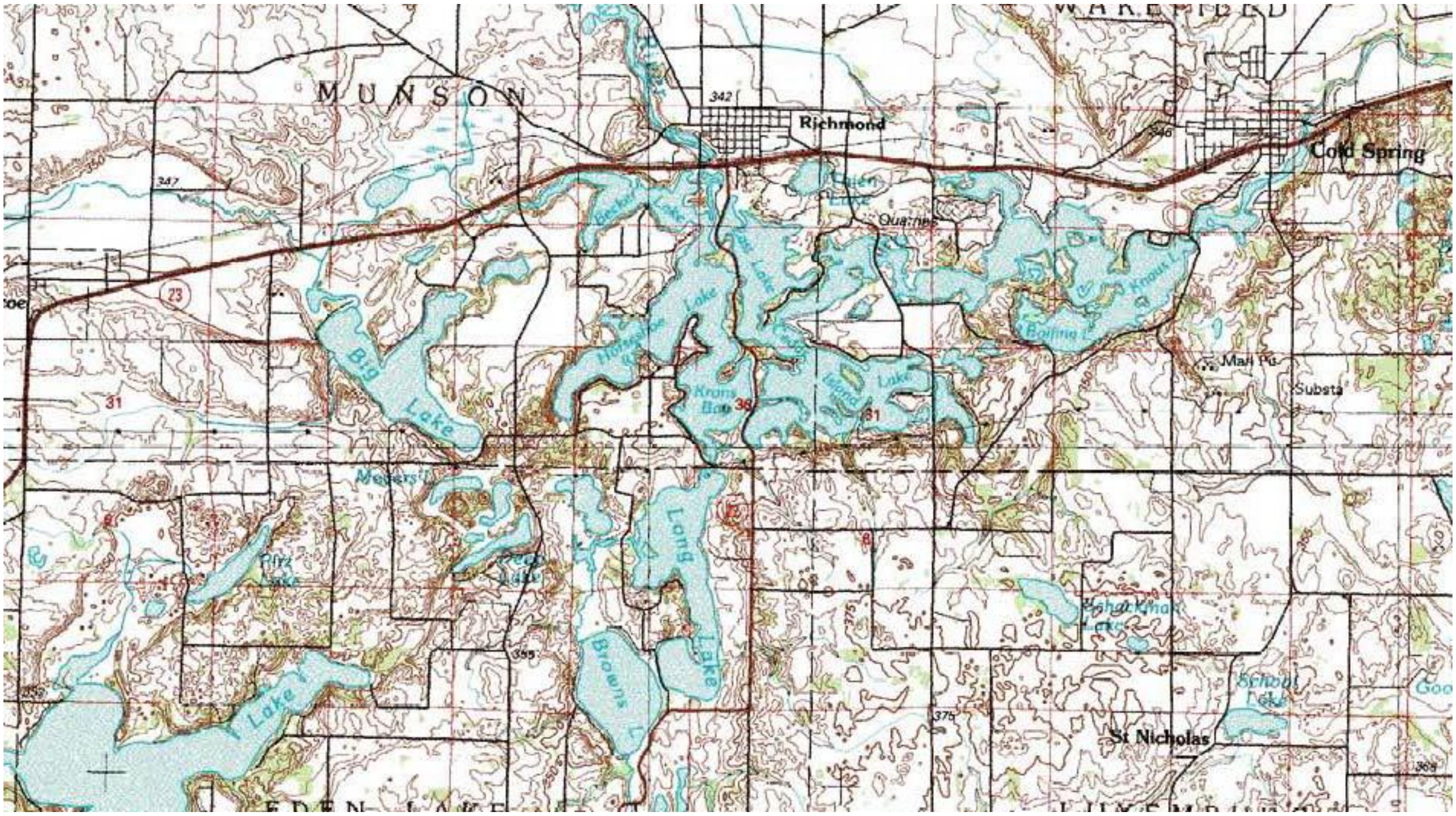
Sauk River Chain of Lakes Proposed Site-Specific Standards



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CLEAN WATER LAND & LEGACY AMENDMENT

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Introduction

The Sauk River Chain of Lakes (SRCL) is located near the Cities of New Richmond and Cold Spring in Stearns County. Several of the lakes are located directly on the Sauk River, while several others are off channel but yet are influenced by the river. A dam at the outlet of the chain near Cold Spring makes this in effect a reservoir system.

The SRCL have been extensively monitored by the Sauk River Watershed District, MPCA, citizen volunteers and other entities. Trophic status data from multiple sources was used in the 2004 303(d) assessment. The lakes were deemed impaired for nutrients and placed on the 2004 3030(d) list.

The Sauk River Watershed District in concert with the MPCA undertook development of a TMDL for the SRCL in 2007-2009 with consulting assistance from Dr. William Walker, Jr. The draft TMDL report raises several issues that prompted the MPCA and Sauk River Watershed District to seek development of site-specific standards for the lakes in the SRCL. Among the relevant concerns:

1. The SRCL is a reservoir system and the lake eutrophication standards (Ch. 7050) allow for development of site-specific standards for reservoirs;
2. Lakes directly on the flowage of the river have very short water residence time and their water quality is largely driven by the Sauk River; and
3. Several of the deep lake basins, just off channel from the Sauk River and flowage lakes, are influenced to varying degrees by their connection to the river and flowage lakes and their water quality standards may need be to ensure that a comprehensive set of water quality standards are developed to ensure that aquatic recreational and aquatic life uses are met for the SRCL.

Background

Ch. 7050 site-specific standards development as applied to Sauk River Chain of Lakes (SRCL)

Minnesota Rules Chapter 7050 (2008) subp.2a D provides for the development of site-specific eutrophication standards for reservoirs. This section reads as follows: "D. When applied to reservoirs, the eutrophication standards in this subpart and subpart 2 may be on a site-specific basis to account for characteristics unique to reservoirs that can affect trophic status, such as water temperature, variations in hydraulic residence time, watershed size, and the fact that reservoirs may receive drainage from more than one ecoregion. Information supporting a site-specific standard can be provided by the commissioner or by any person outside the agency. The commissioner shall evaluate all data in support of a standard and determine whether a change in the standard for a specific reservoir is justified. Any total phosphorus effluent limit determined to be necessary based on a standard shall only be required after the discharger has been given notice of the specific proposed effluent limits and an opportunity to request a hearing as provided in part 7000.1800."

The Sauk River Chain of Lakes (SRCL) meets the reservoir definition based on the series of lakes located along the length of the Sauk River and presence of the outlet dam near Cold Spring. The damming that served to form basins directly on the flowage dates back to 1856 when a milldam was constructed at a constriction at Cold Spring. Based on notes from a 1901 court case (excerpt in Appendix), "The effect of the dam was to raise the level of the waters of the river to a height of 7½ feet, cause the same to set back and overflow large tracts of adjacent land to a distance of sixteen miles up the river, and the formation of several lakes and ponds along its course."

Prior to the damming, maps (Appendix Figure 1) indicate a distinct linkage among the Sauk River and the various lakes that constitute the SRCL today (Appendix); however the extent of interaction/connectivity is unclear. Lakes like Horseshoe, Cedar, Schneider, and Bolfing appear as distinct lake basins on early maps; while flowage lakes like East, Zumwalde, and Great Northern were either non-existent or much smaller in size (basically part of river channel). Based on the early maps it is hard to discern the "impact" the Sauk River would have had on the hydrology and water quality on the deeper lakes that are not directly on the flowage of the Sauk River. For example, the Sauk flowed into and out of the north arm of Horseshoe Lake (similar to present-day). However, lakes like Cedar Island and Schneider drain to the Sauk River and may have been minimally influenced by the Sauk River prior to damming of the river.

The entire "chain" of lakes is comprised of several lake basins of varying shape, depth, and size. Several of the lakes are located on the mainstem of the river and include Horseshoe North, East, Koetter, Zumwalde, Great Northern, Krays, and Knaus (Figure 1). These lakes range in size from 0.25 km^2 (Horseshoe North) to 1.09 km^2 (East). These lakes are all quite shallow with mean depths ranging from 0.8 m (East) to 2.1 m (Krays) and all, with the exception of Horseshoe North, are 94% or more littoral. Because of their shallowness and size of the upstream watershed, average water residence time ranges from 0.4 days in Horseshoe North to 1.5 days in Knaus Lake and collectively is < 7 days for these "flowage" lakes (Figure 2). As a result, on an individual basis, these flowage lakes may have insufficient residence time to be deemed a "reservoir" based on 7050.0150 subpart 4 Definitions S. "Reservoir" means a body of water in a natural or artificial basin or watercourse where the outlet or flow is artificially controlled by a structure such as a dam. Reservoirs are distinguished from river systems by having a hydraulic residence time of at least 14 days. For purposes of this item, residence time is determined using a flow equal to the $122Q_{10}$ for the months of June through September, a $122Q_{10}$ for the summer months."

303(d) Assessment

The lakes of the Sauk River Chain were assessed in 2004 based on the ten most recent years of data from 1994-2003. At the time of the assessment numeric lake standards were not yet promulgated and numeric translators were used to interpret the existing narrative standard. In that assessment there was no differentiation among deep and shallow lakes and the NCHF ecoregion thresholds for listing were: TP >45 µg/L, Chl-a >18 µg/L and Secchi <1.1 m. The lakes of the chain with sufficient data for assessment were well above these thresholds and all were listed on the 2004 303(d) list. Since that time, lake eutrophication standards were promulgated and this allowed for differentiation among deep and shallow lakes. A comparison of the lake standards and range of values for the deep and shallow SRCL are in Table 1. These numeric standards were the basis for the modeling and draft TMDL report.

Table 1 Observed water quality vs. eutrophication standards for North Central Hardwood Forest Ecoregion lakes.

