Minnesota lake water quality on-line database and visualization tools for exploratory trend analyses

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August 31, 2009

Technical Report: NRRI/TR-2009/28

Final Report: Phase 1: *Climate change impacts on Minnesota's Aquatic Resources W-12*
Prepared for: Legislative Citizens Committee on Minnesota Resources, St. Paul, Minnesota

I. Minnesota lake water quality on-line database and visualization tools for exploratory trend analyses

A. Background

Warming temperatures have been shown to have negative environmental impacts in both lakes and streams. In lakes, warmer temperatures may increase temperatures in the upper mixed layer (epilimnion) enough to affect algal, aquatic plant, invertebrate and fish communities. The IPCC analysis for the Upper Midwest suggested the following potential consequences of increased water temperatures due to increased air temperatures:

> *Earlier and longer period of density/thermal stratification in summer in deeper lakes, leading to longer periods of hypolimnetic "stagnation" and isolation from atmospheric oxygen mixing into the epilimnion. This can lead to the increased duration and magnitude of oxygen depletion in the hypolimnion, increasing the risk of developing a 'dead zone' and associated fish kills.*

These consequences were in part based upon more detailed models developed to predict potential climate change effects on Minnesota lakes (Stefan et al. 1993; Stefan et al. 2001; Fang and Stefan 1999).

In such cases, this increased duration of stratification can reduce oxygen inputs to bottom layers, increasing the risk of oxygen-poor or oxygen-free "dead zones" that will stress or kill fish and other organisms. In culturally nutrient-enriched lakes in particular, enhanced oxygen depletion would also be expected to increase phosphorus diffusion from bottom sediments leading to larger injections of bio-available phosphorus during periods of intermittent mixing in spring and summer, and during fall turnover. Such sudden inputs of P typically lead to large blooms of algae, in some cases producing noxious scums and increased likelihood of cyanobacterial (i.e. "bluegreen algae") toxins (e.g. MPCA 2007). Oxygen depleted bottom waters also are characterized by increased concentrations of chemically reduced nitrogen (ammonium-N) and sulfur (hydrogen sulfide); both can be toxic to fish and other aquatic animals at concentrations that often are found in such lakes, and the injection of ammonium along with phosphate into the epilimnion during mixing usually leads to more algal growth than would P alone. In lakes with contaminated sediments, warmer water and low-oxygen conditions may act to mobilize mercury and other persistent pollutants, potentially increasing health hazards for animals that eat fish from the lakes, including humans (e.g. Dodds 2002, Stefan et al. 2001, MPCA 2004). Poff et al. (2002) and Kling et al. (2003) list specific impacts to lakes that include an increase in nuisance algae, the reduction of fish habitat with the warming of lakes, and changes in runoff (both increases and decreases), that will in turn affect lake levels, and finally, expansion and contraction of aquatic species ranges.

The Water Quality component of the project was included in the following main objective:

<u>Summarize the follow variables in lakes and streams</u>:

(1) lake transparency (secchi depth);
(2) lake chlorophyll (a measure of algal abundance);

(3) lake total phosphorus (and nitrogenous nutrients when available);
(4) lake levels (see Appendix B);
(5) Stream flows, specifically annual mean flow, annual maximum flow, annual minimum daily low, and mean monthly flow (see Appendix D);
(6) Timing of stream flows, such as date of annual maximum daily flow, date of spring maximum daily flow, date of spring freshet (initiation of the spring/snowmelt runoff), date of annual minimum daily flow (see Appendix D); and
(7) Other ancillary water quality parameters, including temperature and total dissolved solids / specific conductance, dissolved oxygen, DOC/color, pH/alkalinity, TSS/turbidity

These parameters were selected for two reasons: a) their direct linkage to climate; and b) their potential direct impact on water quality and ecology (see Proposal Appendix A). Influences of land use changes, e.g. urbanization or agricultural use, have to be acknowledged, and to the extent possible based on funding limitations, will be taken into account in the interpretation of the results.

B. Lake Water Quality Trends Specific Objectives

The amount of lake water quality data that has been collected for Minnesota lakes is enormous and therefore, a series of meetings were held with project partners to distill down the scope of this task based on available funding to:

1) Compile existing water quality data from lakes with long ice-out records to test for statistical associations;

2) Compile water quality data from lakes with >15 years of at least one water quality parameter and perform exploratory trend analyses on all available parameters.

As the project proceeded, using a third component became possible as a result of tools developed from other non-LCCMR funded projects:

3) Develop an on-line Google-map based website for summarizing and presenting the results of the exploratory statistical analyses to allow other investigators to better visualize the data. The Water Quality Trend Tool would be a prototype for a MPCA and MDNR to consider for improving public access and understanding of water quality data.

C. Methods

1). Data compilation: Data from MPCA STORET files was re-organized and summarized in various ways (see below) in preparation for determining statistical associations with ice-out and ice-on data that was being compiled as a separate component of the overall project. With help from MPCA, we began by compiling data for an initial set of 26 lakes with long-term ice-out records compiled by co-PI V. Card. This set of lakes was then augmented to include an additional set of ~255 lakes for which ice-out records had been compiled. However, since the *ice-out record lakes set* had no *a priori* relationship to the amount of water quality data available for these lakes, we examined a larger set of lakes that contained at least 15 years of data for at least one parameter. This generated a set of 560 Minnesota lakes which ultimately grew to total

638 lakes totaling 1.9 million data records as other data bases were discovered that included quality assured data. Several water quality data sets were investigated, including those from MPCA (EDA), EPA (STORET), DNR Fisheries, Metropolitan Council, and our own (NRRI-UMD) cooperative work with Itasca County and Three Rivers Park District.

2). Water quality variables: Measured parameters comprise a primary *Core Suite* that includes the field sensor parameters that typically determine a meter-by-meter depth profile of temperature, dissolved oxygen (and a calculated percentage oxygen saturation), specific electrical conductivity (EC25, that estimates total salt/ion concentrations), and pH; and water clarity estimated by Secchi disk depth. Lake level is also considered to be a *Core* parameter, but trends in lake level were analyzed as a separate TASK by co-PI H. Stefan's group for the overall project (see Appendix B for details). A second group of *Advanced Suite* parameters includes most of the other "routine" water quality variables such as chlorophyll (in lakes), nutrients (nitrogen and phosphorus in its limnologically relevant forms), dissolved and total organic carbon and/or color, SiO_2, Hardness, the major anions (ANC/alkalinity, SO_4, Cl) and the major cations (Ca, Mg, Na, K). These classifications derive from the *Vital Signs* program used by the National Park which was used by NRRI-UMD to structure analyses of historical water quality in the Great Lakes Network of National Parks (Axler et al. 2005, 2006; Pennoyer 2003). It is useful since there will be many more *Core* than *Advanced Suite* data available for Minnesota lakes and streams.

3). Data quality assurance was assumed to have been properly completed prior to being stored in the MPCA EDA (Electronic Data Access) data base and EPA's STORET databases. However, numerous erroneous and anomalous values were uncovered during initial data screening that involved visually inspecting the data for outliers due to either entry error or changes in method detection limits. Outliers were identified based on best professional limnological judgment by NRRI staff and PI. In most cases, the problem was clearly due to a typographic error and was corrected. Ultimately, these outliers were either deleted from the data set used for statistical analyses, or allowed to remain in the database for lack of evidence to reject them. For some data we made assumptions about sampling depths based on maximum depths (Z_{max}) taken from MN DNR morphometry data available on the agency's Lake Finder website (http://www.dnr.state.mn.us/lakefind/index.html). Water quality parameter terminology follows standard limnological procedures (e.g. APHA 2003).

4). Depth strata: After data were manually reorganized and sorted into spreadsheets, a computer program was developed to automate the computation of depth stratum mean values, tabulation of data summaries, graphical presentation, and export to trend analysis software.

Each parameter from each site was averaged for all sampling dates and sampling periods for the following depth strata; 0m (surface values), 0-2m, 3-5m, 6-8m, 9-11m, 12-14m, 15-19m, 20-24m, 25-29m, 30-34m, etc. Strata were chosen for limnological reasons as well as data availability for the deeper strata in order to facilitate analyses of epi- meta- and hypolimnetic waters as manageable, but limnologically relevant "habitats" within a lake. These strata were selected to accommodate comparisons of lake trends across climatic regions and across groups of lakes classified by maximum depth. For example, our visual inspection of temperature and dissolved oxygen (DO) profiles from many shallow and deep, and productive and unproductive lakes has indicated that the strata 0-2, 3-5, 6-8 and 9-11m should capture the key seasonal and depth changes in temperature and DO for most lakes and eliminate the need for meter by meter comparisons of profiles. This also would eliminate about one third of the statistical analyses needed:

- [0-2m] - near-surface water in the mixed layer (epilimnion) where surface scums of algae can lead to supersaturated DO; averaging data from 0, 1 and 2m should also facilitate comparisons with chlorophyll and water chemistry measurements which have mostly been collected using 2m integrating tube samplers over the past 20 years.

- [3-5m] and [6-8m] – near-bottom water in polymictic shallow lakes (~4-8m bottom depth) and the thermocline region in stratified lakes whether the stratification persists throughout the ice-free growing season or not.

- [9-11m] - sub thermocline (uppermost hypolimnion) for most stratified lakes; may also be near-bottom for many lakes.

- [?-?] – undetermined for deeper hypolimnion strata. These analyses will likely focus on specific lakes within the set of ~ 255 lakes for which ice records exist.

