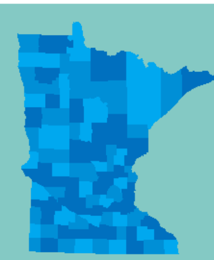
Site-specific standard

December 2017

Technical Justification for Draft Lake Zumbro (55-0004-00) Site-Specific Eutrophication Standard

MINNESOTA POLLUTION CONTROL AGENCY



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Executive summary

As part of Minnesota rule, site-specific standards (SSS) can be developed when available information demonstrates that a site-specific modification to statewide or ecoregion standards is appropriate (Minn. R. 7050.0220 subp. 7). This document describes the process for establishing SSS and proposes site-specific modifications to the lake eutrophication standards (LES) for Lake Zumbro (55-0004-00). The proposed SSS are not part of a Use Attainability Analysis (UAA) to demonstrate that the current designated beneficial use (Class 2) cannot be attained. Rather, these SSS are based on a demonstration that modifications to the LES, which apply to this waterbody, will still result in attainment of Class 2 designated beneficial uses (aquatic life and recreation).

Description of Lake Zumbro

Lake Zumbro (55-0004-00) is a run-of-the-river reservoir on the Zumbro River that was created by a dam built in 1919. The lake lies in southeastern Minnesota, near the community of Oronoco and is less than 20 miles north of the city of Rochester. Lake Zumbro straddles Olmsted and Wabasha counties. There are three primary tributaries to the lake, the South Fork of the Zumbro River, the Middle Fork Zumbro River, and Dry Run Creek. Additional inputs to the lake include direct drainage and a few smaller creeks directly surrounding the lake. The Zumbro River Watershed upstream of Lake Zumbro drains an area of 2,185 km^2 and is transitional between two U.S. Environmental Protection Agency (EPA) Level III ecoregions. The upper reaches of the watershed drain lands in the Western Corn Belt Plains Ecoregion (42%) and the lower reaches drain a portion of the Driftless Area (58%; Figure 1). A mosaic of land uses are present in the watershed (Table 1; Figure 2) although agriculture is dominant (60%), especially in the upper reaches of the watershed and in upland areas. Urban land use (12%) is the second largest land use behind agriculture. Grassland (10%), pasture (9%), and forest (8%) land uses are also important with most of these land uses in the downstream reaches and in the stream and river valleys (Figure 2).

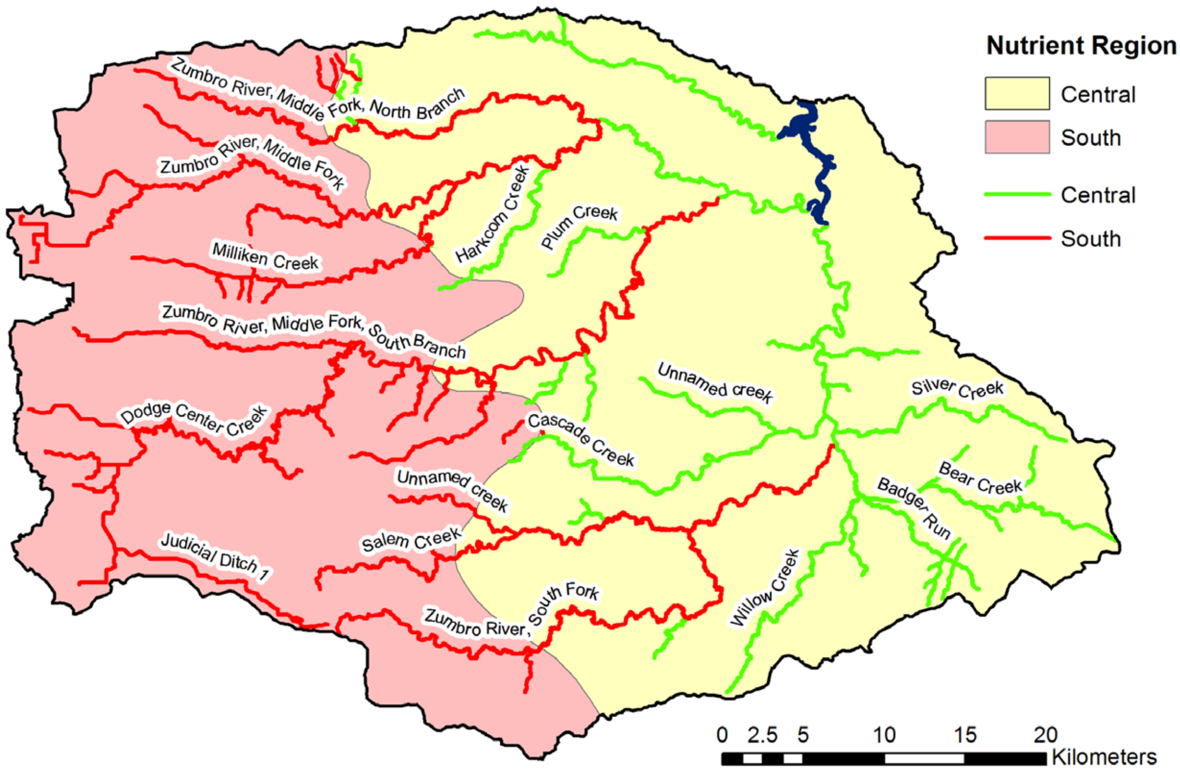

Figure 1. River nutrient regions and river nutrient region designations for streams in the Lake Zumbro Watershed. ***Note: Although Lake Zumbro is currently assigned a site-specific standard, this standard is equivalent to the southern, deep-water lake type.***

Table 1: Generalized land cover in the Lake Zumbro Watershed. Delineations are based on the Minnesota Department of Natural Resources Catchments shapefile. Land cover is derived from the 2006 national land cover database. ***Note: surface area of Zumbro Reservoir (2.65 km^2) is subtracted from water land cover.***

Generalized Land Cover	Area (km^2)	%
Agriculture	1307	60%
Forest	169	8%
Grassland	225	10%
Pasture	193	9%
Urban	252	12%
Water	7	0%
Wetlands	32	1%
Total	2185	100%

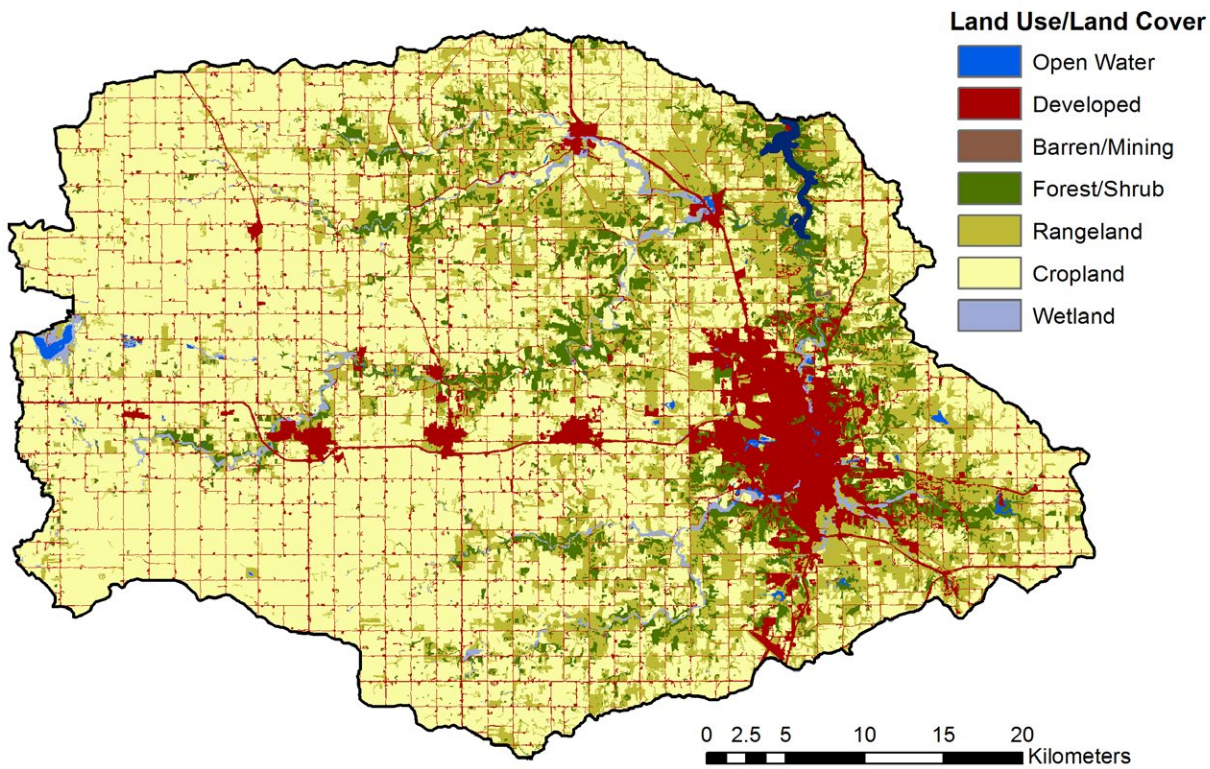

Figure 2: Land use in the Lake Zumbro Watershed. Delineations are based on the Minnesota Department of Natural Resources Catchments shapefile. Land cover is derived from the 2006 national land cover database.

With a surface area of about 655 acres (2.65 km^2), the lake has a high watershed to surface area ratio (825:1). As a result, water loading is very high and water residence time is rather short (typically below 14 days). As modeled using HSPF, the summer (June through September) average residence times from 1996 through 2009 ranged from 3.9 to 26.7 days with an average of 10.6 days. The lake has three somewhat distinct segments (Figure 3): a shallow inflow segment (Segment 1) where the South and Middle Forks of the Zumbro River enter the lake, a deeper, more lake-like middle segment (Segment 2) and a deeper, near-dam segment (Segment 3) which includes the inflow from Dry Run Creek. Lake Zumbro has one public boat access and is used for swimming, skiing, boating, and fishing and a second access that is used for launching canoes and kayaks. The lake is popular due to its proximity to the city of Rochester. A majority of the recreation in the reservoir takes place in the middle and near-dam segments (Segments 2 and 3). The lake's fishery supports good populations of bluegill, black crappie, channel catfish, largemouth bass, and smallmouth bass and also supports white crappie, white bass, yellow perch, northern pike, and muskellunge. The lake is stocked by the Minnesota Department of Natural Resources (DNR) with walleye with a goal of establishing a fishery.

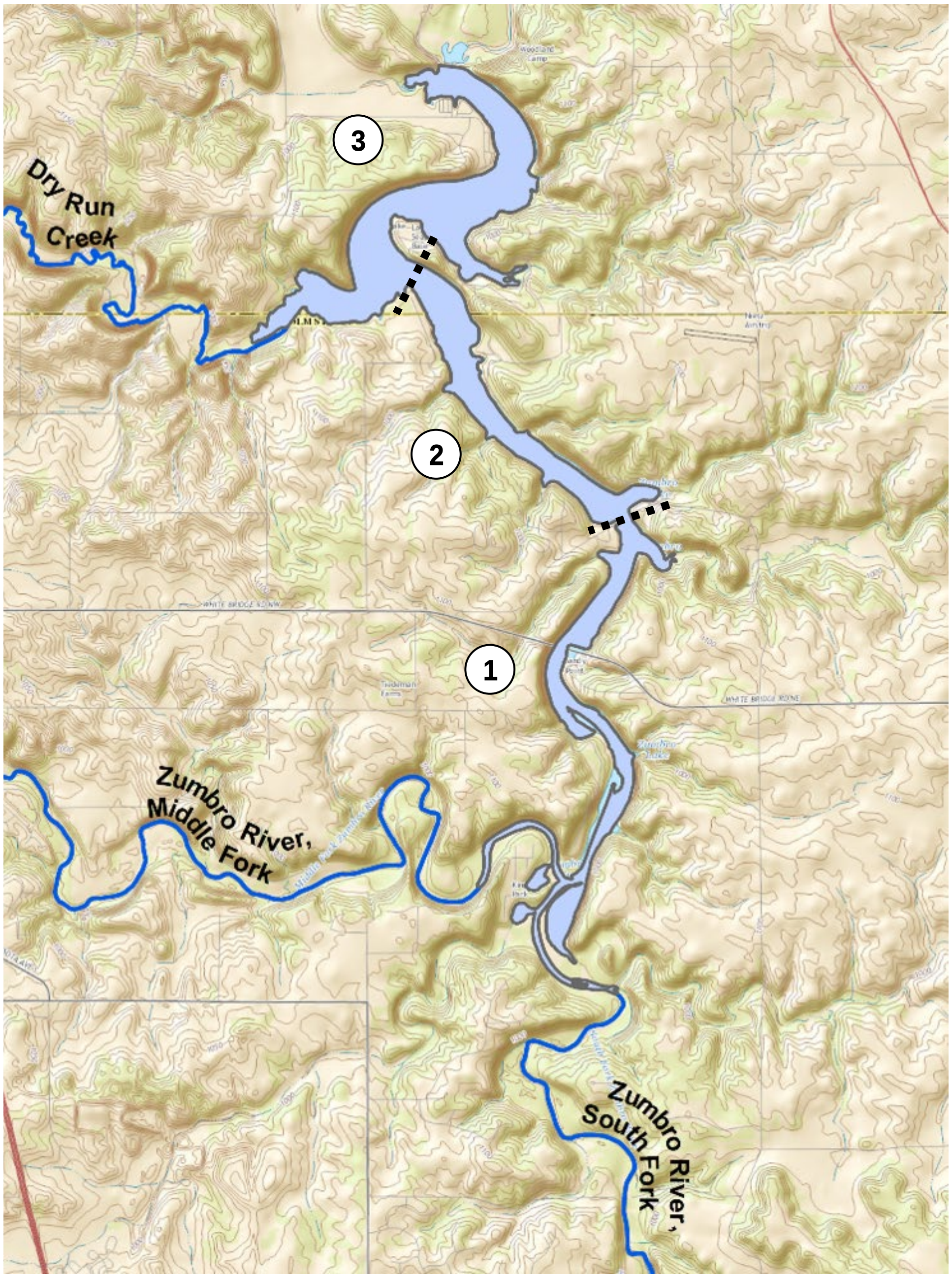

Figure 3. Map of Lake Zumbro indicating the location of the three segments.

Applicable standards

Lake eutrophication standards

The LES are designed to protect Class 2 designated uses (aquatic life and recreation). They are based on an analysis of water quality relationships in Minnesota lakes and user perceptions relative to Secchi depth and the frequency and severity of nuisance algae blooms (Heiskary and Wilson 2005). The deep-lake standards place an emphasis on the ecological health of lakes, but are also designed to be supportive of aquatic recreational use (e.g. swimming, wading, boating etc.), where these beneficial uses are attainable (State of Minnesota 2007, p. 74). The Statement of Need and Reasonableness (State of Minnesota 2007) and the promulgated LES, which were reviewed by an administrative law judge and approved by the EPA, state that these standards will not prevent algae blooms; however, they will serve to minimize the intensity and duration of very severe nuisance blooms, which often make waters unusable (State of Minnesota 2007, p. 66). Therefore, a proposed SSS for Lake Zumbro will need to set goals that, if attained will support and protect aquatic recreation in and on the waterbody including boating, wading, skiing, swimming, etc. It must be noted that attainment of the designated beneficial use, pursuant to the promulgated lake water quality standards, does not require elimination of all algae blooms.

The LES standard that is currently applied to Lake Zumbro is equivalent to the southern, deep-lake standard (total phosphorus [TP] < 65 µg/L, chlorophyll-a [chla] < 22 µg/L, and Secchi depth > 0.9 m; Table 2). Because Lake Zumbro is in the Driftless Area ecoregion, the current standard was applied as a SSS (see [Minn. R. 7050.0222 subp. 4a, Item A]). The application of the southern, deep-lake standard as a SSS was based on the depth of the lake and the fact that the upper portion of the lake drains from the Western Corn Belt Plains ecoregion. In 2002, the lake was designated as impaired for eutrophication due to excess phosphorus.

Table 2. Lake eutrophication criteria (NLF = Northern Lakes and Forests, CHF = North Central Hardwoods, WCBP = Western Corn Belt Plains, NGP = Northern Glaciated Plains). * Standard currently applied to Lake Zumbro.

Ecoregion	TP (ppb)	Chl-a (ppb)	Secchi (m)
North			
NLF – Lake trout (Class 2A)	< 12	< 3	≥ 4.8
NLF – Stream trout (Class 2A)	< 20	< 6	≥ 2.5
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	≥ 2.0
Central			
CHF – Stream trout (Class 2A)	< 20	< 6	≥ 2.5
CHF – Aquatic Rec. Use (Class 2B)	< 40	< 14	≥ 1.4
CHF – Aquatic Rec. Use (Class 2B) Shallow lakes	< 60	< 20	≥ 1.0
South			
WCBP & NGP – Aquatic Rec. Use (Class 2B)*	< 65	< 22	≥ 0.9
WCBP & NGP – Aquatic Rec. Use (Class 2B) Shallow lakes	< 90	< 30	≥ 0.7

Site-specific standards

The following two rules govern MPCA's adoption of site-specific standards:

Minn. R. 7050.0220, subp. 7, Items A, B and C:

Subp. 7. ***Site-specific modifications of standards.***

A. The standards in this part and in parts 7050.0221 to 7050.0227 are subject to review and modification as applied to a specific surface water body, reach, or segment. If site-specific information is available that shows that a site-specific modification is more appropriate than the statewide or ecoregion standard for a particular water body, reach, or segment, the site-specific information shall be applied.

