whitewater	2.7	6.7	834
Trempealeau	7.6	24.2	1,856
Black	14.2	120.1	5,840
LaCrosse	3.4	6.4	1,217
Root	10	48.7	4,299
Upper Iowa	4	37.9	2,565
Wisconsin	124.3	444.6	30,809
Turkey	6.9	71.1	4,356
Grant	2.4	7.9	815
Maquoketa	10.9	65.1	4,807
Apple	1	10.5	653
Plum	1.9	12.4	707
Wapsipinicon	8.1	132	6,525
Rock	79	413.5	28,077
Iowa	50.1	623	32,727
Skunk	6.4	239.3	11,223
Des Moines	20.5	589.1	37,394
Salt	1.4	162.6	7,391
Cuivre	0.2	38.2	3,175
Illinois	212.1	1608.6	74,522
Missouri	1,106	4,924	1,353,000
Meramec	16.6	224.6	10,247
Kaskaskia	4	294.5	14,981
Big Muddy	2.8	161.4	5,665

Table from Wasley (2000) - Data range 1970-1997

Low Flow – 90 percent chance flow;
High Low – 10 percent chance flow

The hydrology of the UMR is strongly tied to the influence of tributaries. The 12 most hydrologically significant tributaries to the UMR contribute about 80 percent of its total flow (Lubinski 1999). Table 3-1 lists 30 of the 32 most significant UMR tributaries, which account for over 90 percent of the drainage area of the basin (Wasley 2000)[4]. Data for the Missouri River has also been added for the purposes of this report. The low flow and high flow columns contain the flow, in cubic meters per second, that each river exceeds in approximately 90 percent of measurements and in 10 percent of measurements, respectively. The 90 percent flow approximates baseflow; 10 percent flow is roughly equivalent to flood stage.

Figures 3-8 and 3-9 display the 90 percent and 10 percent data from Table 3-1 in pie chart form, less the Missouri River, which has an overwhelming influence that obscures the role of smaller rivers in the upper basin. Some characteristics are common between the two charts, with two prominent examples being the flow of the Illinois River outstripping other rivers, and the cluster of fairly small discharges from the Zumbro through Upper Iowa Rivers, and again from the Turkey to the Wapsipinicon Rivers. The most obvious distinction between the two charts is the overall disparity in flows between large and small tributaries; in Figure 3-8 seven rivers account for most of the cumulative discharge, whereas Figure 3-9 shows a more equal distribution of flow between tributaries. The Kaskaskia River, for example, represents a vanishingly small section of the overall chart under base flow conditions, but a much more significant amount of the total flow under flood conditions.

The implication for the hydrology of the UMR is that base flow conditions are dominated by a few of the larger rivers, whereas smaller rivers likely increase their contribution to overall flow under extreme conditions – reflecting the larger dynamic range, or "flashiness" of smaller rivers.

Not shown on the charts is that the Missouri dominates tributary inputs to the UMR below St. Louis. Table 3-1 demonstrates that discharge values for the Missouri are 3-5 times greater than the next most significant contributor, the Illinois.

[4] Low flow and high flow data was not available for the Coon Creek and Bad Axe Rivers, but these two drain the smallest areas of the 32 tributaries identified by Wasley.

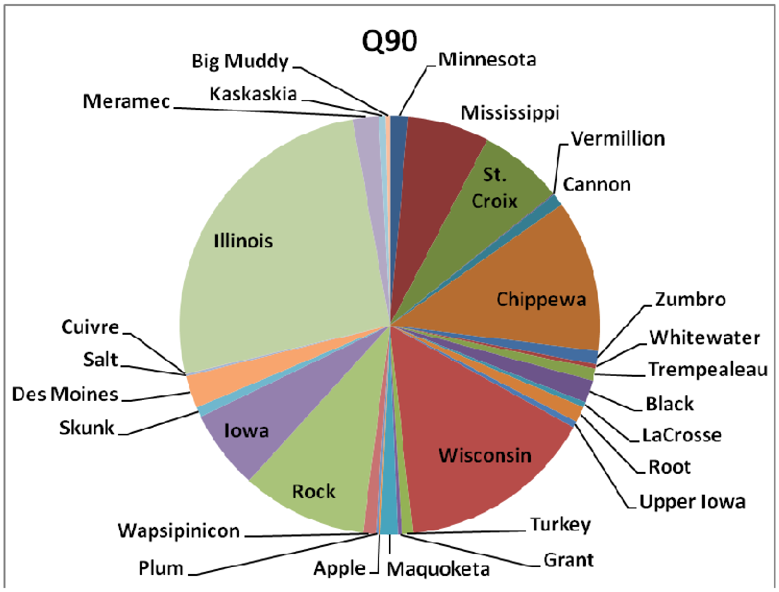


Figure 3-8: Relative discharges of UMR tributaries (excluding the Missouri River) at 90% likelihood flow.

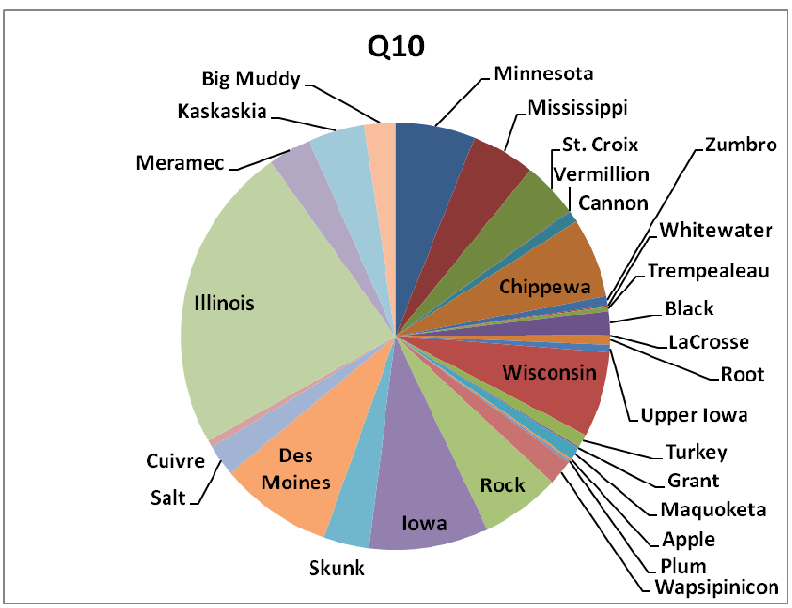


Figure 3-9: Relative discharges of major UMR tributaries (excluding the Missouri River) at 10% likelihood flow.

Trends

Long Term Concentrations and Trends

Numerous researchers have investigated the historical concentrations and trends of nutrients on the UMR and have observed increasing concentrations over time, including Houser and Richardson (2010), Engstrom et al. (2009), and Goolsby et. al (2000). These investigations are typically focused on total nitrogen or nitrate, which have a historical record of measurement extending to approximately 1900, and less frequently on total phosphorus, which lacks a long-term historical record but can be estimated by other techniques such as core sampling. Overall, these investigations have indicated that both nitrate and total phosphorus concentrations in the UMR have increased substantially from pre-settlement conditions. However, the extent of historical information is limited in terms of both parameters available and spatial coverage. Therefore, investigations into nutrient trends on the UMR often rely upon statistical models in addition to historical data to draw conclusions. A summary of information available regarding historical trends of nitrogen and phosphorus on the UMR follows.

Nitrogen

Estimates of the increase in historical nitrogen concentrations vary between 2- and 10-fold, depending upon the research conducted and the parameter examined. Goolsby et al. relied heavily upon a 1906-7 USGS study of nitrate in the UMR basin in their 1999 paper, and compared these results to more recent nitrate concentrations. Their focus was on loading to the mouth of the Mississippi/Atchafalaya River Basin (MARB), and their data set includes a number of sites in the UMR basin, including on the Illinois, Rock, Cedar, Des Moines, and Minnesota rivers – but only one mainstem site (at New Orleans). The Goolsby et al. study found that nitrate concentrations at the mouth of the MARB increased 2-3 times between the 1955-70 and the 1980-96 span. As seen in Table 3-2, their data also showed that concentrations at many UMR basin sites more than quadrupled between the first recorded concentrations and 1980-96 levels, and that MARB concentrations measured at New Orleans increased approximately 10-fold in the same time span.

The data show that concentrations of nitrate in tributaries to the Mississippi are higher than concentrations in the Mississippi itself (as measured at New Orleans) for each of the time spans examined. That pattern is consistent with more recent LTRMP data where, for example, UMR main stem samples (all strata) had 1.69 mg/L mean, while the Illinois River had a 3.05 mg/L mean.

Table 3-2: Historic Mean Nitrate Concentrations in UMR Basins

River Basin	Year(s)	Number of Samples	Nitrate (mg/L)
Upper Illinois	1896-99	Weekly	1.89
	1906-07	36	1.49
	1980-96	175	4.25
Lower Illinois	1897-99	Weekly	1.01
	1906-07	36	0.97
	1980-96	187	4.12
Rock	1906-07	36	0.86
	1980-96	152	3.49
Cedar	1906-07	37	0.7
	1944-50	175	1.53
	1980-96	83	4.67
Des Moines	1906-07	37	0.75
	1955-65	28	3.02
	1980-96	88	4.12
Minnesota	1906-07	30	0.32
	1980-96	122	4.19
Mississippi (New Orleans/ St Francisville)	1900-01	9	0.14
	1905-06	52	0.56
	1955-65	308	0.65
	1980-96	182	1.45

From Goolsby et al. 2000

Mean nitrate levels recorded at New Orleans in the 1980-96 span are similar to the nitrate mean of 1.24 mg/L recorded by the EMAP-GRE program in the UMR main channel border, and to the LTRMP results described above. In all, the Goolsby data suggest between a 4-fold increase and a 10-fold increase in nitrate concentrations on the UMR over the past 100 years, depending on the results for a particular sampling point/tributary basin.

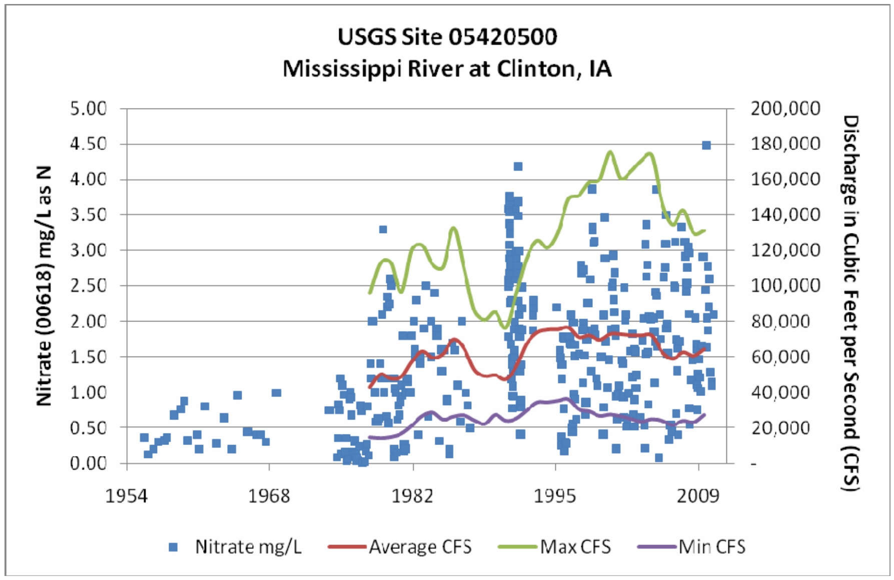


Figure 3-10: Nitrate concentrations at Clinton, Iowa. Average, maximum, and minimum discharges are displayed as 5-year moving averages.

USGS site-specific data illustrate some of the more recent (1955-present) trends in nitrate concentrations. With about 445 nitrate samples and records extending back to 1956, the site at Clinton, Iowa presents the most complete picture of trends. Figure 3-10 shows median concentrations from 1956 to approximately 1968 hovering around 0.4 mg/L, slightly lower than the 0.65 mg/L recorded for the same time period in New Orleans. Between approximately 1968 and 1990 the upper limit of nitrate concentrations steadily rises, and the median concentration from 1990-2010 is 1.8 mg/L, somewhat higher than the 1.45 recorded in New Orleans for a slightly earlier period.

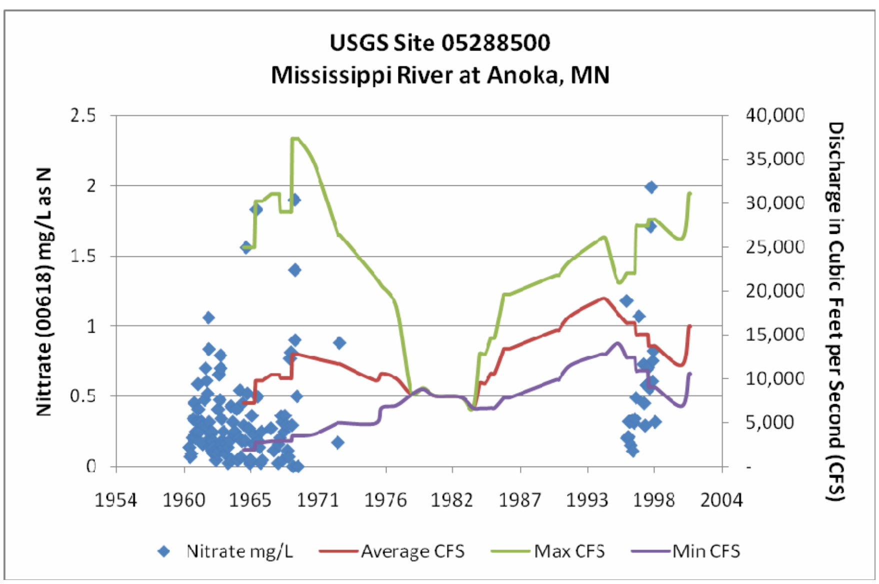


Figure 3-11: Nitrate concentrations at Anoka, Minnesota. Average, maximum, and minimum discharges are displayed as 5-year moving averages.

At Anoka, Minnesota (Figure 3-11), the UGS site with the next best combination of number of samples and period of record, a similar pattern of increase is seen, though the concentration values are generally lower than those seen in the Clinton, Iowa data.

At first glance the Anoka data sets from 1960-1970 and 1995-1998 seem to have very similar distributions. However, the median for the first span is 0.2 mg/L, whereas the median for the more recent data is 0.5 mg/L, a more than twofold increase.

Table 3-3: Minnesota Milestone Data Summary (Trends from 1950-60s to 1990s)

Minnesota			
	↑	=	↓
BOD	0	0	12
TSS	0	11	1
TP	0	3	8
NO_x	10	3	0
NH_x	0	0	13

Interstate UMR			
	↑	=	↓
BOD	1	0	12
TSS	2	8	3
TP	0	4	9
NO_x	10	3	0
NH_x	0	0	13

St. Croix			
	↑	=	↓
BOD	0	0	6
TSS	0	0	5
TP	0	0	5
NO_x	1	2	0
NH_x	1	2	1

Non-interstate UMR			
	↑	=	↓
BOD	0	3	11
TSS	0	8	6
TP	0	11	3
NO_x	12	1	0
NH_x	0	1	12

The ↑ column shows the number of sites in the basin with an increase in concentrations between 1950-60s and 1990s; = totals sites with no trend, and ↓ totals sites with a decreasing trend. Some sites had insufficient data for trend analysis.

Data compiled by the MPCA through the River Milestone Monitoring Program (Minnesota Pollution Control Agency 2010) compares concentrations and values between the 1950s - 1960s and the 1990s for BOD_5, TSS, TP, NO_x, and NH_x. Table 3-3 shows how many sites displayed increased, decreased, or relatively unchanged parameter values from the 1950s/1960s to the 1990s in the UMR basin and the basins of three major tributaries. Most parameters show decreasing (improving) trends at most sites in all basins. The exception to the general trend is nitrate, which increased in concentration during the time span examined at a majority of sites in three of the four basins.

The MPCA report foregoes analysis of total nitrogen in favor of nitrate, which is the approach used in most of the literature. However, Houser and Richardson (2010) found that total nitrogen has doubled in the lower Mississippi, as opposed to the 4- to 10-fold increase in nitrate in the same region. More recent increases in TN (since 1970) are tied directly to nitrate; all of the increase in TN concentration at the mouth of the MARB in the past 40 years is due to an increase in nitrate levels (Goolsby et. al., 2000). Research on Gulf of Mexico loading indicates that the disparity between TN and nitrate loading trends is due to a decrease in particulate nitrogen as a result of dams on the Missouri (Goolsby and Battaglin, 2000). However, LTRMP data indicate that study reaches of the UMR north of the confluence with the Missouri have lower or equivalent TN concentrations with the Open River reach south of the confluence (Johnson and Hagerty, 2008), and the Missouri has been shown to have an overall diluting effect on nitrate (Meade, 1996). This indicates that, at the confluence with the Missouri, there is still a significant shift toward particulate nitrogen making up a greater portion of TN, though evidence suggests that the influx of particulate nitrogen is not as great as it has been historically.

Without a monitoring program that has recorded nitrate or nitrogen levels in the UMR prior to 1951 (the earliest sample of either parameter is from the USGS station at Keokuk, IA), Goolsby et al.'s study of concentrations in the MARB discussed above has assembled the best long-term nitrogen data set available. Other studies that have examined historic (pre-1950) nitrogen flux to the Mississippi or the Gulf of Mexico have used the same data as Goolsby et al., or relied heavily upon their work (Houser and Richardson, 2010).

The estimates based on the Goolsby data set represent the most likely historical scenario. While they are not without issues (the lack of direct records for the UMR, primarily, and a lack of records prior to European settlement), they agree with the indirect evidence. Increased runoff and subsurface flow would be expected to increase nitrogen concentrations in surface waters. Donner et al. (2002) conclude that about a quarter of the upward trend in nitrogen concentrations in the Mississippi River Basin since the 1950s is due to increased rainfall. The remaining increase accords with the increase in nitrogen loading that would be expected as a watershed like the UMR basin becomes more agricultural and urban.

Phosphorus

Data records for phosphorus are significantly shorter than those for nitrogen. National-level monitoring of phosphorus on the Mississippi has only been conducted since 1972 (Houser and Richardson, 2010); the MPCA has records available via the US EPA STORET database that date back to 1958. Any analysis of long-term trends in phosphorus levels must therefore rely upon sediment cores obtained from the bed of the river. The only study of this kind on the UMR thus far was conducted in Lake Pepin (Engstrom et al. 2009).

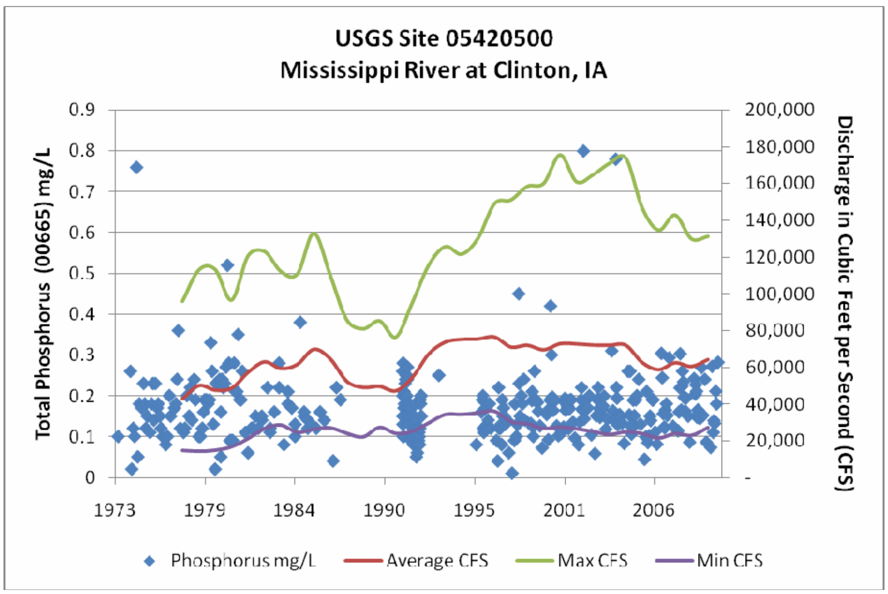


Figure 3-12: Phosphorus concentrations at Clinton, Iowa. Mean, maximum, and minimum discharges are displayed as 5-year moving averages.

