

Executive Summary

Background—The Problem with Phosphorus

Concerns about the phosphorus content of automatic dishwashing detergents, from the Minnesota State Legislature and other interested stakeholders, resulted in legislation requiring a study of all of the sources and amounts of phosphorus entering publicly-owned treatment works (POTWs) and Minnesota surface waters.

Phosphorus is the nutrient primarily responsible for the eutrophication (nutrient enrichment of waterbodies) of Minnesota's surface waters. An overabundance of phosphorus—specifically usable (bioavailable) phosphorus—results in excessive algal production in Minnesota waters. Phosphorus from point sources may be more bioavailable, impacting surface water quality more than a similar amount of nonpoint source phosphorus that enters the same surface water. Phosphorus contributions to Minnesota surface waters by point and nonpoint sources are known to vary, both geographically and over time, in response to annual variations in weather and climate. Nonpoint sources of phosphorus tend to comprise a larger fraction of the aggregate phosphorus load to Minnesota surface waters during relatively wet periods, while point sources become increasingly important during dry conditions.

Purpose of Assessment

This Detailed Assessment of Phosphorus Sources to Minnesota Watersheds was conducted to provide the Minnesota Pollution Control Agency (MPCA) with the information necessary to comply with newly enacted legislation surrounding phosphorus sources. The assessment inventories the following:

1. Sources and amounts of phosphorus entering three different sizes and categories of publicly-owned treatment works (POTWs; i.e., wastewater treatment plants).

Sizes: (average daily flow rate)

- Less than 0.2 million gallons per day (mgd)
- 0.2 to 1.0 mgd
- Greater than 1.0 mgd

Categories:

- Primarily domestic
- Domestic with some commercial/industrial
- Predominately commercial/industrial

Sources: (individual and/or categorical)

- Automatic dishwasher detergents (ADWD)
- Other household cleaners or household non-ingested sources
- Commercial/industrial, including:
 - Process wastewater

- Noncontact cooling water
- Other additives
- Water supply, including water treatment chemicals
- Human waste products (ingested sources)
- Groundwater intrusion to sanitary sewers

Information developed in this portion of the phosphorus inventory is intended to assist the MPCA in complying with MN Laws 2003, Chap. 128 Art. 1, Sec. 122:

The state goal for reducing phosphorus for non-ingested sources entering municipal wastewater treatment systems is at least 50 percent reduction based on the timeline for reduction developed by the commissioner under section 166, and a reasonable estimate of the amount of phosphorus from non-ingested sources entering municipal wastewater treatment system in calendar year 2003.

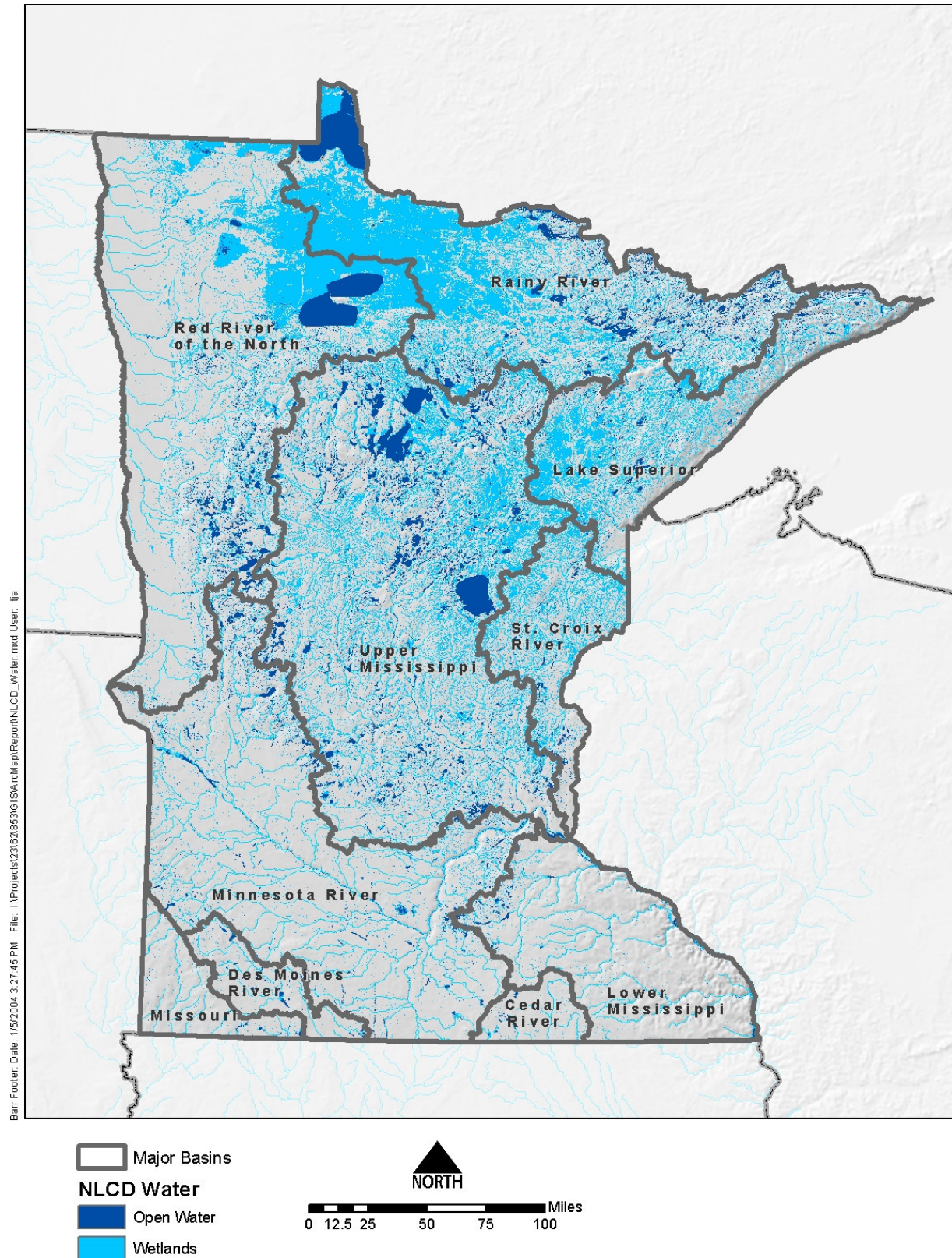
2. Sources and amounts of phosphorus entering Minnesota surface waters for each of the ten major basins (see Figure EX-1) and for the entire state of Minnesota from point- and nonpoint-sources during low (dry), average, and high (wet) flow conditions; and the effect of various phosphorus source reduction options on water quality.

Information developed in this portion of the phosphorus inventory is intended to assist the MPCA in complying with MN Laws 2003, Chap. 128, Art. 1, Sec. 166:

The commissioner of the pollution control agency must study the concept of lowering phosphorus in the wastewater stream and the effect on water quality in the receiving waters and how to best assist local units of government in removing phosphorus at public wastewater treatment plants, including the establishment of a timeline for meeting the goal in Minnesota Statutes, section 115.42.

Estimating the phosphorus source contributions to Minnesota surface waters for each of the ten major basins required a clear definition of surface waters, as well as knowledge about the amount of phosphorus produced and the mechanisms of delivery for each point and nonpoint source category, to establish a “frame of reference,” or a basis for comparison by source category and by basin. For the purposes of this analysis, Minnesota surface waters were defined by mapping all of the various types of water bodies contained in the Minnesota Department of Natural Resources 24K Stream Layer (all records, including ditches and intermittent streams) and all land cover types identified as wetlands or lakes in the U.S. Geological Survey (USGS) National Land Cover Database. Figure EX-1 shows the areas of all of the Minnesota surface waters, within each of the ten major basins.

Figure EX-1 Major Basins and Surface Waters



General Project Approach

This assessment estimates the annual phosphorus loading, or amounts of phosphorus (total and bioavailable), entering all of the various types of surface waters from each of the source categories under low (dry), average and high (wet) flow conditions. The general nature and scale of this analysis allows for summarizing the estimated loadings for each major basin, and on a statewide basis. The characteristics of smaller watershed units, or subwatersheds, were not utilized to estimate the phosphorus loadings from each source category. Since each subwatershed typically drains to wetlands, lakes, ditches or streams that possess their own unique processes for transformation or phosphorus uptake, no further breakdown of phosphorus inflow or outflow loadings by subwatershed or surface water type is possible within the scope of this analysis. As a result, the phosphorus loadings discussed in this report represent the total amount of phosphorus entering all of the surface water areas that are present within each major basin for each flow condition.

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Because of the general nature of this analysis, it can be true that sources of phosphorus which are deemed minor at the basin scale, may actually contribute the majority of phosphorus to specific surface water bodies, at a localized scale. For example, point sources typically contribute little or no phosphorus to Twin Cities Metropolitan and most outstate lakes, but can represent a significant portion of the total phosphorus load to rivers under low flow conditions. Likewise, nonpoint source amounts or categories will vary at a localized scale. Because of this, there is still a need to complete individual assessments of specific watersheds to evaluate specific loading conditions. The phosphorus loading estimates from this assessment are only intended to quantify the phosphorus source contributions originating in Minnesota for Minnesota surface waters. No attempt has been made to estimate the phosphorus loadings to the St. Croix River basin that originate from Wisconsin, to the Minnesota River basin from South Dakota, to the Rainy River basin from Canada, or to the Red River basin from North Dakota.

While the context for this analysis does not allow for direct assessments to be made about the observed water quality at the mouth of each major river basin, it does allow for a direct “apples-to-apples” comparison of the amounts of phosphorus originating from various source categories under various flow conditions. This analysis also facilitates comparison between each major basin so that

the relative magnitude of each source category can be compared throughout the state. The results of this assessment should be used to make broader policy and management planning decisions and are not intended to be used in the place of Total Maximum Daily Load (TMDL) studies or detailed

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assessments based on site-specific water quality monitoring and modeling data. The results of this study should also be used to focus continuing monitoring efforts and prioritize additional water quality, biological and/or physical assessments.