B. The information supporting a site-specific modification can be provided by the commissioner or by any person outside the agency. The commissioner shall evaluate all relevant data in support of a modified standard and determine whether a change in the standard for a specific water body or reach is justified.

C. Any effluent limit determined to be necessary based on a modified standard shall only be required after the discharger has been given notice of the specific proposed effluent limits and an opportunity to request a hearing as provided in part 7000.1800.

Minn. R. 7050.0222, subp. 4a, Items A and E (emphasis added)**:**

Subp. 4a. ***Narrative eutrophication standards for class 2B lakes, shallow lakes, and reservoirs.***

A. Eutrophication standards applicable to lakes, shallow lakes, and reservoirs that lie on the border between two ecoregions or that are in the Red River Valley (also referred to as Lake Agassiz Plains), Northern Minnesota Wetlands, or ***Driftless Area Ecoregion*** *must be applied on a case-by-case basis. The commissioner shall use the standards applicable to adjacent ecoregions as a guide.*

E. When applied to reservoirs, ***the eutrophication standards in this subpart and subpart 4 may be modified on a site-specific basis to account for characteristics of reservoirs that can affect trophic status****, such as water temperature, variations in hydraulic residence time, watershed size, and the fact that reservoirs may receive drainage from more than one ecoregion. Information supporting a site-specific standard can be provided by the commissioner or by any person outside the agency. The commissioner shall evaluate all data in support of a modified standard and determine whether a change in the standard for a specific reservoir is justified. Any total phosphorus effluent limit determined to be necessary based on a modified standard shall only be required after the discharger has been given notice of the specific proposed effluent limits and an opportunity to request a hearing as provided in part 7000.1800.*

Criteria for determining whether to develop a site-specific water quality standard

In 2008, the state of Minnesota promulgated eutrophication water quality standards for Class 2 lakes (Minn. R. 7050.0222). The standards provide, among other things, the following:

a. Definition of a reservoir, which is met by Lake Zumbro (see Minn. R. 7050.0150, subp. 4, Item S):

   "Reservoir" means a body of water in a natural or artificial basin or watercourse where the outlet or flow is artificially controlled by a structure such as a dam. Reservoirs are distinguished from river systems by having a hydraulic residence time of at least 14 days. For purposes of this item, residence time is determined using a flow equal to the 122Q10 for the months of June through September, a 122Q10 for the summer months.

b. In-lake eutrophication criteria (numeric values for TP, chla, Secchi depth) differ according to ecoregion and in some ecoregions the standards assign different numeric values for shallow and deep lakes (Minn. R. 7050.0222).

c. A provision stating that eutrophication standards for reservoirs may be formulated on a site-specific basis to account for characteristics unique to reservoirs that can affect trophic status, such as water temperature, variations in hydraulic residence time, watershed size, and the fact that reservoirs may receive drainage from more than one ecoregion (see Minn. R. 7050.0222, subp. 4a, Item E).

d. A provision that states that the application of standards for lakes in the Driftless Area ecoregion be applied on a case-by-case basis (see [Minn. R. 7050.0222](), subp. 2a, Item E, subp. 3a, Item A, and subp. 4a, Item A).

As a result of the following factors it is reasonable to consider the establishment of a SSS for Lake Zumbro:

1. Lake Zumbro is located in the Driftless Area ecoregion, and as stated in rule (Minn. R. 7050.0222, subp. 4a, Item A), eutrophication standards are applied on a case-by case basis to lakes in this ecoregion. Lake Zumbro was originally assigned the southern, deep-lake LES due to the depth of the lake and because ~42% of the watershed drains the Southern (Western Corn Belt Plains & Northern Glaciated Plains) LES region. However, this assignment was based on limited information compared to the review contained in this report.
2. Lake Zumbro is a reservoir that often does not meet the 14-day residence time. It has a large watershed that drains both the Western Corn Belt Plains and Driftless Area ecoregions. As a result, its hydrology is not typical of natural lakes in Minnesota and different from lakes used to develop the LES. The ability of the lake to grow undesirable levels of algae that harm the beneficial designated uses (aquatic life and recreation) is impacted by residence time and shading due to turbidity. Therefore, Minn. R. 7050.0222, subp. 4a, Item E is applicable to Lake Zumbro.

Lake Zumbro presents precisely the case addressed by Minn. R. 7050.0222, subp. 4a, Items A and E. It is a unique waterbody, to which the ecoregion-based LES may not apply. A site-specific standard consideration is therefore appropriate.

Water quality characteristics

The following section describes the data (sampling locations, data collection methods, etc.) used in the analyses in this report and characterizes temporal and spatial patterns of TP, chla, and Secchi depth in Lake Zumbro.

Water chemistry sampling sites and initial data filters

Available water quality data (TP, chla, Secchi depth, lake physical appearance, lake recreational suitability) from Lake Zumbro (55-0004-00) were queried from EQUIS (April 12, 2017) (see Appendices A, B and C). The TP and chla data included some samples collected using unknown methods (LEG*) and should be treated with caution although there is no reason to assume these data are erroneous (Table 3).

Table 3. Table of parameters and laboratory methods for Lake Zumbro data.

Parameter	Method Code	Years in Dataset
Total phosphorus	LEG_P00665	1976-1998
Total phosphorus	LEG_P00666	1976
Total phosphorus	365.1	2000-2008
Chlorophyll-a, corrected for pheophytin	LEG_P32211	1976-1998
Chlorophyll-a, corrected for pheophytin	10200-H	2000-2008
Secchi	Field Method	1976-2016
Lake physical appearance	Field Method	1988-2016
Lake recreational suitability	Field Method	1988-2016

The lake was divided into four segments for the development of a BATHTUB model (Wasley 2016; see Figure 26). In this report, the lake is divided into three or four segments depending on the analysis. Much of the water quality analysis is based on three segments (Figure 3). These segments correspond to the segments used in the Bathtub model with Segments 3A and 3B combined into Segment 3. Segments 3A and 3B were combined because there was not sufficient field data to perform analyses on these segments separately and because the morphology of the lake is similar in Segments 3A and 3B.

Data from 16 water chemistry sites, including five stations each in Segments 1 and 2 and six stations in Segment 3 (Table 4), were used in the analyses for the Lake Zumbro site-specific standard. In cases where duplicate samples were collected at the same station or where multiple stations were sampled on the same day from the same lake segment, water chemistry values were averaged. Only data from the summer season (June-September) were used. In some cases, samples were collected at multiple depths in the lake. Only water quality grab samples collected within 1 meter (m) of the surface were used in the analyses. Non-detect values were rare for the parameters examined so sophisticated analytical methods were not used to address these values. In the Lake Zumbro database analyzed, a single non-detect occurred for TP in Segment 3 in 1991. For this non-detect, the value used was the midpoint between 0 and the minimum detect limit for the method (10 µg/L).

Table 4. Water chemistry sampling sites

Segment 1	Segment 2	Segment 3
55-0004-00-110	55-0004-00-203	55-0004-00-202
55-0004-00-103	55-0004-00-120	55-0004-00-107
55-0004-00-109	55-0004-00-100	55-0004-00-205
55-0004-00-204	55-0004-00-208	55-0004-00-209
55-0004-00-105	55-0004-00-207	55-0004-00-206
		55-0004-00-201

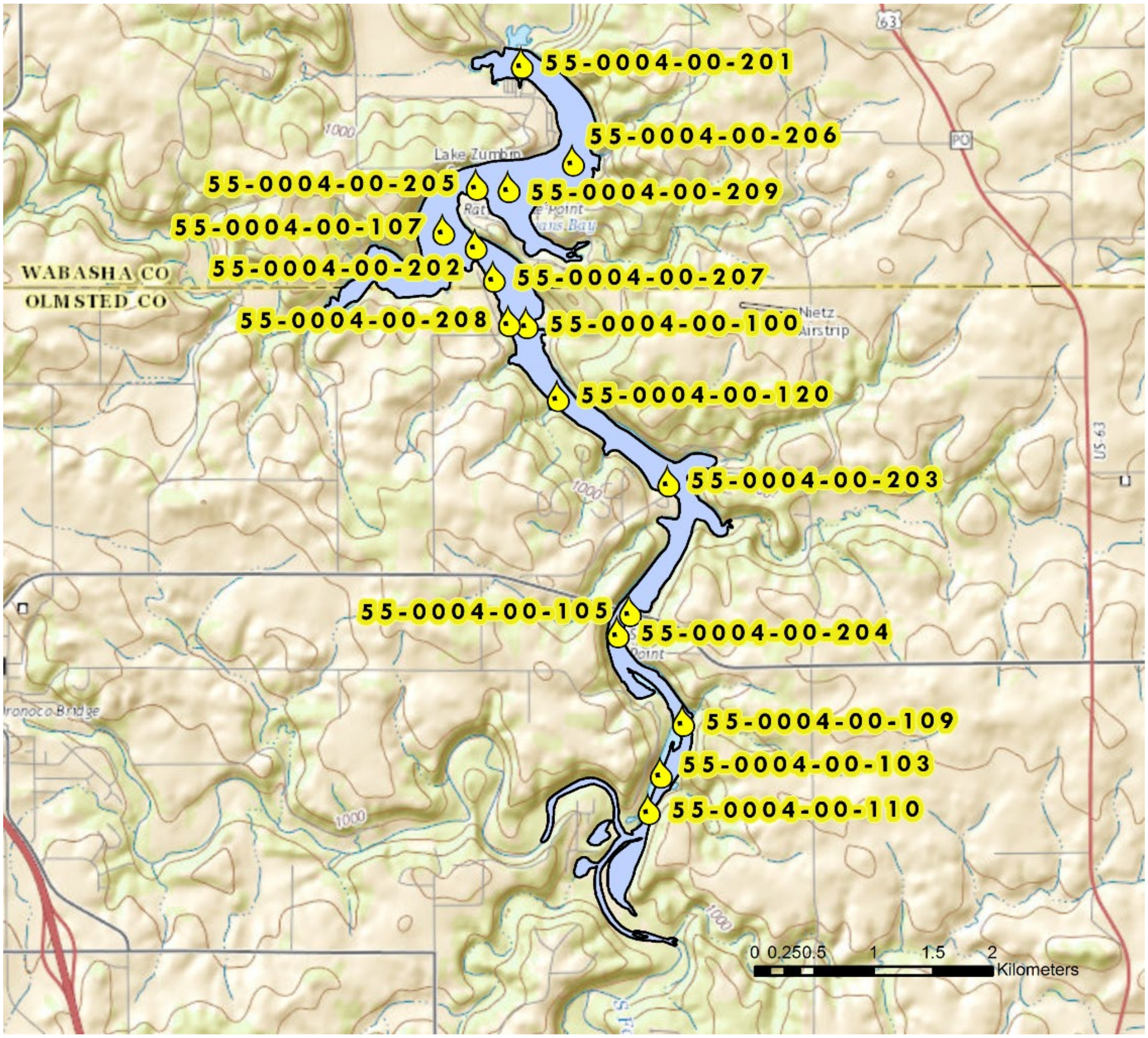

Figure 4. Location of water quality sampling station in Lake Zumbro.

Total phosphorus

Total phosphorus (TP) summer season data (June through September) from 1976-2008 consisted of two to eight sample dates per year. There were also several years with a single sample, but these are excluded from this analysis. Time-weighted, 10-year averages were calculated from 1977 through 2016 where at least two years of data were available (Figure 5A). A steep decline in the concentration of TP is apparent from 1985/1986 through 1990, largely due to improvements in wastewater treatment. Since 1990, the annual mean concentrations have averaged 151, 119, and 86 µg/L for Segments 1, 2, and 3, respectively. These patterns were generally similar for all three segments of the lake although TP concentrations drop from Segment 1 to Segment 3 (discussed further in “Longitudinal Patterns”). These patterns were similar for the annual time-weighted concentrations (Figure 5B).

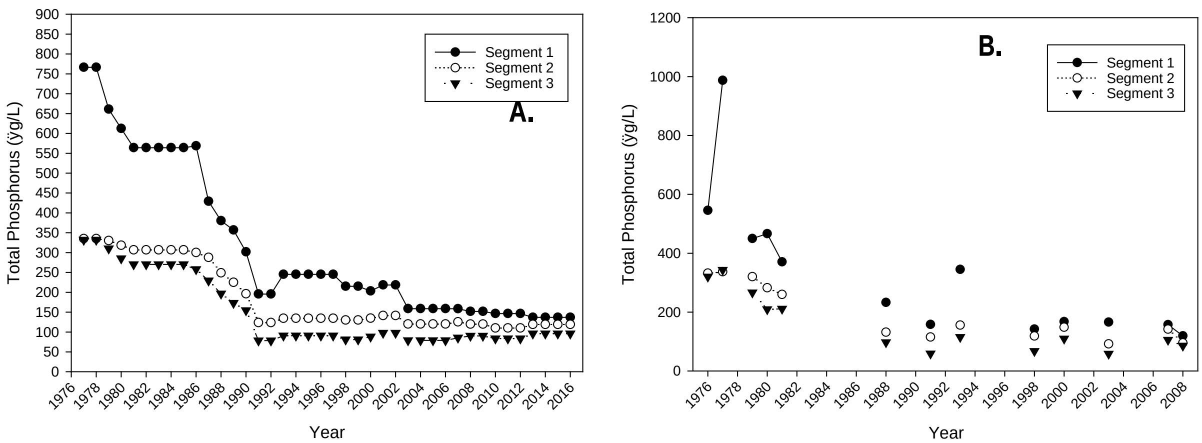

Figure 5: A) 10-year, time-weighted average and B) annual time-weighted average total phosphorus concentrations for the 3 segments of Lake Zumbro (55-0004-00).

Chlorophyll-a

Chlorophyll-a (chla) summer season data (June through September) from 1976-2008 consisted of two to eight sample dates per year. There were also several years with a single sample, but these are excluded from this analysis. Time-weighted, 10-year averages were calculated from 1977 through 2016 where at least two years of data were available (Figure 6A). A steep decline in the concentration of chla is apparent from 1985/1986 through 1998. This was similar to TP, although the decline in chla lagged behind TP. The slower decline in the 10-year average in chla was due to high concentrations of chla measured in 1988. Since 1998, the annual mean concentrations of chla have averaged 34, 38, and 32 µg/L for Segments 1, 2, and 3, respectively. The chla patterns were generally similar for all three segments of the lake. Unlike TP, there was no consistent drop in chla concentrations from Segment 1 to Segment 3 (discussed further in "Longitudinal Patterns"). The 10-year average chla patterns were similar for the annual time-weighted concentrations (Figure 6B).

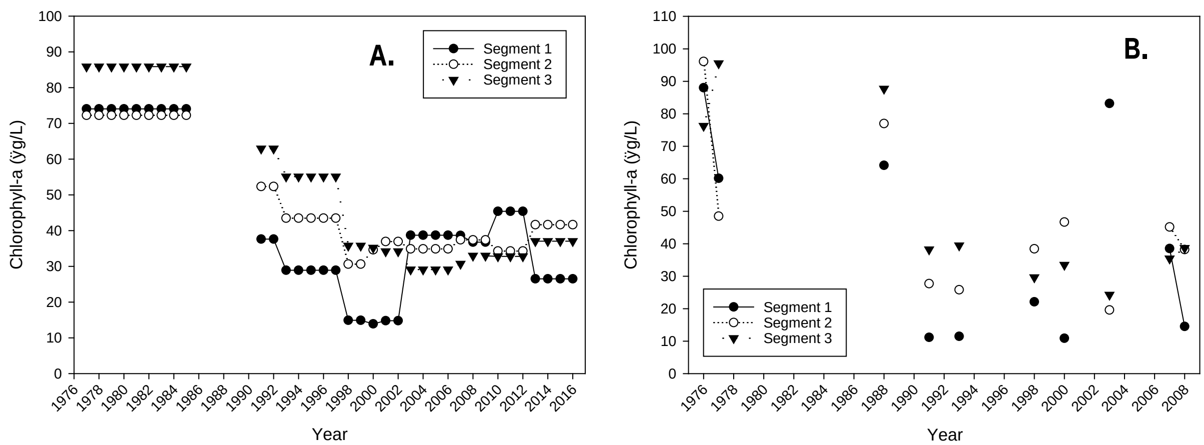

Figure 6: A) 10-year, time-weighted average and B) annual time-weighted average chlorophyll-a concentrations for the 3 segments of Lake Zumbro (55-0004-00).

Secchi depth

Secchi depth summer season data (June through September) from 1976-2016 consisted of 2 to 26 sample dates per year. Time-weighted, 10-year averages were calculated from 1977 through 2016 where at least two years of data were available (Figure 7A). An increase in Secchi depth is apparent from 1993 through 2005/2006. This increase may correspond to the decline in chla, although the decline in Secchi depth lagged behind chla. In addition, Secchi depth is influenced by suspended sediment which complicates the pattern in transparency as it relates to eutrophication. Since 2006, the annual mean concentrations of chla have averaged 0.6, 1.4, and 1.7 m for Segments 1, 2, and 3, respectively. The Secchi depth patterns were similar for Segments 2 and 3 and although an increase in Secchi depth is also apparent for Segment 1, this increase in less pronounced and more gradual. As with TP, there was a relatively consistent pattern between the three segments with an increase in Secchi depth from Segment 1 to Segment 3 (discussed further in "Longitudinal Patterns"). The 10-year average Secchi depth patterns were similar for the annual time-weighted concentrations although there is high annual variability as observed for chla (Figure 7B).

