Development of Phosphorus TMDL for The Sauk River Chain of Lakes, Minnesota

prepared for

Sauk River Watershed District
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by

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Table of Contents

List of Figures

List of Tables

Units & Terms

Units	Definition	Conversions
hm^3 *	cubic hectometer	10^6 m^3 or 810 acre-feet
km^2	square kilometer	0.39 mi^2 or 247 acres
ppb	parts per billion	1 microgram per liter
m	meter	3.28 feet
kg	kilogram	2.2 pounds
mt	metric ton	1000 kg or 2200 lbs

*Water balances are formulated on May-September basis. To convert the total flow volume in hm^3 to the average flow rate in cubic feet per second (cfs), multiply by 2.67.

Algal Bloom Frequency: Percent of days between June-September when chlorophyll-a (algal pigment) concentrations exceed 40, 60, or 80 ppb.   These statistics have been correlated with aesthetic qualities and recreational use potential as perceived by lake users (Heiskary & Wilson, 2008).

Introduction

The Sauk River Chain of Lakes (SRCL) is comprised of more than 15 interconnected lakes and shallow impoundments located in central Minnesota (Figure 1[1]). The Sauk River watershed accounts for 85% of the total watershed area above the lake outlet (Figure 2). Most of the lakes do not meet Minnesota's water quality standards as a consequence of excessive nutrient concentrations and nuisance algal blooms (MPCA, 2005; Heiskary & Wilson, 2008). The blooms result from an unfortunate combination of excessive phosphorus loads from the large agricultural watershed and limited assimilative capacity.

While point sources accounted for more than half of the phosphorus loads prior to 1991, current loads originate primarily from agricultural areas (cropland, pasture) and urban areas dispersed throughout the watershed. Some of the lakes and bays are impacted by runoff and septic tank discharges from adjacent developed shorelines.

SRCL's limited assimilative capacity reflects a high watershed area to lake area ratio, shallow depths, and low water residence times. These characteristics are particularly important in the most heavily impacted lakes located along the mainstem of the Sauk River, which starts in Horseshoe Lake and ends in Knaus Lake (Figure 1). These "lakes" are more appropriately classified as run-of-the-river impoundments because water levels are partially controlled by a dam at the lake outlet. Water residence time averages only 7 days, which is insufficient to allow significant trapping of nutrients but sufficient to allow dense algal growth, particularly in dry years. The shallow depth of the mainstem lakes (~1.5 m) is also conducive to nutrient recycling and algal growth. Water depth typically fluctuates ~0.6 m seasonally and ~0.2 m or more from year to year, depending on flow.

Significant water-quality improvements have been accomplished through implementation of point- and non-point source controls to reduce phosphorus loads by more than 60% relative to pre-1991 conditions. Despite these improvements, most of the lakes still experience nuisance algal blooms and do not meet eutrophication criteria established by the Minnesota Pollution Control Agency for this ecoregion (Heiskary & Wilson, 2008):

Table 1 Observed Water Quality vs. Eutrophication Criteria for Lakes in the North Central Hardwood Forest Ecoregion of Minnesota

	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%; Sauk River Mainstem

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

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[1] See also http://www.wwwalker.net/srcl/srcl.kmz

The Clean Water Act requires development and adaptive implementation of a plan to achieve water quality standards by reducing nutrient loads. The "Total Maximum Daily Load" (TMDL) regulations provide a template for this process (USEPA, 2009; MPCA, 2009). Despite the terminology, TMDLs for lakes are typically formulated on long-term-average time scales, which tend to govern lake water quality response to nutrient loads and are consistent with expressions of eutrophication criteria as long-term summer means (Walker, 2003). Effects of seasonal and year-to-year variations in TP loads and other factors are buffered to some extent by storage and recycling of historical loads in the lake water column, biota, and sediments (Figure 3). Spatial and temporal variations are also reflected in correlations between average phosphorus concentrations and frequencies of nuisance algal blooms, which have been linked with user perceptions of aesthetic qualities and recreational potential. Such relationships were used as a partial basis for developing Minnesota's eutrophication criteria (Heiskary & Wilson, 2008) and are evident in SRCL monitoring data analyzed below.

The TMDL can be simply defined as the long-term average TP load consistent with achieving lake water quality standards. This report develops and applies mathematical models to estimate TMDLs for lakes in the Sauk River chain and Eden Valley chain. The latter drains into the Sauk River chain from the south but is not influenced by Sauk River water quality. The models simulate cause-effect pathways linking phosphorus loads to eutrophication-related water quality conditions (Figure 3). While considerable complexity is introduced in this case because of the number and inter-connected features of the lakes, the underlying model equations and calibrations are relatively simple and have been tested against data from large populations of lakes in Minnesota and other regions (Walker, 2006).

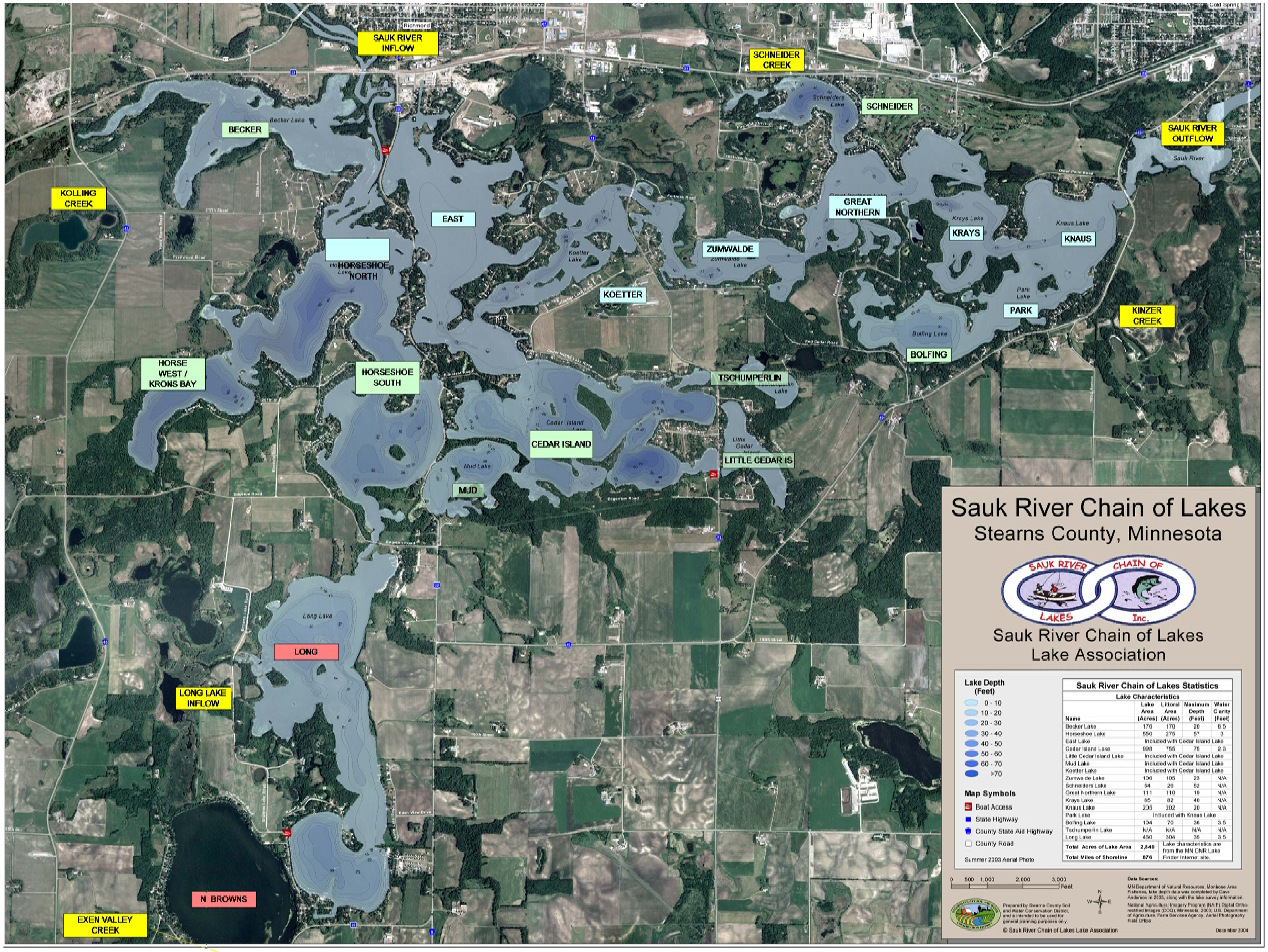
TMDLs estimated thru lake modeling provide cornerstones for future development of load allocations and adaptive implementation of watershed management measures to achieve the required load reductions. The framework can be distilled into the following equations (Walker, 2003):

$$\text{TMDL} = K\,P^* \qquad (1)$$

$$\text{TMDL} = \text{Nonpoint Sources} + \text{Point Sources} + \text{Margin of Safety} \qquad (2)$$

This report focuses on the first equation, which evaluates the total load consistent with achieving phosphorus criteria (P*) on a spatially-averaged basis and for individual lakes. Chlorophyll-a and transparency criteria are also considered (Table 1). Models are used to estimate the proportionality constant (K), which depends upon lake inflow volumes and assimilative capacity, in turn controlled by morphometry, hydraulics, and nutrient cycling dynamics.

Figure 1 Aerial Photo with Major Lakes in the TMDL Area



Sauk River Chain of Lakes Statistics

Lake Characteristics				
Name	Lake Area (Acres)	Littoral Area (Acres)	Maximum Depth (Feet)	Water Clarity (Feet)
Becker Lake	176	170	20	5.5
Horseshoe Lake	550	275	57	3
East Lake	Included with Cedar Island Lake			
Cedar Island Lake	998	755	75	2.3
Little Cedar Island Lake	Included with Cedar Island Lake			
Mud Lake	Included with Cedar Island Lake			
Koetter Lake	Included with Cedar Island Lake			
Zumwalde Lake	136	105	23	N/A
Schneiders Lake	54	26	52	N/A
Great Northern Lake	111	110	19	N/A
Krays Lake	65	82	40	N/A
Knaus Lake	205	202	20	N/A
Park Lake	Included with Knaus Lake			
Bolfing Lake	134	70	36	3.5
Tschumperlin Lake	N/A	N/A	N/A	N/A
Long Lake	450	304	35	3.5
Total Acres of Lake Area	**2,849**	Lake characteristics are from the MN DNR Lake Finder internet site.		
Total Miles of Shoreline	**876**			

Prepared by Stearns County Soil and Water Conservation District, and is intended to be used for general planning purposes only.

© Sauk River Chain of Lakes Lake Association

Data Sources:

MN Department of Natural Resources, Montrose Area Fisheries, lake depth data was completed by Dave Anderson in 2003, along with the lake survey information.

National Agricultural Imagery Program (NAIP) Digital Ortho-rectified Images (DOQ), Minnesota, 2003; U.S. Department of Agriculture, Farm Services Agency, Aerial Photography Field Office .

December 2004

Figure 2 Sauk River Watershed

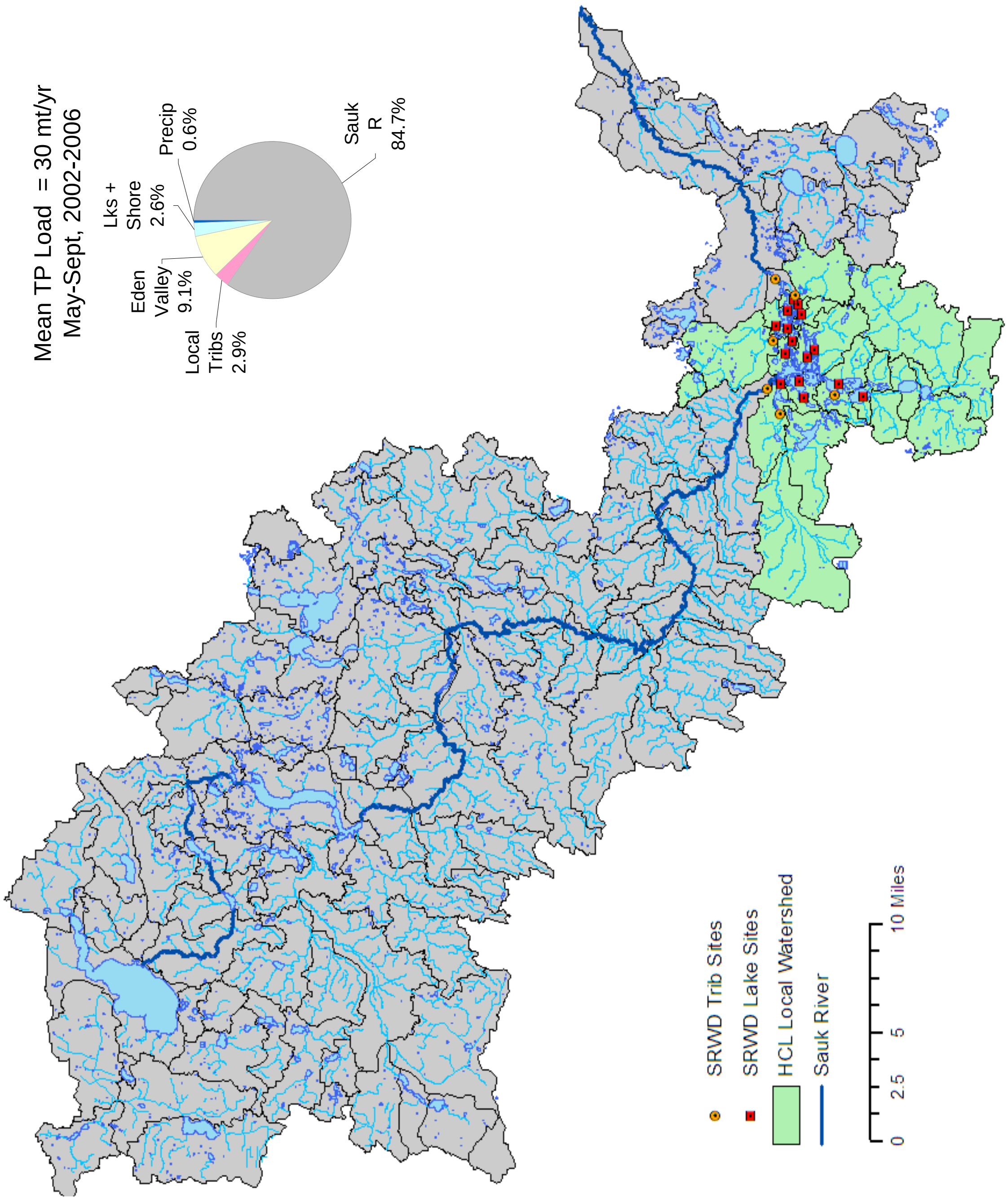
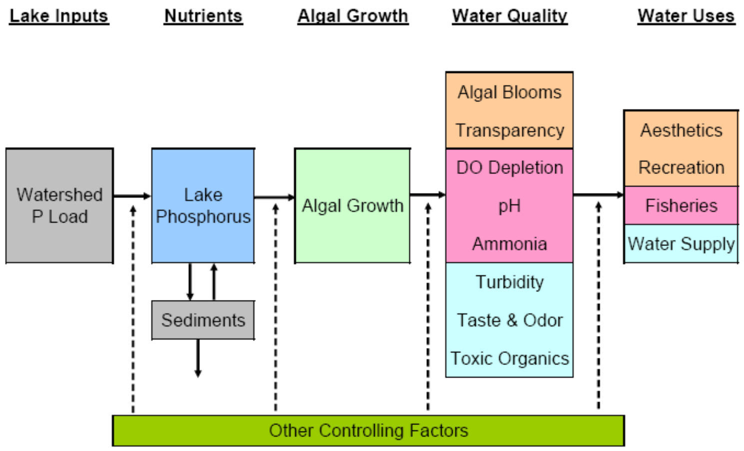


Figure 3 Causal Pathways Linking TP Load to Lake Water Quality & Uses



Modeling results indicate that the TMDL is largely determined by the 60 ppb TP criterion for the mainstem lakes, as driven primarily by the Sauk River inflow concentration. Because of data limitations and modeling complexities, there is greater uncertainty associated with predicting responses of deeper lakes located off the mainstem (Figure 1). It is estimated that achieving the TP criteria in shallow and deep lakes would require an overall reduction in TP load of approximately 64 ± 3% relative to 2002-2006 conditions. This could be accomplished by limiting the long-term-average, flow-weighted-mean TP concentration in each tributary to a maximum of 60 ppb and reducing inputs from shoreline areas (runoff and septic systems) by approximately 50%. While subject to greater uncertainty because of data limitations, a similar remedy is prescribed for the Eden Valley lakes (North Browns and Long Lake). It is unlikely that mean chlorophyll-a criteria would be achieved in most of the lakes with a 64% load reduction; however, the frequency of severe nuisance algal blooms (chlorophyll-a > 60 ppb) would be reduced to less than 5% as compared with baseline values of 30 to 60%. Further studies are needed to determine the optimal combination of tributary and shoreline source reductions to achieve the overall reduction and meet the lake criteria.

The analysis is built upon previous diagnostic studies (MPCA, 1985; WRM, 1992) and monitoring data collected by Sauk River Watershed District (SRWD), Minnesota Pollution Control Agency (MPCA), and local citizens over the 1978-2006 period. Results are described in the following sections:

- Data Sources
- Watershed Characteristics
- Lake Segments
- Water & Mass Balances
- Lake Water Quality
- Model Development
- TMDL Scenarios
- Conclusions

Appendices contain detailed documentation of supporting data, statistical analyses, and modeling results:

- Watershed Maps & Data
- Hydrology and Phosphorus Loads
- Lake Water Quality Data
- Model Calibration and Testing
- Baseline and TMDL Simulations

Data Sources

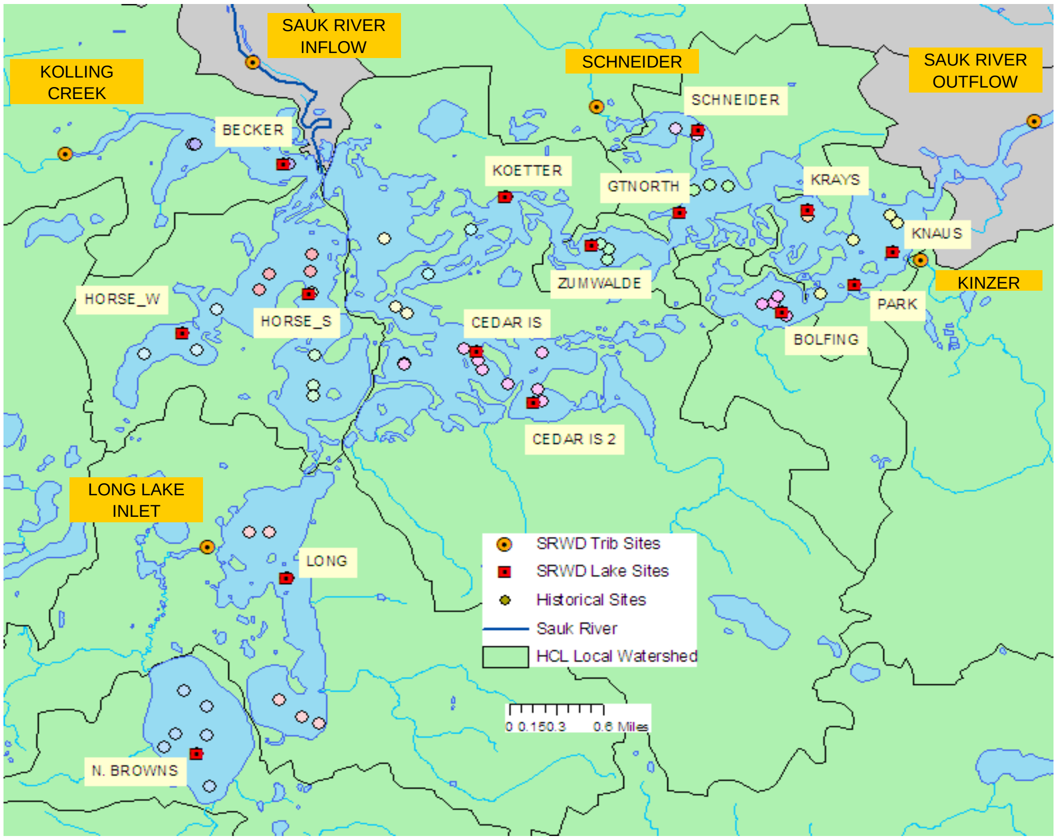
Watershed delineations, land use, and lake morphometry data have been extracted from GIS layers and other information provided by SRWD. Land use data are listed and mapped in Appendix A.

Sources of hydrologic data and methods used to develop water and phosphorus mass balances are summarized in Appendix B. While limited monitoring data are available from the local tributaries, the 5-year record of Sauk River inflow and outflow, combined with the 15-year record at the mouth of the Sauk River provide a reasonable hydrologic baseline. Regression models and flow from data other regional sites have been used to fill gaps in historical flow record and loading data. The resulting 29-year record (1978-2006) of water and phosphorus budgets provides a good basis for model development and testing. Because of limitations in the historical flow and loading data, the 2002-2006 period is used as a baseline for TMDL development. Historical data are used for model testing and evaluating long-term trends.

Lake and tributary monitoring sites are shown in Figure 4. Data sources include diagnostic studies in 1983 (MPCA, 1985) and 1989 (WRM, 1992), Citizens Monitoring Program (transparency data), and intensive surveys by SRWD in 1996-2006. Historical (pre-2006) data have been downloaded from the internet (MPCA, 2009b). These data were collected under several monitoring programs. Sampling intervals, protocols, parameter coverage, and site locations varied widely within and among lakes over the years. Intensive monitoring conducted by the SRWD in 1997-2006 has provided the cornerstone for TMDL development.

Tributary samples were generally collected weekly during high flow periods and monthly otherwise. Paired flow and phosphorus data for the local tributaries were available only for 2006 Tributary data and load calculations are summarized in Appendix B. Lake samples were generally collected at monthly or biweekly frequencies between May and September. Lake data are summarized by monitoring site and year in Table 2 and Appendix C.

Figure 4 Lake and Tributary Monitoring Sites



Historical sites extracted from MPCA/STORET database. Period of Record – 1978-2008. Symbol colors indicated sites in different model segments (Figure 6).

Table 2 Lake Total Phosphorus Concentrations, 1997-2006

Lake Segment	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Mean	Criterion
Koetter	140	177	147	162	198	193				157	169	60
Zumwalde	140	170	158	175	197	184	176	121	154	170	162	60
Great Northern	145	160	147	162	211	186				168	171	60
Krays	140	133	144	180	211	179	184	131	159	158	161	60
Knaus/Park	135	128	126	146	197	145	166	100	147	137	143	60
Becker	52	30	35	46	66	37				87	51	60
Horseshoe West	35	57	45	34	64	116				35	57	40
Horseshoe South	100	187	118	126	145	186	159	120	117	90	130	40
Cedar	55	63	67	60	102	95	123	78	74	65	81	40
Schneider	60	47	32	53	81	62	77	104	52	48	65	40
Bolfing	65	59	72	63	121	110				71	81	40
Long	140	103	75	75	135	87				79	96	40
North Browns			91			119			59	110	91	40

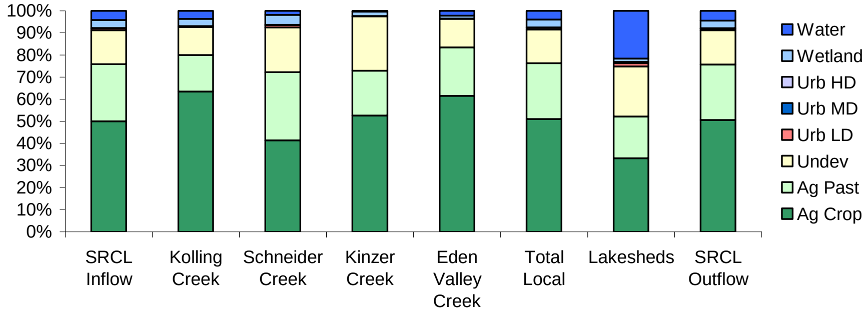
Lake TP Concentrations, June-September, 0 - 2 meters

Watershed Characteristics

The Sauk River Chain of Lakes has a total surface area of 13.2 km^2 and a total watershed area of 4,024 km^2 (Figure 2). The SRCL inflow at Richmond accounts for 85% of the total watershed area above the SRCL outlet and similar percentage of the phosphorus load to the entire lake chain. The Sauk River and Eden Valley Creek together account for ~91% of the total drainage area and ~94% of the estimated total phosphorus load. These tributaries have the higher TP concentrations than others in the local watershed and discharge directly into the most eutrophic lakes in the chain (Sauk River mainstem and North Browns).

Appendix A contains detailed land use inventories and maps showing land uses and monitoring sites. Cropland and pasture are the dominant land uses throughout the basin (Figure 5). Land use distributions in the local watersheds are similar to those of the upper basin. The “lakeshed” category includes the lake surfaces and adjacent shoreline areas that do not drain into a monitored tributary.

Figure 5 Land Use Distributions in SRCL Tributaries



The GIS land use distributions do not reflect the dense urban development around lake shorelines evident in aerial photos (Figure 1, Appendix A-6) and in a lake tour provided by SRWD in 2008. Shorelines contain approximately 2,000 lots and 1,000 septic systems of various age and condition (Appendix E-1). Potentially significant shoreline nutrient sources include runoff from lots with inadequate vegetated buffers and leachate from septic tanks. Some of the lakes off the mainstem (North Browns, Schneider, and Cedar) have densely developed shorelines, small lots, and septic systems likely to be located within 50-100 meters of the lake shoreline, based upon lot dimensions estimated from aerial photos.

Lake Segments

The SRCL has been divided into 15 segments for purposes of summarizing the data and modeling (Figure 6). 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 classified into three groups, as indicated by the color codes in Figure 6:

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.

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 2) 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.

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).

The SRWD monitoring program provided morphometric, hydrologic, and water quality data for each lake segment. Limitations that influence the spatial resolution and accuracy of the modeling include:

1. Two segments (East Lake and the extreme northern portion of Horseshoe Lake) do not contain monitoring sites. Based upon locations and modeling results, it is assumed that water quality conditions in these segments are similar to those observed in the other mainstem segments.

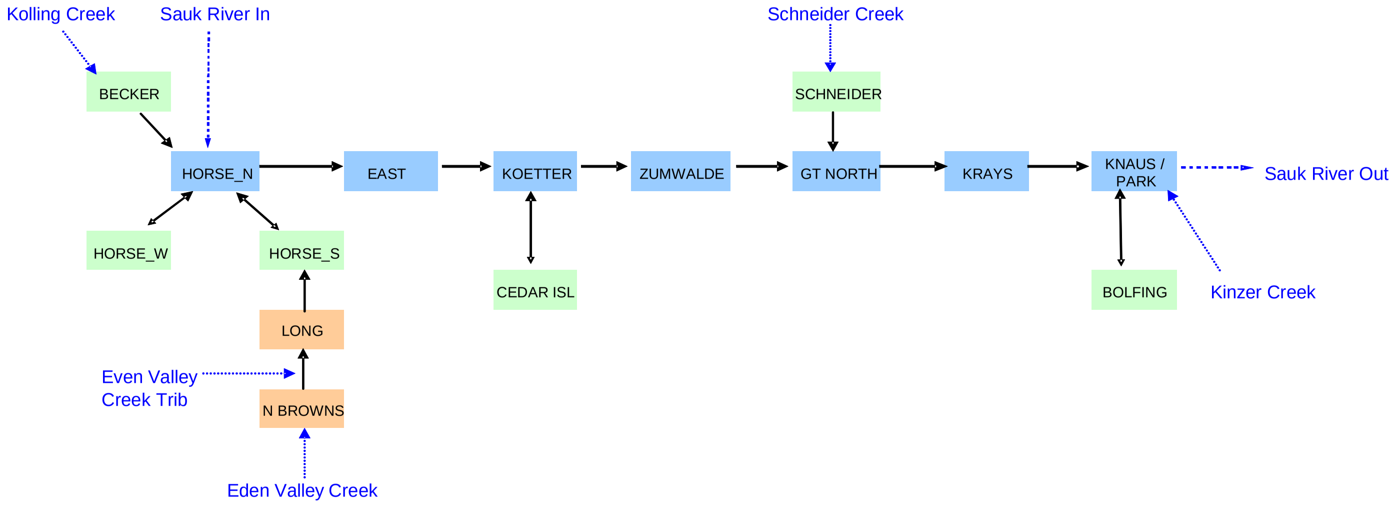
2. The monitoring network does not cover major portions of Horseshoe Lake (southern end of the east arm or the northern end of the west arm, Figure 4). This lake contains segments classified shallow (northern) and deep (south and west arms). Data indicate more than a three-fold spatial variation in TP concentrations within Horseshoe, generally reflecting the extent of influence by the Sauk River. The Horseshoe Lake monitoring site immediately to the south of the SR inflow region has TP concentrations similar to the mainstem, but significantly lower chlorophyll-a levels and greater Secchi depths, probably as a consequence of greater depth and mixing.

3. Park and Knaus Lakes have similar water quality and are represented as one segment for modeling purposes.

4. The Cedar Island segment includes five lakes (Cedar Island, Little Cedar Island, Mud, and Tschumperlin). There are insufficient data to model these separately. The four smaller lakes are remote from the mainstem and likely to have lower TP concentrations, as compared with the Cedar Island site used for model calibration purposes.

5. Data to support modeling of the North Browns segment are extremely limited (4 years of lake data and 0 years of inflow data). Monitoring of the inflow and outflow did not begin until 2008 and 2006, respectively. Flow and load estimates have been inferred using the mass balance model and reconciled against the limited direct monitoring data from the other SRCL tributaries and lakes. Because of these data limitations, the TMDL estimate for North Browns should be considered a placeholder pending collection of additional data. Extension of the segment network to include upstream lakes in the Eden Valley watershed is also recommended to support TMDL updates.

Figure 6 Lake Segments & Mass Balances, 2002-2006



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

Samp. Years	TP ppb	Chla ppb	Secchi m	Algal Bloom Freq > 40	> 60	> 80
0						
0						
2	175	65	0.67	88%	63%	38%
5	161	57	0.62	60%	50%	18%
2	177	65	0.64	88%	50%	25%
5	162	63	0.63	76%	50%	20%
5	139	69	0.70	81%	54%	30%
2	62	21	1.01	25%	0%	0%
2	76	35	1.11	38%	0%	0%
5	134	66	1.07	73%	48%	30%
5	87	48	1.12	61%	34%	5%
5	68	35	1.84	39%	15%	3%
2	90	57	1.19	88%	38%	13%
2	83	52	0.96	50%	38%	25%
3	96	39	1.64	25%	25%	17%
	161	65	0.66	80%	53%	27%
	92	47	1.13	56%	26%	10%
	88	47	1.22	40%	33%	22%
	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.

Blue = mainstem segments; Green SR lake segments; Orange = Eden Valley lake segments

Water & Mass Balances

Formulation

Flow and phosphorus loads have been evaluated for external inflows and outflows in the following categories:

1. Monitored:
    - Sauk River Inflow at Richmond
    - Local Tributaries (Kolling, Long Lake Inlet, Schneider, Kinzer)
    - Sauk River Outflow at Cold Spring
2. Estimated:
    - Small watersheds adjacent to the lakes (“lakesheds”)
    - Excess runoff from shoreline lots (above lakeshed background)
    - Wastewater disposal systems (septic tanks) on shoreline lots.
    - Atmospheric deposition

The Sauk River accounts for ~85% of the baseline TP load and has more extensive flow and phosphorus data, as compared with the other tributaries. Despite the uncertainties associated with estimated sources, they account for ~3 % of the total load to the entire lake chain and 8% of the load to the SR lakes off the mainstem. Percentages are higher for individual lakes and will approximately double with future reductions in tributary loads under the TMDL scenarios evaluated below.

Appendix B describes the data and methods used to calculate loads and to construct water and mass balances for May-September of each year between 1978 and 2006. Results for 1989-2001 are used for trend analysis and model testing. Chloride balances have also been formulated to support calibration and testing of flow exchanges between lakes. Appendices E-G contain detailed water and mass balances for each lake segment under baseline conditions and various TMDL scenarios.

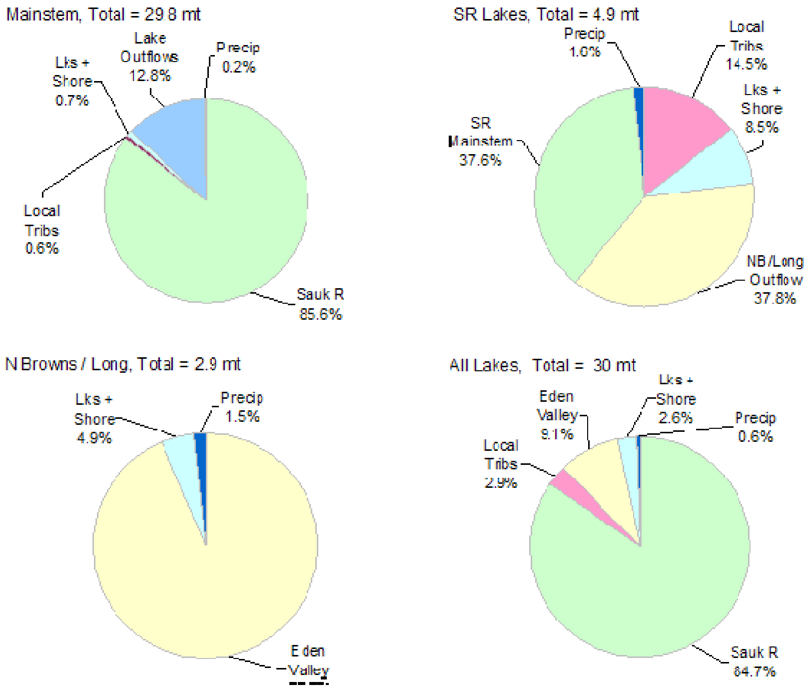
The 5-year interval from 2002 to 2006 has been used as a baseline for modeling and TMDL development. While lake monitoring was slightly more intensive in 1997-2001 (Table 2), continuous monitoring of Sauk River inflows and outflows began in June 2001. Trends in the Sauk River inflow or outflow P concentrations are not evident within the 2002-2006 period. This period provides a stable baseline for TMDL development and is reasonably representative of long-term (1978-2006) flow and precipitation records (Figure 17, Appendix B). While it does not include extreme wet years, algal blooms tend to be less severe in wet years because of high flushing rates (Appendix C).

While an April-September averaging period has also been explored, water and mass balances have been formulated for May-September of each year. While this excludes early spring runoff, model calibration and testing results were generally more favorable using a May-September averaging period. SRCL outflow TP loads and concentrations typically equal or exceed inflow values during April (Appendix C). The May-September interval is also consistent with guidelines for modeling lakes and reservoirs with relatively short hydraulic residence times (Walker, 1999; 2006).

Monitoring early spring runoff is complicated by timing, extreme flows, ice, and other factors. Consequently, flow and load estimates for April are typically limited with respect to completeness, accuracy, and precision. Formulating the TMDLs on a May-September basis does not mean that phosphorus loads during April can be ignored in evaluating watersheds and designing BMPs. Lakes segments with longer residence times (in particular, Cedar, North Browns and Long) may be sensitive to phosphorus loads in April, although there are insufficient data to evaluate that possibility or factor April TP loads into the modeling framework.

Figure 6 summarizes water and phosphorus balances for the entire lake chain for the 2002-2006 baseline period. Figure 7 illustrates sources of phosphorus to each lake region. Sources include transport between the mainstem and offline lakes as a result of outflow and mixing, as well as external inflows.

Figure 7 Phosphorus Sources by Lake Category



The overall water budget for the baseline period closes to within 4% (total inflow = 175 hm^3 vs. measured outflow = 168 hm^3 Figure 6). This deviation is acceptable, given that 23% of the inflows have been estimated or extrapolated from 2006 data and potential inaccuracies in the Sauk River inflow data (M. Evenson, MPCA, Personal Com., 2009).

Sauk River Inflows & Outflows

Figure 8 shows long-term variations in daily flow and phosphorus concentrations in the SRCL inflow and outflow between 1978 and 2006. Monthly and yearly time series are shown in Appendix B. Pre-2002 flows have been estimated using regression models calibrated to flow data from other sites (Sauk River at St Cloud or Crow River at Rockford, Appendix B). These estimates are relatively uncertain under extreme high-flow conditions that exceeded the calibration range for the regression equations. Fortunately, these conditions occurred primarily in April and had small impacts on the May-September loading estimates used for modeling purposes.

Daily inflow and outflow phosphorus concentrations have been estimated using multiple regressions calibrated separately to data from each site. The regression equations account for concentration variations to flow, flow derivative (rising vs. falling stage), season, and long-term trend. Residuals (observed – predicted concentrations) are interpolated between sampling events to increase precision in periods with frequent sampling. (Walker & Havens, 2003). A database and software package developed for other projects (enhanced version of FLUX, Walker.1999) has been used for the load calculations (Appendix B).

Figure 9 demonstrates the significant reduction in Sauk River TP load around 1991 in conjunction with control of the Melrose STP, which formerly discharged to the Sauk River ~70 km upstream of the SRCL inlet at Richmond (MPCA, 1985). Adjusted for variations in flow, it is estimated that average May-September TP load decreased by 46 ± 10 mt between 1978-1990 and 1996-2006. The flow-weighted-mean concentration decreased from 511 to 171 ppb, or 68%.

The historical annual TP load from the Melrose STP discharge was estimated at75 mt/yr (MPCA, 1985). If it were evenly distributed across months, the May-September STP load would have been 31 mt, as compared with the apparent 46 ± 10 mt reduction in the SRCL inflow load. While the difference may not be significant in the context of uncertainties in the flow and load data, it is possible that the additional load reduction reflected implementation of nonpoint source controls in the watershed over this same period. The divergence of the load vs. flow regressions at high flows shown in Figure 9 supports that hypothesis because nonpoint sources would be expected to dominate under those conditions.

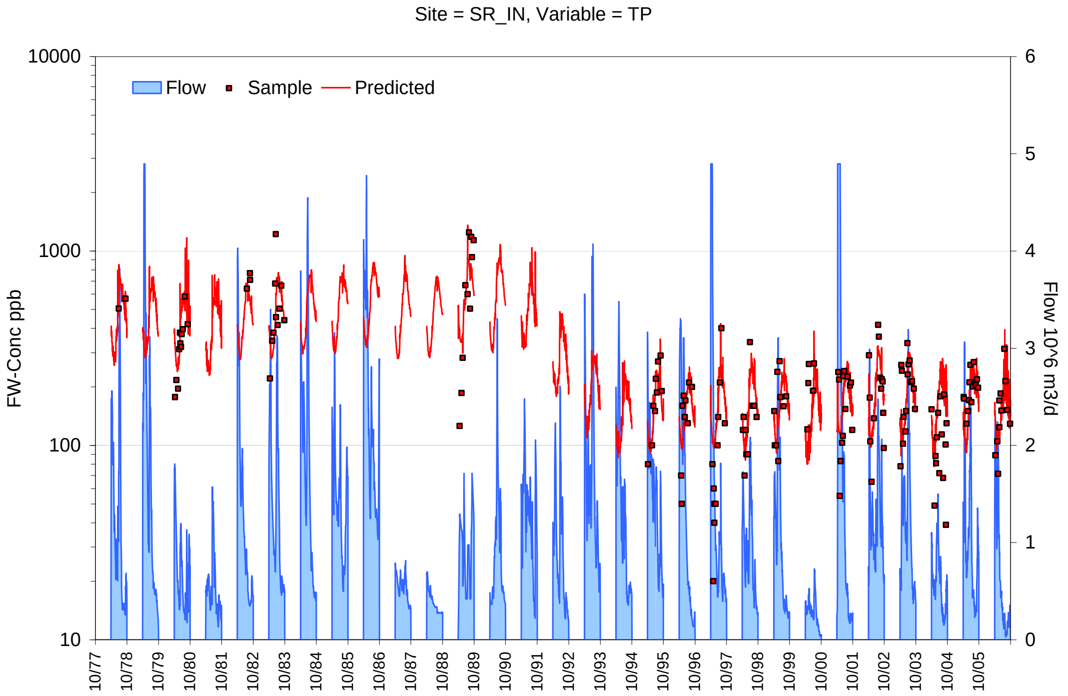
Local Tributaries

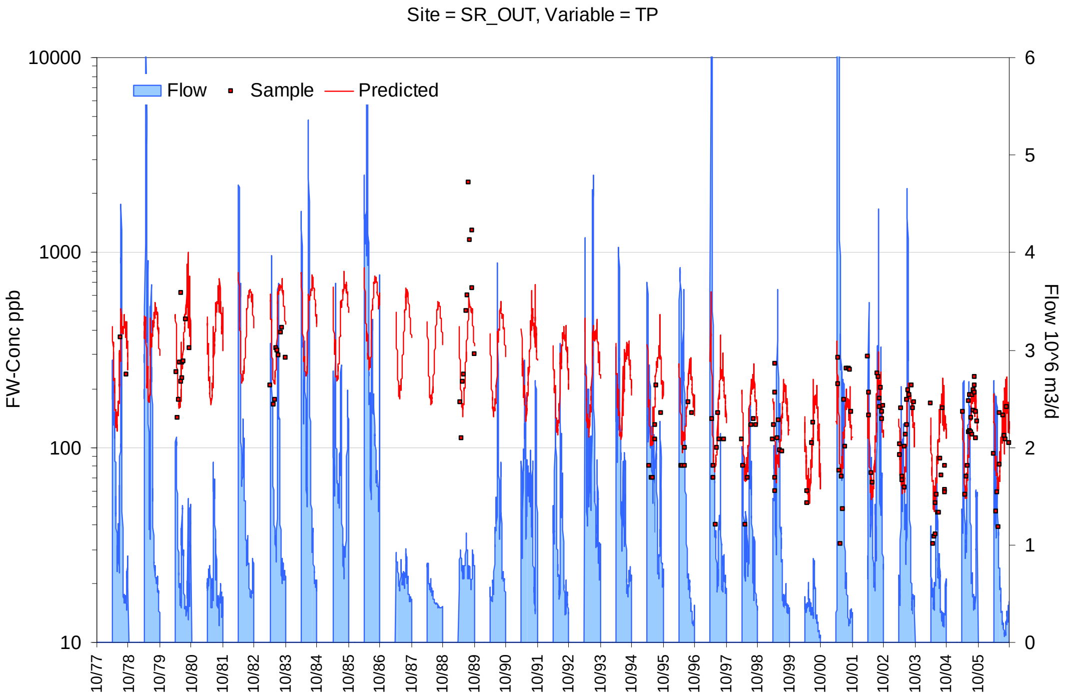
Local tributary flow and water quality data were available only for 2006, which was a relatively dry year. Regressions vs. the Sauk River inflow or outflow have been used to extrapolate the 2006 flow data to other years. The limited concentration data for 2006 has been supplemented with data from 2007 and 2008 in order to increase precision of load estimates. It is assumed that concentrations in 2007-2008 were similar to those in the 2002-2006 baseline. For purposes of constructing the North Browns Lake phosphorus balance, the average inflow concentration measured in 2008 (135 ppb) has been paired with flows inferred from the measured outflow and lake water balance.

Runoff volume and concentration estimates for the local tributaries and Sauk River in 2006-2008 are shown Figure 10. Flow-weighted mean concentrations in each month and year have been computed using sample concentrations paired with corresponding daily flows. While based upon limited data collected at the inlet to Long Lake, runoff rates from the Eden Valley Creek watershed exceeded those from other watersheds in April-June, but decreased later in the summer. The runoff averages shown in Figure 10 reflect dates when samples were collected (excluding dry periods). During the 2002-2006 baseline period, May-September runoff from the Sauk River averaged 6 cm, as compared with an estimated range of 8 to 19 cm for the other tributaries (Figure 6). The differences may reflect evaporative losses from lakes in the upper watershed, variations in soil characteristics, variations point-source contributions, and uncertainties in the flow data.

The fact that the relative magnitudes of the tributary concentrations are consistent from year to year supports use of 2007-2008 concentration data to estimate the 2002-2006 baseline loads (Figure 10). Concentrations ranged from 40-80 ppb in the minor tributaries (Kolling, Schneider, Kinzer) and from 100 to 200 ppb in the major tributaries (Sauk River, Long Lake Inlet). Corresponding ranges in May-September flow-weighted means are 45-77 ppb in the minor tributaries vs. 135-188 ppb in the major tributaries (Figure 6). Modeling results described below indicate that TP concentrations in the Sauk River and Eden Valley Creek would have to be reduced to values similar to those measured in the smaller tributaries in order to achieve the lake eutrophication criteria.

Figure 8 Sauk River Daily Flows & TP Concentrations, 1978-2006


Site = SR_IN, Variable = TP


Site = SR_OUT, Variable = TP

April-September values. Flows estimated in 1978-1991. Red symbols: observed concentrations.
Red lines: regression model conc = Function (trend, season, flow, flow derivative) Walker & Havens, 2003.

Figure 9 Sauk River at Richmond TP Loads, May-September 1978-2006

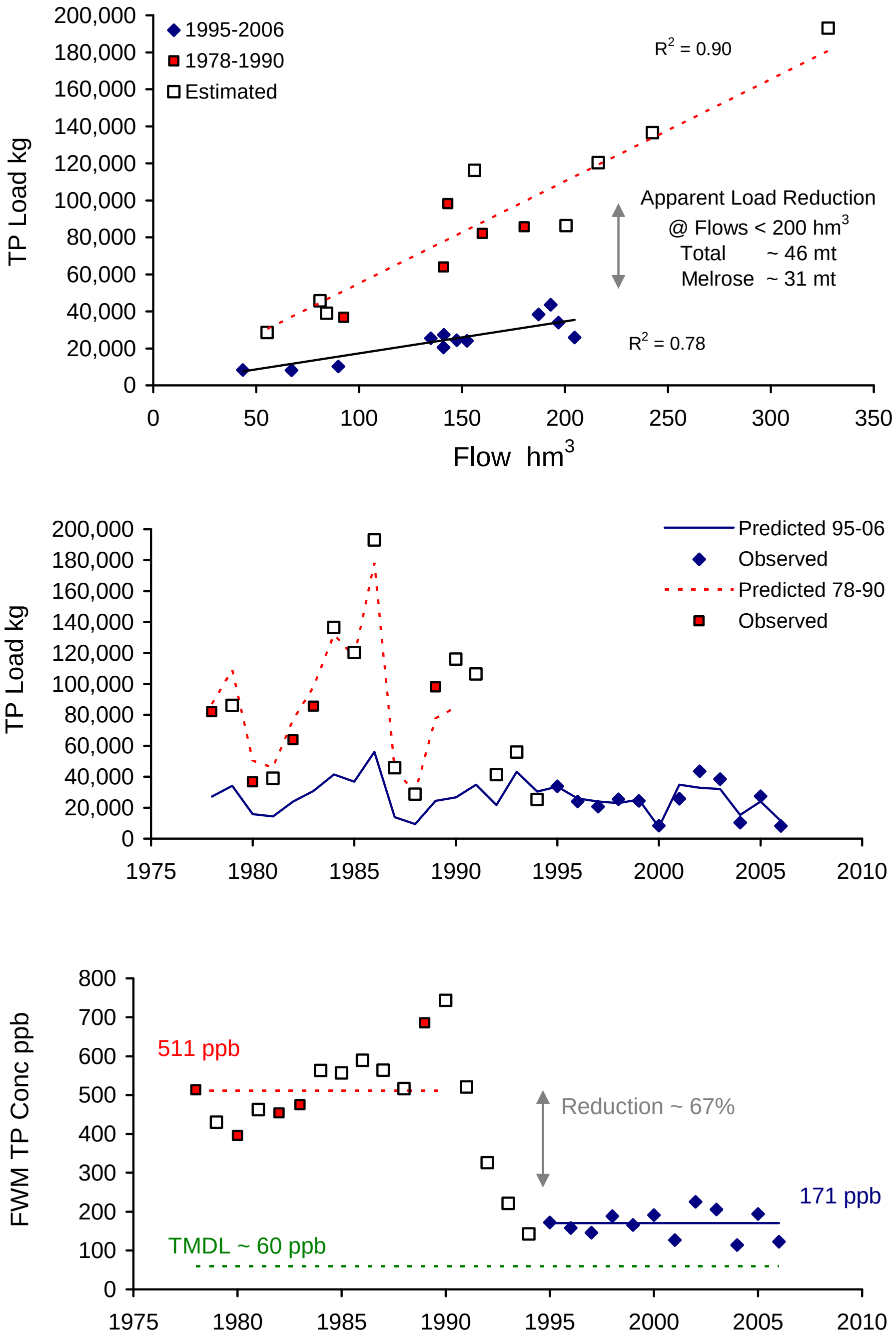
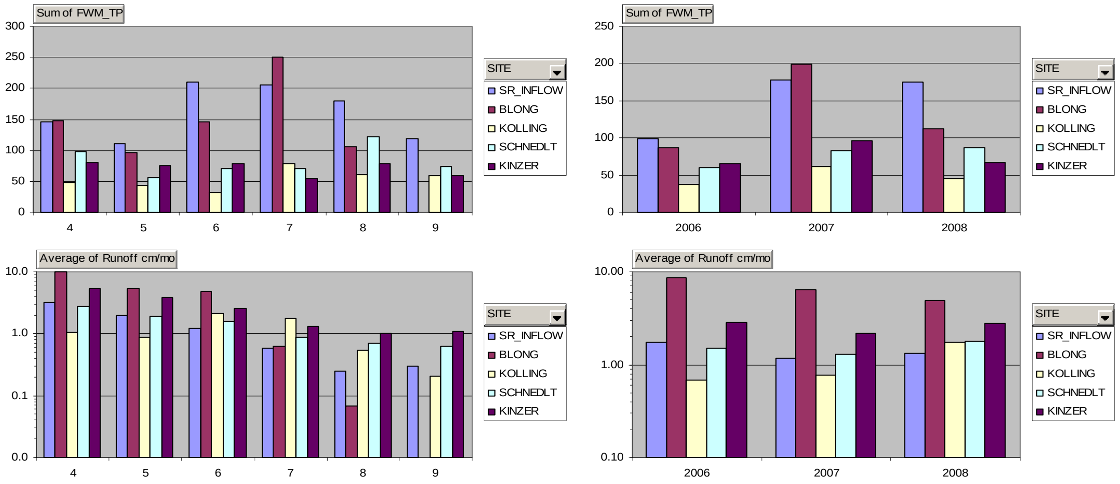


Figure 10 Tributary Runoff and TP Concentrations vs. Month & Year



Computed from paired flow and concentration data.   Tributary flows estimated from SR Inflows for 2007-2008.

Lakesheds, Shoreline Areas, and Atmospheric Deposition

Lakesheds drain directly into the lakes or unmonitored tributaries. They comprise ~27% of the local watershed below the Sauk River inflow. It is assumed that flows and phosphorus loads are proportional to drainage area. Unit area values have been calibrated to the combined inflows from the gauged local tributaries (Kolling, Schneider, Kinzer). Subwatershed delineations are approximate, although the total lakeshed area is constrained by the total difference between the total and tributary drainage areas specified in the watershed GIS layer.

Comparisons of land use maps with aerial photography indicate that GIS datasets may underestimate the extent of urban land use around the lake shorelines. The mass balances include additional terms to account for loadings from shoreline lots in runoff and seepage from onsite wastewater disposal systems. Lot and septic system inventories provided by SRWD are used for estimating shoreline loads using methods similar to those used in other lake modeling frameworks (Griese & Reed, 2008; Paterson et al, 2006).

The shoreline runoff component reflects load from impervious surfaces and cleared areas above the lakeshed background load estimated as described above. Areal photos and views from the lakes suggest that shoreline areas are potentially potent sources of phosphorus in runoff and septic tank effluents, particularly around North Browns, Schneiders, and Cedar Lakes. Some of the lots are located on narrow peninsulas, which suggest limited opportunity for P attenuation in soils.

The estimated septic tank load (444 kg/yr between May-September) is based primarily on inventories of shoreline lots provided by SRWD. The assumed unit load (0.4 kg/unit) is likely to vary widely across lots and across lakes. It is based upon several assumptions, including 0.66 kg/capita/year (Paterson et al, 2006), 3 people per lot, 0.8 seasonal loading factor, 10% failure rate, and 90% attenuation in functioning units. Unit load estimates derived from other studies using different assumptions vary widely[2]:

Table 3 Unit Load Estimates for Septic Systems

TP Load kg/unit	Study	Reference
.19 to 0.38	Sauk Lake TMDL	HMS, 2008
0.18	Itasca County Lakes	Griese & Reed, 2008
1.6	Ontario Lakes <100 m	Paterson et al, 2006
0	“ >300 m setback	“
1.5	SRCL	MPCA 2005; WRM, 1992.

Only the Sauk Lake estimates are based upon direct measurements. Others are estimated using various assumptions. It is unclear whether the higher estimates in previous SRCL studies reflect conservative assumptions and/or conditions prior to phosphorus detergent bans. Site-specific information on set-backs, groundwater movements, age, soil characteristics, and runoff hazards would be needed to refine the estimates of shoreline sources and develop control programs.

With the above assumptions, the estimated total unit area from shoreline lots averages 1.4 kg/hectare (4% background, 21% excess runoff, 74% septic tanks). Mass balances indicate that shoreline sources account for ~0.7% of the TP budget for mainstem lakes and ~5% for other SRCL lakes under existing conditions (Figure 7). These percentages would approximately double with tributary P loads reduced under TMDL conditions. Septic tank loads would be more influential during dry periods and/or in isolated bays that are not captured in the monitoring network or modeling.

Mass Balance Dynamics

Mass balances for Total P, Soluble Reactive P, and Chloride are shown vs. month and year in Appendix B. Because Eden Valley Creek was not monitored, these calculations exclude North Browns Lake. Terms include Sauk River inflow, total inflow (all sources), outflow, and net retention (total inflow – outflow). Water and chloride balances generally close to within 5 percent. SRP and TP outflow loads and concentrations tend to equal or exceed inflow values during April. That is consistent with high flows, low water temperatures, and low algal productivity. Significant retention of phosphorus in June-July also reflects algal uptake and sedimentation. Very little retention is observed in August and September. This most likely reflects recycling of antecedent phosphorus loads from the shallow lake bottom sediments, a process that is accelerated by higher

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[2] Estimates adjusted where possible to assumed 3 people/unit and seasonal loading factor of 0.8 (May-September load / Annual load)

water temperatures and has a greater impact on the phosphorus budgets of the shallow mainstem segments during summer low-flow periods.

Lake Water Quality

Water quality data are summarized in Appendix C. SRCL water quality conditions vary significantly over long-term, seasonal, and yearly time scales. These variations provide good signals for model calibration and testing.

Long-term variations are reflected in comparisons of 1978-1990 and 1997-2006 data. This period brackets the reduction in Sauk River TP load around 1991 (Figure 9). Water quality conditions are shown vs. lake and time period in Figure 11. Trophic State Indices (TSI, Carlson, 1977) are compared in Figure 12. Major patterns include:

1. Significant improvements in most lakes between 1978-1990 and 1997-2006, particularly with respect to TP concentrations in the mainstem lakes.

2. Chlorophyll-a and transparency levels also improved but less than TP on a percentage basis. This is consistent with the fact that TP concentrations generally exceeded levels likely to limit algal productivity during both periods.

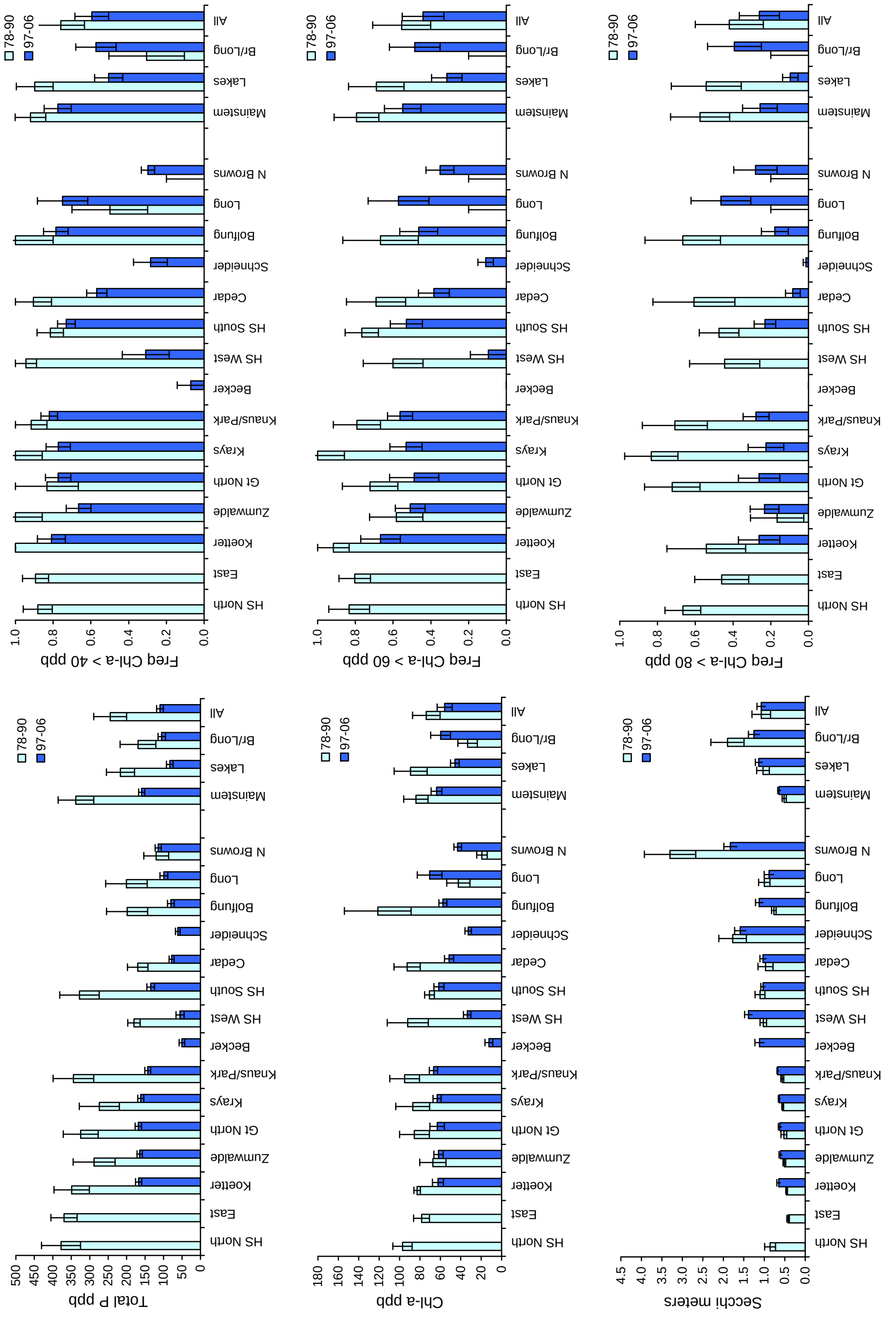
3. The responses of SR offline lakes generally reflected the extent of mixing with the mainstem flows.

4. In contrast with the Sauk River mainstem and lakes, water quality appears to have deteriorated in North Browns and Long Lakes, especially with respect to transparency and algal bloom frequency. The historical data from these lakes are limited, however, so the magnitudes of the changes are relatively uncertain.

Pronounced seasonal variations (Figure 13) are typical of shallow eutrophic lakes (Sondergaard et al., 1999). Following the early spring runoff pulse, both inflow and lake TP concentrations are lowest in May, probably as a consequence of sedimentation and predation of spring diatom booms in the SRCL and lakes in the upper Sauk River watersheds. Subsequent increases in TP over the summer period can be attributed to increases in inflow P concentration beginning in June and phosphorus recycling from bottom sediments later in the summer. Algal booms develop over the summer as conditions become increasingly favorable to growth due to decreases in flushing rate, depth, turbidity, and predation and increases in temperature, light, and TP concentration.

Variations in chlorophyll-a and bloom frequency at mainstem sites are strongly correlated with variations in flow (Figure 14). Despite higher phosphorus loads in wet years, algal bloom development is limited by higher flushing rates, turbidity levels, and greater water depths. Conditions are very conducive to algal growth in dry years, when there is ample time for blooms to develop. TP loads recycled from bottom sediments have greater impacts on water column concentrations in drier years because there is less dilution available. These relationships are simulated by the dynamic model described below.

Figure 11 Long-Term Variations in Lake Water Quality: 1978-1990 vs. 1997-2006



Standard errors computed from distribution of yearly means. Last four categories are area-weighted means across lake subsets.

Figure 12 Long-Term Variations in Trophic State Indices: 1978-1990 vs. 1997-2006

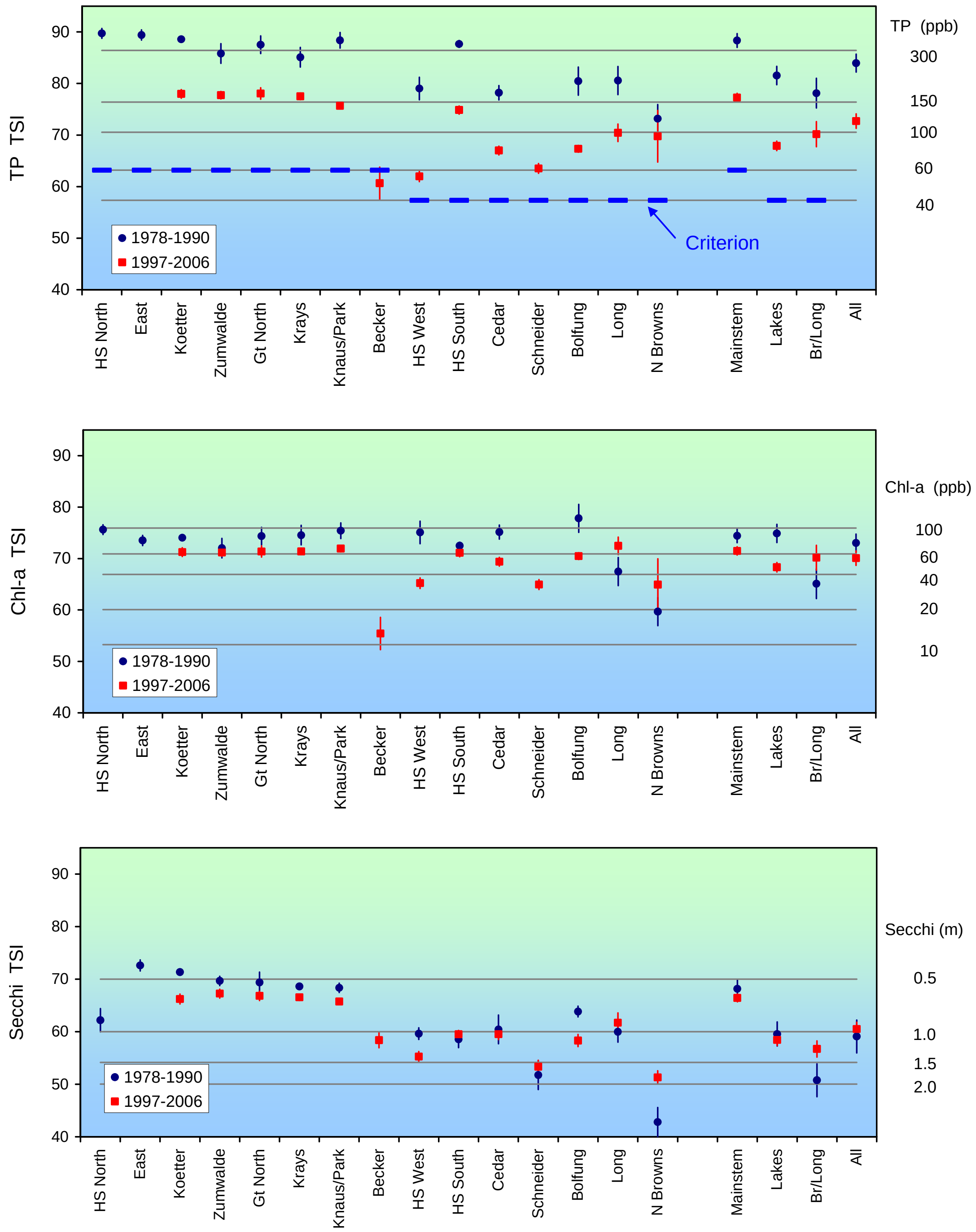


Figure 13 Seasonal Variations in Trophic State Indices

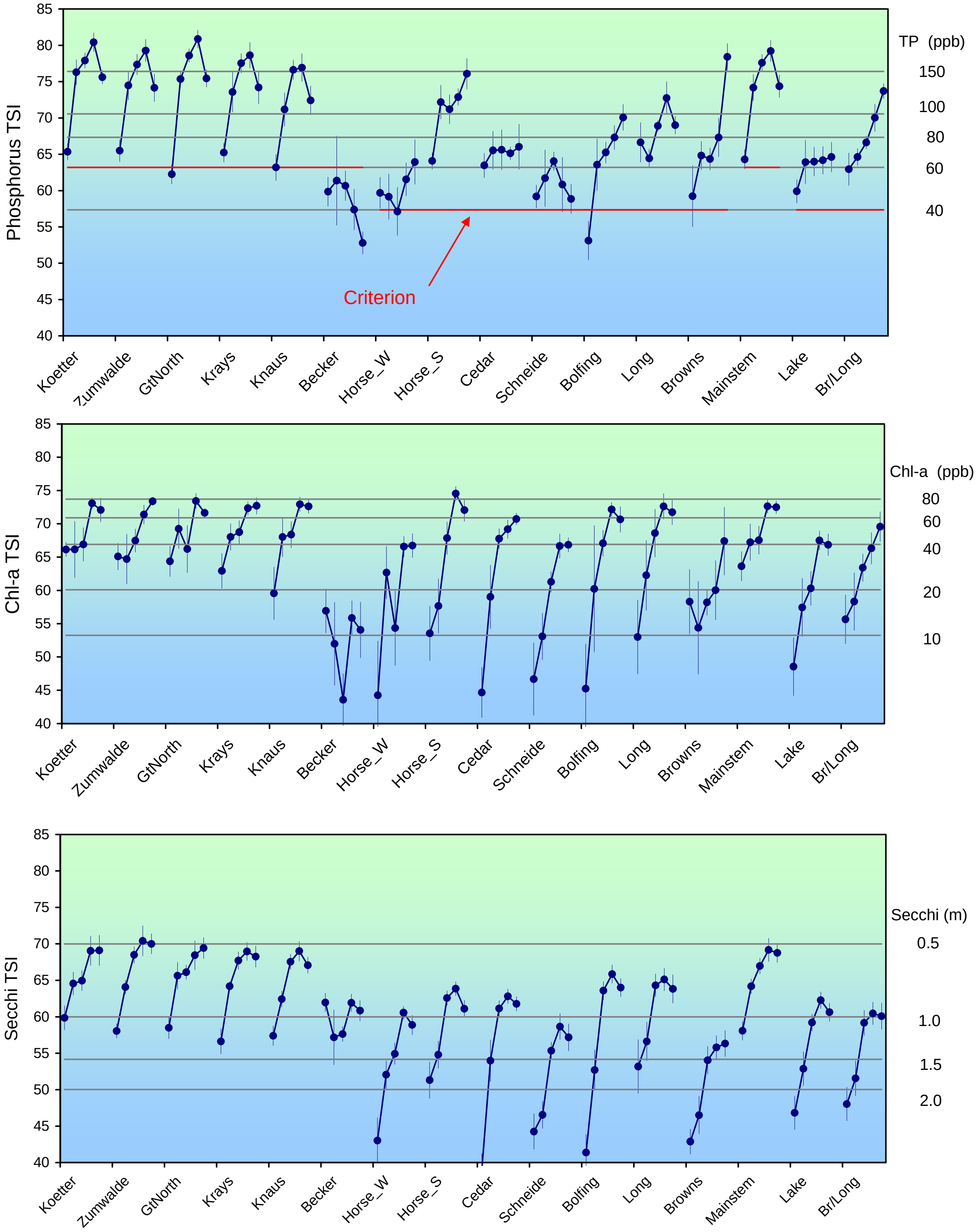
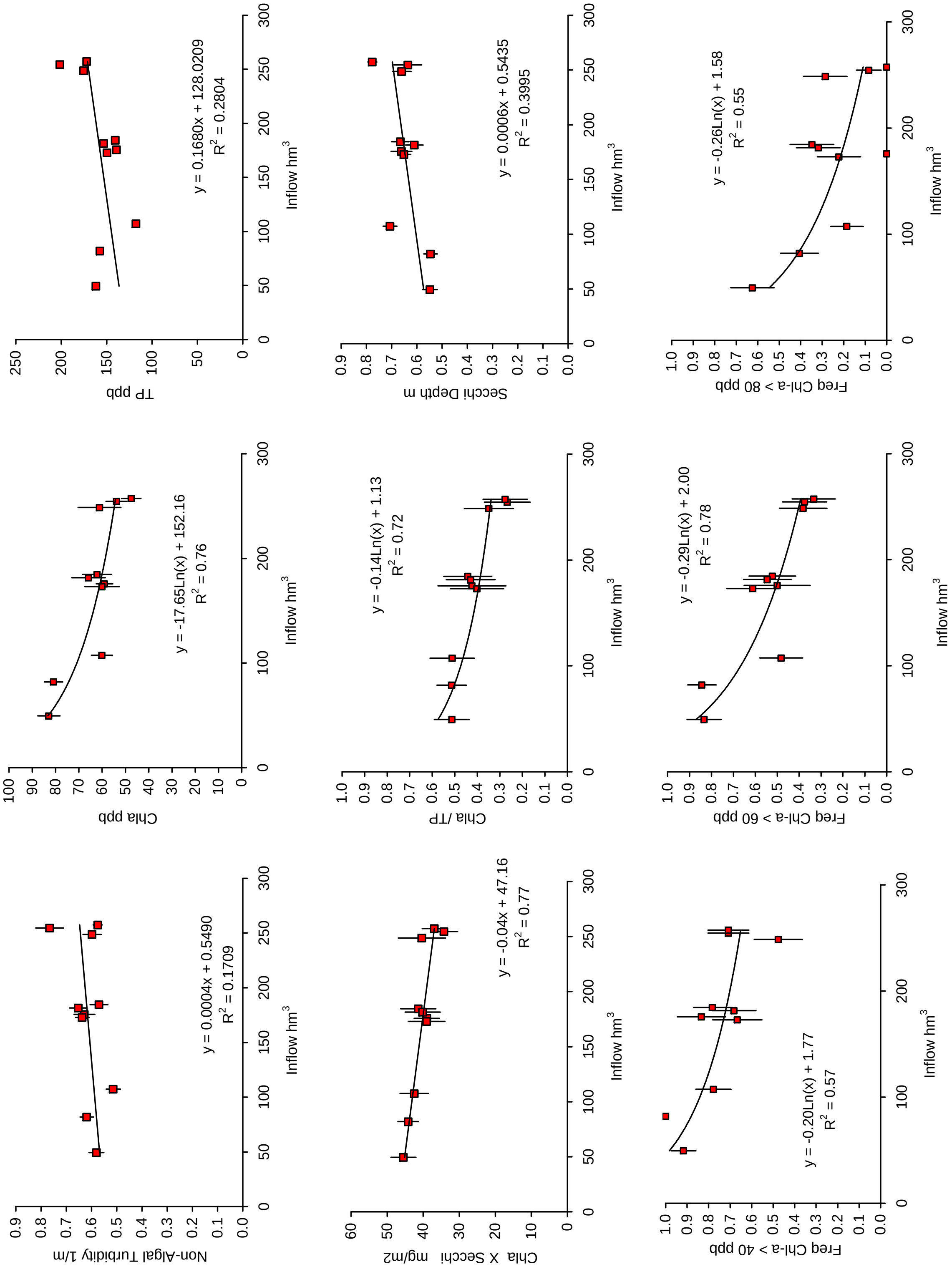
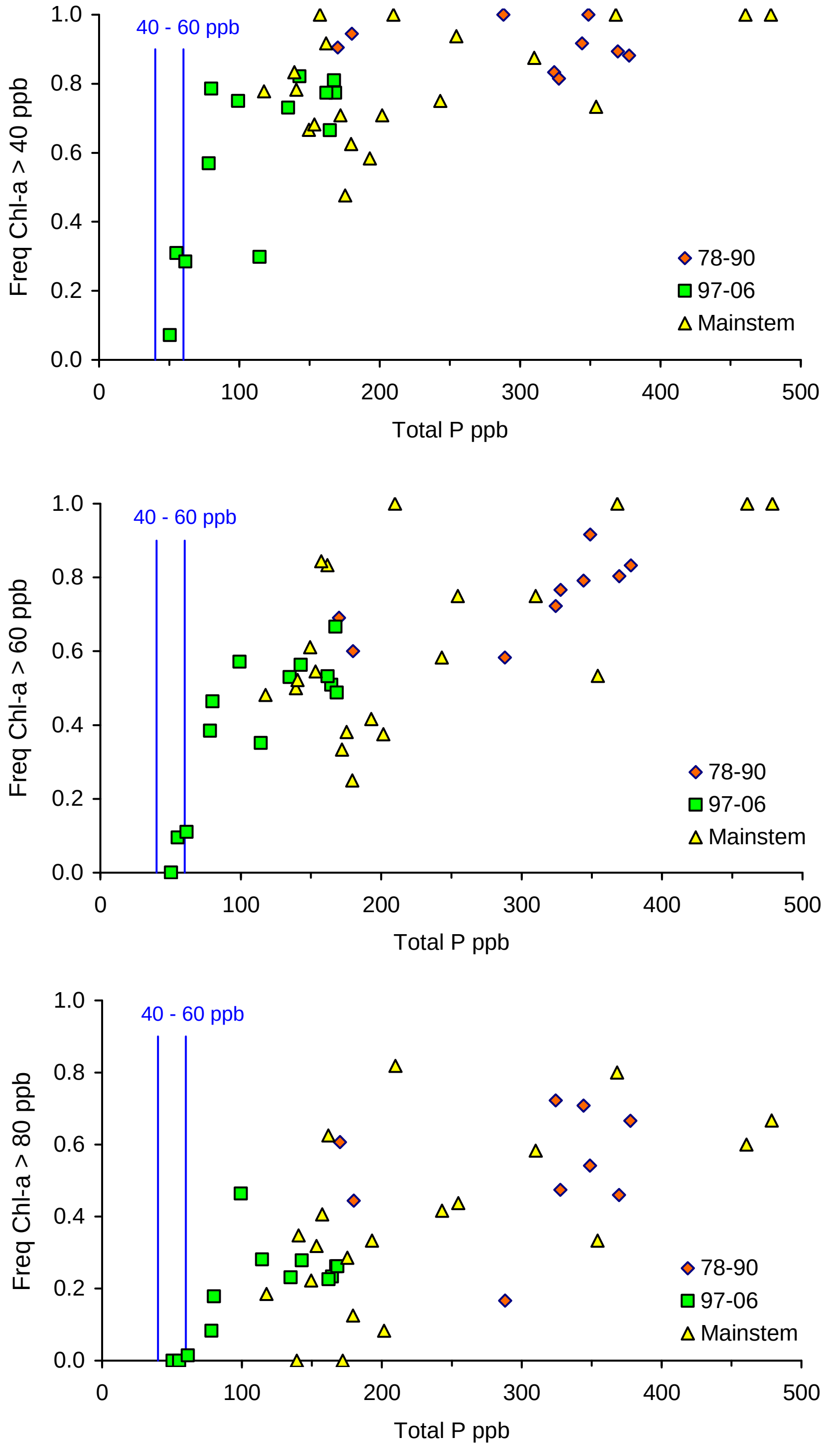


Figure 14 Mainstem Water Quality vs. Net Inflow



Correlations of mainstem June-September mean water quality variables with May-September Net Inflow Volume, 1997-2006.