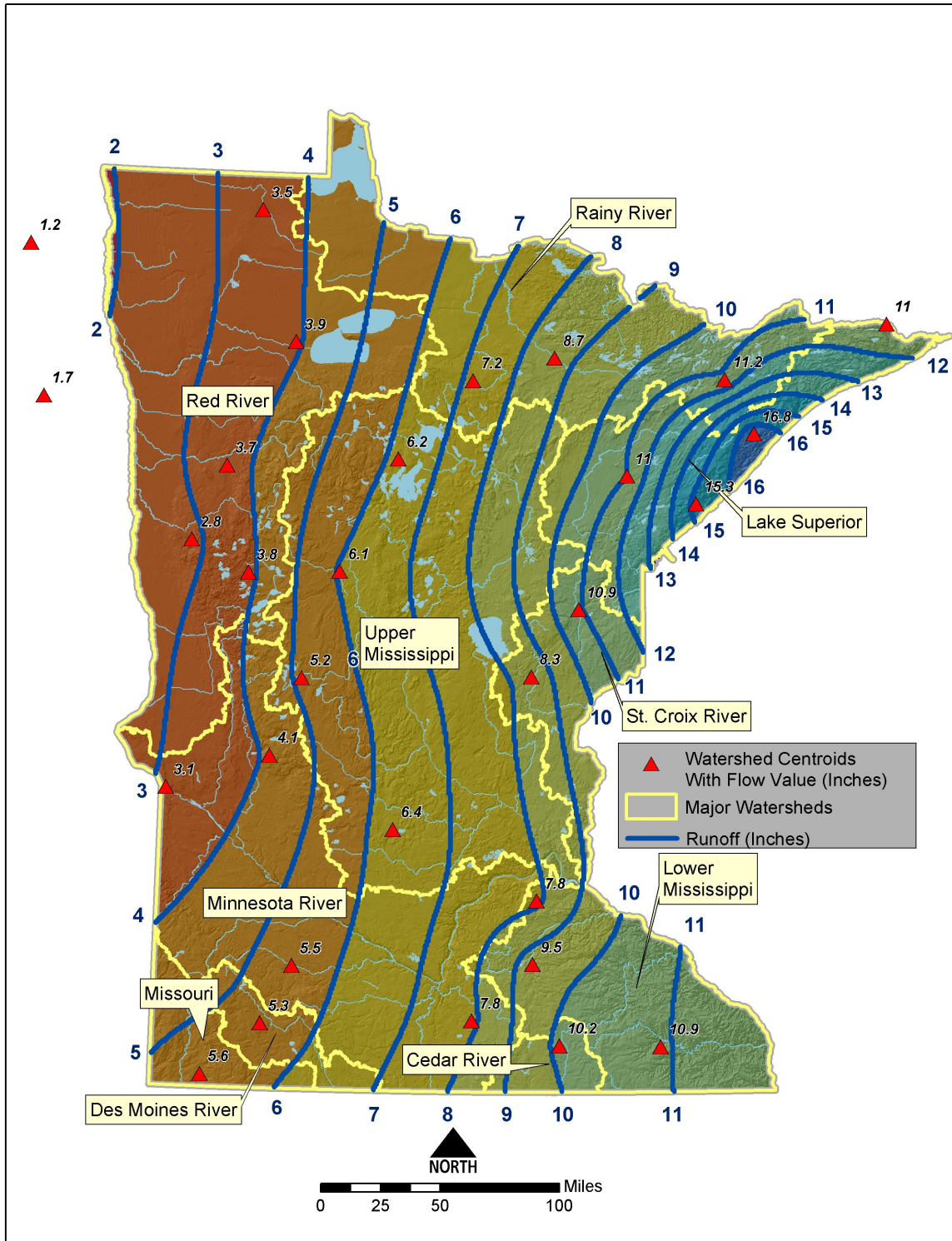
Methods Used

In general, relatively simple methods were employed in this assessment to provide a rapid means of evaluating the relative significance of different sources and identifying critical source areas with minimal effort and data requirements. Each portion of this assessment typically involved the following stepwise approach:

1. Obtain data on source and watershed characteristics (such as per capita use/land cover/land use/soils), conduct published literature review and obtain site-specific data, where available
2. Use available site-specific data to develop and apply a basin-specific, regional, ecoregional or statewide phosphorus load estimation methodology that utilizes source and watershed characteristics
3. Use data from nearby study areas or other established empirical relationships applied to watershed characteristics
4. Apply best professional judgment when any data or published literature information are absent

This assessment began with an evaluation of the historical runoff and precipitation data for each basin in the state. This analysis resulted in runoff and precipitation datasets that defined what constituted low (dry), average, and high (wet) flow conditions in each of the ten major basins. The data, throughout the state, indicated that there is a general trend of decreasing runoff from east to west (see Figure EX-2). This is significant because nonpoint sources are strongly influenced by precipitation and runoff amounts.

Figure EX-2 Annual Runoff Volumes, Average Flow Conditions (Period of Record, 1979-2002)



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The Lake Superior basin has the highest runoff rate in the state, with the Baptism River watershed having the highest values within that basin (an average annual runoff of 15.3 inches). The Red River basin had the least runoff, with the Buffalo River watershed experiencing only 2.8 inches of runoff in an average year. Decreasing runoff from east to west also occurs in southern Minnesota, but the trend is less dramatic than in the north. Increases in runoff are more dramatic moving south in the state, as flows approach high flow conditions. Statewide, the gradient in runoff volumes increases significantly from low to average flow, and from average to high flow, conditions.

Categories of Findings

This assessment resulted in a number of findings, broken down into the following categories:

- Phosphorus source category loadings statewide
- Phosphorus source category loadings by major basins
- Statewide phosphorus source category loadings by flow condition
- Major basin phosphorus source category loadings by flow condition

Phosphorus Source Category Loadings Statewide

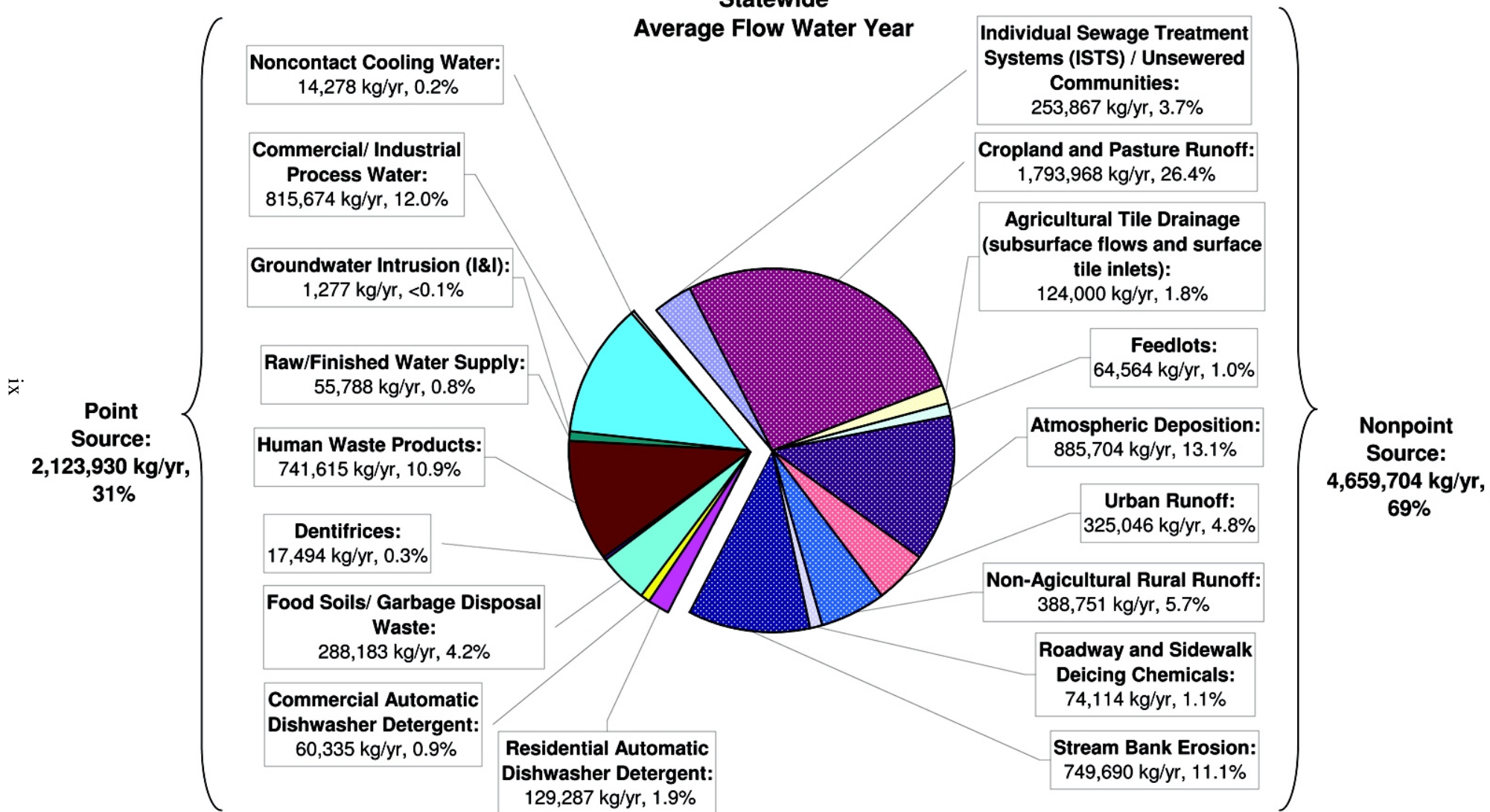
This assessment found that, under average flow conditions, the point source total phosphorus contribution represents 31 percent, while nonpoint sources of total phosphorus represent 69 percent of the loadings to surface waters, statewide (see Figure EX-3). The point source phosphorus loadings to surface waters are broken down in proportion to the influent phosphorus loadings (inflows) to wastewater treatment plants (WWTPs) in the state from each wastewater source category. This assumes that the proportion of the phosphorus load from each source category in the wastewater influent remains the same in the wastewater effluent (or treated discharge) from each treatment facility.

Figure EX-3 shows for average flow conditions the major phosphorus sources to surface waters are as follows:

- cropland and pasture runoff (26%)
- atmospheric deposition (13%)
- commercial/industrial process water (12%)

It should be noted that the Metropolitan Council Environmental Services (MCES) Metro WWTP—which discharges to the Upper Mississippi River basin—was required to implement phosphorus removal to 1 mg/L from 2.97 mg/L (average phosphorus effluent concentration) by the end of 2005, but is already achieving the 1 mg/L limit. A reduction in the phosphorus concentration to 1 mg/L will result in a reduction of an estimated 581,000 kg of phosphorus per year, shifting the point source contribution to approximately 25 percent and raising the nonpoint source contribution to 75 percent of the total load statewide.

