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LAKE WINGRA
WATER QUALITY ANALYSES (1996-2001)

By Jill Leale

ABSTRACT

Lake Wingra is a shallow lake system located in the city of Madison, Wisconsin. The lake is consistently monitored under the program the North Temperate Lakes Long Term Ecological Research (LTER) which is executed by the Center for Limnology at the University of Wisconsin-Madison, Wisconsin. The LTER program provides access to their observations to interested parties. This data was used to examine the trophic status of Lake Wingra by analyzing the lake variables: Chlorophyll a (CHL), Secchi Disc (SD) depth and Total Phosphorus (TP). The average CHL concentration for the dataset (1997-2001) is 21.7 ug/l. The range of the averages is 11.8 ug/l (2000) to 32.7 ug/l (2002). The overall average for SD (1996-2001) is 0.72 m with a range of 0.52 m to 0.98 m. The average of TP (1996-2001) is 40.0 ug/l with a range of 32.0 ug/l (1998) to 58 ug/l (2001). All parameters suggest the lake is highly eutrophic with a Trophic State Index (TSI) of TSI (CHL) 60, TSI (SD) 65, TSI (TP) 59. Comparison of TSI for the three parameters suggests that non-algal constituents contribute to low water clarity. In addition, TSI (SD) is affected by sediment due to a close relationship with TP (TSI), which indicate the presence of fine sediment laden with phosphorus.

Year	Avg CHL (ug/l) Ice off Season	Avg SD (m) June-August	Year Average TP (ug/l)	TSI (CHL)	TSI (SD)	TSI (TP)
1996	N/A	0.98	36	N/A	60	56
1997	19.9	0.59	44	60	68	59
1998	22.2	0.75	32	61	64	54
1999	22.9	0.66	49	61	66	60
2000	11.8	0.81	46	65	63	59
2001	32.7	0.52	58	55	69	63

LAKE WINGRA

INTRODUCTION

Lake Wingra is a lake in the city of Madison, Wisconsin. The lake is 139.6 ha and fairly shallow with a mean depth of 2.7 m. Bordering its shoreline are a zoo, parks, natural and urbanized areas. The lake has significant recreational and aesthetic value for the people of Madison and like many urban lakes; it is under a threat of continued degradation from pollution. Unlike many urban lakes, Lake Wingra is the topic of many scientific investigations by scholars, students, and people in local and state agencies. The group, Friends of Lake Wingra (FOLW) is addressing the task of synthesizing this information to provide outreach opportunities and to create programs to improve the environmental conditions of Lake Wingra and the surrounding watershed.

As stated, there is a litany of information about many aspects of the lake from a historical view of changes in the ecology to in-depth analyses of current stormwater management opportunities for water quality improvement. Much of this information was summarized in the publication "Lake Wingra: A Watershed Approach" by Water Resources Management Workshop (1998). This publication and others can be found on the FOLW website (http://danenet.danenet.org/fowingra/index.html). The lake also has a frequent monitoring regime that is executed by the program the North Temperate Lakes Long Term Ecological Research (LTER).

The LTER program is sponsored by The National Science Foundation. More information about LTER network can be found at http://www.lternet.edu and http://www.lternet.edu/sites/ntl. In brief, the LTER program is a network of sites across North America, which provide ecological information to be accessible to scientists to study broad spatial and temporal scale environmental phenomenon. Part of the mission of the network is to create a legacy of well designed long-term observations and to disseminate this information to the broader scientific community. Under the LTER program, the Center for Limnology at the University of Wisconsin-Madison, Wisconsin, executes a consistent sampling regime throughout the year on lakes in the Madison area. The data is made available to interested parties via the web. These mission goals were instrumental in providing the information to examine the waters of Lake Wingra in this report. This report utilizes LTER data from 1996 to 2001 as a resource to portray many ecological functions in Lake Wingra. The specific goals of this report were to answer the following questions.

1. What is the trophic status of the lake?
2. Is there evidence of water quality trends in the lake?
3. What system attributes are commonly found in the lake?
4. How do these attributes behave seasonally?

To address these questions, lake attributes were analyzed from the years, 1996 to 2001. Specifically, the results of Chlorophyll *a* (CHL), Total Phosphorus (TP) and Secchi Disc Depth (SD) are shown and discussed in this report. These parameters are then examined in context with the classification system, the Trophic State Index (TSI). The report begins with a discussion of the concept of tropic state because of its relevance to the lake parameters that are discussed individually (CHL, TP, and SD). This section provides some background to each lake constituent although only a brief introduction is presented regarding the topics. Therefore, see Appendix I for a list of references, Internet sites, and suggested readings to examine the science of lakes in more detail. Also, in the appendix is a description of the data and the data sources.