	Shallow Lakes*		Deep Lakes	
Variable	Criterion	Range**	Criterion	Range
Total P (ppb)	< 60	143 - 171	< 40	57 - 130
Chlorophyll-a (ppb)	< 20	61 - 67	< 14	13 - 64
Secchi Depth (meters)	> 1.0	0.6 - 0.7	> 1.4	0.9 - 1.8

* Depth < 4.5 meters or Littoral Zone > 80%;

** Range of observed 10-year means across Sauk River Mainstem lakes, 1997-2006.

Figure 1 Map of Sauk River Chain of Lakes. From Walker (2009)

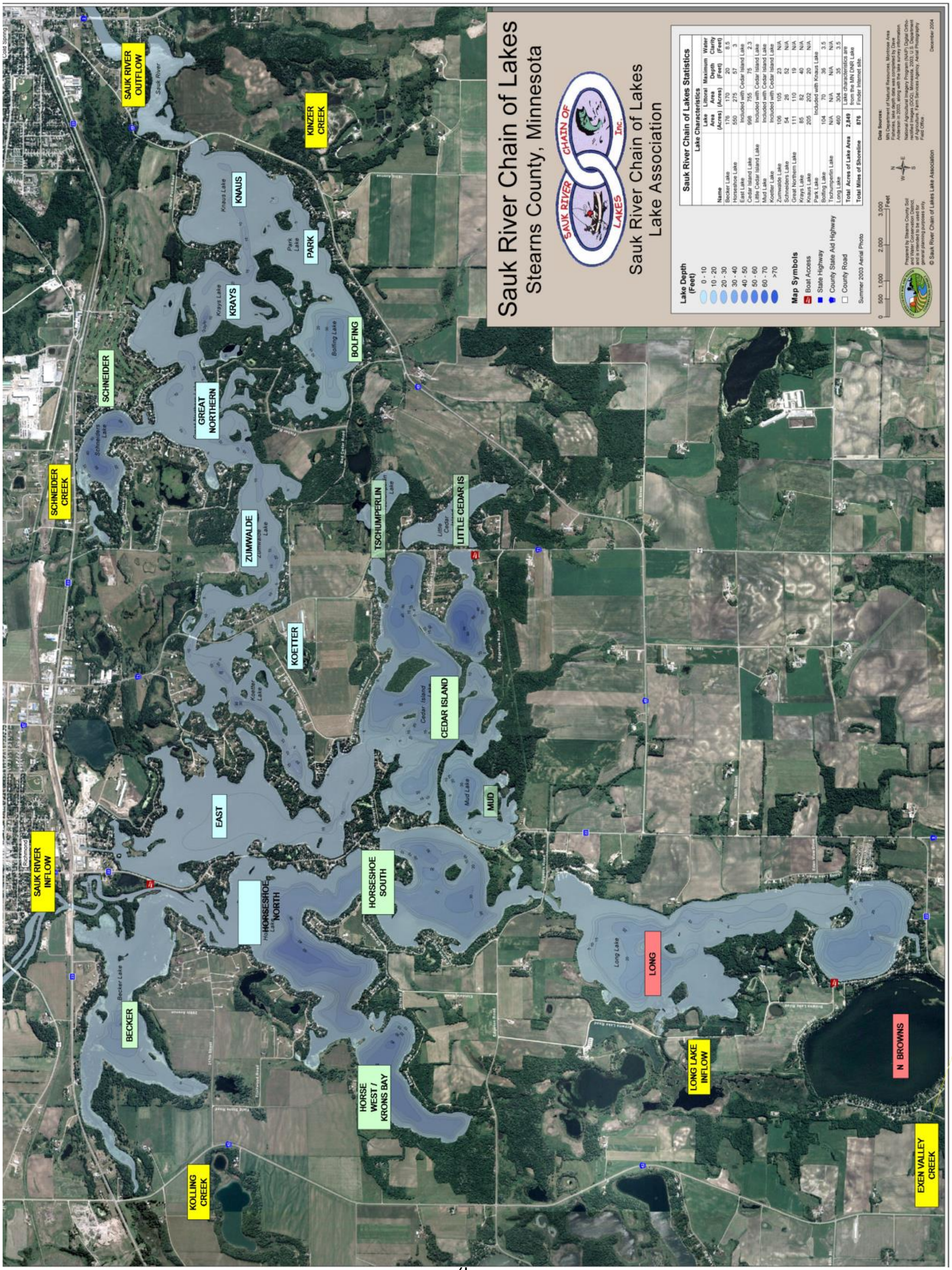
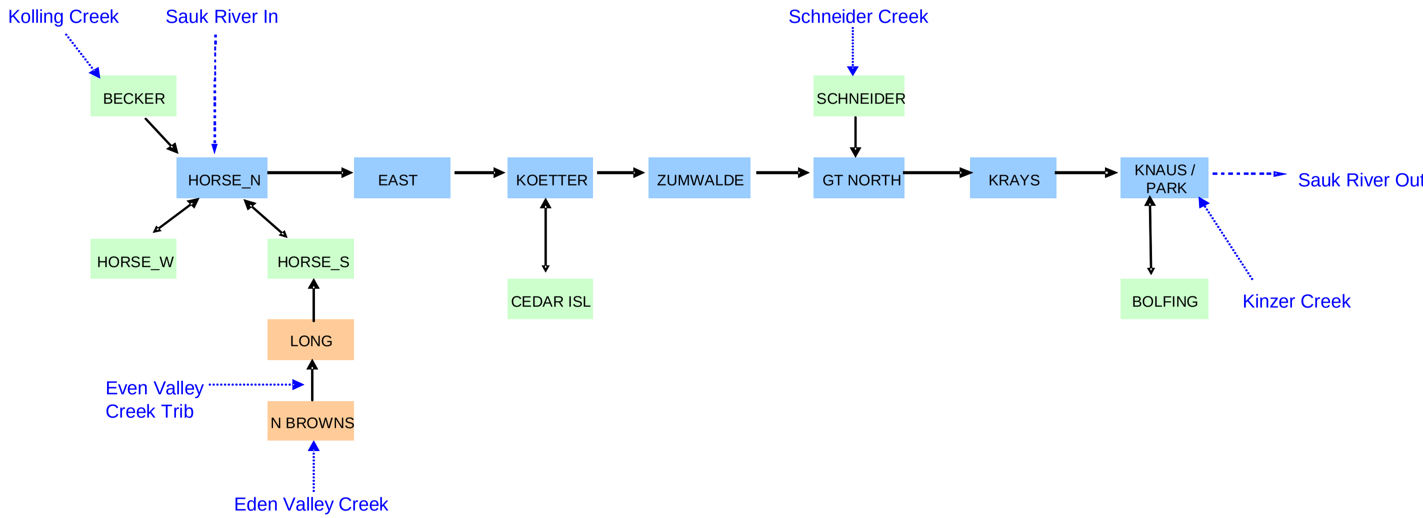


Figure 2 Stick diagram for SRCL (from Walker 2009). Symbol colors indicate different model segments.



Morphometry

Segment	Area km^2	Depth m Mean	Vol	Max	Littor. Zone	HRT** Days	Type*
01_Horse_N	0.25	1.6	0.4	4.3	64%	0.4	S
02_East	1.09	0.8	0.8	4.2	100%	0.8	S
03_Koetter	0.52	1.1	0.6	9.2	94%	0.5	S
04_Zumwalde	0.49	1.9	0.9	6.5	98%	0.8	S
05_Gt Northern	0.76	1.9	1.4	4.9	99%	1.2	S
06_Krays	0.37	2.1	0.8	12.3	96%	0.7	S
07_Knaus/Park	0.85	2.0	1.7	4.9	99%	1.5	S
08_Becker	0.66	2.4	1.6	6.1	97%	22	S
09_Horse_W	1.02	5.9	6.0	15.2	15%	4964	D
10_Horse_S	1.27	3.5	4.5	9.1	64%	33	D
11_Cedar	2.04	4.3	8.9	21.3	56%	705	D
12_Schneider	0.22	6.1	1.3	16.8	46%	70	D
13_Bolfing	0.43	4.0	1.7	10.7	63%	821	D
14_Long	1.97	3.0	6.0	10.4	68%	44	D
15_Browns	1.26	5.6	7.1	10.7	40%	54	D
Mainstem (1-7)	4.33	1.5	6.6	6.0	96%	6	S
Offline Lk (8--13)	5.64	4.3	24.0	14.7	55%	99	D
Br Long (14-15)	3.24	4.0	13.1	10.5	57%	96	D
All - Area Wtd.	13.21	3.3	43.7	10.8	69%	38	

Water Quality, June-Sept, 2002-2006

Segment	Samp. Years	TP ppb	Chla ppb	Secchi m	Algal Bloom Freq > 40	> 60	> 80
01_Horse_N	0						
02_East	0						
03_Koetter	2	175	65	0.67	88%	63%	38%
04_Zumwalde	5	161	57	0.62	60%	50%	18%
05_Gt Northern	2	177	65	0.64	88%	50%	25%
06_Krays	5	162	63	0.63	76%	50%	20%
07_Knaus/Park	5	139	69	0.70	81%	54%	30%
08_Becker	2	62	21	1.01	25%	0%	0%
09_Horse_W	2	76	35	1.11	38%	0%	0%
10_Horse_S	5	134	66	1.07	73%	48%	30%
11_Cedar	5	87	48	1.12	61%	34%	5%
12_Schneider	5	68	35	1.84	39%	15%	3%
13_Bolfing	2	90	57	1.19	88%	38%	13%
14_Long	2	83	52	0.96	50%	38%	25%
15_Browns	3	96	39	1.64	25%	25%	17%
Mainstem (1-7)		161	65	0.66	80%	53%	27%
Offline Lk (8--13)		92	47	1.13	56%	26%	10%
Br Long (14-15)		88	47	1.22	40%	33%	22%
All - Area Wtd.		114	53	1.00	60%	37%	18%

Water & Phosphorus Balance, May-Sept, 2002-2006

Source	Drainage Area km^2	Flow hm^3	Flow cfs	Load kg	Conc ppb	Load %	Runoff cm	Export kg/km^2
Sauk River Inflow	2088	136	363	25536	188	84.7%	6	12
Kolling Creek	97	11	30	496	45	1.6%	11	5
Schneider Inflow	34	3	7	211	77	0.7%	8	6
Kinzer Creek	18	3	7	182	73	0.6%	14	10
Eden Valley Creek	106	20	52	2655	135	8.8%	19	25
Trib to Long L Inlet	4	1	2	102	135	0.3%	19	25
Lakesheds	44	5	13	261	54	0.9%	11	6
Excess Runoff				118		0.4%		
Septic Systems				404		1.3%		
External Inflow	2392	177	474	29965	169	99.4%	7	13
Precipitation	13	6	17	186	30	0.6%	47	14
Evaporation		8	22				61	
Net Inflow	2405	175	469	30150	172	100.0%	7	13
Obs SR Outflow	2405	168	449	21366	127	70.9%	7	
Retention		8		3518		11.7%		

Flows & volumes in hm^3 = cubic hectameters; 1 hm^3 = 10^6 m^3 = 810 acre-feet

*Lake Classification for TP Criteria = S= Shallow (60 ppb), D = Deep (40 ppb)

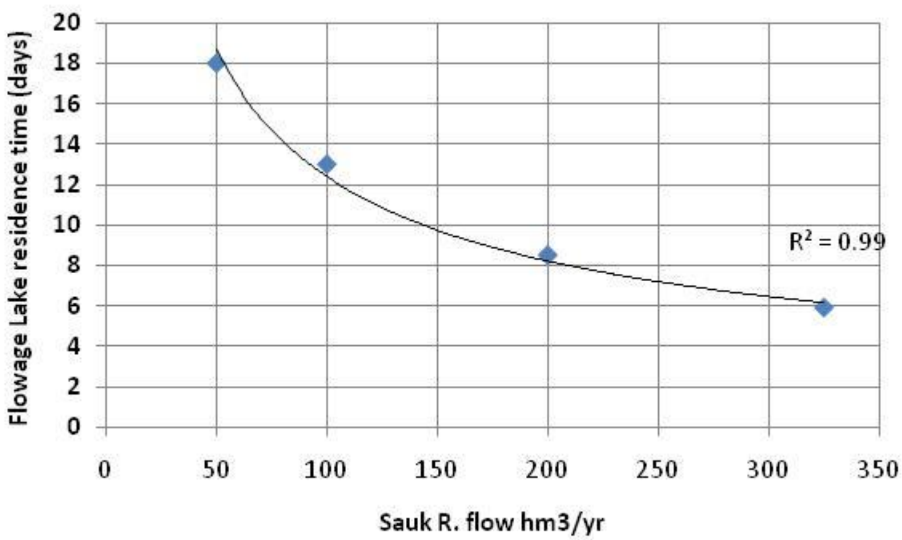
** HRT = Hydraulic Residence Time = Lake Vol / Outflow Vol x 153 days/yr, May-Sept

Actual HRT's are lower because calculation does not account for mixing among lakes.

