Final

FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION
Division of Environmental Assessment and Restoration,
Bureau of Watershed Restoration
SOUTHWEST DISTRICT • TAMPA BAY BASIN

TMDL Report

Nutrients
For
Bellows Lake (WBID 1579A)

Douglas Gilbert

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Acknowledgments

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Editorial assistance provided by Jan Mandrup-Poulsen, Moira Rojas and Linda Lord.

For additional information on the watershed management approach and impaired waters in the Tampa Bay Basin, contact:

Terry Hansen
Florida Department of Environmental Protection
Bureau of Watershed Restoration
Watershed Planning and Coordination Section
2600 Blair Stone Road, Mail Station 3565
Tallahassee, FL 32399-2400
Email: terry.hansen@dep.state.fl.us
Phone: (850) 245–8561
Fax: (850) 245–8434

Access to all data used in the development of this report can be obtained by contacting:

Douglas Gilbert
Florida Department of Environmental Protection
Bureau of Watershed Restoration
Watershed Evaluation and TMDL Section
2600 Blair Stone Road, Mail Station 3555
Tallahassee, FL 32399-2400
Email: douglas.gilbert@dep.state.fl.us
Phone: (850) 245–8450
Fax: (850) 245–8536

Kevin Petrus, Environmental Manager
Florida Department of Environmental Protection
Bureau of Watershed Restoration
Watershed Evaluation and TMDL Section
2600 Blair Stone Road, Mail Station 3555
Tallahassee, FL 32399-2400
Email: Kevin.Petrus@dep.state.fl.us
Phone: (850) 245–8459
Fax: (850) 245–8444

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Web sites

Florida Department of Environmental Protection, Bureau of Watershed Restoration

TMDL Program

http://www.dep.state.fl.us/water/tmdl/index.htm

Identification of Impaired Surface Waters Rule

http://www.dep.state.fl.us/legal/Rules/shared/62-303/62-303.pdf

STORET Program

http://www.dep.state.fl.us/water/storet/index.htm

2012 Integrated Report

http://www.dep.state.fl.us/water/docs/2012_integrated_report.pdf

Criteria for Surface Water Quality Classifications

http://www.dep.state.fl.us/water/wqssp/classes.htm

Basin Status Report for the Tampa Bay Basin

http://waterwebprod.dep.state.fl.us/basin411/tampa/status/TAMPA_BAY.pdf

Basin Water Quality Assessment Report for the Tampa Bay Basin

http://waterwebprod.dep.state.fl.us/basin411/tampa/assessment/Tampa-Bay-WEBX.pdf

U.S. Environmental Protection Agency

Region 4: Total Maximum Daily Loads in Florida

http://www.epa.gov/region4/water/tmdl/florida/

National STORET Program

http://www.epa.gov/storet/

Chapter 1: INTRODUCTION

1.1 Purpose of Report

This report presents the Total Maximum Daily Load (TMDL) for nutrients in Bellows Lake (WBID 1579A) in the Tampa Bay Basin. Bellows Lake was verified as impaired for nutrients due to elevated Trophic State Index (TSI) and therefore was included on the Verified List of impaired waters for the Tampa Bay Basin that was adopted by Secretarial Order on June 3, 2008. This TMDL establishes the allowable loadings to Bellows Lake that would restore the waterbody so that it meets the applicable water quality criteria for nutrients.

1.2 Identification of Waterbody

Bellows Lake is one of 39 waterbody segments in the Tampa Bay Basin, Coastal Hillsborough Bay Tributary Unit. It was verified as impaired for nutrients during the Cycle 2 verification period (January 1, 2000, through June 30, 2007).

There is some question as to the actual identification (name) of the affected waterbodies. The name “Bellows” is the name associated with the impaired waterbodies in the FDEP database and geographic information system (GIS). However, Hillsborough County (County) documents refer to the lake as East Lake (Lake). The civic association that participates in LAKEWATCH data collection is the East Lake Park Civic Association. The park located along the shore of the lake is called East Lake Park. The County Stormwater Management Master Plan is for the East Lake Area. From this point forward in the document, Bellows Lake will be referred to as either East Lake or Lake. East Lake is located in Central Hillsborough County (**Figure 1.1**). The watershed is primarily urban and drains to the Tampa By-Pass Canal and then to Tampa Bay. The basin is generally bounded on the north by the Harney Canal, to the east by the Tampa By-Pass Canal, along the south side by Columbus Drive, and the west side by the C.S.X. Railroad and 50th/56th Street. Information about this waterbody is available in the Basin Status Report for the Tampa Bay Basin (Florida Department of Environmental Protection [Department], 2003). Significant additional information is contained in the “East Lake Area Stormwater Management Master Plan” (Plan) published by the County (September 1999). The Plan provides detailed information on soils, land uses (current and future), water routing through more than 200 subbasins and the calculation of water budgets and loadings for various future scenarios possible within the East Lake Area. Copies of this report can be obtained from the Hillsborough County website:

ftp://ftp.hillsboroughcounty.org/pwe/pub/masterplan/East_lake/

Historic land survey information suggests that the lake is a man-made feature. Imagery of the 1845 to 1879 U.S. General Land Office survey of the area does not indicate the presence of the lake. The land survey imagery is available at the following Hillsborough County Water Atlas website:

http://maps.wateratlas.usf.edu/hillsborough/

The lake is approximately 98 acres in size and receives drainage from 1,127 acres. The Lake is up to 8 feet deep, with a mean depth of 5.45 ft and an annual average volume of 536 acre-feet. Outflow from the lake is controlled by two non-adjustable control structures in the southeast corner of the lake. A small island (0.79 acres) is located in the northeast corner of the lake (**Figures 1.2 and 1.3**). The island was either created by spoil from the creation of the two arms of the lake (**Figure 1.2**) or was a remnant upland site left after the two arms were created. This island (called Bird Island in the Plan) is reported to be owned by the Tampa Audubon Society.

For assessment purposes, the Department has divided the Tampa Bay Basin into water assessment polygons with a unique **w**ater**b**ody **id**entification (WBID) number for each watershed or stream reach. East Lake is assigned to WBID 1579A (**Figure 1.2**). **Figure 1.4** depicts the watershed for the East Lake Area as contained in the Plan. From this figure, it can be seen that the actual watershed drains a larger area than is represented by the WBID.

1.3 Background

This report was developed as part of the Department's watershed management approach for restoring and protecting state waters and addressing TMDL Program requirements. The watershed approach, which is implemented using a cyclical management process that rotates through the state's 52 river basins over a 5-year cycle, provides a framework for implementing the TMDL Program–related requirements of the 1972 federal Clean Water Act and the 1999 Florida Watershed Restoration Act (FWRA) (Chapter 99-223, Laws of Florida).

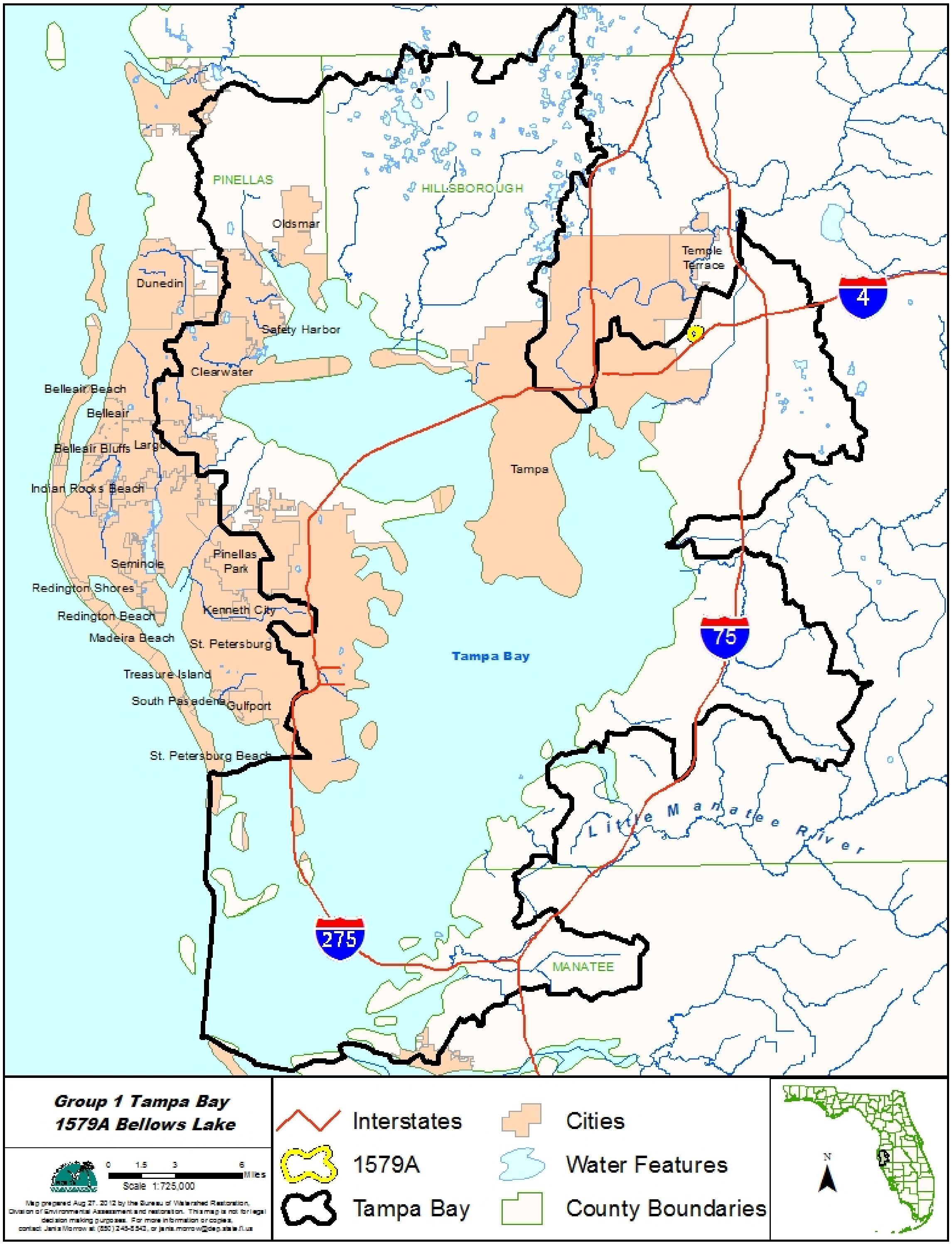
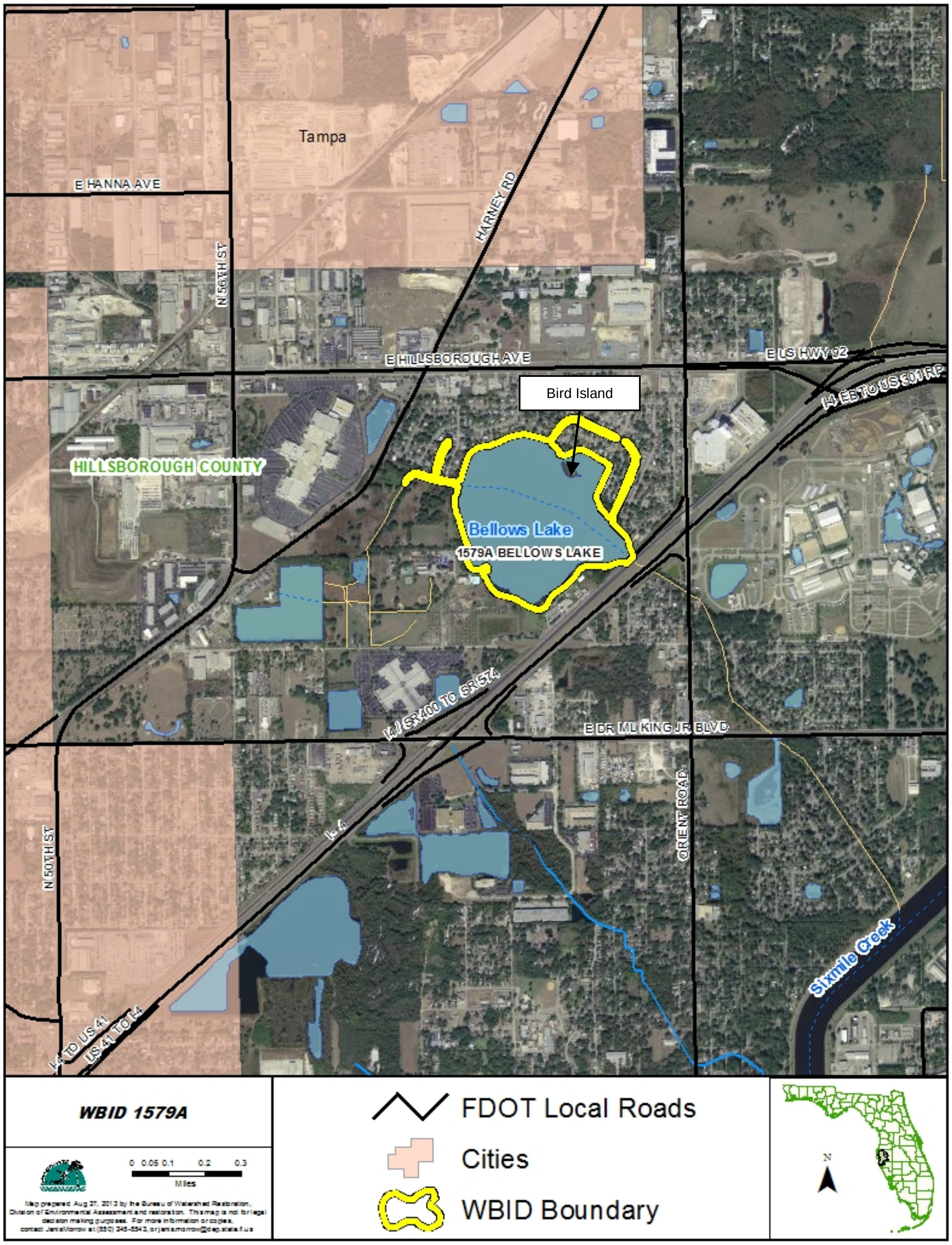


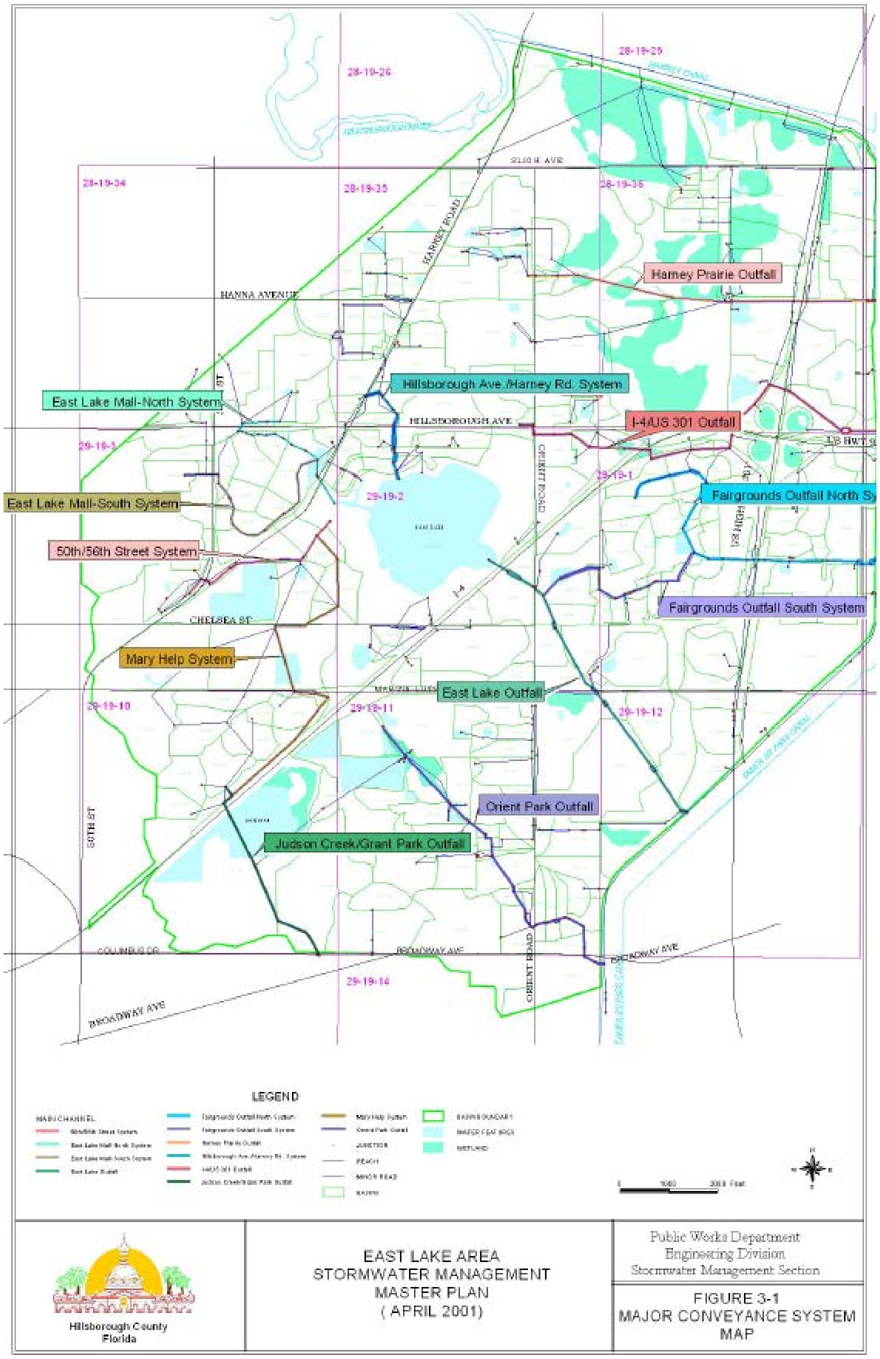
Figure 1.1. Location of the East (Bellows) Lake WBID in Hillsborough County and Major Geopolitical Features in the Area



Note: *FDOT local roads are for illustration purposes only and are not meant to depict roadways for which FDOT is responsible.*

Figure 1.2. Location of the East (Bellows) Lake WBID (1579A) boundary and Bird Island

Figure 1.3. Bird Island (~0.8 acres) within East Lake (WBID 1579A)



* From the Plan

Figure 1.4. Location of Drainage Network and Model Catchments in the East Lake Area

A TMDL represents the maximum amount of a given pollutant that a waterbody can assimilate and still meet water quality standards, including its applicable water quality criteria and its designated uses. TMDLs are developed for waterbodies that are verified as not meeting their water quality standards. They provide important water quality restoration goals that will guide restoration activities.

This TMDL Report will be followed by the development and implementation of a restoration plan to reduce the amount of nutrients that caused the verified impairment of East Lake. These activities will depend heavily on the active participation of the Southwest Florida Water Management District (SWFWMD), Hillsborough County, local governments, businesses, and other stakeholders. The Department will work with these organizations and individuals to undertake or continue reductions in the discharge of pollutants and achieve the established TMDL for the impaired waterbody.

Chapter 2: DESCRIPTION OF WATER QUALITY PROBLEM

2.1 Statutory Requirements and Rulemaking History

Section 303(d) of the federal Clean Water Act requires states to submit to the U.S. Environmental Protection Agency (EPA) lists of surface waters that do not meet applicable water quality standards (impaired waters) and establish a TMDL for each pollutant causing impairment of listed waters on a schedule. The Department has developed such lists, commonly referred to as 303(d) lists, since 1992. The list of impaired waters in each basin, referred to as the Verified List, is also required by the FWRA (Subsection 403.067[4], Florida Statutes [F.S.]); the state's 303(d) list is amended annually to include basin updates.

Florida's 1998 303(d) list included 47 waterbodies in the Tampa Bay Basin. As a result of the resegmentation process for the Group 1 Basins, there are currently 59 Consent Decree waterbody segments in the Tampa Bay Basin. However, the FWRA (Section 403.067, F.S.) stated that all previous Florida 303(d) lists were for planning purposes only and directed the Department to develop, and adopt by rule, a new science-based methodology to identify impaired waters. After a long rulemaking process, the Environmental Regulation Commission adopted the new methodology as Rule 62-303, Florida Administrative Code (F.A.C.) (Identification of Impaired Surface Waters Rule, or IWR), in April 2001; the rule was modified in 2006 and 2007.

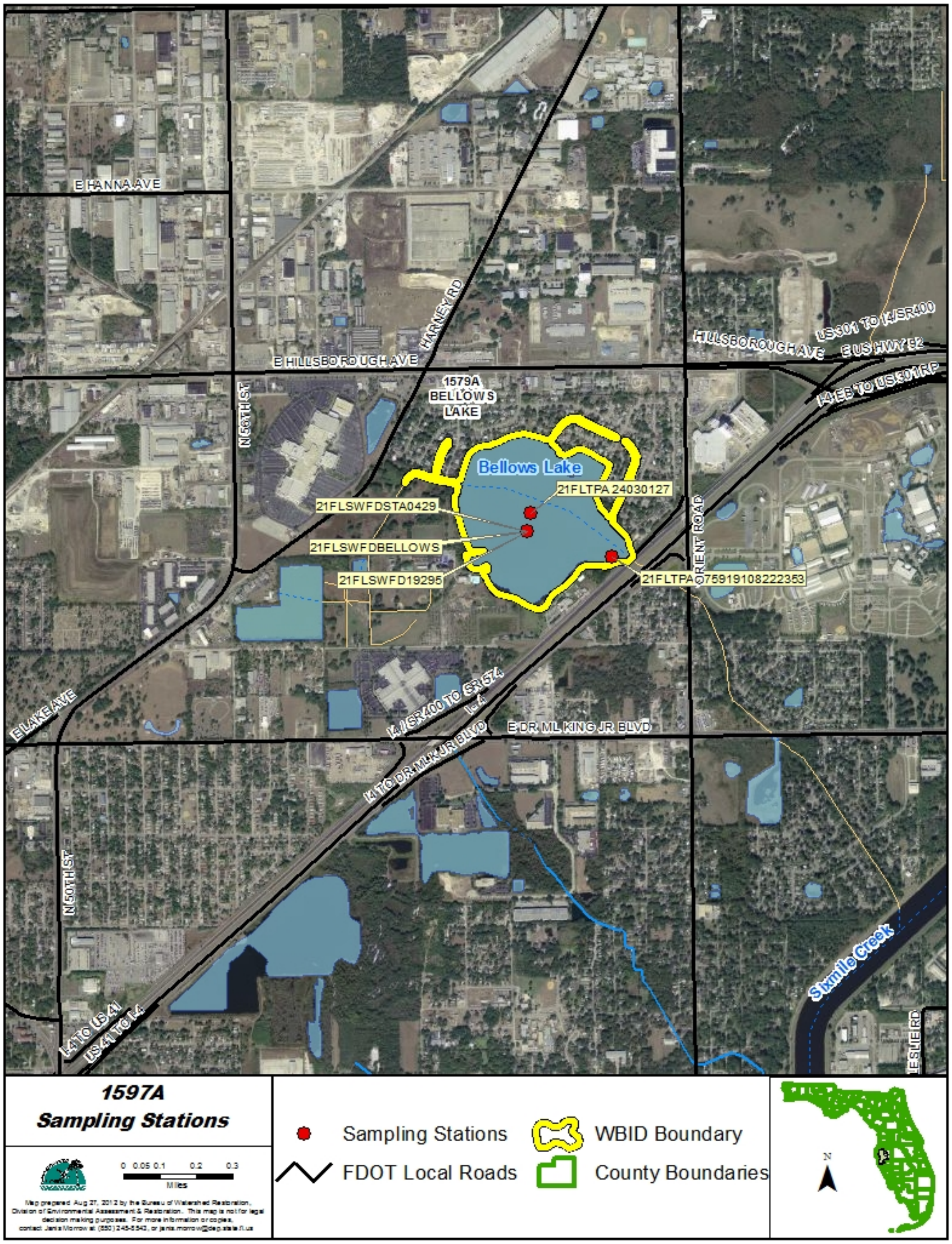
2.2 Information on Verified Impairment

The verified impairments were based on data collected by the Southwest Florida Water Management District and the DEP Southwest District. The WBID location and the STORET stations are shown in **Figure 2.1** and listed in **Table 2.1.**

Table 2.1. Stations Where Water Quality Samples Were Collected during the Cycle 2 Verified Period (January 1, 2000, through June 30, 2007)

Station ID	Alias	Agency
21FLSWFD19295	SWFWMD-1	Southwest Florida Water Management District
21FLSWFDBELLOWS	SWFWMD-2	Southwest Florida Water Management District
21FLSWFDSTA0429	SWFWMD-3	Southwest Florida Water Management District
21FLTPA 24030127	TPA-C	FDEP Southwest District
21FLTPA 275919108222353	TPA-O	FDEP Southwest District

The Department used the IWR to assess water quality impairments in the East Lake watershed and verified the impairment during the second cycle of the TMDL program. **Table 2.2** summarizes the cause of impairment based on water quality data collected during the verification period (January 1, 2000, through June 30, 2007).



Note: *FDOT local roads are for illustration purposes only and are not meant to depict roadways for which FDOT is responsible.*

Figure 2.1 Location of Water Quality and Flow Stations for East (Bellows) Lake WBID 1579A

Table 2.2.Verified Impairments for East Lake (WBID 1579A)

WBID	Waterbody Segment	Waterbody Type	Waterbody Class	1998 303(d) Parameters of Concern	Parameter Causing Impairment
1579A	East Lake	Fresh	III	N/A	TSI = 70.3

*NA – Not applicable

Annual average concentrations for the year of impairment (2006) corrected chlorophyll a (CChl a), 50.79 micrograms/liter (µg/L), total nitrogen (TN) 2.13 milligrams/liter (mg/L), and total phosphorus (TP) of 0.082 mg/L resulted in a trophic state index (TSI) of 70.3.

The TSI is calculated based on concentrations of TP, TN, and corrected chlorophyll a (Chl a) as follows:

$CHLA_{TSI} = 16.8 + 14.4 * LN(Chl\ a)$ Chl *a* in µg/L
$TN_{TSI} = 56 + 19.8 * LN(N)$ N in mg/L
$TN2_{TSI} = 10 * [5.96 + 2.15 * LN(N + 0.0001)]$
$TP_{TSI} = 18.6 * LN(P * 1000) – 18.4$ P in mg/L
$TP2_{TSI} = 10 * [2.36 * LN(P * 1000) – 2.38]$

If $N/P > 30$, *then* $NUTR_{TSI} = TP2_{TSI}$
If $N/P < 10$, *then* $NUTR_{TSI} = TN2_{TSI}$
if $10 < N/P < 30$, *then* $NUTR_{TSI} = (TP_{TSI} + TN_{TSI})/2$

$TSI = (CHLA_{TSI} + NUTR_{TSI})/2$ (TSI has no units)

Rainfall:

Rainfall data for the period 1992 through 2007 was obtained for the NOAA station closest to East Lake. This station is located within the City of Tampa at the Tampa International Airport (TIA), about 9.2 miles west of East Lake. **Figure 2.2** depicts the daily rainfall for this period.

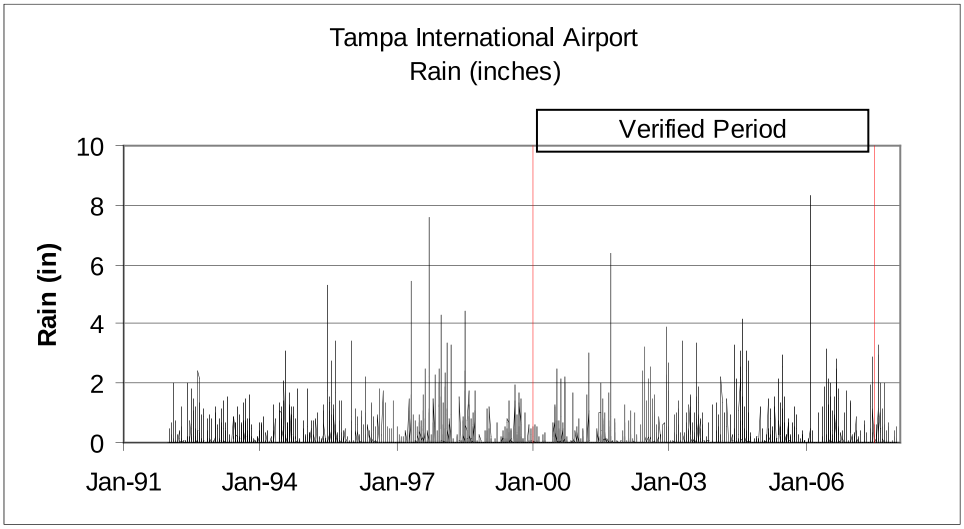


Figure 2.2 Daily Rainfall (inches) 1992-2007

Table 2.3 and **Figure 2.3** depict the annual average rainfall from 1992 through 2007. Based on this period of record (POR), the annual average is 47.6 inches. This is slightly less than the long -term annual average at this gage of 52 inches/year. During the verified period, the years 2000 (29.9 in), 2001 (39.8 in), and 2005 (39.0 in) had lower than average rainfall, with 2000 as the least rainfall in the POR. The years 2002 (wettest year, 62.1 in), 2004 (59.6 in), and 2006 (56.6 in) were wetter than average. Therefore, the verified period contained a good mix of wet and dry conditions.