Figure EX-3
Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Statewide
Average Flow Water Year



- streambank erosion (11%)
- human waste products (11%)

All of the remaining source category contributions are below 6 percent. The combination of residential and commercial automatic dishwasher detergent (ADWD) represents approximately 3 percent of the total phosphorus contributions to surface waters in the state, during an average year.

Phosphorus Source Category Loadings by Major Basin

This assessment found that, under average flow conditions, the relative magnitude of the total phosphorus loadings from the sum of all source categories in the Upper Mississippi River basin is significantly higher than the remaining basins, with the second highest phosphorus loadings occurring in the Minnesota River basin (see Figure EX-4a). The Lower Mississippi and Red River basin total phosphorus loadings are approximately one-third less than the Minnesota River basin loadings.

Figure EX-4a illustrates the relative magnitudes of each of the phosphorus source category loadings estimated for each basin under average flow conditions, while Figure EX-4b shows the same information normalized to the basin area, as another way to compare the phosphorus loadings from basin to basin. Figures EX-4a and EX-4b show that, relative to the other phosphorus source categories in each basin, agricultural runoff is a significant source of phosphorus in all but the Lake Superior and Rainy River basins. Human waste products are a significant source of phosphorus in the Upper Mississippi River basin, along with commercial/industrial process water and food soils.

It should be noted that the data used for this study to assess point source loadings is from the years 2001, 2002 and the first half of 2003. Since that time period, phosphorus removal was implemented at the MCES' Metro WWTP (see blue sidebar on page viii). Because this one facility accounted for approximately 74 percent of the point source phosphorus load to the Upper Mississippi River basin and an estimated 40 percent statewide, continued phosphorus removal at this one facility will have a significant impact on the future relative phosphorus loads in this basin and the state.

Figures EX-4a and EX-4b also show that atmospheric deposition comprises significant percentages of the annual phosphorus loads as follows:

- Upper Mississippi River basin (11%)
- St. Croix River basin (20%)
- Red River basin (29%)
- Rainy River basin (34%)

Figure EX-4a Total Phosphorus Loads to Minnesota Surface Waters - By Major Drainage Basin: Average Flow Conditions

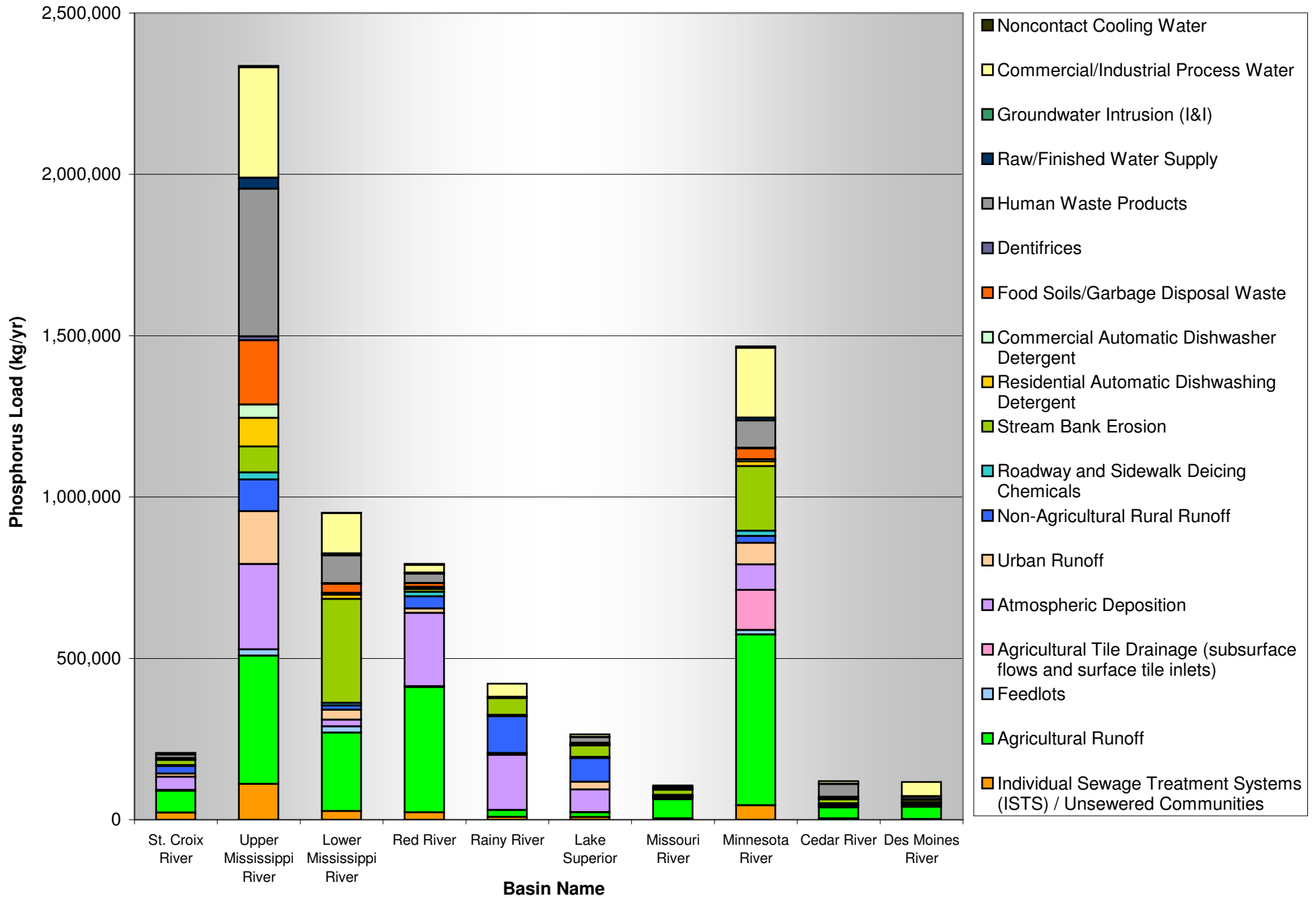
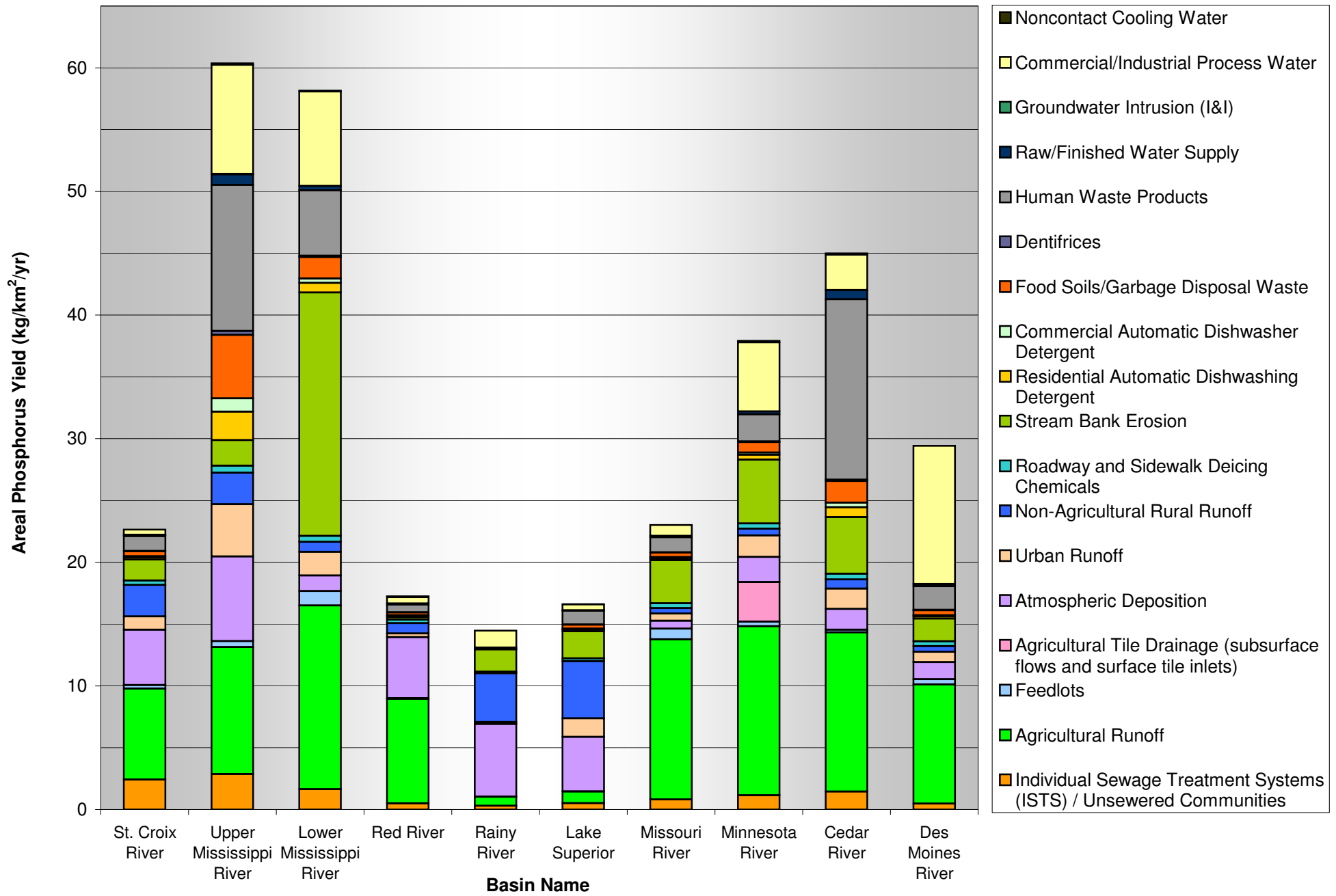


Figure EX-4b Watershed Total Phosphorus Yields to Minnesota Surface Waters - By Major Drainage Basin: Average Flow Conditions



This reflects the large amount of surface water and the relatively low amounts of other sources in these basins.