The Lake Pepin sediment study determined that phosphorus concentrations in sediment have doubled since 1830 (the approximate date of initial European settlement in the region), and that phosphorus concentrations in water have quadrupled, from 50 µg/L to 200 µg/L, from pre-settlement times to the present. The study also concluded that most of the increased in total phosphorus concentration occurred after 1970.

Two difficulties exist in attempting to extrapolate long-term trends from Lake Pepin to other parts of the UMR. One is the proximity of the impoundment to the Twin Cities metropolitan area. Water quality downstream of the Twin Cities has been closely linked to the output and treatment capacity of the Twin Cities Metropolitan Wastewater Treatment Plant since 1938, when the plant was built (Lubinski 1999). The other difficulty is the unique nature of Lake Pepin as a large, natural impoundment of the Mississippi that retains much more particulate matter than it discharges downstream, where some amount phosphorus may be retained in the lake's sediment. In light of these two distinct characteristics, extrapolating results from Lake Pepin the rest of the UMR is challenging and it is possible that the UMR as a whole did not experience increases in phosphorus loading at the same time or in the same manner as Lake Pepin. As such, further core sampling work in other areas of the UMR would provide important historic data in estimating phosphorus trends.

In recent history, UMR TP concentrations have either remained flat (Johnson and Hagerty, 2008) or decreased somewhat (Houser and Richardson, 2010), indicating that much of the increase in phosphorus loading to the UMR occurred prior to 1990. The trends for major rivers in Minnesota (Table 3-3) since the 1950s and 60s are generally decreasing or flat. This agrees with USGS site data from Clinton, Iowa as shown in Figure 3-12, where TP concentrations appear to have been relatively stable from the 1970s to the present.

Pollutant Loading

Computation of main channel load and cumulative tributary load illustrates that UMR nutrient loading is mostly determined by inputs from major tributaries. Wasley (2000) calculated UMR loads for nutrients and some nutrient-related parameters at major tributaries and some corresponding UMR monitoring sites. Figure 3-13 and Figure 3-14 chart the cumulative tributary load along with the calculated UMR load. TN load in the UMR mainstem appears to closely correspond with cumulative tributary TN load. TP load in the mainstem, though it also corresponds to some degree with cumulative tributary load, appears to vary less directly with tributary loading than TN.

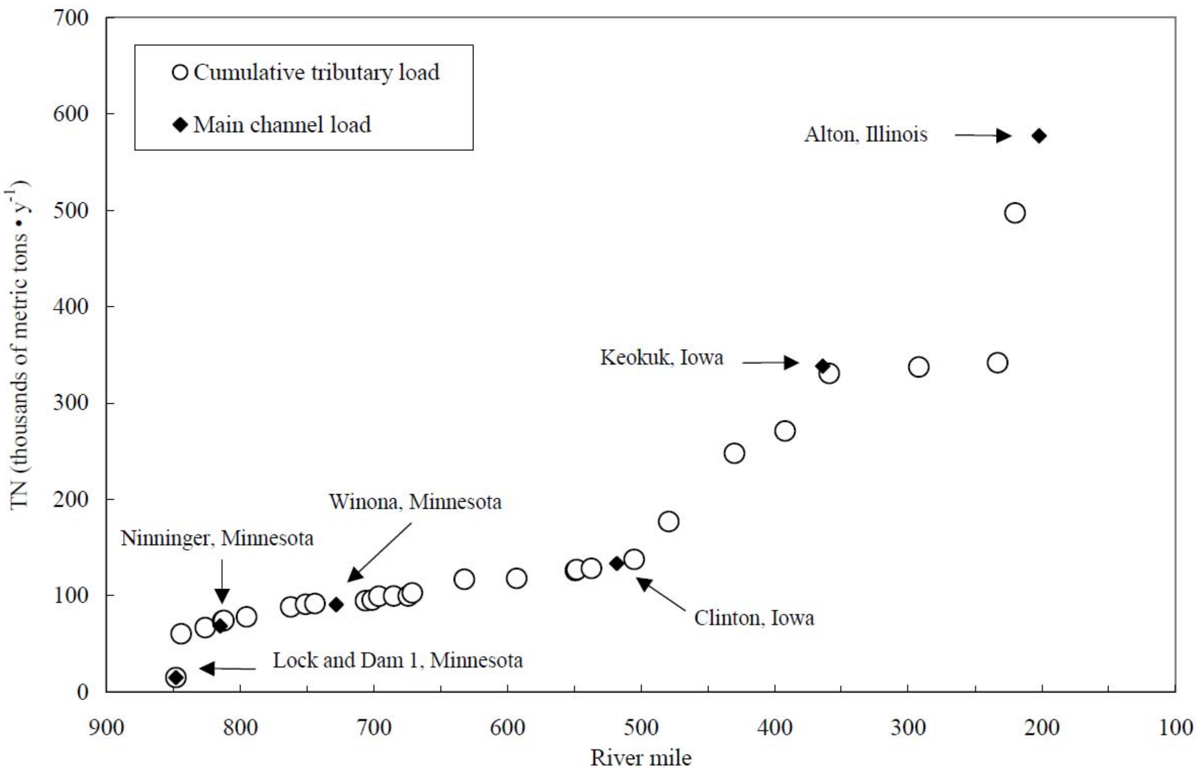


Figure 3-13: Cumulative loads of total nitrogen (TN) through the Upper Mississippi River. Arrows identify locations of Upper Mississippi River mainstem sites (from Wasley 2000).
Note that Alton is downstream of the mouth of the Illinois River, but upstream of the Missouri River.

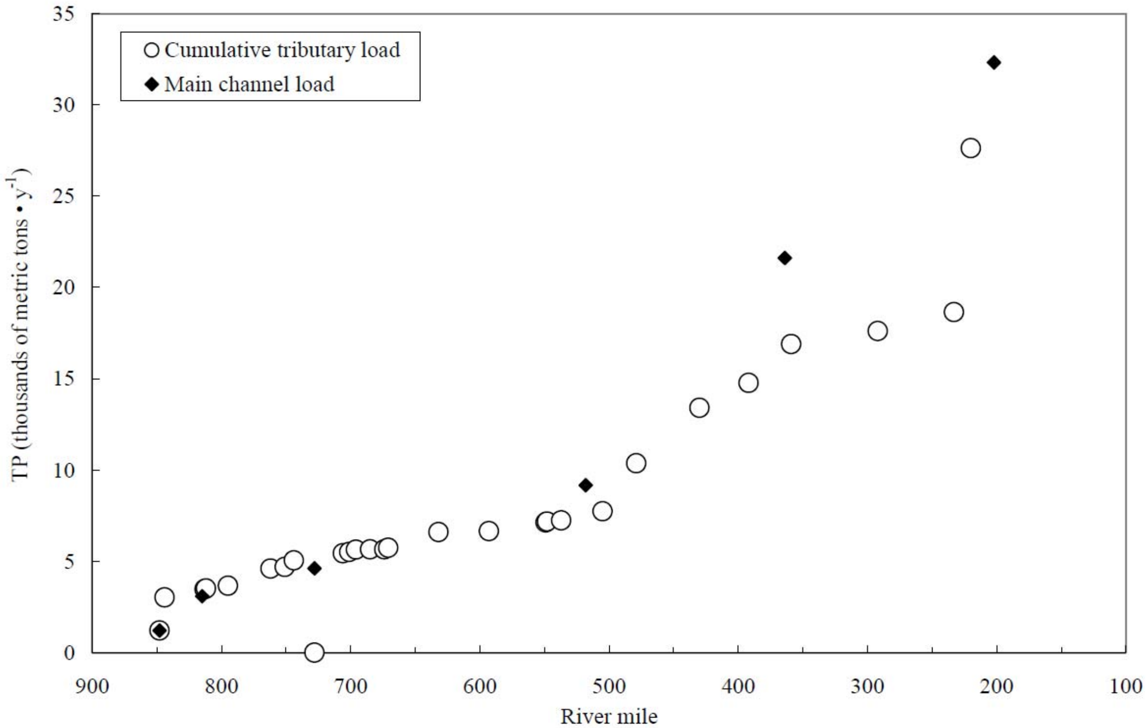


Figure 3-14: Cumulative loads of total phosphorus (TP) through the Upper Mississippi River (from Wasley 2000).

Conclusions Regarding Historic Trends of N and P

The limited direct evidence that exists for nutrient levels prior to 1950 indicates an approximately 4-fold increase in phosphorus and a 4- to 10-fold increase in nitrogen concentrations in the UMR from pre-settlement to post-settlement conditions. Direct evidence for nitrogen (particularly nitrate) concentrations is stronger than that of phosphorus, as it is based on water samples recorded in the UMR basin around 1900, although application of that evidence to the UMR is limited due to the lack of nitrate sample locations on the Upper Mississippi River itself. Phosphorus concentrations interpreted from lake bed core samples are the strongest evidence of phosphorus water concentration increases, but are hampered by having been conducted only in Lake Pepin, a unique feature on the UMR which may or may not be representative of the increases in phosphorus in the river as a whole.

Augmenting the limited direct historical evidence of nutrient loading trends is the degree to which these trends correlate with the indirect evidence. Between 1830 and the present, most of the land within the UMR basin underwent a conversion from primarily natural, permanent vegetative cover to agricultural and (to a lesser degree) urban land uses, and the human population grew dramatically. Numerous studies have linked urban effluent with phosphorus and nitrogen concentrations, and agricultural runoff with nitrate concentrations (including Alexander, 2004; Alexander, 2008; Houser and Richardson, 2010; and Terrio, 2006). Given these links and the demographic and landcover trends in the UMR basin, increases in nutrient concentrations are expected in the UMR. While determining the precise degree to which loading and concentrations have increased is difficult due to the lack of historical data, the evidence that loading and concentrations have increased significantly post-settlement is strong overall.

Current Conditions

While historic data are somewhat limited, there are robust data sets regarding current nutrient concentrations in the UMR. The most complete of these comes from the LTRMP, and EMAP-GRE provides extensive additional data for the main channel.

Main Channel

The 2008 LTRMP Status and Trends report (Johnson and Hagerty, 2008) summarizes TN and TP concentrations in the main channel (Figure 3-15 and Figure 3-16). TN is described in this report as exceeding US EPA ecoregion guidelines of 0.2 - 2.18 mg/L 50 percent of the time in the Upper Impounded Reach, and most of the time in the Lower Impounded and Open River reaches. Specifically, TN concentrations ranged from 1 to 8 mg/L between 1994 and 2002. TP is described as almost always exceeding US EPA ecoregion guidelines of 0.01 – 0.08 mg/L, with measured values ranging from 0.05 to 0.3 mg/L. While not calculated in the Status and Trends report, TP concentrations appear to regularly exceed the 0.1 mg/L Wisconsin standard as well. Additionally, TP concentrations are higher in the downstream study reaches (Pool 26, Open River) when compared to the upstream study reaches. In terms of temporal changes, the 2008 LTRMP Status and Trends report stated that TP and TN concentrations were stable over the time period addressed by the report (1994-2002).

EMAP-GRE data also represent a relatively current snapshot of the nutrients on the UMR main channel during the program's sampling period (2004-2006), as summarized in Table 3-4. The mean concentrations derived from the EMAP-GRE data (Table 3-4) are very similar to the LTRMP-derived means, indicating that the flat trend observed in LTRMP likely continued through at least 2006.

Taken together, data from the LTRMP and EMAP-GRE programs indicate that UMR nutrient concentrations have neither increased nor decreased appreciably in the past twenty years. However, a recent USGS study (Sprague et al. 2011) utilizing flow-normalized NASQAN and NAWQA data found increases in UMR nitrate concentrations at some locations in the period of 1980-2008. This finding echoes the pattern in MPCA River Milestone Monitoring program data discussed earlier in this chapter, where nitrate was the exception to the general trend of decreasing or leveling nutrient concentrations.

Table 3-4: Summary of EMAP-GRE Nutrient Data for the UMR (2004-2006)

Reach	Statistic	Mean DO	TP	Orthophosphate	TN	Nitrate	Percent Nitrate
Upper Impounded	First Quartile	5.1	0.13	0.04	1.2	0.54	45%
	Mean	7.8	0.17	0.08	1.9	1.05	55%
	Max	12.8	0.35	0.25	5.7	4.19	74%
Lower Impounded	First Quartile	7.5	0.14	0.03	1.8	0.75	42%
	Mean	8.7	0.17	0.06	2.7	1.71	63%
	Max	12.4	0.30	0.15	6.2	5.87	95%
Open River	First Quartile	6.9	0.21	0.09	1.4	0.65	46%
	Mean	7.2	0.25	0.11	1.7	0.93	55%
	Max	8.0	0.46	0.17	2.9	1.95	67%

All parameters in mg/L.

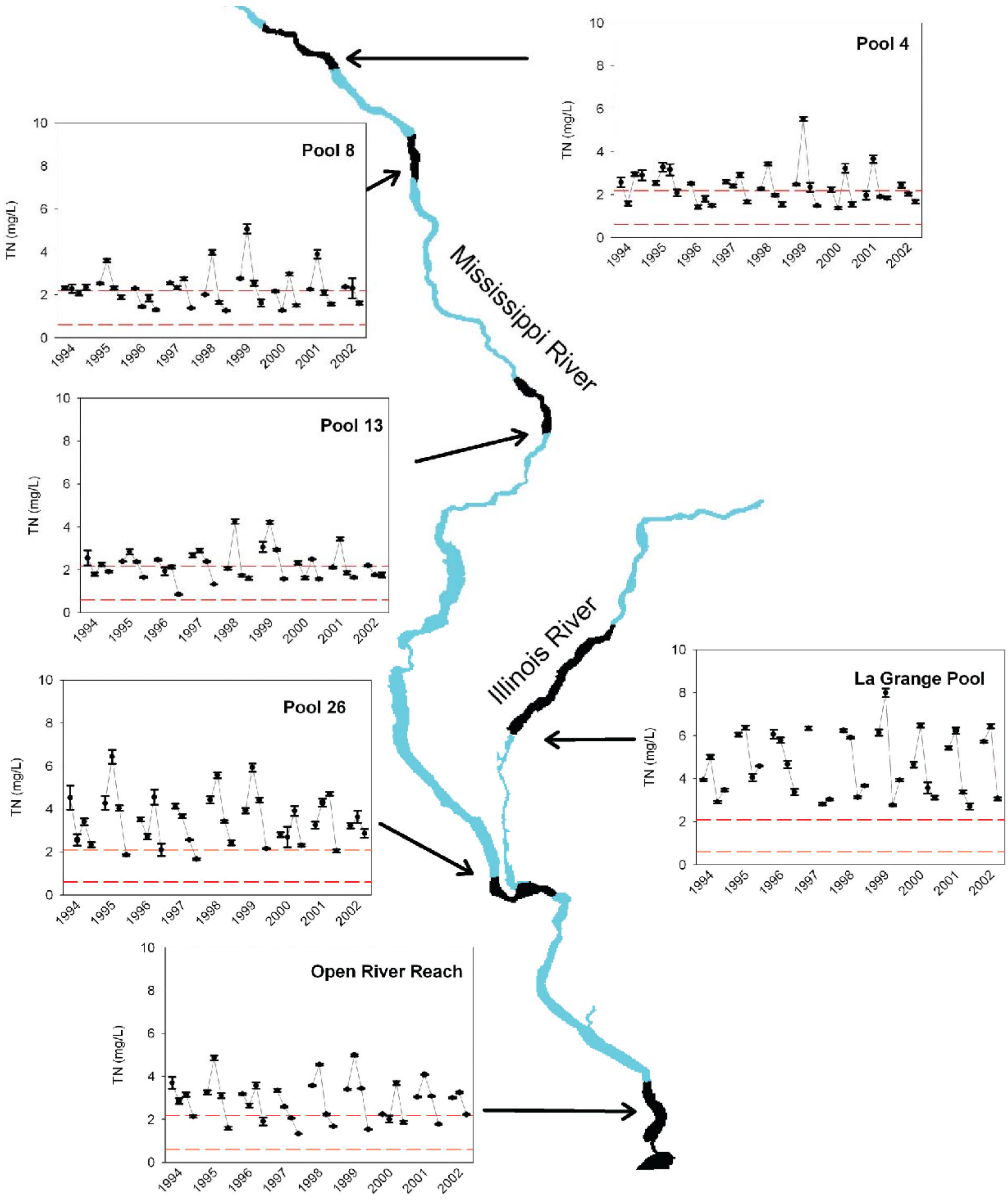


Figure 3-15: TN concentrations in the main channel of the six LTRMP study reaches from 1994 to 2002. Data points are means from SRS episodes for winter, spring, summer, and fall. Error bars are one standard error. Dashed lines are lower and upper limits of suggested range for TN concentrations (EPA recommended guidelines; see Chapter 1). (Figure and caption text from Johnson & Hagerty, 2008)

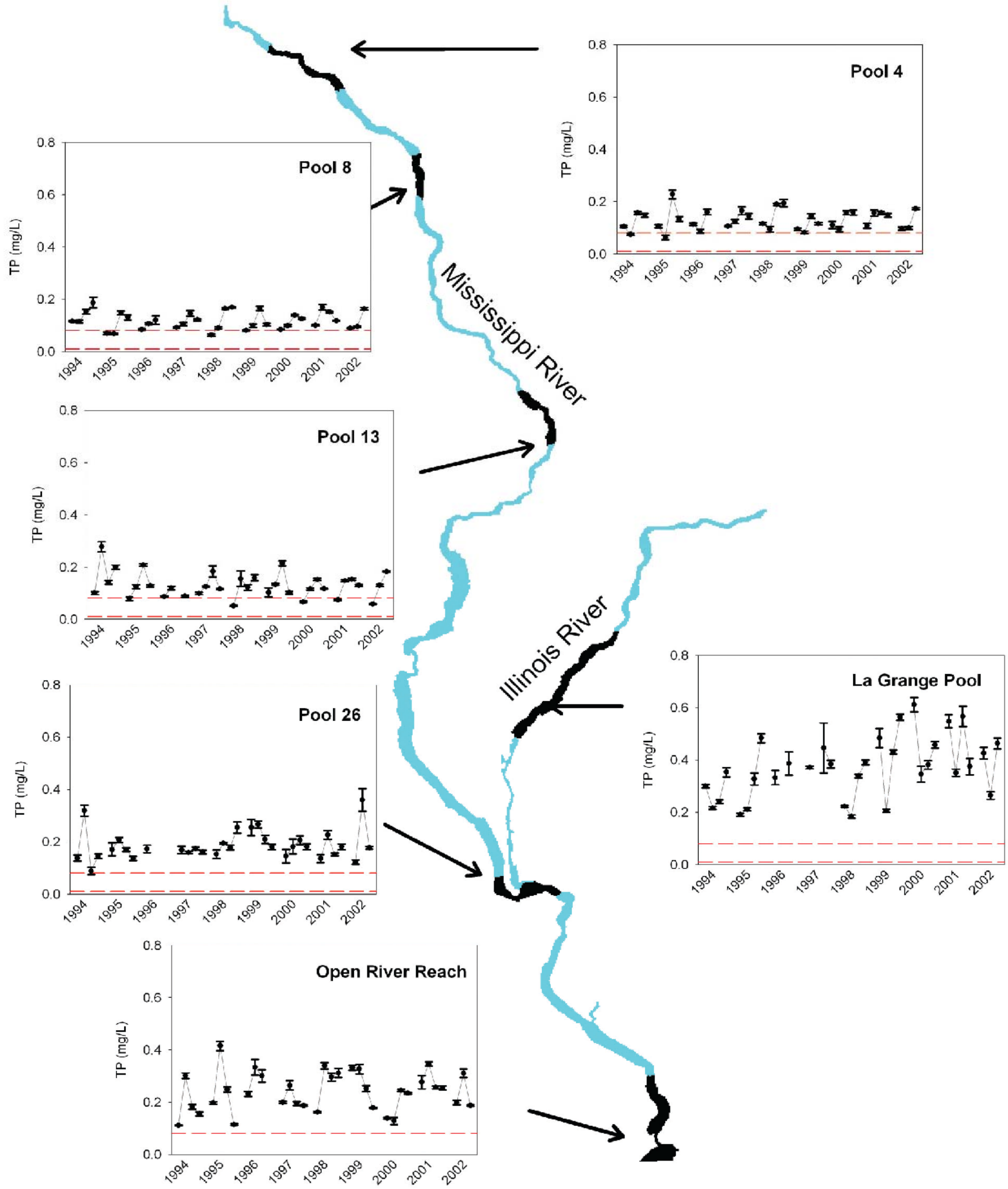


Figure 3-16: TP concentrations in the main channel stratum of the six LTRMP study reaches from 1994 to 2002. Data points are means from SRS episodes for winter, spring, summer, and fall. Error bars are one standard error. Dashed lines are lower and upper limits of suggested range for TP concentrations (EPA recommended guidelines; see Chapter 1). (Figure and caption text from Johnson & Hagerty, 2008)

For main channel TP and TN concentration ranges, the LTRMP and EMAP-GRE data generally agree with one another. However, there are some differences between the data which may result, at least in part, from differences in sample site selection and years covered in each data set.