From **Figure 2.3**, it can be seen that the first year of the verified period (2000) was at the end of three years of declining rainfall. The year 2002 (at 62.1 inches of rain) was the wettest year in the verified period.

Table 2.3 Annual Average Rainfall at TIA

Year	Rain (inches)
1992	35.0
1993	37.5
1994	47.2
1995	54.1
1996	49.4
1997	67.7
1998	55.4
1999	34.3
2000	29.9
2001	39.8
2002	62.1
2003	52.0
2004	59.3
2005	39.0
2006	56.6
2007	42.0
All Data Average	47.6
VP+ Data Average	47.6

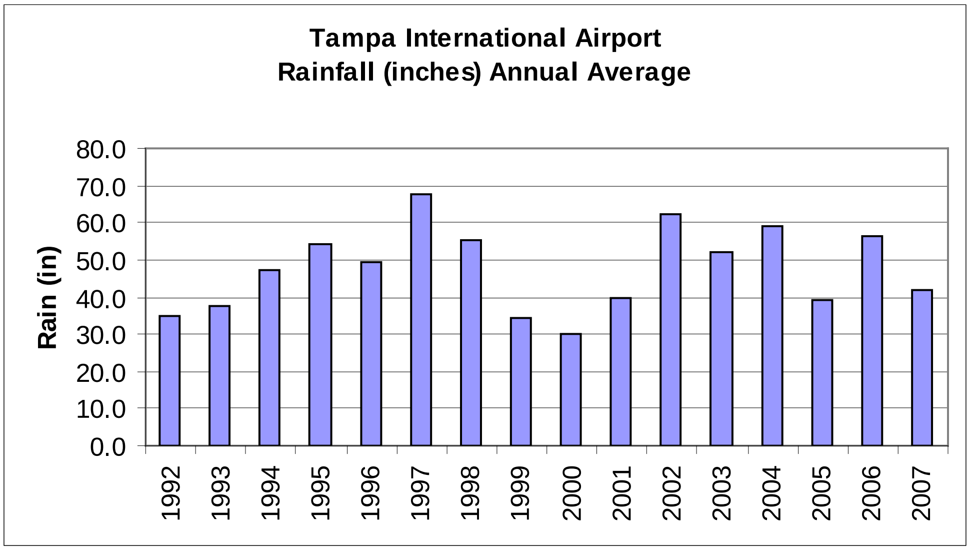


Figure 2.3 Annual Average Rainfall

Table 2.4 and **Figure 2.4** present the monthly average rainfall. It is clear from these data that June, July, August, and September are much wetter than other months of the year and the wet season was wetter and the dry season drier during the verified period than for the POR.

Table 2.4 Monthly Average Rainfall

Month	All Data Rain (in)	VP+ Rain (in)
Jan	2.4	1.5
Feb	2.9	3.0
Mar	2.3	2.1
Apr	2.5	1.8
May	1.3	1.3
Jun	7.4	9.4
Jul	6.8	7.0
Aug	8.3	8.5
Sep	6.8	7.0
Oct	2.4	1.7
Nov	1.2	1.2
Dec	3.1	3.1
Average	4.0	4.0

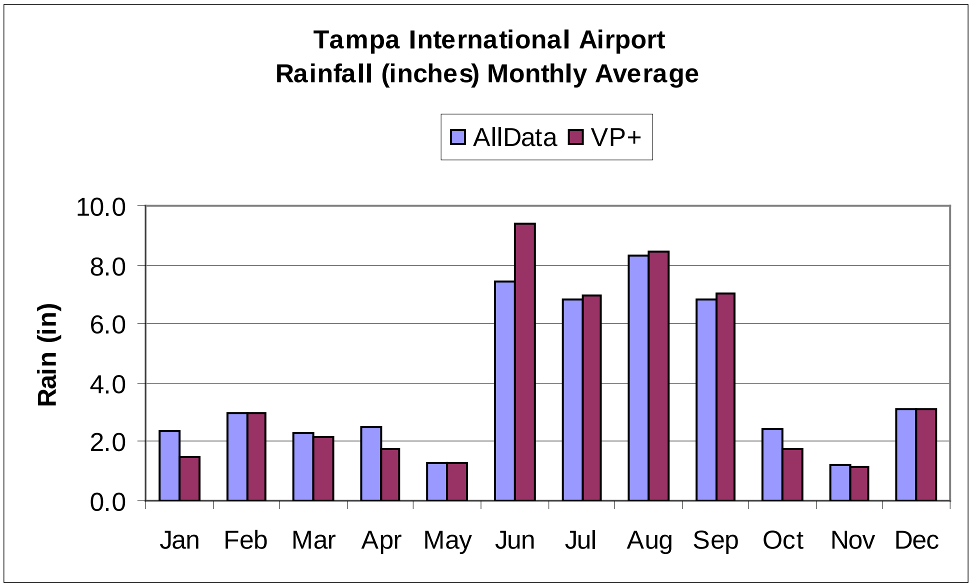


Figure 2.4 Monthly Average Rainfall

Color:

Table 2.5 and **Figure 2.5** depict the lake data for color. From these data (excluding data for true color) the color in the lake varies between 60 and 80 PCU, with an average of 69.6 PCU.

Table 2.5 Color East Lake (1579A)

East Lake Color (PCU)	Period of Record	Count	Min	25th Percentile	Average (a)	Median	75th Percentile	Max
All Data	7/95, 1/96, 8/01, 2/06-11/06, 2/07	28	15.0	55.0	58.4	60.0	80.0	80.0
All Data-Verified Period (a)	8/01, 2/06-11/06, 2/07	26	15.0	60.0	61.3	60.0	80.0	80.0
SWFWMD-1 *	2/06, 8/06, 2/07	4	20.0	27.5	30.0	30.0	32.5	40.0
SWFWMD-2 *	8/01	1	15.0	15.0	15.0	15.0	15.0	15.0
SWFWMD-3 *	7/95, 1/96	2	20.0	20.0	20.0	20.0	20.0	20.0
TPA-C	2/06 - 11/06	11	60.0	60.0	68.2	60.0	80.0	80.0
TPA-O	2/06 - 11/06	10	60.0	60.0	71.0	75.0	80.0	80.0

* True Color (filtered sample)
(a) Straight arithmetic average

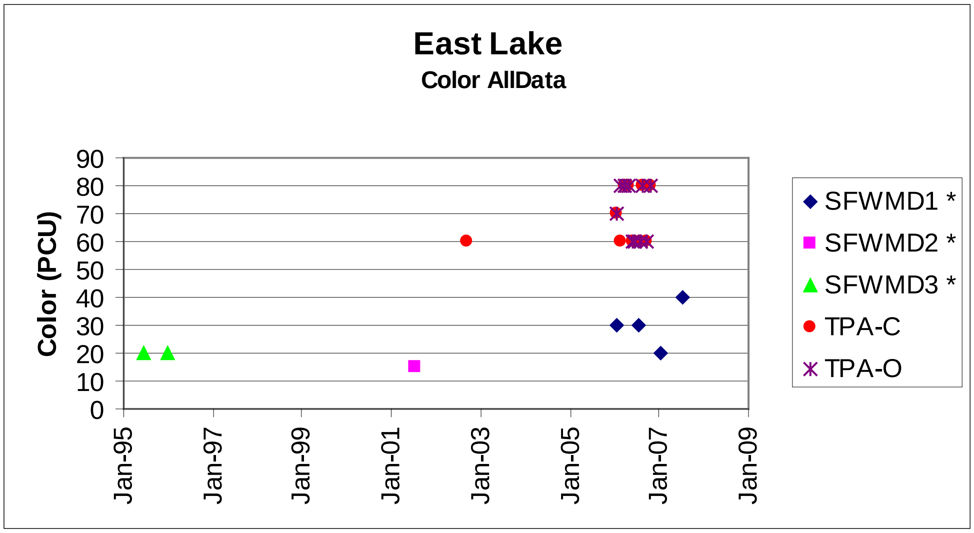


Figure 2.5 Color All Data East Lake

* = True (filtered) color

Dissolved Oxygen:

Table 2.6 and **Figure 2.6** depict the lake data for DO. From these data, the DO in the lake varies between < 1.0 mg/L and 13.9 mg/L, with an average during the verified period (VP) of 9.26 mg/L. DO is generally higher at the station in the middle of the lake as opposed to near the outlet.

Table 2.6 Dissolved Oxygen East Lake (1579A)

East Lake Dissolved Oxygen (mg/L)	Period of Record	Count	Minimum	25th Percentile	Average (a)	Median	75th Percentile	Maximum
All Data	7/95, 1/96, 8/01, 2/06-12/06,2/07	31	0.66	8.22	9.33	9.81	10.56	13.90
All Data-Verified Period (a)	8/01, 2/06-12/06, 2/07	27	0.66	7.97	9.26	9.81	10.49	13.90
SWFWMD-1	2/06, 8/06, 2/07, 8/07	7	0.66	9.61	8.94	9.96	10.45	11.81
SWFWMD-2	8/01	1	11.19	11.19	11.19	11.19	11.19	11.19
SWFWMD-3	7/95, 1/96	4	8.15	8.25	9.77	9.78	11.30	11.35
TPA-C	2/06 - 12/06	8	7.40	9.02	10.00	9.99	10.48	13.90
TPA-O	2/06 - 12/06	11	6.41	7.20	8.76	8.96	9.91	12.95

(a) Straight arithmetic average

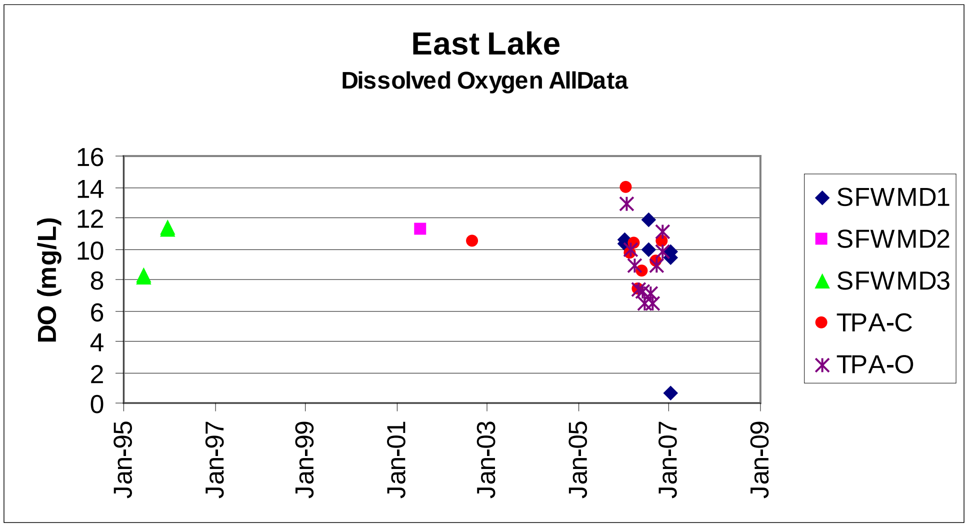


Figure 2.6 Dissolved Oxygen All Data East Lake

The data in **Table 2.7** and **Figure 2.7** indicate that the monthly average DO is never below 5.0 mg/L in the lake (levels indicate excessive daytime algal respiration throughout the year). Additionally, as can be seen in **Table 2.8**, the DO percent saturation in the lake is greater than 100 percent 75 percent of the time.

Table 2.7 DO Monthly Averages

Month	East Lake All Data Dissolved Oxygen (mg/L)
Jan	11.32
Feb	9.66
Mar	9.79
Apr	9.66
May	7.39
Jun	7.90
Jul	7.62
Aug	10.99
Sep	6.78
Oct	9.55
Nov	9.86
Dec	10.77
Average	9.27

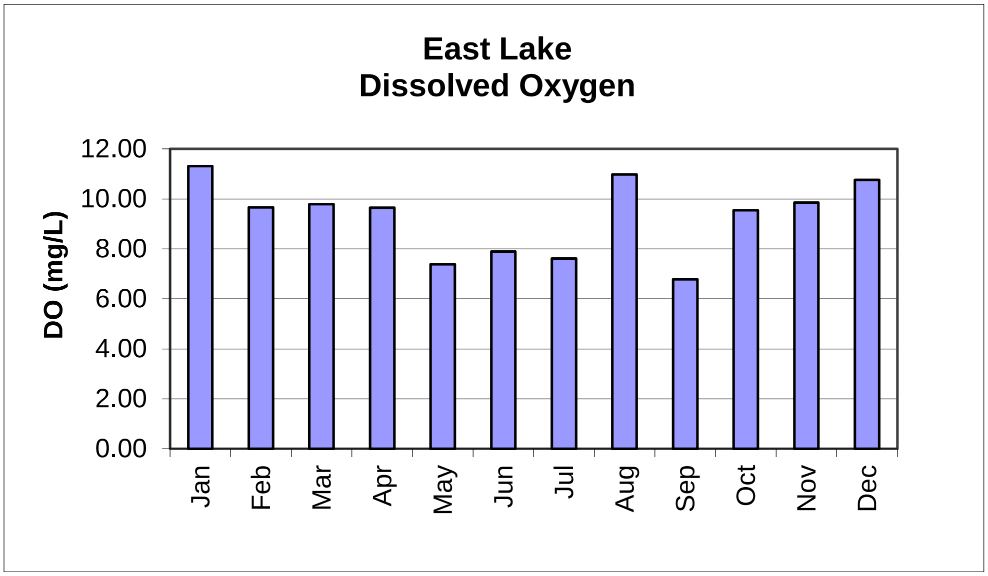


Figure 2.7 Dissolved Oxygen Monthly Average

Table 2.8 DO Percent Saturation in East Lake

DO Saturation (Percent)	Period of Record	Count	Min	25th Percentile	Average	Median	75th Percentile	Max
All Data	7/95, 1/96, 8/01, 2/06-11/06, 2/07	23	83.7	100.7	112.3	110.8	119.8	153.0
All Data-Verified Period (a)	8/01, 2/06-11/06, 2/07	19	83.7	95.2	112.3	110.8	124.4	153.0

Data in **Table 2.9** indicate that the lowest overall DO occurs during the third quarter in both the lake and the stream.

Table 2.9 DO Calendar Quarters and Annual Average

Year	Dissolved Oxygen (mg/L) Q1	Dissolved Oxygen (mg/L) Q2	Dissolved Oxygen (mg/L) Q3	Dissolved Oxygen (mg/L) Q4	Dissolved Oxygen (mg/L) Annual Average
East Lake 2006	10.86	8.31	8.03	9.90	9.28

Chlorophyll A (Chl a):

Table 2.10 and **Figure 2.8** depict the lake data for CChl a. From these data, the CChl a in the lake varies between 4.20 µg/L and 124.2 µg/L, with an average during the verified period (VP) of 52.5 µg/L. CChl a is generally higher at the station located near the outfall from the lake.

Table 2.10 Corrected Chlorophyll a (CChl a) East Lake (1579A)

East Lake CChla (µg/L)	Period of Record	Count	Minimum	25th Percentile	Average (a)	Median	75th Percentile	Maximum
All Data	7/95, 1/96, 8/01, 2/06-12/06,2/07, 8/07	29	4.20	35.00	52.94	53.00	71.00	124.15
All Data-Verified Period (a)	8/01, 2/06-12/06, 2/07, 8/07	27	4.20	33.00	52.52	53.00	70.50	124.15
SWFWMD-1	2/06, 8/06, 2/07, 8/07	4	79.29	79.52	93.88	86.05	100.41	124.15
SWFWMD-2	8/01	1	38.20	38.20	38.20	38.20	38.20	38.20
SWFWMD-3	7/95, 1/96	2	39.02	48.85	58.68	58.68	68.51	78.34
TPA-C	2/06 - 12/06	11	4.20	24.00	41.94	50.00	54.50	78.00
TPA-O	2/06 - 12/06	11	11.00	32.00	49.36	56.00	64.50	78.00

(a) Straight arithmetic average

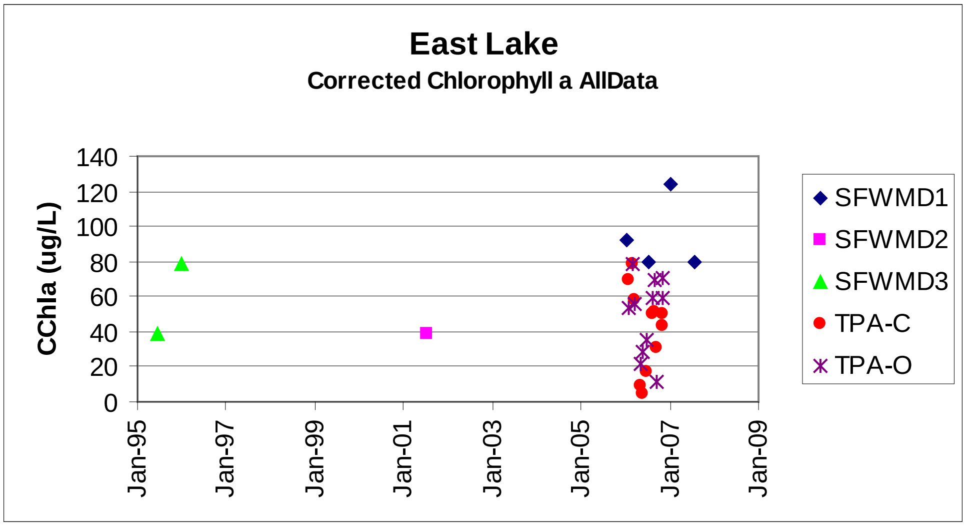


Figure 2.8 Corrected Chlorophyll a All Data East Lake

The limited (one year) data in **Table 2.11** and **Figure 2.9** indicate that monthly average CChl a in this system peaks during spring and drops during the summer.

Table 2.11 Chlorophyll a Monthly Averages

Month	East Lake All Data CChla (µg/L)
Jan	78.34
Feb	84.91
Mar	78.00
Apr	57.00
May	15.55
Jun	16.60
Jul	30.34
Aug	65.70
Sep	57.50
Oct	21.00
Nov	54.50
Dec	57.00
Average	51.37

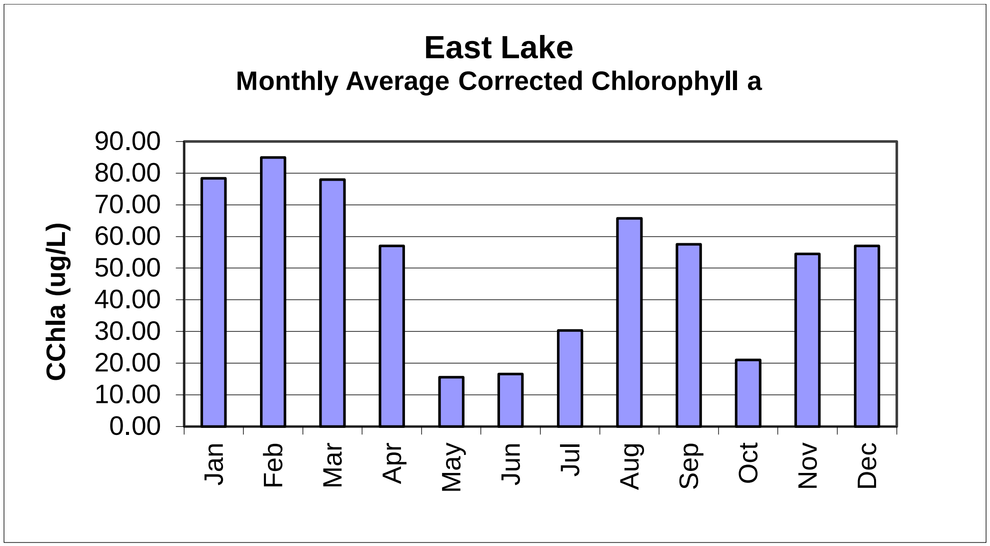


Figure 2.9 Chlorophyll a Monthly Averages

Data in **Table 2.12** indicate that the lake peaks in the first Quarter (January – March).

Table 2.12 Chlorophyll a Calendar Quarter and Annual Average

Year	Chla (µg/L) Q1	Chla (µg/L) Q2	Chla (µg/L) Q3	Chla (µg/L) Q4	Chla (µg/L) Annual Average
East Lake 2006	74.92	29.72	54.37	44.17	50.79

Five Day Biological Oxygen Demand (BOD_5):

Table 2.13 and **Figure 2.10** depict the lake data for BOD_5. From these data, the BOD_5 in the lake varies between 2.80 mg/L and 8.30 mg/L, with an average during the verified period (VP) of 5.50 mg/L. BOD_5 is slightly higher (as is CChl a) at the station located near the outlet from the lake.

Table 2.13 Five Day Biological Oxygen Demand East Lake

East Lake BOD_5 (mg/L)	Period of Record	Count	Minimum	25th Percentile	Average (a)	Median	75th Percentile	Maximum
All Data	8/98, 10/02, 2/06-12/06	24	2.80	4.80	5.60	5.45	6.53	8.30
All Data-Verified Period (a)	10/02, 2/06-12/06	23	2.80	4.80	5.50	5.40	6.25	8.30
SWFWMD-1	ND	0	ND	ND	ND	ND	ND	ND
SWFWMD-2	ND	0	ND	ND	ND	ND	ND	ND
SWFWMD-3	ND	0	ND	ND	ND	ND	ND	ND
TPA-C	8/98, 10/02, 2/06 - 12/06	13	3.10	4.60	5.42	5.20	6.10	8.00
TPA-O	2/06 - 12/06	11	2.80	5.10	5.81	5.50	6.70	8.30

(a) Straight arithmetic average
ND = No data

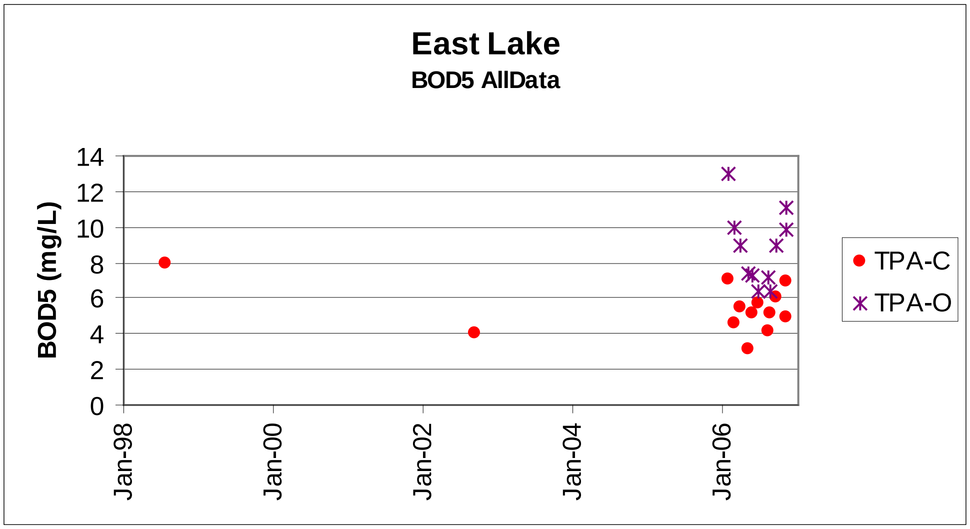


Figure 2.10 BOD₅ All Data East Lake

The limited data (one year) in **Table 2.14** and **Figure 2.11** indicate that monthly average BOD_5 in this system follows the seasonal pattern of CChl a peaking in the first and third quarters of the year.

Table 2.14 BOD₅ Monthly Average

Month	East Lake All Data BOD_5 (mg/L)
Jan	
Feb	7.70
Mar	4.70
Apr	6.45
May	2.95
Jun	5.30
Jul	5.60
Aug	8.00
Sep	5.23
Oct	5.50
Nov	4.85
Dec	6.95
Average	5.79

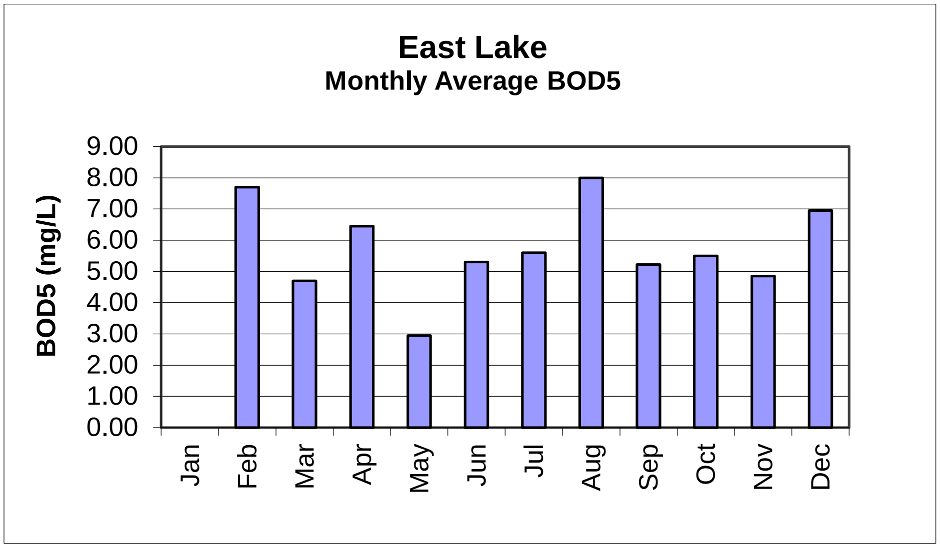


Figure 2.11 BOD_5 Monthly Average

Data in **Table 2.15** indicate that the highest overall BOD_5 occurs during the first and fourth quarters (October-March), as does the CChl a.

Table 2.15 BOD_5 Calendar Quarter and Annual Average

Year	BOD_5 (mg/L) Q1	BOD_5 (mg/L) Q2	BOD_5 (mg/L) Q3	BOD_5 (mg/L) Q4	BOD_5 (mg/L) Annual Average
East Lake 2006	6.20	4.90	5.41	6.02	5.63

Total Nitrogen (TN):

Table 2.16 and **Figure 2.12** depict the lake data for TN. From these data, the TN in the lake varies between 0.64 mg/L and 3.41 mg/L, with an average during the verified period (VP) of 1.85 mg/L. TN is slightly higher (as is CChl a, and BOD_5) at the station located near the outlet from the lake.

Table 2.16 Total Nitrogen East Lake

East Lake TN (mg/L)	Period of Record	Count	Minimum	25th Percentile	Average (a)	Median	75th Percentile	Maximum
All Data	7/95, 1/96, 8/01, 2/06-11/06, 2/07	26	0.64	1.75	2.08	2.10	2.57	3.41
All Data-Verified Period (a)	8/01, 2/06-11/06, 2/07	24	1.11	1.85	2.11	2.10	2.50	3.41
SWFWMD-1	2/06, 8/06, 2/07	3	2.14	2.25	2.40	2.36	2.54	2.71
SWFWMD-2	8/01	1	1.27	1.27	1.27	1.27	1.27	1.27
SWFWMD-3	7/95, 1/96	2	0.64	1.18	1.72	1.72	2.25	2.79
TPA-C	2/06 - 11/06	10	1.11	1.78	2.06	2.05	2.19	3.41
TPA-O	2/06 - 11/06	10	1.20	1.93	2.16	2.05	2.72	2.92

(a) Straight arithmetic average

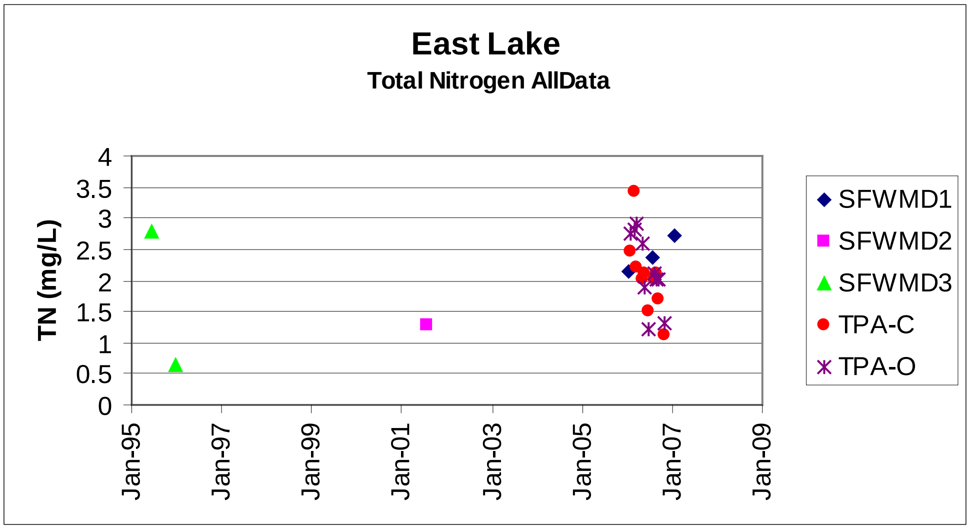


Figure 2.12 Total Nitrogen All Data East Lake

The limited data (one year) in **Table 2.17** and **Figure 2.13** indicate that monthly average TN in this system follows the same pattern peaking in the spring and fall of the year with the seasonal TN in the same less than in the lake except during November.

