Grace College

Comparative Study of Kosciusko County Lake Water Quality

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Introduction

The purpose of this study was to obtain a current, county-wide profile of lake water quality in Kosciusko County. In particular, it was our goal to identify a current average of various water quality measurements in the county, and to identify lakes that stand out from the average with regard to these measurements. In order to accomplish this purpose, 30 lakes within the county were selected from which to take measurements. Various water quality measurements were taken from these lakes on three different occasions during the summer of 2007: once in June, once in July, and once in August.

Lakes in this Study, and Data Collected

There are approximately 95 lakes in the county (more or less, depending on the agreement of what constitutes a lake). The number of lakes in this study was limited to 30 lakes for feasibility. These 30 lakes were selected based upon the following criteria:

1. An attempt was made to sample from all large lakes (or lake chains); for lake chains, only some lakes were selected within the chain so as to limit the number of lakes in the study for feasibility.
2. An attempt was made to sample lakes which are small, or which have typically received less monitoring attention than the larger lakes in the county (particularly, attention was given to lakes in the southwestern part of the county).
3. An attempt was made to sample lakes from all regions of the county where lakes exist (Northeast, North, East, Center, West, Southeast, South, Southwest).

With these criteria, the following lakes were identified for our sampling plan:

Lakes in this Study

Beaver Dam Lake	Hoffman Lake	Shoe Lake
Big Barbee Lake	Irish Lake	Silver Lake
Big Chapman Lake	Loon Lake	Spear Lake
Carr Lake	McClures Lake	Syracuse Lake
Center Lake	Palestine Lake	Tippecanoe Lake
Crystal Lake	Papakeechie Lake	Waubee Lake
Dewart Lake	Pike Lake	Wawasee Lake
Diamond Lake	Ridinger Lake	Webster Lake
Goose Lake	Rock Lake	Winona Lake
Hill Lake	Sellers Lake	Yellow Creek Lake

Sampling Sites: Deep Water, Shallow Water, and Inlet

For the purposes of this report, a *sampling site* is a location on a lake where measurements were taken. There were 451 sampling sites total on the 30 lakes in this study. There were 15 planned sampling sites on each lake; one more sampling site was selected on Winona Lake for a video documentation of our field work. It was decided to take measurements at deep water sampling sites (this data would be most comparable to data collected by many water quality monitoring organizations), at shallow water sampling sites (this data was thought to have more value for some measurements, such as E. Coli and nutrients), and at an identified inlet (one selected inlet for each lake, to see if there were any atypical measurements in relation to the rest of the lake). Lake inlets were

identified with the advice of the Kosciusko County Surveyor's office. There were four lakes which did not have an identified inlet, and on these lakes another random shallow water sampling site was selected instead; these four lakes are Crystal Lake, Goose Lake, Shoe Lake, and Spear Lake.

It was decided to take measurements from each lake on three different occasions (once in June, once in July, and once in August) in order to obtain a breadth of measurements throughout the summer. During each of the monthly samplings, an attempt was made to sample from all lakes within as few days as possible; in June all 30 lakes were sampled within a four day period (6/25/07-6/28/07), in July all 30 lakes were sampled within a three day period (7/16/07-7/18/07), and in August all 30 lakes were sampled within a three day period (8/6/07-8/8/07). During each of the monthly samplings from a lake, 5 sampling sites were visited. Specifically, during each visit to a lake:

- Two deep water sampling sites (away from the shoreline) were chosen; some attempt was made to select sites with a lake depth over 5 meters, although this was not always possible when attempting to achieve good sampling coverage in the middle of the lake. The two deep water sampling sites were chosen at different locations for each of the three visits to the lake, so there was a total of 6 randomly selected deep water sampling sites on each lake.

- Two shallow water sampling sites (in close proximity to the shoreline) were chosen; no regard was given to whether or not the shoreline was developed. The two shallow water sampling sites were chosen at different locations for each of the three visits to the lake, so there was a total of 6 randomly selected shallow water sampling sites on each lake (exceptions to this were Winona Lake, which had 7, and Crystal Lake, Goose Lake, Shoe Lake, and Spear Lake which all had 9, respectively).

- One inlet sampling site was chosen in close proximity to a selected lake inlet; the selected inlet was chosen with the advice of the Kosciusko County Surveyor's office. There were four lakes on which we could not identify an inlet, and on these lakes another random shallow water location was selected. These lakes are: Crystal Lake, Goose Lake, Shoe Lake, and Spear Lake. Upon each visit to the lake, measurements were taken in the general vicinity of the same selected inlet.

Data Collected

The data that was gathered in this study is generally desirable information for water quality monitoring purposes. The following water quality measurements were taken; note that some measurements were not taken at every sampling site.

Water Quality Measurements that were Observed at Sampling Sites

E. Coli, measured in colonies per hundred milliliters.

Samples were drawn for E. Coli testing at every sampling site; laboratory testing for E. Coli was performed by the Kosciusko County Health Department.

Nutrients: Total phosphorus, measured in milligrams per liter, and Nitrogen (Nitrates plus Nitrites), measured in milligrams per liter.

Samples were drawn for nutrient testing at approximately 2/3 of the sampling sites; we had to limit nutrient samples to approximately 100 per month, so in general nutrient samples were taken from one deep water sampling site, one shallow water sampling site, and one inlet sampling site per lake each month. Laboratory testing for nutrients was performed by the Indiana State Department of Health Chemistry Laboratory

Dissolved oxygen, measured in percent saturation, was measured on site with a YSI 95 Dissolved Oxygen meter. Measurements were made at 1 meter or less at every sampling site, at 3 meters where lake depth permitted, and at 5 meters where lake depth permitted. Note: all measurements of 1 meter or less were recorded as 1 meter for data analysis.

pH was measured on site with an ExStikII pH meter. Measurements were made at every sampling site.

Chlorophyll-a (in vivo), measured in total fluorescence, was measured on site with an Aquafluor handheld fluorometer by Turner Designs. Measurements were made at every sampling site.

Turbidity, measured in NTU's, was measured on site with an Aquafluor handheld fluorometer by Turner Designs. Measurements were made at every sampling site.

Secchi disk depth, measured in feet, was measured on site with a standard secchi disk. Measurements were made at every sampling site where the secchi disk did not hit the bottom.

Chlorophyll-a, measured in milligrams per liter. Fifteen sampling sites were selected (one on each of 15 different lakes) from which to collect a sample for laboratory chlorophyll-a analysis. The purpose of this data collection was to build a regression model to use for transforming total fluorescence measurements (in vivo chlorophyll-a measurements made with the Turner Designs fluorometer) into micrograms per liter measurements (the standard chlorophyll-a laboratory measurement). At each of these 15 sampling sites, a water sample was drawn from an integrated six foot column of water and filtered for laboratory chlorophyll-a analysis. The laboratory testing for this chlorophyll-a analysis was performed by: Great Lakes Environmental Center, Inc., 739 Hastings Street, Traverse City, MI 49686.

Other Data that was Collected at Sampling Sites

Date of sample; recorded at every sampling site.

Time of day; recorded at every sampling site.

Depth of lake at point of sample, measured on site with the depth sensor from a Garmin Fishfinder 90; recorded at every sampling site.

Water temperature at point of sample (with each measurement of dissolved oxygen), measured on site with a YSI 95 Dissolved Oxygen meter; recorded at every sampling site.

Air temperature at point of sample, measured on site with an Acu.Rite indoor-outdoor thermometer. (Note: abnormal temperature fluctuations in the equipment box and malfunctions in the thermometer render this data unreliable).

Weather conditions at time of sample; recorded at every sampling site.

Weather conditions in 48 hours prior to sample; recorded at every sampling site.

GPS location, measured on site with the Garmin GPSmap 76; recorded at every sampling site. Maps showing the lakes and sampling sites are provided in Appendix 1.

Data Collection: Methods and Fieldwork

Data collection was planned over a three month period in order to gather a breadth of measurements throughout the summer of 2007. Within each month, however, it was desired to gather all data within a short period of time in order to control for the confounding effect of time (month to month) when comparing lake averages. Consequently, it was decided that during each of the monthly samplings, an attempt would be made to sample from all lakes within as few days as possible. With this in mind, data was collected throughout the day, as long as sunlight made data collection possible. Data collection times ranged from around 7:20 a.m. to around 9:00 p.m.; note that this deviates from the data collection practice to which some monitoring organizations adhere of collecting data only at certain times of the day. In order to control for the confounding effect of time (time of day that measurements were taken), time of day was planned as a covariate in the statistical analysis of the data. Moreover, the order in which the lakes were sampled during each monthly sampling was changed (the order was not entirely random, since it was within reason to sample from nearby lakes while in a vicinity of the county). In the statistical analysis, the incorporation of time of day as a covariate allowed for the statistical adjustment of average lake measurements to the average lake measurement that would likely have been observed if the measurements had all been taken at the same time of day (about 1:45 p.m.).

Given that the end goal of this study was to obtain a current county average for the various water quality measurements, it was decided that measurements would be taken from different sampling sites during each monthly sampling (with the exception of the inlet sampling sites; measurements were taken at the same inlet sampling site during each visit to a lake). Note that this deviates from the data collection practice to which some monitoring organizations adhere of repeatedly sampling the same location on a lake. The purpose for this deviation was to have more samples from around each lake so as to more accurately estimate average measurements throughout the lake; the goal of this study was to obtain average lake measurements, and not lake measurement trends.

The fieldwork of taking measurements was carried out on most lakes with the aid of a small inflatable boat with a five horsepower gas motor. This allowed for quick entry and exit into the lakes, and easy transport between lakes.

For consistency of field practices and measurements, the same instruments were used and the same protocol was followed at each sampling site (see the Water Monitoring Data Sheet in Appendix 2):

- Date, time, sampling site ID, air temperature and weather conditions were recorded.
- GPS Location was recorded.
- A sample was taken for nutrient testing (at sites selected for nutrient testing); nitrogen and phosphorus were both analyzed from one 125 mL water sample. This was gathered as a grab sample taken at arm's depth and preserved with an acid pad. Samples were placed into an iced cooler upon arrival to shore.
- A sample was taken for E. Coli testing. E. coli was sampled by a 100 mL grab sample taken at arm's depth. Samples were placed into an iced cooler upon arrival to shore.
- Lake Depth at the site was recorded.
- Secchi depth (or that the disk hit the bottom) was measured. Secchi Depth was typically measured by the same individual each time to reduce inconsistency in the data. Note: no regard was given to the shady or sunny side of the boat for secchi depth measurement.
- In vivo chlorophyll-a and turbidity were measured. A grab sample at arm's depth was used to fill a plastic cuvette with approximately 2 mL of water; both total fluorescence and turbidity were measured on this sample with the Aquafluor fluorometer.
- pH was measured. A 125 mL grab sample of water was taken at arm's depth. pH was measured on this water sample.
- Dissolved Oxygen was measured. The dissolved oxygen meter was turned on approximately 20 minutes before daily use to allow it time to warm up. Measurements were made at 1 meter (or less when restricted by depth, but recorded at 1 meter), 3 meters (when possible) and 5 meters (when possible).

A sample numbering system was created for data management purposes. Each of the 30 lakes studied was assigned a number code between 1 and 30; the assignment of these number codes was random, so as to blind the laboratories to the lakes which they represented. Samples were assigned number codes for the month in which the samples were taken: 1 for June, 2 for July, and 3 for August. Deep water sampling sites were coded as sites 1 and 2, shallow water sampling sites were coded as sites 3 and 4 (and 6 for the extra shallow water sampling site on Winona Lake), and inlet sampling sites were coded as site 5; the laboratories were not informed of this sampling site identification, so they were blinded to the distinction of deep, shallow, and inlet sampling sites. Hence each sampling site was assigned a unique four digit identification code; for example, 03-2-4 represents lake 3, month 2, shallow water sample site 4.

For measurements that required lab analysis, only the sampling site number code was written on the sampling bottle. Both the Kosciusko County Health Department and the Indiana State Department of Health Chemistry Laboratory were blinded to this numbering scheme to eliminate bias toward lake and/or sampling site location (deep, shallow, or inlet).

The following is an index of lake number codes:

	Lake Number		Lake Number		Lake Number
Beaver Dam Lake	15	Hoffman Lake	7	Shoe Lake	27
Big Barbee Lake	8	Irish Lake	25	Silver Lake	6
Big Chapman Lake	24	Loon Lake	20	Spear Lake	12
Carr Lake	10	McClures Lake	13	Syracuse Lake	11
Center Lake	2	Palestine Lake	4	Tippecanoe Lake	14
Crystal Lake	17	Papakeechie Lake	21	Waubee Lake	28
Dewart Lake	9	Pike Lake	18	Wawasee Lake	1
Diamond Lake	19	Ridinger Lake	30	Webster Lake	5
Goose Lake	29	Rock Lake	26	Winona Lake	3
Hill Lake	22	Sellers Lake	23	Yellow Creek Lake	16

Maps showing sampling sites on each lake are provided in Appendix 1.

Data Analysis

Analysis of Measurements at Deep Water Sites

Using data collected at deep water sampling sites (sites denoted 1 and 2 on each lake), averages were found for each of the following water quality measurements:

- E. Coli Measurement (Deep Water Sites)

- Total Phosphorus Measurement (Deep Water Sites)

- Nitrogen Measurement (Deep Water Sites)

- Dissolved Oxygen Measurement at 1 meter (Deep Water Sites)

- Dissolved Oxygen Measurement at 3 meters (Deep Water Sites)

- Dissolved Oxygen Measurement at 5 meters (Deep Water Sites)

- pH Measurement (Deep Water Sites)

- Total Fluorescence Measurement (Deep Water Sites)

- Turbidity Measurement (Deep Water Sites)

- Secchi Depth Measurement (Deep Water Sites)

For each of these measurements, a statistical analysis was carried out which accounted for the month and the time of day that measurements were taken (an analysis of covariance). Under these analyses, estimates were obtained for the average of each of these measurements in each of the 30 lakes. Lakes that stand out from the county average (with over 99.5% confidence) were identified.

For each of these measurements on shallow water sites, a boxplot of raw data by lake is given, followed by a table which shows the county average for that measurement and the lakes that stand out from the average.