- depth of the mixed layer (epilimnion depth for thermally stratified lakes); mean and maximum

- thermocline depth for stratified lakes - defined by the maximum temperature gradient with depth where the value exceeds 1 ^{o}C/meter (and 0.7 ^{o}C/meter); mean and maximum

- depth of anoxia – defined by DO $\leq$ 1 mgO_2/L; mean and maximum depth of acute warm, cool and cold water fish stress defined by values of 3 mgO_2/L, 5 mgO_2/L, and 7 mgO_2/L, respectively; these values are used as water quality criteria by the MPCA in various sections of Chapter 7050 (e.g. http://www.revisor.leg.state.mn.us/arule/7050/0222.html 7050.0222 SPECIFIC STANDARDS OF QUALITY AND PURITY FOR CLASS 2 WATERS OF THE STATE; AQUATIC LIFE AND RECREATION and http://www.epa.gov/waterscience/standards/wqslibrary/mn/mn_5_0150.htm 7050.0216 REQUIREMENTS FOR AQUACULTURE FACILITIES. As with temperature data, analyses will likely focus on specific lakes within the set of ~ 255 lakes for which ice records exist.

The statistics for each layer were calculated using the average of the daily averages within each time period. <u>Note that stratum averages were not volumetrically weighted and only represent water column means for a site in the deepest portion of the lake.</u>

5). Detection limit issues: We also needed to develop a set of "rules" for incorporating data listed as below detection into the database. This was particularly important for low nutrient lakes. There were two possibilities in the "raw" dataset extracted from the MPCA database -- "*Non-detect*" and "**Present <QL*", where QL is the *Quantitation Limit* for which the follow rules were adopted:

- If the record contains a value for "*MinDetectLimit*": use MinDetectLimit/2
- If the record contains a value for "*MinQuantLimit*": use MinQuantLimit/6
- Otherwise skip the record "*for now*"; we intend to examine this dataset more closely to see how important these deletions are to the results of the nutrient trends analyses.

6). *Secondary* parameters: In addition to the primary set of *Core* and *Advanced* suite water quality variables, several secondary, calculated parameters were generated for trend analysis:

- The Carlson Trophic State Index (TSI) was included because of its regulatory and management importance to lakes in Minnesota and its wide use in general. The index is actually three calculations based on midsummer secchi depth, surface TP and surface chlorophyll-*a* concentrations (details below in the Metadata).

- Algorithms were developed to calculate thermocline depth and the rate of change, or gradient, of temperature at the thermocline for over 500 lakes in the database since these are potentially important indicators of thermal trends in lakes. Thermal stratification and its stability (i.e. strength) act to structure habitat for aquatic organisms. This effort is also important because it provides a prototype for new calculated MPCA EDA (Electronic Data Access) thermal parameters since field temperature profiles are now simply entered into the database without further analysis.

- A third set of parameters compiled for each lake includes the various morphometric characteristics (e.g. surface area, maximum depth, mean depth, lake area to watershed area ratio, fetch, shoreline development, relative depth, et al.) as well as spatial classifications such as climate region and ecoregion.

7). Time intervals: Since this initial phase of the Climate Change project was intended to be exploratory, it was decided that trend analyses should be performed for a variety of potentially useful periods that could be used to characterize a particular year. For example, the MPCA has long requested Citizen Lake Monitoring Program (CLMP) volunteers, the group that has collected most of Minnesota's long-term Secchi disk water clarity data, to focus their measurements from June 15 – September 15. Therefore, all data within this time frame can be averaged to generate a single value for a particular year as has been routinely done by the agency for many years. Alternatively, a set of monthly or bimonthly mean values could be calculated and then analyzed singly for the year or considering their within-year variation. A monthly average for August, when algal biomass is usually thought to be at its peak could be useful to examine in comparison to weather patterns either at that time or perhaps over a longer period to include the contribution of spring runoff to the lake's nutrient loading. Similar arguments can be made for other ice-free months, or for any particular month, or two or three month period for that matter.
Limnological researchers have also used several different time periods and methods for generating annual averages, the most common periods perhaps being entire calendar year or the USGS *Water Year* defined as Oct 1 –Sep 30 of the following year, the *summer* (defined by the calendar season, or Jun-Aug, or Jun-Sep), or the *ice-free season* which on average could reasonably be defined as May through Oct (R.Axler, personal observations). Therefore, data was

compiled in a manner that would allow analyses to be performed using any or all of these time intervals. Consideration was also made of the potential for biasing averages if sampling was not spread evenly over a given interval and further statistical considerations of this issue are discussed below.

Initial examination of exploratory analyses focused on the following four time intervals:

- All data for the entire calendar year

- May through October 15, corresponding to the vast majority of the "ice-free growing season" for most lakes and most years.

- June 15 – September 15; the summer period as defined by MPCA for its Citizen Lake Monitoring Program (CLMP), CLMP-Plus, and most of its Lake Diagnostic studies. At least 4 monthly surveys will be required for this data set.

- June 1 – September 30; the "summer" as defined in Minnesota Rules, Chapter 7050, 7050.0150 DETERMINATION OF COMPLIANCE WITH WATER QUALITY STANDARDS AND WATER QUALITY CONDITION (http://www.epa.gov/waterscience/standards/wqslibrary/mn/mn_5_0150.htm)

- A midsummer window for some specified July – August period that is selected to maximize our use of data for a lake even if there was only a single survey for a year.

8). Trend analyses: Trends and trend rates over time were determined using the *Seasonal Kendall Trend Analysis* software developed by the U.S. Geological survey (2005; Computer Program for the Kendall Family of Trend Tests, Dennis R. Helsel, David K. Mueller, and James R. Slack SIR 2005-5275, U.S. Geological Survey; available at http://pubs.usgs.gov/sir/2005/5275) that allow for trend analyses both seasonally and regionally. The main advantage of the seasonal Kendall trend test is that it is a non-parametric, rank-based procedure suitable for non-normally distributed data, censored data, data containing outliers, and non-linear trends (Helsel et al. 2005; Helsel and Hirsch 1992; Hirsch and Slack 1984).

Sites were initially identified sites as "Qualifying" if they had records from at least 5 different years and with a level of significance of $p \leq 0.1$ for either a positive or negative trend over time. Additional exploratory trend summaries with accompanying mapping tools were generated for $p < 0.05$ and lakes having more years of data (8, 12 and >18 years).

It should be noted that in order to have been included in the original data set for which trend analyses were performed, a lake had to have "some" data for at least 15 different years and in virtually all cases, this long-term monitoring parameter was secchi depth clarity. Data records for all other parameters were considerably sparser.

9). Data, analyses, and visualization options: Mapping tools were added for retrieving and displaying trend data including a search tool for lakes; ecoprovince, ecoregion and county boundary overlays; selection options for the long-term "Ice Out" lakes and for the new

DNR/MPCA *SLICE* (i.e. sentinel) lakes. A comprehensive subproject website was constructed to make the trend results available to other project scientists. Our Minnesota Lake Trends website:

Minnesota Lake Trends Analyses website: ***http://mnbeaches.org/gmap/trends***

includes "processed raw" data, complete metadata, summary tables, links to Google maps that identify sites with descriptive statistics, and graphs (box and whisker and regressions). Detailed metadata were also created for the website and are included below.

The data are also incorporated into the larger project database that is now being used for more detailed examinations of geographic patterns, size and depth patterns, and associations with fish, macrophyte, weather, and ice cover data.

D. Results

1). Trend analyses: All statistical information is indexed at http://mnbeaches.org/gmap/trends/results/avg/index.html via a table with hyperlinks to specific statistical analyses (Figure 1). "Seasons" define how the data are averaged. For example, a one (1) season analysis computes the median of all data for a particular interval during the year, such as a single month, two months, or the generalized ice-free growing season (May 1 – Oct15). These analyses weight all data equally, even if there is a bias towards one period within the specified interval. In order to account for this potential bias, several additional "seasons" were defined, in particular the 3-"season" summer field season period that groups data into one month "seasons" from Jun15 - Jul15, Jul16 - Aug15, and Aug16 - Sep15, that collectively encompass the MPCA's historically defined Jun15 - Sep15 field season. Additional analyses were performed based on a standard 4-season year and a 12-month year, but we focused our initial conclusions on the results from the 3 season statistical analyses. In fact, because most data were collected during the period June through September, and distributed relatively uniformly in summer when multiple surveys were performed on a lake, the results from the 3-season analyses did not differ much from the 1-season Jun-Aug, 1-season Jun-Sep, or 1-season May-Oct15 interval results.

Figure 1. **MN Lake Trends - Seasonal Kendall Results**

These results were calculated by first averaging the results for each layer by day, then averaging those results for each time period (season).

Go to Metadata for details.

# of seasons per year	Season definition	≥ 5 yrs data & $p \le 0.1$	≥ 5 yrs data & $p \le 0.05$	≥ 8 yrs data & $p \le 0.05$	≥ 12 yrs data & $p \le 0.05$	≥ 18 yrs data & $p \le 0.05$	≥ 8 yrs data & $p \le 0.01$	≥ 12 yrs data & $p \le 0.01$
12	Monthly	-X-	-X-	-X-	-X-	-X-	-X-	-X-
4	JanFebMar, AprMayJun, JulAugSep, OctNovDec	-X-	-X-	-X-	-X-	-X-	-X-	-X-
3	Jun15 - Jul15, Jul16 - Aug15, Aug16 - Sep15	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	May01 - Oct15	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	Jun15 - Sep15	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	Jun - Jul - Aug	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	Jun - Jul - Aug - Sep	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	May - Jun	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	Jun - Jul	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	Jul - Aug	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	Aug - Sep	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	April	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	May	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	June	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	July	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	August	-X-	-X-	-X-	-X-	-X-	-X-	-X-
1	September	-X-	-X-	-X-	-X-	-X-	-X-	-X-

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Exemplary results for temperature are show in Figure 2 for the 3-season summer analysis where the criteria for a statistically significant trend required at least 5 years of data for the particular parameter of interest, and a significance level of 5% (i.e. $p \leq 0.05$). The row highlighted in the

Figure 2.

