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Subject: Mille Lac Lake Water Quality Analysis

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1. Introduction

The Mille Lacs Band of Ojibwe (Band) performs routine monitoring on Mille Lacs Lake, per Clean Water Act (CWA), Section 106 Tribal Guidance. Currently, the monitoring being conducted is based on guidance set forth in the Long-Term Monitoring Plan (Brown and Caldwell, 2003), which follows the required elements of a tribal monitoring and assessment program. These monitoring strategies need to be reviewed and updated every 3-5 years, as required by the Tribal Guidance. Further, as a sovereign tribe, the Band is required to develop a nutrient criteria plan to ensure protection of lake health for Mille Lacs Lake and documenting water quality improvement. Nutrient criteria can be based on approaches suggested by the United States Environmental Protection Agency (US EPA, 2000). Among other things, developing a nutrient criteria plan requires that the monitoring approach, parameters, and end points are clearly identified. To support the Band in this task, Houston Engineering, Inc. (HEI) completed an analysis of available water quality data for Mille Lacs Lake.

The goal of the water quality analysis was to identify patterns, trends, or conditions that would influence a nutrient criteria plan for Mille Lacs Lake. To meet this goal, the objective of the analysis was to address the following questions:

1. What is a representative baseline condition for the lake? The baseline condition would serve as the end point for the nutrient criteria plan to protect and maintain lake health.
2. Does the quality of the water vary significantly over the broad surface area of the lake? This would serve to guide future monitoring efforts.
3. Are there trends in water quality through time? Trends would potentially indicate the historic and current vulnerability, or health, of the lake relative to external influences.

Various studies and monitoring efforts have been implemented for Mille Lacs Lake by groups other than the Band. This analysis synthesizes and condenses these various monitoring efforts that have been performed. The approaches taken for this analysis are consistent with the methodologies suggested in the Long-Term Monitoring Plan (Brown and Caldwell, 2003).

2. Background

Water quality sampling of various forms has been conducted on Mille Lacs Lake dating back to 1974 at many different locations on the lake (see **Map 1**). Many different entities have been involved in monitoring the health of Mille Lacs Lake. Data for this water quality analysis came from five main program sources: Citizen Lake Monitoring Program (1974-2006), Minnesota Pollution Control Agency (MPCA) Lake Monitoring Program Project (1981), Clean Lakes Project study (1992), Mille Lacs Lake Watershed Management Project (2000), and Surface Water Quality Monitoring for Long Term Trend Analysis program (2005-2006). Data from all these various sources was filtered out to three main parameters, which were: total phosphorus (TP) in parts per billion (ppb), chlorophyll-a (CHLA) in ppb, and secchi disk depth (SD M) in meters (m). These parameters were chosen as they are considered key trophic indicators for lake health.

The State of Minnesota uses these same three parameters to assess water quality conditions in lakes. Numeric nutrient criteria have been developed for the different ecoregions in Minnesota by the MPCA. These criteria were largely determined statistically based on US EPA guidance of using the 75th percentile interval for datasets taken from "minimally impacted" reference lakes (25th percentile for secchi disk readings). For the Northern Lakes and Forests ecoregion, which includes Mille Lacs Lake, the following criteria are considered protective of deep lakes:

- TP = 30 ppb
- CHLA = 9 ppb
- SD M = 2.0 m

It is noteworthy that nutrient criteria can be based on one or a combination of variables. TP is considered a causal parameter, while CHLA and SD M are response parameters. A key assumption in lake management is that TP directly influences CHLA and thus indirectly affects SD M. However, lake clarity can be affected by a number of factors, such as inorganic sediment.

3. Water Quality Data Analysis

3.1 Overview

Descriptive statistics were calculated for the Mille Lacs Lake water quality data by spatially and temporally aggregating all data sources discussed in Section 2. Following US EPA guidance for setting nutrient criteria, as discussed, the 75th percentile for TP and CHLA and 25th percentile for SD M for the Mille Lacs Lake data are as follows:

- TP = 28.00 ppb
- CHLA = 4.80 ppb
- SD M = 2.13 m

Data analysis protocols were followed as per the Brown and Caldwell (2003) report. For Mille Lacs Lake, frequency distributions for the water quality data were not normally distributed. Further, SD M, TP, and CHLA are all explained by a log-normal distribution, which is typical for environmental data (Limpert et al., 2001). As such, the median value is a good descriptor of central tendency for log-normally distributed data.

