Technical Memo

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To: Big Kandiyohi Lake Association
Attn: Jerry Brustuen

From: Jeff Strom, Wenck Associates, Inc.
Tom Langer, Wenck Associates, Inc.

Date: November 16, 2018

Subject: Big Kandiyohi Lake Sediment Analysis

Big Kandiyohi Lake is a large (~2,700 acres), shallow (max depth 18 feet) lake located in Kandiyohi County, Minnesota. Recent water quality monitoring efforts (Attachment A) suggest Big Kandiyohi Lake does not currently meet state water quality standards. Growing season total phosphorus (TP) concentrations in Big Kandiyohi Lake have averaged 167 µg/L over the most recent 15-year period, which is above the 90 µg/L standard for shallow lakes in the Western Corn Belt Plain (WCBP) Ecoregion.

Big Kandiyohi Lake was placed on the State of Minnesota's 303(d) list of impaired waters in 2008 and a Total Maximum Daily Load (TMDL) study for the lake was completed in 2018 (MPCA, 2018a). The TMDL study estimates that internal phosphorus loading accounts for approximately 61% (~18,000 lbs/yr) of the lake's total annual phosphorus budget and that internal load will need to be reduced by approximately 11,500 lbs/yr (64%) in order for Big Kandiyohi Lake to meet State water quality standards.

The Big Kandiyohi Lake Association (BKLA) contracted with Wenck Associates, Inc. (Wenck) to conduct an internal load assessment study for Big Kandiyohi Lake. The objective of this study is to better characterize the potential drivers, specifically common carp and sediment release of phosphorus, of internal load in Big Kandiyohi Lake. The common carp portion of this study is detailed in a separate technical memorandum (Wenck, 2018). This memo presents the results of the sediment analysis which includes the following components:

- Review of temperature and dissolved oxygen (DO) profile data
- Sediment core collection and laboratory analysis
- Discussion of results and how they compare to TMDL study
- Final recommendations

Water Column Profile Results

Water column stability can have a significant impact on phosphorus loading and lake nutrient cycling. Lake stratification, mixing, and absence of DO can all affect whether a lake releases phosphorus from benthic sediments. Temperature and DO profiles have been recorded at three locations in Big Kandiyohi Lake (Attachment B), most recently in 2013. These profiles show lake stratification occasionally occurs during the summer growing season, however anoxic (DO <2.0 mg/L) conditions have never been observed in the hypolimnion. Stratification establishes anywhere from 5-13 feet below the surface in June, July and August. The profiles also showed that large storm events, high winds and changes

in air temperatures can cause stratification to weaken and breakdown during the summer growing season which results in mixing and re-oxygenation throughout the water column.

Sediment Core Methods

Four intact sediment cores were collected at one location (Figure 1) in Big Kandiyohi Lake on September 27, 2018 using a gravity sediment coring device (Aquatic Research Instruments, Hope ID) equipped with an acrylic core liner (6.5-cm ID and 50-cm length). The sediment core location is located in the northeast portion of Big Kandiyohi within the 15-foot depth contour near water quality station 101.

The sediment cores were transported to the University of Wisconsin - Stout Discovery Center Laboratory where they were analyzed for phosphorus release under anoxic conditions. Additionally, one of the cores was sectioned vertically at 2-cm intervals over the upper 10-cm to evaluate variations in sediment physical-textural and chemical characteristics, including phosphorus fractionation. Phosphorus fractionation characterizes the different types of phosphorus within the sediment total phosphorus pool. In most lakes, the primary fractions that drive phosphorus release from the sediments are phosphorus bound to iron (iron-bound P) and phosphorus in the sediment porewater (loosely-bound P). Collectively, iron-bound P and loosely-bound P is referred to as redox sensitive phosphorus (redox P) as this is the form of phosphorus that is released during anoxic periods. Lakes with a high fraction of redox P have the potential to release phosphorus at a high rate. Attachment C provides explanations of the different phosphorus fractions that were analyzed in this study.