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MN Lake Trends

Seasonal Kendall Trend Analysis
3Periods_Jun15_thru_Sep15 Summary (3 seasons/year)

The statistics for each layer were calculated using the average of the daily averages of the result values within each time period.

Temperature, water

Qualifying sites: Sites with records from at least 5 different years and with p ≤ 0.05

[Download the complete results (csv)]

Summary type (averaged values)	Characteristic	Layer	[A]	[B]	Sites with significant trends (p ≤ 0.05) & data from at least 5 different years			Trend direction				Map	List
								Count		% of C			
			# of Sites with data	# of sites with data from at least 5 different years	[C] Count	% of A	% of B	Negative trend count	Positive trend count	Negative trend percent	Positive trend percent		
3Periods_Jun15_thru_Sep15	Temp_H2O	00-00m	543	218	30	5.5%	13.8%	1	29	3%	97%	map	list
3Periods_Jun15_thru_Sep15	**Temp_H2O**	**00-02m**	**551**	**247**	**65**	**11.8%**	**26.3%**	**5**	**60**	**8%**	**92%**	map	list
3Periods_Jun15_thru_Sep15	Temp_H2O	03-05m	524	187	35	6.7%	18.7%	10	25	29%	71%	map	list
3Periods_Jun15_thru_Sep15	Temp_H2O	06-08m	444	155	34	7.7%	21.9%	25	9	74%	26%	map	list
3Periods_Jun15_thru_Sep15	Temp_H2O	09-11m	374	119	25	6.7%	21.0%	19	6	76%	24%	map	list
3Periods_Jun15_thru_Sep15	Temp_H2O	12-14m	283	81	20	7.1%	24.7%	15	5	75%	25%	map	list
3Periods_Jun15_thru_Sep15	Temp_H2O	15-19m	203	52	9	4.4%	17.3%	7	2	78%	22%	map	list
3Periods_Jun15_thru_Sep15	Temp_H2O	20-24m	127	27	8	6.3%	29.6%	7	1	88%	13%	map	list
3Periods_Jun15_thru_Sep15	Temp_H2O	25-29m	67	8	1	1.5%	12.5%	1	0	100%	0%	map	list

red box shows summary trends data for these criteria for near surface temperature (the 0-2 m depth stratum). There were 551 lakes that had data for this stratum, of which 247 had at least 5 different years with data. Sixty-five (65) had a significant trend (26% of the 247 *qualifying* sites) and 92% of these showed a positive, i.e. warming trend. Clicking on the hyperlink **list** at the end of the row opens up a table listing all of the lakes by MDNR DOW #, shown in red if the trend was positive and blue if negative (see Figure 3) and grouped based on how many years of data each had (through 2007). The **map** hyperlink provides the *Googlemap*™ based geographic distribution of the lakes with significant trends, and if desired, of the entire set of lakes with data (Figure 4). Overlays of counties, MPCA Ecoregions and MDNR Ecoprovinces are also available. Markers denoting individual lakes are coded to indicate the sign, magnitude (%-ile), and level of statistical significance of the trend. Individual lake trends are shown as box and whiskers plots that show the data color coded and shown for each "season" according to the specific seasonal Kendall analysis, along with trend slope and its significance (Figure 5). Further description of the analysis outputs are found in the website METADATA below.

Figure 3.

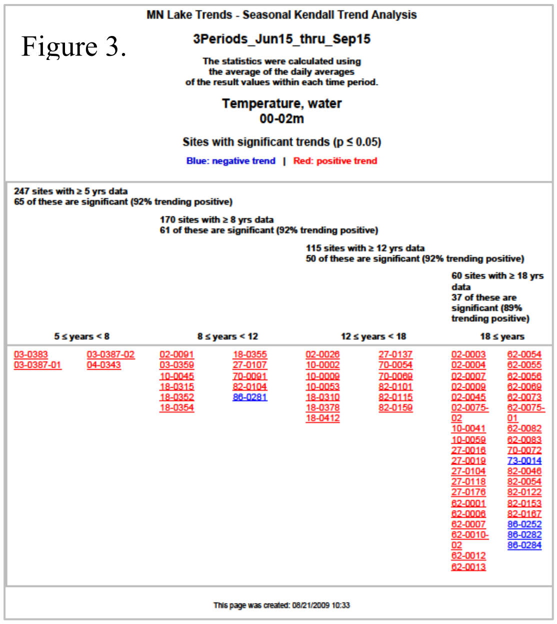


Figure 4.

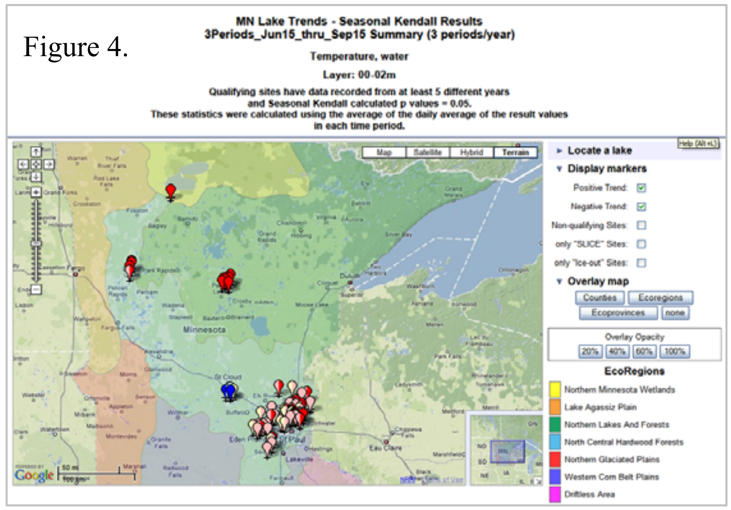
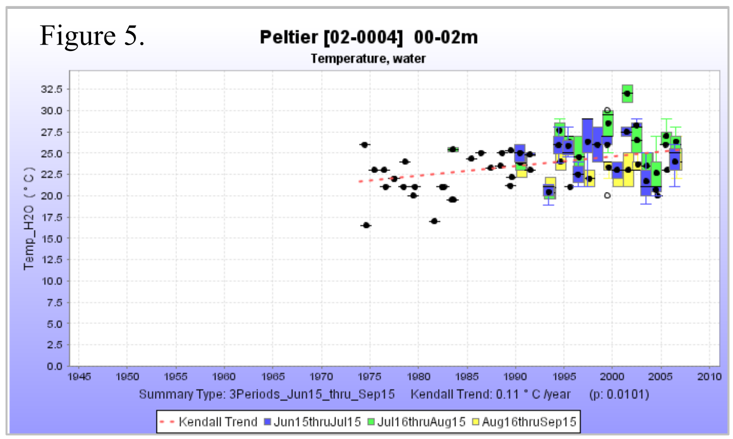


Figure 5.



2). Comparison with MPCA Citizen's Lake Monitoring Program (CLMP) trends analyses: This comparison was of immediate interest because the MPCA has been performing trend analyses for lakes with more than about 8-10 years of volunteer secchi data. The statistical basis for these analyses are apparently now being reviewed but it appears that MPCA has been using a similar type of Kendall analysis (details are currently unavailable). MPCA staff provided a spreadsheet summarizing the results of their trend calculations based on the average of the secchi readings taken each year between June 1 and September 30. Therefore, we compared our results with these for the identical time period as a "single season" in the sense of the Seasonal Kendall test software (see METHODS).

We initially examined sites that had the largest discrepancy between our calculated trends and theirs. We discovered that 7 of these sites had Secchi data that was improperly entered in STORET. Some of the readings were recorded in feet, but the units were entered as meters. MPCA had apparently caught these errors, and corrected them for their calculations and on their website where these data are posted (http://www.pca.state.mn.us/water/clmp/clmpSearch.cfm), but the corrections had not filtered back to STORET. These entries were corrected in our dataset and the trends were recalculated. This resulted in 274 sites showing significant trend results ($p \leq 0.1$) with 268 reported to show statistically trends by MPCA (% agreement, Figure 6).

Figure 7 displays the magnitude of the trend rate difference between the two analyses across all sites. All but 5 of the MPCA results were within 0.05 m/yr of the NRRI results and >90% were within 0.02 m/yr. These differences did not seem to be due to differences in the way annual means were computed since there was close agreement between NRRI annual means and those posted on the MPCA website- usually within 0.1 m for each year's average result which is approximately the method detection limit for volunteer secchi data. There were however, some differences in the methodology NRRI used to calculate the annual averages compared to MPCA. NRRI averaged all of the results for a site that were taken on the same day (i.e. from different stations) and then averaged all of these averages for the entire season. Most sites only have one reading for a given day, but there are some that have more than one. For example, site #29-0146 (the right-most data point in Figure 7) has 4-5 records in STORET for that StationID on some days, with different ActivityIDs and although NRRI averaged them all together for that day, MPCA seems to have only considered records with certain ActivityIDs, presumably using local information as a basis for their data editing. Three of the five sites with the largest discrepancy had identical data posted to what we used in our calculations. The differences seem to be explainable by the fact that MPCA did not use data from all of the years posted on their website when doing their trend calculations. For example, site #31-0424 has data posted from 13 years, but MPCA's summary spreadsheet indicates that only 8 were used in the calculation and unfortunately there are no notes explaining why this was done.