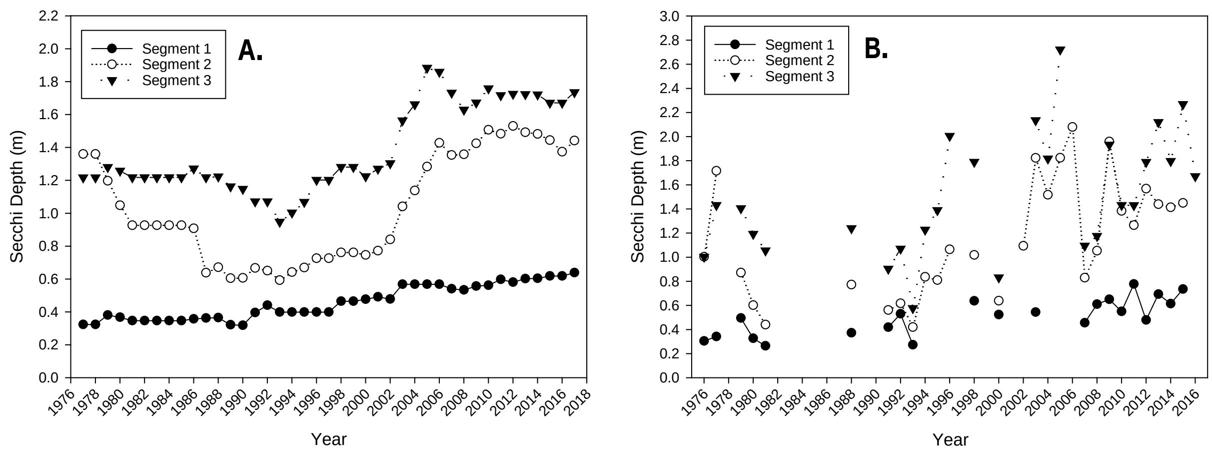

Figure 7: A) 10-year, time-weighted average and B) annual time-weighted average chlorophyll-a concentrations for the 3 segments of Lake Zumbro (55-0004-00).

Longitudinal patterns

The longitudinal water quality characteristics in Lake Zumbro were also examined by comparing summer mean values between the three lake segments. Average discharge during the summer months was also considered as part of this analysis. Depending on the parameter analyzed, these patterns varied. TP had a clear decreasing pattern from Segment 1 down through Segment 3 (Figure 8A, B). Using data from all discharges, the decrease between Segments 1 and 3 was on average 42% with a range of 26-65%. Although variable, the decrease in TP between Segments 1 and 3 was greater during years with lower average discharge. This is a common pattern for reservoirs as lower flows allow more sedimentation of TP inputs. Longitudinal patterns were similar when the sample events above the 85th percentile discharge were removed (Figure 8B). Longitudinal patterns in chla were variable with the greatest concentration measured in Segment 2 for three years and one year each for Segments 1 and 3 (Figure 8C, D). Secchi depth consistently increases from Segment 1 through Segment 3 (Figure 8E, F). Using data from all discharges, this increase was on average 151% with a range of 50-293%.

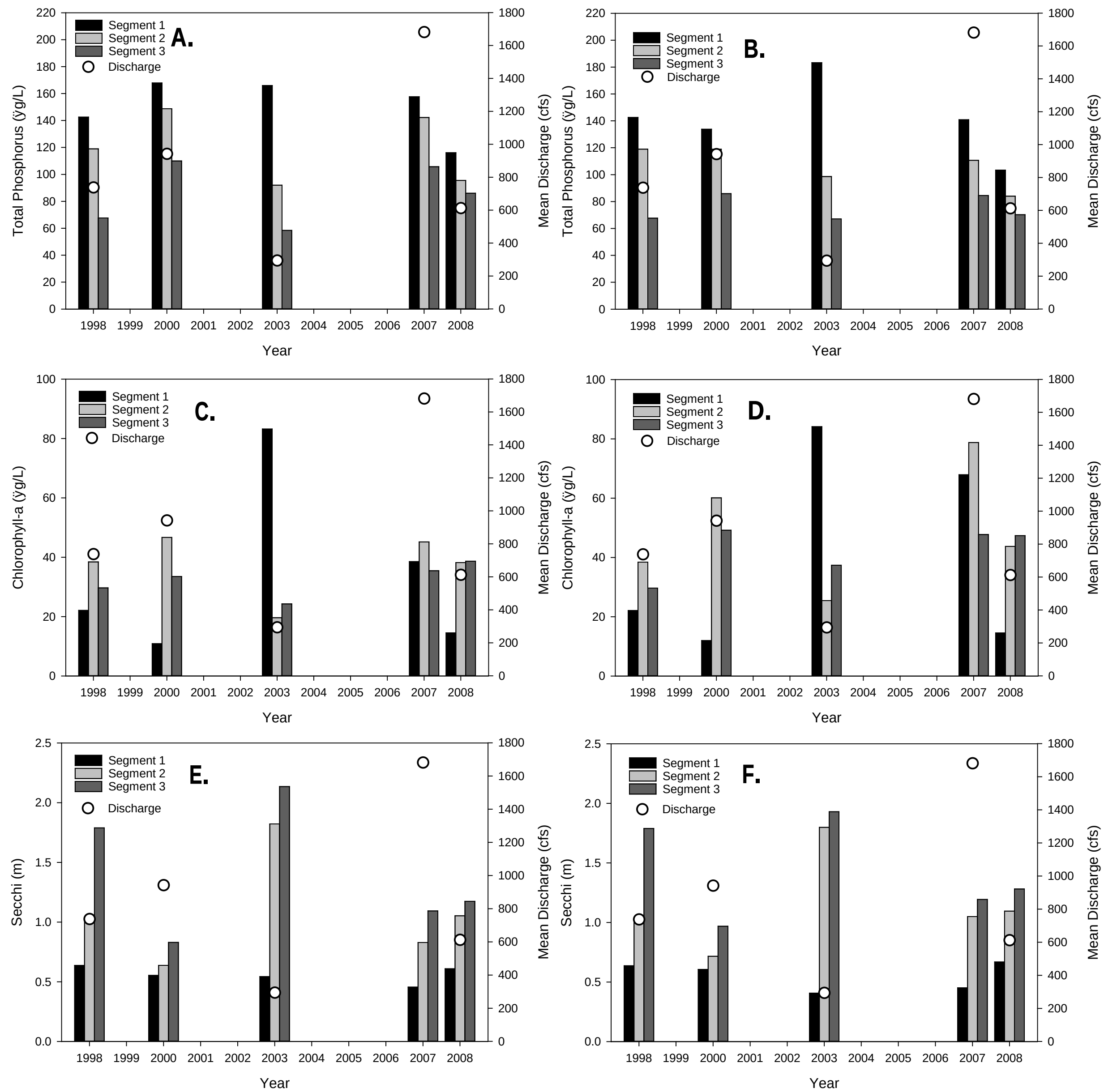

Figure 8: Longitudinal patterns in Lake Zumbro for A) total phosphorus – all flows, B) total phosphorus – flows below the 85th percentile, C) chlorophyll-a – all flows, D) chlorophyll-a – flows below the 85th percentile E) Secchi depth – all flows, F) Secchi depth – flows below the 85th percentile, (1998-2008).

Algal composition

The composition of major algal groups in lakes can provide insight regarding whether or not beneficial designated uses are being attained. Specifically, the high abundance or dominance of the algal community by blue-greens (i.e., cyanobacteria) can be an indication that the beneficial uses are not protected. Conversely, the opposite can be indicative of good conditions and may be used in the SSS development process. This was the case for the Lake Pepin SSS, were it was determined that a higher chla concentration was acceptable because the abundance of blue-greens was relatively low at these concentrations (Heiskary and Wasley 2011, Heiskary and Wasley 2012).

Algal composition was measured in Lake Zumbro in 2003 and 2007 using the Minnesota Rapid Algal Assessment procedure. For this comparison, the major groups included are blue-greens (Cyanobacteria), diatoms (Bacillariophyta), and others (Chlorophyta, Chrysophyta, Cryptophyta, Euglenophyta, and Pyrrophyta). To provide a quantitative estimate of the abundance of these groups, the relative biovolume is weighted by chla. This does not provide an entirely accurate measure of the relative contribution of each group to the chla concentration because algal taxa have different chla concentrations to cell volume relationships and chla cell contents can vary due to other factors such as environmental conditions (Reynolds 1984, Felip and Catalan 2000). However, this calculation provides a reasonable quantitative estimate of the abundance of these algal groups for the purpose of this assessment.

For most of the summer season, Lake Zumbro is dominated by diatoms and other algae (Figure 9). Blue-greens tend not to dominate the community when chla concentrations are high especially in Segments 2 and 3. The highest estimated abundance of blue-greens were measured in Segment 1 in 2007 that preceded high flows in late August of that year. In 2003, a year with lower than average discharge (i.e., long residence time), the composition of blue-greens remained low throughout the year. This is important because during low flow conditions, the potential to grow undesirable levels of blue-greens is typically higher. Although 2007 had higher than average flows, the first part of the summer through to mid-August had low discharge and large algal blooms. The exact mechanisms that limit the growth of blue-greens in Lake Zumbro are unknown, but could include: 1) lake morphometry, 2) phosphorus limiting concentrations during warmer periods (i.e., during low flow conditions), or 3) nitrogen is not limiting which benefits non-nitrogen fixing algae.

Comparison of algal composition in Lake Zumbro to other Minnesota lakes and reservoirs can provide further insight into the status of the designated uses in Lake Zumbro. In Byllesby Reservoir, blue-greens dominated the algal community, including in samples when the overall abundance of the algae was very high. In comparison to Lake Zumbro, Byllesby Reservoir had a higher estimated abundance of blue-greens (Figure 10). In Lake Pepin, the algal community is almost always dominated by diatoms with blue-greens rarely being dominant (Figures 11 and 12). The algal composition in Lake Pepin is similar to that of Lake Zumbro although in 2007 Lake Zumbro had higher concentrations of “other” taxa (Chlorophyta, Chrysophyta, Cryptophyta, Euglenophyta, or Pyrrophyta) than are typically observed in Lake Pepin.

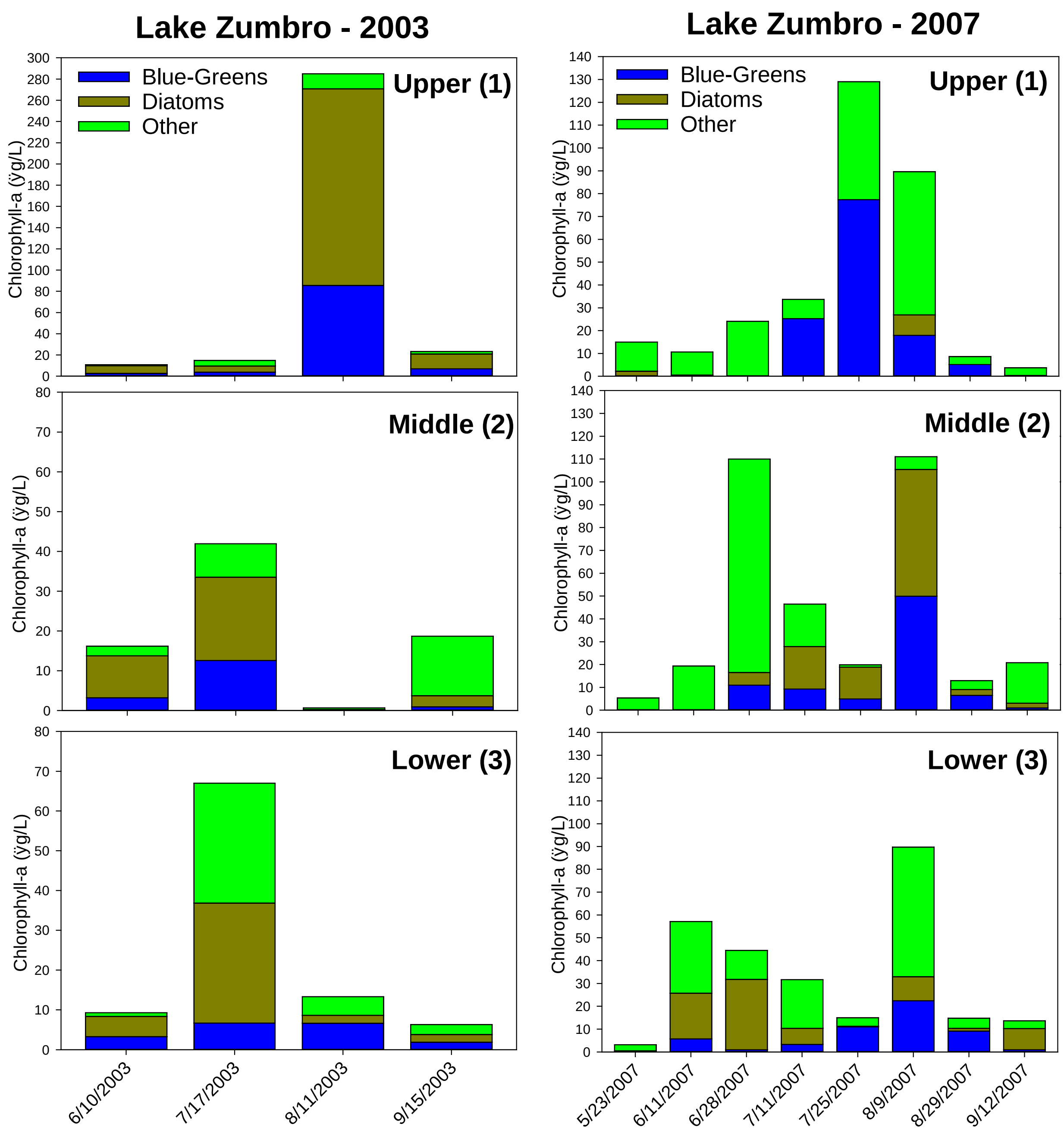

Figure 9. Composition of major algal groups in Lake Zumbro (2003, 2007). Note – y-axis scale varies between plots.

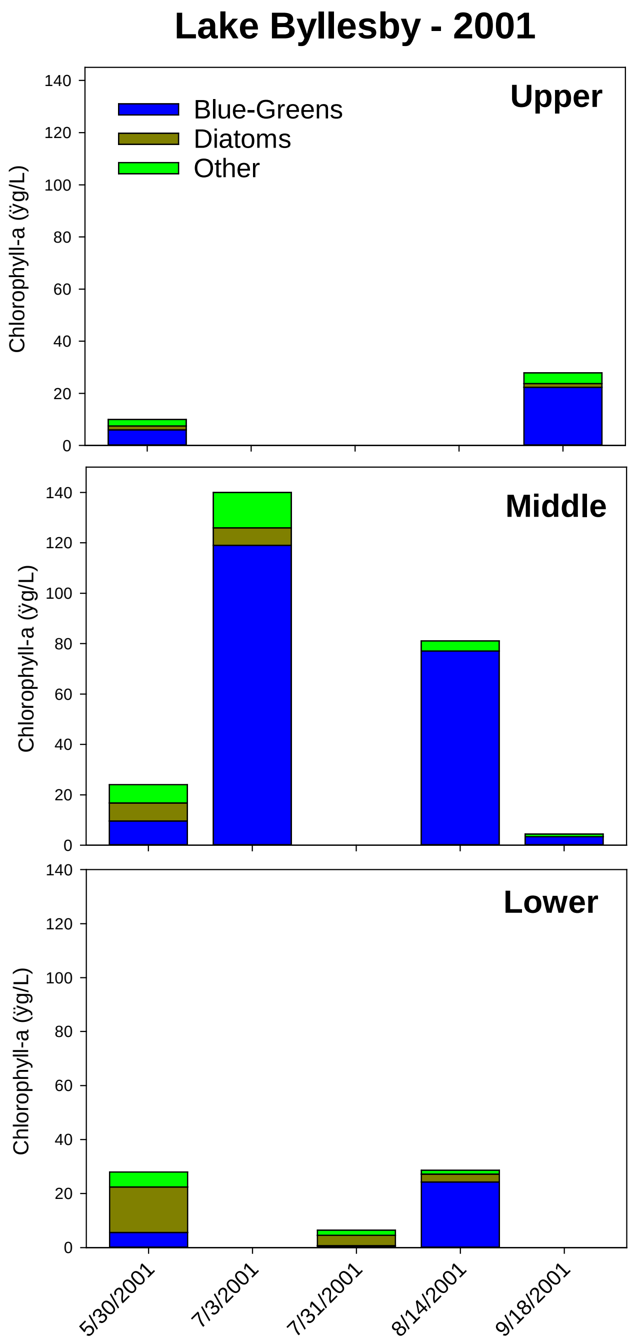

Figure 10. Composition of major algal groups in Byllesby Reservoir (2001).