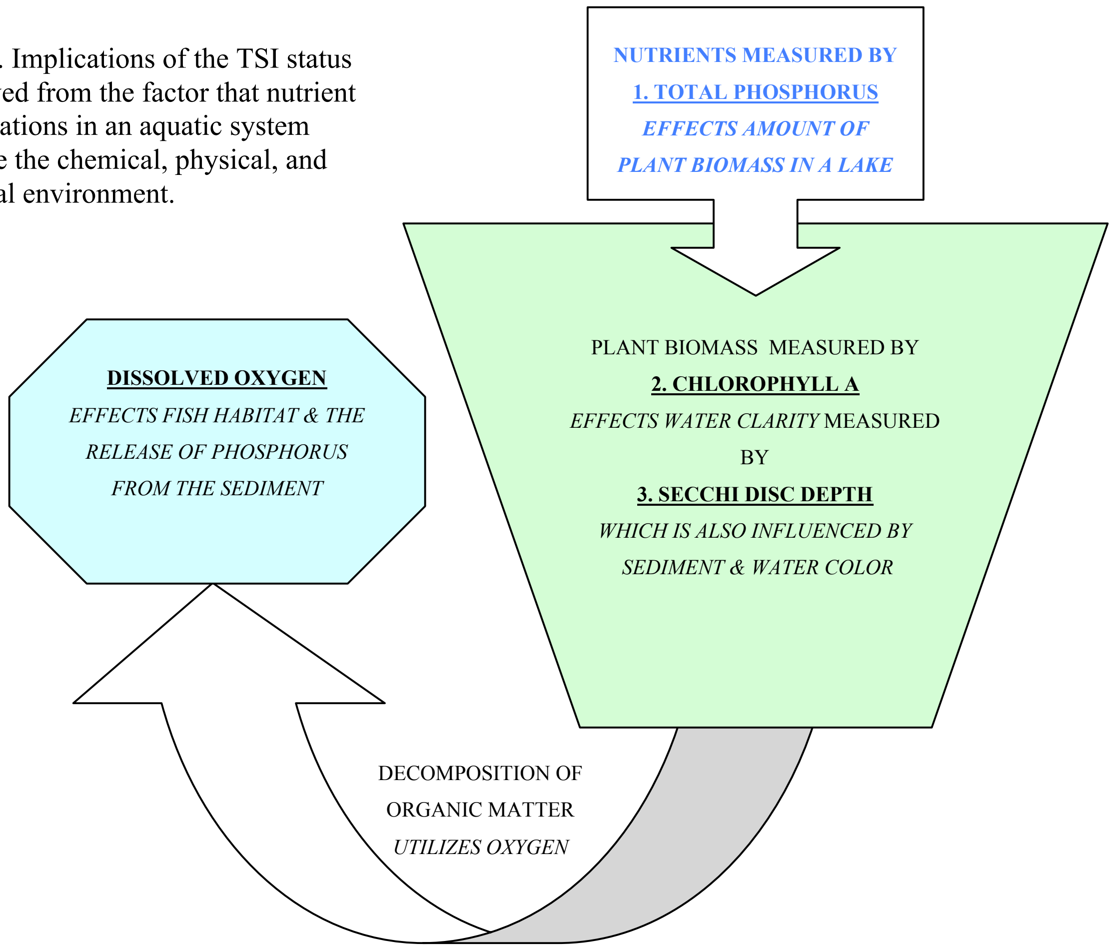
Lake Wingra is a very interesting aquatic system because of its shallow nature. While many limnological studies have focused on the dynamics of deeper lake systems, shallow lakes behave quite differently then their stratified counterparts. Thus, analyses of attributes in Lake Wingra contribute to a better understanding of shallow lake systems. In addition, baseline information may provide insight to possible outcomes when lake management strategies are implemented to improve the water quality in Lake Wingra.

BACKGROUND

TROPHIC STATE INDEX

Many physical, chemical, and biological components are used to portray the characteristics of lakes. Commonly, lakes are described by a classification termed, Trophic State Index (TSI). Trophic literally means "nutrition or growth". In context with an aquatic systems, eutrophic relates to a well-nourished lake, by contrast an oligotrophic lake is nutrient poor, while a mesotrophic lake lies somewhere between a nutrient poor lake and a nutrient rich lake. The significance for measuring nutrient concentrations is that the cycling of nutrients has an impact on other environmental condition in a lake from algae concentration to dissolved oxygen levels. Thus, in an aquatic system, a main driver is the availability of nutrients, which implies a variety of other conditions will be observed in the lake. The diagram below brings together some of the basic components of concepts of TSI.

Figure 1. Implications of the TSI status are derived from the factor that nutrient concentrations in an aquatic system influence the chemical, physical, and biological environment.



The Trophic State Index is a multi-dimensional concept, which uses the correlation of nutrient concentration to the amount of plankton biomass in a lake (Carlson 1977). This relationship of nutrient to the quantity of plankton biomass also impacts the water clarity. Commonly three indices are measured to determine the trophic state of a lake. These are

1. Total Phosphorus (TP) concentrations: Phosphorus is commonly a limiting nutrient in lakes. Whereas other nutrients such as nitrogen are in ample supply for algal requirements, phosphorus is not often found in an unlimited supply for plant production. Therefore, the availability of phosphorus often dictates the algal production in a lake.