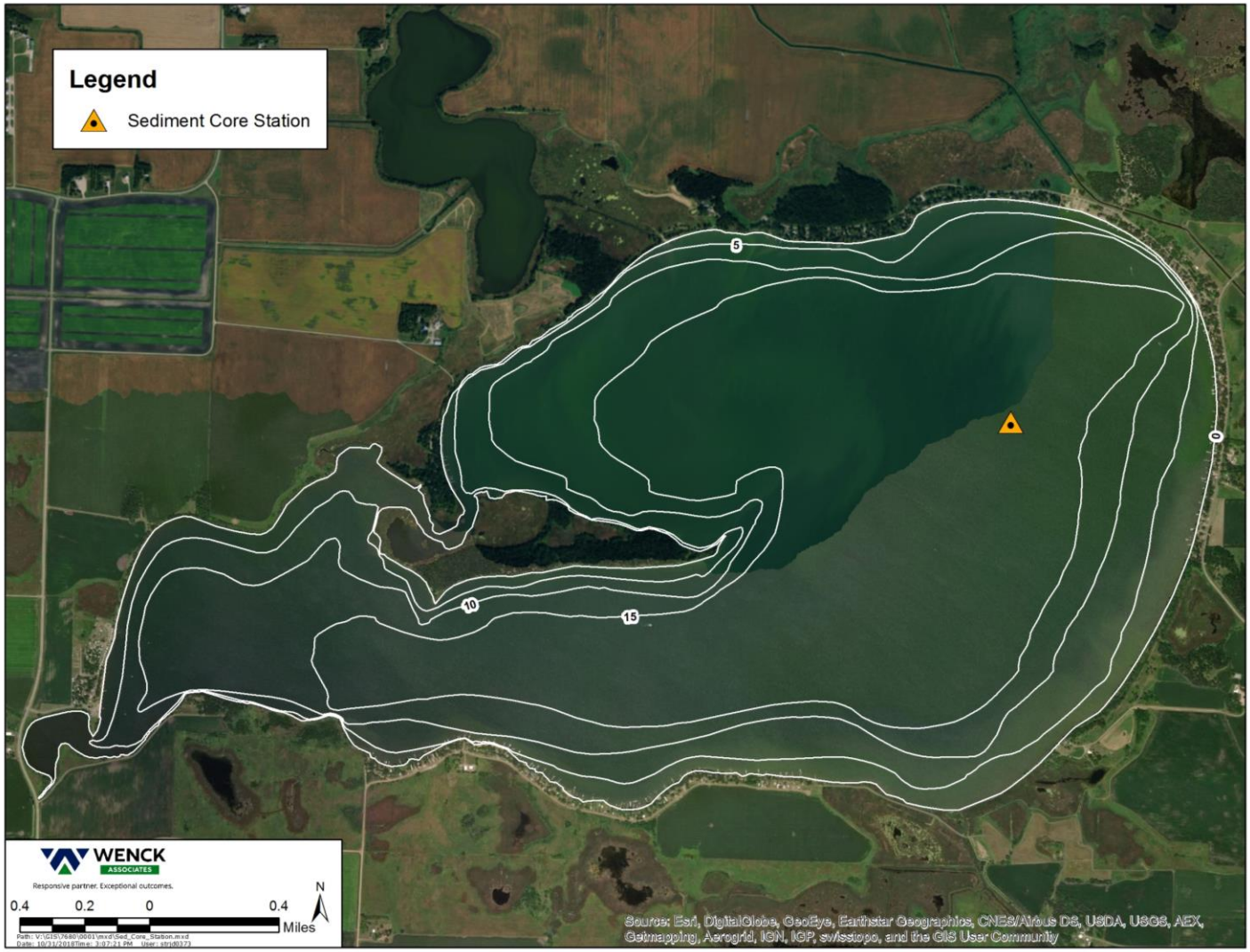


Figure 1. Big Kandiyohi Lake sediment core location.

