

# Historical Trends in Phosphorus Loading to the St. Croix National Scenic Riverway from Permitted Point Source Discharges, 1900-2000

(PMIS Project 71951)

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## PROJECT SUMMARY

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We have determined the historical contribution of point source phosphorus (P) loadings to the St. Croix watershed from 1900-2000. Historical loadings were estimated based on discharge volumes, demographics, industrial sources, wastewater technologies, and from direct facility discharge records when available. Point-source discharges were compared to historical total loadings estimated from an earlier study of Lake St. Croix (Triplett et al. 2003) to calculate the historical contribution of point-sources, non-point sources, and natural or background sources. Sewering in the basin began at Stillwater in 1905. Since that time, there have been as many as 169 permitted point source dischargers basinwide including municipal, industrial, and agricultural facilities. Early wastewater management typically discharged untreated sewage; technological advances had secondary treatment in place at most facilities by the 1960s-1970s and much of the population served by tertiary treatment by the 1990s. Peak nutrient discharges from point sources occurred in the 1960s-1970s. Detergent phosphorus bans put in place in the late 1970s for Minnesota and Wisconsin, greater use of land and groundwater effluent discharges, and improvements in treatment technology brought about decreases in P loading in the 1980s and 1990s. We estimated 1990s point source loadings at 48 metric tons P per year. This represents about 10% of the total phosphorus loading (460 metric tons P per year) to the basin. Without further controls on nutrient loading to the St. Croix River, annual P loadings are projected to increase to 540 metric tons P per year; annual point source phosphorus loading will be 70 metric tons or 13% of the total loading. However, if we discount for natural P loading to the St. Croix (166 metric tons P per year), point sources contribute 16-19% of the current and future phosphorus load that can be attributed to human activities in the watershed.

## INTRODUCTION

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Landscape changes due to natural processes and human modification have significantly impacted surface waters worldwide. Increased nutrient loadings have resulted in wide-spread eutrophication across North America. Of lakes and rivers classified as impaired, approximately 50% of the lakes and 60% of the rivers suffer from excess nutrient loading (Carpenter et al. 1998, Correll 1998). Consequently, an interagency team of federal, state, university, and research scientists have identified protecting and improving water quality, and in particular, nutrients, as the number one issue facing the future of the St. Croix River (St. Croix Basin Water Resources Planning Team 1998).

The St. Croix River is a major tributary to the upper Mississippi River; its watershed is located in east-central Minnesota and northwest Wisconsin (Fig. 1). The St. Croix River (266 km long) drains a watershed of approximately 22,196 km<sup>2</sup> in conjunction with 16 secondary tributary systems. The river serves a basinwide population of over 400,000 (Andersen et al. 1996, [www.census.gov](http://www.census.gov)) including almost 100 permitted point-source dischargers (Meyer et al. 1999). The river basin has undergone significant land-use changes since European settlers arrived in the 1840s. Andersen et al. (1996) used historical land surveys and demographic records to reconstruct the land-use history of the lower basin and noted three major phases. European settlement was initiated by logging interests around 1839 with the construction of the first sawmill in the lower St. Croix watershed. Logging activity peaked in 1889 and was done in conjunction with land clearance and a shift to agriculture. During the second phase, from 1880 to 1940, the population was stable and agricultural land-use dominated the watershed; farming acreage peaked c. 1935. The third phase, from 1940 to present, has seen farming decline and urbanization increase with an expanding St. Paul-Minneapolis metropolitan area in the lower watershed (Andersen et al. 1996).