2. Chlorophyll a (CHL) concentrations: Chlorophyll *a*, a pigment found in all types of algae, is used to estimate the algal biomass in a lake. Often, chlorophyll *a* measurements will correlate with phosphorus concentrations in a lake.

3. Secchi Disc (SD) depth: Secchi Disc depth is the measurement at which a Secchi disc can be viewed after being lowered into the water column. The depth of this measurement is related to the clarity of the water in a lake, which is effected by the presence of algae and sediment, in addition to the inherent color of the color.

Table 1. Trophic State Index adapted from The Great North American Secchi Dip-In, Kent State University, Kent, Ohio. http://dipin.kent.edu/index.htm

Trophic Class	**Total Phosphorus (ug/l)**	**Chlorophyll *a* (ug/l)**	**Secchi Disc (m)**	**Trophic State Index (Carlson 1977) Characteristics of Trophic Categories**
Oligotrophy	< 6	< 0.95	> 8	< 30 Clear water, oxygen present throughout water column Salmonid fisheries dominate
	6 - 12	0.95 – 2.6	8 - 4	30 – 40 lower depths of the lake may become anoxic Salmonid fisheries in deep lakes only
Mesotrophy	12 - 24	2.6 – 7.3	4 - 2	40 – 50 Water moderately clear, increasing probability lower depths of lakes will become anoxic (oxygen deficit). Increase probability of algae blooms Walleye may predominate
Eutrophy	24 - 48	7.3 - 20	2 – 1	50 – 70 Anoxic lower depths of lake, macrophytes intrusion, algae blooms common, warm water fisheries, bass may dominate
	48 - 96	20 - 56	0.5 - 1	60 – 70 Water is not clear, blue-green algae dominate and increased macrophytes
Hypereutrophy	96 - 192	56 - 155	0.25 – 0.5	70 – 80 water clarity very low causing light limited productivity,
	192 - 384	> 155		> 80 Algal scums, few macrophytes Rough fish dominate, summer fish kills possible

The TSI numbers are derived from the equations (Carlson 1977)

- Trophic State Index TSI (Secchi Disc Dept, SD, m) = 10* (6- (LN(SD) / LN(2))) or
  60 – 14.41 LN (SD)

- Trophic State Index TSI (Chlorophyll a, CHL, ug/l) = 10*(6- ((2.04 - 0.68 ln (CHL) / LN (2))) or
  9.81* LN (CHL) + 30.6

- Trophic State Index TSI (Total Phosphorus, TP, ug/l) = 10(6- (LN(48(TP) / LN(2))) or
  14.42 LN(TP) + 4.15

One advantages of using the system is the ability to examine the relationship of the three parameters (SD, CHL, and TP). For example, given the CHL equation was derived from the relationship to SD, deviation in the two parameter shown in the TSI numbers could illuminate other factor regulating SD.

The trophic class of a lake should be viewed in the context that a lake is a dynamic system that does not always fit in a specified class. Within the same system a lake can have the characteristics of different trophic classes. For example, Lake Michigan's shorelines near cities are often eutrophic, while in the northern reaches of the basin the waters fall into the oligotrophy class. Difference in weather conditions from year to year has a large impact on parameters used to describe trophic class. For instance, years where precipitation is less than average, lakes commonly are less productive. In this case, over-land runoff and stream inflow is decreased; therefore less nutrients are distributed to the lake. Nevertheless, the classification system is a useful guide to evaluate a lake system. It is also helpful means to communicate typical features of a lake.

RESULTS: SECCHI DISC DEPTH (1996-2001)

Data Source: Secchi Disc Depth. North Temperate Lakes Long Term Ecological Research program (http://lter.limnology.wisc.edu), NSF, contact person: Timothy K. Kratz; Trout Lake Station, WI.

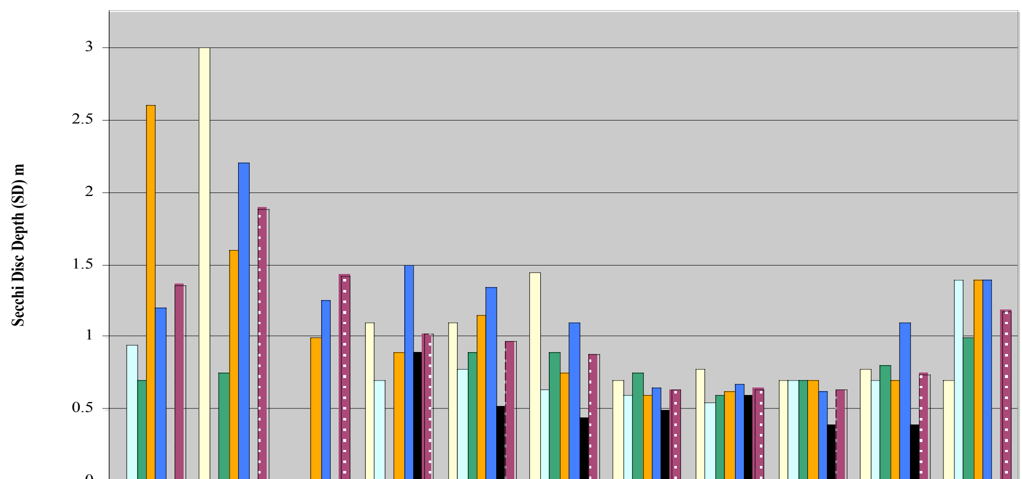
AVERAGE SECCHI DISC DEPTH (1996-2001)

