St. Croix River Basin Water Resources Planning Team
Implementation Committee

Lake St. Croix Total Phosphorus Loading Study

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Executive Summary

On April 6, 2006, representatives from the states of Minnesota and Wisconsin signed an agreement to cooperate on a goal to achieve a 20% reduction in phosphorus loading to Lake St. Croix by the year 2020. Lake St. Croix is a naturally-dammed riverine lake within the lower 40 km of the St. Croix River, which serves as part of the boundary between the two states. The reduction goal had been developed in 2004 by a team of water resource professionals known as the St. Croix Basin Water Resources Planning Team, also known as the Basin Team. The agreement included an objective to "perform a point and non-point source nutrient loading study and develop an implementation plan by June 30, 2009". This report is the result of an ensuing study conducted by staff at the St. Croix Watershed Research Station, on behalf of the Basin Team, with funding from an EPA 319 grant from the Minnesota Pollution Control Agency. At the time this study began in 2007, neither Minnesota nor Wisconsin had yet listed Lake St. Croix as an impaired water on their 303(d) lists. However, the technical findings used to develop the reduction goal had shown clear evidence of historical impairment, and both states included Lake St. Croix on their 2008 303(d) lists, citing impairment of aquatic recreation due to nutrients and eutrophication. Therefore, the Basin Team committed to develop as much information as possible for all that would be necessary for a basin-scale Lake St. Croix Total Maximum Daily Load (TMDL) project. Hence, the Lake St. Croix Total Phosphorus Loading Study began.

The federal guidance on the development of nutrient TMDLs (EPA 1999) was chosen to direct the Loading Study to maximize the relevance and application of the results toward a Lake St. Croix Phosphorus TMDL. In addition, the Loading Study took the subwatershed approach, knowing that much of water resource management in the basin was generally divided into subwatershed monitoring units and that some subwatershed studies were already under way for the development of local small-to-moderate-scale TMDL projects. It was also expected that the implementation tasks for a basin-scale Lake St. Croix TMDL would likely be conducted at the subwatershed scale.

The first step of the Loading Study was to develop a conceptual framework or model of phosphorus routing through the St. Croix Basin. This was done to account for the spatial scaling of phosphorus loads, and loading rates, that result from the complex physical, chemical, and biological interactions that dictate phosphorus routing. A simplified model would route phosphorus through three stages or settings in the basin: land and stream processes that occur within tributary areas, river processes that occur within the mainstem of the St. Croix River, and lake processes that occur within Lake St. Croix itself. In reality, the geography of the St. Croix Basin is not so simplified.

The development of an inventory of phosphorus sources contributing to Lake St. Croix identified three major portions of the total load: natural background nonpoint source loading, cultural nonpoint source loading and cultural point source loading. Key combinations of these groups were total nonpoint source loading and total cultural loading. These categories were used to identify and estimate the phosphorus loads in basin-wide and subwatershed analyses. Natural background nonpoint source phosphorus loading to Lake St. Croix has been assumed to have been constant since 1800 at 166 T/yr (Triplett et al. 2009). Cultural nonpoint source loads were estimated using landcover-specific phosphorus export coefficients, and accounted for 60% of total nonpoint source loads in the 1990s. Cultural point source loads were estimated from wastewater treatment discharge data, and accounted for 11% of the total load in the 1990s. Cultural point source loads have decreased 55% across the basin since the 1990s due to regulatory changes that have resulted in improved treatment technologies for phosphorus reduction. The goal of reducing total loads to Lake St. Croix by 20% is equivalent to reducing total cultural loads to Lake St. Croix by 34%.

List of Abbreviations:

BMP	best management practice
CAFO	concentrated animal feeding operation
EPA	(U.S.) Environmental Protection Agency
ha	hectare
kg	kilogram
mg/L	milligram per liter (part per million)
MPCA	Minnesota Pollution Control Agency
MCES	Metropolitan Council Environmental Services
NCHF	North Central Hardwood Forest ecoregion
NLCD	National Land Cover Dataset
NLF	Northern Lakes and Forest ecoregion
NPS	National Park Service
SWAT	Soil and Water Assessment Tool watershed model
SWS	subwatershed
T	metric ton (1,000,000 grams)
TMDL	total maximum daily load
TP	total phosphorus
TPEC	total phosphorus export coefficient
USC	upper St. Croix River
USGS	United States Geological Survey
WDNR	Wisconsin Department of Natural Resources
yr	year

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1.0 INTRODUCTION

1.1 Basin Description

The St. Croix River is a sixth-order stream with a mean discharge of 120 m^3/sec (4,238 cfs), draining an area of 20,098 square kilometers (7,760 square miles). The St. Croix River serves as a portion of the border between Minnesota and Wisconsin, with 45% of the basin located within Minnesota and 55% of the basin located within Wisconsin. Historical land uses changes include deforestation, expansion of agriculture, and urbanization. The St. Croix River Basin (Figure 1) borders on the burgeoning Twin Cities (Minneapolis-St. Paul, Minnesota) Metropolitan Area; basin-wide, 39-percent population growth is projected by 2020. The basin drains across three major ecoregions (see Figure 1, map inset): Northern Lakes and Forest (NLF), North Central Hardwood Forest (NCHF), and Western Corn Belt Plains (WCBP). The mainstem of the river, along with the mainstem of the Namekagon River, is designated as the St. Croix National Wild and Scenic Riverway within the National Park system. The lower 40 km (25 miles) of the St. Croix River forms a naturally-impounded riverine lake known as Lake St. Croix, which discharges to the Mississippi River at Prescott, Wisconsin.

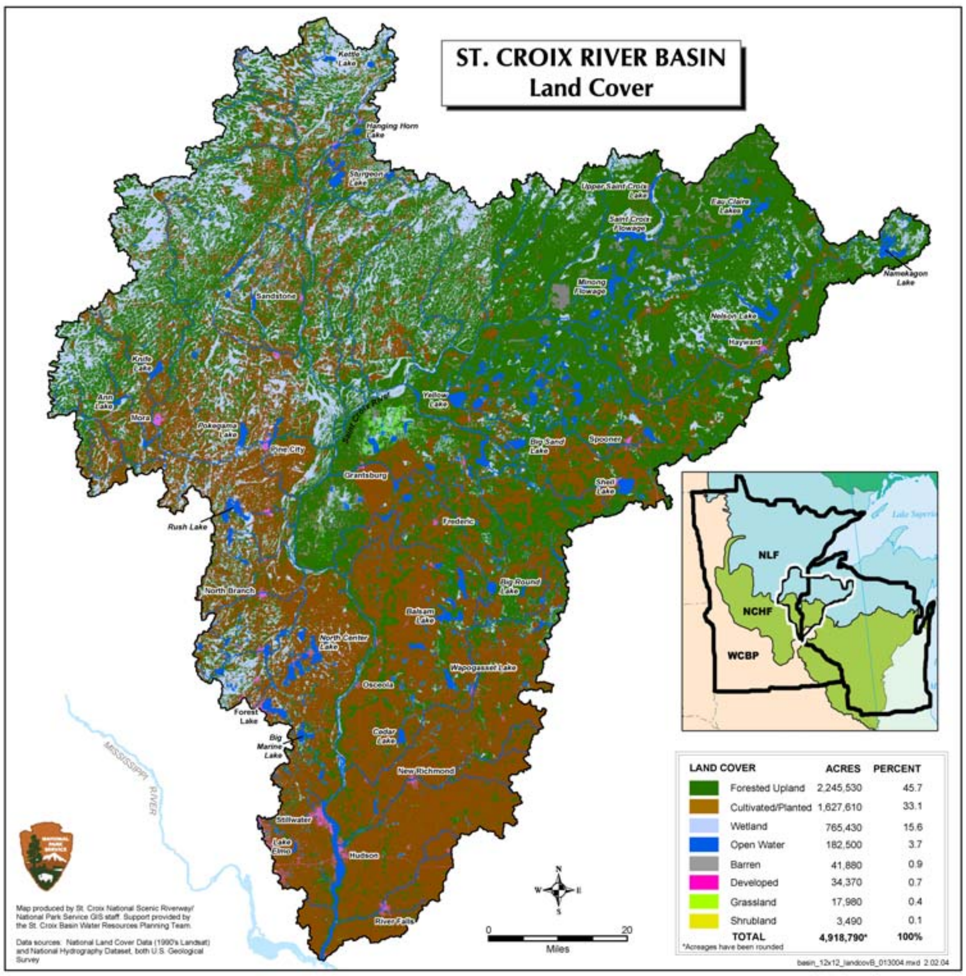

Figure 1. St. Croix River Basin land cover, 1992 (NPS 2004a).

1.2 Previous Efforts

Recent research, much of it summarized by Davis (2004), indicates that Lake St. Croix, which integrates the upstream water quality conditions of the basin, has undergone measurable degradation and current regulatory policies will not prevent further eutrophication as the population grows within the region.

1.2.1. Technical Findings

Summary of research findings:

- The land cover distribution for the St. Croix River Basin in 1992 (Figure 1) was over 60-percent forested uplands and wetlands, 33-percent agriculture, and 1-percent urban (NPS 2004a).
- Sediment cores from Lake St. Croix indicated that sedimentation rates in the 1990s were eight times greater (Figure 2) and phosphorus deposition to the lake was four times greater (figure 3a) than pre-settlement rates in 1880. By 1950, planktonic diatoms had surpassed benthic diatoms as the dominant ecological group in the lake (Figure 3b) (Triplett et al. 2009).
- USGS snowmelt sampling in 1997 indicated that runoff from snowmelt in agricultural areas and areas with low permeability soils had significantly greater nutrient concentrations than forested areas (Lenz et al. 2003).
- USGS sampling of 11 tributaries in 1998 indicated that the Apple, Willow and Kinnickinnic Rivers were the major contributors of suspended sediments and nutrients during base flow and storm-runoff events (Lenz et al. 2003).
- USGS calculations of annual tributary loading in 1999 indicated that the Sunrise River had the highest annual suspended-sediment and nutrient yields for that year.
- USGS modeling analysis of 1999 loading to St. Croix Basin riverine lakes indicated that a 50-percent reduction in phosphorus loading may be required to improve Lake St. Croix to mesotrophic status (Robertson and Lenz 2002).
- Historical analysis of point source phosphorus loads indicates that point sources account for 11-percent of current loads and 19-percent of future phosphorus loads to the St. Croix (Edlund et al. 2009).

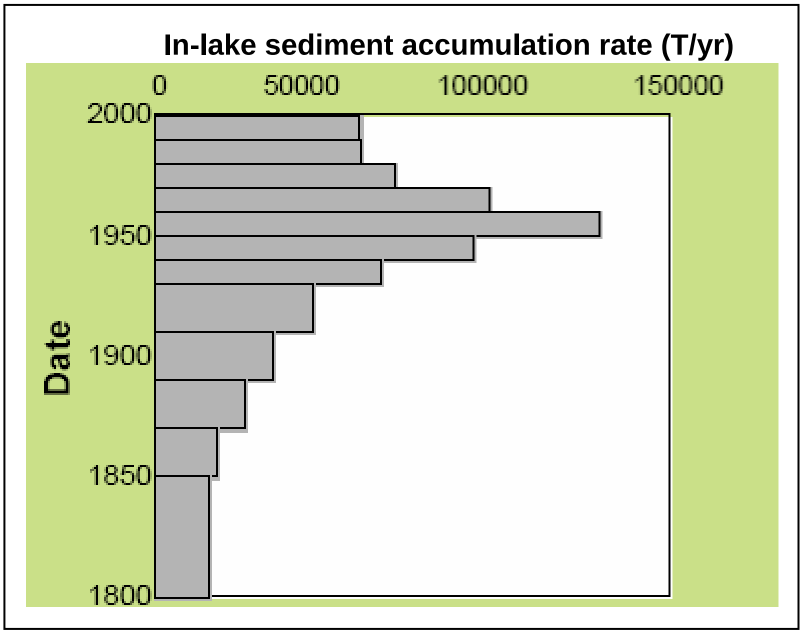

Figure 2. Sediment accumulation rate in Lake St. Croix sediments over the last 200 years (Triplett et al. 2009).

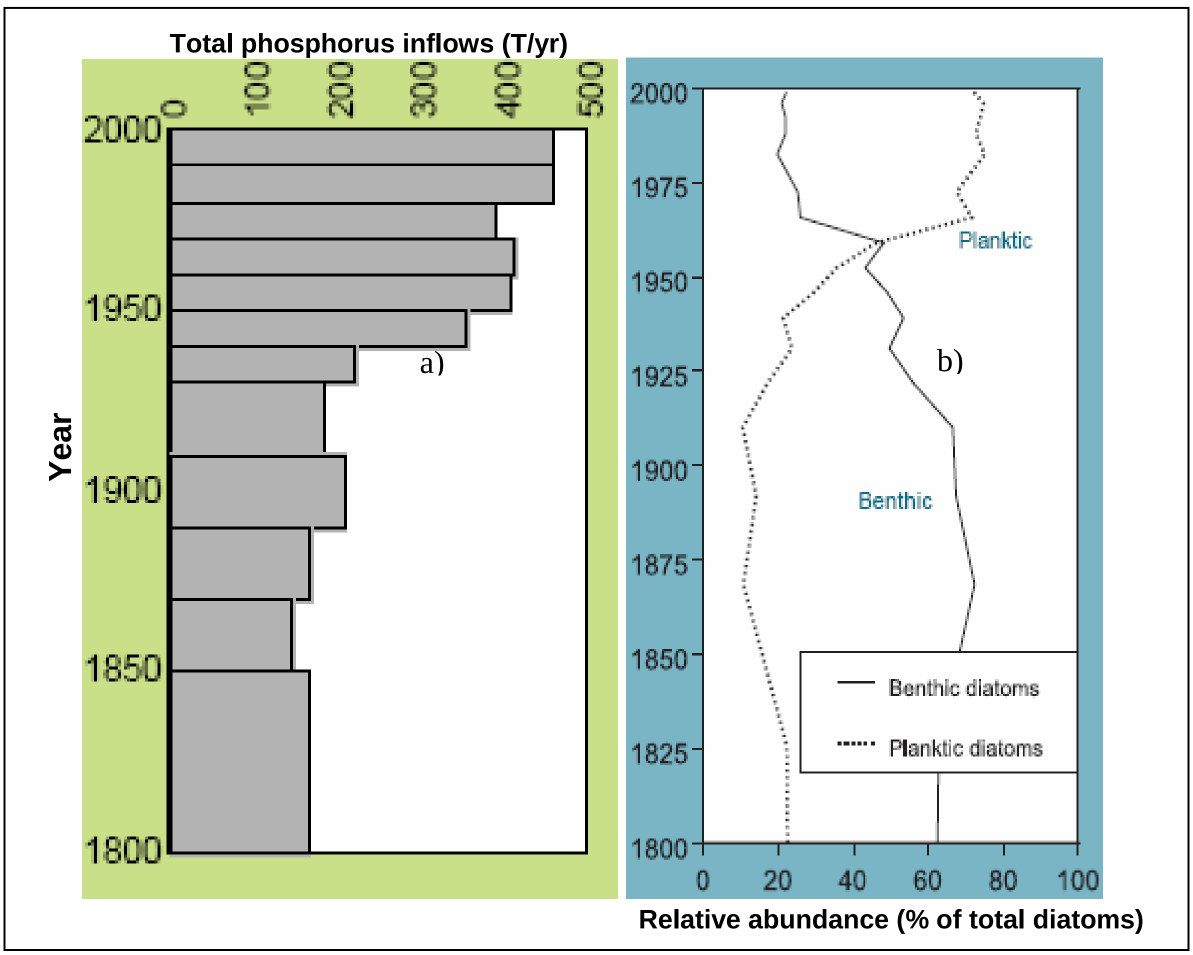

Figure 3. Historical reconstruction of a) total phosphorus loads of Lake St. Croix inflows, and b) diatom relative abundance (from Triplett et al. 2009).

1.2.2. Goal Setting Process

In 2003, the St. Croix River Basin Water Resources Planning Team (hereafter, Basin Team) began a year-long series of meetings to assess water-quality data and modeling results from nutrient and sediment studies. The research and assessment has revealed that major ecological changes have occurred in Lake St. Croix. Since the mid-1900s, total phosphorus loading has increased sharply and diatom communities, the dominant type of algae in this aquatic ecosystem, have changed drastically (Figure 3).

Based on the projected 39-percent population growth in the St. Croix Basin by the year 2020, water quality in Lake St. Croix will continue to degrade under the current regulatory path (Figure 4). Therefore, the Basin Team established a water quality improvement goal for Lake St. Croix (Davis 2004). The goal is defined as a 20-percent reduction in the mean annual total phosphorus (TP) load entering Lake St. Croix. A 20-percent reduction in total phosphorus inflows will approximate the ecological conditions of Lake St. Croix in the 1940s, after European settlement and major land-use changes in the late 1880s, but before large increases in nutrient loadings occurred during 1950-60, causing major changes in diatom communities and algal productivity (Table 1).

On April 6, 2006, this nutrient reduction goal was incorporated into a formal agreement between the Minnesota Pollution Control Agency (MPCA) and the Wisconsin Department of Natural Resources (WDNR). A portion of the agreement reads as follows:

> The Minnesota Pollution Control Agency and the Wisconsin Department of Natural Resources will work together to accomplish the following objectives:
> 1. Jointly evaluate and establish water quality standards related to eutrophication which are applicable to Lake St. Croix by the end of 2009;
> 2. In partnership with the St. Croix Basin Water Resources Planning Team, perform a point and non-point source nutrient loading study and develop an implementation plan by June 30, 2009;
> 3. Coordinate and improve water quality monitoring and assessment capabilities to track progress on the achievement of the recommended 20% phosphorus loading reduction goal for Lake St. Croix; and,
> 4. Provide continued staff and funding support to the St. Croix Basin Water Resources Planning Team.

The four objectives listed in the agreement set a new agenda for the Basin Team and its subcommittees. Specifically, the Implementation Subcommittee was mandated with achieving the second objective: to perform a point and non-point source nutrient loading study, and to develop an implementation plan by June 30, 2009.

Following the signing of the nutrient reduction agreement, staff at the MPCA began assessing Lake St. Croix for impairment. Based on 1998 to 2006 summer mean concentrations, including data collected within the lake at Stillwater and Prescott by Metropolitan Council Environmental Services, Lake St. Croix was found to exceed the phosphorus and chlorophyll-a impaired listing criteria for the NCHF ecoregion (Wasley 2007, included in the Appendix) of 45 μg/L and 18 μg/L, respectively. Therefore, Lake St. Croix was recommended for addition to the Minnesota proposed 2008 303(d) list of impaired waters. Subsequently, WDNR staff followed suit and listed Lake St. Croix on the Wisconsin proposed 2008 303(d) list of impaired waters. Since that time, the two agencies have been expanding their collaboration and coordination within the St. Croix River Basin, toward the development of an interstate, basin-wide phosphorus TMDL.

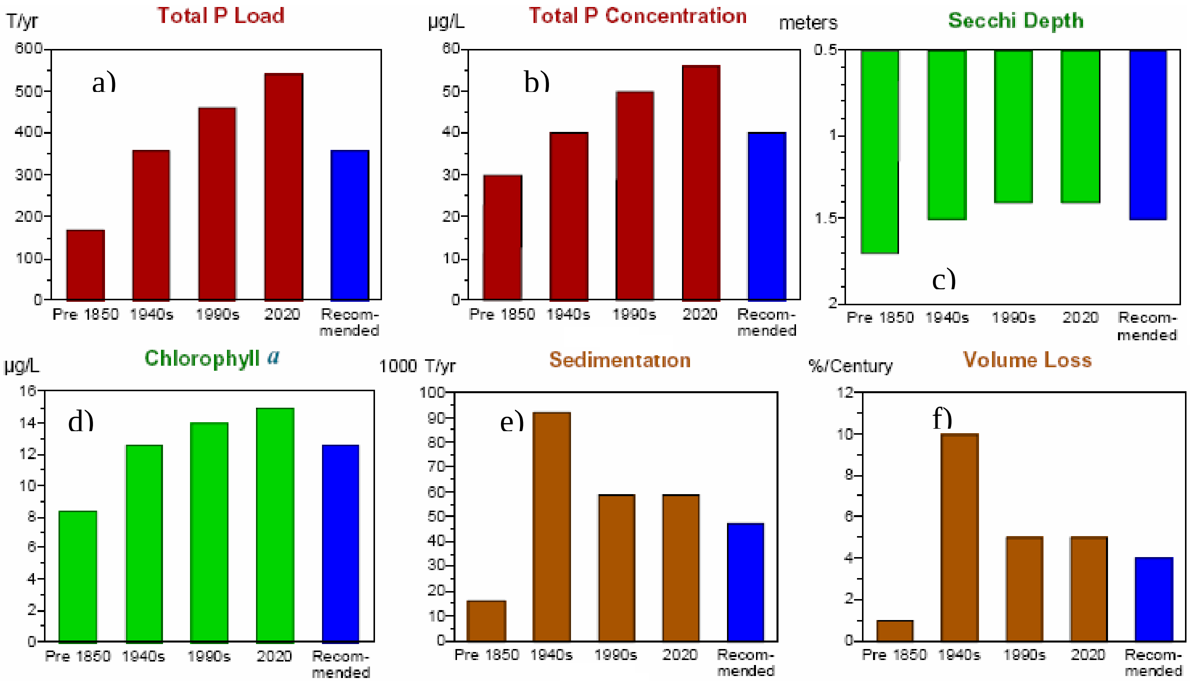

Figure 4. Effect of management scenarios on six Lake St. Croix ecological indicators: a) total phosphorus load (t/yr), total phosphorus concentration (µg/L), Secchi depth (m), chlorophyll-a concentration ((µg/L), sediment accumulation rate (t/yr), and loss of lake volume (%/century) (from Kohlasch, 2004).

Table 1. Nutrient goal-setting scenarios spreadsheet (modified from Davis, 2004).