Sediment Core Results

The primary sediment factors driving internal loading in most lakes is phosphorus bound to iron (iron-bound P) and phosphorus in the sediment porewater (loosely-bound P). Collectively, iron-bound P and loosely-bound P is referred to as redox sensitive phosphorus (redox P) as this is the form of phosphorus that is released during anoxic periods, which occurs when dissolved oxygen (DO) in overlying water goes below 2 mg/L. Lakes with a high fraction of redox P have the potential to release phosphorus at a high rate. Based on our dataset of over 100 lakes in Minnesota, the median concentration of redox P in lakes is 0.37 mg/g. Generally, we have found that lakes with redox P concentrations greater than 0.37 mg/g have higher phosphorus release rates.

Laboratory analyses of Big Kandiyohi Lake sediment phosphorus fractions indicate redox P concentrations ranged from 0.30 in the upper 2-cm layer to 0.24 mg/g at the 6-8 cm layer. Based on our dataset of over 100 lakes in Minnesota, the median concentration of redox P in lakes is 0.37 mg/g. Generally, we have found that lakes with redox P concentrations greater than 0.37 mg/g have higher phosphorus release rates (Table 1; Attachment C).

Table 1. Redox P measured in the top 10 cm.

Sediment Depth	Redox P (mg/g)	Other MN Lakes		
		25th Percentile	Median	75th Percentile
0 – 2 cm	0.30	0.24	0.37	0.69
2 – 4 cm	0.27			
4 – 6 cm	0.26			
6 – 8 cm	0.24			
8 – 10 cm	0.26			

Anaerobic phosphorus release rates for Big Kandiyohi Lake were 2.5 mg/m^2/day (Table 2). This rate is considered low and near the 25th percentile for release rates measured in lakes throughout Minnesota. The anaerobic release rate for Big Kandiyohi Lake was also compared to release rates at three other Western Corn Belt Plain Ecoregion impaired lakes in the Redwood and Cottonwood River Watersheds (Benton, Double and School Grove; Table 2). Big Kandiyohi Lake anaerobic release rates were lower than all three of these lakes further indicating the low potential of phosphorus release from sediments in Big Kandiyohi Lake.

Table 2. Anaerobic phosphorus release rates.

Lake	Anaerobic Release Rate (mg/m^2/day)	Other MN Lakes		
		25th Percentile	Median	75th Percentile
Big Kandiyohi Lake	2.5	2.7	5.1	9.3
Benton Lake (Lincoln Co.)	9.1			
Double Lake (Cottonwood Co.)	9.2			
School Grove Lake (Lyon Co.)	5.9			

Discussion

The Big Kandiyohi Lake TMDL study used a shallow lake anoxic factor (AF) calculation (Nürnberg 2005) to determine the volume of lake water under anoxic conditions throughout the summer growing season. In order to calculate phosphorus release from the sediment in Big Kandiyohi Lake, the AF (days) was multiplied by an estimated phosphorus release rate ($mg/m^2/day$). Sediment cores and laboratory measured sediment phosphorus release rates were not collected and analyzed for the original TMDL study. Instead, the sediment phosphorus release rate was the "final" calibration piece for the TMDL lake response model and was adjusted until the average annual model predicted surface water phosphorus concentrations (model years 2005-2006) matched monitored data. Through this approach, Big Kandiyohi Lake was assigned a sediment phosphorus release rate of 10.0 $mg/m^2/day$ and average annual internal load was estimated to be ~18,000 lbs/year.

As discussed in the previous section, the laboratory measured sediment phosphorus release rate for Big Kandiyohi Lake was 2.5 $mg/m^2/day$, which is significantly lower than the TMDL assigned release rate of 10.0 $mg/m^2/day$. Wenck updated the Big Kandiyohi Lake response model using the 2.5 $mg/m^2/day$ phosphorus release rate and the same AF (64 days) used in the original TMDL model. The updated model suggests phosphorus release from the sediment accounts for up to ~7,000 lbs/year (Figure 2), which is ~11,000 lbs/year less than the original TMDL model. This difference, referred to as "model residual load", could be the result of one (or more) of the defined loading sources (i.e. watershed, septics, atmosphere) being under-represented, or one or more loading source(s) that is not currently accounted for in the model. Other potential sources could include inputs from rough fish (i.e. common carp), wind resuspension, and curly-leaf pondweed senescence.