Sauk River Flow and Water Quality

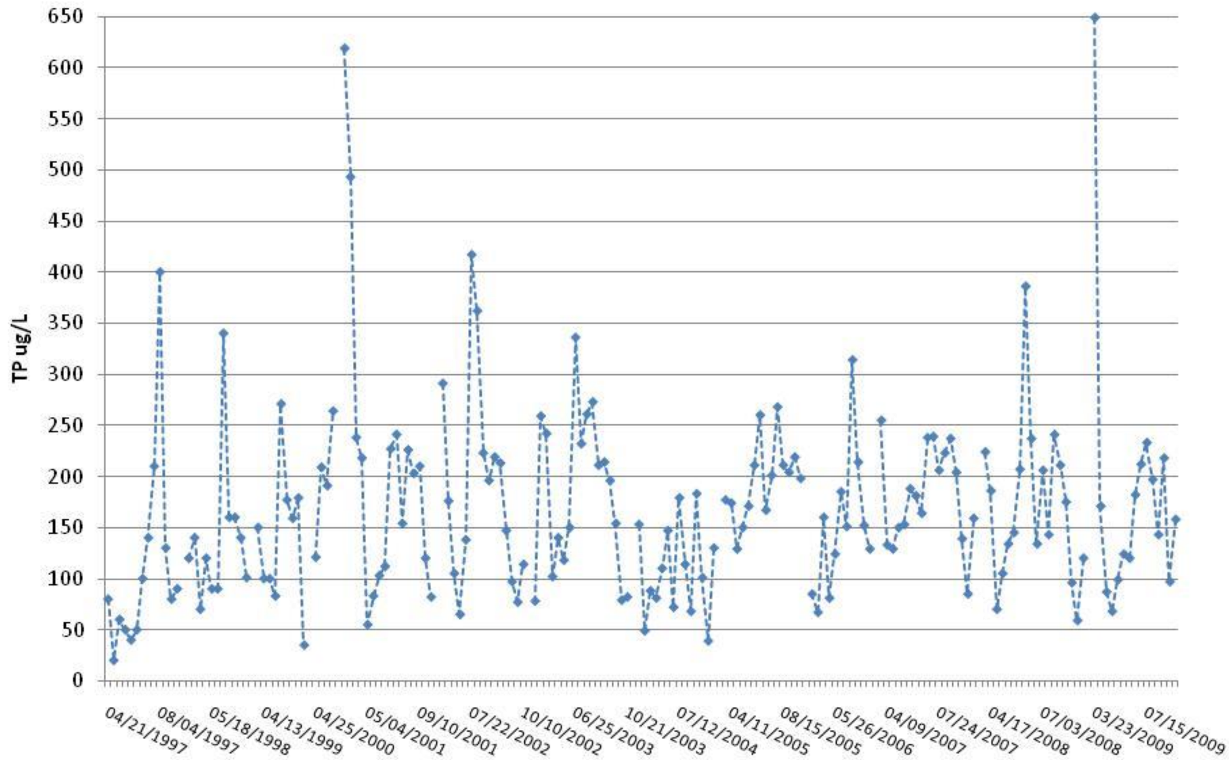
The Sauk River is the principal inflow to the SRCL and is the primary driver of the water and P budget for the overall system. Walker (2009) calculated water and P budgets based on May-Sept. 2002-2006 data and estimated that the Sauk River contributed 85% of the P load and about 77% of the water loading to the system. These percentages are even higher, on a relative basis, for the flowage lakes. Flowage lake residence time varies as a direct function of the Sauk River flows (Figure 3). At flows above ~100 HM^3/yr (112 cfs) residence time falls below 14 days – a level that has been used as a basis for defining reservoirs. For perspective, the 10^{th}, 25^{th}, and 50^{th} percentile summer-mean flows (based on the 79-year flow record) are: 53 cfs, 122 cfs and 225 cfs respectively. This implies that flowage lake residence time is less than 14 days over 75% of recorded flows but does meet the 14-day threshold at a flow of $122Q_{10}$.

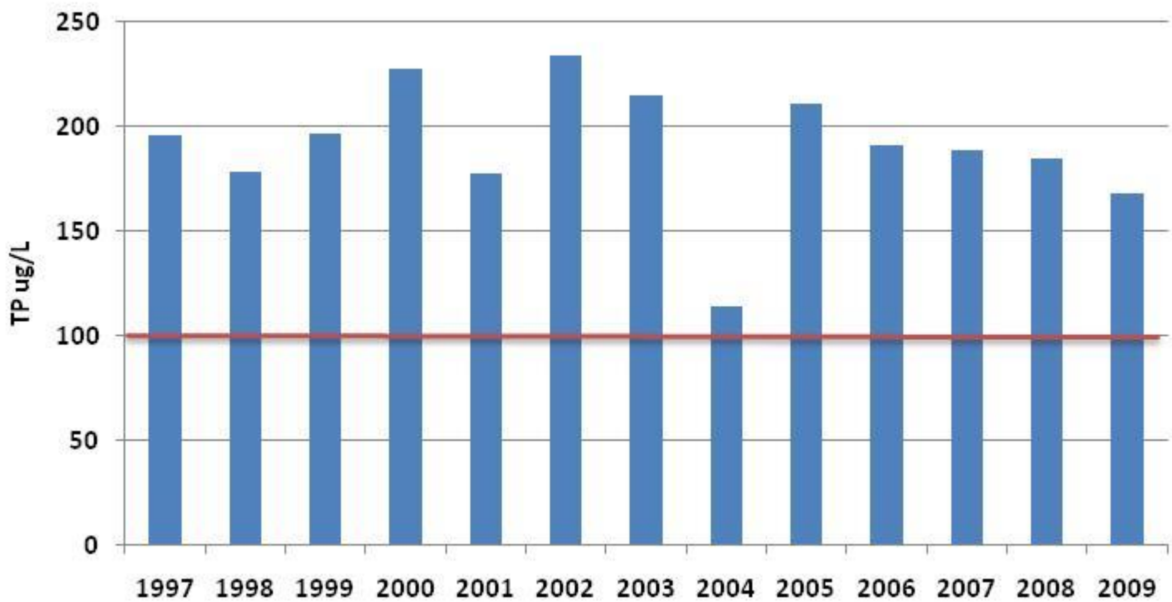
Figure 3 Flowage lake residence time as a function of Sauk River flow



TP concentrations in the Sauk River are high based on a consistent dataset collected by SRWD near Richmond. Based on data from 1997-2009, TP averaged 172 µg/L and the interquartile range was 101-211 µg/L. Walker (2009) noted a decline in TP when comparing recent data with 1980s data. A review of recent data indicates a slight decline in TP from 2006-2009; however there is no trend across the 1997-2009 timeframe (Figure 4). Summer-mean TP remains high and all years are well above the proposed river eutrophication standard for a Central River Nutrient Region (RNR) river (100 µg/L). As a frame of reference a summer-mean concentration of 191 µg/L ranks near the 70^{th} percentile for a Central RNR stream (implying 70% of monitored streams are less than this value; Appendix Figure 2).

Figure 4 Sauk River inflow total phosphorus (TP) individual and summer-mean concentrations: 1997-2009.





Results and Discussion

The water quality analysis and modeling conducted by Walker (2009) and previous efforts (e.g. Wilson 2004) provide much of the background on the need for site-specific standards for the SRCL. This work has been augmented with more recent data from 2005-2010. Collectively they provide justification for the site-specific standards for the SRCL.

Lake segments and water quality

The SRCL was divided into 15 segments for purposes of summarizing the data and modeling (Figure 2). Morphometry and water quality characteristics of each segment are summarized, along with average water and phosphorus balances for the 2002-2006 baseline period used for TMDL development. The segment network has been designed to reflect morphometry, data availability, and observed spatial variations in water quality. It is similar to one developed in a previous modeling effort by Wilson et al. (2004).

The segments are assembled into three groups, as indicated by the color codes in Figure 2. A general description as provided by Walker (2009) is as follows:

1. **Sauk River Mainstem Segments**: Northern Horseshoe, East, Koetter, Zumwalde, Great Northern, Krays, Park, and Knaus. These segments are dominated by inflows from the Sauk River. They have a combined mean hydraulic residence time of only 7 days, mean depth of 1.5 meters, a high watershed to lake area ratio (555:1). Monitored inflows include the Sauk River at Richmond and Kinzer Creek. Baseline phosphorus concentrations range from 139 to 177 ppb, as compared with the 60 ppb criterion for shallow lakes (Table 1). While longitudinal gradients are occasionally observed along the river channel between the inflow and outflow, the mainstem segments tend to have similar mean phosphorus, chlorophyll-a, and transparency levels. These lakes will be referred to as the “flowage” lakes.

2. **Sauk River Lake Segments**: Becker, Southern Horseshoe, Western Horseshoe (Kron’s Bay), Cedar Island, Schneiders, and Bolfing. These lakes are driven to various degrees by the Sauk River, local tributaries, and shoreline sources. Monitored local sources include the inflow to Becker Lake (Kolling Creek) and the inflow to Schneiders Lake (unnamed). The 62-134 ppb range in baseline mean TP concentrations (Table 1) reflects the extent of mixing with the Sauk River mainstem. Modeling results indicate minimal mixing between the Sauk River and two of the tributary lakes (Becker and Schneiders). With the exception of Becker, the 40 ppb TP criterion for deep lakes is applicable to each of these segments. As compared with the SR mainstem, modeling these segments is more challenging because they are influenced by sources that are more difficult to evaluate, including local tributaries, lakeshed and shoreline runoff, septic tanks, and hydraulic exchanges with the mainstem segments. These lakes will be referred to as the “non-flowage” lakes.