Table 2.17 TN Monthly Average

Month	East Lake All Data Total Nitrogen (mg/L)
Jan	0.64
Feb	2.52
Mar	3.11
Apr	2.57
May	2.31
Jun	2.00
Jul	1.83
Aug	1.82
Sep	2.05
Oct	1.85
Nov	1.21
Dec	
Average	1.95

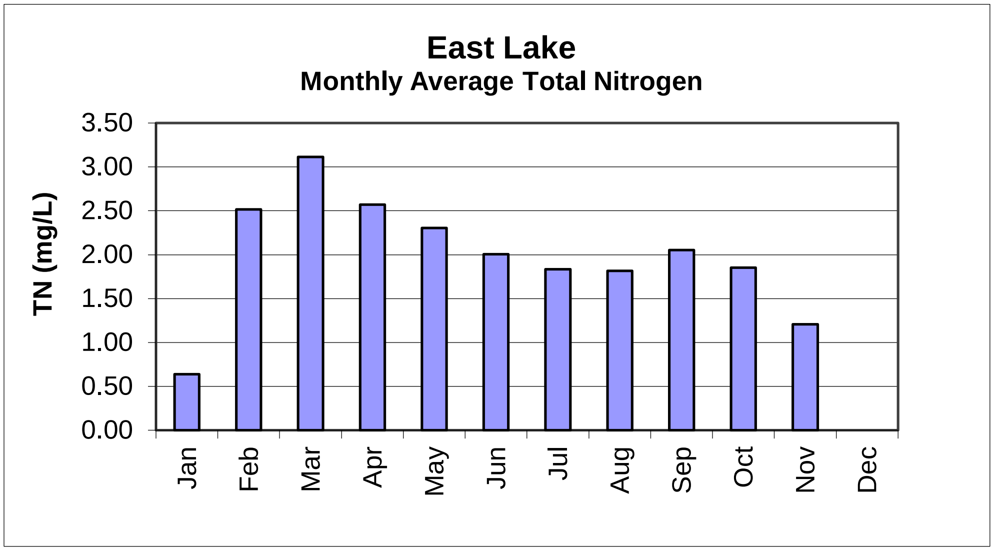


Figure 2.13 Total Nitrogen Monthly Average

Data in **Table 2.18** indicate that the highest overall TN occurs during the first quarter (January-March) in the lake.

Table 2.18 TN Calendar Quarter and Annual Average

Year	Total Nitrogen (mg/L) Q1	Total Nitrogen (mg/L) Q2	Total Nitrogen (mg/L) Q3	Total Nitrogen (mg/L) Q4	Total Nitrogen (mg/L) Annual Average
East Lake 2006	2.78	2.29	1.90	1.53	2.13

Total Phosphorus (TP):

Table 2.19 and **Figure 2.14** depict the lake data for TP. From these data, the TP in the lake varies between 0.005 mg/L and 0.170 mg/L, with an average during the verified period (VP) of 0.082 mg/L. TP is slightly lower (as opposed to CChl a, BOD_5, and TN)) at the station located near the outlet from the lake.

Table 2.19 Total Phosphorus East Lake

East Lake TP (mg/L)	Period of Record	Count	Minimum	25th Percentile	Average (a)	Median	75th Percentile	Maximum
All Data	7/95, 1/96, 8/01, 2/06-11/06, 2/07	26	0.005	0.053	0.081	0.083	0.110	0.170
All Data-Verified Period (a)	8/01, 2/06-11/06, 2/07	24	0.005	0.054	0.082	0.083	0.110	0.170
SWFWMD-1	2/06, 8/06, 2/07	3	0.020	0.024	0.051	0.027	0.066	0.105
SWFWMD-2	8/01	1	0.005	0.005	0.005	0.005	0.005	0.005
SWFWMD-3	7/95, 1/96	2	0.019	0.042	0.065	0.065	0.088	0.111
TPA-C	2/06 - 11/06	10	0.040	0.076	0.086	0.085	0.099	0.130
TPA-O	2/06 - 11/06	10	0.044	0.071	0.095	0.098	0.110	0.170

(a) Straight arithmetic average

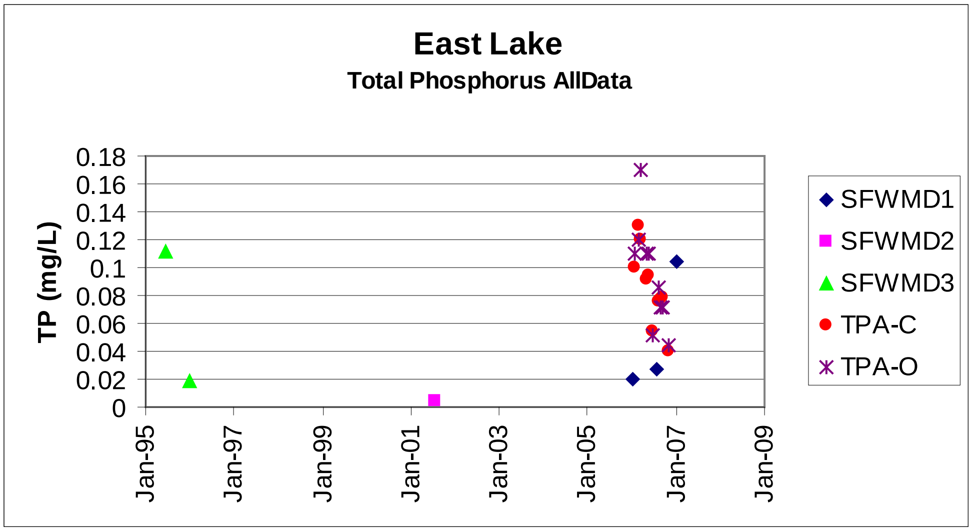


Figure 2.14 Total Phosphorus All Data East Lake

The limited data (one year) in **Table 2.20** and **Figure 2.15** indicate that monthly average TP in this system follows a similar seasonal pattern as TN, peaking in the spring.

Table 2.20 TP Monthly Average

Month	**East Lake All Data Total Phosphorus (mg/L)**
Jan	0.019
Feb	0.084
Mar	0.125
Apr	0.145
May	0.101
Jun	0.103
Jul	0.072
Aug	0.016
Sep	0.078
Oct	0.076
Nov	0.042
Dec	
Average	0.08

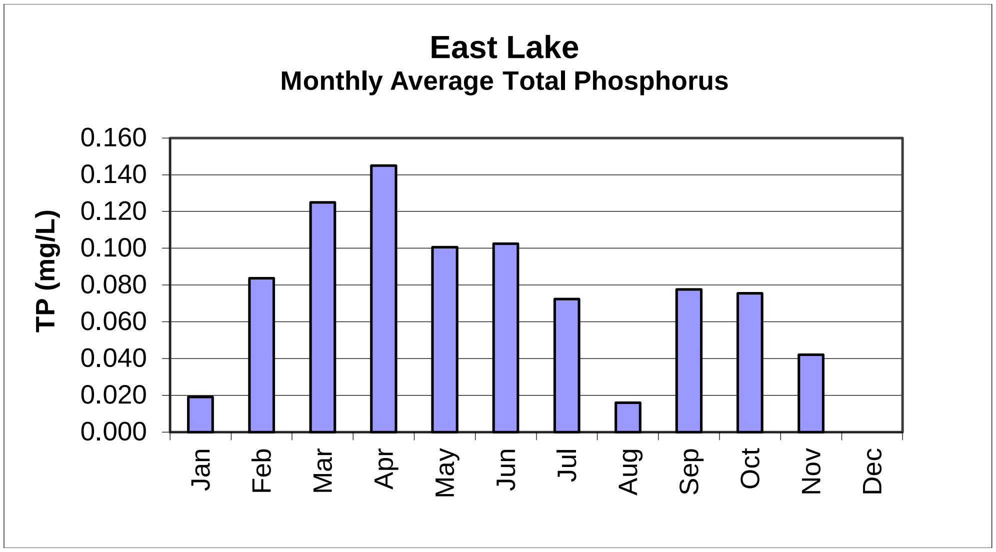


Figure 2.15 Total Phosphorus Monthly Average

Data in **Table 2.21** indicate that the highest overall TP in this system occurs during the second quarter (April-June).

Table 2.21 TP Calendar Quarter and Annual Average

Year	Total Phosphorus (mg/L) Q1	Total Phosphorus (mg/L) Q2	Total Phosphorus (mg/L) Q3	Total Phosphorus (mg/L) Q4	Total Phosphorus (mg/L) Annual Average
East Lake 2006	0.101	0.116	0.053	0.059	0.082

Total Nitrogen to Total Phosphorus Ratio (TN/TP):

Table 2.22 and **Figure 2.22** contain a summary of the information for limiting nutrients for the lake. From these data, the lake would always be co-limited, approaching phosphorus limitation, except for a TN to TP ratio of over 160 in August. Because of the limited data, the high TN/TP value for August brings the average for the entire dataset to phosphorus limitation. The limited data indicate that extreme phosphorus limitation may occur during the late summer and explain the low CChl a during this period.

Table 2.22 TN to TP Ratio

TN/TP Ratio	Period of Record	Count	Minimum	25th Percentile	Average (a)	Median	75th Percentile	Maximum
East Lake	7/95, 1/96, 8/01, 2/06-11/06, 2/07	26	17.2	23.2	39.1	25.5	27.8	254.0

(a) Straight arithmetic average

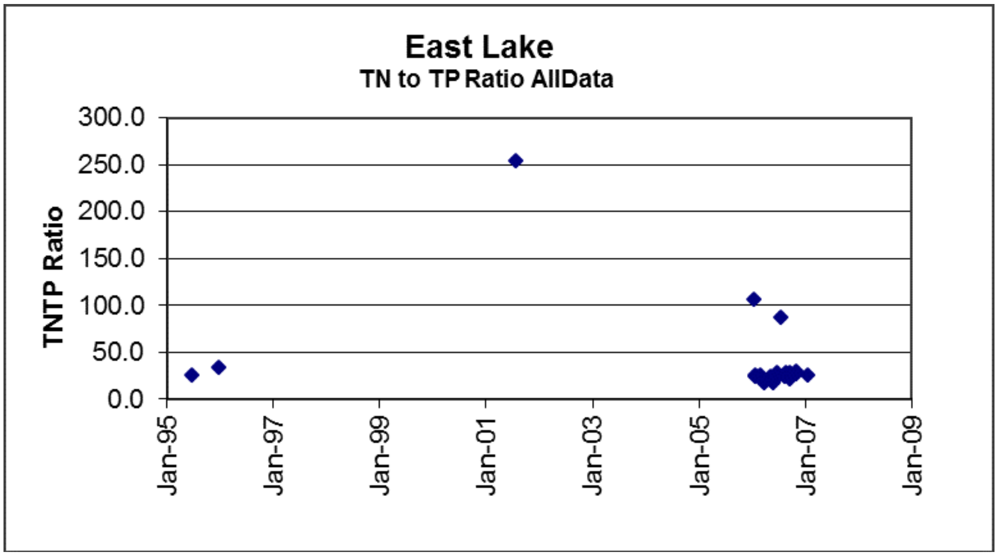


Figure 2.16 Total Nitrogen to Total Phosphorus Ratio

The limited data (one year) in **Tables 2.23** and **2.24,** and **Figure 2.17** indicate that the lake, (while co-limited) is close to phosphorus limitation.

Table 2.23 TN to TP Ratio Monthly Average

Month	East Lake All Data TN/TP Ratio
Jan	33.7
Feb	45.6
Mar	24.8
Apr	17.9
May	22.9
Jun	19.7
Jul	25.4
Aug	170.7
Sep	26.6
Oct	24.7
Nov	28.7
Dec	
Average	39.1

Table 2.24 TN to TP Ratio Calendar Quarter and Annual Average

Year	TN/TP Ratio Q1	TN/TP Ratio Q2	TN/TP Ratio Q3	TN/TP Ratio Q4	TN/TP Ratio Annual Average
East Lake 2006	34.7	20.1	74.2	26.7	38.9

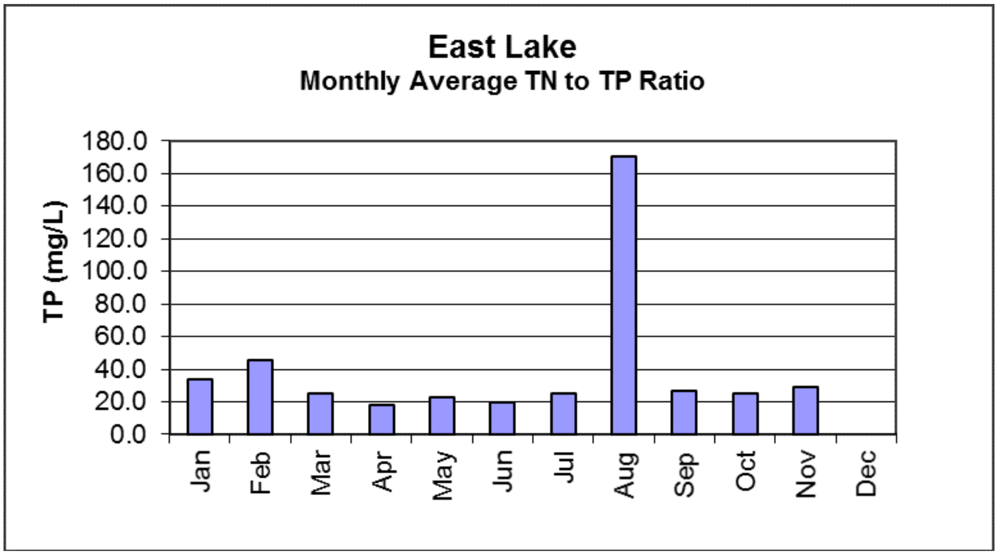


Figure 2.17 TN TP Ratio Monthly Average

Chapter 3. DESCRIPTION OF APPLICABLE WATER QUALITY STANDARDS AND TARGETS

3.1 Classification of the Waterbody and Criteria Applicable to the TMDL

Florida’s surface waters are protected for five designated use classifications, as follows:

Class I	**Potable water supplies**
Class II	**Shellfish propagation or harvesting**
Class III	**Recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife**
Class IV	**Agricultural water supplies**
Class V	**Navigation, utility, and industrial use (there are no state waters currently in this class)**

East Lake is a Class III waterbody, with a designated use of recreation, propagation, and the maintenance of a healthy, well-balanced population of fish and wildlife. The criteria applicable to this TMDL is the Class III fresh water criteria for nutrients.

3.2 Applicable Water Quality Standards and Numeric Water Quality Target

3.3 Narrative Nutrient Criteria Definitions

3.3.1 Chlorophyll a

Chlorophyll, a green pigment found in plants, is an essential component in the process of converting light energy (sunlight) into chemical energy through the process of photosynthesis. In photosynthesis, the energy absorbed by chlorophyll transforms carbon dioxide and water into carbohydrates and oxygen. The chemical energy stored by photosynthesis in carbohydrates drives biochemical reactions in nearly all living organisms. Thus, chlorophyll is at the center of the photosynthetic oxidation-reduction reaction between carbon dioxide and water.

There are several types of chlorophyll; however, the predominant form is chlorophyll *a* (Chl a). The measurement of Chl a in a water sample is a useful indicator of phytoplankton biomass, especially when used in conjunction with an analysis of algal growth potential and species abundance. The greater the abundance of Chl a, typically the greater the abundance of algae. Algae are the primary producers in the aquatic food web, and thus are very important in characterizing the productivity of aquatic systems.

3.3.2 Total Nitrogen as N

TN is the combined measurement of nitrate (NO_3), nitrite (NO_2), ammonia, and organic nitrogen found in water. Nitrogen compounds function as important nutrients for many aquatic organisms and are essential to the chemical processes that exist between land, air, and water. The most readily bioavailable forms of nitrogen are ammonia and nitrate. These compounds, in conjunction with other nutrients, serve as an important base for primary productivity.

The major sources of excessive amounts of nitrogen in surface water are the effluent from municipal treatment plants and runoff from urban and agricultural sites. When nutrient concentrations consistently exceed natural levels, the resulting nutrient imbalance can cause undesirable changes in a waterbody's biological community and drive an aquatic system into an accelerated rate of eutrophication. Usually, the eutrophication process is observed as a change in the structure of the algal community and includes severe algal blooms that may cover large areas for extended periods. Large algal blooms are generally followed by depletion in DO concentrations as a result of algal decomposition.

3.3.3 Total Phosphorus as P

Phosphorus is one of the primary nutrients that regulates algal and macrophyte growth in natural waters, particularly in fresh water. Phosphate, the form in which almost all phosphorus is found in the water column, can enter the aquatic environment in a number of ways. Natural processes transport phosphate to water through atmospheric deposition, ground water percolation, and terrestrial runoff. Municipal treatment plants, industries, agriculture, and domestic activities also contribute to phosphate loading through direct discharge and natural transport mechanisms. The very high levels of phosphorus in some Florida streams and estuaries are usually caused by phosphate mining and fertilizer processing activities.

High phosphorus concentrations are frequently responsible for accelerating the process of eutrophication, or accelerated aging, of a waterbody. Once phosphorus and other important nutrients enter the ecosystem, they are extremely difficult to remove. They become tied up in biomass or deposited in sediments. Nutrients, particularly phosphates, deposited in sediments generally are redistributed to the water column. This type of cycling compounds the difficulty of halting the eutrophication process.

3.4 Dissolved Oxygen

Florida's DO criterion for Class III fresh waterbodies states that DO shall not be less than 5.0 mg/L. Normal daily and seasonal fluctuations above these levels shall be maintained. However, DO concentrations in ambient waters can be controlled by many factors, including DO solubility, which is controlled by temperature and salinity; DO enrichment processes influenced by reaeration, which is controlled by flow velocity; the photosynthesis of phytoplankton, periphyton, and other aquatic plants; DO consumption from the decomposition of organic materials in the water column and sediment and oxidation of some reductants such as ammonia and metals; and respiration by aquatic organisms.

3.5 Nutrients

Florida's nutrient criterion is narrative only, i.e., nutrient concentrations of a body of water shall not be altered so as to cause an imbalance in natural populations of aquatic flora or fauna. Accordingly, a nutrient-related target was needed to represent levels at which an imbalance in flora or fauna is expected to occur.

Numeric criteria for nutrients such as Total Nitrogen (TN) and Total Phosphorus (TP) are not explicitly stated in Chapter 62-302, FAC.

The IWR Rule 62-303.350 and 62-303.352, FAC, (Nutrients in Lakes) states that a lake with a mean color greater than 40 platinum cobalt units, is impaired when any annual mean TSI during the verified period exceeds 60, unless paleolimnological information indicates the lake was naturally greater than 60. Additionally a lake can be impaired, if data indicate that annual mean TSIs have increased over the assessment period, as indicated by a positive slope in the means plotted versus time, or the annual mean TSI has increased by more than 10 units over historical values. When evaluating the slope of mean TSIs over time, the Department shall require at least a 5 unit increase in TSI over the assessment period. The IWR Rule allows use of additional information indicating imbalance of flora or fauna due to nutrient enrichment. These include algal blooms, changes in alga species richness, excessive macrophyte growth, a decrease in the aerial coverage or density of seagrasses or other submerged aquatic vegetation, and excessive diel oxygen variation. There were only sufficient data to calculate an annual average TSI for the year 2006. The TSI of 70.3 for East Lake in 2006 resulted from annual average CChl a of 50.79 µg/L, TN of 2.13 mg/L, and a TP of 0.082 mg/L. This TSI of 70.3 in 2006 is greater than the threshold of 60. Exceeding this threshold in any one year of the verified period is sufficient to list the lake as impaired for nutrients.

3.6 Nutrient Target Development

In translating the narrative nutrient criterion for this TMDL, the TSI target was derived from the conclusions of a paleolimnological study of East Lake, which is used as the site-specific threshold to address the lake's nutrient impairment. Researchers from the University of Florida conducted a paleolimnological investigation of the lake based on sediment cores collected in October 2010. The study found that the lake was naturally in the mesotrophic to eutrophic range, having diatom inferred pre-disturbance TSI values ranging from 56.4 to 62.0, **Appendix D**. Based on the study results, a TSI target of 60 was selected for TMDL development.

The TMDL for nutrients in East Lake was based on using the TSI calculation method and reducing the nutrient and corrected Chl a concentrations to levels that would produce an annual average TSI of less than 60, while maintaining the lake as a co-limited system for nutrients (median TN/TP ratio ~25). Percent reductions were then calculated for TN and TP based on the highest annual median from either 2005 or 2006 (the only years with sufficient data to calculate annual medians). While the lake was not impaired for DO, the downstream channel (WBID 1579) is impaired for DO. As a result of this downstream impairment, the anthropogenic sources of BOD_5 in the lake (and thus entering the stream) must be eliminated as a part of the solution to address the low DO in the stream. The development of the BOD_5 limit is described in Chapter 5.

Chapter 4: ASSESSMENT OF SOURCES

4.1 Types of Sources

An important part of the TMDL analysis is the identification of pollutant source categories, source subcategories, or individual sources of pollutants in the impaired waterbody and the amount of pollutant loadings contributed by each of these sources. Sources are broadly classified as either “point sources” or “nonpoint sources.” Historically, the term point sources has meant discharges to surface waters that typically have a continuous flow via a discernable, confined, and discrete conveyance, such as a pipe. Domestic and industrial wastewater treatment facilities (WWTFs) are examples of traditional point sources. In contrast, the term “nonpoint sources” was used to describe intermittent, rainfall-driven, diffuse sources of pollution associated with everyday human activities, including runoff from urban land uses, agriculture, silviculture, and mining; discharges from failing septic systems; and atmospheric deposition.

However, the 1987 amendments to the Clean Water Act redefined certain nonpoint sources of pollution as point sources subject to regulation under the EPA’s National Pollutant Discharge Elimination System (NPDES) Program. These nonpoint sources included certain urban stormwater discharges, including those from local government master drainage systems, construction sites over five acres, and a wide variety of industries (see **Appendix A** for background information on the federal and state stormwater programs).

To be consistent with Clean Water Act definitions, the term “point source” will be used to describe traditional point sources (such as domestic and industrial wastewater discharges) ***and*** stormwater systems requiring an NPDES stormwater permit when allocating pollutant load reductions required by a TMDL (see **Section 6.1**). However, the methodologies used to estimate nonpoint source loads do not distinguish between NPDES stormwater discharges and non-NPDES stormwater discharges, and as such, this source assessment section does not make any distinction between the two types of stormwater.

4.2 Potential Sources of Nutrients and BOD in the East Lake Watershed

4.2.1 Point Sources

There are no NPDES permitted domestic or Industrial wastewater facilities that discharge within the watershed.

Municipal Separate Storm Sewer System Permittees

The stormwater collection systems owned and operated by Hillsborough County and Co-Permittees, including FDOT District 7 are covered by a Phase I NPDES municipal separate storm sewer system (MS4) permit (FLS000006). There are no Phase II MS4 permits identified for this watershed.

4.2.2 Land Uses and Nonpoint Sources

As reported in the Hillsborough County Master Stormwater Plan (Plan) for this watershed, residential areas are concentrated around the north rim of lake and along the stream corridor. The majority of these developments are older developments with little to no stormwater treatment in place.

The Plan includes results from a set of calibrated and validated water quantity and quality models. One of the models used was the National Resources Conservation Service (NRCS) Dimensionless Unit Hydrograph Method. This model was used to generate runoff hydrographs that were input and routed through a modified version of the Storm Water management Model (SWMM) version 4.31 using the curve number method. The SWMM modification was to allow for directly integrating the curve number method to generate the runoff hydrographs, entrance and exit head loss coefficient, and conduit stretch factors.

The model was calibrated to the July 13-19 1990 storm event due to availability of data and verified for rain events in 1991, 1992, and 1999. The computed maximum water levels in the lake were slightly higher than the observed and the simulated water level in the lake drops faster than the recorded data. The report states that this was due to seepage inflow and inflows from directly connected areas to the lake that were not included in the model. This resulted in model stage declining faster than the recorded data. In general, the county concluded that the model was calibrated and verified and suitable for simulating major storm events in the watershed.

Parsons Engineering Sciences Inc., in 1998 was contracted to develop a water quality model capable of quantifying pollutant loading and removal. The model was incorporated into a Visual Basic-driven Excel spreadsheet model. The model is based on land use, soils, runoff coefficient, runoff amounts, event mean concentrations, and Best Management Practices (BMPs). The Plan provides a summary by subbasin of estimated loadings for BOD_5, TSS, TKN, NO23, TN, TP, TDP, oil/grease, cadmium, copper, lead, and zinc for a variety of conditions, current, past, and future.

In 1995, Hillsborough County and the SWFWMD commissioned Environmental Research and Design (ERD) to perform a study on the lake as part of a restoration/evaluation plan. This study indicated that a major loading source for nitrogen, phosphorus, and BOD_5 being introduced into the lake had its origins in the bird rookery that exists on a small island (Bird Island) in the northeast portion of the lake (**Figures 1.2, 1.3, and 4.1**).

The Plan contains conflicting information regarding the water and mass balance. In the text, it states that the annual average water budget is made up of 50% stormwater runoff, 11% baseflow, 20% ground water seepage, and 19% rainfall directly on the lake. However, Table 7.5 in the Plan states that baseflow is 50 percent and that runoff is only 11 percent. As the text and the tables in the report do not match up, no further discussion of these findings are presented in this report. However, as noted above, the report also states that the major source of pollutants to the lake was attributed to the bird population of Bird Island (**Figure 4.1**). The island is reported to generate 2619 kg/yr (15.8 lbs/day) of TN (about 30% of the total mass of TN entering the lake), 1065 kg/yr (6.43 lbs/day) of TP or about 75% of all the TP entering the lake, and 18,489 kg/yr (111.67 lbs/day) of BOD_5, about 66% of all the BOD_5.

Data reported for nutrient loadings from waterfowl in the TMDL for West Clark Lake “Nutrient TMDL for West Clark Lake (WBID 1971)” by Dr. Andrzej Baniukiewicz, November 3, 2005 indicated that annual average loadings in the literature range from values as low as 3.89 grams of TN per bird per year (g/b/y) and 1.31 g/b/y for TP by Marion et al. for Lake Grand-Lieu in France, to values as high as 41.8 g/b/y TN and 16.8 g/b/y for TP found by Andersen et al. for a wetland in California.

Based on these bird loading rates for TN and TP, and the loads reported in the Plan, the number of birds roosting on the 0.8 acre island each day should range from a low of 172 (assuming the highest loading rate) to 2227 (assuming the lowest loading rate).

Figure 4.1 Bird Island

After a visual inspection of the watershed, it is DEP’s expectation that loadings from the canal system extending out from the lake into the surrounding neighborhood (**Figures 4.2** and **4.3**), as well as internal recycling of nutrients within the lake, may be contributing a substantial fraction of the loadings attributed to birds in the Plan. Actual data on the numbers of birds and data from the island should be collected together with a better characterization of the mass loading from the canal network, before this large a load is attributed to birds.

Figure 4.2 Western Arm of the Lake

Figure 4.3 Eastern Arm of the Lake

Nonpoint source pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. Nonpoint pollution is caused by rainfall moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water (EPA, 1994). Potential nonpoint sources of BOD and nutrients include loadings from surface runoff, wildlife, livestock, pets, leaking sewer lines, and leaking septic tanks.

Land Uses

The spatial distribution and acreage of different land use categories for WBID 1579A were identified using the SWFWMD's 2009 land use data (scale 1:40,000) contained in the Department's geographic information system (GIS) library.

The land use information analyzed for this TMDL represents a modified area from WBID 1579 (East Lake Outfall) which surrounds the East Lake WBID (654.4 acres), and the East Lake WBID area (104.1 acres). The modified area encompasses the northern-most parts of WBID

1579, north of the I-4 corridor. Land use categories were aggregated and are tabulated in **Table 4.1**. **Figure 4.4** shows the acreage of the principal land uses in the modified watershed and in WBID 1579.