3.2 Spatial Analysis

The surface area of Mille Lacs Lake is 207 square miles, and ranks as one of the largest lakes in Minnesota. The lake has a complex bottom morphometry and an irregular shoreline. Approximately 11 % of the lake is considered littoral, with depths of 15 feet or less (as defined by the MPCA and Minnesota Department of Natural Resources). There are 13 tributaries that drain an additional contributing watershed land area of 182 square miles. Land use varies in the different Mille Lacs Lake contributing subwatershed areas, ranging from forested to urban to cultivated land. Each of these inherent factors can influence water quality conditions in Mille Lacs Lake. Spatial analysis was performed to assess the affect these factors may have in influencing the establishment of a nutrient criteria for Mille Lacs Lake.

3.2.1 Shallow versus Deep

The littoral zone is the transition area of the lake between dry land and open water and where aquatic plants often abound. The limnetic zone is the open water area further from the shoreline and is defined as depths greater than 15 feet. The littoral zone for Mille Lacs Lake can be seen in **Map 2**. It was found that there was a notable significant different in SD M between shallow and deep zones of the lake; confidence intervals about the median SD M values were separated by an increment of 1.05 m. This could be a function of different sample sizes. The median values and range in confidence intervals are shown in **Table 1**.

Table 1: Depth Analysis Results.

	SD M (m)		TP (ppb)		CHLA (ppb)	
	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic
Upper Median 95% CI	2.13	3.05	25.00	23.33	3.56	3.74
Median Value	2.10	2.90	25.00	22.72	3.20	3.53
Lower Median 95% CI	2.00	2.74	24.00	21.49	2.67	3.20
Sample size (n)	182	778	201	321	145	222

The SD M values were then tested for significant difference between the littoral and limnetic groups with the Kruskal-Wallis test. This test showed that there was a significant difference between the shallow and deep zones, based on SD M, at the 95% confidence interval.

A difference in water clarity (and associated variables, such as TP and CHLA) can be expected between the littoral (shallow) and limnetic (deep) zones of the lake. Recognizing that there is a difference will affect sampling approaches and in inferring the status of overall lake health.

3.2.2 Quadrants

Different areas of a lake receive different amounts of inputs from contributing watershed areas. There can also be areas of a lake that receive localized inputs, such as groundwater inflow. Other environmental factors, such as prevailing wind direction, can affect various areas of a lake of this size differently. Recognizing these factors, Mille Lacs Lake was divided into four different quadrants and the following are the list of streams that generally contribute to the different quadrants:

NE: Ditch 36, Borden Creek, Seventeen Creek, Reddick Creek, Marmon/Reddie Creek
NW: Seguchie Creek, Garrison Creek
SE: Peterson Creek, Cedar Creek, Thaines/Malone Creek, Groundhouse River
SW: Rum River, Whitefish Creek

Quadrant divisions for Mille Lacs Lake can be found in **Map 2**.

Through the analysis, it was found that there was a difference in SD M between the NE quadrant and the other quadrants of the lake. The median values and range in confidence intervals are shown in **Table 2**.

Table 2: Quadrant Analysis Results.

	SD M (m)			
	NE	NW	SE	SW
Upper Median 95% CI	3.50	2.50	2.74	2.74
Median Value	3.20	2.44	2.60	2.50
Lower Median 95% CI	3.05	2.29	2.59	2.40
Sample size (n)	141	122	557	143
	TP (ppb)			
	NE	NW	SE	SW
Upper Median 95% CI	27.00	27.00	25.00	23.00

Median Value	24.00	25.00	24.00	21.74
Lower Median 95% CI	21.00	24.00	23.00	20.65
Sample size (n)	43	68	195	219
	CHLA (ppb)			
	NE	NW	SE	SW
Upper Median 95% CI	6.80	3.70	3.59	3.74
Median Value	4.27	3.20	3.19	3.53
Lower Median 95% CI	3.00	2.67	2.67	3.20
Sample size (n)	31	59	135	142

The difference between quadrants was tested with the Kruskal-Wallis test and was found to be significant at the 95% confidence level. In this analysis, there could be an effect due to varying sample sizes.