Streambank erosion is a significant source of phosphorus in the Lower Mississippi River basin (34%) and, to a lesser degree, in the Minnesota River basin (14%). Commercial/industrial process water is an important source of phosphorus in the Lower Mississippi (13%), Minnesota (15%), Des Moines (38%), and the Rainy River (10%) basins. Non-agricultural rural runoff sources of phosphorus are important in the Rainy River (27%) and Lake Superior (28%) basins. Finally, human waste products are a significant source of phosphorus in the Upper Mississippi (20%) and Cedar River (32%) basins.

Statewide Phosphorus Source Category Loadings by Flow Condition

Both total and bioavailable phosphorus source estimates vary significantly under each flow condition. This is the result of changes in the nonpoint source loading from different flow conditions. Point source loads remain constant for the three flow conditions. Total amount and relative source contributions are summarized in Table EX-1 and Figures EX-5 through EX-9.

Low Flow Conditions

Under low flow conditions, the total point source phosphorus contribution represents 45 percent, while nonpoint sources of phosphorus represent 55 percent of the statewide loadings to surface waters. The expected load reduction of approximately 581,000 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTP would shift the point source contribution to approximately 37 percent of the total load and the nonpoint source contribution to 63 percent. The commercial/industrial process water represents 38 percent of the point source total phosphorus contributions, while human waste products represent 35 percent. The remaining point source categories contribute less than 14 percent of the statewide point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 9 percent of the point source total phosphorus contributions.

Cropland and pasture runoff represent 33 percent of the nonpoint source total phosphorus loadings, while atmospheric deposition represents 30 percent, with the remaining nonpoint source contributions below 11 percent.

Under low flow conditions, the bioavailable point source phosphorus contribution represents 57 percent of the statewide loadings to surface waters (see Figure EX-6). The expected load reduction of approximately 496,800 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTP would shift the point source contribution to approximately 50 percent of the total bioavailable phosphorus load. Commercial/industrial process water represents 40 percent of the point source bioavailable phosphorus contributions, while human waste products represent 35 percent. The

remaining point source categories contribute less than 12 percent of the statewide point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 10 percent of the point source bioavailable phosphorus contributions.

As shown in Figure EX-6, cropland and pasture runoff represents approximately 34 percent of the nonpoint source bioavailable phosphorus loadings; atmospheric deposition represents 19 percent; and Individual Sewage Treatment Systems (ISTS)/unsewered communities represent 17 percent, with the remaining nonpoint source contributions below 12 percent. Table EX-1 generally indicates that point sources of phosphorus are more bioavailable than nonpoint sources.

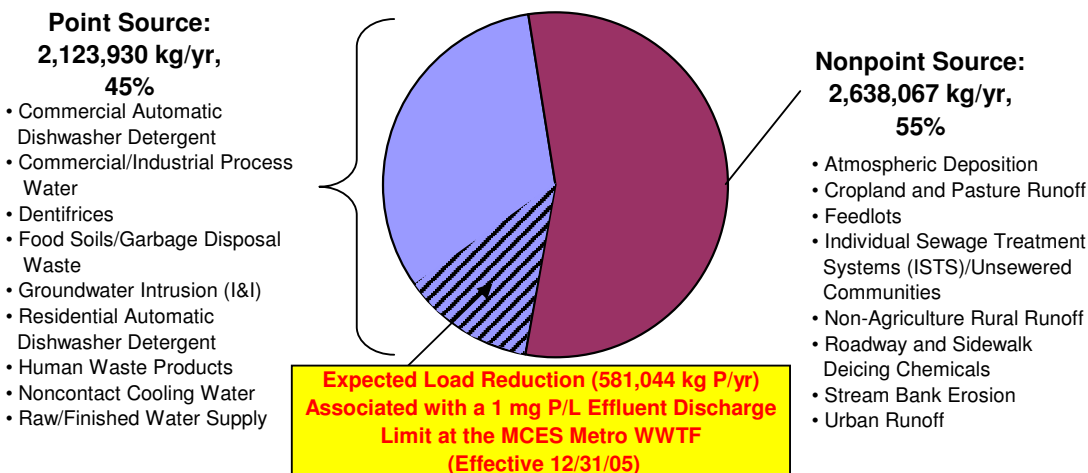
Table EX-1 Statewide phosphorus contributions of point and nonpoint sources by flow condition

	Flow Condition		
	Low (Dry)	Average	High (Wet)
Total Phosphorus			
Point Source (kg/yr)	2,123,930 (45%)	2,123,930 (31%)	2,123,930 (19%)
Nonpoint Source (kg/yr)	2,638,067 (55%)	4,659,704 (69%)	8,932,735 (81%)
Total	4,761,997	6,783,634	11,056,665
Bioavailable Phosphorus			
Point Source (kg/yr)	1,975,757 (57%)	1,975,757 (44%)	1,975,757 (30%)
Nonpoint Source (kg/yr)	1,472,784 (43%)	2,559,026 (56%)	4,648,570 (70%)
Total	3,448,542	4,534,783	6,624,327

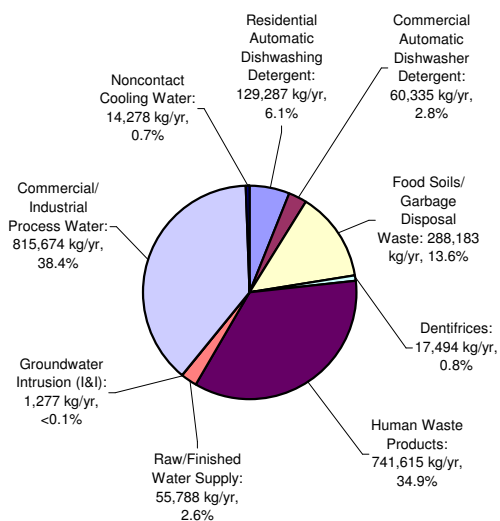
Looking more specifically at each source category in comparing Figures EX-5 and EX-6, on a proportional basis, indicates that ISTS/unsewered communities exhibits a significant increased contribution, while atmospheric deposition exhibits a significant decreased contribution, relative to the other sources for the bioavailable contribution of phosphorus. The relative shift for the remaining source categories is less than 2 percent in comparing the bioavailable and total phosphorus contributions.

Figure EX-5

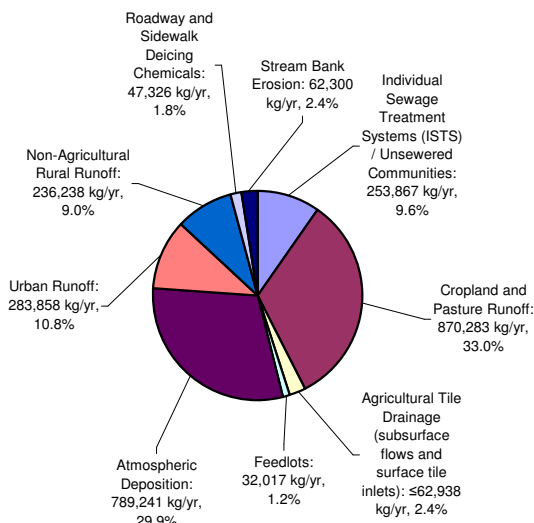
Estimated Total Phosphorus Contributions to Minnesota Surface Waters Statewide Dry, Low Flow Water Year



Point Source Total Phosphorus Contributions



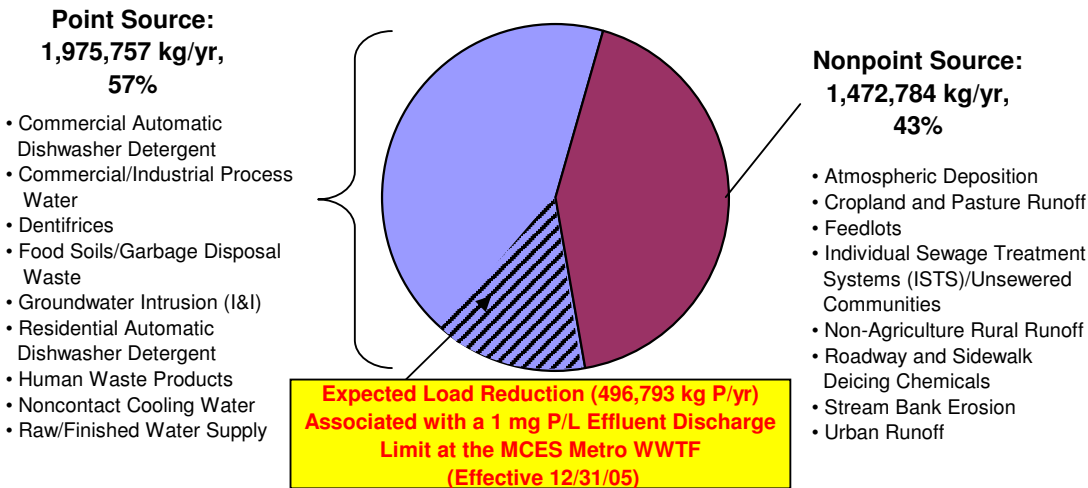
Nonpoint Source Total Phosphorus Contributions



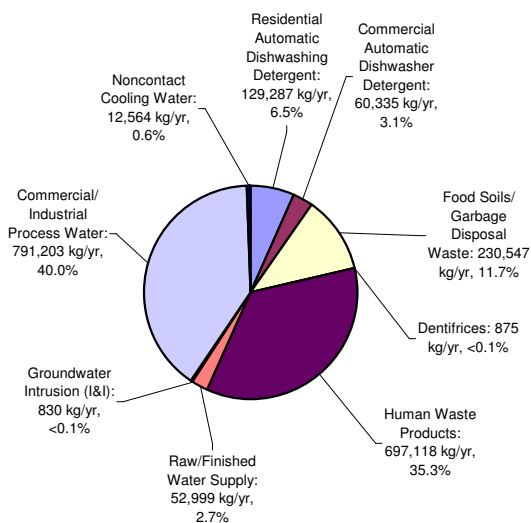
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Figure EX-6