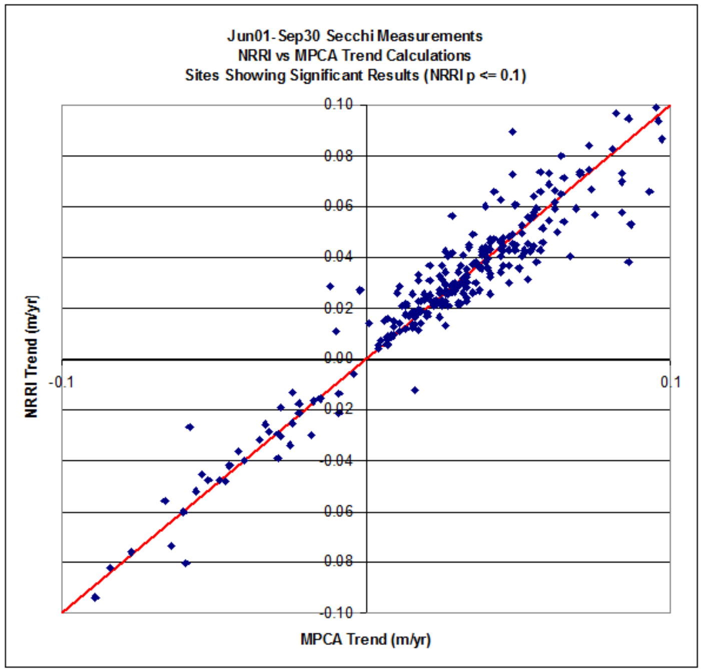


Figure 6. Comparison of Kendall analysis trend rates between NRRI (this study) and MPCA (CLMP, unpublished) for 274 lake sites selected on the basis of having at least 15 years of "some" data (see METHODS). Red line denotes 1:1 correspondence.

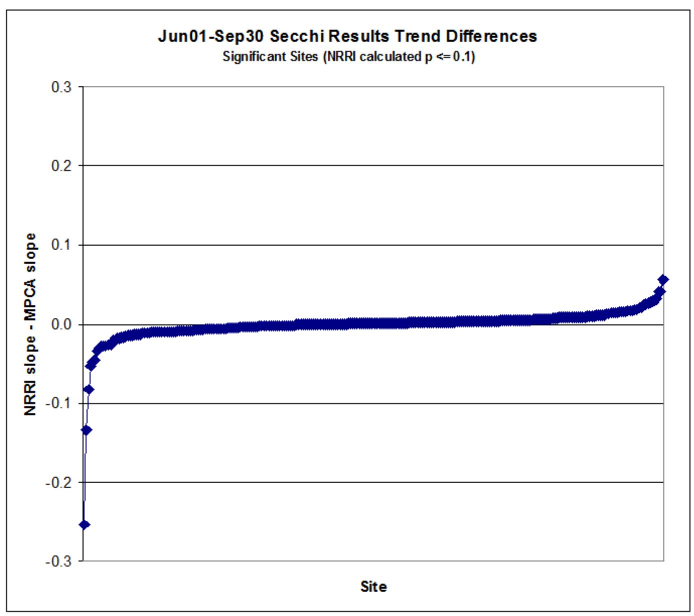


Figure 7. Magnitude of difference between NRRI and MPCA calculated trend rate for sites with $\geq$ 15 years of data.

Site #21-0106-01 shows the largest difference (-0.25 m/yr), even though the data used as input to the NRRI Kendall trend calculation is the same as what is shown on the MPCA website and so some of the data from the MPCA's EDA website suffers from the same unit-conversion errors mentioned above. MPCA seems to have corrected the data for their trend calculations, but not in the EDA database, so the discrepancy wasn't caught when we did our site by site comparisons. Figure 8 shows a plot of NRRI results, showing the effect of the erroneous values.

Although there are likely other uncaught errors, the close agreement between the two independent analyses is taken to be supportive of our approach to identifying the overall trends in Minnesota lakes.

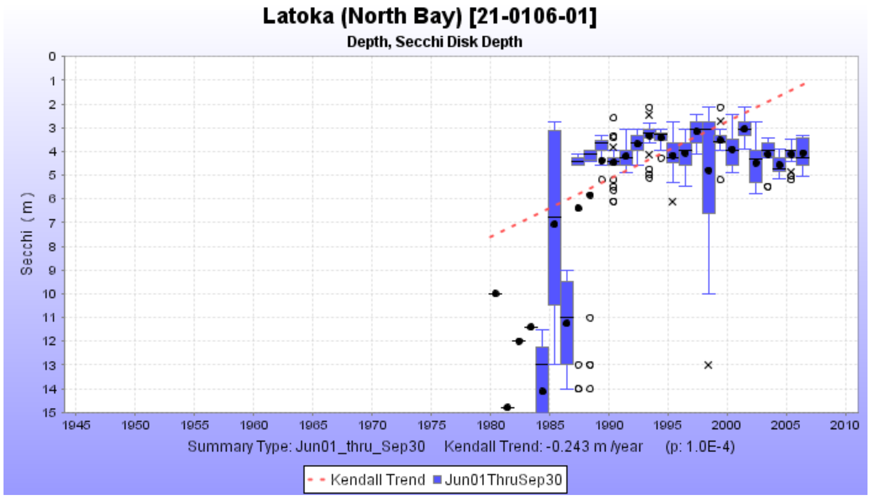


Figure 8. Secchi depth trend for site 21-0106-01 illustrating the effect of feet-to-meter conversion error the early years of the data record.

Discovering significant errors in the EDA and STORET databases almost exclusively due to *feet-to-meter* mis-conversions led us to conduct an extensive computerized and manual (visual) re-screening to identify and correct other secchi errors as well as for temperature, where we found additional unit errors from the *Fahrenheit-to-Celsius* conversion. All errors discovered as part of this project will be reported to MPCA for complete correction in the EDA and STORET databases.

3). A second confirmation of the web-reported trends was performed using the Mann-Kendall (MK) function in R from the Kendall software package written and maintained by McLeod (2005). The analysis was recreated from the NRRI website data summaries for near-surface temperature (0-2m), secchi depth, thermocline depth, TSI-Secchi, near-surface chlorophyll-*a* concentration (0-2m), and near-surface total phosphorus concentration (0-2m). Values for each parameter were averaged for the Jun15-Sep15 season (i.e. comparable to the 1-season analysis in Figure 1) and then the means for each lake and year were entered into the MK function as a vector. Table 1 compares the percent of lakes that showed a trend at a 5% level of significance for the different software analyses and indicates excellent agreement.

Table 1. Comparison of Helsel (2006; USGS) and McLeod (2005) trend analyses. Values indicate the percentage of lakes with at least 5 years of "some" data that showed a statistically significant trend at $p \leq 0.05$. RPD = relative percent difference.

	Helsel (2006)	McLeod (2005)	RPD
Secchi depth	32.3	32.1	0.6 %
Total Phosphorus	20.2	19.9	1.5 %
Chlorophyll-*a*	10.4	11.0	5.6 %
TSI-Secchi	31.3	31.2	0.3 %
Thermocline depth	10.3	9.6	7.0 %
Surface temperature	7.3	7.2	1.4 %

4). Summary of exploratory trend analyses (provisional observations, August 2009)

In the context of the climate change issue that spawned the present study, the most important result derived from the exploratory trend analyses has been that for lakes with significant time trends during the period June – September, more than 90% showed surface water warming as compared to cooling (Figure 9). This result was found for over 26% of those lakes with at least 5 years of data (247 of the 551 lakes examined) and almost 2/3 of the 60 lakes with 18 years or more data. For the 37 lakes that showed statistically significant warming over their period of record, the mean trend was 0.080 $\pm$ ^{o}C/yr. This would project to an average increase of 0.8 ^{o}C (1.4 ^{o}F) in 10 years, and 3.3 ^{o}C (5.9 ^{o}F) by 2050.

Another important effect predicted from models of the thermal characteristics of lakes in response to climate change relates to the depth of the summer thermocline in deeper lakes and its thermal stability (i.e. resistance to wind mixing and destratification). Warmer growing season air temperatures have generally been predicted to decrease the depth of the thermocline (i.e. creating a shallower epilimnion) in most lakes as a consequence of increased warming of the epilimnion and increased thermal stability. The period of stable stratification is also predicted to begin earlier due to earlier ice-out and persist longer into the fall (e.g. Kling et al. 2003; Fang and Stefan 1999; Schindler et al. 1996). Both empirical and theoretical (i.e., modeling) studies have qualified these predictions because of the variability introduced by the uncertainty of wind velocities, site specific morphometry, and the potential effects of water color changes and light penetration due to changes in dissolved organic matter (DOM) loading and the effect of DOM on light absorption (i.e. heat storage) with depth (Parker et al. 2007; Fang and Stefan 1999).

Although only 16% of lakes with >5 years of data had significant trends in thermocline depth, 85% of those that did exhibited decreasing (i.e. shallower) thermocline depths (Figure 9). Thermocline gradient (stability) only showed statistically significant trends in 10-18% of lakes depending on the length of data record, but almost all trends were positive (Figure 9). Together, these thermal effects over time suggest a shallower, but more stable depth of stratification, which is consistent with surface warming. The data also suggest that in those lakes, the hypolimnion could be more isolated from mixing of epilimnetic water although the population of lakes with such trends is relatively small. Trends in hypolimnetic water for depth strata below a depth of 6 meters, showed the opposite effect with about 20% of the lakes having at least 5 years of temperature profile data having statistically significant trends and more than 75% of those being negative (cooling)(data not shown but see http://mnbeaches.org/gmap/trends/results/avg/3Periods_Jun15_thru_Sep15Summary_5yrs-005p.html). This result is consistent with the surface warming and thermocline trends described above and the findings were similar whether there were 5, 8, 12 or 18 years of data. Both patterns, warming epilimnia and cooling hypolimnia when trends were found, were consistent across the many exploratory analyses that were performed for the period June through September, whether data were pooled for two or three months or examined for individual months (see http://mnbeaches.org/gmap/trends/results/avg/index.html)

The duration of thermal stratification was not investigated for this study and it is presumed that most of the lake data sets lack enough surveys during the ice-free season to assess potential trends in this important parameter. However, there may be some lakes with frequent enough summer sampling for enough years to warrant closer examination.