The St. Croix River has been declared by the states of Wisconsin and Minnesota to have "outstanding" to "exceptional resource value" and is federally managed as a National Scenic Riverway. The Riverway was established in 1968 by the National Wild and Scenic Rivers Act and the lower river, from St. Croix Falls to Prescott, was added in 1972 through an amendment to the Act. The St. Croix is considered by most to be near-pristine today; the water quality is good compared to major midwestern rivers such as the Mississippi and Minnesota (Kroenig and Stark 1997). The St. Croix Basin Water Resources Planning Team, an interagency cooperative of federal, state, university, and research organizations (Minnesota and Wisconsin), identified management of nutrient loadings as crucial to protecting and improving water quality in the St. Croix River and established an interim recommendation of "no net increase of nutrients in permitted discharges" (St. Croix Basin Water Resources Planning Team 1998). In conjunction with this relatively conservative management goal, the St. Croix Basin Water Resources Planning Team initiated a series of research projects to estimate modern point source loading (St. Croix Basin Water Resources Planning Team, unpublished), determine baseline (pre-European settlement) and post-European nutrient loading (Triplett et al. 2003, this study), and model future nutrient scenarios (Robertson and Lenz 2002).

Triplett et al. (2003) analyzed a series of 24 dated sediment cores taken from Lake St. Croix, the terminal 37 km of the St. Croix River, to construct a historical model of total phosphorus (P)

loading to Lake St. Croix. The two-pronged approach first analyzed diatom remains in two sediment cores. A transfer function relating diatom communities to total phosphorus was applied to the downcore diatom assemblages to reconstruct historical water column total phosphorus. These values were multiplied by decadal flows to estimate historical loss of phosphorus to the Mississippi River. Second, the amount of phosphorus preserved in the sediment cores was calculated for decadal increments throughout the entire depositional area of the lake basin. By summing the amount of phosphorus lost to the Mississippi River with the amount deposited in the sediments, a model of decadal historical loading to the lake was constructed. Background or natural P loading to Lake St. Croix was 166 tons P/yr. Minor increases in P loading began at the turn of the 20<sup>th</sup> century; major increases in P loading started in the 1940s and have generally continued to rise to 460 tons P/yr by the 1990s.

Two major landuse changes individually or concomitantly may have driven the post-1940 patterns in nutrient loading. This period saw dramatic changes in agricultural practices toward more mechanization and increase dependence on chemical fertilizer application (Mulla et al. 1999, Bennett et al. 2001). Secondly, increased urbanization and suburbanization pressure in the St. Croix basin, which began in the 1950s, forced many municipalities to develop industrial and municipal wastewater treatment facilities. Thus the post-1940s increases in phosphorus loading may reflect contributions from both nonpoint and point sources. In this study we reconstruct the historical contribution of point source phosphorus loading to the St. Croix basin beginning with initial sanitary sewerage of Stillwater, Minnesota, in 1905. From this reconstruction we determine the relative contribution of point, nonpoint, and natural source phosphorus loadings to the St. Croix River.

## METHODS-DATA SOURCES

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Historical point source loading estimates were compiled using monitoring records, facility histories, and demographics from published data sources and from facility and agency monitoring records. Data sources varied by decade and between Minnesota and Wisconsin. For some decades, data were simply unavailable (e.g. 1900-1930 Wisconsin point sources). Operational histories of Minnesota municipal treatment plants and municipal demographics were compiled from annual MPCA facility inventories (Minnesota State Board of Health et al. 1946, Minnesota Department of Health 1952, 1964, Minnesota Pollution Control Agency 1974, 1975, 1982, 1991). Treatment types, dates of upgrades, design flows, and population served were generally available for municipal permitted facilities from 1900 to 1990. Additionally, several agency studies reported phosphorus loadings for specific facilities; these data were preferentially used if available (Pacific Northwest Environmental Research Laboratory and National Environmental Research Center 1975, Metropolitan Waste Control Commission 1993)

Operational histories of Wisconsin permitted dischargers and municipal demographics were compiled from agency studies and facility inventories (Minnesota State Board of Health et al. 1946, WDNR 1972, 1975, 1980, 1993, 2002). Several agency studies reported phosphorus loadings for specific Wisconsin facilities; these data were preferentially used when available (WDNR 1972, Pacific Northwest Environmental Research Laboratory and National Environmental Research Center 1975, Metropolitan Waste Control Commission 1993, Schreiber 2000).