Figure 15 Algal Bloom Frequency vs. Lake TP



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.

Correlations between TP concentrations and algal bloom frequencies across lakes and time periods are shown in Figure 15. These patterns are generally consistent with those observed in other Minnesota lakes and supported establishment of the phosphorus criteria (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 criteria in a few cases. Bloom frequencies were relatively low in 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 concentrations would be needed to achieve the eutrophication criteria in most of the segments.

Model Development

Basic Concepts

Several modeling approaches have been explored. These involved various temporal scales (daily, monthly, yearly, long-term mean), spatial scales (spatially averaged vs. segmented), and phosphorus storage compartments. A segmented, dynamic model with a daily time step and two compartments (water column and sediment) was found to be feasible, but required several assumptions to fill data gaps. Similar models have been developed for other lakes, reservoirs, and wetlands (Walker 2000b, 2001; Walker & Kadlec, 2005). While potentially useful for further evaluating SRCL phosphorus dynamics (e.g., time scale of response to reduction in loads, seasonal variations, effects of temporal variations in water depth, and impacts of early spring loads), that level of complexity would require additional data and is not required for the purpose of TMDL development.

Application of two models in parallel provides a basis for testing the sensitivity of the TMDL estimates to modeling assumptions. The models are essentially applications of BATHTUB (Walker, 2006) with different spatial and temporal scales. BATHTUB has been used extensively to evaluate eutrophication problems and develop TMDLs in Minnesota and elsewhere[3] . Because of the number and diversity of lake characteristics (e.g., shallow vs. deep, impoundment vs. lake, extreme year-to-year variability), the SRCL application is more complex than most previous applications.

The first model simulates year-to-year variations in the mainstem lakes. The second simulates 5-year-average conditions in each lake segment (Figure 6). Each is anchored in baseline water balances, phosphorus balances, and lake data described above. Empirical equations originally developed from large lake and reservoir datasets (Walker, 1985) are used to predict chlorophyll-a, transparency, and related trophic state indicators with minimal site-specific calibration. Variables and control pathways are shown in Figure 16).

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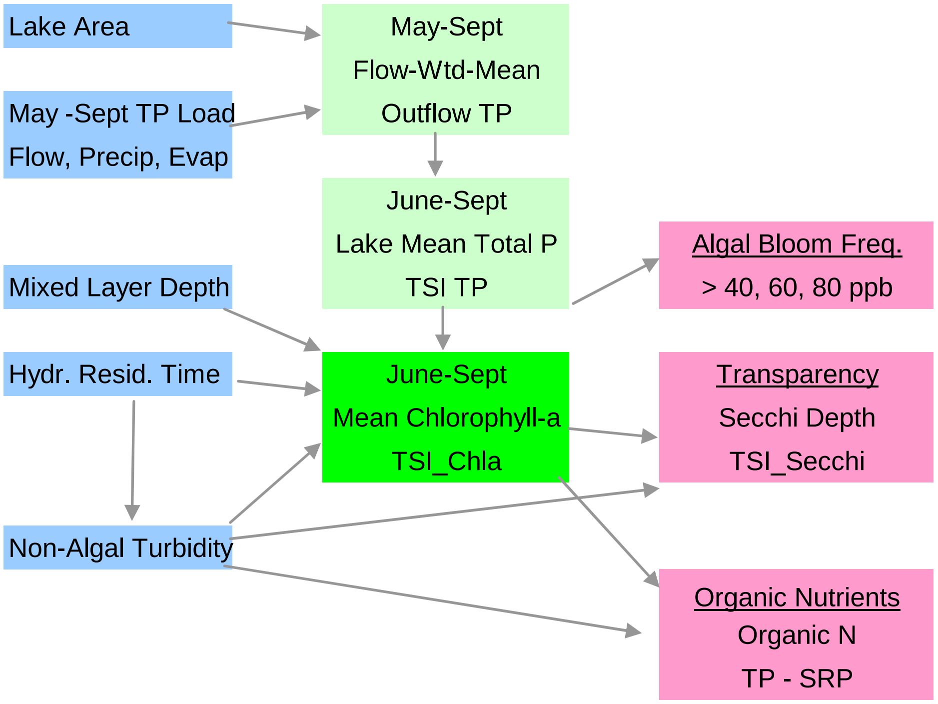
[3] See google.com/search?hl=en&q=BATHTUB+phosphorus+lake+reservoir

Figure 16 Structure of BATHTUB Model



While temporal and spatial scales differ, each model assumes that net phosphorus sedimentation per unit area is proportional to the average concentration in the water column. The proportionality constant is typically described as a “settling velocity” because it has units of meters per year, although processes other than simple particle settling are responsible for TP removal. This formulation has been used widely in modeling other northern lakes (Vollenweider, 1968; Chapra, 1977; Paterson et al., 2006).

The phosphorus retention model predicts the long-term average net phosphorus removal rate, which represents the difference between sedimentation and recycling from bottom sediments (Figure 3). Sediment P release rates (“internal loadings”) have been measured in the SRCL (James, 2006). These are useful for evaluating lake dynamics and potential in-lake control measures, such as chemical treatment, aeration, dredging. Extrapolating rates measured in the laboratory to actual lake conditions is risky because of potential experimental artifacts. Explicit consideration of “internal loading” in the steady-state phosphorus balance used as a basis for TMDL derivation is inappropriate because it reflects recycling of P within the lake, as opposed to an independent external source (Walker, 2000). Internal loadings would be likely to decrease over time if the external loadings were reduced.

Dynamic Model for Mainstem Lakes

The first model predicts summer-average phosphorus concentrations in the mainstem lakes on a yearly basis. Equations are listed in Appendix D. The model is "dynamic" in the sense that predicted lake P concentrations in any year are dependent on the loading in the current and previous year. While its effect is not large, consideration of the latter improves simulation of dry years, when lake P concentrations are strongly influenced by recycling from bottom sediments, as opposed to external inflows. Phosphorus gradients along the mainstem are represented by specifying a single segment with plug-flow hydraulics, as opposed to mixed segments in series. The yearly time step allows simulation of the substantial year-to-year variations in algal bloom frequency, as controlled by flushing rate, non-algal-turbidity, and inflow TP concentrations (Figure 14).

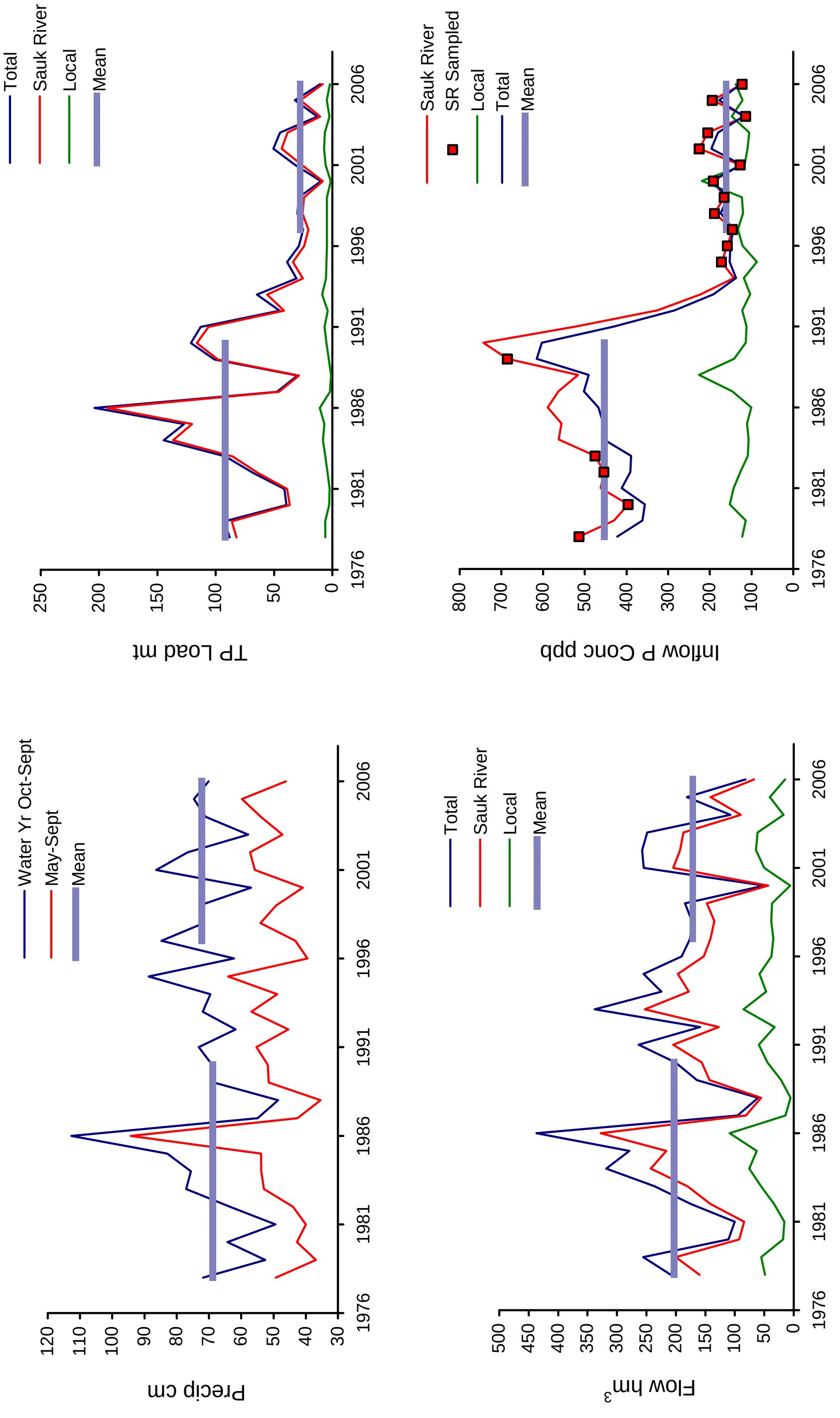
Approximately 96% of the total contributing watershed (including Sauk River, Eden Valley, Kolling Creek, and some lakesheds) is above the inflow to the mainstem lakes at the northern end of Horseshoe Lake (Figure 6, Appendix A-1). Despite the spatial distribution of inflows from local tributaries, the load/response relationship of the mainstem lakes is insensitive to the local tributary loads and the phosphorus budgets of the adjacent SR and EV lakes. This feature permits modeling of the mainstem lakes separately from the others.

The model has been calibrated to data from 1997-2006 and tested against data from 1978-1996. Input and output time series are shown in Figures 17 and 18, respectively. Approximate confidence intervals for the model predictions are based upon the standard deviation of model residuals (observed – predicted values) over the calibration period.

Substantial long-term and year-to-year variations in phosphorus and other trophic state indicators provide strong signals for model testing. The model captures both long-term variations associated with control of Melrose STP in 1991 and yearly variations in lake water quality driven primarily by variations in SR inflow concentration, sediment P recycling during dry years, and algal growth control primarily by flushing rate. Simulated phosphorus fluxes illustrate the increased importance of P recycling in years with lower inflow (Appendix D-4).

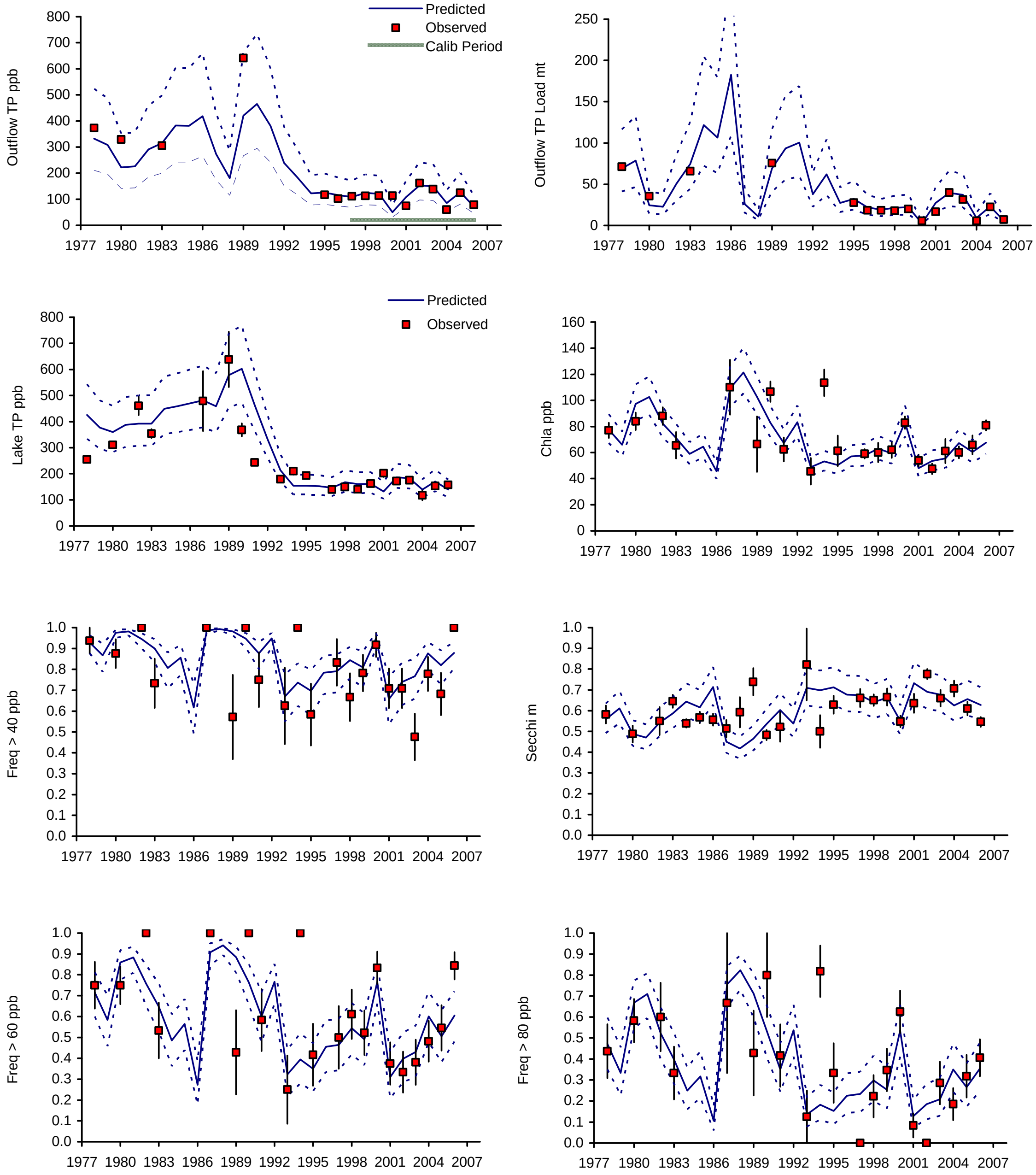
Figure 19 shows predicted responses of mainstem TP and algal bloom frequencies to hypothetical reductions in inflow P load based upon simulations of the 1997-2006 hydrologic record. Lake responses are expressed in terms of the frequency distribution of yearly mean values (10th percentile, mean, 90th percentile) and the confidence interval for the long-term mean. While the lake TP response is linear, the bloom frequency response is nonlinear and exhibits a threshold similar to that apparent in the lake data. The lake TP concentration approaches the 60 ppb criterion at 10-year flow-weighted-mean inflow concentration of 60 ± 5 ppb, which is equivalent to an overall load reduction of about 64 ± 3 %. Yearly time series under this reduced loading scenario are shown in Figure 20.

Figure 17 Input Time Series for Dynamic Model



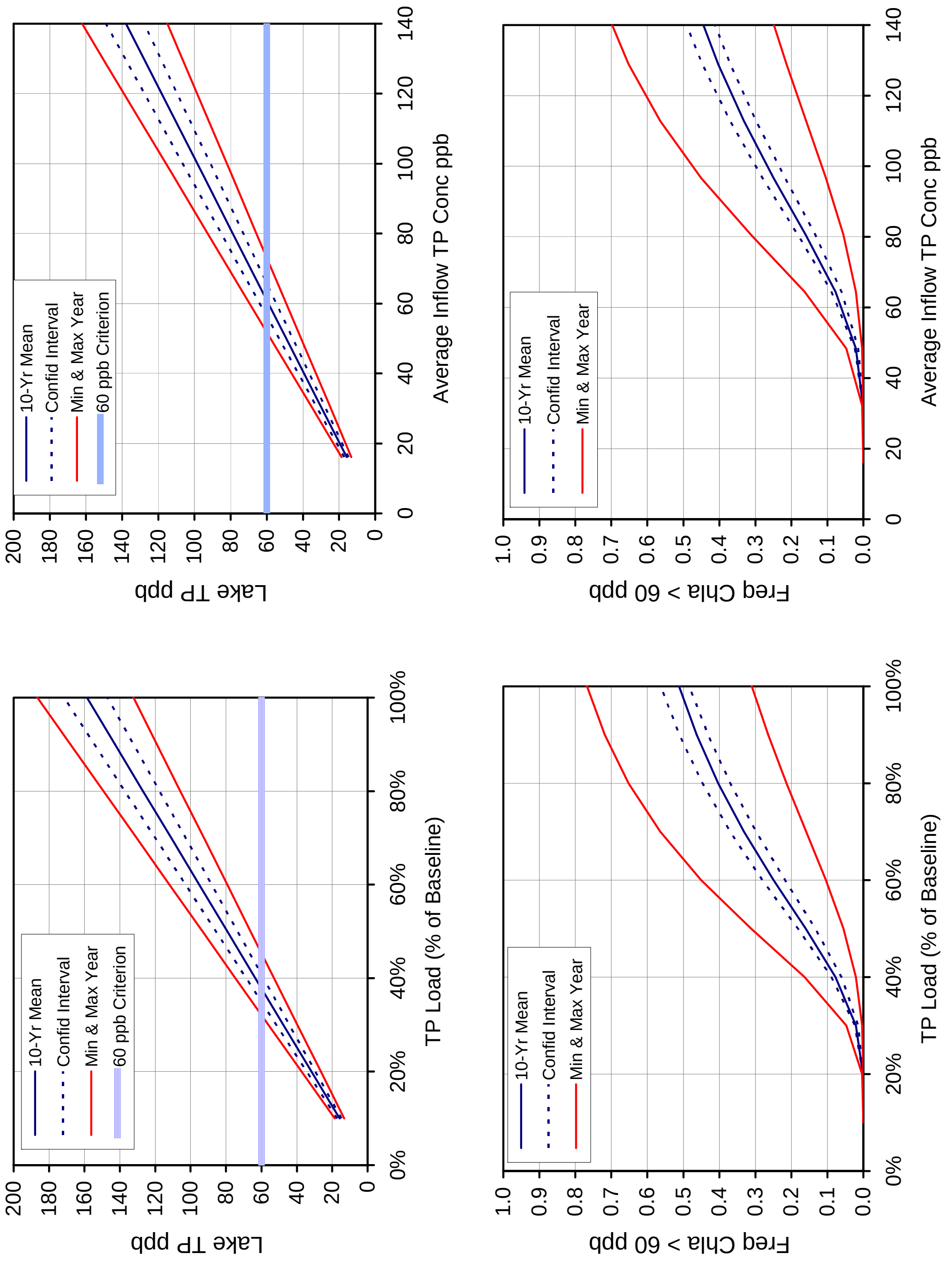
May-September flow, load, & flow-weighted-mean concentration. Local = All sources except Sauk River.

Figure 18 Yearly Simulations of Mainstem Sites, 1978-2006



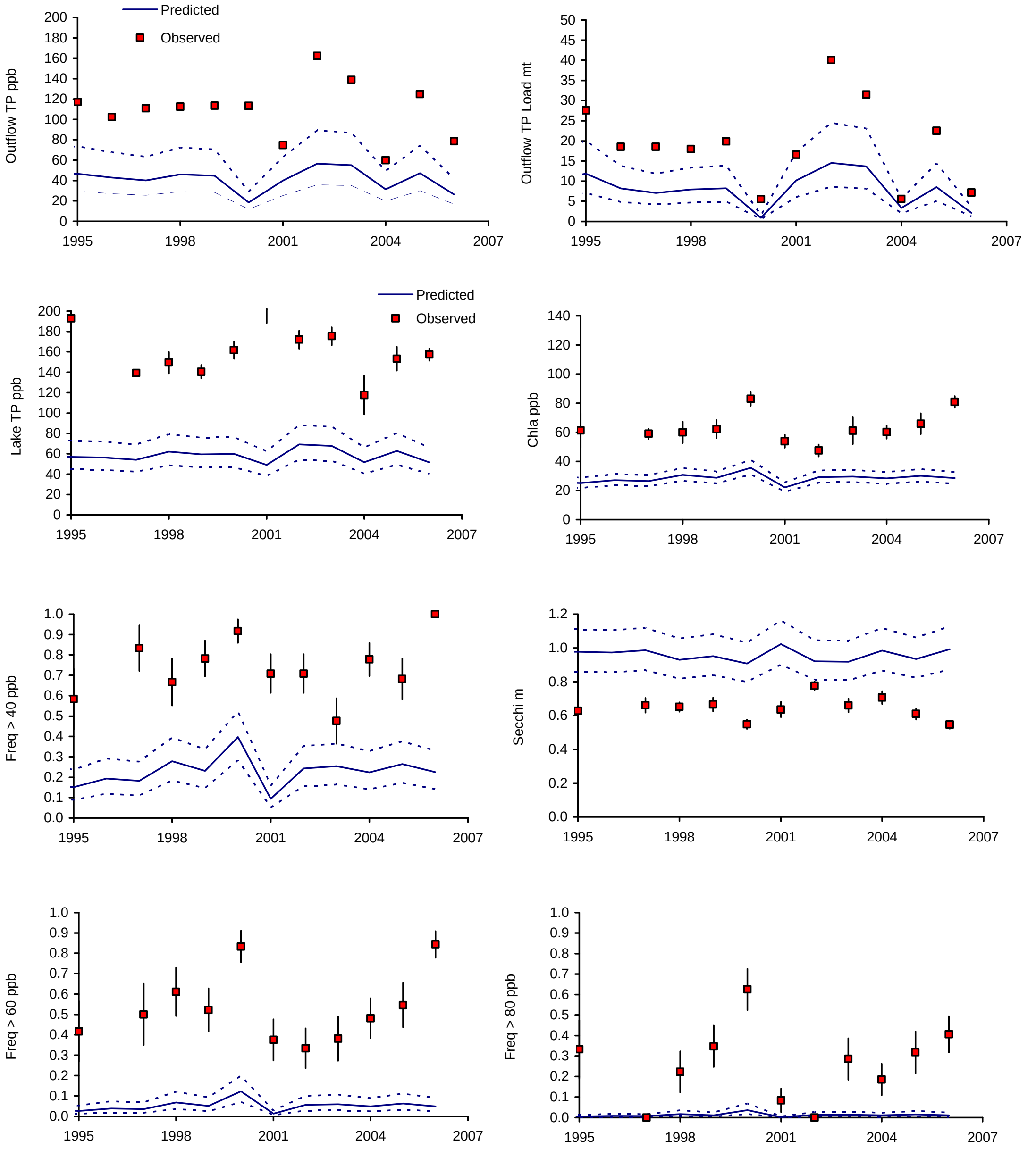
Symbols show observed means +/- 1 standard error computed across mainstem sites & samples in each year, June-September.
The model is driven by May-September inflow volumes and loads for the entire lake chain.
Lines show 80% prediction interval for models (10th, 50th, and 90th percentiles) calibrated to 1997-2006 data.

Figure 19 Responses of Mainstem Lakes to Reductions in TP Load



Confidence intervals (dotted lines) reflect uncertainty in 10-year mean, 1997-2006 hydrologic time series.
Red lines show minimum and maximum yearly values. Loads and inflow concentrations reflect all sources.

Figure 20 Yearly Simulations with Inflow TP Concentration Reduced to 60 ppb



Symbols show observed means +/- 1 standard error computed across mainstem sites & samples in each year, June-September.
The model is driven by May-September inflow volumes and loads for the entire lake chain, rescaled to a average inflow TP Conc of 60 p
Lines show 80% prediction interval for models (10th, 50th, and 90th percentiles) calibrated to 1997-2006 data.

Steady-State Model for the Entire Lake Chain

While the dynamic model is useful for the mainstem lakes, greater spatial resolution is necessary to determine the load reductions required to achieve the more stringent eutrophication criteria for deep lakes in the chain (Table 1). A second modeling approach utilizes BATHTUB to predict 5-year-average water quality conditions across 15 lake segments (Figure 6) for a specified spatial distribution of inflow volumes and loads. While BATHTUB can be applied to data from individual years, dynamic modeling results indicate that yearly variations in lake conditions depend partially on antecedent loads; i.e. the lakes do not reach steady-state with the loads occurring in each year. The lag effect is significantly attenuated over a 5-year time scale. Since the MPCA eutrophication criteria are expressed as long-term averages, simulation of 5-year intervals is sufficient for TMDL development.

Previous modeling by Wilson et al. (2004) provided a foundation for the BATHTUB application. Figure 6 shows the segment linkage and data used in model calibration to the baseline period (2002-2006). Appendix D provides details on the spatial distribution of inflow volumes and loads, as well as results of model testing against data from other time periods. Model input and output for baseline and TMDL scenarios are listed in Appendices E-G.

A spreadsheet version of BATHTUB has been used as a platform for model calibration, testing, and application. Final results have been translated into BATHTUB input files potentially useful for reviewing the modeling results and refining the TMDL estimates after collection of additional monitoring data. These are attached to Appendices E-G.

Parameters calibrated to 2002-2006 data are listed in Appendix E-1. These include:

1. **Phosphorus Settling Rates.** Calibrated values are 14.4 m/yr North Browns, 9.6 m/yr for Schneiders, and 4.8 m/yr for the remaining segments. Higher values for North Browns and Schneiders may reflect the greater depth of these lakes (5.6 and 6.1 meters, respectively) as compared with the other lakes (0.8 to 5.9 m/yr) and/or uncertainty in loading estimates. Adjusting for differences in depths and averaging period, the SRCL calibrated settling rates are similar to those used by HMS (2008) in Sauk Lake TMDL modeling (2–12 m/yr)[4].

2. **Hydraulic Exchanges**. The spatial distribution of lake TP concentrations depends partially on hydraulic exchanges, in turn controlled by morphometry, flow, water level, and wind. Because they cannot be measured directly, they have been calibrated to match the spatial distributions of TP and chloride concentrations. Chloride simulations generally confirm the exchange rate calibrations based upon the phosphorus data, subject to limitations in the flow and

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[4] HMS(2008) used BATHUB Model 8 with a removal rate of 1 yr^{-1}, segment depths ranging from 1.5 to 8 meters, and an averaging period of 0.66 years. Adjusting for differences in depth and averaging period, these parameters are equivalent to settling rates between 2 and 12 m/yr.

chloride data from local tributaries. Results indicate that Becker and Schneiders do not mix appreciably with the mainstem. The calibrated exchange rates are listed in the BATHTUB input file (Appendix E-9)

3. **Chlorophyll-a Flushing Term (0.4)**. The default value (1.0) has been adjusted to provide a better fit of the chlorophyll-a data. This adjustment could reflect the fact that flushing rates are lower in the peak algal growth season (July-August), as compared with the May-September average.

4. **Mixed Layer Depth (<= 3 meters).** While this is below the default value (< 5 meters), it improved the chlorophyll-a fit for the deeper lake segments. The adjustment may reflect buoyancy of blue-green algal populations and/or algal growth in shallow littoral zones.

5. **Algal and Non-Algal Light Extinction Coefficients**. These parameters have been calibrated to chlorophyll-a and Secchi data. The algal extinction coefficient (.015 m^2/mg) is below the default value (0.025 m^2/mg) derived from nationwide data, but is typical of northern lakes with bluegreen algal populations. As expected based upon Sauk River influences, non-algal turbidities are higher in mainstem segments (0.6-0.7 m^{-1}) as compared with lake segments (0.1-0.2 m^{-1}).

6. **Chlorophyll-a Coefficient of Variation (0.45)**. This parameter is used to predict bloom frequencies as a function of mean chlorophyll-a. Because of strong seasonal variation (Figure 13), the SRCL chlorophyll-a distributions tend to have less skewness, as compared with the log-normal distribution assumed in BATHTUB. Improved calibrations to observed bloom frequencies were achieved by eliminating the bias adjustment factor in the equation (Appendix D-5).

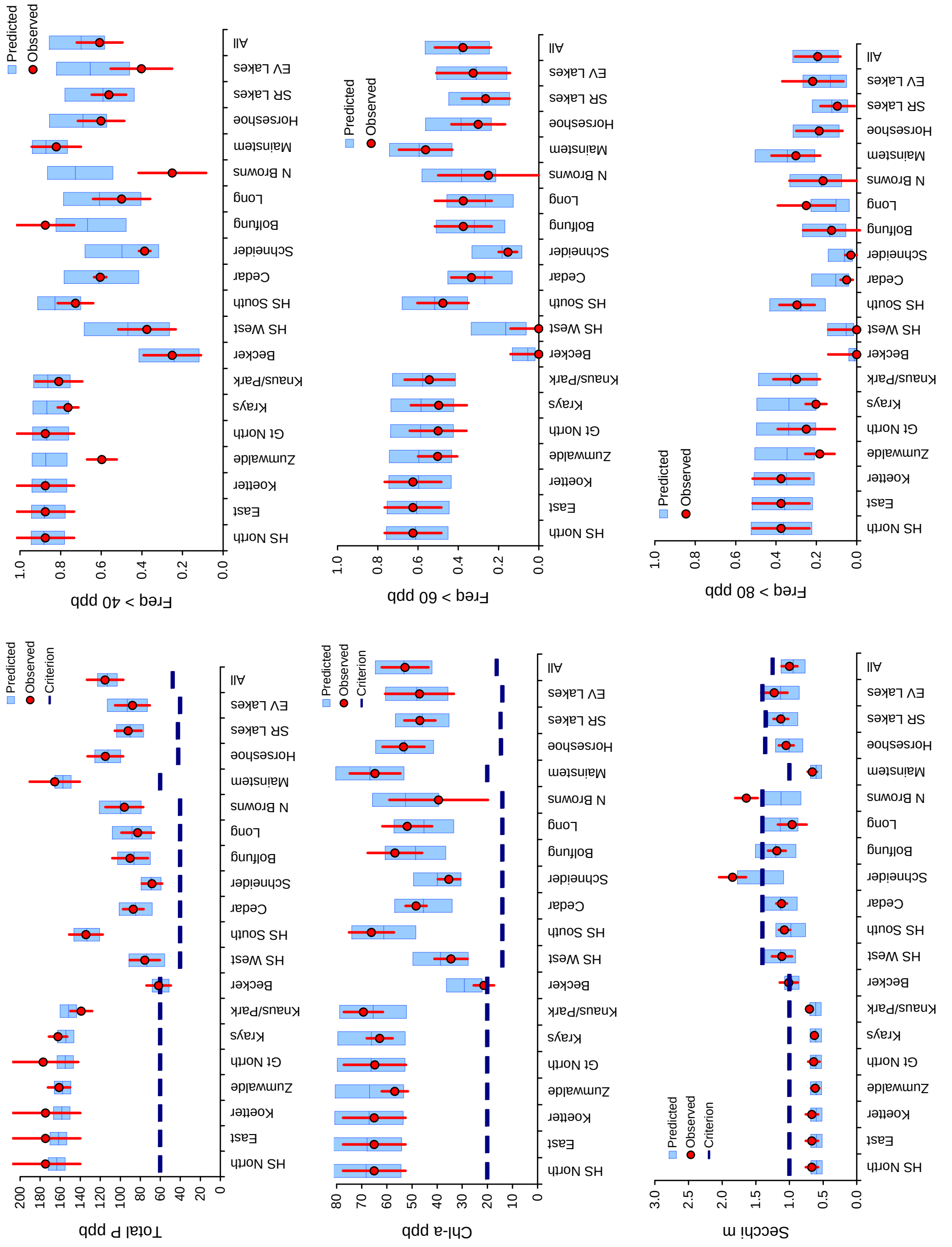
Appendix E has detailed output for the 2002-2006 simulation. Figure 21 Observed & Predicted Values, 2002-2006 compares observed and predicted values in each segment. The model captures most of the spatial and temporal variations in phosphorus and related trophic state indicators. Water and mass balances for each lake region are summarized in Table 4. The overall mass balance and predicted water quality conditions are summarized in Figure 22.

Appendix D contains results of model testing against data from other periods with sufficient inflow and lake monitoring data (1983, 1989, 1997-2001). The historical simulations are limited by the quantity and quality of historical data available for estimation of loads and comparison of observed and predicted lake conditions.

Mainstem TP concentrations in 1997-2001 are under-predicted by ~18%. This could reflect inaccuracies in the flow and/or load estimates because Sauk River flows were not directly measured. The result could also reflect a lagged response to the significant reduction in P load that occurred in 1991 (Figure 9), the effects of which are considered in the dynamic model (Figure 18) but not in the steady-state model.

Secchi depths in 1989 are under-predicted by a substantial margin (Appendix D-8). The measured values extracted from the MPCA/STORET database are inconsistent with the reported chlorophyll-a and TP concentrations and significantly higher in some cases than those measured in recent years. The pattern may reflect lower non-algal turbidity in that year due to extreme drought. It is also possible that the data were recorded in the wrong units (feet instead of meters). Similar problems were identified in historical transparency data from other periods and sources, but could not be entirely resolved.

Figure 21 Observed & Predicted Values, 2002-2006



Means +/- 1 standard error of observed (symbols) and predicted (bars) values.
Blue lines indicate MPCA criteria for deep & shallow lakes. (TP < 40 or 60 ppb, Chla < 14 or < 20 ppb, Secchi >1.4 or 1.0 m

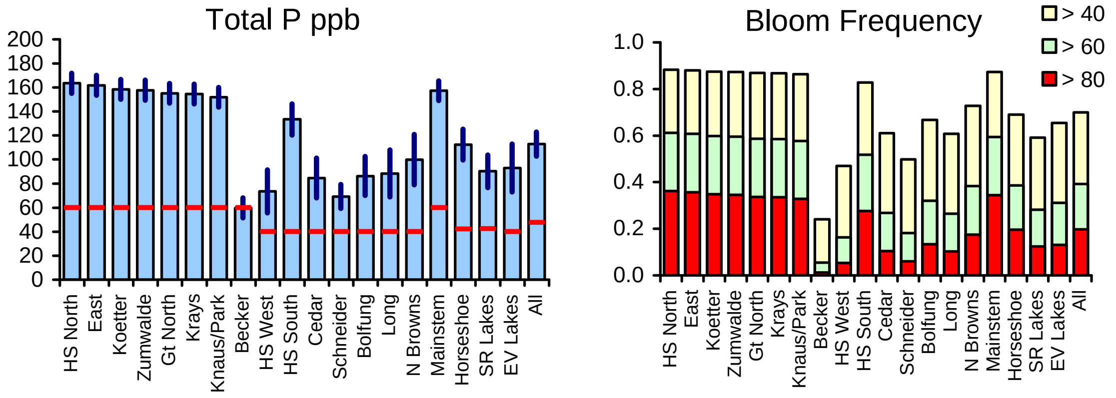
Table 4 Regional Water and Phosphorus Balances for the 2002-2006 Simulation

Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Mainstem Lakes (Horseshoe North - Knaus)									
Sauk River	2088	135.7	25536	188	87%	76%	91%	0.06	12.2
Kinzer Creek	18	2.5	182	73	1%	1%	1%	0.14	9.9
Lakeshed	6	0.6	34	54	0%	0%	0%	0.11	5.9
Septic Tanks	0		138				0%		
Shoreline Runoff	0		50				0%		
Total External	2112	138.8	25941	187	88%	78%	93%	0.07	12.3
Outflow from Lakes	288	37.1	3824	103	12%	21%	14%	0.13	13.3
Exchange with Lakes			-1831				-7%		0.0
Precip	4	2.0	61	30	0%	1%	0%	0.47	14.1
Evap		0.0				0%	0%		
Net Inflow	2405	178.0	27995	157	100%	100%	100%	0.07	11.6
Outflow	2405	175.3	26632	152	100%	99%	95%	0.07	11.1
Retention			1363				5%		
Offline Lakes (Becker, HS South, HS West, Cedar, Schneider, Bolfung)									
Kolling Creek	97	11.1	496	45	34%	27%	10%	0.11	5.1
Schneider Inflow	34	2.7	211	77	12%	7%	4%	0.08	6.2
Lakesheds	30	3.3	178	54	10%	8%	4%	0.11	5.9
Septic Tanks			186				4%		
Shoreline Runoff			52				1%		
Total External	162	17.1	1122	65	56%	42%	23%	0.11	6.9
Inflow from Long	121	20.8	1840	88	42%	51%	38%	0.17	15.2
Exchange with Mainstem			1831				38%		0.0
Precip	6	2.6	79	30	2%	7%	2%	0.47	14.1
Evap		0.0				0%	0%		
Net Inflow	288	40.6	4872	120	100%	100%	100%	0.47	16.9
Outflow	288	37.1	3824	103	100%	92%	78%	0.47	13.3
Retention			1048				22%		
North Browns + Long									
Eden Valley Creek	106	19.6	2655	135	87%	94%	90%	0.19	25.1
Trib to Long L Inlet	4	0.7	102	135	3%	4%	3%	0.19	25.1
Lakeshed	8	0.9	49	54	7%	4%	2%	0.11	5.9
Septic Tanks	0		80				3%		
Shoreline Runoff	0		15				1%		
Total External	118	21.3	2901	137	97%	102%	98%	0.18	24.6
Precip	3	1.5	46	30	3%	7%	2%	0.47	14.1
Evap		2.0				9%			
Net Inflow	121	20.8	2947	142	100%	100%	100%	0.17	24.3
Outflow	121	20.8	1840	88	100%	100%	62%	0.17	15.2
Retention			1107				38%		
Overall									
Sauk River	2088	135.7	25536	188	87%	77%	85%	0.06	12.2
Kolling Creek	97	11.1	496	45	4%	6%	2%	0.11	5.1
Schneider Inflow	34	2.7	211	77	1%	2%	1%	0.08	6.2
Kinzer Creek	18	2.5	182	73	1%	1%	1%	0.14	9.9
Eden Valley Creek	106	19.6	2655	135	4%	11%	9%	0.19	25.1
Trib to Long L Inlet	4	0.7	102	135	0%	0%	0%	0.19	25.1
Lakesheds	44	4.8	261	54	2%	3%	1%	0.11	5.9
Septic Tanks			404				1%		
Shoreline Runoff			118				0%		
Total External	2392	177.2	29965	169	99%	101%	99%	0.07	12.5
Precip	13	6.2	186	30	1%	4%	1%	0.47	14.1
Evap		8.1				5%			
Net Inflow	2405	175.3	30150	172	100%	100%	100%	0.07	12.5
Outflow	2405	175.3	26632	152	100%	100%	88%	0.07	11.1
Retention			3518				12%		

May-September, 2002-2006.

Figure 22 Predicted Water Quality for the 2002-2006 Simulation

Lake	Criterion	TP	TP_SE	Chl-a	Secchi	Algal Bloom Frequencies			Trophic State Indices		
Segment	ppb	ppb	ppb	ppb	m	> 40	> 60	> 80	Total P	Chl-a	Secc
HS North	60	163	8	68	0.60	0.88	0.61	0.36	78	72	67
East	60	162	8	68	0.60	0.88	0.61	0.36	77	72	67
Koetter	60	158	8	67	0.60	0.87	0.60	0.35	77	72	67
Zumwalde	60	158	8	67	0.60	0.87	0.60	0.35	77	72	67
Gt North	60	155	8	66	0.61	0.87	0.59	0.34	77	72	67
Krays	60	154	8	66	0.61	0.87	0.59	0.34	77	72	67
Knaus/Park	60	152	8	65	0.61	0.86	0.58	0.33	77	72	67
Becker	60	60	8	29	0.96	0.24	0.05	0.01	63	64	61
HS West	40	73	18	39	1.14	0.47	0.16	0.05	66	67	58
HS South	40	133	13	61	0.98	0.83	0.52	0.28	75	71	60
Cedar	40	85	16	45	1.13	0.61	0.27	0.10	68	68	58
Schneider	40	69	10	40	1.43	0.50	0.18	0.06	65	67	55
Bolfung	40	86	16	49	1.21	0.67	0.32	0.13	68	69	57
Long	40	88	20	45	1.14	0.61	0.27	0.10	69	68	58
N Browns	40	100	21	53	1.13	0.73	0.38	0.18	71	70	58
Mainstem	60	157	8	67	0.61	0.87	0.59	0.34	77	72	67
Horseshoe	42	112	13	53	1.01	0.69	0.39	0.20	72	70	60
SR Lakes	42	90	14	46	1.10	0.59	0.28	0.12	69	68	59
EV Lakes	40	93	20	48	1.13	0.65	0.31	0.13	70	69	58
All	48	113	10	53	0.94	0.70	0.39	0.20	72	70	61



Sensitivity Analysis

A sensitivity analysis has been performed to identify factors having the strongest impacts on predicted TP concentrations in each segment (Table 5). This is useful for evaluating potential responses to variations in tributary loads and consequences of uncertainty in the model input values and parameters. The analysis uses methods similar developed for lake modeling in Vermont (Walker, 1982) and later incorporated into BATHTUB (Walker, 1999; 2006). Sensitivities to the following factors have been evaluated:

1. Inflow volumes from sources in four categories (Sauk River, Eden Valley Creek, other local tributaries, and lakesheds).

2. Inflow concentrations for each of the above source categories. For a given flow, sensitivities to concentrations and load would be identical.

3. Model parameters, including settling and hydraulic exchange (mixing) rates.

Sensitivity to each factor has been evaluated by reducing its value by 20%, running the model, and computing the percent change in the predicted lake P concentration in each model segment.

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.

The uncertainty in the predicted TP concentration for each segment has been computed from the sensitivity analysis results and uncertainty in each model input or parameter. Uncertainty is expressed as Relative Standard Error (RSE = Standard Error / Mean). RSE values for the mainstem segments are low (0.05) because they are strongly correlated with the Sauk River inflow concentration, which is based upon several years of direct measurements. RSE values for the other segments are higher (0.10-0.24) because they are more strongly dependent on estimated inflows from the local watersheds and model parameters. Appendices E-G contain similar tables for alternative loading scenarios.

Table 5 Sensitivity Analysis for 1997-2006 Simulation

Percent Reduction in Lake P for with a 20% Reduction in Source or Model Coefficient

	Total P		Source Flow				Source Concentration				Settling Rate		Exchange
Segment	ppb	RSE	Sauk R	Tribs	Eden V	Lakeshed	Sauk R	Tribs	Eden V	Lakeshed	Mainstem	Lake	Rates
HS North	163	0.05	3	-1	-1	0	18	0	1	0	0	-1	0
East	162	0.05	3	-1	-1	0	18	0	1	0	0	-1	0
Koetter	158	0.05	3	-1	-1	0	18	0	1	0	0	-1	0
Zumwalde	158	0.05	3	-1	-1	0	18	0	1	0	-1	-1	0
Gt North	155	0.05	4	-1	-1	0	18	0	1	0	-1	-1	0
Krays	154	0.05	4	-1	-1	0	18	0	1	0	-1	-1	0
Knaus/Park	152	0.05	4	-1	0	0	18	1	1	0	-1	-1	0
HS West	60	0.24	2	-1	0	5	11	0	1	7	0	-16	7
HS South	73	0.10	2	-1	-1	0	14	0	5	0	0	-3	3
Cedar	133	0.19	3	-1	0	0	14	0	1	5	0	-10	7
Schneider	85	0.14	0	2	0	3	0	16	0	4	0	-5	0
Bolfung	69	0.19	3	-1	0	1	13	0	1	5	-1	-10	7
Long	86	0.22	0	0	8	1	0	0	19	1	0	-9	0
N Browns	88	0.21	0	0	6	0	0	0	19	1	0	-6	0
Mainstem	100	0.05	4	-1	-1	0	18	0	1	0	-1	-1	0
Horseshoe	157	0.11	2	-1	-1	1	14	0	3	2	0	-6	4
SR Lakes	112	0.15	2	-1	-1	1	12	2	2	3	0	-8	5
EV Lakes	90	0.22	0	0	7	0	0	0	19	1	0	-8	0
All	93	0.09	2	-1	1	0	12	1	5	1	0	-5	2
Assumed Input Uncertainty (RSE)			10%	15%	20%	20%	5%	15%	20%	30%	20%	20%	40%

Shading: 🟥 >15% 🟧 >5% 🟨 >2% reduction for a 20% reduction in model input value

RSE = Relative Standard Error in predicted Total P computed using first-order error analysis (Walker, 1982; 2006)

Lakeshed sources include ungauged runoff, shoreline runoff and septic systems.

TMDL Scenarios

Load/Response Relationships

This section applies the steady-state model to evaluate lake responses to hypothetical 40-70% reductions in phosphorus load relative to baseline conditions (30 metric tons in May-September, 2002-2006). Results indicate that an overall load reduction of 64± 3 % would be required to achieve the phosphorus criteria in each segment category (Mainstem, Sauk River lakes, Eden Valley lakes). Results are consistent with those derived from the dynamic model of the mainstem lakes (Figure 19). Model predictions are among other technical, regulatory, and policy factors to be considered by SWRD and regulatory agencies in deciding upon appropriate TMDLs for the Sauk River lakes and Eden Valley lakes.

TMDL determinations for individual lakes are typically independent of specific allocations of loads across source categories and tributaries. That is not the case for the SRCL because of the spatial distribution of inflows, interactions among the lake segments, and multiple criteria. Accordingly, a consistent method for distributing the load reductions across sources (specific tributaries, shoreline areas) is needed in order to derive the overall load reduction requirement. These distributions are not necessarily the same as those that would be used in final TMDL allocation (Equation 2), which would also involve more detailed evaluation of sources and specific control options, as well as provision of a margin of safety.

Spatial variations in water quality, depth, hydraulic exchanges within and among lake segments also introduce uncertainty as to the appropriate spatial averaging procedures for application of the eutrophication criteria (Table 1). Hypothetically, the criteria could apply to each segment separately, to the average across segments within each lake (e.g. Horseshoe), or the average across segments in each category of connected lakes (mainstem vs. lake, shallow vs. deep). The fact that a particular segment of the lake chain may have its own name does not mean that it is functionally independent or can be managed independently of the others. As compared with individual, well-mixed lakes, the SRCL as a whole provides a diversity of conditions that might adequately support desired biota and recreational uses, even if model predictions exceed criteria in some segments. These regulatory/policy factors can be considered by SRWD and MPCA in interpreting the simulation results and deciding upon an appropriate TMDL.

Alternative loading scenarios have been developed by applying maximum inflow concentration constraints ranging from 40 to 100 ppb simultaneously to each tributary. The minimum of the 2002-2006 baseline concentration and the constraint is applied to each tributary; i.e. it is assumed that a TMDL allocation would not exceed the baseline load. This allocation procedure automatically targets tributaries with the highest inflow concentrations (Sauk River and Eden Valley Creek, Figure 10) and is consistent with the fact that the tributaries have similar land uses (Figure 5). Flow volumes have been held constant at baseline values; predicted lake TP concentrations are relatively insensitive to flow (Table 5). Sensitivity to shoreline sources has been evaluated by running the model twice for each inflow concentration assuming 0% and 50% reduction in the total shoreline load to each segment (septic tanks + runoff).

Simulation results for 14 scenarios are listed in Appendix D-10. Table cells are shaded to indicate scenarios consistent with achieving TP, chlorophyll-a, or Secchi depth criteria (Table 1) in each segment, segment category, and the average of 3 segments in Horseshoe Lake (Figure 6). Both the predicted values and the criteria are weighted by surface area in listing results for segment groups involving combinations of shallow and deep segments.

Figure 28 shows the predicted responses of lakes in each category. Maximum tributary TP concentrations and corresponding percentage load reductions consistent with achieving eutrophication criteria on a spatially-averaged basis in the shallow and deep segments are summarized in Table 6.

Table 6 Loading Scenarios Consistent with Achieving Criteria

	Total P	Chl-a	Secchi
Lake Criteria			
Mainstem	< 60 ppb	< 20 ppb	> 1.0 m
Deep	< 40 ppb	< 14 ppb	> 1.4 m
All	< 48 ppb	< 16 ppb	> 1.2 m
Max. Tributary Inflow Conc (ppb)			
Mainstem	65	40	50
Deep	55	< 30	100
All	60	< 35	90
Reduction in 2002-2006 TP Load (30 metric tons/yr)			
Mainstem	61%	74%	69%
Deep	66%	> 80%	43%
All	64%	>77%	48%

Results for each criterion are discussed below:

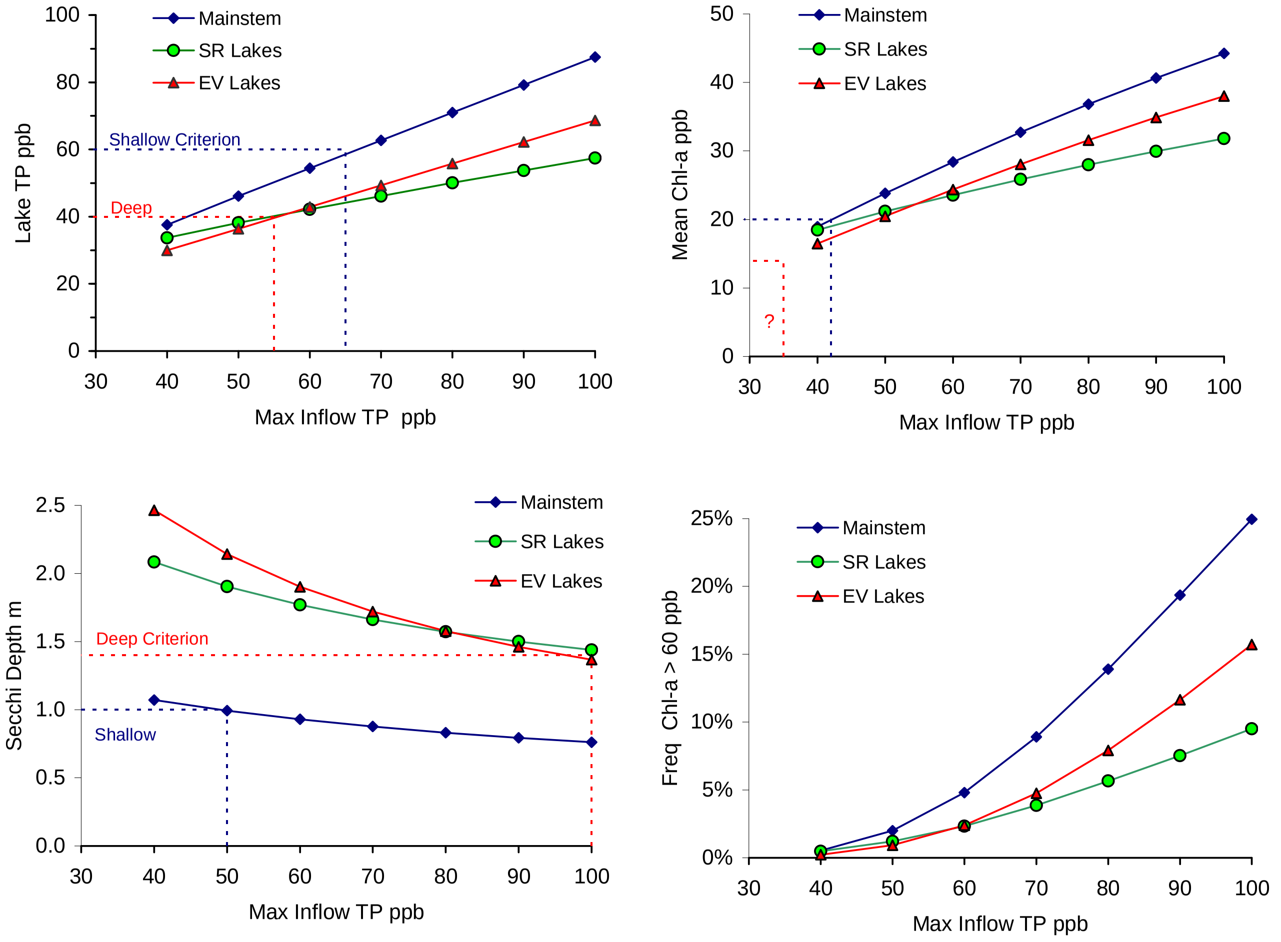
1. Achieving phosphorus criteria would require inflow TP concentrations less than approximately 65 ppb for the mainstem segments and 55 ppb for the deep segments. These correspond to overall load reductions of 61 and 66%, respectively. The range reflects differences in criteria (60 vs. 40 ppb) and mixing among the lake segments. The difference is not statistically significant, given uncertainty in the model predictions and limited data available for estimating loads from local tributaries and shoreline sources. Dynamic model forecasts also indicate that a combined inflow TP concentration of 60 ppb would be required to achieve the mainstem TP criterion (Figure 19).

2. While achieving the TP criteria is sufficient for regulatory purposes because impairment is determined by excessive nutrient levels (Heiskary & Wilson, 2008),

achieving Secchi depth criteria in the mainstem segments would require maximum inflow TP concentrations of 50 ppb for the mainstem lakes and 100 ppb for the deep lakes. These correspond to overall load reductions of 69% and 43%, respectively. The more stringent result for the mainstem segments reflects differences in non-algal turbidities, which are higher in the mainstem lakes (0.6 vs. 0.1-0.3 m^{-1}) because of shallow depths and sediment loads from the Sauk River. Implementing BMPs to reduce TP loads would also be expected to reduce sediment loads and non-algal turbidity levels in the mainstem lakes. Accordingly, the model may under-predict Secchi depths under TMDL conditions.

3. Achieving mean chlorophyll-a criteria would require an inflow TP concentration of 40 ppb for the mainstem lakes and < 30 ppb for the deep lakes, respectively. These correspond to overall load reductions of 74% and >80%, respectively. The 14 ppb criterion for deep lakes is apparently not attainable within the range of inflow concentrations considered. With an inflow P concentration of 60 ppb, however, frequencies of severe nuisance blooms (Chl-a > 60 ppb) would be reduced to <5% in the mainstem segments and <3 % in the deep segments, as compared with baseline values of 59%% and 30%%, respectively. With an inflow P concentration of 100 ppb, bloom frequencies would be reduced to < 25% and <11 %, respectively. Inflow TP concentrations in 60 to 100 ppb range required to achieve the TP or Secchi depth criteria would provide significant improvements in aesthetics and recreational potential, even though it is unlikely that the mean chlorophyll-a criteria would be met.

Figure 23 Lake Responses to Reductions in Tributary TP Concentrations



Predicted lake water quality vs. maximum tributary TP concentration with a 50% reduction in shoreline sources.
Dotted lines = Criteria for shallow (mainstem) and deep lakes. Predicted values are area-weighted means in each category.
Inflow TP concentrations of 40 - 100 ppb correspond to Total P loads of 8 - 17 mt vs. 30 mt baseline load to the entire SRCL.

Three Scenarios

Based upon the above results, three loading scenarios have been selected for more detailed evaluation and comparison:

1. **Baseline.** 2002-2006 Conditions**.**

2. **Tributaries < 100 ppb without shoreline load reduction.** This is consistent with achieving transparency criteria in the deep segments and mainstem segments if allowance is made for high non-algal turbidity in the latter.

3. **Tributaries < 60 ppb with 50% shoreline load reduction.** This is consistent with achieving phosphorus and transparency criteria on a spatially-averaged basis in each segment category, as well as in most of the individual lake segments. TP concentrations in Schneiders, North Browns, and the southern portion of Horseshoe Lake are above the 40 ppb criterion but within the uncertainty bands (standard error = 3 to 8 ppb, or 90% confidence interval = 5 to 14 ppb). Limitations in the local tributary monitoring data and the monitoring network for Horseshoe Lake (see Lake Segmentation) should also be considered.

Predicted water quality conditions in each segment are compared in Figure 24. Detailed results and BATHTUB input files are listed Appendices E, F, and G, respectively.

Figures 25 and 26 show load reductions for individual tributaries and regional mass balances under the 60 ppb scenario, respectively The combined inflow concentration from all local sources (tributary + lakeshed + shoreline) would be similar to that of the Sauk River (61 and 60 ppb, respectively). Without the 50% shoreline load reduction, local sources would have a combined inflow concentration of 68 ppb and the predicted area-weighted mean of the SR deep lake segments would increase by about 4 ppb, subject to the uncertainties associated with the shoreline load estimates. Without shoreline load reduction, the tributary concentration constraint would have to be reduced from ~60 to ~50 ppb in order to meet the deep-lake TP criterion on a spatially-averaged basis (Appendix D-10).

The sensitivities of TP concentrations in individual segments to shoreline reductions are shown in Figure 27. Sensitivity varies with lot density, lake area, and dilution capacity for septic tank loads. Impacts of shoreline loads from septic systems would be greater than those shown in dry years and isolated bays. Despite uncertainties and relatively small magnitudes, addressing shoreline loads would be consistent with the substantial efforts required in the local and upper watersheds to reduce tributary concentrations to ~60 ppb. The sensitivities shown in Figure 27 may be useful for focusing management efforts.

Figure 24 Spatial Variations in Water Quality under Three Loading Scenarios

Baseline, 2002-2006

ource	Flow hm3	Load kg	Load %	Conc ppb
auk River	135.7	13,569	77.7	100
ocal Tribs	36.7	2,924	16.7	80
akesheds	4.8	261	1.5	54
eptic Tanks		404	2.3	
ot Runoff		118	0.7	
tmospheric	-1.9	186	1.1	
otal	175.3	17,461	100.0	100
orth Browns	20.2	2,081	11.9	103
RCL + Long	175.3	16,892	96.7	96

Trib. Inflow P < 100 ppb

Source	Flow hm3	Load kg	Load %	Conc ppb
Sauk River	135.7	25,536	84.7	188
Local Tribs	36.7	3,646	12.1	99
Lakesheds	4.8	261	0.9	54
Septic Tanks		404	1.3	
Lot Runoff		118	0.4	
Atmospheric	-1.9	186	0.6	
Total	175.3	30,150	100.0	172
North Browns	20.2	2,777	9.2	138
SRCL + Long	175.3	29,392	97.5	168

Trib. Inflow P < 60 ppb, 50% Shoreline Reduc.

Source	Flow hm3	Load kg	Load %	Conc ppb
Sauk River	135.7	8,141	74.8	60
Local Tribs	36.7	2,031	18.7	55
Lakesheds	4.8	261	2.4	54
Septic Tanks		202	1.9	
Lot Runoff		59	0.5	
Atmospheric	-1.9	186	1.7	
Total	175.3	10,879	100.0	62
North Browns	20.2	1,266	11.6	63
SRCL + Long	175.3	10,534	96.8	60

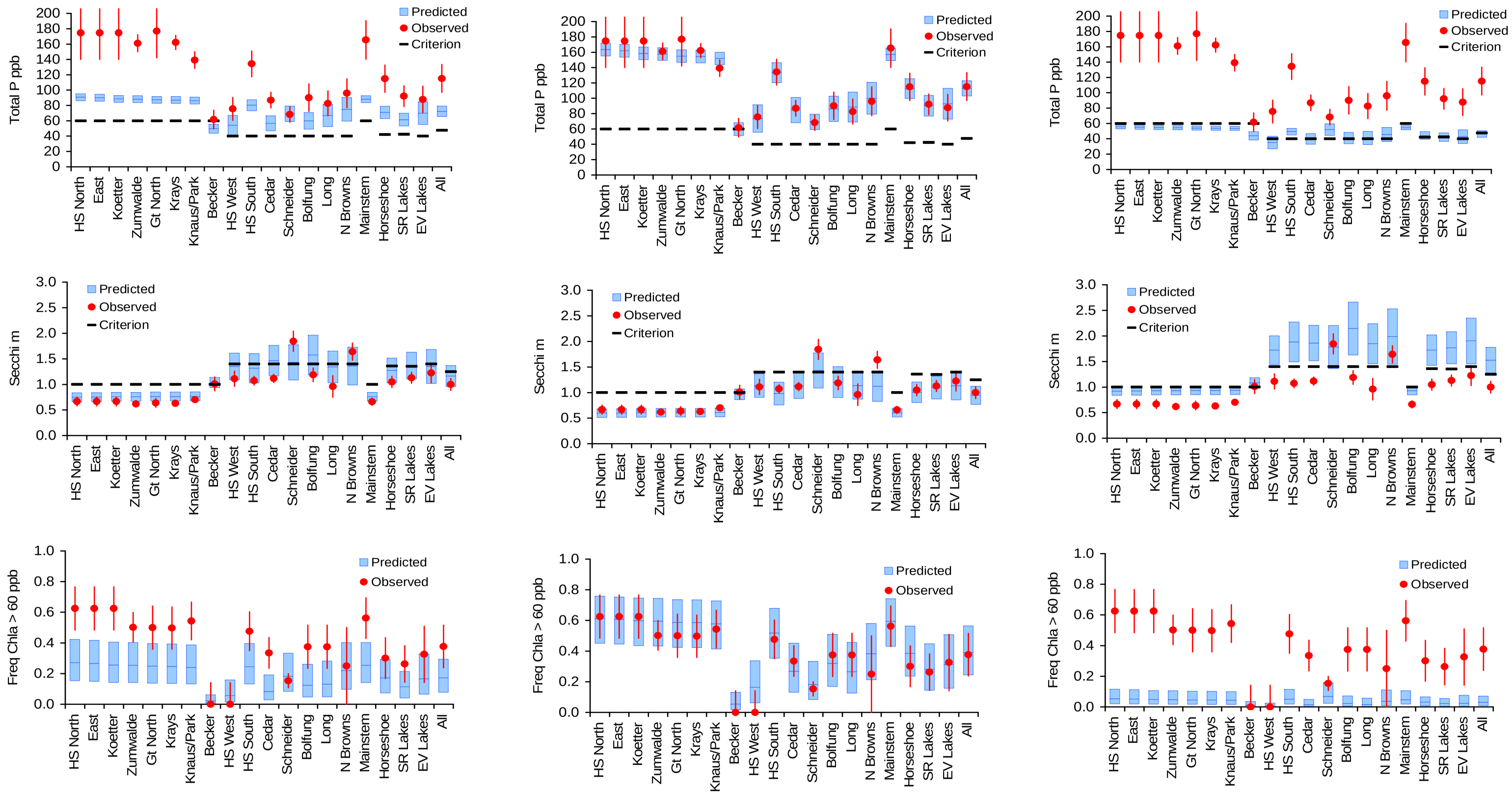
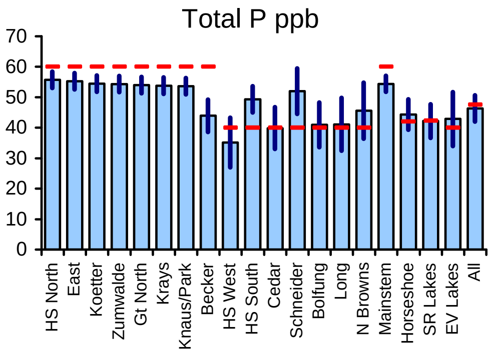
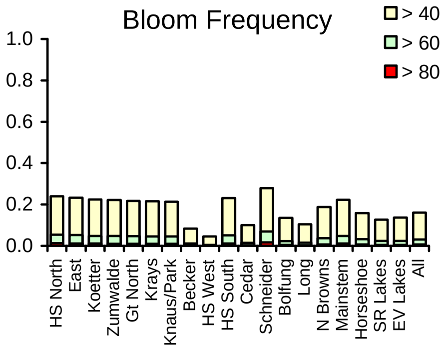


Table 7 Mass Balances & Water Quality under 60 ppb Inflow Scenario

Lake	Criterion	TP	TP_SE	Chl-a	Secchi	Algal Bloom Frequencies			Trophic Strate Indices		
Segment	ppb	ppb	ppb	ppb	m	> 40	> 60	> 80	Total P	Chl-a	Secchi
HS North	60	56	3	29	0.92	0.24	0.05	0.01	62	64	61
East	60	55	3	29	0.92	0.23	0.05	0.01	62	64	61
Koetter	60	55	3	28	0.93	0.22	0.05	0.01	62	64	61
Zumwalde	60	54	3	28	0.93	0.22	0.05	0.01	62	64	61
Gt North	60	54	3	28	0.93	0.22	0.05	0.01	62	63	61
Krays	60	54	3	28	0.93	0.22	0.05	0.01	62	63	61
Knaus/Park	60	54	3	28	0.94	0.21	0.04	0.01	62	63	61
Becker	60	44	5	21	1.09	0.08	0.01	0.00	59	61	59
HS West	40	35	8	19	1.72	0.05	0.00	0.00	55	59	52
HS South	40	49	4	29	1.88	0.23	0.05	0.01	60	64	51
Cedar	40	40	7	22	1.86	0.10	0.01	0.00	57	61	51
Schneider	40	52	7	31	1.78	0.28	0.07	0.02	61	64	52
Bolfung	40	41	7	24	2.15	0.14	0.02	0.00	58	62	49
Long	40	41	9	23	1.85	0.10	0.02	0.00	58	61	51
N Browns	40	46	9	27	1.99	0.19	0.04	0.01	59	63	50
Mainstem	60	54	3	28	0.93	0.22	0.05	0.01	62	64	61
Horseshoe	42	44	5	25	1.72	0.16	0.03	0.01	59	62	52
SR Lakes	42	42	5	24	1.77	0.13	0.02	0.00	58	62	52
EV Lakes	40	43	9	24	1.90	0.14	0.02	0.00	58	62	51
All	48	46	4	25	1.53	0.16	0.03	0.01	59	62	54

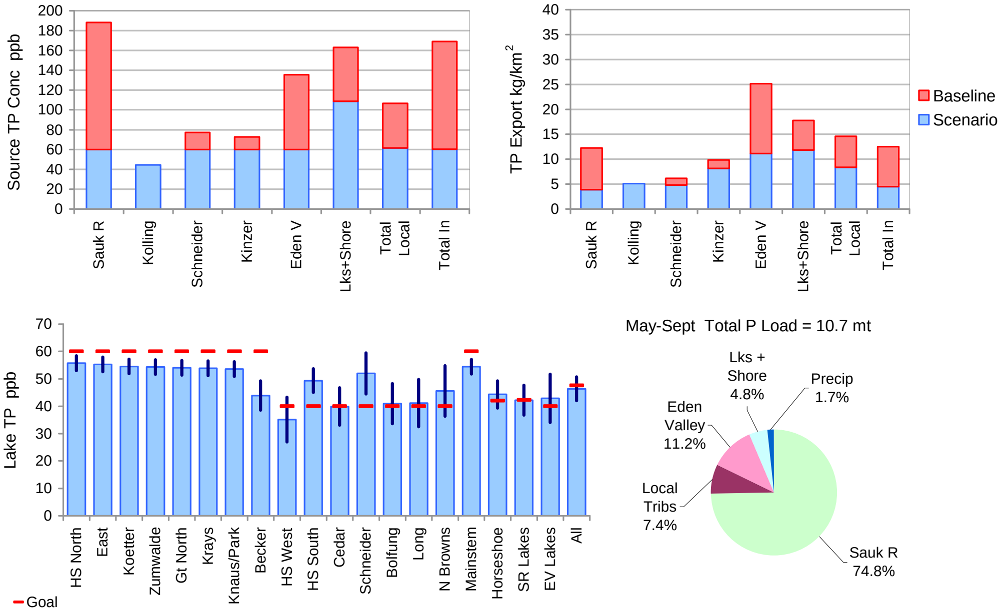




Water & Mass Balance (May - September)

TMDL_TR_60_SL_50								2002-2006 Baselin		Load
	Dr Area	Flow	Load	Conc	Runoff	Export	Percent	Load	Conc	Reduc
Source	km^2	hm^3	kg	ppb	cm	kg/km^2	of Load	kg	ppb	%
Sauk River Inflow	2088	136	8141	60	6	4	75%	25536	188	68%
Kolling Creek	97	11	496	45	11	5	5%	496	45	0%
Schneider Inflow	34	3	164	60	8	5	2%	211	77	22%
Kinzer Creek	18	3	150	60	14	8	1%	182	73	18%
Eden Valley Creek	106	20	1176	60	19	11	11%	2655	135	56%
Trib to Long L Inlet	4	1	45	60	19	11		102	135	56%
Lakesheds	44	5	261	54	11	6	2%	261	54	0%
Septic Systems			202				2%	404		50%
Excess Runoff			59					118		50%
External Inflow	2392	177	10694	60	7	4	98%	29965	169	64%
Precipitation	13	6	186	30	47	14	2%	186	30	0%
Evaporation		8			61					
Net Inflow	2405	175	10879	62	7	5	100%	30150	172	64%
Outflow	2405	175	9401	54	7	4	86%	26632	152	65%
Retention			1478				14%	3518		

Figure 25 Source Reductions and Lake TP Responses under 60 ppb Inflow Scenario



Predicted Summer Mean TP +/- 1 Standard Error

Lks+Shore = Lakesheds 2.4% + Septic Tanks 1.9% + Excess Lot Runoff 0.5%

Total Local = All Sources Except Sauk River & Precipitation

Figure 26 Phosphorus Sources by Region under 60 ppb Inflow Scenario

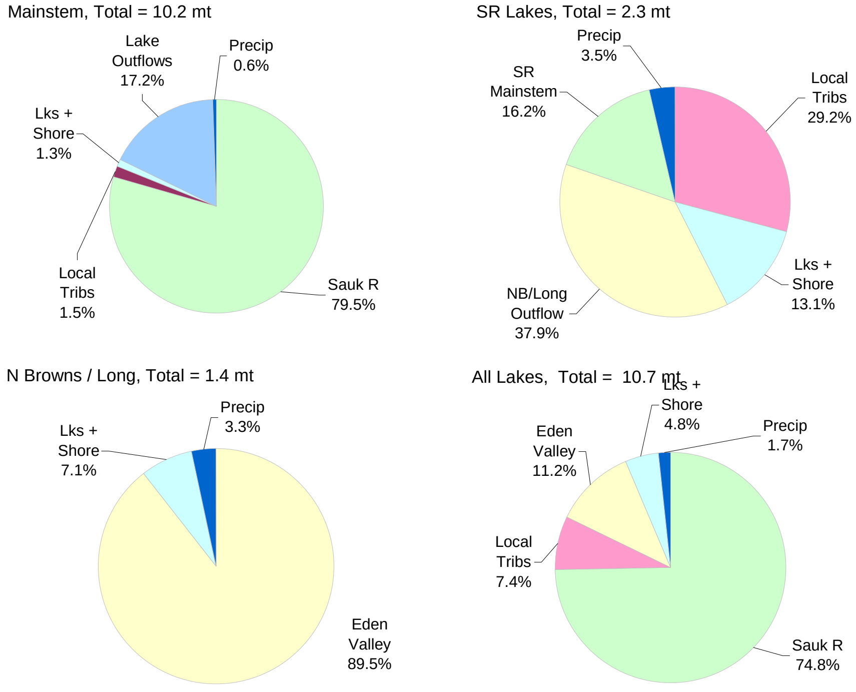
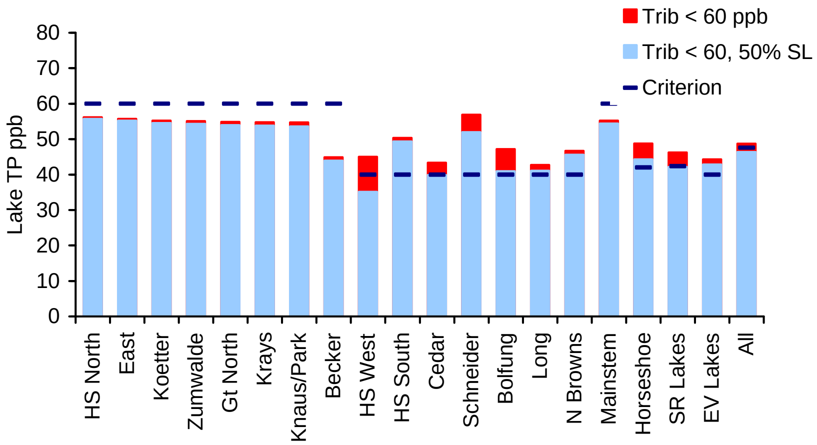


Figure 27 Sensitivity of Lake TP Concentration to Shoreline Load Reduction



Red bars show sensitivity to shoreline load reduction (0%, 50%) with tributary inflow TP < 60 ppb.