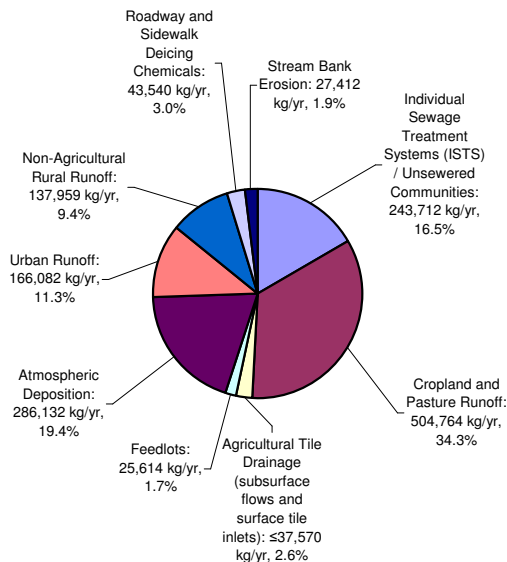
Estimated Bioavailable P Contributions to Minnesota Surface Waters Statewide Dry, Low Flow Water Year



Point Source Bioavailable P Contributions



Nonpoint Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Average Flow Conditions

Under average flow conditions (see Figure EX-7), the total point source phosphorus contribution drops to 31 percent, compared to 45 percent for the statewide loadings to surface waters under low flow conditions. Cropland and pasture runoff represents 39 percent of the nonpoint source total phosphorus loadings; atmospheric deposition represents 19 percent; and streambank erosion represents 16 percent, with the remaining nonpoint source contributions below 9 percent. Compared to low flow conditions (see Figure EX-6), the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, increased slightly for cropland and pasture runoff, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities. Table EX-1 also shows that the nonpoint source phosphorus loadings nearly double from low to average flow conditions. All nonpoint source categories except ISTS/unsewered communities increase from low to average flow conditions.

High Flow Conditions

Under high flow conditions (see Figure EX-8), the total point source phosphorus contribution drops to 19 percent, compared to 31 and 45 percent for the statewide loadings to surface waters under average and low flow conditions, respectively. Streambank erosion represents 40 percent of the nonpoint source total phosphorus loadings; cropland and pasture runoff represents 31 percent; and atmospheric deposition represents 11 percent, with the remaining nonpoint source contributions below 7 percent. Compared to an average flow year (Figure EX-7), Figure EX-8 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, decreased slightly for cropland and pasture and non-agricultural rural runoff, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities. Table EX-1 shows a 3.3-fold increase in nonpoint source phosphorus loadings from low to high flow conditions and a near two-fold increase from average to high flow conditions.

Major Basin Phosphorus Source Category Loadings by Flow Condition

Table EX-2 presents the contributions of each source category to the total and bioavailable phosphorus loadings to surface waters in each basin and the state, by flow condition. The importance of the total and bioavailable phosphorus contributions from each source category varies significantly by basin, and somewhat by flow condition. Human waste products represent a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi and Cedar River basins under each flow condition, and on a statewide basis, for the low and to a lesser extent average flow conditions. During low flow conditions, human waste products contribute

Figure EX-7

**Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Statewide
Average Flow Water Year**

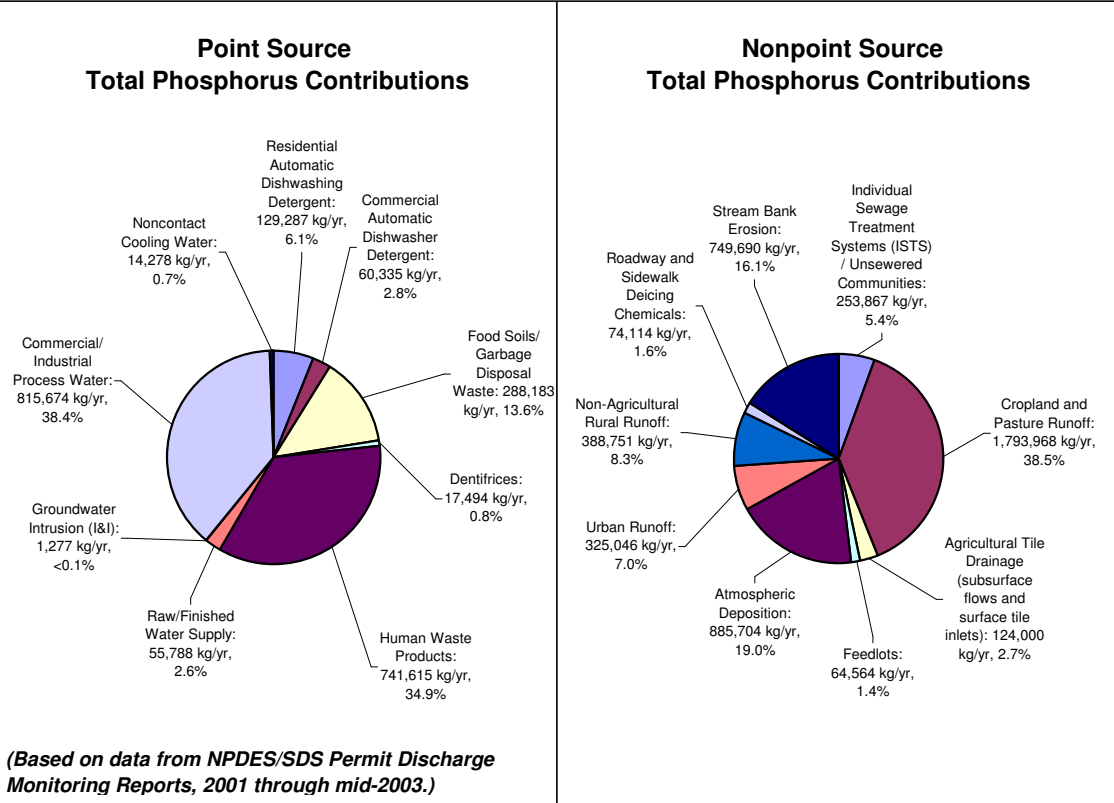
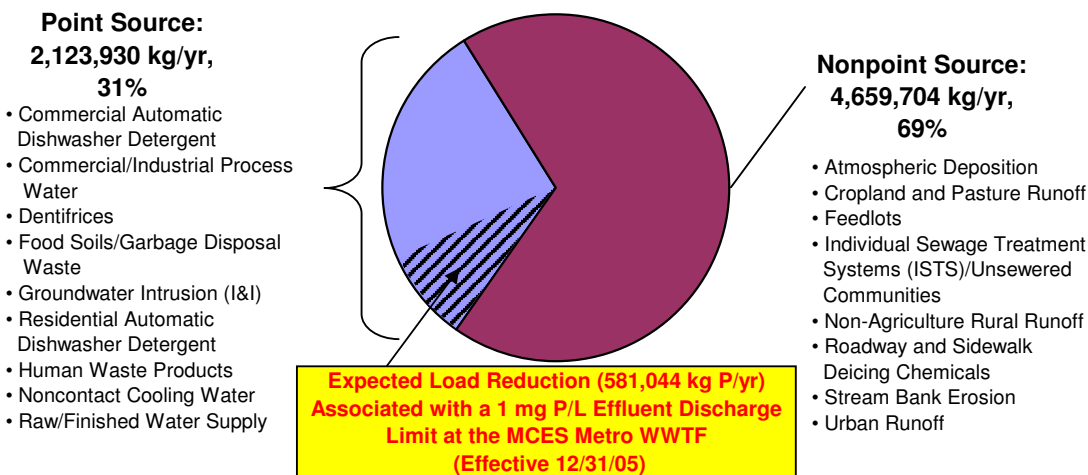


Figure EX-8

Estimated Total Phosphorus Contributions to Minnesota Surface Waters Statewide Wet, High Flow Water Year

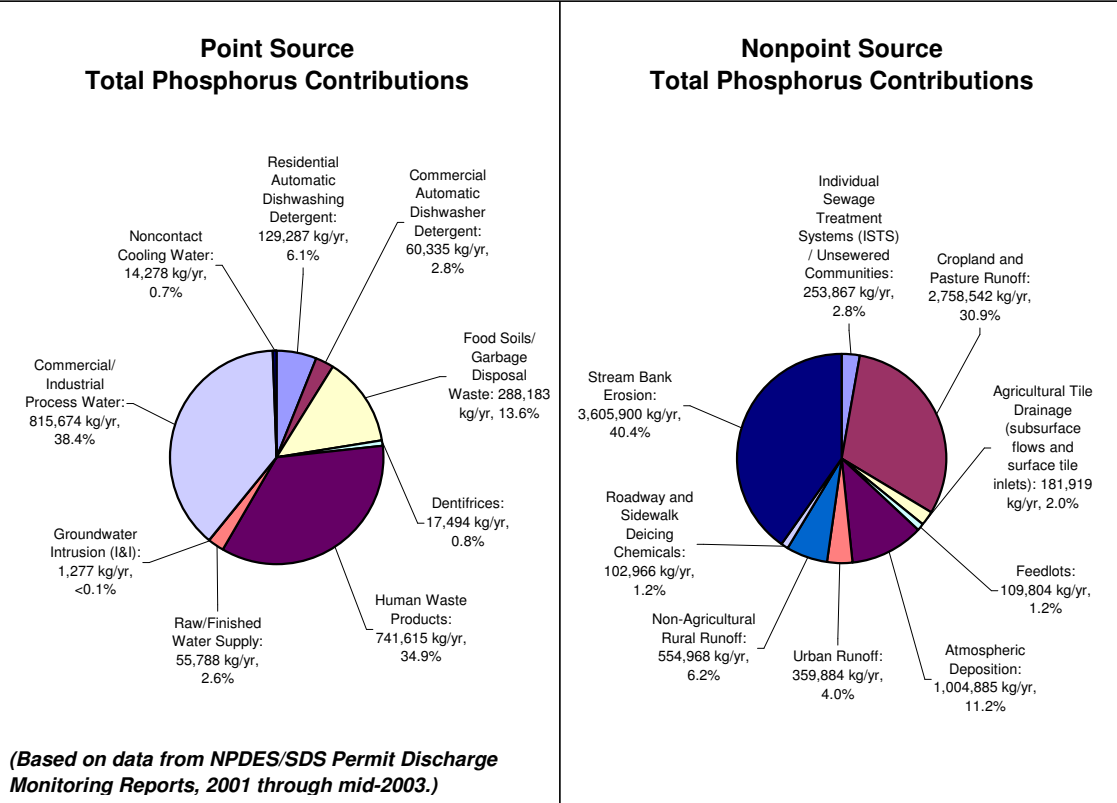
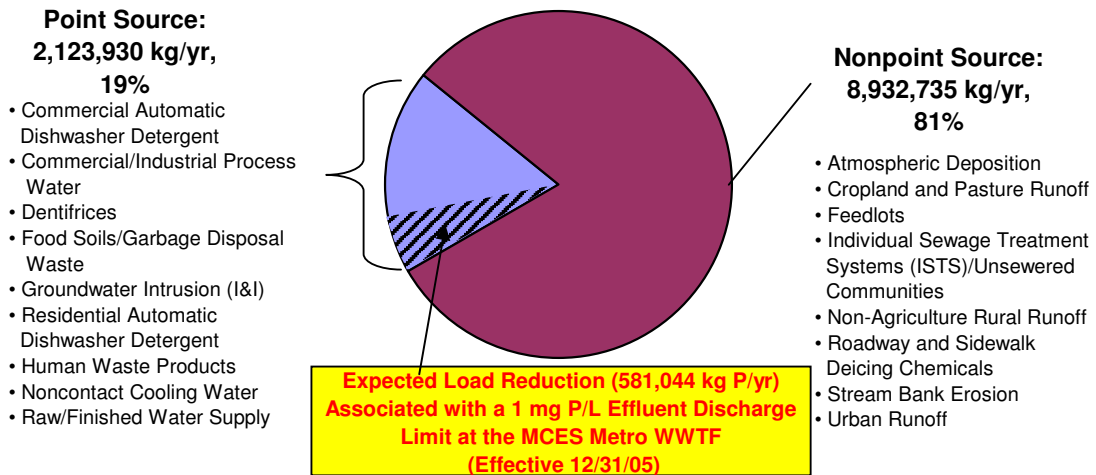