3. **Eden Valley Lake Segments:** North Browns and Long. As distinct from the other segments, these are not influenced by inflows from the Sauk River, but by inflows from Eden Valley Creek, lakesheds, and shoreline sources. Baseline TP concentrations in both lakes (96 and 83 ppb,

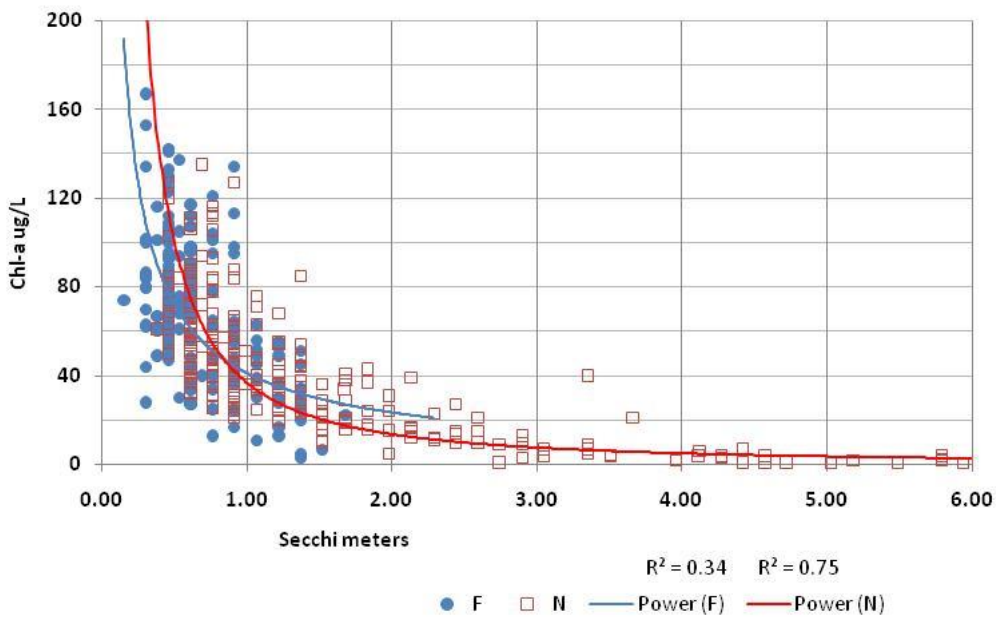
respectively) exceed the 40 ppb criterion for deep lakes. It is estimated that Eden Valley Creek at the inflow to North Browns accounts for 90% of the total P load to both lakes, which reflects a high watershed area to lake area ratio (90:1).

Water quality patterns and interrelationships

It is important to characterize the relationships among the trophic status variables for the SRCL and see how this compares to lakes that were used to develop the lake eutrophication standards. The previous datasets used in development of the draft TMDL and more recent data from 2005-2010 are useful for this purpose.

There are distinct differences in the range of Secchi and Chl-a values among the flowage vs. the non-flowage lakes. Flowage lake Secchi values range from about 0.5-1.5 m and average 0.7 m. Chl-a range from 20-120 µg/L (ppb) on most dates and average 69 µg/L. The non-flowage lakes exhibit a wide range in Secchi from 0.5-6.0 m and average 1.7 m. Chl-a is highly variable ranging from <5 -120 µg/L and averaging 43 µg/L. The relationship among Secchi and Chl-a is quite strong for the non-flowage lakes and is quite comparable to that seen in the ecoregion reference lakes (Heiskary and Wilson 2005). The relationship is somewhat poorer in the flowage lakes, where high TSS from the river and resuspension of bottom sediments also serve to reduce transparency (Walker 2009).

Figure 5 Individual Secchi and Chl-a measurements from flowage (F) and non-flowage (N) SRCL based on 2005-2010 data.



Summer average data for the flowage vs. non-flowage lakes also shows some distinct patterns. The flowage lakes with consistently high TP exhibit high Chl-a over most summers. The flowage lakes exhibit distinctly higher TP and Chl-a, as compared to the non-flowage lakes (Figure 6). Declines in summer-mean Chl-a are evident as TP falls below 100 µg/L.

The flowage and non-flowage lakes exhibit a very strong relationship among mean and maximum Chl-a (Figure 7), which is similar to the ecoregion reference lakes (Heiskary and Wilson 2008). This suggests that as summer-mean TP and Chl-a decline, so will very severe blooms, as reflected by maximum Chl-a. As summer-mean Chl-a declines below 40-50 µg/L the risk of Chl-a maxima above 80 µg/L (a level noted as very severe nuisance blooms for the SRCL) is reduced.

Figure 6 Summer-mean total phosphorus and chlorophyll-a for flowage (Flow) and non-flowage (Non) SRCL: 2005-2010

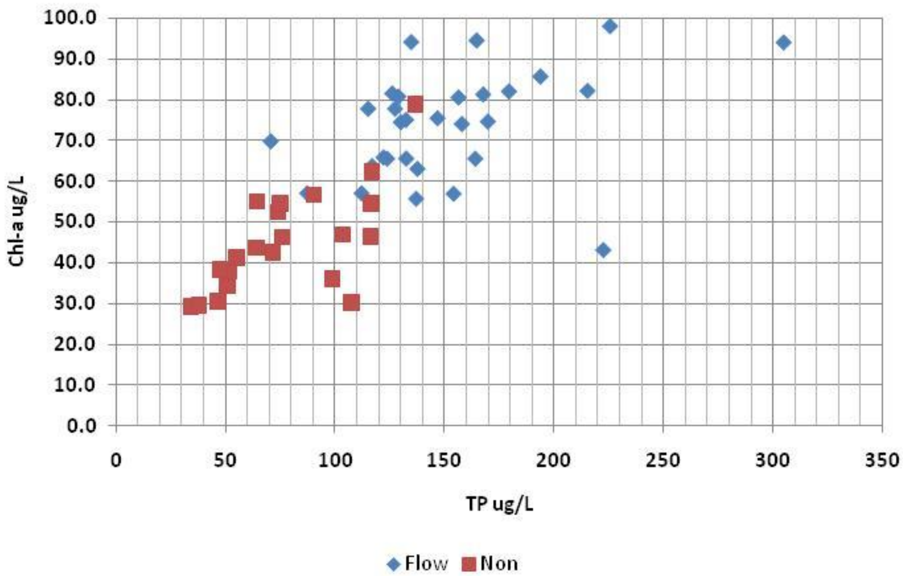
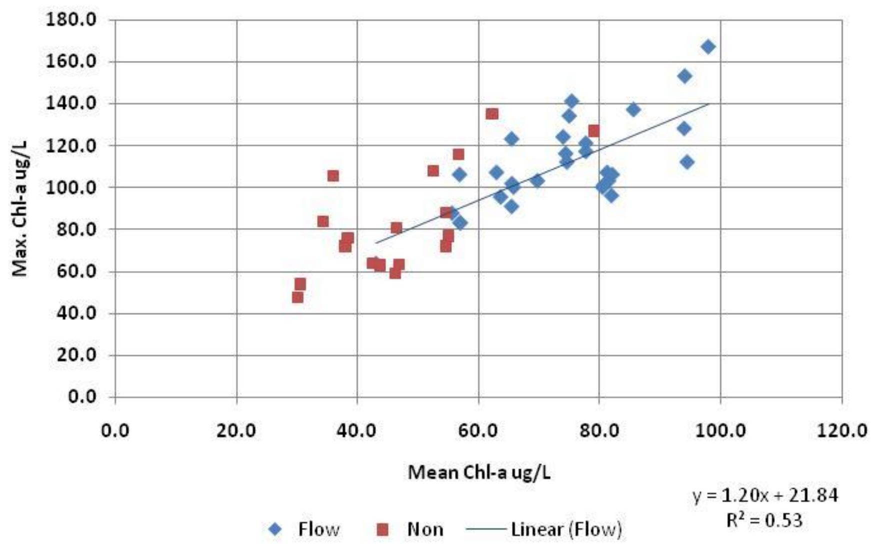
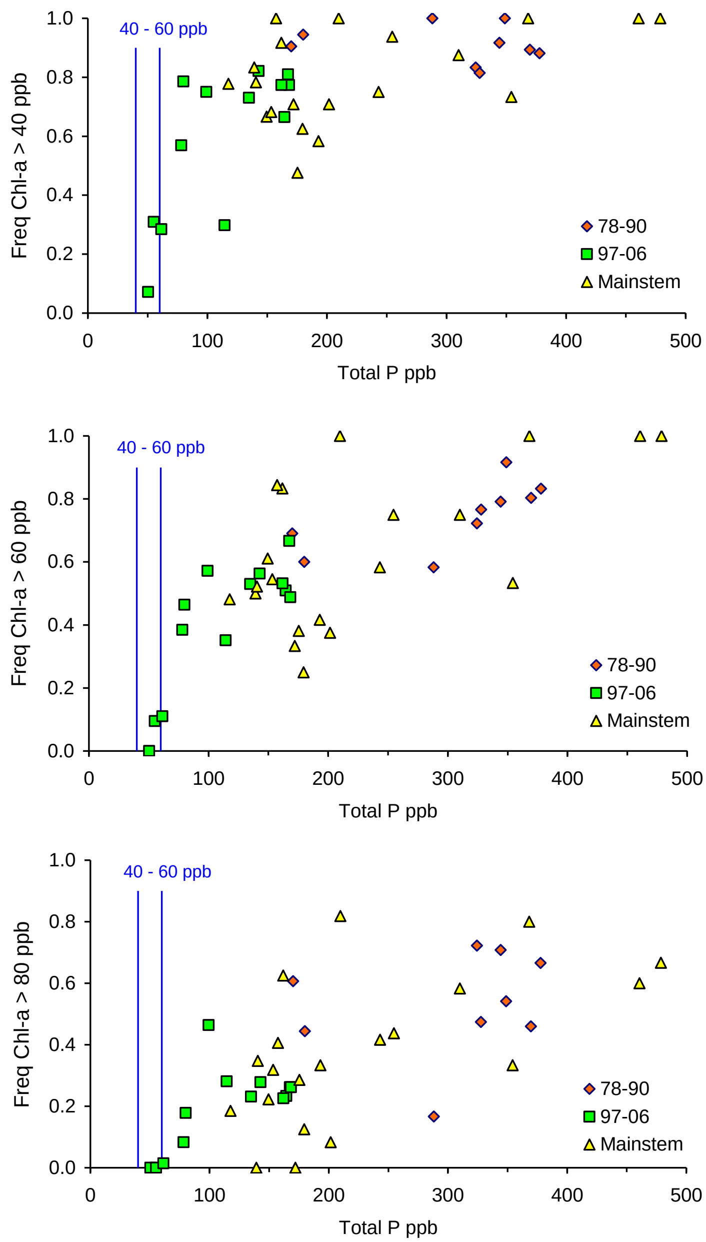


Figure 7 Summer-mean and maximum chlorophyll-a for flowage and non-flowage SRCL: 2005-2010



Walker (2009) demonstrated correlations between TP concentrations and algal bloom frequencies across lakes and time periods (Figure 8). These patterns are generally consistent with those observed in other Minnesota lakes and were used in development of the lake eutrophication standards (Heiskary & Wilson, 2008). Bloom frequencies became increasingly sensitive to TP concentrations as the latter decreased from historical levels (>200 ppb) and approached the 40-60 ppb range in a few cases. Bloom frequencies were relatively low in non-flowage lakes with mean TP values in the 40-60 ppb range (Becker, Horseshoe West, and Schneider). While historical improvements are evident, further significant reductions in TP would be needed to achieve the eutrophication standards in most segments.