Discussion

Simulations using both the dynamic model and BATHTUB indicate that reducing combined flow-weighted-mean concentration to ~ 60 ppb from all sources would be required to achieve phosphorus and transparency criteria, as well as provide significant reductions in the frequencies of nuisance algal blooms. This could be accomplished by limiting the inflow TP concentration from each tributary to 60 ppb or to the baseline value (whichever is lower) and achieving a 50% reduction in shoreline sources (runoff + septic tanks).

The 60 ppb /50% recipe has been posed for the purposes of estimating lake assimilative capacity. Detailed source assessments and additional modeling would be required to develop a cost-effective strategy for addressing local sources and achieving criteria in the lakes off the mainstem. A 60-65 ppb limit for the Sauk River would be required to achieve the 60 ppb criterion for the mainstem segments and is relatively insensitive to uncertainties in loads from the local watersheds and shorelines.

Corresponding TMDL estimates are 10.9 mt for the SRCL as a whole and 1.3 mt for North Browns, each expressed as 5-year means of measured loads between May and September. The relative standard errors of predicted TP concentrations under this scenario are on the order of 5% for the SR mainstem segments, 16 % for the SR deep lake segments, and 11% for North Browns. Appendix G provides more details and a BATHTUB input file that can be used to investigate other loading scenarios and develop future refinements supported by additional monitoring data.

Similarities between the 60 ppb inflow TP concentration and the 40-60 ppb lake criteria reflect the following:

1. Low assimilative capacity for external P loads, which, in turn reflects physical characteristics of the mainstem lakes (shallow depth, low water residence times, and high watershed area to lake area ratio) and mixing between the offline deep lakes and the mainstem lakes.

2. Seasonal variations in inflow and lake TP concentrations. The inflow concentration is expressed as a May-September flow-weighted mean. The lake criteria are expressed as a June-September arithmetic means. The two averaging methods are not equivalent, particularly given that flows tend to be higher and concentrations tend to be lower in May, as compared with June-September (Figure 10, Figure 13)

TMDL estimates for other shallow lakes with large watersheds and high watershed/lake area similar (Walker, 2000). Examples include Lake Okeechobee (inflow TP ~ 50 ppb, lake TP criterion ~ 40 ppb, Walker 2000b) and Upper Klamath Lake, Oregon (inflow TP ~ 60 ppb, lake TP ~ 40 ppb, Walker, 2001). These lakes have more assimilative capacity than the SRCL because of their longer hydraulic residence times (2.7 and 0.36 vs. 0.10 years).

A 60 ppb concentration limit for SRCL inflows is at the lower end of the range typically observed in the NCHF ecoregion (60 – 150 ppb, MPCA (2003)), but is within the range of limited data from SRCL local tributaries (45 - 77 ppb). Implementation of watershed BMPs and retention of TP loads by lakes in the upper watershed would help to reduce TP concentrations and loads at the SRCL inflows. Achieving the 40 ppb criterion for upstream Sauk Lake (HMS, 2008) would contribute to achieving 60 ppb at the SRCL inflow. More detailed watershed studies and monitoring would be required to evaluate attainability and develop specific management programs. Adaptive implementation of the TMDL will provide opportunities for future refinements supported by additional information.

Table 8 lists the components of phosphorus loads above and below the inflow to the lake chain under the 60 ppb inflow scenario. These components include point sources, urban storm-water runoff, and other nonpoint sources. Estimates in the first two categories are based upon data provided by MPCA (VanEeckhout, 2009, pers. com.). Loads in the third category have been estimated by difference from the total measured or estimated loads (Table 7). It is likely that the actual percentage contributions from point sources and stormwater are substantially lower then those listed. The point-source loads assume that the facilities are operated at maximum permit levels. The urban stormwater loads do not reflect effects of any Best Management Practices that may have been implemented in the watershed. Neither the point-source nor the stormwater estimates reflect load attenuation in overland flow, streams, and lakes between the points of discharge and the SRCL inflow. Because they are estimated by difference from the measured total loads, the effects of attenuation are implicit in the estimates of other nonpoint sources (third category). Watershed modeling would provide a basis for refining the estimates of loads in each category and developing a plan to achieve the required load reductions.

Table 8 Phosphorus Load Components under the 60 ppb Inflow Scenario

Source *	Receiving Water	Area km^2	Annual Load kg/yr	May-Sept Load kg	Percent of Total Watershed
Stormwater Runoff - All Urban Land Uses (mixed residential, light industry, shopping)					
Sauk Centre	Sauk River	11.44	1,144	858	7.9%
Richmond	Sauk River	1.75	175	131	1.2%
Richmond	Cedar Lake	0.15	15	11	0.1%
Northern Chain Lakeshore	Northern SRCL	5.44	544	408	3.8%
South Knaus Lakeshore	Knaus	4.15	415	311	2.9%
Cold Spring	Knaus	9.59	959	719	6.6%
Total Stormwater Runoff		32.52	3,252	2,439	22.4%
Total Above SRCL Inflow	Sauk River	13.18	1,318	989	9.1%
Total Below SRCL Inflow	Chain of Lakes	19.34	1,934	1,450	13.3%
Point Sources	Permit ID				
St Martin WWTP	MN0024783		57	24	0.2%
Sauk Centre WWTP	MN0024821		1,205	505	4.6%
Richmond WWTP	MN0024597		175	73	0.7%
Melrose WWTP	MN0020290		3,500	1,466	13.5%
GEM Sanitary District	MN0056863		112	47	0.4%
Freeport WWTP	MNG580019		241	101	0.9%
Albany WWTP 2002	MN0020575		762	319	2.9%
Total Point Sources			6,052	2,535	23.3%
Total Above SRCL Inflow	Sauk River		6,052	2,535	23.3%
Total Below SRCL Inflow	Chain of Lakes		0	0	0.0%
All Phosphorus Sources - Sauk River Watershed above SRCL Inflow					
Point Sources				2,535	23.3%
Urban Stormwater		13.2		989	9.1%
Other Non Point (by difference)		2074.8		4,617	42.4%
Total (Table 7)		2088.0		8,141	74.8%
All Phosphorus Sources - SRCL Local Watershed					
Point Sources				0	0.0%
Urban Sources		13.2		1,450	13.3%
Other Non Point (by difference)		303.8		1,288	11.8%
Total (Table 7)		317.0		2,738	25.2%
All Phosphorus Sources - Entire Watershed					0.0%
Point Sources				2,535	23.3%
Urban Sources		32.5		2,439	22.4%
Other Non Point (by difference)**		2372.5		5,905	54.3%
Total (Table 7)		2405.0		10,879	100.0%

* Area and point-source data compiled by Greg VanEeckhout, MPCA, 2009.

Stormwater loads assume annual TP export rate= 100 kg/km^2-yr (Walker, 1985b)
& seasonal loading factor = 0.75 = % of annual precip between May and Sept.

Point sources based upon discharge permits; seasonal loading factor = fraction of year between May & Sept = 0.42

Contributions from point-sources and stormwater are upper-bound estimates (see text).

Conclusions

1. Sauk River phosphorus loads measured in 1978-1990 were reduced by approximately 68% in the early 1990's through implementation of upstream point and nonpoint source controls. Lake water quality improved significantly, particularly in the shallow mainstem lakes and deeper lakes that mix with the mainstem. Limited data suggest that water quality deteriorated over this same time period in two lakes that are isolated from the Sauk River (North Browns and Long Lakes). Further reductions in both upstream and local TP sources are required to achieve water quality standards in the SRCL as a whole.

2. Historical data and modeling results indicate that algal blooms in the mainstem lakes are more severe in dry years than in wet years. This pattern is more typical of rivers than lakes and reflects control of algal growth by flushing and turbidity. Phosphorus recycling from bottom sediments has a greater impact on lake TP concentrations in dry years when less dilution is available. Significant reductions in both the average and variability in algal bloom frequency would be expected as TP levels decrease during TMDL implementation.

3. Results indicate that a 64±3% reduction in total P load relative to 2002-2006 levels would be required to achieve phosphorus and transparency criteria for shallow and deep lake segments on a spatially-averaged basis and in most of the individual lake segments. While this would provide substantial reductions in the frequencies of nuisance algal blooms, it is unlikely that mean chlorophyll-a criteria would be met because of shallow depths and other site-specific factors.

4. One formula for achieving the 64% reduction would be to limit the long-term flow-weighted mean TP concentration in each tributary to a maximum of 60 ppb or the baseline value (whichever is lower) and reduce shoreline sources (runoff + septic tanks) by 50%. This would require load reductions in the individual tributaries ranging from 0% for Kolling Creek to 68% for the Sauk River. Specific allocations among local tributaries and shoreline areas can be refined with additional tributary monitoring data, evaluation of shoreline sources, and modeling. There is less uncertainty in the load reduction requirement for the Sauk River because it is based upon more substantial inflow and lake monitoring data and subject to less modeling uncertainty.

5. Based upon the above formula for allocating loads, TMDL estimates and corresponding flows are summarized in Table 9. Corresponding water and phosphorus balances are summarized in Figure 24 and Appendix G-5. The TMDL estimate for North Browns Lake is based upon very limited data and should be considered as a place-holder pending collection of additional data.

Table 9 Summary of TMDL Estimates

		Entire Lake Chain		North Browns	
Variable	Units	Mean	Std Er	Mean	Std Er
Flow	hm3	175.3		20.2	
Flow	cfs	468		54	
Load	mtons	10.9	1.0	1.27	0.3
Conc	ppb	62	6	63	13
Load Reduc	%	64%	3%	54%	9%

May-September, 2002-2006 Hydrologic Conditions

Totals Include Tributaries, Lakesheds, Shoreline, & Precip.

6. Sensitivity analyses indicate that the mainstem lakes are driven primarily variations in Sauk River inflow TP concentration, as opposed to variations in flow or load. Direct comparison of future measured loads with the TMDL values will be complicated by year-to-year variations in flow. Comparing measured TP concentrations in the lake tributaries with the TMDL assumption (60 ppb) would be a more robust method for tracking progress of management efforts to achieve long-term load reduction goals.

7. Lakes off the mainstem are sensitive to inflow volumes, concentrations, model parameters, complex mixing patterns, and assumptions used to estimate shoreline sources. For these reasons, there is greater uncertainty associated with predicted phosphorus levels in these lakes relative to the 40 ppb TP criterion. Further monitoring and evaluations are needed to refine the load estimates for local watersheds and shoreline areas, as well as to develop specific management plans.

8. The time scales for achieving the required load reductions and lake nutrient criteria are likely to be long because of the substantial load reductions required and size of the watershed. Because current phosphorus concentrations are sufficiently low to limit algal growth, as compared with historical conditions, one would expect significant improvements in water quality as incremental reductions in load are achieved during the course of TMDL implementation.

9. While lake water quality improvements will lag behind reductions in external loads as stored phosphorus is released from the lake sediments, that time scale is likely to be shorter than that required for full implementation of BMPs to achieve the required load reductions. Lake water quality responded within a few years to the 68% reduction in external TP load that occurred around 1991. Response times will be longer in isolated bays with enriched sediments but are difficult to predict.

10. Integrating existing BATHTUB applications to Sauk Lake and SRCL would provide a framework for TMDL implementation in the entire Sauk River watershed, including the reach downstream of the SRCL outlet. Consideration of phosphorus retention by lakes in the upper watershed would be required to evaluate the response of SRCL segments to BMP implementation in specific watersheds and develop cost-effective programs for achieving load reductions.

11. Development of a long-term program to achieve water quality standards would not be possible without the substantial water quality and hydrologic databases developed by the SRWD and MPCA. Continued monitoring of the lakes and tributaries is essential to track the progress of TMDL implementation. The existing databases and model sensitivity analyses could be used to identify critical data needs and increase the cost-effectiveness of the monitoring program.

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Appendices

Development of a Phosphorus TMDL for the Sauk River Chain of Lakes, Minnesota

prepared for

Sauk River Watershed District

by

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Appendix A

Watershed Data & Maps

App A - 1 Drainage Areas and Land Use

		Drainage Areas (km^2)										
Segment	Downstream Seg	Lake	Total Ex Lake	Total	Water	Wetland	Undev	Ag Past	Ag Crop	Urb LD	Urb MD	Urb HD
B												
C												
Kolling Creek	01_Horse_N		97.43	97.43	3.62	3.05	12.36	16.01	61.89	0.48	0.02	0.01
Schneider Creek	12_Schneider		34.15	34.15	0.63	1.52	6.97	10.49	14.16	0.31	0.06	0.02
Kinzer Creek	07_Knaus/Park		18.49	18.49	0.08	0.36	4.56	3.73	9.74	0.03	0.00	0.00
Eden Valley Creek	15_Browns		105.68	105.68	1.87	1.27	13.47	23.15	65.78	0.14	0.00	0.00
Trib to EV Creek	14_Long		4.04	4.04	0.56	0.13	0.74	0.86	1.74	0.01	0.00	0.00
Long Lake Inflow *			118.03	118.03	4.15	1.48	15.31	25.68	71.26	0.16	0.00	0.00
Total			259.79	259.79	6.76	6.31	38.09	54.24	153.31	0.97	0.08	0.04
Lakesheds												
01_Horse_N	02_East	0.25	1.08	1.34	0.53	0.01	0.33	0.11	0.35	0.01	0.00	0.00
02_East	03_Koetter	1.09	0.15	1.24	0.22	0.02	0.31	0.26	0.40	0.02	0.00	0.00
03_Koetter	04_Zumwalde	0.52	0.72	1.24	0.22	0.02	0.31	0.26	0.40	0.02	0.00	0.00
04_Zumwalde	05_Gt Northern	0.49	0.56	1.04	0.37	0.02	0.32	0.22	0.10	0.02	0.00	0.00
05_Gt Northern	06_Krays	0.76	1.62	2.37	0.50	0.09	0.66	0.54	0.37	0.15	0.03	0.04
06_Krays	07_Knaus/Park	0.37	0.49	0.86	0.37	0.00	0.24	0.05	0.18	0.01	0.00	0.00
07_Knaus/Park	SRCL Outflow	0.85	1.14	2.00	0.87	0.00	0.55	0.12	0.42	0.02	0.00	0.00
08_Becker	01_Horse_N	0.66	1.01	1.66	0.11	0.12	0.20	0.20	1.02	0.01	0.00	0.00
09_Horse_W	01_Horse_N	1.02	2.99	4.01	1.58	0.02	1.00	0.32	1.05	0.03	0.00	0.00
10_Horse_S	01_Horse_N	1.27	0.07	1.34	0.53	0.01	0.33	0.11	0.35	0.01	0.00	0.00
11_Cedar	03_Koetter	2.04	20.25	22.29	3.98	0.30	5.58	4.77	7.13	0.40	0.08	0.05
12_Schneider	05_Gt Northern	0.22	2.15	2.37	0.50	0.09	0.66	0.54	0.37	0.15	0.03	0.04
13_Bolfing	07_Knaus/Park	0.43	3.53	3.97	0.42	0.01	0.80	0.94	1.79	0.01	0.00	0.00
14_Long	10_Horse_S	1.97	1.26	3.23	0.45	0.10	0.59	0.69	1.39	0.01	0.00	0.00
15_Browns	14_Long	1.26	7.05	8.31	1.71	0.09	1.10	1.67	3.74	0.01	0.00	0.00
Total		13.21	44.05	57.26	12.38	0.88	12.96	10.81	19.05	0.88	0.16	0.14
Sauk River Inflow	01_Horse_N		2087.8	2087.8	87.5	74.1	321.0	539.3	1044.3	17.10	3.49	1.08
Total Tributaries			259.8	259.8	6.8	6.3	38.1	54.2	153.3	0.97	0.08	0.04
Total Lakesheds		13.2	44.1	57.3	12.4	0.9	13.0	10.8	19.1	0.88	0.16	0.14
SRCL Total Inflow	SRCL Outflow		2391.7	2404.9	93.4	81.3	372.1	604.3	1216.6	18.95	3.73	1.25
SRCL Outflow			2404.9	2404.9	106.6	81.3	372.1	604.3	1216.6	18.95	3.73	1.25

App A - 1 Drainage Areas and Land Use

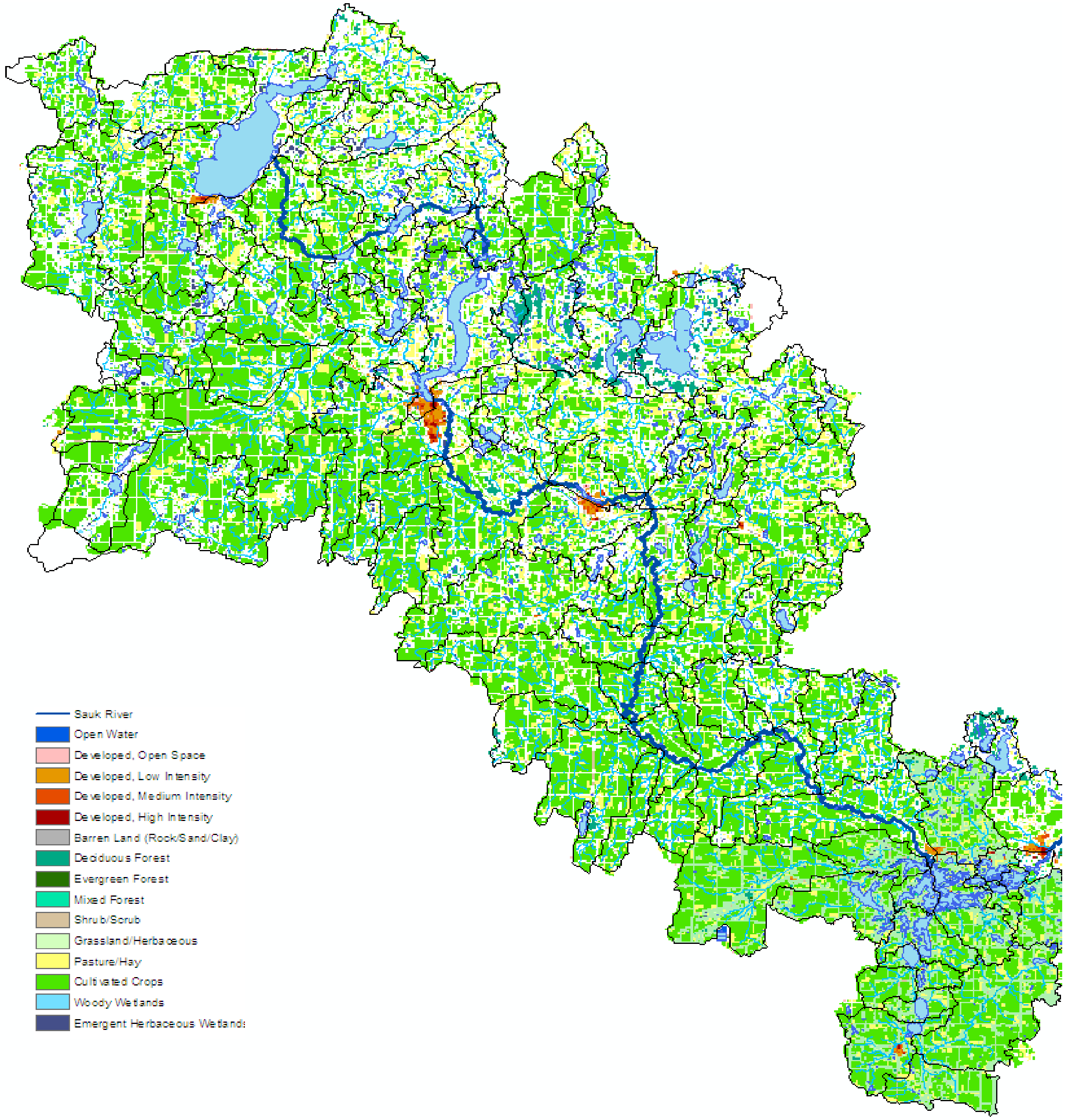
		Drainage Areas (km^2)										
Segment	Downstream Seg	Lake	Total Ex Lake	Total	Water	Wetland	Undev	Ag Past	Ag Crop	Urb LD	Urb MD	Urb HD
Percent of Total Subwatershed Area												
C												
Kolling Creek			100.0	100.0	3.7	3.1	12.7	16.4	63.5	0.5	0.0	0.0
Schneider Creek			100.0	100.0	1.8	4.4	20.4	30.7	41.5	0.9	0.2	0.1
Kinzer Creek			100.0	100.0	0.4	1.9	24.6	20.2	52.7	0.2	0.0	0.0
Eden Valley Creek			100.0	100.0	1.8	1.2	12.7	21.9	62.2	0.1	0.0	0.0
Long Lake Inflow *			100.0	100.0	3.5	1.3	13.0	21.8	60.4	0.1	0.0	0.0
Total			100.0	100.0	2.6	2.4	14.7	20.9	59.0	0.4	0.0	0.0
Lakesheds												
01_Horse_N		19.0	81.0	100.0	39.5	0.5	24.9	8.0	26.3	0.9	0.0	0.0
02_East		88.1	11.9	100.0	17.9	1.3	25.0	21.4	32.0	1.8	0.4	0.2
03_Koetter		42.2	57.8	100.0	17.9	1.3	25.0	21.4	32.0	1.8	0.4	0.2
04_Zumwalde		46.8	53.2	100.0	35.4	2.0	30.5	21.1	9.4	1.6	0.0	0.0
05_Gt Northern		31.8	68.2	100.0	21.0	3.7	27.6	22.8	15.4	6.3	1.4	1.8
06_Krays		42.7	57.3	100.0	43.8	0.2	27.7	6.1	21.2	1.0	0.0	0.0
07_Knaus/Park		42.8	57.2	100.0	43.8	0.2	27.7	6.1	21.2	1.0	0.0	0.0
08_Becker		39.5	60.5	100.0	6.8	7.0	11.8	12.3	61.5	0.7	0.0	0.0
09_Horse_W		25.4	74.6	100.0	39.5	0.5	24.9	8.0	26.3	0.9	0.0	0.0
10_Horse_S		95.1	4.9	100.0	39.5	0.5	24.9	8.0	26.3	0.9	0.0	0.0
11_Cedar		9.2	90.8	100.0	17.9	1.3	25.0	21.4	32.0	1.8	0.4	0.2
12_Schneider		9.3	90.7	100.0	21.0	3.7	27.6	22.8	15.4	6.3	1.4	1.8
13_Bolfing		10.9	89.1	100.0	10.7	0.3	20.1	23.7	45.1	0.1	0.0	0.0
14_Long		61.0	39.0	100.0	13.9	3.1	18.3	21.3	43.1	0.3	0.0	0.0
15_Browns		15.2	84.8	100.0	20.6	1.0	13.2	20.1	45.0	0.1	0.0	0.0
Total		23.1	76.9	100.0	21.6	1.5	22.6	18.9	33.3	1.5	0.3	0.2
Sauk River Inflow		0.0	100.0	100.0	4.2	3.5	15.4	25.8	50.0	0.8	0.2	0.1
Total Tributaries		0.0	100.0	100.0	2.6	2.4	14.7	20.9	59.0	0.4	0.0	0.0
Total Lakesheds		23.1	76.9	100.0	21.6	1.5	22.6	18.9	33.3	1.5	0.3	0.2
SRCL Total Inflow		0.0	99.5	100.0	3.9	3.4	15.5	25.1	50.6	0.8	0.2	0.1
SRCL Outflow		0.0	100.0	100.0	4.4	3.4	15.5	25.1	50.6	0.8	0.2	0.1

App A - 1 Drainage Areas and Land Use

		Drainage Areas (km^2)										
Segment	Downstream Seg	Lake	Total Ex Lake	Total	Water	Wetland	Undev	Ag Past	Ag Crop	Urb LD	Urb MD	Urb HD
Cumulative Areas km^2												
01_Horse_N		0.3	2308.4	2314.9	98.4	78.9	351.1	582.4	1181.6	17.8	3.5	1.1
02_East		1.1	2308.6	2316.1	98.7	78.9	351.4	582.7	1182.0	17.8	3.5	1.1
03_Koetter		0.5	2329.5	2339.6	102.9	79.2	357.3	587.7	1189.5	18.3	3.6	1.1
04_Zumwalde		0.5	2330.1	2340.7	103.2	79.2	357.6	587.9	1189.6	18.3	3.6	1.1
05_Gt Northern		0.8	2368.0	2379.6	104.9	80.9	365.9	599.5	1204.5	18.9	3.7	1.3
06_Krays		0.4	2368.5	2380.4	105.2	80.9	366.1	599.6	1204.7	18.9	3.7	1.3
07_Knaus/Park		0.9	2391.7	2404.9	106.6	81.3	372.1	604.3	1216.6	18.9	3.7	1.3
08_Becker		0.7	98.4	99.1	3.7	3.2	12.6	16.2	62.9	0.5	0.0	0.0
09_Horse_W		1.0	3.0	4.0	1.6	0.0	1.0	0.3	1.1	0.0	0.0	0.0
10_Horse_S		1.3	118.1	122.6	5.1	1.6	16.2	26.5	73.0	0.2	0.0	0.0
11_Cedar		2.0	20.2	22.3	4.0	0.3	5.6	4.8	7.1	0.4	0.1	0.0
12_Schneider		0.2	36.3	36.5	1.1	1.6	7.6	11.0	14.5	0.5	0.1	0.1
13_Bolfing		0.4	3.5	4.0	0.4	0.0	0.8	0.9	1.8	0.0	0.0	0.0
14_Long		2.0	118.0	121.3	4.6	1.6	15.9	26.4	72.7	0.2	0.0	0.0
15_Browns		1.3	112.7	114.0	3.6	1.4	14.6	24.8	69.5	0.1	0.0	0.0
Cumulative Areas % of Total Watershed Above Lake Segment												
01_Horse_N		0.0	99.7	100.0	4.3	3.4	15.2	25.2	51.0	0.8	0.2	0.0
02_East		0.0	99.7	100.0	4.3	3.4	15.2	25.2	51.0	0.8	0.2	0.0
03_Koetter		0.0	99.6	100.0	4.4	3.4	15.3	25.1	50.8	0.8	0.2	0.0
04_Zumwalde		0.0	99.5	100.0	4.4	3.4	15.3	25.1	50.8	0.8	0.2	0.0
05_Gt Northern		0.0	99.5	100.0	4.4	3.4	15.4	25.2	50.6	0.8	0.2	0.1
06_Krays		0.0	99.5	100.0	4.4	3.4	15.4	25.2	50.6	0.8	0.2	0.1
07_Knaus/Park		0.0	99.5	100.0	4.4	3.4	15.5	25.1	50.6	0.8	0.2	0.1
08_Becker		0.7	99.3	100.0	3.8	3.2	12.7	16.4	63.5	0.5	0.0	0.0
09_Horse_W		25.4	74.6	100.0	39.5	0.5	24.9	8.0	26.3	0.9	0.0	0.0
10_Horse_S		1.0	96.3	100.0	4.2	1.3	13.2	21.6	59.5	0.1	0.0	0.0
11_Cedar		9.2	90.8	100.0	17.9	1.3	25.0	21.4	32.0	1.8	0.4	0.2
12_Schneider		0.6	99.4	100.0	3.1	4.4	20.9	30.2	39.8	1.3	0.3	0.2
13_Bolfing		10.9	89.1	100.0	10.7	0.3	20.1	23.7	45.1	0.1	0.0	0.0
14_Long		1.6	97.3	100.0	3.8	1.3	13.1	21.7	59.9	0.1	0.0	0.0
15_Browns		1.1	98.9	100.0	3.1	1.2	12.8	21.8	61.0	0.1	0.0	0.0

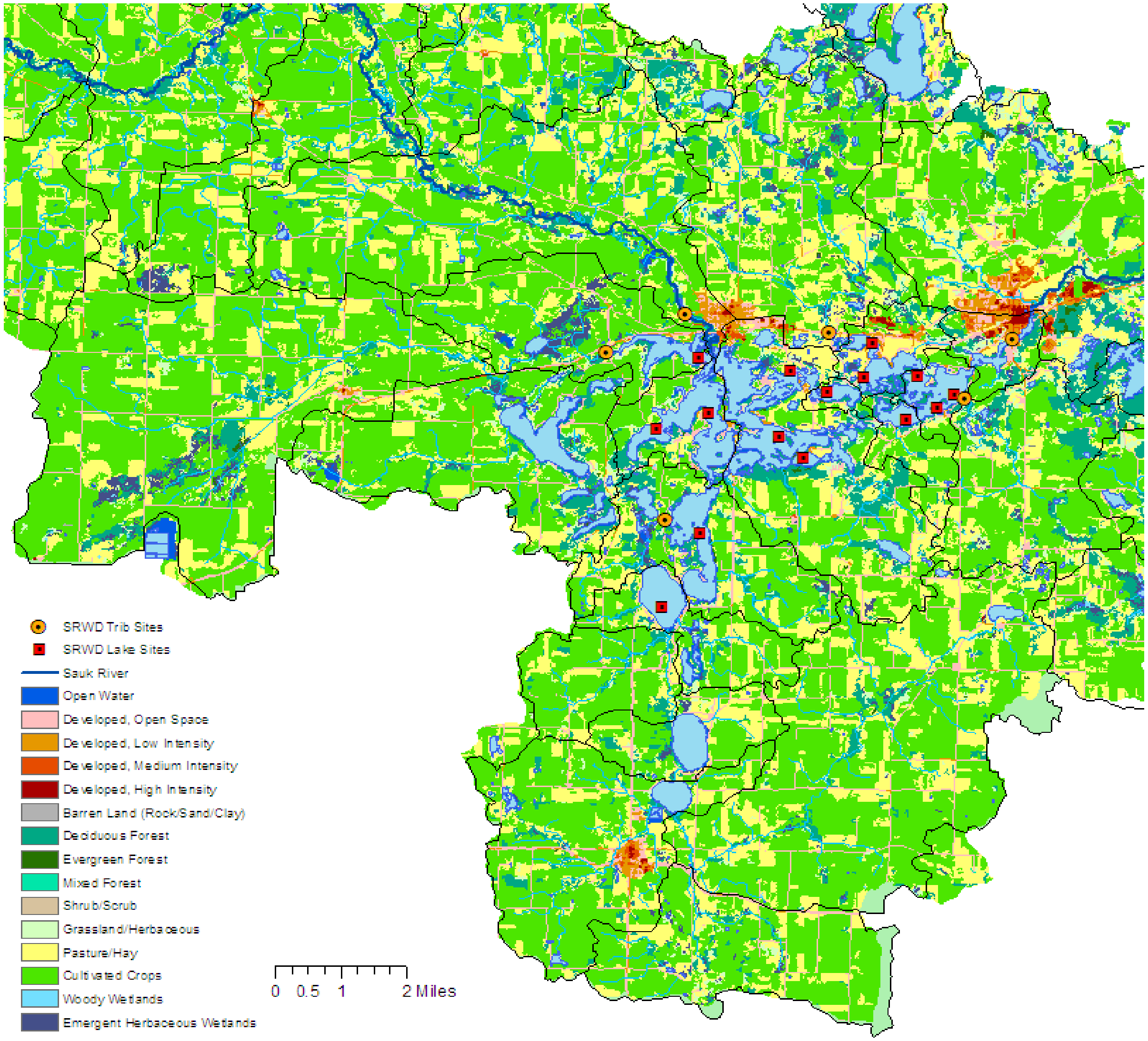
* Long Lake Outflow is embedded in the segment network and not represented as an external source to the lake chain.

App A - 2 Land Uses in the Sauk River Watershed



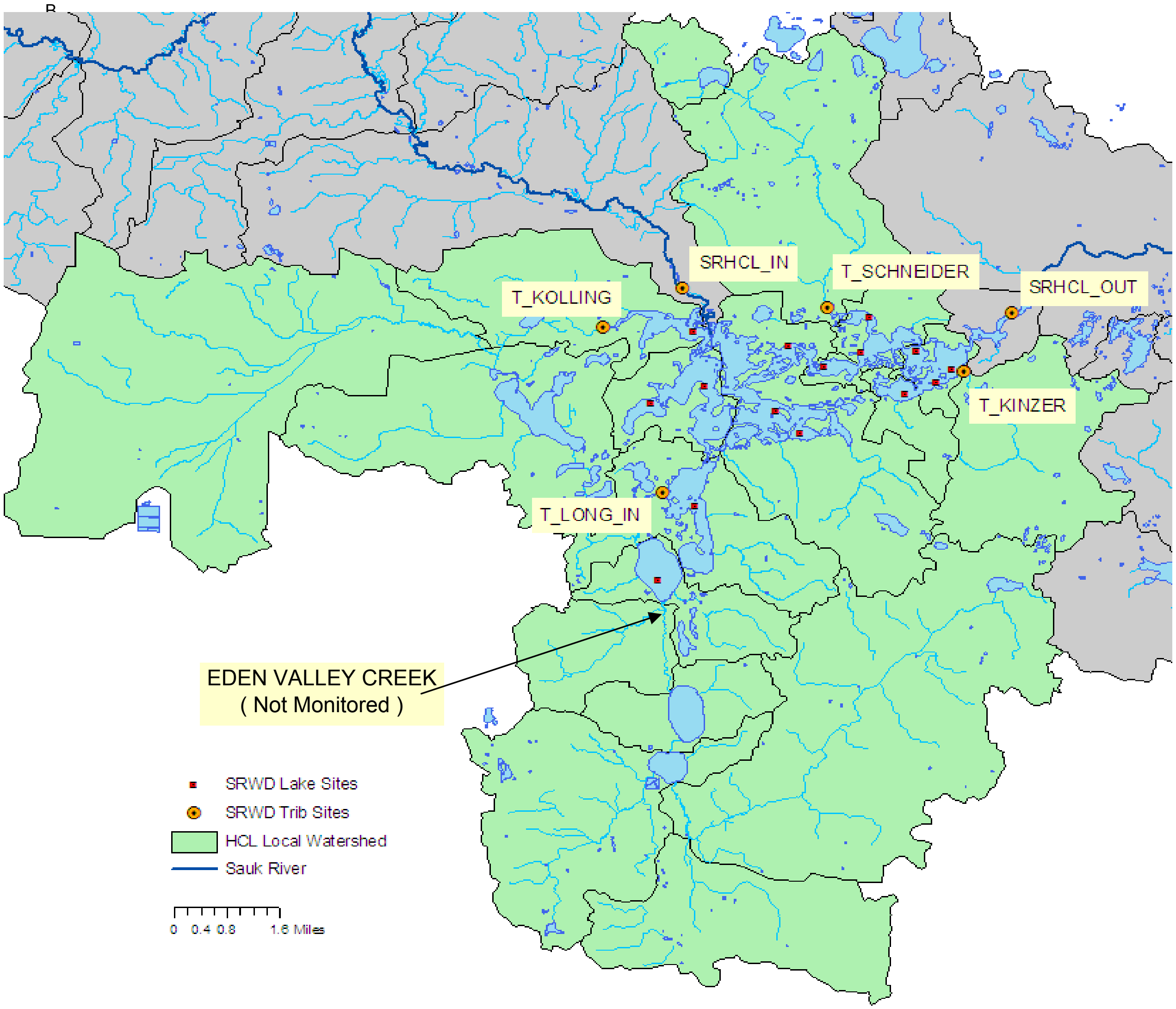
App A - 3

Land Uses in SRCL Local Watersheds

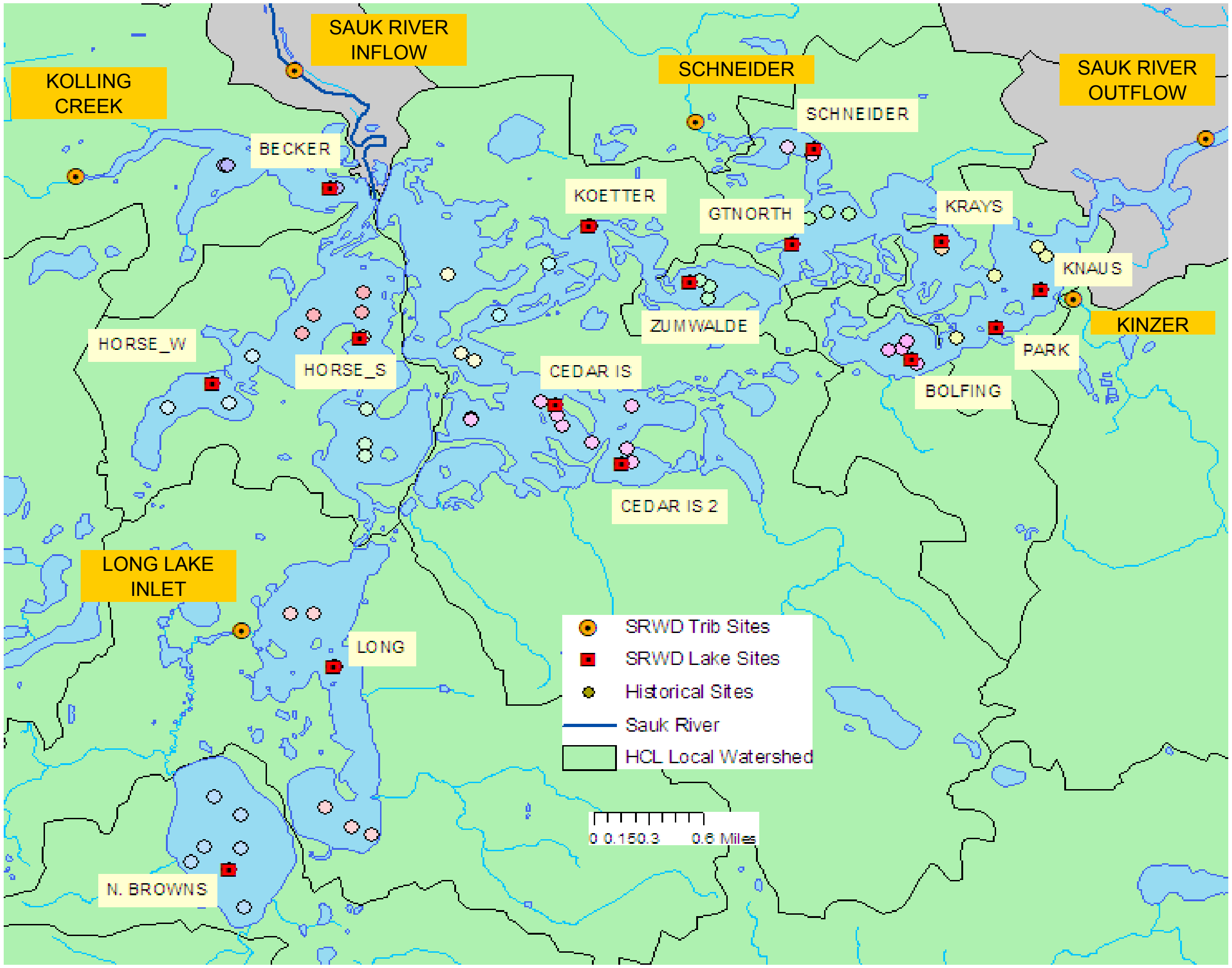


App A - 4

SRCL Local Subwatersheds & Tributary Monitoring Sites



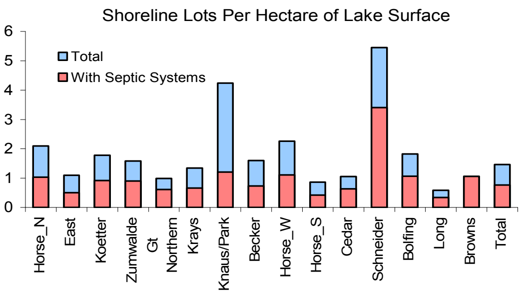
App A - 5 Recent & Historical Tributary & Lake Monitoring Sites

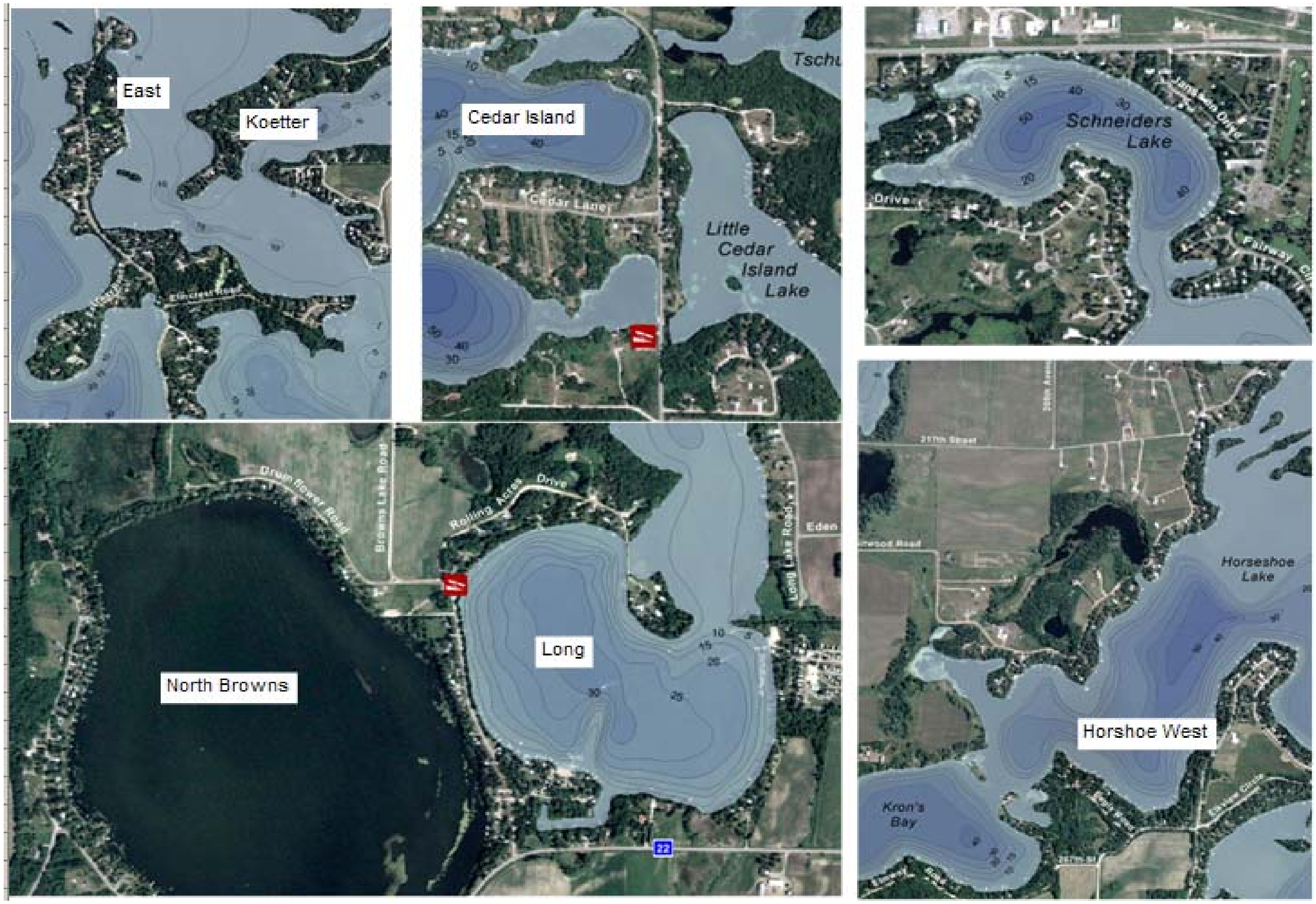


Historical sites extracted from MPCA/STORET database. Period of Record = 1978 to Present.

App A - 6

Aerial Photos of Developed Shorelines


Shoreline Lots Per Hectare of Lake Surface



Appendix B

Hydrology and Phosphorus Loads

App B - 1 Water & Phosphorus Balances by Year, May-September

Gauged Sources

🟩 Estimated from Correl. with Crow River

🟦 Estimated from correl with SR St Cloud

🟨 Estimated from correlation with SR Inflow or Outflow, 2006

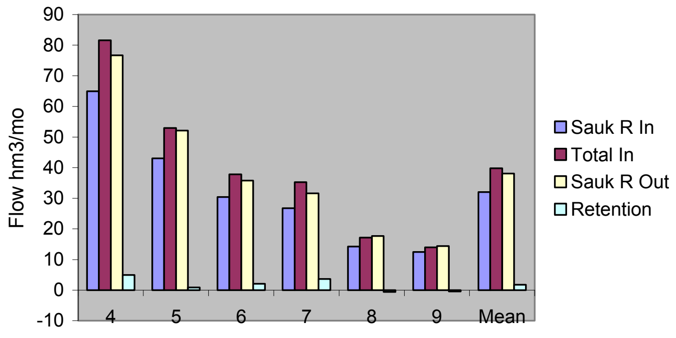
B	Sauk Riv @ Rich (HCL Inflow)				Sauk Riv @ Cold Sp (HCL Out)				Long Lake Inlet				Kinzer Creek				Kolling Creek				Schneider Creek			
C		Flow	Load	Conc		Flow	Load	Conc		Flow	Load	Conc		Flow	Load	Conc		Flow	Load	Conc		Flow	Load	Conc
Year	Samp	hm3	kg	ppb	Samp	hm3	kg	ppb	Samp	hm3	kg	ppb	Samp	hm3	kg	ppb	Samp	hm3	kg	ppb	Samp	hm3	kg	ppb
1978	2	160	82098	514	2	191	71160	372	0	25.1	3364	134	0	3.0	230	76	0	14.8	940	63	0	3.0	239	81
1979	0	201	86173	430	0	240	74890	312	0	33.8	4076	121	0	3.4	259	77	0	13.1	598	45	0	3.5	279	80
1980	9	93	36655	396	9	108	35683	329	0	8.0	1307	164	0	1.9	126	67	0	6.0	271	45	0	2.0	158	77
1981	0	84	38947	462	0	98	32479	330	0	6.5	906	140	0	1.8	123	70	0	6.6	301	45	0	1.9	151	78
1982	3	141	63933	454	0	167	51787	309	0	18.4	2467	134	0	2.5	188	74	2	8.8	401	45	0	2.7	213	79
1983	9	180	85615	475	8	215	65768	306	0	28.4	3644	128	0	3.1	235	76	8	16.6	754	45	0	3.2	258	80
1984	0	243	136505	563	0	291	124375	427	0	44.5	5323	120	0	4.0	313	79	0	18.4	837	45	0	4.1	329	80
1985	0	216	120248	556	0	259	112215	433	0	37.3	4533	121	0	3.6	284	79	0	14.7	670	45	0	3.7	299	80
1986	0	328	193042	589	0	395	193995	491	0	66.1	7388	112	0	5.1	428	83	0	22.8	1035	45	0	5.2	427	82
1987	0	81	45673	563	0	94	42110	446	0	3.6	639	176	0	1.7	113	66	0	6.4	290	45	0	1.9	146	77
1988	0	55	28585	516	0	63	27526	436	0	0.6	109	176	0	1.4	90	66	0	3.7	169	45	0	1.5	119	77
1989	9	143	98107	685	10	118	75523	641	0	7.9	1385	176	0	2.6	187	72	0	7.4	339	45	0	2.2	166	77
1990	0	156	116095	743	0	186	107293	577	0	22.6	2954	131	0	2.8	208	75	0	13.9	631	45	0	2.9	232	79
1991	0	204	106324	520	0	244	100462	411	0	35.0	4270	122	0	3.4	272	79	0	14.1	643	45	0	3.6	288	81
1992	0	127	41307	326	0	150	35627	237	0	16.2	2154	133	0	2.3	171	73	0	10.3	469	45	0	2.5	197	79
1993	0	253	55922	221	0	304	50798	167	0	47.4	5675	120	0	4.1	331	80	0	22.7	1031	45	0	4.3	343	81
1994	0	178	25300	142	0	212	21324	100	0	27.4	3501	128	0	3.0	231	76	0	11.5	525	45	0	3.2	254	80
1995	8	197	33839	172	6	235	27554	117	3	32.5	2734	84	0	3.3	260	78	0	14.3	634	44	0	3.5	278	80
1996	7	152	24053	158	5	181	18549	102	0	23.9	2858	119	0	2.7	206	76	0	8.3	380	46	0	2.8	227	80
1997	9	141	20559	146	8	167	18568	111	0	18.0	2760	153	0	2.5	181	72	0	10.2	472	46	0	2.7	211	79
1998	7	135	25423	189	5	160	17969	112	0	17.6	2578	147	0	2.5	180	73	0	12.2	548	45	0	2.6	207	79
1999	6	148	24390	165	4	175	19902	114	0	22.5	2778	124	0	2.6	199	75	0	8.2	381	47	0	2.8	223	79
2000	4	43	8290	191	3	49	5509	113	0	0.9	187	199	0	1.2	79	66	0	3.7	177	48	0	1.4	106	77
2001	11	205	25887	126	10	222	16554	75	0	34.9	3914	112	0	3.4	263	78	0	7.7	353	46	0	3.2	261	80
2002	10	193	43511	225	10	247	40054	162	0	35.3	4510	128	0	3.3	253	77	0	17.6	783	44	0	3.6	289	80
2003	12	187	38351	205	12	227	31495	139	0	32.2	4005	124	0	3.2	248	77	0	18.7	823	44	0	3.4	271	80
2004	13	90	10250	114	13	93	5584	60	0	6.6	1092	165	0	1.8	128	70	0	5.7	267	47	0	1.9	146	78
2005	12	141	27334	194	19	180	22500	125	0	21.9	2966	135	0	2.6	188	74	0	10.4	475	46	0	2.9	227	79
2006	10	67	8235	123	10	92	7197	79	3	9.1	908	99	10	1.6	95	58	9	3.3	131	40	8	1.9	120	63
2007	13	64	10510	163	14	72	7874	110	3	5.8	1554	267	14	1.5	144	98	13	2.8	176	62	14	1.6	140	86
2008	14	109	17173	158	13	136	9643	71	10	14.5	1659	114	13	2.1	126	61	14	7.6	346	46	12	2.3	188	80
1978-1990	32	160	87052	544	29	187	78062	418	0	23.3	2930	126	0	2.8	214	76	10	11.8	557	47	0	2.9	232	80
1997-2006	94	135	23223	172	94	161	18533	115	3	19.9	2570	129	10	2.5	181	73	9	9.8	441	45	8	2.6	206	78
1997-2001	37	134	20910	156	30	155	15700	102	0	18.8	2443	130	0	2.4	180	74	0	8.4	386	46	0	2.5	202	79
2002-2006	57	136	25536	188	64	168	21366	127	3	21.0	2696	128	10	2.5	182	73	9	11.1	496	45	8	2.7	211	77

App B - 1 Water & Phosphorus Balances by Year, May-September

Estimated Sources

	Eden Val (to N Brown)			Eden Val (to Long)			Lakesheds			Shoreline						Total Inflow								
	Flow	Load	Conc	Flow	Load	Conc	Flow	Load	Conc	Sp Tnk	Runoff	Precipitation			Evap	Flow	Load	Conc	Sauk River		Total Gauged		Out / Inflow	
Year	hm3	kg	ppb	hm3	kg	ppb	hm3	kg	ppb	kg	kg	kg	cm	hm3	hm3	hm3	kg	ppb	Flow%	Load%	Flow%	Load%	Flow%	Load%
1978	23.3	3313	142	0.9	127	142	6.1	414	68	404	103	162	41	5.4	8.1	208	88031	422	77%	93%	77%	93%	92%	81%
1979	31.4	4014	128	1.2	153	128	5.9	334	57	404	85	135	34	4.5	8.1	255	92435	362	79%	93%	79%	93%	94%	81%
1980	7.4	1287	174	0.3	49	174	2.9	163	56	404	107	168	43	5.6	8.1	111	39389	356	84%	93%	84%	93%	98%	91%
1981	6.0	893	148	0.2	34	148	3.0	169	56	404	86	135	34	4.5	8.1	100	41242	411	84%	94%	84%	94%	98%	79%
1982	17.1	2430	142	0.7	93	142	4.1	235	57	404	104	165	42	5.5	8.1	174	68167	391	81%	94%	81%	94%	96%	76%
1983	26.4	3589	136	1.0	137	136	6.7	366	54	404	128	202	51	6.7	8.1	236	91688	389	76%	93%	76%	93%	91%	72%
1984	41.4	5243	127	1.6	200	127	7.8	434	56	404	122	193	49	6.4	8.1	318	144581	454	76%	94%	76%	94%	91%	86%
1985	34.8	4465	128	1.3	171	128	6.5	368	57	404	119	188	48	6.3	8.1	279	127216	456	77%	95%	77%	95%	93%	88%
1986	61.5	7276	118	2.4	278	118	9.7	555	57	404	193	304	77	10.1	8.1	437	203943	467	75%	95%	75%	95%	90%	95%
1987	3.4	629	186	0.1	24	186	2.9	161	55	404	106	167	42	5.6	8.1	95	47714	502	85%	96%	85%	96%	99%	88%
1988	0.6	107	186	0.0	4	186	1.9	111	57	404	81	128	32	4.3	8.1	61	29797	490	91%	96%	91%	96%	104%	92%
1989	7.3	1364	186	0.3	52	186	3.6	203	57	404	111	176	44	5.9	8.1	164	101110	615	87%	97%	87%	97%	72%	75%
1990	21.0	2909	138	0.8	111	138	5.7	314	55	404	108	170	43	5.7	8.1	201	121184	603	78%	96%	78%	96%	93%	89%
1991	32.6	4206	129	1.2	161	129	6.2	353	57	404	111	175	44	5.8	8.1	263	112938	429	78%	94%	78%	94%	93%	89%
1992	15.1	2121	141	0.6	81	141	4.4	246	55	404	95	150	38	5.0	8.1	159	45242	285	80%	91%	80%	91%	94%	79%
1993	44.1	5589	127	1.7	214	127	9.1	501	55	404	135	213	54	7.1	8.1	338	64683	191	75%	86%	75%	86%	90%	79%
1994	25.5	3449	135	1.0	132	135	5.2	297	57	404	102	161	41	5.4	8.1	225	30855	137	79%	82%	79%	82%	94%	69%
1995	30.3	2692	89	1.2	103	89	6.2	344	56	404	147	233	59	7.8	8.1	255	38935	153	77%	87%	77%	87%	92%	71%
1996	22.3	2815	126	0.9	108	126	4.0	239	59	404	94	149	38	5.0	8.1	190	28676	151	80%	84%	80%	84%	95%	65%
1997	16.8	2719	162	0.6	104	162	4.5	254	56	404	101	159	40	5.3	8.1	176	25164	143	80%	82%	80%	82%	95%	74%
1998	16.4	2539	155	0.6	97	155	5.1	274	54	404	127	201	51	6.7	8.1	173	30000	173	78%	85%	78%	85%	92%	60%
1999	20.9	2736	131	0.8	105	131	4.0	236	59	404	108	171	43	5.7	8.1	185	28952	157	80%	84%	80%	84%	95%	69%
2000	0.9	184	211	0.0	7	211	1.8	106	58	404	96	152	38	5.1	8.1	49	9602	194	88%	86%	88%	86%	98%	57%
2001	32.5	3855	119	1.2	147	119	4.2	258	61	404	108	170	43	5.7	8.1	255	31706	125	80%	82%	80%	82%	87%	52%
2002	32.9	4441	135	1.3	170	135	7.2	389	54	404	123	195	49	6.5	8.1	257	50560	196	75%	86%	75%	86%	96%	79%
2003	30.0	3944	131	1.1	151	131	7.4	394	53	404	109	173	44	5.8	8.1	249	44868	180	75%	85%	75%	85%	91%	70%
2004	6.2	1076	174	0.2	41	174	2.8	159	58	404	131	207	52	6.9	8.1	107	12808	119	84%	80%	84%	80%	87%	44%
2005	20.4	2921	143	0.8	112	143	4.6	261	56	404	128	202	51	6.7	8.1	181	32251	178	78%	85%	78%	85%	99%	70%
2006	8.5	894	105	0.3	34	105	2.0	102	51	404	97	153	39	5.1	8.1	82	10264	125	82%	80%	90%	84%	112%	70%
2007	Not Estimated																							
2008	Not Estimated																							
1978-1990	21.7	2886	133	0.83	110	133	5.1	294	57	404	112	177	45	5.9	8.1	203	92038	453	79%	95%	87%	96%	92%	85%
1997-2006	18.5	2531	136	0.71	97	136	4.4	243	56	404	113	178	45	5.9	8.1	171	27618	161	79%	84%	87%	87%	94%	67%
1997-2001	17.5	2406	138	0.67	92	138	3.9	225	57	404	108	171	43	5.7	8.1	167	25085	150	80%	83%	88%	86%	92%	63%
2002-2006	19.6	2655	135	0.75	102	135	4.8	261	54	404	118	186	47	6.2	8.1	175	30150	172	77%	85%	87%	88%	96%	71%

App B - 2 Seasonal Water & Mass Balances for TP, SRP, & Chloride



Seasonal Water & Mass Balances for TP, SRP, & Chloride

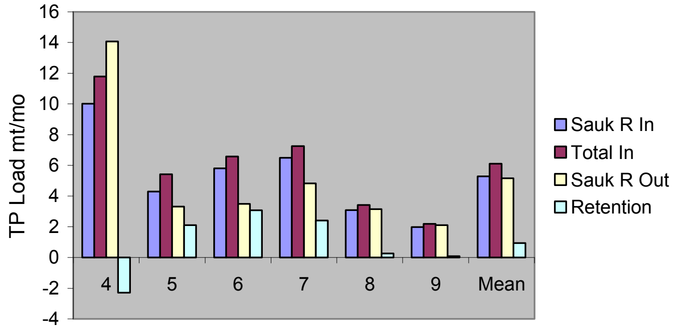
Years: 1997 thru 2008

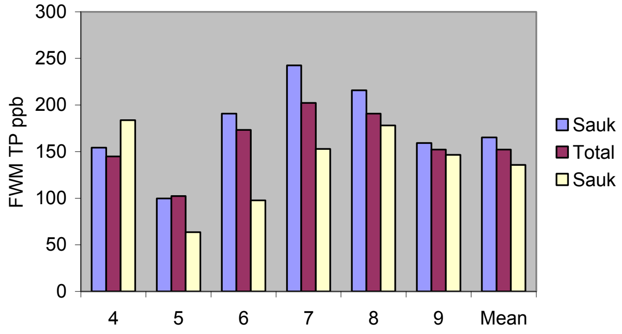
Months: 4 thru 9

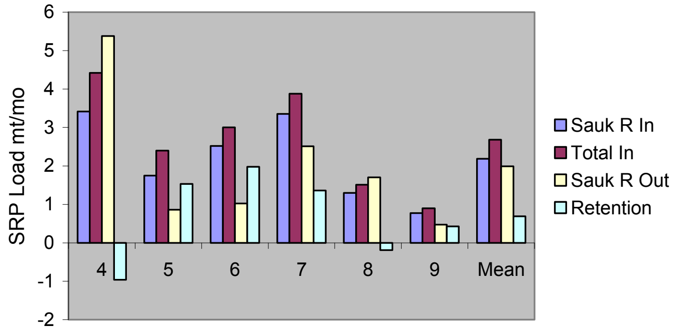
Gauged Inputs & Outputs (Excludes North Browns Lake)

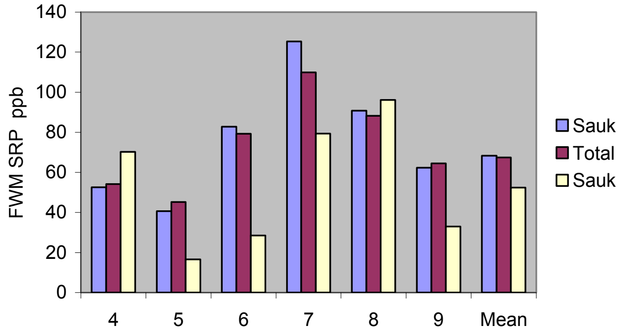
Total Input = Sauk River + Local Tribs + Precip - Evap

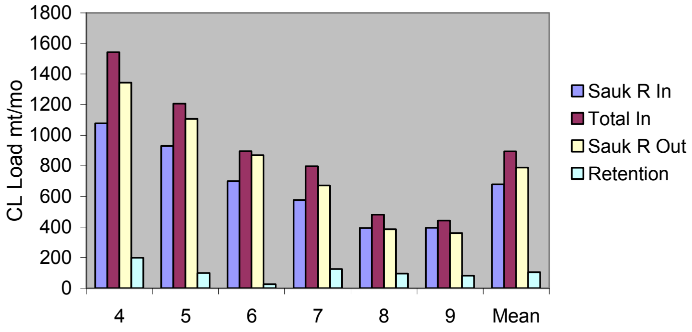
Local Tribs = Kolling + Kinzer + Schneider + Long Lake Inlet

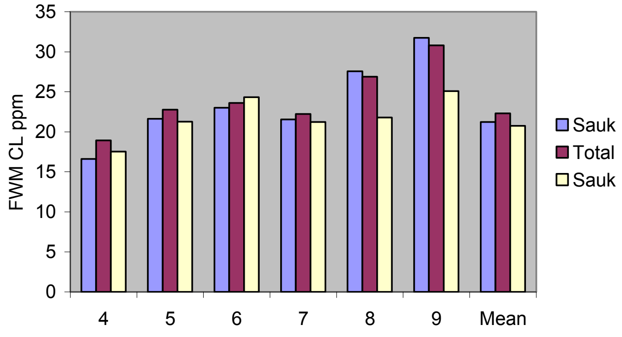




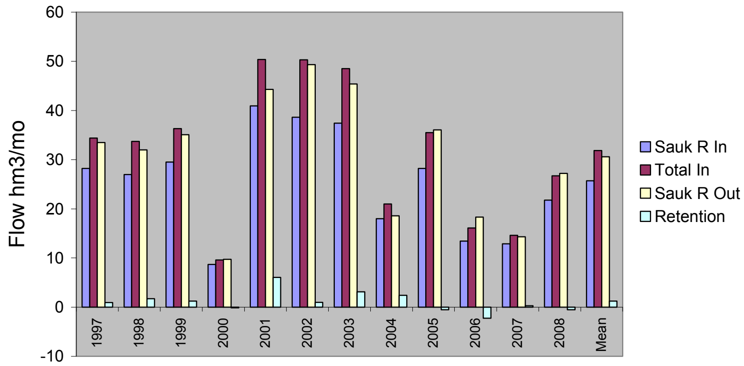








App B - 3 Annual Water & Mass Balances for TP, SRP, & Chloride - May thru September



Annual Water & Mass Balances for TP, SRP, & Chloride

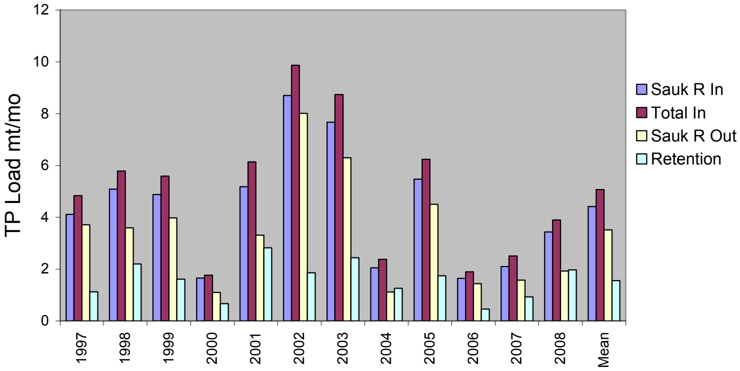
Years: 1997 thru 2008

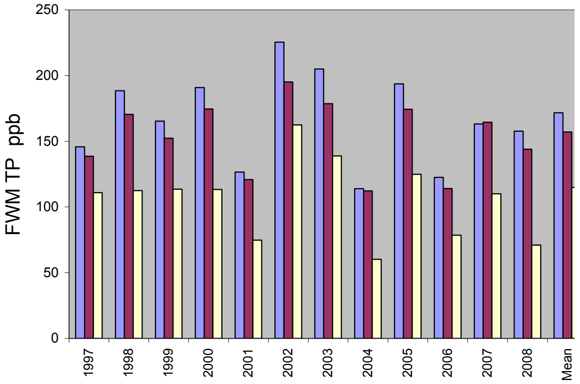
Months: 5 thru 9

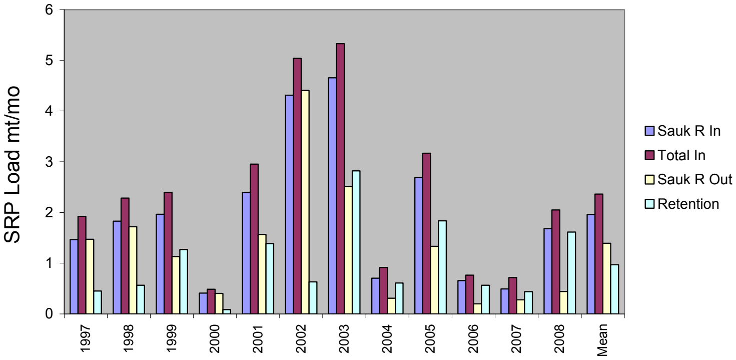
Gauged Inputs & Outputs (Excludes North Browns Lake)

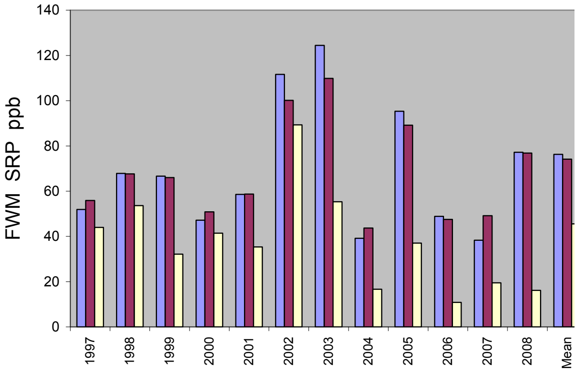
Total Input = Sauk River + Local Tribs + Precip - Evap

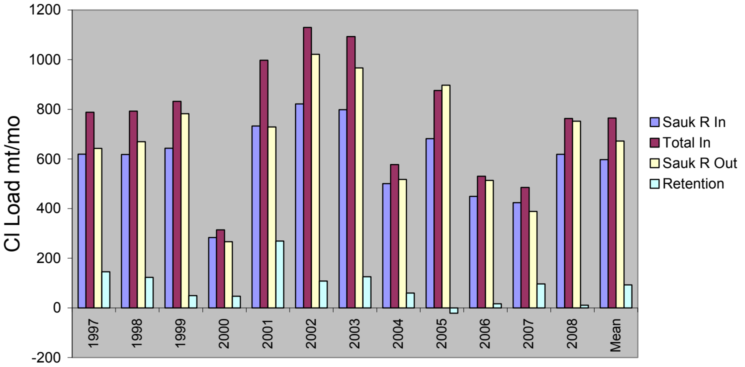
Local Tribs = Kolling + Kinzer + Schneider + Long Lake Inlet