Table EX-2 Major Source Category Contributions of Total and Bioavailable Phosphorus to Each Basin and the State, by Flow Condition

Basin	St. Croix River			Upper Mississippi River			Lower Mississippi River			Red River			Rainy River			Lake Superior			Missouri River			Minnesota River			Cedar River			Des Moines River			Statewide					
	Low	Average	High	Low	Average	High	Low	Average	High	Low	Average	High	Low	Average	High	Low	Average	High	Low	Average	High	Low	Average	High	Low	Average	High	Low	Average	High	Low	Average	High			
Flow Condition	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP
Source Category																																				
Point Sources																																				
Residential ADWD																																				
Commercial ADWD																																				
Food Soils/ Garbage Disposal Waste							◆	◆																												
Dentifrices																																				
Human Waste Products	◆						◆	◆	◆	◆	◆	◆	◆						◆						◆						◆	◆	◆	◆	◆	◆
Raw/Finished Water Supply																																				
Groundwater Intrusion (I&I)							◆	◆	◆	◆	◆	◆	◆	◆	◆										◆						◆	◆	◆	◆	◆	◆
Commercial/Industrial Process Water							◆	◆	◆	◆	◆	◆	◆	◆	◆										◆						◆	◆	◆	◆	◆	◆
Noncontact Cooling Water																																				
NonPoint Sources																																				
ISTS/Unsewered Communities	◆	◆	◆	◆	◆	◆																			◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
Cropland and Pasture Runoff	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆							◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
Agricultural Tile Drainage																																				
Feedlots													◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆							◆	◆	◆	◆	◆	◆
Atmospheric Deposition	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆												
Urban Runoff													◆	◆	◆	◆	◆	◆																		
Non-Agricultural Rural Runoff	◆	◆	◆										◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆												
Roadway and Sidewalk Deicers													◆	◆	◆	◆	◆	◆							◆	◆	◆	◆	◆	◆						
Stream Bank Erosion				◆	◆		◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆

KEY: TP – Total Phosphorus
 BP – Bioavailable Phosphorus
 ADWD – Automatic Dishwashing Detergent

 – Source category represents more than 20% of the total basin phosphorus loading.
 – Source category represents between 10% and 20% of the total basin phosphorus loading.
 – Source category represents less than 10% of the total basin phosphorus loading.

between 10 and 20 percent of the bioavailable phosphorus loadings in the Lake Superior and St. Croix, Lower Mississippi, Red, Missouri, and Minnesota River basins. Commercial/industrial process water represents a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi, Lower Mississippi, Minnesota, and Des Moines River basins under each flow condition, and on a statewide basis, for the low and to a lesser extent average flow conditions. Phosphorus contributions from ISTS/unsewered communities are of relative importance in the St. Croix River basin.

Cropland and pasture runoff represents significant total and bioavailable phosphorus loadings in the St. Croix, Lower Mississippi, Red, Missouri, Minnesota, Cedar and Des Moines River basins, and on a statewide basis, under all flow conditions. The phosphorus contribution from cropland and pasture runoff is also significant in the Upper Mississippi River basin for the average and high flow conditions. Atmospheric deposition represents a significant portion of the phosphorus loadings in the Lake Superior, St. Croix, Red, and Rainy River basins for each flow condition. Non-agricultural rural runoff contributes a significant portion of the phosphorus loadings in the Lake Superior and Rainy River basins for each flow condition. It should be noted, based on the analyses used in this study, that the typical rate of total phosphorus export from each acre of non-agricultural land is approximately four times lower than the corresponding load from each acre of contributing agricultural land (cropland and pasture). Finally, Table EX-2 shows that streambank erosion is an important source of phosphorus under high flow conditions for all of the basins, and is fairly significant in the Lake Superior, Lower Mississippi, Rainy and Missouri River basins under average flow conditions. Streambank erosion can also contribute somewhat significant amounts of total phosphorus statewide and to the Minnesota and Cedar River basins under average flow conditions.

Concepts for Lowering Phosphorus Export from Point Sources

The concepts for lowering the phosphorus export from point sources are presented in two parts:

- 1) Lowering phosphorus loading discharged to POTWs
- 2) Lowering point source phosphorus loading to surface waters

Lowering Phosphorus Loading Discharged to POTWs

The assessment of phosphorus sources entering POTWs are intended to assist the MPCA in complying with MN Laws 2003, Chap. 128 Art. 1, Sec. 122., as follows:

The state goal for reducing phosphorus from non-ingested sources entering municipal wastewater treatment systems is at least a 50 percent reduction developed by the commissioner under section

166, and a reasonable estimate of the amount of phosphorus from non-ingested sources entering municipal wastewater treatment systems in calendar year 2003.

For purposes of complying with this legislation, this study has estimated that the current non-ingested phosphorus load entering POTWs is 2,573,000 kg/yr. A 50 percent reduction would require decreasing the phosphorus discharged to POTWs by at least 1,286,000 kg/yr. (Note: in this study, human wastes are the only ingested source; all other sources are defined as non-ingested.) The following reduction tactics for non-ingested sources are listed in descending order of applicability:

- Next to human wastes, a variety of industrial and commercial dischargers contribute the most phosphorus to POTWs. The contribution of phosphorus from these commercial and industrial sources accounts for approximately 46 percent (1,183,600 kg/yr) of the non-ingested phosphorus load discharged into POTWs. Total removal of phosphorus from commercial and industrial wastewater is not a feasible option. In most cases, reduction would have to come from resource/product substitution, improvements in technology, through recycling and reuse, and through pretreatment of wastewater prior to discharge to the POTW. Reducing commercial and industrial phosphorus contribution to POTWs by one half would reduce the total non-ingested phosphorus discharged to POTWs by almost 23 percent. Excise taxes and/or effluent strength charges may provide an incentive to reduce this source of phosphorus discharged to POTWs.
- Food soils and garbage disposal wastes account for approximately 28 percent (725,000 kg/yr) of the non-ingested phosphorus discharged to POTWs. This is a substantial amount, but it would be difficult to implement product modification or prohibit the discharge of food wastes into the sewer systems. Approximately 25 percent of the phosphorus from this source is discharged into the sewer system as garbage disposal waste. Garbage disposal waste could be sent elsewhere (trash, compost, etc.), whereas it would be more difficult to manage the food associated phosphorus from dish rinsing and dish washing. Short of inducing the food product industries to reduce their use of phosphates or eliminating garbage disposals and prohibiting the discharge of food wastes down the drain, there appears to be few choices for reducing this phosphorus load to POTWs. Public education about this issue might help reduce the discharge of food wastes down the drain.
- Residential ADWD contributes almost 13 percent (334,500 kg/yr) of the non-ingested phosphorus load to POTWs. Although there has been a slight decline in the consumption of

phosphorus for residential ADWD, SRI publication Chemical Economics Handbook - Industrial Phosphates (SRI, 2002) states that “it is unlikely that detergents with much lower phosphorus contents will be available in the near future.” Currently, at least one brand of ADWD does not contain phosphorus; the phosphorus content of other brands varies significantly. Advertising and prominent content labeling would help reduce this source by aiding consumers in choosing low phosphorus products.

- Commercial and institutional ADWD contributes a statewide average of approximately 6 percent (152,000 kg/yr) of the influent non-ingested phosphorus load discharged into POTWs.
- Water supply chemicals account for an estimated 5.5 percent (141,500 kg/yr) of the non-ingested phosphorus load to POTWs statewide. Phosphorus is used for the sequestration (withdrawal) of metals, such as iron and manganese, and for the corrosion control of lead and copper, which in some cases is a human health issue and is required by law for those communities that do not pass the state corrosion tests. Reduction options include iron and manganese removal or substituting alternative water treatment chemicals in place of those containing phosphorus.
- Dentifrices (toothpaste, mouth wash, denture cleaners) account for less than 2 percent of the total non-ingested phosphorus load to POTWs. Because the phosphorus load from this source is so minimal, it does not warrant major reduction steps.
- Stormwater inflow and infiltration (I & I) contribute a negligible amount of phosphorus to POTW influent. Although there are many good reasons to limit inflow and infiltration into sewer systems—such as preventing hydraulic overloading of treatment facilities—the reduction of influent phosphorus is not one of them.

Overall Recommendation for Lowering Phosphorus Loads to POTWs

Given that food soils would be very difficult to reduce, and that dentifrices, noncontact cooling water, and I & I contribute so little to the influent phosphorus load discharged to POTWs, it is recommended that reduction efforts focus on the following:

- residential ADWD
- commercial and industrial process wastewater
- commercial and institutional ADWD
- water treatment chemicals

A summary of the phosphorus load discharged to POTWs and the reduction potential is presented in Table EX-3.