Loadings for the 1990s were estimated from a study initiated by the St. Croix Basin Water Resources Planning Team. Approximately 50 of the permitted municipal and industrial dischargers throughout the Minnesota and Wisconsin parts of the St. Croix basin initiated a one to four year monitoring period to estimate P discharges (St. Croix Basin Water Resources Planning Team, unpublished).

Population densities in the basin were compiled from 1900 to 2000 using U.S. census data for counties in Minnesota and Wisconsin (Table 1, [www.census.gov](http://www.census.gov)). For counties only partially within the St. Croix drainage, census data were adjusted by including or removing major communities within each county. Because the town of Prescott, Wisconsin, discharges to the Mississippi River, census data for this municipality were excluded from estimates. Future basinwide population estimates for 2020 were provided by Metropolitan Council Environmental Services (Kent Johnson, pers. comm.)

## METHODS-DECADAL LOADING CALCULATIONS

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From our initial compilation of facility histories, discharge data, and demographics, we developed an estimate of historical decadal point source loadings to the St. Croix River. For many decades (1900-1970) phosphorus effluent concentrations are not available and had to be estimated; P monitoring records from major dischargers were generally available by the 1980s. For those decades where monitoring data are lacking, P loading estimates were calculated based on conversion factors available in the literature (Litke 1999, Hall et al. 1999) which provided the following six assumptions: 1) a pre-1940s per capita P production of 0.4 kg P/yr, 2) to the 1970s with 1.5 kg P/yr, 3) and in the 1990s a drop to 0.7 kg P/yr, 4) primary sewage treatment with 8% P removal, 5) secondary treatment with 25% P removal, 6) tertiary treatment with 84% P removal. The rise and fall of per capita P production reflects the increased use of phosphorus-based detergents between the 1940s and 1970s. The decline into the 1990s of per capita P production resulted from the ban on phosphorus-based detergents that was instituted in Minnesota in 1977 and Wisconsin in 1979 (Litke 1999). In this analysis, per capita P production was linearly increased from 0.4 kg P/yr in the 1940s to 1.5 kg P/yr in the 1970s. Because the phosphorus bans began in the late 1970s, a per capita value of 0.7 kg P/yr was used for the 1980s and 1990s. If monitoring data were available, average effluent total P concentrations were multiplied by average daily flows and used to estimate annual loads. Finally, facilities with effluent that represented only cooling water waste or with effluent that was land- or groundwater-applied were excluded from the loading estimates.

Estimated historical point source loadings were compared to the historical P loading model for Lake St. Croix (Table 2, Triplett et al. 2003) to partition historical loadings into point and nonpoint sources. The background or natural P load to Lake St. Croix, estimated at 166 tons P/yr, was subtracted from the total load to estimate the cultural P burden, or the amount of P loading resulting from culturally produced landscape changes and point sources. An estimate of future nonpoint source loadings was made by projecting a linear model of increasing loadings from 1950s to 1990s to the year 2020. An estimate of future point source loading assumed no technological improvements and applied a 1990s per capita loading to population projections for 2020.

## RESULTS & DISCUSSION-BASIN POPULATION

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Population in the St Croix basin has increased nearly four-fold since 1900, with a minor population peak in the 1920s and steady increases since the 1950s (Fig. 2). Population increases since the 1950s reflect broadscale suburbanization especially in the southern portion of the basin as the Twin Cities metropolitan area has expanded (Andersen et al. 1996). After the 1950s the basin population in Minnesota increased more quickly than Wisconsin's basin population. Minnesota basin residents now make up nearly two-thirds of the current population (Fig. 2). Population projections for the year 2020 from Metropolitan Council Environmental Services (Kent Johnson, pers. comm.) suggest that the basin will then be home to 533,900 residents, a population increase of 36.5% since 2000.