Table 4.1 Classification of Land Use Categories for the Modified WBID 1579 Area and the East Lake WBID

FLUCCs Code	Land Use	Modified WBID 1579 Acreage	Modified WBID 1579 % Acreage	WBID 1579A Acreage	WBID 1579A % Acreage
1200	Residential Medium Density	10.7	1.6%	0.0	0%
1300	Residential High Density	111.5	17.0%	0.4	0.4%
1400	Commercial And Services	143.8	22.0%	0.0	0.0%
1500	Industrial	130.4	19.9%	0.0	0%
1700	Institutional	65.5	10.0%	0.7	0.7%
1900	Open Land	19.4	3.0%	0.0	0.0%
2100	Cropland And Pastureland	67.0	10.2%	0.0	0.0%
4340	Hardwood Conifer Mixed	5.2	0.8%	0.0	0.0%
5200	Lakes	4.2	0.6%	100.5	96.6%
5300	Reservoirs	37.5	5.7%	0.0	0.0%
6410	Freshwater Marshes	2.1	0.3%	2.4	2.3%
6430	Wet Prairies	3.4	0.5%	0.0	0.0%
6440	Emergent Aquatic Vegetation	1.6	0.2%	0.0	0.0%
8100	Transportation	52.2	8.0%	0.0	0.0%
	Total	**654.4**	**100%**	**104.1**	**100%**

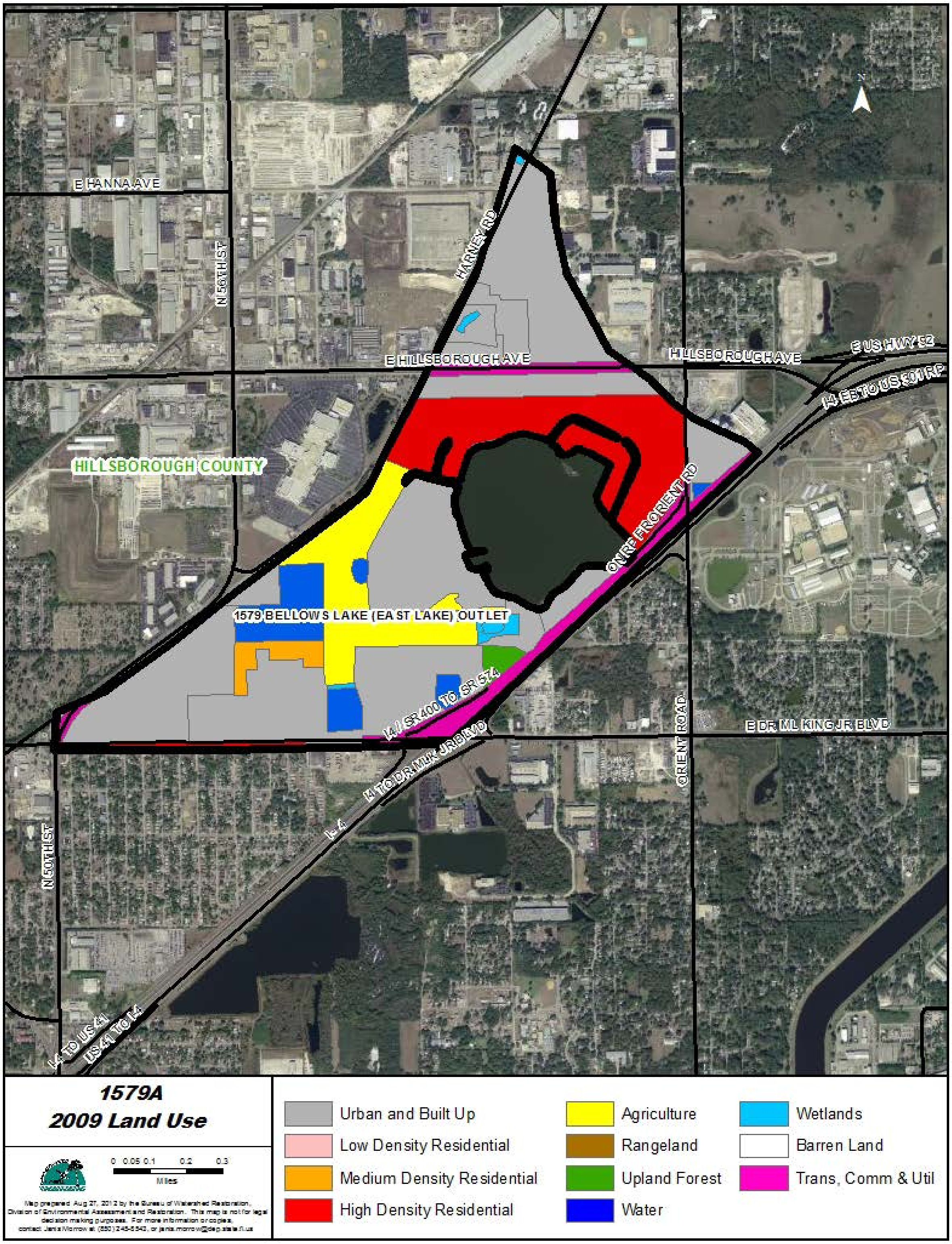


Figure 4.4. Principal Land Uses in the Modified WBID 1579 Area and the East Lake WBID

Septic Tanks

Septic tanks are another potentially important source of BOD and nutrients. In areas with a relatively high ground water table, the drainage field can be flooded during the rainy season, and pollutants can be transported to the surface water through storm runoff. Additionally, any well that is installed in the surficial aquifer system will cause a drawdown around the well. If the septic tank system is built too close to the well (e.g., less than 75 feet), the septic tank discharge will be within the cone of influence of the well. As a result, septic tank effluent may go into the well and once the polluted water is used to irrigate lawns, pollutants may reach the land surface and wash into surface waters during rain events.

Fifteen housing units (*N*) with septic systems were identified in the modified area corresponding to WBID 1579 (**Figure 4.5**). This number is based on the 2012 Florida Department of Health (FDOH) onsite sewage GIS coverage (http://www.doh.state.fl.us/environment/programs/EhGis/EhGisDownload.htm). Given the small number of septic tanks in the area, BOD and nutrient contributions from septic tanks to East Lake is not expected to be significant.

Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) can also be a potential source of nutrients and BOD pollution. Human sewage can be introduced into surface waters even when storm and sanitary sewers are separated. Leaks and overflows are common in many older sanitary sewers where capacity is exceeded, high rates of infiltration and inflow occur (i.e., outside water gets into pipes, reducing capacity), frequent blockages occur, or sewers are simply falling apart due to poor joints or pipe materials. Power failures at pumping stations are also a common cause of SSOs. The greatest risk of an SSO occurs during storm events; however, few comprehensive data are available to quantify SSO frequency and bacteria loads in most watersheds.

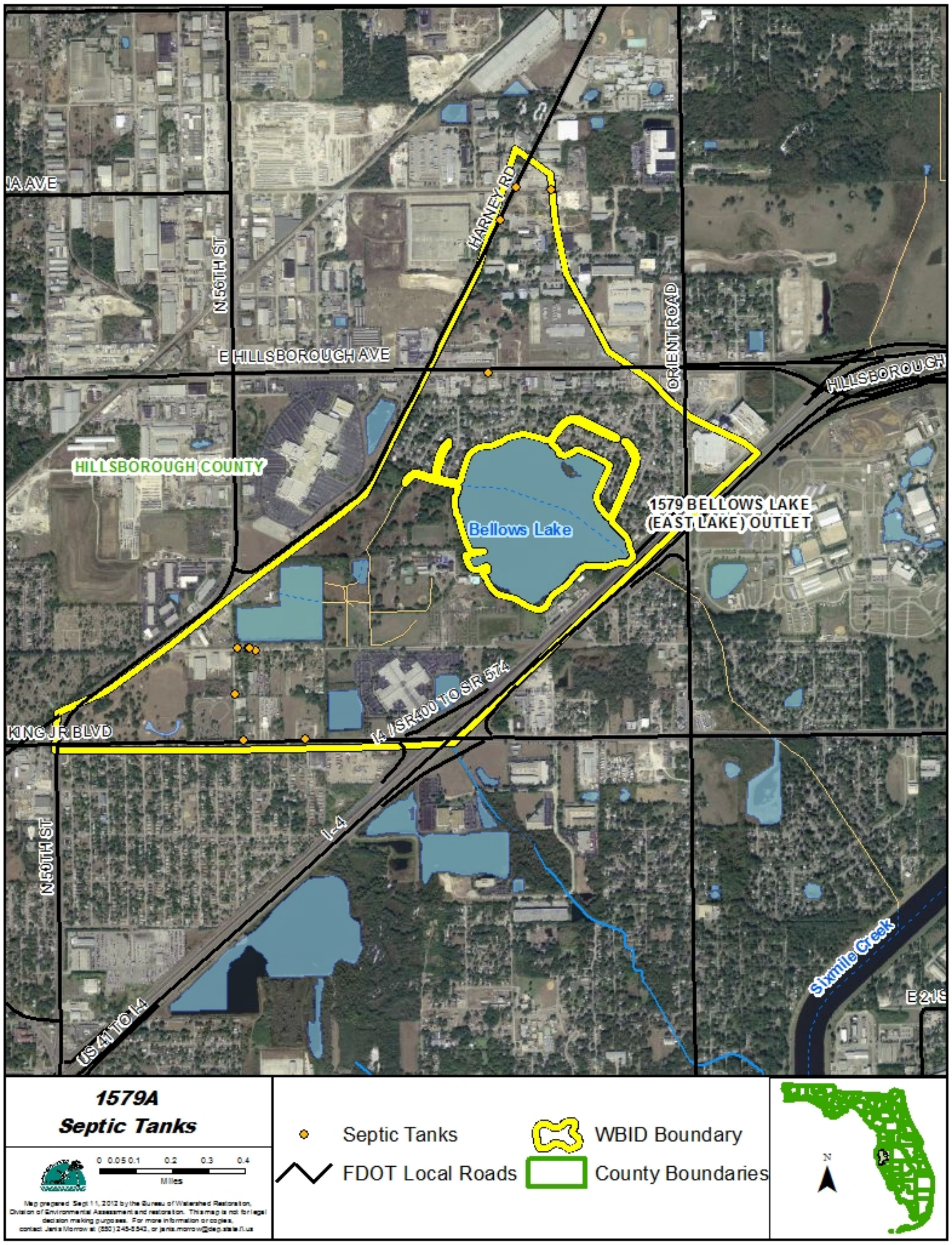


Figure 4.5. Location of OSTDS Based on FDOH Data in the Residential Land Use Areas within the Modified East Lake Outfall WBID Boundary

Chapter 5: DETERMINATION OF ASSIMILATIVE CAPACITY

5.1 Determination of Loading Capacity

The TMDL development process identifies pollutant target concentrations and pollutant reductions for East Lake, for the waterbody to achieve the applicable nutrient water quality criteria, and maintain its function and designated use as a Class III fresh water. The nutrient TMDL targets for the lake were based on reductions in the TSI. The nutrient TMDL was established using a percent reduction approach in existing nutrient concentrations (verified period only 2000 – 2007) to meet the water quality targets, based on data collected in the Cycle 2 verified period from all stations. The percent reductions for TN and BOD_5 make up the nutrient and DO TMDL for the lake needed to meet the applicable criteria for DO and nutrients.

The TMDL for nutrients in East Lake was based on achieving a target TSI of less than 60 for both nutrients and CChl a. Using the equations for calculating TSI as shown in Chapter 2, reductions in TN and TP were made while maintaining the TN to TP ratio at the median ratio from the lake data of 25 (co-limitation) until a nutrient TSI less than 60 was achieved. The TMDL percent reductions were developed using the highest annual median concentrations of TN, TP, and CChl a during the years 2005 or 2006 (only years with sufficient data to calculate annual medians). Additionally, a BOD_5 TMDL was established in East Lake to address anthropogenic sources of BOD and to improve the DO in the downstream water (East Lake Outfall, WBID 1579), as it is impaired for DO.

5.1.1 Data Used in the Determination of the TMDL

The data used to develop this TMDL were obtained through the IWR dataset “Run 35-3”, and are listed in **Appendix B**.

5.1.2 TMDL Development Process for East Lake

As described in **Section 5.1**, the method used to determine the percent reductions in the lake was to achieve a nutrient and CChl a TSI of less than 60 and a reduction in BOD as required to improve DO in the downstream impaired waterbody. The resulting percent reductions in TN, TP, and BOD_5 were applied to the entire watershed of the lake.

Percent reduction was calculated by subtracting the TMDL target concentration from the worst-case impairment concentration, dividing by the worst-case concentration and multiplying times 100.

Percent Reduction:
Percent reduction = $\{$**(Impairment – TMDL)/Impairment**$\}$***100**

BOD5:

Table 5.1 presents the annual median concentrations for BOD_5 in the lake. The highest annual median BOD_5 of 5.45 mg/L occurred during 2006. Based on the DEP experience assessing DO impairments, if the BOD_5 is elevated above 2.0 mg/L it may be considered as causing or contributing to low DO conditions in the waterbody. Therefore, to address uncertainty and provide for margin of safety for the DO impairment, the BOD TMDL was established as an annual average of 2.00 mg/L.

Percent Reduction =
((5.45 – 2.00)/5.45)*100)
= 63.3 percent.

Corrected Chlorophyll a:

Table 2.12 presents the quarterly and annual average data for CChl a in the lake. The annual average CChl a in the lake was 50.79.

Using the TSI calculation method as shown in Chapter 2, CChl a concentrations were reduced from the annual average of 50.79 until a CChl a TSI less than 60 was achieved. A CChl a of 20 ug/L results in a chlorophyll TSI of 59.9. The percent reduction in algal biomass in the lake was calculated as the reduction from 50.79 ug/L to 20.0 ug/L, or 60.6 percent.

Percent Reduction =
(50.79-20.00)/50.79)*100

= 60.6 percent.

Total Nitrogen:

Table 5.1 presents the annual median concentrations for TN in the lake. The highest annual median TN of 2.01 mg/L occurred during 2006. Based on the results from the TSI calculation, a TN of 1.40 mg/L in combination with a TP of 0.055 mg/L results in a nutrient TSI of 59.4 (TN/TP ratio = 25.4). The TN concentration of 1.40 mg/L is the target concentration for the TN TMDL for the lake and the worst-case impairment concentration identified in **Table 5.1** is 2.01 mg/L.

The TN TMDL for the lake was calculated as the percent reduction required to reduce a TN of 2.01 mg/L to 1.40 mg/L or 30.5 percent.

Percent Reduction =
((2.014 – 1.40)/2.014)*100);
= 30.5 percent.

Total Phosphorus:

Table 5.1 presents the annual median concentrations for TP in the lake. The highest annual median TP of 0.825 mg/L occurred in 2006. Based on the results from the TSI calculation, a TP of 0.055 mg/L in combination with a TN of 1.40 mg/L results in a nutrient TSI of 59.4 (TN/TP ratio = 25.4). The TP concentration of 0.055 mg/L is the target concentration for the TMDL and the worst-case concentration identified for the lake is 0.0825 mg/L. The TP TMDL was calculated as the percent reduction required to reduce a TP of 0.0825 mg/L to 0.055 mg/L or 33.3 percent.

Percent Reduction =
((0.0825 – 0.055)/0.0825)*100);
= 33.3 percent.

Table 5.1 East Lake TMDL Target Concentrations and Percent Reductions for TN and TP required to meet Water Quality Standards for Nutrients and BOD_5 Required to meet DO Standards Downstream In East Lake Outfall

Parameter	TMDL Lake	VP Annual Median Lake	Lake Percent Reduction
TN (mg/L)	1.40	2.01	30.5
TP (mg/L)	0.055	0.0825	33.3
BOD_5 (mg/L)	2.00	5.45	63.3

5.1.3 Critical Conditions/Seasonality

The critical conditions for nutrient and BOD_5 loadings in a given watershed depend on the existence of point sources, land use patterns, and rainfall in the watershed. Typically, the critical condition for nonpoint sources is an extended dry period, followed by a rainfall runoff event. During wet weather periods, pollutants that have built up on the land surface under dry weather conditions are washed off by rainfall, resulting in wet weather loadings. However, significant nonpoint source contributions could also occur under dry weather conditions without any major surface runoff event. This usually happens when nonpoint sources contaminate the surficial aquifer, and pollutants are brought into the receiving waters through baseflow. Animals with direct access to the receiving water could also contribute to the exceedances during dry weather conditions. The critical condition for point source loading typically occurs during periods of low stream flow, when dilution is minimized. As previously noted, there are no point source discharges within the watershed. The evaluation of rainfall in 2005 and 2006 indicated that rainfall was fairly typical, with neither being an extreme wet or dry year.

Chapter 6: DETERMINATION OF THE TMDL

6.1 Expression and Allocation of the TMDL

The objective of a TMDL is to provide a basis for allocating acceptable loads among all of the known pollutant sources in a watershed so that appropriate control measures can be implemented and water quality standards achieved. A TMDL is expressed as the sum of all point source loads (Wasteload Allocations, or WLAs), nonpoint source loads (Load Allocations, or LAs), and an appropriate margin of safety (MOS), which takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$\textbf{TMDL} = \sum \square \mathrm{WLAs} + \sum \square \mathrm{LAs} + \mathrm{MOS}$$

As discussed earlier, the WLA is broken out into separate subcategories for wastewater discharges and stormwater discharges regulated under the NPDES Program:

$$\textbf{TMDL} \cong \sum \square \mathrm{WLAs}_{\textbf{wastewater}} + \sum \square \mathrm{WLAs}_{\textbf{NPDES Stormwater}} + \sum \square \mathrm{LAs} + \mathrm{MOS}$$

It should be noted that the various components of the revised TMDL equation may not sum up to the value of the TMDL because (a) the WLA for NPDES stormwater is typically based on the percent reduction needed for nonpoint sources and is also accounted for within the LA, and (b) TMDL components can be expressed in different terms (for example, the WLA for stormwater is typically expressed as a percent reduction, and the WLA for wastewater is typically expressed as mass per day).

WLAs for stormwater discharges are typically expressed as “percent reduction” because it is very difficult to quantify the loads from MS4s (given the numerous discharge points) and to distinguish loads from MS4s from other nonpoint sources (given the nature of stormwater transport). The permitting of stormwater discharges also differs from the permitting of most wastewater point sources. Because stormwater discharges cannot be centrally collected, monitored, and treated, they are not subject to the same types of effluent limitations as wastewater facilities, and instead are required to meet a performance standard of providing treatment to the “maximum extent practical” through the implementation of best management practices (BMPs).

This approach is consistent with federal regulations (40 CFR § 130.2[I]), which state that TMDLs can be expressed in terms of mass per time (e.g., pounds per day), toxicity, or **other appropriate measure**. The TMDL for East Lake is expressed in terms of a percent reduction, this TMDL represents the maximum water column concentrations that East Lake can assimilate to attain the applicable nutrient criteria **(Table 6.1).**

Table 6.1. TMDL Components for Nutrients and BOD_5 in East Lake (WBID 1579A)

Parameter	WLA Wastewater	WLA NPDES Stormwater (% reduction)	LA (% reduction)	MOS
Total Nitrogen	N/A	30.5	30.5	Implicit
Total Phosphorus	N/A	33.3	33.3	Implicit
BOD_5	N/A	63.3	63.3	Implicit

N/A – Not applicable.

6.2 Load Allocation

A percent reduction in TN of 30.5% and TP of 33.3% is needed from nonpoint sources in the East Lake watershed for the lake to achieve a TSI of 60. A BOD_5 TMDL reduction of 63.3% was established for the Lake as the downstream waterbody is impaired for DO. It should be noted that the LA includes loading from stormwater discharges regulated by the Department and the water management districts that are not part of the NPDES Stormwater Program (see **Appendix A).**

6.3 Wasteload Allocation

6.3.1 NPDES Wastewater Discharges

There are no NPDES surface water dischargers within the East Lake watershed.

6.3.2 NPDES Stormwater Discharges

The WLA for stormwater discharges with an MS4 permit is a percent reduction in TN of 30.5% and TP of 33.3%. These reductions are needed from nonpoint sources in the East lake watershed for the lake to achieve a TSI of 60 on an annual average basis. A BOD_5 TMDL reduction of 63.3% was established for the Lake as the downstream waterbody is impaired for DO. It should be noted that any MS4 permittee is only responsible for reducing the anthropogenic loads associated with stormwater outfalls that it owns or otherwise has responsible control over, and it is not responsible for reducing other nonpoint source loads in its jurisdiction.

6.4 Margin of Safety

TMDLs must address uncertainty issues by incorporating a MOS into the analysis. The MOS is a required component of a TMDL and accounts for the uncertainty about the relationship between pollutant loads and the quality of the receiving waterbody (Clean Water Act, Section 303[d][1][c]). Considerable uncertainty is usually inherent in estimating pollutant loading from nonpoint sources, as well as predicting water quality response. The effectiveness of management activities (e.g., stormwater management plans) in reducing loading is also subject to uncertainty.

The MOS can either be implicitly accounted for by choosing conservative assumptions about loading or water quality response, or explicitly accounted for during the allocation of loadings. Consistent with the recommendations of the Allocation Technical Advisory Committee (Department, February 2001), an implicit MOS was used in the development of this TMDL.

6.5 Evaluating Effects of the TMDL on DO

It is expected that with the required reductions of 30.5 percent in TN loadings, 33.3 percent in TP loadings, and a 63.3 percent reduction in BOD_5 loadings for the East Lake WBID, the impaired downstream waterbody, the East Lake Outfall (WBID 1579), will attain water quality standards following the implementation of the TMDL for nutrients and BOD_5 in the East Lake WBID. The nutrient reductions will result in an annual average reduction in CChl a in East Lake of 60.6 percent (from 50.79 µg/L to 20.0 µg/L) and a corresponding reduction in algal biomass entering the East Lake Outfall channel. These reductions will significantly improve overall water quality in the watershed, including DO levels. These reductions will have a positive effect on reducing the diurnal fluctuations in DO and will improve the DO levels of water in both the lake and the stream. These reductions in algal biomass (averaging 60.6 percent) will reduce the DO fluctuations and the BOD_5 that results from the breakdown of algal cells in the lake and stream by a relative amount. As the total BOD is composed of both a carbonaceous fraction and a nitrogenous fraction, additional reductions in BOD will occur as a result of reducing the mass of TN entering the system.

6.6 Evaluating Effects of the TMDL on BOD

The elevated BOD_5 measured in East Lake is contributing to the low DO in downstream waters. These values (as high as 8.3 mg/L) could in part be related to the occasionally high CChl a concentrations measured in the system. Once the external anthropogenic sources of BOD and nutrients from stormwater contributions into the system are reduced through the implementation of the TMDL, it is expected that any remaining DO values below the Class III fresh water criteria can be attributed to pollution (as a result of the man-made conditions) and the stream will attain water quality standards.

Chapter 7: NEXT STEPS: IMPLEMENTATION PLAN DEVELOPMENT AND BEYOND

7.1 Basin Management Action Plan

Following the adoption of these TMDLs by rule, the Department will determine the best course of action regarding its implementation. Depending on the pollutant(s) causing the waterbody impairment and the significance of the waterbody, the Department will select the best course of action leading to the development of a plan to restore the waterbody. Often this will be accomplished cooperatively with stakeholders by creating a Basin Management Action Plan, referred to as the BMAP. BMAPs are the primary mechanism through which TMDLs are implemented in Florida (see Subsection 403.067[7], F.S.). A single BMAP may provide the conceptual plan for the restoration of one or many impaired waterbodies.

If the Department determines that a BMAP is needed to support the implementation of these TMDLs, a BMAP will be developed through a transparent, stakeholder-driven process intended to result in a plan that is cost-effective, technically feasible, and meets the restoration needs of the applicable waterbodies. Once adopted by order of the Department Secretary, BMAPs are enforceable through wastewater and municipal stormwater permits for point sources and through BMP implementation for nonpoint sources. Among other components, BMAPs typically include the following:

- *Water quality goals (based directly on the TMDL);*
- *Refined source identification;*
- *Load reduction requirements for stakeholders (quantitative detailed allocations, if technically feasible);*
- *A description of the load reduction activities to be undertaken, including structural projects, nonstructural BMPs, and public education and outreach;*
- *A description of further research, data collection, or source identification needed in order to achieve the TMDL;*
- *Timetables for implementation;*
- *Implementation funding mechanisms;*
- *An evaluation of future increases in pollutant loading due to population growth;*
- *Implementation milestones, project tracking, water quality monitoring, and adaptive management procedures; and*
- *Stakeholder statements of commitment (typically a local government resolution).*

BMAPs are updated through annual meetings and may be officially revised every five years. Completed BMAPs in the state have improved communication and cooperation among local stakeholders and state agencies; improved internal communication within local governments; applied high-quality science and local information in managing water resources; clarified the obligations of wastewater point source, MS4, and non-MS4 stakeholders in TMDL implementation; enhanced transparency in the Department's decision making; and built strong relationships between the Department and local stakeholders that have benefited other program areas.

7.2 Other TMDL Implementation Tools

However, in some basins, and for some parameters, particularly those with fecal coliform impairments, the development of a BMAP using the process described above will not be the most efficient way to restore a waterbody, such that it meets its designated uses. This is because fecal coliform impairments result from the cumulative effects of a multitude of potential sources, both natural and anthropogenic. Addressing these problems requires good old-fashioned detective work that is best done by those in the area.

A multitude of assessment tools is available to assist local governments and interested stakeholders in this detective work. The tools range from the simple (such as Walk the WBIDs and GIS mapping) to the complex (such as bacteria source tracking). Department staff will provide technical assistance, guidance, and oversight of local efforts to identify and minimize fecal coliform sources of pollution. Based on work in the Lower St Johns River tributaries and the Hillsborough Basin, the Department and local stakeholders have developed a logical process and tools to serve as a foundation for this detective work. In the near future, the Department will be releasing these tools to assist local stakeholders with the development of local implementation plans to address fecal coliform impairments. In such cases, the Department will rely on these local initiatives as a more cost-effective and simplified approach to identify the actions needed to put in place a road map for restoration activities, while still meeting the requirements of Subsection 403.067(7), F.S.

7.3 Implementation Considerations for East Lake

In addition to addressing reductions in pollutant contributions within the watersheds of impaired waters during the implementation phase, it may also be necessary to consider the impacts of internal loadings (e.g. sediment nutrient fluxes or the presence of nitrogen-fixing cyanobacteria) on surface water quality. In the case of East Lake, the sedimentary evidence from the paleolimnological study indicates reduced water depth and the accumulation of organic-rich sediments in recent decades is likely contributing to an increased likelihood of wind-generated resuspension of sediments and internal nutrient loading, **Appendix D**. Therefore, it is recommended that the contribution of nutrients from the sediments be considered in the lake restoration efforts.

References

Andersen, D., Sartoris, J., Thullen, J., Reusch, P., 2003. *The Effects of Bird Use on Nutrient Removal in a Constructed Wastewater-Treatment Wetland,* Wetlands, 2003, Vo. 23, Issue 2, pp. 423-435.

Baniukiewicz, Andrzej, 2005. *Nutrient TMDL for West Clark Lake (WBID 1971)* Florida Department of Environmental Protection.

Florida Administrative Code. *Rule 62-302, Surface water quality standards.*

Florida Administrative Code. *Rule 62-303, Identification of impaired surface waters.*

Florida Department of Environmental Protection. February 2001. *A report to the Governor and the Legislature on the allocation of Total Maximum Daily Loads in Florida.* Tallahassee, Florida: Bureau of Watershed Management.

———. 2003. *Basin Status Report: Tampa Bay Basin.* Tallahassee, Florida: Bureau of Watershed Management.

Florida Department of Health Website. 2008. Available: http://www.doh.state.fl.us/environment/OSTDS/statistics/ostdsstatistics.htm.

Florida Watershed Restoration Act. *Chapter 99-223, Laws of Florida.*

Marion, L., Clergeau, P.,Brient, L., Bertru, G., 1994. *The Importance of Avian-Contributed Nitrogen (N) and Phosphorus (P) to Lake Grand-Lieu, France,* Hydrobiologia, 279/280: 133-147.

U.S. Census Bureau Web site. 2007. Available at http://www.census.gov/.

U.S. Department of Agriculture. 2002. *Agricultural Census Report*.

U.S. Environmental Protection Agency. 1994. *Nonpoint source pollution: The nation's largest water quality problem.* Pointer No. 1. EPA-841-F-94-005. Available: http://www.epa.gov/owow/nps/facts/point1.htm.

U.S. Environmental Protection Agency. 1999. *Protocol for Developing Nutrient TMDLs.* EPA 841-B-99-007. Washington, DC: Office of Water.

Appendices

Appendix A: Background Information on Federal and State Stormwater Programs

In 1982, Florida became the first state in the country to implement statewide regulations to address the issue of nonpoint source pollution by requiring new development and redevelopment to treat stormwater before it is discharged. The Stormwater Rule, as authorized in Chapter 403, F.S., was established as a technology-based program that relies on the implementation of BMPs that are designed to achieve a specific level of treatment (i.e., performance standards) as set forth in Rule 62-40, F.A.C. In 1994, the Department's stormwater treatment requirements were integrated with the stormwater flood control requirements of the water management districts, along with wetland protection requirements, into the Environmental Resource Permit regulations.

Rule 62-40 also requires the state's water management districts to establish stormwater pollutant load reduction goals (PLRGs) and adopt them as part of a Surface Water Improvement and Management (SWIM) plan, other watershed plan, or rule. Stormwater PLRGs are a major component of the load allocation part of a TMDL. To date, stormwater PLRGs have been established for Tampa Bay, Lake Thonotosassa, the Winter Haven Chain of Lakes, the Everglades, Lake Okeechobee, and Lake Apopka.