			Recommended Scenario	2020	1990s	1940s	Pre 1850
Management Setting			20% reduction in nutrient loading from 1990s conditions	No action: operate under current regulations, and 39% population growth	Current conditions: maintaining these conditions would require changes	Recommended nutrient reduction scenario approximates these conditions except sedimentation	Conditions prior to European settlement
Category	Attribute	Variable					
Algae	Composition	Benthic:planktonic ratio	Benthic dominance	n/a	30:70	60:40	80:20
	Concentration	May-Sept median surface Tchl-α (µg/L)	12	15	14	12	9
	Bloom Frequency	May-Sept Tchl-α >20µg/L frequency (%)	6	9	7	6	1
Nutrients	Concentration	May-Sept median surface TP (µg/L)	40	56	50	40	30
	Load	TP load (t/yr)	360	540	460	360	170
Clarity	Transparency	May-Sept mean secchi depths (m)	1.5	1.4	1.4	1.5	1.7
Lake Sediments	Accum. Rate	Basin-wide mass load (t/yr)	47200	59000	59000	92000	16000
	Loss of lake volume	Volume lost per century (%)	4	5	5	10	1

1.3 Purpose and Approach

The purpose of this Lake St. Croix Total Phosphorus Loading Study (hereafter, Loading Study) is to enhance the current understanding of phosphorus loading within the St. Croix Basin by integrating available loading data with basin-scale loading concepts. The study is designed to support the preparation of a basin-wide phosphorus total maximum daily load (TMDL) plan. The objectives of the study were to: 1) estimate the geographic distribution of point and nonpoint source phosphorus loads across subwatersheds of the basin, and 2) compare the phosphorus source load estimates with water quality data for the subwatersheds of the basin.

1.3.1. TMDL Approach and Guidance

Since the goal of this study was to support the development of a phosphorus TMDL for Lake St. Croix, this work was informed by the national protocol for the development of nutrient TMDL plans (EPA, 1999). The elements of a TMDL plan that correspond with the Loading Study include the Source Assessment, Linkages, and Effectiveness Monitoring components. These components will be referred to throughout this document. The Basin Team's recommendation of limiting TP loading to Lake St. Croix to 360 tons/yr is equivalent to a total maximum daily load of 986 kg/day (2174 lb/day). It was a goal of the Loading Study to further the development of allocations, but not to propose allocations for the final TMDL plan.

1.3.2. Spatial Nesting and Subwatershed Framework

The larger context for the water quality impairments in Lake St. Croix is that impairments are occurring across the landscape, both upstream and downstream of Lake St. Croix. The upstream impairments encompass smaller drainage areas, or subwatersheds of the St. Croix River that provide inputs to Lake St. Croix, while the downstream impairments encompass larger drainage areas, including inputs from the St. Croix Basin. Every documented impairment requires TMDL assessment and implementation, so that any individual source of impairment could be regulated by TMDL limits at multiple spatial scales. For example, the municipal wastewater treatment facility in New Richmond, Wisconsin, which discharges to the Willow River, is one among four point source dischargers upstream of the impaired Lake Mallalieu; it's also one among fifty point source discharges upstream of the impaired Lake St. Croix, and one among hundreds of point source discharges upstream of the impaired Lake Pepin in the Mississippi River. Summarizing Minnesota examples of nested TMDLs, Finley (2008) described small-scale TMDLs (e.g., Lake Mallalieu) as the most detailed plan for restoration of a local water body, moderate-scale TMDLs (e.g., Lake St. Croix) as more general basin-scale planning, and large-scale TMDLs (e.g., Lake Pepin as broad strategic resource planning).

This study adopted the subwatershed framework for a number of reasons:

1. To support and encourage interagency coordination of TMDLs within the St. Croix Basin;
2. Subwatershed outlets have been the target of long-term water flow and water quality monitoring by federal, state, and local monitoring agencies; and,

3. Although much of the relevant data are compiled by counties, subwatersheds serve as convenient accounting units for basin-wide analysis, made easier with improved GIS capabilities.

Therefore, impairments in the St. Croix Basin will be addressed at two spatial scales: in a basin-wide analysis (section 3) and in a subwatershed analysis (section 4). The major subwatershed areas are listed in Table 2, which is color-coded to the subwatershed map in Figure 5 (NPS 2004b).

Table 2. Tributary outlet and gaged areas of the major subwatersheds and miscellaneous small streams that comprise the St. Croix River Basin, listed in the order of their confluence with the mainstem of the St. Croix River, from the top of the watershed at the Namekagon River to the bottom of the watershed at the Kinnickinnic River.

	Major subwatershed	Tributary area (ha)	Gaged area (ha)	USGS Gage #	1990s flow (cfs)	2000's flow (cfs)
Tributaries to St. Croix R. above Lake St. Croix (LSC)	Namekagon River	159,916				
	Upper St. Croix River	133,115				
	Upper Tamarck River	26,304	25,671	05333579		
	Yellow River	97,305	81,634	05335031		
	Lower Tamarack River	50,398	46,993	05335151		
	Crooked Creek	25,348	23,936	05335170		
	Clam River	99,180	93,354	05335500		
	Sand River	28,623	28,113	05335900		
	Bear Creek	16,261				
	Kettle River	269,455	223,423	05336700	728	606
	Snake River	260,027	250,030	05338500	574	655
	Wood River	44,630	20,917	05338955		
	Rock Creek	14,247				
	Rush Creek	15,485				
	Goose Creek	17,277				
	Sunrise River	96,535	95,761	05340050		
	Trade River	39,546	34,446	05340390		
	Wolf Creek	97,680				
Tribs to LSC	Apple River	144,703	140,631	05341500	446	438
	Silver Creek	2,040				
	Browns Creek	5,040				
	Willow River	76,539	75,506	05341752		130
	Valley Creek	11,492				
	Kinnickinnic River	44,939	42,662	05342000	111	111
	Misc. small streams	213,915				
	TOTAL BASIN	1,990,609				

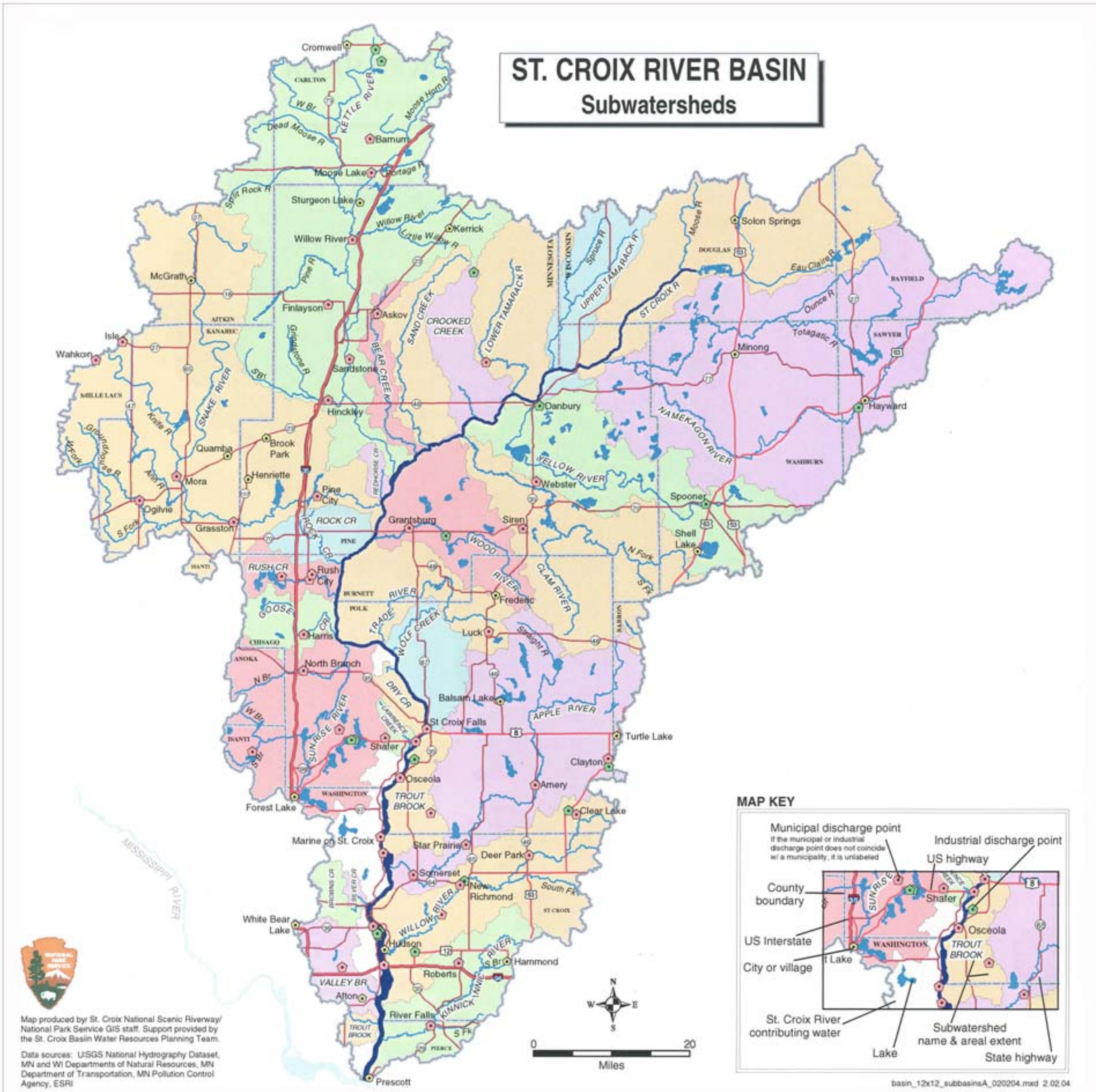

Figure 5. St. Croix River Basin, showing major subwatersheds and locations of municipal and industrial wastewater treatment facilities (NPS 2004b).

2. 0 PHOSPHORUS SOURCES WITHIN THE ST. CROIX BASIN

2.1. Conceptual Framework for Phosphorus Routing and Delivery Pathways

A conceptual model of phosphorus routing through the St. Croix Basin was developed to provide a simpler framework for the complex physical, chemical, and biological processes that govern the distribution of phosphorus throughout the basin. A series of simple input-output processing boxes was selected as the starting point, where the output for one box becomes the input for the next box (Figure 6). In the simplified model of the St. Croix Basin, this processing occurs in three stages or settings: land and stream processes within the tributary subwatersheds, large river processes within the mainstem of the St. Croix River, and lake processes within the wide and slow-moving Lake St. Croix. The Phosphorus Reduction Goal targets a 20% reduction in phosphorus inputs to Lake St. Croix (the red-outlined box in Figure 6) by 2020. In reality, the configuration of phosphorus routing is more complex, in that there is not one, but eighteen tributaries that flow into the mainstem of the St. Croix River, and five tributaries that flow directly into Lake St. Croix (Figure 7). Runoff from those five tributaries and the tributaries that enter the St. Croix River just upstream of Lake St. Croix are expected to have greater impact on the Lake St. Croix impairments, as represented by relatively shorter-length processing arrows and relatively larger output areas. The 20% Phosphorus Reduction Goal pertains to all inputs to Lake St. Croix, or the red-outlined areas in Figure 7. Since Lake St. Croix is the outlet of the entire basin, it is assumed that the entire basin drains into the lake.

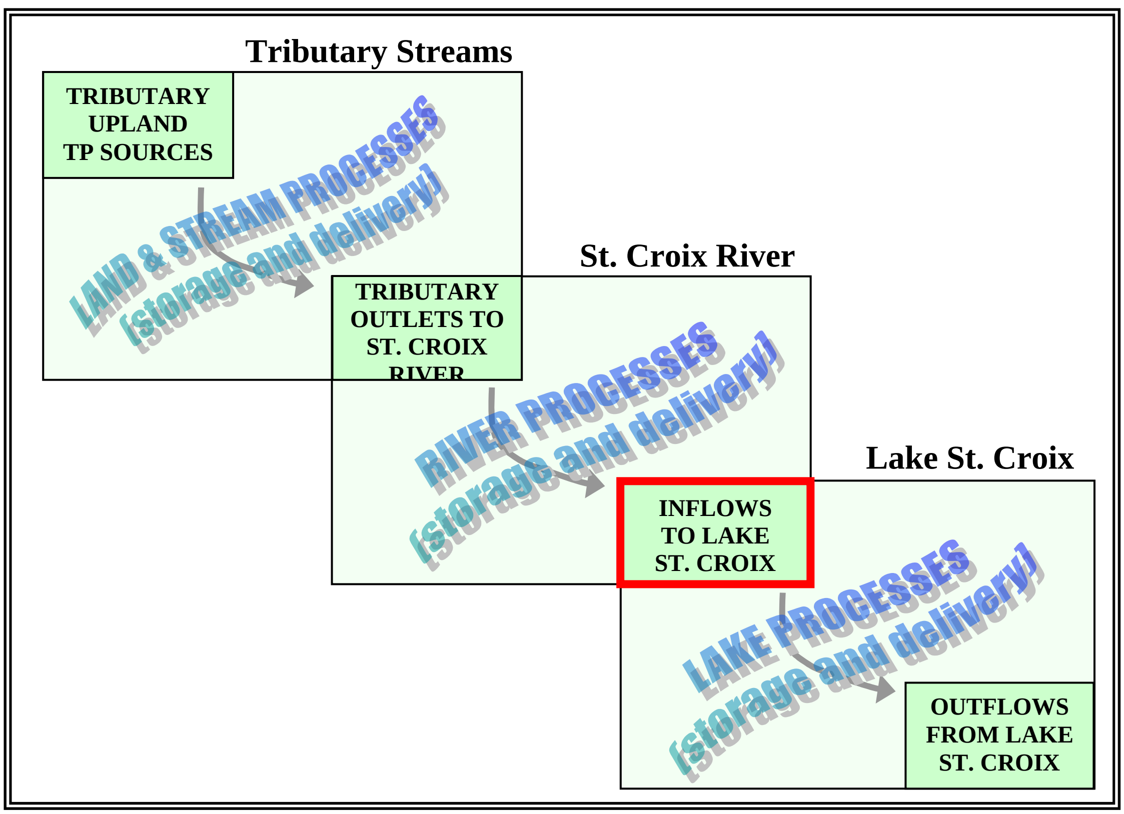

Figure 6. Simplified input-output conceptual model for phosphorus routing through the St. Croix Basin. Reduction goal is targeted for the inflows to Lake St. Croix (red outline).

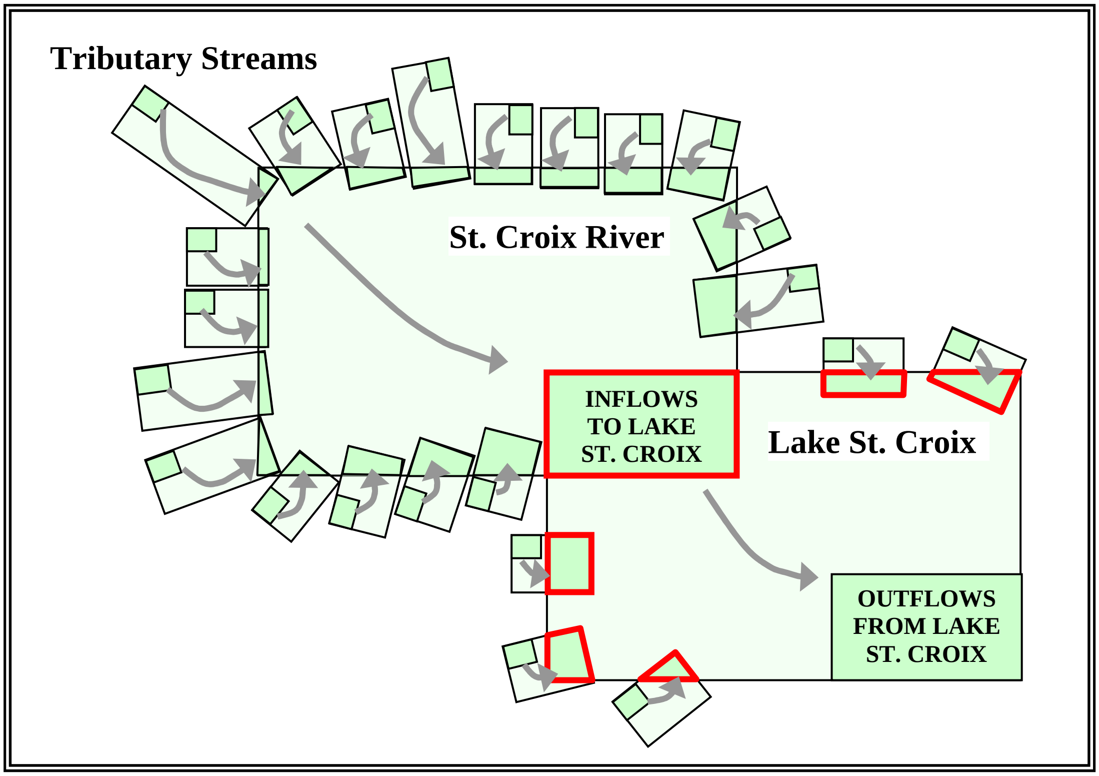

Figure 7. Less simplified input-output conceptual model for phosphorus routing through the St. Croix Basin. Tributaries closest to Lake St. Croix are expected to have greater proportional effect on lake water quality than tributaries farther upstream. Reduction goal is targeted for the inflows to Lake St. Croix (red outlines).

In this less simplified conceptual model, phosphorus loads are moved from their sources in the tributary uplands through the riverway to the inflows of Lake St. Croix. From an ecological mass balance perspective, one might expect all eroded phosphorus to eventually be delivered downstream. However during this study, calculated loads did not match those expectations; the 1990s-decadal-average upland source loads were greater than the St. Croix inflow loads for the same period (see step 6 in section 3.2.1). Local water resource managers generally accept that Lake St. Croix is a long-term phosphorus sink, storing phosphorus via reservoir sedimentation, and this phenomenon may also occur at smaller scales within the drainage ways above Lake St. Croix. The duration of phosphorus storage on the landscape above Lake St. Croix may be greater than the current monitoring period. The land, stream, river, and lake processes at each stage in Figure 6 possibly reduce the amounts of phosphorus that are output to the next stage. Therefore, even though the mass loads accumulate and increase as they're moved downstream, the mass load per unit drainage area is decreased by these processes. This concept of eroded load per area is referred to by several terms: loading rate, delivery ratio, and export coefficient. When discussing loading rates, it is important to remember the spatial scales at which the loads were measured, and the location on the landscape where a given loading rate applies (Figure 8).

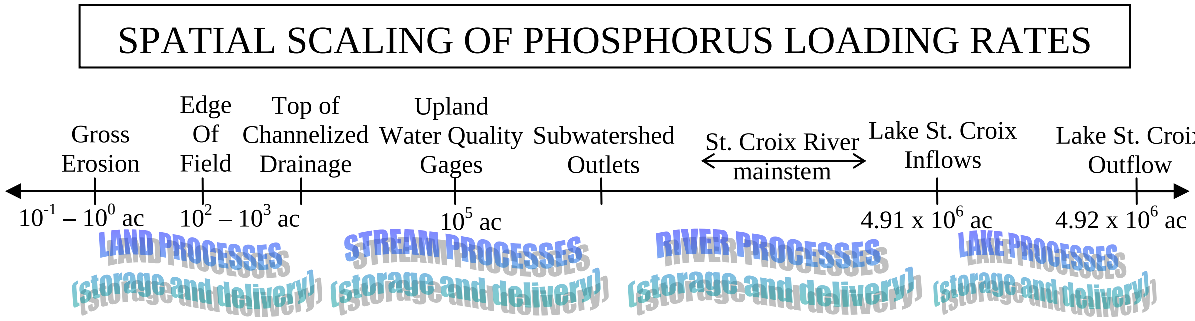

Figure 8. Spatial scaling of phosphorus loading rates across the St. Croix Basin landscape.

2.2. TMDL Guidance for Identifying Phosphorus Source Categories

The U.S. EPA (1999) recommends 1) developing a comprehensive list of the potential nutrient sources to the water body, Lake St. Croix; 2) using the list of potential sources and the watershed inventory to identify actual sources and to develop a plan for estimating their magnitude; 3) using GIS or maps to document the location of sources and the processes important for delivery to Lake St. Croix; and, 4) estimating the relative magnitude of phosphorus loads from sources, using a range of analytical tools and methods including monitoring data, empirical methods, and computer models. Sources of information that can be used to identify and document these activities include land use maps, aerial photographs, local conservation organizations, tax maps, field surveys, and point source discharge permits. After compiling an inventory of all possible sources of phosphorus to Lake St. Croix, the TMDL source assessment step includes focusing on the primary and controllable sources of nutrients.

Appropriate delineation between potential source categories during the source assessment step will facilitate completion of the analytical and allocation steps that follow (EPA, 1999). Under EPA TMDL protocols, source allocations are divided between Waste Load Allocations (WLA) and Load Allocations (LA), generally equivalent to point sources and nonpoint sources, respectively. This division is an appropriate starting point for the eventual accounting that will be required by the Lake St. Croix TMDL allocation process. In addition, EPA recognizes a distinction between 1) large point sources that are controlled via regulatory permits, and 2) smaller (more numerous) point sources without regulation or permit controls (e.g., street runoff from small communities), viewing the latter group as more analogous to nonpoint sources.

2.3 Source Assessment

Phosphorus sources can be divided into two groups: natural background and anthropogenic, or cultural. The natural sources are assumed to be distributed across the landscape akin to nonpoint sources. The cultural sources can be further divided into point sources (those discharging from discrete outlets) and nonpoint sources (those discharging diffusely across the landscape). Thus, the three major types of phosphorus sources include natural background nonpoint sources, cultural nonpoint sources, and cultural point sources (Figure 9). However, the Loading Study employed the TMDL distinction of permit controls on point source loads. Therefore, the three major types of phosphorus sources to Lake St. Croix are defined as: 1) background nonpoint sources delivered by natural processes that afford little or no control, 2) cultural nonpoint sources and point sources without permit controls, and 3) cultural point sources with permit controls.