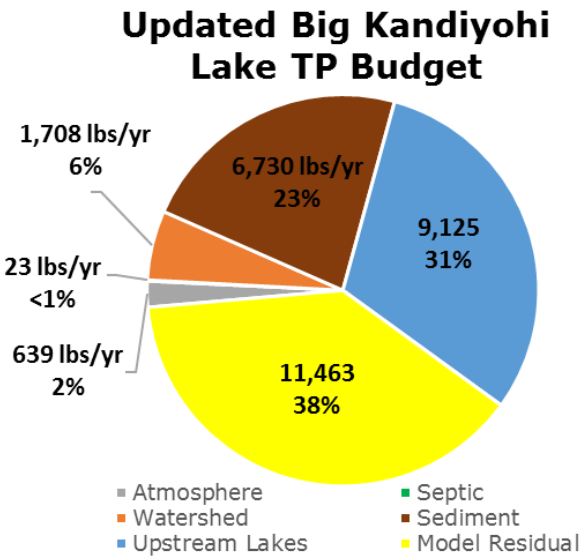


Figure 2. Big Kandiyohi Lake TP Budget.

The common carp population assessment performed by Wenck in September 2018 estimated that carp biomass density in Big Kandiyohi Lake is approximately 8 times greater than the density threshold (100 kg/ha) that can negatively impact vegetation coverage, water fowl populations, turbidity and water quality in shallow lakes (Bajer *et al.* 2009). Thus, it is likely that a sizeable portion of the model residual load may be attributed to common carp, however we are not able to quantify the exact load contribution at this time.

Recommendations

Although phosphorus release from the sediment in Big Kandiyohi Lake likely accounts for a sizeable portion of the lake's annual phosphorus load (~23%), the lab measured release rates were low compared to other shallow lakes in southwest Minnesota and the open water portions of the lake are weakly stratified and rarely experience low oxygen levels. For these

reasons, Wenck does not recommend that the BKLA pursue strategies to manage sediment phosphorus release at this time. Instead, ***we recommend that the BKLA focus initial management efforts on reducing the lake's common carp population*** as discussed in the Big Kandiyohi Lake Carp Assessment Memo (Wenck, 2018). Below is a list of other strategies the BKLA should consider to better understand water quality sources/drivers in Big Kandiyohi Lake, reduce phosphorus loading to the lake and track changes as water quality improvement projects are implemented.

- ***Monitor in-lake water quality on an annual basis***. Sampling should include a at least four samples during the summer growing season (June through September). Parameters to include: TP, total nitrogen (TN), Chlorophyll-a, Secchi depth, total suspended solids (TSS), and temperature/DO profiles.
- ***Monitor major inlet channel/ditch to lake*****.** Sampling should include at least 5-6 samples during various flow conditions. Parameters to include: TP, Ortho-phosphorus, TN and TSS. Results of these monitoring efforts should be compared to the HSPF watershed model used to develop the TMDL.
- ***Assess status of septic systems immediately surrounding the lake.***
- ***Identify and implement watershed Best Management Practices (BMPs).*** The TMDL study calls for a watershed load reduction of ~1,300 lbs/year. The South Fork Crow WRAPS report (MPCA, 2018b; pp. 86-71 & Appendix A p. 112) identifies general strategies for the Big Kandiyohi Lake Subwatershed.

References

Bajer, P.G, G. Sullivan, and P.W. Sorensen. 2009. Effects of a rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. Hydrobiologia 632: 235-245.