## RESULTS & DISCUSSION-HISTORICAL POINT SOURCE LOADING

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There are currently 87 permitted discharges in the St. Croix Basin split among 33 industrial and 54 municipal facilities (Fig. 1). Permitted discharging in the basin began with construction of sanitary sewers in the City of Stillwater in 1905 (Minnesota Department of Health 1952) and in the nearly hundred years since there have been approximately 169 permitted dischargers in the basin. By the mid-1940s, numerous reaches on both sides of the river had severe local impacts from discharges of raw or only primary treated sewage (Minnesota State Board of Health et al. 1946). Estimates of historical point source loading to the St. Croix basin show increasing loadings until the 1960s when point sources were contributing nearly 94 metric tons of P annually to the basin (Table 2, Fig. 3). The peak in point source loading reflects the increased use of phosphate-based detergents, which began in the 1940s (Litke 1999) and the continued discharge of often only primary-treated or raw sewage into the river. In Wisconsin, several municipal treatment plants (e.g. Dresser) were severely overburdened due to creamery wastes. Point source loadings decreased slightly in the 1970s as more facilities put secondary and even tertiary treatment technology in place as a result of the 1972 Federal Water Pollution Control Act, the 1974 Safe Drinking Water Act, and the 1977 Clean Water Act. The 1970s also brought about phosphorus detergent bans in Minnesota in January 1977 and Wisconsin in January 1979 (0.5 wt. % P in both states; Litke 1999). As a result, point source loadings in the 1980s decreased as per capita P production estimates fell from 1.5 kg P/yr in the 1970s to 0.7 kg P/yr in the 1980s (Litke 1999). State and federal assistance programs in the 1980s also resulted in further technology improvements and the development of widespread land and groundwater application of effluent (K. Bartilson, WDNR, pers. comm.). In this analysis these discharges were no longer included in the calculation of loading; however, these discharges may represent potential nonpoint source loadings (Bennett et al. 2001). Improvements in loadings during the 1980s were short-lived; by the 1990s, increases in population quickly led to increased P loading from point sources. Similar temporal patterns of point source loading were reconstructed for the Hudson River permitted dischargers (Hetling et al. 2003).

The relative contribution of point sources to historical total P loading in the St. Croix River has varied considerably in the 20<sup>th</sup> century. Point sources became increasingly important contributors to the total P load from the 1900s until peak contributions of over 20% in the 1960s and 1970s (Table 2). In more recent decades, point sources have contributed approximately 10% of the

total P load to the St. Croix River (Table 2). An earlier study in the 1970s found that point source loading accounted for 11.2% of the total P load to Lake St. Croix alone (Pacific Northwest Environmental Research Laboratory and National Environmental Research Center 1975). A 2002 study on Lake St. Croix took into account annual flow variation and found point source contribution to vary between 7.8% (high flow years) and 28.7% (low flow years) of total P loading to the Lake (Robertson and Lenz 2002).

A critical finding from Triplett et al. (2003) was that natural or background P loading to Lake St. Croix was 166 tons P/yr. Because this portion of the total phosphorus load is unavailable for control measures, we recalculated the controllable phosphorus loading as both the nonpoint and point source "cultural burden" of loading to the St. Croix River by subtracting background loading from the historical total P loading (Fig 4). The cultural burden represents the amount of phosphorus above background levels in the St. Croix River that has resulted from landuse changes and point source discharges. Point source loadings become quantitatively much more important to the culturally-induced historical loading record of the St. Croix. By discounting for natural P sources, we estimate that early in the 20<sup>th</sup> century, point sources contributed over 40% (1920s) of the cultural phosphorus load and were again accounting for nearly 40% of the cultural P burden in the 1960s and 1970s. By the 1980s and 1990s, point sources contributed approximately 15% of the cultural P burden to the St. Croix River.

## RESULTS & DISCUSSION-FUTURE POINT SOURCE LOADING

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If no further control measures are instituted on future phosphorus loading to the St. Croix River, total phosphorus loading is estimated to increase from 459 tons P/yr in the 1990s to 540 tons P/yr in the 2020s. A linear model through nonpoint loads from the 1950s to 1990s and projected to 2020 indicates that nonpoint source loading will continue to increase from 411 tons P/yr in the 1990s to 470 tons P/yr in the 2020s. Furthermore, without any increases beyond current wastewater treatment technologies and applying per capita P loading rates, point sources are estimated to increase from 48 tons P/yr in the 1990s to nearly 70 tons P/yr in the 2020s. Point source contribution to the total load of P in the St. Croix River will be 13% in the 2020s and its contribution to the cultural burden would climb to nearly 19% in the 2020s.