Several interesting traits stand out in Table 3-4.

- As with the LTRMP data, the EMAP-GRE data show that the mean concentrations of TP and orthophosphate appear higher in the Open River reach than in either impounded reach.
- The relationship between TN and nitrate as concentrations increase is also of interest. At lower concentrations nitrate makes up less than half of the overall TN in the water in all three reaches; at higher concentrations of TN that percentage increases, to between 67% and 95% of TN at maximum concentrations. That is in contrast to the ratio between orthophosphate and TP, which does not change significantly at higher or lower concentrations.
- The increase in nitrate as a percent of total nitrogen is an indication that nitrate makes up the majority of TN at higher concentrations, and agrees with both the Goolsby (1999) finding that nitrate is driving increased TN concentrations and the Heiskary (2008) finding that Kjeldahl nitrogen (primarily plant material) comprises the majority of TN only at lower concentrations of nitrogen.
- The drop in nitrate:TN ratios at higher concentrations in the Open River reach (as compared to the Lower Impounded reach) agrees with the finding articulated in Johnson and Hagerty (2008) that the Missouri River dilutes nitrate.

EMAP-GRE and LTRMP tell similar, but not identical, stories regarding current nutrient concentrations in the UMR. For example, as Figures 3-17 and 3-18 illustrate, both EMAP-GRE and LTRMP data show increases in TN concentration in the lower river, though EMAP-GRE data for TN in assessment reaches 9 (Pools 20 and 21) and 11 (Pool 26) show more pronounced increases than the concentration changes recorded at Pool 26 in the LTRMP data set. However, in the Open River (assessment reaches 12 and 13), LTRMP TN concentrations are greater than those seen in EMAP-GRE data.

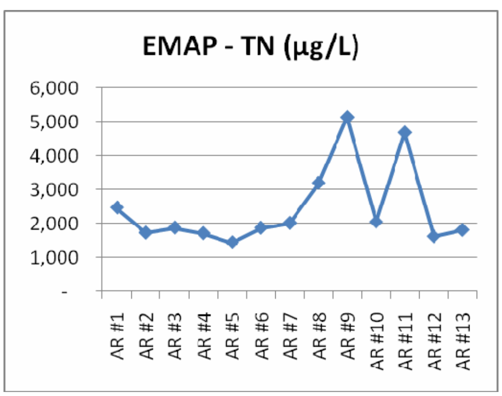


Figure 3-17 (above): Longitudinal TN concentrations from EMAP-GRE. 2004-2006 data.

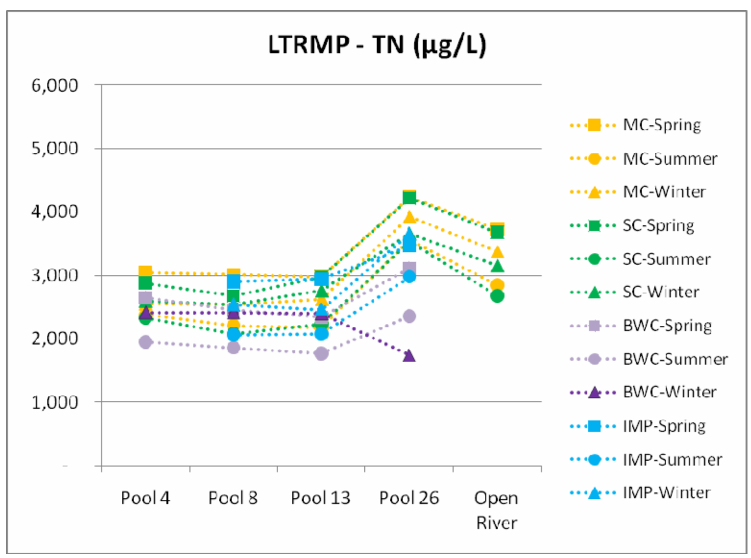
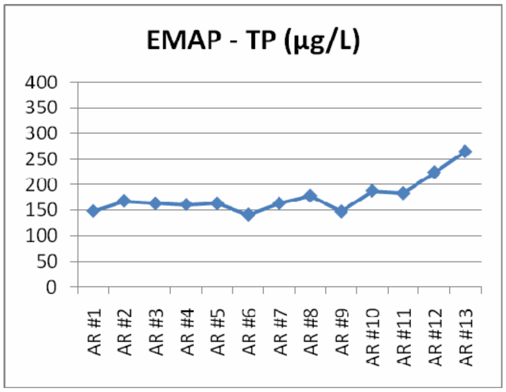


Figure 3-18 (right): Longitudinal TN concentrations from LTRMP. 1994-2008 data.

Figures 3-19 and 3-20 show similar patterns for LTRMP and EMAP-GRE TP data, with both data sets demonstrating an increase in TP concentrations moving downstream along the UMR. However, EMAP-GRE data fail to capture some of the lateral and seasonal complexity, such as fact that spring flowing channel TP concentrations are higher in the downstream reaches than summer and winter concentrations in the same strata and study reach.



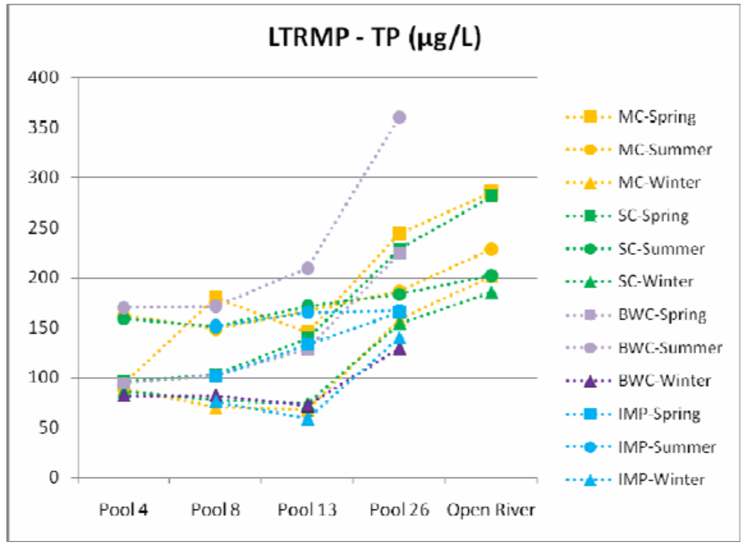


Figure 3-19 (above): Longitudinal TP concentrations from EMAP-GRE. 2004-2006 data.

Figure 3-20 (right): Longitudinal TP concentrations from LTRMP. 1994-2008 data.

As discussed in Chapter 1, a number of nutrient criteria have been proposed for the mainstem of the UMR. While Chapter 4 of this report discusses how a numeric nutrient criteria are unlikely to fully protect CWA uses on the River by themselves, research indicates that attaining full recreational, aquatic life, and/or drinking water use likely requires reducing nutrient concentrations below certain thresholds. That is, while nutrient reductions are unlikely to eliminate all CWA impacts by themselves, they are likely a prerequisite for use attainment in much of the UMR. Table 3-5 summarizes the scientific and regulatory thresholds proposed for nutrient concentrations which are relevant to the main channel of the UMR, and compares these thresholds to EMAP-GRE monitoring results.

Table 3-5: Nutrient Concentrations from EMAP-GRE Data Compared To P and N Thresholds Relevant to the UMR Main Channel (all values in mg/l)

Source of Threshold	TP Threshold (mg/l)	% EMAP-GRE Samples Above Threshold		TN Threshold (mg/l)	% EMAP-GRE Samples Above Threshold	
		Above Lowest Value (if range)	Above Highest Value (if range)		Above Lowest Value (if range)	Above Highest Value (if range)
Wisconsin Rivers Study (threshold range)[1]	0.034 - 0.150	99	68	0.53 -1.99	100	47
EPA Ecoregion (range from applicable ecoregions)[2]	0.010 - 0.080	99	98	0.60 - 2.18	100	35
USGS Alternative Regionalization (range from applicable environmental zones)[3]	0.012 - 0.023	99	99	N/A	N/A	
Wisconsin Numeric Standard[4]	0.100	96		N/A	N/A	
Minnesota Numeric Standard (proposed)[5]	0.100	96		N/A	N/A	

[1]Robertson et al., 2008
[2]US EPA Office of Water 2001
[3]Robertson et al., 2001
[4]Wisconsin DNR Rule NR 102
[5]Heiskary and Wasley, 2010

Overall, Table 3-5 indicates that current UMR main channel nutrient concentrations are routinely above the targets emerging from several scientific and regulatory efforts to identify appropriate limits for meeting aquatic life and recreation uses under the CWA, particularly recreation and aquatic life. TP is more frequently found in concentrations in excess of proposed thresholds than TN, based on EMAP-GRE data.

Backwaters and Off-Channel Areas

In addition to sampling the main channel, LTRMP regularly samples contiguous backwaters, side channels, and impounded areas. Table 3-6 summarizes these data (as compiled in UMRBA 2011) for TP and TN, and compares average values to a proposed set of criteria for UMR backwaters. This proposed set of nutrient criteria in off-channel areas was designed to apply to backwaters on that part of the UMR mainstem contiguous with Wisconsin (Sullivan 2008) to prevent excessive metaphyton (filamentous algae and duckweed) growth. This comparison suggests that existing nutrient conditions are regularly amenable to excessive metaphyton growth in UMR backwaters.

Table 3-6: UMR Nutrient Concentrations (Summer Average for LTRMP Data, 1994-2008) Compared To Proposed P and N Thresholds for Off Channel Areas

LTRMP Study Reach	Stratum	Summer Average Total Phosphorus (mg/L)	Summer Average Total Nitrogen (mg/L)
Pool 4	Contiguous Backwater	0.170	1.95
	Side Channel	0.159	2.33
	Impounded	N/A	N/A
	Main Channel*	0.162	2.38
Pool 8	Contiguous Backwater	0.171	1.86
	Side Channel	0.151	2.08
	Impounded	0.151	2.06
	Main Channel*	0.148	2.21
Pool 13	Contiguous Backwater	0.209	1.77
	Side Channel	0.171	2.23
	Impounded	0.165	2.08
	Main Channel*	0.167	2.17
Pool 26	Contiguous Backwater	0.360	2.36
	Side Channel	0.183	3.54
	Impounded	0.167	2.98
	Main Channel*	0.186	3.56
Open River	Contiguous Backwater	N/A	N/A
	Side Channel	0.202	2.68
	Impounded	N/A	N/A
	Main Channel*	0.228	2.85
Backwater Metaphyton-based Proposed Criteria Range[1]		**0.077 - 0.107**	**0.97 -1.23**

*Main channel data shown for comparative purposes only.

[1]Sullivan, 2008

Comparison of Nutrient Concentrations Across River Strata

There is some variety in nutrient concentrations across strata, as described in detail by UMRBA's draft designated uses report (UMRBA 2011). For example, in spring, total phosphorus mean concentrations are generally higher in the main channel than in backwaters (see Figure 3-20). However, in the summer the opposite is true – the main channel has lower TP concentrations than the backwaters. Also, total nitrogen mean concentrations are higher in the main channel than in backwaters (see Figure 3-18).

Historically, backwaters may have removed significant amounts of nitrogen from the UMR via denitrification. However, recent work suggests that backwaters do not currently fulfill that role to any substantial degree (Cavanaugh et al. 2006; James et. al. 2008; Kreiling et al. 2010).

Summary

Nitrogen and phosphorus concentrations in surface waters are tied to both naturally occurring and human-related sources. Research and modeling indicate that agricultural land use is the primary determinant of nutrient loading in the UMR, followed by urban areas. Additionally, both nitrogen and phosphorus loads to the UMR are largely tied to contributions from major tributaries.

Available research and data indicate that both nitrogen and phosphorus concentrations in the UMR mainstem have increased between 4 and 10 times over pre-settlement conditions, depending on the parameter examined and the method of estimation. These increases are documented in much of the data from the relevant period, and are backed by substantial indirect evidence. Increased rainfall since 1940 may explain a small amount of the increase, but the majority of the change is likely tied to altered land use, both urban and agricultural.

Trends in nutrient concentrations since 1990 appear relatively flat across phosphorus and nitrogen parameters. However, nitrate may be an exception to this trend, as there is evidence that nitrate concentrations have continued to increase in at least some UMR locations.

Current concentrations of both phosphorus and nitrogen in the UMR mainstem are generally in excess of all proposed nutrient benchmarks, including EPA ecoregion recommendations, other regional recommendations, and the 100 µg/L phosphorus criterion recently adopted for the UMR by Wisconsin. These elevated concentrations indicate that the UMR regularly experiences nutrient conditions that may impact attainment of some CWA uses. Such impacts to CWA uses are examined in detail in the next chapter.

Chapter 4:
Nutrient Impacts to UMR CWA Designated Uses

General Impacts of Nutrients on Clean Water Act Designated Uses

A variety of water quality issues are attributed to elevated nutrient concentrations in surface waters, including:

- excessive algal growth, which can lead to toxic cyanobacteria blooms, create drinking water supply issues, and impede recreational use of waters;
- direct and indirect changes in aquatic life composition, resulting from excessive algal growth, that causes lowered DO concentrations, reduced light availability, and other environmental changes; and
- toxicity to aquatic organisms from elevated concentrations of ammonia and nitrate, and to humans from nitrate, with the latter affecting drinking water treatment operations.

Table 4-1 illustrates the relationships between nutrient levels, outcomes, and impacts on CWA designated uses.

Table 4-1: Relationships Between Elevated Nutrient Levels and CWA Uses

	Direct Outcome	**Secondary Outcome**	**CWA Designated Use Impacted**
Elevated Nutrient Levels (Nitrogen and Phosphorus)	Excessive Algal Growth (Periphyton, metaphyton, sestonic algae)	Green water, floating algae mats	Recreation
		Decay/respiration causing lower DO, leading to fish kills	Aquatic life
		Alter aquatic community composition/reduce SAV cover	Aquatic life
		Toxicity (cyanobacteria)	Recreation Aquatic Life
		Impacts to drinking water operations	Drinking water
	Ammonia and Nitrate Toxicity	Not Applicable	Aquatic life Drinking water

Nutrient Impacts on the UMR Mainstem

Nutrients have been cited as a water quality concern on the UMR mainstem by federal agencies (EPA 2008), state agencies, non-governmental organizations (Gulf Restoration Network et al. 2008), and research bodies (NRC, 2007). However, these reports have not typically attempted to make an explicit link between elevated nutrient levels and adverse responses at a system level (outside of contributions to Gulf hypoxia) and have not attempted to fully catalog reported impacts of nutrients on a local level across the UMR [Note: the Lake Pepin TMDL is a notable example of a localized attempt to catalog nutrient responses]. This chapter attempts to inventory what is known about local nutrient impacts on the UMR, using currently available data, scientific literature, personal communication with river professionals, and a survey of UMR water suppliers executed specifically under the auspices of this project.

Excessive Algae Growth

Types of Algae Growth

In discussing algae growth on the UMR, it is critical to understand that the term 'algae' encompasses at least three distinct groups, as follows:

- ***Metaphyton*** refers to floating, clustered algae, most commonly filamentous algae. "Pond scum" is another term generally applied to this category. ***Duckweed*** is a floating aquatic plant that is often considered as metaphyton, due to its role in the ecosystem and its capacity for sudden, extensive growth. For purposes of this report, our discussion of metaphyton will include duckweed.
- ***Sestonic*** algae are free-floating single-cell organisms; three major subsets of this category are simple ***green algae***; ***diatoms***, which grow silica-based shells; and ***cyanobacteria***, some strains of which produce toxins. Along with macrophytes (large, vascular submerged or floating plants), sestonic algae are predominant primary producers, or photosynthetic organisms, on the UMR.
- ***Periphyton*** is attached to submerged plants and surfaces, such as rocks and underwater structures. It is in fact a community of organisms, including both algae and bacteria. The term ***epiphyton*** is a similar but more specific term, used to describe aquatic plants that grow upon other aquatic plants.

Algae Growth, Eutrophication, and Limiting Factors

Excessive algae growth and low DO concentrations are symptoms of a nutrient enrichment condition in surface water known as eutrophication (or hypereutrophication). Algae in surface waters grow and multiply as long as all of their essential needs are met. When one of these needs is absent in the water, algae's population is limited. Either nitrogen or phosphorus is commonly the limiting factor that most constrains algal biomass. In the UMR basin, algae growth in rivers is often constrained by phosphorus (Wisconsin Department of Natural Resources 2006). However, certain species, specifically duckweed, may be primarily constrained by nitrogen instead (Giblin et al. 2009). When more nutrients are supplied, the algae generally grow in greater numbers, resulting in a waterbody with an excessive amount of algae – i.e., a eutrophic or hypereutrophic waterbody. Other factors limiting algal growth include access to light; duration of exposure to nutrients (water residence time); and, for diatoms, concentration of dissolved silica. Any of these other limiting factors can control algal growth, even when both nitrogen and phosphorus concentrations are excessive. Limitations in one or more factors may also tend to favor the growth of one type of algae over another.

Residence time is an important factor in algae dynamics on the UMR. Slower water gives algae more time to take in nutrients from the water and multiply. Residence times on the UMR main channel are generally short enough to prevent algae from fully absorbing nutrients from the water column, which in turn may limit overall algal growth. The "tipping point" where residence time becomes a limiting factor for sestonic algae accumulation is about 10-14 days (Heiskary and Walker 1995). Pool 4 (primarily Lake Pepin) has a median residence time of about 9 days. The rest of the navigable main channel ranges between 1 and 2 days median residence time (Houser et al. 2010). However, residence times in off channel areas, such as backwaters, may be considerably longer and more conducive to algae growth.

General Impacts of Excessive Algae Growth

Many of the undesirable conditions that the UMR states list in their narrative criteria can be directly related to excessive algae growth (see Tables 1-2 and 4-1). When algae blooms and aquatic biomass increases suddenly, the resulting metaphyton mats and/or turbid water from sestonic algae are generally considered a detriment to primary contact recreation, such as swimming, for aesthetic reasons. In more severe cases, the proportion of cyanobacteria relative to other sestonic algae can increase, particularly when the N:P ratio decreases below approximately 10 (Wagner 2010). In these instances, the toxins that these organisms may produce can be a hazard to human health and aquatic life. The presence of excess algae can also foul drinking water plant components. As discussed later in this chapter, algal decay and respiration can decrease levels of dissolved oxygen, leading to fish kills and other aquatic life issues. This process that is somewhat mediated by water temperature, as cold water can sustain greater DO saturation than warm water. Mass photosynthesis also tends to increase the pH of water, which can put a strain on some aquatic organisms and increase the potential toxicity of ammonia.

The degree to which the use of a waterbody is impaired due to excessive algal growth depends upon both the use in question and the makeup of the algal community. For example, excessive metaphyton is an important recreational issue, and can be detrimental to drinking water operations and to aquatic life, but it does not pose a human health threat and is not directly toxic to aquatic life. Diatoms contribute to pH changes and DO fluctuation and are therefore an important aquatic life consideration, but are less of a concern to recreation simply because they are less visible to users of the water and, like metaphyton, do not produce toxins. The role of periphyton is less studied, but it is known to cover aquatic macrophytes and limit their growth, and is therefore a concern for aquatic life (Phillips et al. 1978), though evidence indicates that periphyton does not significantly contribute to DO fluctuation (Heiskary and Markus 2003).

Determining the Extent of Algae Blooms on the UMR

Photo 4-1: Filamentous algae mat on Crosby Slough, Pool 8, UMR (John Sullivan, WI DNR, July 2010)

Algae blooms are commonly cited as one of the primary impacts of elevated nutrient levels. Therefore, describing the extent of blooms on the UMR, to the degree possible given existing information, is critical to characterizing the impacts of nutrients on CWA designated uses. Determining the extent of algae blooms helps establish the likelihood and frequency with which recreational, aquatic life, and drinking water uses on the UMR may be affected.