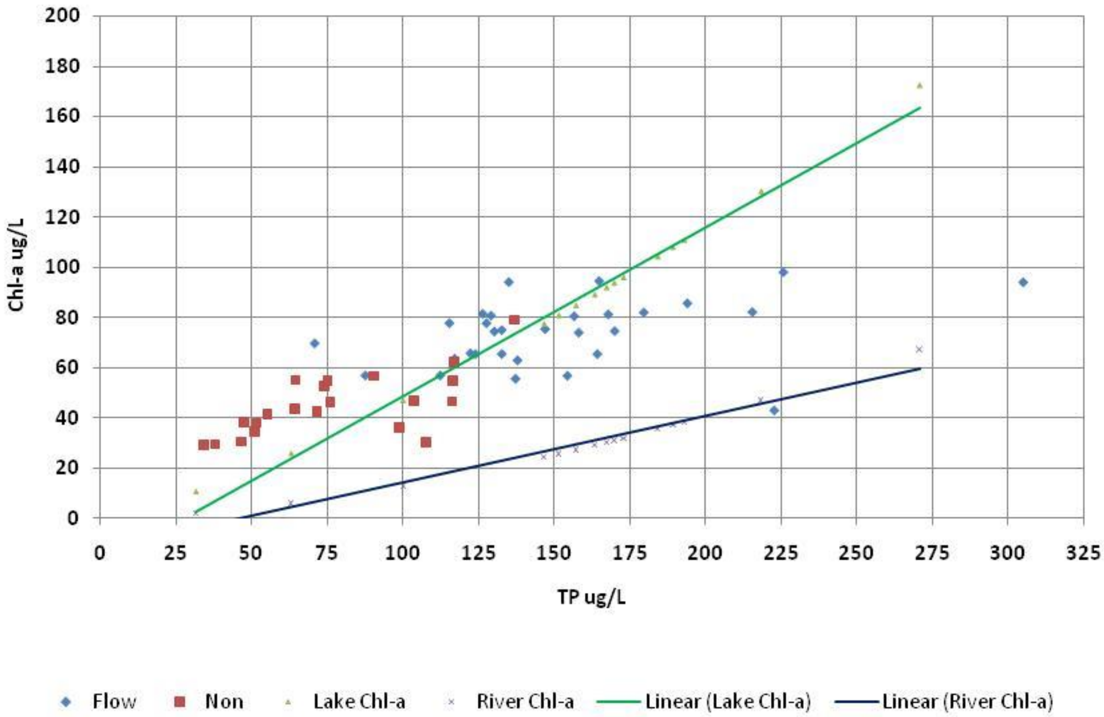
Figure 8 TP and nuisance bloom (>40, >60 & >80 µg/L) frequencies for SRCL flowage and non-flowage lakes (Walker 2009).



Squares & diamonds reflect different lakes & periods (1978-1990) vs. (1997-2006)
Triangles reflect individual yearly means for all mainstem sites combined, 1978-2006.
Bloom freq, (Chla > 40, 60, 80 ppb) computed from >= 5 samples, June-September.
Vertical lines show MPCA phosphorus criterion for shallow (60 ppb) & deep (40 ppb) lakes.

Given the strong influence of the Sauk River on the water quality of the flowage lakes, and to some degree the non-flowage lakes, it is useful to consider Sauk River water quality data and examine TP & Chl-a relationships for flowage and non-flowage lakes, relative to standard regressions for Minnesota lakes and rivers. In terms of in-lake TP and Chl-a relationships, the SRCL flowage and non-flowage lakes cluster about the Minnesota's ecoregion reference lakes regression line (Figure 9). At higher TP, the flowage lakes yield slightly lower Chl-a per unit TP as compared to the lake regression and at lower TP the non-flowage lakes produce slightly more Chl-a per unit TP. Overall the SRCL relate more closely to the lake regression as compared to the river regression. The SRCL, flowage and non-flowage combined, yield a R^2 =0.60, which is slightly lower than the established lake and river regressions at R^2=0.87.

Figure 9 SRCL flowage and non-flowage lake summer-mean TP & Chl-a (2005-2010) as compared to Minnesota lake and river regression equations. Linear scale shown but regressions are log-log.



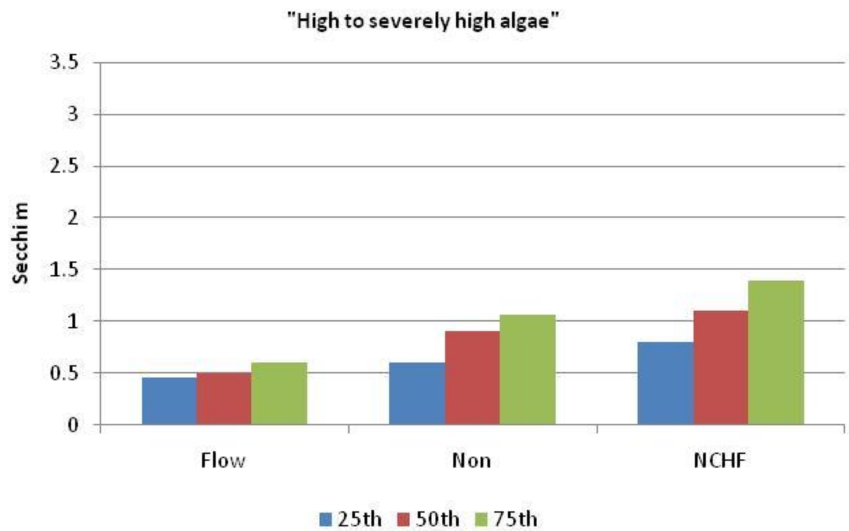
User perceptions

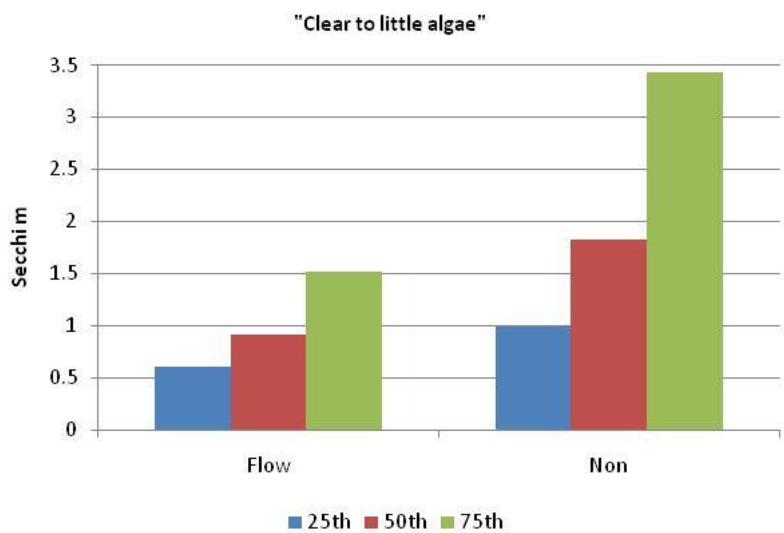
Algal bloom intensity and frequency are important drivers in how lake users perceive water quality. Regional differences in user perceptions are evident for Minnesota and were one of the factors used to derive the ecoregion-based standards (Heiskary and Wilson 2008). In general, for NCHF ecoregion lakes, Chl-a >20 µg/L = mild bloom, >30 µg/L = nuisance bloom and >60 µg/L = very severe nuisance blooms. Lake eutrophication standards seek to minimize bloom intensity and frequency and account for regional variation in perceptions of blooms.

User perceptions of "physical appearance" and "recreational suitability" are routinely recorded by CLMP volunteers in conjunction with Secchi disk measurement. As with Chl-a there are distinct regional patterns. Previous analysis of statewide user perception data is summarized in Heiskary and Walker (1988) and Smeltzer and Heiskary (1990). The median Secchi associated with the recreational suitability measures “no swim or no use” was 1.1 m with an interquartile range from 0.8-1.4 m for NCHF ecoregion users and the median Secchi associated with the physical appearance of “high to severely high algae” was 0.9-1.0 m (Smeltzer and Heiskary 1990).

There are differences in user perception of what constitutes “high to severely high algae” and “clear to little algae” in the SRCL flowage vs. non-flowage lakes (Figure 10). In general, Secchi transparencies <0.7 m in the flowage lakes and <1.0 m in non-flowage lakes are associated with “high to severely high algae.” These ranges of transparency are lower than the typical range based on user perceptions across the NCHF ecoregion (Figure 10). On the other end of the scale, perceptions of “clear to little algae” are associated with transparencies of 0.6-1.5 m and 1.0-3.4 m for the flowage and non-flowage lakes respectively.

Figure 10 Sauk River Chain of Lakes user perception of physical appearance relative to Secchi transparency for flowage and non-flowage lakes. Based on available CLMP data from 2005-2010. IQ range for NCHF volunteers drawn from Heiskary and Wilson (2008).





While we did not have direct linkage among Chl-a and user perception for the flowage and non-flowage lakes one can relate the Secchi ranges in Figure 10 to Chl-a based on the distribution of values in Figure 5. The Chl-a interquartile (IQ) range associated with flowage lake Secchi values of 0.6 m or lower is 67-102 µg/L, with a median of 80 µg/L. The corresponding Chl-a IQ range for non-flowage lakes with Secchi <1.1 m is 40-71 µg/L with a median of 54 µg/L. For the flowage lakes, this implies that that Chl-a should remain below 60-80 µg/L a majority of the time to minimize the risk of Secchi values of 0.6 m or lower and the perception of "high to severely high algae". For the non-flowage lakes, Chl-a should remain below 40-50 µg/L a majority of the time to avoid the risk of Secchi values 1.1 m or lower and the perception of "high to severely high algae".

Model projections relative to lake standards and river inflow P

Table 1 provides a comparison of current trophic status measurements for the flowage and non-flowage lakes relative to the shallow and deep lake standards. In each case current concentrations are well above the standards.

Walker (2009) provides a detailed analysis of loading required to meet Minnesota's lake eutrophication standards for the lakes of the SRCL. Some of the findings from the BATHTUB simulations bear repeating here, as they are pertinent to the development of site-specific standards.