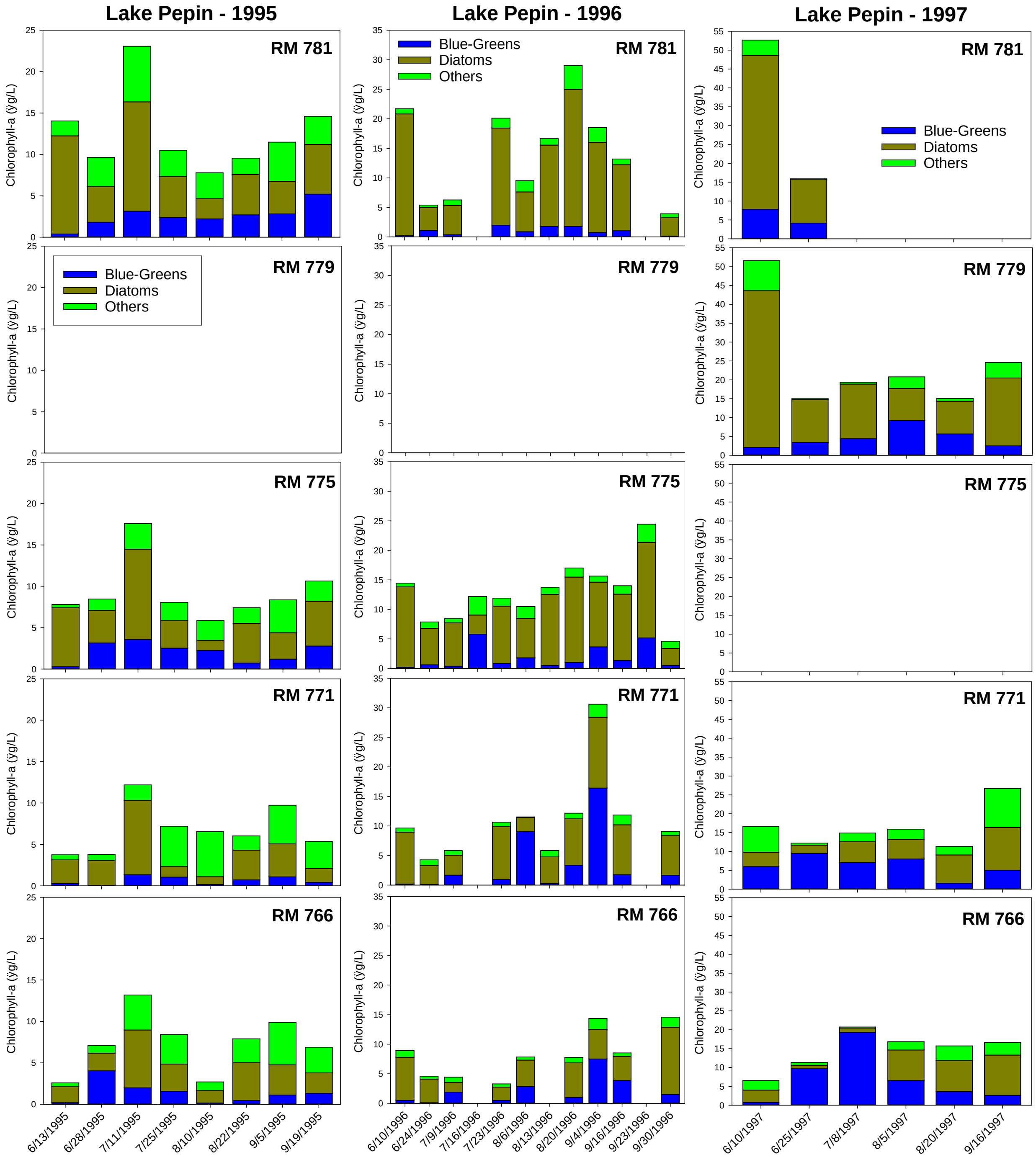

Figure 11. Composition of major algal groups in Lake Pepin (1995-1997). Plots are arranged longitudinally through the lake by river mile, with the upper plots from the upper portion of Lake Pepin. Note – y-axis scale varies between plots.

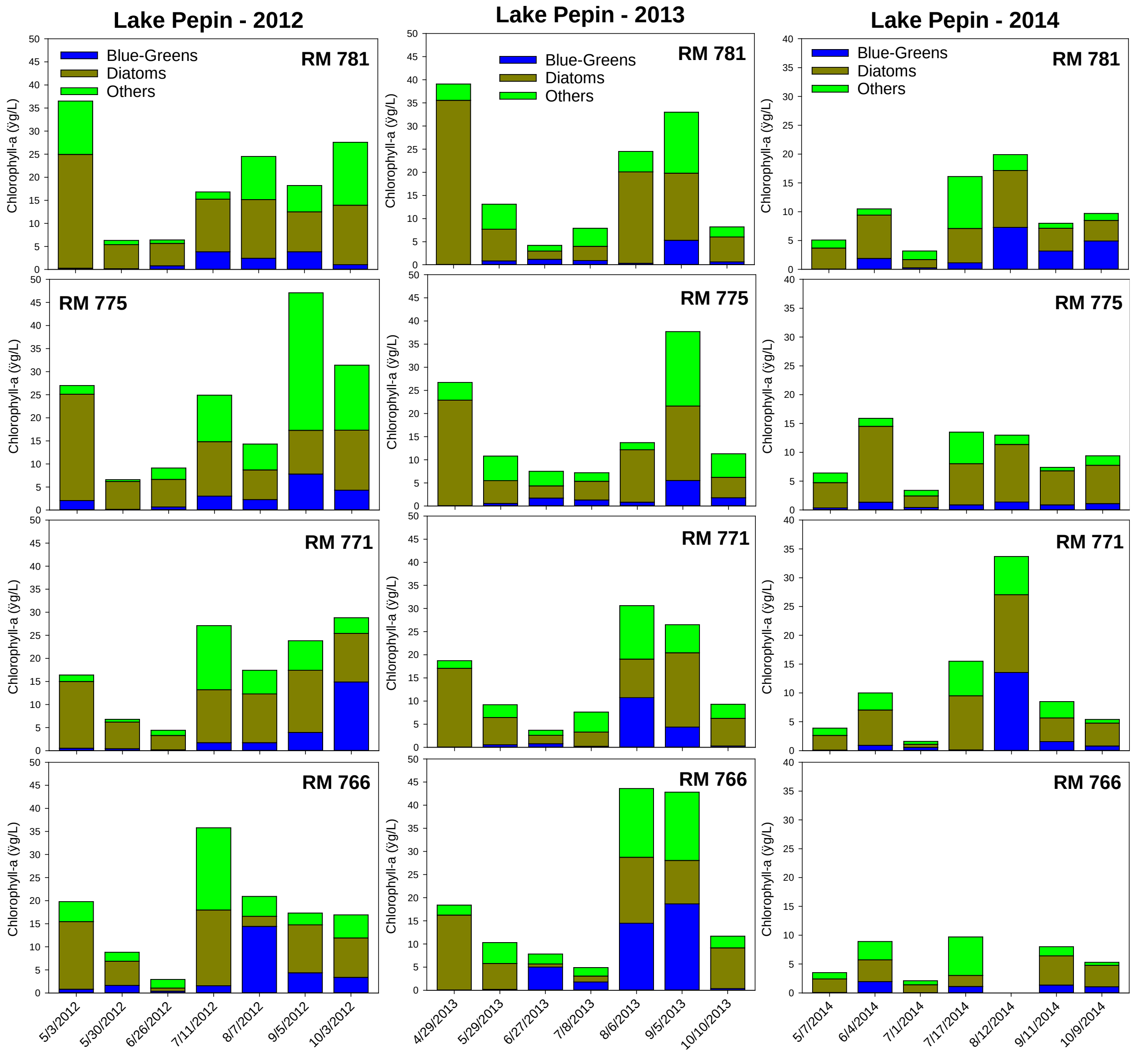

Figure 12. Composition of major algal groups in Lake Pepin (2012-2014). Plots are arranged longitudinally through the lake by river mile, with the upper plots from the upper portion of Lake Pepin. Data provided by the U.S. Army Corps of Engineers' Upper Mississippi River Restoration (UMRR) program, Long Term Resource Monitoring (LTRM) element in collaboration with the Minnesota Department of Natural Resources. Note – y-axis scale varies between plots.

Aquatic life

Limited aquatic life data are available for Lake Zumbro. Furthermore, the fact that this waterbody is unlike most natural lakes for which biological indicators have been developed in Minnesota means that biological assessment tools may not be appropriate for Lake Zumbro. However, Lake Zumbro has been regularly surveyed for gamefish since the 1960s by the DNR to assess the status of the fishery and to guide management of the fishery. The latest survey from 2015 (DNR 2016) indicated that the fishery in Lake Zumbro is doing well with good populations of black crappie, bluegill, channel catfish, largemouth bass, and smallmouth bass as well as supporting white crappie, white bass, and northern pike. Stocking efforts for muskellunge and walleye have also had moderate success. Although quantitative biological assessment data are not available, the DNR surveys indicate that aquatic life is currently protected in the lake.

Water quality relationships

The following section examines the relationships between TP, chla, Secchi depth, recreational suitability, and physical appearance. The primary goal of this section is to put these relationships into the context of the LES and to provide evidence for establishing TP, chla, and Secchi depth thresholds that are protective of the designated beneficial uses.

Discharge and water chemistry

Lake Zumbro has a relatively large watershed for a lake of this size and is fed by the South Fork and Middle Forks of the Zumbro River. As a result, the residence time in this lake is variable and can impact water quality parameters. Relationships between flow and individual water quality parameters were examined using locally weighted least squares regression (LOESS) with the "loess" function in the "splines" package in R (R Development Core Team 2016). Pseudo-R^2 values were also calculated for each regression. As demonstrated in the "Longitudinal Patterns" section, water quality parameters differ in part due to differences in discharge. From the LOESS regressions it is also apparent that flow-water quality relationships differ between lake segments (Figures 14-15). For all three segments, there is a positive relationship between discharge and TP concentration (Figure 14). In general, there is a negative relationship between flow and chla concentration although there may be a positive relationship at low discharges (Figure 13). This positive relationship at low discharges is more apparent in Segments 2 and 3 although there is also an indication that it occurs in Segment 1. Based on other relationships (see "Total Phosphorus, Chlorophyll-a, and Secchi depth"), chla concentrations are controlled by TP concentrations at low discharge and residence time (or shading) at high concentrations. However, in Lake Zumbro these patterns may be complicated by the fact that the South and Middle Forks of the Zumbro River can be a source of algae into Lake Zumbro. Secchi depth has a negative relationship with discharge although this relationship is more variable than with TP and chla (Figure 15).

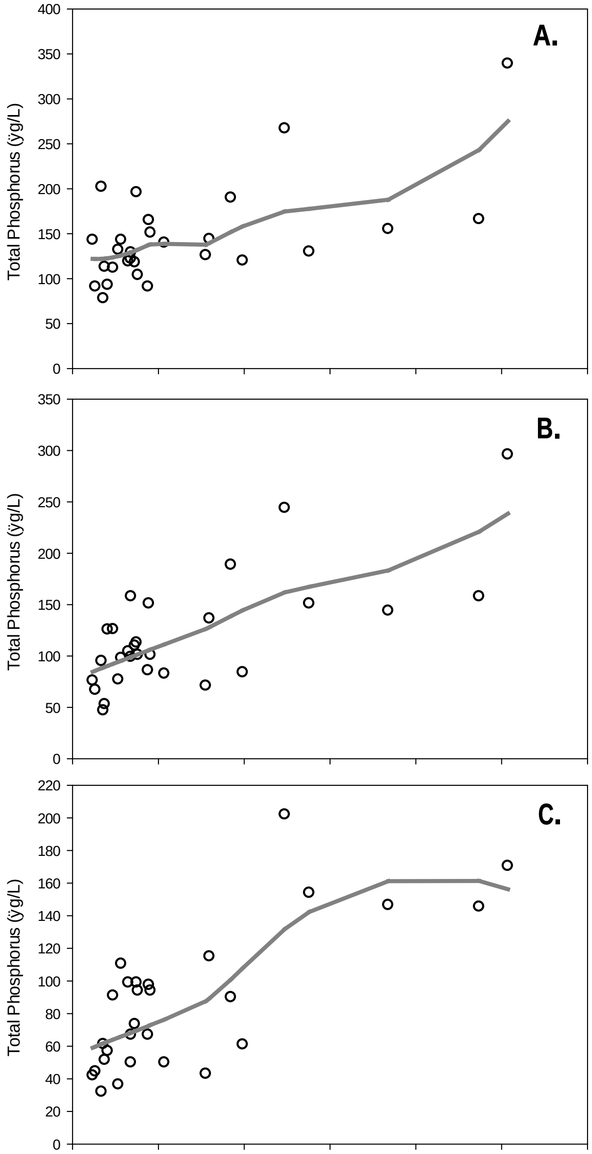

Figure 14: Relationship between discharge and total phosphorus in Segments A) 1, B) 2, and C) 3 of Lake Zumbro (1998-2008). Discharge data are values at the dam and were modeled using HSPF. Fit is a LOESS regression (A. span = 0.75, degree = 2, Pseudo-R2 = 0.46; B. span = 0.95, degree = 2, Pseudo R2 = 0.53; C. span = 0.95, degree = 2, Pseudo R2 = 0.61).

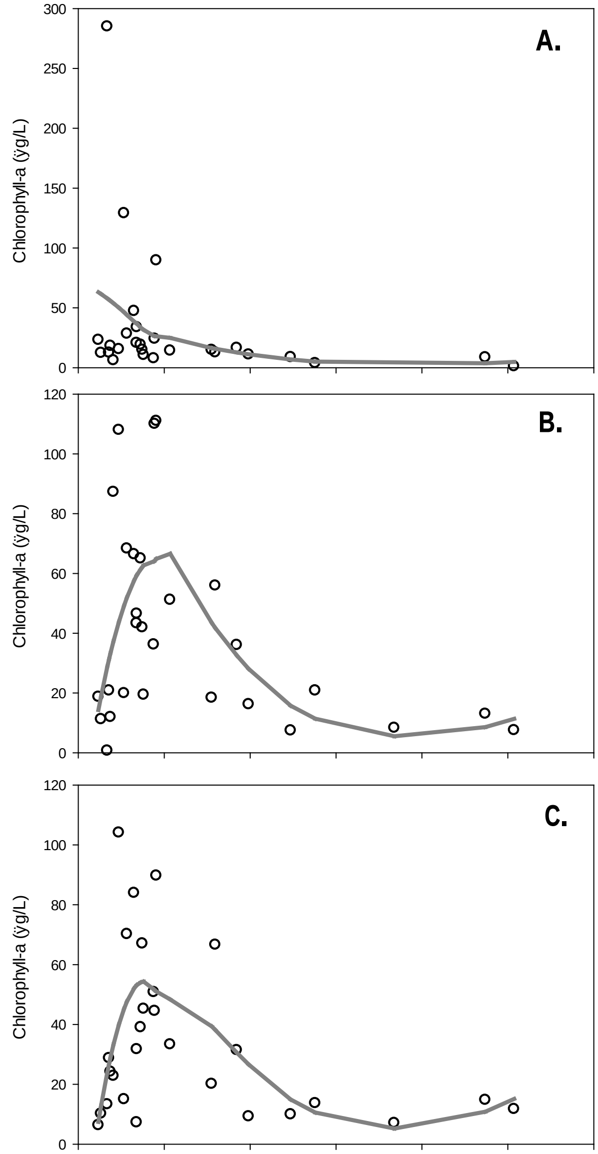

Figure 13: Relationship between discharge and chlorophyll-a in Segments A) 1, B) 2, and C) 3 of Lake Zumbro (1998-2008). Discharge data are values at the dam and were modeled using HSPF. Fit is a LOESS regression (A. span = 0.75, degree = 2, Pseudo-R2 = 0.11; B. span = 0.75, degree = 2, Pseudo R2 = 0.38; C. span = 0.75, degree = 2, Pseudo R2 = 0.37).

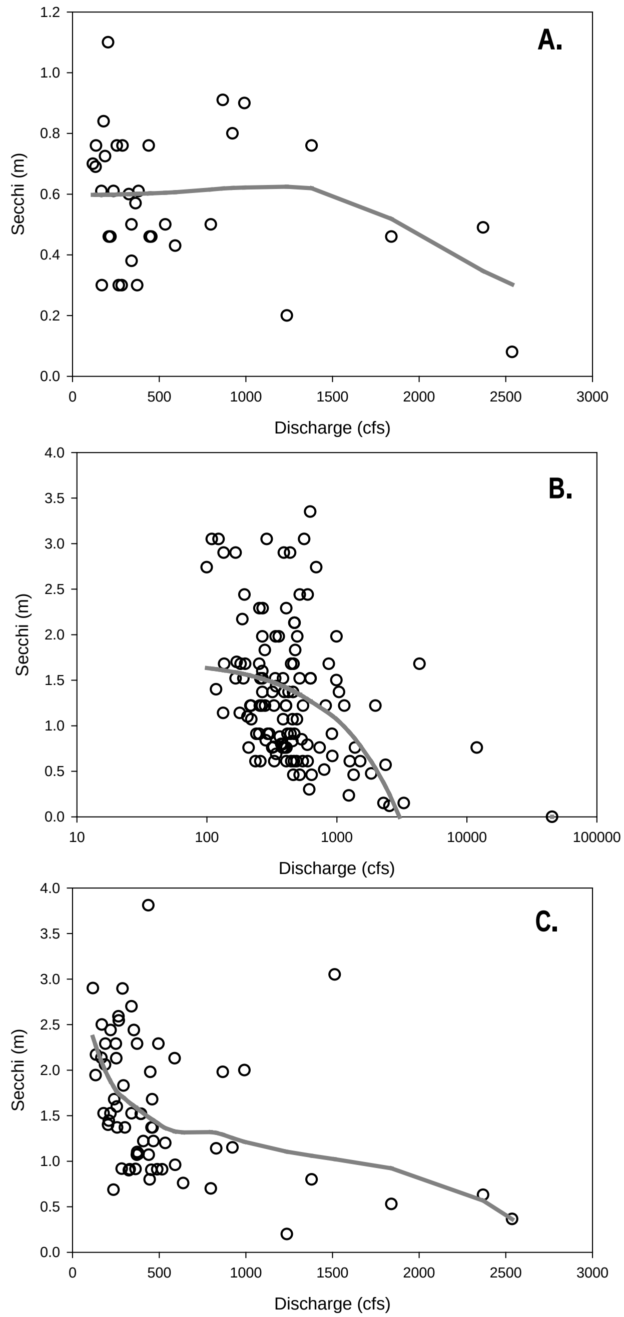

Figure 15: Relationship between discharge and Secchi in Segments A) 1, B) 2, and C) 3 of Lake Zumbro (1998-2008). Discharge data are values at the dam and were modeled using HSPF. Fit is a LOESS regression (A. span = 0.95, degree = 2; Pseudo-R^2 = 0.417; B. span = 0.95, degree = 1, Pseudo R^2 = 0.08; C. span = 0.75, degree = 2, Pseudo R^2 = 0.20).