Trend results were less clear for dissolved oxygen (DO). The number of positive versus negative trends in surface waters was approximately similar although 60-75% showed increasing DO in the lakes with 12 to more than 18 yrs of data – an anomalous finding since one might have expected slightly decreasing DO due to warmer water (Figure 9). However, hypolimnetic strata for >20% of the lakes with available data showed significant trends with a clear (>75%) preponderance of increased DO.

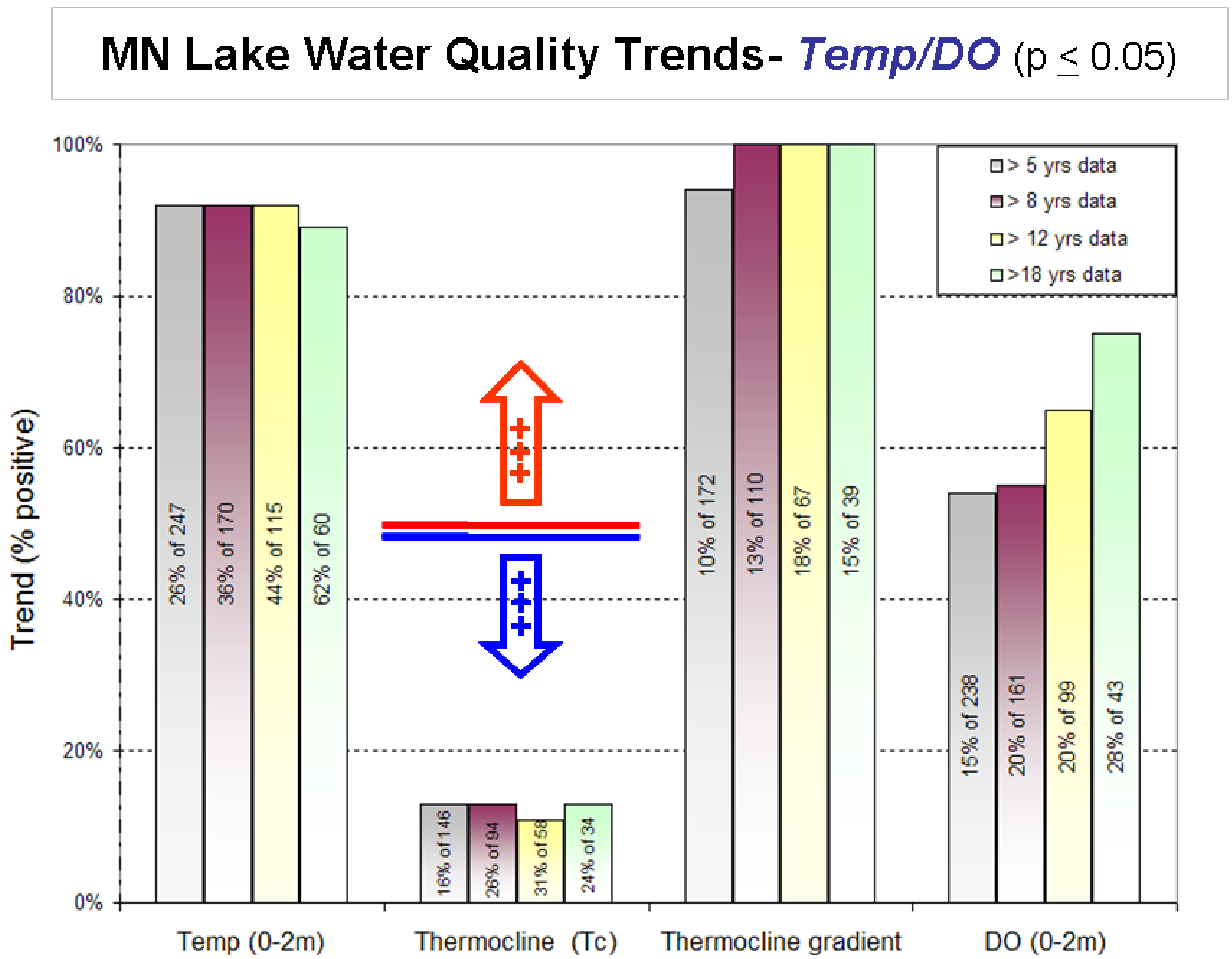


Figure 9. Summary of temperature and dissolved oxygen related trends for Minnesota lakes having at least 15 years of at least one water quality parameter. Bars indicate the percentage of statistically significant trends at $p \leq 0.05$ that were positive for sites with a given number of years of data. Bar colors denote the length of the parameter records; numbers inside the bars indicate the percentage of those sites that were statistically significant. A Trend value of 50% indicates equal likelihood of the significant trend being + or – This is show by the red (positive) and blue (negative) arrows.

The salt content of surface waters, as estimated by specific electrical conductivity (EC25) and chloride concentration has increased over time in more than a third of the lakes with >5 years of data, 50% of those with >8 years, and 90% with >18 years of data (Figure 10). This is consistent with increased summer surface warming but also with potential increased exposure to winter de-icing salts and/or increased stormwater runoff from either urban or agricultural areas. Increased loading to the whole lake such as would occur from runoff inputs are suggested by the fact that the trends with depth examined for the entire summer and for just the warmest month (July) all exhibited large (82-100%) predominance in increased relative to decreased salinity.

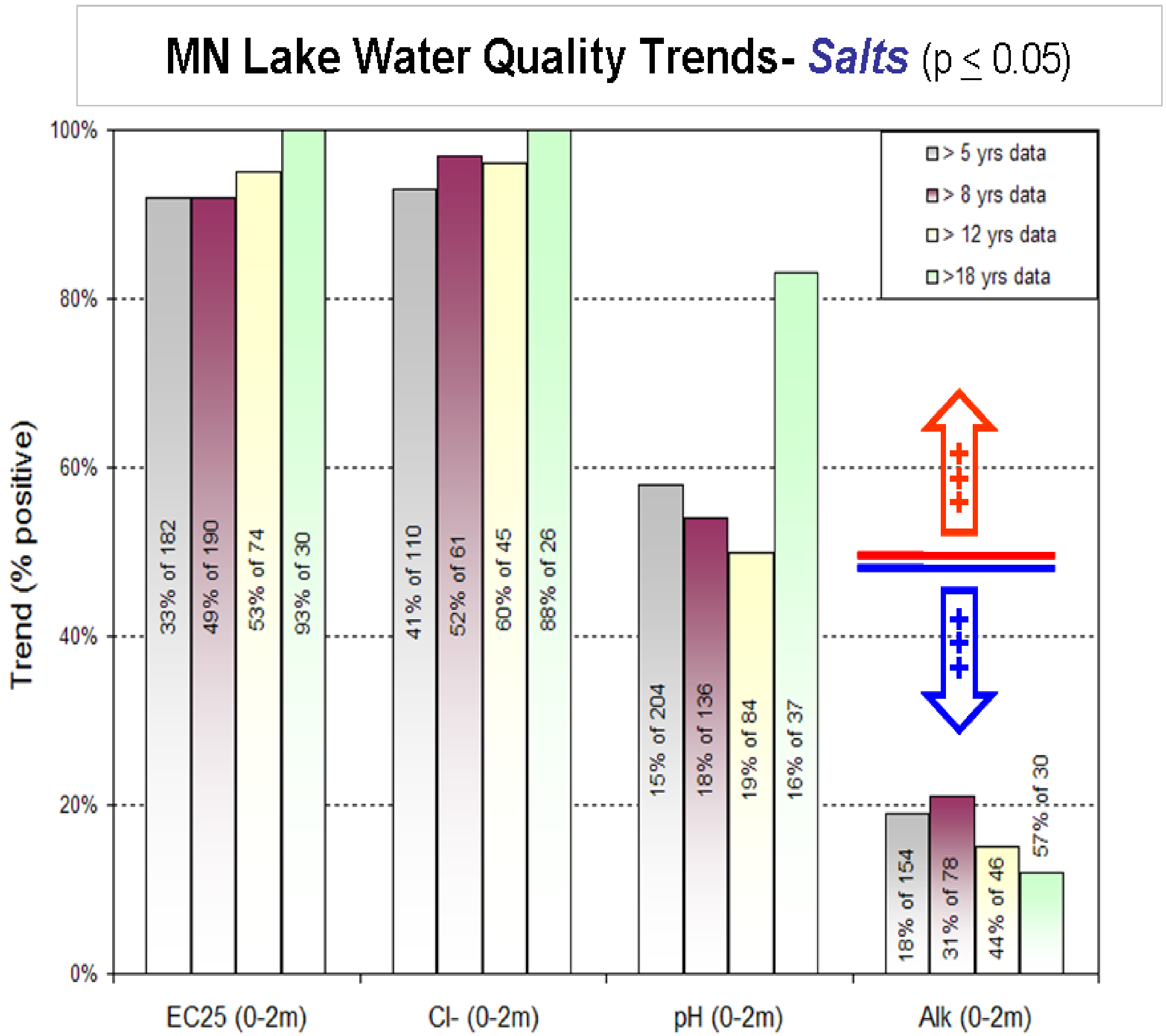


Figure 10. Summary of specific electrical conductivity (EC25), chloride concentration, pH and alkalinity trends for Minnesota lakes having at least 15 years of at least one water quality parameter. Bars indicate the percentage of statistically significant trends at $p \leq 0.05$ that were positive for sites with a given number of years of data. Bar colors denote the length of the parameter records; numbers inside the bars indicate the percentage of those sites that were statistically significant. A trend value of 50% indicates equal likelihood of the significant trend being + or – This is show by the red (positive) and blue (negative) arrows.