Minnesota Pollution Control Agency. 2018a. South Fork Crow River Watershed Total Maximum Daily Load Report. https://www.pca.state.mn.us/sites/default/files/wq-iw8-52e.pdf

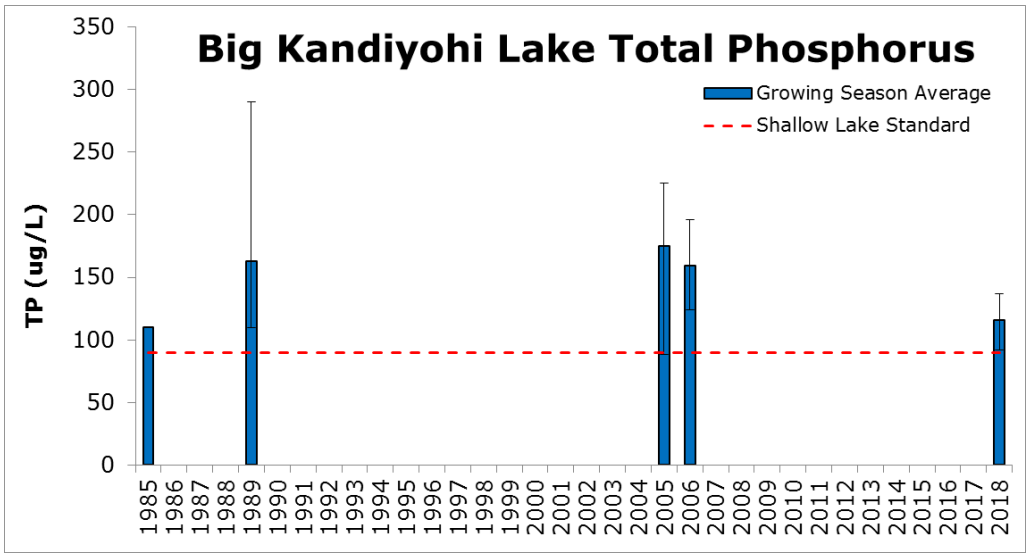
Minnesota Pollution Control Agency. 2018b. South Fork Crow River Watershed Restoration and Protection Strategy Report. https://www.pca.state.mn.us/sites/default/files/wq-ws4-47a.pdf

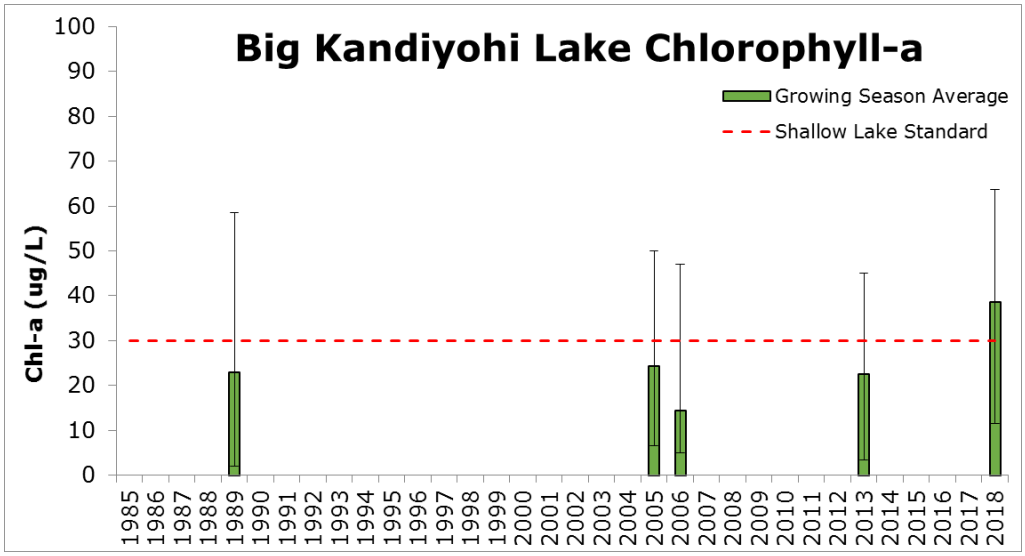
Nürnberg, G. 2005. Quantification of Internal Phosphorus Loading in Polymictic Lakes. Verhanlungen Interationalen Vereinigung Limnologie (SIL). Vol. 29.