Comparison to Minnesota lake and river datasets

As part of LES development (Heiskary and Wilson 2005), a set of approximately 90 lakes were selected from the four ecoregions in Minnesota which contains 98% of Minnesota lakes (Northern Lakes and Forests, North Central Hardwoods, Western Corn Belt Plains, and Northern Glaciated Plains). A similar set of data (called the "River Nutrient" dataset) were used as part of River Eutrophication Standards (RES) development (Heiskary et al. 2013). These comprised river sites sampled as part of a series of projects to understand the relationships among eutrophication parameters in streams and rivers. As with the lake study, sites were selected from different ecoregions and included rivers from all six EPA Level III ecoregions in Minnesota. Comparisons between the LES and RES development datasets and Lake Zumbro data were made for each lake segment for TP-chla and chla-Secchi depth relationships. No comparison for chla-Secchi relationships were made with the river data because Secchi depth was not examined as part of the RES development. All values presented are summer means.

A comparison of Lake Zumbro summer mean relationships for TP-chla, demonstrated different relationships between these parameters among the lake segments. The relationship for Segment 1 is most similar to the river dataset (Figure 16) indicating this segment is not behaving like a typical Minnesota lake. Segment 2 is intermediate between the lake and river datasets and Segment 3 is performing similarly to other Minnesota lakes. This indicates that Segments 1 and 2 grow less algae per unit of TP than do typical lakes. Although in most years, Segment 2 grows less algae than predicted using the LES model, most years fall within the scatter of the LES lake relationship. Removing samples collected at discharges above the 85th percentile does not change this pattern although it reduces the year-to-year variability in the mean concentrations for TP and chla (Figure 16B, D, and F).

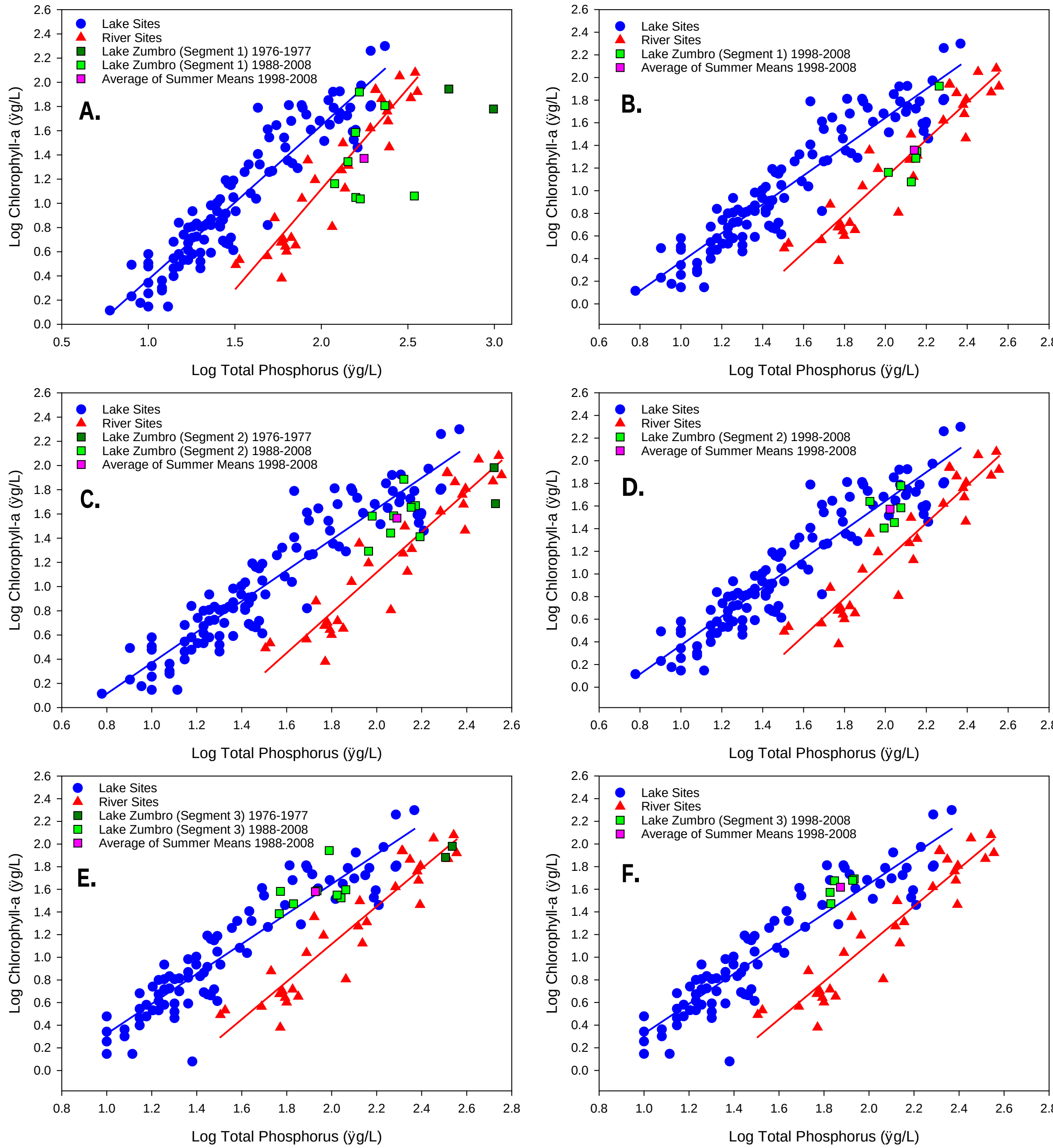

Figure 16. Comparison of total phosphorus-chlorophyll-a relationships for Lake Zumbro segments for different time periods and Minnesota lakes and rivers used to develop eutrophication standards.

Patterns among the segments were similar for the chla-Secchi relationships although for this relationship, Segment 2 was most similar to the LES dataset. Segment 1 fell below the regression line for the LES lakes and Segment 3 fell above. This indicates that there is lower clarity in Segment 1 of Lake Zumbro than expected based on the chla-Secchi relationship. However, in Segment 3, water clarity is higher than expected based on the LES model.

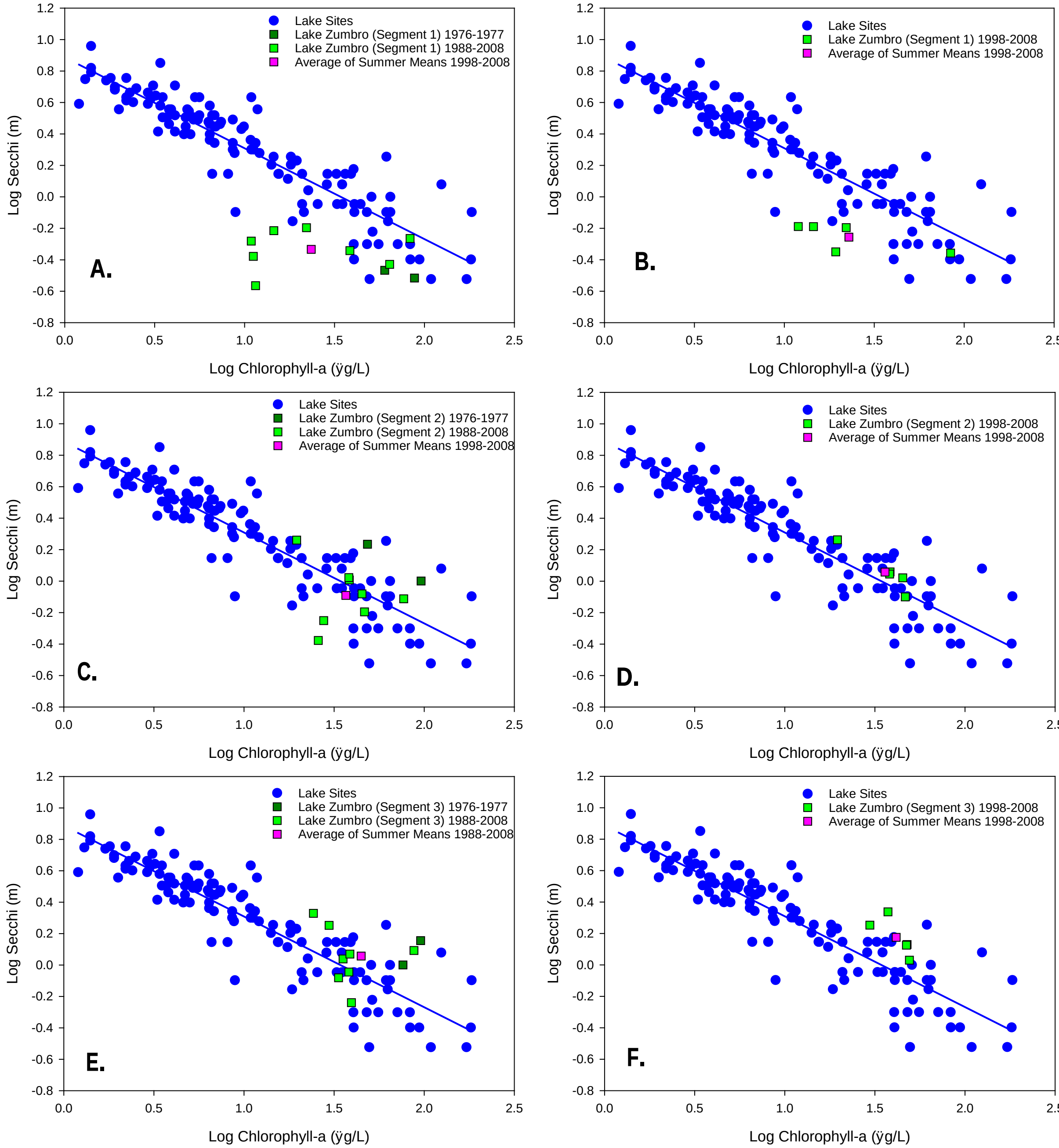

Figure 17. Comparison of chlorophyll-a-Secchi relationships for Lake Zumbro segments for different time periods and Minnesota reference lakes.

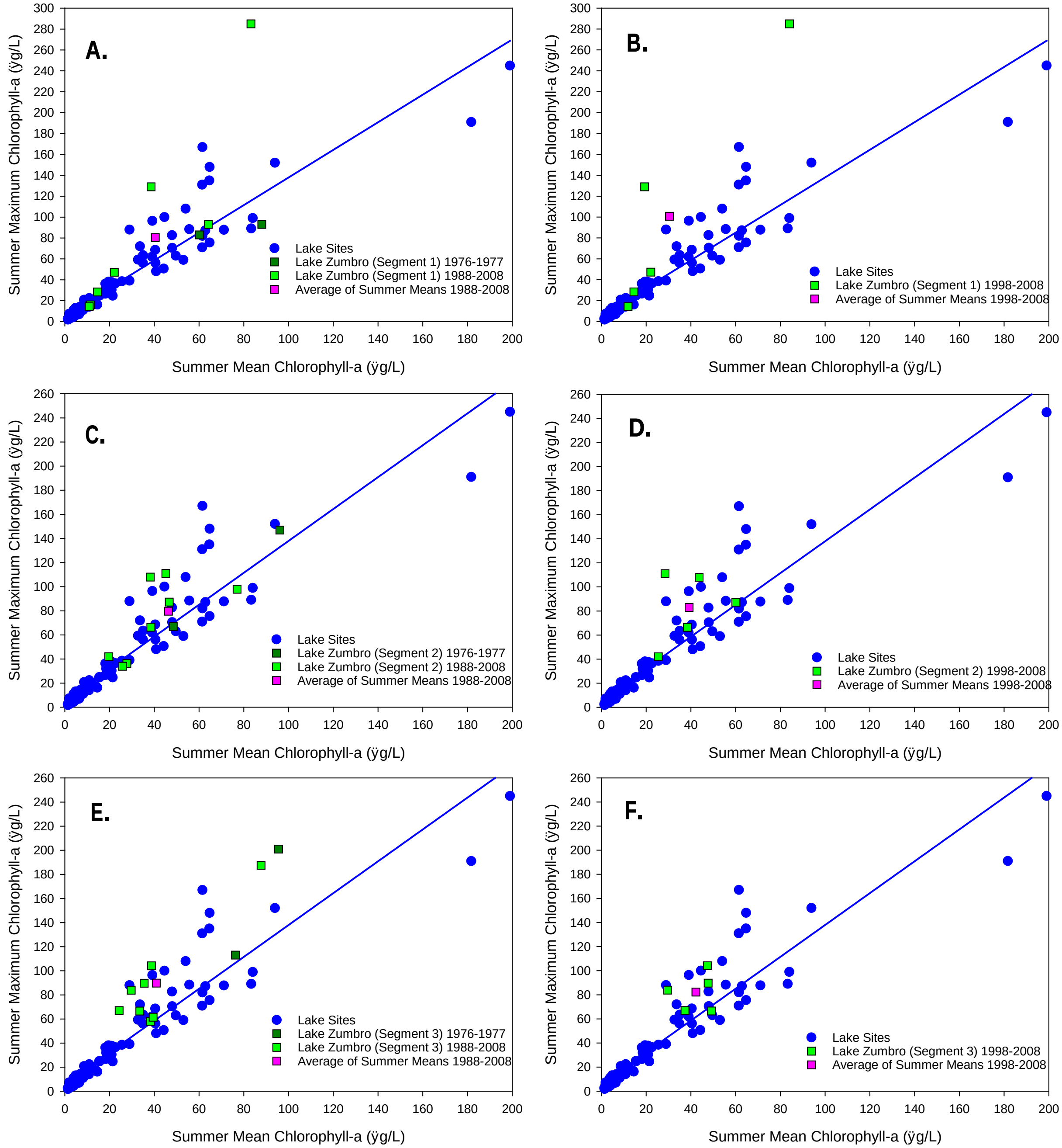

Figure 18. Comparison of summer average and maximum chlorophyll-a-for Lake Zumbro segments for different time periods and Minnesota reference lakes.

The three segments of Lake Zumbro all behave similarly in comparison to the Minnesota reference lakes in that they all have higher summer maximum chla than predicted from the reference lakes model (Figure 18). This emphasizes the dynamic conditions in Lake Zumbro resulting from hydrology that differs from most Minnesota lakes. During some periods, conditions are favorable for the growth of algae. However, large storm events and low flow conditions result in low algal production and low chla concentrations in Lake Zumbro. In order to achieve summer average chla levels similar to typical lake,

Lake Zumbro has higher chla values during other portions of the summer. However, as stated previously, the algal blooms in Lake Zumbro also differ from most other lakes in that greater Secchi depth is maintained at higher chla concentrations than predicted from relationships developed from Minnesota reference lakes.

Overall, it is apparent that the segments of Lake Zumbro behave differently from each other in regards to water quality relationships. These patterns are the result of differences in depth and residence time through the lake and the effects that settling and in-lake processes has on these parameters. Some parts of the lake behave similarly to other lakes in Minnesota (Segments 2 and 3) while other parts are more riverine (Segment 1). As a result, it is necessary to account for these differences as part of the SSS development. In addition, these analyses also make it apparent that in some regards (e.g., summer average-maximum chlorophyll-a relationship) Lake Zumbro differs from other Minnesota lakes and that a SSS is warranted.

Physical appearance and recreational suitability

Defining the relationship between user expectations and lake water quality measurements is typically part of developing criteria, including SSS. In Minnesota, this process relates an observer survey ratings (Table 5) and water quality data to provide a basis for identifying levels of nuisance algae.

Table 5. Description of physical appearance and recreational suitability ratings used in lake surveys.