Transport pathways (i.e., air, surface water, groundwater) and mechanisms (e.g, runoff, infiltration) are important factors in the time scale of loading to Lake St. Croix (i.e., duration and frequency of nutrient discharge to receiving waters). Figure 7 is less simplified than Figure 6, but it's still simplified with respect to delivery pathways. The three delivery pathways from phosphorus sources in the St. Croix basin to Lake St. Croix are: 1) runoff via surface waters, 2) infiltration to groundwater that discharges to surface waters, and 3) wind-blown atmospheric transport. In the Figures 10-12, delivery pathways are denoted with an initial: S=surface runoff, G=groundwater, A=atmospheric transport.

Another factor to consider when grouping sources is the degree to which various sources contribute bioavailable or other forms of a nutrient. This is especially important for phosphorus because some sources might contribute largely non-bioavailable phosphorus, and therefore a reduction in their loadings will not be as significant as would a comparable reduction in loads of bioavailable phosphorus. This might be an important issue in rivers because the shorter residence times (compared to lakes) do not allow for effective decomposition of organic phosphorus.

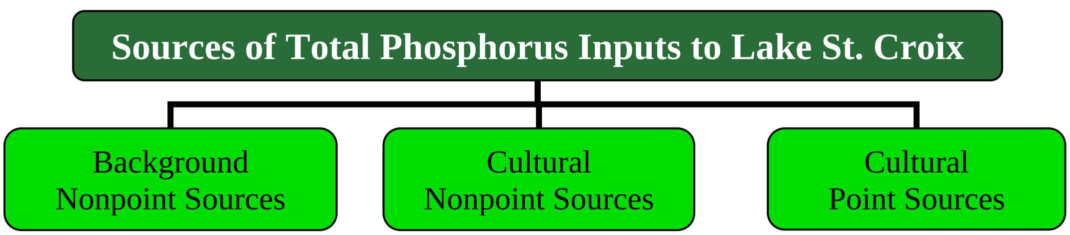

Figure 9. The three major types of phosphorus sources within the St. Croix River Basin.

2.3.1. Background Nonpoint Sources (BKGD-NPS)

Background nonpoint sources (Figure 10) include nonpoint sources that existed in the St. Croix Basin prior to European settlement and are delivered by naturally-occurring processes independent of human-influenced controls. Land cover types include open water, wetlands, grasslands, and forest lands (Figure 6). Pre-settlement phosphorus yields are considered to be the minimum possible yields from the human-influenced landscape (i.e., best management practices cannot reduce nutrient runoff below these levels). The natural background sources of phosphorus to Lake St. Croix include:

- Surface runoff from the natural landscape
- Infiltration to groundwater, transport and discharge from the subsurface
- Atmospheric deposition of windblown sediments from the natural landscape

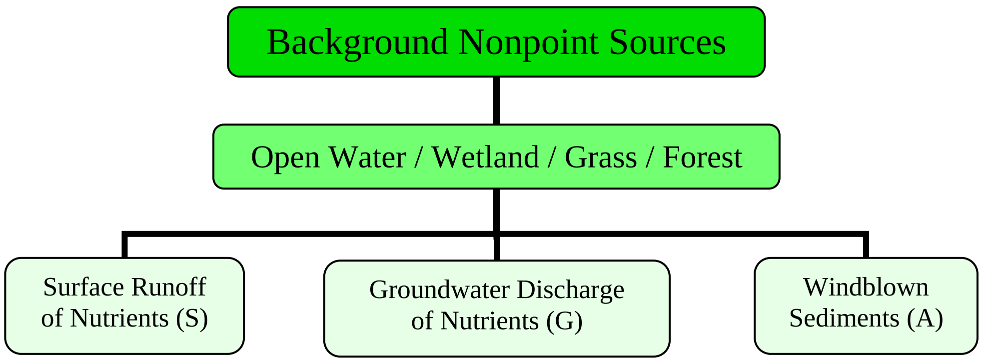

Figure 10. Natural background nonpoint sources of phosphorus in the St. Croix River Basin. Source delivery pathways: S=surface runoff, G=groundwater, A=atmospheric transport.

2.3.2. Cultural Nonpoint Sources (and Small Point Sources without Permit Controls) (CULT-NPS)

Cultural nonpoint sources (Figure 11) are human-induced nonpoint sources and smaller, unregulated point sources. These sources tend to be distributed widely across the landscape in four land cover types (open water, agricultural lands, rural residential lands, and urban lands). Phosphorus reductions from these sources tend to require a broad application of various best management practices (BMPs) across the landscape, especially those BMPs that have been identified by watershed models to yield the greatest reductions in a given watershed. The cultural (anthropogenic) nonpoint sources include:

- Streambank erosion accelerated by human activities
- Surface runoff from smaller, non-regulated concentrated animal feeding operations (CAFOs), pasturelands, croplands, and smaller, non-regulated municipal stormwater runoff
- Infiltration beneath crop land and individual sewage treatment systems, and eventual discharge from groundwater
- Atmospheric deposition of windblown sediments from exposed croplands

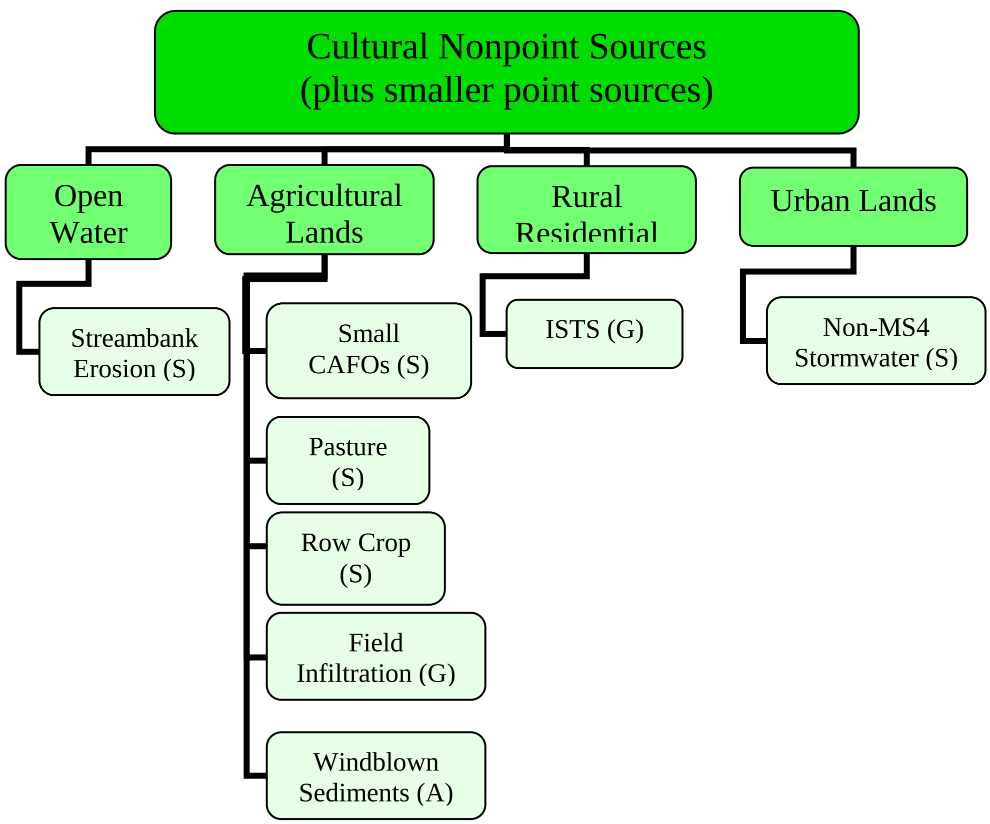

Figure 11. Cultural nonpoint sources (and smaller, non-regulated point sources) of phosphorus in the St. Croix Basin. Source delivery pathways: S=surface runoff, G=groundwater, A=atmospheric transport.

2.3.3. Cultural Point Sources (with Permit Controls) (CULT-PS)

Cultural point sources (Figure 12) are regulated point sources that afford control via the regulatory permit process. With regulatory controls, these sources tend to have better documentation of measured phosphorus concentrations and loads, which are reported to regulatory agencies. Historically, regulation of phosphorus inputs has been limited to those sources that deliver phosphorus directly to surface waters. The cultural (anthropogenic) point sources in the St. Croix Basin include surface runoff from:

- Larger concentrated animal feeding operations (CAFOs)
- Wastewater treatment facilities
- Industrial discharges
- Separated or combined sewer outfalls (SSO/CSO)
- Municipal separate storm sewer systems (MS4)
- Construction sites

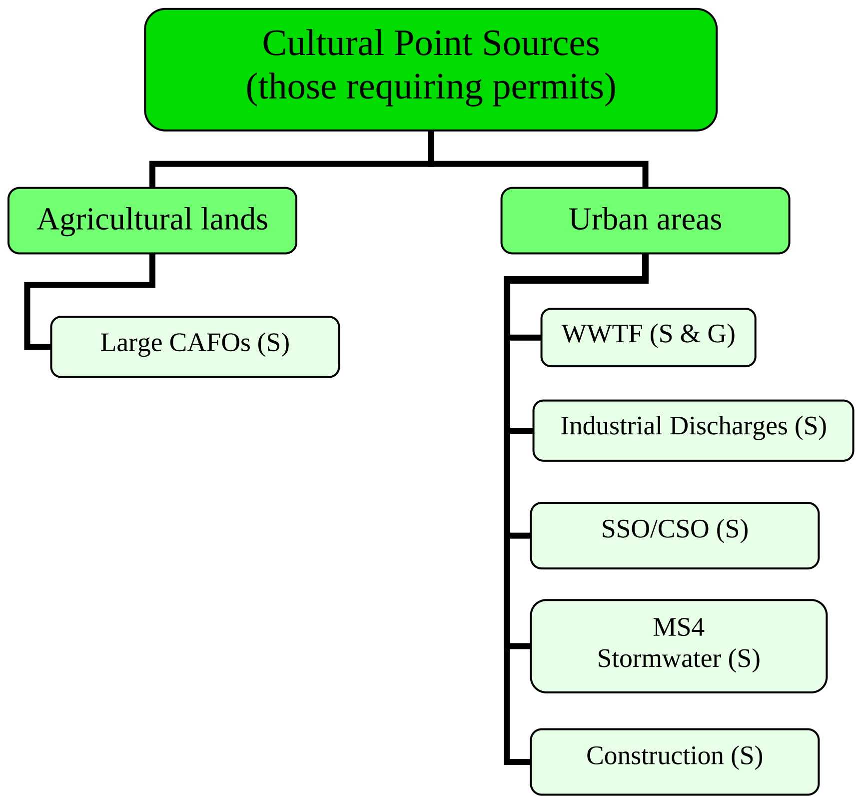

Figure 12. Cultural point sources of phosphorus in the St. Croix Basin. Source delivery pathways: S=surface input, G = groundwater infiltration.

A comprehensive phosphorus source inventory is the most challenging part of employing the subwatershed approach (e.g. requiring an accounting column appended to Table 3 for each major subwatershed of the St. Croix River Basin). Much of the relevant data is stored in county offices and databases, requiring a county-by-county search to document the number, location, and contributing load of all phosphorus sources in every county that covers each subwatershed. The Loading Study avoided the time and expense of a direct inventory by using more expedient methods (see section 3.1).

Table 3. Summary list of sources of total phosphorus within the St. Croix River Basin.

Source Type	Source description
BKGD-NPS	Natural erosion processes
CULT-NPS	Streambank erosion
	Small concentrated animal feeding operations (CAFOs)
	Pasture runoff
	Row crop runoff
	Stormwater runoff from non-MS4 communities
	Field infiltration and groundwater discharge
	Individual sewage treatment systems (ISTSs)
	Wind erosion and atmospheric transport
CULT-PS	Large concentrated animal feeding operations (CAFOs)
	Wastewater treatment facilities (WWTFs)
	Industrial discharges
	Construction runoff
	Stormwater runoff from MS4 communities
	Separated or combined sewer outfalls (SSO/CSO)

3.0 BASIN-WIDE ANALYSIS OF PHOSPHORUS SOURCE LOADS

Phosphorus source loads are measured or estimated at particular locations on the landscape. During the loading analysis of this study, it became apparent that loads and loading rates were unique to the spatial scale at which they were calculated. Therefore, the loading analysis focused on estimates of loads and loading rates at two spatial scales: 1) within channelized drainage of the tributary uplands, and 2) at Lake St. Croix inflows.

3.1. Source Load Estimation Methods

This study used a variety of methods to estimate phosphorus source loads, including indirect estimates, direct evidence, and actual measurement records. The major components of source loads were background nonpoint sources (BKGD-NPS), cultural nonpoint sources (CULT-NPS), cultural point sources (CULT-PS), and total loads (TOTAL) within tributary uplands and Lake St. Croix inflows. In addition, the subsets of total nonpoint source loads (TOT-NPS) and total cultural loads (TOT-CULT) were used to estimate the other loads by difference.

3.1.1. Estimating Background Nonpoint Source (BKGD-NPS) Loads

According to Triplett et al. (2009), the rate of phosphorus loading to Lake St. Croix in the early 1800's, before major human settlement and disturbance of the basin, was 166 metric tons of total phosphorus per year (see Figure 3a). Therefore, the natural background nonpoint source loading to Lake St. Croix is estimated to be 166 T/yr.

3.1.2. Estimating Cultural Nonpoint Source (CULT-NPS) Loads

For this study, cultural nonpoint source loads were calculated using one of two methods: 1) by difference from total nonpoint source loads and background nonpoint source loads, or 2) by difference from total cultural loads and cultural point source loads.

3.1.3. Estimating Total Nonpoint Source (TOT-NPS) Loads

Due to the widespread nature of nonpoint sources, it is impossible to monitor the totality of nonpoint source runoff loads in a watershed. Therefore, calculation of nonpoint source load contributions across large areas usually requires some form of model estimation. For ongoing and upcoming subwatershed-scale TMDLs within the St. Croix Basin, mapped soils and topography data enable a Soil and Water Assessment Tool (SWAT) model estimation of nonpoint source runoff. In addition, a basin-wide SWAT model will eventually be developed that will estimate the nonpoint source contributions to phosphorus loads across the entire St. Croix Basin. However, SWAT model development at that scale will take time and those results won't be available until sometime in the future.

Therefore, the Loading Study used a more expedient form of model estimation: total phosphorus export coefficients (TPECs). A TPEC is the phosphorus runoff yield (i.e., loading rate) for a given land use, applicable in a given region having common surface features and a comparable climate record. Since separate land areas that have similar land covers and uses are more likely to exhibit similar loading behavior, land use analysis is an appropriate method to divide the landscape into smaller groupings for runoff loading analysis. Improvements in GIS computing technologies have made land use classification techniques much more convenient for landscape analysis. Generally, TPEC modeling is the concept that, if there are known ranges of nonpoint source TP yields from the land uses in a region (i.e., TPECs), and the areal extent of those land uses within a given study area of the region are known, then one can estimate the range of nonpoint source loads from the study area that are contributed by surface runoff.

The most reliable TPEC references are published reports of runoff studies conducted by natural scientists and water resource managers. For the Lake St. Croix Total Phosphorus Loading Study, a comprehensive literature search was conducted to find published TPEC values, with a focus on values published for Minnesota, Wisconsin, and/or Upper Midwest landscapes. In addition, the decision was made to select the most recently published values from the last few decades, ignoring data from the 1960s and 1970s, so that the data best represent modern landscape conditions and responses. Table 4 summarizes these recently published values, organized by the seventeen land cover categories from the 1992 National Land Cover Dataset (NLCD).

Most of the literature reported an average TPEC value plus a range representing variations in mean annual rainfall: from dry conditions (i.e., 10^{th} percentile annual rainfall) to average conditions (i.e., 50^{th} percentile annual rainfall) to wet conditions (i.e., 90^{th} percentile annual rainfall). Some studies also reported minimum and maximum values. Table 4 includes the dry-average-wet ranges of TPECs, as a way to account for climate variability and to incorporate estimates of uncertainty into the loading analysis.

Upon close inspection and discussion of the TPECs compiled in Table 4, a group of runoff specialists from the Basin Team's Implementation Committee pooled their collective knowledge of runoff behavior within the St. Croix Basin; they developed a customized list (Table 5) of dry-, average-, and wet-condition TPECs for six land cover groupings in the St. Croix Basin (open water, forest, shrub, grass, agriculture, and urban). The basis for these groupings was dictated by a watershed analysis tool available from Purdue University (Choi and Engel 2003); further details are given in Section 4.0.

In the basin-wide loading analysis, 1990s-decadal-average total nonpoint source TP loads (Table 6) were estimated from the land use analysis of the seventeen 1992 land cover classes (NPS 2004a), which were combined into the corresponding six land cover groupings and multiplied by the TPEC ranges in Table 5. The same technique was applied to basin-wide land use data for 2007, provided by Dr. Marvin Bauer (University of Minnesota), to estimate the total nonpoint source TP loads for the current period. Since TPEC values compiled from runoff studies are loading rates measured in the stream setting (see Figures 6-8), the loads estimated by the TPEC method are properly assigned to the spatial scale of channelized drainage in the subwatershed uplands. The range of upland total nonpoint source TP loading in 2007 (242 – 363 – 544 T/yr) was less than the range of upland total nonpoint source TP loading in 1992 (315 – 472 – 708 T/yr), but it is doubtful that these upland loads were less than the values necessary to achieve the 20% reduction goal (step 7 of section 3.2.3). This incongruity points to a drawback of the TPEC method: the presumed errors in estimates of TPEC values are amplified by errors in land use estimates.

Table 4. Compilation of published total phosphorus export coefficient values (kg/ha/yr) for dry, average, and wet climate conditions in Minnesota, Wisconsin, and/or Upper Midwest landscapes, listed for the 1992 NLCD landcover classes.

Landcover Class (1992 NLCD)	Dry	Avg	Wet	Literature Source
Open Water	0	0	0	MPCA (2004)
Emergent Herbaceous Wetlands	0	0	0	MPCA (2004)
	---	0.10	---	Heiskary and Wilson (1994)
Woody Wetlands	0	0	0	MPCA (2004)
	---	0.10	---	Heiskary and Wilson (1994)
Mixed Forest	0.064	0.107	0.155	MPCA (2004)
(OR ALL FORESTS)	0.08	0.10	0.20	Heiskary and Wilson (1994)
	0.05	0.09	0.18	Panuska and Lillie (1995)
	0.089	0.112	0.135	Clesceri et al (1986)
Deciduous Forest	0.034	0.057	0.084	MPCA (2004)
	0.19	0.29	0.38	Heiskary and Wilson (1994)
	0.03	0.07	0.19	Endreny and Wood (2003)
Evergreen Forest	0.056	0.092	0.132	MPCA (2004)
	0.22	0.31	0.44	Heiskary and Wilson (1994)
	0.04	0.20	0.31	Endreny and Wood (2003)
Shrubland	0.051	0.087	0.129	MPCA (2004)
Grasslands/Herbaceous	0.077	0.122	0.172	MPCA (2004)
	0.20	0.30	0.80	Heiskary and Wilson (1994)
Urban/Recreational Grasses	0.705	0.820	0.894	MPCA (2004)
	0.20	0.30	0.80	Heiskary and Wilson (1994)
Pasture/Hay	0.121	0.260	0.477	MPCA (2004)
	0.20	0.30	0.80	Heiskary and Wilson (1994)
Row Crops	0.121	0.260	0.477	MPCA (2004)
	0.20	0.40	0.80	Heiskary and Wilson (1994)
	0.20	1.00	3.00	Panuska and Lillie (1995)
	0.140	0.262	0.374	Clesceri et al (1986)
Small Grains	0.121	0.260	0.477	MPCA (2004)
	0.20	0.40	0.80	Heiskary and Wilson (1994)
Transitional	0.065	0.104	0.147	MPCA (2004)
Quarries/Gravel Pits	na	na	na	
Low-Intensity Residential	0.755	0.878	0.958	MPCA (2004)
	0.50	0.88	1.25	Heiskary and Wilson (1994)
High-Intensity Residential	0.983	1.143	1.247	MPCA (2004)
	0.50	0.88	1.25	Heiskary and Wilson (1994)
Commercial/Industrial/ Transportation	1.148	1.335	1.456	MPCA (2004)
	0.50	0.88	1.25	Heiskary and Wilson (1994)

na = none available for extraction pits

Table 5. St. Croix River Basin total phosphorus export coefficient (TPEC) values (kg/ha/yr) for each of Purdue's landcover groupings (Erdmann et al. 2009).

Purdue Landcover Groupings	TPEC (kg/ha/yr)		
	Dry	Avg	Wet
Water	0.033	0.050	0.075
Forest	0.067	0.100	0.150
Shrub	0.067	0.100	0.150
Grass	0.167	0.250	0.375
Agriculture	0.500	0.750	1.125
Urban	0.500	0.750	1.125

Table 6. Summary of St. Croix River Basin land use analysis and estimates of total nonpoint source upland loading, including basin-averaged export coefficients, 1992 and 2007.