E. Coli Measurement (Deep Water Sites)

Boxplot of E. Coli (col/100 mL) vs Lake

E. Coli

Lake	Sample Mean for Deep Water Samples	County Deep Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	6.441	8.93		x	
Big Barbee Lake	1.684	8.93		x	
Big Chapman Lake	0.996	8.93		x	
Carr Lake	0.783	8.93		x	
Center Lake	8.999	8.93		x	
Crystal Lake	9.597	8.93		x	
Dewart Lake	3.538	8.93		x	
Diamond Lake	2.516	8.93		x	
Goose Lake	4.580	8.93		x	
Hill Lake	12.687	8.93		x	
Hoffman Lake	0.305	8.93		x	
Irish Lake	2.089	8.93		x	
Loon Lake	28.754	8.93		x	
McClures Lake	9.208	8.93		x	
Palestine Lake	3.483	8.93		x	
Papakeechie Lake	90.890 (3.88 w/o outlier)	8.93		x	
Pike Lake	10.840	8.93		x	
Ridinger Lake	3.217	8.93		x	
Rock Lake	13.598	8.93		x	
Sellers Lake	12.577	8.93		x	
Shoe Lake	5.504	8.93		x	
Silver Lake	6.109	8.93		x	
Spear Lake	8.355	8.93		x	
Syracuse Lake	0.242	8.93		x	
Tippecanoe Lake	2.403	8.93		x	
Waubee Lake	0.343	8.93		x	
Wawasee Lake	0.065	8.93		x	
Webster Lake	2.444	8.93		x	
Winona Lake	0.621	8.93		x	
Yellow Creek Lake	14.998	8.93		x	

Total Phosphorus Measurement (Deep Water Sites)

Boxplot of Total Phosphorus (mg/L) vs Lake

Total Phosphorus

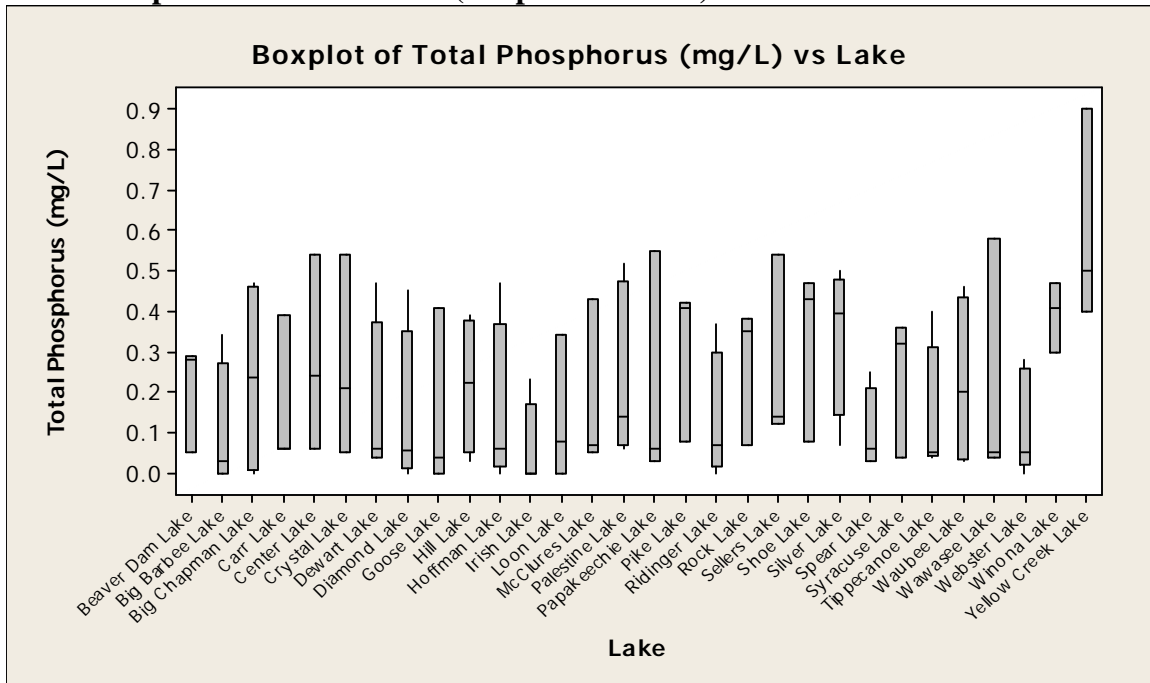| Lake	Sample Mean for Deep Water Samples	County Deep Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	0.220	0.217		x	
Big Barbee Lake	0.086	0.217		x	
Big Chapman Lake	0.228	0.217		x	
Carr Lake	0.153	0.217		x	
Center Lake	0.225	0.217		x	
Crystal Lake	0.257	0.217		x	
Dewart Lake	0.202	0.217		x	
Diamond Lake	0.148	0.217		x	
Goose Lake	0.142	0.217		x	
Hill Lake	0.220	0.217		x	
Hoffman Lake	0.100	0.217		x	
Irish Lake	0.068	0.217		x	
Loon Lake	0.166	0.217		x	
McClures Lake	0.208	0.217		x	
Palestine Lake	0.218	0.217		x	
Papakeechie Lake	0.232	0.217		x	
Pike Lake	0.267	0.217		x	
Ridinger Lake	0.076	0.217		x	
Rock Lake	0.273	0.217		x	
Sellers Lake	0.291	0.217		x	
Shoe Lake	0.331	0.217		x	
Silver Lake	0.356	0.217		x	
Spear Lake	0.136	0.217		x	
Syracuse Lake	0.234	0.217		x	
Tippecanoe Lake	0.194	0.217		x	
Waubee Lake	0.224	0.217		x	
Wawasee Lake	0.226	0.217		x	
Webster Lake	0.092	0.217		x	
Winona Lake	0.362	0.217		x	
Yellow Creek Lake	0.570	0.217			x

Nitrogen Measurement (Deep Water Sites)
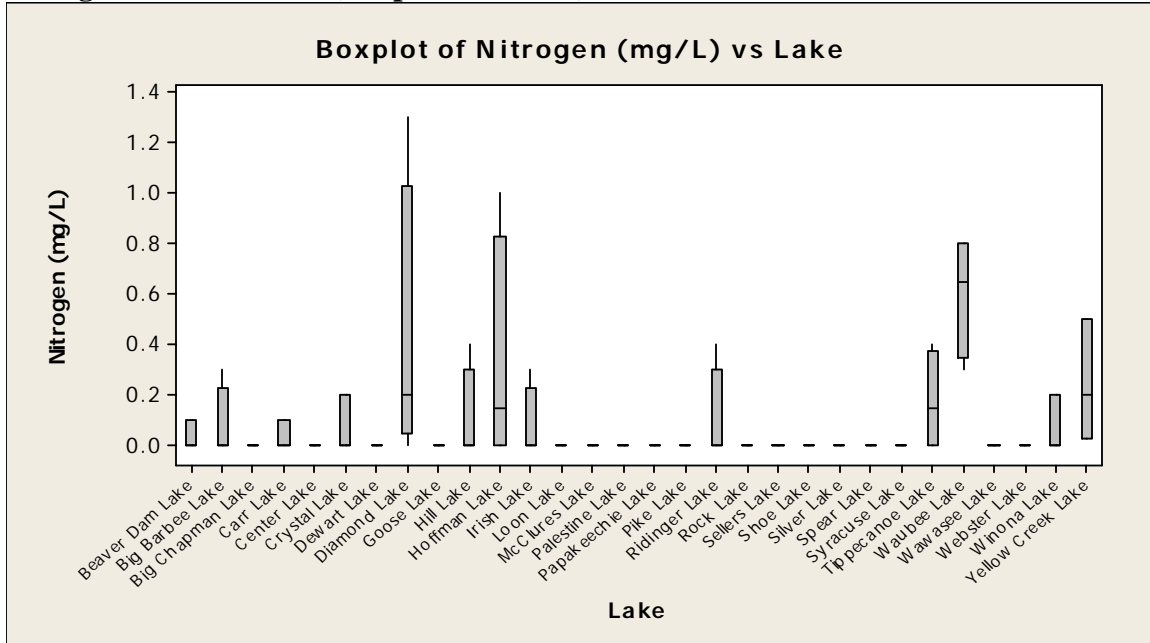
Nitrogen

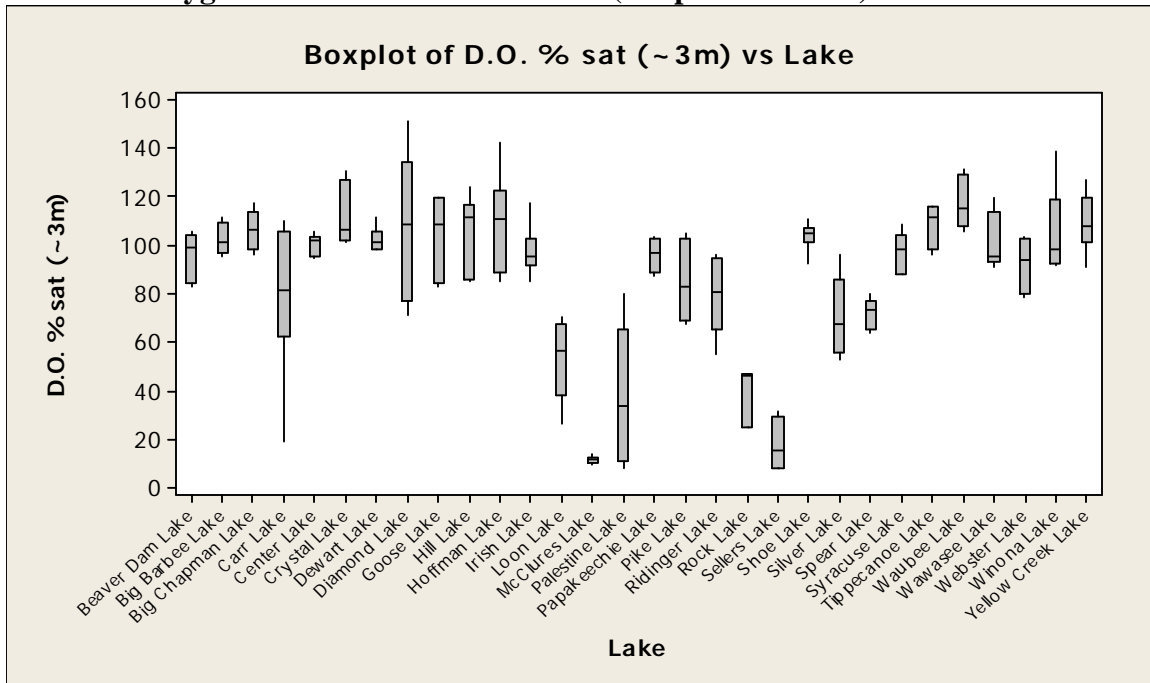| Lake	Sample Mean for Deep Water Samples	County Deep Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	0.036	0.078		x	
Big Barbee Lake	0.096	0.078		x	
Big Chapman Lake	0.022	0.078		x	
Carr Lake	0.030	0.078		x	
Center Lake	0.000	0.078		x	
Crystal Lake	0.065	0.078		x	
Dewart Lake	0.000	0.078		x	
Diamond Lake	0.433	0.078			x
Goose Lake	0.000	0.078		x	
Hill Lake	0.107	0.078		x	
Hoffman Lake	0.339	0.078		x	
Irish Lake	0.101	0.078		x	
Loon Lake	0.006	0.078		x	
McClures Lake	0.005	0.078		x	
Palestine Lake	0.018	0.078		x	
Papakeechie Lake	0.004	0.078		x	
Pike Lake	0.000	0.078		x	
Ridinger Lake	0.112	0.078		x	
Rock Lake	0.001	0.078		x	
Sellers Lake	0.005	0.078		x	
Shoe Lake	0.001	0.078		x	
Silver Lake	0.010	0.078		x	
Spear Lake	0.000	0.078		x	
Syracuse Lake	0.000	0.078		x	
Tippecanoe Lake	0.157	0.078		x	
Waubee Lake	0.570	0.078			x
Wawasee Lake	0.001	0.078		x	
Webster Lake	0.000	0.078		x	
Winona Lake	0.060	0.078		x	
Yellow Creek Lake	0.237	0.078		x	

Dissolved Oxygen Measurement at 1 meter (Deep Water Sites)
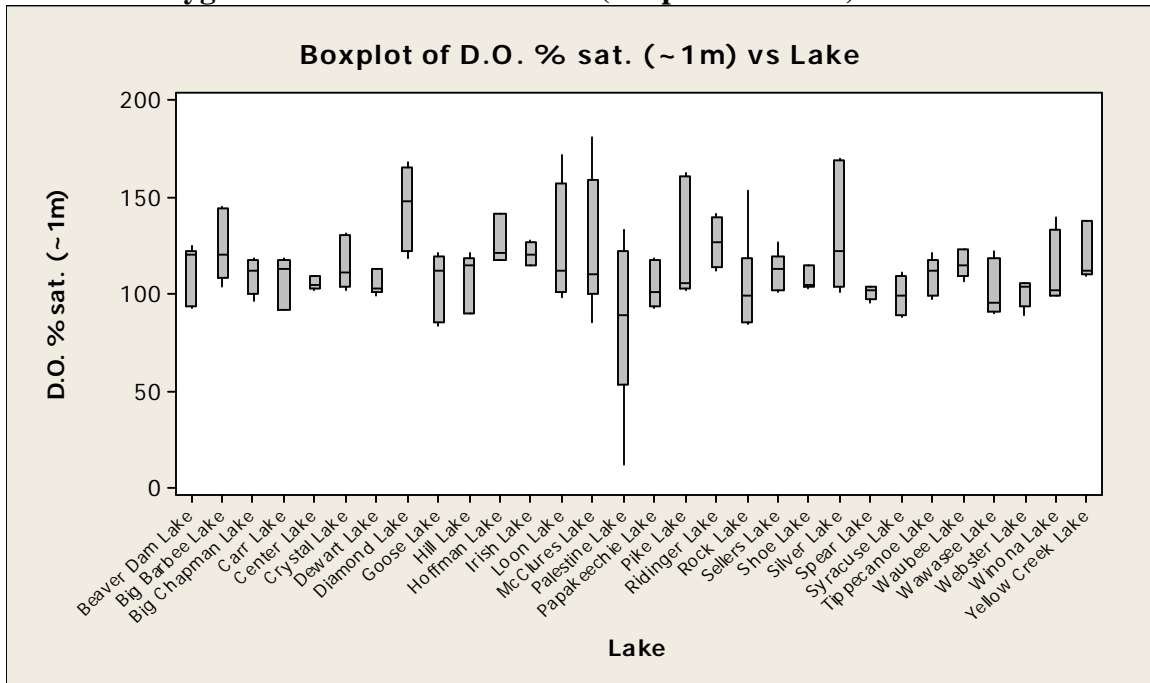
D.O. at 1 meter