Physical Appearance Key			Recreational Suitability Key	
#	Description		#	Description
1	Crystal clear water		1	Beautiful, could not be any nicer
2	Not quite crystal clear, a little algae present/visible		2	Very minor aesthetic problems; excellent for swimming, boating, enjoyment
3	Definite algal green, yellow, or brown color apparent		3	Swimming and aesthetic enjoyment slightly impaired because of algae levels
4	High algal levels with limited clarity and/or mild odor apparent		4	Desire to swim and level of enjoyment of the lake substantially reduced because of algae levels (would not swim, but boating is okay)
5	Severely high algae levels with one or more of the following: massive floating scums on lake of washed up on shore, strong foul odor, or fish kill		5	Swimming and aesthetic enjoyment of the lake nearly impossible because of algae levels

Plots of chla and user survey results (recreational suitability and physical appearance) did not indicate any strong relationship between these measures (Figures 19 and 21). There were a greater number of 2 ratings (i.e., Very minor aesthetic problems; excellent for swimming, boating, enjoyment) in Segment 3 at lower chla concentrations, but in general there are few 4s or 5s (Figure 19E, F). There was also an apparent relationship between chla and recreational suitability in Segment 1 where there were more 2 ratings than 3 ratings at lower chla concentrations (Figure 19A, B). In Segment 1, most ratings of 2 or 3 were observed below 35 µg/L of chla. However, as with the other two segments, there were few 4 or 5 ratings, especially once the discharges above the 85th percentile were removed (Figure 19B, D, F). In general, it appears users are responding more strongly to the negative impacts of suspended sediments on recreational suitability (Figure 19A, C, E).

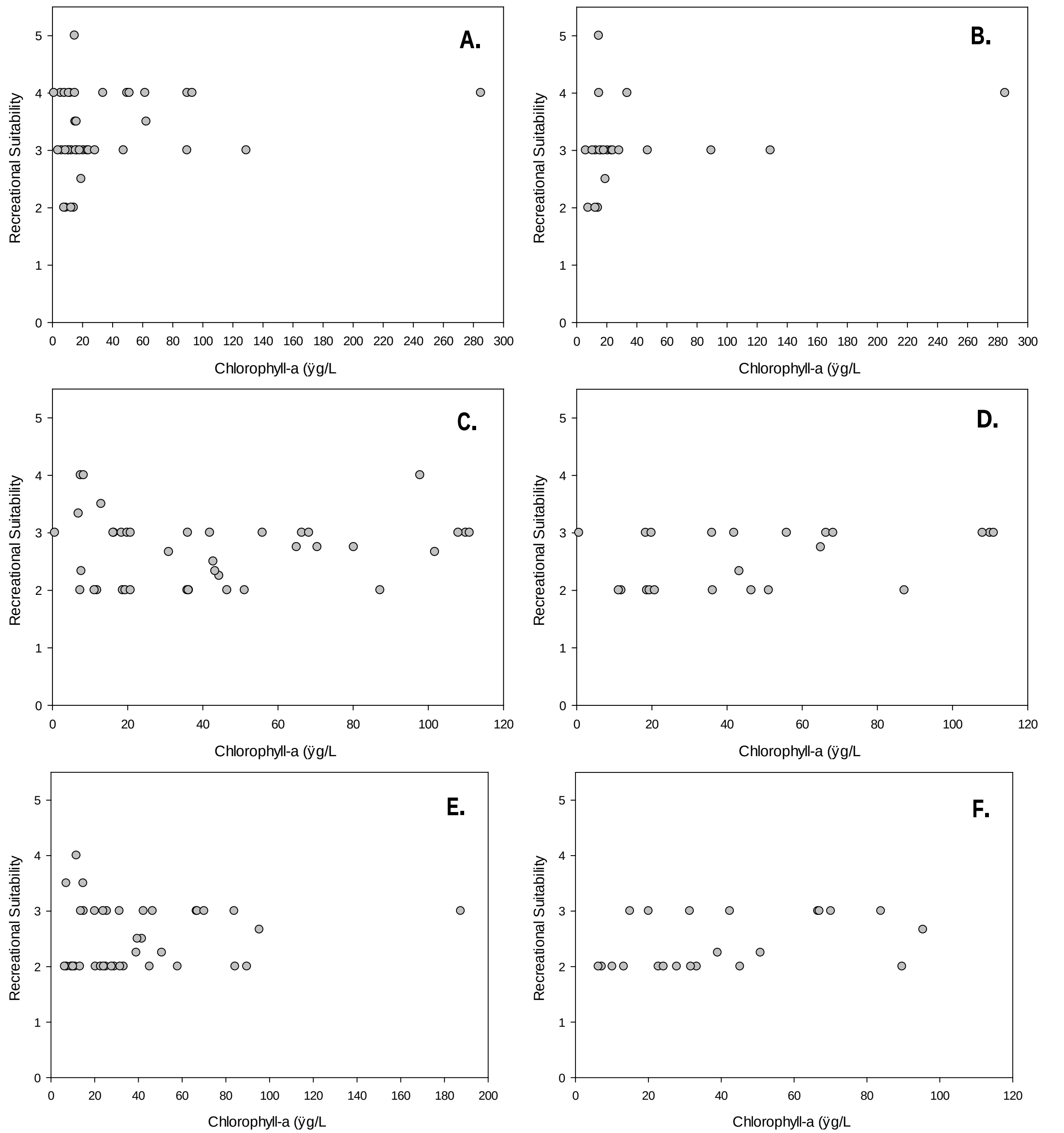

Figure 19: Relationship between chlorophyll-a and Recreational Suitability in Lake Zumbro for Segments 1 (A,B), 2 (C,D), and 3 (E,F) for all discharges (A,C,E) and for only discharges (modelled using HSPF at the dam) below the 85th percentile (B,D,F). Data are June through September from 1998-2008.

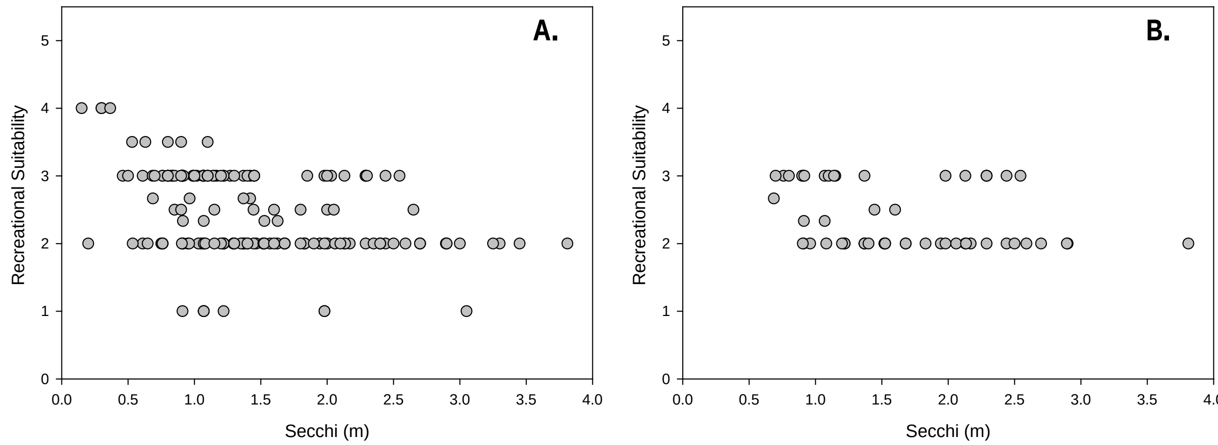

Figure 20: Relationship between Secchi depth and Recreational Suitability in Lake Zumbro for Segments 1 at all discharges (A) and for only discharges (modelled using HSPF at the dam) below the 85th percentile (B). Data are June through September from 1988-2016.

In general, the recreational suitability raters seem to be responding to water clarity. There is a relationship between recreational suitability and Secchi depth when data at all discharges are included (Figure 20A). Above 1.1 m there are no 4 or 5 ratings. Above 1.5 m most user ratings are 2 (i.e., Very minor aesthetic problems; excellent for swimming, boating, enjoyment). Once the flows above the 85th percentile are removed the relationship is weaker and there are no 4 or 5 ratings. This demonstrates that users are sensitive to water clarity and that most of the low ratings are likely associated with higher levels of suspended sediment as these are associated with higher flows.

There was a pattern for physical appearance, although there was a weak or no relationship between physical appearance and chla apparent for Segments 2 and 3 (Figure 21). Segment 1 did have a relatively strong relationship where ratings of 2 and 3 were only observed below 35 µg/L of chla (Figure 21A, B).

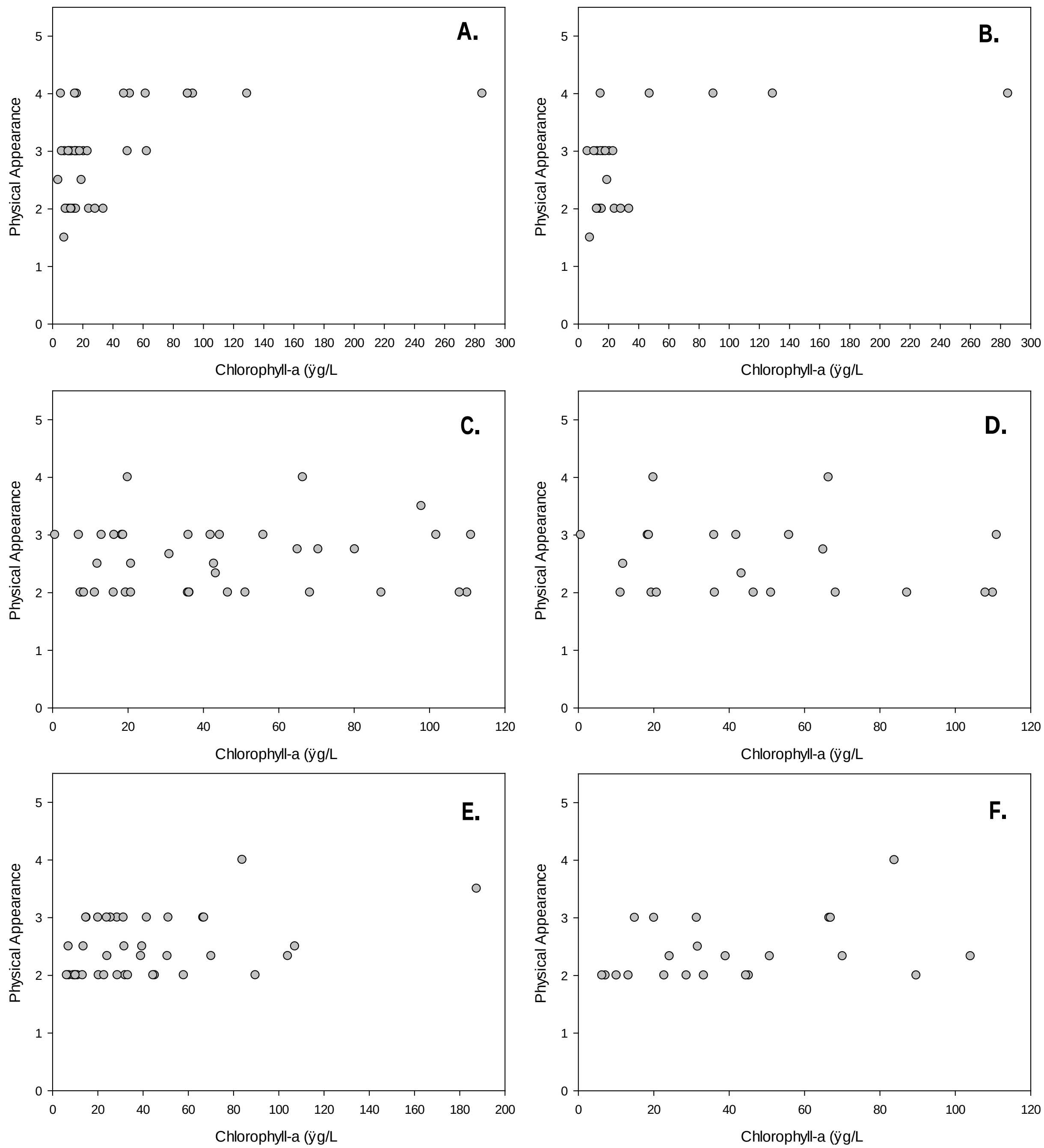

Figure 21: Relationship between chlorophyll-a and Physical Appearance in Lake Zumbro for Segments 1 (A,B), 2 (C,D), and 3 (E,F) for all discharges (A,C,E) and for only discharges (modelled using HSPF at the dam) below the 85th percentile (B,D,F). Data are from 1998-2008.

User perception surveys indicate that the lake usually meets a condition that is defined as: "Swimming and aesthetic enjoyment slightly impaired because of algae levels." This is generally considered to be in attainment of the recreation beneficial use. Poorer survey results are typically associated with lower clarity resulting from suspended sediment. The lack of strong relationships between recreational suitability and physical appearance and chla concentrations raises questions regarding whether or not there is something fundamentally different about the algal blooms in Lake Zumbro or if it is related to differences in user perceptions. User perceptions can vary regionally and be impacted by other factors such as the types of algae species present (Smeltzer and Heiskary 1990, Heiskary and Wilson 2005, Heiskary and Wilson 2008). It is interesting that the user perceptions as they relate to chla differ between the three segments with Segment 1 showing the strongest relationship. It is also curious that the relationship between physical appearance, a measure that specifically gages perceived algal concentrations, and chla had no relationship in Segments 2 and 3.

Overall, available user data indicate attainment of recreational uses in Lake Zumbro. This is further supported by the MPCA database on complaints related to nuisance algae and pet or human illness related to algal blooms which does not contain any complaints related to these issues for Lake Zumbro.

Current conditions

The current conditions for the three lake eutrophication parameters were calculated as the average of summer mean concentrations using data available from 1998-2008 (Table 6). The longitudinal patterns follow those described in the "Longitudinal Patterns" section. As expected, removal of the flows above the 85th percentile reduces the total phosphorus concentration and increases the chla concentration and the Secchi depth. Based on the previous analysis which demonstrated little change in these parameters since the mid-1990s (Figures 5, 6, and 7), these values provide an estimate of the current conditions in Lake Zumbro.

Table 6. Average of summer mean concentrations for eutrophication measures from Lake Zumbro. Averages of the summer means was used to reduce the effects of unequal sampling efforts between years.

	Total Phosphorus (µg/L)	Chlorophyll-a (µg/L)	Secchi Depth (m)
All Flows			
Segment 1	148.5	34.5	0.5
Segment 2	119.1	39.1	1.4
Segment 3	84.6	33.6	1.7
Flows <85th Percentile			
Segment 1	137.6	43.4	0.6
Segment 2	105.4	46.7	1.5
Segment 3	70.3	39.5	1.7

Total phosphorus, chlorophyll-a, and Secchi depth

As part of the development of the LES, relationships between TP and chla and between chla and Secchi depth were determined and used in setting criteria (Heiskary and Wilson 2005, Heiskary and Wilson 2008). The same types of relationships can be used to determine a protective SSS for Lake Zumbro. The following differs from the LES analyses in that it examines relationships between grab samples from a single waterbody whereas the LES analyses used summer mean values from a statewide dataset of lakes. It is important to note that although these fits are useful for understanding the relationships between TP, chla, and Secchi depth in Lake Zumbro, because they are based on individual grab samples, they may not accurately predict mean summer concentrations. This is more of an issue for the chla-Secchi depth relationships because this relationship is non-linear and interpolated values from chla-Secchi depth models will predict lower Secchi depth than in measured conditions. The TP-chla models will provide more accurate predictions of summer mean concentrations because this relationship is largely linear. The original LES analysis used log-log transformed data for the TP-chla model to correct heteroscedasticity (i.e., unequal variance) and not to address non-linearity.

The relationship between chla and Secchi depth was compared for the three lakes segments. Eliminating samples collected at discharges above the 85th percentile resulted in reasonable fits (Figures 22 and 23). The log-log relationships are similar to that used in the development of the LES (Figure 22). A similar fit can also be achieved with a power function (Figure 23). The relationship between these parameters is tighter for Segment 3 compared to Segments 1 and 2. A comparison of the power function (Figure 23C) fits to the original LES development data, it is apparent that Secchi depth is greater per unit of chla in Segment 3 of Lake Zumbro (also described in “Comparison to Minnesota Lake and River Datasets”). In Segments 1 and 2 this pattern is weaker. Although the pattern is reasonably similar between the reference lakes and Segment 2, the pattern in Segment 1 is clearly different with much lower Secchi depths at all concentrations of chla (Figure 23).