1992					
Land Use Grouping	LU area (ha)	LU area (%)	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	178,004	8.9%	5874	8,900	13,350
Forest	1,114,373	56.0%	74663	111,437	167,156
Shrub	1,420	0.0%	95	142	213
Grass	341,873	17.3%	57093	85,468	128,202
Agriculture	324,082	16.3%	162041	243,061	364,592
Urban	30,857	1.5%	15429	23,143	34,714
TOTAL	1,990,609	100.0%	315,195	472,152	708,228
TOT-NPS Basin-wide Avg. TPEC (kg/ha/yr)			0.158	0.237	0.356

2007					
Land Use Grouping	LU area (ha)	LU area (%)	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	270,646	13.6%	8,931	13,532	20,298
Forest	1,187,084	59.6%	79,535	118,708	178,063
Shrub	84,736	4.3%	5,677	8,474	12,710
Grass	229,426	11.5%	38,314	57,356	86,035
Agriculture	172,691	8.7%	86,346	129,519	194,278
Urban	46,561	2.3%	23,280	34,921	52,381
TOTAL	1,991,145	100%	242,084	362,510	543,765
TOT-NPS Basin-wide Avg. TPEC (kg/ha/yr)			0.122	0.182	0.273

3.1.4. Estimating Cultural Point Source (CULT-PS) Loads

Wastewater treatment facility discharge records were obtained from staff at the MPCA and WDNR. Discharge records for Minnesota included monthly average flow discharge and monthly average total phosphorus concentrations, while the records from Wisconsin included daily flow discharge and measured total phosphorus concentrations. Based on an assessment of the range of monitoring frequencies, a range of methods was used to calculate annual loads for each facility:

1. Annual-to-monthly monitoring (1-12x per year) used the mean of concentration measurements, multiplied by each discharge measurement.
2. Bimonthly-to-weekly monitoring (2-4x per month) used the mean concentration calculated from a 90-day moving window, multiplied by each discharge measurement.
3. Weekly-to-daily monitoring (1-7x per week) used the mean concentration calculated from a 30-day moving window, multiplied by each discharge measurement.
4. Partial year (<365 days) monitoring used the mean daily load calculated from measured data, multiplied by the number of unmonitored days.

In 1992, the state of Wisconsin passed Chapter NR 217 of its natural resource rules aimed at reducing the amount of phosphorus discharged to surface waters by point sources. Large wastewater facilities were required to meet a phosphorus effluent concentration limit of 1 mg/L when their 5-year permits came up for renewal. In addition, all Wisconsin point sources were required to report their discharge concentrations starting in 1999. During the same period, improvements were also made in Minnesota with regard to phosphorus limits and reporting requirements in wastewater permits. Figure 14 shows the annual phosphorus loads from Minnesota and Wisconsin wastewater point sources. Compared to the baseline 1990s decadal-average load (51.7 T/yr), the average load during the current 2005-2007 period (23.5 T/yr) have decreased by 55%. An estimate of the current decadal average (1999-2007) indicates a 45% decrease since the 1990s. Figure 14 also compares the loading record with a scenario that predicts the potential maximum loading if point sources were allowed to discharge at their current permitted levels, a slight increase from the 1990s baseline loading, suggesting that wastewater permits may need to be modified when they are reviewed by the MPCA and WDNR.

3.1.5. Estimating Total Cultural (TOT-CULT) Loads

For this study, total cultural loads were calculated by one of two methods: 1) summing the cultural point and cultural nonpoint loads, or 2) subtracting background nonpoint source loads from total loads.

3.1.6. Estimating Total (TOTAL) Loads

The estimate of 1990s-decadal-average total phosphorus load at the Lake St. Croix inflow (460 T/yr) was calculated by Triplett et al. (2009) from the sum of long-term in-lake sedimentation and estimates of outflow loads inferred from diatom assemblages. Lafrancois et al. (2009) compared the decadal-average outflow concentrations from the lake-sediment core record with data from a 29-year water quality monitoring record. Average outflow concentrations determined by the two methods were closely matched for the 1980s and 1990s, supporting the credibility of the diatom-inferred outflow concentration estimates for previous decades in Lake

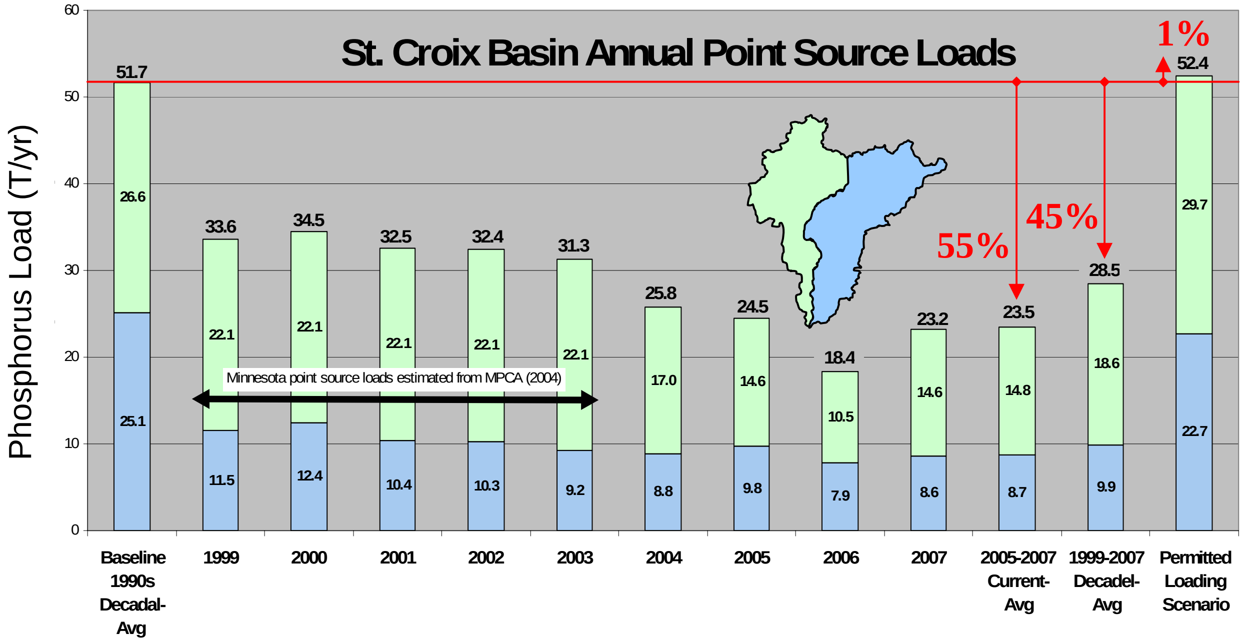

Figure 13. Annual total phosphorus loads from Minnesota and Wisconsin wastewater treatment facilities in the St. Croix Basin.

St. Croix (Triplett et al. 2009). Using the difference between the long-term water quality records from Stillwater and Prescott, Lafrancois et al. (2009) estimated the 1980s and 1990s decadal-average phosphorus retention loads for comparison with the lake-sediment core record. After adjustments for unmonitored portions of the phosphorus loading into Lake St. Croix (including direct point source, tributary, atmospheric, and bedload inputs), the water quality record matched the core record of about 130 T/yr retained by Lake St. Croix sediments in the 1980s and 1990s.

The total inflow load for the current (2005-2007) period was calculated by adding inflow point source loads to inflow total nonpoint source loads. The total inflow load identified for the 2020 reduction goal, 360 T/yr, was determined from the results of Triplett et al. (2009); the Basin Team selected a reduction target that would replicate the 1940s conditions in Lake St. Croix, before the severest degradations had occurred.

3.2. Source Load Estimates

Using the above methods, the spatial scaling of phosphorus loading within the St. Croix Basin, from upland source loads to Lake St. Croix inflow loads, was estimated for three time periods: the 1990s-decadal-average baseline, the 2005-2007 current average, and the 2020 reduction goal. The following sections detail the steps used to calculate each estimate.

3.2.1 Basin-wide Analysis of 1990s-Decadal-Average Baseline Loads

The following steps were used to estimate the dry-average-wet ranges of upland and Lake St. Croix inflow loads during the 1990s (Figure 14), beginning with the known factors and making the following assumptions:

1. Total nonpoint source TP loads in the uplands estimated from 1992 land use distributions ranged from, 315 to 472 to 708 T/yr, for dry-average-wet conditions (this study);
2. Phosphorus inputs to Lake St. Croix averaged 460 T/yr during the decade of the 1990s (Triplett et al. 2009);
3. Background nonpoint source TP loading to Lake St. Croix averaged 166 T/yr during pre-settlement times (Triplett et al. 2009);
4. Total point source TP loading in the uplands averaged 52 T/yr during the decade of the 1990s (Edlund et al. 2009);
5. Assuming that all of the point source loads were delivered to Lake St. Croix (i.e., 0% reduction), then by difference (= 460-52), the average total nonpoint source TP loading to Lake St. Croix was 408 T/yr;
6. Total nonpoint source TP loads estimated for Lake St. Croix inflows (408 T/yr) were 14% less than those estimated for the uplands (472 T/yr)[1];
7. If we assume point sources also decrease by 14% (not 0%) from the uplands to Lake St. Croix, then calculation steps 5 and 6 can be re-iterated until both point sources and total nonpoint sources are decreased by the same ratio[2]. This resolved to a basin-wide average 12.2% reduction in TP loads from the uplands to Lake St. Croix;
8. Therefore, the average upland point source loads should have decreased from 52 to 46 T/yr at Lake St. Croix inflows;
9. Assuming that municipal and industrial point source loads did not vary significantly with dry or wet weather conditions, then the "range" of point source loading to Lake St. Croix was a constant 46 – 46 – 46 for dry, average, and wet conditions, respectively;
10. Assuming that the dry-average-wet range of total upland nonpoint source loads was decreased by 12.2% in all weather conditions[3] before reaching Lake St. Croix, then the range of total nonpoint source TP loading to Lake St. Croix was 277 – 414 – 622 T/yr;

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[1] Possible explanations for this difference include 1) a basin-wide average 14% overestimation of TOT-NPS loads using TPECs, and 2) long-term (>decades) sedimentation in the drainage ways above Lake St. Croix.

[2] It should be noted here that this assumption, that both point source loads and nonpoint source loads are decreased by the same ratio during transport from subwatershed uplands to Lake St. Croix, is imprecise. Point source loads tend to contain larger proportions of bio-available phosphorus than nonpoint source loads (MPCA, 2004); bio-available forms of phosphorus are consumed more readily in the natural environment than non-bio-available forms. However, both forms, and hence both source types, of phosphorus are probably decreased by some degree during transport; probably neither form is reduced by 0%.

[3] The percent reduction from uplands to Lake St. Croix inflows is probably higher than 12.2% in wet years when phosphorus is more sediment-bound, and probably lower than 12.2% in dry years when phosphorus is more soluble.

11. Combining steps 9 and 10, the dry-average-wet range of total loading to Lake St. Croix during the 1990s was 323 – 460 – 668 T/yr, respectively;
12. Assuming the average background nonpoint source loading to Lake St. Croix, 166 T/yr, was also reduced by 12.2%, then the average background nonpoint source loading in the uplands was 189 T/yr, and by difference (= 472 – 189) the average cultural nonpoint source loading in the uplands was 283 T/yr;
13. The dry-average-wet range of TPECs for natural background land uses (the first eight listed in Table 4) varied as 67% - 100% - 151% of the average value for those eight land uses;
14. Assuming the resulting upland background nonpoint source loads vary by the same ratios, the dry-average-wet range of upland background nonpoint source loading was 127 – 189 – 285 T/yr;
15. By difference, the dry-average-wet range of upland cultural nonpoint source loads was 188 – 283 – 423 T/yr;
16. Assuming the upland loads in steps 14 and 15 were decreased by 12.2% before reaching Lake St. Croix, then the range of background nonpoint source TP loading to Lake St. Croix was 112 – 166 – 250 T/yr, and the range of cultural nonpoint source TP loading to Lake St. Croix was 165 – 248 – 371 T/yr;
17. Combining the cultural point source TP loads from step 9 and the cultural nonpoint source TP loads from step 16, the range of total cultural TP loading to Lake St. Croix in the 1990s was 211 – 294 – 417 T/yr (the same values resulting from subtracting the range of background loads from the range of total loads).

3.2.2 Basin-wide Analysis of 2005-2007 Current-Average Loads

The following steps were used to estimate the dry-average-wet ranges of upland and Lake St. Croix inflow loads during the current period (2005-2007 average) (Figure 15), beginning with the known factors and making the following assumptions:

1. Total nonpoint source TP loads in the uplands estimated from 2007 land use distributions ranged from 242 to 362 to 544 T/yr, for dry-average-wet conditions (this study);
2. Background nonpoint source TP loading to Lake St. Croix averaged 166 T/yr during pre-settlement times (Triplett et al. 2009);
3. We assume the dry-average-wet ranges of background nonpoint source TP loading within the uplands (127 – 189 – 287 T/yr) and Lake St. Croix inflows (112 – 166 – 251 T/yr) have remained the same over time;
4. If the total nonpoint sources in the uplands decrease by 12.2% before reaching Lake St. Croix, then the dry-average-wet range of total nonpoint source loading to Lake St. Croix is 213-318-478 T/yr;
5. By difference, the dry-average-wet range of cultural nonpoint source loads would be 115-173-257 T/yr in the uplands, and 101-152-227 T/yr at Lake St. Croix inflows.
6. Total point source TP loading in the uplands averaged 23.5 T/yr during the current period (this study);
7. Assuming the upland point source loads are decreased by 12.2% to 21 T/yr, then the dry-average-wet range of point source TP loading to Lake St. Croix is constant at 21 – 21 – 21 T/yr;

8. By addition, the total uplands loads for dry-average-wet conditions are 266-386-567 T/yr, and total St. Croix inflow loads for dry-average-wet conditions are 234-339-499 T/yr.

3.2.3. Basin-wide Analysis of 2020 Reduction Goal Loads

The following steps were used to estimate the dry-average-wet ranges of upland and Lake St. Croix inflow TP loads after the 20% reduction goal has been achieved (Figures 16 and 17), beginning with the known factors and making the following assumptions:

1. The reduction goal would result in Lake St. Croix inflows being reduced by 100 T/yr to 360 T/yr;
2. We again assume that background nonpoint source loads will not change with time, therefore the total cultural loads to Lake St. Croix will be reduced by 100 T/yr from 294 T/yr in the 1990s to 194 T/yr by 2020;
3. This is equivalent to a 34% reduction in total cultural TP loads to Lake St. Croix;
4. Assuming the 34% rate of reduction applies to the full range of conditions, then the dry-average-wet range of total cultural TP loads to Lake St. Croix will be 127-194-341 T/yr.
5. Assuming that both cultural load components will be reduced equally by 34% since the 1990s, then cultural point source TP loads to Lake St. Croix would be 33-33-33 and cultural nonpoint source loads to Lake St. Croix would be 94-161-308 T/yr;
6. By addition, the dry-average-wet range of total nonpoint source TP loads to Lake St. Croix would be 206-327-559 T/yr;
7. Assuming that uplands loads have been reduced by 12.2%, then cultural nonpoint source loads would range 108-183-350 and total nonpoint source loads would range 235-372-637 T/yr in the uplands;
8. Total TP loads to Lake St. Croix would range 239-360-592 T/yr for dry-average-wet conditions.

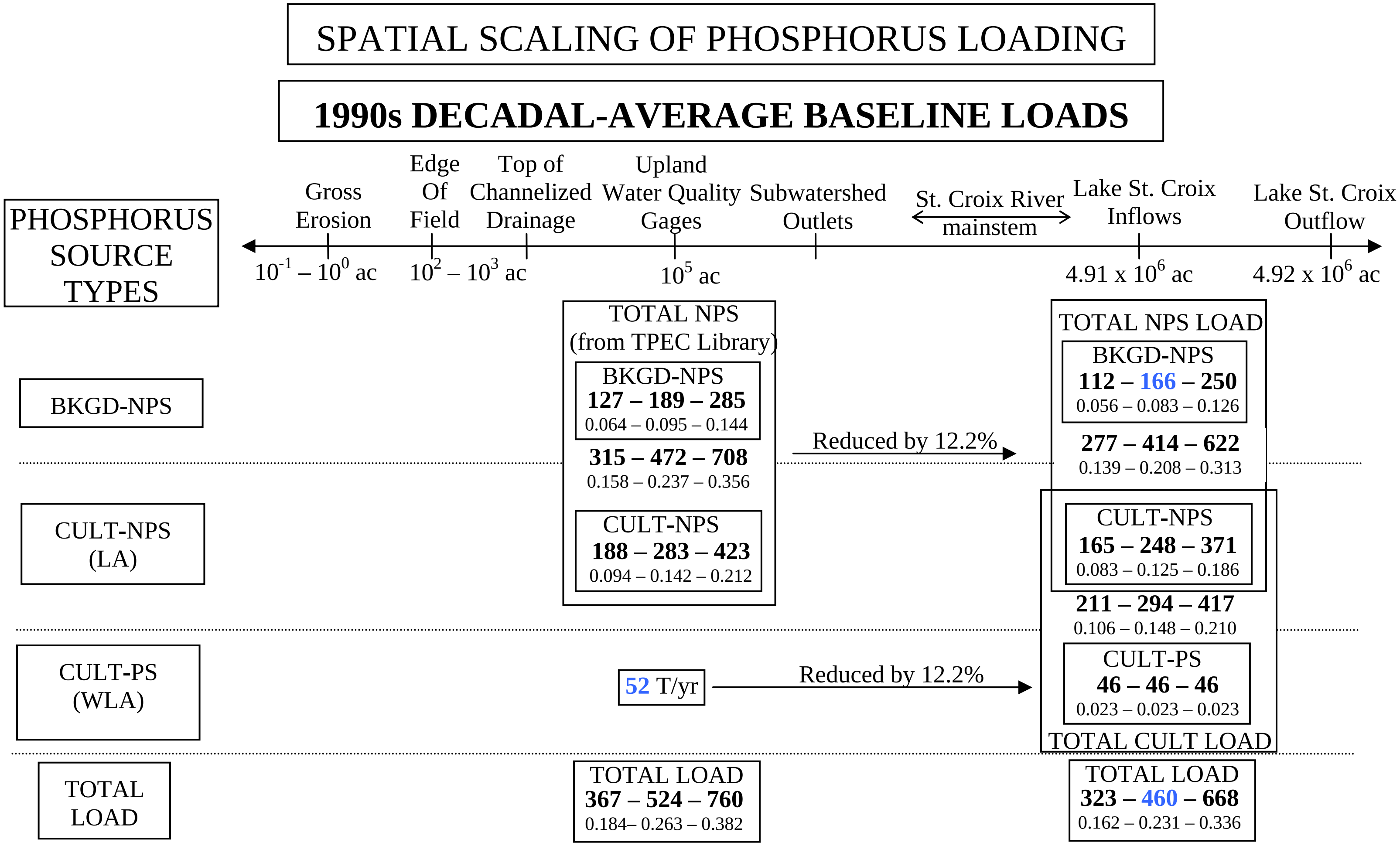

Figure 14. Spatial scaling of baseline phosphorus loads within the St. Croix Basin averaged over the 1990s, indicating the range of loads (T/yr, in large bold font) and equivalent export coefficients (kg/ha/yr, in smaller font), under dry-average-wet conditions. The numbers in blue font are the variables known from other references (see section 3.2.1).

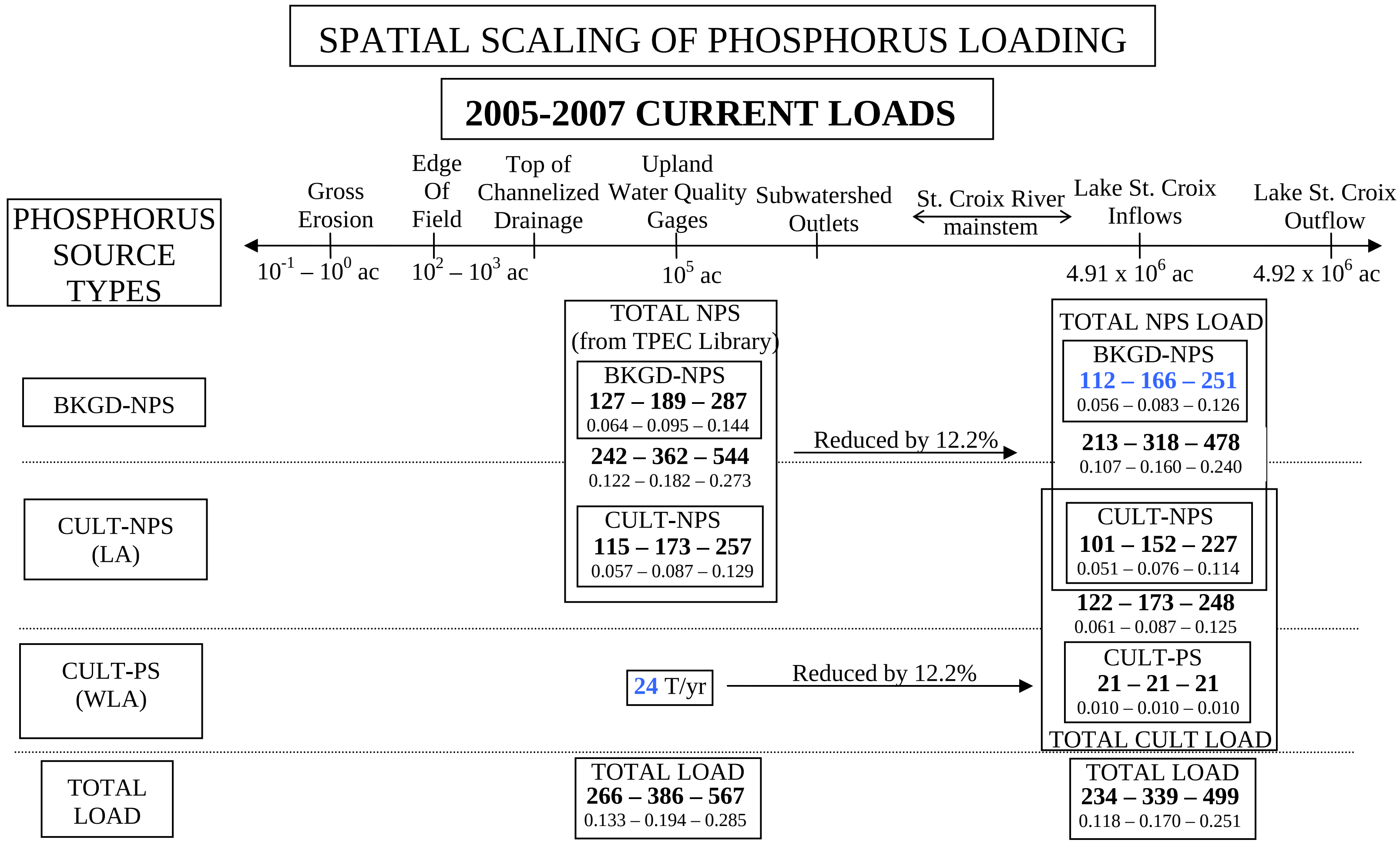

Figure 15. Spatial scaling of current phosphorus loads within the St. Croix Basin averaged over 2005-2007, indicating the range of loads (T/yr, in large bold font) and equivalent export coefficients (kg/ha/yr, in smaller font), under dry-average-wet conditions. The numbers in blue font are the variables known from other references (see section 3.2.2).