## SUMMARY COMMENTS

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Our analysis of historical point source loading to the St. Croix River has shown that point sources were an increasingly important contributor to the total P load in the 20<sup>th</sup> century, with peak loadings in the 1960s and 1970s. Improvements in point source loading that were realized in the 1980s and 1990s through treatment technologies and P-detergent bans will not continue without putting additional nutrient control measures in place. While nonpoint sources have historically been the dominant source of P to the St. Croix, modern point sources do contribute about 10% of the total P load to the St. Croix River and 15% of the controllable P load, that portion which can be attributed to cultural activities in the basin.

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## ACKNOWLEDGEMENTS

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## TABLES

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Table 1. Decadal population estimates of entire St. Croix basin, and Minnesota and Wisconsin portions of basin, (1900-2000).

Decade	Basin	Minnesota	Wisconsin
1900	113805	55707	58097
1910	127292	61984	65309
1920	146074	69914	76160
1930	143117	68605	74512
1940	149174	72757	76417
1950	149259	75167	74092
1960	163483	88605	74879
1970	200213	118059	82154
1980	259468	156671	102797
1990	302651	188927	113724
2000	391055	252765	138289

Table 2. Decadal total phosphorus load estimates from point sources, nonpoint sources, and the cultural burden for Lake St. Croix and the St. Croix watershed, 1900s-1990s. Total P load estimates are from Triplett et al. (2003). Point source loadings are estimated from monitoring data, facilities histories, and demographics. Nonpoint source load is calculated by subtracting the point source load from total P load estimates from Lake St. Croix. The cultural burden of phosphorus is calculated by subtracting the natural or background loading estimate (166 tons P/yr; Triplett et al. 2003) from the total P load.

Decade	Total P load (tons P/yr)	Point source load (tons P/yr)	Nonpoint source load (tons P/yr)	% Point source load	Cultural P burden (tons P/yr)	% Point source of cultural burden
1900s	210.0	2.8	207.2	1.3	44.0	6.4
1910s	184.0	6.1	177.9	3.3	18.0	33.8
1920s	184.0	7.5	176.5	4.1	18.0	41.7
1930s	220.0	12.8	207.2	5.8	54.0	23.8
1940s	357.0	14.0	343.0	3.9	191.0	7.3
1950s	408.0	33.6	374.4	8.2	242.0	13.9
1960s	413.0	93.9	319.1	22.7	247.0	38.0
1970s	390.0	84.6	305.4	21.7	224.0	37.8
1980s	458.0	41.7	416.3	9.1	292.0	14.3
1990s	459.0	48.2	410.8	10.5	293.0	16.4
-	-	-	-	-	-	-
2020s	540.0	70.0	470.0	13.0	374.0	18.7