Over the past six years, Lake Wingra average Secchi Disc (SD) depth was 0.72 m. The season of the highest lake clarity occurred in 1996 (0.98 m) with the next highest year average in 2000 (0.81 m). Both 1997 and 2001 show very low water clarity at 0.59 m and 0.52 m, respectively.

Table 1. Lake Wingra average Secchi Disc Depth

Year	Avg SD (m) June-August
1996	0.98
1997	0.59
1998	0.75
1999	0.66
2000	0.81
2001	0.52

SEASONAL AND YEARLY SECCHI DISC DEPTH



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1996		3.00		1.10	1.10	1.45	0.70	0.78	0.70	0.78	0.70
1997	0.95			0.7	0.78	0.63	0.6	0.55	0.7	0.7	1.4
1998	0.70	0.75			0.9	0.9	0.75	0.6	0.7	0.8	1
1999	2.6	1.6	1	0.9	1.15	0.75	0.6	0.63	0.7	0.7	1.4
2000	1.2	2.2	1.25	1.5	1.35	1.1	0.65	0.68	0.62	1.1	1.4
2001				0.9	0.52	0.45	0.5	0.6	0.4	0.4	
Avg Month SD 96-01	1.36	1.89	1.43	1.02	0.97	0.88	0.63	0.64	0.64	0.75	1.18

Figure 1. Lake Wingra average SD by month and year

Overall, water clarity shows a distinct pattern of the highest SD measurement during the winter months. A gradual decrease in clarity occurs in the spring, dropping to the lowest SD readings in the summer and early fall, then a slow upward trend begins in the late fall. January and February has the highest average SD. The lowest clarity occurs in July (0.63 m), although August and September are only slightly above this average at 0.64 m.

A characteristic trend in water clarity is shown in 1999 (Figure 2). Beginning in January with low water temperature and light, algal growth is limited and SD is at its highest measurement. A very steep rise occurs in February due to increase in turbidity from growth of algae population and/or sediment in the water. The rise continues until July with the lowest SD reading. Water clarity continues to be quite low throughout the late summer and fall. Only in November does a substantial increase in water clarity occur.

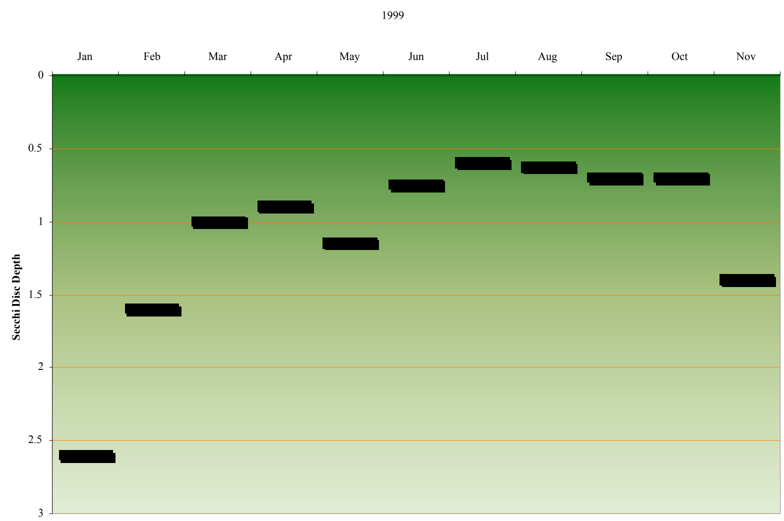


Figure 2. Lake Wingra Secchi Disc Depth in the year 1999.

RESULTS: CHLOROPHYLL *A* (1997-2001)

Data Source: Chlorophyll - Madison Lakes Area. North Temperate Lakes Long Term Ecological Research program (http://lter.limnology.wisc.edu), NSF, contact person: Timothy K. Kratz; Trout Lake Station, WI.