Table EX-3 Reduction Potential for Phosphorus Loads to POTW

Summary	Phosphorus Load to POTWs (kg/yr)	Portion of Total Load to POTW
Total Phosphorus Load Discharged to POTWs	4,468,000	
Human Waste Load	1,900,000	43
Non-Ingsted Waste Load	2,573,000	57
Phosphorus Source	% Reduction to Non-Ingsted Phosphorus Load (%)	Cumulative Reduction to Non-Ingsted Phosphorus Load (%)
Residential ADWD reduced to 0	13	13
Commercial ADWD reduced to 0	6	19
Commercial and Industrial Process Water reduced by one half	23	42
Total Reduction		42

To reach the state goal of a 50 percent reduction in the total non-ingested phosphorus contribution to POTWs, residential and commercial/institutional ADWD and water treatment chemicals would need to be eliminated completely and commercial and industrial process wastewater would need to be reduced more than 64 percent. Given that it will be difficult to completely eliminate commercial/institutional ADWD and water treatment chemicals, while reducing the commercial and industrial process wastewater loading by such a substantial amount, a 50 percent reduction in the total non-ingested phosphorus contribution to POTWs appears to be an ambitious goal.

Lowering Phosphorus Loads to Surface Waters

Recommendations for lowering the point source phosphorus load discharged to surface waters in each major basin vary, based on the type of treatment facility and treatment processes employed. Phosphorus that comes from POTW outflows (effluent) represents, on average, more than 80 percent of the total point source loads to waters of the state. The largest source of phosphorus from POTWs is from large (> 1.0 mgd) facilities (88%). Phosphorus reduction efforts should begin at these facilities. As discussed previously, many POTWs have implemented phosphorus removal and others will begin to implement it in the near future. The largest impact, as noted previously, is phosphorus removal at the MCES' Metro WWTP (see blue sidebar on page viii). The reduction of the effluent

phosphorus concentration to 1 mg/L at this one facility will result in the effluent phosphorus from POTWs being reduced from 80 percent to 74 percent of the point source load to waters of the state.

Privately owned wastewater treatment systems account for less than 0.5 percent of the total point source phosphorus discharged statewide. Increased phosphorus removal at these facilities will have only a negligible impact on the statewide point source phosphorus load.

Direct commercial and industrial sources statewide constitute approximately 18 percent of the point source phosphorus load. Combining direct commercial/industrial discharges with commercial/industrial discharges following treatment at POTWs represents 38 percent, statewide. It was not within the scope of this study to categorize the phosphorus loading data by commercial and industry type or to determine which industries are the largest contributors. However, it is recommended that industrial dischargers that make major contributions to the phosphorus loadings be evaluated in further detail.

Current Effluent Phosphorus Reduction Efforts by Wastewater Treatment Plants

As part of this study, several WWTPs were surveyed regarding phosphorus treatment methods and a review of the efforts of each of the cities to reduce phosphorus in their effluent was completed. The WWTPs ranged in size (0.7 to 24 million gallons per day), treatment methods (chemical and/or biological), and phosphorus discharge requirements (0.07 mg/L to 2.41 mg/L). Four of the eight WWTPs surveyed used chemical treatment only for phosphorus removal. Four of the eight WWTPs used enhanced biological phosphorus removal (EBPR). In addition to EBPR, three of the four plants surveyed also use chemical treatment to meet total phosphorus discharge requirements below 1 mg/L. The Rock Creek and Durham WWTPs in Portland, Oregon use EBPR and two-point alum addition to meet a stringent 0.07 mg/L total phosphorus discharge requirement set for the Tualatin Watershed west of Portland. Pilot testing and full-scale system modifications were required to reach the high level of phosphorus removal achieved by these plants. Alum is added to the primary clarifier prior to EBPR, as well as the secondary clarifier. The effluent from the secondary clarifier is then filtered for an average total phosphorus effluent concentration of 0.05 mg/L. Significant cost savings were observed once enhanced biological phosphorus removal was implemented at the Durham facility (i.e., the chemical costs for alum were cut by one third).

The City of St. Cloud has a Phosphorus Management Plan (PMP), with a primary goal of limiting the amount of phosphorus coming into the facility by means of a phosphorus reduction program and public outreach. The goal of the phosphorus reduction program is to assist non-domestic nutrient contributors (NDNC) in developing phosphorus reduction strategies that will reduce the amount of

phosphorus that enters the wastewater collection system and eliminate phosphorus slug loads. The city works with industrial users to keep phosphorus discharges to the WWTP below 6 mg/L. This method is effective at reducing spike loads and the average influent phosphorus concentrations.

The following summarizes the conclusions of the survey evaluating phosphorus reduction efforts by wastewater treatment plants:

- The cities implementing source reduction programs all achieved significant reduction in phosphorus loading on their WWTPs using a variety of methods: public outreach, phosphorus bans, surcharges for phosphorus treatment, and maximum limits on significant industrial users (SIU) phosphorus discharges.
- The St. Cloud WWTP showed that a reduction in influent phosphorus loading and phosphorus slug loads lead to a reduction in effluent phosphorus concentration.
- Chemical treatment is capable of reaching the lowest phosphorus effluent concentrations.
- The cost per unit of total phosphorus removed varied from \$0.96 to \$20.00 per pound of total phosphorus removed. The cost of treating phosphorus chemically appeared to show an economy of scale.
- The cost for chemical treatment was lower for those WWTPs that used a combination of EBPR and chemical treatment.
- EBPR alone is generally effective at achieving 0.5 mg/L to 1 mg/L effluent phosphorus concentrations. Chemical addition is necessary to achieve effluent phosphorus concentrations less than 0.5 mg/L. One of the best available bio/chemical treatment facilities (Durham WWTP, OR) was able to achieve an average effluent phosphorus concentration of 0.05 mg/L. To reach this low effluent concentration, significant pilot testing was required and phosphorus removal efficiency was dependent upon wastewater characteristics.
- Once the initial capital improvements are made there are no additional costs associated with phosphorus removal using EBPR.
- In some cases, EBPR can be implemented with simple process modifications (e.g., St Cloud aeration modifications) that achieve reductions in effluent phosphorus concentrations. St

Cloud was able to achieve an effluent phosphorus concentration of approximately 1 mg/L with this approach.

The Minnesota Environmental Science and Economic Review Board (MESERB) received funding from the legislature to complete a Wastewater Phosphorus Control and Reduction Initiative. The Initiative consists of an independent examination of selected wastewater treatment facilities by nationally recognized experts in biological phosphorus removal. A final report will evaluate actual and potential methods of phosphorus reduction, and develop a list of recommended cost-effective reduction strategies. Two seminars will also provide wastewater operators with the tools to implement immediate measures to reduce phosphorus in the final effluent. Project completion is scheduled for April 2005.

Concepts for Lowering Phosphorus Export from Nonpoint Sources

Agricultural Runoff

Comparing past agricultural runoff loadings with the current phosphorus loading estimates—when it is assumed that moldboard plowing (which lifts, fractures and inverts the soil, producing furrows) is used on all row cropland—allows for an evaluation of the extent of progress in controlling phosphorus losses over the last twenty years, due to improvements in tillage management. Modeling indicates that in the Minnesota River basin, compared to an era when moldboard plowing was widely practiced, current day phosphorus losses from agricultural cropland have been reduced by about 146,000 kg/yr (from about 664,000 to 518,000 kg/yr), for a 28% reduction. In the Upper Mississippi River basin, current phosphorus losses from agricultural land have been reduced by about 87,000 kg/yr, for a 24% reduction. Similar comparisons show a 7% reduction for the Red River basin and no significant reduction for the Lower Mississippi River basin.

Although modeling indicates improvements in phosphorus reduction over the past 20 years, increased reduction could come from improved phosphorus fertilizer and manure management. If University of Minnesota recommendations were followed more consistently, phosphorus fertilizer usage could be reduced. For instance, the University has set a threshold above which crops do not respond to additional phosphorus. But phosphorus fertilizer is spread on significant areas of land in the Minnesota River basin, and elsewhere, even if soil test phosphorus levels exceed that threshold. Excess applications in the past were considered cheap forms of insurance for crop yield needs and, since even high soil phosphorus levels were wrongly perceived not to be released from soils, the environmental impact was considered minimal. Modeling indicates that in the Minnesota River basin, reductions in the rate of phosphorus fertilizer application could reduce phosphorus losses to surface

waters by about 81,000 kg/yr, as compared to existing conditions, for a 16% reduction. Comparable levels of reduction could occur with improved phosphorus fertilizer management in the Red River, and the Upper and Lower Mississippi River basins.

The potential impact of improved manure application methods is significant in the Red River basin. Phosphorus loads to surface waters could be reduced by about 75,000 kg/yr, for a 20% reduction. Improved manure application methods could potentially reduce phosphorus loads to surface waters in the Upper Mississippi (12%), Lower Mississippi (7%), and Minnesota River (7%) basins. Decreasing the area of cropland within 100 m of surface waters, which corresponds to land retirement programs such as those promoted in the Conservation Reserve and Conservation Reserve Enhancement Programs, are estimated to decrease the phosphorus loadings to levels that are comparable to non-agricultural rural runoff.

Atmospheric Deposition

Soil dust is estimated to be the largest source of atmospheric phosphorus. Therefore, reducing soil dust, particularly from wind erosion from agricultural fields, through the application of wind erosion best management practices (shelterbelts, no till planting, use of cover crops, etc.) should be a high priority.

Deicers

Efforts are currently underway, as part of MnDOT's road weather information system (RWIS), to use timely and accurate weather and road data in deicing application decisions to optimize the use of deicing materials. More accurate weather information could lead to reduced usage of deicing agents. These types of efforts should be used by other winter road maintenance agencies throughout the state. The use of brines should be considered to improve the effectiveness of deicing agents and thereby reduce the use of other deicers. The high phosphorus content of many of the agriculturally derived alternatives to road salt is of concern, as many of these products have phosphorus concentrations 100 to 10,000 times greater than road salt or sand. Testing should be done on these road salt alternatives and an assessment should be done to weigh their benefits against their environmental implications.