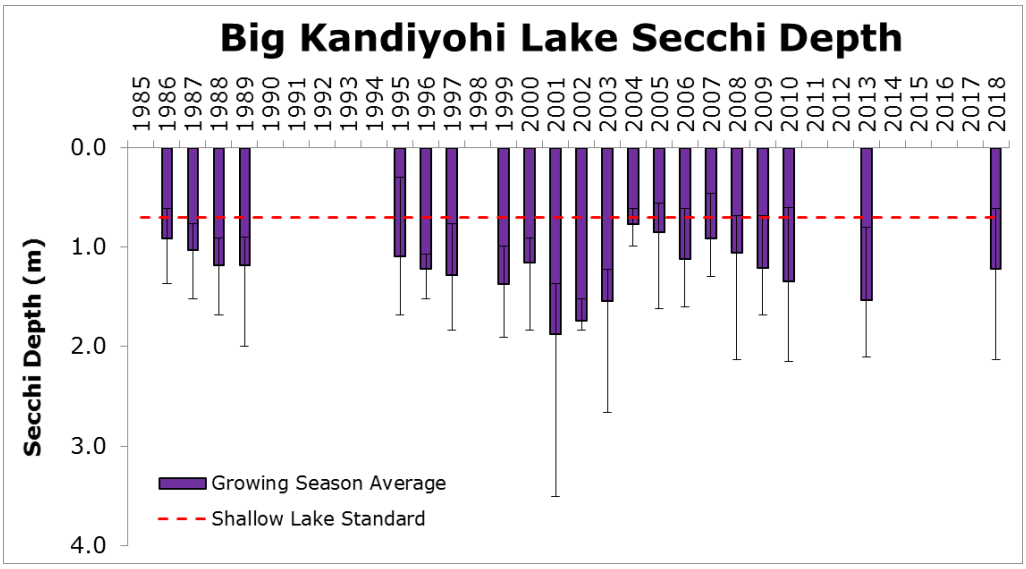
Wenck Associates, Inc. 2018. Big Kandiyohi Lake Carp Assessments.

Attachment A

Big Kandiyohi Lake Historic Water Quality


Big Kandiyohi Lake Total Phosphorus
Growing Season Average
Shallow Lake Standard
TP (ug/L)
350
300
250
200
150
100
50
0
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