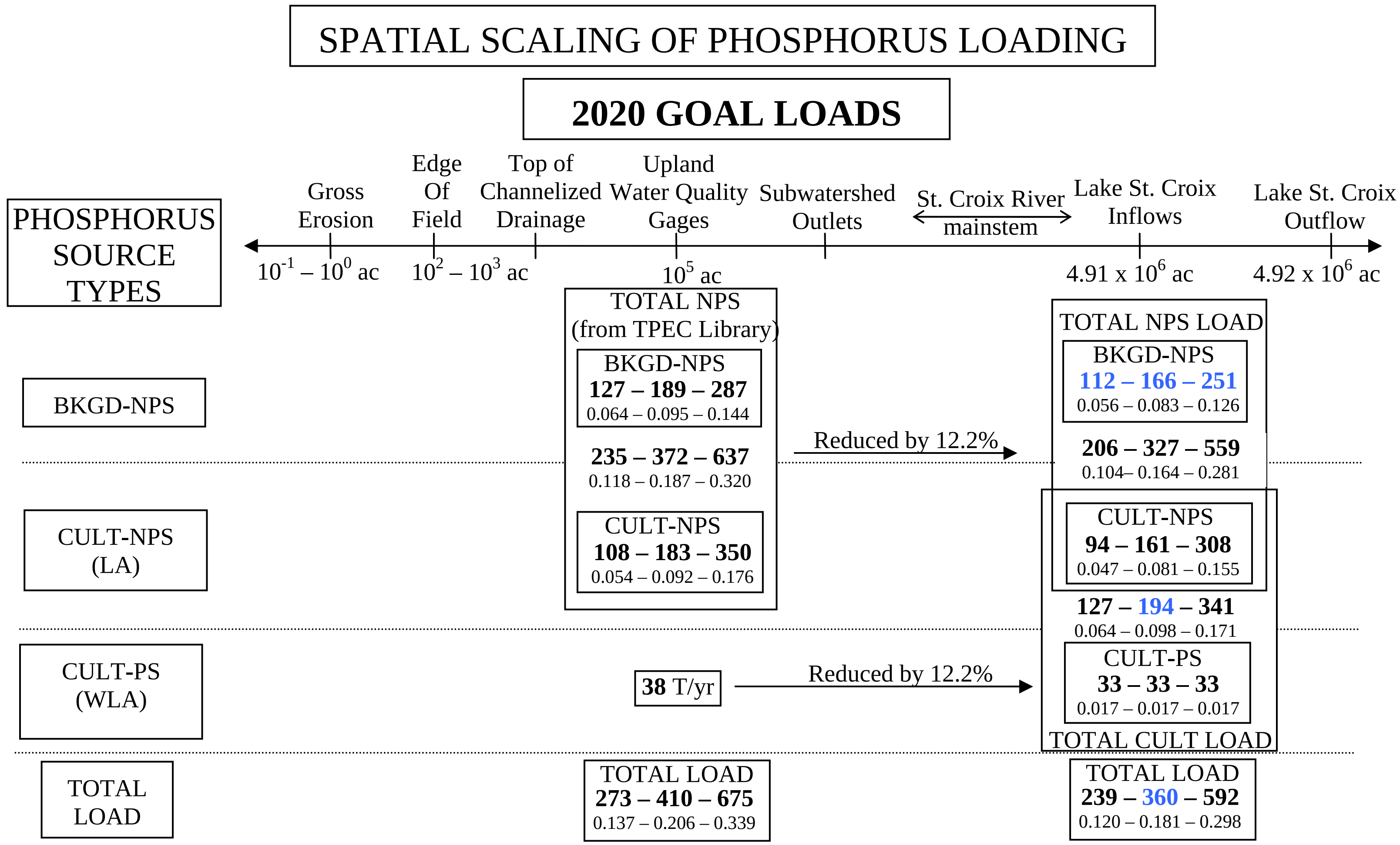

Figure 16. Spatial scaling of phosphorus loads within the St. Croix Basin for the goal of 20% reduction in St. Croix inflow loads by 2020, indicating the range of loads (T/yr, in large bold font) and equivalent export coefficients (kg/ha/yr, in smaller font), under dry-average-wet conditions. The numbers in blue font are the variables known from other references (see section 3.2.3).

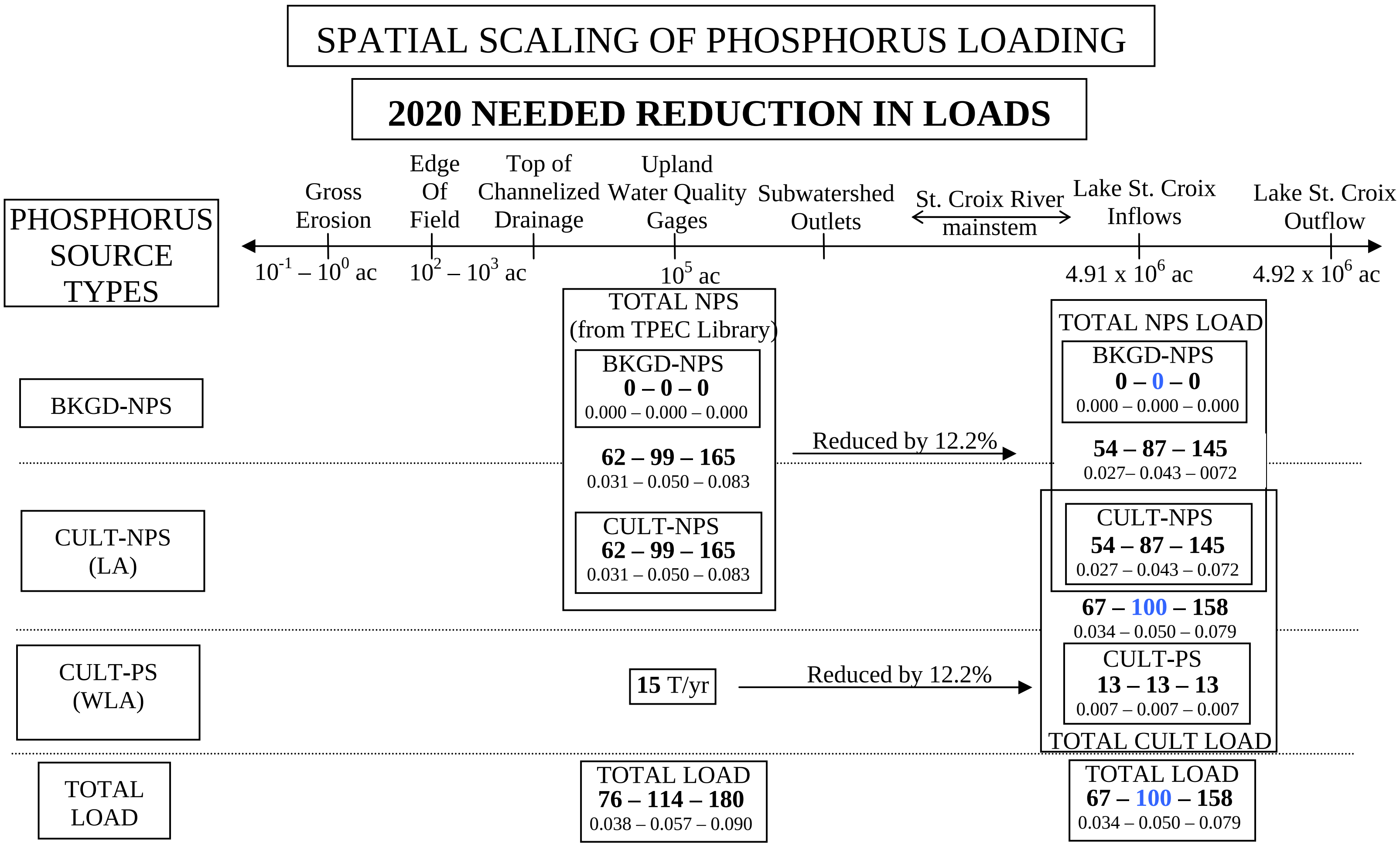

Figure 17. Spatial scaling of needed reduction in phosphorus loads within the St. Croix Basin for the goal of 20% reduction in St. Croix inflow loads by 2020, indicating the range of loads (T/yr, in large bold font) and equivalent export coefficients (kg/ha/yr, in smaller font), under dry-average-wet conditions. The numbers in blue font are the variables known from other references (see section 3.2.3).

4.0 SUBWATERSHED ANALYSIS OF PHOSPHORUS SOURCE LOADS

As explained in the Introduction, this project is being approached from nested spatial scales, both in basin-wide analysis and separate watershed studies. St. Croix Basin-wide data were already available for the 1992 NLCD (NPS 2004), but we needed to understand how land uses were distributed between the subwatersheds of the basin. A web-enabled watershed analysis tool offered by Purdue University (http://cobweb.ecn.purdue.edu/~watergen/owls/htmls/reg5.htm) uses the 1992 NLCD data to identify the land use data for the area upstream of any point selected in a mapping software (Choi and Engel 2003). Using this tool on subwatershed outlet locations and USGS flow gage locations across the St. Croix Basin, we were able to retrieve the number of acres in each of eight land use categories: four urban categories that were combined into one urban category, and four other categories (open water, forestland, grass/hayland, and cropland). WDNR staff noticed an error in the Purdue data: "Industrial lands on Soiltype A" should have been coded as "Shrubland". Therefore, the shrubland category was separated out for loading analysis. Table 7 summarizes the proportions of these six landcover categories within each of the major subwatersheds of the St. Croix Basin. The land cover areas of the miscellaneous small streams were determined by difference from basin-wide land coverages. The upper portion of the basin is dominated by forests, while the largest proportions of urban and agricultural lands occupy the southern portion of the basin.

Table 7. Landcover distribution of the major subwatersheds of the St. Croix Basin (1992 NLCD), listed from north to south.

Subwatershed	% Water	% Forest	% Shrub	% Grass	% Agri	% Urban
Namekagon River	6.8	79.8	0.4	5.5	6.8	0.5
Upper St. Croix River	5.5	85.4	6.0	1.6	1.2	0.4
Upper Tamarack River	5.5	90.3	0.004	1.8	2.3	0.1
Yellow River	9.4	63.2	0.4	11.4	14.5	0.9
Lower Tamarack River	4.7	89.8	0.02	1.1	4.1	0.2
Crooked Creek	4.2	78.3	0.04	5.9	11.2	0.4
Clam River	5.5	59.3	0.4	17.2	17.2	0.4
Sand River	10.2	71.4	0.2	10.8	6.9	0.5
Bear Creek	12.1	64.5	0.1	19.1	3.8	0.5
Kettle River	9.9	68.4	0.2	17.2	3.4	0.9
Snake River	15.2	54.7	0.1	21.5	7.7	0.9
Wood River	8.4	42.2	0.7	21.3	26.7	0.6
Rock Creek	8.5	15.9	0	48.8	25.9	1.0
Rush Creek	18.4	27.2	0.1	32.7	19.5	2.1
Goose Creek	14.4	38.3	0.2	25.8	20.7	0.5
Sunrise River	19.3	26.2	0.0	27.7	24.9	1.9
Trade River	7.5	45.7	3.7	19.7	23.0	0.5
Wolf Creek	2.5	26.1	0.01	32.1	39.2	1.0
Apple River	4.7	31.3	0	25.4	38.2	0.4
Silver Creek	6.8	12.8	0	49.4	30.8	0.2
Browns Creek	6.3	15.7	0	48.2	25.1	4.7
Willow River	1.3	12.3	0	29.2	56.6	0.6
Valley Creek	3.7	13.1	0	47.0	33.9	2.3
Kinnickinnic River	0.3	9.9	0	26.6	62.0	1.2
Misc. small streams	9.1	54.0	0	14.9	16.1	5.9

The land use areas within each subwatershed were multiplied by the TPEC values listed in Table 5 to estimate the total nonpoint source (TOT-NPS) loads from the uplands of each subwatershed. The upland background nonpoint source TPEC range (0.064 – 0.095 – 0.144 kg/ha/yr) calculated in the basin-wide analysis were applied to the each subwatershed area to calculate the background nonpoint source (BKGD-NPS) TP loads for each subwatershed. The cultural nonpoint source (CULT-NPS) TP loads were determined by difference. The point source records compiled for the basin-wide analysis were used to assign cultural point source (CULT-PS) loads to the subwatersheds. The corresponding loads for the small miscellaneous streams were calculated by difference from the basin-wide loads. The resulting partitioning of 1990s phosphorus source loads in subwatershed uplands is listed in Table 8 and shown in Figure 18. In addition, Figure 19 shows how the total-basin upland phosphorus load is distributed across the subwatersheds of the St. Croix River Basin, and Figure 20 shows the subwatershed-averaged TPEC values superimposed on the 1992 land cover map.

Table 8. Partitioning of 1990s upland source loads between phosphorus source types for an average flow year, as distributed across the major subwatersheds, and the resulting subwatershed-averaged total phosphorus export coefficients. Subwatersheds are color-coded to Figure 5.

Major Subwatershed	TOT-NPS (T/yr)	BKGD-NPS (T/yr)	CULT-NPS (T/yr)	CULT-PS (T/yr)	TOT-CULT (T/yr)	TOTAL LOAD (T/yr)	SWS-Avg TPEC (kg/ha/yr)
Namekagon River	24.4	15.2	9.2	0.0	9.2	24.4	0.153
Upper St. Croix River	14.6	12.6	2.0	0.0	2.0	14.7	0.109
Upper Tamarack River	3.0	2.5	0.5	0.0	0.5	3.0	0.116
Yellow River	20.7	9.2	11.5	0.1	11.6	20.8	0.214
Lower Tamarack River	6.4	4.8	1.6	0.0	1.6	6.4	0.127
Crooked Creek	4.6	2.4	2.2	0.0	2.2	4.6	0.182
Clam River	23.5	9.4	14.1	0.8	14.9	24.4	0.246
Sand River	4.6	2.7	1.8	0.0	1.8	4.6	0.159
Bear Creek	2.5	1.5	0.9	0.2	1.1	2.6	0.161
Kettle River	40.1	25.6	14.5	5.5	20.0	45.6	0.169
Snake River	46.9	24.7	22.2	4.8	27.1	51.8	0.199
Wood River	13.6	4.2	9.4	1.4	10.8	15.0	0.336
Rock Creek	4.9	1.4	3.5	0.0	3.5	4.9	0.344
Rush Creek	4.3	1.5	2.9	0.7	3.6	5.0	0.325
Goose Creek	4.7	1.6	3.0	0.1	3.1	4.7	0.274
Sunrise River	29.6	9.2	20.4	9.1	29.5	38.7	0.401
Trade River	11.0	3.8	7.3	0.5	7.8	11.5	0.291
Wolf Creek	7.3	2.5	4.8	0.0	4.4	7.4	0.198
Apple River	55.9	13.7	42.2	2.0	44.2	57.9	0.400
Silver Creek	0.8	0.2	0.6	0.0	0.6	0.8	0.373
Browns Creek	2.8	0.7	2.1	0.0	2.1	2.8	0.363
Willow River	39.4	7.3	32.1	4.4	36.5	43.8	0.572
Valley Creek	4.6	1.1	3.6	0.0	3.6	4.6	0.404
Kinnickinnic River	24.7	4.3	20.5	6.6	27.1	31.3	0.697
Misc. small streams	78.6	28.0	50.0	15.6	65.7	94.2	0.308
BASIN TOTALS	**472**	**189**	**283**	**52**	**335**	**524**	**0.263**

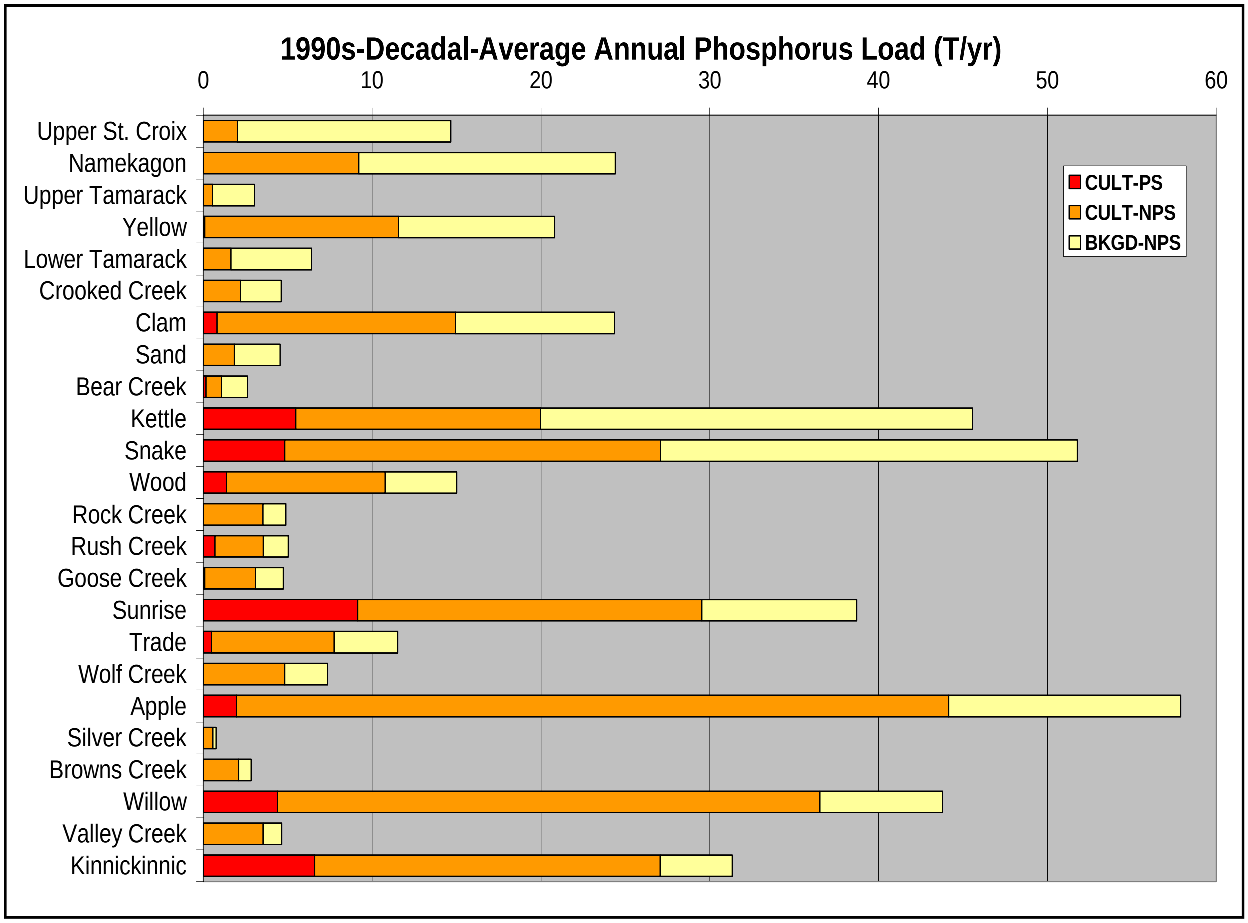

Figure 18. 1990s-decadal-average cultural point source loads (CULT-PS), cultural nonpoint source loads (CULT-NPS), and natural background nonpoint source loads (BKGD-NPS) estimated in tons TP/yr, in the uplands of subwatersheds of the St. Croix River Basin for an average flow year. Note that the controllable cultural load within each subwatershed is marked by the red and/or orange portions of each bar. The yellow portion of each bar is the natural background load, which is not controllable or effected by any management practices.

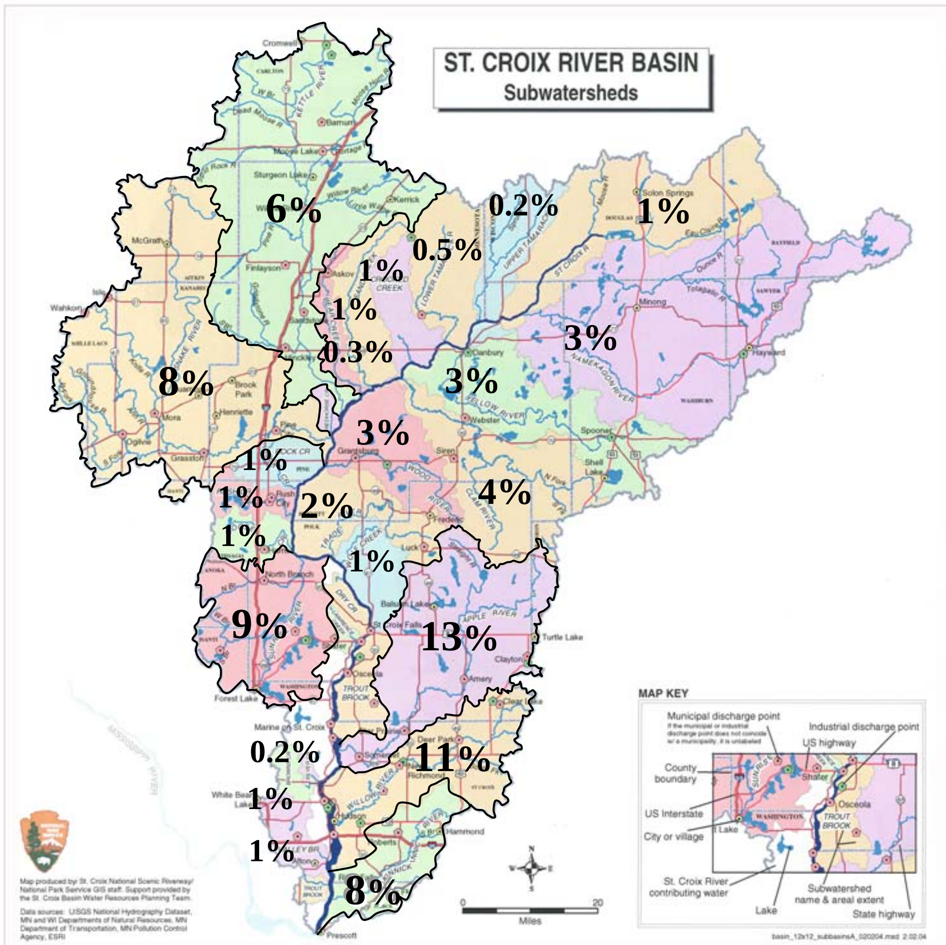

Figure 19. Percent of the total upland cultural load for an average flow year in the 1990s, as distributed across the major subwatersheds of the St. Croix Basin.