Only ~15-19% of the lakes with >5 years of surface water pH data exhibited trends and there were roughly similar numbers of positives and negatives; only for the 37 lake data set having >18 years of data was there an excess in one direction - this being towards higher pH. This could potentially be a consequence of the Minnesota sulfate emission standards program but would need to be assessed on a lake by lake basis. Anomalously, alkalinity trends were overwhelming negative by > 80%: 20% for a substantial number of lakes and for all lengths of data records. We currently do not have an explanation for this rather striking result.

The Minnesota Lake Trends website also summarizes exploratory trend analyses for the major ions calcium, magnesium, potassium, sodium, and sulfate, hardness, color and dissolved organic carbon (see http://mnbeaches.org/gmap/trends/results/avg/3Periods_Jun15_thru_Sep15Summary_5yrs-005p.html for the 3-season period Jun15-Sep15). Most of these analyses either lack enough years of data to test for trends, or the number of statistically significant trends that were found were few enough that we are not confident in drawing even provisional conclusions at present.

Perhaps the most surprising result found in this study was that there was internal consistency within the group of trophic status indicators (secchi depth clarity, chlorophyll-a, total phosphorus and total Kjeldahl nitrogen) that suggests a strong overall improvement in water quality (Figure 11). These trends were found for a large number of lakes- ~40% of the lakes in the secchi data set had statistically significant trends, and of these >80% were increasing (i.e. clearer water). This result was similar whether there were 5, 8, 12 or 18 years of data so the trend is nearly 2 decades old. We corroborated this result using an independent (software) Kendall statistical analysis for surface temperature, thermocline depth, secchi depth, surface chlorophyll-a, surface total phosphorus, and TSI-secchi data (Table 1) and also by cross-comparing our secchi trend rates with MPCA's estimates for CLMP lakes with more than 15 years of data (Figures 6 and 7). In both cases, the differences in results were negligible.

Additional analyses were performed on other nutrient fractions, including ammonium-, nitrate+nitrite-N, nitrate-N, nitrite-N, total Kjeldahl-N (TKN), and ortho-phosphorus. Ammonium-N, TKN and ortho-phosphorus also exhibited a predominance of negative relative to positive trends although there were fewer overall data. The other nutrient fraction data sets were inconclusive because of even fewer data (see http://mnbeaches.org/gmap/trends/results/avg/3Periods_Jun15_thru_Sep15Summary_5yrs-005p.html). Analyses of Carlson TSI's similarly indicated that about 80% of the lakes with > 5 years of data that had significant trends had shown improvement (data not show but available at http://mnbeaches.org/gmap/trends/results/avg/3Periods_Jun15_thru_Sep15Summary_5yrs-005p.html).

Overall, many lakes showed trends for many water quality parameters. However, it is extremely important to note that the current set of lakes is not distributed randomly across the state and is visually heavily biased towards the Minneapolis-St-Paul metropolitan area. More work is needed to examine individual lake records to see if these general trends are consistent for well monitored lakes. The analysis should also be extended to lakes with 5 or more years of data for parameters highlighted by this exploratory analysis since many of the trends found for longer data records were also significant when lakes were pooled with those with 5-8 years of data. There is also a need to calculate % dissolved oxygen saturation as a "check" on some of the DO concentration results. Irrespective of temperatures in the upper mixed layer (epilimnion), most lakes would be expected to be saturated with oxygen in surface and near-surface water. This parameter was historically not calculated nor entered into STORET but could be calculated from DO concentration based upon corresponding temperature and EC25 values coupled with approximate lake surface elevation. As for other components of this overall *Climate Change* project, the exploratory analyses conducted to date point to the value and need for consistently collected environmental data over long periods of time for a large number of geographically distributed lakes in order to manage them most effectively.

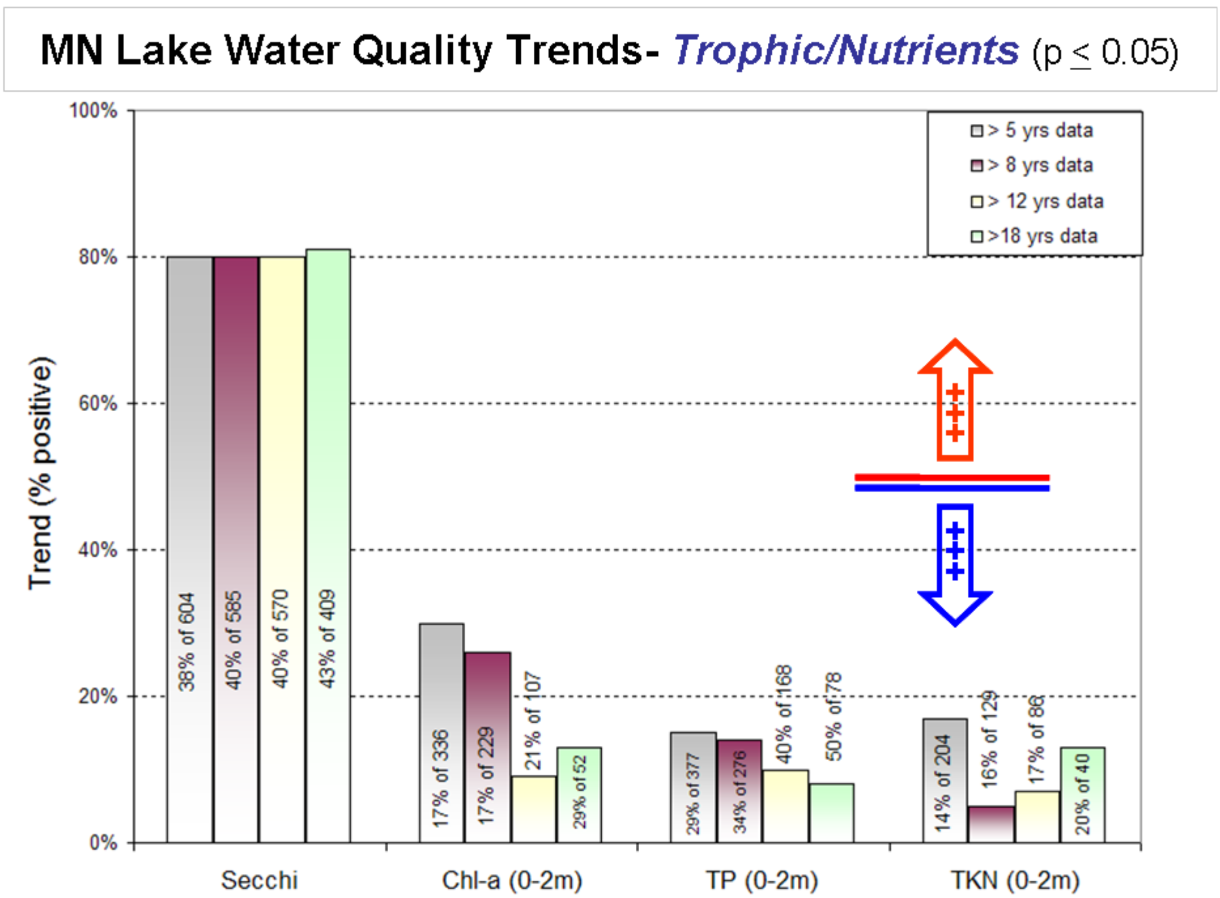


Figure 11. Summary of temperature and dissolved oxygen related trends for Minnesota lakes having at least 15 years of at least one water quality parameter. Bars indicate the percentage of statistically significant trends at $p \leq 0.05$ that were positive for sites with a given number of years of data. Bar colors denote the length of the parameter records; numbers inside the bars indicate the percentage of those sites that were statistically significant. A trend value of 50% indicates equal likelihood of the significant trend being + or – This is show by the red (positive) and blue (negative) arrows

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Attachment: Minnesota Lake Trends website home page and metadata:

: ***http://mnbeaches.org/gmap/trends***

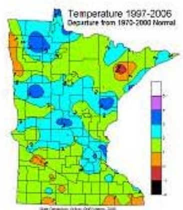
Minnesota Lake Trends Analyses

Page ▾ Safety ▾ Tools ▾

Minnesota Lake Trends Analyses

The data analysis in this websection is one element of a collaborative University-State Agency project funded in 2006 to compile and analyze data that would help Minnesota address natural resource issues associated with potential changes in climate. Phase I (2006-2009) objectives are to:

1. Quantify historic trends in lake fish and higher plant (macrophyte) communities and stream hydrologic and water quality responses to climate
   - Responses of hydrologic and water quality parameters to climate in streams and lakes will be extracted from historical data and summarized.
   - Existing data will be examined to determine if patterns exist for Minnesota, if these patterns are related to climate, and if possible to land use.
2. Develop a database of historic and future climate data for Minnesota
   - Examine existing data sets of climate and records of lake ice-out to determine if patterns can be documented for Minnesota over the past 50 years.