Any attempt to assess the extent of UMR algae blooms must consider metaphyton, sestonic algae, and periphyton. Approaches to measurement, available data, and known extent are described below for each of these types of algae. Overall, while there is widespread evidence of algae blooms on the UMR, there is no systemic tracking mechanism for algae blooms and the ability to characterize blooms varies between algal types.

Currently, there is very little data available that directly measure the extent of algal blooms on the UMR. Some of this lack of data is due to a strong emphasis on blue-green algae in tracking efforts, to the exclusion of other algal issues and some is attributable to the lack of a tracking mechanism specific to the UMR. Research conducted for this project has found that of the five UMR states, only Minnesota maintains a database of algal blooms, and that database is targeted primarily toward reported occurrences of blue-green algae. In addition, national data sets are primarily focused upon blue-green algae and estuary blooms. While cyanobacteria is an important surface water use consideration, blue-green algae blooms are a small subset of the total blooms that occur nationally, within the UMR basin, and likely on the UMR itself.

Additionally, the characteristics of individual river strata (e.g., main channel, side channel, backwater) may affect both the concentrations of nutrients present and how elevated nutrient concentrations are expressed in terms of algal production. For example, areas with lower velocity may allow for the formation of algae mats that cannot persist in areas with more flow. As such, the presence of visible algae issues may not always be a direct indication of the nutrient levels in the water.

Metaphyton

Metaphyton is generally measured via direct observation, rather than by water sampling, as water samples are typically taken below the duckweed and filamentous algae habitat at the surface of the water. Therefore, much of the information available regarding metaphyton blooms on the UMR results from recreational user observations. Due to the limited extent of standardized monitoring, there is no system for tracking the extent of metaphyton growth, including occurrences of excessive or nuisance biomass, in the UMR basin or on the UMR mainstem.

Recently, LTRMP and Wisconsin DNR have been working on a system to measure metaphyton in UMR backwaters. The results of these efforts provide the best quantified data source for estimating the extent of metaphyton growth on the UMR. Between 2005 and 2007, LTRMP and Wisconsin DNR staff collected information on metaphyton coverage at SRS sampling sites on contiguous backwaters in Pools 4, 8, and 13. Using a scale of 0 (0% coverage) to 5 (> 80% coverage), researchers separately recorded the amount of surface water covered by duckweed and by filamentous algae during the summer sampling period (Giblin et al. 2009).

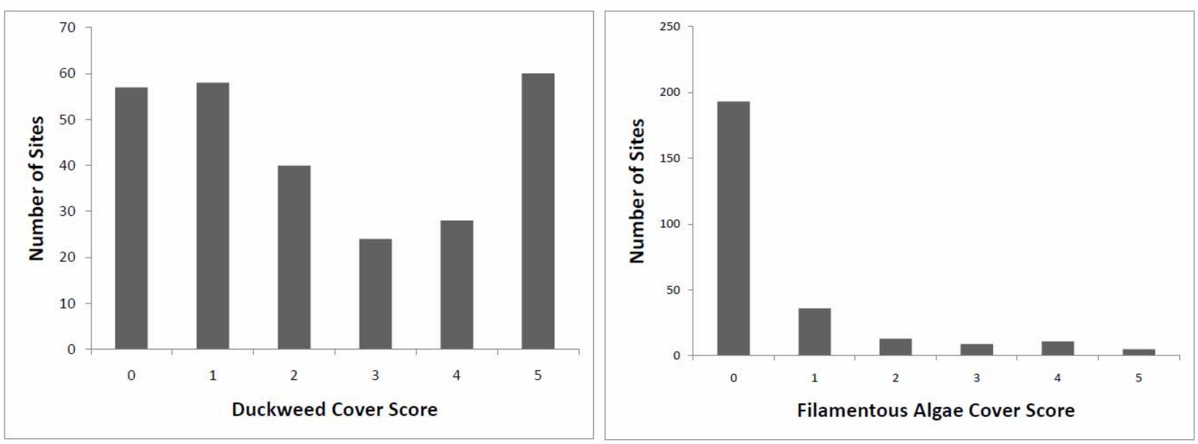


Figure 4-1: Contiguous backwater metaphyton cover scores from Pools 4 and 13 in 2007 and Pool 8 in 2005-2007, from summer SRS sampling. 0 = 0% cover; 5 = >80% cover. Figures from Giblin et al. (2009)

The data displayed in Figure 4-1 show that 80-100% duckweed coverage is as frequent during the summer sampling season as 0%, 1-20% and 21-40% coverage, and even more prevalent than 41%-80% coverage. Filamentous algae display a very different trend, with samples much more frequently finding lower coverage percentage than duckweed. Some of this difference is likely due to duckweed outcompeting filamentous algae at higher nutrient concentrations (ibid). Giblin et. al. (2009) also noted that metaphyton cover of both varieties appeared to vary positively with nitrogen concentrations.

This initial work has provided insight regarding both metaphyton assessment methodology and metaphyton occurrence in backwaters. While the work is limited to backwaters, metaphyton tends to form surface mats only under low velocity conditions, so studying the slow flowing backwater strata should provide a fairly complete picture of metaphyton growth in the UMR.

The Wisconsin DNR also conducted a separate evaluation of metaphyton by studying two groups of UMR mainstem backwaters, one with extensive metaphyton growth and one with limited or no growth most years (Sullivan 2008). The results of this study confirm that duckweed and filamentous algae cover is positively correlated with low DO concentrations, with extensive duckweed cover being particularly associated with near-zero (<0.5 mg/L) DO concentrations. The C:N:P ratios of the species examined, as well as the correlation between metaphyton coverage and nutrient concentrations, indicate that filamentous algae and duckweed growth is more likely limited by N, or N and P, than by P alone in UMR backwaters.

These findings from LTRMP and Wisconsin DNR accord with reporting from state agencies and recreational users, which indicate that backwaters and side channels host significant metaphyton blooms every year (John Sullivan, WI DNR personal communication). While the currently available data only give a general sense of the extent of metaphyton coverage, it is strong enough to state that backwaters on the UMR routinely experience substantial metaphyton (particularly duckweed) blooms. The data also strongly suggest that both recreational impacts (i.e., direct impediments to fishing, boating, and swimming due to extensive metaphyton coverage) and aquatic life impacts (i.e., low DO concentrations that may adversely affect fish and other aquatic life) are common metaphyton-related issues in UMR backwaters.

Sestonic Algae

While generally visually distinct from metaphyton mats, sestonic algae blooms may be included in observational reporting of "green water" and therefore might be captured as part of the agency and citizen reporting described above. However, since sestonic algae are distributed throughout the water column, simple observational reports cannot precisely measure the severity of this type of algae bloom. Fortunately, sestonic algal biomass can be estimated through analysis of the concentration of chlorophyll-a, a parameter that reflects the amount of chlorophyll created by algae and which is currently collected by many, though not all, active monitoring programs on the UMR. The relative abundance of chl-a data makes estimating the severity and frequency of sestonic algae blooms easier than estimating the severity and frequency of metaphyton blooms.

Cyanobacteria, as a subset of sestonic algae posing special concern, are most often tracked by users reporting unexplained sickness in humans or animals after water activities, or the characteristic blue coloration that indicates significant cyanobacteria growth.

Direct testing of samples for cyanobacteria toxins is possible, but has historically been relatively expensive and is not conducted on a system-wide basis by any UMR monitoring program. However, these tests are becoming more affordable and practical (Hedman et. al. 2008). Currently, state agencies will often simply make the assumption that some amount of cyanobacteria is present when algae blooms are reported, since cyanobacteria are part of the sestonic algae group.

Photo 4-2: Cyanobacteria bloom, with blue pigment beginning to accumulate
(Source: http://commons.wikimedia.org/wiki/File:Efflorescence_verte_3_Cyanobacteria.JPG)

Photo 4-3: Aerial photo of UMR Pool 8 in August 2008, with streaks of blue-green algae visible
(Source: USDA NAIP imagery)

The percentage of the algal community made up of cyanobacteria is typically greater in the fall and during low flow. Figure 4-2 illusrates relative contribution of cyanobacteria in the Lower Minnesota River, a direct tributary to the UMR. The following discussion regarding sestonic algae makes the assumption that cyanobacteria comprise a subset of the described extent of sestonic algae blooms.

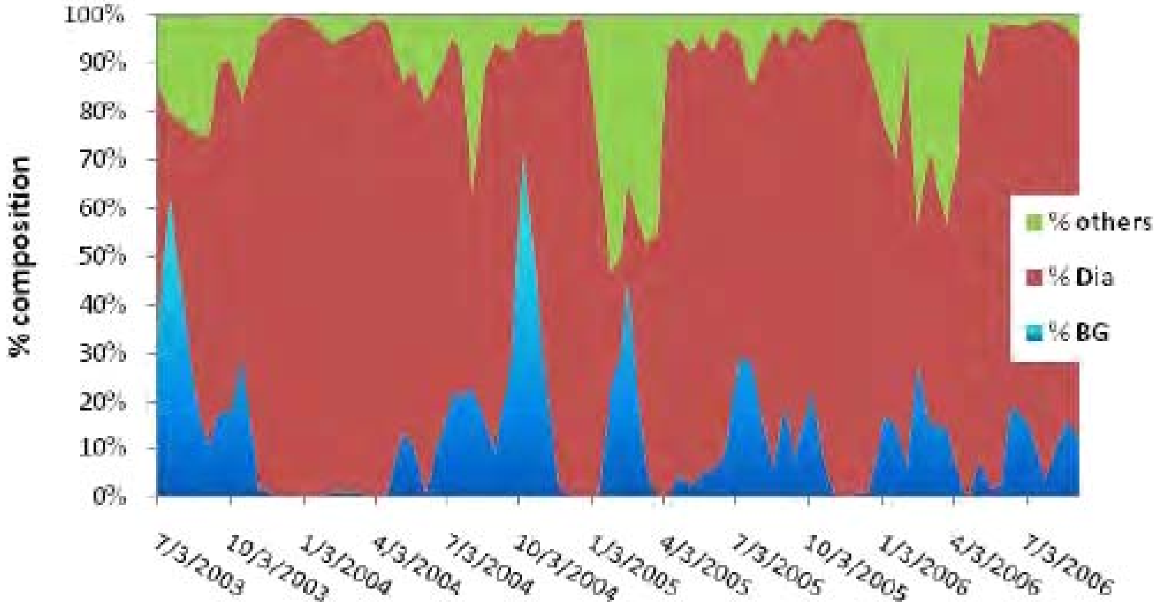


Figure 4-2: Minnesota River (mile 3.5) sestonic phytoplankton based on ~bimonthly MCES data: July 2003-September 2006. From Heiskary and Wasley (2010). % Dia: Percent diatoms; % BG: Percent blue-green algae (cyanobacteria); % others: Percent other algae.

Sestonic algal impacts to CWA recreational use can be estimated by determining threshold chl-a concentrations that correspond with what are considered nuisance blooms by users. The only significant work on the UMR examining how biomass relates to the definition of a nuisance algae bloom is research performed on Lake Pepin tying chl-a concentrations to the likelihood of perceived algal blooms, as reported by surveyed volunteers (Heiskary and Walker, 1995). On Lake Pepin, at about 10 µg/L chl-a, the number of blooms reported is negligible, rising to about a 50 percent frequency of reported blooms at 40 µg/L, and continuing to rise from there, with regular reporting of "severe" blooms at 60 µg/L.

However, it is important to consider the unique hydrologic conditions of Lake Pepin in applying these results to the rest of the UMR. Lake Pepin has much higher residence times and sedimentation rates than other parts of the River, resulting in physical and chemical conditions that have no direct corollary elsewhere on the UMR. Additionally, the makeup of the algal community may differ between various locations on the UMR. Thus, any use of chl-a levels to represent the recreational impact of algal blooms outside of Lake Pepin must be done with the recognition that conclusions from Lake Pepin may not be entirely transferable. That being said, using findings from Lake Pepin provides a useful initial comparison point in estimating the extent of sestonic algal blooms systemwide.

Using the Heiskary and Walker research as a base, Figures 4-3, 4-4, and 4-5 are boxplots with horizontal lines at 10, 32 (the targeted concentration in the Lake Pepin TMDL), 40, and 60 µg/L chl-a from LTRMP SRS data.[5]

With the exception of Pool 26, chl-a concentration ranges and central tendencies are generally similar across strata within the same reach during the spring and summer seasons. Median values generally fall within the 10-32 µg/L range, above the value where nuisance algae blooms begin to be reported, but below the Lake Pepin threshold value. However, a significant number of samples lie in the 32-40, 40-

[5] In the referenced figures, MC = Main Channel, SC = Side Channel, BWC = Contiguous Backwater, IM = Impounded, and LP = Lake Pepin or Swan Lake.

60, and >60 µg/L ranges, indicating frequent conditions where sestonic algae biomass is likely high enough to interfere with the recreational use of the UMR. The most recent LTRMP Status and Trends Report (Johnson and Hagerty 2008) found high variability in chl-a concentrations across all seasons and pools within the main channel, which agrees with the results in Figures 4-3 through 4-5. Additionally, LTRMP data were not found to indicate any yearly trend from 1994 to 2004, despite the varied median concentrations between years.

Two additional trends emerge from the three graphs. First, backwaters in Pool 26 have very high chl-a concentrations relative to other strata and other pools. Second, winter chl-a concentrations are substantially lower in all reaches and strata than spring and summer concentrations. The latter trend is due to reduced plant activity in cold seasons, but does not preclude the possibility of algal growth under ice, which has occurred on the UMR in the past (John Sullivan, WI DNR, personal communication, 1/6/2011). Pool 26's higher backwater concentrations may be related to residence time, as discussed earlier in this chapter, or may be at least in part a statistical anomaly related to the lower proportion of backwaters in Pool 26, which results in comparatively fewer sample sites, increasing the potential influence of anomalous results. Turbidity and mixing depth also likely play roles in regulating chl-a concentrations in most reaches and strata of the UMR.

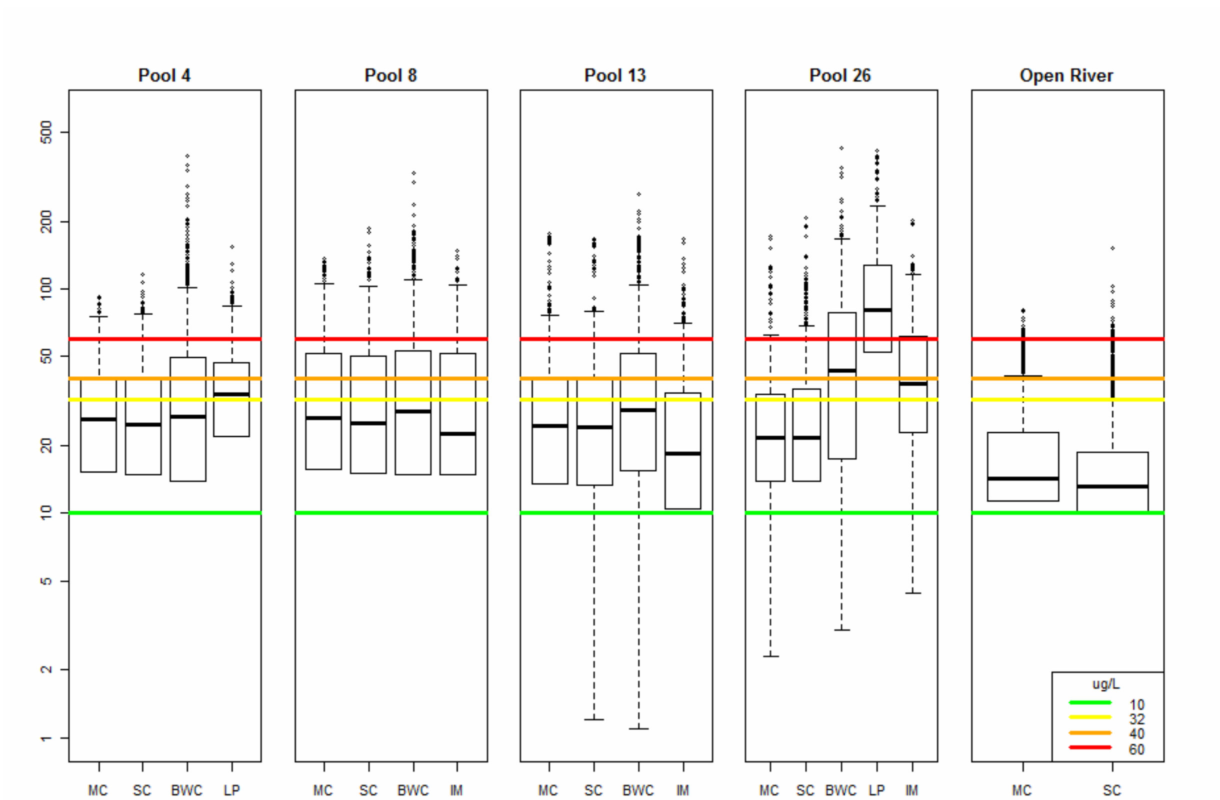


Figure 4-3: Spring LTRMP chl-a concentrations by pool, broken into horizontal strata
Where MC = Main Channel, SC = Side Channel, BWC = Contiguous Backwater, and LP = Lake Pepin in Pool 4 and Swan Lake (a backwater lake more closely associated with the Illinois River) in Pool 26

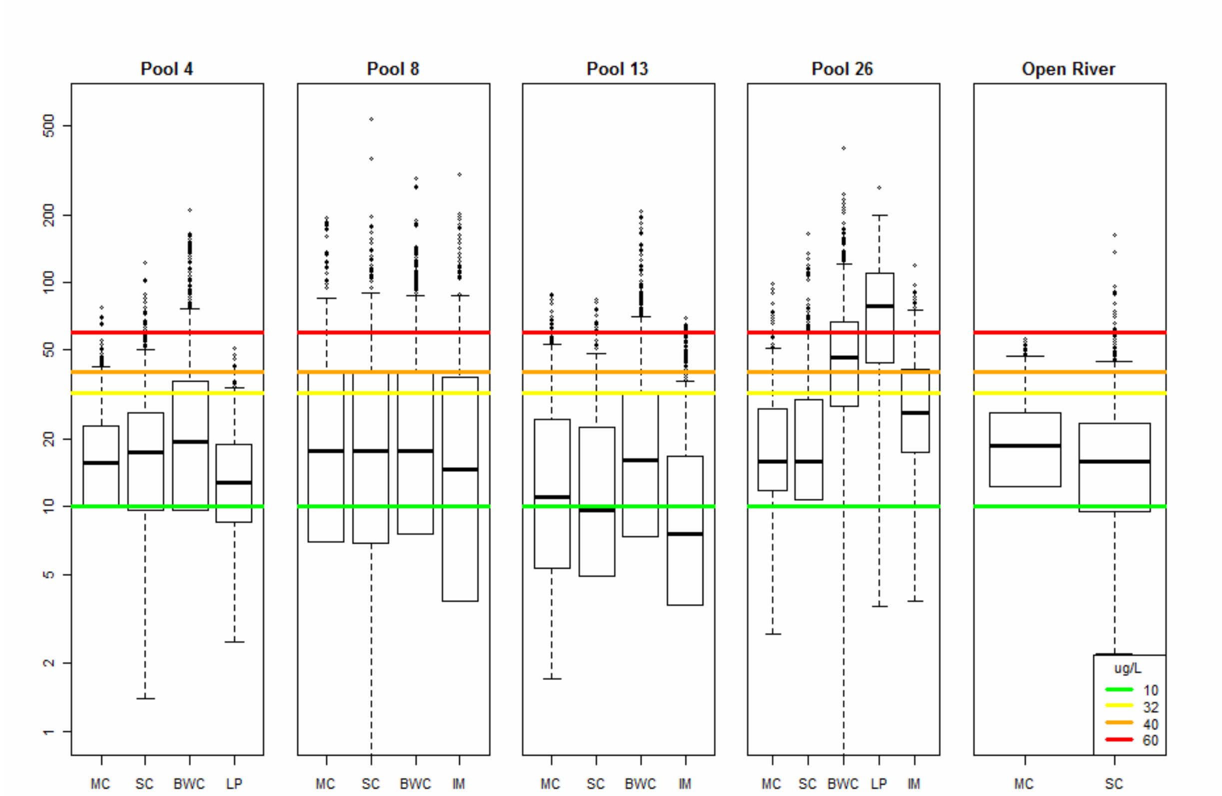


Figure 4-4: Summer LTRMP chl-a concentrations by pool, broken into horizontal strata.