"Results generally reflect the spatial distribution and magnitudes of the inflow TP loads, hydraulic loads, mixing, and time scale of phosphorus retention." Basic patterns include:

1. Responses to variations in flow are generally low (< 5% lake TP response to 20% decrease in flow). This indicates that model results are insensitive to uncertainty in the estimated inflows from local tributaries and lakesheds. Results tend to be more sensitive to flow in segments that have lower hydraulic loads and are isolated from the mainstem (Bolfing, Cedar, and Horseshoe West).
2. Mainstem TP concentrations are nearly proportional to the SR inflow concentration (>18%) and insensitive to the other sources (<2%). In contrast, Becker, Schneider, Long, & Browns are driven by local tributaries and independent of the SR inflow concentration or flow. Others are driven by both Sauk River and local sources, depending on the extent of mixing with the mainstem lakes.

3. Variations in model parameters (settling rate, exchange rates) have very little impact on predicted TP concentrations in the mainstem segments because of high flushing rates. Parameter variations impact other lake segments to various degrees, depending on hydraulic load and proximity to the mainstem."

Since the Sauk River contributes ~85 percent of the TP loading to the SRCL it is appropriate to frame TMDL reductions primarily based on Sauk River inflow P and loads. In turn, the Sauk River inflow P should be considered while establishing site-specific standards for the SRCL. Figure 11, which relates lake response to reductions in tributary TP, is useful for this purpose.

Figure 11 Lake responses to reductions in tributary TP concentrations. BATHTUB model predictions from Walker (2009)

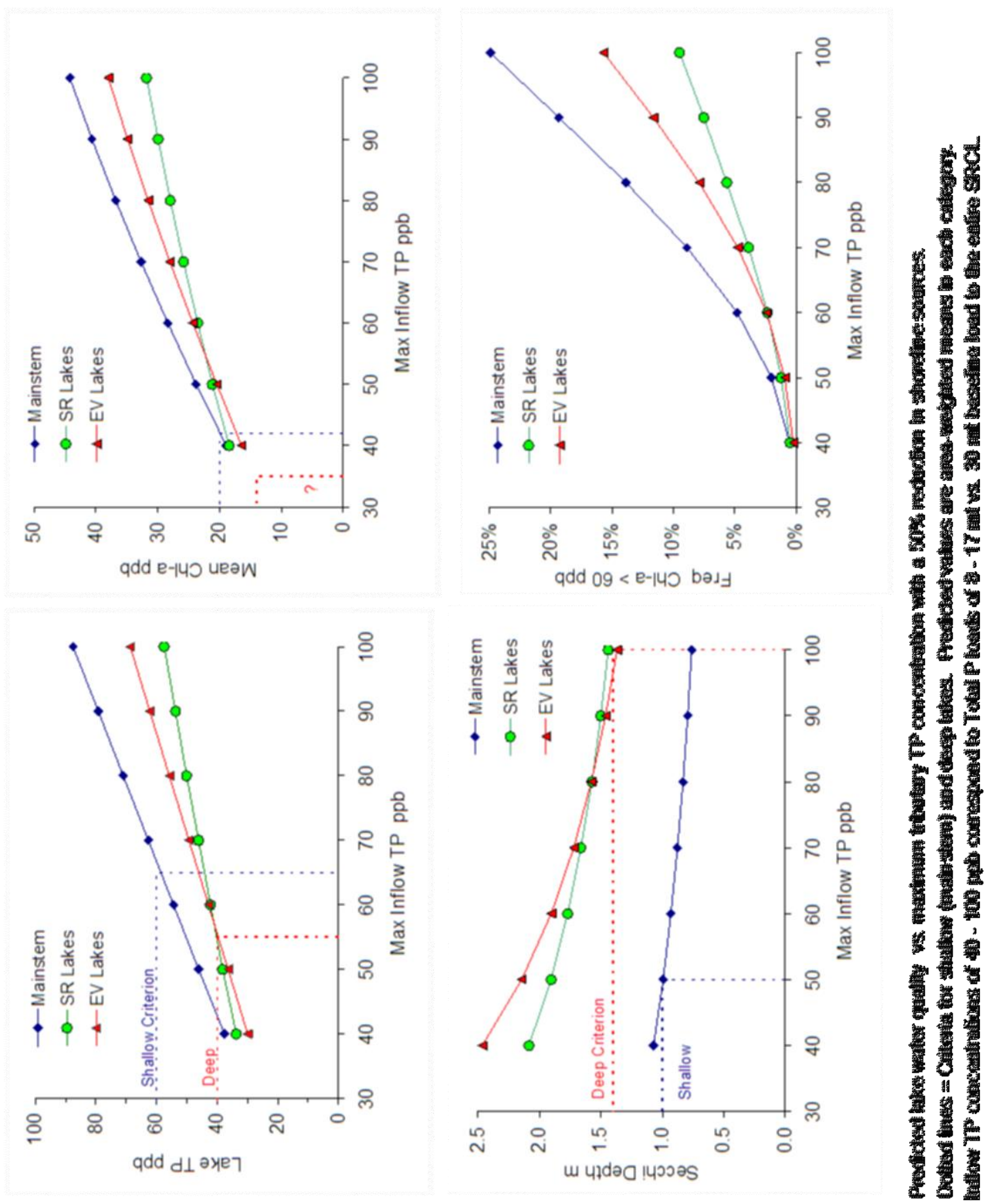


Figure 11 indicates exceedingly low inflow TP of 65 µg/L and 55 µg/L would be required to meet the deep (40 µg/L) and shallow (60 µg/L) lake standards for the non-flowage and flowage lakes, respectively.

For Central RNR streams this corresponds to approximately the 25th and 15th percentiles respectively (Appendix Figure 1). This analysis also suggests that even lower inflow TP may be required to meet the Chl-a standards (Figure 11). The analysis does, however, indicate that reductions in the frequency of severe nuisance blooms (>60 µg/L) may be attained over the range of inflow P tested. For example at an inflow TP of 100 µg/L severe nuisance blooms would be reduced to 25 percent of the summer in the flowage and 11 percent in the non-flowage lakes (Figure 11).

Summary and proposed site-specific standard for SRCL

The SRCL is an assemblage of deep and shallow basins that are either directly on the Sauk River ("flowage") or off the flowage but have a direct connection to the Sauk River ("non-flowage"). The following considerations were the primary basis for the proposed site-specific standards.

1. The SRCL is a reservoir system and it is appropriate to propose site-specific eutrophication standards.
2. Site-specific standards must protect beneficial uses. For the SRCL and lake eutrophication standards, the emphasis is on aquatic recreational use. While summer-mean Secchi and Chl-a are the standard response variables (standards), the frequency and intensity of algal blooms is a recognized metric routinely used in modeling projections, TMDLs, and was a primary metric used in development of Minnesota's lake eutrophication standards (Heiskary and Wilson 2005). Because of the factors included in this report it is appropriate to establish site-specific eutrophication standards for the SRCL that focus on reduction in the frequency and intensity of algal blooms so that aquatic recreational uses are protected for a majority of the summer as is the case in the adopted lake eutrophication standards.
3. Based on user perception data in the flowage lakes, Chl-a should remain below 60-80 µg/L a majority of the time to minimize risk of Secchi values of 0.6 m or lower and perception of "high to severely high algae." For the non-flowage lakes, Chl-a should remain below 40-50 µg/L a majority of the time to avoid risk of Secchi values 1.1 m or lower and perception of "high to severely high algae." On the other end of the scale, perceptions of "clear to little algae" are associated with transparencies of 0.6-1.5 m and 1.0-3.4 m for the flowage and non-flowage lakes respectively.
4. The flowage lakes are very shallow and as a result of the large upstream watershed (555:1) water and phosphorus loading rates are very high and water residence time is very low (less than 14 days at flow of 112 cfs or greater) over 75% of recorded flows. This is a large deviation from lakes used to establish the general eutrophication standards.
5. The non-flowage lakes are influenced by phosphorus and water loads that enter the flowage lakes and any modification of standards for the flowage lakes requires that non-flowage lakes be adjusted accordingly to ensure appropriate standards are developed.
6. Since the 1980s phosphorus load reductions from upstream WWTFs and to some degree nonpoint sources, have occurred and resulted in lower P in the Sauk River and flowage lakes. These reductions did not yield significant changes in summer-mean Chl-a; however, the frequency and intensity of nuisance algal blooms did decline and has been noticed by lake users.
7. BATHTUB model projections were developed to predict reductions needed to achieve deep (40 µg/L for non-flowage) and shallow (60 µg/L for flowage) lake standards and employed scenarios

for the Sauk River of 40, 60, and 100 µg P/L (Figure 11). River concentrations of 40 to 60 µg/L are more consistent with streams in the Northern RNR (rank from 40th-70th percentiles) as compared to the Central RNR, where these concentrations rank near the 10th-15th percentiles (Appendix Figure 1).

8. It is exceedingly difficult to attain river P concentrations of 40-60 µg/L in a large, highly agricultural watershed such as the Sauk. An inflow P concentration of 100 µg/L is equal to the proposed river eutrophication standard for the Central RNR (Heiskary et al. 2010). A TP of 100 µg/L ranks at the 35th percentile for rivers for the Central RNR and represents a significant reduction from the current Sauk River concentrations in the 150-200 µg/L range (Figure 4). Model projections based on 100 µg/L river inflow are provided in the Appendix, Figure 2.
9. User perceptions as related to Secchi transparency (Figure 10) and algal bloom frequency, recognition that the SRCL is a reservoir system, the extremely large contributing watershed and very short residence time, the role of the Sauk River in determining in-lake TP, Chl-a and Secchi for the flowage vs. the non-flowage lakes (Figure 11), and BATHTUB model projections (Appendix) were the multiple lines of evidence used to develop the proposed site-specific standards (Table 2). The frequency of severe nuisance blooms is included as a metric for evaluating progress and communicating a desired outcome from achieving these standards. A TP of 55 µg/L for the non-flowage lakes keeps frequency of Chl-a >60 µg/L <10 percent of the summer, allows for summer-mean Secchi = 1.4 m, and is attainable in most basins with a Sauk River inflow of 100 µg/L (Figure 11). A TP of 90 µg/L for the flowage lakes keeps frequency of Chl-a >60 µg/L <25 percent of the summer, allows for summer-mean Secchi = 0.8 m, and is attainable with a Sauk River inflow of 100 µg/L (Figure 11). Based on user perceptions the proposed site-specific standards are supportive of beneficial uses for these lakes. Applicable standards for other SRCL lakes noted as well in Table 2. All standards are expressed as summer-means not to be exceeded.
10. The proposed Chl-a standards for the flowage and non-flowage lakes are based on BATHTUB model predictions and need to minimize the frequency of severe nuisance blooms. These summer-mean Chl-a values are higher than values predicted based on a standard MPCA regression commonly used to predict Chl-a as a function of TP (e.g., Figure 9). This suggests attainment of the proposed TP standards may result in Chl-a lower than the proposed standards; however, it remains difficult to project a precise response until in-lake TP is reduced down to the range of the proposed site-specific standards.
11. Because of their exceedingly short residence and location on the Sauk River main-stem the flowage lake standards should be assessed across all flowage lakes collectively. Standard sites for future monitoring and assessment should be established (preferably consistent with historic monitoring sites). Data averaged across these sites will provide the basis for assessing condition and progress toward achieving water quality standards. The non-flowage lake standards may be applied individually since they have adequate residence time to be assessed as lakes, their interaction with the Sauk River varies, and there is the possibility of some lake-specific strategies for achieving water quality standards. Standard monitoring sites should be established for continued monitoring and assessment of these basins as well.