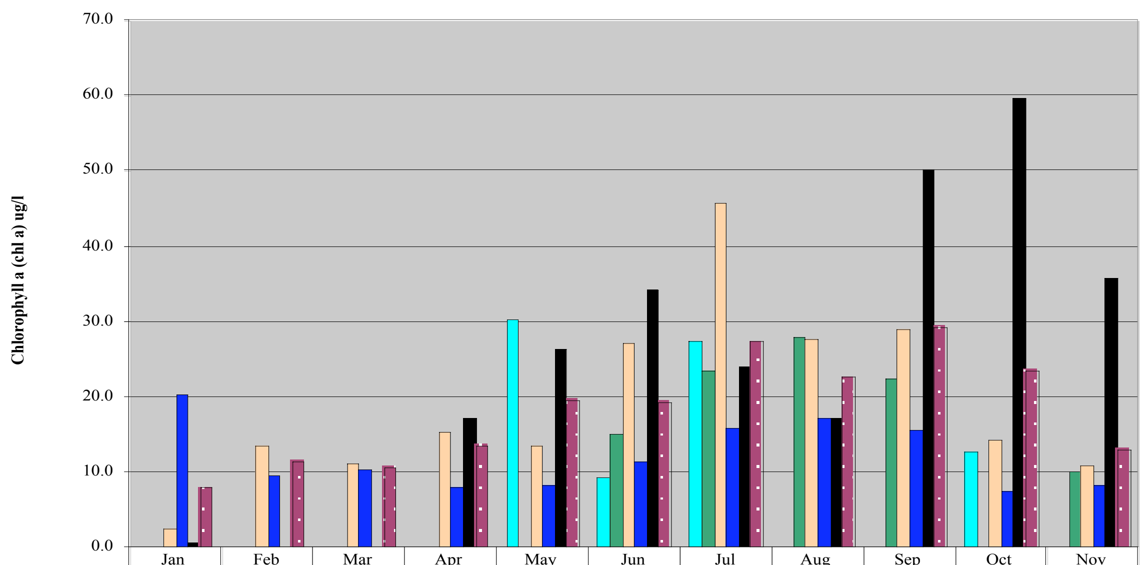
AVERAGE CHLOROPHYLL A (1997-2001)

The average Chlorophyll *a* (CHL) concentration for the years 1997 - 2001 is 21.7 ug/l. The highest average occurs in 2001 at 32.7 ug/l with the lowest found in 2001 at 11.9 ug/l (Table 1). These two averages differ a great deal than the means from 1997, 1998, and 1999, which are very near 20 ug/l. This difference can be translated to 45% decrease in CHL in 2000 and a 60% increase in 2001. Although in the case of 2001, CHL was not measured in the March, which shows to have low CHL concentrations. Thus the omission of March could contribute to the higher average for 2001. Although, omission of data does not explain the low CHL average of 2000.

Table 1. Lake Wingra average Chlorophyll *a* (CHL) concentration

Year	Avg CHL (ug/l) Ice off Season	Month of observations
1997	19.9	May-Jul, Oct
1998	22.2	Jun-Sep
1999	22.9	Mar-Oct
2000	11.8	Mar-Oct
2001	32.7	Apr-Oct

SEASONAL AND YEAR CHLOROPHYLL *A*



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1997					30.3	9.2	27.3			12.7	
1998						15.0	23.5	28.0	22.3		10.2
1999	2.5	13.4	11.0	15.4	13.4	27.0	45.7	27.7	29.1	14.3	11.0
2000	20.4	9.5	10.3	7.9	8.1	11.4	15.9	17.3	15.7	7.5	8.2
2001	0.7			17.1	26.3	34.2	23.9	17.3	50.2	59.7	35.9
Month Avg 97-01	7.9	11.4	10.6	13.5	19.5	19.4	27.3	22.6	29.3	23.5	13.0

Figure 1. Lake Wingra average CHL by year and month.

Overall, CHL in Lake Wingra increase during the warm summer months and show a substantial decrease beginning in October. These low CHL concentrations continue until March. September shows the highest CHL concentration followed by July. January has the lowest CHL average followed by March then February. The cycle of CHL concentrations does not always conform each year for example in 1997 shows very high concentrations in May (30.3 ug/l), then a contrasting low measurement in June (11.4 ug/l). A typical rise and fall occurs in 1998 and 1999. In the year 2000 the same trend occurs with an exception of a very high CHL measurement occurring in January (20.4 ug/l). 2001 also does not conform to a cyclic trend; rather CHL has enormous peaks occurring September through November.

A characteristic trend of rising CHL concentration in the summer is shown in the year 1999 (Figure 2). Also exemplified in the figure is the difference of CHL occurring within a month. Bimonthly measurements taken in June show an overall rise from previous month, however a drop occurs two weeks later (June 22). Again in August measurements show a decrease from July of – 15.5 ug/l, while two weeks later concentrations increase by 5.6 ug/l. This shows CHL concentrations can vary quite substantially during a month, which has an impact on evaluating the average concentrations per month. Also this range will have an impact on the water clarity during a given month.