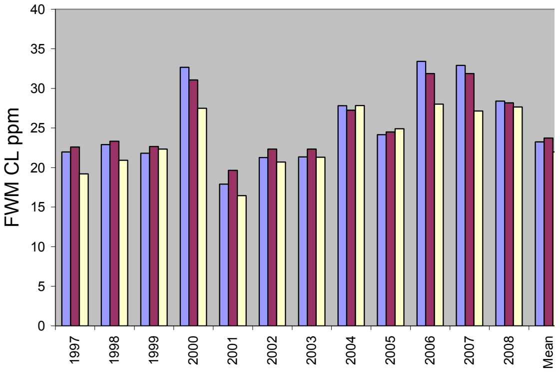












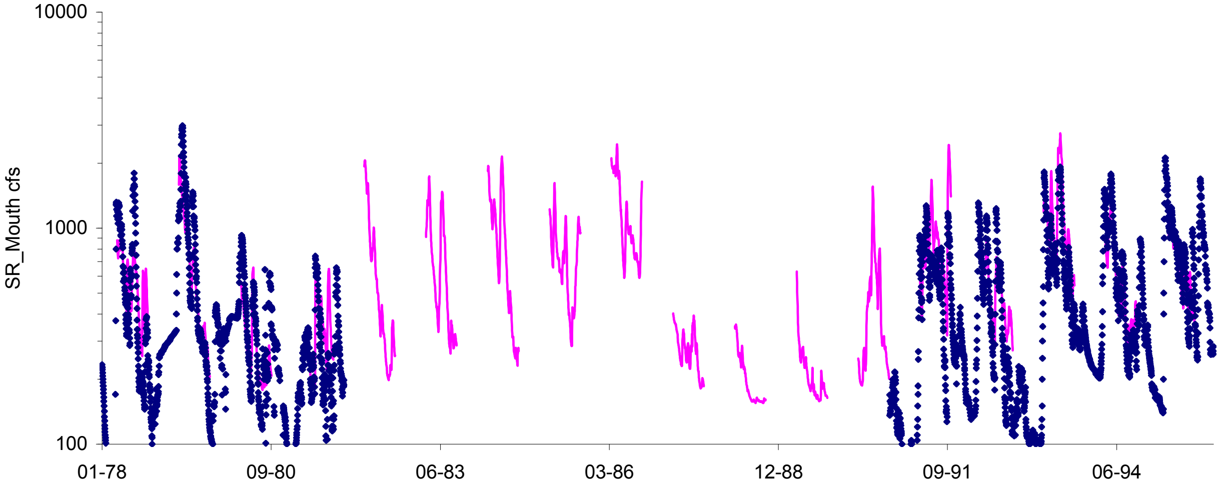
App B - 4

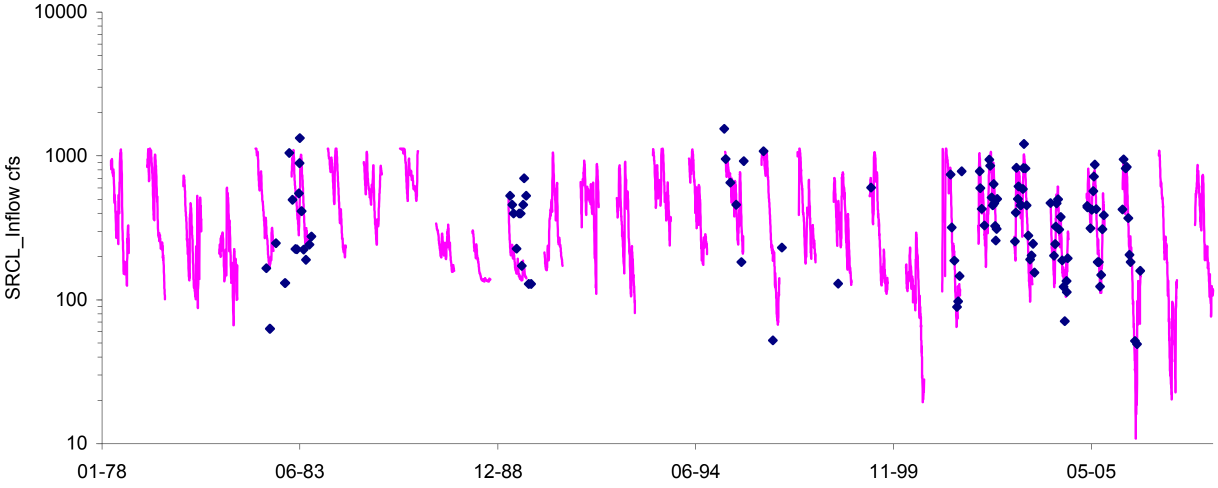
Flow & Load Estimation Methods

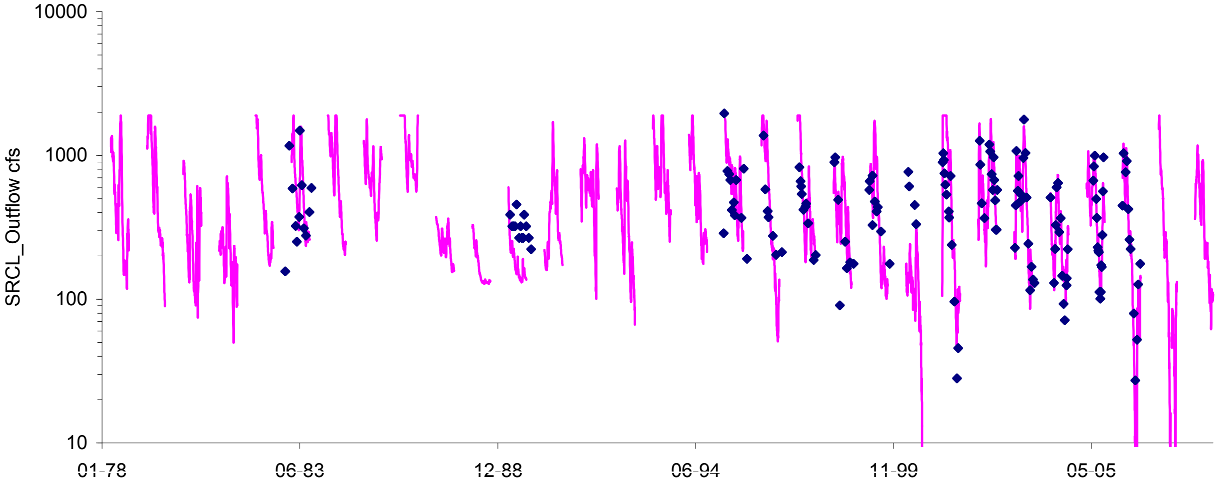
Term	Period	Conc	Flow cfs	Load Calculation
B				
C	1970-1981		measured	N/A
used to estimate missing SRCL	1982-1990		regress vs. Crow R @ Rockford, 1977-80, 91-96	
inflows & outflows			monthly y = 0.262 QC + 149.6, r2 = 0.80	
	1991-2006		measured	
SRCL Outflow @ Cold Spring	1978-1990	sparse	regression vs. SR at Mouth, 2005-2008 data	regression vs. flow, season, trend
	1991-1994	sparse	y = 1.0204 QM - 15.5, r2 = 0.97	
	1995-2001	biweekly		
	2002-2006	biweekly	measured	
SRCL Outflow @ Cold Spring	1978-1990	sparse	regression vs. SR at Mouth, 2005-2008 data	regression vs. flow, season, trend
	1991-1995	sparse	y = 0.838 QM - 2.95, r2 = 0.94	
	1997-2001	biweekly		
	2002-2006	biweekly	measured	
Local Tributaries	1978-2005		regressions vs.SR Qin or SR Qout	
			calibrated to 2006 daily data	
Schneider Creek	2006	biweekly	y = 0.0113 Qout + 2.23, r2 = 0.94	FLUX Method 2; calib to 2006-2008 data
Kinzer Creek	2006	"	y = 0.0141 Qin + 1.56, r2 = 0.94	"
Kolling Creek	2006	"	scale vs. Qout by month	"
Long Lake Inflow	2006	"	y = 0.213 Max (220, Qout) -45.8, r2 = 0.99	"
Eden Valley Creek			inferred from water balance	Rescale to Mean TP = 135 ppb, 2008 Data
Ungauged Lakesheds			rescale based upon drainage area	same as flow
			vs schneider + kinzer + kolling	
			drainage area ratio = 0.29	
Shoreline Septic Systems				septic system inventory by lake
				0.4 kg/septic system (see text)
Shoreline Parcel Runoff				lot inventory by lake
				0.5 acres per lot
				30 kg/km2-season, above lakeshed load
Rainfall			Univ Minn website, Sauk Center	Rainfall x 30 ppb
			http://climate.umn.edu/doc/historical.htm	
Evaporation			61 cm, May-Sept	N/A

App B - 5

Calibration of Models for Estimating Missing Flow Data

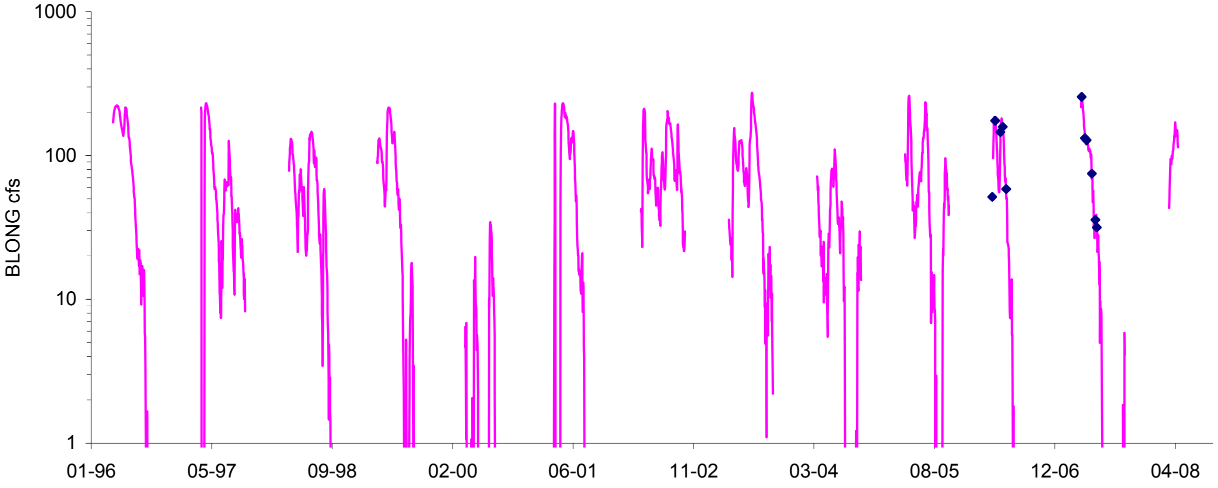


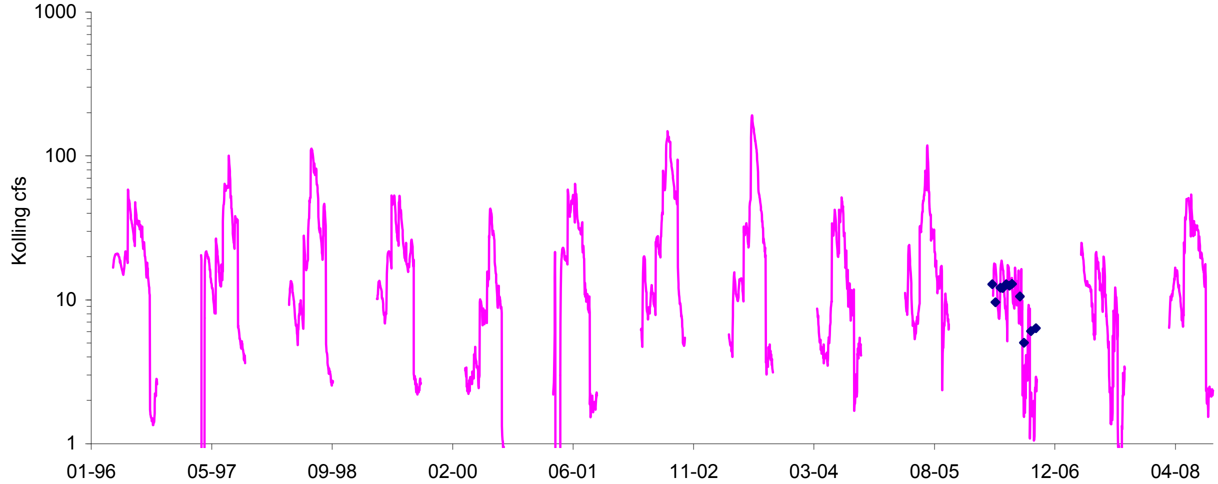


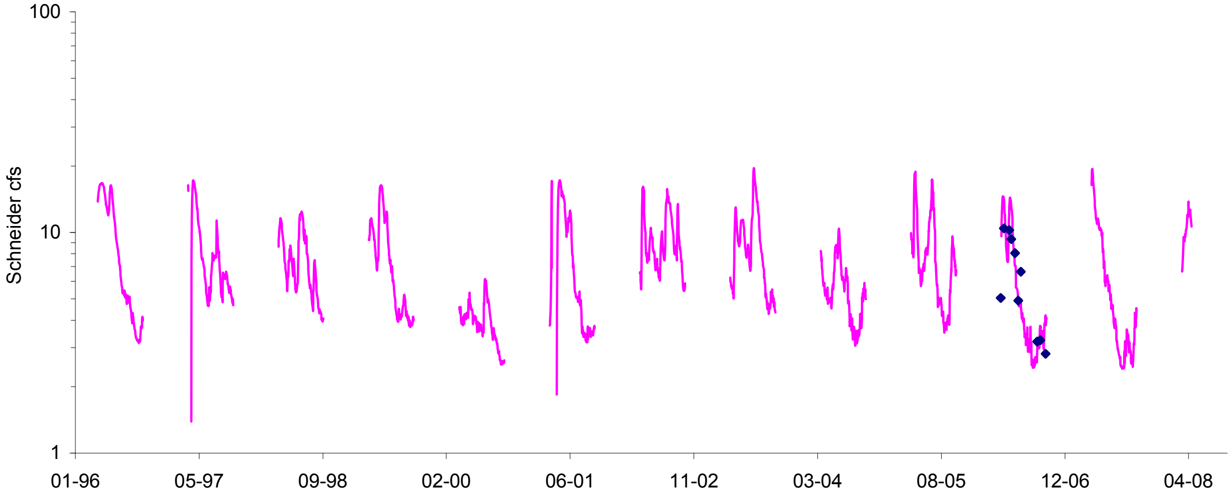


App B - 5

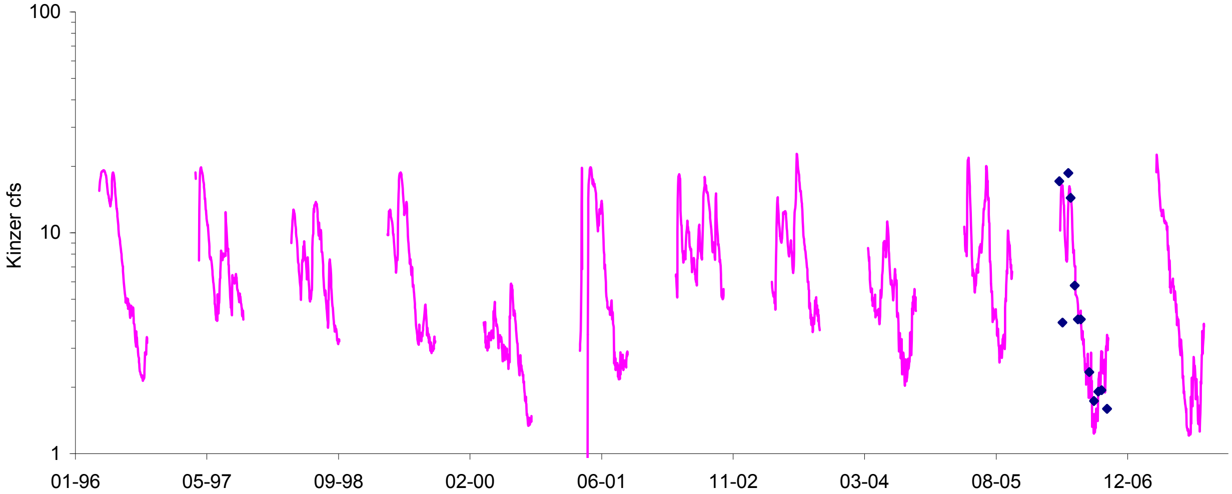
Calibration of Models for Estimating Missing Flow Data



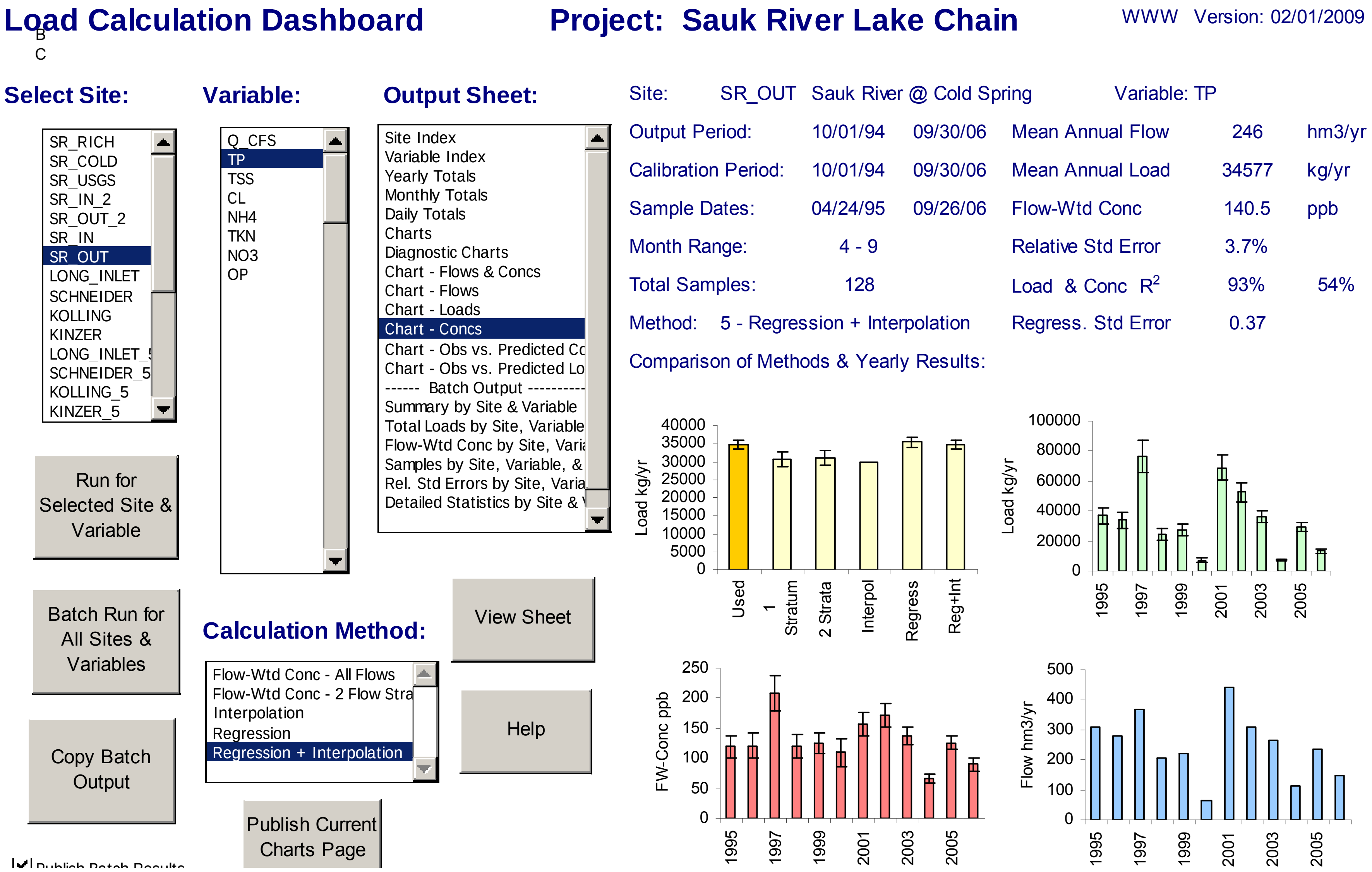




App B - 5 Calibration of Models for Estimating Missing Flow Data



Daily Flows, April - September, Symbols = observed flow on sampling dates (all dates for SR_Mouth).



Load Calculation Dashboard **Project: Sauk River Lake Chain** WWW Version: 02/01/2009

Site: SR_OUT Sauk River @ Cold Spring Variable: TP

Output Period:	10/01/94	09/30/06	Mean Annual Flow	246	hm3/yr
Calibration Period:	10/01/94	09/30/06	Mean Annual Load	34577	kg/yr
Sample Dates:	04/24/95	09/26/06	Flow-Wtd Conc	140.5	ppb
Month Range:	4 - 9		Relative Std Error	3.7%	
Total Samples:	128		Load & Conc R^2	93%	54%
Method:	5 - Regression + Interpolation		Regress. Std Error	0.37	

Comparison of Methods & Yearly Results:

Select Site:

SR_RICH
SR_COLD
SR_USGS
SR_IN_2
SR_OUT_2
SR_IN
SR_OUT
LONG_INLET
SCHNEIDER
KOLLING
KINZER
LONG_INLET_5
SCHNEIDER_5
KOLLING_5
KINZER_5

Variable:

Q_CFS
TP
TSS
CL
NH4
TKN
NO3
OP

Output Sheet:

Site Index
Variable Index
Yearly Totals
Monthly Totals
Daily Totals
Charts
Diagnostic Charts
Chart - Flows & Concs
Chart - Flows
Chart - Loads
Chart - Concs
Chart - Obs vs. Predicted Cc
Chart - Obs vs. Predicted Lo
------ Batch Output ----------
Summary by Site & Variable
Total Loads by Site, Variable
Flow-Wtd Conc by Site, Varia
Samples by Site, Variable, &
Rel. Std Errors by Site, Varia
Detailed Statistics by Site & V

Calculation Method:

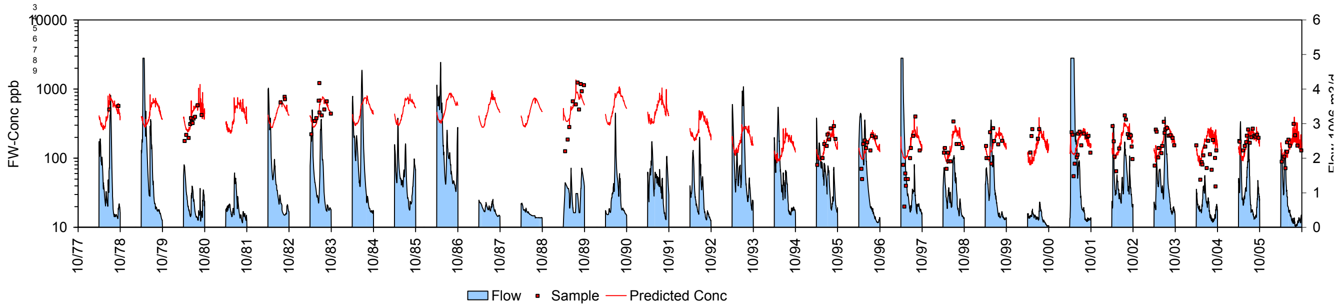
Flow-Wtd Conc - All Flows
Flow-Wtd Conc - 2 Flow Stra
Interpolation
Regression
Regression + Interpolation

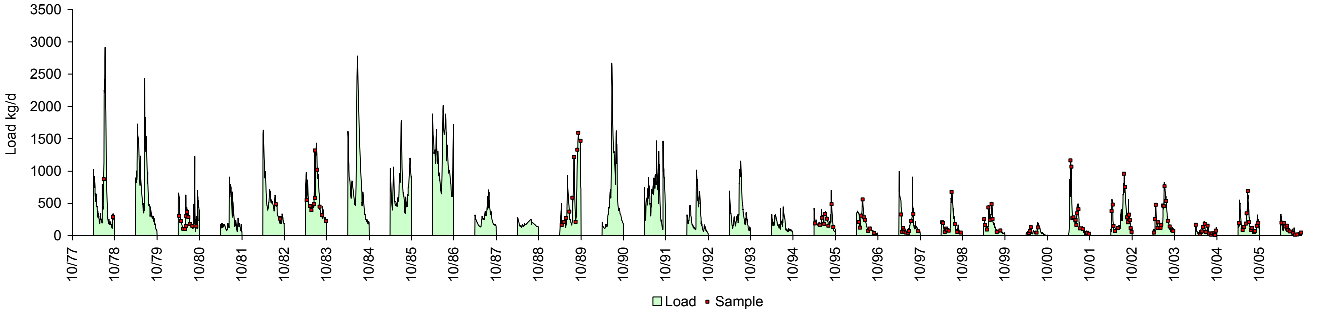
App B - 7 Sauk River Inflow Time Series, 1978-2006

Site: **SR_IN** **Variable:** **TP** **Total P ppb** **Month Interval:** **4** **9** **Dates:** **10/01/1977 - 09/30/2006**

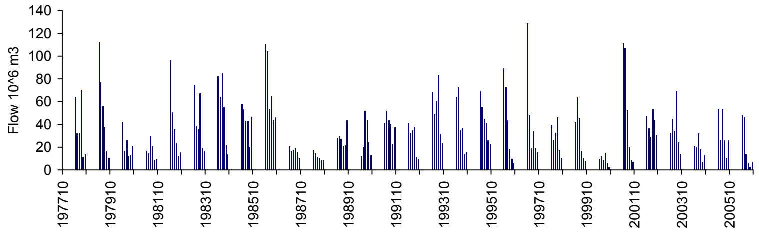
Flow 10^6 m3 **3129.7** **Load kg** **998725** **FW-Conc ppb** **319.1** **RSE** **5%**

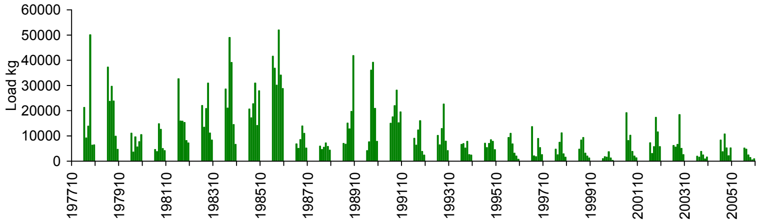
Daily Time Series:

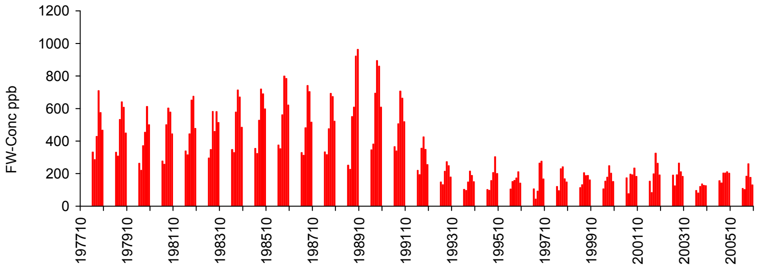




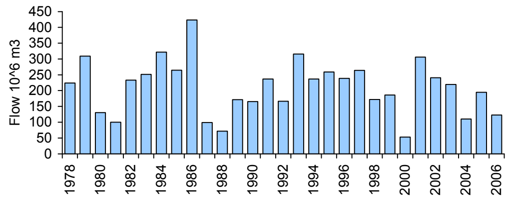
Monthly Time Series:

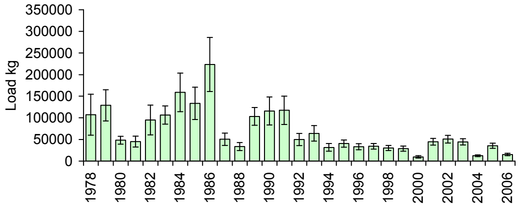


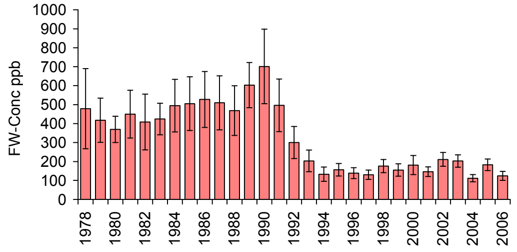




Yearly Time Series:







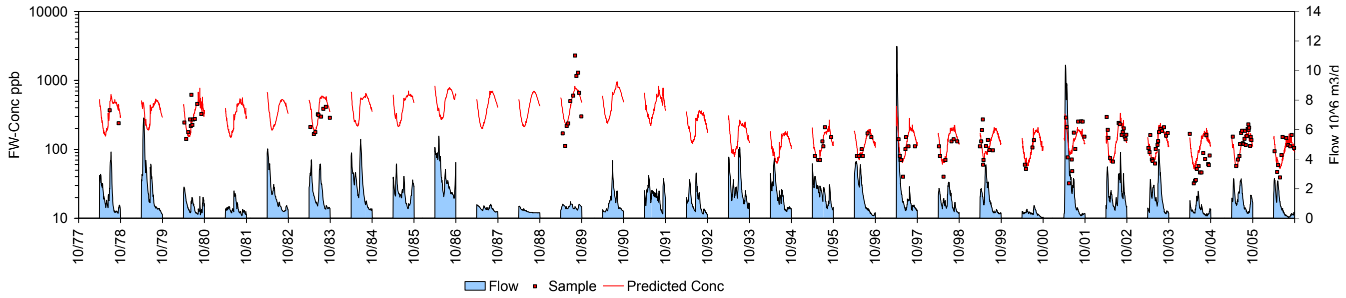
03/04/2009

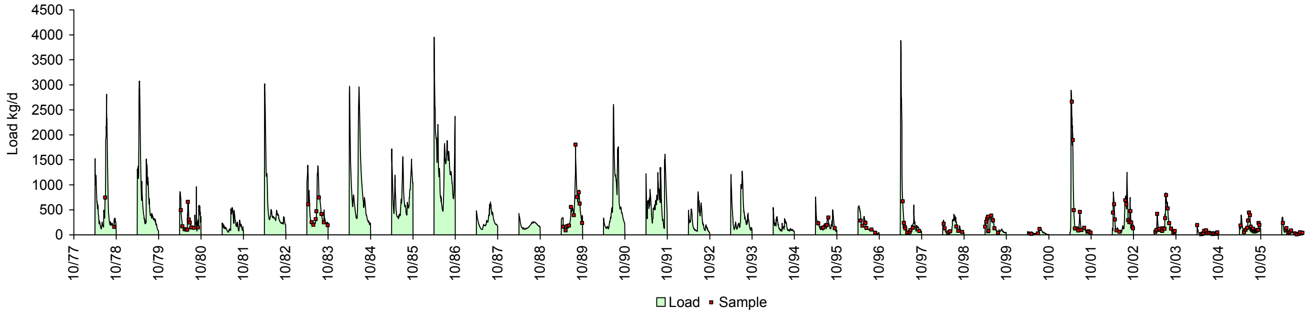
App B - 8 Sauk River Outflow Time Series, 1978-2006

Site: **SR_OUT** **Variable:** **TP** **Total P ppb** **Month Interval:** **4** **9** **Dates: 10/01/1977 - 09/30/2006**

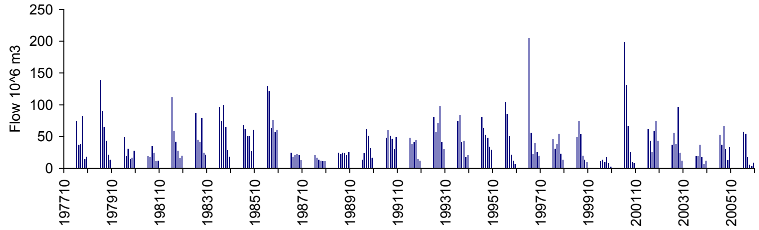
Flow 10^6 m3 **3785.5** **Load kg 1019758** **FW-Conc ppb** **269.4** **RSE** **5%**

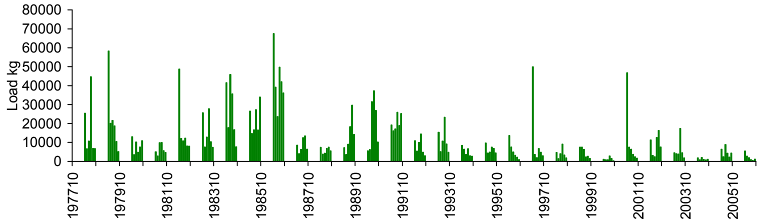
Daily Time Series:

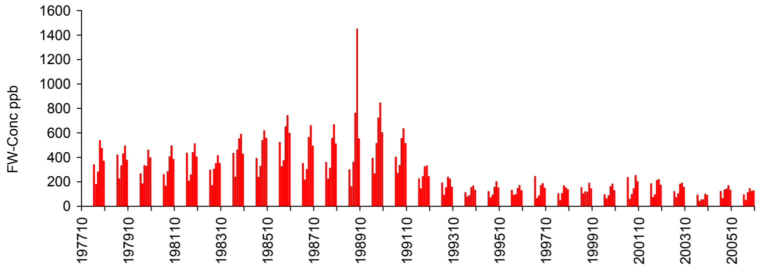




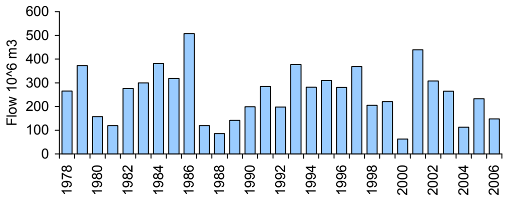
Monthly Time Series:

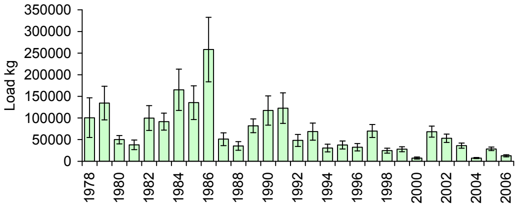


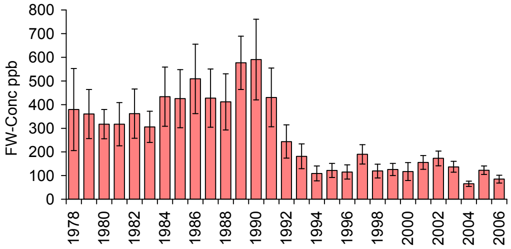




Yearly Time Series:





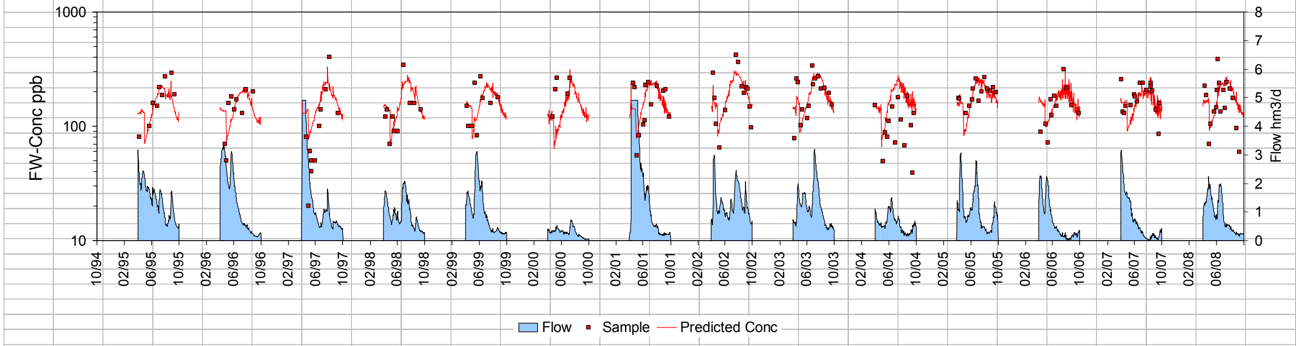


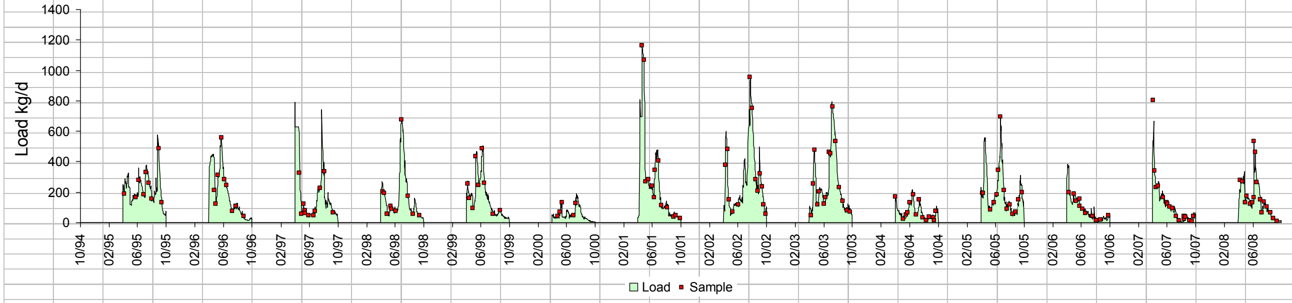
03/04/2009

App B - 9 Sauk River Inflow Time Series, 1996-2008

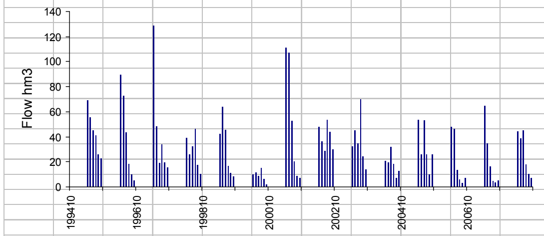
Site:	SR_IN	Variable:	TP	Total P ppb	Month Interval:	4	9
Dates:	10/01/1994 - 09/30/2008						
Totals:	Flow hm3	2658.8	Load kg	432202	FW-Conc ppb	162.6	RSE 4%

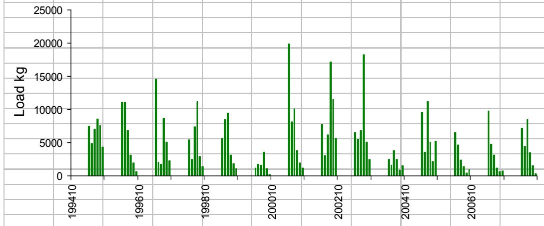
Daily Time Series:

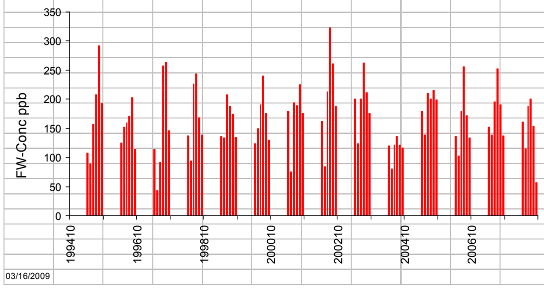




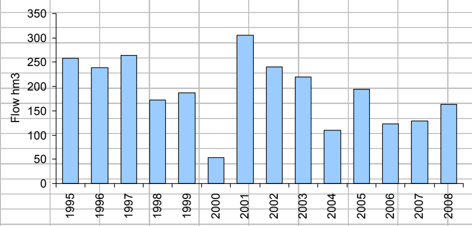
Monthly Time Series:

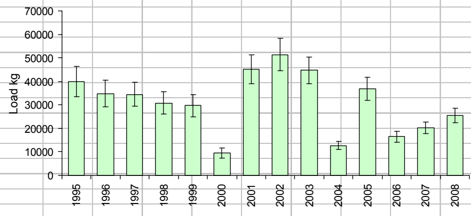


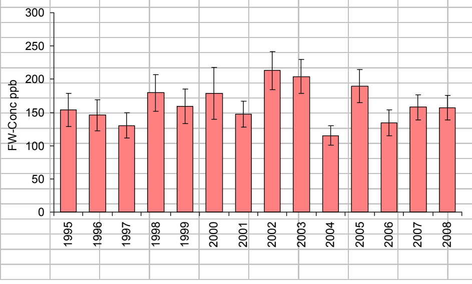




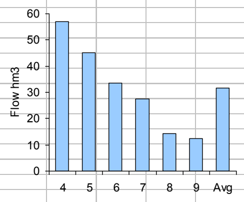
Yearly Time Series:

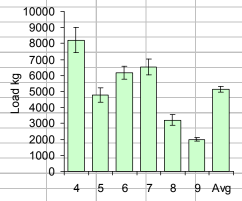


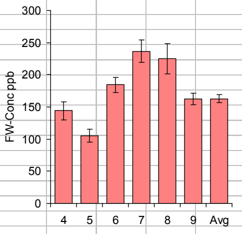




Monthly Means:





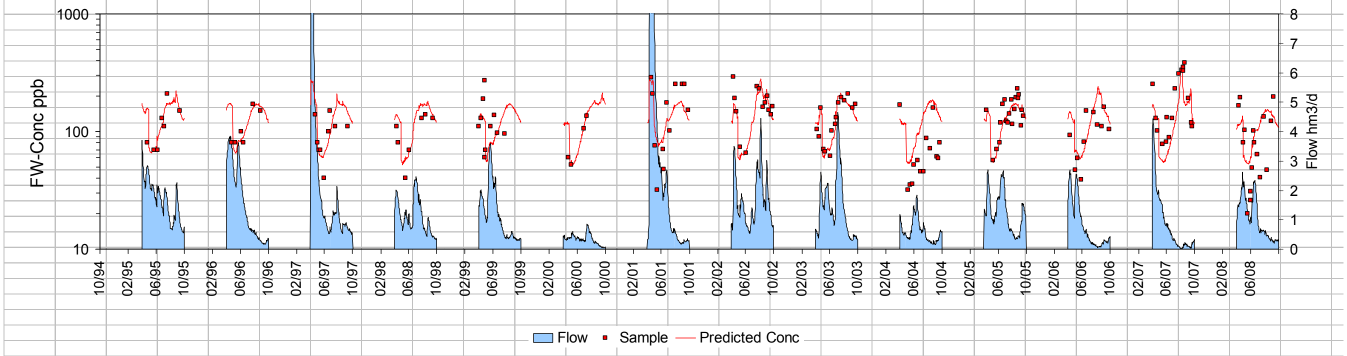


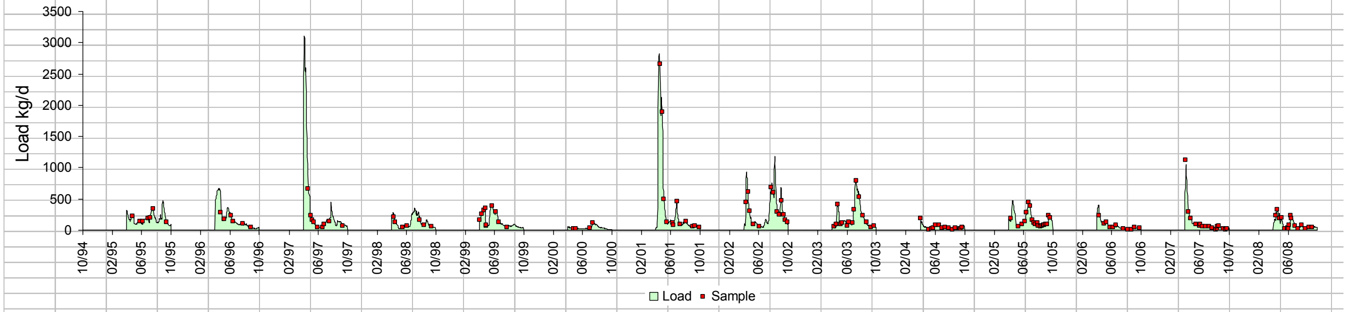
03/16/2009

App B - 10 Sauk River Outflow Time Series, 1996-2008

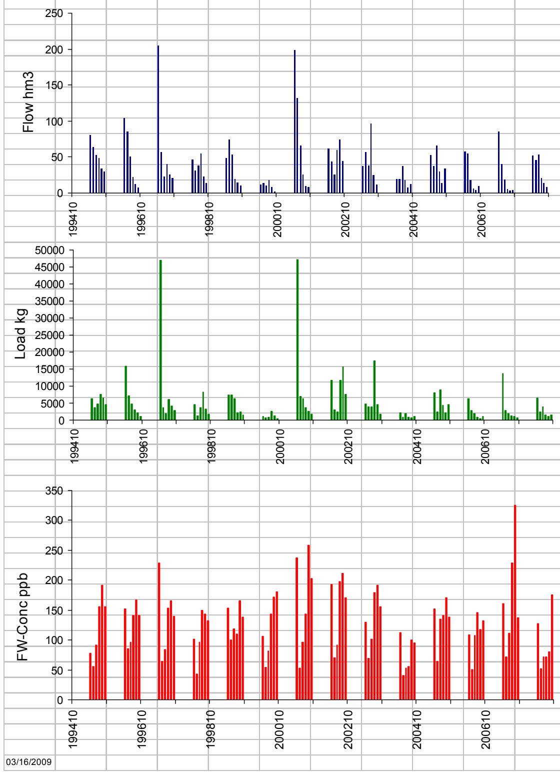
Site:	SR_OUT	Variable:	TP	Total P ppb	Month Interval:	4	9	Dates:	10/01/1994 - 09/30/2008
Totals:	Flow hm3	3302.7	Load kg	437427	FW-Conc ppb	132.4		RSE	4%

Daily Time Series:

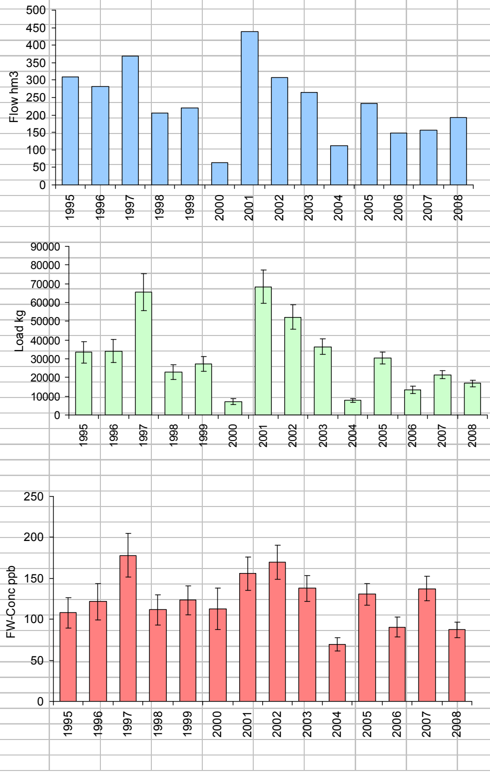




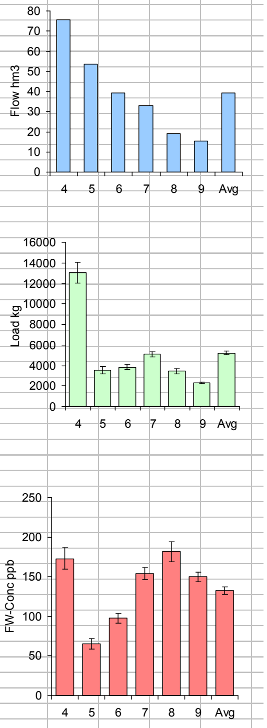
Monthly Time Series:



Yearly Time Series:



Monthly Means:

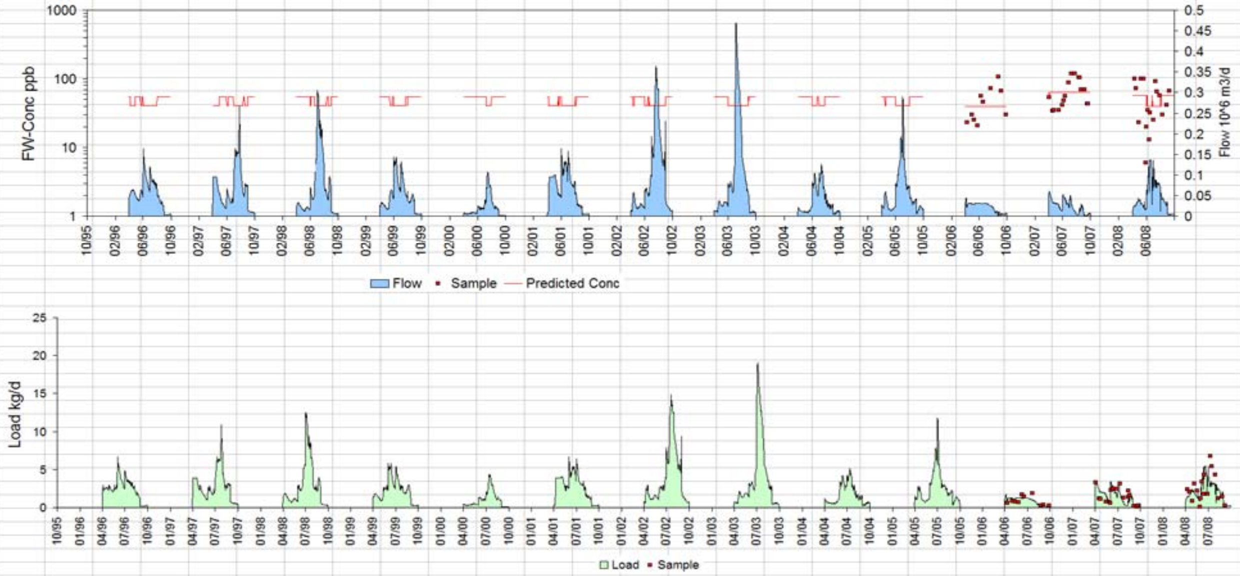


03/16/2009

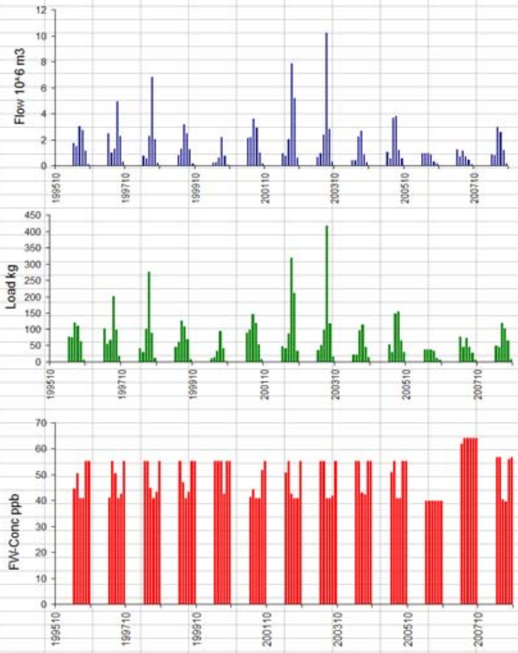
App B - 11 Kolling Creek Inflow Time Series, 1996-2008

Site:	KOLLING	Variable:	TP	Total P ppb	Month Interval:	4	9	Dates: 10/01/1995 - 09/30/2008
Totals:	Flow 10^6 m3	129.1	Load kg	5744	FW-Conc ppb	44.5	RSE	11%

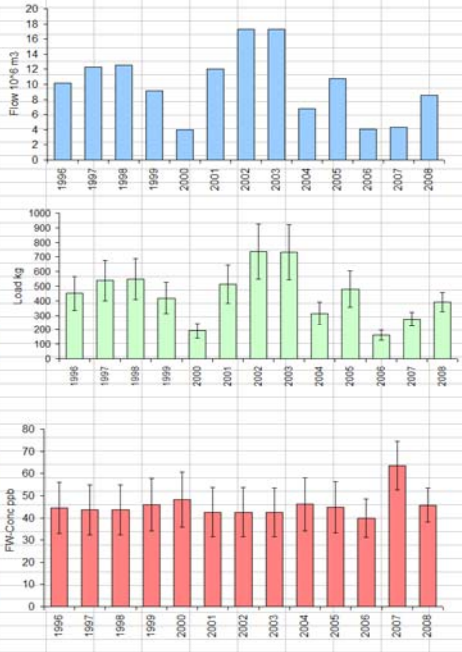
Daily Time Series:



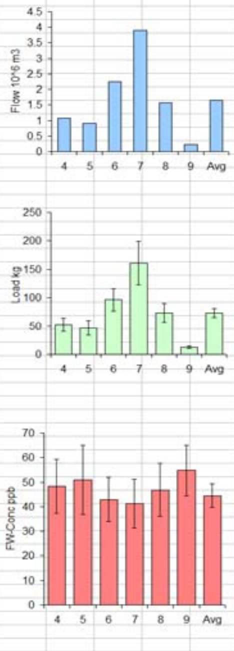
Monthly Time Series:



Yearly Time Series:



Monthly Means:

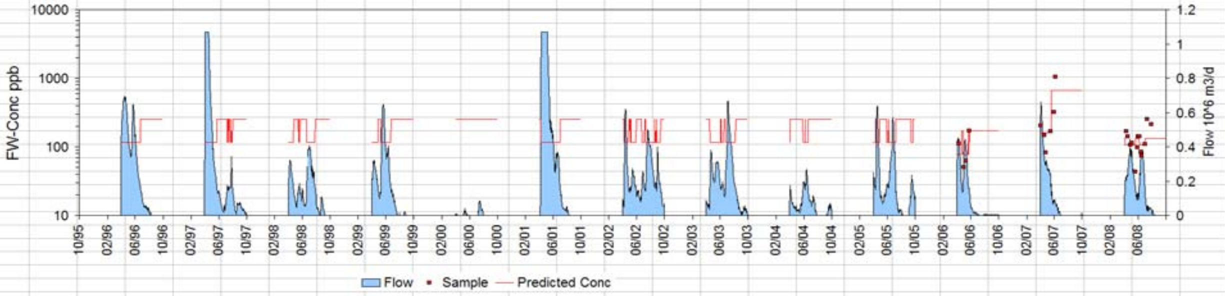


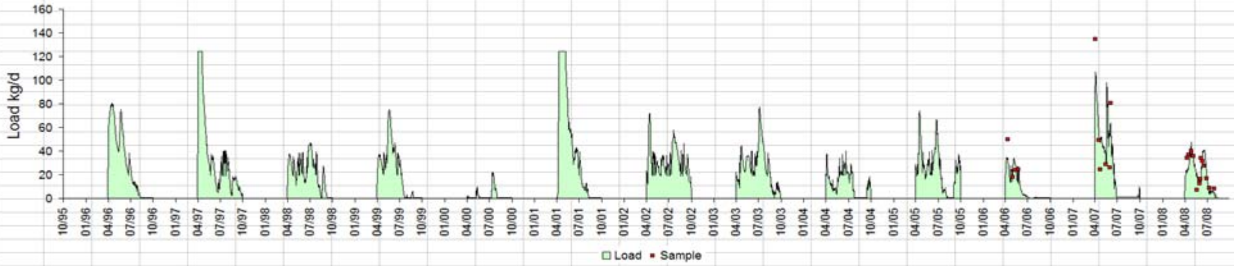
03/11/2009

App B - 12 Long Lake Inlet Time Series, 1996-2008

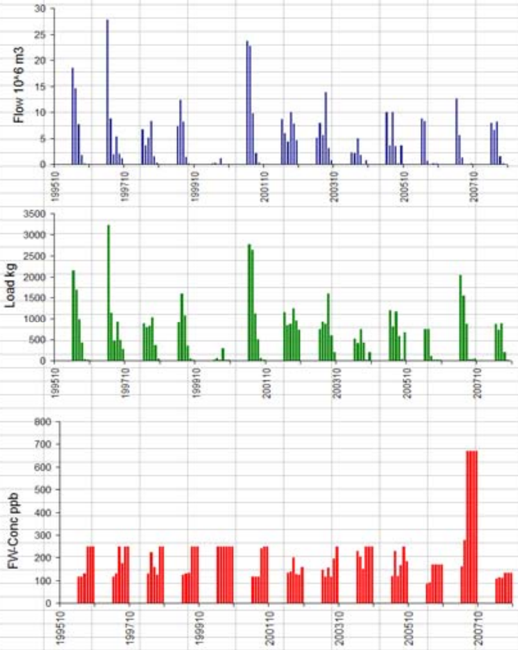
Site:	LONG_INLET	Variable:	TP	Total P ppb	Month Interval:	4	9	Dates: 10/01/1995 - 09/30/2008
Totals:	Flow 10^6 m3	386.0	Load kg	53684	FW-Conc ppb	139.1	RSE	10%

Daily Time Series:

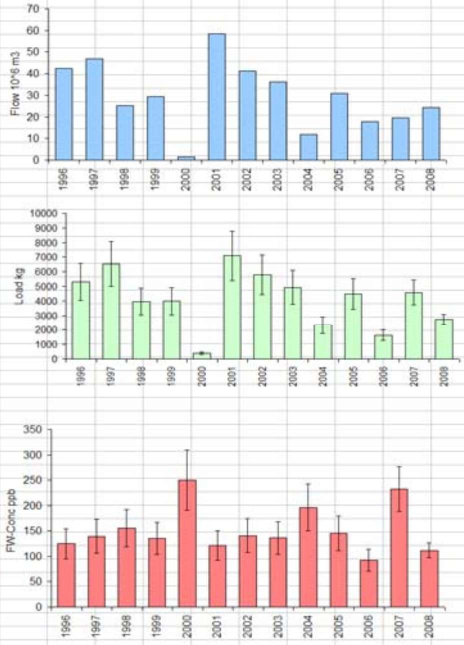




Monthly Time Series:



Yearly Time Series:



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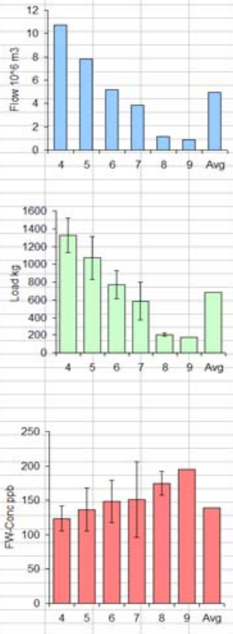
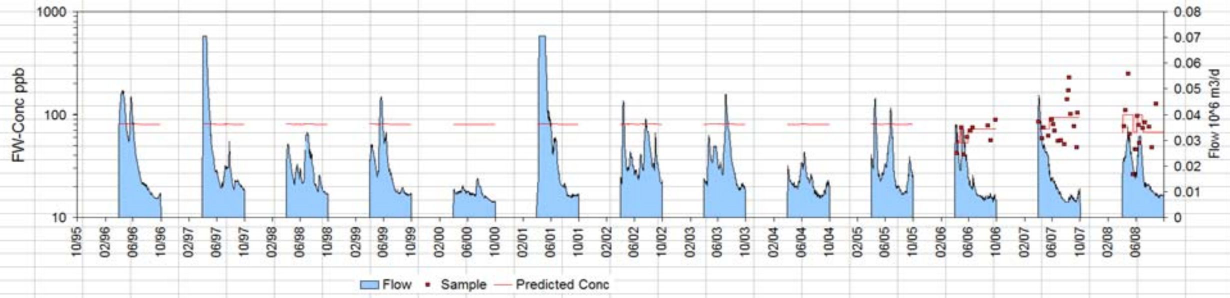


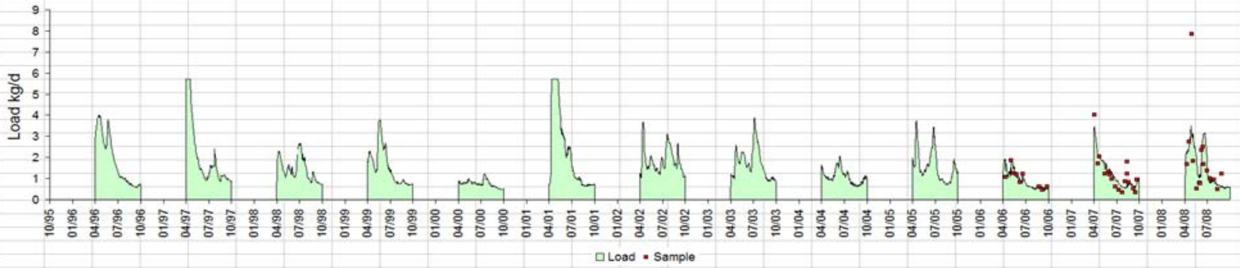
03/11/2009

Schneider Creek Inflow Time Series, 1996-2008

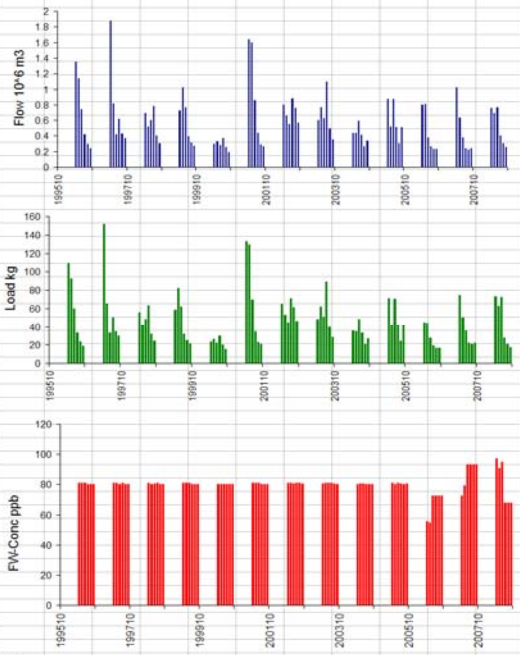
Site:	SCHNEIDER	Variable:	TP	Total P ppb	Month Interval:	4	9	Dates:	10/01/1995 - 09/30/2008
Totals:	Flow 10^6 m3	45.1	Load kg	3613	FW-Conc ppb	80.1		RSE	11%

Daily Time Series:



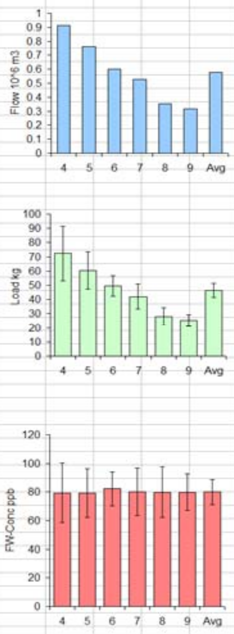


Monthly Time Series:



Yearly Time Series:

Monthly Means:



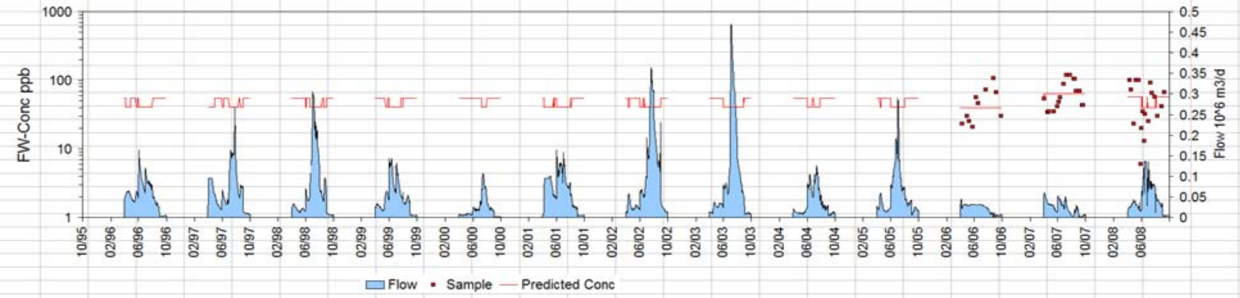
03/11/2009

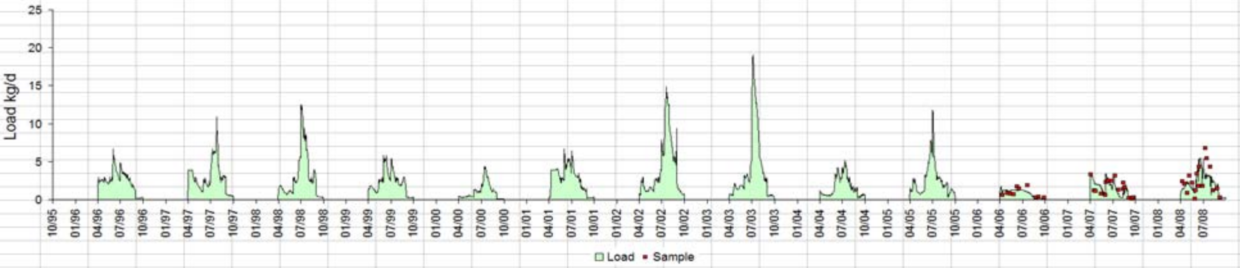
App B - 14

Kinzer Creek Inflow Time Series, 1996-2008

Site:	KOLLING	Variable:	TP	Total P ppb		Month Interval:	4	9	Dates:	10/01/1995 - 09/30/2008
Totals:	Flow 10^6 m3	129.1	Load kg	5744		FW-Conc ppb	44.5		RSE	11%

Daily Time Series:





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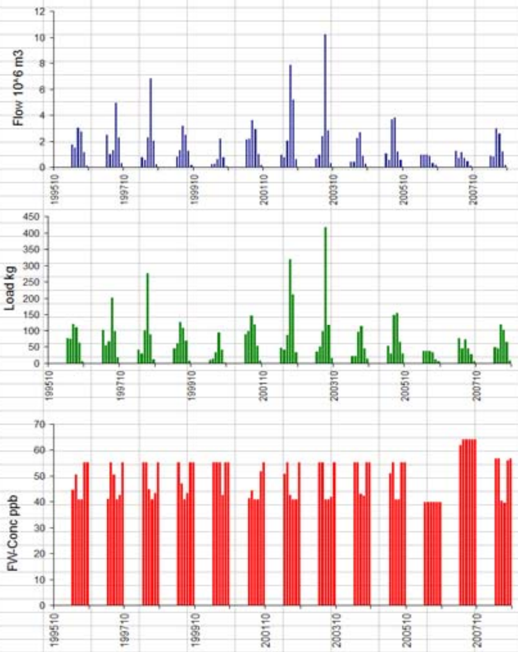
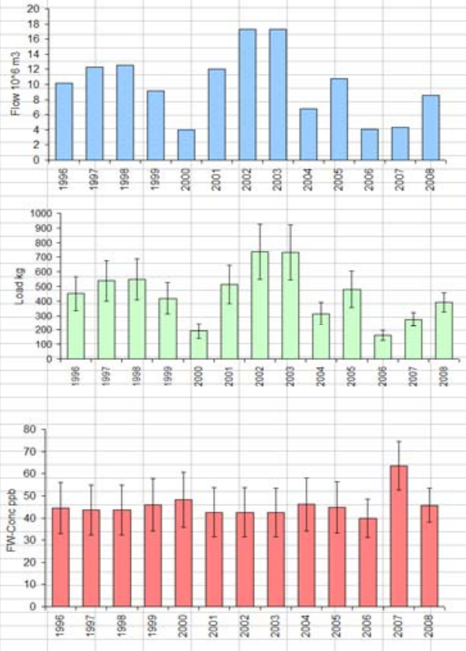
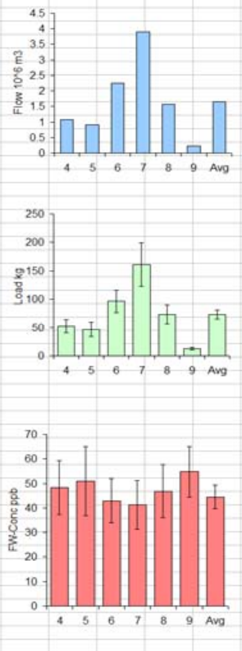


Yearly Time Series:



Monthly Means:



03/11/2009

Appendix C

Lake Water Quality Data Summaries & Diagnostics

App C - 1

Lake Water Quality Crosstab by Segment and Year

June-September

Lake Segment	1997	1998	2000	2001	2002	2003	2004	2005	2006	Mean	Criterion
Total P (ppb)											
Koetter	140	177	162	198	193				157	169	60
Zumwalde	140	170	175	197	184	176	121	154	170	162	60
Great Northern	145	160	162	211	186				168	171	60
Krays	140	133	180	211	179	184	131	159	158	161	60
Knaus/Park	135	128	146	197	145	166	100	147	137	143	60
Becker	52	30	46	66	37				87	51	60
Horseshoe West	35	57	34	64	116				35	57	40
Horseshoe South	100	187	126	145	186	159	120	117	90	130	40
Cedar	55	63	60	102	95	123	78	74	65	81	40
Schneider	60	47	53	81	62	77	104	52	48	65	40
Bolfing	65	59	63	121	110				71	81	40
Long	140	103	75	135	87				79	96	40
North Browns					119			59	110	91	40
Mean Chlorophyll-a, Algal Pigment (ppb)											
Koetter	66	60	76	40	50				81	62	20
Zumwalde	47	69	86	54	45	60	48	57	75	61	20
Great Northern	48	58	96	49	48				81	65	20
Krays	61	53	90	58	43	66	66	66	74	65	20
Knaus/Park	67	60	75	61	50	58	66	78	94	67	20
Becker	5	7	11	12	35				8	13	20
Horseshoe West	27	45	22	43	42				27	34	14
Horseshoe South	70	52	63	48	41	96	71	62	61	64	14
Cedar	41	68	40	80	38	58	39	53	55	51	14
Schneider	30	23	33	47	43	39	18	38	38	33	14
Bolfing	65	62	53	64	44				70	57	14
Long	112	110	46	72	27				77	64	14
North Browns					32			10	77	30	14
Mean Transparency, Secchi Depth (meters)											
Koetter	0.7	0.7	0.5	0.7	0.8				0.5	0.6	1.0
Zumwalde	0.7	0.6	0.5	0.6	0.8	0.6	0.6	0.6	0.4	0.6	1.0
Great Northern	0.7	0.6	0.5	0.6	0.8				0.5	0.6	1.0
Krays	0.6	0.7	0.5	0.7	0.8	0.6	0.7	0.6	0.6	0.6	1.0
Knaus/Park	0.7	0.7	0.6	0.6	0.7	0.7	0.8	0.6	0.6	0.7	1.0
Becker	1.2	1.3	0.8	0.8	1.1				0.9	1.1	1.0
Horseshoe West	1.7	1.5	1.3	1.3	1.1				1.1	1.5	1.4
Horseshoe South	1.1	0.8	1.1	0.9	1.2	1.0	0.9	1.4	1.0	1.0	1.4
Cedar	0.8	0.8	1.1	0.7	0.9	1.1	1.2	1.3	1.0	1.1	1.4
Schneider	1.4	1.6	1.3	1.1	1.9	1.8	2.6	1.7	1.3	1.6	1.4
Bolfing	1.1	0.7	1.0	1.0	1.1	1.4	1.3	1.5	0.7	1.1	1.4
Long	0.6	0.6	1.0	0.7	1.0		1.5	0.7	0.6	0.9	1.4
North Browns	2.4	1.3	2.5	1.4	1.7	2.0	1.7	1.8	1.0	1.8	1.4
Frequency of Severe Algal Blooms (Fraction of Chlorophyll-a Measurements > 60 ppb)											
Koetter	1.00	0.67	1.00	0.25	0.50				0.75	0.64	-
Zumwalde	0.00	0.67	0.75	0.50	0.50	0.43	0.33	0.38	0.88	0.52	-
Great Northern	0.00	0.67	1.00	0.25	0.25				0.75	0.52	-
Krays	0.50	0.33	1.00	0.50	0.00	0.43	0.56	0.75	0.75	0.57	-
Knaus/Park	0.75	0.67	0.63	0.38	0.38	0.29	0.56	0.50	1.00	0.56	-
Becker	0.00	0.00	0.00	0.00	0.00				0.00	0.00	-
Horseshoe West	0.00	0.67	0.00	0.00	0.00				0.00	0.08	-
Horseshoe South	1.00	0.67	0.50	0.50	0.00	0.71	0.67	0.50	0.50	0.53	-
Cedar	0.00	0.67	0.25	0.75	0.00	0.63	0.30	0.38	0.38	0.40	-
Schneider	0.00	0.00	0.00	0.33	0.25	0.14	0.00	0.25	0.13	0.12	-
Bolfing	1.00	0.50	0.25	0.50	0.25				0.50	0.42	-
Long	1.00	1.00	0.00	0.75	0.00				0.75	0.50	-
North Browns					0.00			0.00	0.75	0.17	-

* June-September Means, 0-2 meters.