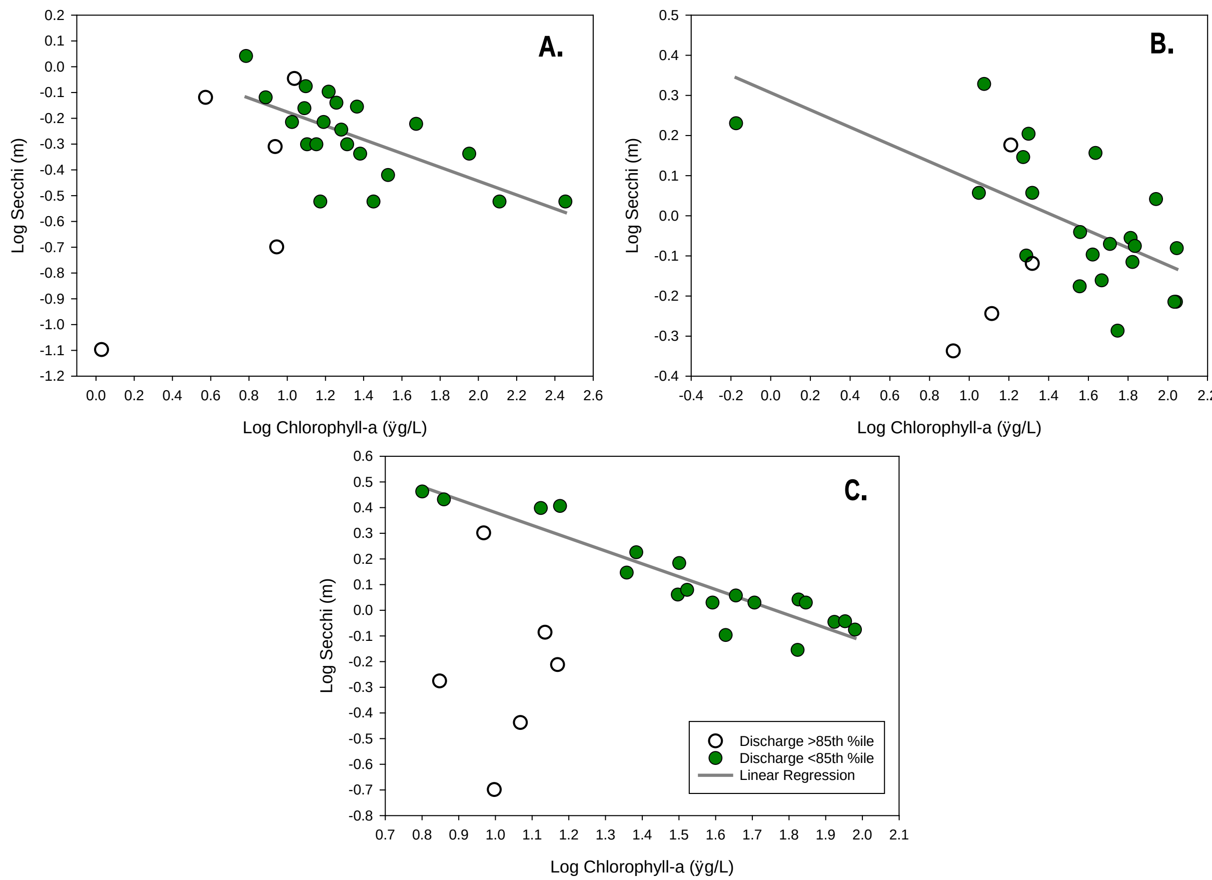

Figure 22: Relationships between summer chlorophyll-a and Secchi depth in Lake Zumbro Segments 1 (A), 2 (B), and 3 (C) (1998-2008) using least squares regression. Regressions only use samples collected at flows below the 85th percentile (modelled using HSPF at the dam). Segment 1: $\log_{10}$ Secchi = -0.27 • $\log_{10}$ chla + 0.09, R^2 = 0.44; Segment 2: $\log_{10}$ Secchi = -0.22 • $\log_{10}$ chla + 0.31, R^2 = 0.43; Segment 3: $\log_{10}$ Secchi = -0.50 • $\log_{10}$ chla + 0.88, R^2 = 0.85.

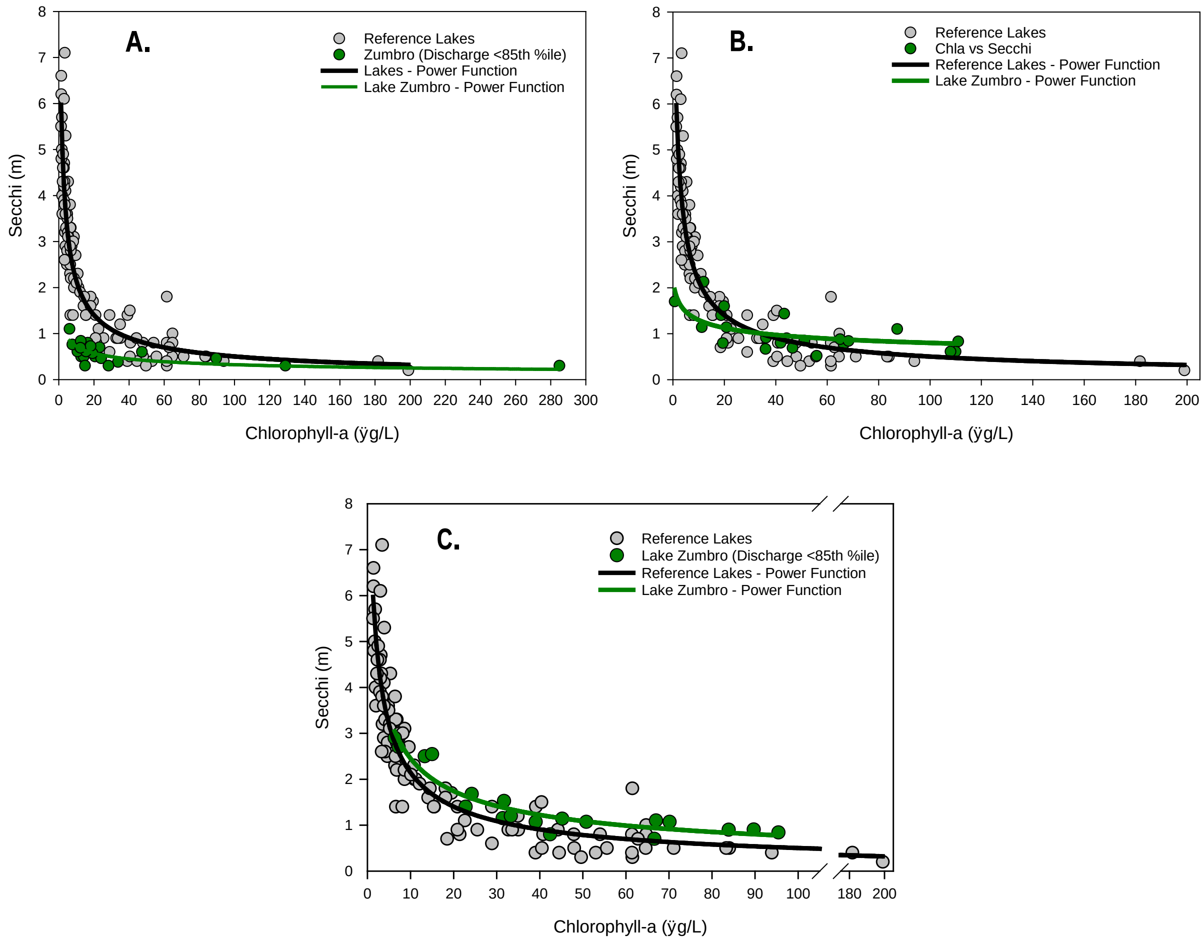

Figure 23. Relationship between summer chlorophyll-a and Secchi depth for LES development lakes and for Lake Zumbro for Segments 1 (A), 2 (B), and 3 (C) (1998-2008). Regression fits are power function fits (power function fits: SigmaPlot 12.0 [Systat Software 2014]) using only data collect at discharges below the 85th percentile (modelled using HSPF at the dam). Reference Lakes: Secchi = 10.30 • $(1 + chla)^{-0.65}$, R^2 = 0.85; Segment 1: Secchi = 10.30 • $(1 + chla)^{-0.65}$ R^2 = 0.44; Segment 2: Secchi = 2.19 • $(1 + chla)^{-0.22}$, R^2 = 0.43; Segment 3: Secchi = 8.72 • $(1 + chla)^{-0.53}$, R^2 = 0.89.

Reasonable fits to TP-chla relationships can be made using a variety of methods including simple linear regression (Figure 24C), nonparametric regression (Figure 24A, B), and fits to log-log transformed data (Figure 25) if the 15% highest flows are removed. The fits to the log-log transformed data (Figure 25) are similar to that used in the development of the LES. As with other relationships, the best fits are observed in Segment 3. In addition, Segment 3 (Figure 25C) is most similar to the LES development dataset although Segment 2 (Figure 25B) is also very similar. Using the current chla concentration of 40 µg/L (measured as the mean of summer average concentrations from 1998-2008 as flows below the 85th percentile; Table 6), the models can be used to predict TP concentrations. The log-transformed data predict that a chla concentration of 40 would be achieved at 76 µg/L.

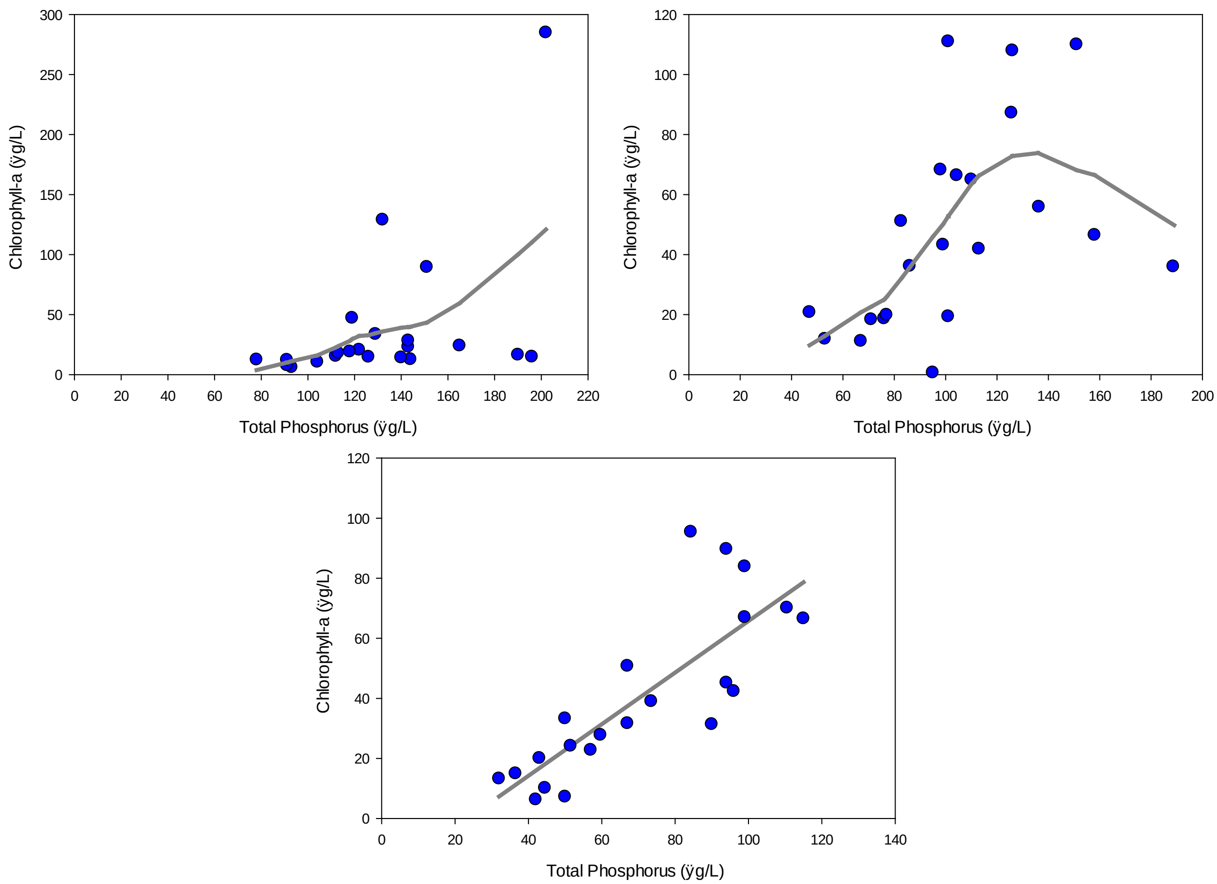

Figure 24: Relationship between summer total phosphorus and chlorophyll-a in Lake Zumbro for Segments 1 (A), 2 (B), and 3 (C) for flows (modelled using HSPF at the dam) below the 85th percentile (959 cfs) (1998-2008). Fits are loess (A, B) and linear (C) regressions (loess: "loess" in base package; R Development Core Team 2017; linear regression: SigmaPlot 12.0 [Systat Software 2014]). Segment 1: pseudo R^2 = 0.29; Segment 2: pseudo R^2 = 0.47; Segment 3: chla = -0.86 • TP + 20.12, R^2 = 0.66.

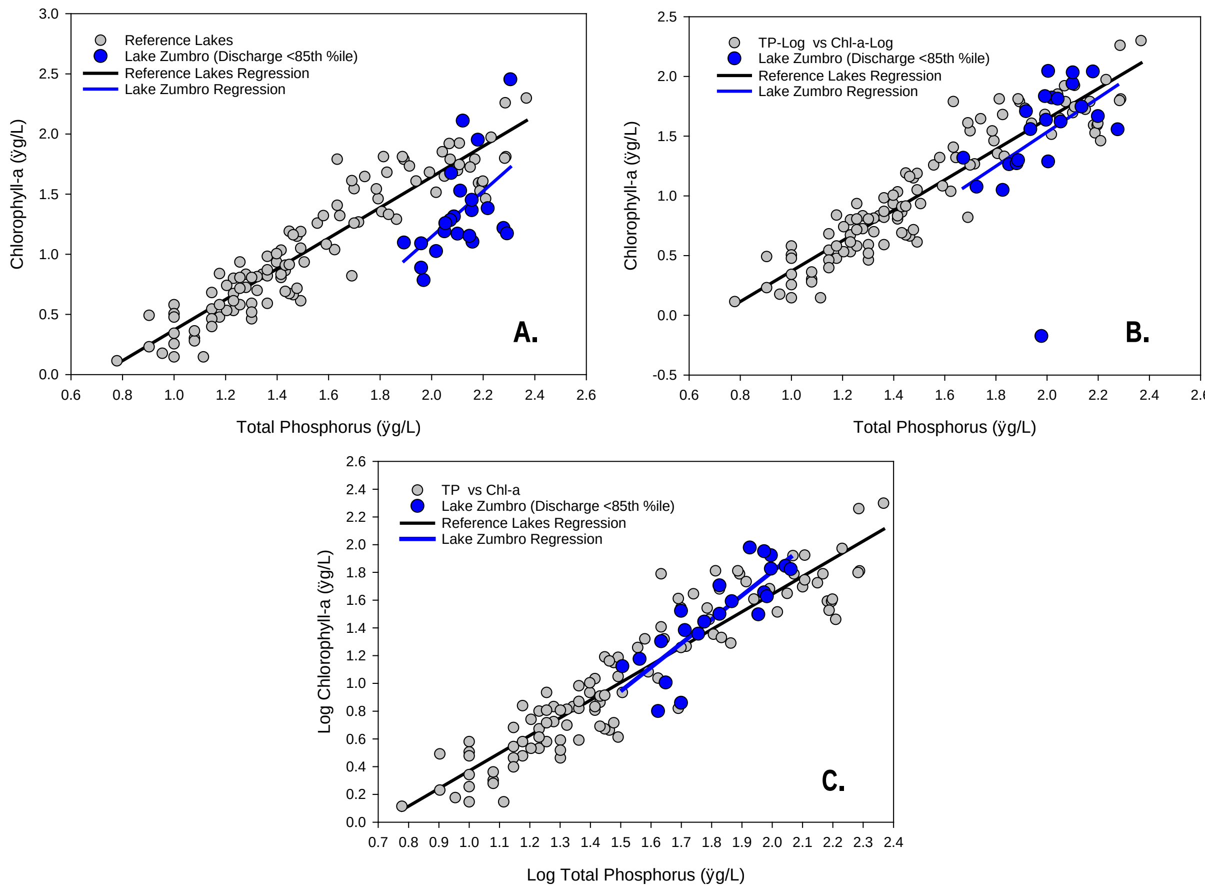

Figure 25. Comparison of summer total phosphorus-chlorophyll-a relationships for Lake Zumbro segments and Minnesota lakes and rivers used to develop eutrophication standards. Reference Lakes: $\log_{10}$ chla = 1.27 • $\log_{10}$ TP 0.90, R^2 = 0.87; Segment 1: $\log_{10}$ chla = 1.89 • $\log_{10}$ TP - 2.64, R^2 = 0.28; Segment 2: $\log_{10}$ chla = 1.43 • $\log_{10}$ TP - 1.32, R^2 = 0.19; Segment 3: $\log_{10}$ chla = 1.72 • $\log_{10}$ TP - 1.64, R^2 = 0.70.

BATHTUB modelling

The BATHTUB model is useful for both the eutrophication total maximum daily load (TMDL) for Lake Zumbro and development of the SSS for Lake Zumbro. The Zumbro River watershed HSPF model was used to calculate flow-weighted mean concentration (FWMC) TP and streamflow for each individual BATHTUB model year. The BATHTUB model divided Lake Zumbro into 3-4 segments (Figure 26; for further details see Wasley [2016]). Only flows below the top 15% of flows were included in the FWMC and flow inputs for each individual BATHTUB model year. The removal of the top 15% of flows results in a residence time similar to that of waters defined as reservoirs in [Minn. R. 7050.0150, subp. 4] (Figure 27). Including all flows for the 122-day (June-September) averaging period made model fits difficult. During high flows, the lake receives very high TP inputs and grows relatively little algae due to a rapid flushing rate and reduced clarity. At flows below the top 15% of flows, TP inputs are moderate and algal production in the lake increases.

Figure 26. Map and BATHTUB model segments used for BATHTUB modelling of Lake Zumbro.