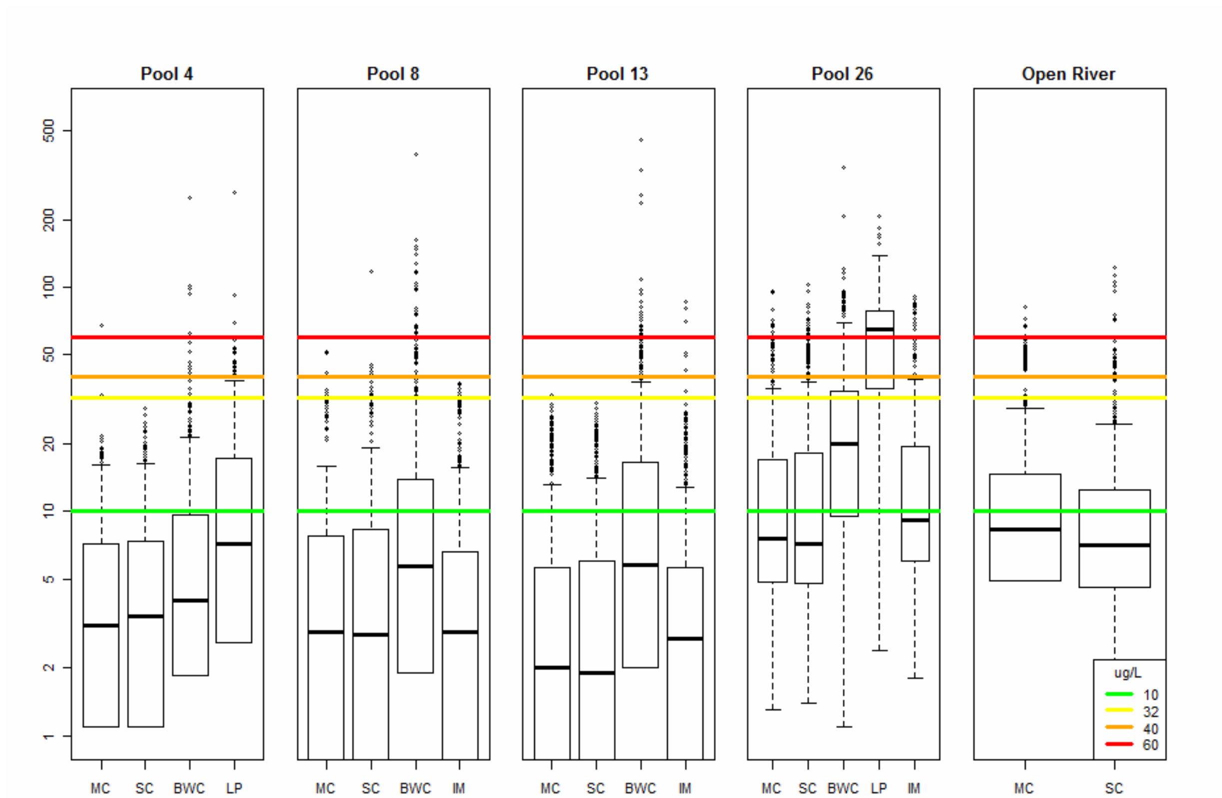


Figure 4-5: Winter LTRMP chl-a concentrations by pool, broken into horizontal strata.

Periphyton

Periphyton is not systematically measured in the UMR. While the depth of water and lack of light penetration on main and side channels limits the relevance of periphyton in these strata, SAV growth on parts or all of the impounded and backwater strata may be limited by periphyton coverage. The UMR states have all approached periphyton sampling differently, as described below:

- Minnesota performed regular biological monitoring, including some limited periphyton sampling, at nine UMR (interstate and non-interstate) stations as well as five tributary stations. However, the sampling was aimed more at evaluating the composition of the periphyton community than evaluating the magnitude of periphyton growth (Minnesota Pollution Control Agency 2004) and is not an ongoing monitoring activitiy (Shannon Lotthammer, MPCA, personal communication, 5/20/2011).
- Illinois did conduct limited periphyton sampling in wadeable streams as part of a two-year effort, but does not currently conduct periphyton monitoring in rivers and has no near-term plans to resume such sampling (Illinois Environmental Protection Agency 2007; Gregg Good, IL EPA, personal communication, 5/10/2011).
- Iowa identifies the lack of periphyton monitoring as a concern, but has no concrete plans to address the monitoring gap (USEPA Region 7; Iowa Department of Natural Resources 2006).
- Missouri and Wisconsin do not sample for periphyton, and do not appear to have plans to do so.

The EMAP-GRE program, did also collect periphyton samples (Angradi 2006), though the program is no longer active on the UMR. As with Minnesota, the sampling protocol did not aim to measure the degree of growth or biomass of periphyton.

Due to the lack of any systemic, or even more regional, mechanism for estimating or quantifying periphyton on the UMR, conclusions about its prevalence cannot be drawn at this time.

Summary Regarding Extent of UMR Algae Blooms

The lack of systemic UMR algae bloom tracking, or even comprehensive state monitoring, limits the conclusions that can be made regarding the prevalence of nuisance algae blooms on the mainstem UMR. However, existing information, including studies by LTRMP, Wisconsin DNR, and Minnesota PCA, as well as relatively plentiful chl-a data, gives a strong indication that metaphyton and sestonic algae blooms are a recurring issue on the UMR, particularly in off-channel and other lower velocity strata.

Impacts to Recreation from Excessive Algal Growth

The occurrence of algae blooms tends to dissuade people from swimming, boating, or otherwise participating in recreational activities on affected waters. As such, excessive algal growth on the off-channel and other lower velocity UMR strata, as described in the preceding section, is likely a frequent issue for recreational users of these river strata. Of note, the one current CWA 303(d) listing for the UMR driven by nutrient concentrations is Minnesota's impairment of the recreation use for Lake Pepin.

The extent to which cyanobacteria present a health concern related to contact recreation use is difficult to determine, given the previously discussed difficulties in cyanobacteria measurement. Moreover, while not all cyanobacteria blooms produce toxins, there is no method to predict which will produce toxins or how long toxins will be present. Also, while the relatively widespread occurrence of chl-a concentrations indicative of sestonic blooms implies that there may potentially be widespread cyanobacteria presence, the co-occurrence of sestonic green algae blooms may provide a deterrent for recreational contact, thereby reducing the likelihood of exposure. In addition, cyanobacteria itself is highly visible and generally discourages aquatic recreation. However, accidental exposure is by no means impossible.

Aquatic Community Relationships and Impacts from Excessive Algal Growth

Submersed Aquatic Vegetation

Submersed aquatic vegetation (SAV) abundance is primarily determined by light penetration through water (Barko et al.1986). Water clarity, algal abundance, and SAV abundance may be interconnected through a clear state/turbid state dynamic. This dynamic can apply to any shallow pool in the UMR basin, possibly including backwaters of the UMR mainstem (Houser et al. 2005). Under conditions of low to moderate nutrient input, shallow lake plant life is dominated by macrophytes and water is generally clear. As nutrient inputs increase, the proportion of plant life given over to algae increases gradually, until a tipping point is reached. At the tipping point, the light available to macrophytes is drastically reduced through periphyton and metaphyton shading, resulting in an equally drastic reduction of macrophyte growth, which further increases turbidity by destabilizing bottom sediments through loss of root structure. Combined shading by algae and sediments requires reducing the nutrient inputs well below the original 'tipping point' level before the water body will return to its original, clear state. Loose bottom sediments help maintain the elevated turbidity, which contributes to suppressed macrophyte growth. This dynamic may be modified by other factors, such as bottom-foraging fish disturbing SAV and increasing turbidity absent any increase in nutrient inputs; thus increased turbidity is not a certain sign of increased nutrient input.

The links between nutrient input, algae growth, and SAV abundance are well established in the scientific literature. Lake Wingra near Madison, Wisconsin is a classic example of SAV die-off attributed to algal growth (Barko et al. 1986). In the Chesapeake Bay, both SAV occurrence and native:non-native macrophyte ratios have been linked to TN concentrations (Ruhl and Rybicki 2010). Nevertheless, in the UMR, the degree to which abundance of submersed aquatic plants is driven by nutrient-associated turbidity versus other regulating factors (e.g., presence of rough fish, water velocity, and depth) is not fully established. LTRMP data indicate that turbidity and water depth jointly explain much of the variation in SAV occurrence on the UMR, where vegetation is denser from lower Pool 4 to Pool 13 and entirely absent below Pool 26 (Johnson and Hagerty 2008). However, the degree to which turbidity is determined by algal growth versus suspended sediments is not addressed in this analysis. There is also evidence that metaphyton growth, specifically duckweed, alters the SAV community by suppressing *Vallisneria. americana* (Wild Celery), an aquatic plant of key ecological importance (Giblin et al. 2009).

Work is currently underway to establish a Submersed Macrophyte Index (SMI) for SAV on the UMR based on EMAP-GRE methods and data. Such an index will likely start to bridge the gap between known causal chains on one hand, and known local distributions of SAV on the other, and begin to fill in the understanding of the relative influence of local factors, including nutrients, on SAV in the UMR.

Fish Kills

Excessive nutrients can alter the aquatic community in a variety of ways. One of the more obvious impacts is a concentration of fish deaths, referred to as a fish kill, which can occur when algal respiration or decay removes most or all of the oxygen from the water, asphyxiating the fish. As will be discussed in the following section, the UMR basin has seen regular occurrences of fish kills and some fish kills have occurred on the UMR mainstem, though the cause of kills is typically not determined.

Determining the Extent of Fish Kills on the UMR

As is the case for metaphyton blooms, there is no single central reporting mechanism or database for fish kills on the UMR mainstem or in the UMR basin. While four of the UMR states track fish kill reports internally,[6] there is no unified data repository for the UMR. Additionally, state databases vary

[6] The following specific agencies maintain state databases: Iowa DNR, Minnesota Duty Officer, Missouri DoC, and Wisconsin DNR.

in their scope and structure. For example, Iowa and Wisconsin have dedicated fish kill databases, while Missouri's database tracks toxic leaks and spills and only incidentally record fish kills as a result of these events. The Izaak Walton League (IWL) hosts a fish kill database on its website with data for the five UMR states from approximately 1980 through 2005; but the database has not been updated or maintained since 2006 (Brad Walker, IWL, personal communication, 9/14/2010).

Combining reports from IWL and the UMR state databases[7] resulted in a list of approximately 5,100 fish kill incidents with an estimated 22 million fish killed in the UMR basin over the time period of 1980 to 2010. Of these, just 63 events were associated with the UMR mainstem[8], accounting for approximately 200,000 dead fish.

Not all fish kills on the UMR mainstem or in the basin are driven by nutrient-related hypoxic conditions, and classification of fish kills can be difficult. The data show that for many of the fish kills reported, the cause of the deaths is unknown. Some kills may be caused by toxic spills, while others may be caused by viruses.

UMR Mainstem Data

The relative lack of fish kill data in the UMR mainstem, as compared to the basin as a whole, makes meaningful data analysis difficult. There may be a seasonal trend in the number of fish kill events, with a peak in the winter/spring and a minimum in the fall (Figure 4-6), but again the lack of data points makes this observation tenuous. The month with the greatest number of fish kill events for the entire period examined is May, with just ten. The relationship between water temperature and oxygen saturation may also play into potential seasonal patterns for fish kills. Figure 4-7 demonstrates that no longitudinal trends over time are apparent in the frequency of fish kill events.

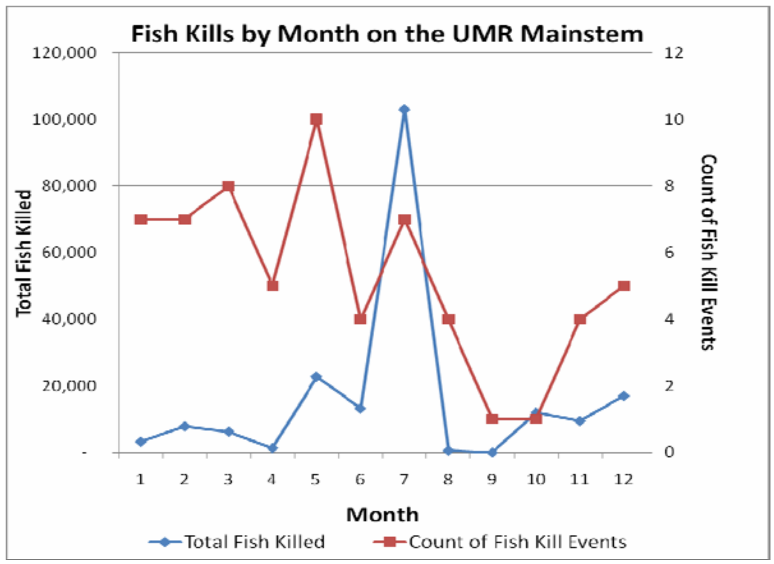


Figure 4-6: Fish kills by month on the UMR mainstem, 1980-2009

A July 1988 fish kill in Lake Pepin, with an estimated 89,000 dead fish, overwhelms all other data points. Tellingly, when the Wisconsin DNR responded to this incident, the water was observed to be dark green, the blue-green algae *Aphanizomenon flos-aquae* was observed, *Microcystis sp*. was detected in subsequent laboratory analysis, and DO concentrations varied between 0.5 and 20 mg/L, leaving little doubt that this major event was caused by an algae bloom (John Sullivan, WI DNR, personal communication, 7/21/2010).

[7] The IWL data set contains numerous duplicates with state records, likely due to cooperation between IWL and state agency staff while the database was actively maintained (John Olson, Iowa DNR, personal communication). These were removed via the MS Excel "Remove Duplicates" function using select fields, and a manual comparison of remaining records.

[8] Events that occurred on waterbodies with the words "Mississippi" or "Pepin" in their names. Backwaters or impounded areas of the mainstem not explicitly referred to as "Mississippi" may not be included in this total.

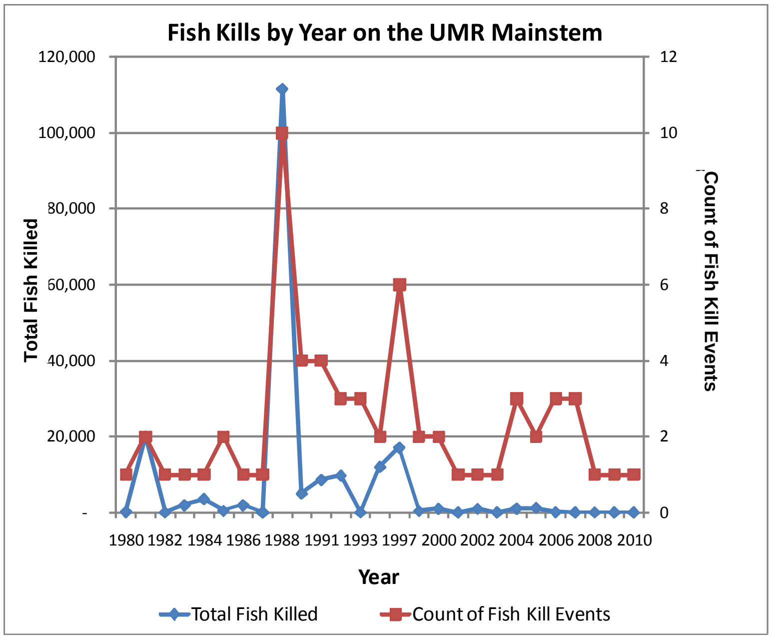


Figure 4-7: Fish kills by year on the UMR mainstem, 1980-1999

The summaries of fish kills in Figures 4-6 and 4-7 show no long-term temporal trend, nor do they show a strong seasonal trend. Without corresponding data about the chemical and physical state of the waters in which the kill events took place, it is very difficult to determine whether a particular event was driven by nutrient-related hypoxic conditions, acute or chronic effects of a pollutant, or a naturally-occurring event or condition. For example, it is known that some backwaters of the UMR regularly experience low DO conditions, particularly in northern reaches during the winter. However, the frequency with which low DO conditions naturally occur, and the degree to which they are tied to nutrient loading as opposed to hydrologic alteration, is unknown (Johnson and Hagerty 2008). The strongest statement that can be made about the relationship between nutrients and fish kills on the UMR is that some fish kills, including the most severe recorded in the past three decades, are very likely related to nutrient-driven algal blooms leading to hypoxic conditions.

Fish Community Health

Knights et al. (2008) found that TN, along with TSS, DO flux, and water depth, are the physical/chemical parameters that do the best job of explaining differentiation between fish communities in UMR backwaters. This is some of the first evidence of direct (TN) and indirect (DO) impacts of nutrient loading on fish communities in the UMR. Major northern tributaries of the UMR have been preliminarily shown to demonstrate an inverse relationship between TN concentrations and fish community biotic integrity, although a single high-quality river may have skewed that result and further investigation is warranted (Heiskary and Markus 2003). The same study revealed a much weaker (inverse) correlation between TP concentrations and fish community health, though Robertson et al. (2008) found just the opposite. In this latter analysis, major rivers in Wisconsin showed TP to be more strongly correlated with significant fish community indicators than TN.

In general, there is evidence of both direct and indirect impacts to the UMR fish community from nutrient loading, but research directly linking nutrients to fish community health is still limited on the UMR. Fish kill data tell us that some significant nutrient-related kills have occurred, though not whether their frequency or severity is greater than would be expected under pre-settlement conditions. The links between nutrient and DO concentrations and between DO concentrations and fish survival in general (i.e., in surface waters broadly, not specific to the UMR) are well established. Initial research that has been conducted on the UMR and in the UMR basin tends to show that fish communities are affected by nutrient concentrations, particularly of nitrogen. What remains unknown is precisely how and to what degree those concentrations alter communities.

Macroinvertebrates

A third aquatic community that may be affected by increasing nutrient concentrations is macroinvertebrates. This group is dominated by insects with an aquatic life stage, such as nymphs of dragonflies and mayflies, though bivalves, such as mussels, may also be included in this group. At least one incident of population recovery (the *Hexegenia* genus of mayflies) on the UMR has been linked to improved water quality, particularly increased DO concentrations, as a result of lower nutrient inputs from the Twin Cities Metropolitan Wastewater Treatment Plant (Fremling and Johnson 1989). Despite this concrete example, Angradi and Jicha (2010) found little correlation between water quality parameters in the UMR, including nutrients, and macroinvertebrate assemblage metrics. Heiskary and Markus (2003) also found little direct connection between either TN or TP and macroinvertebrate community health, but did find significant correlation between the nutrient "response" metrics chl-a and BOD_5 and macroinvertebrate metrics. In major Wisconsin rivers (excluding the UMR), TP and TN are both significantly correlated with macroinvertebrate community health, though the influence of nutrients is difficult to separate from other basin and land use variables (Robertson et al. 2008).

Summary of Aquatic Community Impacts and Interactions

The general (i.e., non UMR-specific) links between all three biotic assemblages discussed above (SAV, fish, and macroinvertebrates) and nutrients are well documented in the scientific literature, but none of these assemblages is *exclusively* affected by nutrients. There are, instead, are many factors that play into the overall community health of these assemblages. To the best of our knowledge, the scientific literature on the UMR has documented just one fairly unambiguous case of biotic response (beyond a solely algal response) to decreases in nutrient concentration – i.e., the resurgence of *Hexegenia* just downstream of the Twin Cities. UMR fish kills have been documented but not studied in the scientific literature, though some research is beginning to link fish community health in the UMR with nutrient inputs. Overall, it can be said that nutrients are having an impact upon all three assemblages on the UMR, but confounding factors complicate efforts to determine the causal mechanisms.

Impacts on Drinking Water Supplies from Excessive Algal Growth

As part of this project, UMRBA surveyed 15 public water suppliers[9] that rely on the UMR for source water. These surveys were intended to identify the impacts of UMR nutrients on public water suppliers, particularly in terms of cost, operations, public perception, and regulatory compliance. Complete responses were received from only eight of these suppliers to date and are limited by the fact that the largest suppliers (i.e., Minneapolis, St. Paul, and St. Louis) did not respond in full. However, even with these limitations, the survey results do provide preliminary insight into the impacts of nutrients on public water suppliers.