App C - 2 Lake Water Quality Summary by Segment and Year June-September

		Total P ppb			Secchi meters			Chl-a ppb			Algal Bloom Frequencies				Chloride ppm			Organic N ppb			SRP ppb		
Segment	Year	N	Mean	SE	N	Mean	SE	N	Mean	SE	>30	>40	>60	>80	N	Mean	SE	N	Mean	SE	N	Mean	SE
C	1997	2	140	10	2	0.7	0.1	2	66	0	1.00	1.00	1.00	0.00	2	22	3	2	1665	75	2	32	3
	1998	3	177	22	3	0.7	0.1	3	60	25	0.67	0.67	0.67	0.33	3	23	3	3	1333	119	3	60	19
	1999	4	147	14	4	0.6	0.1	4	64	20	0.75	0.75	0.50	0.50	3	24	4	4	1445	661	4	43	16
	2000	4	162	19	4	0.5	0.1	4	76	3	1.00	1.00	1.00	0.25	4	32	2	4	1980	211	4	38	3
	2001	4	198	32	4	0.7	0.2	4	40	11	0.50	0.50	0.25	0.00	4	24	4	4	1310	262	4	62	16
	2002	4	193	19	4	0.8	0.1	4	50	11	0.75	0.75	0.50	0.00	4	17	1	4	1343	198	4	94	31
	2006	4	157	21	4	0.5	0.0	4	81	11	1.00	1.00	0.75	0.75	3	36	3	4	1201	29	4	22	14
Mean		25	169	8	25	0.6	0.0	25	62	5	0.80	0.80	0.64	0.28	23	25	2	25	1458	121	25	51	8
04_Zumwalde	1997	2	140	0	2	0.7	0.1	2	47	8	1.00	0.50	0.00	0.00	2	20	11	2	1680	210	2	29	2
	1998	3	170	15	3	0.6	0.1	3	69	19	1.00	0.67	0.67	0.33	3	20	5	3	1407	127	3	59	29
	1999	3	158	12	3	0.6	0.1	3	78	11	1.00	1.00	0.67	0.33	2	26	4	3	1023	507	3	33	11
	2000	4	175	23	4	0.5	0.1	4	86	16	1.00	0.75	0.75	0.75	4	31	2	4	2038	174	4	45	5
	2001	4	197	29	4	0.6	0.1	4	54	12	0.75	0.75	0.50	0.00	4	24	4	4	1823	201	4	60	18
	2002	4	184	22	4	0.8	0.0	4	45	12	0.75	0.50	0.50	0.00	4	21	1	4	1200	156	4	92	28
	2003	7	176	17	7	0.6	0.1	7	60	15	0.71	0.43	0.43	0.43	1	27		7	1520	99	7	78	15
	2004	9	121	36	8	0.6	0.1	9	48	9	0.89	0.56	0.33	0.11	0			9	1370	153	9	11	2
	2005	8	154	15	8	0.6	0.1	8	57	10	0.75	0.50	0.38	0.25	3	28	1	8	1429	56	8	74	14
	2006	8	170	17	8	0.4	0.0	8	75	6	1.00	1.00	0.88	0.13	7	36	2	8	1194	47	8	22	7
Mean		52	162	8	51	0.6	0.0	52	61	4	0.87	0.65	0.52	0.23	30	27	1	52	1439	57	52	49	6
05_GtNorth	1997	2	145	5	2	0.7	0.1	2	48	10	1.00	0.50	0.00	0.00	2	28	4	2	1360	530	2	31	7
	1998	3	160	31	3	0.6	0.0	3	58	25	0.67	0.67	0.67	0.33	3	22	2	3	1177	125	3	56	35
	1999	4	147	17	4	0.6	0.1	4	63	14	0.75	0.75	0.50	0.25	3	23	3	4	1030	368	4	35	6
	2000	4	162	21	4	0.5	0.0	4	96	7	1.00	1.00	1.00	0.75	4	31	2	4	1978	117	4	41	3
	2001	4	211	35	4	0.6	0.2	4	49	9	0.75	0.75	0.25	0.00	4	24	3	4	1578	278	4	62	24
	2002	4	186	21	4	0.8	0.1	4	48	12	0.75	0.75	0.25	0.00	4	20	1	4	1313	215	4	86	28
	2006	4	168	10	4	0.5	0.0	4	81	12	1.00	1.00	0.75	0.50	3	35	3	4	1259	50	4	18	10
Mean		25	171	9	25	0.6	0.0	25	65	6	0.84	0.80	0.52	0.28	23	26	1	25	1395	102	25	48	8
06_Krays	1997	2	140	0	2	0.6	0.0	2	61	11	1.00	1.00	0.50	0.00	2	24	3	2	1690	0	2	40	12
	1998	3	133	28	3	0.7	0.1	3	53	10	1.00	0.67	0.33	0.00	3	19	6	3	1133	121	3	47	33
	1999	4	144	13	4	0.6	0.0	4	56	14	0.75	0.75	0.50	0.25	3	23	3	4	1233	514	4	31	5
	2000	4	180	29	4	0.5	0.0	4	90	3	1.00	1.00	1.00	1.00	4	31	2	4	2320	95	4	49	9
	2001	4	211	44	4	0.7	0.1	4	58	11	1.00	0.50	0.50	0.00	4	25	2	4	1680	199	4	64	15
	2002	4	179	22	4	0.8	0.0	4	43	10	0.75	0.75	0.00	0.00	4	18	2	4	1380	142	4	84	30
	2003	7	184	16	7	0.6	0.1	7	66	20	0.86	0.43	0.43	0.29	1	26		7	1477	91	7	82	18
	2004	9	131	38	7	0.7	0.1	9	66	7	0.89	0.89	0.56	0.22	0			9	2128	649	9	8	2
	2005	8	159	25	8	0.6	0.1	8	66	12	0.75	0.75	0.75	0.25	3	28	1	8	1579	111	8	71	14
	2006	8	158	8	8	0.6	0.0	8	74	8	1.00	1.00	0.75	0.25	7	34	1	8	1252	78	8	17	6
Mean		53	161	9	51	0.6	0.0	53	65	4	0.89	0.77	0.57	0.25	31	26	1	53	1611	125	53	47	6
07_Knaus	1997	4	135	6	13	0.7	0.1	4	67	4	1.00	1.00	0.75	0.00	4	29	4	4	1788	92	4	37	2
	1998	6	128	20	14	0.7	0.0	6	60	14	0.67	0.67	0.67	0.17	6	18	3	6	1228	106	6	40	15
	1999	8	126	13	15	0.7	0.1	8	58	12	0.75	0.75	0.50	0.38	6	24	2	8	1215	306	8	24	4
	2000	8	146	14	16	0.6	0.0	8	75	11	1.00	0.88	0.63	0.50	8	31	1	8	2006	211	8	40	5
	2001	8	197	26	16	0.6	0.1	8	61	9	0.88	0.88	0.38	0.25	8	24	1	8	1929	221	8	60	12
	2002	8	145	15	16	0.7	0.0	8	50	7	0.75	0.75	0.38	0.00	8	20	1	8	1543	151	8	46	12
	2003	7	166	14	15	0.7	0.1	7	58	14	1.00	0.57	0.29	0.14	1	25		7	1448	72	7	61	15
	2004	9	100	26	18	0.8	0.1	9	66	6	1.00	0.89	0.56	0.22	0			9	2127	983	9	5	1
	2005	8	147	22	14	0.6	0.0	6	78	17	1.00	0.83	0.50	0.50	3	28	1	8	1691	68	8	48	9
	2006	7	137	8	13	0.6	0.0	8	94	8	1.00	1.00	1.00	0.63	7	33	1	8	1406	81	8	9	3
Mean		73	143	6	150	0.7	0.0	72	67	4	0.90	0.82	0.56	0.29	51	26	1	74	1650	129	74	36	4
08_Becker	1997	3	52	16	3	1.2	0.1	3	5	1	0.00	0.00	0.00	0.00	3	14	4	2	925	165	2	12	6
	1998	3	30	0	3	1.3	0.2	3	7	3	0.00	0.00	0.00	0.00	3	14	1	3	623	103	3	12	1
	1999	4	35	5	4	1.6	0.6	4	10	4	0.00	0.00	0.00	0.00	3	17	2	4	580	191	4	10	1
	2000	4	46	15	4	0.8	0.0	4	11	3	0.00	0.00	0.00	0.00	4	21	2	4	1025	164	4	12	4
	2001	4	66	11	4	0.8	0.1	4	12	2	0.00	0.00	0.00	0.00	4	18	1	4	1073	73	4	13	3
	2002	4	37	8	4	1.1	0.1	4	35	13	0.50	0.50	0.00	0.00	4	19	1	4	825	143	4	14	7
	2006	4	87	52	4	0.9	0.1	4	8	1	0.00	0.00	0.00	0.00	3	21	1	4	759	37	4	12	2
Mean		26	51	9	26	1.1	0.1	26	13	3	0.08	0.08	0.00	0.00	24	18	1	25	831	58	25	12	1
10_Horse_S	1997	2	100	0	26	1.1	0.1	2	70	8	1.00	1.00	1.00	0.00	2	26	2	2	1790	0	2	32	8
	1998	3	187	32	16	0.8	0.0	3	52	22	0.67	0.67	0.67	0.33	3	21	4	3	1250	55	3	55	8
	1999	4	118	17	16	1.1	0.1	4	51	20	0.75	0.75	0.25	0.25	3	24	3	4	1628	814	4	33	10
	2000	4	126	20	18	1.1	0.1	4	63	12	1.00	0.75	0.50	0.25	4	32	2	4	1558	108	4	41	8
	2001	4	145	17	20	0.9	0.1	4	48	13	0.75	0.50	0.50	0.00	4	22	4	4	1468	268	4	57	19
	2002	4	186	16	16	1.2	0.1	4	41	12	0.75	0.75	0.00	0.00	4	21	1	4	1423	163	4	100	21
	2003	7	159	27	21	1.0	0.1	7	96	31	0.86	0.86	0.71	0.29	1	27		7	1648	242	7	54	20
	2004	9	120	32	9	0.9	0.2	9	71	11	0.89	0.78	0.67	0.44	0			9	1514	275	9	7	1
	2005	8	117	14	8	1.4	0.3	8	62	17	0.63	0.50	0.50	0.50	3	28	1	8	1459	129	8	49	11
	2006	8	90	9	8	1.0	0.2	8	61	10	0.88	0.75	0.50	0.25	7	37	2	8	1205	125	8	13	6
Mean		53	130	8	158	1.0	0.0	53	64	6	0.81	0.72	0.53	0.28	31	28	1	53	1474	86	53	39	5

App C - 2 Lake Water Quality Summary by Segment and Year June-September

		Total P ppb			Secchi meters			Chl-a ppb			Algal Bloom Frequencies				Chloride ppm			Organic N ppb			SRP ppb		
Segment	Year	N	Mean	SE	N	Mean	SE	N	Mean	SE	>30	>40	>60	>80	N	Mean	SE	N	Mean	SE	N	Mean	SE
11_Cedar	1997	2	55	5	10	1.4	0.3	2	41	5	1.00	0.50	0.00	0.00	2	26	4	2	1290	0	2	24	4
	1998	3	63	17	14	1.1	0.2	3	68	26	0.67	0.67	0.67	0.33	3	20	3	3	1223	119	3	28	9
	1999	4	67	11	10	1.1	0.2	4	44	17	0.75	0.50	0.50	0.00	3	24	1	4	1145	471	4	19	6
	2000	4	60	11	13	1.5	0.2	4	40	10	0.75	0.25	0.25	0.00	4	33	1	4	1333	138	4	19	3
	2001	4	102	15	11	1.1	0.1	4	80	25	0.75	0.75	0.75	0.25	4	28	2	4	1730	132	4	19	6
	2002	4	95	25	13	1.1	0.1	4	38	7	0.75	0.50	0.00	0.00	4	23	1	4	1193	210	4	24	14
	2003	8	123	30	15	1.2	0.2	8	58	10	0.75	0.75	0.63	0.13	1	25		7	1470	172	7	19	5
	2004	9	78	23	29	1.5	0.1	10	39	6	0.70	0.40	0.30	0.00	0			9	1161	190	9	4	1
	2005	8	74	10	16	1.3	0.3	8	53	11	0.88	0.63	0.38	0.13	3	29	0	0			0		
	2006	12	56	5	20	1.0	0.1	11	49	5	0.82	0.64	0.27	0.00	10	32	1	12	1073	37	12	6	0
Mean		58	78	7	151	1.3	0.1	58	50	4	0.78	0.57	0.38	0.07	34	28	1	49	1254	64	49	14	2
12_Schneider	1997	2	60	10	2	1.4	0.2	2	30	8	0.50	0.00	0.00	0.00	2	17	3	2	1025	35	2	17	9
	1998	3	47	22	3	1.6	0.5	3	23	6	0.33	0.00	0.00	0.00	3	9	3	3	813	133	3	15	4
	1999	4	32	11	4	1.3	0.2	4	19	6	0.25	0.00	0.00	0.00	3	12	2	4	833	300	4	10	2
	2000	4	53	7	4	1.3	0.1	4	33	5	0.75	0.25	0.00	0.00	4	25	1	4	1155	65	4	15	4
	2001	4	81	8	4	1.1	0.2	3	47	12	0.67	0.67	0.33	0.00	3	20	3	4	1088	369	4	13	4
	2002	4	62	11	4	1.9	0.3	4	43	13	0.75	0.75	0.25	0.00	4	15	2	4	1148	222	4	13	4
	2003	7	77	9	7	1.8	0.5	7	39	11	0.43	0.43	0.14	0.14	1	20		7	1142	99	7	20	3
	2004	9	104	43	8	2.6	0.6	9	18	4	0.11	0.00	0.00	0.00	0			9	1118	169	9	15	9
	2005	8	52	3	17	1.7	0.2	8	38	8	0.50	0.38	0.25	0.00	8	20	1	8	1255	116	8	25	4
	2006	8	48	6	16	1.3	0.2	8	38	7	0.63	0.38	0.13	0.00	7	26	2	8	918	64	8	7	0
Mean		53	65	8	69	1.6	0.1	52	33	3	0.46	0.29	0.12	0.02	35	19	1	53	1072	54	53	15	2
13_Bolfing	1997	2	65	5	11	1.1	0.4	2	65	3	1.00	1.00	1.00	0.00	2	28	5	2	1840	50	2	35	1
	1998	4	59	5	12	0.7	0.1	4	62	17	1.00	0.50	0.50	0.50	4	17	2	3	1520	83	3	203	194
	1999	4	72	10	11	1.5	0.3	4	46	15	0.75	0.75	0.25	0.00	3	15	7	4	1015	350	4	18	5
	2000	4	63	12	12	1.0	0.2	4	53	14	0.75	0.75	0.25	0.25	4	32	0	4	1515	153	4	21	3
	2001	4	121	9	12	1.0	0.3	4	64	15	0.75	0.75	0.50	0.25	4	23	1	4	1810	191	4	26	6
	2002	4	110	19	12	1.1	0.2	4	44	11	0.75	0.75	0.25	0.00	4	22	1	4	1468	150	4	24	13
	2003	0			9	1.4	0.2	0			0.00	0.00	0.00	0.00	0			0			0		
	2004	0			10	1.3	0.2	0			0.00	0.00	0.00	0.00	0			0			0		
	2005	0			9	1.5	0.4	0			0.00	0.00	0.00	0.00	0			0			0		
	2006	4	71	7	9	0.7	0.1	4	70	13	1.00	1.00	0.50	0.25	3	31	1	3	1414	26	4	6	1
Mean		26	81	6	107	1.1	0.1	26	57	5	0.85	0.77	0.42	0.19	24	24	2	24	1488	86	25	42	23
14_Long	1997	2	140	40	2	0.6	0.0	2	112	19	1.00	1.00	1.00	1.00	2	25	5	2	2285	595	2	61	12
	1998	3	103	7	3	0.6	0.0	2	110	0	1.00	1.00	1.00	1.00	3	23	0	3	1463	130	3	39	15
	1999	4	75	10	4	1.3	0.4	4	49	18	0.75	0.75	0.50	0.25	3	24	1	4	2563	1736	4	13	3
	2000	4	75	7	4	1.0	0.2	4	46	4	1.00	0.75	0.00	0.00	4	28	1	4	1768	31	4	23	5
	2001	4	135	35	4	0.7	0.2	4	72	17	0.75	0.75	0.75	0.50	4	25	1	4	2135	388	4	25	5
	2002	4	87	7	7	1.0	0.1	4	27	6	0.75	0.00	0.00	0.00	4	24	0	4	1308	136	4	17	4
	2004	0			3	1.5	0.1	0			0.00	0.00	0.00	0.00	0			0			0		
	2005	0			5	0.7	0.1	0			0.00	0.00	0.00	0.00	0			0			0		
	2006	4	79	3	4	0.6	0.1	4	77	9	1.00	1.00	0.75	0.50	3	33	0	4	1349	57	4	8	1
Mean		25	96	8	36	0.9	0.1	24	64	7	0.88	0.71	0.50	0.38	23	26	1	25	1818	272	25	23	4
15_Browns		0			18	2.4	0.4	0			0.00	0.00	0.00	0.00	0			0			0		
	1998	0			13	1.3	0.1	0			0.00	0.00	0.00	0.00	0			0			0		
	1999	4	91	21	17	2.4	0.2	4	13	4	0.00	0.00	0.00	0.00	0			0			0		
	2000	0			13	2.5	0.3	0			0.00	0.00	0.00	0.00	0			0			0		
	2001	0			9	1.4	0.2	0			0.00	0.00	0.00	0.00	0			0			0		
	2002	4	119	21	18	1.7	0.2	4	32	7	0.75	0.00	0.00	0.00	4	26	1	4	1208	221	4	45	24
	2003	0			13	2.0	0.3	0			0.00	0.00	0.00	0.00	0			0			0		
	2004	0			16	1.7	0.2	0			0.00	0.00	0.00	0.00	0			0			0		
	2005	6	59	3	21	1.8	0.3	6	10	3	0.00	0.00	0.00	0.00	0			0			0		
	2006	4	110	34	21	1.0	0.1	4	77	17	0.75	0.75	0.75	0.50	4	35	0	4	1134	77	4	26	15
Mean		18	91	11	159	1.8	0.1	18	30	7	0.33	0.17	0.17	0.11	8	30	2	8	1171	109	8	35	14

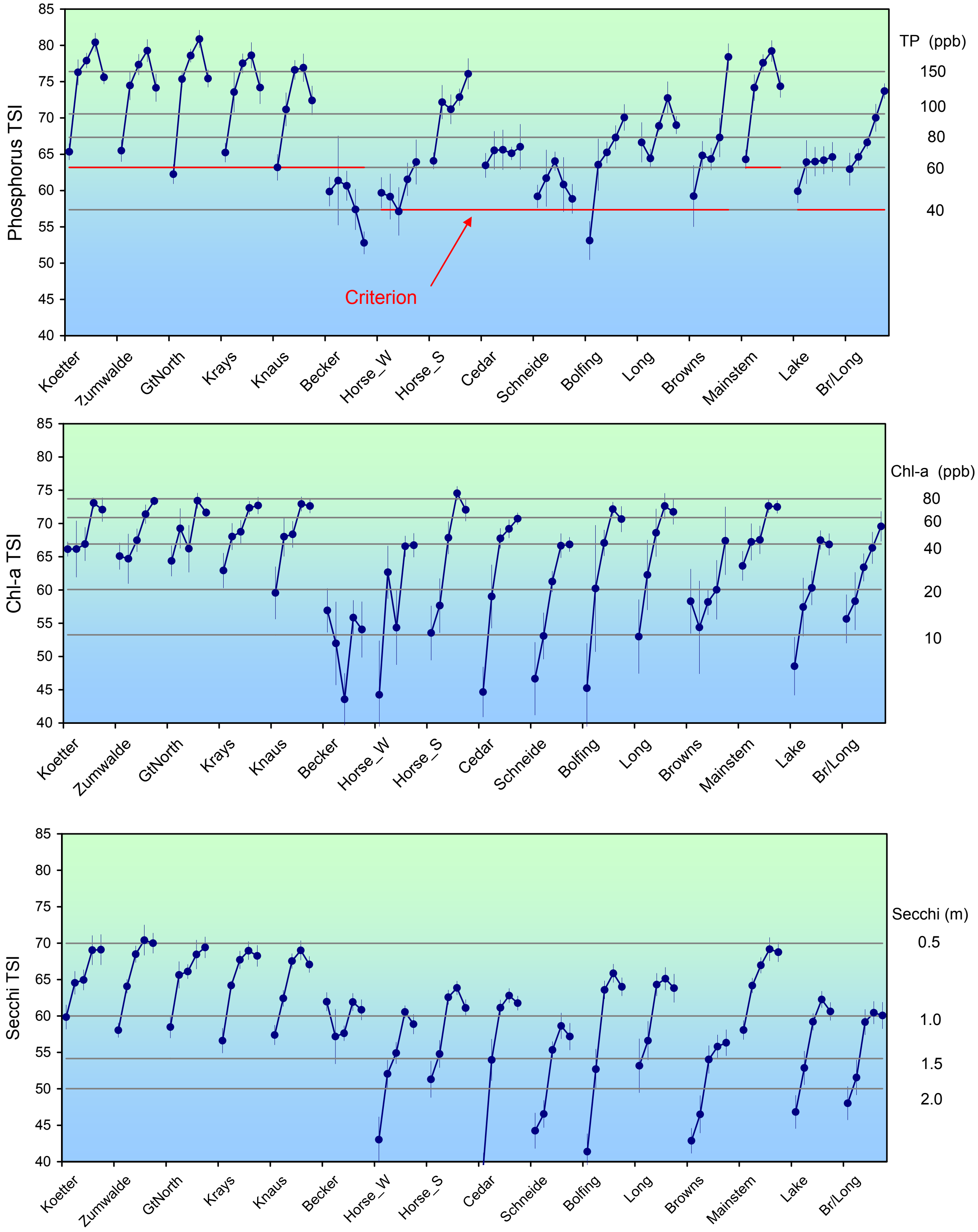
App C - 3 Lake Water Quality Summary by Year & Segment June-September

			Total P ppb			Secchi meters			Chl-a ppb			Algal Bloom Frequencies				Chloride ppm			Organic N ppb			SRP ppb		
Year	Category	Segment	N	Mean	SE	N	Mean	SE	N	Mean	SE	>30	>40	>60	>80	N	Mean	SE	N	Mean	SE	N	Mean	SE
B	CATEGOR`	Segment	Count of TP	Average of TP	StdDev of TP2	Count of Secchi	Average of Secchi2	StdDev of Secchi2	Count of Chla	Average of Chla2	StdDev of Chla3	Average of BF_30_	Average of BF_40	Average of BF_60	Average of BF_80	Count of CL3	Average of CL	StdDev of CL2	Count of OrgN	Average of OrgN2	StdDev of OrgN3	Count of TP-SRP	Count of OP	Average of OP2
C	MAIN	03_Koetter	2	140	10	2	0.7	0.1	2	66	0	1.00	1.00	1.00	0.00	2	22	3	2	1665	75	2	32	3
		04_Zumwalde	2	140	0	2	0.7	0.1	2	47	8	1.00	0.50	0.00	0.00	2	20	11	2	1680	210	2	29	2
		05_GtNorth	2	145	5	2	0.7	0.1	2	48	10	1.00	0.50	0.00	0.00	2	28	4	2	1360	530	2	31	7
		06_Krays	2	140	0	2	0.6	0.0	2	61	11	1.00	1.00	0.50	0.00	2	24	3	2	1690	0	2	40	12
		07_Knaus	4	135	6	13	0.7	0.1	4	67	4	1.00	1.00	0.75	0.00	4	29	4	4	1788	92	4	37	2
	MAIN Total		12	139	3	21	0.7	0.0	12	59	4	1.00	0.83	0.50	0.00	12	25	2	12	1662	88	12	34	2
C	LAKE	08_Becker	3	52	16	3	1.2	0.1	3	5	1	0.00	0.00	0.00	0.00	3	14	4	2	925	165	2	12	6
		10_Horse_S	2	100	0	26	1.1	0.1	2	70	8	1.00	1.00	1.00	0.00	2	26	2	2	1790	0	2	32	8
		11_Cedar	2	55	5	10	1.4	0.3	2	41	5	1.00	0.50	0.00	0.00	2	26	4	2	1290	0	2	24	4
		12_Schneider	2	60	10	2	1.4	0.2	2	30	8	0.50	0.00	0.00	0.00	2	17	3	2	1025	35	2	17	9
		13_Bolfing	2	65	5	11	1.1	0.4	2	65	3	1.00	1.00	1.00	0.00	2	28	5	2	1840	50	2	35	1
		14_Long	2	140	40	2	0.6	0.0	2	112	19	1.00	1.00	1.00	1.00	2	25	5	2	2285	595	2	61	12
		15_Browns	0			18	2.4	0.4	0			0.00	0.00	0.00	0.00	0			0			0		
	LAKE Total		13	77	11	72	1.5	0.1	13	50	10	0.69	0.54	0.46	0.15	13	22	2	12	1526	165	12	30	5
1998	MAIN	03_Koetter	3	177	22	3	0.7	0.1	3	60	25	0.67	0.67	0.67	0.33	3	23	3	3	1333	119	3	60	19
		04_Zumwalde	3	170	15	3	0.6	0.1	3	69	19	1.00	0.67	0.67	0.33	3	20	5	3	1407	127	3	59	29
		05_GtNorth	3	160	31	3	0.6	0.0	3	58	25	0.67	0.67	0.67	0.33	3	22	2	3	1177	125	3	56	35
		06_Krays	3	133	28	3	0.7	0.1	3	53	10	1.00	0.67	0.33	0.00	3	19	6	3	1133	121	3	47	33
		07_Knaus	6	128	20	14	0.7	0.0	6	60	14	0.67	0.67	0.67	0.17	6	18	3	6	1228	106	6	40	15
	MAIN Total		18	149	11	26	0.7	0.0	18	60	7	0.78	0.67	0.61	0.22	18	20	2	18	1251	53	18	50	10
1998	LAKE	08_Becker	3	30	0	3	1.3	0.2	3	7	3	0.00	0.00	0.00	0.00	3	14	1	3	623	103	3	12	1
		10_Horse_S	3	187	32	16	0.8	0.0	3	52	22	0.67	0.67	0.67	0.33	3	21	4	3	1250	55	3	55	8
		11_Cedar	3	63	17	14	1.1	0.2	3	68	26	0.67	0.67	0.67	0.33	3	20	3	3	1223	119	3	28	9
		12_Schneider	3	47	22	3	1.6	0.5	3	23	6	0.33	0.00	0.00	0.00	3	9	3	3	813	133	3	15	4
		13_Bolfing	4	59	5	12	0.7	0.1	4	62	17	1.00	0.50	0.50	0.50	4	17	2	3	1520	83	3	203	194
		14_Long	3	103	7	3	0.6	0.0	2	110	0	1.00	1.00	1.00	1.00	3	23	0	3	1463	130	3	39	15
		15_Browns	0			13	1.3	0.1	0			0.00	0.00	0.00	0.00	0			0			0		
	LAKE Total		19	80	13	64	1.0	0.1	18	51	9	0.61	0.44	0.44	0.33	19	17	1	18	1149	87	18	59	32
1999	MAIN	03_Koetter	4	147	14	4	0.6	0.1	4	64	20	0.75	0.75	0.50	0.50	3	24	4	4	1445	661	4	43	16
		04_Zumwalde	3	158	12	3	0.6	0.1	3	78	11	1.00	1.00	0.67	0.33	2	26	4	3	1023	507	3	33	11
		05_GtNorth	4	147	17	4	0.6	0.1	4	63	14	0.75	0.75	0.50	0.25	3	23	3	4	1030	368	4	35	6
		06_Krays	4	144	13	4	0.6	0.0	4	56	14	0.75	0.75	0.50	0.25	3	23	3	4	1233	514	4	31	5
		07_Knaus	8	126	13	15	0.7	0.1	8	58	12	0.75	0.75	0.50	0.38	6	24	2	8	1215	306	8	24	4
	MAIN Total		23	141	7	30	0.7	0.0	23	62	6	0.78	0.78	0.52	0.35	17	24	1	23	1201	185	23	32	4
1999	LAKE	08_Becker	4	35	5	4	1.6	0.6	4	10	4	0.00	0.00	0.00	0.00	3	17	2	4	580	191	4	10	1
		10_Horse_S	4	118	17	16	1.1	0.1	4	51	20	0.75	0.75	0.25	0.25	3	24	3	4	1628	814	4	33	10
		11_Cedar	4	67	11	10	1.1	0.2	4	44	17	0.75	0.50	0.50	0.00	3	24	1	4	1145	471	4	19	6
		12_Schneider	4	32	11	4	1.3	0.2	4	19	6	0.25	0.00	0.00	0.00	3	12	2	4	833	300	4	10	2
		13_Bolfing	4	72	10	11	1.5	0.3	4	46	15	0.75	0.75	0.25	0.00	3	15	7	4	1015	350	4	18	5
		14_Long	4	75	10	4	1.3	0.4	4	49	18	0.75	0.75	0.50	0.25	3	24	1	4	2563	1736	4	13	3
		15_Browns	4	91	21	17	2.4	0.2	4	13	4	0.00	0.00	0.00	0.00	0			0			0		
	LAKE Total		28	70	7	66	1.6	0.1	28	33	6	0.46	0.39	0.21	0.07	18	19	2	24	1294	330	24	17	3
2000	MAIN	03_Koetter	4	162	19	4	0.5	0.1	4	76	3	1.00	1.00	1.00	0.25	4	32	2	4	1980	211	4	38	3
		04_Zumwalde	4	175	23	4	0.5	0.1	4	86	16	1.00	0.75	0.75	0.75	4	31	2	4	2038	174	4	45	5
		05_GtNorth	4	162	21	4	0.5	0.0	4	96	7	1.00	1.00	1.00	0.75	4	31	2	4	1978	117	4	41	3
		06_Krays	4	180	29	4	0.5	0.0	4	90	3	1.00	1.00	1.00	1.00	4	31	2	4	2320	95	4	49	9
		07_Knaus	8	146	14	16	0.6	0.0	8	75	11	1.00	0.88	0.63	0.50	8	31	1	8	2006	211	8	40	5
	MAIN Total		24	162	9	32	0.5	0.0	24	83	5	1.00	0.92	0.83	0.63	24	31	1	24	2055	85	24	42	2
2000	LAKE	08_Becker	4	46	15	4	0.8	0.0	4	11	3	0.00	0.00	0.00	0.00	4	21	2	4	1025	164	4	12	4
		10_Horse_S	4	126	20	18	1.1	0.1	4	63	12	1.00	0.75	0.50	0.25	4	32	2	4	1558	108	4	41	8
		11_Cedar	4	60	11	13	1.5	0.2	4	40	10	0.75	0.25	0.25	0.00	4	33	1	4	1333	138	4	19	3
		12_Schneider	4	53	7	4	1.3	0.1	4	33	5	0.75	0.25	0.00	0.00	4	25	1	4	1155	65	4	15	4
		13_Bolfing	4	63	12	12	1.0	0.2	4	53	14	0.75	0.75	0.25	0.25	4	32	0	4	1515	153	4	21	3
		14_Long	4	75	7	4	1.0	0.2	4	46	4	1.00	0.75	0.00	0.00	4	28	1	4	1768	31	4	23	5
		15_Browns	0			13	2.5	0.3	0			0.00	0.00	0.00	0.00	0			0			0		
	LAKE Total		24	71	7	68	1.4	0.1	24	41	5	0.71	0.46	0.17	0.08	24	28	1	24	1392	68	24	22	3
2001	MAIN	03_Koetter	4	198	32	4	0.7	0.2	4	40	11	0.50	0.50	0.25	0.00	4	24	4	4	1310	262	4	62	16
		04_Zumwalde	4	197	29	4	0.6	0.1	4	54	12	0.75	0.75	0.50	0.00	4	24	4	4	1823	201	4	60	18
		05_GtNorth	4	211	35	4	0.6	0.2	4	49	9	0.75	0.75	0.25	0.00	4	24	3	4	1578	278	4	62	24
		06_Krays	4	211	44	4	0.7	0.1	4	58	11	1.00	0.50	0.50	0.00	4	25	2	4	1680	199	4	64	15
		07_Knaus	8	197	26	16	0.6	0.1	8	61	9	0.88	0.88	0.38	0.25	8	24	1	8	1929	221	8	60	12
	MAIN Total		24	202	13	32	0.6	0.0	24	54	4	0.79	0.71	0.38	0.08	24	24	1	24	1708	109	24	61	7

App C - 3 Lake Water Quality Summary by Year & Segment June-September

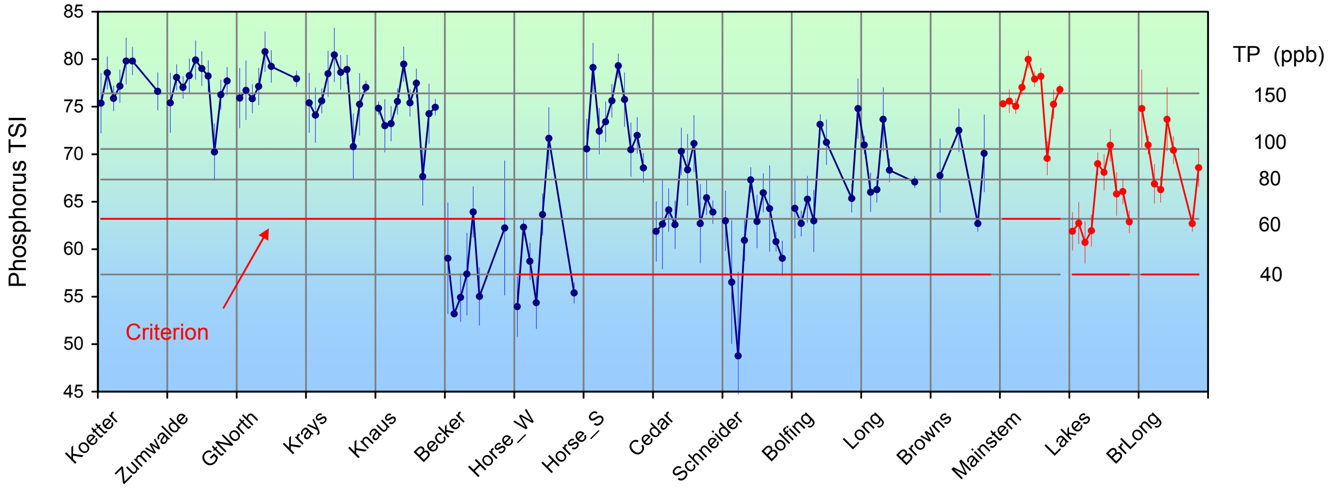
			Total P ppb			Secchi meters			Chl-a ppb			Algal Bloom Frequencies				Chloride ppm			Organic N ppb			SRP ppb		
Year	Category	Segment	N	Mean	SE	N	Mean	SE	N	Mean	SE	>30	>40	>60	>80	N	Mean	SE	N	Mean	SE	N	Mean	SE
2001	LAKE	08_Becker	4	66	11	4	0.8	0.1	4	12	2	0.00	0.00	0.00	0.00	4	18	1	4	1073	73	4	13	3
		10_Horse_S	4	145	17	20	0.9	0.1	4	48	13	0.75	0.50	0.50	0.00	4	22	4	4	1468	268	4	57	19
		11_Cedar	4	102	15	11	1.1	0.1	4	80	25	0.75	0.75	0.75	0.25	4	28	2	4	1730	132	4	19	6
		12_Schneider	4	81	8	4	1.1	0.2	3	47	12	0.67	0.67	0.33	0.00	3	20	3	4	1088	369	4	13	4
		13_Bolfing	4	121	9	12	1.0	0.3	4	64	15	0.75	0.75	0.50	0.25	4	23	1	4	1810	191	4	26	6
		14_Long	4	135	35	4	0.7	0.2	4	72	17	0.75	0.75	0.75	0.50	4	25	1	4	2135	388	4	25	5
		15_Browns	0			9	1.4	0.2	0			0.00	0.00	0.00	0.00	0			0			0		
	LAKE Total		24	108	9	64	1.0	0.1	23	54	8	0.61	0.57	0.48	0.17	23	22	1	24	1550	125	24	25	5
2002	MAIN	03_Koetter	4	193	19	4	0.8	0.1	4	50	11	0.75	0.75	0.50	0.00	4	17	1	4	1343	198	4	94	31
		04_Zumwalde	4	184	22	4	0.8	0.0	4	45	12	0.75	0.50	0.50	0.00	4	21	1	4	1200	156	4	92	28
		05_GtNorth	4	186	21	4	0.8	0.1	4	48	12	0.75	0.75	0.25	0.00	4	20	1	4	1313	215	4	86	28
		06_Krays	4	179	22	4	0.8	0.0	4	43	10	0.75	0.75	0.00	0.00	4	18	2	4	1380	142	4	84	30
		07_Knaus	8	145	15	16	0.7	0.0	8	50	7	0.75	0.75	0.38	0.00	8	20	1	8	1543	151	8	46	12
	MAIN Total		24	172	9	32	0.8	0.0	24	48	4	0.75	0.71	0.33	0.00	24	19	1	24	1387	76	24	75	10
2002	LAKE	08_Becker	4	37	8	4	1.1	0.1	4	35	13	0.50	0.50	0.00	0.00	4	19	1	4	825	143	4	14	7
		10_Horse_S	4	186	16	16	1.2	0.1	4	41	12	0.75	0.75	0.00	0.00	4	21	1	4	1423	163	4	100	21
		11_Cedar	4	95	25	13	1.1	0.1	4	38	7	0.75	0.50	0.00	0.00	4	23	1	4	1193	210	4	24	14
		12_Schneider	4	62	11	4	1.9	0.3	4	43	13	0.75	0.75	0.25	0.00	4	15	2	4	1148	222	4	13	4
		13_Bolfing	4	110	19	12	1.1	0.2	4	44	11	0.75	0.75	0.25	0.00	4	22	1	4	1468	150	4	24	13
		14_Long	4	87	7	7	1.0	0.1	4	27	6	0.75	0.00	0.00	0.00	4	24	0	4	1308	136	4	17	4
		15_Browns	4	119	21	18	1.7	0.2	4	32	7	0.75	0.00	0.00	0.00	4	26	1	4	1208	221	4	45	24
	LAKE Total		28	99	10	74	1.3	0.1	28	37	4	0.71	0.46	0.07	0.00	28	21	1	28	1225	71	28	34	7
2003	MAIN	04_Zumwalde	7	176	17	7	0.6	0.1	7	60	15	0.71	0.43	0.43	0.43	1	27		7	1520	99	7	78	15
		06_Krays	7	184	16	7	0.6	0.1	7	66	20	0.86	0.43	0.43	0.29	1	26		7	1477	91	7	82	18
		07_Knaus	7	166	14	15	0.7	0.1	7	58	14	1.00	0.57	0.29	0.14	1	25		7	1448	72	7	61	15
	MAIN Total		21	175	9	29	0.7	0.0	21	61	9	0.86	0.48	0.38	0.29	3	26	0	21	1481	49	21	74	9
2003	LAKE	10_Horse_S	7	159	27	21	1.0	0.1	7	96	31	0.86	0.86	0.71	0.29	1	27		7	1648	242	7	54	20
		11_Cedar	8	123	30	15	1.2	0.2	8	58	10	0.75	0.75	0.63	0.13	1	25		7	1470	172	7	19	5
		12_Schneider	7	77	9	7	1.8	0.5	7	39	11	0.43	0.43	0.14	0.14	1	20		7	1142	99	7	20	3
		13_Bolfing	0			9	1.4	0.2	0			0.00	0.00	0.00	0.00	0			0			0		
		15_Browns	0			13	2.0	0.3	0			0.00	0.00	0.00	0.00	0			0			0		
	LAKE Total		22	120	15	65	1.4	0.1	22	64	12	0.68	0.68	0.50	0.18	3	24	2	21	1420	109	21	31	7
2004	MAIN	04_Zumwalde	9	121	36	8	0.6	0.1	9	48	9	0.89	0.56	0.33	0.11	0			9	1370	153	9	11	2
		06_Krays	9	131	38	7	0.7	0.1	9	66	7	0.89	0.89	0.56	0.22	0			9	2128	649	9	8	2
		07_Knaus	9	100	26	18	0.8	0.1	9	66	6	1.00	0.89	0.56	0.22	0			9	2127	983	9	5	1
	MAIN Total		27	118	19	33	0.7	0.0	27	60	5	0.93	0.78	0.48	0.19	0			27	1875	387	27	8	1
2004	LAKE	10_Horse_S	9	120	32	9	0.9	0.2	9	71	11	0.89	0.78	0.67	0.44	0			9	1514	275	9	7	1
		11_Cedar	9	78	23	29	1.5	0.1	10	39	6	0.70	0.40	0.30	0.00	0			9	1161	190	9	4	1
		12_Schneider	9	104	43	8	2.6	0.6	9	18	4	0.11	0.00	0.00	0.00	0			9	1118	169	9	15	9
		13_Bolfing	0			10	1.3	0.2	0			0.00	0.00	0.00	0.00	0			0			0		
		14_Long	0			3	1.5	0.1	0			0.00	0.00	0.00	0.00	0			0			0		
		15_Browns	0			16	1.7	0.2	0			0.00	0.00	0.00	0.00	0			0			0		
	LAKE Total		27	101	19	75	1.6	0.1	28	42	6	0.57	0.39	0.32	0.14	0			27	1264	125	27	9	3
2005	MAIN	04_Zumwalde	8	154	15	8	0.6	0.1	8	57	10	0.75	0.50	0.38	0.25	3	28	1	8	1429	56	8	74	14
		06_Krays	8	159	25	8	0.6	0.1	8	66	12	0.75	0.75	0.75	0.25	3	28	1	8	1579	111	8	71	14
		07_Knaus	8	147	22	14	0.6	0.0	6	78	17	1.00	0.83	0.50	0.50	3	28	1	8	1691	68	8	48	9
	MAIN Total		24	153	12	30	0.6	0.0	22	66	7	0.82	0.68	0.55	0.32	9	28	1	24	1566	50	24	64	7
2005	LAKE	10_Horse_S	8	117	14	8	1.4	0.3	8	62	17	0.63	0.50	0.50	0.50	3	28	1	8	1459	129	8	49	11
		11_Cedar	8	74	10	16	1.3	0.3	8	53	11	0.88	0.63	0.38	0.13	3	29	0	0			0		
		12_Schneider	8	52	3	17	1.7	0.2	8	38	8	0.50	0.38	0.25	0.00	8	20	1	8	1255	116	8	25	4
		13_Bolfing	0			9	1.5	0.4	0			0.00	0.00	0.00	0.00	0			0			0		
		14_Long	0			5	0.7	0.1	0			0.00	0.00	0.00	0.00	0			0			0		
		15_Browns	6	59	3	21	1.8	0.3	6	10	3	0.00	0.00	0.00	0.00	0			0			0		
	LAKE Total		30	76	7	76	1.5	0.1	30	43	7	0.53	0.40	0.30	0.17	14	23	1	16	1357	88	16	37	6
2006	MAIN	03_Koetter	4	157	21	4	0.5	0.0	4	81	11	1.00	1.00	0.75	0.75	3	36	3	4	1201	29	4	22	14
		04_Zumwalde	8	170	17	8	0.4	0.0	8	75	6	1.00	1.00	0.88	0.13	7	36	2	8	1194	47	8	22	7
		05_GtNorth	4	168	10	4	0.5	0.0	4	81	12	1.00	1.00	0.75	0.50	3	35	3	4	1259	50	4	18	10
		06_Krays	8	158	8	8	0.6	0.0	8	74	8	1.00	1.00	0.75	0.25	7	34	1	8	1252	78	8	17	6
		07_Knaus	7	137	8	13	0.6	0.0	8	94	8	1.00	1.00	1.00	0.63	7	33	1	8	1406	81	8	9	3
	MAIN Total		31	157	6	37	0.5	0.0	32	81	4	1.00	1.00	0.84	0.41	27	35	1	32	1270	33	32	17	3
2006	LAKE	08_Becker	4	87	52	4	0.9	0.1	4	8	1	0.00	0.00	0.00	0.00	3	21	1	4	759	37	4	12	2
		10_Horse_S	8	90	9	8	1.0	0.2	8	61	10	0.88	0.75	0.50	0.25	7	37	2	8	1205	125	8	13	6
		11_Cedar	12	56	5	20	1.0	0.1	11	49	5	0.82	0.64	0.27	0.00	10	32	1	12	1073	37	12	6	0
		12_Schneider	8	48	6	16	1.3	0.2	8	38	7	0.63	0.38	0.13	0.00	7	26	2	8	918	64	8	7	0
		13_Bolfing	4	71	7	9	0.7	0.1	4	70	13	1.00	1.00	0.50	0.25	3	31	1	3	1414	26	4	6	1
		14_Long	4	79	3	4	0.6	0.1	4	77	9	1.00	1.00	0.75	0.50	3	33	0	4	1349	57	4	8	1
		15_Browns	4	110	34	21	1.0	0.1	4	77	17	0.75	0.75	0.75	0.50	4	35	0	4	1134	77	4	26	15
	LAKE Total		44	72	6	82	1.0	0.1	43	52	4	0.74	0.63	0.37	0.16	37	31	1	43	1094	39	44	10	2

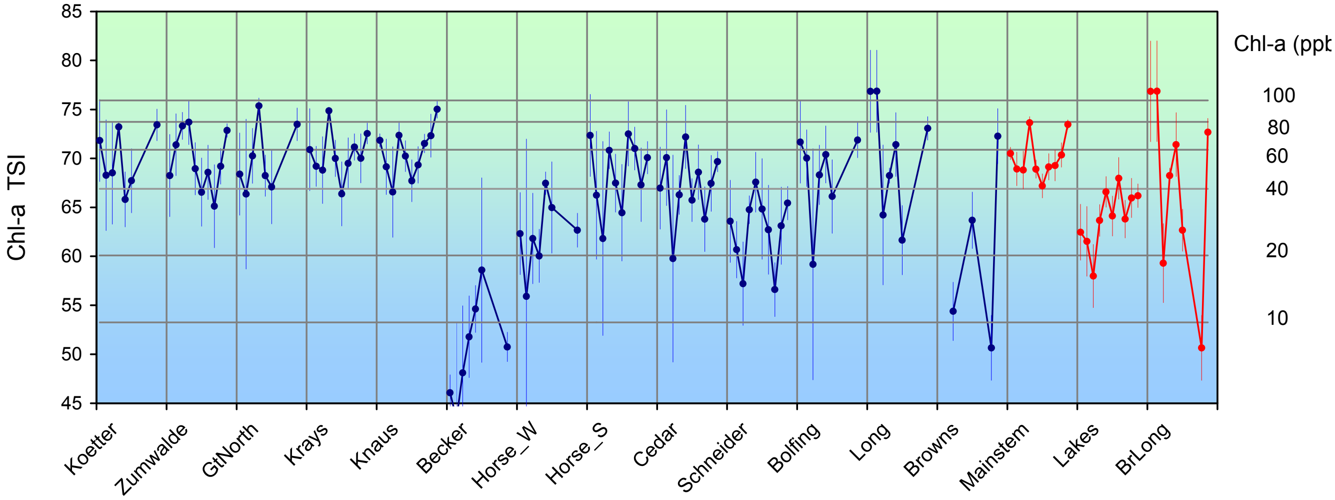
Seasonal Variations in Trophic State Indices, 1997-2006

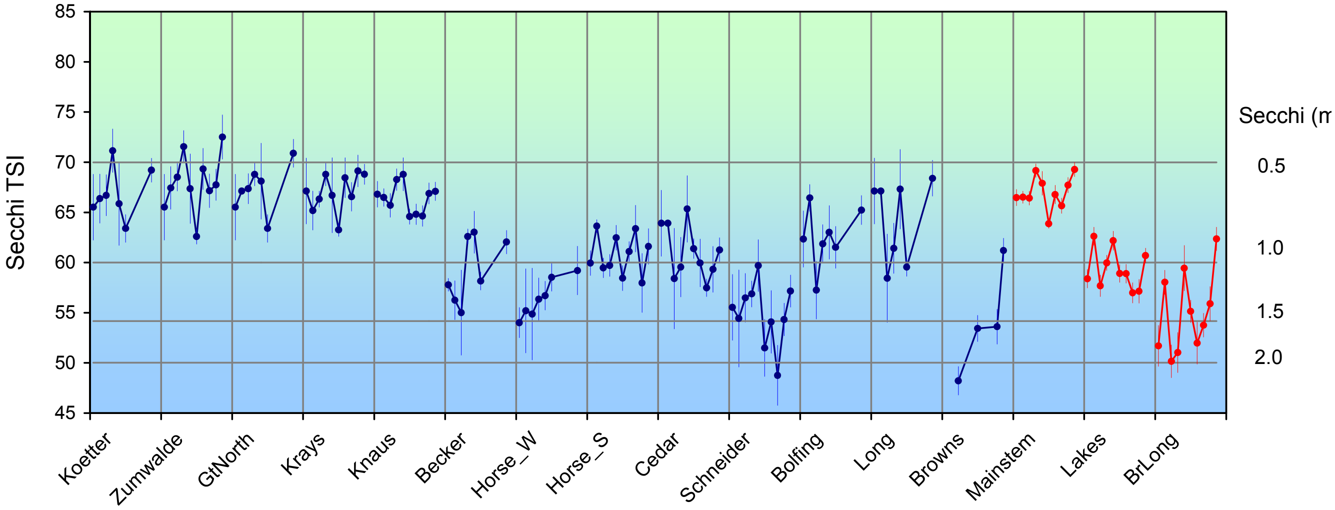


Monthly Means +/1 Standard Error by Lake, May-September, 1997-2006

Yearly Variations in Trophic State Indices, 1997-2006







June-September means by lake, 1997-2006; bars = +/- 1 standard error.

App C - 6 Means and Correlations Across Lakes - Phosphorus TSI

Variable: Phosphorus TSI

B
C
Means by Lake and Year >70 >60 <60

Year	Koetter	Zumwalde	GtNorth	Krays	Knaus	Mainstem	Becker	Horse_W	Horse_S	Cedar	Schneider	Bolfing	Long	Browns	Lake Mn	All
1997	75	75	76	75	75	75	59	54	71	62	63	64	75		64	69
1998	79	78	77	74	73	76	53	62	79	63	57	63	71		64	69
1999	76	77	76	76	73	75	55	59	72	64	49	65	66	68	62	68
2000	77	78	77	78	76	77	57	54	73	63	61	63	66		63	69
2001	80	80	81	80	79	80	64	64	76	70	67	73	74		70	74
2002	80	79	79	79	75	78	55	72	79	68	63	71	68	73	69	73
2003		78		79	77	78			76	71	66				71	74
2004		70		71	68	70			70	63	64				66	68
2005		76		75	74	75			72	65	61			63	65	70
2006	77	78	78	77	75	77	62	55	69	64	59	65	67	70	64	69
Mean	78	76	78	76	74	76	58	60	73	66	61	67	69	68	66	70

Correlation Matrix *

Segment	Koetter	Zumwalde	GtNorth	Krays	Knaus	Mainstem	Becker	Horse_W	Horse_S	Cedar	Schneider	Bolfing	Long	Browns	Lake Mn	All
Koetter	·															
Zumwalde	90	·														
GtNorth	83	86	·													
Krays	57	87	85	·												
Knaus	52	87	85	95	·											
Mainstem	77	95	97	96	97	·										
Becker	2	19	54	59	77	60	·									
Horse_W	84	65	60	33	20	48	-28	·								
Horse_S	81	55	36	36	33	46	-53	83	·							
Cedar	78	52	91	69	67	66	38	74	47	·						
Schneider	50	-3	70	30	32	22	59	21	10	49	·					
Bolfing	70	66	88	76	76	83	43	70	34	98	55	·				
Long	15	-11	20	-1	41	20	34	5	12	17	60	26	·			
Browns	94	95	99	90	56	84	0	76	44	40	15	88	100	·		
Lake Mn	84	26	92	47	46	43	37	77	46	92	73	94	41	38	·	
All	86	62	96	78	78	76	45	67	55	94	64	91	39	47	91	·

* Product-Moment Correlation Coefficients x 100.

Value	>80	>50	<50
Approx. Statistical Significance	<.05	<.10	>0.10

App C - 7 Means and Correlations Across Lakes - Chlorophyll-a TSI

Variable: Chlorophyll-a TSI

Means by Lake and Year   >70   >60   <60

Year	Koetter	Zumwalde	GtNorth	Krays	Knaus	Mainstem	Becker	Horse_W	Horse_S	Cedar	Schneider	Bolfing	Long	Browns	Lake Mn	All
1997	72	68	68	71	72	71	46	62	72	67	64	72	77		64	67
1998	68	71	66	69	69	69	43	56	66	70	61	70	77		63	66
1999	69	73	70	69	67	69	48	62	62	60	57	59	64	54	58	63
2000	73	74	75	75	72	74	52	60	71	66	65	68	68		64	69
2001	66	69	68	70	70	69	55	67	67	72	68	70	71		67	68
2002	68	67	67	66	68	67	59	65	64	66	65	66	62	64	64	65
2003		69		69	69	69			73	69	63				68	69
2004		65		71	72	69			71	64	57				64	66
2005		69		70	72	70			67	67	63			51	63	66
2006	73	73	73	73	75	73	51	63	70	70	65	72	73	72	67	70
Mean	70	69	70	71	71	70	51	62	69	67	62	68	69	59	64	67

Correlation Matrix *

Segment	Koetter	Zumwalde	GtNorth	Krays	Knaus	Mainstem	Becker	Horse_W	Horse_S	Cedar	Schneider	Bolfing	Long	Browns	Lake Mn	All
Koetter	·															
Zumwalde	49	·														
GtNorth	76	72	·													
Krays	77	45	85	·												
Knaus	76	12	61	76	·											
Mainstem	89	60	89	92	82	·										
Becker	-25	-42	9	-21	-8	-17	·									
Horse_W	-34	-52	-6	-23	-1	-23	77	·								
Horse_S	69	-23	41	61	67	50	-16	-5	·							
Cedar	-9	-3	-16	13	41	17	5	11	37	·						
Schneider	8	10	16	16	36	29	60	58	22	73	·					
Bolfing	31	-24	1	41	77	41	-10	0	82	88	71	·				
Long	26	6	-12	37	54	32	-70	-39	63	62	13	76	·			
Browns	78	11	48	34	44	46	26	28	54	53	63	100	72	·		
Lake Mn	19	-21	16	27	51	27	34	39	69	79	67	87	41	77	·	
All	54	7	52	64	76	65	16	15	79	69	63	83	46	73	90	·

* Product-Moment Correlation Coefficients x 100.

Value	>80	>50	<50
Approx. Statistical Significance	<.05	<.10	>0.10

App C - 8 Means and Correlations Across Lakes - Secchi TSI

Variable: Secchi TSI

B

Means by Lake and Year

>70 >60 <60

Year	Koetter	Zumwalde	GtNorth	Krays	Knaus	Mainstem	Becker	Horse_W	Horse_S	Cedar	Schneider	Bolfing	Long	Browns	Lake Mn	All
1997	66	66	66	67	67	66	58	54	60	64	56	62	67	50	57	59
1998	66	67	67	65	66	67	56	55	64	64	54	66	67	56	61	63
1999	67	69	67	66	66	66	55	55	59	58	56	57	58	48	55	59
2000	71	72	69	69	68	69	63	56	60	60	57	62	61	48	58	61
2001	66	67	68	67	69	68	63	57	62	65	60	63	67	56	62	64
2002	63	63	63	63	65	64	58	59	58	61	51	62	60	53	58	60
2003		69		68	65	67			61	60	54	57		52	57	61
2004		67		67	65	66			63	57	49	57	54	54	56	59
2005		68		69	67	68			58	59	54	58	66	54	57	60
2006	69	73	71	69	67	69	62	59	62	61	57	65	68	61	61	64
Mean	67	68	67	67	66	67	59	55	61	60	55	61	63	53	58	61

Correlation Matrix *

Segment	Koetter	Zumwalde	GtNorth	Krays	Knaus	Mainstem	Becker	Horse_W	Horse_S	Cedar	Schneider	Bolfing	Long	Browns	Lake Mn	All
Koetter	·															
Zumwalde	94	·														
GtNorth	82	96	·													
Krays	87	78	84	·												
Knaus	59	42	65	43	·											
Mainstem	89	88	94	83	78	·										
Becker	50	47	54	58	76	68	·									
Horse_W	9	17	23	-1	-8	12	54	·								
Horse_S	13	20	48	-10	5	9	16	-7	·							
Cedar	-43	-26	-14	-27	50	6	20	-13	27	·						
Schneider	51	46	74	37	83	70	57	-10	-5	51	·					
Bolfing	12	9	29	-20	52	28	33	28	32	75	43	·				
Long	10	23	42	31	67	52	37	3	6	76	67	74	·			
Browns	-5	15	39	0	10	19	34	64	46	34	6	51	47	·		
Lake Mn	10	23	46	-4	53	39	50	41	55	72	49	83	70	75	·	
All	38	48	68	17	61	60	63	45	53	54	57	71	62	69	95	·

* Product-Moment Correlation Coefficients x 100.

Value	>80	>50	<50
Approx. Statistical Significance	<.05	<.10	>0.10

Appendix D

Model Calibration & Testing

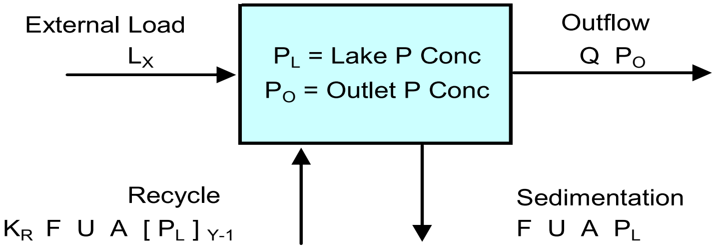
App D - 1

Dynamic Model for Sauk River Mainstem Lakes

				Observed 1997-2006		Predicted	Yearly Residual CV's	
Variable	Units	Definition	Equation	Mean	Std Err	Mean	1997-2006	1978-2006
Yearly Phosphorus Mass Balance								
L_X	kg	External + Atmospheric Total Phosphorus Load	Measured	27618	1660	27618		
L_R	kg	Net Recycle of Load Retained in Previous Year	$F\ K_R\ U\ A\ [P_L]_{Y-1}$			9034		
L_S	kg	Gross Sedimentation in Current Year	$F\ U\ A\ P_L$			15793		
L_O	kg	Outflow P Load	$Q\ P_O$	19714	1898	20734		
P_O	ppb	FWM Outlet P Conc, April-Sept, Plug Flow	$(L_X + L_R)/Q\ \text{Exp}(-D)$	115	11	121	0.33	0.29
P_L	ppb	Arith Mean Lake P Conc, June-Sept, Plug Flow	$(L_X + L_R)/Q\ [1 - \text{Exp}(-D)]/D$	157	10	159	0.17	0.26
D	-	Dimensionless Retention Rate	$F\ U\ A / Q$			0.58		
Steady-State Solution								
P_L	ppb	Lake P Concentration	$(Lx/Q)\ [(1-K_R)\ D + H]^{-1}$	157	10			
P_O	ppb	Outlet P Concentration	$H\ P_L$	115				
H	-	Outlet P / Lake P	$D/[\text{Exp}(D) - 1]$	0.73				
Trophic State Response Variables (BATHTUB)								
B	ppb	Mean Chlorophyll-a, June-Sept	$K_B\ B_P / [(1 + G\,b\,B_P)(1 + G\ a)]$	63	6	62	0.10	0.22
B_P	ppb	Phosphorus-Limited Chlorophyll-a	$0.205\ P_L^{1.46}$			213		
G	-	Light Limitation Factor	$(0.19 + 1.53/T_S)\ Z_{MIX}$			0.51		
T_S	days	Hydraulic Residence Time, July-Sept = A Z / QS	$A\ Z / Q_S$			9		
BF (B*)	-	Bloom Frequency - Fraction of Chl-a data > B*	FNORMAL [ln (B / B*) / S_B]					
BF (40)		Moderate Bloom (Chl-a > 40 ppb)	""	0.76	0.09	0.81	0.13	0.15
BF (60)		Heavy Bloom (Chl-a > 60 ppb)	""	0.54	0.10	0.51	0.10	0.20
BF (80)		Extremely Heavy Bloom (Chl-a > 80 ppb)	""	0.25	0.07	0.28	0.13	0.20
FNORMAL		Cumul. Standardized Normal Frequency Distrib.	Excel NORMSDIST Function					
a	1/m	Non-Algal Turbidity, Regression vs. Q (1997-2006)	0.54 + 0.00038 Q	0.60	0.03	0.61	0.10	0.31
S	m	Mean Secchi Depth, June-Sept	$(a + b\ B)^{-1}$	0.65	0.03	0.65	0.09	0.17

Input Variables			Mean Value
Q	hm^3	Net Inflow = Inflow + Precip - Evap = Outflow	171
F	-	Mass Balance Period (Frac of Y) =0.5 for April-Sept	0.42
A	km^2	Lake Surface Area	4.3
Z	m	Mean Depth	1.5
Z_{MIX}	m	Mean Depth of Mixed Layer = Mean Depth	1.5
Q_S	hm^3/d	Mean Net Inflow, July-September	0.77

Calibrated Parameters			Value
U	m/yr	First-Order Net Settling Velocity	55
K_R	-	Sediment P Recycle Fraction	0.56
K_B	-	Chlorophyll-a Calibration Factor	1.00
b	m^2/mg	Algal Light Extinction Coefficient	0.015
S_B	-	Chl-a Within-Yr Coef of Variation	0.45

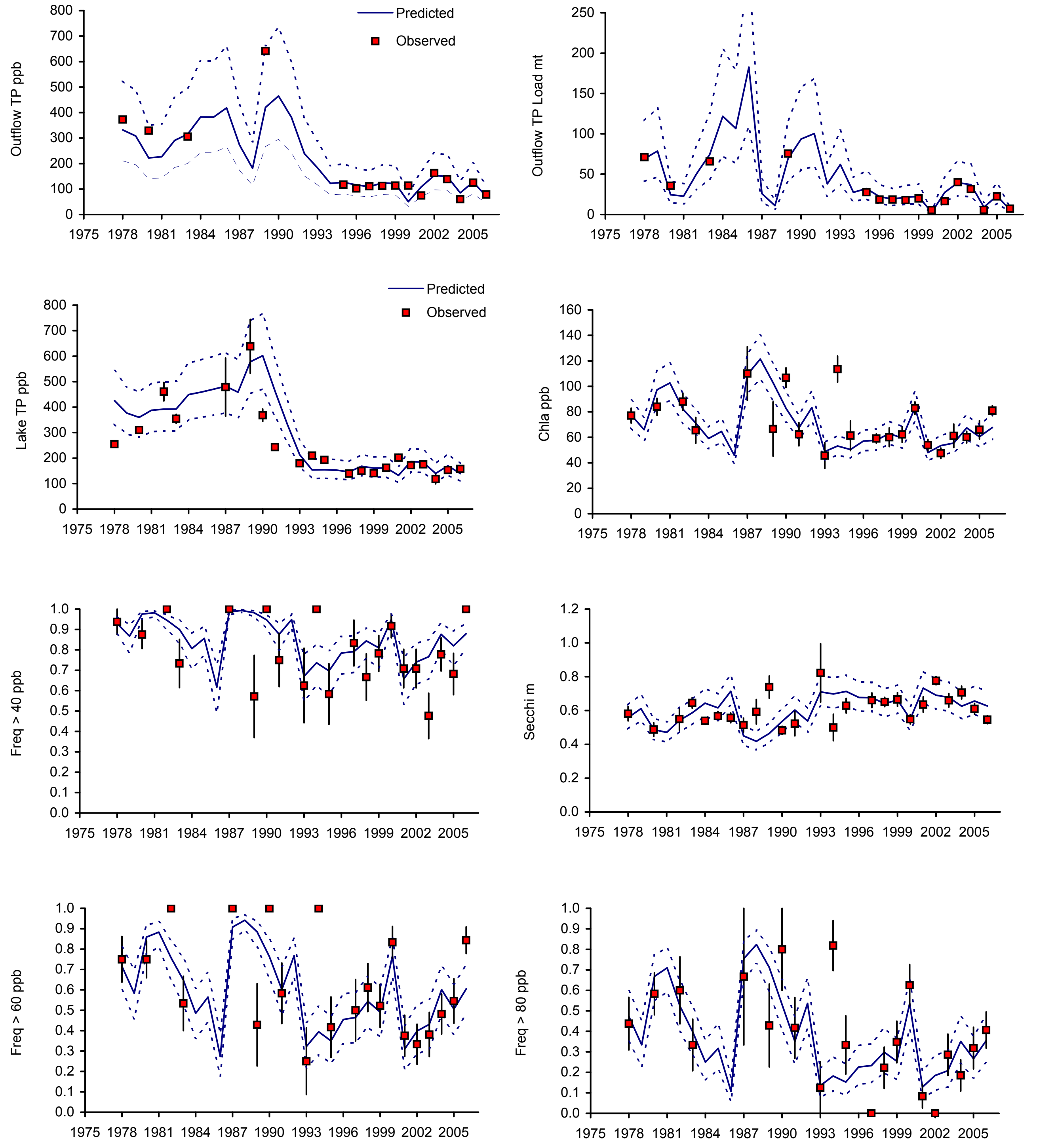


Steady-State Solution

Net Sedimentation

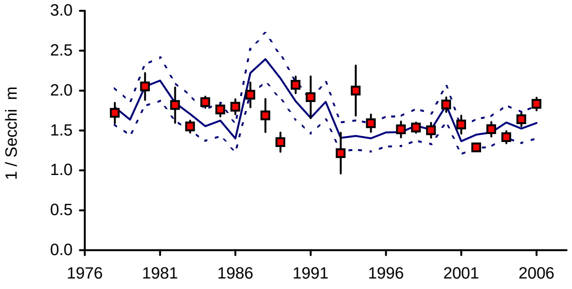
$F\ U\ A\ P_L\ (1 - K_R)$

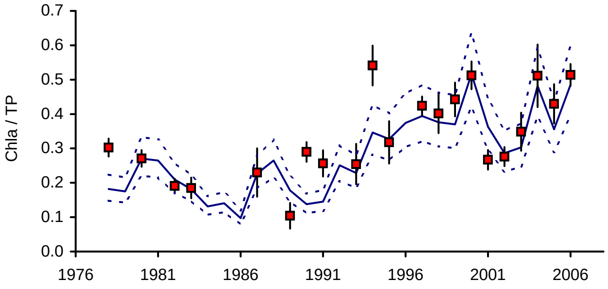
App D - 2 Yearly Simulations of Mainstem Sites, 1978-2006

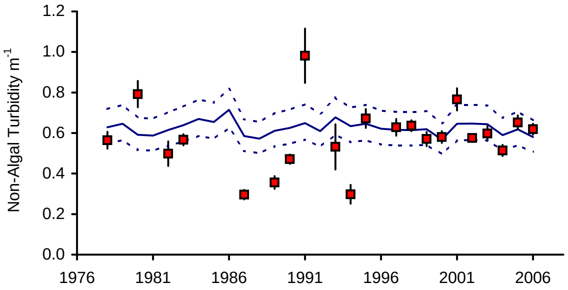


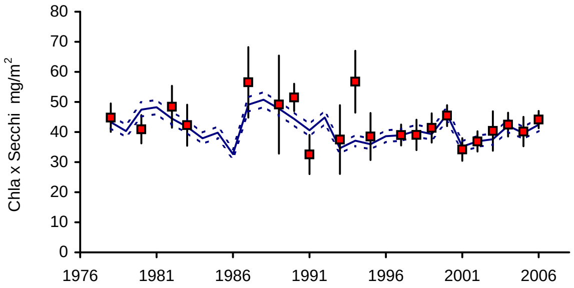
Symbols show observed means +/- 1 standard error computed across mainstem sites & samples in each year, June-September.
The model is driven by May-September inflow volumes and loads for the entire lake chain, rescaled to a average inflow TP Conc of 60 p
Lines show 80% prediction interval for models (10th, 50th, and 90th percentiles) calibrated to 1997-2006 data.