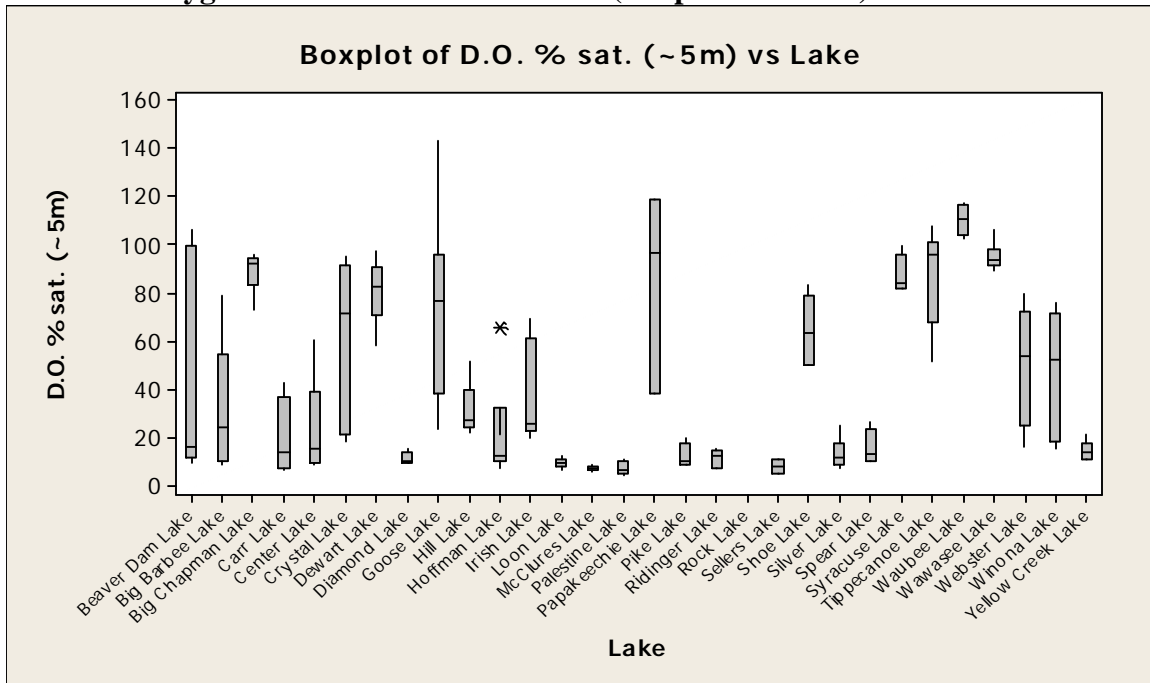| Lake	Sample Mean for Deep Water Samples	County Deep Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	110.37	112.81		x	
Big Barbee Lake	123.02	112.81		x	
Big Chapman Lake	106.08	112.81		x	
Carr Lake	110.26	112.81		x	
Center Lake	113.44	112.81		x	
Crystal Lake	116.31	112.81		x	
Dewart Lake	100.07	112.81		x	
Diamond Lake	146.28	112.81			x
Goose Lake	106.94	112.81		x	
Hill Lake	109.79	112.81		x	
Hoffman Lake	127.26	112.81		x	
Irish Lake	114.42	112.81		x	
Loon Lake	120.44	112.81		x	
McClures Lake	120.20	112.81		x	
Palestine Lake	86.70	112.81	x		
Papakeechie Lake	101.19	112.81		x	
Pike Lake	128.58	112.81		x	
Ridinger Lake	129.33	112.81		x	
Rock Lake	103.67	112.81		x	
Sellers Lake	108.59	112.81		x	
Shoe Lake	106.79	112.81		x	
Silver Lake	129.64	112.81		x	
Spear Lake	96.50	112.81		x	
Syracuse Lake	99.99	112.81		x	
Tippecanoe Lake	103.05	112.81		x	
Waubee Lake	119.44	112.81		x	
Wawasee Lake	101.70	112.81		x	
Webster Lake	102.72	112.81		x	
Winona Lake	116.95	112.81		x	
Yellow Creek Lake	124.44	112.81		x	

Dissolved Oxygen Measurement at 3 meters (Deep Water Sites)

D.O. at 3 meters

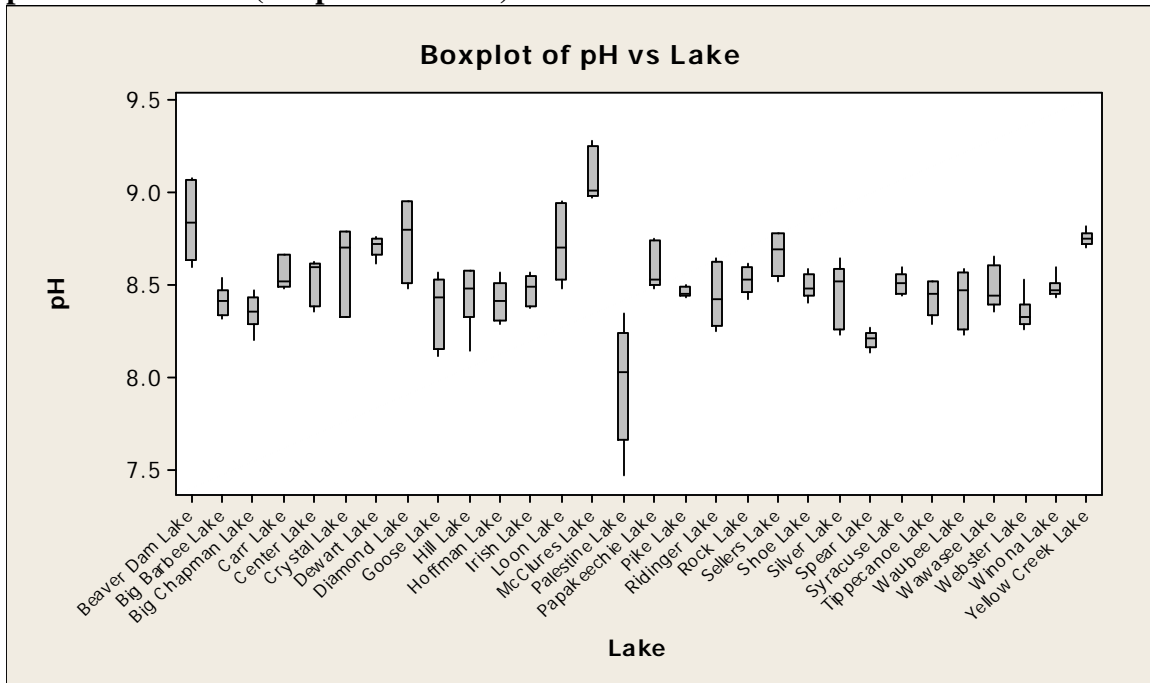| Lake	Sample Mean for Deep Water Samples	County Deep Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	94.733	87.29		x	
Big Barbee Lake	102.181	87.29		x	
Big Chapman Lake	103.865	87.29		x	
Carr Lake	80.625	87.29		x	
Center Lake	106.025	87.29			x
Crystal Lake	113.119	87.29			x
Dewart Lake	98.967	87.29		x	
Diamond Lake	109.034	87.29			x
Goose Lake	105.053	87.29		x	
Hill Lake	106.888	87.29			x
Hoffman Lake	109.655	87.29			x
Irish Lake	93.409	87.29		x	
Loon Lake	50.363	87.29	x		
McClures Lake	9.026	87.29	x		
Palestine Lake	38.666	87.29	x		
Papakeechie Lake	92.119	87.29		x	
Pike Lake	88.732	87.29		x	
Ridinger Lake	81.466	87.29		x	
Rock Lake	39.031	87.29	x		
Sellers Lake	15.695	87.29	x		
Shoe Lake	103.590	87.29		x	
Silver Lake	69.816	87.29		x	
Spear Lake	69.135	87.29	x		
Syracuse Lake	97.978	87.29		x	
Tippecanoe Lake	103.686	87.29		x	
Waubee Lake	120.134	87.29			x
Wawasee Lake	101.002	87.29		x	
Webster Lake	93.754	87.29		x	
Winona Lake	108.631	87.29			x
Yellow Creek Lake	112.316	87.29			x

Dissolved Oxygen Measurement at 5 meters (Deep Water Sites)

D.O. at 5 meters

Lake	Sample Mean for Deep Water Samples	County Deep Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	42.739	43.13		x	
Big Barbee Lake	32.194	43.13		x	
Big Chapman Lake	88.273	43.13			X
Carr Lake	20.441	43.13		x	
Center Lake	25.042	43.13		x	
Crystal Lake	61.593	43.13		x	
Dewart Lake	79.691	43.13			X
Diamond Lake	11.806	43.13	x		
Goose Lake	74.043	43.13			X
Hill Lake	31.875	43.13		x	
Hoffman Lake	21.923	43.13		x	
Irish Lake	36.085	43.13		x	
Loon Lake	8.996	43.13	x		
McClures Lake	6.859	43.13	x		
Palestine Lake	8.411	43.13	x		
Papakeechie Lake	83.932	43.13			X
Pike Lake	13.406	43.13		x	
Ridinger Lake	12.186	43.13	x		
Rock Lake	*	43.13			
Sellers Lake	6.828	43.13		x	
Shoe Lake	64.376	43.13		x	
Silver Lake	13.375	43.13	x		
Spear Lake	15.600	43.13	x		
Syracuse Lake	86.650	43.13			X
Tippecanoe Lake	86.093	43.13			X
Waubee Lake	110.855	43.13			X
Wawasee Lake	95.018	43.13			X
Webster Lake	49.221	43.13		x	
Winona Lake	48.482	43.13		x	
Yellow Creek Lake	14.873	43.13		x	

pH Measurement (Deep Water Sites)

Boxplot of pH vs Lake

pH

Lake	Sample Mean for Deep Water Samples	County Deep Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	8.826	8.514			X
Big Barbee Lake	8.405	8.514		x	
Big Chapman Lake	8.332	8.514	x		
Carr Lake	8.570	8.514		x	
Center Lake	8.571	8.514		x	
Crystal Lake	8.610	8.514		x	
Dewart Lake	8.673	8.514		x	
Diamond Lake	8.757	8.514			X
Goose Lake	8.378	8.514		x	
Hill Lake	8.450	8.514		x	
Hoffman Lake	8.416	8.514		x	
Irish Lake	8.437	8.514		x	
Loon Lake	8.694	8.514			x
McClures Lake	9.060	8.514			x
Palestine Lake	7.973	8.514	x		
Papakeechie Lake	8.569	8.514		x	
Pike Lake	8.490	8.514		x	
Ridinger Lake	8.457	8.514		x	
Rock Lake	8.518	8.514		x	
Sellers Lake	8.646	8.514		x	
Shoe Lake	8.483	8.514		x	
Silver Lake	8.448	8.514		x	
Spear Lake	8.177	8.514	x		
Syracuse Lake	8.510	8.514		x	
Tippecanoe Lake	8.391	8.514		x	
Waubee Lake	8.450	8.514		x	
Wawasee Lake	8.477	8.514		x	
Webster Lake	8.362	8.514		x	
Winona Lake	8.507	8.514		x	
Yellow Creek Lake	8.779	8.514			x

Total Fluorescence Measurement (Deep Water Sites)
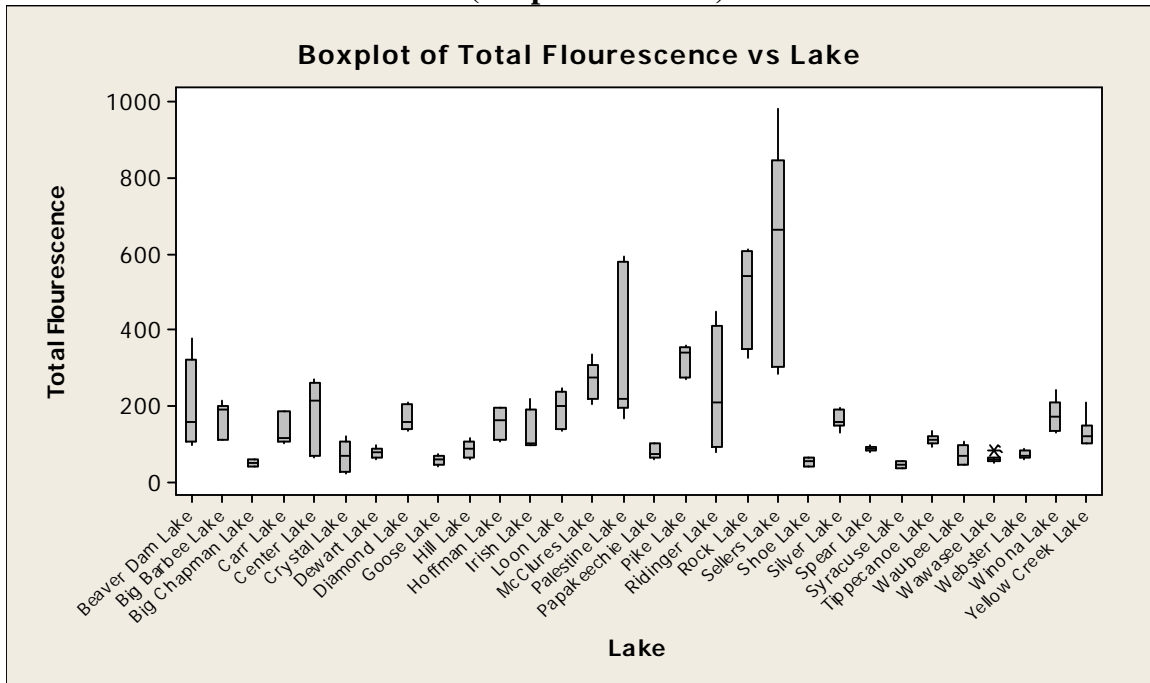
Boxplot of Total Flourescence vs Lake