Algae were the top nutrient-related water quality issue for three of the eight respondents and was also among the top three issues for three other respondents. While the responses do not provide enough specificity to determine whether these concerns were primarily related to metaphyton, periphyton, or sestonic algae – or whether the resulting problems are operational and/or regulatory – at minimum these results indicate that algae is a nutrient-related issue of concern for UMR water suppliers.

Among other issue areas, ammonia and nitrate emerged as a leading concern, along with disinfection byproducts and total organic carbon. Phosphorus and cyanobacteria were characterized as comparatively lower priorities. Additional observations related to the survey outcomes are made later in this chapter and in Chapter 5.

[9] Twenty-six suppliers in all use the UMR directly for source water. UMRBA did not survey the eleven suppliers that did not respond to repeated pre-survey communication.

Table 4-2: UMR Water Supplier Survey Results*

	Supplier**							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Algae	4	6	6	6	5	1	3	4
Ammonia & Nitrate	6	5	3	4	4	3	4	6
Phosphorus	3	2	2	3	2	1	2	2
Disinfection Byproducts	1	4	5	5	3	3	5	5
Cyanobacteria	2	1	4	2	5	1	1	3
Other***		3			6		6	

* Water suppliers that completed the survey were asked to rate each of six potential nutrient-related drinking water issues from 1-6, with 6 being the issue of greatest concern and 1being the least.

** Each letter represents an individual UMR public water supplier.

***All three respondents that listed "other" as a concern specified that Total Organic Carbon (TOC) was the issue.

Nitrate and Ammonia Toxicity

The water quality issues discussed thus far in Chapter 4 are related to increasing primary productivity in surface water as a result of nutrient influx. A completely separate mechanism – direct toxicity – can also negatively impact the use of surface waters. Specifically, two nitrogen compounds can occur in surface waters at concentrations that may cause adverse health effects. Nitrate (NO_3^-) can be toxic to humans and aquatic life, and ammonia (NH_3) at excess levels is detrimental to aquatic life. To explore toxicity issues related to these compounds on the UMR, both USGS fixed-site and LTRMP SRS data sets were examined. The drinking water suppliers' survey also contained questions related to this issue.

Nitrate

Nitrate Criteria

Drinking Water

All the UMR states have adopted the Safe Drinking Water Act Maximum Contaminant Level (MCL) of 10 mg/L nitrate as nitrogen as a water quality criterion to protect the drinking water use in designated waters. This 10 mg/l level has been set to prevent the occurrence of methemoglobinemia (i.e., blue baby syndrome) in infants consuming water. This standard is not applicable to the entire UMR, however, as Minnesota and Wisconsin do not assign the drinking water use to the interstate UMR and Iowa applies the drinking water use only to intake points.

Aquatic Life

Nitrate can be toxic to aquatic organisms, affecting macroinvertebrates at lower concentrations, amphibians at moderate concentrations, and fish at higher concentrations (Monson 2010). At present, no UMR states have nitrate standards applicable to aquatic life protection, and there is no US EPA guidance concerning nitrate and aquatic life use protection. Minnesota's effort to identify appropriate criteria for the protection of aquatic life from nitrate toxicity (see Chapter 1) is unique in the UMR basin. Of note, any new aquatic life-based nitrate criteria would likely apply to Minnesota's portion of the interstate UMR, unlike the current, drinking water-based nitrate criterion.

Nitrate Occurrence on the UMR

The USGS NAWQA program found that 2% of river and stream water quality samples nationwide exceeded the nitrate MCL (Dubrovsky et al. 2010) in the period of 1992 to 2004. The NAWQA analysis indicates that the likelihood of exceedence is significantly lower in the UMR mainstem than in waterbodies nationwide. Figure 4-8 shows that for the entire monitoring period at Winona, Minnesota; Clinton, Iowa; and Keokuk, Iowa the UMR did not exceed even half the MCL concentration for nitrate in any sample between 1949 and 2009. LTRMP SRS monitoring data from 1993 to 2009 included just five samples exceeding the MCL out of approximately 17,400 mainstem NO_x values samples. In sum, these results indicate that human health impacts resulting from nitrate on the UMR are very unlikely, at least based on comparison to existing water quality standards.

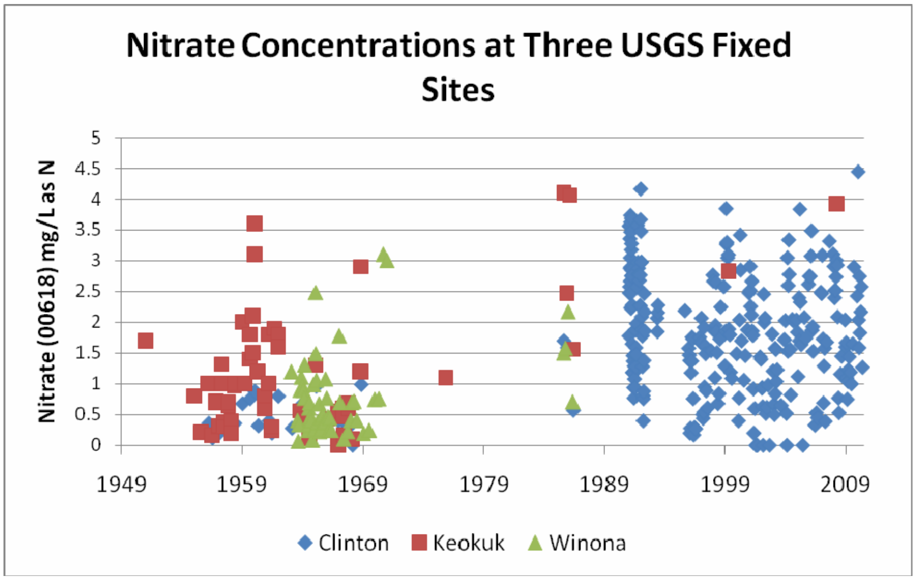


Figure 4-8: Nitrate concentrations at three fixed monitoring sites on the UMR (at Winona, Minnesota, Clinton, Iowa, and Keokuk, Iowa).

Ammonia

Ammonia Criteria

<u>Aquatic Life</u>

Ammonia can be toxic to aquatic life, with freshwater mussels generally representing the first assemblage affected (US EPA Office of Water 2009). Depending on temperature and pH, ammonia in water readily converts between the highly toxic NH_3 form (un-ionized ammonia) and the much less toxic NH_4^- form (ammonium). For this reason all five UMR states have adopted ammonia criteria that vary with water temperature and pH[10]. The states have both acute and chronic criteria, which refer to protecting aquatic life from adverse effects over different periods of exposure – generally one day for the former, and one week to one month for the latter.

All states except Minnesota base their criteria on the 1999 EPA guidance for ammonia aquatic life toxicity (Chapter 1), making the calculated limits for the same pH and temperature values very similar. The most significant differences among the states relate to when (i.e., which month) fish early life stages are assumed to be present in one state. In Illinois the early life stage period is March to October, while in Iowa it is February through September, and Missouri applies the early life stages present criteria to the UMR year-round. Consequently, fall and spring months show the greatest difference between state criteria.

[10] Most states use total ammonia criteria (sum of ionized and un-ionized ammonia). Minnesota uses a single criterion for un-ionized ammonia instead of total ammonia, but gives a temperature- and pH-based equation for deriving the un-ionized amount from total ammonia. Illinois has criteria for both. See Table 1-3 for greater detail.

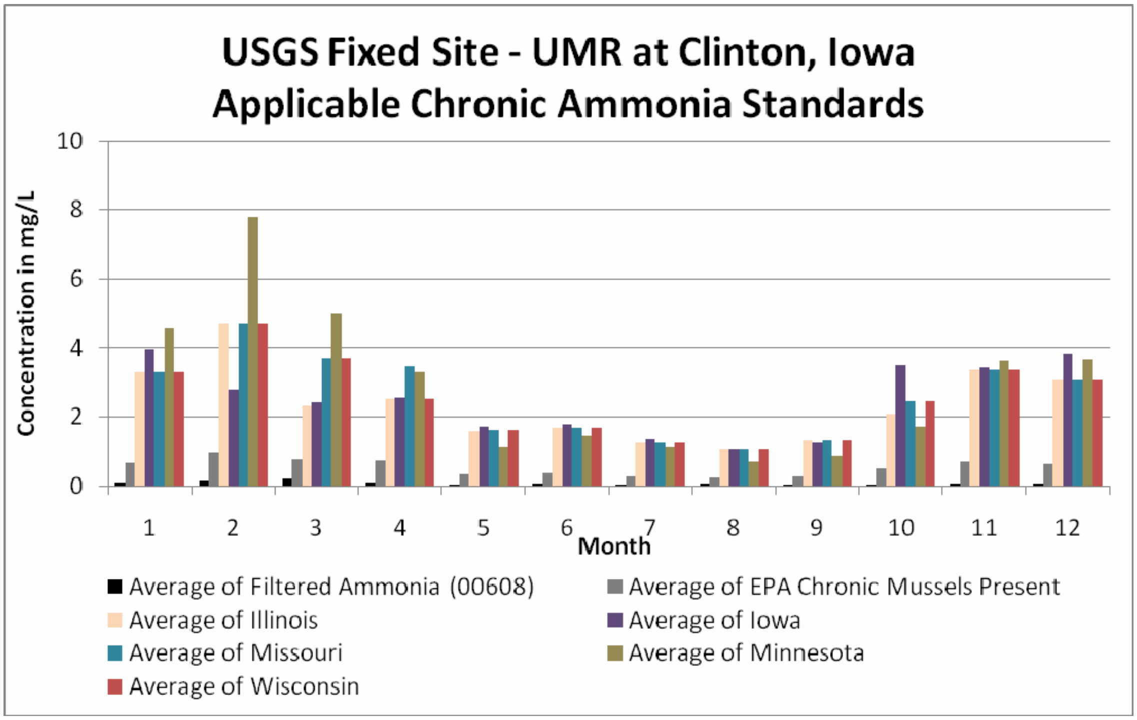


Figure 4-9: Averages of total ammonia on the UMR compared to state standards by month at Clinton, Iowa for 1952-2010. Temperature and pH values used to calculate standards are not shown.

Because the permissible ammonia concentration varies with pH and temperature, the only way to determine whether a given sample exceeds a criterion is to use pH and temperature values collected with the sample to calculate the maximum permissible level for the conditions under which the sample was taken, and then compare that value to the actual ammonia concentration. pH and temperature values vary between samples and seasons, so even if the same equation governs threshold values all year long, the actual criterion will vary as conditions vary. As an example, Figure 4-9 shows the monthly averages of these calculated threshold values for the states and for new EPA (draft) recommended criteria, alongside the actual measured ammonia concentration values at Clinton, Iowa[11].

Despite the modest differences between their calculation techniques, the UMR states all appear to show very similar results in their ammonia assessments of the UMR. None of the samples examined from Clinton, Iowa exceed any of the acute or chronic thresholds set by the states. While not displayed graphically as has been done for the Clinton site, the same is true for ammonia data collected at Keokuk, Iowa and Winona, Minnesota.

LTRMP SRS data tell a story similar to that of the USGS data. For approximately 19,000 samples collected throughout various strata from 1993-2009, just 21 exceeded Iowa standards, 22 exceeded Illinois standards, and 30 exceeded Missouri standards[12]. This represents less than a 0.2 percent rate of exceeding existing criteria for all three states.

[11] While the state criteria generally call for unfiltered ammonia (USGS code 00610), filtered ammonia (00608) is more prevalent in the data set. For the 24 samples at the Clinton site where both filtered and unfiltered parameters were analyzed, the average difference was 0.063 mg/L and the median difference was 0.02 mg/L. While unfiltered concentrations are typically higher than filtered, the unfiltered ammonia concentration for each of the 24 samples was also below every threshold established by the states' criteria.

[12] Exceedances were calculated as a single sample concentration exceeding the calculated criterion. Other requirements in state statute were ignored; for example, Illinois requires a set of 4 samples to exceed their calculated criteria for a standards violation, which was **not** taken into account in determining the number of exceedances. Thus exceedance rates cite above should not be equated with actual standards violations.

Under new US EPA guidance, states would adopt lower ammonia limits for waters with mussels, such as the UMR. Even with the significantly lower allowable concentrations, ammonia in the UMR appears to be consistently less concentrated than the proposed limit. For example, of 542 samples at Clinton during the period in question, only two exceeded the threshold concentration calculated using the new US EPA guidance (Figure 4-9).

Results of Water Suppliers Survey

The data described above are somewhat at odds with the results of the drinking water suppliers survey. Despite the relatively low concentrations of nitrate and ammonia recorded, drinking water suppliers consistently ranked nitrogen compounds (ammonia/nitrate) in the middle or at the top of their source water treatment concerns (Table 4-2). Possible explanations for this seeming discrepancy include:

1. The LTRMP SRS and three fixed site data sets do not accurately reflect concentrations at drinking water intakes, in which case raw water sample results from suppliers would be more representative of conditions.
2. The regulatory thresholds are not the relevant thresholds for water suppliers. Other considerations, potentially operational or public perception-related, are the drivers of suppliers' concerns regarding nitrate and ammonia.
3. The survey's design may have lead to over-reporting of operators' nutrient-related concerns, as it asked respondents to rank the relative significance of several nutrient-related issues. As such, it may have implied that all issues are by default significant and does not provide a comparison against other (i.e., non-nutrient) issues.

Given the broad spatial extent (both longitudinal and lateral) of the LTRMP SRS data examined, the first explanation appears least likely, but regardless this issue begs further discussion with water suppliers.

Summary

A variety of nutrient related effects have been observed in the UMR. Metaphyton blooms appear to be a common issue in off-channel areas of the UMR, but consistent, systemic documentation conducive to scientific analysis is limited. Using chl-a concentrations as a guide, it appears that sestonic blooms are likely a significant recreational issue system-wide, but applying relationships derived from Lake Pepin to the entire river is not fully representative of the UMR as a whole. Aquatic life, including vegetation, fish, and invertebrates appear to be affected by nutrients, but examples of documented, direct impacts are limited. The literature tying nutrients to aquatic life issues in general is extensive, but the precise degree to which nutrients (vs. other stressors) contribute to aquatic life impacts on the UMR has not yet been fully established. Algae was a leading concern in the survey of UMR water suppliers, but more investigation is needed to explore what types of algae blooms are of concern, and the specific nature of their impacts.

Nitrate and ammonia toxicity data are widely available, as most monitoring programs collect nitrate and ammonia samples. These data do not indicate likely issues with toxicity, though nitrate toxicity to aquatic life bears further investigation. The fact that the data indicate concentrations almost entirely below the statutory criteria, yet drinking water suppliers characterize ammonia and nitrate as ongoing concerns, merits further inquiry.

Chapter 5:
Emerging Issues

In the course of this project, issues emerged that could not be addressed fully in this report, both due to limited time and resources available and the nascent state of research in these areas. These emerging issues do merit potential future investigation and as such are briefly outlined in this chapter.

Relationships between Nutrients, Bacteria, and Eutrophication

Current CWA Approaches to Address Bacteria

All UMR states use bacterial indicators as a measure of the presence of pathogens in surface waters. A common indicator has been fecal coliform, though recently many agencies have moved to the more specific *Escherichia coli* (*E. coli*), as some fecal coliforms do not originate from human or animal waste. Indicator bacteria themselves are not necessarily pathogenic, though the indicator bacteria groups may include pathogens. The states use indicator bacteria to determine attainment of primary contact recreation uses. Therefore, tools are in place to address bacteria under the CWA, though their direct application is restricted to determining contact recreation use support. Bacteria are not used to determine support of aquatic life or drinking water uses on the UMR.

Bacteria and nutrients in surface waters share many of the same sources. Combined sewer overflows, wastewater treatment plant discharges, concentrated animal feeding operations, field application of manure, and even wildlife are potential sources of both of these pollutants. Thus, elevated concentrations of bacteria in surface waters may correspond to elevated concentrations of nutrients in these same waters. Further, efforts to reduce nutrient inputs are likely to reduce bacteria inputs, and vice versa.

Emerging Areas and Interactions

Beyond simple co-occurrence, research is emerging regarding more complex relationships between nutrients, bacteria, and eutrophication.

Effect of Nutrients on Bacteria Growth and Dissolved Oxygen

While indicator bacteria are not employed to evaluate eutrophication, this does not mean that bacteria in general are irrelevant to the DO concentration in surface waters.

The rate of oxygen removal within a waterbody is generally measured via biochemical oxygen demand (BOD). This is the amount of oxygen required by heterotrophic microbes to break down the organic material present in surface water. A standard model of surface water dynamics relates BOD to nutrients through algae growth, specifically sestonic algae growth measured via chl-a. The model operates as a chain of cause and effect. First, nutrients stimulate the growth of algae, which leads to an increase in algal biomass. Then, when the algae die, the rate of decomposition accelerates due to the greater mass of decaying organic material. This in turn increases BOD.

Recent research indicates that, in some waters, algae are not a necessary intermediary between increased nutrient inputs and increased BOD (Mallin et al. 2006). In these systems bacteria, are directly stimulated by nutrient inputs, presumably because consumable organic material is already available in the water from external sources. Systems like this call for both monitoring programs and restoration approaches that are distinct from algae-dominated systems. For example, chl-a concentrations won’t fully explain the causes of dissolved oxygen concentration changes, and the N:P ratio that primarily stimulates decompositional microbes is not necessarily the same as the ratio that stimulates various types of algae growth.

The degree to which UMR BOD, and by extension DO, concentrations, are driven by algae growth vs. heterotrophic microbes is not addressed in the scientific literature to date, though it seems likely that algae regulate oxygen demand in some parts of the river. It is unknown whether this dynamic changes during seasons, during specific hydrologic events, between lateral strata, or between longitudinal reaches of the UMR. Further UMR-specific research into this area would greatly illuminate the relationship of nutrients, algae, and bacteria to DO levels.

Encouragement of the Growth of Pathogenic Bacteria

A related issue is the concern that nutrient-driven growth of bacteria either will increase pathogenic bacteria which will in turn adversely impact the safety of the water for recreational use. Research in this area is just emerging and it may be an important consideration for the states in their future work on nutrients.

Organic Carbon and Drinking Water Suppliers

One issue to emerge from the drinking water survey distributed as an element of this project, and from work session discussions, is that drinking water suppliers on the UMR are concerned with elevated concentrations of organic carbon in their source water. This is not an issue isolated to the UMR, as water suppliers in other areas have experienced economic and other impacts associated with elevated organic carbon levels (e.g., Raleigh, North Carolina, see Waldroup 2010).

Water suppliers typically disinfect their water with chlorine. When organic carbon is present in the water during disinfection, trihalomethanes (THMs) and other disinfection byproducts (DBPs) may be produced (Hua and Yeats 2010). These DBPs are a serious health concern, having been linked to cancer and reproductive issues. DBPs are regulated under the Safe Drinking Water Act (SWDA), and TOC monitoring is required for systems using surface water. In addition, operators may be required to remove TOC from their raw water, depending on the TOC levels detected.

Total organic carbon (TOC) levels in the UMR, and other water bodies, are related to phosphorus and/or nitrogen concentrations because algal growth, and sestonic algae in particular, is typically a primary factor in determining the amount of available organic carbon in the system.

Data from the City of Moline (Figure 5-1) indicate that average TOC concentrations at the city intake declined from around 8.0 mg/L to around 6.0 mg/L between 2002 and 2010. However, in the spring of 2010, the trend began to swing upward again. While this is a preliminary result that may not be indicative of a long-term or UMR-wide trend, further exploration of the possible upswing in TOC concentrations at Moline, and TOC concentrations and trends throughout the UMR, is appropriate.

The issue of TOCs is somewhat different than other nutrient-related issues in that the problem caused by TOCs emerges in the treatment process, rather than in the source water itself. As such, it may not be a direct CWA issue *per se*. Nevertheless, further conversation between UMR water suppliers and CWA program managers on the topic would enhance understanding of the issue across disciplines and perhaps suggest opportunities to address TOCs , either directly or indirectly, through the states' nutrient reduction efforts under the CWA.