## FIGURES

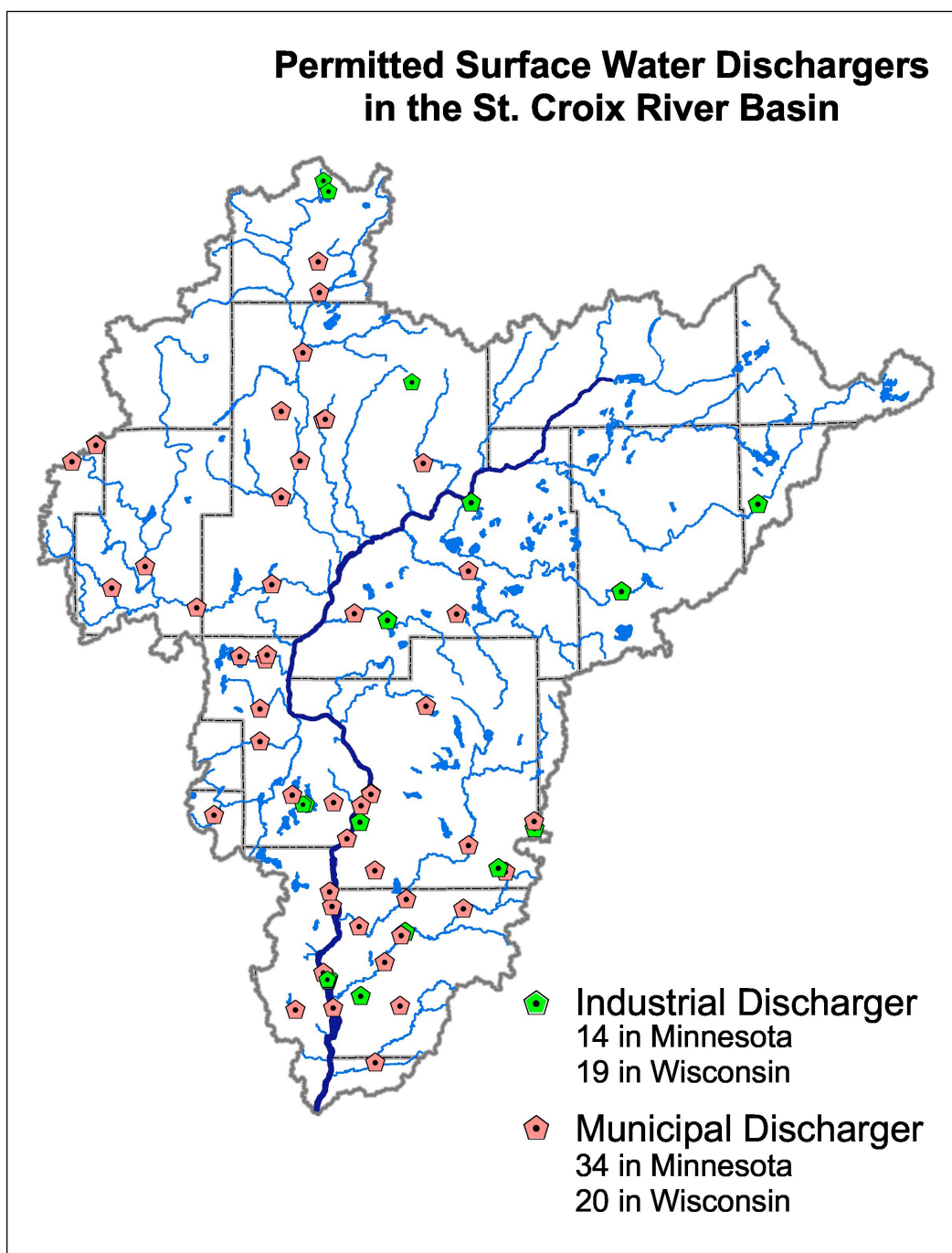


Figure. 1. Municipal and industrial permitted point source dischargers in the St. Croix basin, Minnesota and Wisconsin, 2003. Graphic prepared by Marianna Young, National Park Service.