Total Fluorescence

Lake	Sample Mean for Deep Water Samples	County Deep Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	206.07	167.1		x	
Big Barbee Lake	170.72	167.1		x	
Big Chapman Lake	58.59	167.1	x		
Carr Lake	129.15	167.1		x	
Center Lake	163.04	167.1		x	
Crystal Lake	65.32	167.1	x		
Dewart Lake	89.31	167.1		x	
Diamond Lake	163.94	167.1		x	
Goose Lake	55.59	167.1	x		
Hill Lake	83.36	167.1		x	
Hoffman Lake	154.24	167.1		x	
Irish Lake	148.43	167.1		x	
Loon Lake	201.76	167.1		x	
McClures Lake	276.73	167.1			x
Palestine Lake	325.13	167.1			x
Papakeechie Lake	86.22	167.1		x	
Pike Lake	310.44	167.1			x
Ridinger Lake	233.69	167.1		x	
Rock Lake	499.90	167.1			x
Sellers Lake	624.02	167.1			x
Shoe Lake	55.05	167.1	x		
Silver Lake	168.43	167.1		x	
Spear Lake	98.21	167.1		x	
Syracuse Lake	43.30	167.1	x		
Tippecanoe Lake	127.52	167.1		x	
Waubee Lake	61.97	167.1	x		
Wawasee Lake	61.21	167.1	x		
Webster Lake	67.22	167.1	x		
Winona Lake	163.19	167.1		x	
Yellow Creek Lake	120.16	167.1		x	

Turbidity Measurement (Deep Water Sites)
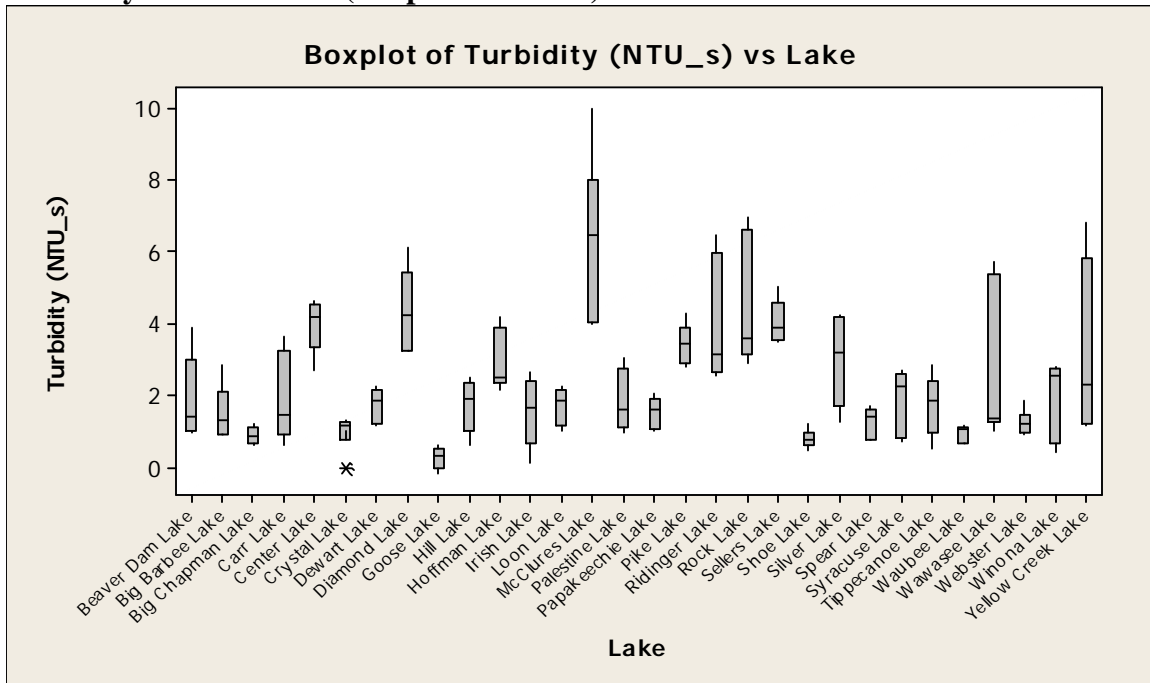
Boxplot of Turbidity (NTU_s) vs Lake

Turbidity

Lake	Sample Mean for Deep Water Samples	County Deep Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	1.941	2.337		x	
Big Barbee Lake	1.545	2.337		x	
Big Chapman Lake	0.952	2.337	x		
Carr Lake	1.864	2.337		x	
Center Lake	3.860	2.337			x
Crystal Lake	0.964	2.337	x		
Dewart Lake	1.831	2.337		x	
Diamond Lake	4.369	2.337			x
Goose Lake	0.246	2.337	x		
Hill Lake	1.701	2.337		x	
Hoffman Lake	2.923	2.337		x	
Irish Lake	1.627	2.337		x	
Loon Lake	1.778	2.337		x	
McClures Lake	6.431	2.337			x
Palestine Lake	1.834	2.337		x	
Papakeechie Lake	1.586	2.337		x	
Pike Lake	3.365	2.337		x	
Ridinger Lake	3.926	2.337			x
Rock Lake	4.475	2.337			x
Sellers Lake	4.100	2.337			x
Shoe Lake	0.803	2.337	x		
Silver Lake	3.009	2.337		x	
Spear Lake	1.341	2.337		x	
Syracuse Lake	1.892	2.337		x	
Tippecanoe Lake	1.847	2.337		x	
Waubee Lake	0.908	2.337	x		
Wawasee Lake	2.684	2.337		x	
Webster Lake	1.228	2.337		x	
Winona Lake	1.909	2.337		x	
Yellow Creek Lake	3.172	2.337		x	

Secchi Depth Measurement (Deep Water Sites)

Boxplot of Secchi Depth (ft) vs Lake
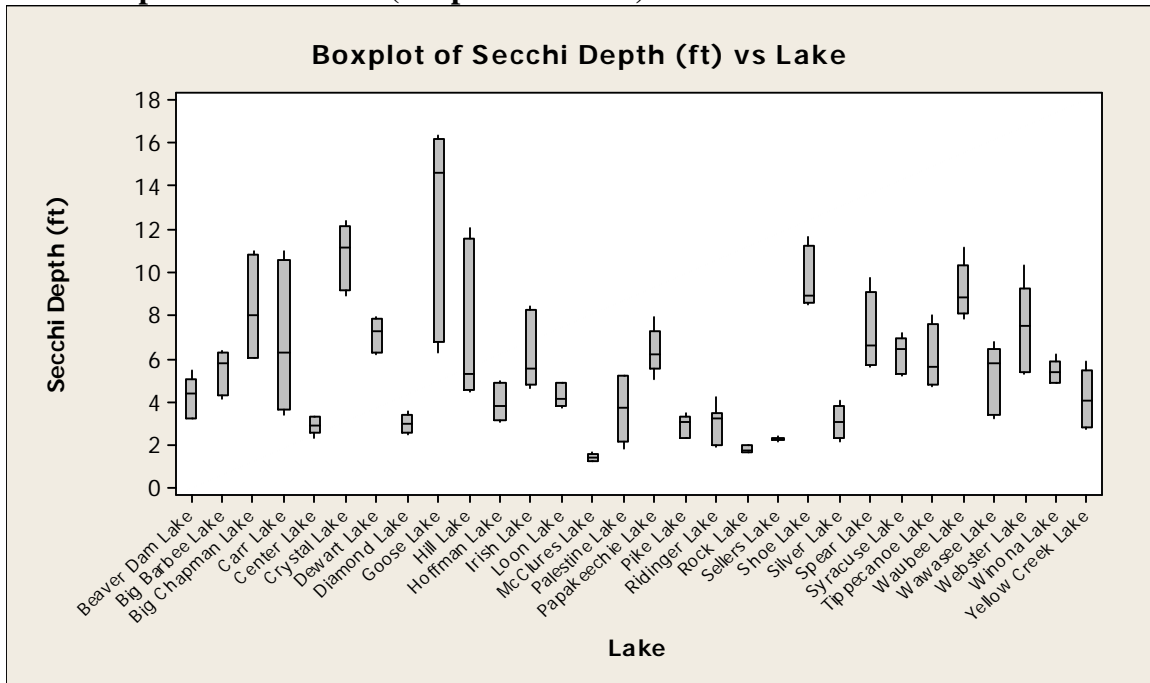
Secchi Depth

Lake	Sample Mean for Deep Water Samples	County Deep Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	4.338	5.598		x	
Big Barbee Lake	5.468	5.598		x	
Big Chapman Lake	8.433	5.598			x
Carr Lake	6.774	5.598		x	
Center Lake	2.681	5.598	x		
Crystal Lake	10.759	5.598			x
Dewart Lake	7.276	5.598		x	
Diamond Lake	2.971	5.598	x		
Goose Lake	12.451	5.598			x
Hill Lake	7.126	5.598		x	
Hoffman Lake	3.912	5.598		x	
Irish Lake	6.402	5.598		x	
Loon Lake	4.371	5.598		x	
McClures Lake	1.541	5.598	x		
Palestine Lake	3.633	5.598		x	
Papakeechie Lake	6.469	5.598		x	
Pike Lake	2.748	5.598	x		
Ridinger Lake	2.889	5.598	x		
Rock Lake	1.816	5.598	x		
Sellers Lake	2.381	5.598	x		
Shoe Lake	9.635	5.598			x
Silver Lake	3.129	5.598	x		
Spear Lake	7.315	5.598		x	
Syracuse Lake	6.240	5.598		x	
Tippecanoe Lake	6.216	5.598		x	
Waubee Lake	9.023	5.598			x
Wawasee Lake	5.240	5.598		x	
Webster Lake	7.432	5.598		x	
Winona Lake	5.277	5.598		x	
Yellow Creek Lake	3.997	5.598		x	

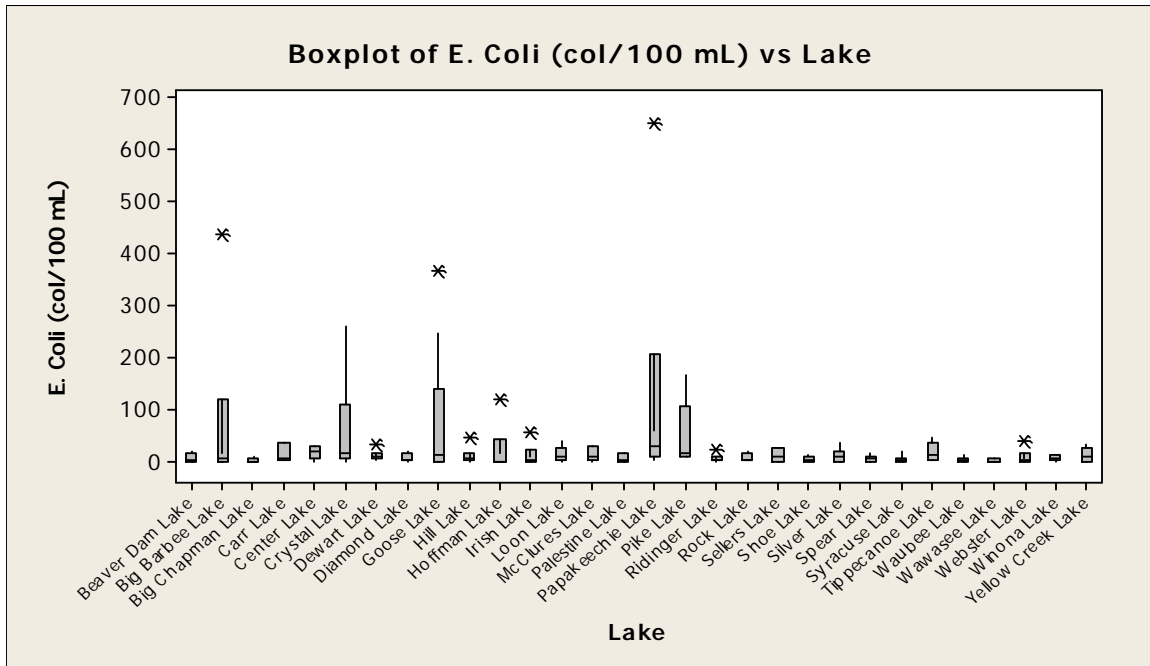**Analysis of Measurements at Shallow Water Sites**

Using data collected at shallow water sites (sites denoted 3 and 4 on each lake, as well as sites denoted 5 on Crystal Lake, Goose Lake, Shoe Lake, and Spear Lake), averages were found for each of the following water quality measurements:

- E. Coli Measurement (Shallow Water Sites)

- Total Phosphorus Measurement (Shallow Water Sites)

- Nitrogen Measurement (Shallow Water Sites)

- Dissolved Oxygen Measurement at 1 meter (Shallow Water Sites)

- pH Measurement (Shallow Water Sites)

- Total Fluorescence Measurement (Shallow Water Sites)

- Turbidity Measurement (Shallow Water Sites)

For each of these measurements, a statistical analysis was carried out which accounted for the month and the time of day that measurements were taken (an analysis of covariance). Under these analyses, estimates were obtained for the average of each of these measurements in each of the 30 lakes. Lakes that stand out from the county average (with over 99.5% confidence) were identified.