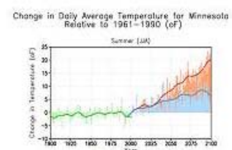


Minnesota Climatology Working Group

Data Summaries

MetaData

Project Team



Wuebbles & Hayhoe (2004)

NRRI Natural Resources Research Institute | UMD Duluth | Minnesota Pollution Control Agency

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Funding:
Legislative-Citizen Commission on Minnesota Resources

Updated: August 13, 2009

Minnesota Lake Trends - Metadata

Page updated: Aug 13, 2009

I. Data sources

- STORET via MPCA retrieval
- Water quality data from lakes with >15 years of at least one water quality parameter to perform exploratory trend analyses on all available parameters
- Status (8/31/09): 638 Minnesota lakes having more than 15 years of at least "some" water quality data totaling 1.9 million data records.
- MPCA data is "current" through 2007
- Met Council data is "current" through 2006
-

II. Data screening

- Already screened for basic QA/QC via STORET data entry rules
- Further "visual, but non-systematic" scanning for errors, outliers, and anomalies
- After comparing NRRI trend analyses of secchi records with Minnesota Pollution Control Agency (MPCA) trends calculated for their Citizen Lake Monitoring Program (CLMP) on a lake-by-lake basis, a number of STORET errors were discovered. These had been previously corrected for the CLMP analysis, but not corrected in STORET. Errors were largely associated with the feet-to-meters conversion. Therefore, the entire MN Lake Trends data set was screened and corrected as needed. A similarly small but significant set of lakes also had Fahrenheit to Celsius conversion errors.

III. Data censoring rules

- For incorporating data listed as below detection into the database and this is particularly important for low nutrient lakes.
- There were two possibilities in the raw dataset -- "*Non-detect" and "*Present <QL", where QL is the Quantitation Limit:
    1. If the record contains a value for "MinDetectLimit": use MinDetectLimit/2 (one-half the specified detection limit). This technique has been widely used for decades and there is still no "accepted" guidelines for censoring below-detection data (e.g. EPA. 2004. Revised Assessment of Detection and Quantitation Approaches. EPA-821-B-04-005. October 2004. Office of Science and Technology, Office of Water (4303T), U.S. Environmental Protection Agency, Washington, DC 20460 (www.epa.gov/waterscience/methods/det/rad.pdf; Helsel, D. 2005. More

Than Obvious: Better methods for interpreting non-detect data. Environ. Sci. Technol., 2005, 39 (20), pp 419A–423A.).

2. If the record contains a value for "MinQuantLimit": use MinQuantLimit/6.6 based on the approximation that MDL ~ 3*SD and QL ~ 10*SD where SD is the Standard Deviation for a set of replicate water samples in the lower concentration range of interest (cf. EPA. 2004 above)
3. Otherwise skip the record "for now (7/14/09)"; we intend to examine this dataset more closely to see how important these deletions are to the results of the nutrient trends analyses if continued funding becomes available.

IV. Parameter groups

- ***Core Suite*** - field sensor parameters that typically determine a meter-by-meter depth profile of temperature, dissolved oxygen (and a calculated percentage oxygen saturation), specific electrical conductivity (EC25, that estimates total salt/ion concentrations), and pH; and water clarity estimated by Secchi disk depth.
- ***Advanced Suite*** - most of the other "routine" water quality variables such as chlorophyll-a, nutrients (TN [measured and calculated], TKN, [nitrate+nitrite]-N, ammonium-N, TP, ortho-P), dissolved and/or total organic carbon and/or color, SiO2, Hardness, major anions (ANC/alkalinity, SO4, Cl) and major cations (Ca, Mg, Na, K).
- We think this is a useful classification since there will be many more *Core* than Advanced Suite data available for Minnesota lakes and streams. This nomenclature was borrowed from the *Vital Signs* long-term monitoring program of the U.S. National Park Service.
- ***Calculated Indicators*** —

1. Carlson Trophic State Index (TSI) as individual TSI-secchi, TSI-TP, TSI-Chlorophyll-a; Mean-TSI (= [TSI-P + TSI-C + TSI-S]/3).
   - TSIs calculated for data collected only during the period May 1 - Oct 15;
   - if there is a 0-2m value, use it, otherwise use the value from the shallowest reading if it's < 5m, otherwise do not calculate the TSI;
   - any records for Secchi, Chlor, or TP that had result values of “0” were ignored because they would cause the TSI formulas to *explode* due to the log function. These records were probably data entry errors, obviously for Secchi depth.
   - The TSI values are calculated as show below (from MPCA;
   - *www.pca.state.mn.us/water/basins/305blake.html ; Carlson 1977*)

Secchi disk (SD): TSI (TSIS) = 60 - [14.41(natural log)(Secchi average)]

Total phosphorus (TP): TSI (TSIP) = [14.42 (natural log)(TP average)] + 4.15

Chlorophyll-a (chl-a): TSI (TSIC) = [9.81(natural log)(chl-a average)] + 30.6

(TP and chl-a in micrograms per liter (ug/L) and SD transparency in meters).

The index ranges from 0 to 100 with higher values indicating more eutrophic conditions. The TSI values were calculated for each variable, then averaged for each lake (Figure 1). Although *Mean TSI* values were calculated, they must be used with caution since this analysis assumes that water clarity is controlled by algal biomass, which is in turn controlled by available phosphorus as estimated by TP. TSIS, TSIP, and TSIC might be expected to diverge in lakes that are turbid due to high loads of suspended or re-suspended sediment, or when algal biomass is regulated by another factor such as nitrogen availability or grazing by invertebrates.

Figure 1. Carlson's Trophic State Index (TSI)

TSI <30	Classic Oligotrophy: Clear water, oxygen through the year in the hypolimnion, salmonid fisheries in deep lakes.
TSI 30-40	Deeper lakes still exhibit classical oligotraphy, but some shallower lakes will become anoxic in the hypolimnion during the summer.
TS 40-50	Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.
TS 50-60	Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnion during the summer, macrophyte problems evident, warm-water fisheries only.
TSI 60-70	Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.
TSI 70-80	Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.
TSI > 80	Algal scums, summer fish kills, few macrophytes, dominance of rough fish.

2. <u>Actual thermocline depth</u> – calculated directly from temperature profiles as the depth of the maximum temperature gradient provided it is > 1°C /meter for each site with a H2O Temp dataset.

For each profile in the dataset:

- combine any adjacent readings that are within 0.25 m into a single reading consisting of the averaged depths and temperatures

- calculate dtdz between adjacent readings in the profile,
- determine which is the maximum dtdz,
- ignore and move on to the next profile if dtdz_max is < 0.7 °C /m,
- otherwise:
  - create a record in the Thermocline_Rate dataset for the site,
  - set the upperDepth & lowerDepth variables to the depths of the 2 adjacent readings that gave dtdz_max,
  - if the dtdz for the previous (shallower) reading pair is within 0.05 of dtdz_max use its upper depth for upperDepth,
  - if the dtdz for the next (deeper) reading pair is within 0.05 of dtdz_max use its lower depth for lowerDepth,
  - calculate the thermocline depth = (lowerDepth + upperDepth) /2,
  - create a record in the ThermoclineDepth(rate ≥ 0.7 °C /m) dataset for the site,
  - if dtdz_max is >= 1.0 °C /m create a record in the ThermoclineDepth (rate ≥ 1.0 °C/m) dataset for the site

3. Predicted thermocline depth (to be done)– estimated based on lake morphometry from the equation developed in: Gorham, E. and F.M. Boyce, 1989. Influence of lake surface area and depth upon thermal stratification and the depth of the summer thermocline. Journal of Great Lakes Research, 15(2): 233-245.

V. Depth strata

- After data were manually reorganized and sorted into spreadsheets, a computer program was developed to automate the computation of depth stratum mean values, tabulation of data summaries, graphical presentation, and export to trend analysis software. Each parameter from each site was averaged for all sampling dates and sampling periods for the following depth strata; 0m (surface values), 0-2m, 3-5m, 6-8m, 9-11m, 12-14m, 15-19m, 20-24m, 25-29m, 30-34m, 35-39m, 40-49m, 50-59m, 60-69m, 70-79m, 80plus. Strata were chosen for limnological reasons as well as based on data availability for the deeper strata. The statistics for each layer were calculated using the average of the daily averages of the result values within each time period.

VI. Time intervals

- Since there are many periods of interest for these data, we performed trend analyses for a variety of periods that could be used to characterize a particular year. For example, the MPCA has long requested Citizen Lake Monitoring Program (CLMP) volunteers who have collected most of Minnesota's long-term Secchi disk water clarity data to take their measurements from June 15 – September 15. Therefore, all data within this time frame can be averaged to generate a single value for a particular year.

- Alternatively, a set of monthly or bimonthly mean values can be calculated and then analyzed singly for the year, or considering their within-year variation. A monthly average for August, when algal biomass is usually thought to be at its peak, would be useful to examine in comparison to weather patterns either at that time or perhaps over a longer period to include the contribution of spring runoff to the lake's nutrient loading.

- The statistical analysis software described below also permits the user to select a single period to characterize a year (e.g. the mean of data from the period Jun 15 – Sep 15 for each year), and also incorporate the variability from sub-periods within that period that are defined as "seasons". For example, each year can be characterized by its mean (or median) parameter value for the MPCA field season defined as all data from June 15 - September 15. Or, the variation from three separate month-long seasons from June15-July 15, July16 - August 15, and August 16 - September 15) can be identified and incorporated into the statistical analysis.