Table 2 Sauk River Chain of Lakes Proposed Site-specific Standards. Expressed as summer mean values.

Lakes	TP (µg/L)	Chl-a (µg/L)	Secchi (m)	Notes
Flowage	90	45	0.8	Shallow
Non-flowage	55	32	1.4	Deep
Becker	60	20	1.0	CHF shallow lake standards
Schneider	40	14	1.4	CHF deep lake standards
Long & N. Browns	40	14	1.4	CHF deep lake standards

Flowage lakes = Horseshoe North, Koetter, Zumwalde, Great Northern, Krays and Knaus/Park
Non-flowage lakes = Horseshoe, Cedar and Bolfing

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Appendix

Excerpt from 1901 court case that provides background on the damming of Sauk River at Cold Spring and describes formation of the lakes.

PHILIP H. KRAY v. ANTON MUGGLI and Others.[1]

June 28, 1901.[2]

Nos. 12,647—(152).

Diversion of Water—Prescriptive Right.

Where the flow of a stream of water has been diverted from its natural channel, or obstructed by a permanent dam, and such diversion or

[1] JACOB FRIEDMAN v. ANTON MUGGLI and Others.

June 28, 1901.

Nos. 12,646—(151).

Appeal by plaintiff from an order of the district court for Stearns county, Searle, J., denying a motion for a new trial. Reversed.

Reynolds & Roeser, for appellant.

G. W. Stewart, for respondents.

BROWN, J.

The decision in Kray v. Muggli controls the determination of this case, and the same order is made.

Order reversed.

START, C. J., dissents.

[2] Reported in 86 N. W. 882, 1102.

obstruction has continued for the time necessary to establish a prescriptive right perpetually to maintain the same, the riparian owners along such stream of water, who have improved their property with reference to the change and in reliance on the continuance thereof, acquire a reciprocal right to have the artificial conditions remain undisturbed; and the person who placed the obstruction in the stream, or caused the diversion of the waters, and all those claiming under or through him, are estopped upon principles of equity from restoring the waters to their natural channel or state to the injury of such riparian owners.

Appeal by plaintiff from an order of the district court for Stearns county, Searle, J., denying a motion for a new trial. Reversed.

Reynolds & Roeser, for appellant.

G. W. Stewart and *Stewart & Brower*, for respondents.

BROWN, J.

This was an action to restrain and enjoin defendants from removing or destroying a certain milldam across Sauk river at Cold Springs, in Stearns county. The defendants recovered in the court below, and plaintiff appeals from an order denying a new trial. A former appeal in the case is reported in 77 Minn. 231, 79 N. W. 964, 1026, 1064.

The facts are substantially as follows: In 1856 a dam was built and constructed across Sauk river at Cold Springs, Stearns county, by the Cold Springs Mill Company, which has ever since, except during a short period in 1865, when out of repair, been maintained for the purpose of developing water power to propel and operate mill machinery. No authority was obtained to so construct or maintain the dam by application or resort to legal proceedings, but the same was so built and constructed without special or granted right, and subsequently maintained by the mill company and its successors for over forty years, with the acquiescence and consent of the owners of riparian property affected thereby, by reason of which continued maintenance, and the consequent raising of the level of the water, and the adverse, uninterrupted, and exclusive use of the dam for said period of forty years, the mill company and its successors, Muggli and his grantors, acquired the right by prescription perpetually to maintain the same. The effect of the dam was to raise the level of the waters of the river to a height of 7½ feet, cause the same to set back and overflow large tracts of adjacent land to a distance of about sixteen miles up the river, and the formation of several lakes and ponds along its course. By the construction of the dam, and the consequent raising of the level of the waters of the river, the greater part of the land described in the complaint has since that time been overflowed and rendered valueless for agricultural purposes.

The defendants, other than defendant Muggli, own land abutting upon the river, and are residents and freeholders of the towns through which the river runs and flows. Nearly all of said defendants and their grantors have for more than forty years owned and occupied the lands so adjacent to said river and the lakes, and have cultivated and improved the same with reference to the conditions created and caused by the dam and the increased quantity of water occasioned thereby. Some of the defendants owned and occupied land bordering on the river prior to the construction of the dam, and so far as the record in the case shows at no time did they object to the dam or to its maintenance. At the time of the construction of the dam the public domain in this section of the state was unsurveyed. It was subsequently surveyed, and with reference to the conditions existing, with the waters of the river raised above its natural level 7½ feet, and the lakes formed thereby were meandered in all respects as though natural bodies of water. Some time prior to the commencement of this action defendant Muggli, who owns the mill property, entered into a contract with the other defendants by which he attempted to sell and transfer to them the right to take out and remove the dam; such other defendants paying him for that right and privilege the sum of $5,000. It is claimed by such defendants that by the removal of the dam large tracts of submerged land will be reclaimed and made valuable for agricultural purposes. Acting under this contract, such defendants threatened to take out and remove the dam, and this action was brought to restrain them from doing so.

Figure 1 Historical maps of the Sauk River Chain of Lakes. Derived from Stearns County archives.

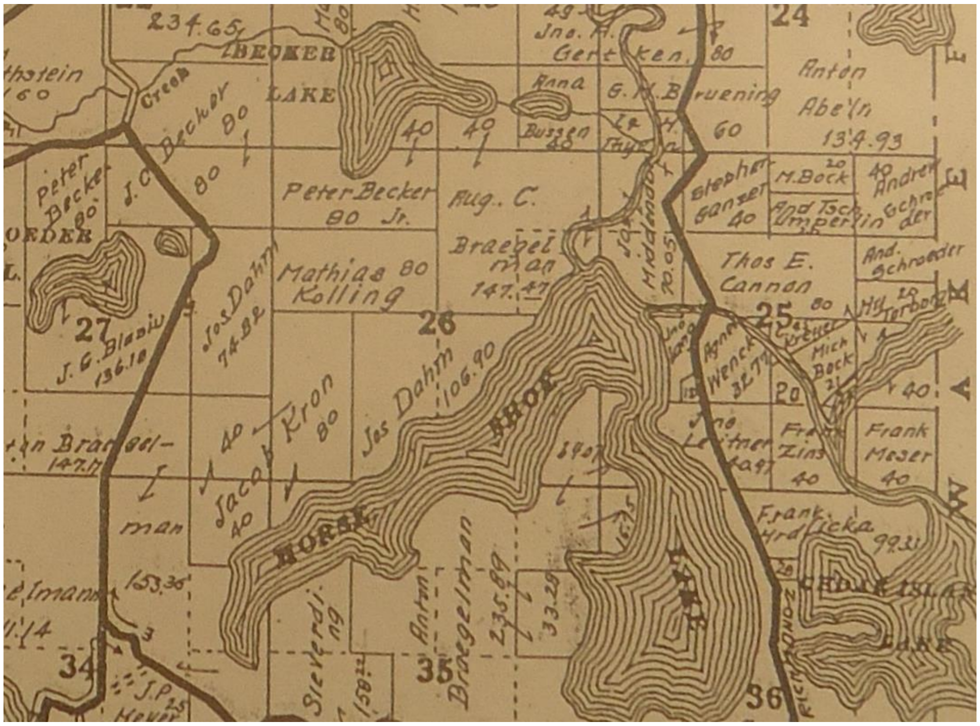


Figure 2 Cumulative distribution functions for stream total phosphorus concentrations by RNR. Mean summer (June through September) concentrations for AUIDs from 1995-2009 data drawn from STORET. North= 128 AUIDs, Central=239 AUIDs, and South=206 AUIDs. Dashed lines interpolate the proportion of sites meeting or not meeting the draft total phosphorus criteria for each RNR (from Heiskary et al. 2010).