For each of these measurements on shallow water sites, a boxplot of raw data by lake is given, followed by a table which shows the county average for that measurement and the lakes that stand out from the average.
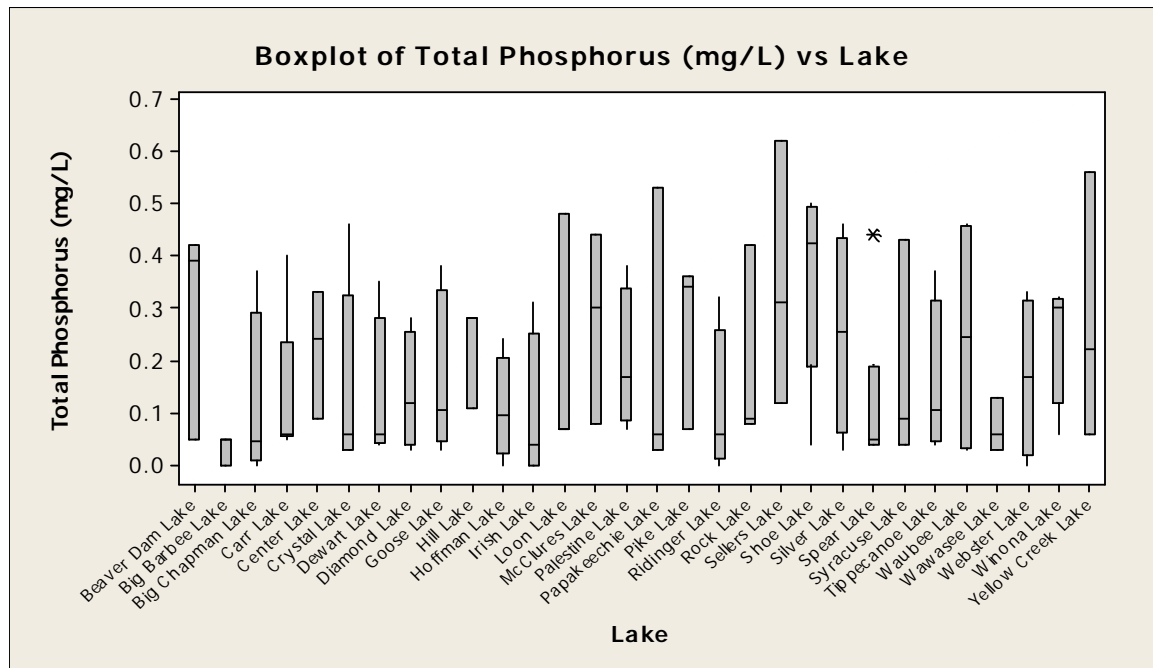
E. Coli Measurement (Shallow Water Sites)

Boxplot of E. Coli (col/100 mL) vs Lake

E. Coli

Lake	Sample Mean for Shallow Water Samples	County Shallow Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	7.491	19.44		x	
Big Barbee Lake	77.050 (6.01 w/o outliers)	19.44		x	
Big Chapman Lake	2.098	19.44		x	
Carr Lake	17.946	19.44		x	
Center Lake	22.741	19.44		x	
Crystal Lake	66.677 (42.00 w/o outliers)	19.44		x	
Dewart Lake	10.715	19.44		x	
Diamond Lake	9.137	19.44		x	
Goose Lake	76.641 (10.49 w/o outliers)	19.44		x	
Hill Lake	12.824	19.44		x	
Hoffman Lake	24.687	19.44		x	
Irish Lake	11.022	19.44		x	
Loon Lake	12.792	19.44		x	
McClures Lake	13.780	19.44		x	
Palestine Lake	8.685	19.44		x	
Papakeechie Lake	131.12 (28.41 w/o outliers)	19.44		x	
Pike Lake	54.545 (29.45 w/o outliers)	19.44		x	
Ridinger Lake	9.346	19.44		x	
Rock Lake	8.927	19.44		x	
Sellers Lake	11.957	19.44		x	
Shoe Lake	5.553	19.44		x	
Silver Lake	11.357	19.44		x	
Spear Lake	4.709	19.44		x	
Syracuse Lake	6.308	19.44		x	
Tippecanoe Lake	17.205	19.44		x	
Waubee Lake	7.064	19.44		x	
Wawasee Lake	2.914	19.44		x	
Webster Lake	11.380	19.44		x	
Winona Lake	9.912	19.44		x	
Yellow Creek Lake	16.475	19.44		x	

Total Phosphorus Measurement (Shallow Water Sites)

Boxplot of Total Phosphorus (mg/L) vs Lake

Total Phosphorus

Lake	Sample Mean for Shallow Water Samples	County Shallow Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	0.294	0.187		x	
Big Barbee Lake	0.036	0.187		x	
Big Chapman Lake	0.104	0.187		x	
Carr Lake	0.144	0.187		x	
Center Lake	0.191	0.187		x	
Crystal Lake	0.149	0.187		x	
Dewart Lake	0.163	0.187		x	
Diamond Lake	0.137	0.187		x	
Goose Lake	0.160	0.187		x	
Hill Lake	0.188	0.187		x	
Hoffman Lake	0.077	0.187		x	
Irish Lake	0.095	0.187		x	
Loon Lake	0.221	0.187		x	
McClures Lake	0.285	0.187		x	
Palestine Lake	0.197	0.187		x	
Papakeechie Lake	0.216	0.187		x	
Pike Lake	0.236	0.187		x	
Ridinger Lake	0.074	0.187		x	
Rock Lake	0.200	0.187		x	
Sellers Lake	0.361	0.187		x	
Shoe Lake	0.356	0.187		x	
Silver Lake	0.253	0.187		x	
Spear Lake	0.150	0.187		x	
Syracuse Lake	0.184	0.187		x	
Tippecanoe Lake	0.199	0.187		x	
Waubee Lake	0.257	0.187		x	
Wawasee Lake	0.075	0.187		x	
Webster Lake	0.158	0.187		x	
Winona Lake	0.200	0.187		x	
Yellow Creek Lake	0.262	0.187		x	

Nitrogen Measurement (Shallow Water Sites)
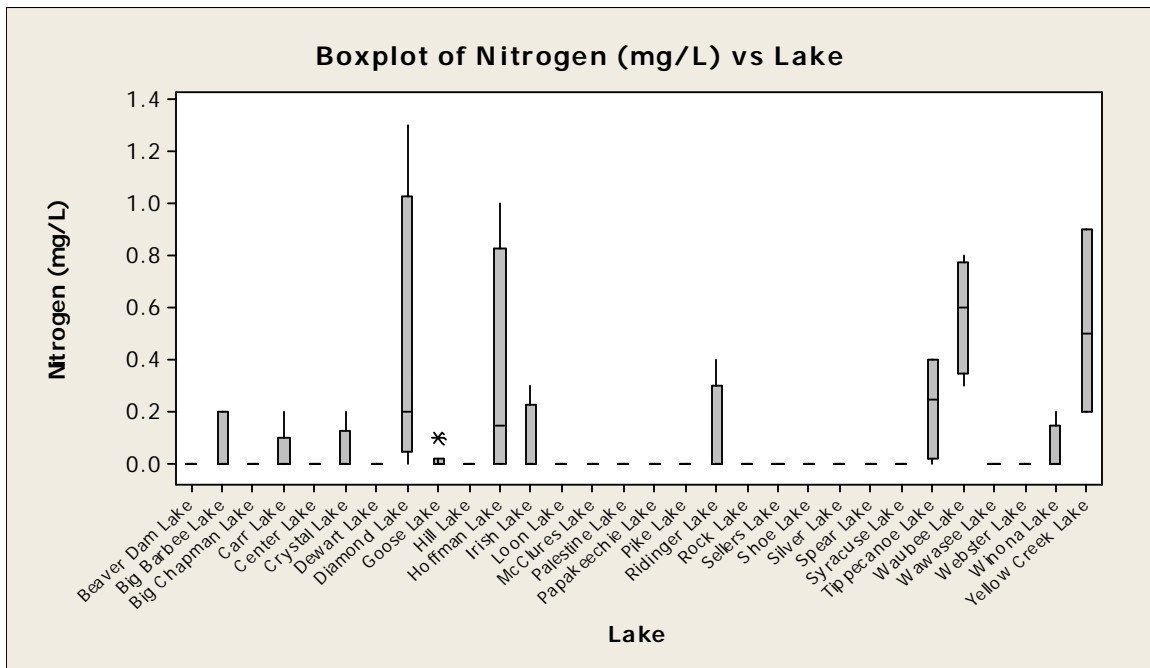
Boxplot of Nitrogen (mg/L) vs Lake

Nitrogen

Lake	Sample Mean for Shallow Water Samples	County Shallow Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	0.002	0.084		x	
Big Barbee Lake	0.067	0.084		x	
Big Chapman Lake	0.022	0.084		x	
Carr Lake	0.025	0.084		x	
Center Lake	0.000	0.084		x	
Crystal Lake	0.048	0.084		x	
Dewart Lake	0.000	0.084		x	
Diamond Lake	0.433	0.084			x
Goose Lake	0.015	0.084		x	
Hill Lake	0.043	0.084		x	
Hoffman Lake	0.340	0.084			x
Irish Lake	0.100	0.084		x	
Loon Lake	0.005	0.084		x	
McClures Lake	0.004	0.084		x	
Palestine Lake	0.008	0.084		x	
Papakeechie Lake	0.003	0.084		x	
Pike Lake	0.000	0.084		x	
Ridinger Lake	0.113	0.084		x	
Rock Lake	0.001	0.084		x	
Sellers Lake	0.004	0.084		x	
Shoe Lake	0.001	0.084		x	
Silver Lake	0.009	0.084		x	
Spear Lake	0.000	0.084		x	
Syracuse Lake	0.000	0.084		x	
Tippecanoe Lake	0.207	0.084		x	
Waubee Lake	0.546	0.084			x
Wawasee Lake	0.001	0.084		x	
Webster Lake	0.000	0.084		x	
Winona Lake	0.059	0.084		x	
Yellow Creek Lake	0.527	0.084			x

Dissolved Oxygen Measurement at 1 meter (Shallow Water Sites)
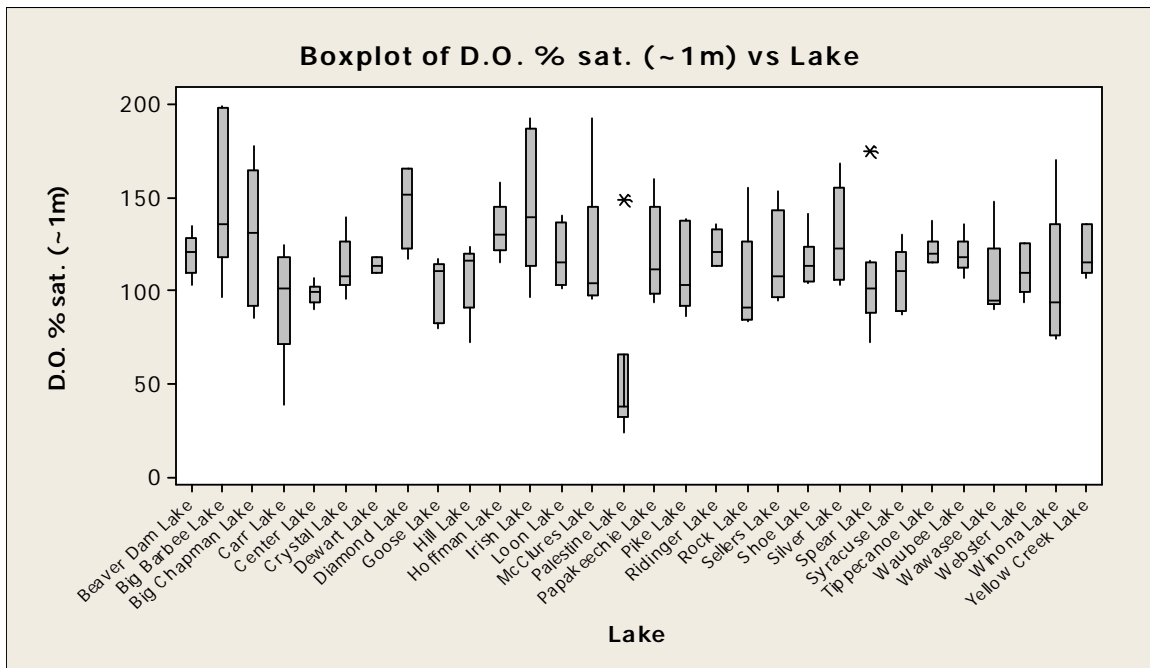
D.O. at 1 meter

Lake	Sample Mean for Shallow Water Samples	County Shallow Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	116.80	115.31		x	
Big Barbee Lake	147.02	115.31			X
Big Chapman Lake	124.52	115.31		x	
Carr Lake	97.36	115.31		x	
Center Lake	110.76	115.31		x	
Crystal Lake	115.13	115.31		x	
Dewart Lake	105.83	115.31		x	
Diamond Lake	147.93	115.31			X
Goose Lake	106.14	115.31		x	
Hill Lake	110.29	115.31		x	
Hoffman Lake	133.57	115.31		x	
Irish Lake	135.54	115.31		x	
Loon Lake	112.06	115.31		x	
McClures Lake	115.29	115.31		x	
Palestine Lake	56.14	115.31	x		
Papakeechie Lake	115.39	115.31		x	
Pike Lake	118.78	115.31		x	
Ridinger Lake	127.03	115.31		x	
Rock Lake	102.00	115.31		x	
Sellers Lake	111.55	115.31		x	
Shoe Lake	114.14	115.31		x	
Silver Lake	126.86	115.31		x	
Spear Lake	100.41	115.31		x	
Syracuse Lake	109.14	115.31		x	
Tippecanoe Lake	111.59	115.31		x	
Waubee Lake	125.44	115.31		x	
Wawasee Lake	105.70	115.31		x	
Webster Lake	113.68	115.31		x	
Winona Lake	116.27	115.31		x	
Yellow Creek Lake	126.94	115.31		x	