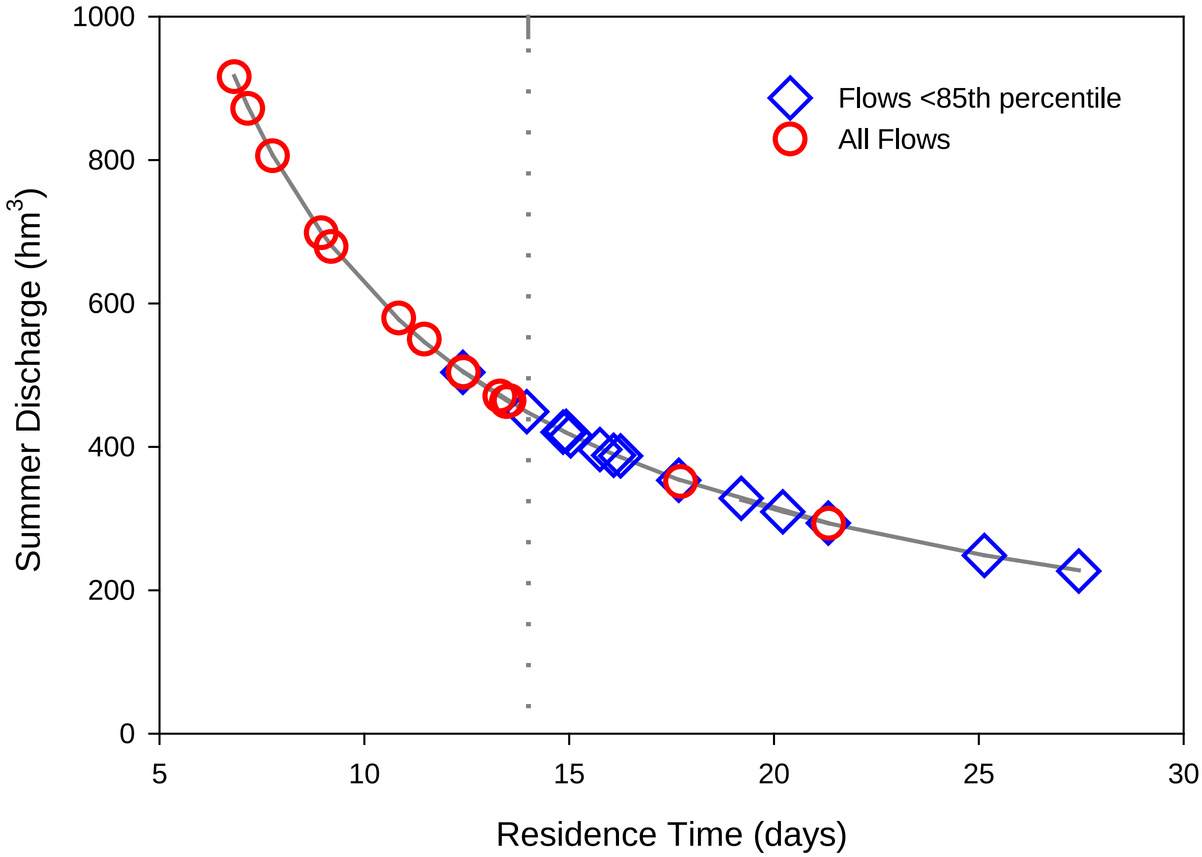

Figure 27. Relationship between modelled residence time and total summer discharge for Lake Zumbro with all discharges and with discharges above the 85th percentile removed (1996-2009). The dashed line at 14 days residence time is the thresholds used for distinguish reservoirs from rivers (Minn. R. 7050.0150, subp. 3).

Model fit was much better when the top 15% of flows were removed compared to relatively extreme calibration needed when all flows were included (Table 7). Given that BATHTUB is a static model, it is very difficult to match two distinct conditions in one model year output. When all summer flows are included, each year with available monitoring data required a unique calibration to match monitored in-lake conditions. Basically, it was difficult to replicate how a very high FWMC TP concentration would be dramatically reduced via sedimentation and yield relatively moderate TP concentration compared to inputs along with high algal levels in a rapidly flushed reservoir. Removing the top 15% of flows allowed for one calibration scenario for all years. The lake inputs and response are quite consistent once the higher flows are removed. Removing the top flows generally reduced the averaging period of the model from 122 days to 100 days on average. Observed lake water-quality monitoring was available for 1998, 2000, 2003, 2007 and 2008.

Table 7. Average summer model output for 1998, 2000, 2003, 2007 and 2008 along with monitored overall average for the same 5 years. Top 15% of flows excluded from model inputs and monitored results. TP = total phosphorus, chla = chlorophyll-a, and Secchi = Secchi depth.

Segment	TP (µg/L)	Chl-a (µg/L)	Secchi (m)	% chl-a >60 (µg/L)
BATHTUB Model Results				
Segments 2 and 3 combined model	84	43	1.33	18
Segment 2 model	105	47	1.06	23
Segment 3 model	70	40	1.53	15
Monitoring Results				
Segment 2 monitored	105	47	1.1	
Segment 3 monitored	70	40	1.5	

There can be some concern that sampled years may not reflect long-term average conditions for a reservoir due the relatively variable inputs to these systems. Summer average predictions from the five calibration years for the BATHTUB model can be compared to summer predicted values from all years from 1996 to 2009 (Table 8). The predictions from all years are slightly higher in terms of TP and chla and slightly lower for Secchi depth. The predictions for all years serves as an estimate of current baseline conditions of the lake as a long-term average.

Table 8. Average BATHTUB model output for all years from 1996 to 2009 along with monitored overall average for 1998, 2000, 2003, 2007 and 2008. Top 15% of flows excluded from model inputs and monitored results. TP = total phosphorus, chla = chlorophyll-a, and Secchi = Secchi depth.

Segment	TP (µg/L)	Chla (µg/L)	Secchi (m)	% chl-a >60 (µg/L)
BATHTUB Model Results				
Segments 2 and 3 combined model	86	44	1.29	20
Segment 2 model	106	48	1.04	24
Segment 3 model	72	41	1.47	16
Monitoring Results				
Segment 2 monitored	105	47	1.1	
Segment 3 monitored	70	40	1.5	

The predicted estimates from BATHTUB that only represent the days when flows were less than the top 15% of flows can be converted to averages for the entire summer by substituting observed values for high flow dates. Monitored values in Segment 3 of Lake Zumbro during the top 15% of flows have relatively high TP, low chla, and lower Secchi depth than during average to low flows. Basically, residence time is so short at high flows that less sediment and TP settle in the upper portions of the lake and less algae are produced throughout the lake. Including all flows also allows comparison to other lake standards that are based on all flows. The estimates for the entire summer are relatively close to the estimated for all flows (Table 9)

Table 9. Average modeled BATHTUB outputs with top 15% of flows excluded (model) for Segment 3 for all years from 1996-2009 along with expected summer average (all days) when monitored numbers are assumed for top 15% of flows. Assumed values for high flow days: total phosphorus 147 g/L, chlorophyll-a 11 µg/L, and Secchi depth 0.8 m. TP = total phosphorus, chla = chlorophyll-a, and Secchi = Secchi depth.

Year	# days < top 15% of flows	# days > top 15% of flows	Model TP (µg/L)	Model chla (µg/L)	Model Secchi (m)	All days TP (µg/L)	All days chla (µg/L)	All days Secchi (µg/L)
1996	108	14	65	36	1.7	75	33	1.6
1997	96	26	77	46	1.3	92	38	1.2
1998	100	22	66	36	1.6	81	32	1.5
1999	90	32	78	46	1.3	96	37	1.2
2000	89	33	68	38	1.6	89	30	1.4
2001	98	24	70	40	1.5	86	34	1.4
2002	85	37	77	45	1.3	98	35	1.2
2003	120	2	67	37	1.6	68	37	1.6
2004	77	45	71	40	1.5	99	29	1.2
2005	108	14	79	47	1.3	87	43	1.2
2006	109	13	74	42	1.4	82	39	1.3
2007	85	37	83	51	1.2	103	39	1.1
2008	108	14	67	36	1.6	76	34	1.5
2009	122	0	69	38	1.6	69	38	1.6
Average	100	22	72	41	1.5	86	36	1.35

Table 10. Average modeled BATHTUB outputs with top 15% of flows excluded (model) for Segment 2 for all years from 1996-2009 along with expected summer average (all days) when monitored numbers are assumed for top 15% of flows. Assumed values for high flow days: total phosphorus 180 µg/L, chlorophyll-a 12 µg/L, and Secchi depth 0.6 m. TP = total phosphorus, chla = chlorophyll-a, and Secchi = Secchi depth.

Year	# days < top 15% of flows	# days > top 15% of flows	Model TP (µg/L)	Model chla (µg/L)	Model Secchi (m)	All days TP (µg/L)	All days chla (µg/L)	All days Secchi (µg/L)
1996	108	14	97	42	1.2	107	39	1.1
1997	96	26	111	51	1.0	126	43	0.9
1998	100	22	93	39	1.2	109	35	1.1
1999	90	32	106	48	1.0	125	38	0.9
2000	89	33	98	43	1.1	120	34	1.0
2001	98	24	99	43	1.1	115	37	1.0
2002	85	37	108	49	1.0	130	38	0.9
2003	120	2	108	49	1.0	110	49	1.0
2004	77	45	97	42	1.1	128	31	0.9
2005	108	14	118	56	0.9	125	51	0.8
2006	109	13	106	48	1.0	114	44	1.0
2007	85	37	122	58	0.8	139	44	0.8
2008	108	14	101	45	1.1	110	41	1.0
2009	122	0	116	54	0.9	116	54	0.9
Average	100	22	106	48	1.0	119	41	1.0

The HSPF model was used to model various reduction scenarios for TP. The impact of each scenario on the FWMC of tributaries to Lake Zumbro is variable. A sensitivity analysis was completed to estimate the impact of a 25% increase or decrease of the baseline tributary FWMC TP on lake predictions (Table 11). The results of the sensitivity analysis indicate that any increase or decrease in TP will affect the TP, chla and Secchi depth levels in Lake Zumbro. This analysis demonstrates the importance of tributary TP to the conditions of Lake Zumbro below the top 15% of flows.

Table 11. Average modeled BATHTUB outputs for 25% increase, baseline and 25% decrease in FWMC TP inputs for all years from 1996-2009. Top 15% of flows excluded from model inputs.

Segment	TP (µg/L)	Chl-a (µg/L)	Secchi (m)	% Chl-a >60 µg/L
25% Increase in TP Model				
Segments 2 and 3 combined model + 25%	104	57	1.02	36
Segment 2 model + 25%	130	65	0.77	46
Segment 3 model + 25%	85	52	1.19	30
Baseline Model				
Segments 2 and 3 combined model base	86	44	1.29	20
Segment 2 model base	106	48	1.04	24
Segment 3 model base	72	41	1.47	16
25% Decline in TP Model				
Segments 2 and 3 combined model - 25%	68	31	1.76	6
Segment 2 model - 25%	80	32	1.50	7
Segment 3 model – 25%	58	30	1.95	6

Protection of downstream beneficial uses

It is also important to consider whether or not maintaining current trophic conditions in Lake Zumbro will protect downstream uses. There are currently a number of impairments downstream of the reservoir including bacteria, mercury in fish tissue, polychlorinated biphenyls (PCBs) in fish tissue, and turbidity. There are no eutrophication impairments on the Zumbro River below the reservoir. Two downstream reaches were assessed for river eutrophication in 2015. One was fully supporting with TP, chla, and dissolved oxygen (DO) flux all meeting standards. The second reach assessment was determined to be inconclusive because total phosphorus exceeded the criterion, but chlorophyll-a was meeting. DO flux data was insufficient for assessment in this second reach, but it also indicated attainment of the criterion. In addition, there are no eutrophication impairments on the Mississippi River between the Zumbro River confluence and the Minnesota/Iowa border. This indicates that the current conditions in the reservoir are not causing downstream impairments related to eutrophication.

Proposed site-specific standard for Lake Zumbro

The following summarizes the findings of this study:

1. The drainage catchment size, ecoregion, and morphology of Lake Zumbro make this waterbody unique in several aspects compared to natural lakes of Minnesota. Its watershed has a larger area and its water budget comes largely by way of the South and Middle Forks of the Zumbro River. As a result, Lake Zumbro has a short residence time that indicates it may be inappropriate to apply an

eutrophication standard designed for natural lakes. This is supported by the LES rule which clearly states that SSS are needed for reservoirs and lakes in the Driftless Area. Lake Zumbro meets both of these criteria.

2. Although Lake Zumbro is atypical compared to most other natural lakes in Minnesota, parts of the lake under the majority of flow conditions behave similarly to natural lakes and relationships between water quality parameters can be predicted. Segment 1 appears largely riverine and the recreation use of this segment is not similar to the two downstream lake segments. It is therefore not appropriate to apply LES standards to this segment. Segments 2 and 3 support typical lake recreational uses and water quality relationships are more similar to natural lakes at discharges below the 85th percentile. There are differences in the relationships of trophic indicators between different segments of Lake Zumbro which should be considered as part of a SSS. The upper portion (Segment 1) is more riverine and has minimal recreational use and is therefore not considered as part of the SSS. Segments 2 (middle) and 3 (lower) both are the primary focus for recreational activities and a SSS standard should be developed to protect these segments for this SSS and for determining compliance with the standard.
3. User surveys indicate that the lake usually meets a condition that is defined as: "Swimming and aesthetic enjoyment slightly impaired because of algae levels." This is generally considered to be in attainment of the recreational beneficial use. Poorer survey results in Lake Zumbro are typically associated with lower clarity resulting from suspended sediment.
4. Based on available biological data (DNR fisheries surveys) gamefish populations are doing well and indicate that the aquatic life beneficial use is currently supported.
5. Lake Zumbro differs from other lentic waterbodies in that it maintains good water clarity at chla concentrations above the existing chla standard. Although the mechanism for this pattern is not understood, it may be the result of the algal species present in the lake or the composition of dissolved organic compounds (e.g., humic compounds). In addition, the current levels of blue-greens is low compared to other lakes in the state indicating that the higher concentrations of chla are not concomitant with serious blooms of blue-greens.
6. Lake Zumbro is more similar to Byllesby Reservoir, Lake Pepin, and the pools on the Mississippi River than to other natural lakes which can help in determining a protective SSS LES for Lake Zumbro. The focus for Lake Zumbro should be on maintaining good water clarity during periods of low to average discharge and avoiding a high frequency of nuisance algae blooms.

Following is a summary of pertinent criteria setting considerations and draft site-specific criteria:

- **Total phosphorus:** A TP summer-mean concentration of <75 parts per billion (ppb), as measured during discharges below the 85th percentile (960 cfs as measured or modelled at the dam), should be maintained in Segment 3. This concentration is approximately halfway between the TP criteria for deep and shallow southern lakes. Segment 2 should meet a TP summer-mean concentration of <105 ppb, as measured during discharges below the 85th percentile. Based on the BATHTUB models, these values are equivalent to approximately an average of 86 and 119 ppb at all flows for Segments 3 and 2, respectively. To achieve this in-lake concentration, current conditions will need to be maintained which includes a time-weighted mean inflow on the order of 110 ppb at flows below the below 85th percentile.
- **Chlorophyll-a:** A chla summer-mean concentration of <40 ppb, as a as measured during discharges below the 85th percentile, should be maintained in Segment 3. Segment 2 should meet a chla summer-mean concentration of <48 ppb, as measured during discharges below the 85th percentile. These values are higher than existing chla standards for lakes and reservoirs, but are not directly comparable due to the elimination of measurements at flows in the top 15%.

These values are equivalent to an average 36 and 41 ppb at all flows for Segments 3 and 2, respectively. The chla concentration in Segment 3 is equivalent to the standard applied to the Mississippi River pools. The Mississippi River pools have a standard of 35 ppb which applies at all flows and the proposed SSS for Lake Zumbro is predicted to result in a chla standard of 36 ppb at all flows. Based on the BATHTUB model this should maintain chla below 60 ppb for about 84 percent of the summer in Segment 3.

- **Secchi depth:** A summer-mean Secchi depth of ≥1.4 m, as measured during discharges below the 85th percentile, should be maintained in Segment 3. This value is equivalent to the criterion for central (i.e., North Central Harwood ecoregion) deep-water lakes (Table 2). Segment 2 should met a Secchi depth of ≥1.1 m as a summer-mean as measured during discharges below the 85th percentile. These values are modeled to be equivalent to an average of 1.4 and 1.0 m at all flows for Segments 3 and 2, respectively.
- These standards are based on current conditions and will protect downstream uses as current assessments of the Zumbro River below Lake Zumbro indicate attainment of river eutrophication standards.
- These values apply over a range of flows up to ~960 cfs (~85th percentile) as measured or modeled at the outlet of Lake Zumbro. This corresponds to a residence time of about 14 days. Above this range, Lake Zumbro is more river-like with high discharges and nuisance algae blooms are not an issue.
- To assess compliance with these criteria, water quality must be monitored at sites within Segments 2 and 3. Data from Segment 3 will be used to assess the designated use and Segment 2 data will be used as supporting information. A minimum of four samples are required per year (at discharges below the 85th percentile) over at least three years. The total number of samples required is 12. For example, three years of data with four samples per year would be sufficient to assess. These values are calculated as an average of the summer mean concentrations. The difference in the data requirements and assessment methods compared to the LES standard are the result of the elimination of discharges above the 85th percentile. The different calculation method is also the reason for the greater number of years that are required to perform an assessment. The BATHTUB model will be used to corroborate the field data.
- Available evidence suggests that the current condition is not preventing attainment of the recreational use. However, since this standard is unique, applied differently, and is higher than other standards applied to natural lakes in Minnesota, this SSS should continue to be evaluated to ensure that aquatic life and recreational uses are protected. This should include at least monitoring of eutrophication parameters and awareness of complaints by users related to nuisance or harmful algal blooms. Monitoring of algal species composition would also be beneficial to do determine if there is an undesirable rise in blue greens.

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