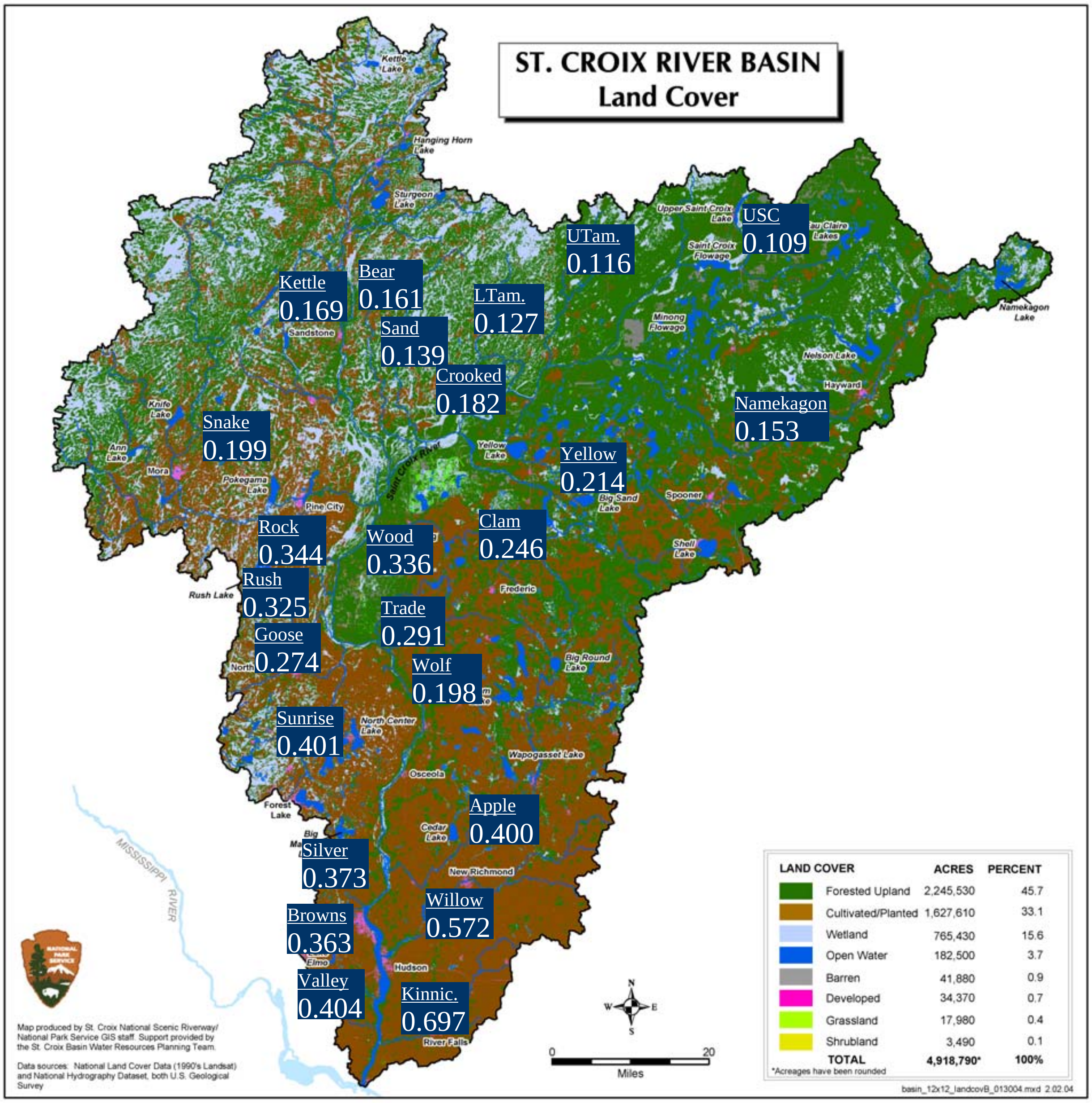

Figure 20. Subwatershed-averaged total phosphorus export coefficients (kg/ha/yr) of 1990s upland source loads.

5.0 PHOSPHORUS ROUTING: COMPARISON BETWEEN SOURCE LOADS AND GAGED WATER QUALITY LOADS

A comprehensive analysis of the distribution and routing of phosphorus loads across the St. Croix Basin should include a thorough assessment of monitored water quality loads. At this time, only one monitoring study has measured annual loads from all major subwatersheds of the St. Croix Basin in the same year, 1999 (Lenz et al. 2003). In Table 9, the 1999 water quality gaged TP loads are compared with the 1990's dry-average-wet range of total upland TP source loads calculated during the this study. The unusual 1999 rainfall pattern (above-average in the northern part of the basin and below-average in the southern part of the basin) would have influenced runoff patterns for that year. Several of the gaged TP loads in the upper portion of the basin fall within range of upland source TP loads, but one (the Upper Tamarack) exceeds the range and the gaged TP loads in the lower half of the basin fall short of the range. Also, the range of subtotals of upland source TP loads (257-368-534 T) for gaged locations exceeds the subtotal of gaged TP loads (198 T); the TPEC method of calculating upland TP loads may overestimate the TP loads measured at water quality gages. Perhaps TPEC loads need to be assigned within channelized drainage even higher on the landscape than gaged locations, leaving room for small amounts of storage to occur before TP loads reach gaged locations. The development of a basin-wide SWAT model should more precisely characterize the linkages between sources and tributary outlets and better estimate phosphorus yields across the St. Croix Basin landscape.

Table 9. Comparison of 1990's total upland source loads estimated for gaged locations with the 1999 gaged water quality phosphorus loads.

Subwatershed	Gaged Area (sq.km)	1990's Upland Source Loads (T)			1999 Gaged Loads (T)
		Dry	Average	Wet	
Upper Tamarack River	257	1.9	2.9	4.3	5.49
Yellow River	816	12.7	19.0	28.5	12.6
Lower Tamarack River	470	4.0	6.0	9.0	8.1
Crooked Creek	239	2.8	4.2	6.4	4.14
Clam River	934	15.9	23.4	34.7	7.74
Sand River	281	3.0	4.5	6.7	4.49
Kettle River	2234	27.4	38.3	54.6	43.4
Snake River	2500	34.7	49.6	71.9	37.4
Wood River	209	6.1	8.5	12.1	3.53
Sunrise River	958	28.7	38.4	53.1	17.5
Trade River	345	7.4	10.8	16.0	3.7
Apple River	1406	37.9	55.8	82.7	25.8
Silver Creek *	20	0.5	0.8	1.1	0.31
Browns Creek *	78	1.9	2.8	4.2	2.95
Willow River	755	30.5	43.5	63.1	10.3
Valley Creek *	115	3.1	4.6	7.0	0.75
Kinnickinnic River	427	22.3	30.1	41.9	9.52
subtotal of loads		257	368	534	198

* upland source loads for tributary outlet

Figure 21 shows the 1999 gaged loads and area-averaged TPECs for both tributary and mainstem gage locations. Note that the unusual 1999 rainfall pattern produced area-averaged TPECs in the northern subwatersheds that were equal to or greater than those from upland source loads in Figure 20, while the southern subwatersheds had runoff TPECs much lower than the upland source load TPECs. Also note that phosphorus loads and loading rates (TPECs) increase in the downstream direction at the water quality checkpoints of the St. Croix River mainstem.

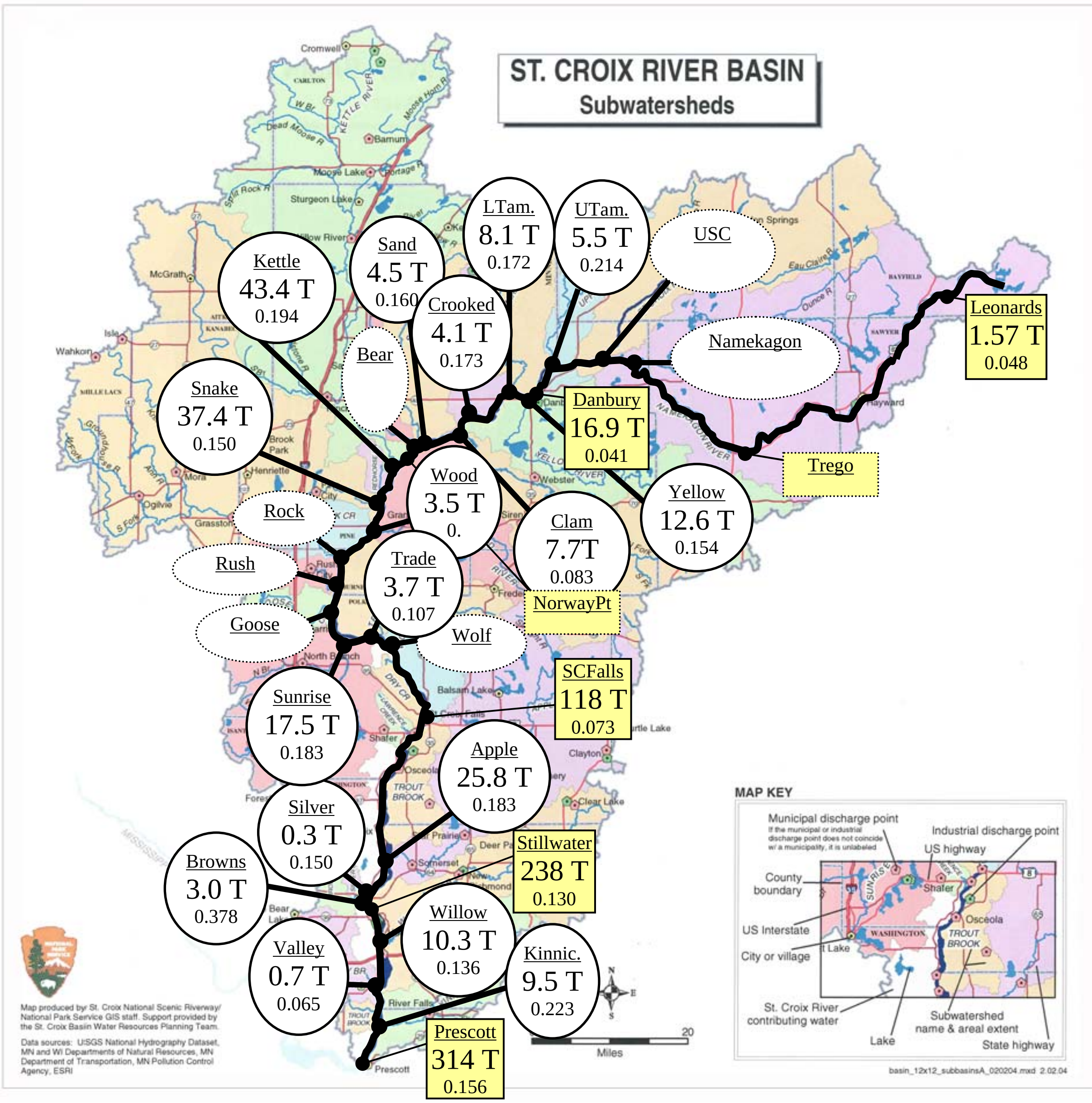

Figure 21. 1999 total phosphorus loads (T/yr) and area-averaged total phosphorus export coefficients (kg/ha) at subwatershed gages (white ovals) and at mainstem water quality checkpoints (yellow boxes).

At greater detail, the 1999 and 2006 BKGD-NPS, CULT-NPS, and CULT-PS loads for the Willow River subwatershed have been estimated by a SWAT model of that subwatershed (Almendinger and Murphy 2007). These results are compared with the dry-average-wet range of upland loads estimated by this study (Table 10). The BKGD-NPS TP load determined by SWAT was within the range estimated by TPECs, but the TPECs from Table 5 overestimated the CULT-NPS portion of TOT-NPS. It is possible that the overestimates of total upland loads in Table 9 are also due to overestimates in the CULT-NPS portion of the load. According to Almendinger (2008), almost 30% of field runoff in the Willow River subwatershed gets trapped in closed depressions (ponds and wetlands), and another 20% gets trapped in reservoirs within channelized flow. The TPEC method of estimating the upland TOT-NPS TP load does not account for these types of reductions.

Table 10. Comparison of 1990's-decadal-average and 2005-2007 current-average phosphorus load estimates at the Willow River gaged location with the SWAT analysis of water quality loads in water years 1999 and 2006.

Model Year	Load Types	Upland Source Loads (T)			SWAT Loads (T)
		Dry	Average	Wet	
1999	1992 BKGD-NPS	4.8	7.2	10.9	6.3
	1992 CULT-NPS	21.2	31.9	47.8	13.6
	1990s CULT-PS	4.4	4.4	4.4	4.4
	1990s TOTAL LOADS	30.5	43.5	63.1	24.3
2006	2007 BKGD-NPS	5.5	8.2	12.4	6.3
	2007 CULT-NPS	16.4	24.5	36.8	13.4
	2005-07 CULT-PS	0.9	0.9	0.9	0.9
	2005-07 TOTAL LOADS	22.8	33.7	50.1	20.5

For the 1990s, the basin-wide analysis estimated 524 T/yr from the uplands was reduced by an average 12.2% to 460 T/yr at Lake St. Croix inflows. In contrast, subwatershed analyses for water year 1999 estimated a 54% reduction from an average 368 T in the uplands to 198 T at water quality gages located in the lower portion of tributary areas. Note that the 460 T estimate of 1990s loading to Lake St. Croix (Triplett et al. 2009) includes the bedload moved into the lake, since it was calculated as the sum of long-term in-lake sedimentation rates and outflow loads inferred from diatom assemblages. A possible explanation of these differences in phosphorus delivery rates is that part of the phosphorus loads in the uplands are deposited as sediments on the stream bed, and then transported downstream as bedload, which is not measured by sampling total phosphorus suspended in the water column. Subsequently, the phosphorus bedload not consumed by biochemical processes in the shallow fast-flowing streams perhaps may have more time to be consumed within the mainstem of the St. Croix River, thereby increasing the delivery ratio in dissolved or suspended phosphorus loading to Lake St. Croix.

6.0 NEXT STEPS TOWARD A LAKE ST. CROIX PHOSPHORUS TMDL

6.1 Assessing Progress Toward the Goal

Lake St. Croix was added to the 303(d) impaired waters list based on 1998-2006 mean summer measurements of total phosphorus and total chlorophyll-a, which exceeded the NCHF ecoregion listing criteria of 45 µg/L and 18 µg/L, respectively, detailed by Wasley (2007) and included in the appendix of the loading study report. Figure 22 shows 1976-2008 MCES TP data for Stillwater, MN and Prescott, WI, including annual summer mean and 10-year mean concentrations, compared to the listing criteria (45 µg/L) and the 20% reduction goal concentration (40 µg/L). Lafrancois et al. (2009) confirmed by seasonal Kendall analysis that total phosphorus concentrations in Lake St. Croix have begun to decline by an average of 0.2 µg/L per year during the 1976-2004 period.

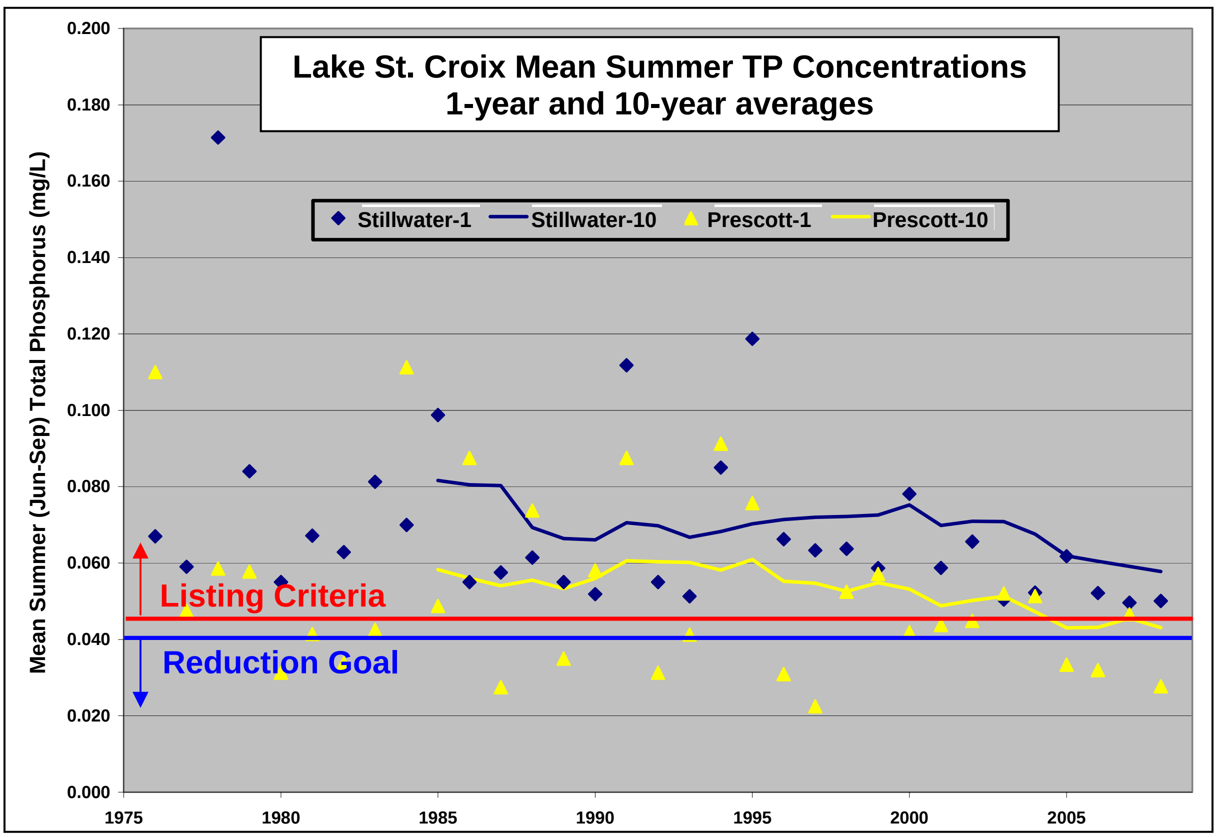

Figure 22. Annual mean summer (June-September) and 10-year summer mean concentrations of total phosphorus within Lake St. Croix at Stillwater, MN and Prescott, WI, compared to the impaired water listing criteria and the 20-percent reduction goal.

An unresolved question for the upcoming TMDL process is: How will we know that we've achieved the water quality improvement goal? The reduction goal (Table 1) is defined by several variables (algae, nutrients, clarity) and criteria. What will be the specific criteria for success? Will there be a single criterion or multiple criteria that need to be met? The goal was developed partially from decadal-average TP loads measured in lake cores. The 1990s-average TP influx to Lake St. Croix estimated from lake cores does not balance with the 1990s-average water quality load at Stillwater. Will the criteria for success be based on annual water quality monitoring, or decadal lake coring? Additional questions, with respect to missing or unknown information, are addressed in section 6.2.

6.2 Gearing-up for the Allocation Process

Figure 23 compares the three main components of TP loads to Lake St. Croix for the 1990s-decadal-average, the 2005-2007-average, and the 2020 reduction goal, including the potential range of loading under dry-, average-, and wet-year climate conditions. Although the range of loading in 2005-2007 appears to be lower than that in the 1990s, it is not as clear from this figure

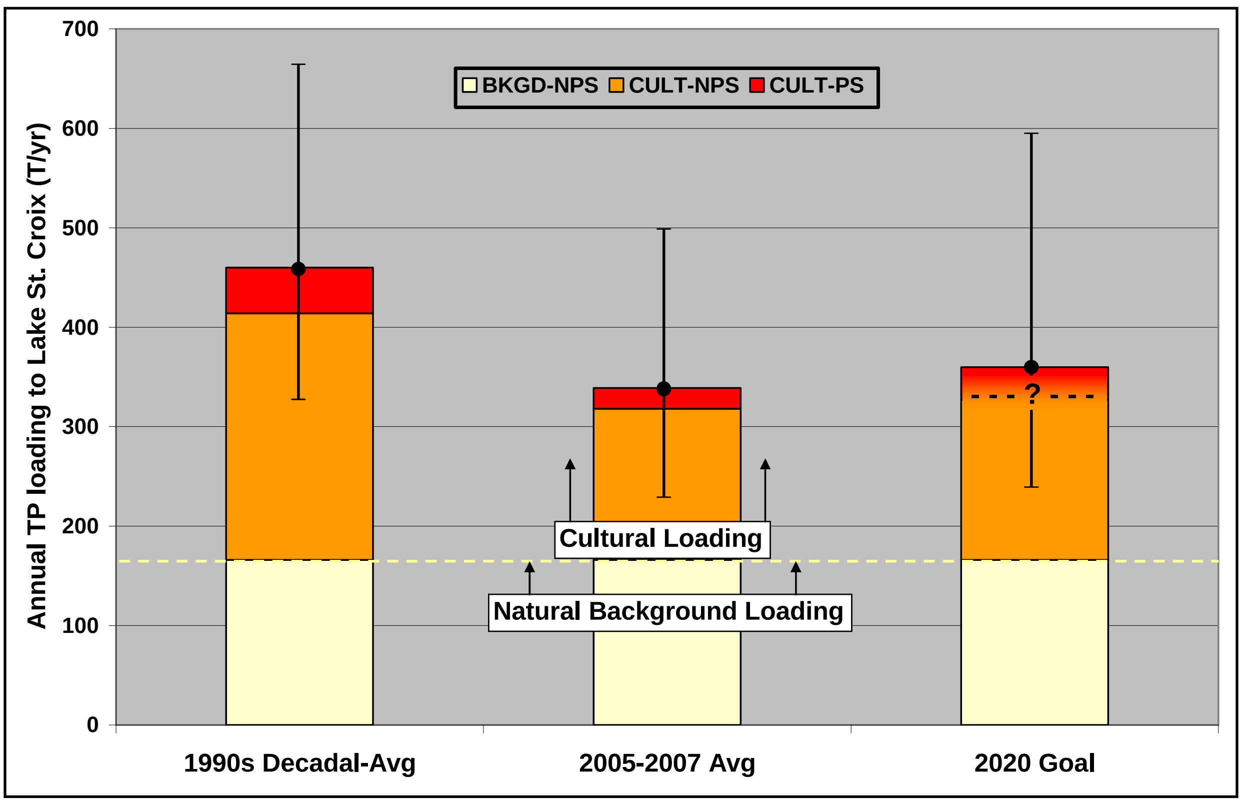

Figure 23. Background nonpoint source (BKGD-NPS), cultural nonpoint source (CULT-NPS), and cultural point source (CULT-PS) total phosphorus loads to Lake St. Croix during the decade of the 1990s, the current period, and after achieving the 20% reduction goal. Error bars represent the range of possible loading for 10^{th}-percentile, 50^{th}-percentile, and 90^{th}-percentile rainfall conditions. The fuzzy boundary between CULT-PS and CULT-NPS for the 2020 goal indicates the coming need to allocate the cultural load.

that definite improvements have occurred, given the wide ranges. It should be noted that the component with the widest range for uncertainty is the cultural nonpoint source (CULT-NPS) loading, since point source (CULT-PS) loads are easier to quantify from regulatory data and background nonpoint source (BKGD-NPS) loading is assumed to have not varied since the 1850s. The lack of a hard line dividing the two cultural loads in the 2020 Goal bar is indicative of the need to choose load allocations (LA) and waste load allocations (WLA) during the TMDL process.