In 1987, the U.S. Congress established Section 402(p) as part of the federal Clean Water Act Reauthorization. This section of the law amended the scope of the federal NPDES permitting program to designate certain stormwater discharges as "point sources" of pollution. The EPA promulgated regulations and began implementing the Phase I NPDES stormwater program in 1990. These stormwater discharges include certain discharges that are associated with industrial activities designated by specific standard industrial classification (SIC) codes, construction sites disturbing 5 or more acres of land, and master drainage systems of local governments with a population above 100,000, which are better known as MS4s. However, because the master drainage systems of most local governments in Florida are interconnected, the EPA implemented Phase I of the MS4 permitting program on a countywide basis, which brought in all cities (incorporated areas), Chapter 298 urban water control districts, and the Florida Department of Transportation throughout the 15 counties meeting the population criteria. The Department received authorization to implement the NPDES stormwater program in 2000.

An important difference between the federal NPDES and the state's stormwater/environmental resource permitting programs is that the NPDES Program covers both new and existing discharges, while the state's program focus on new discharges only. Additionally, Phase II of the NPDES Program, implemented in 2003, expands the need for these permits to construction sites between 1 and 5 acres, and to local governments with as few as 1,000 people. While these urban stormwater discharges are now technically referred to as "point sources" for the purpose of regulation, they are still diffuse sources of pollution that cannot be easily collected and treated by a central treatment facility, as are other point sources of pollution such as domestic and industrial wastewater discharges. It should be noted that all MS4 permits issued in Florida include a reopener clause that allows permit revisions to implement TMDLs when the implementation plan is formally adopted.

Appendix B: Raw Data for Corrected Chlorophyll a, Biological Oxygen Demand (5-Day), Dissolved Oxygen, Total Nitrogen, Total Phosphorus, and Color

Table B-1 East Lake (WBID 1579A): Corrected Chlorophyll a

sta	year	month	day	time	depth	result	Units	rcode
21FLSWFD19295	2006	2	8	1410	0.50	92.49	µg/L	A
21FLSWFD19295	2006	8	14	1515	0.50	79.6	µg/L	A
21FLSWFD19295	2007	2	8	1200	0.50	124.15	µg/L	A
21FLSWFD19295	2007	8	13	1150	0.50	79.29	µg/L	A
21FLSWFDBELLOWS	2001	8	16	1530	.	38.2	µg/L	
21FLSWFDSTA0429	1995	7	17	1100	0.50	39.02	µg/L	
21FLSWFDSTA0429	1996	1	23	1050	0.50	78.34	µg/L	
21FLTPA 24030127	2006	2	21	1105	0.20	70	µg/L	A
21FLTPA 24030127	2006	3	21	935	0.20	78	µg/L	
21FLTPA 24030127	2006	4	17	1215	0.20	58	µg/L	
21FLTPA 24030127	2006	5	31	905	0.20	9.1	µg/L	I
21FLTPA 24030127	2006	6	19	950	0.20	4.2	µg/L	U
21FLTPA 24030127	2006	7	18	920	0.20	17	µg/L	
21FLTPA 24030127	2006	9	5	945	0.20	50	µg/L	A
21FLTPA 24030127	2006	9	18	950	0.20	51	µg/L	A
21FLTPA 24030127	2006	10	16	1125	0.20	31	µg/L	
21FLTPA 24030127	2006	11	27	955	0.20	50	µg/L	A
21FLTPA 24030127	2006	12	4	1235	0.20	43	µg/L	
21FLTPA 275919108222353	2006	2	21	1125	0.20	53	µg/L	
21FLTPA 275919108222353	2006	3	21	950	0.20	78	µg/L	A
21FLTPA 275919108222353	2006	4	17	1240	0.20	56	µg/L	
21FLTPA 275919108222353	2006	5	31	920	0.20	22	µg/L	
21FLTPA 275919108222353	2006	6	19	930	0.20	29	µg/L	A
21FLTPA 275919108222353	2006	7	18	935	0.20	35	µg/L	A
21FLTPA 275919108222353	2006	9	5	930	0.20	59	µg/L	
21FLTPA 275919108222353	2006	9	18	930	0.20	70	µg/L	
21FLTPA 275919108222353	2006	10	16	1115	0.20	11	µg/L	I
21FLTPA 275919108222353	2006	11	27	930	0.20	59	µg/L	
21FLTPA 275919108222353	2006	12	4	1305	0.20	71	µg/L	A

Table B-2 East Lake (WBID 1579A): Biological Oxygen Demand (5-Day):

sta	year	month	day	time	depth	result	Units	rcode
21FLTPA 24030127	1998	8	25	1145	1.00	8	mg/l	
21FLTPA 24030127	2002	10	8	1130	0.20	4	mg/l	
21FLTPA 24030127	2006	2	21	1105	0.20	7.1	mg/l	
21FLTPA 24030127	2006	3	21	935	0.20	4.6	mg/l	
21FLTPA 24030127	2006	4	17	1215	0.20	5.5	mg/l	
21FLTPA 24030127	2006	5	31	905	0.20	3.1	mg/l	
21FLTPA 24030127	2006	6	19	950	0.20	5.2	mg/l	
21FLTPA 24030127	2006	7	18	920	0.20	5.7	mg/l	
21FLTPA 24030127	2006	9	5	945	0.20	4.2	mg/l	
21FLTPA 24030127	2006	9	18	950	0.20	5.2	mg/l	
21FLTPA 24030127	2006	10	16	1125	0.20	6.1	mg/l	
21FLTPA 24030127	2006	11	27	955	0.20	4.9	mg/l	
21FLTPA 24030127	2006	12	4	1235	0.20	6.9	mg/l	
21FLTPA 275919108222353	2006	2	21	1125	0.20	8.3	mg/l	
21FLTPA 275919108222353	2006	3	21	950	0.20	4.8	mg/l	
21FLTPA 275919108222353	2006	4	17	1240	0.20	7.4	mg/l	
21FLTPA 275919108222353	2006	5	31	920	0.20	2.8	mg/l	A
21FLTPA 275919108222353	2006	6	19	930	0.20	5.4	mg/l	
21FLTPA 275919108222353	2006	7	18	935	0.20	5.5	mg/l	
21FLTPA 275919108222353	2006	9	5	930	0.20	5.4	mg/l	
21FLTPA 275919108222353	2006	9	18	930	0.20	6.1	mg/l	
21FLTPA 275919108222353	2006	10	16	1115	0.20	6.4	mg/l	
21FLTPA 275919108222353	2006	11	27	930	0.20	4.8	mg/l	
21FLTPA 275919108222353	2006	12	4	1305	0.20	7	mg/l	

Table B-3 East Lake (WBID 1579A) Dissolved Oxygen

sta	year	month	day	time	depth	result	Units	rcode
21FLSWFD19295	2006	2	8	1410	0.50	10.61	mg/l	
21FLSWFD19295	2006	2	8	1411	1.15	10.29	mg/l	
21FLSWFD19295	2006	8	14	1515	0.50	11.81	mg/l	
21FLSWFD19295	2006	8	14	1516	1.18	9.96	mg/l	
21FLSWFD19295	2007	2	8	1200	0.50	9.81	mg/l	
21FLSWFD19295	2007	2	8	1201	1.10	9.41	mg/l	
21FLSWFD19295	2007	2	8	1202	2.00	0.66	mg/l	
21FLSWFDBELLOWS	2001	8	16	1530	.	11.19	mg/l	
21FLSWFDSTA0429	1995	7	17	2500	0.50	8.28	mg/l	
21FLSWFDSTA0429	1995	7	17	2500	2.00	8.15	mg/l	
21FLSWFDSTA0429	1996	1	23	2500	0.50	11.35	mg/l	
21FLSWFDSTA0429	1996	1	23	2500	1.00	11.28	mg/l	
21FLTPA 24030127	2002	10	8	1130	0.20	10.5	mg/l	
21FLTPA 24030127	2006	2	21	1105	0.20	13.9	mg/l	
21FLTPA 24030127	2006	3	21	935	0.20	9.63	mg/l	
21FLTPA 24030127	2006	4	17	1215	0.20	10.35	mg/l	
21FLTPA 24030127	2006	5	31	905	0.20	7.4	mg/l	
21FLTPA 24030127	2006	6	19	950	0.20	8.54	mg/l	
21FLTPA 24030127	2006	10	16	1125	0.20	9.18	mg/l	
21FLTPA 24030127	2006	12	4	1235	0.20	10.47	mg/l	
21FLTPA 275919108222353	2006	2	21	1125	0.20	12.95	mg/l	
21FLTPA 275919108222353	2006	3	21	950	0.20	9.95	mg/l	
21FLTPA 275919108222353	2006	4	17	1240	0.20	8.96	mg/l	
21FLTPA 275919108222353	2006	5	31	920	0.20	7.37	mg/l	
21FLTPA 275919108222353	2006	6	19	930	0.20	7.25	mg/l	
21FLTPA 275919108222353	2006	7	18	935	0.20	6.42	mg/l	
21FLTPA 275919108222353	2006	9	5	930	0.20	7.15	mg/l	
21FLTPA 275919108222353	2006	9	18	930	0.20	6.41	mg/l	
21FLTPA 275919108222353	2006	10	16	1115	0.20	8.96	mg/l	
21FLTPA 275919108222353	2006	11	27	930	0.20	9.86	mg/l	
21FLTPA 275919108222353	2006	12	4	1305	0.20	11.06	mg/l	

Table B-4 East Lake (WBID 1579A): Total Nitrogen

sta	year	month	day	time	depth	result	Units	rcode
21FLSWFD19295	2006	2	8	1410	0.50	2.14	mg/l	
21FLSWFD19295	2006	8	14	1515	0.50	2.36	mg/l	
21FLSWFD19295	2007	2	8	1200	0.50	2.71	mg/l	
21FLSWFDBELLOWS	2001	8	16	1530	.	1.27	mg/l	Q
21FLSWFDSTA0429	1995	7	17	1100	0.50	2.79	mg/l	
21FLSWFDSTA0429	1996	1	23	1050	0.50	0.64	mg/l	
21FLTPA 24030127	2006	2	21	1105	0.20	2.46	mg/l	+
21FLTPA 24030127	2006	3	21	935	0.20	3.414	mg/l	+
21FLTPA 24030127	2006	4	17	1215	0.20	2.222	mg/l	+
21FLTPA 24030127	2006	5	31	905	0.20	2.004	mg/l	+
21FLTPA 24030127	2006	6	19	950	0.20	2.104	mg/l	+
21FLTPA 24030127	2006	7	18	920	0.20	1.504	mg/l	+
21FLTPA 24030127	2006	9	5	945	0.20	2.004	mg/l	+
21FLTPA 24030127	2006	9	18	950	0.20	2.106	mg/l	+
21FLTPA 24030127	2006	10	16	1125	0.20	1.704	mg/l	+
21FLTPA 24030127	2006	11	27	955	0.20	1.106	mg/l	+
21FLTPA 275919108222353	2006	2	21	1125	0.20	2.761	mg/l	+
21FLTPA 275919108222353	2006	3	21	950	0.20	2.812	mg/l	+
21FLTPA 275919108222353	2006	4	17	1240	0.20	2.922	mg/l	+
21FLTPA 275919108222353	2006	5	31	920	0.20	2.607	mg/l	+
21FLTPA 275919108222353	2006	6	19	930	0.20	1.904	mg/l	+
21FLTPA 275919108222353	2006	7	18	935	0.20	1.204	mg/l	+
21FLTPA 275919108222353	2006	9	5	930	0.20	2.104	mg/l	+
21FLTPA 275919108222353	2006	9	18	930	0.20	2.004	mg/l	+
21FLTPA 275919108222353	2006	10	16	1115	0.20	2.004	mg/l	+
21FLTPA 275919108222353	2006	11	27	930	0.20	1.308	mg/l	+

Table B-5 East Lake (WBID 1579A): Total Phosphorus

sta	year	month	day	time	depth	result	Units	rcode
21FLSWFD19295	2006	2	8	1410	0.50	0.02	mg/l	I
21FLSWFD19295	2006	8	14	1515	0.50	0.027	mg/l	I
21FLSWFD19295	2007	2	8	1200	0.50	0.105	mg/l	
21FLSWFDBELLOWS	2001	8	16	1530	.	0.005	mg/l	T
21FLSWFDSTA0429	1995	7	17	1100	0.50	0.111	mg/l	
21FLSWFDSTA0429	1996	1	23	1050	0.50	0.019	mg/l	
21FLTPA 24030127	2006	2	21	1105	0.20	0.1	mg/l	
21FLTPA 24030127	2006	3	21	935	0.20	0.13	mg/l	
21FLTPA 24030127	2006	4	17	1215	0.20	0.12	mg/l	
21FLTPA 24030127	2006	5	31	905	0.20	0.091	mg/l	
21FLTPA 24030127	2006	6	19	950	0.20	0.095	mg/l	A
21FLTPA 24030127	2006	7	18	920	0.20	0.054	mg/l	I
21FLTPA 24030127	2006	9	5	945	0.20	0.076	mg/l	
21FLTPA 24030127	2006	9	18	950	0.20	0.077	mg/l	
21FLTPA 24030127	2006	10	16	1125	0.20	0.079	mg/l	
21FLTPA 24030127	2006	11	27	955	0.20	0.04	mg/l	I
21FLTPA 275919108222353	2006	2	21	1125	0.20	0.11	mg/l	
21FLTPA 275919108222353	2006	3	21	950	0.20	0.12	mg/l	
21FLTPA 275919108222353	2006	4	17	1240	0.20	0.17	mg/l	
21FLTPA 275919108222353	2006	5	31	920	0.20	0.11	mg/l	
21FLTPA 275919108222353	2006	6	19	930	0.20	0.11	mg/l	
21FLTPA 275919108222353	2006	7	18	935	0.20	0.052	mg/l	I
21FLTPA 275919108222353	2006	9	5	930	0.20	0.086	mg/l	
21FLTPA 275919108222353	2006	9	18	930	0.20	0.071	mg/l	
21FLTPA 275919108222353	2006	10	16	1115	0.20	0.072	mg/l	
21FLTPA 275919108222353	2006	11	27	930	0.20	0.044	mg/l	I

Table B-6 East Lake (WBID 1579A): Color

sta	year	month	day	time	depth	result	Units	rcode
21FLSWFD19295	2006	2	8	1410	0.50	30	PCU	
21FLSWFD19295	2006	8	14	1515	0.50	30	PCU	
21FLSWFD19295	2007	2	8	1200	0.50	20	PCU	I
21FLSWFD19295	2007	8	13	1150	0.50	40	PCU	I
21FLSWFDBELLOWS	2001	8	16	1530	.	15	PCU	I
21FLSWFDSTA0429	1995	7	17	1100	0.50	20	PCU	
21FLSWFDSTA0429	1996	1	23	1050	0.50	20	PCU	
21FLTPA 24030127	2002	10	8	1130	0.20	60	PCU	
21FLTPA 24030127	2006	2	21	1105	0.20	70	PCU	
21FLTPA 24030127	2006	3	21	935	0.20	60	PCU	
21FLTPA 24030127	2006	4	17	1215	0.20	80	PCU	
21FLTPA 24030127	2006	5	31	905	0.20	80	PCU	
21FLTPA 24030127	2006	6	19	950	0.20	60	PCU	
21FLTPA 24030127	2006	7	18	920	0.20	60	PCU	
21FLTPA 24030127	2006	9	5	945	0.20	60	PCU	
21FLTPA 24030127	2006	9	18	950	0.20	80	PCU	
21FLTPA 24030127	2006	10	16	1125	0.20	60	PCU	
21FLTPA 24030127	2006	11	27	955	0.20	80	PCU	
21FLTPA 275919108222353	2006	2	21	1125	0.20	70	PCU	
21FLTPA 275919108222353	2006	3	21	950	0.20	80	PCU	
21FLTPA 275919108222353	2006	4	17	1240	0.20	80	PCU	
21FLTPA 275919108222353	2006	5	31	920	0.20	80	PCU	
21FLTPA 275919108222353	2006	6	19	930	0.20	60	PCU	
21FLTPA 275919108222353	2006	7	18	935	0.20	60	PCU	
21FLTPA 275919108222353	2006	9	5	930	0.20	60	PCU	
21FLTPA 275919108222353	2006	9	18	930	0.20	80	PCU	
21FLTPA 275919108222353	2006	10	16	1115	0.20	60	PCU	
21FLTPA 275919108222353	2006	11	27	930	0.20	80	PCU	

Appendix C: Public comments and FDEP Responses

There were no public comments received by the FDEP for the Bellows (East) Lake TMDL.

Appendix D: East Lake Paleolimnological Study Report

Paleolimnolgical Assessment of Pre-disturbance Water Quality Conditions in Lake Bellows (East Lake), Hillsborough County, Florida

Final Report

Prepared for the

Florida Department of Environmental Protection

by

Thomas J. Whitmore
Melanie Riedinger-Whitmore
Thomas W. Stephens
William Kenney
Renee Price
Jessica L. Black

Department of Geological Sciences,
University of Florida
Gainesville, FL 32611
Tel: (352)-392-2231

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Executive Summary

Paleolimnolgical analyses of sediment cores from Lake Bellows, Hillsborough County, Florida, were undertaken at the University of Florida for the Florida Department of Environmental Protection. One sediment core (core 4) was dated using ^{210}Pb dating methods, and the designated pre-disturbance horizon in that core (c. 1892) was stratigraphically correlated using gravimetric methods to define pre-disturbance horizons in two other sediment cores (cores 1 and 5). Diatoms were analyzed in samples from core 4 and in the pre-disturbance samples from cores 1 and 5. Quantitative estimates of past water quality were obtained using weighted-averaging regression methods and previously published models that are based on a calibration set of 75 Florida lakes. Sedimented algal pigment analyses were provided by the University of Florida as an adjunct to the contractual agreement, and the results are compared with diatom-inferred water-quality estimates.

Diatom assemblages indicate that the lake was naturally in the mesotrophic to eutrophic range, with an average pre-disturbance limnetic total P value of about 0.045 mg/L, an average Florida 305(b) TSI value of 59, and an average limnetic chlorophyll *a* value of about 15 µg/L. Water-quality changes were evident by 1940, with the greatest subsequent change occurring by1969. Water quality changes appear to be consistent with the timing of residential development and the construction of I-4 in the watershed. Sedimented algal pigment profiles show distinct increases in algal production in the lake over time, with the greatest deposition of total carotenoids and chlorophyll derivatives in the middle 1970s. Water-quality conditions appear to have been most eutrophic in the middle 1980s and 1990s and might have improved slightly from then to the present time. Recent water-quality conditions are significantly more eutrophic than pre-disturbance conditions, but paleolimnological evidence suggests that water quality conditions can not be improved below a TSI value of about 59. Sedimentary evidence shows reduced water depth and the accumulation of organic-rich sediments in recent decades, which probably is contributing to an increased likelihood of wind-generated resuspension of sediments and internal nutrient loading. We recommend that sediment sources of nutrients to the water column should be considered in restoration programs.

Introduction

Lake Bellows is a eutrophic to hypereutrophic lake in central Hillsborough County, Florida. Lake Bellows, also known as East Lake (27.9904828, 82.3799308), has an area of ~ 42.9 hectare, a mean depth of 1.8 m, and a maximum depth of 2.7 m (US EPA Region 4, 2009). Anecdotal information suggests that the lake is spring fed.

Lake Bellows is a Class III water body and is considered impaired by nutrients for Trophic State Index (TSI). It was placed on the Verified List of Impaired Waters for the Tampa Bay Basin on May 19th, 2009 (US EPA Region 4, 2009). Water-quality variables measured at stations within the lake during the verified period (2005) documented total nitrogen values ranging from 0.64 mg/L – 3.41 mg/L, (average value of 1.85 mg/L), and total phosphorus concentrations ranging from 0.005 – 0.170 mg/L, (average of 0.082 mg/L). Chlorophyll *a* (corrected), ranged from 4.2-124.2 µg/L, (average value of 52.5 µg/L) and the Florida 305(b) TSI (Paulic et al., 1996) was 70.3 during the verified period. Color ranged from 6080 PCU, with an average of 69.6 PCU.

The watershed surrounding Lake Bellows has an area of about 456 hectares, and it consists primarily of urban and residential areas (US EPA Region 4, 2009). Land use is dominated by high-density residential and commercial development, and by roads. Crop, pasture and open lands represent about 13.8% of the watershed. The lake is bounded on the south/southeast by Interstate-4, and is surrounded on the northwest to southeast shores by East Lake Park, a 325-home residential community that was established in the early 1950s (www.eastlakepark.org). Other adjacent developments include Mary Help of Christians Center on the western and southwestern edge of Lake Bellows, and Iglesia Christiana La Neuva on the southern shore.

Three canals run through East Lake Park and connect to the lake, two of which lie along the eastern shore, and one canal lies along the northwestern edge of the residential development. Lake Bellows outlet (East Lake outlet) drains the lake into the Tampa By-Pass Canal (US EPA Region 4, 2009). A small 0.32-hectare island, Bird Island, is present near the northeastern shore, and serves as a rookery. This island likely represents a spoils deposit that was created during canal construction in East Lake Park (US EPA Region 4, 2009). Remnant citrus agriculture near the southwestern shore is visible on satellite images of the area.

The objective of the present study is to conduct a paleolimnological investigation of sediments in Lake Bellows to document pre-disturbance water-quality conditions in the lake, and to document the timing and extent of water-quality change during approximately the last 100 years. The paleolimnological data will be used to help define appropriate Total Maximum Daily Load (TMDL) guidelines for this lake, in accordance with the state of Florida's Impaired Waters Rule Chapter 62-303 F.A.C. that governs the Total Maximum Daily Loads (TMDL) Program.

Methods

We retrieved 5 sediment cores in October 5, 2010 from 5 stations (Table 1, Figures 1 and 2) from the center of Lake Bellows (East Lake). Sediment cores were collected using a 1.6-m-long sediment/water interface corer (Fisher et al. 1992). Water depths at coring stations varied from 2.0 – 2.2 m (Figure 3). All cores were extruded vertically and sectioned at 5-cm intervals into 237-ml polyethylene cups, and refrigerated until subsampled for analyses.

Organic matter content was measured by loss-on-ignition at 550 °C in a muffle furnace (Håkanson and Jansson 1983) for the sediment cores collected from stations 1, 3, 4 and 5. Percent dry mass was calculated as dry mass/wet mass x 100 for samples used for radioisotope analyses. The percent dry content and organic matter content were used to calculate sediment bulk density (g dry cm^{-3} wet) in each stratigraphic interval using the formula of Binford (1990):

$$p_X = \frac{D(2.5I_X + 1.6C_X)}{D + (1-D)\,(2.5I_X + 1.6C_X)}$$

where p_X is dry density (g dry cm^{-3} wet), x is depth in the sediment profile (cm), D is proportion of dry mass in wet sediment (i.e. dry mass/wet mass), I is the inorganic proportion of dry mass, with density = 2.5 g cm^{-3} dry, and C is the organic proportion of dry material with density = 1.6 g cm^{-3} dry.

^{210}Pb dates were obtained for the sediment core from station 4. Radioisotopic activities for ^{210}Pb dating were obtained by direct gamma counting (Appleby et al. 1986) using an ORTEC Intrinsic Germanium Detector connected to a 4096-channel, multichannel analyzer (Schelske et al. 1994). Unsupported ^{210}Pb activity was calculated by subtracting ^{226}Ra from total ^{210}Pb activity in each sample. Sediment ages and bulk sediment accumulation rates were calculated using the CRS (constant rate of supply) model (Appleby and Oldfield 1983). ^{210}Pb dates correspond to the base of each 5-cm section. Radioisotope activities were assessed for select depths from station 1 and 5 cores to determine supported levels, and along with loss on ignition and rho values, used in selecting predisturbance core intervals for sedimented diatom analyses.

Samples for diatom analyses were collected from a thin layer at the sediment-water interface and at the top of each 5-cm sediment interval in cores from stations 1, 4, and 5 during core extrusion. Diatom samples were digested in 35% H_2O_2 and $K_2Cr_2O_7$ according to Van der Werff (1955), and slides were prepared with Naphrax® mounting medium. At least 500 valves were counted and identified at each level at 1500x magnification using dark-phase microscopy.

Diatoms in core samples were classified with respect to autecological preferences using information compiled from many sources (e.g., Hustedt 1930-1966, Lowe 1974, Patrick and Reimer 1966-1975, Whitmore 1989, Van Dam et al. 1994, Krammer and Lange-Bertalot 1986-1991). Percentages of diatoms in ecological preference categories were summed for each sample. Percentages of taxa that spanned more than one ecological category were divided equally among the categories involved.

Sedimented diatoms were counted for dated sections of the sediment core collected from station 4, and from depths that approximate pre-disturbance levels in the cores from stations 1 and 5. We identified the pre-disturbance horizons in cores 1 and 5 using loss-on-ignition and dry bulk density profiles, and by comparing the profiles with the ^{210}Pb-dated core from station 4. Past limnetic water-quality conditions were inferred using sedimented diatom assemblages and weighted-averaging regression models that were developed previously and applied to Florida lake sediments (Riedinger-Whitmore et al. 2005). Past limnetic total P concentrations were inferred using log-transformed limnetic total P values for a calibration set of 69 P-limited Florida lakes (r^2 adj. = 0.88, s.e. pred. = 0.387). Past limnetic chlorophyll *a* concentrations were inferred using log-transformed limnetic chlorophyll *a* values for a calibration set of 75 Florida lakes (r^2 adj. = 0.79, s.e. pred. = 0.273). Predicted values from these models were de-transformed to yield past limnetic total P and limnetic chlorophyll *a* inferences. Past Florida 305(b) TSI (Paulic et al. 1996) values also were inferred using a calibration set of 72 Florida lakes (r^2 adj. = 0.86, s.e. pred. = 8.163).

Compositional changes in diatom assemblages over time can be revealed by complimentary approaches involving clustering into near-similar assemblages (constrained by depth) and factor analysis of the most dominant environmental responses within a paleolimnological series. Clustering or zonation involves defining sequences of sediment in stratigraphic order that share distinctive but similar natural assemblages, either by through agglomerative or splitting approaches (Gordon and Birks 1972, Grimm 1987). Factor analyses are particularly valuable because diatom indicators for paleolimnology often record responses to multiple, interacting environmental factors, making it essential to reduce these to a single or pair of dominant trends in a dataset (Kovach 1995). Ordination is the most frequently applied paleoecological factor analysis, which generates a series of compound axes which arrange sample sites (e.g., core samples) along principal axes derived from species composition (e.g., those that exhibit the greatest variance by species) (Legendre and Legendre 1998). Most ordination approaches utilize eigenanalysis to extract new axes from linear transformations of multivariate data by assessing covariance and correlation between factors (Legendre and Legendre 1998). Each axis possesses a corresponding eigenvalue that reflects the proportion of total variance within the dataset explained by that axis (Legendre and Legendre 1998). Selecting two axes (typically axes 1 and 2 [$\lambda 1$, $\lambda 2$]), a biplot can be presented to demonstrate similarity in sample, species or environmental variables by proximity in the two-dimensional space (e.g., correlation to $\lambda 1$, $\lambda 2$) (Legendre and Legendre 1998).

Zonation of diatom percentage abundance was undertaken by constrained incremental sum of squares (CONISS) hierarchical agglomerative cluster analysis within the statistical program R by the CHCLUST function of the Rioja package (Juggins 2009). Clusters were defined with Euclidean chord distances generated for a dissimilarity matrix in R using the DISS function of the Rioja package (Juggins 2009). Total variance explained by each cluster is summed into incremental groups to produce a cluster dendrogram.

Unconstrained (indirect) ordinations of diatom assemblages were performed for linear (principal component analysis [PCA]) and unimodal responses (detrended correspondence analysis [DCA]) to paleolimnological change. PCA and DCA are ideal gradient techniques with which to explore species turnover as assemblage sample scores are expressed in units of standard deviation (SD), thereby enabling ready interpretation of between-sample (beta) diversity (Lepš and Šmilauer 2003). Both were performed in the statistical program R using the DECORANA function of the Vegan package (Oksanen et al. 2010). DECORANA detrends DCA ordination axes to remove notable artifacts of correspondence analysis present in unimodal data (‘arch’ or ‘trumpet’ curves [Hill and Gauch, 1980]) via non-linear rescaling of 26 axial segments through repeated iterations (n = 4 [Oksanen et al. 2010]). In PCA and DCA ordinations, rare species have been down-weighted to remove spurious ordination responses too heavily reliant upon infrequent taxa (Hill, 1979). Diatom assemblage data were entered as untransformed percentage abundance estimates (by count) ensuring principal axes record responses to the dominant diatom taxa in the Lake Bellows dataset.