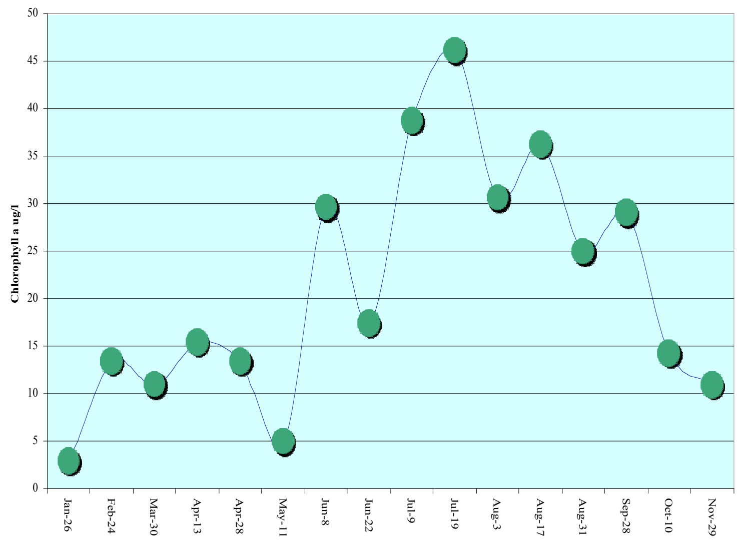


Figure 2. Lake Wingra Chlorophyll *a* concentration in 1999.

RESULTS: TOTAL PHOSPHORUS

Data Source: Nutrients. North Temperate Lakes Long Term Ecological Research program (http://lter.limnology.wisc.edu), NSF, contact person: Emily H. Stanley, Center for Limnology, University of Wisconsin-Madison.

AVERAGE TOTAL PHOSPHORUS (1996-2001)

Over the past six years, Lake Wingra average Total Phosphorus (TP) concentration was 40 ug/l. This average was calculated from the samples in which the temperature of the lake first became uniformed in the early spring (1996-2001). This is in good agreement when an average is calculated by using all the TP concentration recorded throughout the year (44 ug/l). Although by comparison, the spring mixis mean is lower then the yearly averages (Table 1). The lowest TP average occurs in 1998 at 32 ug/l while the highest TP average occurs in 2001.

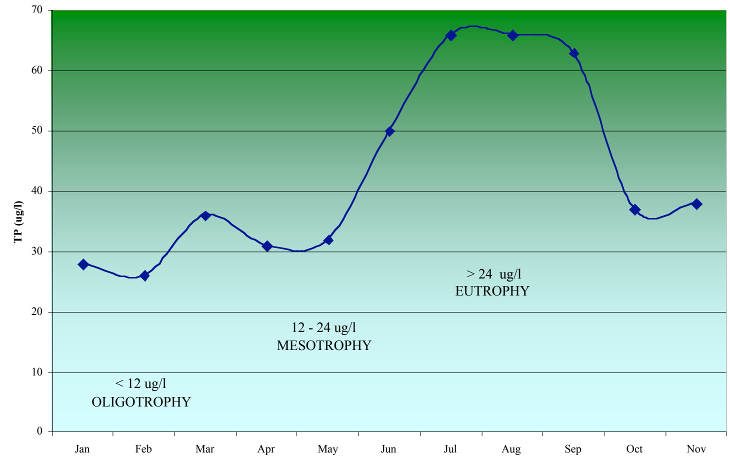
Table 1. Total Phosphorus average of Lake Wingra (1996-2001)

Spring Mixis	Spring Mixis Average TP (ug/l)	Year Average TP (ug/l)
May 2, 1996	29	36
April 10, 1997	45	44
March 25, 1998	24	32
April 28, 1999	44	49
March 27, 2000	36	46
April 12, 2001	42	58

SEASONAL AND YEAR TOTAL PHOSPHORUS

Figure 1. Annual TP concentrations in Lake Wingra.

In Lake Wingra, TP concentrations during 1996 to 2001 show a rise during the midsummer months. In most cases, a peak of TP occurs in July. In 1996, TP appears to change little throughout the year except for the characteristic peak in July. In 1997, the most erratic distribution of the constituent, TP has an uncharacteristic peak in April, although TP increases in July to 59 ug/l. The lowest average occurs in 1998 with a characteristic distribution of TP rising until mid-summer, then slightly decreasing in the fall. In 1999, TP concentration remains fairly consistent throughout the sampling season with a slight peak in July. Again, 2000 shows the characteristics of shallow lake systems with TP increasing into the summer and fall months with decreasing concentration occurring late in the year. In 2001, the highest TP concentration are in June and July and sustaining high concentration well into November. Also in 2001, TP is roughly the highest throughout the year. TP concentrations steadily rose in 1999 to 2001, especially considering 2001 where July TP was 66 ug/l and the year average is 58 ug/l. This steady increase especially can be seen in the July data where TP consistently rose each year with the exception of 1998. Winter months show the least amount of TP concentration. A slow rise of TP occurs in early spring through the summer with a peak in July then levels decrease in the fall as seem in 1998, although another pattern occurs as in 1996, where TP concentrations change little throughout the year. The monthly averages show TP concentrations are lowest in January with increasing concentrations until a peak in July then a gradual decrease of TP in the fall. In general, April through June TP concentrations were lower than the concentrations in the fall months (August through October).