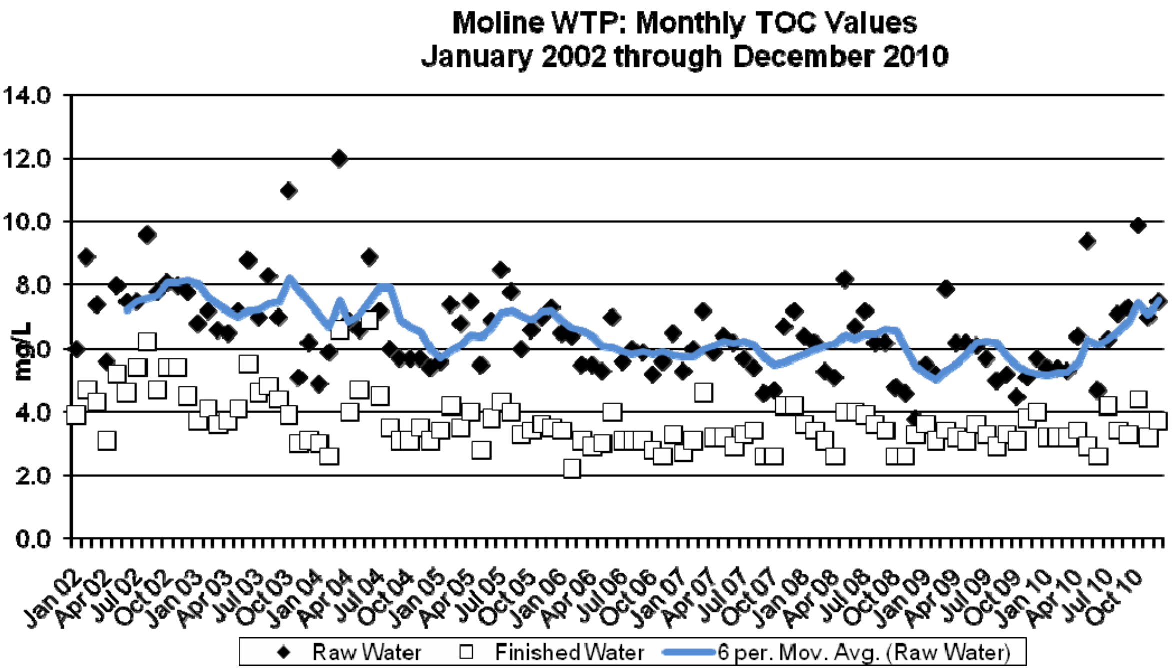


Figure 5-1: City of Moline water utility raw water TOC concentration from 2002-2010.

Chapter 6:
Findings and Recommendations

This chapter summarizes findings presented in this report and makes recommendations for action emerging from these findings. The recommendations are both extensive and ambitious in their scope. As such, the intent of this list of recommendations is not that each and every one will be implemented, but rather it provides a set of options that the states, individually or collectively, may choose to pursue. Further, while these recommendations are primarily addressed to the states, many of them will also require collaboration and participation from other agencies – most prominently from US EPA. The Upper Mississippi River Basin Association Water Quality Executive Committee and Water Quality Task Force provide ongoing venues for the states and their partners to discuss, prioritize, and plan for action regarding these recommendations.

Monitoring and Data Collection

Findings:

A wide variety of monitoring relevant to CWA assessment is being conducted on the UMR mainstem at federal, state, and local levels.

There are several ongoing local, state, and federal water quality monitoring programs collecting nutrient data at one or more monitoring sites on the mainstem of the UMR as of 2011. These programs all collect basic nutrient data, including nitrogen and phosphorus parameters, dissolved oxygen, and pH. Some of the fixed sites monitored under these programs have extensive nutrient data reaching back to the 1950s and 1960s.

Some important differences exist between UMR mainstem monitoring programs, including program designs, parameters sampled, and data reporting and management.

- **Program Design:** Most sampling programs on the UMR rely upon fixed sites. However, LTRMP integrates stratified random sampling (SRS) into its design, as did EMAP-GRE. This can complicate cross-programmatic comparisons. Frequency of sampling also differs among the fixed site programs, ranging between 2 and 32 annual samples. Some programs forego annual sampling in favor of a multi-year cyclical design.
- **Parameters Sampled:** Not all sites are sampled for the full suite of nutrient and nutrient-related parameters. USGS sites no longer include chl-a sampling, and BOD_5 sampling is omitted from many programs. Also of note are differences in how some programs measure TN (i.e., some utilize Kjeldahl nitrogen, some do not).
- **Data Reporting and Management:** Monitoring data is typically stored in an agency- or program-specific database and may also be reported to a national database such as US EPA's Storage and Retrieval Data Warehouse (STORET) or the USGS National Water Information System (NWIS). Reporting formats and requirements may vary between these databases, making comparison and compilation of data challenging.

There are significant spatial gaps in nutrient monitoring on the UMR.

None of the UMR monitoring programs are sufficiently comprehensive in terms of lateral and longitudinal extent, sampling frequency, and parameters measures to fully characterize the nutrient concentrations in the UMR. LTRMP, while the most complete UMR sampling program, is limited to sampling in five study reaches on the UMR. No other monitoring program provides enough data regarding strata off the main channel to provide a laterally complete assessment. However, addressing spatial gaps does not necessarily mean sampling everywhere, and probabilistic design can be very helpful, as demonstrated by EMAP-GRE and LTRMP SRS sampling within study reaches.

There are no standardized, commonly accepted approaches to measuring of nutrient impacts, including algae blooms and fish kills.

Tracking of algae blooms and fish kills occurs on a limited, state- or agency-specific basis. The lack of the coordinated tracking hampers the ability of UMR states and federal agencies to assess the occurrence of these impacts systemwide.

Recommendations:

Pursue more consistent monitoring protocols among water quality programs, including:

- identifying a standard, minimum set of nutrient-related parameters to monitor – this includes adding chl-a to current efforts, and determining whether BOD_5 should be included;
- establishing a minimum sampling frequency for fixed sites;
- expanding the lateral and longitudinal monitoring of the UMR mainstem to address its full spatial extent (but not at the expense of basinwide nutrient monitoring); and
- considering how to integrate LTRMP SRS data with existing or proposed monitoring schemes.

Integrate continuous monitoring for nutrient-related variables into monitoring programs. DO and pH are two primary candidates for continuous monitoring, as these parameters can be monitored in situ without the need for laboratory analysis. In addition, DO daily fluctuation is becoming a widely-used protocol for measuring biological impairment of waters, and pH is useful in measuring photosynthesis activity (and therefore algal biomass).

Develop a UMR-wide, CWA-focused monitoring strategy, as this will address many of the needs listed above.

Harmonize data reporting and sharing, at minimum by documenting data standards and retrieval protocols. Making existing databases more comparable will significantly enhance future efforts to assess the overall condition of the UMR, and nutrient issues in particular. Using a common scheme for coding parameter analysis (such as the USGS parameter code definition[13]) and using that common coding to document which parameters are collected, at which sites, and how frequently would significantly enhance regulators' and researchers' abilities to aggregate data across the UMR mainstem and basin. Improvements to STORET to facilitate data retrieval on larger spatial scales would also be beneficial.

Consider establishing a tributary load monitoring network. There are already monitoring stations at many major tributaries to the UMR run by the primary state monitoring programs. Equipping these stations for load monitoring and setting out minimum sampling frequencies, combined with the harmonized data reporting and sharing suggested above, would allow for more accurate estimates of nutrient loading to the mainstem UMR.

Identify mutually-accepted methods of tracking and reporting algal blooms and fish kills. This may include:

- expanded chl-a monitoring, as recommended above, to estimate sestonic algae blooms;
- expanded implementation of metaphyton quantification efforts, as initiated by LTRMP and Wisconsin DNR; and
- more uniform mechanisms for reporting and tracking fish kills, including a water quality sampling protocol to follow when a kill is reported.

[13] Available at http://nwis.waterdata.usgs.gov/nwis/pmcodes/

UMR Sources, Concentrations, and Trends

Findings:

Nutrient concentrations in the UMR have increased significantly since pre-settlement levels, but levels have stabilized in many locations over the last twenty years, while rates of increase have slowed at other monitoring locations.

Available research and data indicate that both nitrogen and phosphorus concentrations in the UMR mainstem have increased between 4 and 10 times over pre-settlement conditions, depending on the parameter examined and the method of estimation. Trends in nutrient concentrations since 1990 appear relatively flat across phosphorus and nitrogen parameters. However, nitrate may be an exception to this trend, as there is evidence that nitrate concentrations have continued to increase in at least some UMR locations.

Current concentrations of total nitrogen (TN) and total phosphorus (TP) on the UMR are frequently above existing guidelines and criteria (where applicable) to limit excessive nutrient enrichment.

Recent US Army Corps of Engineers Environmental Management Program Long Term Resource Monitoring Program (LTRMP) and US EPA Environmental Monitoring and Assessment Program-Great Rivers Ecosystems (EMAP-GRE) data for the UMR main channel reveal total nitrogen and total phosphorus concentrations that are frequently greater than US EPA ecoregion guidelines, other regional recommendations, and Wisconsin's 100 µg/L TP criterion (currently the only numeric, riverine, eutrophication-based criteria applicable on the UMR).

Nutrient concentrations vary by location on the UMR.

LTRMP and EMAP-GRE data demonstrate that both TN and TP generally show an increasing concentration moving downstream. Studies have confirmed that major tributaries are important drivers of nutrient concentrations. The increase in TN concentrations in the UMR downstream of the Illinois River is an example of this phenomenon. Lateral concentrations also vary. For example, nitrogen concentrations tend to be higher in UMR backwaters than in the main channel.

Research and modeling indicate that agricultural land use is the primary determinant of nutrient loading in the UMR, followed by urban areas.

Nitrogen and phosphorus concentrations in surface waters are tied to both naturally occurring and human-related sources. Research and modeling indicate that agricultural land use is the primary determinant of nutrient loading in the UMR, followed by urban areas. Additionally, both nitrogen and phosphorus loads to the UMR are largely tied to contributions from major tributaries. Other factors affecting nutrient loading include precipitation, atmospheric deposition (for nitrogen) and erosion (for phosphorus).

Agricultural conservation practices have successfully reduced loading in many areas, but important challenges remain, including the loss of nitrogen to surface waters through subsurface flow.

The USDA NRCS Conservation Effects Assessment Project (CEAP) report *Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Upper Mississippi River Basin* found that current agricultural conservation practices do significantly reduce nutrient loading to the UMR and that further conservation practices could lead to additional reductions. The CEAP report notes that the most critical conservation concern in the region is the loss of nitrogen through leaching and that about 51 percent of cropped areas require additional nutrient management to address excessive levels of nitrogen loss in subsurface flow pathways, including tile drainage systems.

Recommendations:

Additional research on nutrient levels over time, starting with pre-settlement levels, similar to the core sampling done for Lake Pepin, should be pursued on a broader scale. This is particularly true for phosphorus, as less historical data is available for phosphorus as compared to nitrogen.

As TN and TP concentrations on the UMR frequently exceed existing guidelines and criteria related to eutrophication, **continued investigation into the occurrence of eutrophication and its impacts on the UMR is warranted**.

As agricultural land use is a dominant factor in UMR basin nutrient loading**, successful approaches to preventing nutrient losses to water will need to address agricultural nonpoint source pollution**, while also addressing point source contributions. Ideally, each source will be addressed in proportion to its contribution.

Ongoing collaboration among local, states, federal, private, and other partners is essential in expanding agricultural conservation practices in the basin and in improving their efficiency.

Impacts to CWA Designated Uses

Findings:

Both nitrogen <u>and</u> phosphorus appear to contribute to local nutrient impacts on the UMR mainstem.

Phosphorus is usually considered the primary algae limiting nutrient in waters in the UMR basin, and research indicates that it plays a primary role in regulating the biomass of sestonic algae in the UMR. However, studies indicate that nitrogen may be more of a factor in metaphyton growth and fish community alteration.

Elevated nutrient concentrations do not necessarily lead to eutrophic or hypereutrophic conditions that constitute an impairment of the aquatic life and recreation uses. Rather, nutrient concentrations over certain locally determined thresholds are prerequisites for eutrophication-related aquatic life and/or recreation use impairments.

A number of factors affect whether and how nutrient concentrations result in impacts to CWA designated uses. The expression of impacts can vary by location, season, and flow condition. As a result, predicting eutrophication or hypereutrophication exclusively via nutrient concentrations is challenging at best. However, as nutrients are a necessary element for algae growth, concentration limits can be identified that are likely to limit eutrophication/hypereutrophication impacts to aquatic life and recreation.

Metaphyton blooms are likely a regular occurrence in backwaters of the UMR.

Recent backwater surveys in Pools 4, 8, and 13 indicate that sampling locations regularly experience duckweed coverage of greater than 80 percent. While this finding is not comprehensive for all UMR backwaters, it is very likely indicative of conditions throughout the UMR backwaters and is consistent with less formal evidence such as citizen and water professional reports. Such metaphyton blooms both impede recreational use and potentially impact aquatic life.

Sestonic algae blooms appear to be commonplace on the UMR.

Chlorophyll-a (chl-a) data for the UMR indicate that sestonic algae concentrations are likely at nuisance levels on a regular basis, with chl-a concentrations exceeding 40 μg/L at some time in most strata during most years. At these levels, both recreational use and aquatic life are potentially affected. However, the only UMR research on public perception of nuisance level thresholds is from

Lake Pepin, a hydrologically unique natural reservoir. More precise, systemic estimates of how frequently UMR recreational use is impacted are not currently available.

Too few data exist to accurately estimate the extent of cyanobacteria blooms on the UMR.

While the presence of sestonic algae blooms implies at least some presence of cyanobacteria on the UMR, parameters that help quantify the presence of cyanobacteria, such as microcystin, are not regularly sampled. Therefore, no quantitative statements can be made at this time regarding cyanobacteria on the UMR.

There is evidence that the UMR fish community and other aquatic communities are being affected by eutrophication caused by nutrient loading. However, the extent, mechanism, and frequency of these impacts are not fully known.

- **Fish:** There is evidence that excessive nutrient inputs have caused DO-related fish kills in the past, and that nitrogen concentrations influence fish community structure. Precisely how fish assemblages in the UMR change as a result of heightened nutrient loading is unknown, as is the frequency of hypoxia events and the precise degree to which hypoxic conditions are caused by nutrients as opposed to hydrology.
- **Submersed Aquatic Vegetation:** Existing research indicates that UMR SAV density is tied both to water turbidity and metaphyton growth, both of which may be connected to nutrient concentrations. However, other mechanisms relating SAV community health to nutrient concentrations have not been extensively studied in the UMR.
- **Macroinvertebrates:** At least one extirpation, then resurgence, of a significant macroinvertebrate population on the UMR has been directly linked to nutrients. Other studies have been more ambiguous, but tend to point toward a correlation between increased nutrient concentrations and decreased macroinvertebrate community health.

Using current criteria as a guide, direct toxicity to aquatic organisms from ammonia and to humans from nitrate does not appear to be an issue on the UMR, but some concerns remain and new criteria could affect this characterization.

LTRMP and EMAP-GRE monitoring results both indicate that ammonia and nitrate levels are consistently below criteria for aquatic life and drinking water uses, respectively. However, the establishment of nitrate standards to protect aquatic life, such as those currently being pursued by Minnesota, may result in the identification of nitrate as a concern for aquatic life use support. Additionally, UMR water suppliers identified nitrate as a leading concern, even though UMR concentrations are below the 10 mg/L Safe Drinking Water Act maximum contaminant level.

Recommendations:

Formalize a metaphyton sampling and quantification protocol, presumably using LTRMP and Wisconsin DNR's methods, and expand existing programs to utilize the new protocol.

Develop definition(s) of nuisance sestonic algae applicable to the entire UMR. The chl-a concentrations defined for Lake Pepin are a starting point, but for various reasons may not be applicable to the entire UMR. More work is required to refine what concentrations of chl-a result in conditions the public considers a detriment to river recreation, keeping in mind differences among longitudinal reaches and lateral strata.

Begin recording and reporting N:P ratios, along with chl-a concentrations, as part of UMR monitoring. As cyanobacteria thrive at low N:P ratios, this additional reporting would improve the accuracy of cyanobacteria bloom estimates. State agencies should investigate recently developed methods of directly measuring cyanobacteria, and consider adopting them into their sampling protocols.

Conduct additional paired fish/water chemistry monitoring and research to clarify the extent and nature of nutrient impacts on fish. Paired biology/chemistry studies significantly expand the potential for scientific study of nutrient impacts on aquatic communities. Carefully examining the relationships between communities of fish and DO concentrations will help to clarify the degree to which hypoxia affects fish assemblages on the UMR.

Work with UMR water suppliers to explore issues related to algae growth and TOC, assemble relevant TOC data, and consider additional and/or expanded monitoring as needed. As TOC is a parameter of concern for a significant designated use (drinking water), state CWA programs should work with UMR water suppliers and their own SDWA programs to explore options for data compilation and monitoring. The programs should also consider whether and how best to address TOC in a CWA context.

CWA Implementation

Findings:

Nutrients affect UMR designated uses in a number of locations, subject to certain conditions. However, there is currently just one nutrient-related CWA 303(d) impairment listing on the UMR, at Lake Pepin.

Nutrient impacts are not uniform in terms of where and when they occur on the UMR, and current monitoring and assessment approaches do not fully capture this diversity. For example, as described in this report, eutrophication effects are most prominently expressed in off-channel areas and less so in the main channel. However, current CWA 305(b) assessments are typically limited to the main channel. The expression of impacts is also dependent on season, and this is not necessarily captured in current CWA 305(b) assessments. These spatial and temporal factors are likely one explanation for the lack of CWA 303(d) impairments, in that current CWA approaches generally do not address either how frequently the strata in a reach may be affected, or what frequency or severity of impact would constitute a use impairment.

All of the UMR states are working to further address nutrients in their CWA programs, but are taking differing approaches and may be at different points in this process, particularly in regarding numeric nutrient criteria.

Each UMR state is in the process of addressing nutrients within its CWA program, as described in Chapter 1, though the emphasis and scope taken by individual states varies and states are at different points in completing their ongoing work. Among recent efforts, Wisconsin has completed a comprehensive phosphorus rule package that includes the first eutrophication-related, flowing waters numeric nutrient criterion applicable to the UMR. Minnesota is also in the process of developing numeric nutrient criteria applicable to the River, as well as corresponding targets for response variables.

The nutrient parameters monitored in NPDES-permitted point source discharges vary between states.

While the majority of states have nitrogen and phosphorus monitoring requirements for "major" dischargers, there is variation among the states in the specifics of these monitoring requirements.

Nitrate criteria for drinking water uses are currently consistent among the five UMR states. At least one state is considering aquatic life criteria for nitrates.

All UMR states have adopted the MCL of 10 mg/L as their CWA target for the drinking water use. Minnesota's investigations into nitrate toxicity for aquatic life may lead to more stringent nitrate standards for the UMR that are not reflected in the standards of other UMR states.

Ammonia criteria are generally consistent among states, though early life stage (ELS) schedules differ.

All UMR states have total ammonia criteria that vary with pH, temperature, and the presence of early life stage (ELS) aquatic organisms. Four of the five states utilize the same EPA recommended equations for calculating criteria, but the UMR states have not coordinated calendars of ELS presence in the UMR. EPA's 2007 draft criteria recommendations for ammonia envision criteria that are lower than those currently utilized by the UMR states.

It is not clear that the states' current approaches to protecting the drinking water use on the UMR are congruent with water suppliers' needs and goals.

The results of the waters suppliers' survey indicate that there is likely some disconnect between adopted CWA standards and the needs of water suppliers. In particular, raw water for drinking water suppliers appears to meet existing regulatory requirements, and yet suppliers have identified nutrient-related issues that apparently require significant resources to address.

Recommendations:

The states and US EPA should consider the following in the development of any numeric nutrient criteria applicable to the UMR:

- **Phosphorus and nitrogen may both require target values,** potentially varying by strata, as evidence indicates that TP and TN affect distinct algae and aquatic life communities to differing degrees and differentially among strata.
- **While phosphorus and nitrogen are the drivers of eutrophication, concentrations of TP and TN alone cannot always predict its occurrence.** Because eutrophication on the UMR is dependent on several factors (e.g., water velocity, light penetration) beyond nutrient concentrations alone, there can be cases where TP and TN are above target values, but eutrophication does not occur. States may wish to consider response variables (e.g., biological parameters, dissolved oxygen, chlorophyll-a, biological oxygen demand) in conjunction with causal variables (TP and TN) in assessing waters. To be successful, such an approach would require, among other things, significant dependency between causal and response variables and protection of downstream uses.
- **Numeric nutrient criteria are most likely to be effective as a component of a comprehensive approach to nutrient reduction.** This includes not only CWA tools focused on monitoring, assessment, and impairment listing, but also other CWA approaches (such as permit limits and technology controls for point sources), and non-CWA tools including nonpoint source reduction techniques. Wisconsin's 2010 phosphorus rule package represents perhaps the most fully developed state framework to incorporate these multiple elements.
- **Interstate considerations are critical.** The states may not necessarily employ identical approaches; however, they should work collaboratively and seek congruence in their development of UMR nutrient criteria. This will help promote consistency in the states' assessment of shared river reaches and aid in the protection of downstream uses. Using shared conceptual models could further the states' efforts in this regard.