pH Measurement (Shallow Water Sites)
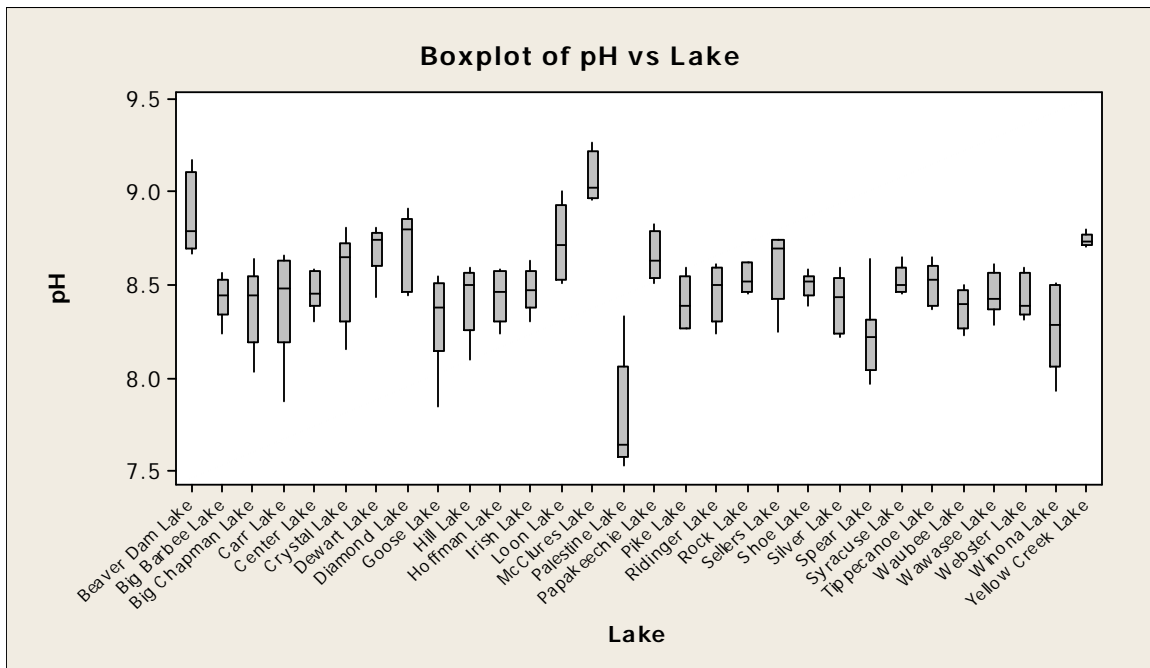
pH

Lake	Sample Mean for Shallow Water Samples	County Shallow Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	8.846	8.494			x
Big Barbee Lake	8.422	8.494		x	
Big Chapman Lake	8.356	8.494		x	
Carr Lake	8.427	8.494		x	
Center Lake	8.543	8.494		x	
Crystal Lake	8.565	8.494		x	
Dewart Lake	8.642	8.494		x	
Diamond Lake	8.721	8.494			x
Goose Lake	8.328	8.494		x	
Hill Lake	8.447	8.494		x	
Hoffman Lake	8.445	8.494		x	
Irish Lake	8.413	8.494		x	
Loon Lake	8.688	8.494		x	
McClures Lake	9.039	8.494			x
Palestine Lake	7.800	8.494	x		
Papakeechie Lake	8.626	8.494		x	
Pike Lake	8.462	8.494		x	
Ridinger Lake	8.489	8.494		x	
Rock Lake	8.522	8.494		x	
Sellers Lake	8.567	8.494		x	
Shoe Lake	8.492	8.494		x	
Silver Lake	8.394	8.494		x	
Spear Lake	8.180	8.494	x		
Syracuse Lake	8.530	8.494		x	
Tippecanoe Lake	8.445	8.494		x	
Waubee Lake	8.419	8.494		x	
Wawasee Lake	8.448	8.494		x	
Webster Lake	8.447	8.494		x	
Winona Lake	8.313	8.494		x	
Yellow Creek Lake	8.788	8.494			x

Total Fluorescence Measurement (Shallow Water Sites)
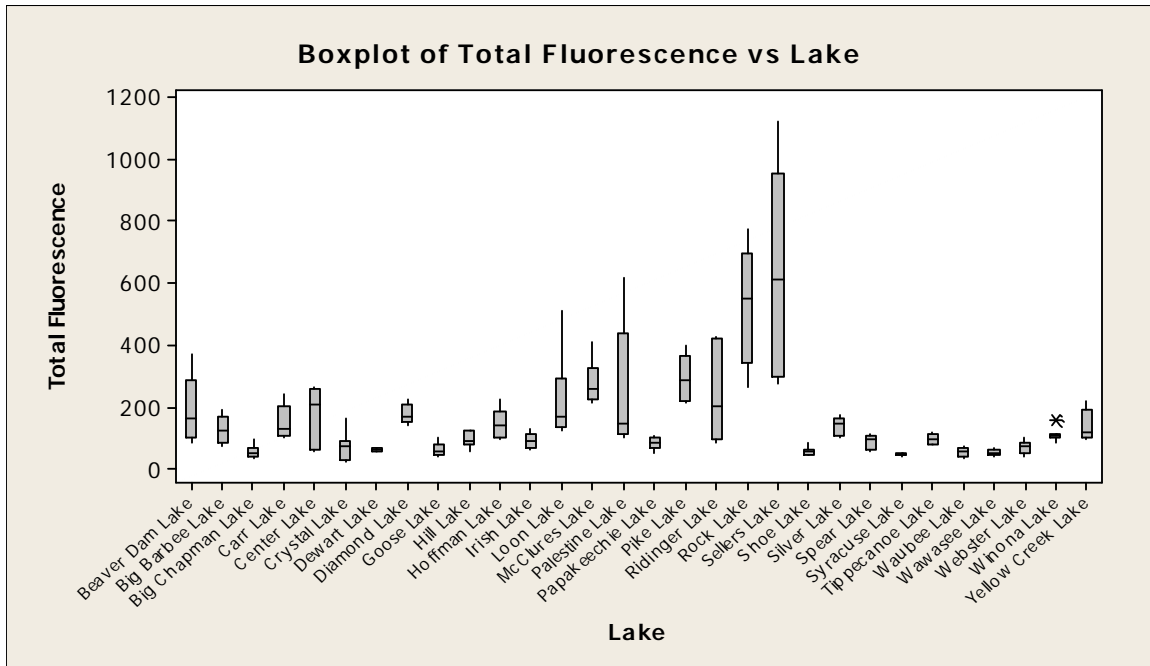
Total Fluorescence

Lake	Sample Mean for Shallow Water Samples	County Shallow Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	197.20	161.4		x	
Big Barbee Lake	130.79	161.4		x	
Big Chapman Lake	62.09	161.4		x	
Carr Lake	146.85	161.4		x	
Center Lake	163.34	161.4		x	
Crystal Lake	71.27	161.4		x	
Dewart Lake	72.72	161.4		x	
Diamond Lake	175.14	161.4		x	
Goose Lake	60.63	161.4	x		
Hill Lake	91.32	161.4		x	
Hoffman Lake	147.08	161.4		x	
Irish Lake	104.29	161.4		x	
Loon Lake	231.09	161.4		x	
McClures Lake	285.36	161.4			x
Palestine Lake	249.66	161.4		x	
Papakeechie Lake	89.92	161.4		x	
Pike Lake	283.50	161.4			x
Ridinger Lake	234.30	161.4		x	
Rock Lake	532.49	161.4			x
Sellers Lake	644.44	161.4			x
Shoe Lake	61.64	161.4	x		
Silver Lake	144.44	161.4		x	
Spear Lake	98.95	161.4		x	
Syracuse Lake	45.16	161.4	x		
Tippecanoe Lake	110.39	161.4		x	
Waubee Lake	48.10	161.4		x	
Wawasee Lake	54.58	161.4		x	
Webster Lake	68.13	161.4		x	
Winona Lake	107.64	161.4		x	
Yellow Creek Lake	130.94	161.4		x	

Turbidity Measurement (Shallow Water Sites)
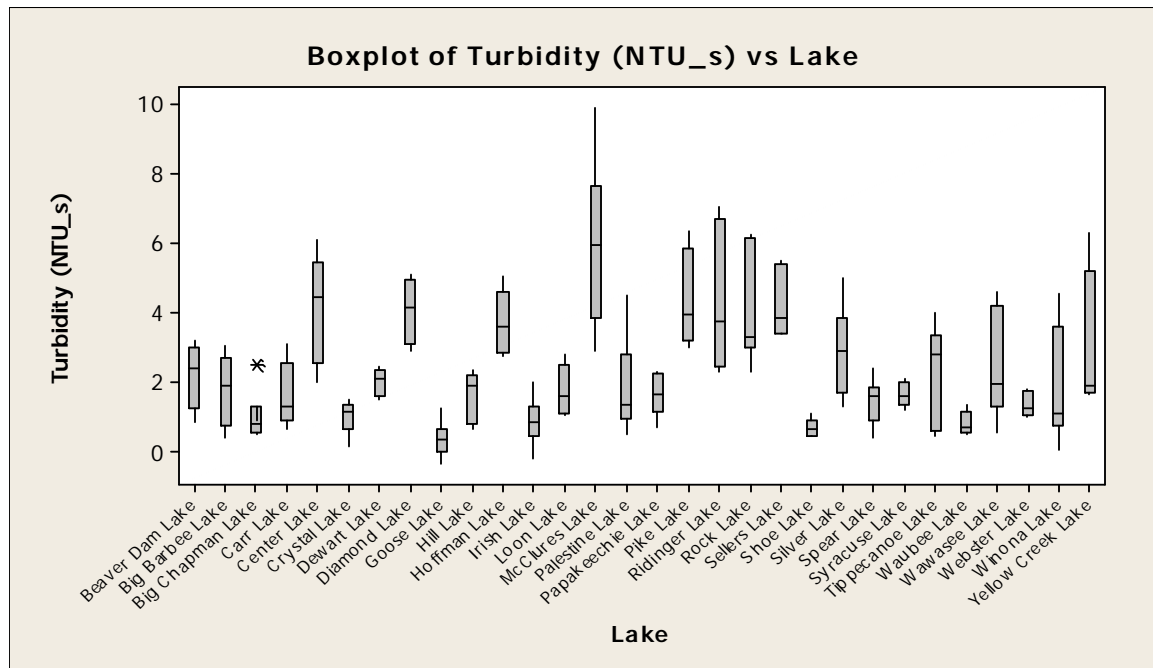
Turbidity

Lake	Sample Mean for Shallow Water Samples	County Shallow Avg	Less than Avg	Average	Larger than Avg
Beaver Dam Lake	2.242	2.394		x	
Big Barbee Lake	1.820	2.394		x	
Big Chapman Lake	1.080	2.394		x	
Carr Lake	1.601	2.394		x	
Center Lake	4.034	2.394			x
Crystal Lake	1.012	2.394	x		
Dewart Lake	2.119	2.394		x	
Diamond Lake	4.056	2.394			x
Goose Lake	0.379	2.394	x		
Hill Lake	1.622	2.394		x	
Hoffman Lake	3.727	2.394		x	
Irish Lake	0.991	2.394		x	
Loon Lake	1.832	2.394		x	
McClures Lake	6.014	2.394			x
Palestine Lake	1.821	2.394		x	
Papakeechie Lake	1.697	2.394		x	
Pike Lake	4.286	2.394			x
Ridinger Lake	4.289	2.394			x
Rock Lake	4.107	2.394			x
Sellers Lake	4.295	2.394			x
Shoe Lake	0.734	2.394	x		
Silver Lake	2.928	2.394		x	
Spear Lake	1.542	2.394		x	
Syracuse Lake	1.658	2.394		x	
Tippecanoe Lake	2.418	2.394		x	
Waubee Lake	0.764	2.394	x		
Wawasee Lake	2.463	2.394		x	
Webster Lake	1.343	2.394		x	
Winona Lake	1.948	2.394		x	
Yellow Creek Lake	2.998	2.394		x	

Comparative Analysis of Shallow Water Sites and Selected Inlet Sites

There were 26 lakes upon which we had identified an inlet from which to take measurements (we did not have an identified inlet for Crystal Lake, Goose Lake, Shoe Lake, or Spear Lake). For each of these 26 lakes, the question of interest was whether or not the measurements at the inlet site (site denoted 5) were different from the measurements at the shoreline sites around the lake (sites denoted 3 and 4); that is, it was of interest to see if there were any atypical measurements at the inlet as compared with the rest of the lake. In order to address this, for each of the 26 lakes a comparative analysis was carried out for each of the measurements:

- E. Coli Measurement

- Total Phosphorus Measurement

- Nitrogen Measurement

- Dissolved Oxygen Measurement at 1 meter

- pH Measurement

- Total Fluorescence Measurement

- Turbidity Measurement

For these analyses on each of the 26 lakes, respectively, data from that lake only was considered, so as to compare the inlet measurements with the other shoreline measurements on that lake. Each analysis compared inlet sampling site versus shallow water sampling site while taking into account which months in which the measurements were taken (an analysis of covariance). The following lakes showed a statistically significant difference in an average water quality measurement at the identified inlet as compared to the average shallow water measurement:

Lake	Water Quality Measurement	Average Shallow Water Measurement	Average Inlet Measurement	Significant p-value
Dewart Lake	Total Fluorescence	62.66	87.67	0.009
Hoffman Lake	pH	8.44	8.537	0.021
Lake Wawasee	pH	8.448	8.177	0.009
Palestine Lake	Total Phosphorus	0.1975	0.3267	0.021
Ridinger Lake	Dissolved Oxygen at 1 m	122.58	97.43	0.049
Rock Lake	E. Coli	9.35	23.467	0.024
Silver Lake	Turbidity	2.907	3.836	0.047
Tippecanoe Lake	Dissolved Oxygen at 1 m	121.9	140.6	0.015
Webster Lake	Total Fluorescence	71.81	419.37	<.001
Webster Lake	Turbidity	1.374	3.467	0.001
Winona Lake	E. Coli	4.258	261.431	0.04

Chlorophyll-a Regression Model for Converting to ug/L

The in vivo chlorophyll-a measurements that were taken at sampling sites were in units of total fluorescence. It is of interest to know how these measurements compare to the standard laboratory measurement units of micrograms per liter. In order to translate the total fluorescence measurements into micrograms per liter measurements, 15 sampling sites were selected (one on each of 15 different lakes) from which to collect samples for laboratory chlorophyll-a analysis. With this data, a regression model was built for predicting what measurement in micrograms per liter a laboratory would have given had laboratory analysis been performed. In building this regression model, it was also seen that the inverse of secchi depth was a good secondary predictor variable, so the resulting regression model that was chosen was:

ug/L lab measurement regressed on total fluorescence and 1/(secchi depth)

The following are scatterplots illustrate the relationship of lab measurement and the predictor variables.
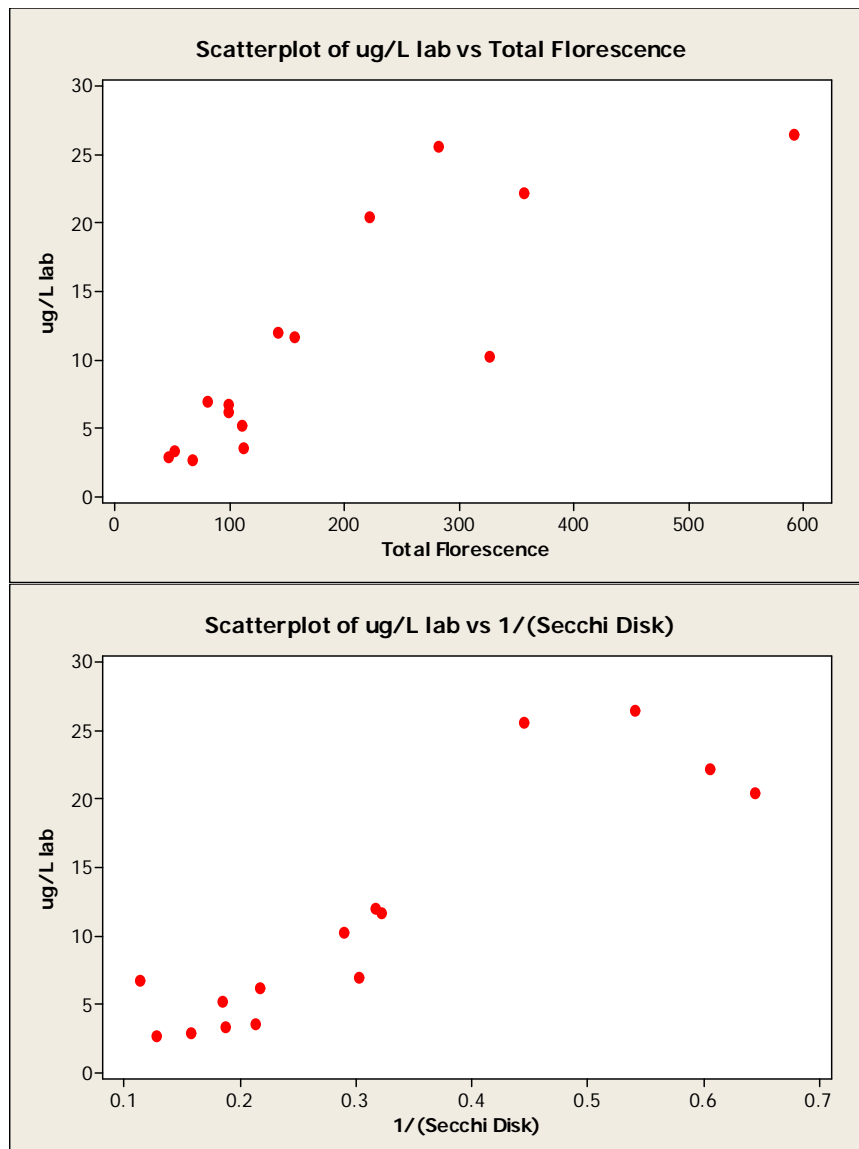
Converted Chlorophyll-a: Predicted ug/L Average Measurements in Lakes

The following table gives predictions of deep water average microgram per liter chlorophyll-a measurements that laboratory analysis is likely to have given.