6.2.1. Fair Allocation

In the current loading analysis, there is no adjustment for wastewater dischargers that intake upstream riverwater containing some phosphorus. For these facilities, calculating the phosphorus loads in their discharges does not accurately assess the amount of phosphorus that the facility adds to the system. This is especially relevant for facilities that cycle large quantities of river water through their facility for cooling purposes. The Wisconsin fisheries may contribute small amounts of phosphorus, but Xcel Energy's King Plant load numbers need to be adjusted by the reporting of the phosphorus load added at the plant.

The highest TP loading rates are in the lower subwatersheds of the St. Croix Basin. These subwatersheds have greater proportions of urban and agricultural land uses. In addition, these subwatersheds are those located closest to Lake St. Croix, and their source loads undergo the least degree of attenuation by natural processes. Therefore, it is probable that a relatively larger portion of the Lake St. Croix loading reductions will come from its nearest subwatersheds.

One step of the TMDL allocation process is reserving a portion for future growth, and the Lake St. Croix TMDL may need to account for the different approaches of the two states to population growth. For example, the smallest communities in Wisconsin receive a WDNR permit to discharge treated wastewater to groundwater. In the current loading study, TP loading to groundwater resources is ignored; only the direct loading to surface waters is under consideration. If these communities grow too much, they may be required to discharge to surface waters, thereby creating new sources of loads to Wisconsin streams, rivers, and to Lake St. Croix.

6.2.2. Missing Information

Not all sources of phosphorus to Lake St. Croix have been accounted for in this loading study. Table 11 includes all of the potential phosphorus sources within the St. Croix River Basin from Table 3, but highlights those sources of phosphorus that have been included in this analysis. Those sources listed in white rows need to be assessed for magnitude of influence and perhaps quantified in further analyses.

Heiskary and Wilson (1994) list potential causes for mass imbalances during loading analysis. The following are highlighted below:

- As mentioned above, TP loading to groundwater, and the subsequent effect of groundwater discharges to surface water was not assessed in this loading study. There is a need to evaluate, with monitoring and/or modeling, how much phosphorus is reaching Lake St. Croix via subsurface discharge of groundwater, especially considering that part of the bedrock geology setting for Lake St. Croix is karstic limestone. [see MPCA (2004) App I p. 39]

- Animal inputs from feedlot runoff and excessive pasturing are not measured by the current regulatory and environmental monitoring practices.
- Climate variability strongly influences runoff and loading. The current loading study attempted to account for this variability by incorporating dry-average-wet ranges into the TPEC method of estimating nonpoint source loading. However, the errors in TPEC estimation and land use areal estimations are compounded or amplified by this method, producing wide ranges of uncertainty (see Figure 23). The uncertainty inherent in the TPEC method points to the need for expand monitoring locations, and especially monitoring frequencies, to get better measurements of the true range of stream and river loading to Lake St. Croix, rather than attempting to estimate the percent reduction that may occur between the sources and the lake. That way, nonpoint source loads could be directly calculated from the measured total loads, less point sources and background.
- Another relevant question is the ratio between dissolved and particulate (suspended load and bedload) forms of phosphorus, in phosphorus routing to the lake, cycling within the lake, and residence time. The upcoming basin-wide SWAT model will not answer all of these questions, but it should help us gain better understanding of phosphorus in the St. Croix Basin.
- To solve the mass balance elements of phosphorus routing through the St. Croix Basin, it may be necessary to investigate the temporal scale of phosphorus storage within the St. Croix drainage system. If, during past decades, significant quantities of phosphorus were stored in streambeds, river channels, and reservoirs, then it may require decades into the future to achieve, not just the reductions in TP source loads, but the reductions in TP loads to Lake St. Croix.

Table 11. List of phosphorus sources in the St. Croix River Basin.

Source Type	Source description
BKGD-NPS	Natural erosion processes
CULT-NPS	Streambank erosion accelerated by human activities
	Small concentrated animal feeding operations (CAFOs)
	Pasture runoff
	Row crop runoff
	Stormwater runoff from non-MS4 communities
	Field infiltration and groundwater discharge
	Individual sewage treatment systems (ISTSs)
	Wind erosion and atmospheric transport
CULT-PS	Large concentrated animal feeding operations (CAFOs)
	Wastewater treatment facilities (WWTFs)
	Industrial discharges
	Construction runoff
	Stormwater runoff from MS4 communities
	Separated or combined sewer outfalls (SSO/CSO)

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APPENDIX

DEPARTMENT: POLLUTION CONTROL AGENCY

SF-00006-05(4/86)
STATE OF MINNESOTA
Office Memorandum

DATE: 08/02/07

TO: Steve Heiskary
Lakes and Streams Unit
Environmental Analysis and Outcomes Division

FROM: Dennis Wasley
Effluent Limits Unit
Environmental Analysis and Outcomes Division

PHONE: 651/296-8860

SUBJECT: Comments on the status of a nutrient impairment in Lake St. Croix

Existing Summary (from 2008 TMDL Nutrient-Impaired Lake List: Status and Review Notes)

82-0001 (St. Croix) – A large reservoir on MN-WI border near the mouth of the St. Croix River. The St. Croix drains principally two ecoregions: the NLF in the northern portion and the NCHF in the central and lower portion of the river. For assessment purposes we have used NCHF thresholds as a basis for assessing the lake. The lake's TSI values fall within the partial support range and as such we have reviewed available data more closely. For the period 1997-2006 there were four summers with four or more values for TP, chlorophyll-a and Secchi. Based on these four years trophic status is variable with TP ranging from 40-51 µg/L in individual summers. Likewise chlorophyll-a varies from 10.8 – 21.9 µg/L. No trend is evident for any of the trophic state variables. Based on the above we propose not to list the lake in this cycle; however we recommend that further monitoring be conducted to provide updated information for the 2010 assessment. Should TSI variables increase it is quite likely the lake could be listed in 2010 – given that it almost over the current listing thresholds and is above the draft criteria values (Appendix).

Updated Assessment

The St. Croix Basin Water Resources Planning Team has determined that a large number of data points were not included in the data analysis portion of the draft 303(d) listing process for 2008. Monitoring data collected by various agencies on Lake St. Croix was included in the existing assessment except with one major exception. A large portion of the data collected by Metropolitan Council Environmental Services (MCES) personnel and volunteers were not in MPCA's Enironmental Data Access (EDA) when the data was retrieved for the 2008 assessment. Only one summer (2005) of monitoring data sampled by MCES volunteers was included in the existing data assessment. The 2005 data dominates the existing assessment due to the high frequency of sampling visits and large number of sites on the lake. The data from 2005 represents 50 of the 69 daily averages of chlorophyll-a that were used in the existing assessment.

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The data from 2005 represents 25 of the 44 total phosphorus averages. As you can see, the existing data assessment is highly biased by the summer of 2005.

Two routine stations on Lake St. Croix have been monitored by MCES personnel during every summer from 1998 through 2006. The routine sites monitored by MCES may have been considered river sites and were not included in the existing assessment. Residence time for Lake St. Croix is 50 days during a dry year and 20 days during a wet year. All monitoring stations within the designated boundaries of Lake St. Croix should be considered lake sites. The MCES routine sites are monitored from two separate bridge crossings at the upper and lowers portions of the lake. Secchi disc depth is not monitored at these stations. Sampling frequency for these sites ranges from weekly to biweekly with occasional monthly sampling. These sites dramatically increase the temporal distribution of the assessment data.

The MCES volunteer monitoring program on Lake St. Croix could provide up to six additional years of data. The spatial coverage of Lake St. Croix is greatly enhanced by this data since there are seven volunteer monitoring stations on the lake. At this point, I have only included the 2005 data from the volunteer monitoring program in the updated results since it was included in the original assessment review. There were some high phosphorus measurements (> 100 µg/L) in some of the early years of the volunteer monitoring program. Probable errors in sampling technique have been corrected in the past few years. If we remove suspected outliers for total phosphorus (all measurements > 100 µg/L) from the entire volunteer dataset, the means of the volunteer dataset are basically the same as the mean from the updated dataset collected by staff from several agencies (Table 1).

Table 1. Existing and updated summer mean total phosphorus, chlorophyll and secchi disc depth measurements for Lake St. Croix. Summer sampling dates range from 1998 to 2006.

Description of Assessment	TP ppb	n TP	Chl ppb	n Chl	Secchi m	n Secchi
Existing	45	44	16.7	69	1.2	76
Updated	**51**	295	**20.5**	318	**1.2**	76
Volunteer Only	50	245	22	282	1.4	276

*Updated dataset includes existing data and MCES routine sampling data

Based on the additional data included in the updated 303(d) assessment for Lake St. Croix, we should add Lake St. Croix as a nutrient impaired lake to the proposed 2008 303(d) list of impaired waters. Listing criteria for the North Central Hardwoods Forest Ecoregion are listed in Table 2. Mean total phosphorus and chlorophyll of the updated dataset exceed the listing threshold. The mean of secchi disc depth does not exceed the listing threshold. While reviewing the lake data, I was quite surprised to find that mean summer chlorophyll for the farthest upstream site in Lake St. Croix (i.e. MCES SC23.3) had an average summer chlorophyll of 29 µg/L. Means for individual summers at this site range from 18 to 40 µg/L. Summer mean chlorophyll from the volunteer stations did not drop below 20 µg/L until the Black Bass Pool portion of Lake St. Croix near Afton. Lake St. Croix is consistently producing larger blooms of algae than originally perceived. Perceptions of the lake's algal abundance could be skewed due to the dark color of the lake which can mask some of the algal color in the water.

Table 2. Trophic Status Thresholds for Determination of Use Support for Lakes. (Carlson's TSI Noted for Each Threshold.). Taken from guidance manual.

Ecoregion (TSI)	TP ppb	Chl ppb	Secchi m	TP Range ppb	TP ppb	Chl ppb	Secchi m
305(b):	Full Support			Partial Support to Potential Non-Support			
303(d):	Not Listed			Review	Listed		
NLF	< 30	<10	≥ 1.6	30 – 35	> 35	> 12	< 1.4
(TSI)	(< 53)	(< 53)	(< 53)	(53 - 56)	(> 56)	(> 55)	(> 55)
NCHF	**< 40**	**< 15**	**≥ 1.2**	**40 - 45**	**> 45**	**> 18**	**< 1.1**
(TSI)	(< 57)	(< 57)	(< 57)	(57 – 59)	(> 59)	(> 59)	(> 59)
WCBP	< 70	< 24	> 1.0	70 - 90	> 90	> 32	< 0.7
& NGP							
(TSI)	(< 66)	(< 61)	(< 61)	(66 – 69)	(> 69)	(> 65)	(> 65)

TSI = Carlson trophic state index; Chl = Chlorophyll-a; ppb = parts per billion or µg/L; m = meters

Our agency and the Wisconsin Department of Natural Resources (WDNR) are very concerned about protecting the water quality of the St. Croix River. Our Agency signed the Agreement on Nutrient and Sediment Reduction on the St. Croix River Basin (web link below) with the state of Wisconsin. The Agreement was signed at the 2006 St. Croix Conference by MPCA commissioner Sheryl Corrigan and WDNR Secretary Scott Hasett. It calls for a 20% phosphorus load reduction to Lake St. Croix. The Agreement was developed with input from the St. Croix Basin Water Resources Planning Team. If we can reduce the nutrient and sediment loading in the St. Croix River Basin by 20%, Lake St. Croix should meet our narrative and proposed nutrient standards for lakes.

Agreement web link http://www.pca.state.mn.us/publications/wq-b6-04.pdf

MEMORANDUM

TO: Suzanne Magdalene, St. Croix Watershed Research Station, Science Museum of Minnesota
FROM: St. Croix River Basin Team, Implementation Committee members: John Erdmann, MPCA; Buzz Sorge, WDNR; Bruce Wilson, MPCA; Pat Oldenburg, WDNR; and Steve Weiss, MPCA
DATE: February 25, 2009
SUBJECT: St. Croix Basin phosphorus (P) export coefficients for use in P loading study

As discussed at the St. Croix River Basin Team's Implementation Committee meeting of Friday, February 20, 2009, this memorandum transmits export coefficient values for total phosphorus (P) that the Basin Team has selected for use in your analysis of nonpoint P loadings. These export coefficient values represent the collective judgment and opinion of the authors, based on many decades of combined experience. For contract purposes, this guidance is provided to you by the Minnesota Pollution Control Agency (MPCA), with concurrence of the Wisconsin Department of Natural Resources (WDNR).

The export coefficients provided herein are regarded as initial values that are likely to be modified in the course of your analysis to account for P retention in portions of the drainage network and, perhaps, other phenomena. Table 1 below summarizes the selected export values, including dry-, average-, and wet-year values. Table 2 (page 2) presents the selected average-year values in context with average-year literature data compiled by you (except for changes in the open water/wetland category) as part of the present P loading study.

Table 1. Dry-year, average-year, and wet-year total phosphorus export coefficient (TPEC) values selected by the Basin Team for use in this study.

LANDCOVER / LANDUSE	TPEC values (kg/ha-yr)		
BRIEF DESIGNATION	Dry	Average	Wet
Water	0.033	0.05	0.075
Forest	0.067	0.10	0.150
Shrubland	0.067	0.10	0.150
Grassland	0.167	0.25	0.375
Agricultural	0.500	0.75	1.125
Urban	0.500	0.75	1.125

Note: Based on reported literature values, dry-year TPECs were estimated to be 2/3 of average-year values, and wet-year TPECs, 1.5 times average-year values, as derived by Suzanne Magdalene, SCWRS, in the current P loading study.

Tables 1 and 2 are not intended to determine table formats in the P loading study report.

Table 2. Average-year total phosphorus export coefficients for Minnesota, Wisconsin, or upper Midwest landscapes.

Landcover / Landuse	Average TPEC (kg/ha-yr)			Landcover / Landuse Brief Designation
	Compilation from published literature		Basin Team-selected value	
	Value	Source		
Open Water	0.000	MPCA (2004), Appendix I, pp. 36-37	0.05	Water
Wetland	0.000	MPCA (2004), Appendix I, pp. 36-37		
	0.100	Heiskary and Wilson (1994), p. 7		
Mixed Forest (OR ALL FORESTS)	0.107	MPCA (2004)	0.10	Forest
	0.100	Heiskary and Wilson (1994)		
	0.090	Panuska and Lillie (1995)		
	0.112	Clesceri et al (1986)		
Deciduous Forest	0.057	MPCA (2004)		
	0.290	Heiskary and Wilson (1994)		
	0.070	Endreny and Wood (2003)		
Evergreen Forest	0.092	MPCA (2004)		
	0.310	Heiskary and Wilson (1994)		
	0.200	Endreny and Wood (2003)		
Shrubland	0.087	MPCA (2004)	0.10	Shrubland
Grasslands/Herbaceous	0.122	MPCA (2004)	0.25	Grassland
	0.300	Heiskary and Wilson (1994)		
Urban/Recreational Grasses	0.820	MPCA (2004)		
	0.300	Heiskary and Wilson (1994)		
Pasture/Hay	0.260	MPCA (2004)		
	0.300	Heiskary and Wilson (1994)		
Row Crops	0.260	MPCA (2004)	0.75	Agriculture
	0.400	Heiskary and Wilson (1994)		
	1.000	Panuska and Lillie (1995)		
	0.262	Clesceri et al (1986)		
Small Grains	0.260	MPCA (2004)		
	0.400	Heiskary and Wilson (1994)		
Transitional	0.104	MPCA (2004)	0.75	Urban
Low-Intensity Residential	0.878	MPCA (2004)		
	0.880	Heiskary and Wilson (1994)		
High-Intensity Residential	1.143	MPCA (2004)		
	0.880	Heiskary and Wilson (1994)		
Commercial/Industrial/Transport	1.335	MPCA (2004)		
	0.880	Heiskary and Wilson (1994)		

Table A-1: Comparison between LU% of TRIB-GAGE pairings, including USGS areas for gaged locations, and TOT-NPS loads for the St. Croix River Basin subwatersheds in 1992.

Namekagon River Tributary

Land Use	LU Area (ac)	LU Area (ha)	LU Area (%)	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	26977	10922	7%	360	546	819
Forest	315395	127690	80%	8555	12769	19154
Shrub	1739	704	0%	47	70	106
Grass	21919	8874	6%	1482	2219	3328
Agri	26924	10900	7%	5450	8175	12263
Urban	2039	825	1%	413	619	929
TOTALS	**394,993**	**159,916**	**100%**	**16,308**	**24,398**	**36,598**

Upper St. Croix River Tributary

Land Use	LU Area (ac)	LU Area (ha)	LU Area (%)	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	18146	7347	6%	242	367	551
Forest	280840	113700	85%	7618	11370	17055
Shrub	19700	7976	6%	534	798	1196
Grass	5106	2067	2%	345	517	775
Agri	3788	1533	1%	767	1150	1725
Urban	1215	492	0%	246	369	553
TOTALS	**328,794**	**133,115**	**100%**	**9,753**	**14,571**	**21,856**

	Upper Tamarack River Tributary			Upper Tamarack River gage			Upper Tamarack River Tributary		
Land Use	LU Area (ac)	LU Area (ha)	LU Area (%)	LU Area (ac)	LU Area (ha)	LU Area (%)	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	3557	1440	5%	3554	1439	6%	48	72	108
Forest	58678	23756	90%	57778	23392	91%	1592	2376	3563
Shrub	2	1	0%	2	1	0%	0	0	0
Grass	1170	474	2%	858	347	1%	79	118	178
Agri	1493	604	2%	1145	464	2%	302	453	680
Urban	70	28	0%	70	28	0%	14	21	32
TOTALS	**64,971**	**26,304**	**100%**	**63,407**	**25,671**	**100%**	**2,035**	**3,041**	**4,561**
			USGS gage web site:						
			Lenz et al.(2003):		**24,500**				

Land Use	Yellow River Tributary LU Area (ac)	Yellow River Tributary LU Area (ha)	Yellow River Tributary LU Area (%)	Yellow River gage LU Area (ac)	Yellow River gage LU Area (ha)	Yellow River gage LU Area (%)	Yellow River Tributary Dry Load (kg/yr)	Yellow River Tributary Avg Load (kg/yr)	Yellow River Tributary Wet Load (kg/yr)
Water	22706	9193	9%	18146	7346	9%	303	460	689
Forest	151975	61528	63%	120560	48810	60%	4122	6153	9229
Shrub	993	402	0%	316	128	0%	27	40	60
Grass	27499	11133	11%	26386	10683	13%	1859	2783	4175
Agri	34921	14138	15%	34049	13785	17%	7069	10604	15905
Urban	2250	911	1%	2178	882	1%	455	683	1025
TOTALS	**240,343**	**97,305**	**100%**	**201,635**	**81,634**	**100%**	**13,836**	**20,723**	**31,084**

USGS gage web site:

Lenz et al.(2003): **94,000**

Land Use	Lower Tamarack River Tributary LU Area (ac)	Lower Tamarack River Tributary LU Area (ha)	Lower Tamarack River Tributary LU Area (%)	Lower Tamarack River gage LU Area (ac)	Lower Tamarack River gage LU Area (ha)	Lower Tamarack River gage LU Area (%)	Lower Tamarack River Tributary Dry Load (kg/yr)	Lower Tamarack River Tributary Avg Load (kg/yr)	Lower Tamarack River Tributary Wet Load (kg/yr)
Water	5911	2393	5%	5343	2163	5%	79	120	179
Forest	111773	45252	90%	104494	42305	90%	3032	4525	6788
Shrub	24	10	0%	22	9	0%	1	1	1
Grass	1374	556	1%	1207	489	1%	93	139	209
Agri	5135	2079	4%	4762	1928	4%	1040	1559	2339
Urban	265	107	0%	245	99	0%	54	81	121
TOTALS	**124,483**	**50,398**	**100%**	**116,073**	**46,993**	**100%**	**4,298**	**6,425**	**9,637**