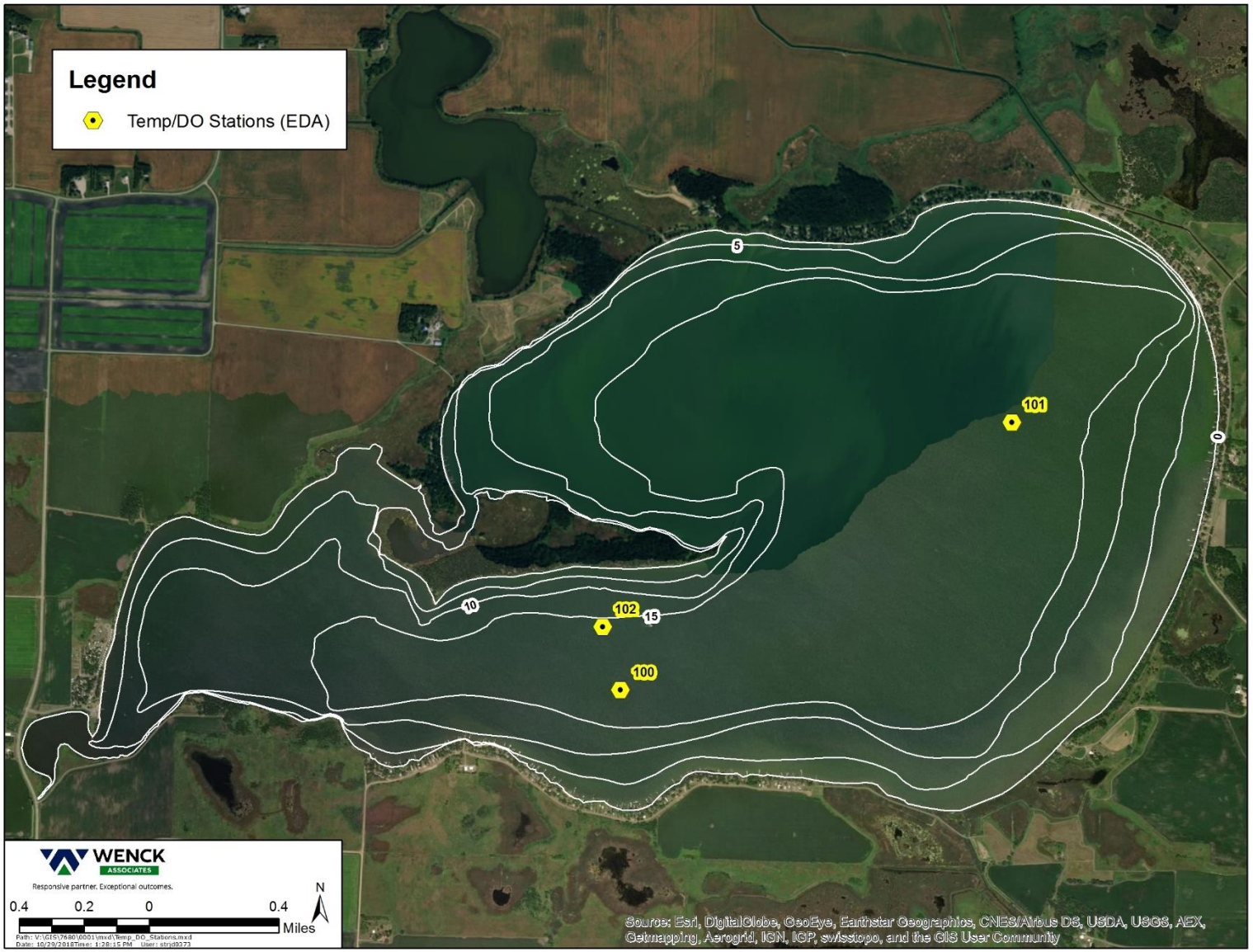

Big Kandiyohi Lake Chlorophyll-a
Growing Season Average
Shallow Lake Standard
Chl-a (ug/L)
100
90
80
70
60
50
40
30
20
10
0
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Big Kandiyohi Lake Secchi Depth
Secchi Depth (m)
0.0
1.0
2.0
3.0
4.0
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Growing Season Average
Shallow Lake Standard

Attachment B

Temperature and Dissolved Oxygen Profiles

Temperature and Dissolved Oxygen Profile Sampling Locations



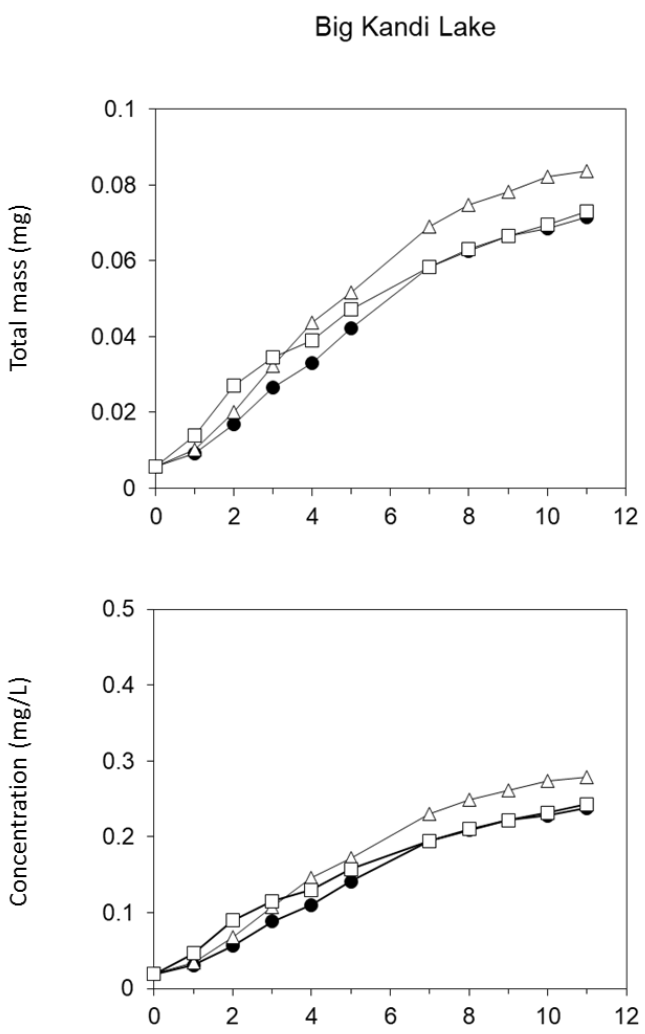
Historic Temperature and Dissolved Oxygen Profile Data Summary (downloaded from EDA)