Sedimented algal pigment analyses were undertaken for core 3 from Lake Bellows. The sediment core was analyzed at 5-cm intervals for chlorophyll derivatives, percent native chlorophyll, total carotenoids (TC), and for the cyanobacterial pigments myxoxanthophyll and oscillaxanthin. Approximately 10 g of homogenized wet sediment were used from each depth interval for algal pigment analyses. Pigments were extracted using ~120 ml of acetone, following the procedures of Swain (1985) and Waters et al. (2005). Extracts were kept in dark containers and refrigerated until absorbance values were measured using a Digilab Hitachi U-2800 spectrophotometer. Extracts for chlorophyll derivatives were measured at 665 nm, and corrected for sample turbidity by using absorbance values at 750 nm. Percent native chlorophyll, used to assess pigment preservation within a core, was determined by acidifying chlorophyll derivatives extracts with dilute HCl, measuring absorbance at 665 nm and at 750 nm, subtracting these readings from chlorophyll derivatives absorbance values, and expressing percent native chlorophyll values as a percentage of chlorophyll derivative absorbance. Subsamples for total carotenoids were saponified with a 20%

KOH/methanol mixture, extracted with petroleum ether, rinsed with distilled water, and the supernatant measured at 448 nm. Subsamples for myxoxanthophyll and oscillaxanthin were extracted with petroleum ether, air dried, and dissolved in ethanol. Pigment concentrations were determined using the trichromatic method, which quantifies pigments based on absorbance at 412, 504, 529 and 750 nm (Swain 1985). Three absorbance readings were recorded for each pigment sample, and the average values are reported here. Loss-on-ignition data were used to determine pigment concentration relative to organic matter content for each depth interval. Chlorophyll derivatives and total carotenoids were expressed as absorbance/g organic matter and myxoxanthophyll and oscillaxanthin were expressed as µg pigment/g organic matter. Loss-on-ignition from the station 4 core were compared to the core from station 3 to assign approximate dates to the station 3 core depth intervals.

Early land survey maps, USGS topographic maps, and aerial photographs available at the Map and Imagery Library at the University of Florida were examined to determine historic land use in the Lake Bellows watershed. We endeavored to relate the timing of changes in water quality inferred from the Lake Bellows sediment cores to the timing of land-use changes in the watershed.

Results

Water depth ranged between 2.0 and 2.2 m at all coring stations. We measured soft sediment thickness at stations 1 and 5 by inserting coring rods into the sediment to the depth at which sandy deposits were encountered, then subtracted water depth to estimate sediment thickness. This revealed that organic sediment deposits were approximately 2.8 m thick at station 1, and 1.6 m thick at station 5.

Radionuclide dating of sediment core 4 resulted in excess ^{210}Pb supported levels at a depth of 45 cm in the core (Table 2). The date represented by the 45-cm level was approximately 1892, which corresponds with low disturbance conditions in the watershed. The mass sediment accumulation rate was approximately 8.4 mg/cm^2/yr at the base of the core, and it increased to a maximum of 67.7 mg/cm^2/yr in the 25-30-cm interval (c. 1969) before it decreased to a value of 25.2 mg/cm^2/yr at the top of the core. The linear sedimentation rate increases rapidly from the base of the sediment core, so although the 40-45-cm interval represents c. 1892, the 30-35-cm interval represents c. 1968. ^{137}Cs activity reached a peak in the 1959-1969 sampling interval, and it is consistent with the timing of above-ground weapons testing, which was the source of that artificial radioisotope.

Percent loss-on-ignition and dry bulk density profiles were used for stratigraphic correlation of cores 1, 3, 4, and 5 (Figure 4). A stable period in loss-on-ignition and dry bulk density values was observed at the base of core 4 beginning at the ^{210}Pb-supported level (c. 1892). This period of stable gravimetric values was used to identify the pre-disturbance horizons in cores 1, 3, and 5 (Figure 4). Because core 3 was taken at approximately the same location as the ^{210}Pb -dated core 4 and because of the similarity in gravimetric profiles, the ^{210}Pb dates from core 4 were used to approximate the ages at depths for the pigment analyses in core 3. The pre-disturbance horizon occurred around the 40-45-cm interval in core 1 and around the 65-70-cm interval in core 5. Comparison of diatoms and other biological sedimentary indicators, such as sponge spicules, charcoal, and pollen, indicated that the samples that best matched the 45-cm level in core 4 were the 40-cm sample in core 1, and the 70-cm level in core 5. The samples below the 45-cm level in core 4, the 40-cm level in core 1, and the 70-cm level in core 5 were indicative of low water-level and were rather incomparable to normal lake conditions. Consequently, the 40-cm level in core 1 and the 70-cm level in core 5 were selected as the pre-disturbance levels for diatom analyses in those cores, and their water-quality inferences were compared with inferences for the 45-cm level in core 4.

Diatom analyses

Approximately 6000 diatom valves were counted and identified in samples from cores 1, 4, and 5. One hundred and nine species were identified in the samples. Diatoms in the pre-disturbance (c. 1890) samples included numerous species of *Pinnularia, Eunotia*, *Gomphonema*, and *Cocconeis*, which indicate the probable influence of wetlands on the lake margins, and the presence of submerged aquatic plants in the lake (Appendix 1). Several taxa near the bottom of core 4, such as *Aulacoseira ambigua* (Grunow) Simonsen and *A. granulata* v. *angustissima* (Otto Müller) Simonsen are more typical of a planktonic lifestyle in open waters. The diatom assemblage proceeded through a period of extremely high dominance by *Staurosira vente*r (Ehrenberg) H. Kobayasi, which most often is found in mesotrophic to eutrophic conditions, and may be found growing on the sediment surface or may be resuspended back into the water column periodically by wind-induced mixing (benthic to tychoplanktonic). This shift from an assemblage with planktonic elements to one dominated by more benthic taxa, such as *S. venter*, often occurs at onset of cyanobacterial growth in many Florida lakes (Riedinger-Whitmore et al. 2005). Above the 15-cm level (c. 1995) in core 4, the diatom assemblages shifted to dominance by *Achnanthidium minutissimum* (Kützing) Czarnecki, which is typically benthic or periphytic and present in eutrophic conditions, and to a lesser extent, dominance by *Achnanthes microcephala* (Kützing) Grunow, which is widely distributed.

CONISS zonation demonstrated a clear definition of three diatom sample clusters whose varying assemblage structure recorded marked paleolimnological change (Figure 5). These sample zones extend from the surface to 10 cm depth (c. 2004), 15 to 30 cm depth (1969 to 1995), and 35 to 45 cm depth (1958 to 1892). Each zone is effectively isolated by the PCA and DCA diatom ordination biplots of λ1 and λ2 (Figure 6). PCA species scores demonstrated that the youngest zone is dominated by *Achnanthidium minutissimum* (Kützing) Czarnecki, the intervening zone by *Staurosira vente*r (Ehrenberg) H. Kobayasi, and the oldest zone by a more diverse community of

Aulacoseira italica (Ehrenberg) Simonsen, *Aulacoseira ambigua*(Grunow) Simonsen and *Discostella stelliger*a (Cleve et Grunow) Houk & Kle. Wide-ranging sample scores in PCA also were noteworthy because Lake Bellows samples ranged >2 SD units (in λ1 and λ2), characteristic of a unimodal diatom response to marked paleolimnological change and stressing the need to present sample responses in a DCA biplot. Overall however, trends are similar to PCA for which unscaled Eigenvalues permit calculation of the proportion of total variance explained by each axis (0.665 and 0.266, λ1 and λ2, respectively).

A summary of autecological trophic-state preferences for the diatoms in the core 4 assemblages, as defined by literature descriptions of diatom ecology, shows that diatom assemblages since the pre-disturbance period (c. 1892) were dominated mostly by taxa that prefer mesotrophic to eutrophic conditions (Figure 7).

Past water quality inferences obtained by weighted-averaging regression models developed for Florida lakes (Riedinger-Whitmore et al., 2005) showed changes in limnetic chlorophyll *a*, limnetic total P, and Florida 305(b) TSI (Paulic et. atl, 1996) values for the period since c. 1892 in Lake Bellows (Table 3). Inferences for the top samples in sediment core 4 compared poorly with modern measured water-quality values for the lake. The 0-cm (c. 2010) sample in core 4 yielded a limnetic chlorophyll *a* inference of 17.1 µg/L as compared with a measure value of 52.5 µg/L, inferred limnetic total P was 0.031 mg/L as compared with a measured value of 0.082 mg/L, and inferred TSI was 56.3 as compared with a measured value of 70.3. In order to understand these discrepancies, we performed an unconstrained ordination of diatom assemblages in the 75 calibration lakes and in the Lake Bellows samples using detrended correspondence analysis (DCA) with CANOCO 4.5 (ter Braak and Smilauer 2002). A biplot of ordination axes 1 and 2 showed that samples between 0-cm and 30-cm depth in Lake Bellows core 4 appear to be outliers with respect to lakes in the calibration data set, and therefore are unlikely to yield reliable water-quality inferences (Figure 8). The reason for this discrepancy might be due to the exceptionally high percentages of *Achnanthidium minutissimum* and *Staurosira vente*r in these samples (Figure 5). The biplot also revealed, however, that the 35-cm, 40-cm, and 45-cm samples from core 4, the 40-cm sample from core 1, and the 70-cm sample from core 5 are reasonably well centered in the set of calibration lakes, and are likely to yield more accurate water-quality inferences (Figure 8).

The following pre-disturbance water-quality conditions were estimated from diatoms in the c. 1890 levels of the Lake Bellows sediment cores. Limnetic chlorophyll *a* inferences in the 45-cm sample from core 4, the 40-cm sample from core 1, and the 70-cm sample from core 5 ranged from 7.9 to 22 µg/L, with a mean of 15.2 µg/L. Limnetic total P inferences in pre-disturbance samples ranged from 0.042 to 0.047 mg/L with a mean of 0.045 mg/L. Florida 305(b) TSI inferences ranged from 56.4 to 62.0 with a mean of 59.0.

Sedimented pigments

Percent native chlorophyll, which is a measure of overall algal pigment preservation, ranged from 0.45% at ~ 65-70 cm, to 36.3% in the 0-5 cm interval in the core (Table 4). The low pigment preservation indicated by the percent native chlorophyll record for Lake Bellows is not unusual for shallow Florida lakes, and has been documented in other paleolimnological studies (Riedinger-Whitmore et al. 2005). Pigment preservation was highest in the upper 10 cm of the core, and was < 12% for most of the core samples examined (Table 4). Decreased pigment preservation was evident in the 30-55 cm section of the core. Chlorophyll derivatives ranged from 0.35 absorbance/g organic matter at ~ 65-70 cm, and to 4.03 absorbance/g organic matter at the top of the core. Concentrations were low below 45-50 cm, and showed a gradual increase between 30-45 cm. Highest concentrations were in the upper 30 cm of the core. Total carotenoids ranged from 0.22 absorbance/ g organic matter at the base of the core sequence to 3.54 absorbance/g organic matter in the upper 10 cm of the core. Concentrations were low below 45-50 cm, and gradually increased at 40-45 cm (Figure 9). Highest concentrations, like chlorophyll derivatives, were in the upper 30 cm of the core. Oscillaxanthin, a cyanobacterial pigment found in the Oscillatoriales, varied between 7.31 to 65.36 µg pigment/g organic matter, with the lowest concentrations below the 60 cm level (Figure 9). Highest values were found in the 40-45 cm interval, and concentrations were generally high, but fluctuated above that depth. Oscillaxanthin concentrations declined at two intervals above the 40 cm depth. Concentrations declined to 40.31µg pigment/g organic matter at 20-25 cm, and to 39.28 µg pigment/g organic matter at 10-15 cm. Myxoxanthophyll concentrations ranged from 12.58 µg pigment/g organic matter at 65-70 cm, and peaked at ~ 233 µg pigment/g organic matter at 5-10 cm. Pigment concentrations were low below 45-50 cm, gradually increased until 30-35, declined to ~30 µg pigment/g organic matter at 25 cm, and increased in the upper 20 cm of the core.

Percent native chlorophyll is highest in the most recent sediments (upper 10 cm) of Lake Bellows, and indicates that pigments in these sections are best preserved. The high chlorophyll derivatives, total carotenoids, myxoxanthophyll and oscillaxanthin pigment concentrations in the top of the core result from good pigment preservation (Figure 9). Increasing pigment concentrations below the uppermost 10 cm of the core, though, where pigment preservation is poorer, likely do reflect increased pigment concentrations, and increased algal productivity. The increase in chlorophyll derivatives, a measure of sedimented chlorophyll (uncorrected for phaeophytin), and total carotenoids around 40-45 cm, correspond to 1892 and ~1941, when citrus agriculture was present within the Lake Bellows watershed, and when the land along the western edge of the lake was being developed for the school. Carotenoid pigments are found in the majority of algae, but tend to be more abundant in cyanobacteria (Swain 1985), and can be used to indicate cyanobacterial productivity. The corresponding increase in oscillaxanthin, a pigment found in a group of cyanobacteria that typically appear early during eutrophication, suggests that nutrient concentrations in the lake were increasing in the early days of shoreline development. Both chlorophyll derivatives and total carotenoids increased after the 1940s, in a time period when the school was being expanded, the residential subdivision of East Lake Park was being developed, and I-4 was being constructed. Initial peaks in both pigments occurred between the 1970s and 1980s and likely reflect increased nutrient input from the surrounding watershed and/or internal loading from the sediments. The presence of oscillaxanthin above 40 cm suggests that the lake has been eutrophic since the 1940s. Concentrations of myxoxanthophyll, a pigment that is a general indicator of the presence of cyanobacteria, was low prior to 1892, increased after that time period, and peaked in 1969, around the time of significant development within the watershed. A 2004 peak in myxoxanthophyll is likely to be an artifact of pigment preservation. The myxoxanthophyll record suggests that cyanobacteria have been present in the lake prior to major disturbances within the watershed. Increases after 1892 provide additional evidence of the establishment of eutrophic conditions in the lake.

Interpretation of watershed history

An early 1882 map of Lake Bellows shows that the land surrounding Lake Bellows was owned by several landowners at that time. U.S. Geological Survey topographic maps show the progressive development of the watershed surrounding Lake Bellows (Figure 10). An orphanage and school for boys, Mary Help of Christians School, was established in 1928 on the southwestern and western sides of Lake Bellows by the Salesians of Don Bosco, on land donated by Alicia Gonzalez Neve. A report on the history of the Salesian Order indicates that the property had a well-kept orange grove and that the shoreline of Lake Bellows was a 'seedy marsh' at the time the school was established. The school expanded in 1938 (http://www.salesianvocation.com/site/data/File/HISTORY/Microsoft%20Word%20-%201922-1944.pdf). The school, and the orange grove, are visible in 1943 and 1947 USGS topographic maps and show the lake surrounded by marsh (Figure 10). Orange groves are present within the watershed by 1943, and likely were present prior to that time. A 1956 topographic map shows a dredged area and swimming beach on the western shore of Lake Bellows, associated with the school, and a canal connecting the lake on the northwestern shore to the citrus groves in the south is also visible (Figure 10). Higher water levels have reduced the area of a wetland along the southern shore of the lake. An outlet stream, likely Lake Bellows outlet, is visible at the southeastern edge of the lake. The 1969 topographic map shows the East Lake Park residential development, and a dredged area along the northeastern shore of the lake where the lake area was expanded. This map also shows two canals on the eastern edge of Lake Bellows, and the one on the northwestern edge of the subdivision. Interstate-4 is visible in this topographic map, and was completed in the early 1960s. Bird Island is visible in a 1985 topographic map. The orange groves near the southwestern shore persisted until recently, and remnant citrus is still visible on satellite images of the area.

Discussion

Diatom assemblages and sedimented algal pigments show distinct changes in Lake Bellows since the period of pre-disturbance water-quality conditions, which for purposes of the present study is defined as c. 1890. Water levels apparently were lower in the early 20th century and wetlands were present on the southernmost shores of the lake. Sedimentary deposits prior to c. 1890 in cores 1, 4, and 5 show evidence of wetland diatoms, submerged macrophytes, and indicators of lower water levels, including charcoal remains, abundant pollen and sponge spicules. Pine pollen was abundant in the bottommost samples and suggests that pine forests were present in the watershed. Diatom assemblages in pre-disturbance (c. 1890) samples indicate that the lake was naturally in the mesotrophic to eutrophic range of water quality, with an average limnetic total P value of about 0.045 mg/L, an average Florida 305(b) TSI value of 59, and an average limnetic chlorophyll *a* value of about 15 µg/L.

Water-quality changes were evident between c. 1890 and 1940. The greatest subsequent changes in water quality occurred after 1969, and appear to be consistent with the timing of residential development and the construction of I-4 in the watershed. The mass sediment accumulation rate peaked in 1969, and sediment deposition in some areas, such as the core 5 site near the southern shore, was nearly twice as rapid as at mid-lake sites. The most likely contributor to increased limnetic nutrient concentrations would have been urban development and nutrient inputs from residential developments immediately adjacent to the lake. By the mid 1970s, algal pigment deposition to sediments, particularly total carotenoids and chlorophyll derivatives, had increased substantially, and diatom communities shifted to benthic dominance by taxa that typically are abundant when cyanobacteria are present. Water-quality conditions appear to have been most eutrophic in the mid 1980s and 1990s, and might have improved slightly from then to the present time because of lake management efforts.

Recent water quality conditions, with a mean total phosphorus value of 0.082 mg/L, a mean chlorophyll *a* value of 52.5 µg/L, and a mean TSI value of 70.3, are significantly more eutrophic than pre-disturbance conditions, but paleolimnological evidence suggests that water-quality conditions can not be improved below a TSI value of about 59.

The principal perceived change in water quality conditions might pertain to the onset of cyanobacterial presence and other algal proliferation in the water column, which is well documented by sedimentary evidence. Consequently, future lake mitigation efforts might reduce algal proliferation and improve the perception of water quality in Lake Bellows. We would like to emphasize, however, that sediment dating shows that the lake has lost an average about 0.3 m of water depth since c. 1970, and 0.5 m since c. 1900, with even greater loss of water depth in certain areas, such as at site 5. The reduced water depth and accumulation of organic-rich sediments, therefore, probably contribute to increased likelihood of wind-generated resuspension of sediments and internal nutrient loading. Internal nutrient loading might increase the difficulty of reducing limnetic nutrient concentrations through TMDL management. Partial sediment removal, therefore, might be an effective part of a future mitigation program.

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References Cited

Appleby, P.G. and F. Oldfield. 1983. The assessment of ^{210}Pb data from sites with varying sediment accumulation rates. Hydrobiologia 103:29-35.

Appleby, P.G., P.J. Nolan, D.W. Gifford, M.J. Godfrey, F. Oldfield, N.J. Anderson, & R.W. Battarbee. 1986. ^{210}Pb dating by low background gamma counting. Hydrobiologia 143:21-27.

Binford, M.W. 1990. Calculation and uncertainty analysis of 210Pb dates for PIRLA project lake sediment cores. J. Paleolimnology 3:253-267.

Fisher, M.M., M. Brenner, and K.R. Reddy. 1992. A simple, inexpensive piston corer for collecting undisturbed sediment/water interface profiles. Journal of Paleolimnology 7:157-161.

Gordon, A., & Birks, H. 1972. Numerical methods in Quaternary palaeoecology. I. Zonation of pollen diagrams. New Phytologist, 71: 961-979.

Grimm, E. 1987. CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. Computers & Geosciences, 13: 13-35.

Håkanson, L. and M. Jansson. 1983. Principles of lake sedimentology. Springer-Verlag, NY. 316 p.

Hill, M., and Gauch, H. 1980. Detrended correspondence analysis: An improved ordination technique. Vegetatio, 42: 47-58.

Hustedt F. 1930-1966. Die Kieselalgen Deutschlands, Österreichs und der Schweiz. In Dr. L. Rabenhorst's Kryptogamen Flora von Deutschlands, Österreichs und der Schweiz. Band 7. Teil 1-3.

Juggins, S. 2009. Rioja package Version 0.5-6. Analysis of Quaternary science data. CRAN R-Project. http://cran.r-project.org/web/packages/rioja/index.html.

Krammer K. and Lange-Bertalot H. 1986-1991. Bacillariophyceae, Teil 1-4. In A. Pascher, Süsswasserflora von Mitteleuropa. Gustav Fischer Verlag, Jena.

Leavitt, P.R. and D. A. Hodgson. 2001. 15. Sedimentary pigments. pp. 295-326 In Smol. J.P., H.J. B. Birks and W.M. Last (eds) Tracking environmental change using lake sediments, Volume 3, Terrestrial, Algal, and Siliceous Indicators. Kluwer Academic Publishers.

Legendre, P., and Legendre, L. 1998. Numerical ecology (2nd Ed.). Elsevier, Amsterdam.

Lepš, J., and Šmilauer, P. 2003. Multivariate analysis of ecological data using Canoco. Cambridge University Press, Cambridge. Pp. 269.

Line J. M., ter Braak C. F., and Birks H. J. 1994. WACALIB version 3.3 -A computer program to reconstruct environmental variables from fossil assemblages by weighted averaging and to derive sample-specific errors of prediation. Journal of Paleolimnology 10:147-152.

Lowe R.L. 1974. Environmental requirements and pollution tolerance of freshwater diatoms. EPA Environmental Monitoring Series EPA-670/4-74-005. 333 pp.

Oksanen, J., Guillaume Blanchet, F., Kindt, R., Legendre, P., O'Hara, R.B., Simpson, G.L., Solymos, P., Henry, M., Stevens, H., and Wagner, H. 2010. Vegan: Community Ecology Package. R Package version 1.17-3. http:// vegan.r-forge.r-project.org/

Patrick R. and Reimer C.W. 1966-1975. The Diatoms of the United States. Monographs of the Philadelphia Academy of Sciences No. 13, Part 1, v. 1-2.

Paulic M., Hand J., and Lord.L. 1996. Water-quality assessment for the State of Florida. Section 305(b) Main Report. Florida Department of Environmental Protection, Tallahassee.

Riedinger-Whitmore, M.A., T.J. Whitmore, M. Brenner, A. Moore, J.M. Smoak, J.H. Curtis, and C.L. Schelske. 2005. Cyanobacterial proliferation is a recent response to eutrophication in many Florida lakes: a paleolimnological assessment. Lake and Reservoir Management 21:423-435.

Schelske, C.L., A. Peplow, M. Brenner, and C.N. Spencer. 1994. Low-background gamma counting: applications for ^{210}Pb dating of sediments. Journal of Paleolimnology 10:115-128.

Swain, E.B. 1985. Measurement and interpretation of sedimentary pigments. Freshwater Biology 15:53-75

ter Braak, C.F.J. and P. Smilauer. 2002. CANOCO reference manual and CanoDraw for Windows user's guide. Software for Canonical Community Ordination (version 4.5). Microcomputer Power, Ithica, NY, USA. 500pp.

US EPA Region 4. 2009. Proposed Total Maximum Daily Load (TMDL) for nutrients and dissolved oxygen in East Lake Outlet/Bellows Lake Outlet (WBID 1579) and East Lake/Bellows Lake (WBID 1579 A). 77 pp.

Van Dam H. 1994. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. Netherlands Journal of Aquatic Ecology 28(1): 117-133.

Van der Werff, A. 1955. A new method of concentrating and cleaning diatoams and other organisms. Int. Ver. Theor. Angew. Limnol. Verh. 12:276-277.

Waters, M.N., C.L. Schelske, W.F. Kenney, and A.D. Chapman. 2005. The use of sedimentary algal pigments to infer historic algal communities in lake Apopka, Florida. Journal of Paleolimnology 33:53-71.

Whitmore, T. J. 1989. Florida diatom assemblages as indicators of trophic state and pH. Limnology and Oceanography 34: 882-895.

Table 1. Location of sediment coring stations in Lake Bellows.

Station	Latitude	Longitude
Station 1:	N 27.98967	W 082.37917
Station 2:	N 27.98987	W 082.38063
Station 3:	N 27.99044	W 082.37991
Station 4:	N 27.99045	W 082.37985
Station 5:	N 27.98872	W 082.38055

Table 2. Radionuclide dating of sediment core from station 4.

Depth Interval (cm)	Total Pb-210 Activity(dpm/g)	Supported Pb-210 Activity(dpm/g)	Cs-137 Activity(dpm/g)	Excess Pb-210 Activity(dpm/g)	AGE at given Depth(yr)	DATE at given Depth	MASS Sedimentation Rate (mg/cm2/yr)
0-5	21.283	1.694	0.648	19.818	1.09	2009	25.2
5-10	20.358	1.752	0.606	18.830	5.85	2004	24.2
10-15	16.950	1.694	0.682	15.441	14.92	1995	23.9
15-20	9.314	1.698	1.051	7.710	23.80	1986	36.1
20-25	9.107	3.436	1.884	5.741	35.61	1974	35.2
25-30	7.370	5.135	3.073	2.263	41.37	1969	67.7
30-35	6.676	4.402	2.873	2.303	52.36	1958	51.4
35-40	5.784	2.867	1.167	2.954	69.21	1941	26.2
40-45	5.708	2.144	0.209	3.611	117.97	1892	8.4
45-50	2.610	1.947	0.212	0.67			

Table 3. Past limnetic water-quality inferences for sediment core samples as inferred by weighted-averaging diatom models. Samples marked ** are likely to represent unreliable inferences because they appear to be outliers with respect to the calibration set of samples from 75 Florida lakes, as indicated by DCA ordination biplots.

Core	Depth (cm)	Chl a (mg/L)	total P (mg/L)	TSI	210Pb date
4	0	17.1	0.031	56.3	(2010)
4	5	26.6	0.044	61.7	2009
4	10	35.9	0.051	65.3	2004
4	15	63.1	0.082	71.7	1995
4	20	67.6	0.082	72.2	1986
4	25	72.3	0.086	72.7	1974
4	30	53.2	0.067	69.7	1969
4	35	19.4	0.029	54.4	1958
4	40	23.8	0.040	58.0	1941
4	45	15.7	0.042	62.0	1892
1	40	22	0.045	58.6	
5	70	7.9	0.047	56.4	

Table 4.

Depth (cm)	% native chlorophyll	chlorophyll derivatives (Abs/g org)	total carotenoids (Abs/g org)	oscillaxan-thin (µg pig/g org)	Myxoxan-thophyll (µg pig/g org)
0-5	36.30	4.03	3.39	54.96	216.09
5-10	21.82	3.80	3.54	45.45	233.19
10-15	7.20	3.14	2.68	39.28	75.28
15-20	11.49	3.62	2.34	56.62	46.79
20-25	9.73	3.72	2.72	40.31	30.19
25-30	12.16	3.12	2.64	44.78	43.11
30-35	2.38	1.40	1.56	58.90	78.91
35-40	2.58	0.96	0.84	61.09	50.62
40-45	6.64	0.79	0.72	65.36	48.08
45-50	11.53	0.56	0.27	11.53	16.68
50-55	1.51	0.45	0.19	15.65	14.31
55-60	11.78	0.44	0.35	12.54	18.75
60-65	10.99	0.45	0.22	7.31	13.65
65-70	0.45	0.35	0.47	9.35	12.58

Abs/g org = Absorbance/g organic matter, µg pig/g org = µg pigment/g organic matter, Oscillaxan = Oscillaxanthin, Myxoxan = Myxoxanthophyll.

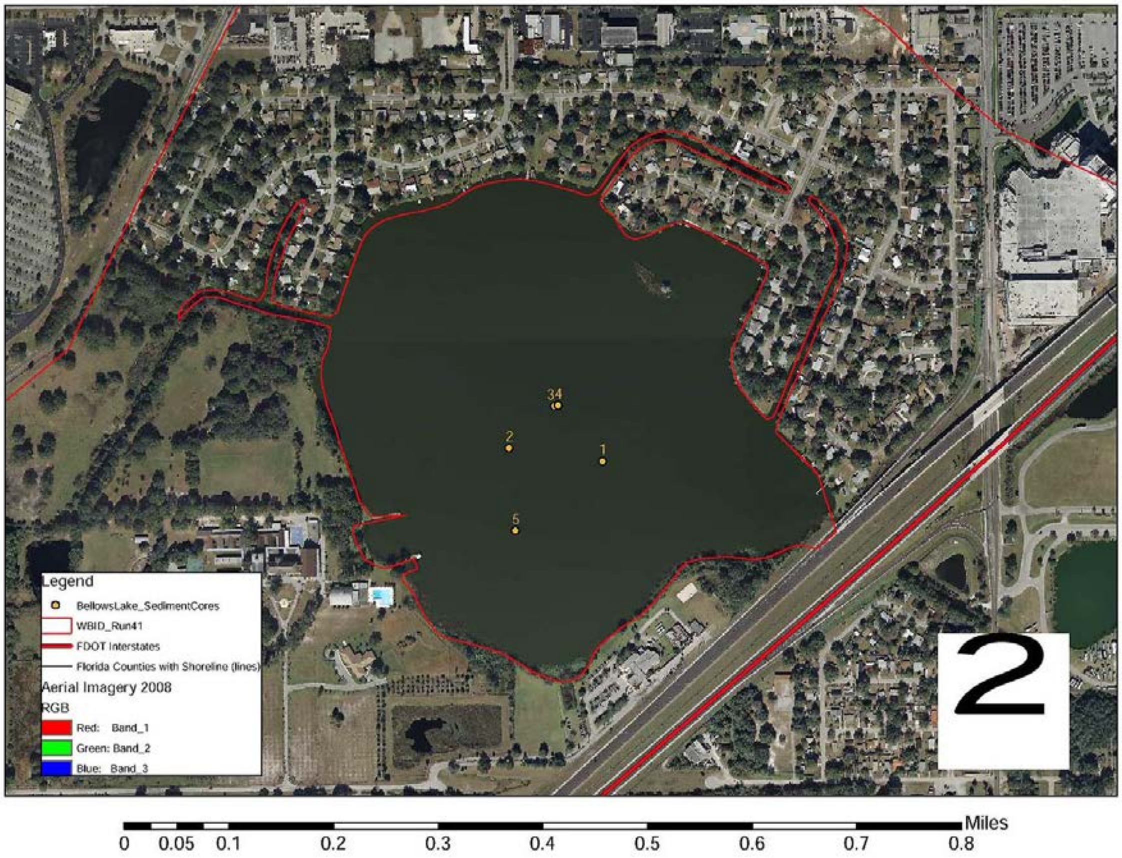


Figure 1. Location of sediment coring sites in Lake Bellows. Figure provided by Florida Department of Environmental Protection.