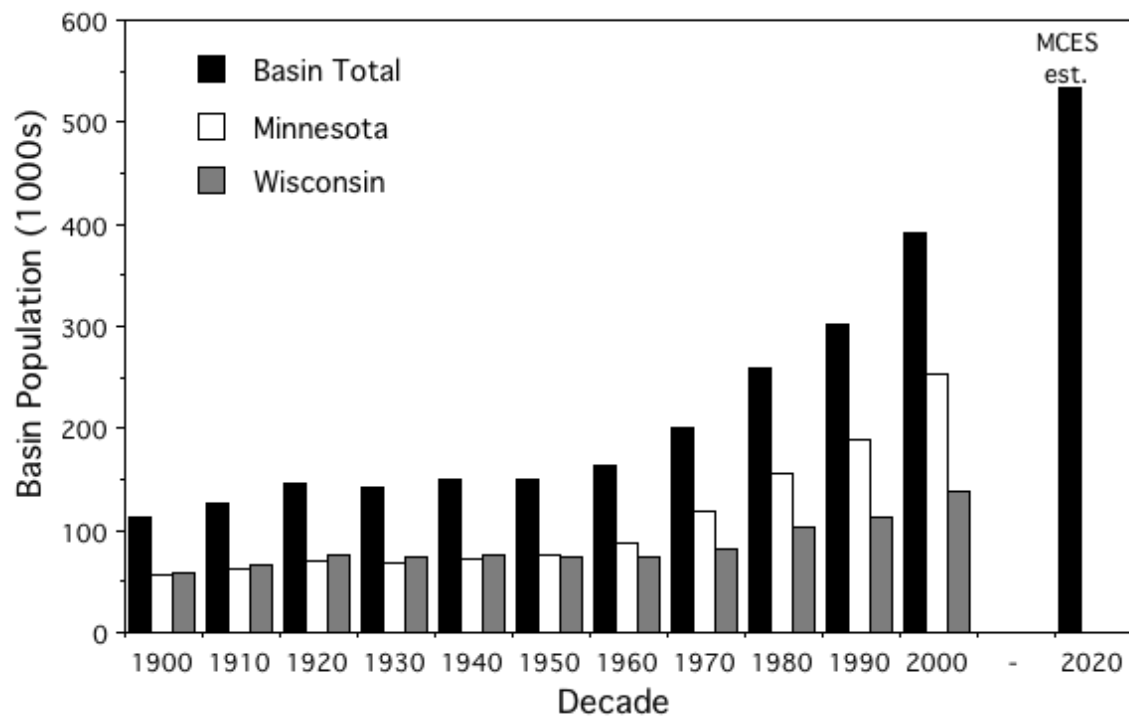


Figure 2. Decadal population estimates for 1900-2000 for entire St. Croix River basin and separated by states of Minnesota and Wisconsin.