EDA Station	Year(s)	Summer Growing Season Profiles [Count]	Profiles Demonstrating Stratification [Count]	Profiles Demonstrating DO < 5.0 mg/L [Count]	Profiles Demonstrating DO < 2.0 mg/L [Count]	Ave Depth of Stratification [ft]	Ave Depth of DO <5.0 mg/L [ft]	Ave Depth of DO <2.0 mg/L [ft]
100	1988-1989	7	0	0	0	NA	NA	NA
101	1978; 1985; 2005; 2013	17	7	2	0	5.0	13.0	NA
102	1978	3	0	0	0	NA	NA	NA

Attachment C

Sediment Core Laboratory Results

Phosphorus In the overlying water column



		ANOXIC		
		Big Kandi		
Station		Rep 1	Rep 2	Rep 3
Incubation period, d		0-7	0-7	0-7
mg/m2 d		2.45	2.87	2.27
		Mean	2.53	mg/m2 d
		SE	0.18	

Definition list of phosphorus fractions measured in sediment

Sediment Fraction	Abbreviation	Description	Mobility in Sediments	Mobile Conditions
Loosely Bound Phosphorus	Loosely-bound	This fraction includes porewater phosphorus and phosphorus that is bound to calcium carbonates.	High	All conditions
Iron Bound Phosphorus	Iron-bound P	Phosphorus that is adsorbed to oxidized iron. This fraction is highly mobile under low oxygen conditions.	High	Low Oxygen Conditions
Labile Organic Phosphorus	Labile-organic P	Phosphorus bound within organic matter that is easily broken down by bacteria. This fraction is mobile under anoxic and oxic conditions.	Moderate	All conditions
Redox Sensitive Phosphorus	Redox-P	This fraction includes loosely-bound P and iron-bound-P. Redox-P represents phosphorus in sediments that is mobile under anoxic conditions (dissolved oxygen <2 mg/L)	High	Low oxygen conditions
Aluminum Bound Phosphorus	Aluminum-bound-P	Aluminum-bound-P represents phosphorus fraction that is relatively stable in most environmental conditions	Low	High pH

Big Kandiyohi Lake Vertical Sediment Trends

Date	Station	Section		Depth		Moisture Content	Wet Bulk Density	Dry Bulk Density	Organic Matter		Loose-P	Fe-P	LOP	Al-P		Redox-P	Bio-labile P
				(cm)		(%)	(g/cm^3)	(g/cm^3)	(%)		(mg/g)	(mg/g)	(mg/g)	(mg/g)		(mg/g)	(mg/g)
9/27/2018	Big Kandi	0	2	-1		84.6	1.086	0.170	16.2		0.228	0.071	0.167	0.035		0.299	0.466
9/27/2018	Big Kandi	2	4	-3		82.2	1.102	0.199	15.6		0.205	0.065	0.179	0.039		0.270	0.449
9/27/2018	Big Kandi	4	6	-5		80.1	1.114	0.225	16.0		0.203	0.061	0.137	0.041		0.264	0.401
9/27/2018	Big Kandi	6	8	-7		78.0	1.130	0.254	14.9		0.188	0.056	0.111	0.035		0.244	0.355
9/27/2018	Big Kandi	8	10	-9		77.3	1.137	0.263	13.4		0.198	0.058	0.115	0.038		0.256	0.371