The implication in differences between quadrants for lake management is to continue considering this factor in in-lake monitoring strategies, but to not weigh it too heavily in considering overall lake health.

3.3 Temporal Analysis

Water quality monitoring efforts have been conducted on Mille Lacs Lake dating back to 1974. Since that time, land use, environmental factors, and lake management has changed. Analysis of the available historical data can provide a glimpse into how water quality and the health of Mille Lacs Lake have changed over time.

All of the water quality data for Mille Lacs Lake was grouped temporally into five year time periods dating from the beginning of the available data record (1970-1974) to the most recent available data record (2005-2009). This provided a more appropriate scale to examine the data over the approximate 30 year time span. It should be noted that all of the water quality data was lumped spatially for all the sampling sites in the lake in this analysis, although it was shown previously there are differences across the lake.

Through various statistical techniques, as described in Brown and Caldwell (2003), it was found that there does appear to be a general trend of improvement in water quality in Mille Lacs Lake over time. The median values and range in confidence intervals are shown in **Table 3**.

Table 3: Temporal Analysis Results.

	SD M (m)						
	1970-1974	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009
Upper Median 95% CI	2.59	2.10	2.44	2.40	3.81	3.51	3.66
Median Value	2.29	1.94	2.13	2.30	3.51	3.35	2.98
Lower Median 95% CI	1.98	1.70	1.98	2.29	3.35	3.05	2.65
Sample size (n)	11	46	20	405	207	185	86
	TP (ppb)						
	1970-1974	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009
Upper Median 95% CI	-	39.00	-	26.00	-	19.12	20.00
Median Value	-	35.00	-	25.00	-	18.05	19.00
Lower Median 95% CI	-	27.00	-	25.00	-	16.82	19.00
Sample size (n)	-	43	-	303	-	112	64

	CHLA (ppb)						
	1970-1974	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009
Upper Median 95% CI	-	9.60	-	3.20	-	3.92	4.01
Median Value	-	7.30	-	2.67	-	3.22	3.47
Lower Median 95% CI	-	6.60	-	2.67	-	2.32	3.00
Sample size (n)	-	29	-	218	-	56	64

Water clarity has improved since the start of the sampling record, while nutrient and algal biomass values have decreased. It also appears that there has been a sharp increase in water clarity during the late 1990's and 2000's in comparison to the 1980's and early 1990's. The difference in clarity between the time groupings, as tested with the Kruskal-Wallis test, was significant. Although there could be an effect due to sample sizes, trends for all the water quality parameters, as examined with the Kendall trend analysis, were significant. The implication for lake management is promising, as there does appear to be an improvement in Mille Lacs Lake water quality over time; however, lake health needs to be continually monitored over time to analyze how conditions are changing in comparison to baseline water quality values.

3.4 Additional Analysis

Other analyses were also performed as a part of this study. Specifically, these were to determine the mixing characteristics of Mille Lacs Lake, compare other environmental indicators with water clarity, and determine the usefulness of remotely sensed data in the determination of lake clarity for Mille Lacs Lake.

3.4.1 Mixing

Field measured parameters collected by the Band during the 2005-2007 time frame were used to examine the mixing characteristics of Mille Lacs Lake. Lake mixing characteristics are important for lake management, since it can provide insight to the potential importance and timing of in-lake loadings of phosphorus. Specifically, lake temperature and dissolved oxygen (DO) data from different depth profiles were used from six different mid-lake sites around the lake. These sites were: ML-6, ML-24, ML-SE, ML-CE, ML-NE, and ML-NW. Graphical profiles of this data were used to investigate how these parameters changed with depth. Based upon the profiles, it appears from the profiles that the different sites behave similarly in terms of mixing characteristics. In general, Mille Lacs Lake appears to be well mixed and does not seem to stratify during the spring, summer, and fall. There is some decrease in temperature and decrease in DO with depth at the sites during the summer months, but the profiles do not display a well defined thermocline. Based on data collected in March, it appears that Mille Lacs Lake does stratify during winter.