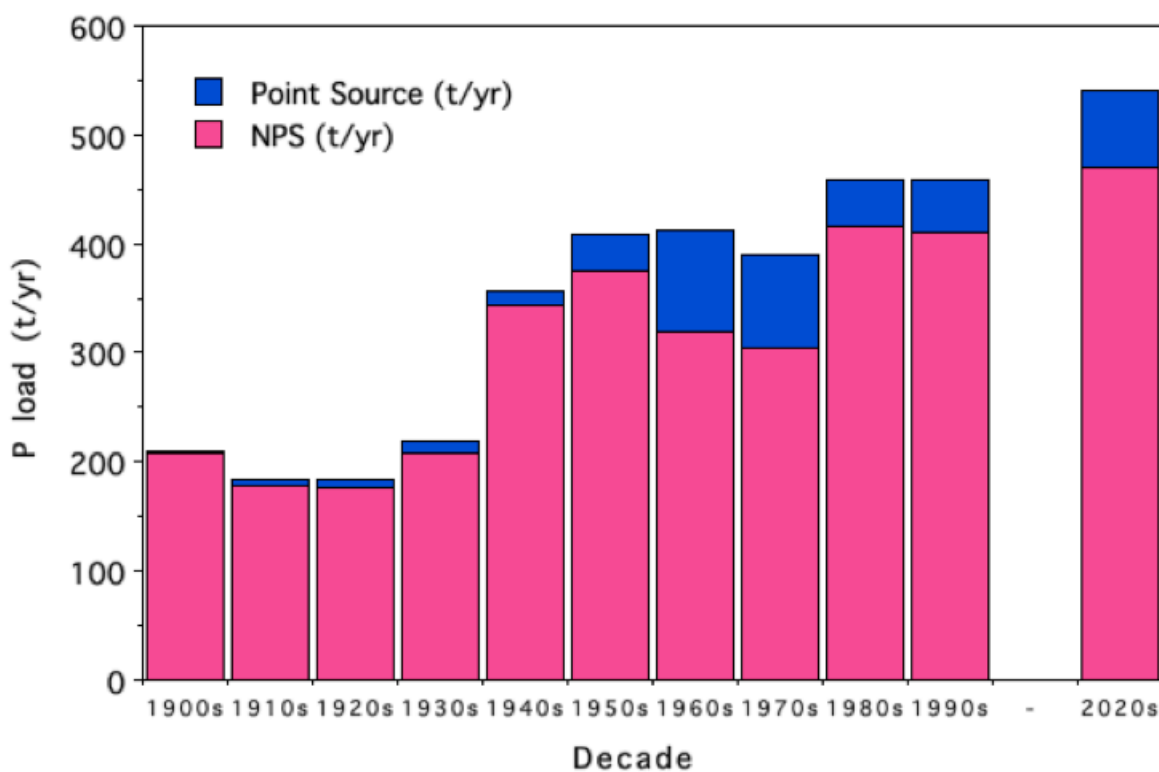


Figure 3. Phosphorus loading to the St. Croix basin. Historical total phosphorus (TP) load was estimated for Lake St. Croix (Triplett et al. 2003) and partitioned to the nonpoint source (NPS) load and the point source load.

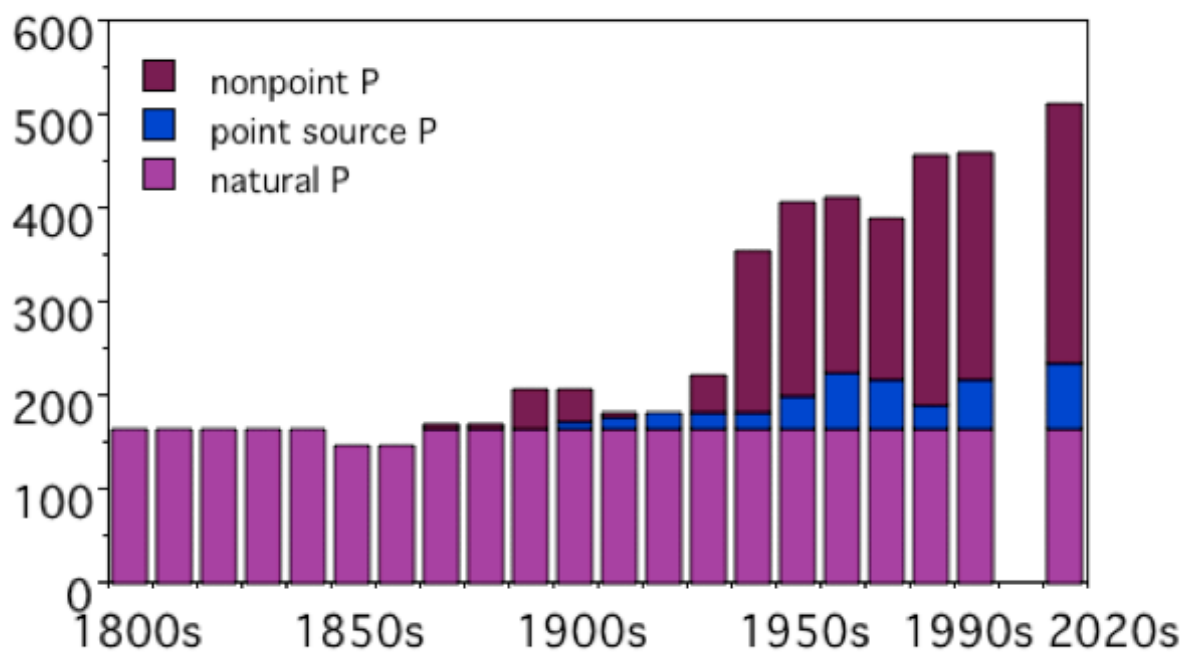


Figure 4. The cultural burden of nonpoint and point source phosphorus loads to the St. Croix River calculated by discounting the background P loading (166 tons P/yr) from the Triplett et al. (2003) model of historical total phosphorus loading to Lake St. Croix.