Streambank Erosion

There is the potential for substantial water quality benefits associated with lowering phosphorus export from streambank erosion, including reduced eutrophication and sedimentation, as well as improved biological habitat within reservoirs, lakes, wetlands, and river systems. Several methods can be implemented to help reduce streambank erosion: Careful land use planning that considers the potential adverse impacts associated with increased runoff volumes; well-designed stream road

crossings that consider the potential hydrodynamic changes to the system; exclusion or controlled access of pastured animals and preservation of riparian vegetation; and rotational grazing. There are opportunities to reduce streambank erosion in watersheds that have experienced flow volume increases from land use changes.

ISTS/Unsewered Communities

Many of the counties in Minnesota have been delegated to implement Minnesota Rules Chapter 7080 for ISTS, which require conformance with state standards for new construction of ISTSs and disclosure of the state of existing ISTS when a property transfers ownership. Several counties require ISTS upgrades at property transfer. Owners of ISTS that pose an Imminent Threat to Public Health and Safety (ITPHS), through direct discharge to tile lines or surface ditches or system seeping to the ground surface should be identified through a statewide survey to help residents determine whether their ISTS are adequately treating and disposing of sewage below grade. Local Units of Government (LUGs), ISTS permitting authorities and inspection programs should be targeted with MPCA audits to determine adequacy of performance in a number of key areas, including spot checks for conformance on new ISTS installations, level of effort on ISTS inspections and follow-through on replacement of noncompliant systems, and dealing with problem ISTS professionals. Since septic system failure is a widespread problem, a basinwide approach to addressing nonconforming systems with potential for high delivery of pollutants to public waters, such as straight pipe discharges and other types of ITPHS should be given priority attention. The LUGs should work with the MPCA to develop, populate and maintain a database, similar to MPCA's feedlot database that shows the location of each nonconforming system, especially where straight pipe discharges and other types of ITPHS are located. LUG personnel should be provided with an incentive to inventory all systems within their jurisdiction, and track system performance and maintenance.

Non-Agricultural Rural Runoff

The protection of natural areas is needed to ensure they retain the hydrologic and ecologic functions that keep surface runoff volumes low, nutrient (phosphorus) export low and groundwater recharge rates high. Many natural areas are under stress due to development pressures, invasion by exotic species and increased nutrient loading associated with runoff coming from adjacent land uses. Conservation easements, such as CREP and RIM, provide additional opportunities for reducing phosphorus export from contributory watershed areas.

Urban Runoff

The design, construction and maintenance of watershed BMPs will help reduce pollutant (phosphorus) loads to surface waters in urban areas. Water quality protection requires that all urban development design use a water budget approach, where the preservation of the infiltration and evapotranspiration components of the hydrologic cycle are primary considerations. Site planning that reduces impervious surface area and preserves infiltration will help attain water quality protection. A number of stormwater management and urban best management practices manuals are available that provide design guidance for controlling the impacts of urban runoff and promoting infiltration (Metropolitan Council, 2001; Schueler, 1995; Brach, 1989; US EPA. 2001). The National Pollutant Discharge Elimination System (NPDES) permit administered by the MPCA regulates runoff from construction sites, industrial facilities and municipal separate storm sewer systems (MS4s) to reduce the pollution and ecological damage. Phase I of the program focused on large construction sites, 11 categories of industrial facilities, and major metropolitan MS4s. Phase II broadened the program to include smaller construction sites, small municipalities (populations of less than 100,000) that were exempted from Phase I regulations, industrial activity, and MS4s. At a minimum, compliance with the stormwater pollution prevention planning requirements of this permit program is critical to minimize the phosphorus loading increases associated with urban runoff.

Relative Phosphorus Source Loading Uncertainty/Recommended Refinements

This assessment assumes that there is some variability and uncertainty surrounding the phosphorus loading estimates used for this study. The variability and uncertainty of the phosphorus loading computations done for each source category can generally be attributed to natural variability (such as variations in watershed and climatic conditions), a lack of source-specific data or regional relationships with watershed characteristics, error associated with extrapolation of available data, and in some cases, a lack of understanding about all of the processes contributing to the phosphorus loadings under each flow condition.

The phosphorus loading estimates for commercial/industrial process water, streambank erosion, cropland and pasture runoff, feedlot runoff, agricultural tile drainage, ISTS/unsewered communities, and atmospheric deposition are expected to have moderate to high variability and uncertainty relative to the other phosphorus source categories. Table EX-2 shows that, of these categories, commercial/industrial process water, streambank erosion, cropland and pasture runoff, and atmospheric deposition represent significant phosphorus contributions to some of the major basins

under more than one flow condition. Phosphorus loading estimates for human waste products are expected to have low variability and uncertainty relative to the other phosphorus source categories.

General recommendations intended to reduce the uncertainty of the phosphorus load estimates associated with the significant phosphorus source categories include:

- Continue to develop, populate and maintain intra- and inter-agency database information (preferably in geographic databases), similar to MPCA's Delta, environmental data access and feedlot databases, that can readily provide both information for resource-specific studies and data for the development of larger scale (such as agroecoregion, ecoregion, or regional) relationships based on existing programs
- Prioritize and complete source-specific studies to better understand the processes, identify and fill in data gaps for the phosphorus source categories with moderate to high uncertainty, and evaluate the effects of best management practices
- Enlist, train and coordinate new large-scale data collection efforts with volunteers and other state, county and local personnel to obtain chemical and biological data for future assessments (e.g., tracking nonconforming septic systems, streambank erosion inventories) that can be completed throughout the state

Overall Conclusions

The results of this assessment indicate that the estimated amounts of total and bioavailable phosphorus entering surface waters within each major basin and the state vary significantly, both by source category and by flow condition. The phosphorus loadings associated with several point and nonpoint source categories can be controlled to various levels, resulting in significant water quality improvements, depending on the water resource and flow condition. The following discussion provides some overall conclusions from this assessment:

- Because of the general nature of this analysis, it can be true that sources of phosphorus which are deemed minor at the basin scale, may actually contribute the majority of phosphorus to specific surface water bodies, at a localized scale. For example, point sources typically contribute little or no phosphorus to Twin Cities Metropolitan and most outstate lakes, but can represent a significant portion of the total phosphorus load to rivers under low flow conditions. Because of this, there is still a need to complete individual assessments of specific watersheds to evaluate specific loading conditions.

- Under average conditions, the point source total phosphorus contribution represents 31 percent of the loadings to surface waters, statewide, whereas nonpoint sources contribute 69 percent. Of these nonpoint sources, cropland and pasture runoff, atmospheric deposition, streambank erosion, human waste products, and commercial/industrial process water each represent between 10 and 30 percent of the total phosphorus loading. All of the remaining source category contributions are below 6 percent. The combination of household and commercial automatic dishwasher detergent represents approximately 3 percent of the total phosphorus contributions to surface waters in the state, during an average year.
- Under low flow conditions, the total point source phosphorus contribution represents 45 percent, compared to 31 and 19 percent for the statewide loadings to surface waters under average and high flow conditions, respectively. The bioavailable low flow point source phosphorus contribution represents 57 percent of the statewide loadings, confirming that point sources of phosphorus are more bioavailable than nonpoint sources. Comparing high flow to average and low flow conditions, the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.
- Nonpoint source phosphorus loadings nearly double from low to average flow conditions, and again from average to high flow conditions.
- Human waste products represent a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi and Cedar River basins under each flow condition; and on a statewide basis, for the low and to a lesser extent average flow conditions. During low flow conditions, human waste products contribute between 10 and 20 percent of the bioavailable phosphorus loadings in the Lake Superior and St. Croix, Lower Mississippi, Red, Missouri, and Minnesota River basins.
- Commercial/industrial process water represents a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi, Lower Mississippi, Minnesota, and Des Moines River basins under each flow condition, and on a statewide basis, for the low and to a lesser extent average flow conditions.
- Phosphorus contributions from ISTS/unsewered communities are of relative importance in the St. Croix River basin.

- Cropland and pasture runoff represents a significant portion of the total and bioavailable phosphorus loadings in the St. Croix, Lower Mississippi, Red, Missouri, Minnesota, Cedar and Des Moines River basins, and on a statewide basis, under all flow conditions. The phosphorus contribution from cropland and pasture runoff is also significant in the Upper Mississippi River basin for the average and high flow conditions.
- Atmospheric deposition represents a significant portion of the phosphorus loadings in the Lake Superior, St. Croix, Red, and Rainy River basins for each flow condition.
- Non-agricultural rural runoff contributes a significant portion of the phosphorus loadings in the Lake Superior and Rainy River basins for each flow condition, although the typical rate of total phosphorus export from each acre of non-agricultural land is approximately four times lower than the corresponding load from each acre of contributing cropland and pasture runoff.
- Streambank erosion is an important source of phosphorus under high flow conditions for all of the basins, and is fairly significant in the Lake Superior, Lower Mississippi, Rainy and Missouri River basins under average flow conditions. Streambank erosion can also contribute somewhat significant amounts of total phosphorus statewide and to the Minnesota and Cedar River basins under average flow conditions.
- The concepts for lowering the phosphorus export from point sources address possible reductions of phosphorus discharged to POTWs as well as phosphorus discharged to the surface waters in each basin. Food soils would be very difficult to reduce, and dentifrices, noncontact cooling water and I & I contribute little to the influent phosphorus load discharged to POTWs. If residential and commercial/institutional ADWD and water treatment chemicals were eliminated completely, commercial and industrial process wastewater would still need to be reduced more than 64 percent to attain a 50 percent reduction in the total non-ingested phosphorus contribution to POTWs (the goal established in MN Laws 2003, Chap. 128 Art. 1, Sec. 122). Given the difficulties in completely eliminating phosphorus from commercial/institutional ADWD and water treatment chemicals, and reducing the commercial and industrial process wastewater loading by more than 64 percent, a 50 percent reduction of non-ingested influent phosphorus appears to be an ambitious goal. In addition, a 50 percent reduction in influent may not mean a 50 percent reduction in the effluent depending upon the type of wastewater treatment processes used.

- A large portion of the influent phosphorus load to POTWs is from human waste products and/or is largely uncontrollable. Continued implementation of enhanced biological phosphorus removal (EBPR) will significantly reduce effluent phosphorus concentrations.
- Public education about the use of ADWD based on hardness and the availability of no- and low-phosphorus content products should be encouraged.