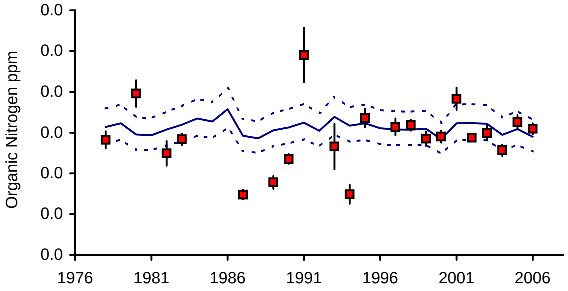
App D - 3 Yearly Simulations of Mainstem Sites - Diagnostic Variables

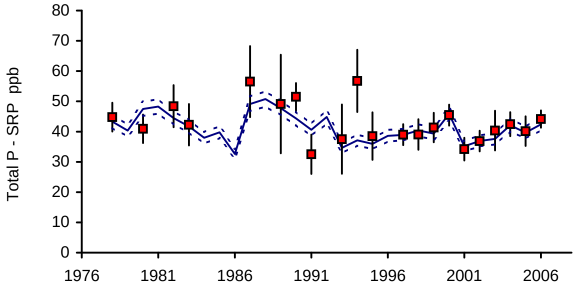




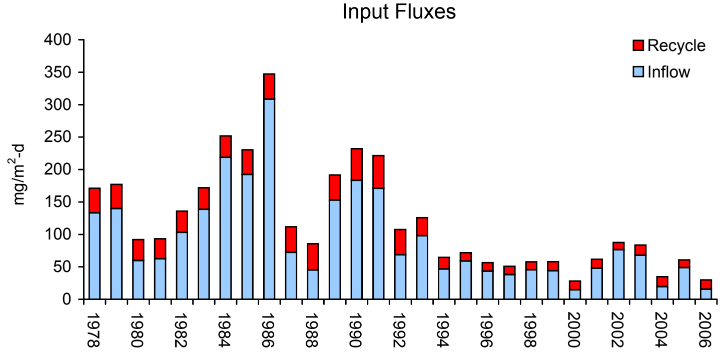






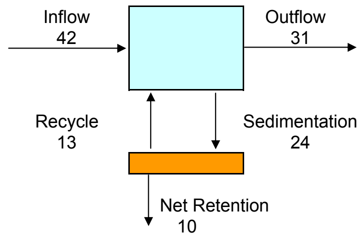


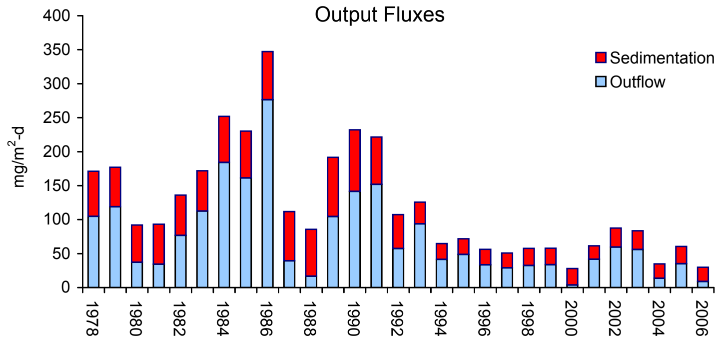
Simulated Phosphorus Fluxes in Mainstem Lakes

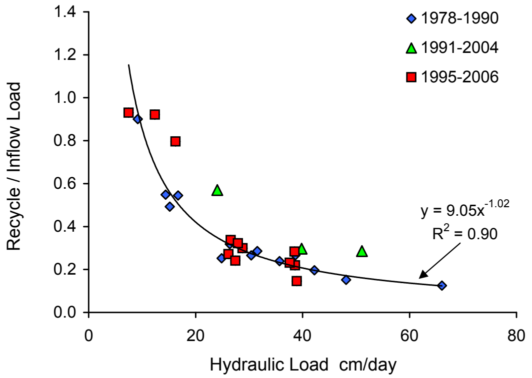


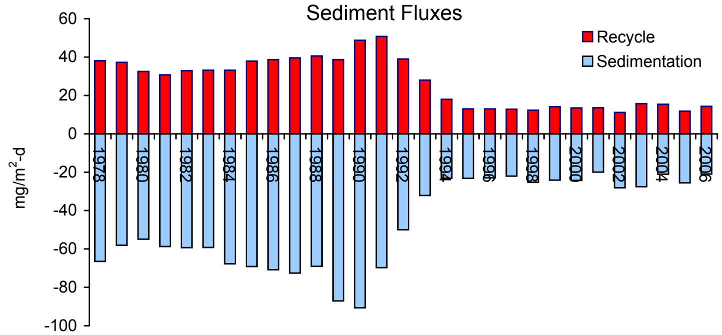
Mean Fluxes (mg/m^2-day)

May-September, 1997-2006

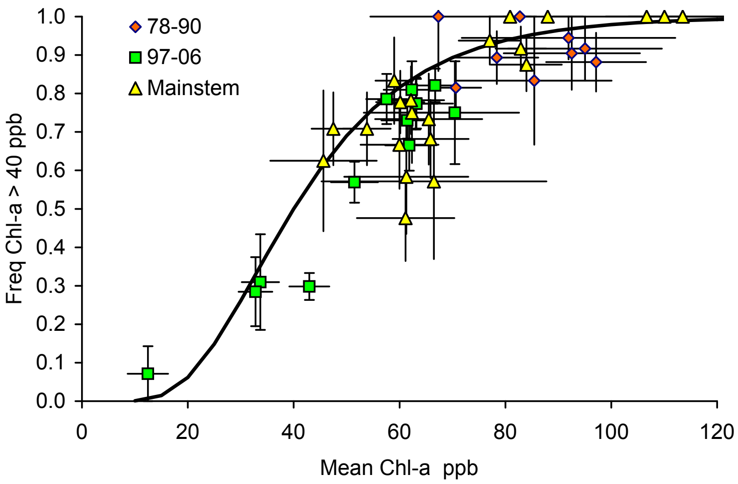


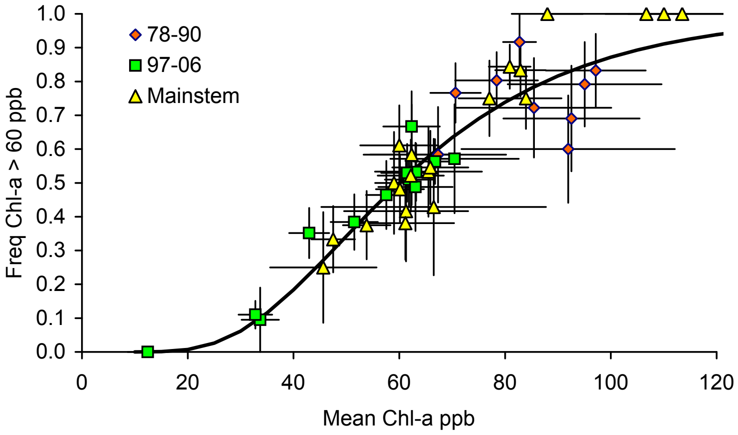


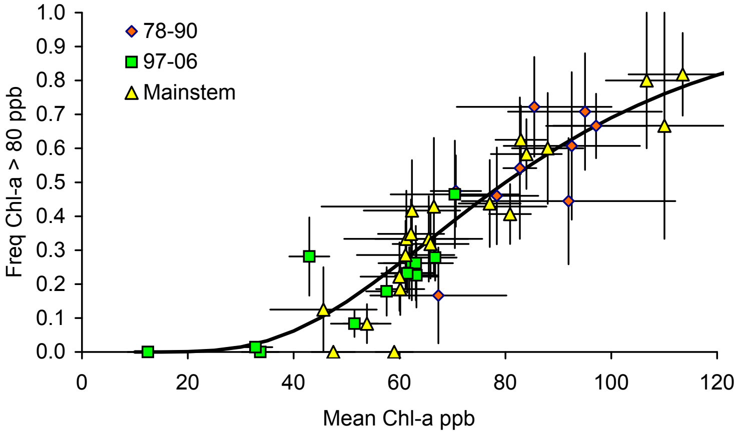




App D - 5 Algal Bloom Frequencies vs. Mean Chlorophyll-a







Symbols = Measured Values +/1 1 Standard Error

Square & circular symbols reflect different lakes & time intervals (1978-1990) vs. (1997-2006)

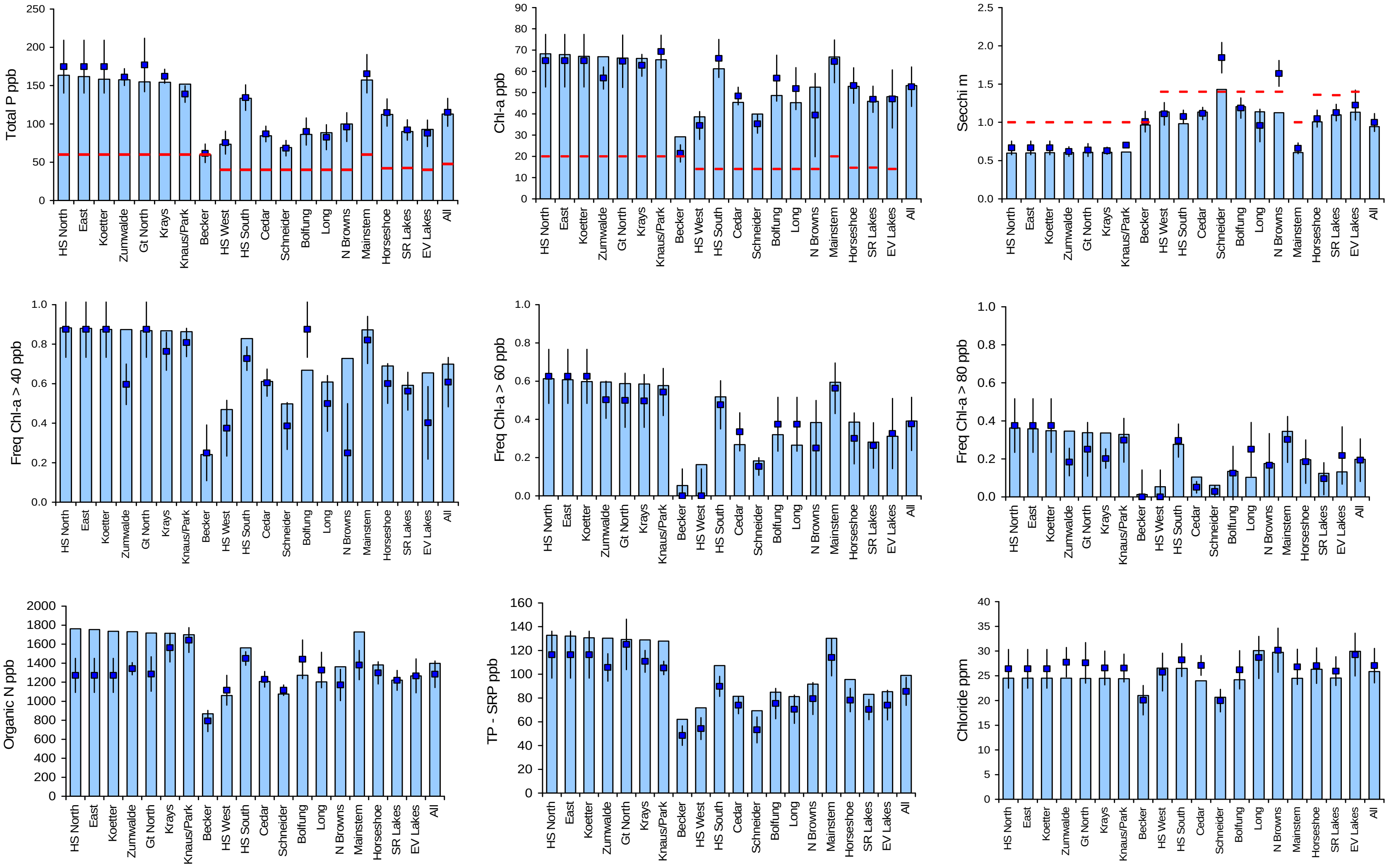
Triangles reflect individual yearly means for all mainstem sites combined, 1978-2006.

Line = Predicted Frequency Using Modified Version of BATHTUB Bloom Frequency Equation

FREQ > B* = NORMSDIST [Ln (B / B*) / CV] CV = 0.45

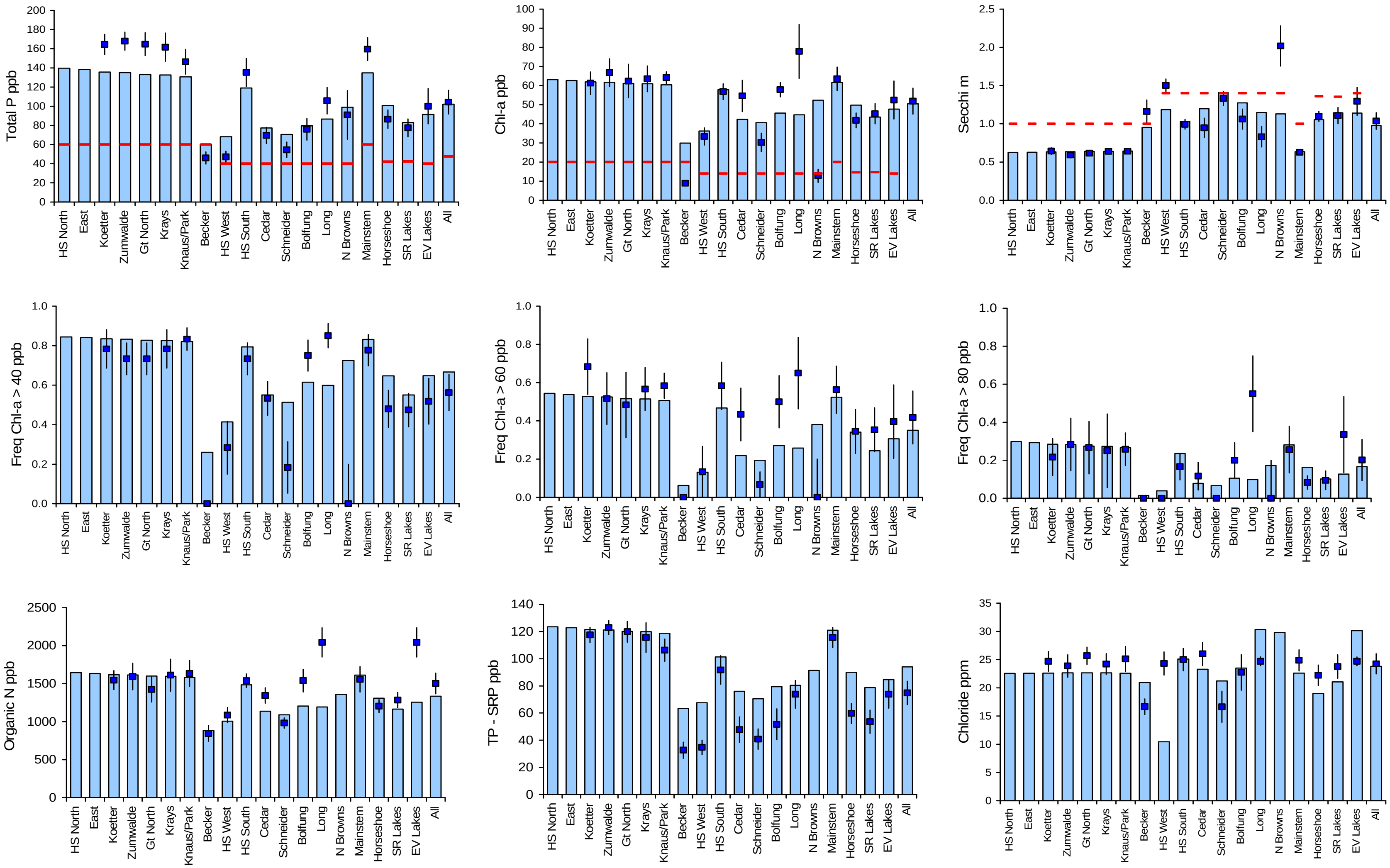
NORMSDIST = Cumulative Standardized Normal Frequency Distribution (Excel Function)

App D - 6 Observed & Predicted Lake Conditions : 2002-2006



Bars = Model Predictions. Symbols = Measured Values +/- 1 Standard Error Computed from Distribution of Summer Means Across Years. Red lines = Criteria

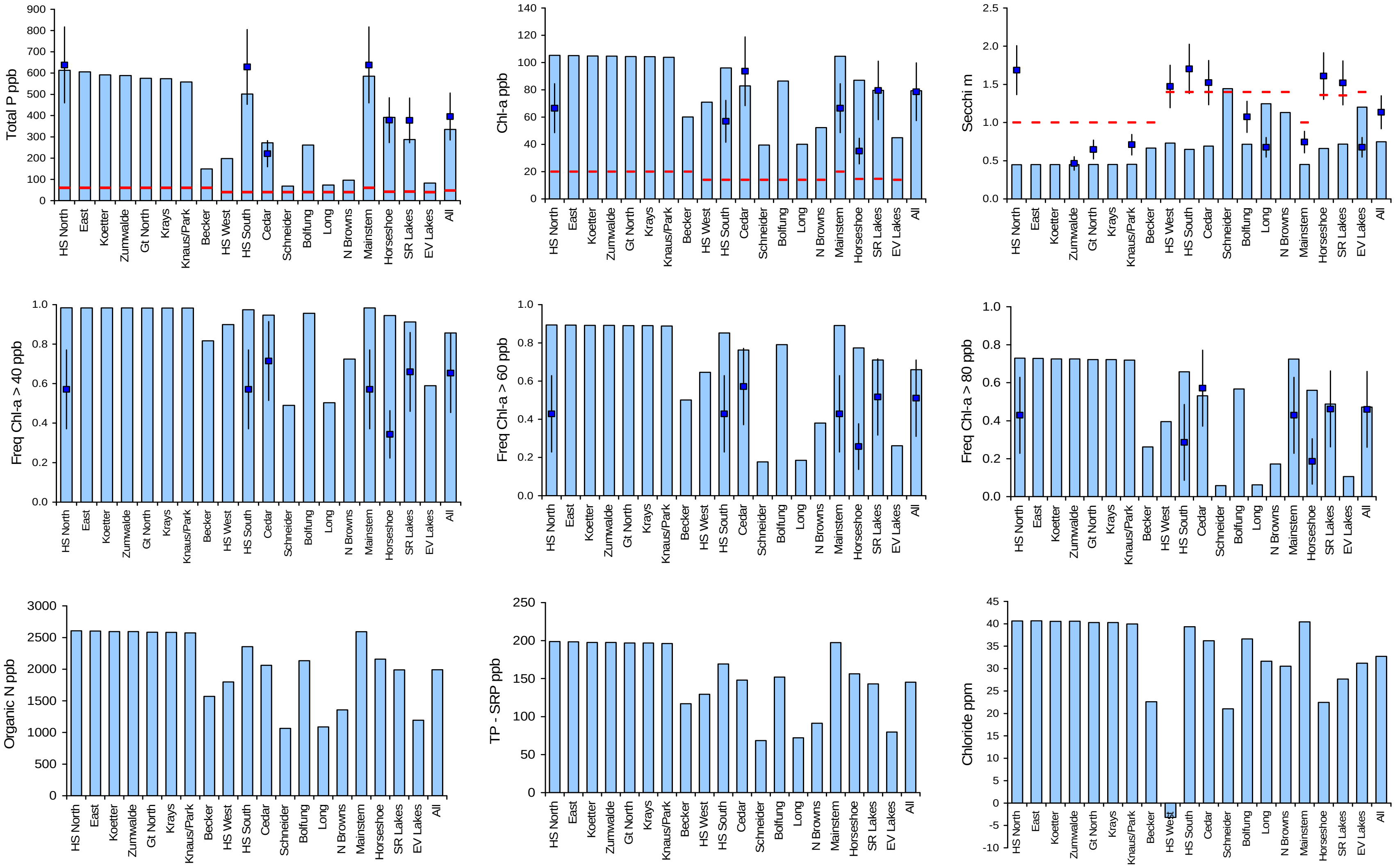
Observed & Predicted Lake Conditions : 1997-2001



Bars = Model Predictions. Symbols = Measured Values +/- 1 Standard Error Computed from Distribution of Summer Means Across Years. Red lines = Criteria

App D - 8

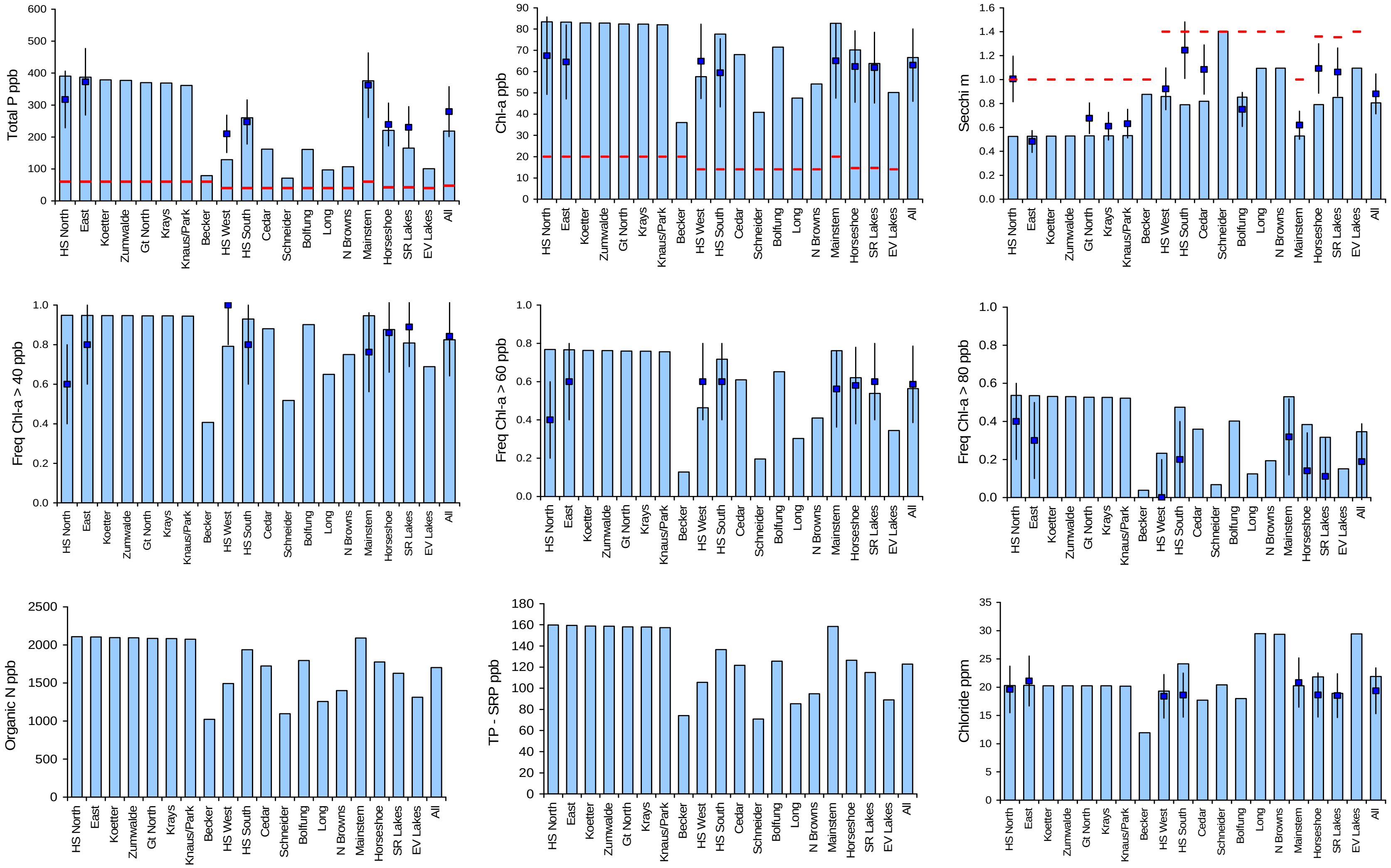
Observed & Predicted Lake Conditions : 1989



Bars = Model Predictions. Symbols = Measured Values +/- 1 Standard Error Computed from Distribution of Summer Means Across Years. Red lines = Criteria

App D - 9

Observed & Predicted Lake Conditions : 1983



Bars = Model Predictions. Symbols = Measured Values +/- 1 Standard Error Computed from Distribution of Summer Means Across Years. Red lines = Criteria

App D - 10 Simulation Results for Several Loading Scenarios

Details in Appendix --> E F G

			Historical				vs. Max Trib Conc							vs. Max Trib Conc, 50% Shoreline Reduc							TMDL Scenarios		
Scenario	Criterion	SE	1978-1990	1997-2006	1997-2001	2002-2006	TRIB_40	TRIB_50	TRIB_60	TRIB_70	TRIB_80	TRIB_90	TRIB_100	TRIB_40_SL	TRIB_50_SL	TRIB_60_SL	TRIB_70_SL	TRIB_80_SL	TRIB_90_SL	TRIB_100_SL	TMDL_BASE	TMDL_TR_100	TMDL_TR_60_SL_50
B																							
C			#N/A	#N/A	#N/A	#N/A	40	50	60	70	80	90	100	40	50	60	70	80	90	100	#N/A	100	60
Local Tributaries			#N/A	#N/A	#N/A	#N/A	40	50	60	70	80	90	100	40	50	60	70	80	90	100	#N/A	100	60
Eden Valley Creek			#N/A	#N/A	#N/A	#N/A	40	50	60	70	80	90	100	40	50	60	70	80	90	100	#N/A	100	60
Shoreline Load Redic			#N/A	#N/A	#N/A	#N/A	0%	0%	0%	0%	0%	0%	0%	50%	50%	50%	50%	50%	50%	50%	0%	0%	50%
Total P Loads kg																							
Sauk River			87052	23223	20910	25536	5427	6784	8141	9498	10855	12212	13569	5427	6784	8141	9498	10855	12212	13569	25536	13569	8141
Local Tributaries			1003	828	768	889	655	757	810	862	889	889	889	655	757	810	862	889	889	889	889	889	810
Eden Valley Creek			2996	2628	2498	2757	814	1017	1221	1424	1628	1831	2035	814	1017	1221	1424	1628	1831	2035	2757	2035	1221
Shoreline+Lakeshed			816	765	747	783	783	783	783	783	783	783	783	522	522	522	522	522	522	522	783	783	522
All Local Sources			4816	4221	4014	4428	2252	2558	2814	3069	3300	3503	3707	1991	2297	2553	2808	3039	3242	3446	4428	3707	2553
Total			92044	27622	25095	30150	7865	9528	11140	12753	14340	15901	17461	7604	9267	10879	12492	14079	15640	17200	30150	17461	10879
Load Reduc vs. Baseline																							
Sauk River			-241%	9%	18%	0%	79%	73%	68%	63%	57%	52%	47%	79%	73%	68%	63%	57%	52%	47%	0%	47%	68%
Local Tributaries			-13%	7%	14%	0%	26%	15%	9%	3%	0%	0%	0%	26%	15%	9%	3%	0%	0%	0%	0%	0%	9%
Eden Valley Creek			-9%	5%	9%	0%	70%	63%	56%	48%	41%	34%	26%	70%	63%	56%	48%	41%	34%	26%	0%	26%	56%
Shoreline+Lakeshed			-4%	2%	5%	0%	0%	0%	0%	0%	0%	0%	0%	33%	33%	33%	33%	33%	33%	33%	0%	0%	33%
All Local Sources			-9%	5%	9%	0%	49%	42%	36%	31%	25%	21%	16%	55%	48%	42%	37%	31%	27%	22%	0%	16%	42%
Total			-205%	8%	17%	0%	74%	68%	63%	58%	52%	47%	42%	75%	69%	64%	59%	53%	48%	43%	0%	42%	64%
Lake TP Conc ppb																							
HS North	60	3	454	152	140	163	39	47	56	65	73	82	91	38	47	56	64	73	82	90	163	91	56
East	60	3	449	150	138	162	38	47	56	64	73	81	90	38	47	55	64	72	81	89	162	90	55
Koetter	60	3	440	147	136	158	38	47	55	64	72	80	89	38	46	55	63	71	80	88	158	89	55
Zumwalde	60	3	438	147	135	158	38	47	55	63	72	80	88	38	46	54	63	71	79	87	158	88	54
Gt North	60	3	429	144	133	155	38	47	55	63	71	79	87	37	46	54	62	70	78	86	155	87	54
Krays	60	3	427	144	133	154	38	47	55	63	71	79	87	37	46	54	62	70	78	86	154	87	54
Knaus/Park	60	3	418	141	131	152	38	47	55	63	71	79	86	37	46	54	62	70	77	85	152	86	54
Becker	60	5	100	60	60	60	39	44	45	46	47	48	50	38	43	44	45	46	48	49	60	50	44
HS West	40	8	151	71	68	73	40	43	45	47	50	52	54	30	33	35	37	40	42	44	73	54	35
HS South	40	4	310	127	119	133	35	43	50	58	65	73	80	34	42	49	57	64	72	79	133	80	49
Cedar	40	7	196	81	77	85	37	40	43	47	50	53	57	33	37	40	43	47	50	53	85	57	40
Schneider	40	7	71	70	71	69	43	50	57	64	69	69	69	38	45	52	59	64	64	64	69	69	52
Bolfung	40	7	193	83	79	86	41	44	47	50	54	57	60	34	38	41	44	47	51	54	86	60	41
Long	40	9	90	88	87	88	31	37	43	49	55	61	67	29	35	41	47	53	59	65	88	67	41
N Browns	40	9	101	99	99	100	33	40	47	54	61	68	75	31	39	46	53	60	67	74	100	75	46
Mainstem	60	3	435	146	135	157	38	47	55	64	72	80	88	38	46	54	63	71	79	87	157	88	54
Horseshoe	42	5	261	107	101	112	38	43	49	54	60	65	71	33	39	44	50	55	61	66	112	71	44
SR Lakes	42	5	197	87	83	90	38	42	46	50	54	58	61	34	38	42	46	50	54	57	90	61	42
EV Lakes	40	9	94	92	91	93	31	38	44	51	57	64	70	30	36	43	49	56	62	69	93	70	43
All	48	4	250	108	102	113	36	43	49	55	61	67	72	34	40	46	52	58	64	70	113	72	46

Simulation Results for Several Loading Scenarios

Details in Appendix --> E F G

			Historical				vs. Max Trib Conc							vs. Max Trib Conc, 50% Shoreline Reduc							TMDL Scenarios		
Scenario	Criterion	SE	1978-1990	1997-2006	1997-2001	2002-2006	TRIB_40	TRIB_50	TRIB_60	TRIB_70	TRIB_80	TRIB_90	TRIB_100	TRIB_40_SL	TRIB_50_SL	TRIB_60_SL	TRIB_70_SL	TRIB_80_SL	TRIB_90_SL	TRIB_100_SL	TMDL_BASE	TMDL_TR_100	TMDL_TR_60_SL_50
Freq Chla > 40 ppb																							
HS North	0.1	0.032	0.97	0.87	0.84	0.88	0.06	0.14	0.24	0.35	0.45	0.54	0.62	0.05	0.14	0.24	0.35	0.45	0.54	0.61	0.88	0.62	0.24
East	0.1	0.031	0.97	0.86	0.84	0.88	0.05	0.14	0.24	0.35	0.45	0.54	0.61	0.05	0.13	0.23	0.34	0.44	0.53	0.61	0.88	0.61	0.23
Koetter	0.1	0.030	0.97	0.86	0.83	0.87	0.05	0.13	0.23	0.34	0.44	0.52	0.60	0.05	0.13	0.22	0.33	0.43	0.52	0.59	0.87	0.60	0.22
Zumwalde	0.1	0.029	0.97	0.86	0.83	0.87	0.05	0.13	0.23	0.34	0.43	0.52	0.60	0.05	0.12	0.22	0.33	0.43	0.51	0.59	0.87	0.60	0.22
Gt North	0.1	0.028	0.97	0.85	0.83	0.87	0.05	0.13	0.23	0.33	0.43	0.51	0.59	0.05	0.12	0.22	0.32	0.42	0.51	0.58	0.87	0.59	0.22
Krays	0.1	0.028	0.97	0.85	0.83	0.87	0.05	0.13	0.23	0.33	0.43	0.51	0.59	0.05	0.12	0.22	0.32	0.42	0.50	0.58	0.87	0.59	0.22
Knaus/Park	0.1	0.028	0.97	0.84	0.82	0.86	0.05	0.13	0.23	0.33	0.42	0.51	0.58	0.05	0.12	0.21	0.31	0.41	0.50	0.57	0.86	0.58	0.21
Becker	0.1	0.008	0.60	0.25	0.26	0.24	0.05	0.08	0.09	0.10	0.11	0.12	0.13	0.04	0.07	0.08	0.09	0.10	0.11	0.13	0.24	0.13	0.08
HS West	0.1	0.004	0.84	0.44	0.41	0.47	0.09	0.11	0.14	0.16	0.19	0.22	0.25	0.02	0.03	0.05	0.06	0.08	0.10	0.13	0.47	0.25	0.05
HS South	0.1	0.032	0.95	0.81	0.79	0.83	0.07	0.15	0.24	0.34	0.44	0.52	0.58	0.06	0.13	0.23	0.33	0.42	0.51	0.58	0.83	0.58	0.23
Cedar	0.1	0.011	0.91	0.58	0.55	0.61	0.07	0.10	0.14	0.18	0.22	0.27	0.31	0.04	0.07	0.10	0.14	0.18	0.22	0.27	0.61	0.31	0.10
Schneider	0.1	0.044	0.52	0.51	0.51	0.50	0.15	0.25	0.35	0.44	0.50	0.50	0.50	0.09	0.18	0.28	0.38	0.44	0.44	0.44	0.50	0.50	0.28
Bolfung	0.1	0.017	0.93	0.64	0.61	0.67	0.13	0.18	0.22	0.27	0.31	0.36	0.40	0.06	0.10	0.14	0.18	0.22	0.27	0.31	0.67	0.40	0.14
Long	0.1	0.012	0.62	0.60	0.60	0.61	0.02	0.06	0.12	0.19	0.27	0.34	0.41	0.02	0.05	0.10	0.17	0.25	0.32	0.40	0.61	0.41	0.10
N Browns	0.1	0.028	0.73	0.73	0.73	0.73	0.05	0.11	0.20	0.30	0.39	0.48	0.55	0.04	0.10	0.19	0.28	0.38	0.47	0.54	0.73	0.55	0.19
Mainstem	0.1	0.029	0.97	0.86	0.83	0.87	0.05	0.13	0.23	0.34	0.44	0.52	0.60	0.05	0.12	0.22	0.33	0.43	0.51	0.59	0.87	0.60	0.22
Horseshoe	0.1	0.025	0.91	0.67	0.65	0.69	0.07	0.13	0.20	0.27	0.34	0.40	0.45	0.04	0.09	0.16	0.23	0.29	0.35	0.40	0.69	0.45	0.16
SR Lakes	0.1	0.018	0.86	0.57	0.55	0.59	0.08	0.12	0.17	0.22	0.27	0.31	0.36	0.04	0.08	0.13	0.17	0.22	0.26	0.31	0.59	0.36	0.13
EV Lakes	0.1	0.019	0.66	0.65	0.65	0.65	0.03	0.08	0.15	0.23	0.32	0.40	0.47	0.03	0.07	0.14	0.22	0.30	0.38	0.45	0.65	0.47	0.14
All	0.1	0.023	0.85	0.68	0.67	0.70	0.06	0.12	0.19	0.26	0.34	0.40	0.46	0.04	0.09	0.16	0.24	0.31	0.37	0.43	0.70	0.46	0.16
Freq Chla > 60 ppb																							
HS North	0.1	0.032	0.83	0.58	0.54	0.61	0.01	0.02	0.06	0.10	0.16	0.21	0.27	0.01	0.02	0.05	0.10	0.15	0.21	0.27	0.61	0.27	0.05
East	0.1	0.031	0.83	0.58	0.54	0.61	0.01	0.02	0.05	0.10	0.15	0.21	0.27	0.01	0.02	0.05	0.09	0.15	0.20	0.26	0.61	0.27	0.05
Koetter	0.1	0.030	0.83	0.57	0.53	0.60	0.01	0.02	0.05	0.09	0.14	0.20	0.26	0.01	0.02	0.05	0.09	0.14	0.20	0.25	0.60	0.26	0.05
Zumwalde	0.1	0.029	0.82	0.56	0.53	0.60	0.01	0.02	0.05	0.09	0.14	0.20	0.25	0.01	0.02	0.05	0.09	0.14	0.19	0.25	0.60	0.25	0.05
Gt North	0.1	0.028	0.82	0.56	0.52	0.59	0.01	0.02	0.05	0.09	0.14	0.19	0.25	0.01	0.02	0.05	0.09	0.13	0.19	0.24	0.59	0.25	0.05
Krays	0.1	0.028	0.82	0.55	0.51	0.59	0.01	0.02	0.05	0.09	0.14	0.19	0.25	0.00	0.02	0.05	0.08	0.13	0.19	0.24	0.59	0.25	0.05
Knaus/Park	0.1	0.028	0.82	0.55	0.51	0.58	0.01	0.02	0.05	0.09	0.14	0.19	0.24	0.00	0.02	0.04	0.08	0.13	0.18	0.23	0.58	0.24	0.04
Becker	0.1	0.008	0.26	0.06	0.06	0.05	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.05	0.02	0.01
HS West	0.1	0.004	0.54	0.15	0.13	0.16	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.16	0.06	0.00
HS South	0.1	0.032	0.76	0.50	0.47	0.52	0.01	0.03	0.06	0.10	0.14	0.19	0.25	0.01	0.02	0.05	0.09	0.14	0.19	0.24	0.52	0.25	0.05
Cedar	0.1	0.011	0.68	0.25	0.22	0.27	0.01	0.02	0.02	0.04	0.05	0.06	0.08	0.00	0.01	0.01	0.02	0.03	0.05	0.06	0.27	0.08	0.01
Schneider	0.1	0.044	0.20	0.19	0.19	0.18	0.03	0.06	0.10	0.15	0.18	0.18	0.18	0.01	0.03	0.07	0.11	0.15	0.15	0.15	0.18	0.18	0.07
Bolfung	0.1	0.017	0.72	0.30	0.27	0.32	0.02	0.03	0.05	0.06	0.08	0.10	0.12	0.01	0.01	0.02	0.03	0.05	0.06	0.08	0.32	0.12	0.02
Long	0.1	0.012	0.27	0.26	0.26	0.27	0.00	0.01	0.02	0.04	0.06	0.10	0.13	0.00	0.01	0.02	0.03	0.06	0.09	0.12	0.27	0.13	0.02
N Browns	0.1	0.028	0.39	0.38	0.38	0.38	0.00	0.02	0.04	0.08	0.12	0.17	0.22	0.00	0.01	0.04	0.07	0.11	0.16	0.21	0.38	0.22	0.04
Mainstem	0.1	0.029	0.82	0.56	0.52	0.59	0.01	0.02	0.05	0.09	0.14	0.20	0.25	0.01	0.02	0.05	0.09	0.14	0.19	0.25	0.59	0.25	0.05
Horseshoe	0.1	0.025	0.68	0.37	0.34	0.39	0.01	0.02	0.04	0.07	0.10	0.14	0.17	0.00	0.01	0.03	0.06	0.09	0.12	0.15	0.39	0.17	0.03
SR Lakes	0.1	0.018	0.61	0.26	0.24	0.28	0.01	0.02	0.03	0.05	0.07	0.09	0.11	0.00	0.01	0.02	0.04	0.06	0.08	0.10	0.28	0.11	0.02
EV Lakes	0.1	0.019	0.32	0.31	0.31	0.31	0.00	0.01	0.03	0.05	0.09	0.12	0.17	0.00	0.01	0.02	0.05	0.08	0.12	0.16	0.31	0.17	0.02
All	0.1	0.023	0.61	0.37	0.35	0.39	0.01	0.02	0.04	0.07	0.10	0.14	0.17	0.00	0.01	0.03	0.06	0.09	0.12	0.16	0.39	0.17	0.03

App D - 10 Simulation Results for Several Loading Scenarios

Details in Appendix --> E F G

			Historical				vs. Max Trib Conc							vs. Max Trib Conc, 50% Shoreline Reduc							TMDL Scenarios		
Scenario	Criterion	SE	1978-1990	1997-2006	1997-2001	2002-2006	TRIB_40	TRIB_50	TRIB_60	TRIB_70	TRIB_80	TRIB_90	TRIB_100	TRIB_40_SL	TRIB_50_SL	TRIB_60_SL	TRIB_70_SL	TRIB_80_SL	TRIB_90_SL	TRIB_100_SL	TMDL_BASE	TMDL_TR_100	TMDL_TR_60_SL_50
Freq Chla > 80 ppb																							
HS North	0.1	0.008	0.62	0.33	0.30	0.36	0.00	0.00	0.01	0.03	0.05	0.08	0.11	0.00	0.00	0.01	0.03	0.05	0.07	0.10	0.36	0.11	0.01
East	0.1	0.008	0.62	0.33	0.29	0.36	0.00	0.00	0.01	0.03	0.05	0.07	0.10	0.00	0.00	0.01	0.03	0.05	0.07	0.10	0.36	0.10	0.01
Koetter	0.1	0.007	0.62	0.32	0.28	0.35	0.00	0.00	0.01	0.03	0.04	0.07	0.10	0.00	0.00	0.01	0.02	0.04	0.07	0.10	0.35	0.10	0.01
Zumwalde	0.1	0.007	0.62	0.32	0.28	0.35	0.00	0.00	0.01	0.02	0.04	0.07	0.10	0.00	0.00	0.01	0.02	0.04	0.07	0.09	0.35	0.10	0.01
Gt North	0.1	0.007	0.61	0.31	0.27	0.34	0.00	0.00	0.01	0.02	0.04	0.07	0.09	0.00	0.00	0.01	0.02	0.04	0.06	0.09	0.34	0.09	0.01
Krays	0.1	0.007	0.61	0.31	0.27	0.34	0.00	0.00	0.01	0.02	0.04	0.07	0.09	0.00	0.00	0.01	0.02	0.04	0.06	0.09	0.34	0.09	0.01
Knaus/Park	0.1	0.007	0.61	0.30	0.27	0.33	0.00	0.00	0.01	0.02	0.04	0.06	0.09	0.00	0.00	0.01	0.02	0.04	0.06	0.09	0.33	0.09	0.01
Becker	0.1	0.001	0.10	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
HS West	0.1	0.001	0.30	0.05	0.04	0.05	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.00
HS South	0.1	0.008	0.53	0.26	0.24	0.28	0.00	0.00	0.01	0.03	0.04	0.07	0.09	0.00	0.00	0.01	0.02	0.04	0.06	0.09	0.28	0.09	0.01
Cedar	0.1	0.002	0.43	0.09	0.08	0.10	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.10	0.02	0.00
Schneider	0.1	0.012	0.07	0.06	0.07	0.06	0.01	0.01	0.03	0.04	0.06	0.06	0.06	0.00	0.01	0.02	0.03	0.05	0.05	0.05	0.06	0.06	0.02
Bolfung	0.1	0.003	0.47	0.12	0.11	0.13	0.00	0.01	0.01	0.02	0.02	0.03	0.04	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.13	0.04	0.00
Long	0.1	0.002	0.11	0.10	0.10	0.10	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.10	0.04	0.00
N Browns	0.1	0.006	0.18	0.17	0.17	0.18	0.00	0.00	0.01	0.02	0.04	0.06	0.08	0.00	0.00	0.01	0.02	0.03	0.05	0.08	0.18	0.08	0.01
Mainstem	0.1	0.007	0.61	0.32	0.28	0.34	0.00	0.00	0.01	0.03	0.04	0.07	0.10	0.00	0.00	0.01	0.02	0.04	0.07	0.09	0.34	0.10	0.01
Horseshoe	0.1	0.006	0.45	0.18	0.16	0.20	0.00	0.00	0.01	0.02	0.03	0.05	0.06	0.00	0.00	0.01	0.02	0.03	0.04	0.06	0.20	0.06	0.01
SR Lakes	0.1	0.004	0.38	0.11	0.10	0.12	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.12	0.04	0.00
EV Lakes	0.1	0.004	0.13	0.13	0.13	0.13	0.00	0.00	0.01	0.01	0.02	0.04	0.05	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.13	0.05	0.00
All	0.1	0.005	0.40	0.18	0.17	0.20	0.00	0.00	0.01	0.02	0.03	0.04	0.06	0.00	0.00	0.01	0.01	0.03	0.04	0.06	0.20	0.06	0.01
Mean Chl-a ppb																							
HS North	20	6	92	66	63	68	20	25	29	34	38	42	46	19	24	29	34	38	42	45	68	46	29
East	20	6	92	65	63	68	19	24	29	34	38	42	45	19	24	29	33	37	41	45	68	45	29
Koetter	20	6	91	65	62	67	19	24	29	33	37	41	45	19	24	28	33	37	41	44	67	45	28
Zumwalde	20	6	91	65	62	67	19	24	29	33	37	41	45	19	24	28	33	37	41	44	67	45	28
Gt North	20	6	91	64	61	66	19	24	29	33	37	41	44	19	24	28	32	36	40	44	66	44	28
Krays	20	6	91	64	61	66	19	24	29	33	37	41	44	19	24	28	32	36	40	44	66	44	28
Knaus/Park	20	6	91	63	60	65	19	24	29	33	37	40	44	19	24	28	32	36	40	43	65	44	28
Becker	20	5	45	30	30	29	19	21	22	23	23	24	24	18	21	21	22	23	23	24	29	24	21
HS West	14	6	63	38	36	39	22	23	24	26	27	28	29	16	17	19	20	21	23	24	39	29	19
HS South	14	6	83	60	58	61	20	25	29	33	37	41	44	20	24	29	33	37	40	44	61	44	29
Cedar	14	6	74	44	42	45	21	23	25	27	28	30	32	18	20	22	24	26	28	30	45	32	22
Schneider	14	8	41	40	41	40	25	29	33	37	40	40	40	22	27	31	35	37	37	37	40	40	31
Bolfung	14	7	78	47	46	49	24	26	28	30	32	34	36	20	22	24	26	28	30	32	49	36	24
Long	14	7	46	45	45	45	16	20	24	27	30	33	36	15	19	23	26	29	33	36	45	36	23
N Browns	14	8	53	52	52	53	19	23	28	32	35	39	42	18	23	27	31	35	38	42	53	42	27
Mainstem	20	6	91	64	62	67	19	24	29	33	37	41	45	19	24	28	33	37	41	44	67	45	28
Horseshoe	15	6	76	51	50	53	21	24	27	30	33	36	38	18	22	25	28	31	33	36	53	38	25
SR Lakes	15	6	70	45	43	46	21	24	26	28	30	32	34	18	21	24	26	28	30	32	46	34	24
EV Lakes	14	7	48	48	48	48	17	21	25	29	32	36	39	16	20	24	28	32	35	38	48	39	24
All	16	6	71	52	50	53	20	23	27	30	33	36	39	18	22	25	29	32	35	37	53	39	25

App D - 10 Simulation Results for Several Loading Scenarios

Details in Appendix --> E F G

			Historical				vs. Max Trib Conc							vs. Max Trib Conc, 50% Shoreline Reduc							TMDL Scenarios		
Scenario	Criterion	SE	1978-1990	1997-2006	1997-2001	2002-2006	TRIB_40	TRIB_50	TRIB_60	TRIB_70	TRIB_80	TRIB_90	TRIB_100	TRIB_40_SL	TRIB_50_SL	TRIB_60_SL	TRIB_70_SL	TRIB_80_SL	TRIB_90_SL	TRIB_100_SL	TMDL_BASE	TMDL_TR_100	TMDL_TR_60_SL_50
Secchi Depth m																							
HS North	1.0	0.08	0.49	0.61	0.63	0.60	1.06	0.98	0.92	0.86	0.82	0.78	0.75	1.06	0.98	0.92	0.87	0.82	0.78	0.75	0.60	0.75	0.92
East	1.0	0.08	0.49	0.61	0.63	0.60	1.06	0.98	0.92	0.87	0.82	0.78	0.75	1.07	0.99	0.92	0.87	0.83	0.79	0.75	0.60	0.75	0.92
Koetter	1.0	0.08	0.49	0.62	0.63	0.60	1.06	0.99	0.92	0.87	0.83	0.79	0.76	1.07	0.99	0.93	0.88	0.83	0.79	0.76	0.60	0.76	0.93
Zumwalde	1.0	0.08	0.50	0.62	0.63	0.60	1.06	0.99	0.93	0.87	0.83	0.79	0.76	1.07	0.99	0.93	0.88	0.83	0.79	0.76	0.60	0.76	0.93
Gt North	1.0	0.08	0.50	0.62	0.64	0.61	1.06	0.99	0.93	0.87	0.83	0.79	0.76	1.07	1.00	0.93	0.88	0.84	0.80	0.76	0.61	0.76	0.93
Krays	1.0	0.08	0.50	0.62	0.64	0.61	1.06	0.99	0.93	0.88	0.83	0.79	0.76	1.07	1.00	0.93	0.88	0.84	0.80	0.77	0.61	0.76	0.93
Knaus/Park	1.0	0.08	0.50	0.63	0.64	0.61	1.06	0.99	0.93	0.88	0.83	0.80	0.77	1.07	1.00	0.94	0.88	0.84	0.80	0.77	0.61	0.77	0.94
Becker	1.0	0.10	0.79	0.96	0.95	0.96	1.13	1.09	1.08	1.07	1.06	1.05	1.04	1.14	1.10	1.09	1.07	1.06	1.05	1.04	0.96	1.04	1.09
HS West	1.4	0.28	0.81	1.16	1.18	1.14	1.60	1.55	1.50	1.46	1.42	1.39	1.35	1.86	1.79	1.72	1.67	1.61	1.56	1.52	1.14	1.35	1.72
HS South	1.4	0.39	0.74	1.00	1.03	0.98	2.48	2.11	1.85	1.66	1.52	1.41	1.32	2.54	2.15	1.88	1.69	1.54	1.42	1.33	0.98	1.32	1.88
Cedar	1.4	0.35	0.76	1.16	1.20	1.13	1.97	1.86	1.76	1.67	1.59	1.53	1.47	2.11	1.97	1.86	1.76	1.68	1.60	1.53	1.13	1.47	1.86
Schneider	1.4	0.42	1.40	1.42	1.41	1.43	2.10	1.85	1.66	1.52	1.43	1.43	1.43	2.32	2.01	1.78	1.61	1.51	1.51	1.51	1.43	1.43	1.78
Bolfung	1.4	0.52	0.79	1.24	1.28	1.21	2.16	2.02	1.91	1.80	1.72	1.64	1.57	2.49	2.30	2.15	2.01	1.90	1.80	1.72	1.21	1.57	2.15
Long	1.4	0.39	1.13	1.14	1.15	1.14	2.24	1.99	1.80	1.65	1.53	1.43	1.34	2.31	2.05	1.85	1.69	1.56	1.45	1.36	1.14	1.34	1.85
N Browns	1.4	0.54	1.12	1.13	1.13	1.13	2.62	2.23	1.95	1.74	1.58	1.46	1.36	2.70	2.28	1.99	1.77	1.61	1.48	1.37	1.13	1.36	1.99
Mainstem	1.0	0.08	0.50	0.62	0.64	0.61	1.06	0.99	0.92	0.87	0.83	0.79	0.76	1.07	0.99	0.93	0.88	0.83	0.79	0.76	0.61	0.76	0.93
Horseshoe	1.4	0.30	0.74	1.03	1.05	1.01	1.98	1.77	1.62	1.50	1.41	1.34	1.27	2.12	1.89	1.72	1.60	1.50	1.41	1.34	1.01	1.27	1.72
SR Lakes	1.4	0.31	0.80	1.12	1.14	1.10	1.94	1.78	1.66	1.57	1.49	1.42	1.37	2.08	1.90	1.77	1.66	1.57	1.50	1.44	1.10	1.37	1.77
EV Lakes	1.4	0.45	1.13	1.14	1.14	1.13	2.39	2.09	1.86	1.69	1.55	1.44	1.35	2.47	2.14	1.90	1.72	1.58	1.46	1.37	1.13	1.35	1.90
All	1.2	0.25	0.78	0.96	0.98	0.94	1.76	1.59	1.47	1.37	1.29	1.22	1.16	1.84	1.66	1.53	1.42	1.33	1.26	1.20	0.94	1.16	1.53
Inflow Volumes hm3																							
Sauk River Inflow			160.1	135.0	134.3	135.7	135.7	135.7	135.7	135.7	135.7	135.7	135.7	135.7	135.7	135.7	135.7	135.7	135.7	135.7	135.7	135.7	135.7
Kolling Creek			11.8	9.8	8.4	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Schneider Inflow			2.9	2.6	2.5	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Kinzer Creek			2.8	2.5	2.4	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Eden Valley Creek			21.7	18.5	17.5	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6
Trib to Long L Inlet			0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Lakesheds			5.1	4.4	3.9	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
All Local Sources			45.2	38.5	35.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5
External Inflow			205.3	173.5	169.8	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2
Precipitation			5.9	5.9	5.7	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
Evaporation			8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1
Net Inflow			203.1	171.4	167.4	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3
Outflow			203.1	171.4	167.4	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3

App D - 10 Simulation Results for Several Loading Scenarios

Details in Appendix --> E F G

			Historical				vs. Max Trib Conc							vs. Max Trib Conc, 50% Shoreline Reduc							TMDL Scenarios		
Scenario	Criterion	SE	1978-1990	1997-2006	1997-2001	2002-2006	TRIB_40	TRIB_50	TRIB_60	TRIB_70	TRIB_80	TRIB_90	TRIB_100	TRIB_40_SL	TRIB_50_SL	TRIB_60_SL	TRIB_70_SL	TRIB_80_SL	TRIB_90_SL	TRIB_100_SL	TMDL_BASE	TMDL_TR_100	TMDL_TR_60_SL_50
Inflow TP Loads kg																							
Sauk River Inflow			87052	23223	20910	25536	5427	6784	8141	9498	10855	12212	13569	5427	6784	8141	9498	10855	12212	13569	25536	13569	8141
Kolling Creek			557	441	386	496	445	496	496	496	496	496	496	445	496	496	496	496	496	496	496	496	496
Schneider Inflow			232	206	202	211	109	136	164	191	211	211	211	109	136	164	191	211	211	211	211	211	164
Kinzer Creek			214	181	180	182	100	125	150	175	182	182	182	100	125	150	175	182	182	182	182	182	150
Eden Valley Creek			2886	2531	2406	2655	784	980	1176	1372	1568	1764	1960	784	980	1176	1372	1568	1764	1960	2655	1960	1176
Trib to Long L Inlet			110	97	92	102	30	37	45	52	60	67	75	30	37	45	52	60	67	75	102	75	45
Lakesheds			294	243	225	261	261	261	261	261	261	261	261	261	261	261	261	261	261	261	261	261	261
Excess Runoff			118	118	118	118	118	118	118	118	118	118	118	59	59	59	59	59	59	59	118	118	59
Septic Systems			404	404	404	404	404	404	404	404	404	404	404	202	202	202	202	202	202	202	404	404	202
All Local Sources			4816	4221	4014	4428	2252	2558	2814	3069	3300	3503	3707	1991	2297	2553	2808	3039	3242	3446	4428	3707	2553
External Inflow			91868	27444	24924	29965	7679	9342	10955	12567	14154	15715	17275	7418	9081	10694	12306	13893	15454	17014	29965	17275	10694
Precipitation			177	178	171	186	186	186	186	186	186	186	186	186	186	186	186	186	186	186	186	186	186
Net Inflow			92044	27622	25095	30150	7865	9528	11140	12753	14340	15901	17461	7604	9267	10879	12492	14079	15640	17200	30150	17461	10879
Outflow			84893	24246	21868	26632	6720	8178	9593	11008	12400	13770	15140	6528	7986	9401	10816	12208	13578	14948	26632	15140	9401
Retention			7151	3377	3227	3518	1145	1350	1547	1745	1940	2131	2321	1075	1281	1478	1676	1871	2061	2252	3518	2321	1478
Inflow Concs ppb																							
Sauk River Inflow			544	172	156	188	40	50	60	70	80	90	100	40	50	60	70	80	90	100	188	100	60
Kolling Creek			47	45	46	45	40	45	45	45	45	45	45	40	45	45	45	45	45	45	45	45	45
Schneider Inflow			80	78	79	77	40	50	60	70	77	77	77	40	50	60	70	77	77	77	77	77	60
Kinzer Creek			76	73	74	73	40	50	60	70	73	73	73	40	50	60	70	73	73	73	73	73	60
Eden Valley Creek			133	136	138	135	40	50	60	70	80	90	100	40	50	60	70	80	90	100	135	100	60
Trib to Long L Inlet			133	136	138	135	40	50	60	70	80	90	100	40	50	60	70	80	90	100	135	100	60
Lakesheds			57	56	57	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
All Local Sources			107	110	113	107	54	62	68	74	79	84	89	48	55	61	68	73	78	83	107	89	61
External Inflow			448	158	147	169	43	53	62	71	80	89	97	42	51	60	69	78	87	96	169	97	60
Precipitation			30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Net Inflow			453	161	150	172	45	54	64	73	82	91	100	43	53	62	71	80	89	98	172	100	62
Outflow			418	141	131	152	38	47	55	63	71	79	86	37	46	54	62	70	77	85	152	86	54

Meets Criterion

Meets Criterion + 1 Standard Error

Standard Errors are computed for the TMDL_TR_60_SL_50% Scenario

Appendix E

Simulation Results

Scenario: 2002-2006
Baseline Condition

Appendix E - 1 Model Input Loads & Parameter Estimates Scenario: 2002-2006

Segment	Parcel Count	Septic Count	Areas km^2 Lake	Watershed	Total Flow hm^3	Mean Flow cfs	----------- Total P Loads kg ------------------ Watershed	Lot Runoff	Septic	Total	% Total	FWM Conc ppb	P Export kg/km^2	Non-Algal Turb 1/m
Local Tributaries														
Sauk River Inflow				2087.8	135.7	363.1	25536			25536	84.7%	188	12	
Kolling Creek				97.4	11.1	29.8	496			496	1.6%	45	5	
Schneider Inflow				34.2	2.7	7.3	211			211	0.7%	77	6	
Kinzer Creek				18.5	2.5	6.7	182			182	0.6%	73	10	
Eden Valley Creek				105.7	19.6	52.5	2655			2655	8.8%	135	25	
Trib to Long L Inlet				4.0	0.7	2.0	102			102	0.3%	135	25	
Total Local Tribs				259.8	36.7	98.3	3646			3645.6	12.1%	99	14	
Total Inflows				2347.6	172.4	461.4	29182			29182	96.8%	287	26	
Lakesheds														
01_Horse_N	53	26	0.25	1.1	0.12	0.3	6	3	10	20	0.1%	170	19	0.65
02_East	120	55	1.09	0.1	0.02	0.0	1	7	22	30	0.1%	1883	205	0.65
03_Koetter	93	48	0.52	0.7	0.08	0.2	4	6	19	29	0.1%	373	41	0.65
04_Zumwalde	77	44	0.49	0.6	0.06	0.2	3	5	18	26	0.1%	422	46	0.65
05_Gt Northern	75	46	0.76	1.6	0.18	0.5	10	5	18	33	0.1%	184	20	0.65
06_Krays	49	24	0.37	0.5	0.05	0.1	3	3	10	15	0.1%	290	32	0.65
07_Knaus/Park	362	103	0.85	1.1	0.12	0.3	7	22	41	70	0.2%	562	61	0.65
08_Becker	105	48	0.66	1.0	0.11	0.3	6	6	19	32	0.1%	287	31	0.60
09_Horse_W	229	112	1.02	3.0	0.33	0.9	18	14	45	77	0.3%	235	26	0.30
10_Horse_S	110	54	1.27	0.1	0.01	0.0	0	7	21	29	0.1%	3985	435	0.10
11_Cedar	215	129	2.04	20.2	2.21	5.9	120	13	52	185	0.6%	84	9	0.20
12_Schneider	120	75	0.22	2.2	0.23	0.6	13	7	30	50	0.2%	213	23	0.10
13_Bolfing	79	46	0.43	3.5	0.39	1.0	21	5	18	44	0.1%	115	12	0.10
14_Long	115	67	1.97	1.3	0.14	0.4	7	7	27	41	0.1%	300	33	0.20
15_Browns	134	134	1.26	7.0	0.77	2.1	42	8	54	103	0.3%	135	15	0.10
Total	1936	1011	13.21	44.1	4.80	12.9	261	118	404	783	2.6%	163	18	
Sauk River Inflow				2087.8	135.7	363	25536			25536	85%	188	12	
Total Local Tribs				260	36.7	98	3646			3646	12%	99	14	
Total Lakesheds	1936	1011	13.2	44.1	4.8	13	261	118	404	783	3%	163	18	
Local+Lakesheds	1936	1011	13.2	304	42	111	3907	118	404	4428	15%	107	15	
Total External Inflow	1936	1011	13.2	2391.7	177.2	474	29443	118	404	29965	99%	169	13	
Precipitation			13.2		6.2	17				186	1%	30	14	
Evaporation			13.2		8.1	22								
Net Inflow				2404.9	175.3	469				30150	100%	172	13	
Predicted Outflow				2404.9	175.3	469	1256			26632	88%	152	11	
Retention										3518	12%			

<u>Assumptions for Shoreline Sources</u>

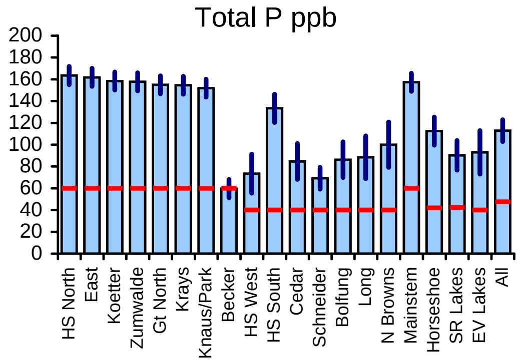
Excess Runoff; Above Lakeshed Background		
Average Lot Size	0.5	acres
Excess Areal Load	30	kg / km^{2}, may-sept, average year
Runoff Load Per Lot	0.061	kg / lot
Load per Septic Tank	0.40	kg
TMDL Reduction	#N/A	

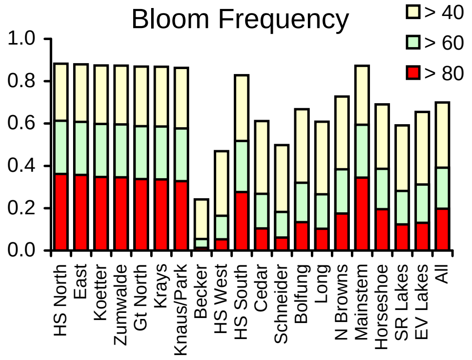
<u>BATHTUB Parameters</u>

Averaging Period	0.42	years	
Net Settling Rate - Other Lakes	4.8	m/yr	BATHTUB P Model 7
Net Settling Rate - North Browns	14.4	m/yr	
Net Settling Rate - Schneders L	9.6	m/yr	
Chlorophyll-a Calibration	1.00		BATHTUB Chl-a Model 2
Algal Light Extinction	0.015	m^2/mg	
Chla Flushing Coefficient	0.40		
Chl-a Coef of Variation	0.45		

Appendix E - 2 Mass Balance & Predicted Lake Responses Scenario: 2002-2006

Lake	Criterion	TP	TP_SE	Chl-a	Secchi	Algal Bloom Frequencies			Trophic Strate Indices		
Segment	ppb	ppb	ppb	ppb	m	> 40	> 60	> 80	Total P	Chl-a	Secchi
HS North	60	163	8	68	0.60	0.88	0.61	0.36	78	72	67
East	60	162	8	68	0.60	0.88	0.61	0.36	77	72	67
Koetter	60	158	8	67	0.60	0.87	0.60	0.35	77	72	67
Zumwalde	60	158	8	67	0.60	0.87	0.60	0.35	77	72	67
Gt North	60	155	8	66	0.61	0.87	0.59	0.34	77	72	67
Krays	60	154	8	66	0.61	0.87	0.59	0.34	77	72	67
Knaus/Park	60	152	8	65	0.61	0.86	0.58	0.33	77	72	67
Becker	60	60	8	29	0.96	0.24	0.05	0.01	63	64	61
HS West	40	73	18	39	1.14	0.47	0.16	0.05	66	67	58
HS South	40	133	13	61	0.98	0.83	0.52	0.28	75	71	60
Cedar	40	85	16	45	1.13	0.61	0.27	0.10	68	68	58
Schneider	40	69	10	40	1.43	0.50	0.18	0.06	65	67	55
Bolfung	40	86	16	49	1.21	0.67	0.32	0.13	68	69	57
Long	40	88	20	45	1.14	0.61	0.27	0.10	69	68	58
N Browns	40	100	21	53	1.13	0.73	0.38	0.18	71	70	58
Mainstem	60	157	8	67	0.61	0.87	0.59	0.34	77	72	67
Horseshoe	42	112	13	53	1.01	0.69	0.39	0.20	72	70	60
SR Lakes	42	90	14	46	1.10	0.59	0.28	0.12	69	68	59
EV Lakes	40	93	20	48	1.13	0.65	0.31	0.13	70	69	58
All	48	113	10	53	0.94	0.70	0.39	0.20	72	70	61

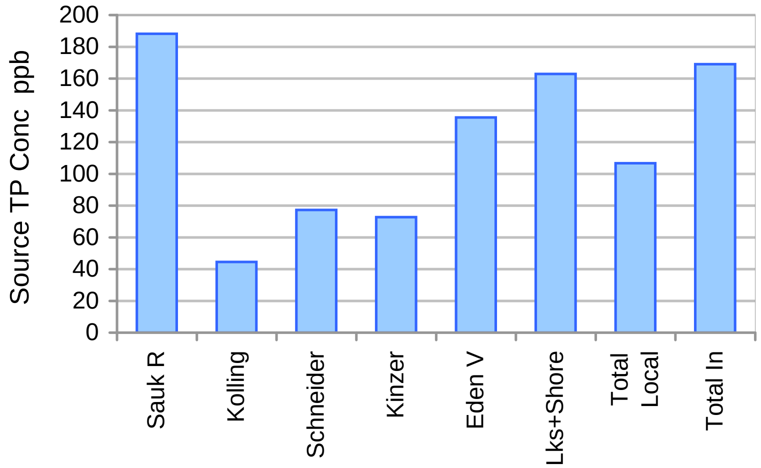

Total P ppb

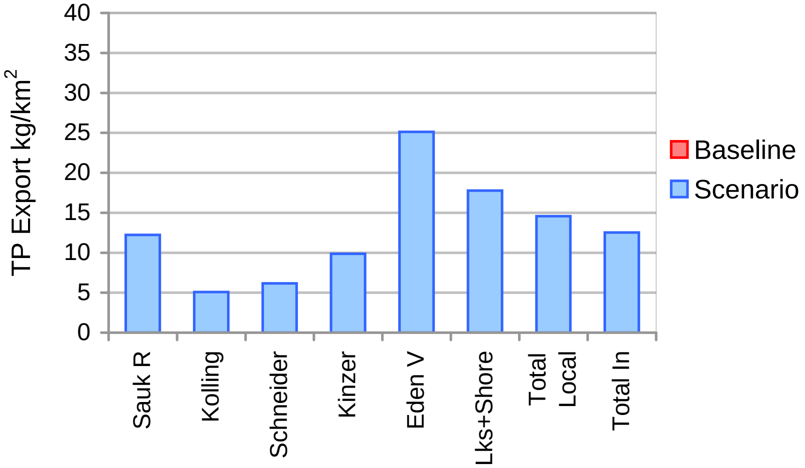

Bloom Frequency

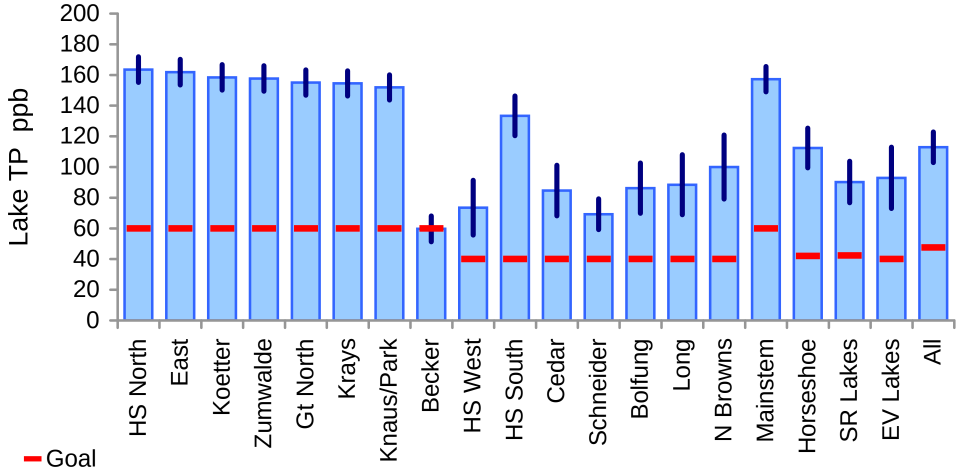
Water & Mass Balance (May - September)

2002-2006								2002-2006 Baseline		Load
	Dr Area	Flow	Load	Conc	Runoff	Export	Percent	Load	Conc	Reduc
Source	km^2	hm^3	kg	ppb	cm	kg/km^2	of Load	kg	ppb	%
Sauk River Inflow	2088	136	25536	188	6	12	85%	25536	188	0%
Kolling Creek	97	11	496	45	11	5	2%	496	45	0%
Schneider Inflow	34	3	211	77	8	6	1%	211	77	0%
Kinzer Creek	18	3	182	73	14	10	1%	182	73	0%
Eden Valley Creek	106	20	2655	135	19	25	9%	2655	135	0%
Trib to Long L Inlet	4	1	102	135	19	25		102	135	0%
Lakesheds	44	5	261	54	11	6	1%	261	54	0%
Septic Systems			404				1%	404		0%
Excess Runoff			118					118		0%
External Inflow	2392	177	29965	169	7	13	99%	29965	169	0%
Precipitation	13	6	186	30	47	14	1%	186	30	0%
Evaporation		8			61					
Net Inflow	2405	175	30150	172	7	13	100%	30150	172	0%
Outflow	2405	175	26632	152	7	11	88%	26632	152	0%
Retention			3518				12%	3518		

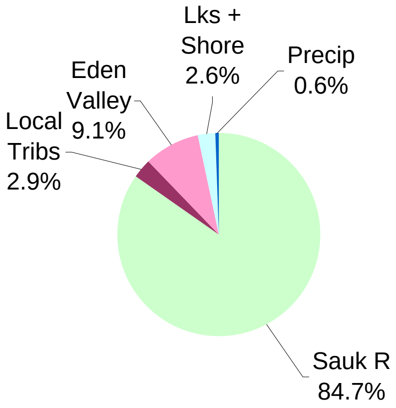
Appendix E - 3 Load Reductions by Tributary Scenario: 2002-2006







May-Sept Total P Load = 30 mt



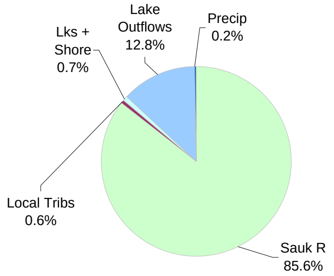
Predicted Summer Mean TP +/- 1 Standard Error

Lks+Shore = Lakesheds 0.9% + Septic Tanks 1.3% + Excess Lot Runoff 0.4%

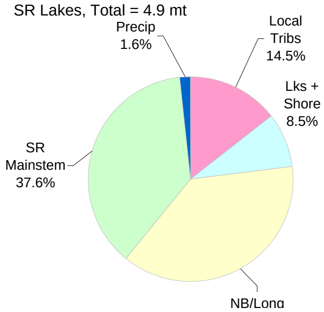
Total Local = All Sources Except Sauk River & Precipitation