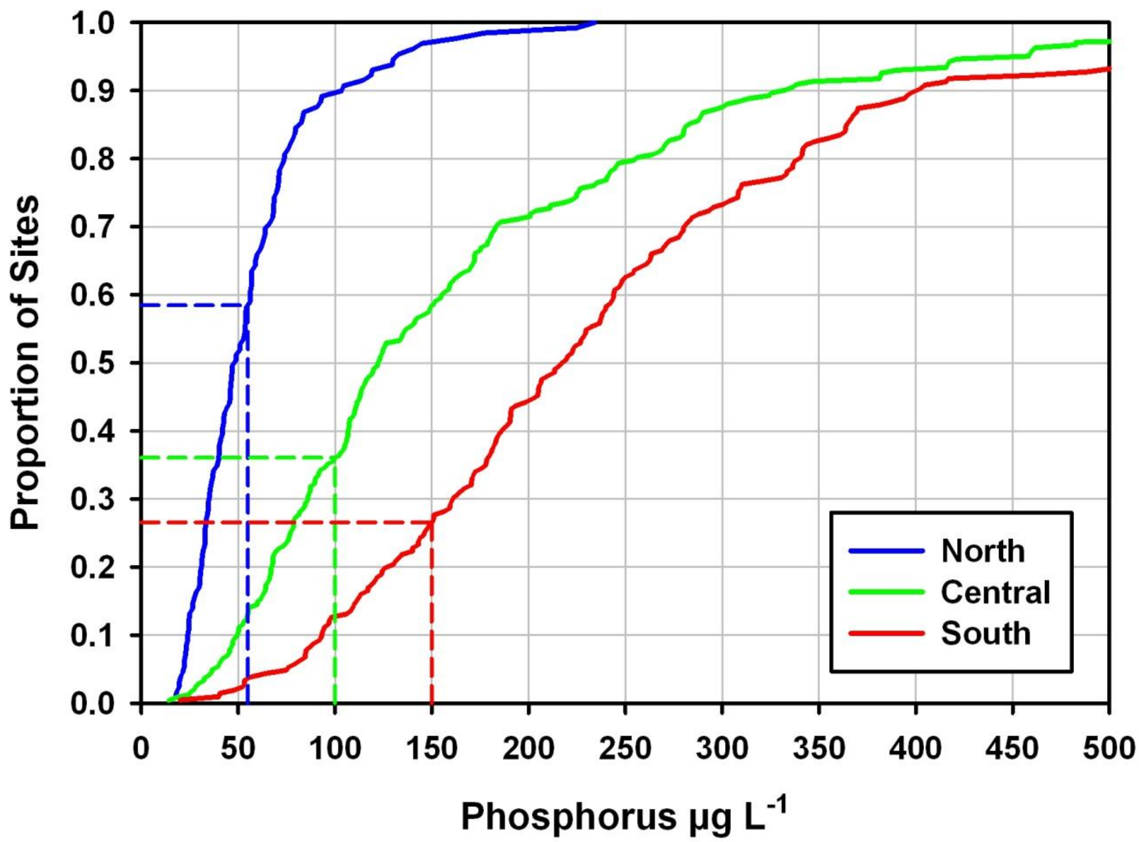
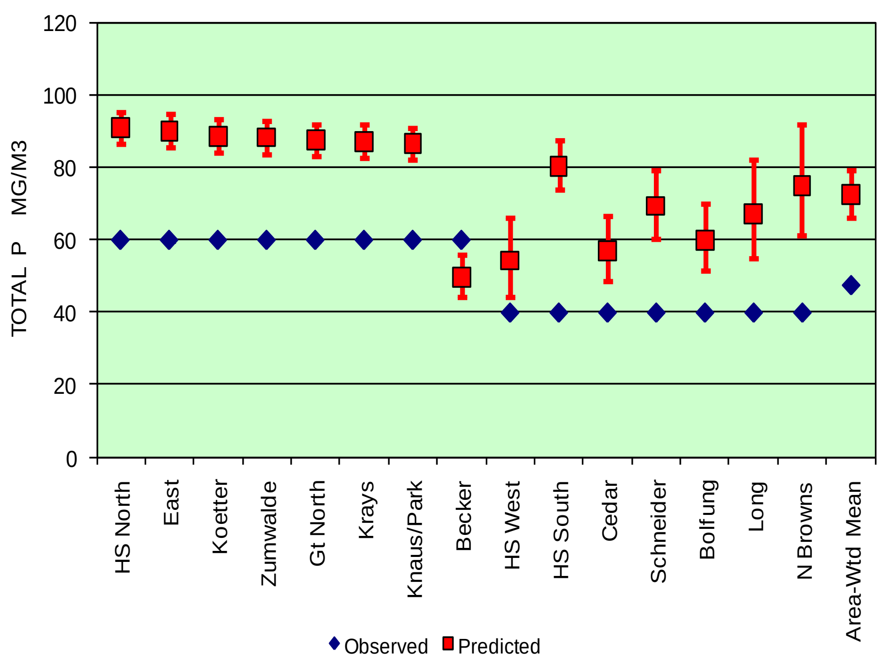
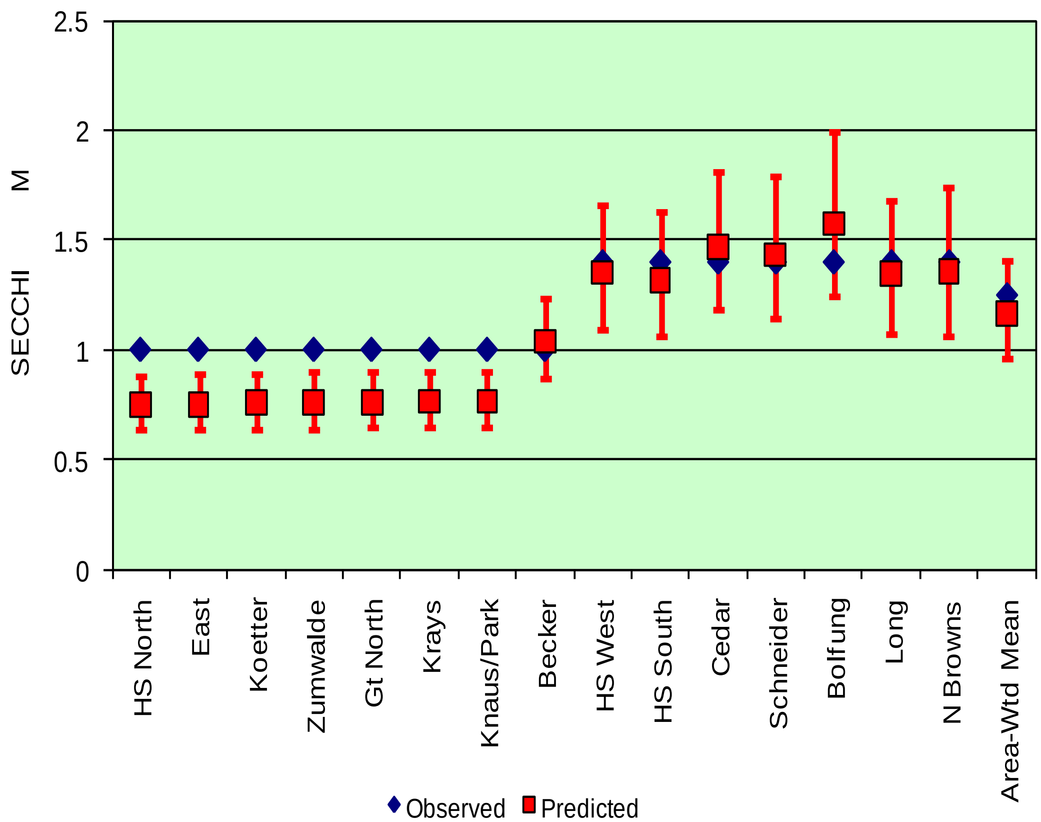


Figure 3 BATHTUB Model Output. Modeled river inflow at 100 µg/L. Observed is based on current WQS and allows for relative comparison with model-predicted values.

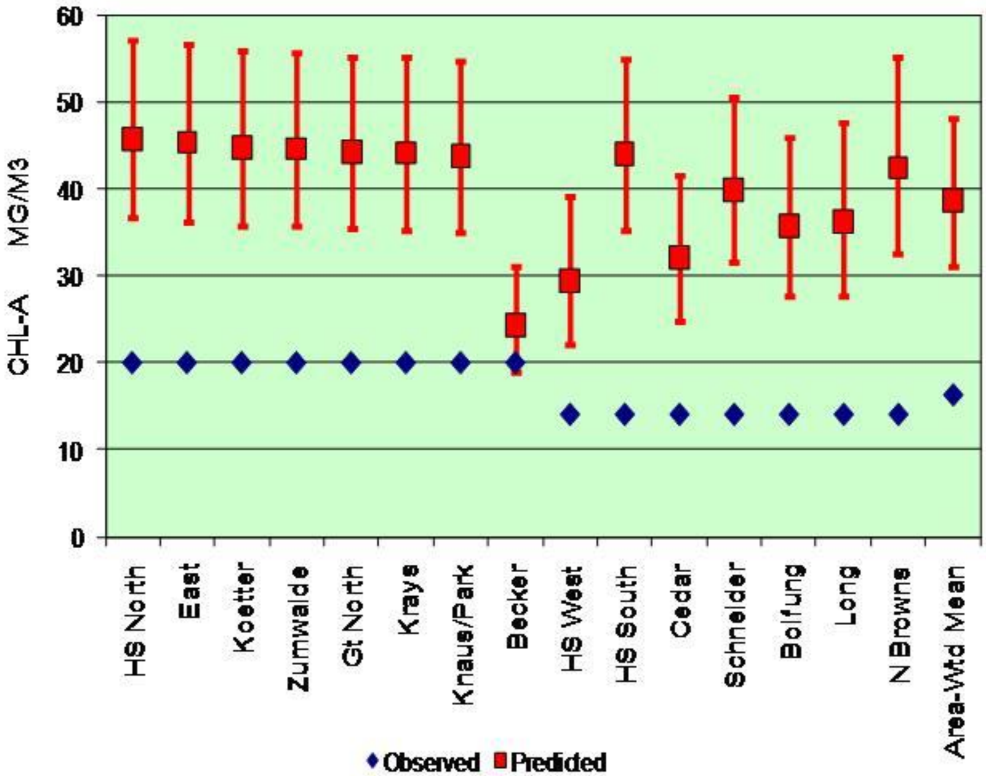
	Predicted TP µg/L		State	
Segment	**Mean**	**CV**	**std**	**CV**
HS North	90.8	0.05	60.0	0.00
East	90.0	0.05	60.0	0.00
Koetter	88.5	0.05	60.0	0.00
Zumwalde	88.2	0.05	60.0	0.00
Gt North	87.3	0.05	60.0	0.00
Krays	87.1	0.05	60.0	0.00
Knaus/Park	86.3	0.05	60.0	0.00
Becker	49.7	0.12	60.0	0.00
HS West	54.2	0.20	40.0	0.00
HS South	80.3	0.09	40.0	0.00
Cedar	56.7	0.16	40.0	0.00
Schneider	69.2	0.14	40.0	0.00
Bolfing	59.9	0.15	40.0	0.00
Long	67.0	0.20	40.0	0.00
N Browns	74.9	0.20	40.0	0.00
Area-Wtd Mean	72.4	0.09	47.6	0.00



Segment	Predicted Secchi m Mean	CV	State std	CV
HS North	0.7	0.17	1.0	0.00
East	0.8	0.17	1.0	0.00
Koetter	0.8	0.17	1.0	0.00
Zumwalde	0.8	0.17	1.0	0.00
Gt North	0.8	0.17	1.0	0.00
Krays	0.8	0.17	1.0	0.00
Knaus/Park	0.8	0.17	1.0	0.00
Becker	1.0	0.17	1.0	0.00
HS West	1.4	0.21	1.4	0.00
HS South	1.3	0.22	1.4	0.00
Cedar	1.5	0.21	1.4	0.00
Schneider	1.4	0.23	1.4	0.00
Bolfing	1.6	0.24	1.4	0.00
Long	1.3	0.22	1.4	0.00
N Browns	1.4	0.25	1.4	0.00
Area-Wtd Mean	1.2	0.19	1.2	0.00



Segment	Predicted Chl-a Mean	CV	State std Mean	CV
HS North	45.7	0.22	20.0	0.00
East	45.3	0.22	20.0	0.00
Koetter	44.7	0.22	20.0	0.00
Zumwalde	44.6	0.22	20.0	0.00
Gt North	44.2	0.22	20.0	0.00
Krays	44.1	0.22	20.0	0.00
Knaus/Park	43.8	0.22	20.0	0.00
Becker	24.3	0.25	20.0	0.00
HS West	29.3	0.28	14.0	0.00
HS South	44.0	0.22	14.0	0.00
Cedar	32.1	0.26	14.0	0.00
Schneider	39.9	0.24	14.0	0.00
Bolfing	35.7	0.25	14.0	0.00
Long	36.3	0.27	14.0	0.00
N Browns	42.4	0.26	14.0	0.00
Area-Wtd Mean	38.6	0.22	16.3	0.00



60
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CHL-A MG/M3
HS North
East
Koetter
Zumwalde
Gt North
Krays
Knaus/Park
Becker
HS West
HS South
Cedar
Schneider
Bolfung
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N Browns
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