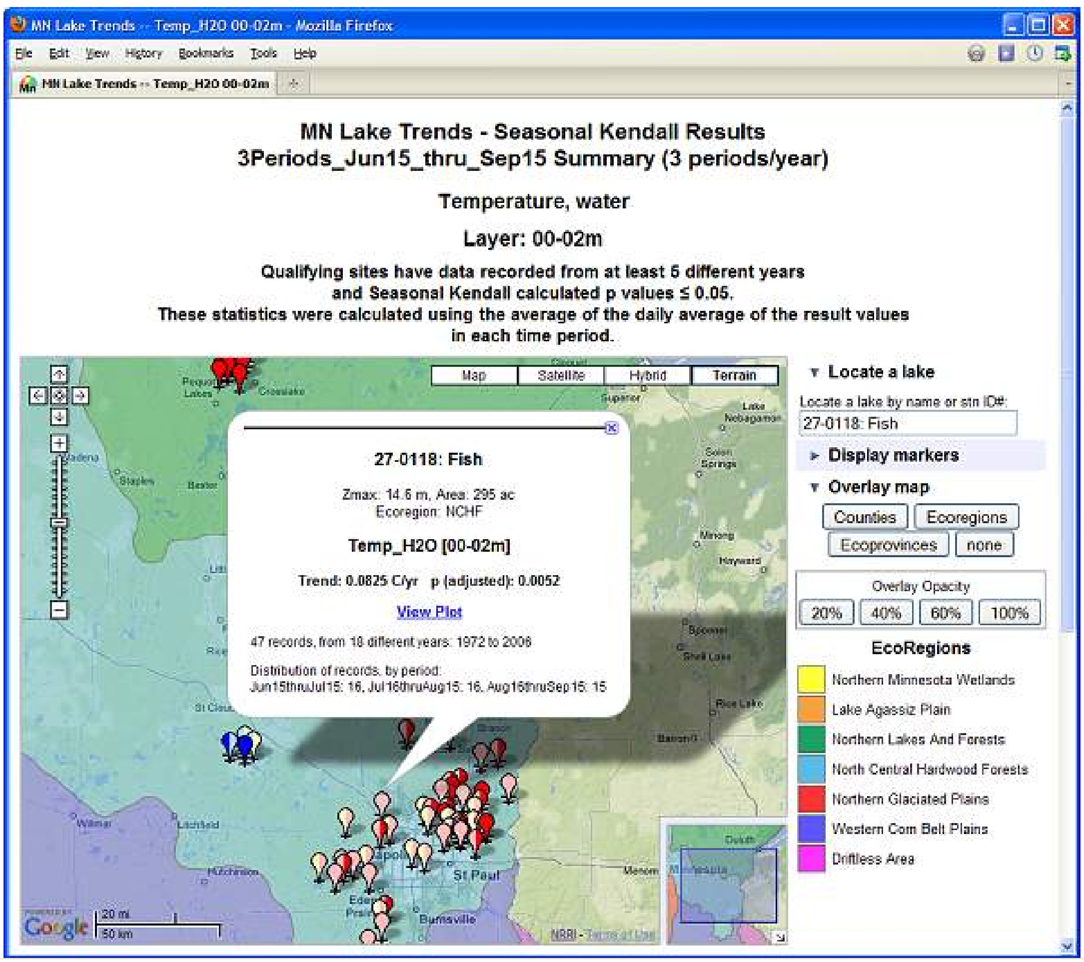
VII. Trend analyses

Trends and trend rates were determined using the Seasonal Kendall Trend Analysis software developed by the U.S. Geological survey (2005; Computer Program for the Kendall Family of Trend Tests, Dennis R. Helsel, David K. Mueller, and James R. Slack SIR 2005-5275, U.S. Geological Survey) that allow for trend analyses both seasonally and regionally. Sites were initially identified sites as "Qualifying" if they had records from at least 5 different years and with a level of significance of $p \leq 0.1$ for either a positive or negative trend over time. Additional exploratory trend summaries with accompanying mapping tools were generated for $p \leq 0.05$ and lakes having more years of data (8, 12 and $\geq$18 years).

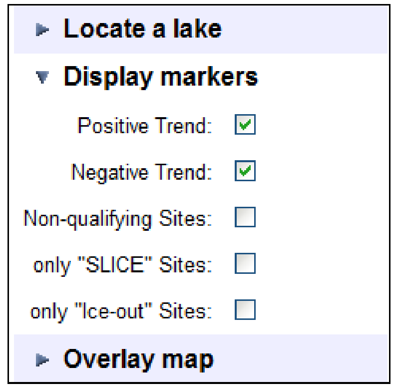
- Minnesota Lake Trends Analyses website*: http://mnbeaches.org/gmap/trends/*
- The USGS report "Computer Program for the Kendall Family of Trend Tests" and the computer program is available at *http://pubs.usgs.gov/sir/2005/5275/*

VIII. Graphical and tabular displays

- Data tabulated in *csv* format for easy import to spreadsheet and database software
- Data have been incorporated into "*Master*" NRRI-UMD Climate Change Database for association with other Project variables and use by other scientists
- Statewide distribution of lakes with statistically significant trends (e.g. $p < 0.1$ with >5 years of data) are denoted as tear drop shaped markers on a zoomable and scrollable map of Minnesota. Red denotes an increasing trend and blue a decreasing trend with half-tones to show the magnitude of the gradient for each plot based on quartiles for that plot. Levels of significance are shown as "hash" marks across the bottom of the tear drop.

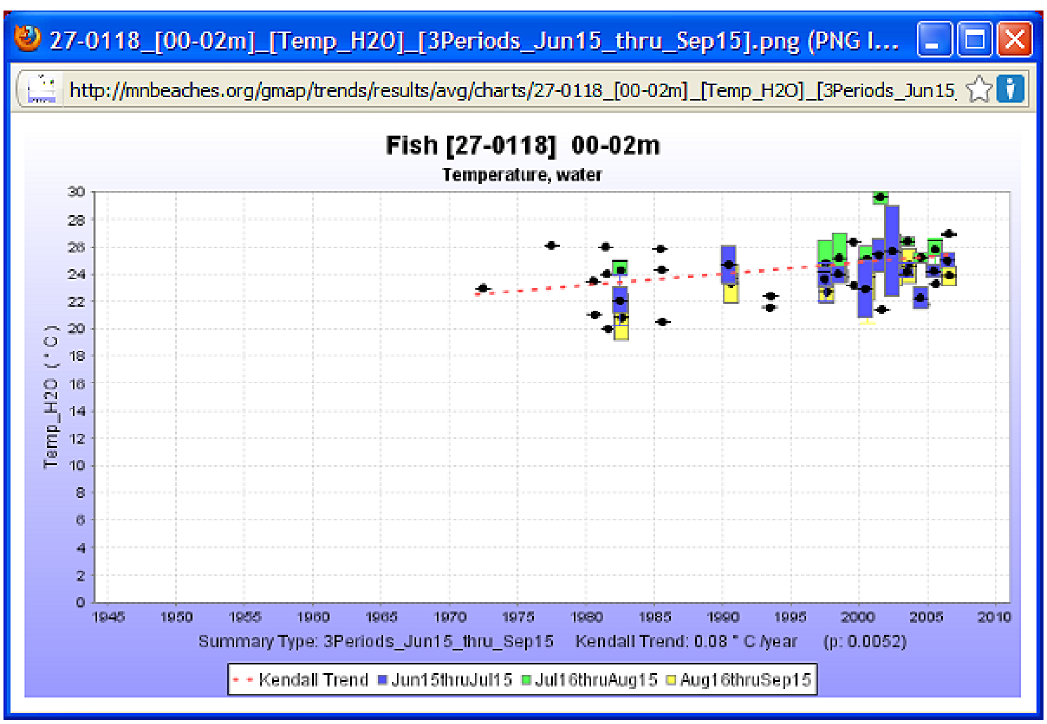


1. **Locate a Lake** is a search tool available for finding individual lakes by Lake Name or MDNR DOW #

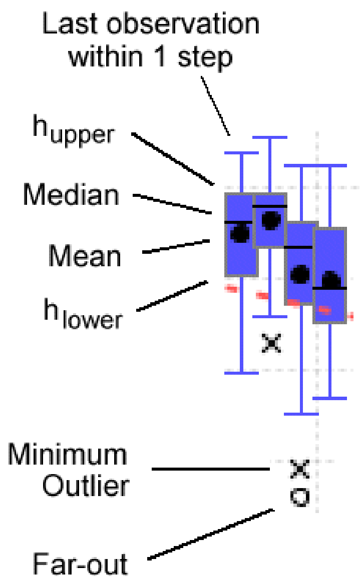


2. **Display Markers** offers choices for displaying markers on the map. Positive and negative trend sites were statistically significant; non-qualifying sites were not statistically significant or did not have data from enough years; "SLICE" sites refers to the 24 lakes from the MN DNR Sustaining Lakes in a Changing Environment (SLICE) project that includes a focus on monitoring basic watershed, water quality, habitat, and fish indicators in 24 sentinel lakes across a gradient of ecoregions, depths, and nutrient levels. "Ice-out" lakes refers to the set of lakes with long-term winter ice records that was compiled for the overarching U of MN Climate Change project.
3. **Overlay map** offers templates for county, ecoprovince and ecoregion boundaries. The data itself is classified in the main project database for these divisions but is not directly retrievable as such from the current MN Lake Water Quality Trends website.

- **Trend lines over time** are available by mouse clicking a particular lake on the map for a particular parameter x depth stratum x time period. This opens an information window with the lake name and MDNR DOW #, the trend slope and its significance, depth, area, ecoregion, and a link to open a box & whisker plot of the data and the calculated trend line:



- o the data are color-coded and shown for each "season" according to the specific seasonal Kendall analysis.
- o the box and whiskers depict the distributional characteristics of the independent measurements for that period are depicted as for that year



Hinges: h_{upper} = median of observations ≥ Median

h_{lower} = median of observations ≤ Median

IQR = Interquartile Range = h_{upper} - h_{lower}

1 step = IQR * 1.5

Upper Outlier Threshhold = h_{upper} + 1 step

Lower Outlier Threshhold = h_{lower} - 1 step

Upper Far-out Threshhold = h_{upper} + (IQR * 2)

Lower Far-out Threshhold = h_{lower} - (IQR * 2)

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Minnesota's Water Resources: Climate Change Impacts

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  - Norman Will (trend analysis programming, graphing, summary and mapping; website development)
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Page updated: August 13, 2009