Appendix E - 4 Phosphorus Sources by Region Scenario: 2002-2006

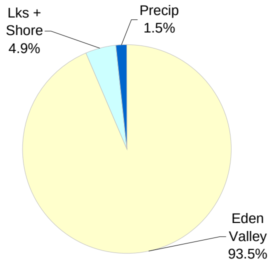
Mainstem, Total = 29.8 mt



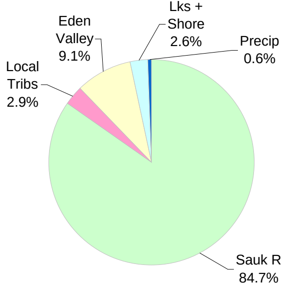
SR Lakes, Total = 4.9 mt



N Browns / Long, Total = 2.9 mt



All Lakes, Total = 30 mt



Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Mainstem Lakes (Horseshoe North - Knaus)									
Sauk River	2088	135.7	25536	188	87%	76%	91.2%	0.06	12.2
Kinzer Creek	18	2.5	182	73	1%	1%	0.7%	0.14	9.9
Lakeshed	6	0.6	34	54	0%	0%	0.1%	0.11	5.9
Septic Tanks	0		138				0.5%		
Shoreline Runoff	0		50				0.2%		
Total External	2112	138.8	25941	187	88%	78%	92.7%	0.07	12.3
Outflow from Lakes	288	37.1	3824	103	12%	21%	13.7%	0.13	13.3
Exchange with Lakes			-1831				-6.5%		0.0
Precip	4	2.0	61	30	0%	1%	0.2%	0.47	14.1
Evap		0.0				0%	0.0%		
Net Inflow	2405	178.0	27995	157	100%	100%	100.0%	0.07	11.6
Outflow	2405	175.3	26632	152	100%	99%	95.1%	0.07	11.1
Retention			1363				4.9%		
Offline Lakes (Becker, HS South, HS West, Cedar, Schneider, Bolfung)									
Kolling Creek	97	11.1	496	45	34%	27%	10.2%	0.11	5.1
Schneider Inflow	34	2.7	211	77	12%	7%	4.3%	0.08	6.2
Lakesheds	30	3.3	178	54	10%	8%	3.6%	0.11	5.9
Septic Tanks			186				3.8%		
Shoreline Runoff			52				1.1%		
Total External	162	17.1	1122	65	56%	42%	23.0%	0.11	6.9
Inflow from Long	121	20.8	1840	88	42%	51%	37.8%	0.17	15.2
Exchange with Mainstem			1831				37.6%		0.0
Precip	6	2.6	79	30	2%	7%	1.6%	0.47	14.1
Evap		0.0				0%	0.0%		
Net Inflow	288	40.6	4872	120	100%	100%	100.0%	0.47	16.9
Outflow	288	37.1	3824	103	100%	92%	78.5%	0.47	13.3
Retention			1048				21.5%		
North Browns + Long									
Eden Valley Creek	106	19.6	2655	135	87%	94%	90.1%	0.19	25.1
Trib to Long L Inlet	4	0.7	102	135	3%	4%	3.4%	0.19	25.1
Lakeshed	8	0.9	49	54	7%	4%	1.7%	0.11	5.9
Septic Tanks	0		80				2.7%		
Shoreline Runoff	0		15				0.5%		
Total External	118	21.3	2901	137	97%	102%	98.5%	0.18	24.6
Precip	3	1.5	46	30	3%	7%	1.5%	0.47	14.1
Evap		2.0				9%			
Net Inflow	121	20.8	2947	142	100%	100%	100.0%	0.17	24.3
Outflow	121	20.8	1840	88	100%	100%	62.4%	0.17	15.2
Retention			1107				37.6%		
Overall									
Sauk River	2088	135.7	25536	188	87%	77%	84.7%	0.06	12.2
Kolling Creek	97	11.1	496	45	4%	6%	1.6%	0.11	5.1
Schneider Inflow	34	2.7	211	77	1%	2%	0.7%	0.08	6.2
Kinzer Creek	18	2.5	182	73	1%	1%	0.6%	0.14	9.9
Eden Valley Creek	106	19.6	2655	135	4%	11%	8.8%	0.19	25.1
Trib to Long L Inlet	4	0.7	102	135	0%	0%	0.3%	0.19	25.1
Lakesheds	44	4.8	261	54	2%	3%	0.9%	0.11	5.9
Septic Tanks			404				1.3%		
Shoreline Runoff			118				0.4%		
Total External	2392	177.2	29965	169	99%	101%	99.4%	0.07	12.5
Precip	13	6.2	186	30	1%	4%	0.6%	0.47	14.1
Evap		8.1				5%			
Net Inflow	2405	175.3	30150	172	100%	100%	100.0%	0.07	12.5
Outflow	2405	175.3	26632	152	100%	100%	88.3%	0.07	11.1
Retention			3518				11.7%		

Appendix E - 5 Water & Mass Balances by Segment Scenario: 2002-2006

Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
North Browns Lake									
Eden Valley Creek	105.7	19.6	2655.2	135	93%	97%	96%	0.19	25
Lakeshed	7.0	0.8	42	54	6%	4%	2%	0.11	6
Septic Tanks			54				2%		
Shoreline Runoff			8				0%		
Total External	112.7	20.4	2759	135	93%	101%	99%	0.18	24
Precip	1.3	0.6	18	30	1%	3%	1%	0.47	14
Evap		0.8				4%		0.61	
Net Inflow	114.0	20.2	2777	138	94%	100%	100%		
Outflow	114.0	20.2	2018	100	100%	100%	73%	0.18	18
Retention			758				27%		
Long Lake									
Trib to Long L Inlet	4.0	0.7	102	135	3%	4%	5%	0.19	25
Lakeshed	1.3	0.1	7.5	54	1%	1%	0%	0.11	6
Septic Tanks			27				1%		
Shoreline Runoff			7				0%		
Total External	5.3	0.9	143	161	4%	4%	7%	0.17	27
Outflow from N Browns	114.0	20.2	2018	100	94%	97%	92%	0.18	18
Precip	2.0	0.9	28	30	2%	4%	1%	0.47	14
Evap		1.2						0.61	
Net Inflow	121.3	20.8	2189	105	100%	100%	100%	0.17	18
Outflow	121.3	20.8	1840	88	100%	100%	84%	0.17	15
Retention			349				16%		
Becker Lake									
Kolling Creek	97.4	11.1	495.8	45	98%	100%	67%	0.11	5
Lakeshed	1.0	0.1	6	54	1%	1%	1%	0.11	6
Septic Tanks			19		0%	0%	3%		
Shoreline Runoff			6		0%	0%	1%		
Total External	98.4	11.2	527	47	99%	101%	71%	0.11	5
Exchange with Main Lake			208				28%		
Precip	0.7	0.3	9	30	1%	3%	1%	0.47	14
Evap		0.4				4%		0.61	
Net Inflow	99.1	11.2	744	67	100%	100%	100%	0.11	8
Outflow	99.1	11.2	666	60		100%	89%	0.11	7
Retention			78				11%		
Schneiders Lake									
Schneider Inflow	34.2	2.7	210.8	77	94%	93%	80%	0.08	6
Lakeshed	2.2	0.2	13	54	6%	8%	5%	0.11	6
Septic Tanks			30		0%	0%	11%		
Shoreline Runoff			7		0%	0%	3%		
Total External	36.3	3.0	261	88	99%	101%	99%	0.08	7
Exchange with Main Lake			0				0%		
Precip	0.2	0.1	3	30	1%	4%	1%	0.47	14
Evap		0.1				5%		0.61	
Net Inflow	36.5	2.9	264	90	100%	100%	100%	0.08	7
Outflow	36.5	2.9	203	69		100%	77%	0.08	6
Retention			61				23%		
Cedar Island Lake (Including Mud, Little C									
Lakeshed	20.2	2.2	120	54	91%	115%	24%	0.11	6
Septic Tanks			52			0%	10%		
Shoreline Runoff			13			0%	3%		
Total External	20.2	2.2	185	84	91%	115%	36%	0.11	9
Exchange with Main Lake			295				58%		
Precip	2.0	1.0	29	30	9%	50%	6%	0.47	14
Evap		1.2				65%		0.61	
Net Inflow	22.3	1.9	508	265	100%	100%	100%	0.09	23
Outflow	22.3	1.9	163	85	100%	100%	32%	0.09	7
Retention			346				68%		
Bolfung Lake									
Lakeshed	3.5	0.4	21	54	89%	119%	20%	0.11	6
Septic Tanks			18		0%	0%	18%		
Shoreline Runoff			5		0%	0%	5%		
Total External	3.5	0.4	44	115	89%	119%	43%	0.11	12
Exchange with Main Lake			52				51%		
Precip	0.4	0.2	6	30	11%	63%	6%	0.47	14
Evap		0.3				81%		0.61	
Net Inflow	4.0	0.3	103	317	100%	100%	100%	0.08	26
Outflow	4.0	0.3	28	86	100%	100%	27%	0.08	7
Retention			75				73%		

Appendix E - 5 Water & Mass Balances by Segment Scenario: 2002-2006

Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Horseshoe West - Krons Bay									
Lakeshed	3.0	0.3	18	54	75%	178%	11%	0.11	6
Septic Tanks			45				28%		
Shoreline Runoff			14				9%		
Total External	3.0	0.3	77	235	75%	178%	47%	0.11	26
Exchange with Main Lake			72				44%		
Precip	1.0	0.5	14	30	25%	260%	9%	0.47	14
Evap		0.6				338%		0.61	
Net Inflow	4.0	0.2	163	889	100%	100%	100%	0.05	41
Outflow	4.0	0.2	13	73	100%	100%	8%	0.05	3
Retention			149				92%		
Horseshoe South									
Lakeshed	0.1	0.0	0	54	0%	0%	0%	0.11	6
Septic Tanks			21				1%		
Shoreline Runoff			7				0%		
Total External	0.1	0.0	29	3985	0%	0%	1%	0.11	435
Outflow from Long Lake	121.3	20.8	1840		99%	101%	60%		
Exchange with Main Lake			1204				39%		
Precip	1.3	0.6	18	30	1%	3%	1%	0.47	14
Evap		0.8				4%		0.61	
Net Inflow	122.6	20.6	3090	150	100%	100%	100%	0.17	25
Outflow	122.6	20.6	2752	133	100%	100%	89%	0.17	22
Retention			339				11%		
Horseshoe North									
Sauk River Inflow	2087.8	135.7	25536.1	188	90%	81%	93%	0.06	12
Lakeshed	1.1	0.1	6	54	0%	0%	0%	0.11	6
Septic Tanks			10				0%		
Shoreline Runoff			3				0%		
Total External	2088.9	135.8	25556	188	90%	81%	93%	0.07	12
Outflow from Becker	99.1	11.2	666	60	4%	7%	2%	0.11	7
Outflow from HS West	4.0	0.2	13	73	0%	0%	0%	0.05	3
Outflow from HS South	122.6	20.6	2752	133	5%	12%	10%	0.17	22
Exchange with Becker			-208				-1%		
Exchange with HS West			-72				0%		
Exchange with HS South			-1204				-4%		
Precip	0.3	0.1	4	30	0%	0%	0%	0.47	
Evap		0.2				0%		0.61	
Net Inflow	2314.9	167.7	27507	164	100%	100%	100%	0.07	12
Outflow	2314.9	167.7	27424	163	100%	100%	100%	0.07	12
Retention			83				0%		
East Lake									
Lakeshed	0.1	0.0	1	54	0%	0%	0%	0.11	6
Septic Tanks			22				0%		
Shoreline Runoff			7				0%		
Total External	0.1	0.0	30	1883	0%	0%	0%	0.11	205
Outflow from Horshoe North	2314.9	167.7	27424	163	100%	100%	100%	0.07	12
Precip	1.1	0.5	15	30	0%	0%	0%	0.47	14
Evap		0.7				0%		0.61	
Net Inflow	2316.1	167.6	27469	164	100%	100%	100%	0.07	12
Outflow	2316.1	167.6	27116	162	100%	100%	99%	0.07	12
Retention			353				1%		
Koetters Lake									
Lakeshed	0.7	0.1	4	54	0%	0%	0%	0.11	6
Septic Tanks			19				0%		
Shoreline Runoff			6				0%		
Total External	0.7	0.1	29	373	0%	0%	0%	0.11	41
Outflow from East Lake	2316.1	167.6	27116	162	99%	99%	100%	0.07	12
Outflow from Cedar Lake	22.3	1.9	163	85	1%	1%	1%	0.09	7
Exchange with Cedar Lake			-295				-1%		
Precip	0.5	0.2	7	30	0%	0%	0%	0.47	14
Evap		0.3				0%	0%	0.61	
Net Inflow	2339.6	169.5	27020	159	100%	100%	100%	0.07	12
Outflow	2339.6	169.5	26854	158	100%	100%	99%	0.07	11
Retention			166				1%		

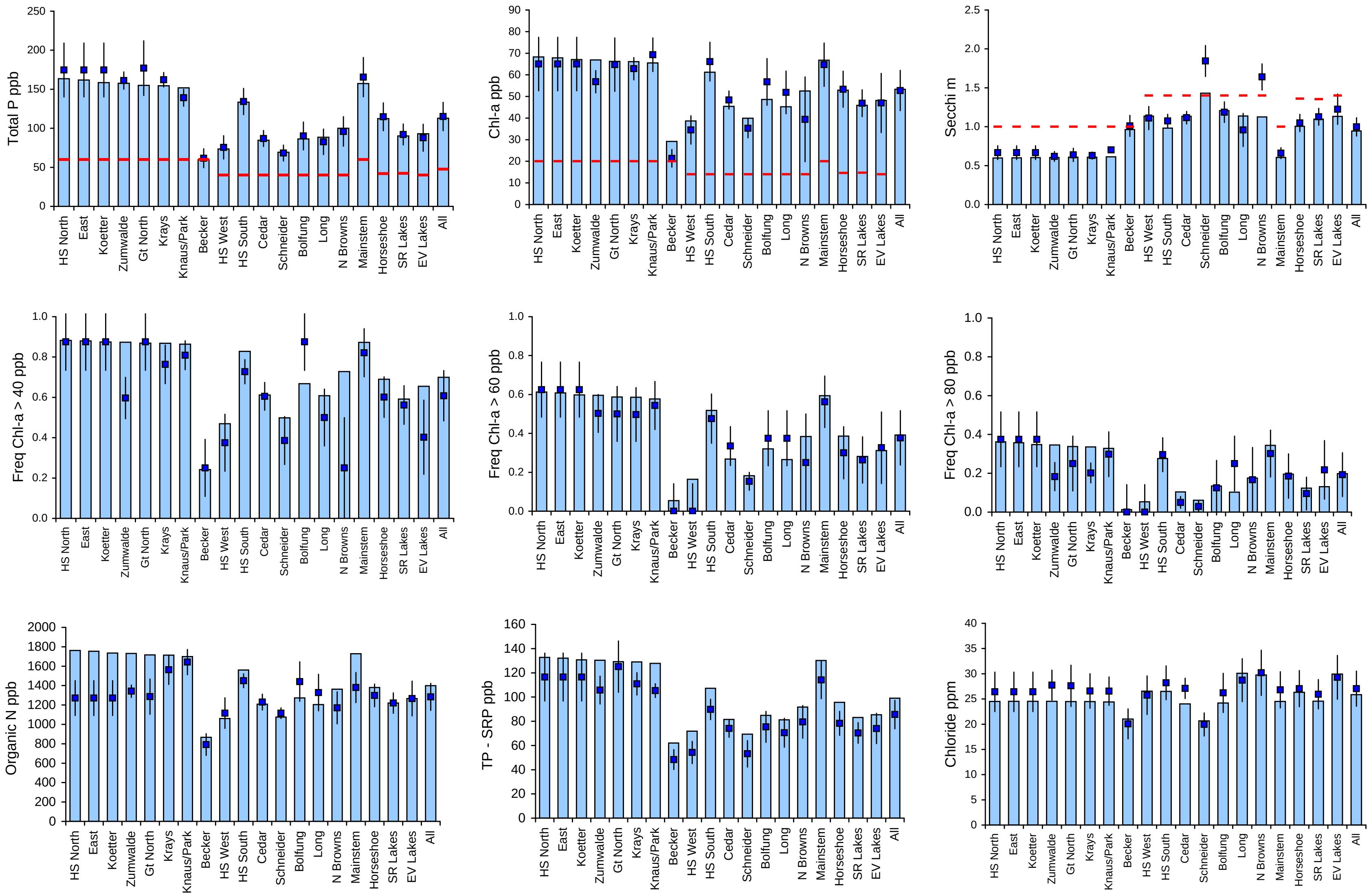
Appendix E - 5 Water & Mass Balances by Segment Scenario: 2002-2006

Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Zumwalde Lake									
Lakeshed	0.6	0.1	3	54	0%	0%	0%	0.11	6
Septic Tanks			18				0%		
Shoreline Runoff			5				0%		
Total External	0.6	0.1	26	422	0%	0%	0%	0.11	46
Outflow from Koetter	2339.6	169.5	26854	158	100%	100%	100%	0.07	11
Precip	0.5	0.2	7	30	0%	0%	0%	0.47	14
Evap		0.3				0%		0.61	
Net Inflow	2340.7	169.5	26887	159	100%	100%	100%	0.07	11
Outflow	2340.7	169.5	26733	158	100%	100%	99%	0.07	11
Retention			154				1%		
Great Northern Lake									
Lakeshed	1.6	0.2	10	54	0%	0%	0%	0.11	6
Septic Tanks			18				0%		
Shoreline Runoff			5				0%		
Total External	1.6	0.2	33	184	0%	0%	0%	0.11	20
Outflow from Zumwalde	2340.7	169.5	26733	158	98%	98%	99%	0.07	11
Outflow from Schneider	36.5	2.9	203	69	2%	2%	1%	0.08	6
Exchange with Schneider			0				0%		
Precip	0.8	0.4	11	30	0%	0%	0%	0.47	14
Evap		0.5				0%		0.61	
Net Inflow	2379.6	172.5	26979	156	100%	100%	100%	0.07	11
Outflow	2379.6	172.5	26744	155	100%	100%	99%	0.07	11
Retention			234				1%		
Krays Lake									
Lakeshed	0.5	0.1	3	54	0%	0%	0%	0.11	6
Septic Tanks			10				0%		
Shoreline Runoff			3				0%		
Total External	0.5	0.1	15	290	0%	0%	0%	0.11	32
Outflow from Great North	2379.6	172.5	26744	155	100%	100%	100%	0.07	11
Precip	0.4	0.2	5	30	0%	0%	0%	0.47	14
Evap		0.2				0%		0.61	
Net Inflow	2380.4	172.5	26765	155	100%	100%	100%	0.07	11
Outflow	2380.4	172.5	26652	154	100%	100%	100%	0.07	11
Retention			113				0%		
Knaus & Park Lakes									
Kinzer Creek	18.5	2.5	182.3	73	1%	1%	1%	0.14	10
Lakeshed	1.1	0.1	7	54	0%	0%	0%	0.11	6
Septic Tanks			41				0%		
Shoreline Runoff			22				0%		
Total External	19.6	2.6	252	96	1%	1%	1%	0.13	13
Outflow from Krays	2380.4	172.5	26652	154	99%	98%	99%	0.07	11
Outflow from Bolfung	4.0	0.3	28		0%	0%	0%		
Exchange with Bolfung			-52				0%		
Precip	0.9	0.4	12	30	0%	0%	0%	0.47	14
Evap		0.5				0%		0.61	
Net Inflow	2404.9	175.3	26892	153	100%	100%	100%	0.07	11
Outflow	2404.9	175.3	26632	152	100%	100%	99%	0.07	11
Retention			260				1%		

Appendix E - 5 Water & Mass Balances by Segment Scenario: 2002-2006

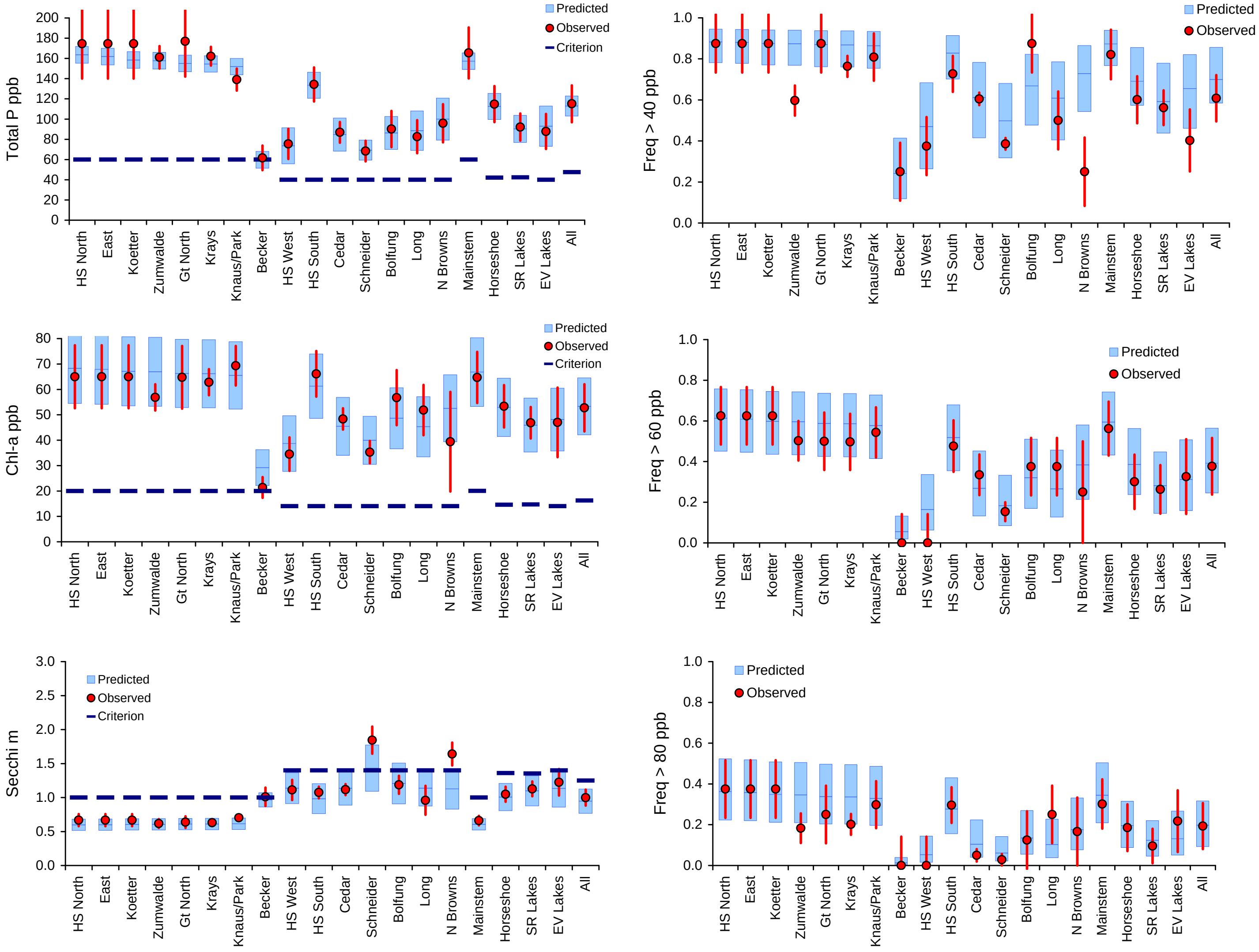
Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Mainstem Lakes (Horseshoe North - Knau									
Sauk River	2087.8	135.7	25536	188	87%	76%	91%	0.06	12
Kinzer Creek	18.5	2.5	182	73	1%	1%	1%	0.14	10
Lakeshed	5.7	0.6	34	54	0%	0%	0%	0.11	6
Septic Tanks			138		0%	0%	0%		
Shoreline Runoff			50		0%	0%	0%		
Total External	2112.1	138.8	25941	187	88%	78%	93%	0.07	12
Outflow from Lakes	288.5	37.1	3824	103	12%	21%	14%	0.13	13
Exchange with Lakes			-1831				-7%		
Precip	4.3	2.0	61	30	0%	1%	0%	0.47	14
Evap		0.0				0%			
Net Inflow	2404.9	178.0	27995	157	100%	100%	100%	0.07	12
Outflow	2404.9	175.3	26632	152	100%	99%	95%	0.07	11
Retention			1363				5%		
Offline Lakes (Becker, HS South, HS West									
Kolling Creek	97.4	11.1	496	45	34%	27%	10%	0.11	5
Schneider Inflow	34.2	2.7	211	77	12%	7%	4%	0.08	6
Lakesheds	30.0	3.3	178	54	10%	8%	4%	0.11	6
Septic Tanks			186				4%		
Shoreline Runoff			52				1%		
Total External	161.6	17.1	1122	65	56%	42%	23%	0.11	7
Inflow from Long	121.3	20.8	1840	88	42%	51%	38%	0.17	15
Exchange with Mainstem			1831				38%		
Precip	5.6	2.6	79	30	2%	7%	2%	0.47	14
Evap		0.0				0%			
Net Inflow	288.5	40.6	4872	120	100%	100%	100%	0.47	17
Outflow	288.5	37.1	3824	103	100%	92%	78%	0.47	13
Retention			1048				22%		
Mainstem + Lakes, Excluding North Brow									
Sauk River	2087.8	135.7	25536	188	87%	75%	88%	0.06	12
Kinzer Creek	18.5	2.5	182	73	1%	1%	1%	0.14	10
Kolling Creek	97.4	11.1	496	45	4%	6%	2%	0.11	5
Schneider Inflow	34.2	2.7	211	77	1%	2%	1%	0.08	6
Lakesheds	35.7	3.9	212	54	1%	2%	1%	0.11	6
Septic Tanks			324		0%	0%	1%		
Shoreline Runoff			102		0%	0%	0%		
Outflow from Long	121.3	20.8	1840	88	5%	11%	6%	0.17	15
Total External	2394.9	176.7	28903	164	100%	97%	100%	0.07	12
Precip	10.0	4.7	140	30	0%	3%	0%	0.47	14
Evap		0.0				0%			
Net Inflow	2404.9	181.4	29043	160	100%	100%	100%	0.08	12
Outflow	2404.9	175.3	26632	152	100%	97%	92%	0.07	11
Retention			2411				8%		
North Browns + Long									
Eden Valley Creek	105.7	19.6	2655	135	87%	94%	90%	0.19	25
Trib to Long L Inlet	4.0	0.7	102	135	3%	4%	3%	0.19	25
Lakeshed	8.3	0.9	49	54	7%	4%	2%	0.11	6
Septic Tanks			80				3%		
Shoreline Runoff			15				1%		
Total External	118.0	21.3	2901	137	97%	102%	98%	0.18	25
Precip	3.2	1.5	46	30	3%	7%	2%	0.47	14
Evap		2.0				9%			
Net Inflow	121.3	20.8	2947	142	100%	100%	100%	0.17	24
Outflow	121.3	20.8	1840	88	100%	100%	62%	0.17	15
Retention			1107				38%		
Overall									
Sauk River	2087.8	135.7	25536	188	87%	77%	85%	0.06	12
Kolling Creek	97.4	11.1	496	45	4%	6%	2%	0.11	5
Schneider Inflow	34.2	2.7	211	77	1%	2%	1%	0.08	6
Kinzer Creek	18.5	2.5	182	73	1%	1%	1%	0.14	10
Eden Valley Creek	105.7	19.6	2655	135	4%	11%	9%	0.19	25
Trib to Long L Inlet	4.0	0.7	102	135	0%	0%	0%	0.19	25
Lakesheds	44.1	4.8	261	54	2%	3%	1%	0.11	6
Septic Tanks			404			0%	1%		
Shoreline Runoff			118			0%	0%		
Total External	2391.7	177.2	29965	169	99%	101%	99%	0.07	13
Precip	13.2	6.2	186	30	1%	4%	1%	0.47	14
Evap		8.1				5%		0.61	
Net Inflow	2404.9	175.3	30150	172	100%	100%	100%	0.07	13
Outflow	2404.9	175.3	26632	152	100%	100%	88%	0.07	11
Retention			3518				12%		

Appendix E - 6 Observed & Predicted Lake Water Quality Scenario: 2002-2006



Bars = Model Predictions. Symbols = Measured Values +/- 1 Standard Error Computed from Distribution of Summer Means Across Years. Red lines = Criteria

Appendix E - 7 Observed & Predicted Confidence Intervals Scenario: 2002-2006



Means +/- 1 standard error of observed (symbols) and predicted (bars) values.

Blue lines indicate MPCA criteria for deep & shallow lakes. (TP < 40 or 60 ppb, Chla < 14 or < 20 ppb, Secchi >1.4 or 1.0 m

Appendix E - 8 Sensitivity Analysis Scenario: 2002-2006

Percent Reduction in Lake P for with a 20% Reduction in Source or Model Coefficient

	Total P		Source Flow				Source Concentration				Settling Rate		Exchange
Segment	ppb	RSE	Sauk R	Tribs	Eden V	Lakeshed	Sauk R	Tribs	Eden V	Lakeshed	Mainstem	Lake	Rates
HS North	163	0.05	3	-1	-1	0	18	0	1	0	0	-1	0
East	162	0.05	3	-1	-1	0	18	0	1	0	0	-1	0
Koetter	158	0.05	3	-1	-1	0	18	0	1	0	0	-1	0
Zumwalde	158	0.05	3	-1	-1	0	18	0	1	0	-1	-1	0
Gt North	155	0.05	4	-1	-1	0	18	0	1	0	-1	-1	0
Krays	154	0.05	4	-1	-1	0	18	0	1	0	-1	-1	0
Knaus/Park	152	0.05	4	-1	0	0	18	1	1	0	-1	-1	0
HS West	60	0.24	2	-1	0	5	11	0	1	7	0	-16	7
HS South	73	0.10	2	-1	-1	0	14	0	5	0	0	-3	3
Cedar	133	0.19	3	-1	0	0	14	0	1	5	0	-10	7
Schneider	85	0.14	0	2	0	3	0	16	0	4	0	-5	0
Bolfung	69	0.19	3	-1	0	1	13	0	1	5	-1	-10	7
Long	86	0.22	0	0	8	1	0	0	19	1	0	-9	0
N Browns	88	0.21	0	0	6	0	0	0	19	1	0	-6	0
Mainstem	100	0.05	4	-1	-1	0	18	0	1	0	-1	-1	0
Horseshoe	157	0.11	2	-1	-1	1	14	0	3	2	0	-6	4
SR Lakes	112	0.15	2	-1	-1	1	12	2	2	3	0	-8	5
EV Lakes	90	0.22	0	0	7	0	0	0	19	1	0	-8	0
All	93	0.09	2	-1	1	0	12	1	5	1	0	-5	2
Assumed Input Uncertainty (RSE)			10%	15%	20%	20%	5%	15%	20%	30%	20%	20%	40%

Shading: >15% >5% >2% reduction for a 20% reduction in model input value

RSE = Relative Standard Error in predicted Total P computed using first-order error analysis (Walker, 1982; 2006)

Lakeshed sources include ungauged runoff, shoreline runoff and septic systems.

Appendix E - 9 BATHTUB Input File Scenario: 2002-2006

Case Title	Sauk River Chain of Lakes Scenario 2002-2006

B	15
C	22
Number of Channels	0

Notes	Scenario 2002-2006

Global Variables

Averaging Period (yrs)	0.42	0
Precipitation (m)	0.47	0.2
Evaporation (m)	0.61	0.3

Atmos. Loads (kg/km2-yr)

Conserv. Substance		
Total P	34	0.5
Total N		

Segment Data

Segment Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Segment Name		HS North	East	Koetter	Zumwald	Gt North	Krays	Knaus/Pa	Becker	HS West	HS South	Cedar	Schneide	Bolfung	Long	N Browns
Outflow Segment Number		2	3	4	5	6	7	0	1	1	1	3	5	7	10	14
Segment Group Number		1	1	1	1	1	1	1	2	3	4	5	6	7	8	9
Segment Morphometry																
Surface Area (km2)		0.25	1.09	0.52	0.49	0.76	0.37	0.85	0.66	1.02	1.27	2.04	0.22	0.43	1.97	1.26
Mean Depth (m)		1.64	0.76	1.14	1.85	1.86	2.14	1.96	2.44	5.86	3.52	4.34	6.12	4.03	3.04	5.60
Length (km)		1.00	1.80	3.00	2.00	1.00	1.00	1.00	2.00	1.00	1.50	2.00	1.00	1.00	3.00	1.80
Mixed Depth (m)	Mean	1.64	0.76	1.14	1.85	1.86	2.14	1.96	2.44	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	CV	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Observed Water Quality																
Non-Algal Turb (1/m)	Mean	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.6	0.3	0.1	0.2	0.1	0.1	0.2	0.1
	CV	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Conservative Subst	Mean			26.42	27.74	27.61	26.58	26.56	20.06	25.75	28.21	27.10	19.96	26.21	28.72	30.19
	CV			0.15	0.11	0.15	0.13	0.11	0.15	0.15	0.12	0.07	0.11	0.15	0.15	0.15
Total P (ppb)	Mean			174.63	161.10	177.00	162.18	139.05	61.63	75.50	134.28	86.90	68.32	90.13	82.63	95.92
	CV			0.20	0.07	0.20	0.06	0.08	0.20	0.20	0.13	0.12	0.15	0.20	0.20	0.20
Chlorophyll-a (ppb)	Mean			65.00	56.85	64.75	62.83	69.30	21.38	34.50	66.10	48.37	35.30	56.75	51.88	39.41
	CV			0.19	0.09	0.19	0.08	0.11	0.19	0.19	0.14	0.09	0.13	0.19	0.19	0.50
Secchi (m)	Mean			0.67	0.62	0.64	0.63	0.70	1.01	1.11	1.07	1.12	1.84	1.19	0.96	1.64
	CV			0.13	0.10	0.13	0.07	0.04	0.13	0.13	0.08	0.07	0.11	0.11	0.22	0.10
Organic N (ppb)	Mean			1271.88	1342.34	1285.63	1563.05	1642.86	792.13	1116.13	1449.67	1230.11	1116.04	1441.04	1328.13	1170.88
	CV			0.14	0.05	0.14	0.10	0.08	0.14	0.14	0.05	0.07	0.05	0.14	0.14	0.14
Total P - Ortho P (ppb)	Mean			116.50	105.74	125.13	110.90	105.30	48.38	54.25	89.78	74.04	53.18	75.38	70.50	79.50
	CV			0.17	0.11	0.17	0.08	0.05	0.17	0.17	0.09	0.10	0.21	0.17	0.17	0.17
Calibration Factors																
Dispersion Rate	Mean	0	0	0	0	0	0	0	4.78689	1.91475	95.7377	9.57377	0	1.91475	0	0
	CV															
Total P	Mean	1	1	1	1	1	1	1	1	1	1	1	2.00	1	1	3.00
	CV															

Tributary Data

		Tributaries							Lakesheds														
Tributary Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Tributary Name		SRCL Inf	Kolling C	Schneide	Kinzer C	Eden Val	Eden Val	SRCL Ou	LS_HS N	LS_East	LS_Koett	LS_Zumw	LS_Gt N	LS_Krays	LS_Knau	LS_Beck	LS_HS W	LS_HS S	LS_Ceda	LS_Schn	LS_Bolfu	LS_Long	LS_N Bro
Segment Number		1	8	12	7	15	14	7	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tributary Type Code		1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Drainage Area (km2)		2087.83	97.43	34.15	18.49	105.68	4.04	2404.88	1.08	0.15	0.72	0.56	1.62	0.49	1.14	1.01	2.99	0.07	20.25	2.15	3.53	1.26	7.05
Flow (hm3/yr)	Mean	324.75	26.65	6.53	6.00	46.91	1.79	401.33	0.28	0.04	0.19	0.14	0.42	0.13	0.30	0.26	0.78	0.02	5.29	0.56	0.92	0.33	1.84
	CV	0.10	0.15	0.15	0.15	0.20	0.20	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Conserv. Subst (-)	Mean	23.96	20.23	20.50	18.03	29.86	29.86	0.00	2.39	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23
	CV	0.05	0.15	0.15	0.15	0.20	0.20	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Total P (ppb)	Mean	188	45	77	73	135	135	127	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
	CV	0.05	0.15	0.15	0.15	0.20	0.20	0.05	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Tributary Data - Shoreline Runoff

		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Tributary Name		R__HS N	R__East	R__Koett	R__Zumw	R__Gt N	R__Krays	R__Knau	R__Beck	R__HS W	R__HS S	R__Ceda	R__Schn	R__Bolfu	R__Long	R__N Browns
Segment Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tributary Type Code		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Flow (hm3/yr)	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total P (ppb)	Mean	7746	17444	13519	11193	10902	7123	52621	15263	33297	15939	31253	17444	11484	16717	19479
	CV	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Tributary Data - Shoreline Septic Tanks

		38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Tributary Name		ST___HS	ST___Ea	ST___Ko	ST___Zu	ST___Gt	ST___Kr	ST___Kr	ST___Be	ST___HS	ST___HS	ST___Ce	ST___Sc	ST___Bo	ST___Lo	ST___N Browns
Segment Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tributary Type Code		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Flow (hm3/yr)	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total P (ppb)	Mean	24988	52656	45954	42125	44039	22977	98610	45954	107410	51418	123502	71803	44039	64144	128289
	CV	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Model Coefficients (Mean, CV)

Dispersion Rate	1	0.4
Total Phosphorus	4.78689	0.2
Total Nitrogen	1	0.55
Chl-a Model	1	0.2
Secchi Model	1	0.1
Organic N Model	1	0.1
TP-OP Model	1	0.15
HODv Model	1	0.15
MODv Model	1	0.22
Secchi/Chla Slope (m2/mg)	0.015	0.1
Minimum Qs (m/yr)	0.1	0
Chl-a Flushing Term	0.4	0
Chl-a Temporal CV	0.45	0
Availability Factor - Total P	1	0
Availability Factor - Ortho P	0	0
Availability Factor - Total N	1	0
Availability Factor - Inorganic N	0	0

Model Options

Conservative Subs	1
Phosphorus Balan	7
Nitrogen Balance	0
Chlorophyll-a	2
Secchi Depth	1
Dispersion	3
Phosphorus Calibr	1
Nitrogen Calibratio	1
Error Analysis	1
Availability Factors	0
Mass-Balance Tab	1
Output Eestination	2

Appendix F

Simulation Results

Scenario: TMDL_TR_100
Tributary TP < 100 ppb
No Reduction in Shoreline Loads

Appendix F - 1 Model Input Loads & Parameter Estimates Scenario: TMDL_TR_100

	Parcel	Septic	Areas km^2		Total	Mean	----------- Total P Loads kg ------------------					FWM	P Export	Non-Algal
Segment	Count	Count	Lake	Watershed	Flow hm^3	Flow cfs	Watershed	Lot Runoff	Septic	Total	% Total	Conc ppb	kg/km^2	Turb 1/m
Local Tributaries														
Sauk River Inflow				2087.8	135.7	363.1	13569			13569	77.7%	100	6	
Kolling Creek				97.4	11.1	29.8	496			496	2.8%	45	5	
Schneider Inflow				34.2	2.7	7.3	211			211	1.2%	77	6	
Kinzer Creek				18.5	2.5	6.7	182			182	1.0%	73	10	
Eden Valley Creek				105.7	19.6	52.5	1960			1960	11.2%	100	19	
Trib to Long L Inlet				4.0	0.7	2.0	75			75	0.4%	100	19	
Total Local Tribs				259.8	36.7	98.3	2924			2923.7	16.7%	80	11	
Total Inflows				2347.6	172.4	461.4	16492			16492	94.5%	180	18	
Lakesheds														
01_Horse_N	53	26	0.25	1.1	0.12	0.3	6	3	10	20	0.1%	170	19	0.65
02_East	120	55	1.09	0.1	0.02	0.0	1	7	22	30	0.2%	1883	205	0.65
03_Koetter	93	48	0.52	0.7	0.08	0.2	4	6	19	29	0.2%	373	41	0.65
04_Zumwalde	77	44	0.49	0.6	0.06	0.2	3	5	18	26	0.1%	422	46	0.65
05_Gt Northern	75	46	0.76	1.6	0.18	0.5	10	5	18	33	0.2%	184	20	0.65
06_Krays	49	24	0.37	0.5	0.05	0.1	3	3	10	15	0.1%	290	32	0.65
07_Knaus/Park	362	103	0.85	1.1	0.12	0.3	7	22	41	70	0.4%	562	61	0.65
08_Becker	105	48	0.66	1.0	0.11	0.3	6	6	19	32	0.2%	287	31	0.60
09_Horse_W	229	112	1.02	3.0	0.33	0.9	18	14	45	77	0.4%	235	26	0.30
10_Horse_S	110	54	1.27	0.1	0.01	0.0	0	7	21	29	0.2%	3985	435	0.10
11_Cedar	215	129	2.04	20.2	2.21	5.9	120	13	52	185	1.1%	84	9	0.20
12_Schneider	120	75	0.22	2.2	0.23	0.6	13	7	30	50	0.3%	213	23	0.10
13_Bolfing	79	46	0.43	3.5	0.39	1.0	21	5	18	44	0.3%	115	12	0.10
14_Long	115	67	1.97	1.3	0.14	0.4	7	7	27	41	0.2%	300	33	0.20
15_Browns	134	134	1.26	7.0	0.77	2.1	42	8	54	103	0.6%	135	15	0.10
Total	1936	1011	13.21	44.1	4.80	12.9	261	118	404	783	4.5%	163	18	
Sauk River Inflow				2087.8	135.7	363	13569			13569	78%	100	6	
Total Local Tribs				260	36.7	98	2924			2924	17%	80	11	
Total Lakesheds	1936	1011	13.2	44.1	4.8	13	261	118	404	783	4%	163	18	
Local+Lakesheds	1936	1011	13.2	304	42	111	3185	118	404	3707	21%	89	12	
Total External Inflow	1936	1011	13.2	2391.7	177.2	474	16753	118	404	17275	99%	97	7	
Precipitation			13.2		6.2	17				186	1%	30	14	
Evaporation			13.2		8.1	22								
Net Inflow				2404.9	175.3	469				17461	100%	100	7	
Predicted Outflow				2404.9	175.3	469	1256			15140	87%	86	6	
Retention										2321	13%			

<u>Assumptions for Shoreline Sources</u>

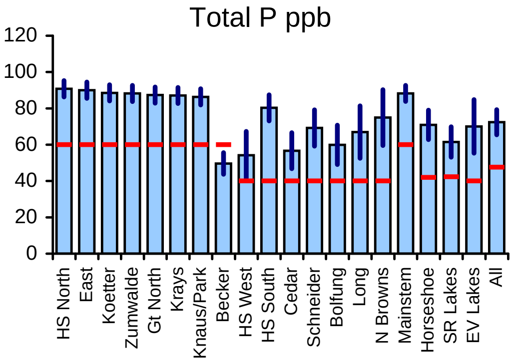
Excess Runoff; Above Lakeshed Background		
Average Lot Size	0.5	acres
Excess Areal Load	30	kg / km^2, may-sept, average year
Runoff Load Per Lot	0.061	kg / lot
Load per Septic Tank	0.40	kg
TMDL Reduction	0%	

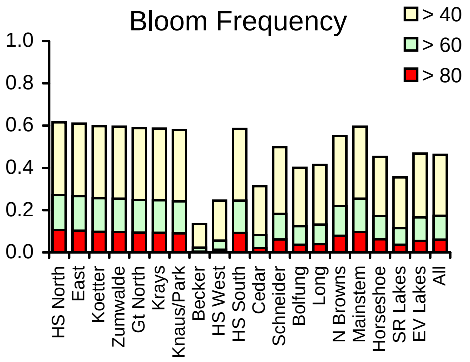
<u>BATHTUB Parameters</u>

Averaging Period	0.42	years	
Net Settling Rate - Other Lakes	4.8	m/yr	BATHTUB P Model 7
Net Settling Rate - North Browns	14.4	m/yr	
Net Settling Rate - Schneders L	9.6	m/yr	
Chlorophyll-a Calibration	1.00		BATHTUB Chl-a Model 2
Algal Light Extinction	0.015	m^2/mg	
Chla Flushing Coefficient	0.40		
Chl-a Coef of Variation	0.45		

Appendix F - 2 Mass Balance & Predicted Lake Responses Scenario: TMDL_TR_1

Lake Segment	Criterion ppb	TP ppb	TP_SE ppb	Chl-a ppb	Secchi m	Algal Bloom Frequencies > 40	 > 60	 > 80	Trophic Strate Indices Total P	 Chl-a	 Secchi
HS North	60	91	4	46	0.75	0.62	0.27	0.11	69	68	64
East	60	90	4	45	0.75	0.61	0.27	0.10	69	68	64
Koetter	60	89	4	45	0.76	0.60	0.26	0.10	69	68	64
Zumwalde	60	88	4	45	0.76	0.60	0.25	0.10	69	68	64
Gt North	60	87	4	44	0.76	0.59	0.25	0.09	69	68	64
Krays	60	87	4	44	0.76	0.59	0.25	0.09	69	68	64
Knaus/Park	60	86	4	44	0.77	0.58	0.24	0.09	68	68	64
Becker	60	50	6	24	1.04	0.13	0.02	0.00	60	62	59
HS West	40	54	13	29	1.35	0.25	0.06	0.01	62	64	56
HS South	40	80	7	44	1.32	0.58	0.25	0.09	67	68	56
Cedar	40	57	10	32	1.47	0.31	0.08	0.02	62	65	54
Schneider	40	69	10	40	1.43	0.50	0.18	0.06	65	67	55
Bolfung	40	60	11	36	1.57	0.40	0.12	0.04	63	66	53
Long	40	67	14	36	1.34	0.41	0.13	0.04	65	66	56
N Browns	40	75	15	42	1.36	0.55	0.22	0.08	66	67	56
Mainstem	60	88	4	45	0.76	0.60	0.25	0.10	69	68	64
Horseshoe	42	71	8	38	1.27	0.45	0.17	0.06	66	66	57
SR Lakes	42	61	8	34	1.37	0.36	0.11	0.04	64	65	55
EV Lakes	40	70	15	39	1.35	0.47	0.17	0.05	65	67	56
All	48	72	7	39	1.16	0.46	0.17	0.06	66	67	58

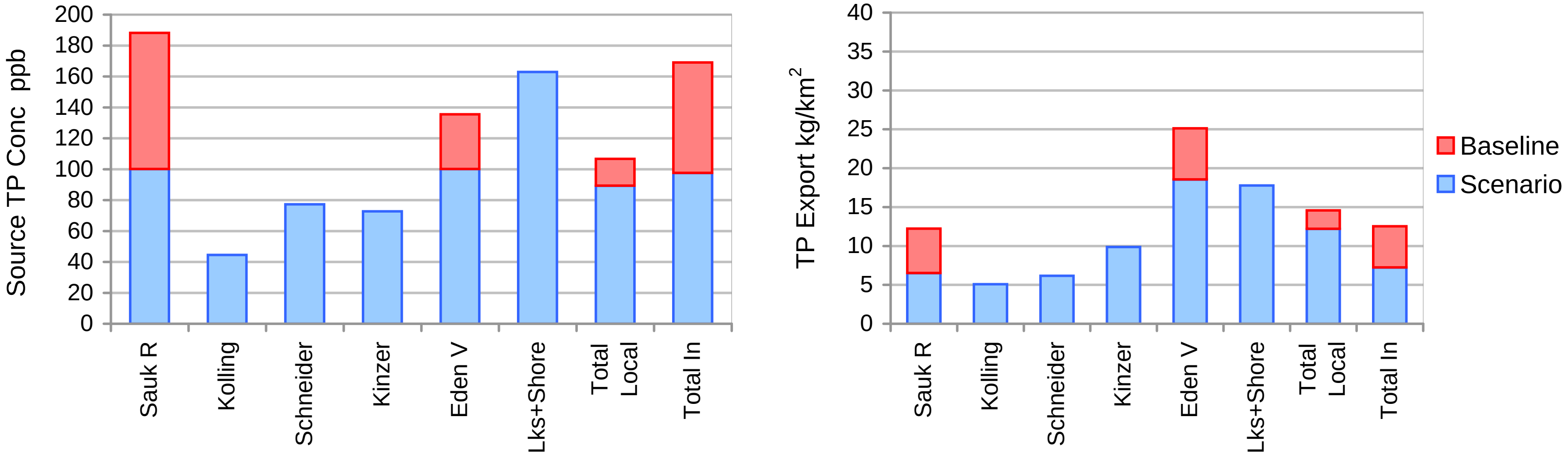


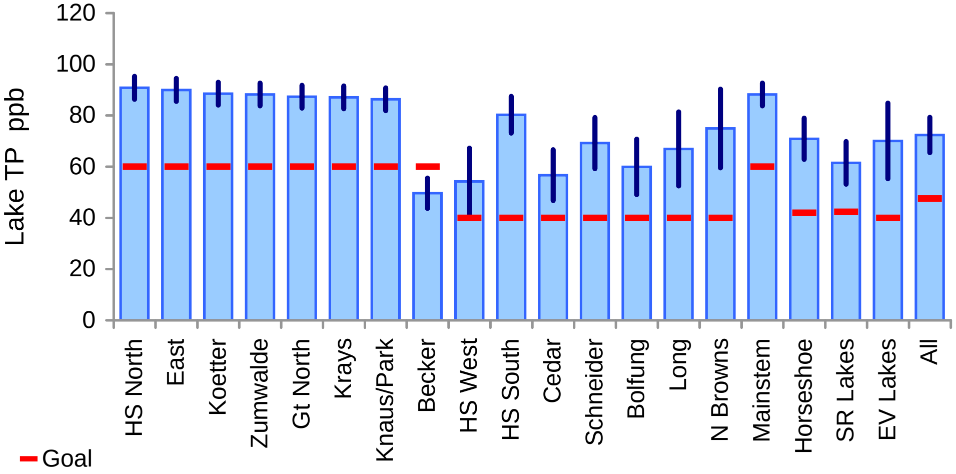


Water & Mass Balance (May - September)

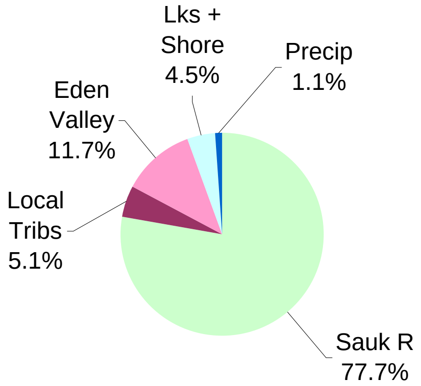
TMDL_TR_100 Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Runoff cm	Export kg/km^2	Percent of Load	2002-2006 Baseline Load kg	 Conc ppb	Load Reduc %
Sauk River Inflow	2088	136	13569	100	6	6	78%	25536	188	47%
Kolling Creek	97	11	496	45	11	5	3%	496	45	0%
Schneider Inflow	34	3	211	77	8	6	1%	211	77	0%
Kinzer Creek	18	3	182	73	14	10	1%	182	73	0%
Eden Valley Creek	106	20	1960	100	19	19	11%	2655	135	26%
Trib to Long L Inlet	4	1	75	100	19	19		102	135	26%
Lakesheds	44	5	261	54	11	6	1%	261	54	0%
Septic Systems			404				2%	404		0%
Excess Runoff			118					118		0%
External Inflow	2392	177	17275	97	7	7	99%	29965	169	42%
Precipitation	13	6	186	30	47	14	1%	186	30	0%
Evaporation		8			61					
Net Inflow	2405	175	17461	100	7	7	100%	30150	172	42%
Outflow	2405	175	15140	86	7	6	87%	26632	152	43%
Retention			2321				13%	3518		

Appendix F - 3 Load Reductions by Tributary Scenario: TMDL_TR_100





May-Sept Total P Load = 17.3 mt



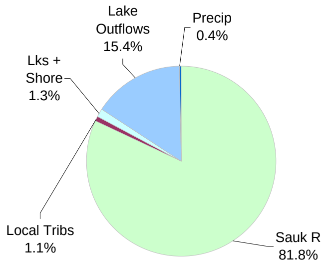
Predicted Summer Mean TP +/- 1 Standard Error

Lks+Shore = Lakesheds 1.5% + Septic Tanks 2.3% + Excess Lot Runoff 0.7%

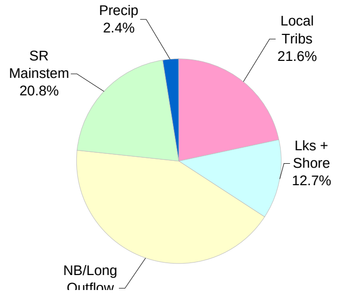
Total Local = All Sources Except Sauk River & Precipitation

Appendix F - 4 Phosphorus Sources by Region Scenario: TMDL_TR_100

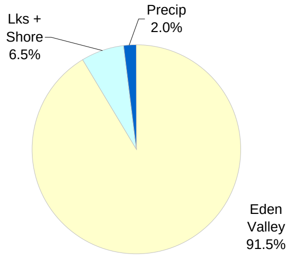
Mainstem, Total = 16.6 mt



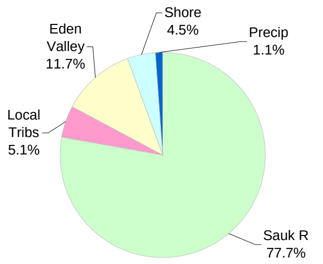
SR Lakes, Total = 3.3 mt



N Browns / Long, Total = 2.2 mt



All Lakes, Total = 17.3 mt



Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Mainstem Lakes (Horseshoe North - Knaus)									
Sauk River	2088	135.7	13569	100	87%	76%	85.3%	0.06	6.5
Kinzer Creek	18	2.5	182	73	1%	1%	1.1%	0.14	9.9
Lakeshed	6	0.6	34	54	0%	0%	0.2%	0.11	5.9
Septic Tanks	0		138				0.9%		
Shoreline Runoff	0		50				0.3%		
Total External	2112	138.8	13974	101	88%	78%	87.9%	0.07	6.6
Outflow from Lakes	288	37.1	2551	69	12%	21%	16.0%	0.13	8.8
Exchange with Lakes			-681				-4.3%		0.0
Precip	4	2.0	61	30	0%	1%	0.4%	0.47	14.1
Evap		0.0				0%	0.0%		
Net Inflow	2405	178.0	15904	89	100%	100%	100.0%	0.07	6.6
Outflow	2405	175.3	15140	86	100%	99%	95.2%	0.07	6.3
Retention			764				4.8%		
Offline Lakes (Becker, HS South, HS West, Cedar, Schneider, Bolfung)									
Kolling Creek	97	11.1	496	45	34%	27%	15.1%	0.11	5.1
Schneider Inflow	34	2.7	211	77	12%	7%	6.4%	0.08	6.2
Lakesheds	30	3.3	178	54	10%	8%	5.4%	0.11	5.9
Septic Tanks			186				5.7%		
Shoreline Runoff			52				1.6%		
Total External	162	17.1	1122	65	56%	42%	34.3%	0.11	6.9
Inflow from Long	121	20.8	1393	67	42%	51%	42.5%	0.17	11.5
Exchange with Mainstem			681				20.8%		0.0
Precip	6	2.6	79	30	2%	7%	2.4%	0.47	14.1
Evap		0.0				0%	0.0%		
Net Inflow	288	40.6	3275	81	100%	100%	100.0%	0.47	11.4
Outflow	288	37.1	2551	69	100%	92%	77.9%	0.47	8.8
Retention			724				22.1%		
North Browns + Long									
Eden Valley Creek	106	19.6	1960	100	87%	94%	88.1%	0.19	18.5
Trib to Long L Inlet	4	0.7	75	100	3%	4%	3.4%	0.19	18.5
Lakeshed	8	0.9	49	54	7%	4%	2.2%	0.11	5.9
Septic Tanks	0		80				3.6%		
Shoreline Runoff	0		15				0.7%		
Total External	118	21.3	2180	103	97%	102%	98.0%	0.18	18.5
Precip	3	1.5	46	30	3%	7%	2.0%	0.47	14.1
Evap		2.0				9%			
Net Inflow	121	20.8	2225	107	100%	100%	100.0%	0.17	18.3
Outflow	121	20.8	1393	67	100%	100%	62.6%	0.17	11.5
Retention			832				37.4%		
Overall									
Sauk River	2088	135.7	13569	100	87%	77%	77.7%	0.06	6.5
Kolling Creek	97	11.1	496	45	4%	6%	2.8%	0.11	5.1
Schneider Inflow	34	2.7	211	77	1%	2%	1.2%	0.08	6.2
Kinzer Creek	18	2.5	182	73	1%	1%	1.0%	0.14	9.9
Eden Valley Creek	106	19.6	1960	100	4%	11%	11.2%	0.19	18.5
Trib to Long L Inlet	4	0.7	75	100	0%	0%	0.4%	0.19	18.5
Lakesheds	44	4.8	261	54	2%	3%	1.5%	0.11	5.9
Septic Tanks			404				2.3%		
Shoreline Runoff			118				0.7%		
Total External	2392	177.2	17275	97	99%	101%	98.9%	0.07	7.2
Precip	13	6.2	186	30	1%	4%	1.1%	0.47	14.1
Evap		8.1				5%			
Net Inflow	2405	175.3	17461	100	100%	100%	100.0%	0.07	7.3
Outflow	2405	175.3	15140	86	100%	100%	86.7%	0.07	6.3
Retention			2321				13.3%		

Appendix F - 5 Water & Mass Balances by Segment Scenario: TMDL_TR_100

Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
North Browns Lake									
Eden Valley Creek	105.7	19.6	1959.9	100	93%	97%	94%	0.19	19
Lakeshed	7.0	0.8	42	54	6%	4%	2%	0.11	6
Septic Tanks			54				3%		
Shoreline Runoff			8				0%		
Total External	112.7	20.4	2063	101	93%	101%	99%	0.18	18
Precip	1.3	0.6	18	30	1%	3%	1%	0.47	14
Evap		0.8				4%		0.61	
Net Inflow	114.0	20.2	2081	103	94%	100%	100%		
Outflow	114.0	20.2	1513	75	100%	100%	73%	0.18	13
Retention			568				27%		
Long Lake									
Trib to Long L Inlet	4.0	0.7	75	100	3%	4%	5%	0.19	19
Lakeshed	1.3	0.1	7.5	54	1%	1%	0%	0.11	6
Septic Tanks			27				2%		
Shoreline Runoff			7				0%		
Total External	5.3	0.9	116	131	4%	4%	7%	0.17	22
Outflow from N Browns	114.0	20.2	1513	75	94%	97%	91%	0.18	13
Precip	2.0	0.9	28	30	2%	4%	2%	0.47	14
Evap		1.2						0.61	
Net Inflow	121.3	20.8	1657	80	100%	100%	100%	0.17	14
Outflow	121.3	20.8	1393	67	100%	100%	84%	0.17	11
Retention			264				16%		
Becker Lake									
Kolling Creek	97.4	11.1	495.8	45	98%	100%	80%	0.11	5
Lakeshed	1.0	0.1	6	54	1%	1%	1%	0.11	6
Septic Tanks			19		0%	0%	3%		
Shoreline Runoff			6		0%	0%	1%		
Total External	98.4	11.2	527	47	99%	101%	85%	0.11	5
Exchange with Main Lake			82				13%		
Precip	0.7	0.3	9	30	1%	3%	1%	0.47	14
Evap		0.4				4%		0.61	
Net Inflow	99.1	11.2	619	55	100%	100%	100%	0.11	6
Outflow	99.1	11.2	554	50		100%	89%	0.11	6
Retention			65				11%		
Schneiders Lake									
Schneider Inflow	34.2	2.7	210.8	77	94%	93%	80%	0.08	6
Lakeshed	2.2	0.2	13	54	6%	8%	5%	0.11	6
Septic Tanks			30		0%	0%	11%		
Shoreline Runoff			7		0%	0%	3%		
Total External	36.3	3.0	261	88	99%	101%	99%	0.08	7
Exchange with Main Lake			0				0%		
Precip	0.2	0.1	3	30	1%	4%	1%	0.47	14
Evap		0.1				5%		0.61	
Net Inflow	36.5	2.9	264	90	100%	100%	100%	0.08	7
Outflow	36.5	2.9	203	69		100%	77%	0.08	6
Retention			61				23%		
Cedar Island Lake (Including Mud, Little C									
Lakeshed	20.2	2.2	120	54	91%	115%	35%	0.11	6
Septic Tanks			52			0%	15%		
Shoreline Runoff			13			0%	4%		
Total External	20.2	2.2	185	84	91%	115%	54%	0.11	9
Exchange with Main Lake			127				37%		
Precip	2.0	1.0	29	30	9%	50%	8%	0.47	14
Evap		1.2				65%		0.61	
Net Inflow	22.3	1.9	341	177	100%	100%	100%	0.09	15
Outflow	22.3	1.9	109	57	100%	100%	32%	0.09	5
Retention			232				68%		
Bolfung Lake									
Lakeshed	3.5	0.4	21	54	89%	119%	29%	0.11	6
Septic Tanks			18		0%	0%	26%		
Shoreline Runoff			5		0%	0%	7%		
Total External	3.5	0.4	44	115	89%	119%	62%	0.11	12
Exchange with Main Lake			21				30%		
Precip	0.4	0.2	6	30	11%	63%	9%	0.47	14
Evap		0.3				81%		0.61	
Net Inflow	4.0	0.3	71	220	100%	100%	100%	0.08	18
Outflow	4.0	0.3	19	60	100%	100%	27%	0.08	5
Retention			52				73%		

Appendix F - 5 Water & Mass Balances by Segment Scenario: TMDL_TR_100

Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Horseshoe West - Krons Bay									
Lakeshed	3.0	0.3	18	54	75%	178%	15%	0.11	6
Septic Tanks			45				37%		
Shoreline Runoff			14				12%		
Total External	3.0	0.3	77	235	75%	178%	64%	0.11	26
Exchange with Main Lake			29				24%		
Precip	1.0	0.5	14	30	25%	260%	12%	0.47	14
Evap		0.6				338%		0.61	
Net Inflow	4.0	0.2	120	656	100%	100%	100%	0.05	30
Outflow	4.0	0.2	10	54	100%	100%	8%	0.05	2
Retention			110				92%		
Horseshoe South									
Lakeshed	0.1	0.0	0	54	0%	0%	0%	0.11	6
Septic Tanks			21				1%		
Shoreline Runoff			7				0%		
Total External	0.1	0.0	29	3985	0%	0%	2%	0.11	435
Outflow from Long Lake	121.3	20.8	1393		99%	101%	75%		
Exchange with Main Lake			421				23%		
Precip	1.3	0.6	18	30	1%	3%	1%	0.47	14
Evap		0.8				4%		0.61	
Net Inflow	122.6	20.6	1860	90	100%	100%	100%	0.17	15
Outflow	122.6	20.6	1656	80	100%	100%	89%	0.17	14
Retention			204				11%		
Horseshoe North									
Sauk River Inflow	2087.8	135.7	13568.5	100	90%	81%	89%	0.06	6
Lakeshed	1.1	0.1	6	54	0%	0%	0%	0.11	6
Septic Tanks			10				1%		
Shoreline Runoff			3				0%		
Total External	2088.9	135.8	13589	100	90%	81%	89%	0.07	7
Outflow from Becker	99.1	11.2	554	50	4%	7%	4%	0.11	6
Outflow from HS West	4.0	0.2	10	54	0%	0%	0%	0.05	2
Outflow from HS South	122.6	20.6	1656	80	5%	12%	11%	0.17	14
Exchange with Becker			-82				-1%		
Exchange with HS West			-29				0%		
Exchange with HS South			-421				-3%		
Precip	0.3	0.1	4	30	0%	0%	0%	0.47	
Evap		0.2				0%		0.61	
Net Inflow	2314.9	167.7	15279	91	100%	100%	100%	0.07	7
Outflow	2314.9	167.7	15233	91	100%	100%	100%	0.07	7
Retention			46				0%		
East Lake									
Lakeshed	0.1	0.0	1	54	0%	0%	0%	0.11	6
Septic Tanks			22				0%		
Shoreline Runoff			7				0%		
Total External	0.1	0.0	30	1883	0%	0%	0%	0.11	205
Outflow from Horshoe North	2314.9	167.7	15233	91	100%	100%	100%	0.07	7
Precip	1.1	0.5	15	30	0%	0%	0%	0.47	14
Evap		0.7				0%		0.61	
Net Inflow	2316.1	167.6	15279	91	100%	100%	100%	0.07	7
Outflow	2316.1	167.6	15082	90	100%	100%	99%	0.07	7
Retention			196				1%		
Koetters Lake									
Lakeshed	0.7	0.1	4	54	0%	0%	0%	0.11	6
Septic Tanks			19				0%		
Shoreline Runoff			6				0%		
Total External	0.7	0.1	29	373	0%	0%	0%	0.11	41
Outflow from East Lake	2316.1	167.6	15082	90	99%	99%	100%	0.07	7
Outflow from Cedar Lake	22.3	1.9	109	57	1%	1%	1%	0.09	5
Exchange with Cedar Lake			-127				-1%		
Precip	0.5	0.2	7	30	0%	0%	0%	0.47	14
Evap		0.3				0%	0%	0.61	
Net Inflow	2339.6	169.5	15100	89	100%	100%	100%	0.07	6
Outflow	2339.6	169.5	15008	89	100%	100%	99%	0.07	6
Retention			93				1%		

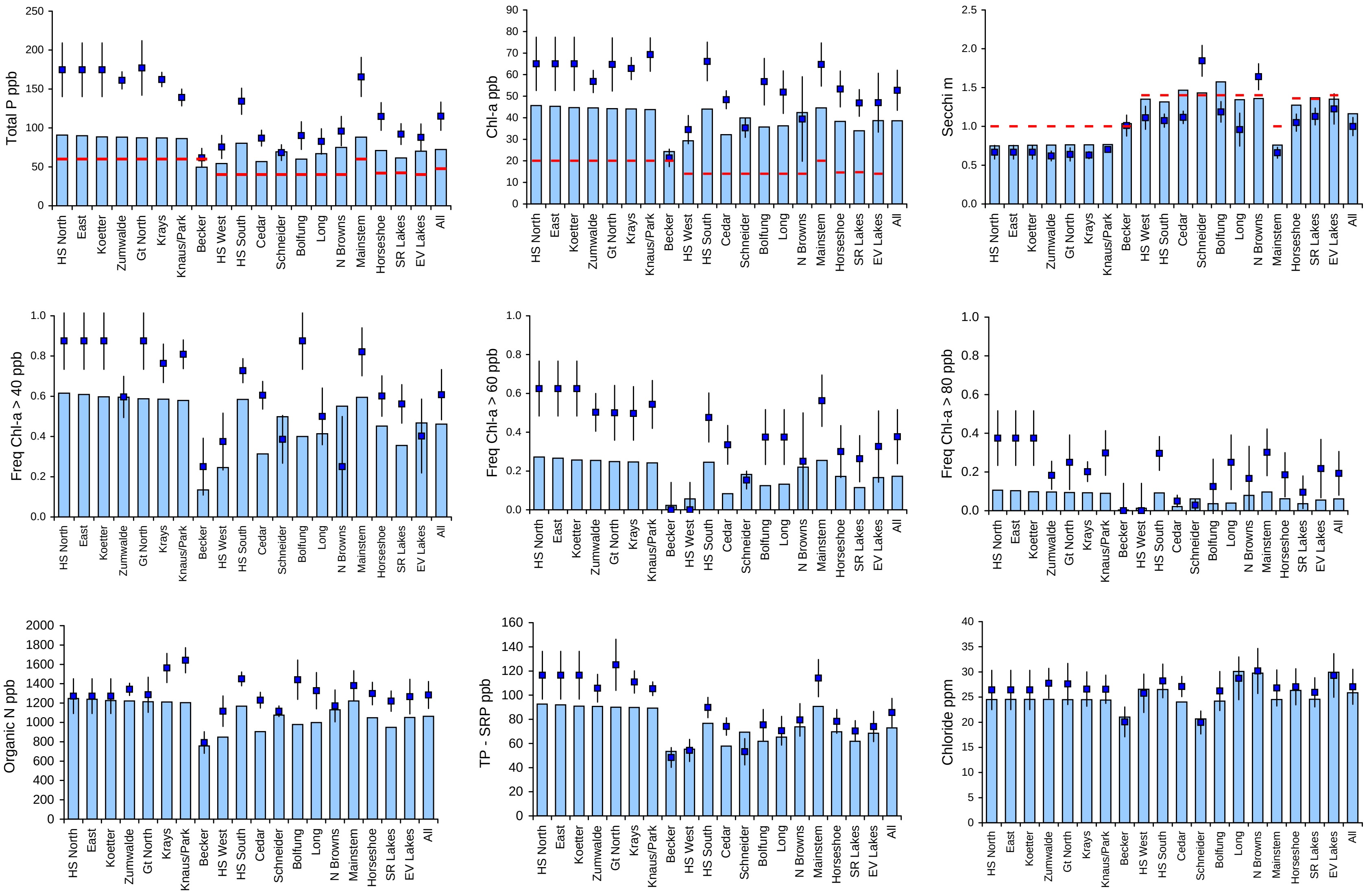
Appendix F - 5 Water & Mass Balances by Segment Scenario: TMDL_TR_100

Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Zumwalde Lake									
Lakeshed	0.6	0.1	3	54	0%	0%	0%	0.11	6
Septic Tanks			18				0%		
Shoreline Runoff			5				0%		
Total External	0.6	0.1	26	422	0%	0%	0%	0.11	46
Outflow from Koetter	2339.6	169.5	15008	89	100%	100%	100%	0.07	6
Precip	0.5	0.2	7	30	0%	0%	0%	0.47	14
Evap		0.3				0%		0.61	
Net Inflow	2340.7	169.5	15040	89	100%	100%	100%	0.07	6
Outflow	2340.7	169.5	14954	88	100%	100%	99%	0.07	6
Retention			86				1%		
Great Northern Lake									
Lakeshed	1.6	0.2	10	54	0%	0%	0%	0.11	6
Septic Tanks			18				0%		
Shoreline Runoff			5				0%		
Total External	1.6	0.2	33	184	0%	0%	0%	0.11	20
Outflow from Zumwalde	2340.7	169.5	14954	88	98%	98%	98%	0.07	6
Outflow from Schneider	36.5	2.9	203	69	2%	2%	1%	0.08	6
Exchange with Schneider			0				0%		
Precip	0.8	0.4	11	30	0%	0%	0%	0.47	14
Evap		0.5				0%		0.61	
Net Inflow	2379.6	172.5	15200	88	100%	100%	100%	0.07	6
Outflow	2379.6	172.5	15068	87	100%	100%	99%	0.07	6
Retention			132				1%		
Krays Lake									
Lakeshed	0.5	0.1	3	54	0%	0%	0%	0.11	6
Septic Tanks			10				0%		
Shoreline Runoff			3				0%		
Total External	0.5	0.1	15	290	0%	0%	0%	0.11	32
Outflow from Great North	2379.6	172.5	15068	87	100%	100%	100%	0.07	6
Precip	0.4	0.2	5	30	0%	0%	0%	0.47	14
Evap		0.2				0%		0.61	
Net Inflow	2380.4	172.5	15089	87	100%	100%	100%	0.07	6
Outflow	2380.4	172.5	15025	87	100%	100%	100%	0.07	6
Retention			64				0%		
Knaus & Park Lakes									
Kinzer Creek	18.5	2.5	182.3	73	1%	1%	1%	0.14	10
Lakeshed	1.1	0.1	7	54	0%	0%	0%	0.11	6
Septic Tanks			41				0%		
Shoreline Runoff			22				0%		
Total External	19.6	2.6	252	96	1%	1%	2%	0.13	13
Outflow from Krays	2380.4	172.5	15025	87	99%	98%	98%	0.07	6
Outflow from Bolfung	4.0	0.3	19		0%	0%	0%		
Exchange with Bolfung			-21				0%		
Precip	0.9	0.4	12	30	0%	0%	0%	0.47	14
Evap		0.5				0%		0.61	
Net Inflow	2404.9	175.3	15288	87	100%	100%	100%	0.07	6
Outflow	2404.9	175.3	15140	86	100%	100%	99%	0.07	6
Retention			148				1%		

Appendix F - 5 Water & Mass Balances by Segment Scenario: TMDL_TR_100

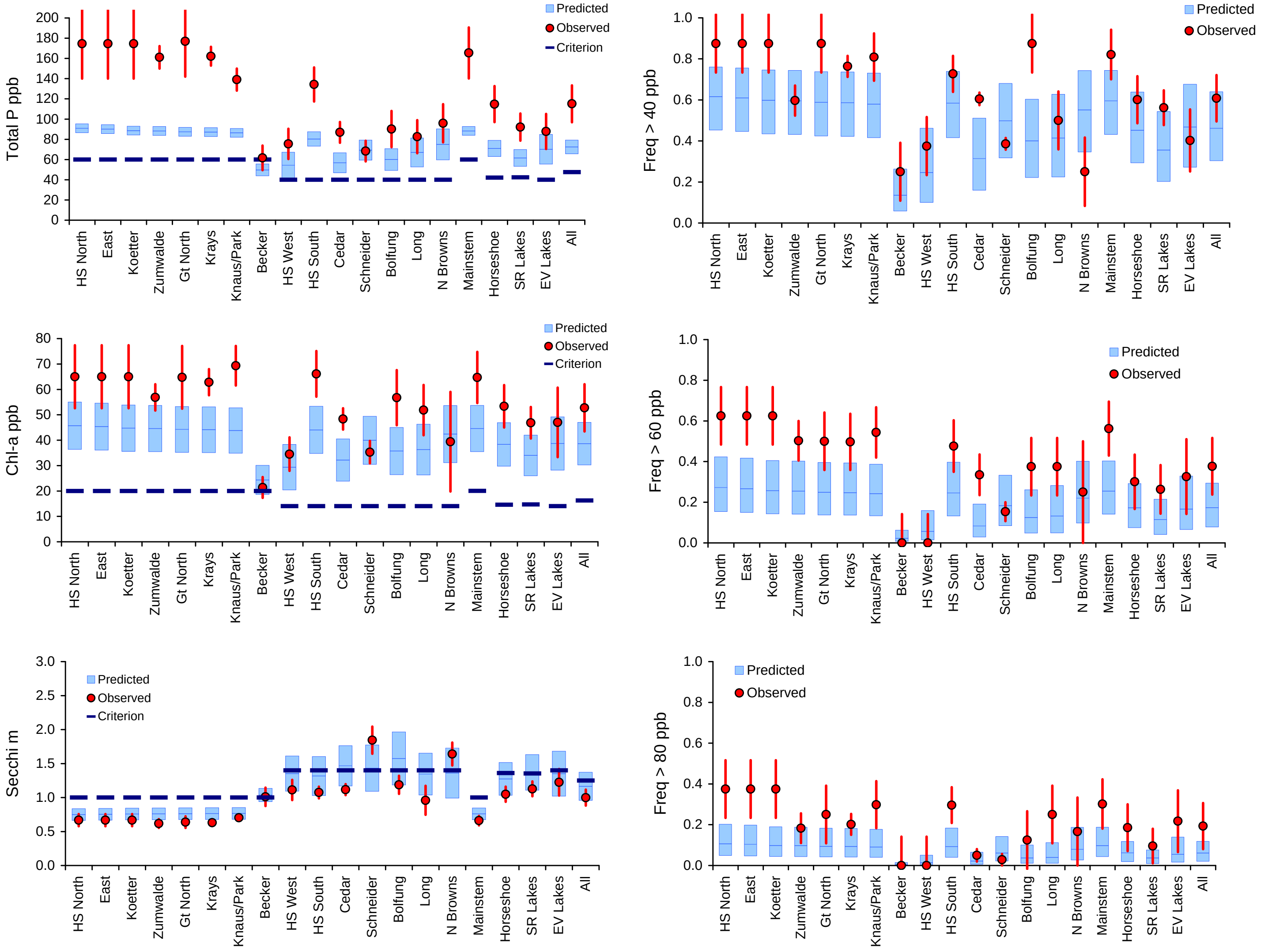
Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Mainstem Lakes (Horseshoe North - Knau									
Sauk River	2087.8	135.7	13569	100	87%	76%	85%	0.06	6
Kinzer Creek	18.5	2.5	182	73	1%	1%	1%	0.14	10
Lakeshed	5.7	0.6	34	54	0%	0%	0%	0.11	6
Septic Tanks			138		0%	0%	1%		
Shoreline Runoff			50		0%	0%	0%		
Total External	2112.1	138.8	13974	101	88%	78%	88%	0.07	7
Outflow from Lakes	288.5	37.1	2551	69	12%	21%	16%	0.13	9
Exchange with Lakes			-681				-4%		
Precip	4.3	2.0	61	30	0%	1%	0%	0.47	14
Evap		0.0				0%			
Net Inflow	2404.9	178.0	15904	89	100%	100%	100%	0.07	7
Outflow	2404.9	175.3	15140	86	100%	99%	95%	0.07	6
Retention			764				5%		
Offline Lakes (Becker, HS South, HS West									
Kolling Creek	97.4	11.1	496	45	34%	27%	15%	0.11	5
Schneider Inflow	34.2	2.7	211	77	12%	7%	6%	0.08	6
Lakesheds	30.0	3.3	178	54	10%	8%	5%	0.11	6
Septic Tanks			186				6%		
Shoreline Runoff			52				2%		
Total External	161.6	17.1	1122	65	56%	42%	34%	0.11	7
Inflow from Long	121.3	20.8	1393	67	42%	51%	43%	0.17	11
Exchange with Mainstem			681				21%		
Precip	5.6	2.6	79	30	2%	7%	2%	0.47	14
Evap		0.0				0%			
Net Inflow	288.5	40.6	3275	81	100%	100%	100%	0.47	11
Outflow	288.5	37.1	2551	69	100%	92%	78%	0.47	9
Retention			724				22%		
Mainstem + Lakes, Excluding North Brow									
Sauk River	2087.8	135.7	13569	100	87%	75%	82%	0.06	6
Kinzer Creek	18.5	2.5	182	73	1%	1%	1%	0.14	10
Kolling Creek	97.4	11.1	496	45	4%	6%	3%	0.11	5
Schneider Inflow	34.2	2.7	211	77	1%	2%	1%	0.08	6
Lakesheds	35.7	3.9	212	54	1%	2%	1%	0.11	6
Septic Tanks			324		0%	0%	2%		
Shoreline Runoff			102		0%	0%	1%		
Outflow from Long	121.3	20.8	1393	67	5%	11%	8%	0.17	11
Total External	2394.9	176.7	16488	93	100%	97%	99%	0.07	7
Precip	10.0	4.7	140	30	0%	3%	1%	0.47	14
Evap		0.0				0%			
Net Inflow	2404.9	181.4	16628	92	100%	100%	100%	0.08	7
Outflow	2404.9	175.3	15140	86	100%	97%	91%	0.07	6
Retention			1488				9%		
North Browns + Long									
Eden Valley Creek	105.7	19.6	1960	100	87%	94%	88%	0.19	19
Trib to Long L Inlet	4.0	0.7	75	100	3%	4%	3%	0.19	19
Lakeshed	8.3	0.9	49	54	7%	4%	2%	0.11	6
Septic Tanks			80				4%		
Shoreline Runoff			15				1%		
Total External	118.0	21.3	2180	103	97%	102%	98%	0.18	18
Precip	3.2	1.5	46	30	3%	7%	2%	0.47	14
Evap		2.0				9%			
Net Inflow	121.3	20.8	2225	107	100%	100%	100%	0.17	18
Outflow	121.3	20.8	1393	67	100%	100%	63%	0.17	11
Retention			832				37%		
Overall									
Sauk River	2087.8	135.7	13569	100	87%	77%	78%	0.06	6
Kolling Creek	97.4	11.1	496	45	4%	6%	3%	0.11	5
Schneider Inflow	34.2	2.7	211	77	1%	2%	1%	0.08	6
Kinzer Creek	18.5	2.5	182	73	1%	1%	1%	0.14	10
Eden Valley Creek	105.7	19.6	1960	100	4%	11%	11%	0.19	19
Trib to Long L Inlet	4.0	0.7	75	100	0%	0%	0%	0.19	19
Lakesheds	44.1	4.8	261	54	2%	3%	1%	0.11	6
Septic Tanks			404			0%	2%		
Shoreline Runoff			118			0%	1%		
Total External	2391.7	177.2	17275	97	99%	101%	99%	0.07	7
Precip	13.2	6.2	186	30	1%	4%	1%	0.47	14
Evap		8.1				5%		0.61	
Net Inflow	2404.9	175.3	17461	100	100%	100%	100%	0.07	7
Outflow	2404.9	175.3	15140	86	100%	100%	87%	0.07	6
Retention			2321				13%		

Appendix F - 6 Observed & Predicted Lake Water Quality Scenario: TMDL_TR_100



Bars = Model Predictions. Symbols = Measured Values +/- 1 Standard Error Computed from Distribution of Summer Means Across Years. Red lines = Criteria

Appendix F - 7 Observed & Predicted Confidence Intervals Scenario: TMDL_TR_100



Means +/- 1 standard error of observed (symbols) and predicted (bars) values.