USGS gage web site: **48,700**

Lenz et al.(2003): **47,000**

Land Use	Crooked Creek Tributary LU Area (ac)	Crooked Creek Tributary LU Area (ha)	Crooked Creek Tributary LU Area (%)	Crooked Creek gage LU Area (ac)	Crooked Creek gage LU Area (ha)	Crooked Creek gage LU Area (%)	Crooked Creek Tributary Dry Load (kg/yr)	Crooked Creek Tributary Avg Load (kg/yr)	Crooked Creek Tributary Wet Load (kg/yr)
Water	2615	1059	4%	2573	1042	4%	35	53	79
Forest	49037	19853	78%	46827	18958	79%	1330	1985	2978
Shrub	23	9	0%	21	8	0%	1	1	1
Grass	3673	1487	6%	3235	1310	5%	248	372	558
Agri	6991	2830	11%	6197	2509	10%	1415	2123	3184
Urban	271	110	0%	269	109	0%	55	82	124
TOTALS	**62,610**	**25,348**	**100%**	**59,122**	**23,936**	**100%**	**3,084**	**4,616**	**6,924**

USGS gage web site: **24,400**

Lenz et al.(2003): **24,400**

Land Use	Clam River Tributary LU Area (ac)	Clam River Tributary LU Area (ha)	Clam River Tributary LU Area (%)	Clam River gage LU Area (ac)	Clam River gage LU Area (ha)	Clam River gage LU Area (%)	Clam River Tributary Dry Load (kg/yr)	Clam River Tributary Avg Load (kg/yr)	Clam River Tributary Wet Load (kg/yr)
Water	13428	5436	5%	12872	5211	6%	179	272	408
Forest	145240	58801	59%	133787	54165	58%	3940	5880	8820
Shrub	1075	435	0%	650	263	0%	29	44	65
Grass	42172	17074	17%	41495	16799	18%	2851	4268	6403
Agri	42179	17077	17%	40924	16568	18%	8538	12807	19211
Urban	882	357	0%	858	347	0%	179	268	402
TOTALS	**244,975**	**99,180**	**100%**	**230,586**	**93,354**	**100%**	**15,716**	**23,539**	**35,309**
				USGS gage web site:	**93,500**				
				Lenz et al.(2003):	**92,600**				

Land Use	Sand River Tributary LU Area (ac)	Sand River Tributary LU Area (ha)	Sand River Tributary LU Area (%)	Sand River gage LU Area (ac)	Sand River gage LU Area (ha)	Sand River gage LU Area (%)	Sand River Tributary Dry Load (kg/yr)	Sand River Tributary Avg Load (kg/yr)	Sand River Tributary Wet Load (kg/yr)
Water	7207	2918	10%	7191	2911	10%	96	146	219
Forest	50468	20432	71%	49290	19955	71%	1369	2043	3065
Shrub	165	67	0%	159	64	0%	4	7	10
Grass	7636	3092	11%	7596	3075	11%	516	773	1159
Agri	4883	1977	7%	4862	1969	7%	989	1483	2224
Urban	341	138	0%	340	138	0%	69	104	155
TOTALS	**70,700**	**28,623**	**100%**	**69,438**	**28,113**	**100%**	**3,044**	**4,555**	**6,833**
				USGS gage web site:	**28,500**				
				Lenz et al.(2003):	**28,400**				

Land Use	Bear Creek Tributary LU Area (ac)	Bear Creek Tributary LU Area (ha)	Bear Creek Tributary LU Area (%)	Bear Creek Tributary Dry Load (kg/yr)	Bear Creek Tributary Avg Load (kg/yr)	Bear Creek Tributary Wet Load (kg/yr)
Water	4842	1960	12%	65	98	147
Forest	25894	10483	64%	702	1048	1572
Shrub	24	10	0%	1	1	1
Grass	7664	3103	19%	518	776	1164
Agri	1537	622	4%	311	467	700
Urban	204	82	1%	41	62	93
TOTALS	**40,164**	**16,261**	**100%**	**1,638**	**2,451**	**3,677**

Land Use	Kettle River Tributary LU Area (ac)	LU Area (ha)	LU Area (%)	Kettle River gage LU Area (ac)	LU Area (ha)	LU Area (%)
Water	65995	26719	10%	46904	18989	8%
Forest	455091	184247	68%	392408	158870	71%
Shrub	1274	516	0%	1197	485	0%
Grass	114629	46409	17%	88533	35843	16%
Agri	22897	9270	3%	18069	7315	3%
Urban	5668	2295	1%	4745	1921	1%
TOTALS	**665,554**	**269,455**	**100%**	**551,856**	**223,423**	**100%**
				USGS gage web site:	**224,800**	
				Lenz et al.(2003):	**225,200**	

Kettle River Tributary Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
882	1336	2004
12345	18425	27637
35	52	77
7750	11602	17403
4635	6953	10429
1147	1721	2582
26,794	**40,088**	**60,132**

Land Use	Snake River Tributary LU Area (ac)	LU Area (ha)	LU Area (%)	Snake River gage LU Area (ac)	LU Area (ha)	LU Area (%)
Water	97392	39430	15%	94151	38118	15%
Forest	351322	142236	55%	341324	138188	55%
Shrub	367	148	0%	341	138	0%
Grass	137982	55863	21%	129470	52417	21%
Agri	49384	19993	8%	46485	18820	8%
Urban	5822	2357	1%	5803	2349	1%
TOTALS	**642,268**	**260,027**	**100%**	**617,573**	**250,030**	**100%**
				USGS gage web site:	**252,370**	
				Lenz et al.(2003):	**252,500**	

Snake River Tributary Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
1301	1971	2957
9530	14224	21335
10	15	22
9329	13966	20949
9997	14995	22493
1179	1768	2652
31,345	**46,939**	**70,408**

Land Use	Wood River Tributary LU Area (ac)	LU Area (ha)	LU Area (%)	Wood River gage LU Area (ac)	LU Area (ha)	LU Area (%)
Water	9310	3769	8%	2790	1129	5%
Forest	46533	18839	42%	19496	7893	38%
Shrub	784	317	1%	0	0	0%
Grass	23430	9486	21%	12920	5231	25%
Agri	29488	11938	27%	16171	6547	31%
Urban	692	280	1%	291	118	1%
TOTALS	**110,236**	**44,630**	**100%**	**51,666**	**20,917**	**100%**
				USGS gage web site:	**36,300**	
				Lenz et al.(2003):	**21,700**	

Wood River Tributary Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
124	188	283
1262	1884	2826
21	32	48
1584	2371	3557
5969	8954	13431
140	210	315
9,101	**13,639**	**20,459**

Rock Creek Tributary

Land Use	LU Area (ac)	LU Area (ha)	LU Area (%)	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	2975	1205	8%	40	60	90
Forest	5584	2261	16%	151	226	339
Shrub	0	0	0%	0	0	0
Grass	17168	6951	49%	1161	1738	2606
Agri	9106	3687	26%	1843	2765	4147
Urban	357	145	1%	72	108	163
TOTALS	**35,190**	**14,247**	**100%**	**3,268**	**4,897**	**7,346**

Rush Creek Tributary

Land Use	LU Area (ac)	LU Area (ha)	LU Area (%)	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	7044	2852	18%	94	143	214
Forest	10419	4218	27%	283	422	633
Shrub	20	8	0%	1	1	1
Grass	12510	5065	33%	846	1266	1899
Agri	7441	3013	19%	1506	2260	3389
Urban	814	330	2%	165	247	371
TOTALS	**38,248**	**15,485**	**100%**	**2,894**	**4,338**	**6,507**

Goose Creek Tributary

Land Use	LU Area (ac)	LU Area (ha)	LU Area (%)	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	6142	2486	14%	82	124	186
Forest	16360	6623	38%	444	662	994
Shrub	96	39	0%	3	4	6
Grass	11025	4464	26%	745	1116	1674
Agri	8825	3573	21%	1786	2680	4020
Urban	226	92	1%	46	69	103
TOTALS	**42,674**	**17,277**	**100%**	**3,106**	**4,655**	**6,982**

Sunrise River Tributary / Sunrise River gage

Land Use	Sunrise River Tributary LU Area (ac)	LU Area (ha)	LU Area (%)	Sunrise River gage LU Area (ac)	LU Area (ha)	LU Area (%)	Sunrise River Tributary Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	46056	18646	19%	46031	18636	19%	615	932	1398
Forest	62357	25246	26%	61703	24981	26%	1691	2525	3787
Shrub	31	12	0%	31	12	0%	1	1	2
Grass	66032	26734	28%	65362	26462	28%	4465	6683	10025
Agri	59329	24020	25%	58769	23793	25%	12010	18015	27022
Urban	4636	1877	2%	4634	1876	2%	938	1408	2112
TOTALS	**238,440**	**96,535**	**100%**	**236,531**	**95,761**	**100%**	**19,720**	**29,564**	**44,346**

USGS gage web site:

Lenz et al.(2003): **43,900**

Land Use	Trade River Tributary LU Area (ac)	Trade River Tributary LU Area (ha)	Trade River Tributary LU Area (%)	Trade River gage LU Area (ac)	Trade River gage LU Area (ha)	Trade River gage LU Area (%)	Trade River Tributary Dry Load (kg/yr)	Trade River Tributary Avg Load (kg/yr)	Trade River Tributary Wet Load (kg/yr)
Water	7278	2947	7%	6807	2756	8%	97	147	221
Forest	44631	18069	46%	34451	13948	40%	1211	1807	2710
Shrub	3596	1456	4%	2751	1114	3%	98	146	218
Grass	19254	7795	20%	18606	7533	22%	1302	1949	2923
Agri	22461	9094	23%	22053	8928	26%	4547	6820	10230
Urban	459	186	0%	413	167	0%	93	139	209
TOTALS	**97,680**	**39,546**	**100%**	**85,081**	**34,446**	**100%**	**7,347**	**11,008**	**16,512**

USGS gage web site: **15,000**

Lenz et al.(2003): **34,500**

Land Use	Wolf Creek Tributary LU Area (ac)	Wolf Creek Tributary LU Area (ha)	Wolf Creek Tributary LU Area (%)	Wolf Creek Tributary Dry Load (kg/yr)	Wolf Creek Tributary Avg Load (kg/yr)	Wolf Creek Tributary Wet Load (kg/yr)
Water	887	359	3%	12	18	27
Forest	9226	3735	26%	250	374	560
Shrub	3	1	0%	0	0	0
Grass	11369	4603	32%	769	1151	1726
Agri	13866	5614	39%	2807	4210	6315
Urban	57	23	0%	11	17	26
TOTALS	**35,409**	**14,335**	**100%**	**3,849**	**5,770**	**8,655**

Land Use	Apple River Tributary LU Area (ac)	Apple River Tributary LU Area (ha)	Apple River Tributary LU Area (%)	Apple River gage LU Area (ac)	Apple River gage LU Area (ha)	Apple River gage LU Area (%)	Apple River Tributary Dry Load (kg/yr)	Apple River Tributary Avg Load (kg/yr)	Apple River Tributary Wet Load (kg/yr)
Water	16944	6860	5%	16878	6833	5%	226	343	515
Forest	111849	45283	31%	110391	44693	32%	3034	4528	6792
Shrub	0	0	0%	0	0	0%	0	0	0
Grass	90681	36713	25%	87926	35598	25%	6131	9178	13767
Agri	136606	55306	38%	130868	52983	38%	27653	41480	62219
Urban	1337	541	0%	1297	525	0%	271	406	609
TOTALS	**357,418**	**144,703**	**100%**	**347,360**	**140,631**	**100%**	**37,315**	**55,935**	**83,903**

USGS gage web site: **149,960**

Lenz et al.(2003): **142,000**

Land Use	Silver Creek Tributary LU Area (ac)	Silver Creek Tributary LU Area (ha)	Silver Creek Tributary LU Area (%)	Silver Creek Tributary Dry Load (kg/yr)	Silver Creek Tributary Avg Load (kg/yr)	Silver Creek Tributary Wet Load (kg/yr)
Water	341	138	7%	5	7	10
Forest	644	261	13%	17	26	39
Shrub	0	0	0%	0	0	0
Grass	2489	1008	49%	168	252	378
Agri	1555	629	31%	315	472	708
Urban	11	4	0%	2	3	5
TOTALS	**5,040**	**2,040**	**100%**	**507**	**760**	**1,140**

Browns Creek Tributary

Land Use	LU Area (ac)	LU Area (ha)	LU Area (%)
Water	1215	492	6%
Forest	3029	1226	16%
Shrub	0	0	0%
Grass	9289	3761	48%
Agri	4838	1959	25%
Urban	906	367	5%
TOTALS	**19,278**	**7,805**	**100%**

Browns Creek Tributary

Land Use	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	16	25	37
Forest	82	123	184
Shrub	0	0	0
Grass	628	940	1410
Agri	979	1469	2204
Urban	183	275	412
TOTALS	**1,889**	**2,832**	**4,247**

	Willow River Tributary			Willow River gage		
Land Use	LU Area (ac)	LU Area (ha)	LU Area (%)	LU Area (ac)	LU Area (ha)	LU Area (%)
Water	2535	1026	1%	2318	939	1%
Forest	23197	9392	12%	21929	8878	12%
Shrub	0	0	0%	0	0	0%
Grass	55216	22355	29%	54708	22149	29%
Agri	107016	43326	57%	106584	43151	57%
Urban	1089	441	1%	960	389	1%
TOTALS	**189,052**	**76,539**	**100%**	**186,499**	**75,506**	**100%**

USGS gage web site: **75,600**

Lenz et al.(2003): **72,100**

Willow River Tributary

Land Use	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	34	51	77
Forest	629	939	1409
Shrub	0	0	0
Grass	3733	5589	8383
Agri	21663	32495	48742
Urban	220	331	496
TOTALS	**26,280**	**39,404**	**59,106**

Valley Creek Tributary

Land Use	LU Area (ac)	LU Area (ha)	LU Area (%)
Water	1037	420	4%
Forest	3731	1510	13%
Shrub	0	0	0%
Grass	13337	5399	47%
Agri	9630	3899	34%
Urban	650	263	2%
TOTALS	**28,384**	**11,492**	**100%**

Valley Creek Tributary

Land Use	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	14	21	31
Forest	101	151	227
Shrub	0	0	0
Grass	902	1350	2025
Agri	1949	2924	4386
Urban	132	197	296
TOTALS	**3,098**	**4,643**	**6,965**

	Kinnickinnic River Tributary			Kinnickinnic River gage		
Land Use	LU area (ac)	LU area (ha)	LU area (%)	LU Area (ac)	LU Area (ha)	LU Area (%)
Water	297	120	0%	295	120	0%
Forest	10995	4451	10%	10286	4164	10%
Shrub	0	0	0%	0	0	0%
Grass	29581	11976	27%	28090	11373	27%
Agri	68800	27854	62%	65379	26469	62%
Urban	1326	537	1%	1326	537	1%
TOTAL	**110,999**	**44,939**	**100%**	**105,376**	**42,662**	**100%**

USGS gage web site: **43,300**

Lenz et al.(2003): **44,900**

Kinnickinnic River Tributary

Land Use	Dry Load (kg/yr)	Avg Load (kg/yr)	Wet Load (kg/yr)
Water	4	6	9
Forest	298	445	668
Shrub	0	0	0
Grass	2000	2994	4491
Agri	13927	20891	31336
Urban	268	403	604
TOTAL	**16,498**	**24,739**	**37,108**

Table A-2: Wisconsin municipal and industrial wastewater treatment facility point source loads (kg/yr).

SWS	Facility	Bkgd Avg 1990s*	1999	2000	2001	2002	2003	2004	2005	2006	2007
Yellow	WI DNR Gov Tommy Thompson Fish Hatchery	79.1	90.5	105.9	121.6	62.1	79.0	51.5	91.5	67.8	38.9
Clam	Siren, Village of	496.6	343.7	385.8	497.8	607.5	655.5	675.5	633.8	677.7	642.2
Clam	Webster, Village of	315.4	467.8	441.6	360.2	236.0	434.0	407.7	332.0	377.9	502.8
Wood	Grantsburg, Village of	1128.6	937.6	1047.0	865.0	910.3	963.3	1206.5	1006.2	1086.2	1218.4
Wood	Burnett Dairy Cooperative	239.4	199.9	193.5	252.5	194.1	195.5	217.8	202.2	215.3	207.8
Trade	Luck, Village of	485.8	639.0	425.9	678.0	757.3	817.2	613.4	648.4	330.7	290.9
SCR	WI DNR St Croix Falls Hatchery	160.3	3.6	5.5	3.2	4.0	3.0	2.5	3.4	3.2	3.2
SCR	St Croix Falls, City of	1159.1	1328.2	1192.9	1223.6	1320.7	1229.9	1397.5	1666.1	1596.2	1302.8
Trout	WI DNR Osceola Fish Hatchery	183.7	1.78	1.78	1.33	1.78	1.61	1.43	1.43	1.40	1.31
Trout	Amani Sanitary District	24.1	7.7	10.9	12.4	9.7	7.4	8.8	10.3	7.6	8.5
SCR	Osceola, Village of	1858.5	286.0	278.1	240.1	201.4	264.4	186.3	436.1	148.9	304.0
Apple	Amery, City of	743.4	665.9	475.0	465.6	416.1	577.9	372.4	645.4	208.7	610.9
Apple	Clayton, Village of	232.5	152.8	155.0	391.8	445.1	414.4	316.8	452.5	201.9	428.4
Apple	Somerset WWTF	986.6	0	243.8	315.1	166.4	146.7	128.7	183.0	108.3	119.6
Apple	Star Prairie WWTF	0.0	0	0	0	0	169.8	250.7	232.8	220.5	197.2
Willow	Clear Lake, Village of	2511.8	2728.1	3457.8	2254.4	2269.8	379.4	176.8	133.9	119.0	132.8
Willow	Deer Park WWTF	107.5	172.5	115.0	143.6	311.8	197.5	133.5	118.9	94.6	46.0
Willow	Lakeside Foods, INC. New Richmond	*11.3*	11.3	20.4	10.9	14.6	3.9	11.3	20.3	22.2	27.7
Willow	New Richmond WWTF	1758.1	1430.8	1648.2	896.0	718.6	557.7	614.5	611.9	622.6	657.5
SCR-WC	Hudson WWTF	6031.3	1143.7	1175.5	766.4	617.5	775.8	954.6	1359.5	968.8	866.5
Kinni	River Falls WWTP	6551.9	846.5	972.1	885.6	1007.5	1293.6	1041.0	959.8	718.0	896.4
Kinni	Roberts WWTF	*41.7*	41.7	45.4	38.9	43.3	40.6	36.8	50.7	60.6	79.3

Table A-3: Minnesota municipal and industrial wastewater treatment facility point source loads (kg/yr).

SWS	Facility	Bkgd Avg 1990s*	1999	2000	2001	2002	2003	2004	2005	2006	2007
Bear	Askov	165.9	0.0	0.0	0.0	0.0	0.0	0.0	82.8	154.0	35.5
Kettle	Aitkin Cromwell Agri-Peat	165.9	6.8	3.5	2.9	10.0	0.0	4.8	17.3	166.9	27.5
Kettle	Barnum WWTF	414.8	0.0	0.0	0.0	6.5	1.6	158.0	217.1	202.9	401.0
Kettle	Moose Lake WWTP	1327.3	0.0	0.0	711.3	579.2	1296.6	499.0	772.2	1069.3	1249.9
Kettle	Willow River WWTP	0.0									
Kettle	Kettle River WWTF	165.9	26.6	24.8	38.7	25.9	40.1	35.9	55.9	52.3	48.0
Kettle	Finlayson WWTP	829.5	0.0	0.0	0.0	11.5	73.5	13.5	9.2	2.4	0.0
Kettle	Sandstone WWTP	1161.4	0.0	1136.7	1903.3	1642.5	2081.6	1681.8	1292.4	1605.1	1326.5
Kettle	Hinckley WWTP	1410.2	317.3	747.3	182.5	0.0	0.0	0.0	244.8	306.7	246.5
Snake	Isle WWTP	*114.2*	114.2	145.4	190.4	147.3	165.8	130.3	210.1	149.2	89.8
Snake	Wahkon #	0.0									
Snake	Ogilvie WWTP	497.7	0.0	0.0	0.0	0.0	326.9	361.9	296.3	287.6	289.9
Snake	Mora WWTP	1981.0	0.0	0.0	0.0	2687.6	2210.2	2499.5	2154.8	2183.6	2403.4
Snake	Grasston WWTF	165.9	0.0	0.0	0.0	9.9	14.3	25.3	13.7	16.7	23.9
Snake	Pine City WWTP	2073.9	0.0	0.0	0.0	0.0	202.8	71.5	180.1	69.0	134.2
Rush	Rush City WWTP	663.6	153.4	595.1	253.8	372.1	24.4	308.4	520.2	524.6	513.2
Rush	Shorewood Park	*27.0*	27.0	25.1	64.2	49.7	55.2	64.2	69.2	40.2	41.7
Goose	Harris WWTP	82.0	40.3	30.7	16.1	37.5	95.3	88.9	96.4	74.4	76.5
Sunrise	Linwood Terrace - Iacarella	16.6	5.0	6.4	6.3	6.5	8.1	7.9	7.4	8.0	7.6
Sunrise	North Branch WWTP	4479.5	0.0	0.0	0.0	0.0	2487.6	3189.5	415.5	122.0	152.3
Sunrise	Chisago	4648.0	0.0	0.0	0.0	5522.8	5178.1	5330.4	5200.9	953.3	3709.3
Lawrence	Shafer WWTP	165.9	0.0	93.0	135.9	0.0	0.0	96.7	234.9	304.3	362.3
SCR	Taylors Falls	374.0	219.8	143.7	309.3	240.1	256.7	218.1	360.2	250.7	107.6
SCR	St Croix Valley WWTP	1237.0	1363.4	2118.8	2116.6	2172.7	2158.7	2238.5	2179.6	1946.9	3333.8
Valley	Cimarron Park WWTF	0.0									
SCR	Xcel King Power Plant	4147.7									