Average for Deep Water Sites	Predicted Deep Water Average ug/L	95% Confidence Intervals for Predicted ug/L averages
All Lakes	6.7711	(4.237, 9.305)
Beaver Dam Lake	9.2070	(6.867, 11.547)
Big Barbee Lake	6.9801	(4.463, 9.498)
Big Chapman Lake	2.5278	(0, 5.178)
Carr Lake	4.9860	(2.391, 7.580)
Center Lake	12.5261	(10.397, 14.656)
Crystal Lake	1.9078	(0, 4.793)
Dewart Lake	3.7849	(1.260, 6.310)
Diamond Lake	11.4512	(9.590, 13.313)
Goose Lake	1.3094	(0, 4.296)
Hill Lake	3.7383	(1.248, 6.228)
Hoffman Lake	8.7980	(6.967, 10.629)
Irish Lake	5.6770	(3.043, 8.311)
Loon Lake	9.0578	(6.743, 11.372)
McClures Lake	23.3792	(18.892, 27.867)
Palestine Lake	13.2264	(9.803, 16.650)
Papakeechie Lake	4.2312	(1.851, 6.612)
Pike Lake	15.5629	(13.103, 18.023)
Ridinger Lake	13.3050	(11.465, 15.145)
Rock Lake	25.4354	(21.247, 29.623)
Sellers Lake	24.2924	(17.399, 31.186)
Shoe Lake	2.0033	(0, 4.773)
Silver Lake	11.0408	(9.270, 12.812)
Spear Lake	3.9627	(1.406, 6.520)
Syracuse Lake	3.4379	(0.980, 5.896)
Tippecanoe Lake	5.3480	(2.901, 7.795)
Waubee Lake	2.3705	(0, 5.086)
Wawasee Lake	4.7601	(2.482, 7.039)
Webster Lake	3.2020	(0.675, 5.729)
Winona Lake	7.0101	(4.626, 9.394)
Yellow Creek Lake	7.8691	(5.977, 9.762)

Beaver Dam Lake
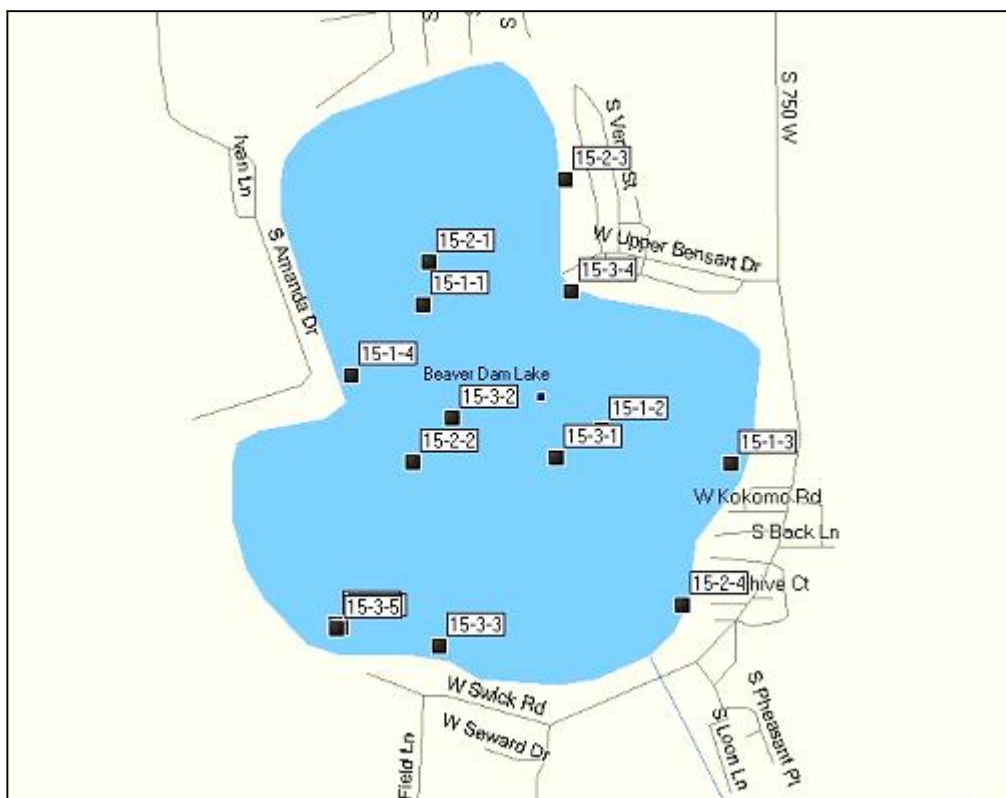
Big Barbee Lake

Big Chapman Lake

Carr Lake
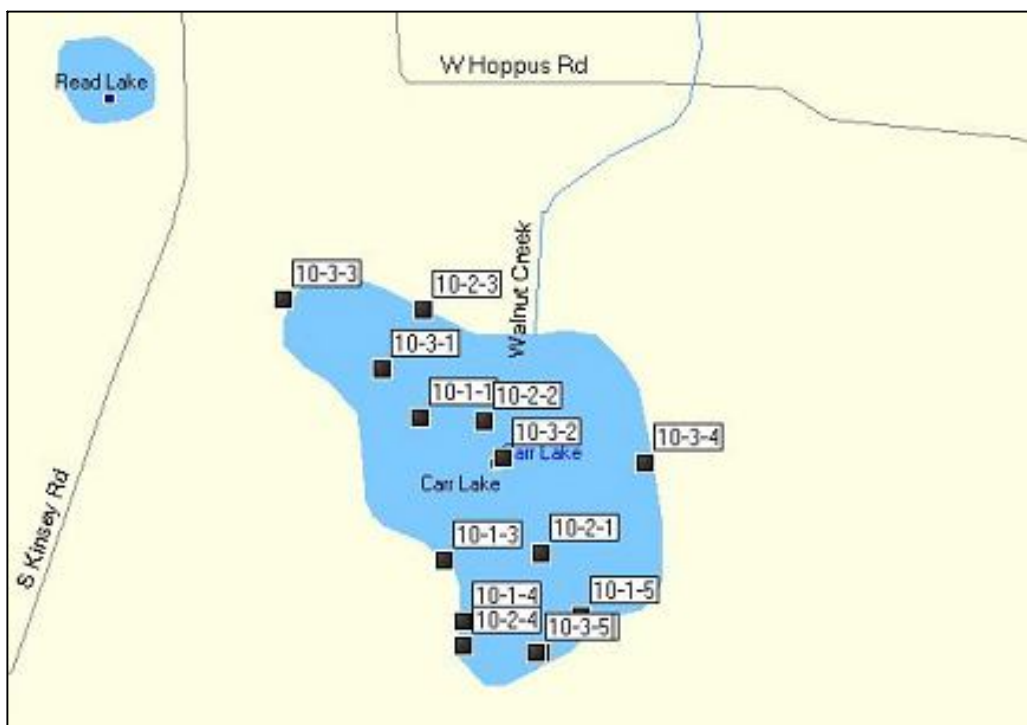
Center Lake
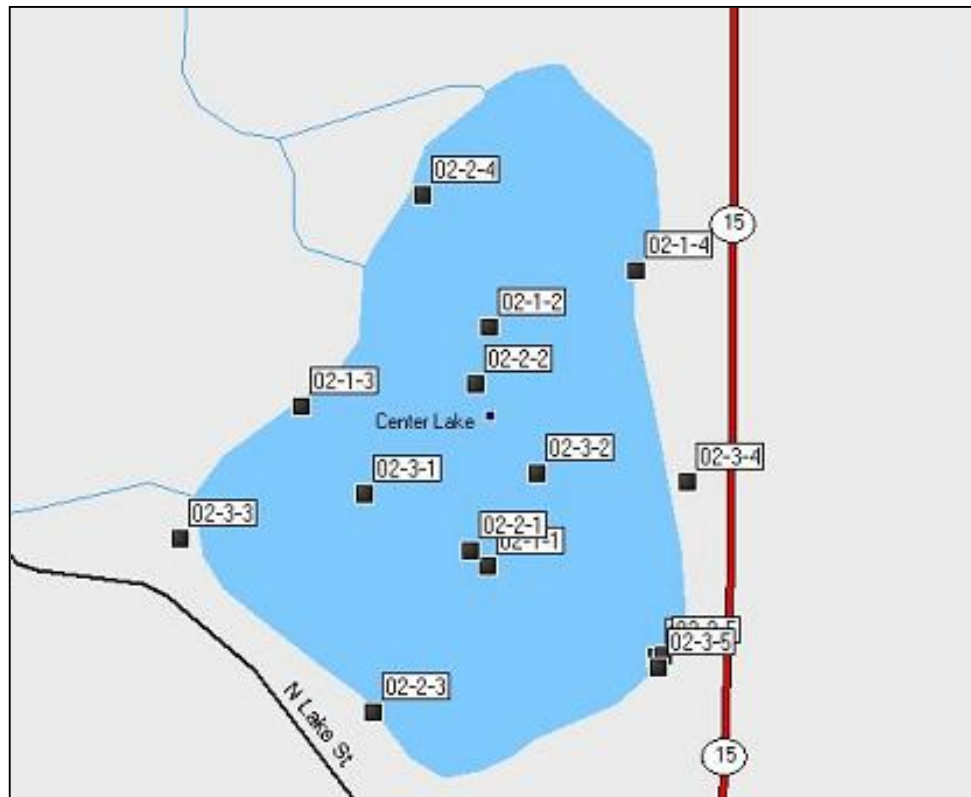
Crystal Lake
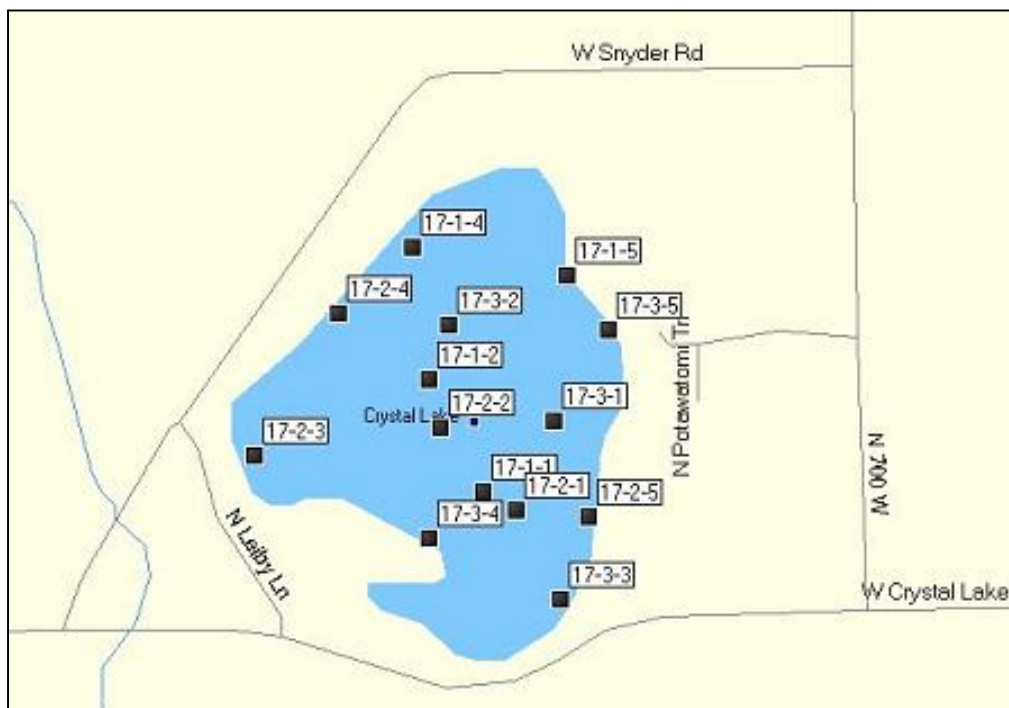
Dewart Lake
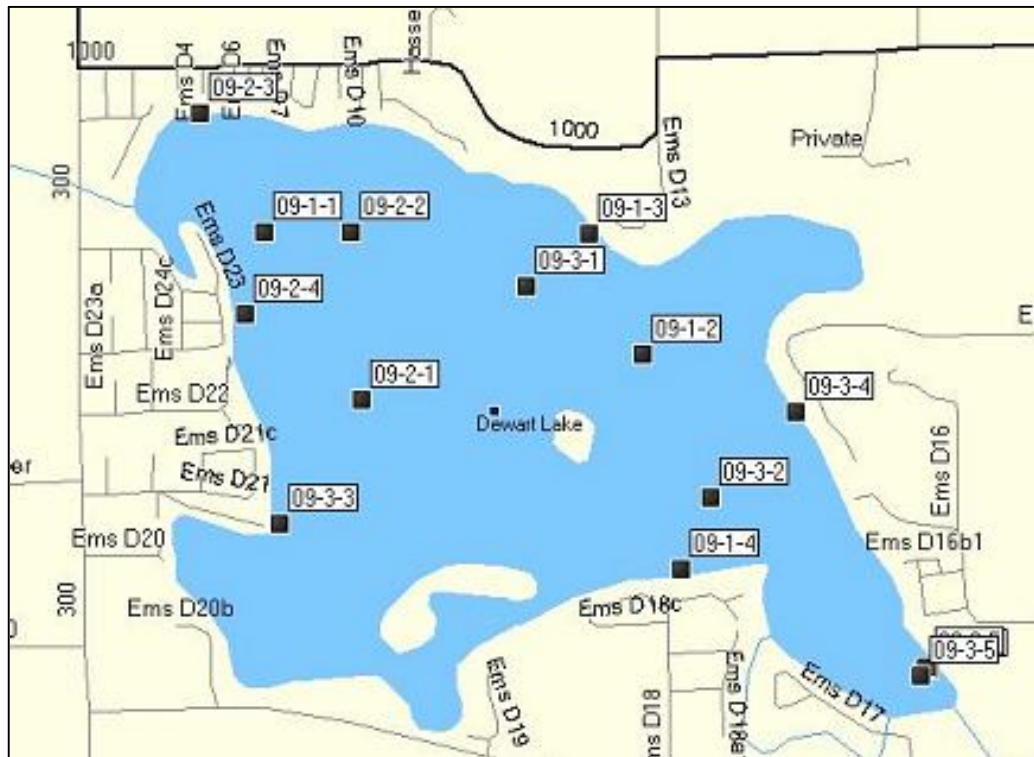
Diamond Lake