Lake Wingra 2000 Total Phosphorus (TP)
Trophic Classification adapted from Carlson 1977

A typical trend of Total Phosphorus concentrations in Lake Wingra was shown in 2000. This is representative of a shallow lake where TP concentration rises during the summer months. This is in contrast to deeper lakes, which becomes stratified by differences in temperature during the summer months. Temperature stratification causes nutrients to be isolated in the upper warm layer of a lake, causing a limitation of TP during the summer. A shallow lake as exemplified in lake Wingra has little difference in temperature throughout the water column, thus a frequent mixing of nutrients will occur in the summer. Also shown is the distribution of TP that is related to a trophic classification. It is quite clear with these TP concentrations the lake is very eutrophic and likely at times to be hypereutrophic. It has been found that when TP concentrations exceed 20 ug/l, lakes become candidates to experience algal blooms and a restriction in its recreational uses. Lake Wingra definitely exceeds this probability and has very turbid waters throughout the summer.

RESULTS TROPHIC STATE INDEX (1997-2001)

AVERAGE TROPHIC STATE INDEX (1997-2001)

Lake Wingra Trophic State Index (TSI) for the three parameters fall under the trophic category; eutrophic (Table 1) with the TSI values > 53. Frequently TSI for the different parameters are under the upper level of eutrophic class with a TSI > 60. While all the parameters indicate the lake is eutrophic, TSI (SD) averages are higher than TSI (CHL) with the exception of 2000, although this difference is minimal (2 TSI). It than appears TSI (TP) shows the lowest values with the exception of 2001 (Figure 1). The largest difference occurs in 2001 between TSI (SD) and TSI (CHL) followed by the difference in TSI between CHL and TP (-8). Overall, the discrepancy between the TSI of the parameters are not large enough to change the trophic classification. In addition in the development of TSI the variables did not have a perfect correlation consequently small variance would not be rare.

Table 1. Lake Wingra Average Trophic State Index (TSI)

	TSI (SD)	**TSI (Chl a)**	**TSI (TP)**	**TSI(CHL) - TSI(SD)**	**TSI(CHL A) - TSI(TP)**
1996	60	N/A	56		
1997	68	60	59	-7.6	1
1998	64	61	54	-3.2	7
1999	66	61	60	-5.0	1
2000	63	65	59	2.0	6
2001	69	55	63	-14.4	-8

AVERAGE TROPHIC STATE INDEX

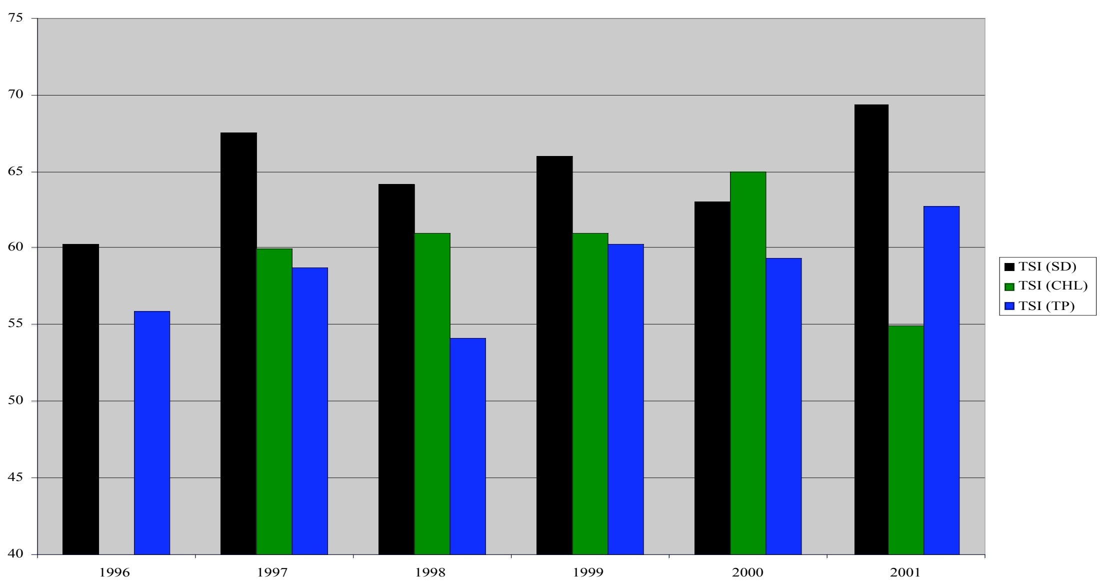


Figure 1. Lake Wingra TSI average for Secchi Disc (SD) depth, Chlorophyll *a* (CHL), and Total Phosphorus (TP)

Overall the discrepancy between the TSI of the parameters are not large enough to change the trophic classification, although they provide insight to the composition of the constituents in the lake. Given that the TSI for SD > CHL > TP show that CHL is not the only factor contributing to higher SD. In the case of Lake Wingra with its high input from stormwater and shallow nature, sediment in the water column is the most likely candidate to contribute to the higher TSI (SD).