Pursue consistent NPDES discharge monitoring requirements for both nitrogen and phosphorus among states.

As discussed throughout this report, both phosphorus and nitrogen have important impacts on the mainstem UMR (as well as in the Gulf of Mexico). Therefore, the states should expand their NPDES discharge monitoring requirements to include both phosphorus and nitrogen and seek to make these requirements more consistent among states.

Agree upon early life stage (ELS) schedules for all 13 of the UMR assessment reaches.

While there is currently good agreement in the ammonia criteria used by states, this consistency would be further enhanced by agreement among the states on schedules of ELS presence for the 13 shared assessment reaches.

Pursue further dialog with water suppliers to explore the relationship between CWA programs and water suppliers' needs.

This project has revealed some potential incongruencies between CWA program implementation and water supplier needs and expectations, including the TOC issue described above. Additional conversations between states and UMR water suppliers may be warranted to further examine how the CWA does and does not meet suppliers' needs and assure attainment of drinking water uses.

Appendix A:
Project Participants

Name	Organization
Gregg Good	Illinois EPA
Bob Mosher	Illinois EPA
Matt Short	Illinois EPA
John Olson	Iowa DNR
Tom Wilton	Iowa DNR
Will Bouchard	Minnesota PCA
Shannon Lotthammer	Minnesota PCA
Steve Heiskary	Minnesota PCA
Wayne Anderson	Minnesota PCA
Mohsen Dkhili	Missouri DNR
Mark Osborn	Missouri DNR
Trish Reilly	Missouri DNR
Jim Baumann	Wisconsin DNR
John Sullivan	Wisconsin DNR
Clint Beckert	US Army Corps of Engineers
Joe Gates	USDA NRCS
Bill Franz	US EPA, Region 5
Tim Henry	US EPA, Region 5
Barb Mazur	US EPA, Region 5
Brian Thompson	US EPA, Region 5
Ron Hammerschmidt	US EPA, Region 7
John DeLashmit	US EPA, Region 7
Art Spratlin	US EPA, Region 7
Larry Shepard	US EPA, Region 7
David Bolgrien	US EPA, Office of Research and Development (ORD)
Bill Richardson	USGS, Upper Midwest Environmental Sciences Center
Jeff Houser	USGS, Upper Midwest Environmental Sciences Center
Bob Buchmiller	USGS, Iowa Water Science Center
Dale Robertson	USGS, Wisconsin Water Science Center
David Saad	USGS, Wisconsin Water Science Center
Greg Swanson	Moline, Il. Water Division
Brent Earley	Iowa American Water
Joanne Burkholder	Mississippi River Collaborative
Albert Ettinger	Mississippi River Collaborative
Chris Yoder	Midwest Biodiversity Institute
Kris Sigford	Minnesota Center for Environmental Advocacy
Gretchen Benjamin	The Nature Conservancy
Gayle Killam	River Network
Roger Wolf	Iowa Soybean Association
Peg Donnelly	UMRBA/US EPA Region 5
Dave Hokanson	UMRBA
Nat Kale	UMRBA
Barb Naramore	UMRBA

Works Cited

Alexander, Richard. B. et al. "Estimates of diffuse phosphorus sources in surface waters of the United States using a spatially referenced watershed model." *Water Science and Technology,* Vol. 49, No. 3 (2004): 1-10.

Alexander, Richard B. et al. "Differences in Phosphorus and Nitrogen Delivery to the Gulf of Mexico from the Mississippi River Basin." *Environmental Science and Technology*, Vol. 42, No.3 (2008): 822-830.

Angradi, Ted R. (editor). *Environmental Monitoring and Assessment Program: Great River Ecosystems, Field Operations Manual.* EPA/620/R-06/002, Washington, DC: U.S. Environmental Protection Agency, 2006.

Angradi, Ted R., and Terri M. Jicha. "Mesohabitat-specific macroinvertebrate assemblage responses to water quality." *Ecological Indicators,* Vol. 10 (2010): 943-954.

Barko, John. W. et al. "Environmental Factors and Their Consideration in the Management of Submersed Aquatic Vegetation: A Review." *Journal of Aquatic Plant Management,* Vol. 24 (1986): 1-10.

Barr Engineering Company. *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds.* LCCMR Study, St. Paul: Minnesota Pollution Control Agency, 2004.

Bobbink, R. et al. "Global assessment of nitrogen deposition effects on terrestrial plant diversity: a synthesis." *Ecological Applications,* Vol. 20 (2010): 30-59.

Cavanaugh, Jennifer C. et al. "Nitrogen Dynamics in Sediment During Water Level Manipulation on the Upper Mississippi River." *River Research and Applications*, Vol. 22 (2006): 651-666.

Donner, Simon D. et al. "Modeling the impact of hydrological changes on nitrate transport in the Mississippi River Basin from 1955 to 1994." *Global Biogeochemical Cycles,* Vol. 16, No. 3 (2002): 1-19.

Dubrovsky, N.M. et al. *The quality of our Nation's waters : nutrients in the Nation's streams and groundwater, 1992–2004.* Circular 1350, U.S. Geological Survey, 2010.

Engstrom, Daniel R. et al. "Historical changes in sediment and phosphorus loading to the upper Mississippi River: mass-balance reconstructions from the sediments of Lake Pepin." *Journal of Paleolimnology*, 2009: 563-588.

Fremling, Calvin R., and D. Kent Johnson. "Recurrence of Hexegenia mayflies demonstrates improved water quality in Pool 2 and Lake Pepin, Upper Mississippi River." In *Mayflies and Stoneflies: Life Histories and Biology*, by I. C. (ed) Campbell, 243-248. Kluwer Academic Publishers, 1989.

Giblin, Shawn et al. *Evaluation of Factors Influencing Metaphyton Abundance and Distribution on Naviation Pools 4, 8, and 13 of Upper Mississippi River.* LTRMP Completion Report, La Crosse: United States Geological Survey, 2009.

Gilliom, Robert J., et al. *Design of the National Water-Quality Assessment Program: Occurrence and Distribution of Water-Quality Conditions.* 1995. United States Geological Survey Circular 1112 (accessed January 31, 2011).

Goolsby, Donald A. et al. "Nitrogen Flux and Sources in the Mississippi River Basin." *Science of the Total Environment*, Vol. 248 (2000): 75-86.

Goolsby, Donald A., and William A. Battaglin. *Nitrogen in the Mississippi Basin - Estimating Sources and Predicting Flux to the Gulf of Mexico.* Fact Sheet 135-00, Washington DC: USGS, 2000.

Gulf Restoration Network et al. *Petition for Rulemakeing Under the Clean Water Act for Numeric Water Quality Standards for Nitrogen and Phosphoros and Total Maximum Daily Loads for the Mississippi River and the Gulf of Mexico.* Submitted to US EPA on July 30, 2008.

Hedman, Curtis J. et al. "New Measurements of Cyanobacteria Toxins in Natural Waters Using High Performance Liquid Chromatography Coupled to Tandem Mass Spectrometry." *Journal of Environmental Quality,* Vol. 37 (2008): 1817-1824.

Heiskary, Steven A. *Relation of Nutrient Concentrations and Biological Responses in Minnesota Streams: Applications for River Nutrient Criteria Development.* EPA Grant Report, St. Paul: Minnesota Pollution Control Agency, 2008.

Heiskary, Steven A., and Dennis Wasley. *Mississippi River Pools 1 through 8: Developing River, Pool and Lake Pepin Eutrophication Criteria.* St. Paul: Minnesota Pollution Control Agency, 2010.

Heiskary, Steven A., and William W. Jr. Walker. "Establishing a Chlorophyll A Goal for a Run-of-the-River Reservoir." *Lake & Reservoir Management*, Vol. 11 (1995): 67-76.

Heiskary, Steven A., and Howard Markus. *Establishing Relationships Among In-stream Nutrient Concentrations, Phytoplankton Abundance and Composition, Fish IBI and Biochemical Oxygen Demand in Minnesota USA Rivers.* Report to USEPA Region 5, St. Paul: Minnesota Pollution Control Agency, 2003.

Houser, Jeffrey N., and W. B. Richardson. "Nitrogen and phosphorus in the Upper Mississippi River: transportation, processing, and the effects on the river ecosystem." *Hydrobiologia*, Vol. 640 (2010): 71-88.

Houser, Jeffrey N. et al. "Longitudinal Trends and Discontinuities in Nutrients, Chlorophyll, and Suspended Solids in the Upper Mississippi River: Implications for Transport, Processing, and Export by Large Rivers." *Hydrobiologia,* Vol. 651 (2010): 127-144.

Houser, Jeffrey N. et al. *Multiyear Synthesis of Limnological Data from 1993 to 2001 for the Long Term Resource Monitoring Program.* LTRMP Technical Report, La Crosse, Wisconsin: U.S. Army Corps of Engineers from the U.S. Geological Survey, 2005.

Hua, Guanghui, and Steven Yeats. "Control of Trihalomethanes in Wastewater Treatment." *Florida Water Resources Journal*, 2010: 6-12.

Hubbard, L., D. W. Kolpin, S. J. Kalkahoff, and D. M. Robertson. "Nutrient and Sediment Concentrations and Corresponding Loads during the Historic June 2008 Flooding in Eastern Iowa." *Journal of Environmental Quality,* Vol. 40 (2011): 166-175.

Illinois Environmental Protection Agency. *Illinois Water Monitoring Strategy, 2007 - 2012.* Bureau of Water Report, Chicago: Illinois Environmental Protection Agency, 2007.

Iowa Department of Natural Resources. *Iowa DNR: Water Quality Standards, Nutrients.* September 2010. http://www.iowadnr.gov/InsideDNR/RegulatoryWater/WaterQualityStandards/Nutrients.aspx (accessed January 19, 2011).

Iowa Department of Natural Resources. *Iowa Water Monitoring Plan.* March 2000. http://www.igsb.uiowa.edu/wqm/Home/WaterMonitoringPlan2000.htm (accessed February 2, 2011).

Iowa Department of Natural Resources. *Water Monitoring Program Highlights 2004-5.* 2005. ftp://ftp.igsb.uiowa.edu/igspubs/pdf/wfs-2004-05.pdf (accessed February 2, 2011).

Iowa Nutrient Science Advisors. *Nutrient Criteria for Iowa Lakes - Recommended Criteria for Class "A" Recreational Uses.* Criteria Recommendation, Des Moines: Iowa Department of Natural Resources, 2008.

Isaak Walton League. *Isaak Walton League Fish Kill Advisory Network.* December 2005. http://www.iwla.org/index.php?ht=display/ContentDetails/i/714/pid/223 (accessed September 3, 2010).

James, William F., et al. "Effects of Residence Time on Summer Nitrate Uptake in Mississippi River Flow-Regulated Backwaters." *River Research and Applications*, Vol. 24 (2008): 1206-1217.

Johnson, Barry L., and Karen H. Hagerty. *Status and Trends of Selected Resources of the Upper Mississippi River System.* La Crosse, WI: U.S. Geological Survey, 2008.

Knight, Brent C. et al. *Fish Assemblages in Off-Channel Areas of the Upper Mississippi and Illinois Rivers: Implications for Habitat Restoration at Management-Relevant Scales.* Completion Report, Rock Island: US Army Corps of Engineers, 2008.

Kreiling, Rebecca M. et al. "Summer nitrate uptake and denitrification in an upper Mississippi River backwater lake: the role of rooted aquatic vegetation." *Biogeochemistry*, Vol. 104 (2010): 309-324.

Larson, Catherine E. *Lower Minnesota River Study: Monitoring and Modeling Water Quality from Jordan, Minnesota, to the Mouth.* Project Report, St. Paul: Metropolitan Council, 2010.

Libra, R. D. et al. *Nitrogen and Phosphorus Budgets for Iowa and Iowa Watersheds.* Technical Information Series, Iowa Geological Survey, 2004.

Lubinski, Kenneth (editor). *Ecological Status and Trends of the Upper Mississippi River System.* La Crosse: US Geological Survey, 1999.

Mallin, Michael A. et al. "Factors contributing to hypoxia in rivers, lakes, and streams." *Limnology and Oceanography,* Vol. 51 (2006): 690-701.

Meade, Robert H. *Contaminants in the Mississippi River, 1987-92.* US Geological Survey Circular 1133, Washington, D.C.: United States Government Printing Office, 1996.

Minnesota Pollution Control Agency. *EDA: Surface Water Search.* May 21, 2010. http://www.pca.state.mn.us/index.php/topics/environmental-data/eda-environmental-data-access/eda-surface-water-searches/eda-surface-water-search-text-based.html (accessed February 3, 2011).

Minnesota Pollution Control Agency. *Minnesota Milestone River Monitoring Program.* September 15, 2010. http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/streams-and-rivers/minnesota-milestone-river-monitoring-program.html (accessed February 1, 2011).

Minnesota Pollution Control Agency. *Minnesota's Water Quality Monitoring Strategy - 2004 to 2013.* Report to the US EPA, St. Paul: Minnesota Pollution Control Agency, 2004.

Missouri Department of Natural Resources. *Missouri Water Quality Report 2008.* CWA 305(b) Report, Jefferson City, Missouri: Missouri Department of Natural Resources, 2009.

Monson, Phil. *Aquatic Life Water Quality Standards Technical Support Document for Nitrate.* Triennial Water Quality Standard Amendments to Minnesota Rules, St. Paul: Minnesota Pollution Control Agency, 2010.

MPCA. *Total Suspended Solids - Submersed Aquatic Vegetation Site-Specific Standard South Metro Mississippi River.* Draft Public Notice, St. Paul: MPCA, 2010.

National Research Council. *Mississippi River Water Quality and the Clean Water Act.* Washington, DC: The National Academies Press, 2008.

Phillips, G. L. et al. "A mechanism to account for macrophyte decline in progressively eutrophicated freshwaters." *Aquatic Botany,* Vol. 4 (1978): 103-126.

Randall, Gyles W., and David J. Mulla. "Nitrate Nitrogen in Surface Waters as Influenced by Climatic Conditions and Agricultural Practices." *Journal of Environmental Quality,* Vol. 30 (2001): 337-344.

Robertson, Dale M. et al. *Nutrient Concentrations and Their Relations to the Biotic Integrity of Nonwadeable Rivers in Wisconsin.* USGS Professional Paper 1754, Reston, VA: US Geological Survey, 2008.

Robertson, Dale M. et al. "A regional classification scheme for estimating reference water quality in streams using land-use-adjusted spatial regression-tree analysis." *Environmental Management,* Vol. 37 (2006): 209-229.

Robertson, Dale M. et al. *An Alternative Regionalization Scheme for Defining Nutrient Criteria for Rivers and Streams.* Investigations Report 01-4073, Middleton, WI: U.S. Geological Survey, 2001.

Robertson, Dale M. et al. "Incorporating Uncertainty into the Ranking of SPARROW Model Nutrient Yields from Mississippi/Atchafalaya River Basin Watersheds." *Journal of the American Water Resources Association*, Vol. 45 (2009): 534-549.

Ruhl, Henry A., and Nancy B. Rybicki. "Long-term reductions in anthropogenic nutrients linked to improvements in Chesapeake Bay habitat." *Proceedings of the National Academy of Sciences,* Vol. 107, No. 38 (2010): 16566-16570.

Schindler, D. W. "Eutrophication and Recovery in Experimental Lakes: Implications for Lake Management." *Science*, Vol. 184 (1974): 897-899.

Short, Matthew B. *Baseline Loadings of Nitrogen, Phosphorus, and Sediments from Illinois Watersheds.* US EPA Grant Report, Springfield, IL: IL EPA Bureau of Water, 1999.

Soballe, D. M., and B. L. Kimmel. "A large-scale comparison of factors influencing phytoplankton abundance in rivers, lakes, and impoundments." *Ecology,* Vol. 68 (1987): 1943-1954.

Soballe, David M., and James R. Fischer. *Long Term Resource Monitoring Program Procedures: Water Quality Monitoring.* Technical Report LTRMP 2004-T002-01, La Crosse, Wisconsin: US Geological Survey, Upper Midwest Sciences Center, 2004.

Sprague, Lori A. et al. Nitrate in the Mississippi River and Its Tributaries, 1980 to 2008: Are We Making Progress? *Environ. Science and Technology,* Vol. 45 (2011): 7209–7216

Strauss, Eric A., et al. "Nitrification in the Upper Mississippi River: patterns, controls, and contribution to the NO3 budget." *Journal of the North American Benthological Society*, Vol. 23 (2004): 1-14.

Sullivan, John F. *The use of Metaphyton to Evaluate Nutrient Impairment and Proposed Nutrient Criteria for Wetlands and Backwaters in the Upper Mississippi River.* Technical Report, La Crosse, WI: Wisconsin DNR, 2008.

Sullivan, John F. et al. *Upper Mississippi River Water Quality Assessment Report.* Summary Report, Chicago: Upper Mississippi River Conservation Committee / US EPA, 2002.

Terrio, Paul J. Concentrations, Fluxes, and Yields of Nitrogen, Phosphorus, and Suspended Sediment in the Illinois River Basin, 1996-2000. Scientific Investigations Report 2006-5078, Reston, VA: US Geological Survey, 2006.

Turner, R. Eugene, and Nancy N. Rabalais. "Linking Landscape and Water Quality in the Mississippi River Basin for 200 Years." *BioScience,* Vol. 53 (2003): 563-572.

Upper Mississippi River Basin Association Water Quality Task Force. *Upper Mississippi River Aquatic Life Use Designations: Improving Protection under the Clean Water Act (DRAFT).* St. Paul: Upper Mississippi River Basin Association, 2011, fothcoming.

U.S. Department of Agriculture. *Conservation Effects Assessment Project: Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Upper Mississippi River Basin (Draft).* Washington D.C.: USDA NRCS, 2010.

US EPA Office of Water. *Ambient Water Quality Criteria Recommendations.* Washington, D.C.: US EPA, 2001.

US EPA Office of Water. *Draft 2009 Update Aquatic Life Ambient Water Quality Criteria For Ammonia - Freshwater.* Criteria Guidance, Washington, DC: United States Environmental Protection Agency, 2009.

US EPA Region 7; Iowa Department of Natural Resources. *Comprehensive Report of Ambient Water Quality Monitoring Programs in Iowa.* Iowa Department of Natural Resources, 2006.

US Geological Survey. *Incorporating Uncertainty into the Ranking of SPARROW Model Nutrient Yields from the Mississippi/Atchafalaya River Basin Watersheds.* April 17, 2009. http://water.usgs.gov/nawqa/sparrow/nutrient_yields/faq.html (accessed March 14, 2011).

Wagner, Ken. "Nutrient Loading to Lake Waco." US EPA Watershed Academy Webcast Presentation. January 26, 2010.

Waldroup, Kenneth. *Potential Impacts of Declining Water Quality in Falls Lake.* Raleigh, NC, Presentation, February 27, 2010.

Walker, William W. Jr. "Significance of eutrophication in water supply reservoirs." *Journal of the American Water Works Association*, (January 1983): 38-42.

Wasley, Dennis. *Concentration and movement of nitrogen and other materials in selected reaches and tributaries of the Upper Mississippi River System.* MS Thesis, La Crosse: University of Wisconsin, La Crosse, 2000.

Wisconsin Department of Natural Resources. *Wisconsin's Long Term Trend Water Quality Monitoring Program for Rivers, July 2001 - June 2005.* River Long Term Trends Work Group Report, Madison: Wisconsin Department of Natural Resources, 2006.

Wisconsin Department of Natural Resources. *Phosphorus Pollution Media Kit.* January 19, 2011. http://dnr.wi.gov/news/mediakits/mk_phosphorus.asp (accessed January 19, 2011).

Wisconsin Department of Natural Resources. *WDNR Water Division Monitoring Strategy.* Planning Document, Madison: Wisconsin Department of Natural Resources, 2008.