Figure 2. Sediment cores obtained from Lake Bellows on October 5, 2010. From left to right, the cores are sequentially from stations 1-5, Sediment cores from stations 1, 3, 4, and 5 were sampled for paleolimnological analyses.

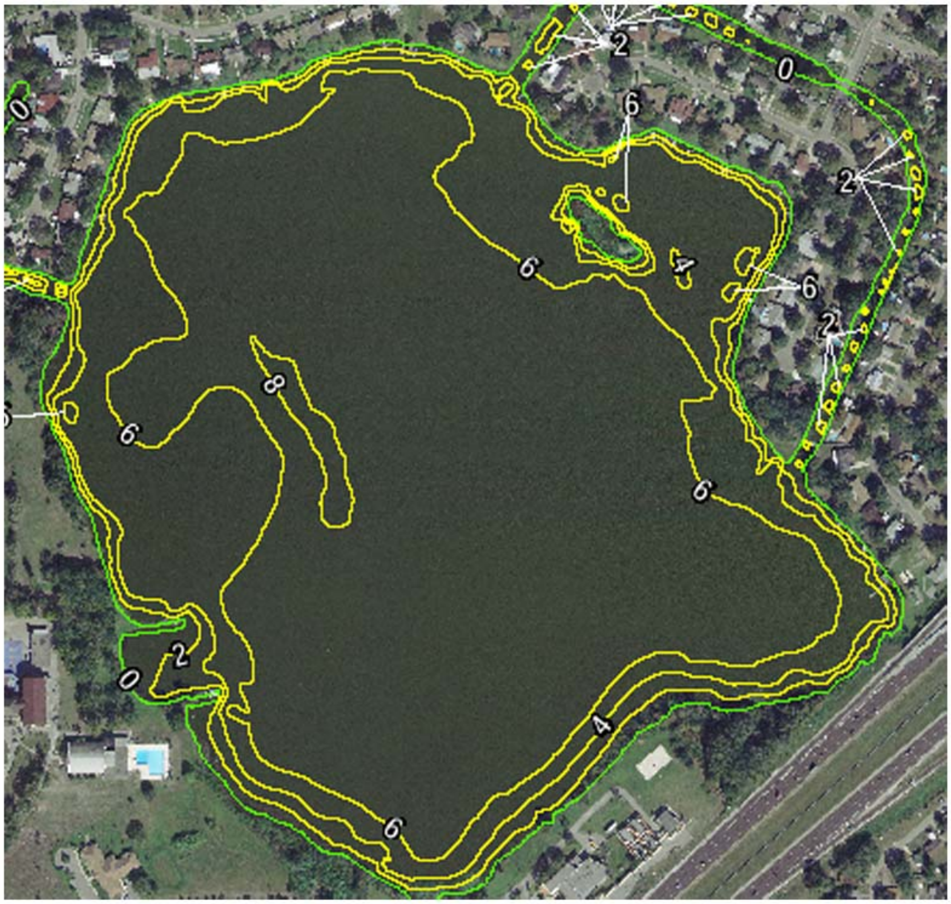


Figure 3. Morphometric map of Lake Bellows. Contours are shown in 2-foot intervals. Figure provided by Florida Department of Environmental Protection.

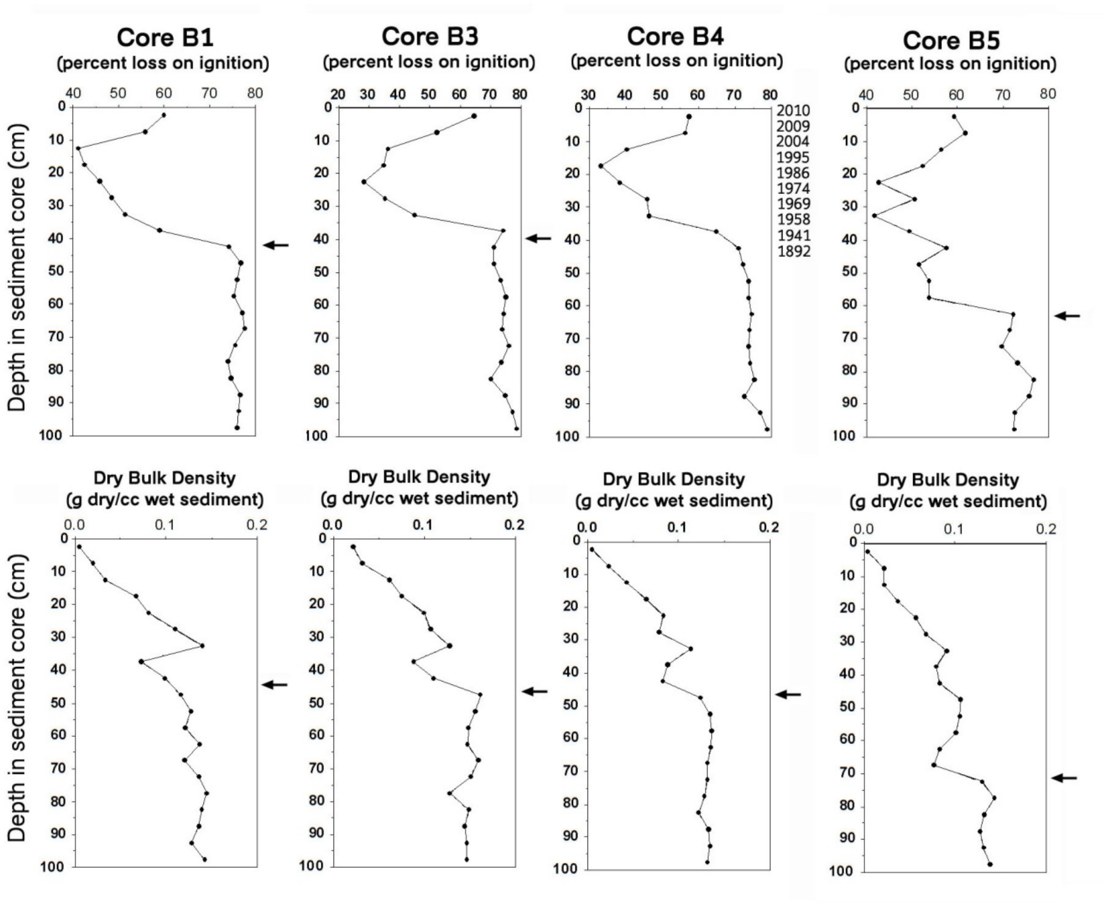


Figure 4. Percent loss-on-ignition and dry bulk density profiles used for stratigraphic correlation of cores 1, 3, 4, and 5. The excess ^{210}Pb supported level in core 4, which corresponds with the pre-disturbance horizon, occurred at approximately 45 cm, a point that represents the top of a stable period of loss-on-ignition and dry bulk density values at the base of the cores. The arrows approximate the levels that correspond strratigraphically with the supported levels in core 4.

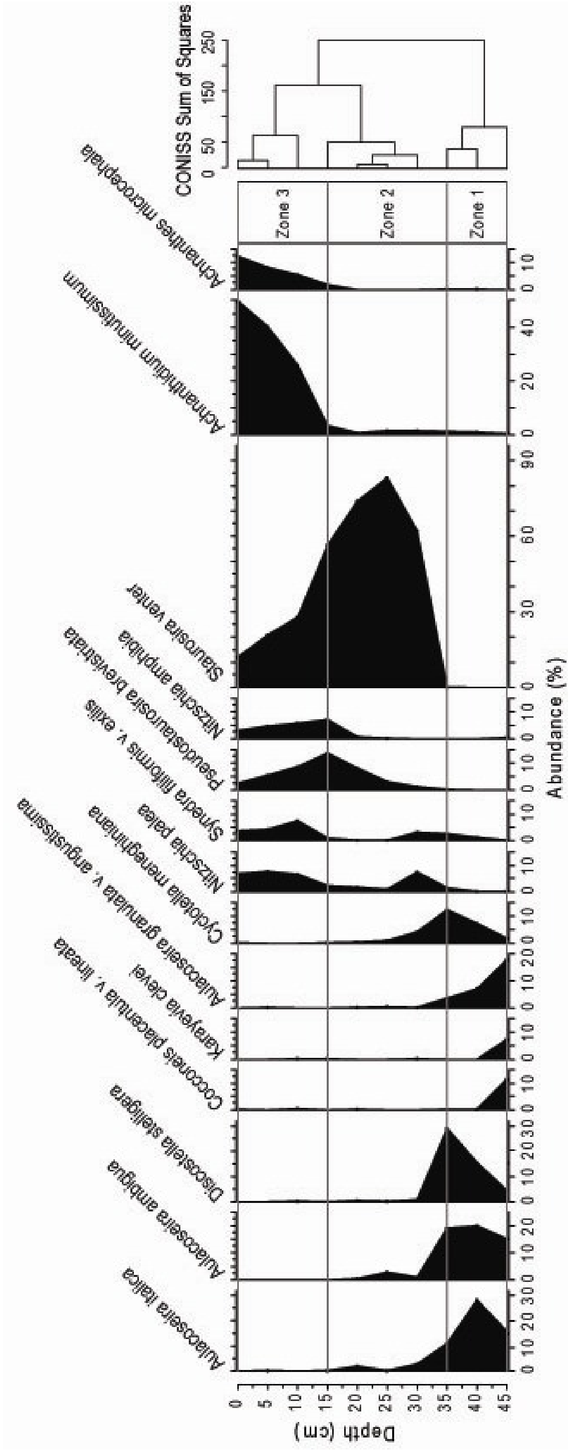


Figure 5. Percentage of diatom species in core 4, and core zonation by Coniss.

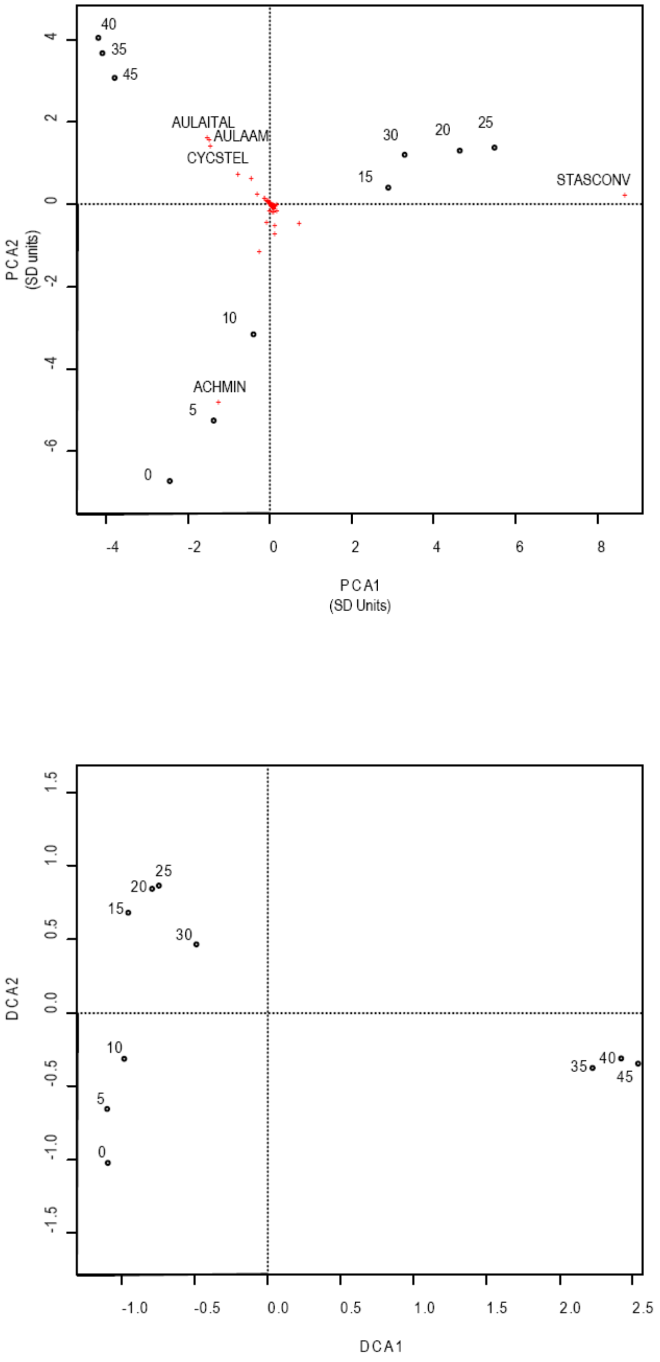


Figure 6. Biplots of axes 1 and 2 scores from principal components analysis (top panel) and detrended correspondence analysis (bottom panel). Taxa designated in the PCA biplot are in the upper right, *Staurosira venter*, in the upper left are *Discotella stelligera*, *Aulacoseira italica, A. ambigua*, and in the lower left is *Achnanthidium minutissimum*

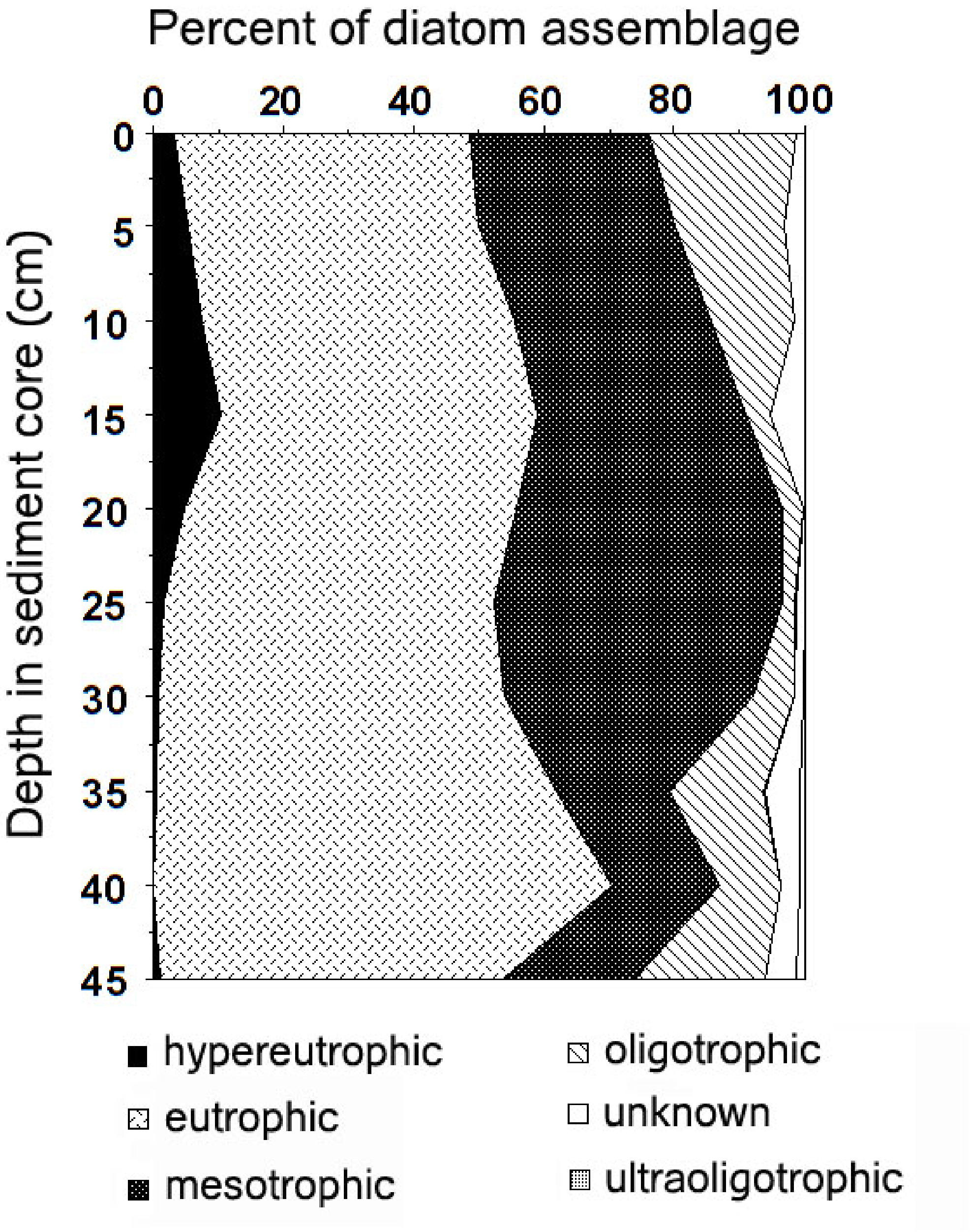


Figure 7. Percentages of the diatom assemblages in various trophic ecological categories, as defined by literature autecological descriptions of taxa in the samples. Eutrophic and mesotrophic taxa represent the largest portion of the diatoms assemblages throughout the historical period (c. 1892 to the present). The ultraoligotrophic percentage is the small portion to the lower right in the figure, and it is less than 1% in all cases.

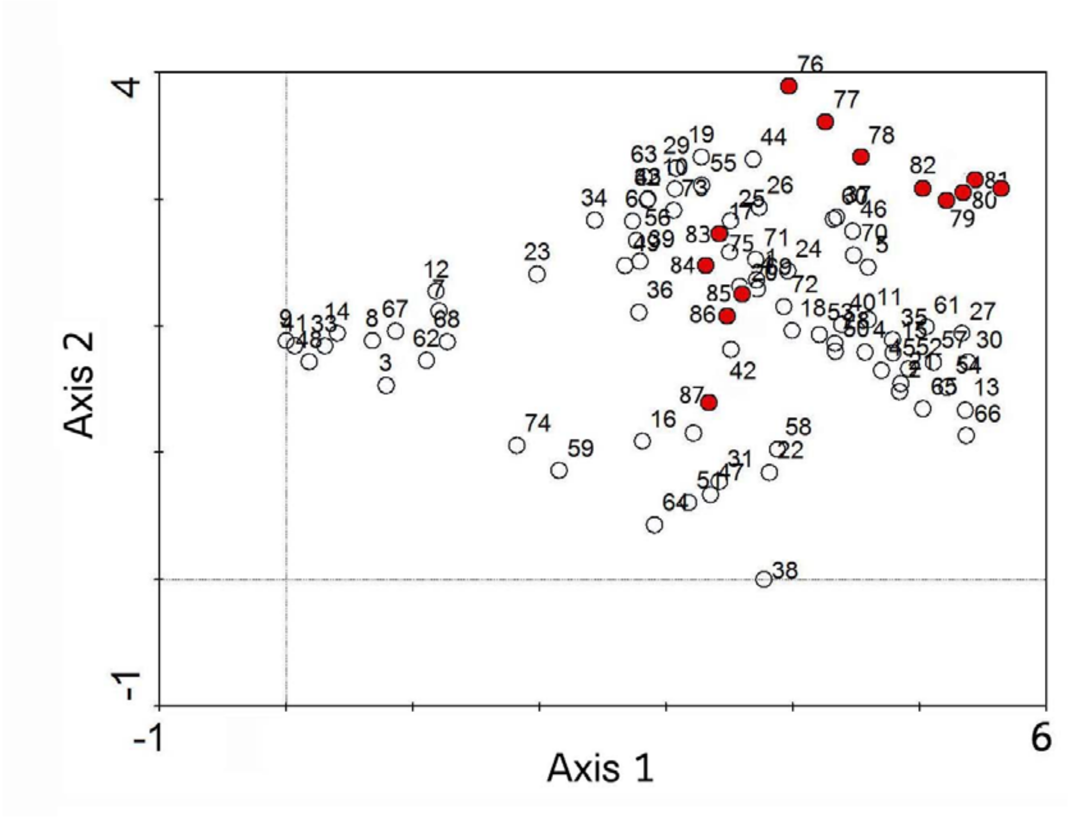


Figure 8. Biplot of axes 1 and 2 from detrended correspondence analysis of species data in the calibration set and in the Lake Bellows core samples. Numbers 1-75 refer to the 75 samples in the calibration data set. Samples 76-82, in the upper right hand portion of the figure, correspond sequentially to the 0-cm through the 30-cm samples in Lake Bellows core 4, and their diatom assemblages appear to be outliers with respect to the lakes in the calibration data set. As a result, those samples are not likely to yield reliable water-quality inferences. Numbers 83-87 correspond respectively to the core 4 35-cm, 40-cm, and 45-cm samples, and to the core 1 40-cm sample, and the core 5 70-cm sample. These latter samples, which represent pre-disturbance to early disturbance conditions in the history of Lake Bellows, are better centered within the calibration set, and therefore are likely to yield more reliable water quality inferences.

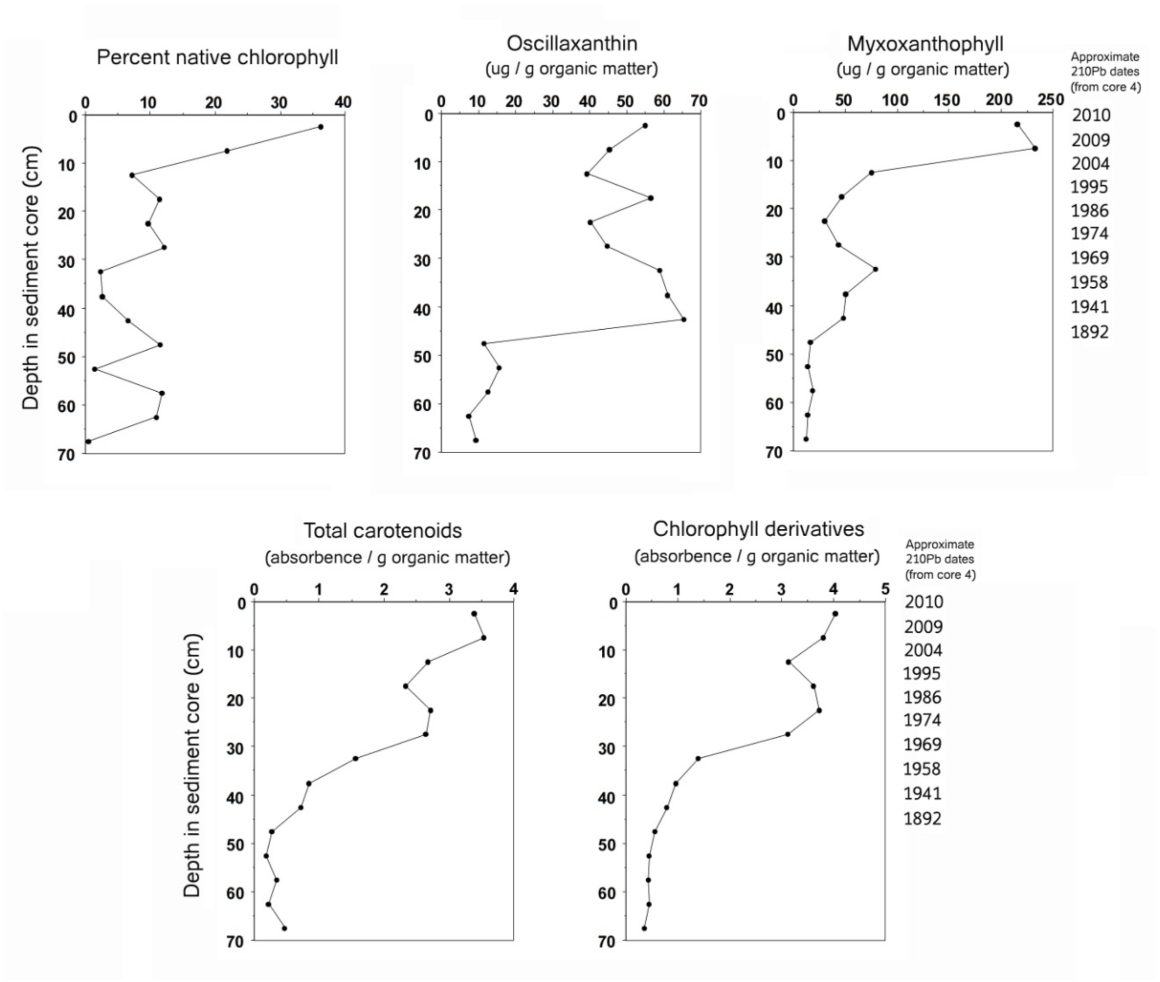
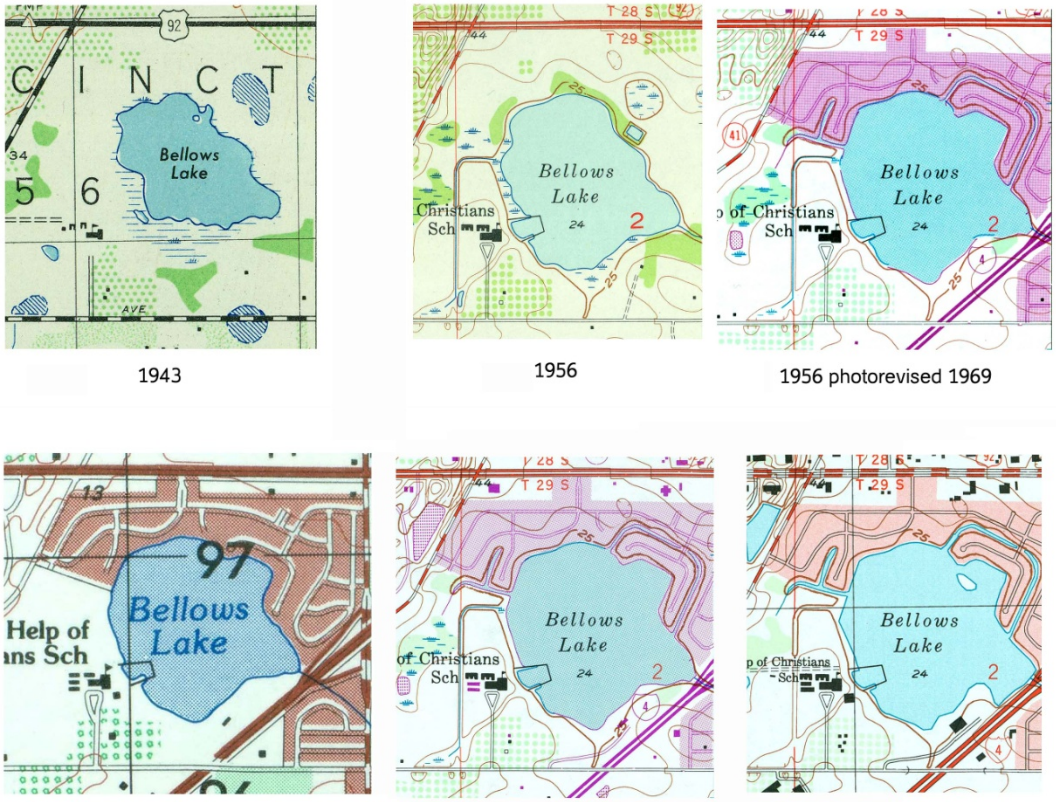


Figure 9. Sedimented algal pigments in core 3. The ^{210}Pb dates obtained from core 4 are shown to provide an approximate time frame for observed changes. Increase pigment preservation in the top 10 cm of sediment, as shown by the percent native chlorophyll panel (upper left), indicate that the apparent increase in pigment concentrations in the top 10 cm of the sediment core probably are an artifact of improved preservation.



1943

1956

1956 photorevised 1969

1979

1956 photorevised 1981

1956 photorevised 1985

Figure 10. Historical changes in the lake and watershed based upon U.S. Geological Survey 7.5-minute series topographic maps. Water level appears to be slightly lower in the 1943 map, citrus agriculture is present on the south side, and wetlands are present on the south and southwest shores. By 1956, water levels appear higher and wetlands are reduced Canals are evident on the eastern and westerns shores. The 1969 map shows extensive residential development on the northern shore with a circular canal, and urbanization and the presence of interstate highway I-4 on the eastern shore. By 1985, the portion of the lake abutting I-4 is expanded on the east side and a promontory was created (near the inset number 2).

Appendix I: Diatom counts for Lake Bellows core 4.