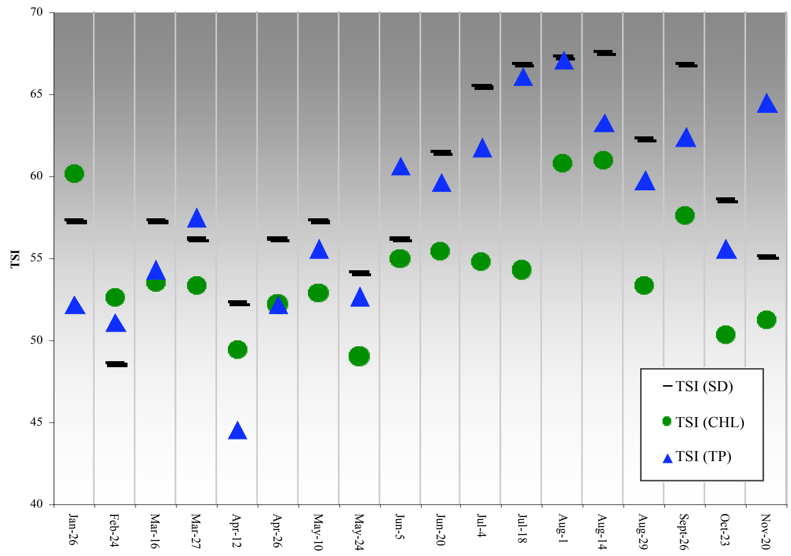


Figure 2. Lake Wingra Trophic State Index in 2000 Carlson (1997).

Table 2.

TSI(CHL) - TSI(SD)	TSI(CHL A) - TSI(TP)	TSI(TP)- TSI(SD)
3	8	-5
4	1	3
-3	-2	-1
-3	-3	0
-5	-3	-2
-4	-6	2
-9	-7	-2
-7	-6	-1
-9	-6	-3
-8	-6	-2
-4	-5	1

A different relationship appears when examining TSI of the three parameters at each sampling point in 2000 (Figure 2), which is common due to annual differences in the parameters composition. Here again, TSI (SD) is highest, in most cases, followed by TSI (TP). Lastly, the TSI (CHL) has the lowest values. The relationship between TSI (SD) and TSI (TP) is very close (Table 3). Again, the difference for most observations does not change the TSI related category of eutrophy. Although a TSI for Lake Wingra calculated from SD will consistently be higher than if the other parameters were used. The foundation of the development of TSI is to predict algal biomass, thus TSI (CHL) should be given priority as the index number. Although TSI (CHL) does not include the presence of macrophytes and will underestimate TSI for macrophyte dominate lakes. In lakes high in sediment TSI (SD) and TSI (TP) are known to have a close relationship, which appears to be the case in Lake Wingra. Phosphorus attached to clay particles would be unavailable to algae yet affect water clarity. In addition, this phosphorus-laden sediment can be later transformed to an available form of phosphorus under anoxic conditions.

APPENDIX I

REFERENCES

Carlson, R. E. 1977. A trophic state index for lakes. Limnology and Oceanography. 22(2): 361-369.

INTERNET LINKS

Friends of Lake Wingra (FOLW)
http://danenet.danenet.org/fowingra/index.html

Great North American Secchi Dip-I, Department of Biological Sciences, Kent State University, Kent OH 44242
http://dipin.kent.edu/tsi.htm

Lillee, R. A. and J.W. Madon. 1983 Limnological characteristics of Wisconsin Lakes. Wisconsin Department of Natural Resources Technical Bulletin. 138, Madison.
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SUGGESTED READINGS

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DATA SOURCES

Chlorophyll *a*
Chlorophyll – Madison Lakes Area. North Temperate Lakes Long Term Ecological Research program (http://lter.limnology.wisc.edu), NSF, contact person: Timothy K. Kratz; Trout Lake Station, WI.

Secchi Disc Depth
Secchi Disc Depth. North Temperate Lakes Long Term Ecological Research program (http://lter.limnology.wisc.edu), NSF, contact person: Timothy K. Kratz; Trout Lake Station, WI.

Total Phosphorus
Nutrients. North Temperate Lakes Long Term Ecological Research program (http://lter.limnology.wisc.edu), NSF, contact person: Emily H. Stanley, Center for Limnology, University of Wisconsin-Madison, WI.