The caveat to this is that there may potentially be some stratification that occurs on a smaller time scale during the middle of summer, when the lake is calm. It can also not be determined from the data, however, when the lake transitions from stratified to mixed (winter to open-water). Investigation to mixing of Mille Lacs Lake is further required.

3.4.2 Environmental Data and Secchi Disk Comparisons

Graphs were produced comparing Mille Lacs Lake annual elevation with median secchi disk depth and Mille Lacs' area average annual precipitation with median secchi disk depth. Anecdotally, one would theorize that as the lake level rises and precipitation increases, secchi disk depth should decrease. For example, increased precipitation would lead to increased overland runoff and associated nutrients that lead to a decrease in lake clarity due to increased algal blooms. From review of the figures, it did not appear that there was a clear correlation in either comparison with secchi disk depth.

3.4.3 Remote Sensing of Water Clarity

Remotely sensed data of water clarity was used in a comparison with measured secchi disk data for Mille Lacs Lake, as research using this technology has yielded successful outcomes and useful insight (Kloiber et al., 2002). It appears that remotely sensed data generally over-predicts observed water clarity values for Mille Lacs; however, remote sensing can still have value for Mille Lacs if regression equations for clarity could be calibrated specifically for Mille Lacs and the data used to provide a detailed analysis of spatial variability within the lake.

4. Discussion and Conclusions

It does generally appear that there are differences in the water quality between shallow and deep zones, as well as between different areas of the lake. Sampling locations that are currently being used by the Band in tracking the long term health of Mille Lacs Lake can be found in **Map 1**. Currently there are 16 sites that the Band monitors, which were recommended by Brown and Caldwell (2003). It does appear that these sampling locations and sampling strategy fit with the analysis that was performed in this report and Tribal guidance documentation. The basic structure of the sampling program should be kept (such as sampling protocol and sampling parameters). Based upon the findings of this study, however, the frequency and number of sampling points should be altered, to increase the inferential capacity of their monitoring strategy.

The Band should consider the reallocation sampling resources in an example manner, as follows. Currently the Band monitors 16 sites quarterly (64 water quality samples). Of these sites, 10 are classified as “near-shore” and 6 are classified as “mid-lake”. Of these “near-shore” sites, it was found that 5 are within the littoral zone of the lake. Since the littoral area only covers 11% of Mille Lacs Lake, the Band should consider reducing the number of “near-shore” and “mid-lake” sampling locations down to one “near-shore”, littoral site and four “mid-lake”, limnetic sites. When considering sites to monitor, precedence should be given to sites that have the longest historical sampling record. Further, the number of water quality samples should be increased to more than one per site in the shallow zone (0-2 m). It is recommended that a shallow and near-bottom sample should be collected at each site, with consideration being given to the bottom depth at each site. This will aid in determining the potential of in-lake mixing of phosphorus. The frequency of water quality sampling and field monitoring should also be adjusted. Monthly water quality samples should be collected during the late spring-summer months (May, June, July, August), with one sampling during the fall and winter periods, respectively. Field monitoring (such as secchi disk, temperature, and dissolved oxygen readings) should be continued during each water quality sampling; however, one mid-lake site should be chosen for weekly field monitoring. This will aid in more closely determining the mixing characteristics of Mille Lacs Lake. Another idea for the Band to consider is recording user perception surveys during secchi disk readings, such as is performed by the MPCA.

It does appear that the health of Mille Lacs Lake has improved over time since the 1970’s, based on the trophic status indicators of secchi disk depth, total phosphorus, and chlorophyll-a; however, upon closer inspection, it does appear that water quality is slightly declining since the mid to late 1990’s. Continued monitoring is necessary to track the health of Mille Lacs Lake, with comparison to the baseline condition. The baseline condition provides a point of reference to compare the current quality of water to and determine the health of the lake system. It is recommended that comparisons be made to the in-lake nutrient criteria baseline that was determined and discussed earlier in this report. These values are more protective of Mille Lacs Lake water quality, as compared to the Northern Lakes and Forests ecoregion determination made by the MPCA.

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