Core 4, 0 cm

Species	Percent	Number
Achnanthes linearis f. curta H.L. Smith	1.57	8
Achnanthes microcephala (Kützing) Grunow	12.40	63
Achnanthidium exiguum (Grunow) Czarnecki	0.39	2
Achnanthidium minutissimum (Kützing) Czarnecki	49.61	252
Cocconeis placentula v. lineata (Ehrenberg) Van Heurck	0.20	1
Cyclotella meneghiniana Kützing	0.39	2
Nitzschia acula (Kützing) Hantzsch	1.38	7
Nitzschia amphibia Grunow	3.15	16
Nitzschia palea (Kützing) W. Smith	6.89	35
Opephora americana M. Peragallo	1.18	6
Pseudostaurosira brevistriata (Grunow) Williams & Round	2.76	14
Rossithidium linearis (W. Smith) Round et Bukhtiyarova	3.15	16
Staurosira construens Ehrenberg	0.79	4
Staurosira venter (Ehrenberg) H. Kobayasi	12.20	62
Staurosirella pinnata (Ehrenberg) Williams & Round	0.20	1
Synedra filiformis v. exilis Cleve-Euler	3.74	19
Total	100.00	508

Core 4, 5 cm

Species	Percent	Number
Achnanthes linearis f. curta H.L. Smith	0.90	5
Achnanthes microcephala (Kützing) Grunow	8.26	46
Achnanthidium minutissimum (Kützing) Czarnecki	40.22	224
Aulacoseira granulata v. angustissima (Otto Müller) Simonsen	0.18	1
Aulacoseira italica (Ehrenberg) Simonsen	0.18	1
Brachysira vitrea (Grunow) R. Ross	0.36	2
Encyonema muelleri (Hustedt) Mann	0.18	1
Gomphonema clevei Fricke in Schmidt et al.	0.36	2
Gomphonema gracile Ehrenb. em. VanHeurck	0.36	2
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin & Witkowski	0.36	2
Lemnicola hungarica (Grunow) Round et Basson	0.18	1
Nitzschia acula (Kützing) Hantzsch	0.72	4
Nitzschia amphibia Grunow	4.67	26
Nitzschia palea (Kützing) W. Smith	7.90	44
Opephora americana M. Peragallo	1.80	10
Pseudostaurosira brevistriata (Grunow) Williams & Round	5.57	31
Sellaphora pupula (Kützing) Mereschkowsky	0.18	1
Staurosira construens Ehrenberg	0.54	3
Staurosirella martyi (Héribaud) E.A. Morales & K.M. Manoylov	0.72	4
Staurosira venter (Ehrenberg) H. Kobayasi	20.83	116
Synedra filiformis v. exilis Cleve-Euler	4.31	24
Synedra rumpens v. familiaris (Kützing) Hustedt	0.36	2
Unknown	0.90	5
Total	100.4	557

Core 4, 10 cm

Species	Percent	Number
Achnanthes linearis f. curta H.L. Smith	0.4	2
Achnanthes microcephala (Kützing) Grunow	5.4	27
Achnanthidium exiguum (Grunow) Czarnecki	0.6	3
Achnanthidium minutissimum (Kützing) Czarnecki	25.8	129
Aulacoseira islandica (Otto Müller) Simonsen	0.4	2
Brachysira vitrea (Grunow) R. Ross	1.0	5
Cocconeis placentula v. lineata (Ehrenberg) Van Heurck	0.6	3
Discostella stelligera (Cleve et Grunow) Houk & Klee	0.2	1
Encyonema muelleri (Hustedt) Mann	0.4	2
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin & Witkowski	0.4	2
Karayevia clevei (Grunow) Bukhtiyarova	0.2	1
Luticola mutica (Kützing) Mann	0.2	1
Nitzschia acula (Kützing) Hantzsch	1.8	9
Nitzschia amphibia Grunow	5.8	29
Nitzschia palea (Kützing) W. Smith	6.6	33
Opephora americana M. Peragallo	1.6	8
Pseudostaurosira brevistriata (Grunow) Williams & Round	8.8	44
Staurosira construens Ehrenberg	2.8	14
Staurosirella martyi (Héribaud) E.A. Morales & K.M. Manoylov	0.6	3
Staurosira venter (Ehrenberg) H. Kobayasi	28.0	140
Synedra filiformis v. exilis Cleve-Euler	7.4	37
Synedra rumpens v. familiaris (Kützing) Hustedt	0.6	3
Ulnaria delicatissima (W. Smith) M. Aboal & P.C. Silva	0.2	1
Ulnaria ulna (C.L. Nitzsch) Compère	0.2	1
Total	100.0	500

Core 4, 15 cm

Species	Percent	Number
Achnanthes linearis f. curta H.L. Smith	0.39	2
Achnanthes microcephala (Kützing) Grunow	1.74	9
Achnanthidium exiguum (Grunow) Czarnecki	0.39	2
Achnanthidium minutissimum (Kützing) Czarnecki	3.49	18
Aulacoseira distans (Ehrenberg) Simonsen	0.19	1
Aulacoseira italica (Ehrenberg) Simonsen	0.39	2
Brachysira brebissonii R. Ross	0.97	5
Craticula cuspidata (Kützing) Mann	0.19	1
Cyclotella meneghiniana Kützing	0.19	1
Encyonema minutum (Hilse in Rabenhorst) Mann	0.19	1
Encyonema silesiacum (Bleisch in Rabenhorst) Mann	0.19	1
Eunotia pectinalis v. minor (Kützing) Rabenhorst	0.19	1
Gomphonema clevei Fricke in Schmidt et al.	0.78	4
Gomphonema gracile Ehrenb. em. VanHeurck	0.19	1
Karayevia clevei (Grunow) Bukhtiyarova	0.19	1
Nitzschia acula (Kützing) Hantzsch	0.39	2
Nitzschia amphibia Grunow	7.17	37
Nitzschia palea (Kützing) W. Smith	2.33	12
Opephora americana M. Peragallo	4.07	21
Pinnularia biceps Gregory	0.19	1
Pseudostaurosira brevistriata (Grunow) Williams & Round	13.76	71
Rhopalodia gibberula v. vanheurckii Otto Müller	0.19	1
Rossithidium linearis (W. Smith) Round et Bukhtiyarova	0.78	4
Staurosira construens Ehrenberg	2.91	15
Staurosirella martyi (Héribaud) E.A. Morales & K.M. Manoylov	0.78	4
Staurosira venter (Ehrenberg) H. Kobayasi	56.40	291
Ulnaria delicatissima (W. Smith) M. Aboal & P.C. Silva	0.39	2
Synedra filiformis v. exilis Cleve-Euler	0.97	5
Total	100.00	516

Core 4, 20 cm

Species	Percent	Number
Achnanthes linearis f. curta H.L. Smith	2.39	13
Achnanthidium exiguum (Grunow) Czarnecki	1.47	8
Achnanthidium minutissimum (Kützing) Czarnecki	0.74	4
Aulacoseira ambigua (Grunow) Simonsen	0.55	3
Aulacoseira granulata v. angustissima (Otto Müller) Simonsen	0.18	1
Aulacoseira italica (Ehrenberg) Simonsen	2.03	11
Brachysira brebissonii R. Ross	0.18	1
Brachysira vitrea (Grunow) R. Ross	0.37	2
Cocconeis placentula v. lineata (Ehrenberg) Van Heurck	0.18	1
Cyclotella meneghiniana Kützing	0.55	3
Discostella stelligera (Cleve et Grunow) Houk & Klee	0.55	3
Eunotia naegelii Migula	0.18	1
Eunotia formica Ehrenberg	0.18	1
Eunotia pectinalis v. minor (Kützing) Rabenhorst	0.18	1
Gomphonema clevei Fricke in Schmidt et al.	0.18	1
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin & Witkowski	0.92	5
Luticola mutica (Kützing) Mann	0.74	4
Navicula gottlandica Grunow	0.18	1
Nitzschia acula (Kützing) Hantzsch	0.55	3
Nitzschia amphibia Grunow	0.92	5
Nitzschia palea (Kützing) W. Smith	1.84	10
Pseudostaurosira brevistriata (Grunow) Williams & Round	8.29	45
Staurosira construens Ehrenberg	1.47	8
Staurosira venter (Ehrenberg) H. Kobayasi	74.03	402
Synedra filiformis v. exilis Cleve-Euler	0.37	2
Ulnaria delicatissima (W. Smith) M. Aboal & P.C. Silva	0.55	3
Unknown	0.18	1
Total	99.95	543

Core 4, 25 cm

Species	Percent	Number
Achnantheiopsis dubia (Grunow) Lange-Bertalot	0.20	1
Achnanthes linearis f. curta H.L. Smith	0.20	1
Achnanthidium exiguum (Grunow) Czarnecki	0.79	4
Achnanthidium minutissimum (Kützing) Czarnecki	1.58	8
Aulacoseira ambigua (Grunow) Simonsen	2.77	14
Aulacoseira granulata v. angustissima (Otto Müller) Simonsen	0.59	3
Aulacoseira italica (Ehrenberg) Simonsen	0.40	2
Brachysira vitrea (Grunow) R. Ross	0.20	1
Capartogramma crucicula (Grunow ex Cleve) Ross	0.20	1
Cyclostephanos dubius (Fricke) Round	0.20	1
Cyclotella meneghiniana Kützing	0.99	5
Discostella stelligera (Cleve et Grunow) Houk & Klee	0.40	2
Eunotia monodon Ehrenberg	0.20	1
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin & Witkowski	0.40	2
Luticola mutica (Kützing) Mann	0.20	1
Navicula exigua v. capitata Patrick	0.20	1
Navicula radiosa v. parva Wallace	0.40	2
Nitzschia amphibia Grunow	0.20	1
Nitzschia palea (Kützing) W. Smith	1.19	6
Parlibellus protracta (Grunow) A. Witkowski, H. Lange-Bertalot & D. Metzeltin	0.20	1
Pinnularia boyeri Patrick	0.20	1
Pinnularia braunii (Grunow) Cleve	0.20	1
Pinnularia caudata (Boyer) Patrick	0.20	1
Planothidium hauckianum v. rostrata (Schulz) Bukhtiyarova	0.20	1
Pseudostaurosira brevistriata (Grunow) Williams & Round	3.17	16
Rhopalodia gibberula v. vanheurckii Otto Müller	0.20	1
Staurosira construens Ehrenberg	0.20	1
Staurosira venter (Ehrenberg) H. Kobayasi	83.17	420
Synedra filiformis v. exilis Cleve-Euler	0.40	2
Synedra rumpens v. familiaris (Kützing) Hustedt	0.40	2
Synedra socia Wallace	0.20	1
Total	100.05	505

Core 4, 30 cm

Species	Percent	Number
Achnantheiopsis dubia (Grunow) Lange-Bertalot	0.97	5
Achnanthes lanceolata v. omissa Reimer	0.19	1
Achnanthidium exiguum (Grunow) Czarnecki	2.73	14
Achnanthidium minutissimum (Kützing) Czarnecki	1.56	8
Aulacoseira ambigua (Grunow) Simonsen	1.17	6
Aulacoseira granulata v. angustissima (Otto Müller) Simonsen	0.39	2
Aulacoseira italica (Ehrenberg) Simonsen	2.73	14
Cyclostephanos dubius (Fricke) Round	0.78	4
Cyclotella meneghiniana Kützing	4.09	21
Discostella stelligeroides (Hustedt) Houk & Klee	0.19	1
Discostella stelligera (Cleve et Grunow) Houk & Klee	0.78	4
Eunotia pectinalis v. minor (Kützing) Rabenhorst	0.19	1
Frustulia rhomboides (Ehrenberg) De Toni	0.39	2
Gomphonema parvulum (Kützing) Kützing	0.19	1
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin & Witkowski	0.19	1
Karayevia clevei (Grunow) Bukhtiyarova	0.19	1
Luticola mutica (Kützing) Mann	0.19	1
Navicula exigua v. capitata Patrick	0.39	2
Nitzschia acula (Kützing) Hantzsch	0.97	5
Nitzschia fonticola (Grunow) Grunow	0.19	1
Nitzschia palea (Kützing) W. Smith	7.60	39
Nitzschia sp	0.19	1
Parlibellus protracta (Grunow) A. Witkowski, H. Lange-Bertalot & D. Metzeltin	0.19	1
Pinnularia biceps Greg	0.19	1
Pinnularia sp	0.19	1
Pseudostaurosira brevistriata (Grunow) Williams & Round	1.36	7
Rhopalodia gibberula v. vanheurckii Otto Müller	0.19	1
Rossithidium linearis (W. Smith) Round et Bukhtiyarova	0.97	5
Sellaphora bacillum (Ehrenberg) D.G. Mann	0.19	1
Sellaphora pupula (Kützing) Mereschkowsky	0.19	1
Staurosira venter (Ehrenberg) H. Kobayasi	61.99	318
Synedra filiformis v. exilis Cleve-Euler	3.31	17
Synedra rumpens v. familiaris (Kützing) Hustedt	0.19	1
Synedra tenera W. Sm.	0.19	1
Ulnaria delicatissima (W. Smith) M. Aboal & P.C. Silva	0.97	5
Ulnaria ulna (C.L. Nitzsch) Compère	3.51	18
Total	99.89	513

Core 4, 35 cm

Species	Percent	Number
Achnantheiopsis dubia (Grunow) Lange-Bertalot	0.20	1
Achnanthes microcephala (Kützing) Grunow	0.20	1
Achnanthidium exiguum (Grunow) Czarnecki	0.98	5
Achnanthidium minutissimum (Kützing) Czarnecki	1.37	7
Aulacoseira ambigua (Grunow) Simonsen	19.22	98
Aulacoseira distans (Ehrenberg) Simonsen	0.20	1
Aulacoseira granulata (Ehrenberg) Simonsen	1.18	6
Aulacoseira granulata v. angustissima (Otto Müller) Simonsen	3.73	19
Aulacoseira italica (Ehrenberg) Simonsen	11.18	57
Brachysira brebissonii R. Ross	0.20	1
Capartogramma crucicula (Grunow ex Cleve) Ross	0.39	2
Cocconeis pediculus Ehrenberg	0.59	3
Cocconeis placentula v. lineata (Ehrenberg) Van Heurck	0.39	2
Cyclostephanos dubius (Fricke) Round	0.59	3
Cyclotella meneghiniana Kützing	12.35	63
Cyclotella striata (Kützing) Grunow in Cleve & Grunow	1.37	7
Discostella stelligeroides (Hustedt) Houk & Klee	0.39	2
Discostella stelligera (Cleve et Grunow) Houk & Klee	29.22	149
Eunotia formica Ehrenberg	0.20	1
Eunotia monodon v. constricta A. Berg	0.20	1
Eunotia pectinalis (Kützing) Rabenhorst	0.20	1
Eunotia pectinalis v. minor (Kützing) Rabenhorst	1.57	8
Frustulia rhomboides (Ehrenberg) De Toni	1.18	6
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin & Witkowski	0.39	2
Lemnicola hungarica (Grunow) Round et Basson	0.39	2
Luticola mutica (Kützing) Mann	1.57	8
Navicula exigua v. capitata Patrick	0.59	3
Navicula radiosa v. parva Wallace	0.59	3
Navicula viridula v. rostellata (Kützing) Cleve	0.20	1
Neidium iridis v. amphigomphus (Ehrenberg) Mayer	0.20	1
Nitzschia palea (Kützing) W. Smith	1.57	8
Parlibellus protracta (Grunow) A. Witkowski, H. Lange-Bertalot & D. Metzeltin	0.39	2
Pinnularia abaujensis (Pantocsek) Ross	0.39	2
Pinnularia biceps Gregory	0.20	1
Pinnularia viridis v. minor Cleve	0.20	1
Placoneis exigua (Gregory) Mereschkowsky	0.20	1
Planothidium stewartii (Patrick) H. Lange-Bertalot	0.20	1
Planothidium apiculatum (Patrick) R. Lowe	0.20	1
Pseudostaurosira brevistriata (Grunow) Williams & Round	0.20	1
Rossithidium linearis (W. Smith) Round et Bukhtiyarova	0.39	2
Rhopalodia gibberula v. vanheurckii Otto Müller	1.37	7
Sellaphora mutata (Krasske) J.R. Johansen	0.39	2

Staurosira venter (Ehrenberg) H. Kobayasi	0.20	1
Staurosirella pinnata (Ehrenberg) Williams & Round	0.20	1
Synedra filiformis v. exilis Cleve-Euler	2.55	13
Synedra incisa Boyer	0.39	2
Total	100.07	510

Core 4, 40 cm

Species	Percent	Number
Achnanthes linearis f. curta H.L. Smith	0.19	1
Achnanthes microcephala (Kützing) Grunow	0.19	1
Achnanthidium exiguum (Grunow) Czarnecki	1.86	10
Achnanthidium minutissimum (Kützing) Czarnecki	0.93	5
Aulacoseira ambigua (Grunow) Simonsen	20.07	108
Aulacoseira distans (Ehrenberg) Simonsen	0.19	1
Aulacoseira granulata (Ehrenberg) Simonsen	3.53	19
Aulacoseira granulata v. angustissima (Otto Müller) Simonsen	7.06	38
Aulacoseira italica (Ehrenberg) Simonsen	28.25	152
Capartogramma crucicula (Grunow ex Cleve) Ross	0.19	1
Cocconeis placentula v. lineata (Ehrenberg) Van Heurck	0.37	2
Cyclotella meneghiniana Kützing	7.25	39
Cyclotella striata (Kützing) Grunow in Cleve & Grunow	0.56	3
Discostella stelligera (Cleve et Grunow) Houk & Klee	15.61	84
Eunotia Vanheurckii Pat.	0.19	1
Eunotia vanheurckii v. intermedia (Krasske ex Hustedt) Patrick	0.19	1
Eunotia monodon v. constricta A. Berg	0.19	1
Eunotia pectinalis v. minor (Kützing) Rabenhorst	1.67	9
Frustulia rhomboides (Ehrenberg) De Toni	0.74	4
Gomphonema affine v. insigne (Greg) An	0.19	1
Gomphonema sp	0.56	3
Luticola mutica (Kützing) Mann	2.04	11
Navicula cryptocephala Kützing	0.19	1
Navicula radiosa v. parva Wallace	1.67	9
Nitzschia palea (Kützing) W. Smith	0.37	2
Tryblionella scalaris (Ehrenberg) P. Siver & P.B. Hamilton	0.37	2
Opephora americana M. Peragallo	0.37	2
Pinnularia braunii (Grunow) Cleve	0.19	1
Pinnularia sp	0.56	3
Planothidium apiculatum (Patrick) R. Lowe	0.74	4
Rhopalodia gibberula v. vanheurckii Otto Müller	0.74	4
Rossithidium linearis (W. Smith) Round et Bukhtiyarova	0.19	1
Sellaphora pupula (Kützing) Mereschkowsky	0.56	3
Sellaphora elliptica (Hustedt) J.R. Johansen	0.19	1
Synedra filiformis v. exilis Cleve-Euler	1.30	7
Synedra rumpens v. meneghiniana Grunow	0.19	1
Unknown	0.37	2
Total	100.02	538

Core 4, 45 cm

Species	Percent	Number
Achnantheiopsis dubia (Grunow) Lange-Bertalot	0.20	1
Achnanthes linearis f. curta H.L. Smith	1.40	7
Achnanthes pinnata Hustedt	0.60	3
Achnanthes saxonica Krasske	0.60	3
Achnanthes sp	0.20	1
Achnanthidium exiguum (Grunow) Czarnecki	0.40	2
Achnanthidium minutissimum (Kützing) Czarnecki	0.40	2
Amphora pediculus (Kützing) Grunow	0.40	2
Aulacoseira ambigua (Grunow) Simonsen	15.17	76
Aulacoseira distans (Ehrenberg) Simonsen	1.60	8
Aulacoseira granulata (Ehrenberg) Simonsen	2.00	10
Aulacoseira granulata v. angustissima (Otto Müller) Simonsen	17.76	89
Aulacoseira italica (Ehrenberg) Simonsen	15.97	80
Aulacoseira lirata (Ehrenberg) R. Ross	0.20	1
Caloneis ventricosa (Ehrenberg) Meister	0.20	1
Cavinula jaernefeltii (Hustedt) D.G. Mann & A.J. Stickle	0.20	1
Cocconeis placentula v. euglypta (Ehrenberg) Grunow	0.40	2
Cocconeis placentula v. lineata (Ehrenberg) Van Heurck	11.58	58
Craticula cuspidata (Kützing) Mann	0.20	1
Cyclotella meneghiniana Kützing	1.80	9
Cyclotella striata (Kützing) Grunow in Cleve & Grunow	0.20	1
Discostella stelligera (Cleve et Grunow) Houk & Klee	4.39	22
Eunotia incisa W. Smith	0.20	1
Eunotia pectinalis (Kützing) Rabenhorst	0.20	1
Eunotia pectinalis v. minor (Kützing) Rabenhorst	1.80	9
Eunotia soleirolii (Kützing) Rabenhorst	0.20	1
Eunotia zygodon Ehrenberg	0.20	1
Frustulia rhomboides (Ehrenberg) De Toni	2.40	12
Gomphonema gracile Ehrenb. em. VanHeurck	0.40	2
Gomphonema parvulum (Kützing) Kützing	0.20	1
Gomphonema sp	0.20	1
Karayevia clevei (Grunow) Bukhtiyarova	7.39	37
Luticola mutica (Kützing) Mann	0.60	3
Navicula exigua v. capitata Patrick	0.20	1
Navicula radiosa Kützing	0.40	2
Navicula radiosa v. parva Wallace	0.40	2
Neidium sp	0.40	2
Nitzschia amphibia Grunow	0.60	3
Nitzschia palea (Kützing) W. Smith	0.40	2
Opephora americana M. Peragallo	0.20	1
Pinnularia abaujensis v. rostrata (Patrick) Patrick	0.20	1
Pinnularia braunii (Grunow) Cleve	0.60	3
Pinnularia braunii v. amphicephala (Mayer) Hustedt	0.40	2
Pinnularia caudata (Boyer) Patrick	0.60	3
Pinnularia dactylus Ehrenberg	0.20	1
Pinnularia legumen Ehrenberg	0.40	2

Pinnularia sp	0.40	2
Planothidium apiculatum (Patrick) R. Lowe	0.40	2
Platessa hustedtii (Krasske) H. Lange-Bertalot	1.00	5
Rhopalodia gibberula v. vanheurckii Otto Müller	0.60	3
Rossithidium linearis (W. Smith) Round et Bukhtiyarova	1.00	5
Sellaphora pupula (Kützing) Mereschkowsky	0.20	1
Sellaphora rectangularis (Gregory) Lange-Bertalot et Metzeltin	0.40	2
Synedra linearis Ehrenberg	0.40	2
Synedra filiformis v. exilis Cleve-Euler	0.40	2
Tryblionella scalaris (Ehrenberg) P. Siver & P.B. Hamilton	0.40	2
Unknown	0.20	1
Total	100.06	501

Appendix I: Diatom counts for Lake Bellows core 1.

Core 1, 40 cm

Species	Percent	Number
Achnanthes linearis f. curta H.L. Sm.	0.19	1
Achnanthidium exiguum (Grunow) Czarnecki	0.39	2
Anomoeoneis serians v. acuta Hust.	0.19	1
Aulacoseira ambigua (Gr.) Sim.	13.79	71
Aulacoseira distans (Ehr.) Sim.	2.52	13
Aulacoseira granulata (Ehr.) Sim.	2.72	14
Aulacoseira granulata v. angustissima (Otto Müller) Simonsen	22.91	118
Aulacoseira italica (Ehr.) Sim.	26.99	139
Brachysira brebissonii R. Ross	0.19	1
Capartogramma cruciclula (Gr ex Cl)Ro	0.58	3
Cocconeis placentula v. lineata (E)VH	0.19	1
Cyclotella meneghiniana Kutz.	6.80	35
Cymbella lunata W Sm.	0.19	1
Discostella stelligera (Cl. et Gr.)HK	6.41	33
Encyonema minuta (Hilse ex Rab.) RCM	0.19	1
Eunotia vanheurckii v. intermedia (Krasske ex Hustedt) Patrick	0.39	2
Eunotia formica Ehr.	1.17	6
Eunotia incisa W. Smith	0.19	1
Eunotia monodon v. constricta A. Berg	0.19	1
Eunotia pectinalis (Kützing) Rabenhorst	0.19	1
Eunotia pectinalis v. minor (Kutz)Rab	1.55	8
Eunotia pectinalis v. recta May	0.19	1
Frustulia rhomboides Ehr. DeT.	0.39	2
Gomphonema clevei Fricke in Schmidt et al.	0.19	1
Gomphonema gracile Ehr.em.V.H.	0.39	2
Karayevia clevei (Grunow) Bukhtiyarova	0.58	3
Luticola mutica (Kützing) Mann	0.39	2
Navicula exigua v. capitata Pat.	0.39	2
Navicula gastrum (Ehr.) Kutz.	0.19	1
Navicula minima Gr.	0.19	1
Navicula radiosa v. parva Wallace	0.19	1
Navicula sp	0.39	2
Neidium iridis v. amphigomphus (Eh)Ma	0.19	1
Opephora americana M.Perag	0.19	1
Parlibellus protracta (Grunow) A. Witkowski, H. Lange-Bertalot & D. Metzeltin	0.19	1
Pinnularia abaujensis (Pant) Ross	0.19	1
Pinnularia abaujensis v. linearis	0.19	1
Pinnularia braunii (Gr) Cl.	0.58	3
Pinnularia caudata (Boyer) Pat.	0.39	2
Pinnularia dactylus Ehr.	0.58	3
Pinnularia latevittata Cl.	0.19	1
Pinnularia legumen Ehrenberg	0.58	3
Pinnularia sp	0.39	2
Planothidium apiculatum (Patrick) R. Lowe	0.39	2

Pseudostaurosira brevistriata (G)W&R	0.19	1
Rhopalodia gibberula v vanheurckii OM	1.17	6
Rossithidium linearis (W. Smith) Round et Bukhtiyarova	0.97	5
Sellaphora pupula var. mutata (Kr) B	0.19	1
Stauroneis anceps f. gracilis Rab.	0.19	1
Surirella linearis v. constricta	0.19	1
Surirella robusta Ehr.	0.19	1
Synedra linearis Ehrenberg	0.19	1
Synedra rumpens v. familiaris (Kützing) Hustedt	0.19	1
Tabellaria fenestrata (Lyngb.) Kutz.	0.19	1
Tryblionella scalaris (Ehrenberg) P. Siver & P.B. Hamilton	0.78	4
Total	99.90	515

Appendix I: Diatom counts for Lake Bellows core 5.

Core 5, 70 cm

Species	Percent	Number
Achnanthes microcephala (Kutz.) Gr.	0.20	1
Aulacoseira ambigua (Gr.) Sim.	7.52	38
Aulacoseira distans (Ehr.) Sim.	7.13	36
Aulacoseira granulata (Ehr.) Sim.	2.57	13
Aulacoseira granulata v. angustissima (Otto Müller) Simonsen	43.17	218
Aulacoseira italica (Ehr.) Sim.	18.42	93
Brachysira brebissonii R. Ross	0.79	4
Caloneis ventricosa (Ehr.) Meist.	0.20	1
Cocconeis placentula v. lineata (E)VH	0.20	1
Discostella stelligera (Cl. et Gr.)HK	2.77	14
Discostella stelligeroides (Hustedt) Houk & Klee	0.20	1
Eunotia diodon Ehr.	0.20	1
Eunotia incisa W. Smith	0.20	1
Eunotia Naegelii Migula	0.20	1
Eunotia pectinalis v. minor (Kutz)Rab	1.78	9
Eunotia pectinalis v. recta May	0.40	2
Eunotia vanheurckii v. intermedia (Krasske ex Hustedt) Patrick	0.20	1
Frustulia rhomboides Ehr. DeT.	3.76	19
Gomphonema parvulum (Kützing) Kützing	0.20	1
Luticola mutica (Kützing) Mann	0.40	2
Neidium iridis v. amphigomphus (Eh)Ma	0.40	2
Neidium sp	0.20	1
Neidium temperei Reim.	0.20	1
Nitzschia palea (Kutz) W.Sm.	0.59	3
Pinnularia abaujensis (Pant) Ross	0.20	1
Pinnularia biceps Greg	0.40	2
Pinnularia braunii (Gr) Cl.	0.59	3
Pinnularia dactylus Ehr.	0.59	3
Pinnularia dactylus Ehr.	0.59	3
Pinnularia legumen Ehrenberg	0.99	5
Pinnularia sp	0.79	4
Pinnularia streptoraphe Cl.	0.20	1
Pinnularia substomatophora Hust.	0.20	1
Pinnularia sudetica (Milse)M. Perag.	0.20	1
Rhopalodia gibba (Ehr) O. Mull.	1.58	8
Stauroneis anceps f. gracilis Rab.	0.20	1
Stauroneis phoenocenteron v. gracilis	0.20	1
Staurosira venter (Ehrenberg) H. Kobayasi	0.40	2
Surirella linearis v. constricta	0.20	1
Surirella tenera Greg.	0.20	1
Unknown	0.59	3
Total	100.02	505

Florida Department of Environmental Protection
Division of Environmental Assessment and Restoration
Bureau of Watershed Restoration
2600 Blair Stone Road, Mail Station 3565
Tallahassee, Florida 32399-2400
www2.dep.state.fl.us/water/