Blue lines indicate MPCA criteria for deep & shallow lakes. (TP < 40 or 60 ppb, Chla < 14 or < 20 ppb, Secchi >1.4 or 1.0 m

Appendix F - 8 Sensitivity Analysis Scenario: TMDL_TR_100

Percent Reduction in Lake P for with a 20% Reduction in Source or Model Coefficient

	Total P		Source Flow				Source Concentration				Settling Rate		Exchange
Segment	ppb	RSE	Sauk R	Tribs	Eden V	Lakeshed	Sauk R	Tribs	Eden V	Lakeshed	Mainstem	Lake	Rates
HS North	91	0.05	2	-1	0	0	18	1	2	0	0	-1	0
East	90	0.05	2	-1	0	0	17	1	2	0	0	-1	0
Koetter	89	0.05	2	-1	0	0	17	1	2	0	0	-1	0
Zumwalde	88	0.05	2	-1	0	0	17	1	2	1	-1	-1	0
Gt North	87	0.05	3	-1	0	0	17	1	2	1	-1	-1	0
Krays	87	0.05	3	-1	0	0	17	1	2	1	-1	-1	0
Knaus/Park	86	0.05	3	-1	0	0	17	1	1	1	-1	-1	0
HS West	50	0.24	1	0	0	7	8	0	1	9	0	-16	4
HS South	54	0.09	1	0	1	0	13	0	6	1	0	-4	2
Cedar	80	0.18	1	0	0	2	11	0	1	7	0	-10	5
Schneider	57	0.14	0	2	0	3	0	16	0	4	0	-5	0
Bolfung	69	0.18	2	0	0	4	10	1	1	8	-1	-10	4
Long	60	0.22	0	0	7	1	0	0	18	1	0	-9	0
N Browns	67	0.21	0	0	5	0	0	0	19	1	0	-6	0
Mainstem	75	0.05	2	-1	0	0	17	1	2	0	-1	-1	0
Horseshoe	88	0.11	1	0	0	3	12	0	4	3	0	-7	2
SR Lakes	71	0.14	1	0	0	3	10	2	2	5	0	-8	3
EV Lakes	61	0.21	0	0	7	1	0	0	18	1	0	-8	0
All	70	0.10	1	0	2	1	10	1	6	2	0	-5	1
Assumed Input Uncertainty (RSE)			10%	15%	20%	20%	5%	15%	20%	30%	20%	20%	40%

Shading: >15% >5% >2% reduction for a 20% reduction in model input value

RSE = Relative Standard Error in predicted Total P computed using first-order error analysis (Walker, 1982; 2006)

Lakeshed sources include ungauged runoff, shoreline runoff and septic systems.

Appendix F - 9 BATHTUB Input File Scenario: TMDL_TR_100

Case Title	Sauk River Chain of Lakes Scenario TMDL_TR_100

B	15
C	22
Number of Channels	0

Notes	Scenario TMDL_TR_100

Global Variables

Averaging Period (yrs)	0.42	0
Precipitation (m)	0.47	0.2
Evaporation (m)	0.61	0.3

Atmos. Loads (kg/km2-yr)

Conserv. Substance		
Total P	34	0.5
Total N		

Segment Data

Segment Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Segment Name		HS North	East	Koetter	Zumwald	Gt North	Krays	Knaus/Pa	Becker	HS West	HS South	Cedar	Schneide	Bolfung	Long	N Browns
Outflow Segment Number		2	3	4	5	6	7	0	1	1	1	3	5	7	10	14
Segment Group Number		1	1	1	1	1	1	1	2	3	4	5	6	7	8	9
Segment Morphometry																
Surface Area (km2)		0.25	1.09	0.52	0.49	0.76	0.37	0.85	0.66	1.02	1.27	2.04	0.22	0.43	1.97	1.26
Mean Depth (m)		1.64	0.76	1.14	1.85	1.86	2.14	1.96	2.44	5.86	3.52	4.34	6.12	4.03	3.04	5.60
Length (km)		1.00	1.80	3.00	2.00	1.00	1.00	1.00	2.00	1.00	1.50	2.00	1.00	1.00	3.00	1.80
Mixed Depth (m)	Mean	1.64	0.76	1.14	1.85	1.86	2.14	1.96	2.44	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	CV	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Observed Water Quality																
Non-Algal Turb (1/m)	Mean	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.6	0.3	0.1	0.2	0.1	0.1	0.2	0.1
	CV	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Conservative Subst	Mean			26.42	27.74	27.61	26.58	26.56	20.06	25.75	28.21	27.10	19.96	26.21	28.72	30.19
	CV			0.15	0.11	0.15	0.13	0.11	0.15	0.15	0.12	0.07	0.11	0.15	0.15	0.15
Total P (ppb)	Mean			174.63	161.10	177.00	162.18	139.05	61.63	75.50	134.28	86.90	68.32	90.13	82.63	95.92
	CV			0.20	0.07	0.20	0.06	0.08	0.20	0.20	0.13	0.12	0.15	0.20	0.20	0.20
Chlorophyll-a (ppb)	Mean			65.00	56.85	64.75	62.83	69.30	21.38	34.50	66.10	48.37	35.30	56.75	51.88	39.41
	CV			0.19	0.09	0.19	0.08	0.11	0.19	0.19	0.14	0.09	0.13	0.19	0.19	0.50
Secchi (m)	Mean			0.67	0.62	0.64	0.63	0.70	1.01	1.11	1.07	1.12	1.84	1.19	0.96	1.64
	CV			0.13	0.10	0.13	0.07	0.04	0.13	0.13	0.08	0.07	0.11	0.11	0.22	0.10
Organic N (ppb)	Mean			1271.88	1342.34	1285.63	1563.05	1642.86	792.13	1116.13	1449.67	1230.11	1116.04	1441.04	1328.13	1170.88
	CV			0.14	0.05	0.14	0.10	0.08	0.14	0.14	0.05	0.07	0.05	0.14	0.14	0.14
Total P - Ortho P (ppb)	Mean			116.50	105.74	125.13	110.90	105.30	48.38	54.25	89.78	74.04	53.18	75.38	70.50	79.50
	CV			0.17	0.11	0.17	0.08	0.05	0.17	0.17	0.09	0.10	0.21	0.17	0.17	0.17
Calibration Factors																
Dispersion Rate	Mean	0	0	0	0	0	0	0	4.78689	1.91475	95.7377	9.57377	0	1.91475	0	0
	CV															
Total P	Mean	1	1	1	1	1	1	1	1	1	1	1	2.00	1	1	3.00
	CV															

Tributary Data

		Tributaries							Lakesheds														
Tributary Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Tributary Name		SRCL Inf	Kolling C	Schneide	Kinzer C	Eden Val	Eden Val	SRCL Ou	LS_HS N	LS_East	LS_Koett	LS_Zumw	LS_Gt N	LS_Krays	LS_Knau	LS_Beck	LS_HS W	LS_HS S	LS_Ceda	LS_Schn	LS_Bolfu	LS_Long	LS_N Bro
Segment Number		1	8	12	7	15	14	7	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tributary Type Code		1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Drainage Area (km2)		2087.83	97.43	34.15	18.49	105.68	4.04	2404.88	1.08	0.15	0.72	0.56	1.62	0.49	1.14	1.01	2.99	0.07	20.25	2.15	3.53	1.26	7.05
Flow (hm3/yr)	Mean	324.75	26.65	6.53	6.00	46.91	1.79	401.33	0.28	0.04	0.19	0.14	0.42	0.13	0.30	0.26	0.78	0.02	5.29	0.56	0.92	0.33	1.84
	CV	0.10	0.15	0.15	0.15	0.20	0.20	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Conserv. Subst (-)	Mean	23.96	20.23	20.50	18.03	29.86	29.86	0.00	2.39	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23
	CV	0.05	0.15	0.15	0.15	0.20	0.20	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Total P (ppb)	Mean	100	45	77	73	100	100	#N/A	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
	CV	0.05	0.15	0.15	0.15	0.20	0.20	0.05	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Tributary Data - Shoreline Runoff

		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Tributary Name		R__HS N	R__East	R__Koett	R__Zumw	R__Gt N	R__Krays	R__Knau	R__Beck	R__HS W	R__HS S	R__Ceda	R__Schn	R__Bolfu	R__Long	R__N Browns
Segment Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tributary Type Code		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Flow (hm3/yr)	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total P (ppb)	Mean	7746	17444	13519	11193	10902	7123	52621	15263	33297	15939	31253	17444	11484	16717	19479
	CV	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Tributary Data - Shoreline Septic Tanks

		38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Tributary Name		ST___HS	ST___Ea	ST___Ko	ST___Zu	ST___Gt	ST___Kr	ST___Kn	ST___Be	ST___HS	ST___HS	ST___Ce	ST___Sc	ST___Bo	ST___Lo	ST___N Browns
Segment Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tributary Type Code		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Flow (hm3/yr)	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total P (ppb)	Mean	24988	52656	45954	42125	44039	22977	98610	45954	107410	51418	123502	71803	44039	64144	128289
	CV	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Model Coefficients (Mean, CV)

Dispersion Rate	1	0.4
Total Phosphorus	4.78689	0.2
Total Nitrogen	1	0.55
Chl-a Model	1	0.2
Secchi Model	1	0.1
Organic N Model	1	0.1
TP-OP Model	1	0.15
HODv Model	1	0.15
MODv Model	1	0.22
Secchi/Chla Slope (m2/mg)	0.015	0.1
Minimum Qs (m/yr)	0.1	0
Chl-a Flushing Term	0.4	0
Chl-a Temporal CV	0.45	0
Availability Factor - Total P	1	0
Availability Factor - Ortho P	0	0
Availability Factor - Total N	1	0
Availability Factor - Inorganic N	0	0

Model Options

Conservative Subs	1
Phosphorus Balan	7
Nitrogen Balance	0
Chlorophyll-a	2
Secchi Depth	1
Dispersion	3
Phosphorus Calibr	1
Nitrogen Calibratio	1
Error Analysis	1
Availability Factors	0
Mass-Balance Tab	1
Output Eestination	2

Appendix G

Simulation Results

Scenario: TMDL_TR_60_SL_50%
Tributary TP Conc = Min (60 ppb, Baseline Value)
50% Reduc in Shoreline Sources (Runoff + Septic Tanks)

Appendix G - 1 Model Input Loads & Parameter Estimates Scenario: TMDL_TR_60_SL_50%

	Parcel	Septic	Areas km^2		Total	Mean	----------- Total P Loads kg	------------------				FWM	P Export	Non-Algal
Segment	Count	Count	Lake	Watershed	Flow hm^3	Flow cfs	Watershed	Lot Runoff	Septic	Total	% Total	Conc ppb	kg/km^2	Turb 1/m
Local Tributaries														
Sauk River Inflow				2087.8	135.7	363.1	8141			8141	74.8%	60	4	
Kolling Creek				97.4	11.1	29.8	496			496	4.6%	45	5	
Schneider Inflow				34.2	2.7	7.3	164			164	1.5%	60	5	
Kinzer Creek				18.5	2.5	6.7	150			150	1.4%	60	8	
Eden Valley Creek				105.7	19.6	52.5	1176			1176	10.8%	60	11	
Trib to Long L Inlet				4.0	0.7	2.0	45			45	0.4%	60	11	
Total Local Tribs				259.8	36.7	98.3	2031			2030.7	18.7%	55	8	
Total Inflows				2347.6	172.4	461.4	10172			10172	93.5%	115	12	
Lakesheds														
01_Horse_N	53	26	0.25	1.1	0.12	0.3	6	2	5	13	0.1%	112	12	0.65
02_East	120	55	1.09	0.1	0.02	0.0	1	4	11	16	0.1%	969	106	0.65
03_Koetter	93	48	0.52	0.7	0.08	0.2	4	3	10	17	0.2%	213	23	0.65
04_Zumwalde	77	44	0.49	0.6	0.06	0.2	3	2	9	14	0.1%	238	26	0.65
05_Gt Northern	75	46	0.76	1.6	0.18	0.5	10	2	9	21	0.2%	119	13	0.65
06_Krays	49	24	0.37	0.5	0.05	0.1	3	1	5	9	0.1%	172	19	0.65
07_Knaus/Park	362	103	0.85	1.1	0.12	0.3	7	11	21	38	0.4%	308	34	0.65
08_Becker	105	48	0.66	1.0	0.11	0.3	6	3	10	19	0.2%	171	19	0.60
09_Horse_W	229	112	1.02	3.0	0.33	0.9	18	7	22	47	0.4%	144	16	0.30
10_Horse_S	110	54	1.27	0.1	0.01	0.0	0	3	11	14	0.1%	2019	220	0.10
11_Cedar	215	129	2.04	20.2	2.21	5.9	120	7	26	152	1.4%	69	8	0.20
12_Schneider	120	75	0.22	2.2	0.23	0.6	13	4	15	31	0.3%	134	15	0.10
13_Bolfing	79	46	0.43	3.5	0.39	1.0	21	2	9	33	0.3%	84	9	0.10
14_Long	115	67	1.97	1.3	0.14	0.4	7	3	13	24	0.2%	177	19	0.20
15_Browns	134	134	1.26	7.0	0.77	2.1	42	4	27	73	0.7%	94	10	0.10
Total	1936	1011	13.21	44.1	4.80	12.9	261	59	202	522	4.8%	109	12	
Sauk River Inflow				2087.8	135.7	363	8141			8141	75%	60	4	
Total Local Tribs				260	36.7	98	2031			2031	19%	55	8	
Total Lakesheds	1936	1011	13.2	44.1	4.8	13	261	59	202	522	5%	109	12	
Local+Lakesheds	1936	1011	13.2	304	42	111	2292	59	202	2553	23%	61	8	
Total External Inflow	1936	1011	13.2	2391.7	177.2	474	10433	59	202	10694	98%	60	4	
Precipitation			13.2		6.2	17				186	2%	30	14	
Evaporation			13.2		8.1	22								
Net Inflow				2404.9	175.3	469				10879	100%	62	5	
Predicted Outflow				2404.9	175.3	469	1256			9401	86%	54	4	
Retention										1478	14%			

<u>Assumptions for Shoreline Sources</u>

Excess Runoff; Above Lakeshed Background

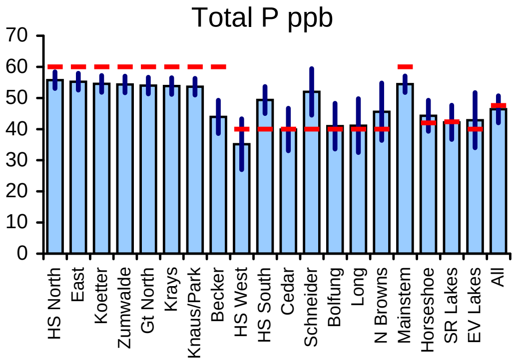
Average Lot Size	0.5	acres
Excess Areal Load	30	kg / km^{2,} may-sept, average year
Runoff Load Per Lot	0.061	kg / lot
Load per Septic Tank	0.40	kg
TMDL Reduction	50%	

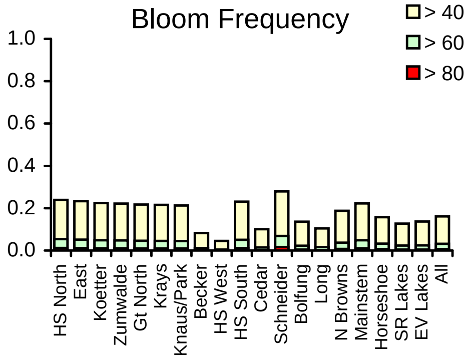
<u>BATHTUB Parameters</u>

Averaging Period	0.42	years	
Net Settling Rate - Other Lakes	4.8	m/yr	BATHTUB P Model 7
Net Settling Rate - North Browns	14.4	m/yr	
Net Settling Rate - Schneders L	9.6	m/yr	
Chlorophyll-a Calibration	1.00		BATHTUB Chl-a Model 2
Algal Light Extinction	0.015	m^2/mg	
Chla Flushing Coefficient	0.40		
Chl-a Coef of Variation	0.45		

Appendix G - 2 Mass Balance & Predicted Lake Responses Scenario: TMDL_TR_6

Lake Segment	Criterion ppb	TP ppb	TP_SE ppb	Chl-a ppb	Secchi m	Algal Bloom Frequencies > 40	> 60	> 80	Trophic Strate Indices Total P	Chl-a	Secchi
HS North	60	56	3	29	0.92	0.24	0.05	0.01	62	64	61
East	60	55	3	29	0.92	0.23	0.05	0.01	62	64	61
Koetter	60	55	3	28	0.93	0.22	0.05	0.01	62	64	61
Zumwalde	60	54	3	28	0.93	0.22	0.05	0.01	62	64	61
Gt North	60	54	3	28	0.93	0.22	0.05	0.01	62	63	61
Krays	60	54	3	28	0.93	0.22	0.05	0.01	62	63	61
Knaus/Park	60	54	3	28	0.94	0.21	0.04	0.01	62	63	61
Becker	60	44	5	21	1.09	0.08	0.01	0.00	59	61	59
HS West	40	35	8	19	1.72	0.05	0.00	0.00	55	59	52
HS South	40	49	4	29	1.88	0.23	0.05	0.01	60	64	51
Cedar	40	40	7	22	1.86	0.10	0.01	0.00	57	61	51
Schneider	40	52	7	31	1.78	0.28	0.07	0.02	61	64	52
Bolfung	40	41	7	24	2.15	0.14	0.02	0.00	58	62	49
Long	40	41	9	23	1.85	0.10	0.02	0.00	58	61	51
N Browns	40	46	9	27	1.99	0.19	0.04	0.01	59	63	50
Mainstem	60	54	3	28	0.93	0.22	0.05	0.01	62	64	61
Horseshoe	42	44	5	25	1.72	0.16	0.03	0.01	59	62	52
SR Lakes	42	42	5	24	1.77	0.13	0.02	0.00	58	62	52
EV Lakes	40	43	9	24	1.90	0.14	0.02	0.00	58	62	51
All	48	46	4	25	1.53	0.16	0.03	0.01	59	62	54

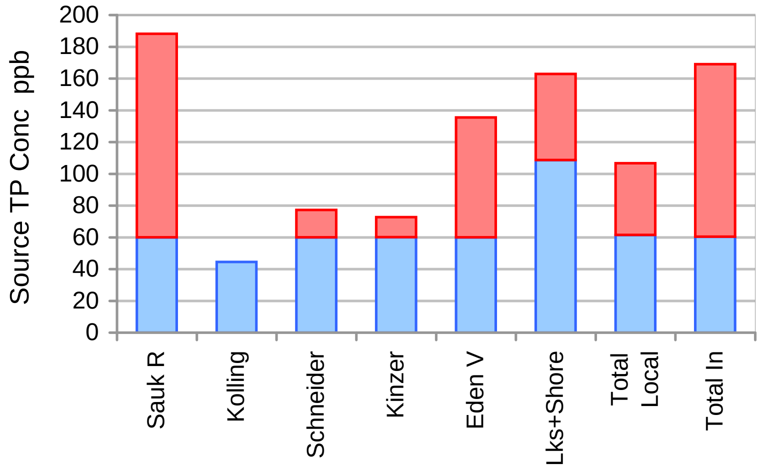


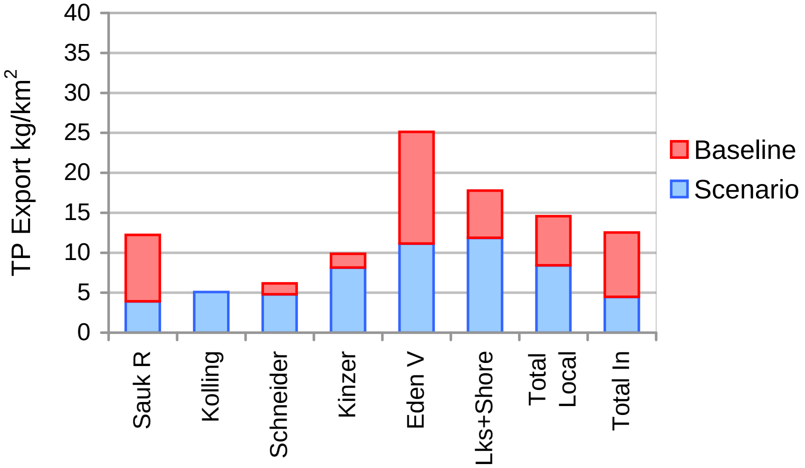


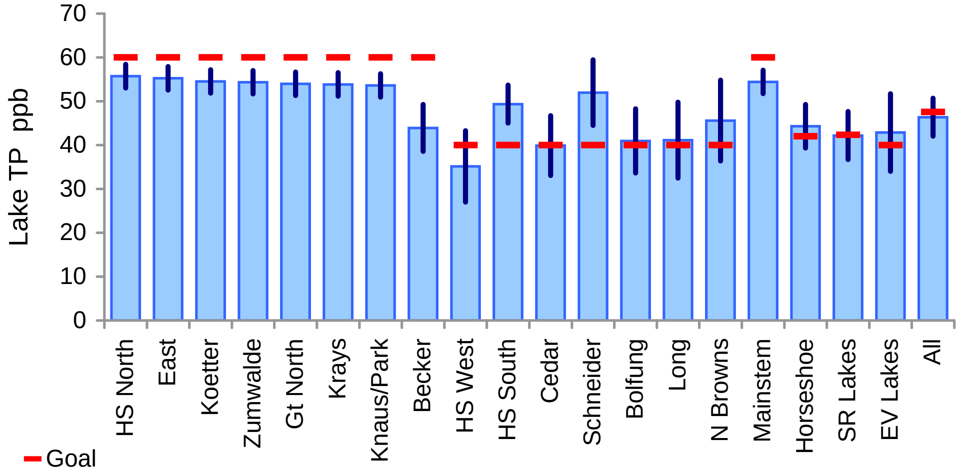
Water & Mass Balance (May - September)

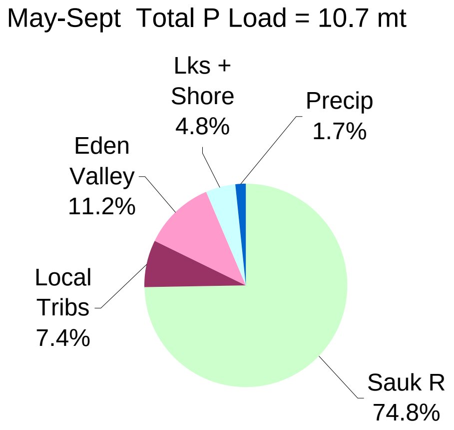
TMDL_TR_60_SL_50% Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Runoff cm	Export kg/km^2	Percent of Load	2002-2006 Baseline Load kg	Conc ppb	Load Reduc %
Sauk River Inflow	2088	136	8141	60	6	4	75%	25536	188	68%
Kolling Creek	97	11	496	45	11	5	5%	496	45	0%
Schneider Inflow	34	3	164	60	8	5	2%	211	77	22%
Kinzer Creek	18	3	150	60	14	8	1%	182	73	18%
Eden Valley Creek	106	20	1176	60	19	11	11%	2655	135	56%
Trib to Long L Inlet	4	1	45	60	19	11		102	135	56%
Lakesheds	44	5	261	54	11	6	2%	261	54	0%
Septic Systems			202				2%	404		50%
Excess Runoff			59					118		50%
External Inflow	2392	177	10694	60	7	4	98%	29965	169	64%
Precipitation	13	6	186	30	47	14	2%	186	30	0%
Evaporation		8			61					
Net Inflow	2405	175	10879	62	7	5	100%	30150	172	64%
Outflow	2405	175	9401	54	7	4	86%	26632	152	65%
Retention			1478				14%	3518		

Appendix G - 3 Load Reductions by Tributary Scenario: TMDL_TR_60_SL_5







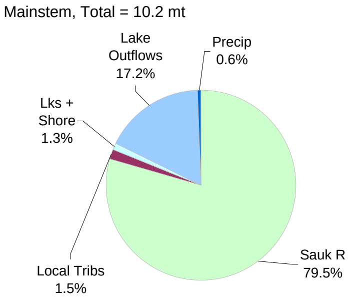


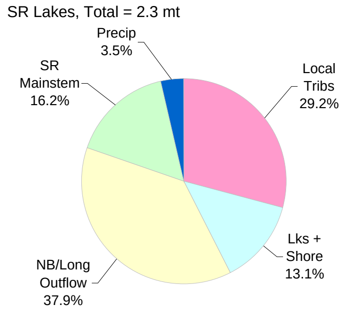
Predicted Summer Mean TP +/- 1 Standard Error

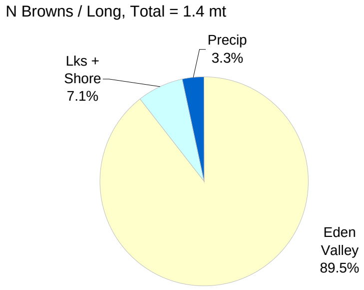
Lks+Shore = Lakesheds 2.4% + Septic Tanks 1.9% + Excess Lot Runoff 0.5%

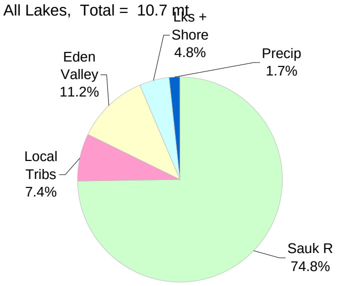
Total Local = All Sources Except Sauk River & Precipitation

Appendix G - 4 Phosphorus Sources by Region Scenario: TMDL_TR_60_SL_


Mainstem, Total = 10.2 mt


SR Lakes, Total = 2.3 mt


N Browns / Long, Total = 1.4 mt


All Lakes, Total = 10.7 mt

Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Mainstem Lakes (Horseshoe North - Knaus)									
Sauk River	2088	135.7	8141	60	87%	76%	82.5%	0.06	3.9
Kinzer Creek	18	2.5	150	60	1%	1%	1.5%	0.14	8.1
Lakeshed	6	0.6	34	54	0%	0%	0.3%	0.11	5.9
Septic Tanks	0		69				0.7%		
Shoreline Runoff	0		25				0.3%		
Total External	2112	138.8	8420	61	88%	78%	85.3%	0.07	4.0
Outflow from Lakes	288	37.1	1756	47	12%	21%	17.8%	0.13	6.1
Exchange with Lakes			-364				-3.7%		0.0
Precip	4	2.0	61	30	0%	1%	0.6%	0.47	14.1
Evap		0.0				0%	0.0%		
Net Inflow	2405	178.0	9873	55	100%	100%	100.0%	0.07	4.1
Outflow	2405	175.3	9401	54	100%	99%	95.2%	0.07	3.9
Retention			472				4.8%		
Offline Lakes (Becker, HS South, HS West, Cedar, Schneider, Bolfung)									
Kolling Creek	97	11.1	496	45	34%	27%	22.0%	0.11	5.1
Schneider Inflow	34	2.7	164	60	12%	7%	7.3%	0.08	4.8
Lakesheds	30	3.3	178	54	10%	8%	7.9%	0.11	5.9
Septic Tanks			93				4.1%		
Shoreline Runoff			26				1.2%		
Total External	162	17.1	956	56	56%	42%	42.4%	0.11	5.9
Inflow from Long	121	20.8	855	41	42%	51%	37.9%	0.17	7.1
Exchange with Mainstem			364				16.2%		0.0
Precip	6	2.6	79	30	2%	7%	3.5%	0.47	14.1
Evap		0.0				0%	0.0%		
Net Inflow	288	40.6	2255	56	100%	100%	100.0%	0.47	7.8
Outflow	288	37.1	1756	47	100%	92%	77.9%	0.47	6.1
Retention			499				22.1%		
North Browns + Long									
Eden Valley Creek	106	19.6	1176	60	87%	94%	86.3%	0.19	11.1
Trib to Long L Inlet	4	0.7	45	60	3%	4%	3.3%	0.19	11.1
Lakeshed	8	0.9	49	54	7%	4%	3.6%	0.11	5.9
Septic Tanks	0		40				2.9%		
Shoreline Runoff	0		8				0.6%		
Total External	118	21.3	1318	62	97%	102%	96.7%	0.18	11.2
Precip	3	1.5	46	30	3%	7%	3.3%	0.47	14.1
Evap		2.0				9%			
Net Inflow	121	20.8	1363	66	100%	100%	100.0%	0.17	11.2
Outflow	121	20.8	855	41	100%	100%	62.7%	0.17	7.1
Retention			508				37.3%		
Overall									
Sauk River	2088	135.7	8141	60	87%	77%	74.8%	0.06	3.9
Kolling Creek	97	11.1	496	45	4%	6%	4.6%	0.11	5.1
Schneider Inflow	34	2.7	164	60	1%	2%	1.5%	0.08	4.8
Kinzer Creek	18	2.5	150	60	1%	1%	1.4%	0.14	8.1
Eden Valley Creek	106	19.6	1176	60	4%	11%	10.8%	0.19	11.1
Trib to Long L Inlet	4	0.7	45	60	0%	0%	0.4%	0.19	11.1
Lakesheds	44	4.8	261	54	2%	3%	2.4%	0.11	5.9
Septic Tanks			202				1.9%		
Shoreline Runoff			59				0.5%		
Total External	2392	177.2	10694	60	99%	101%	98.3%	0.07	4.5
Precip	13	6.2	186	30	1%	4%	1.7%	0.47	14.1
Evap		8.1				5%			
Net Inflow	2405	175.3	10879	62	100%	100%	100.0%	0.07	4.5
Outflow	2405	175.3	9401	54	100%	100%	86.4%	0.07	3.9
Retention			1478				13.6%		

Appendix G - 5 Water & Mass Balances by Segment Scenario: TMDL_TR_60_SL_50%

Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
North Browns Lake									
Eden Valley Creek	105.7	19.6	1175.9	60	93%	97%	93%	0.19	11
Lakeshed	7.0	0.8	42	54	6%	4%	3%	0.11	6
Septic Tanks			27				2%		
Shoreline Runoff			4				0%		
Total External	112.7	20.4	1249	61	93%	101%	99%	0.18	11
Precip	1.3	0.6	18	30	1%	3%	1%	0.47	14
Evap		0.8				4%		0.61	
Net Inflow	114.0	20.2	1266	63	94%	100%	100%		
Outflow	114.0	20.2	921	46	100%	100%	73%	0.18	8
Retention			346				27%		
Long Lake									
Trib to Long L Inlet	4.0	0.7	45	60	3%	4%	4%	0.19	11
Lakeshed	1.3	0.1	7.5	54	1%	1%	1%	0.11	6
Septic Tanks			13				1%		
Shoreline Runoff			3				0%		
Total External	5.3	0.9	69	78	4%	4%	7%	0.17	13
Outflow from N Browns	114.0	20.2	921	46	94%	97%	90%	0.18	8
Precip	2.0	0.9	28	30	2%	4%	3%	0.47	14
Evap		1.2						0.61	
Net Inflow	121.3	20.8	1018	49	100%	100%	100%	0.17	8
Outflow	121.3	20.8	855	41	100%	100%	84%	0.17	7
Retention			162				16%		
Becker Lake									
Kolling Creek	97.4	11.1	495.8	45	98%	100%	91%	0.11	5
Lakeshed	1.0	0.1	6	54	1%	1%	1%	0.11	6
Septic Tanks			10		0%	0%	2%		
Shoreline Runoff			3		0%	0%	1%		
Total External	98.4	11.2	515	46	99%	101%	94%	0.11	5
Exchange with Main Lake			24				4%		
Precip	0.7	0.3	9	30	1%	3%	2%	0.47	14
Evap		0.4				4%		0.61	
Net Inflow	99.1	11.2	547	49	100%	100%	100%	0.11	6
Outflow	99.1	11.2	490	44		100%	89%	0.11	5
Retention			58				11%		
Schneiders Lake									
Schneider Inflow	34.2	2.7	163.6	60	94%	93%	83%	0.08	5
Lakeshed	2.2	0.2	13	54	6%	8%	6%	0.11	6
Septic Tanks			15		0%	0%	8%		
Shoreline Runoff			4		0%	0%	2%		
Total External	36.3	3.0	195	66	99%	101%	98%	0.08	5
Exchange with Main Lake			0				0%		
Precip	0.2	0.1	3	30	1%	4%	2%	0.47	14
Evap		0.1				5%		0.61	
Net Inflow	36.5	2.9	198	68	100%	100%	100%	0.08	5
Outflow	36.5	2.9	152	52		100%	77%	0.08	4
Retention			46				23%		
Cedar Island Lake (Including Mud, Little C									
Lakeshed	20.2	2.2	120	54	91%	115%	50%	0.11	6
Septic Tanks			26			0%	11%		
Shoreline Runoff			7			0%	3%		
Total External	20.2	2.2	152	69	91%	115%	64%	0.11	8
Exchange with Main Lake			59				24%		
Precip	2.0	1.0	29	30	9%	50%	12%	0.47	14
Evap		1.2				65%		0.61	
Net Inflow	22.3	1.9	240	125	100%	100%	100%	0.09	11
Outflow	22.3	1.9	77	40	100%	100%	32%	0.09	3
Retention			163				68%		
Bolfung Lake									
Lakeshed	3.5	0.4	21	54	89%	119%	43%	0.11	6
Septic Tanks			9		0%	0%	19%		
Shoreline Runoff			2		0%	0%	5%		
Total External	3.5	0.4	33	84	89%	119%	67%	0.11	9
Exchange with Main Lake			10				21%		
Precip	0.4	0.2	6	30	11%	63%	12%	0.47	14
Evap		0.3				81%		0.61	
Net Inflow	4.0	0.3	49	150	100%	100%	100%	0.08	12
Outflow	4.0	0.3	13	41	100%	100%	27%	0.08	3
Retention			35				73%		

Appendix G - 5 Water & Mass Balances by Segment Scenario: TMDL_TR_60_SL_50%

Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Horseshoe West - Krons Bay									
Lakeshed	3.0	0.3	18	54	75%	178%	23%	0.11	6
Septic Tanks			22				29%		
Shoreline Runoff			7				9%		
Total External	3.0	0.3	47	144	75%	178%	61%	0.11	16
Exchange with Main Lake			16				21%		
Precip	1.0	0.5	14	30	25%	260%	18%	0.47	14
Evap		0.6				338%		0.61	
Net Inflow	4.0	0.2	78	425	100%	100%	100%	0.05	19
Outflow	4.0	0.2	6	35	100%	100%	8%	0.05	2
Retention			71				92%		
Horseshoe South									
Lakeshed	0.1	0.0	0	54	0%	0%	0%	0.11	6
Septic Tanks			11				1%		
Shoreline Runoff			3				0%		
Total External	0.1	0.0	14	2019	0%	0%	1%	0.11	220
Outflow from Long Lake	121.3	20.8	855		99%	101%	75%		
Exchange with Main Lake			256				22%		
Precip	1.3	0.6	18	30	1%	3%	2%	0.47	14
Evap		0.8				4%		0.61	
Net Inflow	122.6	20.6	1143	55	100%	100%	100%	0.17	9
Outflow	122.6	20.6	1018	49	100%	100%	89%	0.17	8
Retention			125				11%		
Horseshoe North									
Sauk River Inflow	2087.8	135.7	8141.1	60	90%	81%	87%	0.06	4
Lakeshed	1.1	0.1	6	54	0%	0%	0%	0.11	6
Septic Tanks			5				0%		
Shoreline Runoff			2				0%		
Total External	2088.9	135.8	8154	60	90%	81%	87%	0.07	4
Outflow from Becker	99.1	11.2	490	44	4%	7%	5%	0.11	5
Outflow from HS West	4.0	0.2	6	35	0%	0%	0%	0.05	2
Outflow from HS South	122.6	20.6	1018	49	5%	12%	11%	0.17	8
Exchange with Becker			-24				0%		
Exchange with HS West			-16				0%		
Exchange with HS South			-256				-3%		
Precip	0.3	0.1	4	30	0%	0%	0%	0.47	
Evap		0.2				0%		0.61	
Net Inflow	2314.9	167.7	9376	56	100%	100%	100%	0.07	4
Outflow	2314.9	167.7	9348	56	100%	100%	100%	0.07	4
Retention			28				0%		
East Lake									
Lakeshed	0.1	0.0	1	54	0%	0%	0%	0.11	6
Septic Tanks			11				0%		
Shoreline Runoff			4				0%		
Total External	0.1	0.0	16	969	0%	0%	0%	0.11	106
Outflow from Horshoe North	2314.9	167.7	9348	56	100%	100%	100%	0.07	4
Precip	1.1	0.5	15	30	0%	0%	0%	0.47	14
Evap		0.7				0%		0.61	
Net Inflow	2316.1	167.6	9379	56	100%	100%	100%	0.07	4
Outflow	2316.1	167.6	9258	55	100%	100%	99%	0.07	4
Retention			121				1%		
Koetters Lake									
Lakeshed	0.7	0.1	4	54	0%	0%	0%	0.11	6
Septic Tanks			10				0%		
Shoreline Runoff			3				0%		
Total External	0.7	0.1	17	213	0%	0%	0%	0.11	23
Outflow from East Lake	2316.1	167.6	9258	55	99%	99%	100%	0.07	4
Outflow from Cedar Lake	22.3	1.9	77	40	1%	1%	1%	0.09	3
Exchange with Cedar Lake			-59				-1%		
Precip	0.5	0.2	7	30	0%	0%	0%	0.47	14
Evap		0.3				0%	0%	0.61	
Net Inflow	2339.6	169.5	9300	55	100%	100%	100%	0.07	4
Outflow	2339.6	169.5	9243	55	100%	100%	99%	0.07	4
Retention			57				1%		

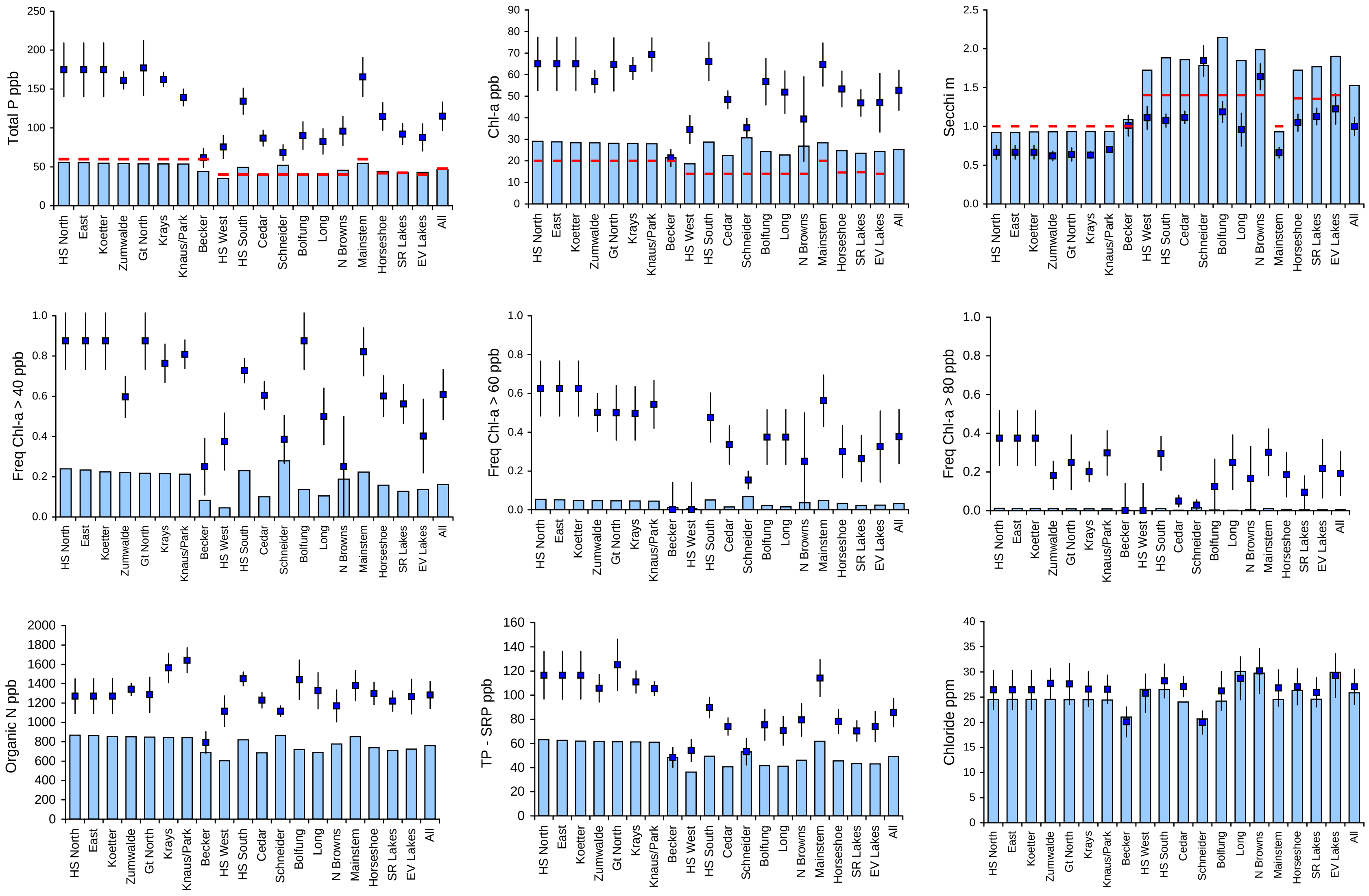
Appendix G - 5 Water & Mass Balances by Segment Scenario: TMDL_TR_60_SL_50%

Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Zumwalde Lake									
Lakeshed	0.6	0.1	3	54	0%	0%	0%	0.11	6
Septic Tanks			9				0%		
Shoreline Runoff			2				0%		
Total External	0.6	0.1	14	238	0%	0%	0%	0.11	26
Outflow from Koetter	2339.6	169.5	9243	55	100%	100%	100%	0.07	4
Precip	0.5	0.2	7	30	0%	0%	0%	0.47	14
Evap		0.3				0%		0.61	
Net Inflow	2340.7	169.5	9265	55	100%	100%	100%	0.07	4
Outflow	2340.7	169.5	9212	54	100%	100%	99%	0.07	4
Retention			53				1%		
Great Northern Lake									
Lakeshed	1.6	0.2	10	54	0%	0%	0%	0.11	6
Septic Tanks			9				0%		
Shoreline Runoff			2				0%		
Total External	1.6	0.2	21	119	0%	0%	0%	0.11	13
Outflow from Zumwalde	2340.7	169.5	9212	54	98%	98%	98%	0.07	4
Outflow from Schneider	36.5	2.9	152	52	2%	2%	2%	0.08	4
Exchange with Schneider			0				0%		
Precip	0.8	0.4	11	30	0%	0%	0%	0.47	14
Evap		0.5				0%		0.61	
Net Inflow	2379.6	172.5	9396	54	100%	100%	100%	0.07	4
Outflow	2379.6	172.5	9314	54	100%	100%	99%	0.07	4
Retention			82				1%		
Krays Lake									
Lakeshed	0.5	0.1	3	54	0%	0%	0%	0.11	6
Septic Tanks			5				0%		
Shoreline Runoff			1				0%		
Total External	0.5	0.1	9	172	0%	0%	0%	0.11	19
Outflow from Great North	2379.6	172.5	9314	54	100%	100%	100%	0.07	4
Precip	0.4	0.2	5	30	0%	0%	0%	0.47	14
Evap		0.2				0%		0.61	
Net Inflow	2380.4	172.5	9328	54	100%	100%	100%	0.07	4
Outflow	2380.4	172.5	9289	54	100%	100%	100%	0.07	4
Retention			39				0%		
Knaus & Park Lakes									
Kinzer Creek	18.5	2.5	150.3	60	1%	1%	2%	0.14	8
Lakeshed	1.1	0.1	7	54	0%	0%	0%	0.11	6
Septic Tanks			21				0%		
Shoreline Runoff			11				0%		
Total External	19.6	2.6	189	72	1%	1%	2%	0.13	10
Outflow from Krays	2380.4	172.5	9289	54	99%	98%	98%	0.07	4
Outflow from Bolfung	4.0	0.3	13		0%	0%	0%		
Exchange with Bolfung			-10				0%		
Precip	0.9	0.4	12	30	0%	0%	0%	0.47	14
Evap		0.5				0%		0.61	
Net Inflow	2404.9	175.3	9493	54	100%	100%	100%	0.07	4
Outflow	2404.9	175.3	9401	54	100%	100%	99%	0.07	4
Retention			92				1%		

Appendix G - 5 Water & Mass Balances by Segment Scenario: TMDL_TR_60_SL_50%

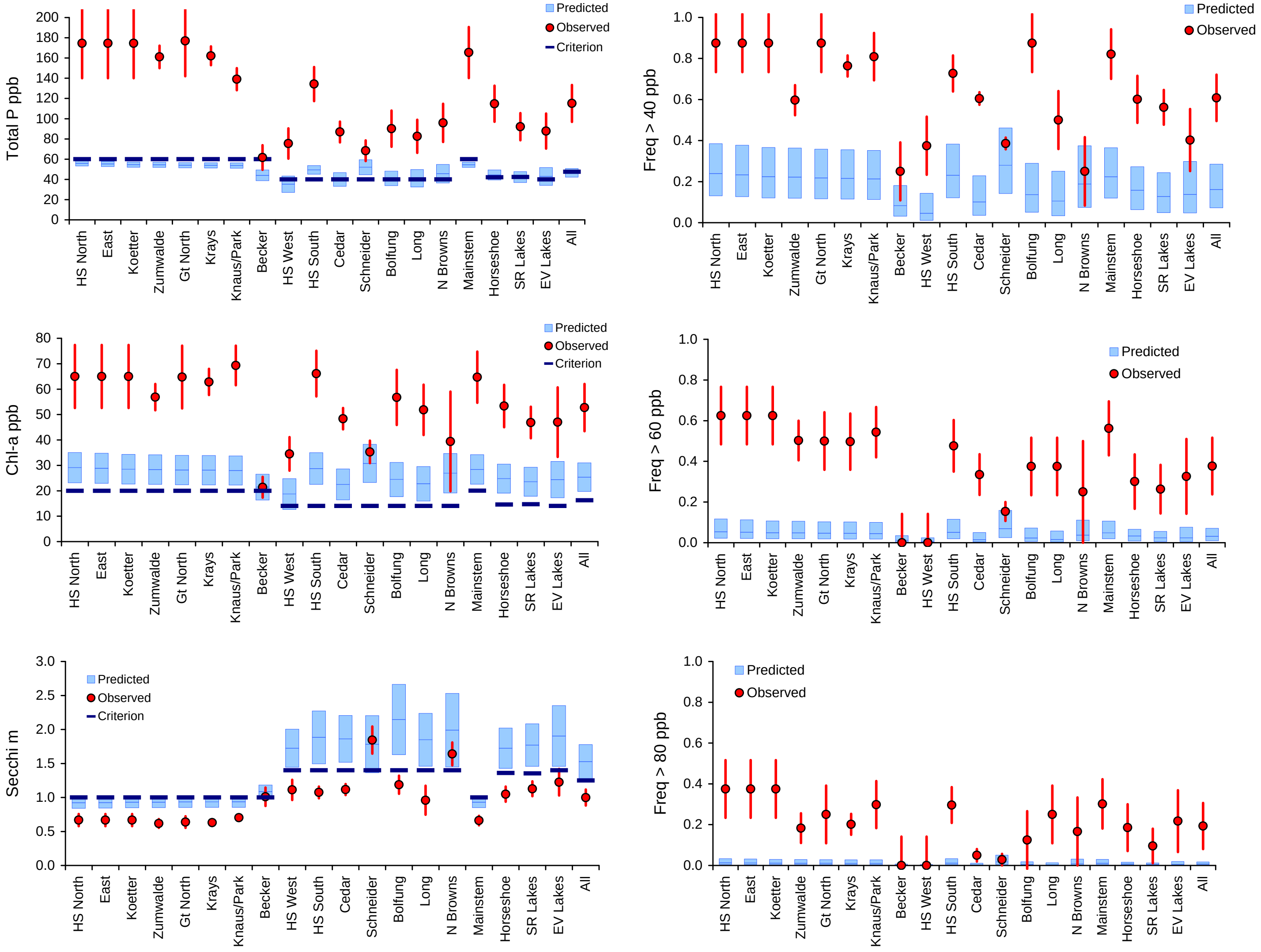
Source	Dr Area km^2	Flow hm^3	Load kg	Conc ppb	Area %	Flow %	Load %	Runoff m	Export kg/km^2
Mainstem Lakes (Horseshoe North - Knau									
Sauk River	2087.8	135.7	8141	60	87%	76%	82%	0.06	4
Kinzer Creek	18.5	2.5	150	60	1%	1%	2%	0.14	8
Lakeshed	5.7	0.6	34	54	0%	0%	0%	0.11	6
Septic Tanks			69		0%	0%	1%		
Shoreline Runoff			25		0%	0%	0%		
Total External	2112.1	138.8	8420	61	88%	78%	85%	0.07	4
Outflow from Lakes	288.5	37.1	1756	47	12%	21%	18%	0.13	6
Exchange with Lakes			-364				-4%		
Precip	4.3	2.0	61	30	0%	1%	1%	0.47	14
Evap		0.0				0%			
Net Inflow	2404.9	178.0	9873	55	100%	100%	100%	0.07	4
Outflow	2404.9	175.3	9401	54	100%	99%	95%	0.07	4
Retention			472				5%		
Offline Lakes (Becker, HS South, HS West									
Kolling Creek	97.4	11.1	496	45	34%	27%	22%	0.11	5
Schneider Inflow	34.2	2.7	164	60	12%	7%	7%	0.08	5
Lakesheds	30.0	3.3	178	54	10%	8%	8%	0.11	6
Septic Tanks			93				4%		
Shoreline Runoff			26				1%		
Total External	161.6	17.1	956	56	56%	42%	42%	0.11	6
Inflow from Long	121.3	20.8	855	41	42%	51%	38%	0.17	7
Exchange with Mainstem			364				16%		
Precip	5.6	2.6	79	30	2%	7%	4%	0.47	14
Evap		0.0				0%			
Net Inflow	288.5	40.6	2255	56	100%	100%	100%	0.47	8
Outflow	288.5	37.1	1756	47	100%	92%	78%	0.47	6
Retention			499				22%		
Mainstem + Lakes, Excluding North Brow									
Sauk River	2087.8	135.7	8141	60	87%	75%	78%	0.06	4
Kinzer Creek	18.5	2.5	150	60	1%	1%	1%	0.14	8
Kolling Creek	97.4	11.1	496	45	4%	6%	5%	0.11	5
Schneider Inflow	34.2	2.7	164	60	1%	2%	2%	0.08	5
Lakesheds	35.7	3.9	212	54	1%	2%	2%	0.11	6
Septic Tanks			162		0%	0%	2%		
Shoreline Runoff			51		0%	0%	0%		
Outflow from Long	121.3	20.8	855	41	5%	11%	8%	0.17	7
Total External	2394.9	176.7	10231	58	100%	97%	99%	0.07	4
Precip	10.0	4.7	140	30	0%	3%	1%	0.47	14
Evap		0.0				0%			
Net Inflow	2404.9	181.4	10371	57	100%	100%	100%	0.08	4
Outflow	2404.9	175.3	9401	54	100%	97%	91%	0.07	4
Retention			970				9%		
North Browns + Long									
Eden Valley Creek	105.7	19.6	1176	60	87%	94%	86%	0.19	11
Trib to Long L Inlet	4.0	0.7	45	60	3%	4%	3%	0.19	11
Lakeshed	8.3	0.9	49	54	7%	4%	4%	0.11	6
Septic Tanks			40				3%		
Shoreline Runoff			8				1%		
Total External	118.0	21.3	1318	62	97%	102%	97%	0.18	11
Precip	3.2	1.5	46	30	3%	7%	3%	0.47	14
Evap		2.0				9%			
Net Inflow	121.3	20.8	1363	66	100%	100%	100%	0.17	11
Outflow	121.3	20.8	855	41	100%	100%	63%	0.17	7
Retention			508				37%		
Overall									
Sauk River	2087.8	135.7	8141	60	87%	77%	75%	0.06	4
Kolling Creek	97.4	11.1	496	45	4%	6%	5%	0.11	5
Schneider Inflow	34.2	2.7	164	60	1%	2%	2%	0.08	5
Kinzer Creek	18.5	2.5	150	60	1%	1%	1%	0.14	8
Eden Valley Creek	105.7	19.6	1176	60	4%	11%	11%	0.19	11
Trib to Long L Inlet	4.0	0.7	45	60	0%	0%	0%	0.19	11
Lakesheds	44.1	4.8	261	54	2%	3%	2%	0.11	6
Septic Tanks			202			0%	2%		
Shoreline Runoff			59			0%	1%		
Total External	2391.7	177.2	10694	60	99%	101%	98%	0.07	4
Precip	13.2	6.2	186	30	1%	4%	2%	0.47	14
Evap		8.1				5%		0.61	
Net Inflow	2404.9	175.3	10879	62	100%	100%	100%	0.07	5
Outflow	2404.9	175.3	9401	54	100%	100%	86%	0.07	4
Retention			1478				14%		

Appendix G - 6 Observed & Predicted Lake Water Quality Scenario: TMDL_TR_60_SL_50%



Bars = Model Predictions. Symbols = Measured Values +/- 1 Standard Error Computed from Distribution of Summer Means Across Years. Red lines = Criteria

Appendix G - 7 Observed & Predicted Confidence Intervals Scenario: TMDL_TR_60_SL_50%



Means +/- 1 standard error of observed (symbols) and predicted (bars) values.
Blue lines indicate MPCA criteria for deep & shallow lakes. (TP < 40 or 60 ppb, Chla < 14 or < 20 ppb, Secchi >1.4 or 1.0 m

Appendix G - 8 Sensitivity Analysis Scenario: TMDL_TR_60_SL_50%

Percent Reduction in Lake P for with a 20% Reduction in Source or Model Coefficient

	Total P		Source Flow				Source Concentration				Settling Rate		Exchange
Segment	ppb	RSE	Sauk R	Tribs	Eden V	Lakeshed	Sauk R	Tribs	Eden V	Lakeshed	Mainstem	Lake	Rates
HS North	56	0.05	1	0	0	0	17	1	2	0	0	-1	0
East	55	0.05	2	0	0	0	17	1	2	0	0	-1	0
Koetter	55	0.05	2	0	0	0	17	1	2	1	0	-1	0
Zumwalde	54	0.05	2	0	0	0	17	1	1	1	-1	-1	0
Gt North	54	0.05	2	0	0	0	16	1	1	1	-1	-1	0
Krays	54	0.05	2	0	0	0	16	1	1	1	-1	-1	0
Knaus/Park	54	0.05	2	0	0	0	16	1	1	1	-1	-1	0
HS West	44	0.23	1	0	0	7	7	0	1	9	0	-16	3
HS South	35	0.09	1	0	0	0	12	1	6	1	0	-4	2
Cedar	49	0.17	1	0	0	3	9	1	1	8	0	-10	3
Schneider	40	0.14	0	3	0	2	0	17	0	3	0	-5	0
Bolfung	52	0.18	1	0	0	4	8	1	1	8	-1	-10	3
Long	41	0.21	0	0	7	1	0	0	18	2	0	-9	0
N Browns	41	0.20	0	0	5	1	0	0	19	1	0	-6	0
Mainstem	46	0.05	2	0	0	0	17	1	1	1	-1	-1	0
Horseshoe	54	0.11	1	0	0	2	11	1	4	3	0	-8	2
SR Lakes	44	0.13	1	0	0	3	8	3	2	5	0	-8	2
EV Lakes	42	0.21	0	0	6	1	0	0	18	1	0	-7	0
All	43	0.09	1	0	1	1	10	2	5	2	0	-5	1
Assumed Input Uncertainty (RSE)			10%	15%	20%	20%	5%	15%	20%	30%	20%	20%	40%

Shading: >15% >5% >2% reduction for a 20% reduction in model input value

RSE = Relative Standard Error in predicted Total P computed using first-order error analysis (Walker, 1982; 2006)

Lakeshed sources include ungauged runoff, shoreline runoff and septic systems.

Appendix G - 9 BATHTUB Input File Scenario: TMDL_TR_60_SL_50%

Case Title	Sauk River Chain of Lakes Scenario TMDL_TR_60_SL_50%

B	15
C	22
Number of Channels	0

Notes	Scenario TMDL_TR_60_SL_50%

Global Variables

Averaging Period (yrs)	0.42	0
Precipitation (m)	0.47	0.2
Evaporation (m)	0.61	0.3

Atmos. Loads (kg/km2-yr)

Conserv. Substance		
Total P	34	0.5
Total N		

Segment Data

Segment Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Segment Name		HS North	East	Koetter	Zumwald	Gt North	Krays	Knaus/Pa	Becker	HS West	HS South	Cedar	Schneide	Bolfung	Long	N Browns
Outflow Segment Number		2	3	4	5	6	7	0	1	1	1	3	5	7	10	14
Segment Group Number		1	1	1	1	1	1	1	2	3	4	5	6	7	8	9
Segment Morphometry																
Surface Area (km2)		0.25	1.09	0.52	0.49	0.76	0.37	0.85	0.66	1.02	1.27	2.04	0.22	0.43	1.97	1.26
Mean Depth (m)		1.64	0.76	1.14	1.85	1.86	2.14	1.96	2.44	5.86	3.52	4.34	6.12	4.03	3.04	5.60
Length (km)		1.00	1.80	3.00	2.00	1.00	1.00	1.00	2.00	1.00	1.50	2.00	1.00	1.00	3.00	1.80
Mixed Depth (m)	Mean	1.64	0.76	1.14	1.85	1.86	2.14	1.96	2.44	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	CV	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Observed Water Quality																
Non-Algal Turb (1/m)	Mean	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.6	0.3	0.1	0.2	0.1	0.1	0.2	0.1
	CV	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Conservative Subst	Mean			26.42	27.74	27.61	26.58	26.56	20.06	25.75	28.21	27.10	19.96	26.21	28.72	30.19
	CV			0.15	0.11	0.15	0.13	0.11	0.15	0.15	0.12	0.07	0.11	0.15	0.15	0.15
Total P (ppb)	Mean			174.63	161.10	177.00	162.18	139.05	61.63	75.50	134.28	86.90	68.32	90.13	82.63	95.92
	CV			0.20	0.07	0.20	0.06	0.08	0.20	0.20	0.13	0.12	0.15	0.20	0.20	0.20
Chlorophyll-a (ppb)	Mean			65.00	56.85	64.75	62.83	69.30	21.38	34.50	66.10	48.37	35.30	56.75	51.88	39.41
	CV			0.19	0.09	0.19	0.08	0.11	0.19	0.19	0.14	0.09	0.13	0.19	0.19	0.50
Secchi (m)	Mean			0.67	0.62	0.64	0.63	0.70	1.01	1.11	1.07	1.12	1.84	1.19	0.96	1.64
	CV			0.13	0.10	0.13	0.07	0.04	0.13	0.13	0.08	0.07	0.11	0.11	0.22	0.10
Organic N (ppb)	Mean			1271.88	1342.34	1285.63	1563.05	1642.86	792.13	1116.13	1449.67	1230.11	1116.04	1441.04	1328.13	1170.88
	CV			0.14	0.05	0.14	0.10	0.08	0.14	0.14	0.05	0.07	0.05	0.14	0.14	0.14
Total P - Ortho P (ppb)	Mean			116.50	105.74	125.13	110.90	105.30	48.38	54.25	89.78	74.04	53.18	75.38	70.50	79.50
	CV			0.17	0.11	0.17	0.08	0.05	0.17	0.17	0.09	0.10	0.21	0.17	0.17	0.17
Calibration Factors																
Dispersion Rate	Mean	0	0	0	0	0	0	0	4.78689	1.91475	95.7377	9.57377	0	1.91475	0	0
	CV															
Total P	Mean	1	1	1	1	1	1	1	1	1	1	1	2.00	1	1	3.00
	CV															

Tributary Data

		Tributaries							Lakesheds														
Tributary Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Tributary Name		SRCL Inf	Kolling C	Schneide	Kinzer C	Eden Val	Eden Val	SRCL Ou	LS_HS N	LS_East	LS_Koett	LS_Zumv	LS_Gt N	LS_Krays	LS_Knau	LS_Beck	LS_HS W	LS_HS S	LS_Ceda	LS_Schn	LS_Bolfu	LS_Long	LS_N Bro
Segment Number		1	8	12	7	15	14	7	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tributary Type Code		1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Drainage Area (km2)		2087.83	97.43	34.15	18.49	105.68	4.04	2404.88	1.08	0.15	0.72	0.56	1.62	0.49	1.14	1.01	2.99	0.07	20.25	2.15	3.53	1.26	7.05
Flow (hm3/yr)	Mean	324.75	26.65	6.53	6.00	46.91	1.79	401.33	0.28	0.04	0.19	0.14	0.42	0.13	0.30	0.26	0.78	0.02	5.29	0.56	0.92	0.33	1.84
	CV	0.10	0.15	0.15	0.15	0.20	0.20	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Conserv. Subst (-)	Mean	23.96	20.23	20.50	18.03	29.86	29.86	0.00	2.39	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23	20.23
	CV	0.05	0.15	0.15	0.15	0.20	0.20	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Total P (ppb)	Mean	60	45	60	60	60	60	#N/A	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
	CV	0.05	0.15	0.15	0.15	0.20	0.20	0.05	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Tributary Data - Shoreline Runoff

		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Tributary Name		R__HS N	R__East	R__Koett	R__Zumv	R__Gt N	R__Krays	R__Knau	R__Beck	R__HS W	R__HS S	R__Ceda	R__Schn	R__Bolfu	R__Long	R__N Browns
Segment Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tributary Type Code		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Flow (hm3/yr)	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total P (ppb)	Mean	3873	8722	6759	5596	5451	3561	26311	7632	16648	7970	15627	8722	5742	8358	9739
	CV	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Tributary Data - Shoreline Septic Tanks

		38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Tributary Name		ST___HS	ST___Ea	ST___Ko	ST___Zu	ST___Gt	ST___Kr	ST___Kr	ST___Be	ST___HS	ST___HS	ST___Ce	ST___Sc	ST___Bo	ST___Lo	ST___N Browns
Segment Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tributary Type Code		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Flow (hm3/yr)	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total P (ppb)	Mean	12494	26328	22977	21062	22020	11489	49305	22977	53705	25709	61751	35902	22020	32072	64144
	CV	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Model Coefficients (Mean, CV)

Dispersion Rate	1	0.4
Total Phosphorus	4.78689	0.2
Total Nitrogen	1	0.55
Chl-a Model	1	0.2
Secchi Model	1	0.1
Organic N Model	1	0.1
TP-OP Model	1	0.15
HODv Model	1	0.15
MODv Model	1	0.22
Secchi/Chla Slope (m2/mg)	0.015	0.1
Minimum Qs (m/yr)	0.1	0
Chl-a Flushing Term	0.4	0
Chl-a Temporal CV	0.45	0
Availability Factor - Total P	1	0
Availability Factor - Ortho P	0	0
Availability Factor - Total N	1	0
Availability Factor - Inorganic N	0	0

Model Options

Conservative Subs	1
Phosphorus Balan	7
Nitrogen Balance	0
Chlorophyll-a	2
Secchi Depth	1
Dispersion	3
Phosphorus Calibr	1
Nitrogen Calibratio	1
Error Analysis	1
Availability Factors	0
Mass-Balance Tab	1
Output Eestination	2