Goose Lake

Hill Lake
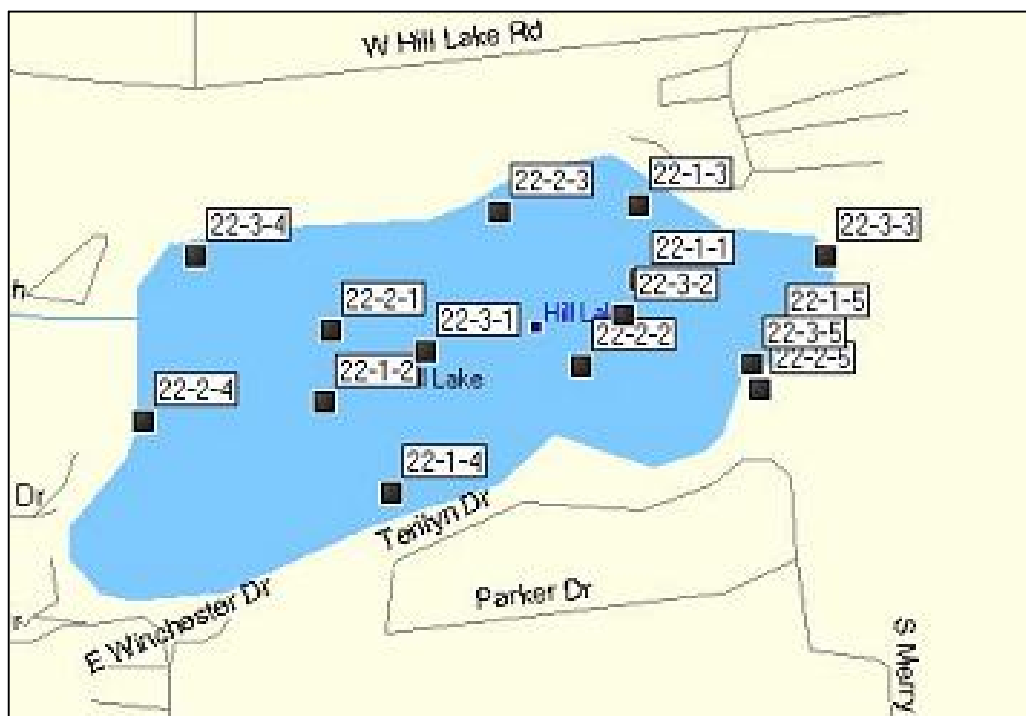
Hoffman Lake
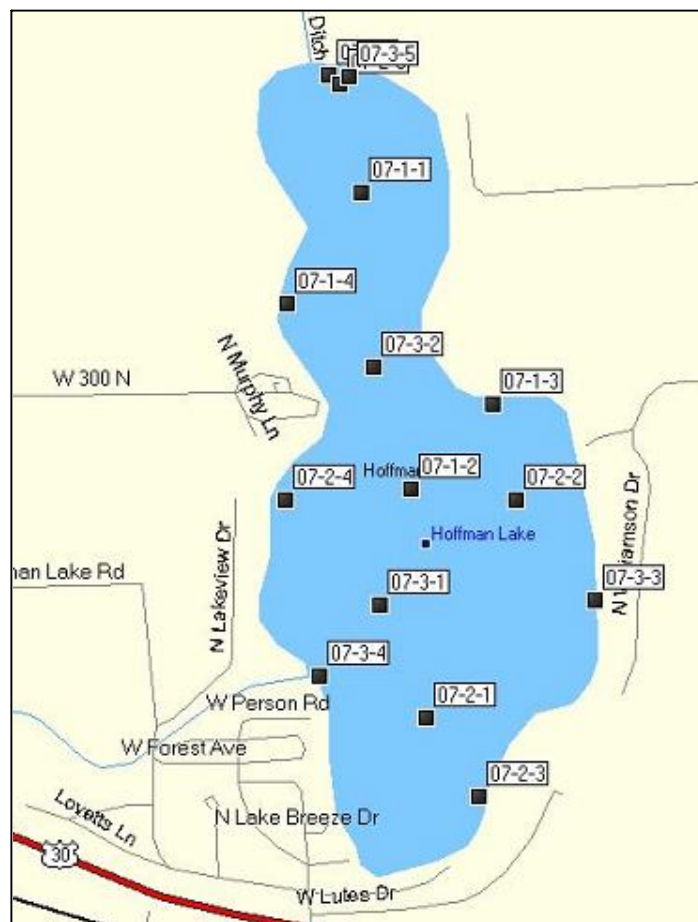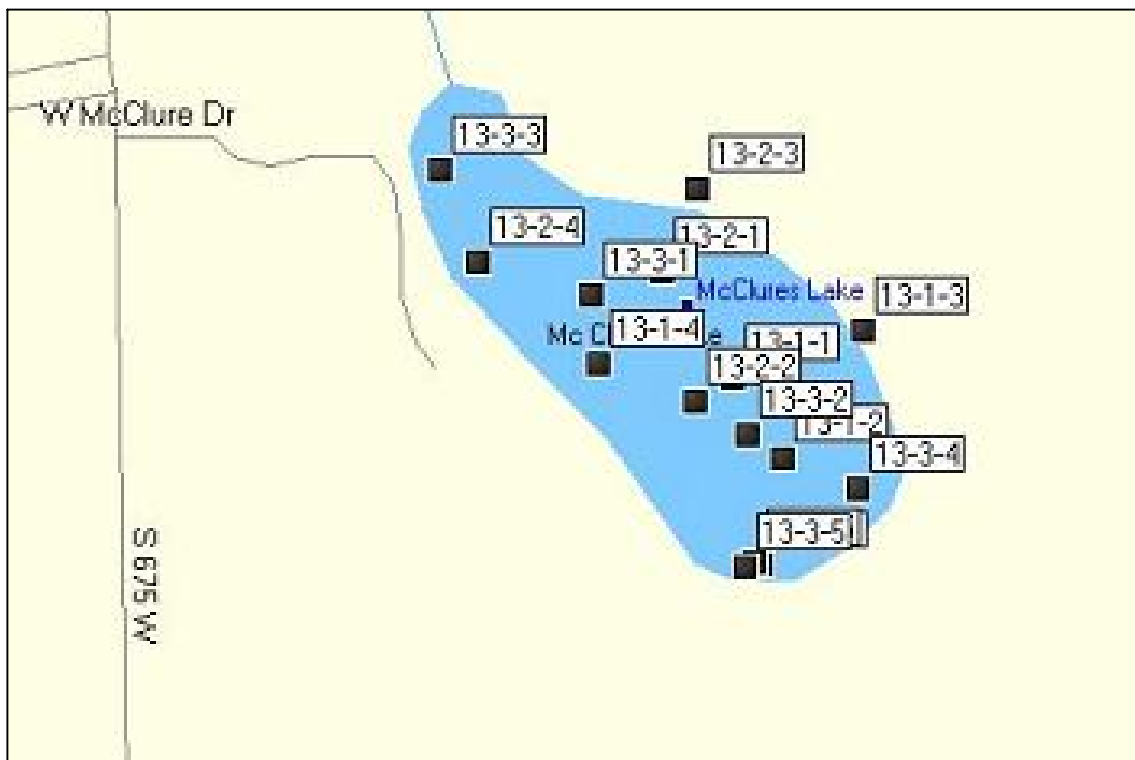

Irish Lake
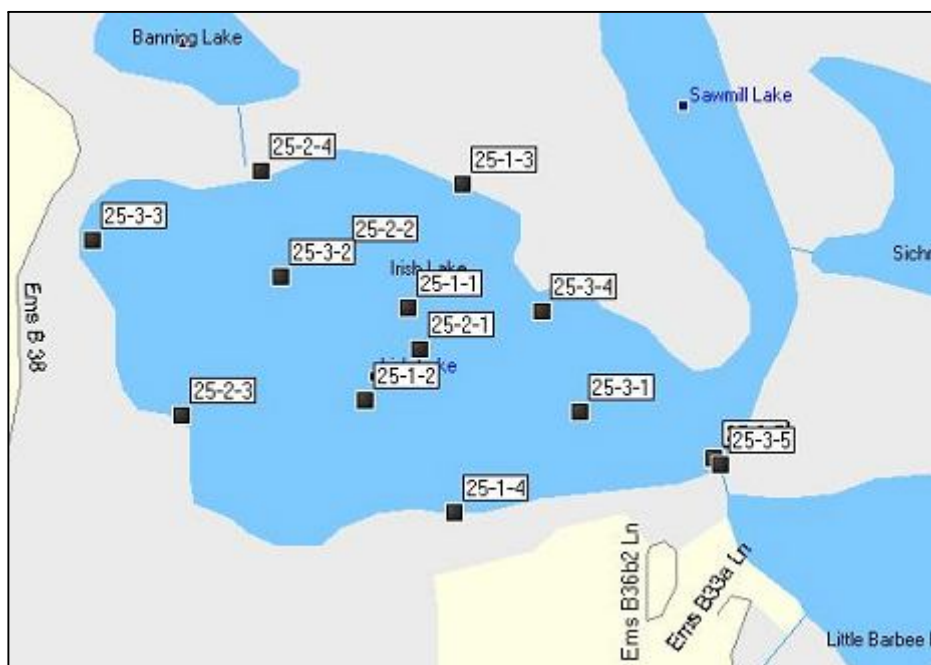
Loon Lake
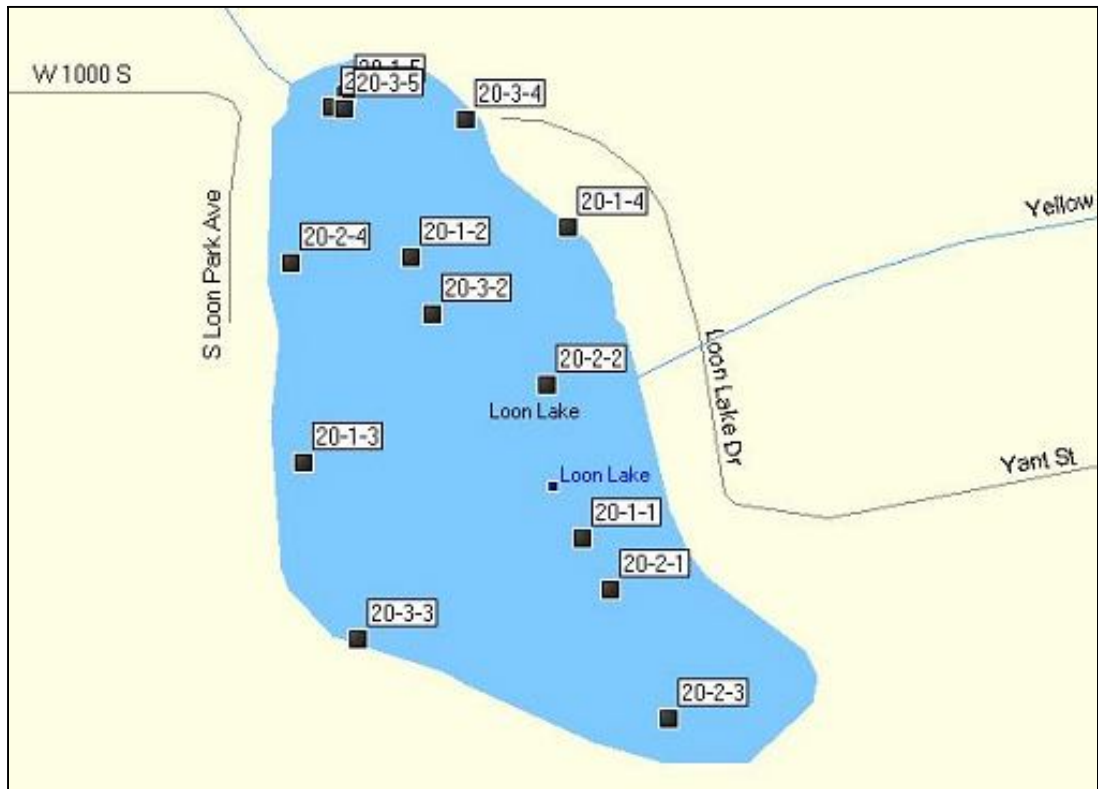
McClures Lake

Palestine Lake
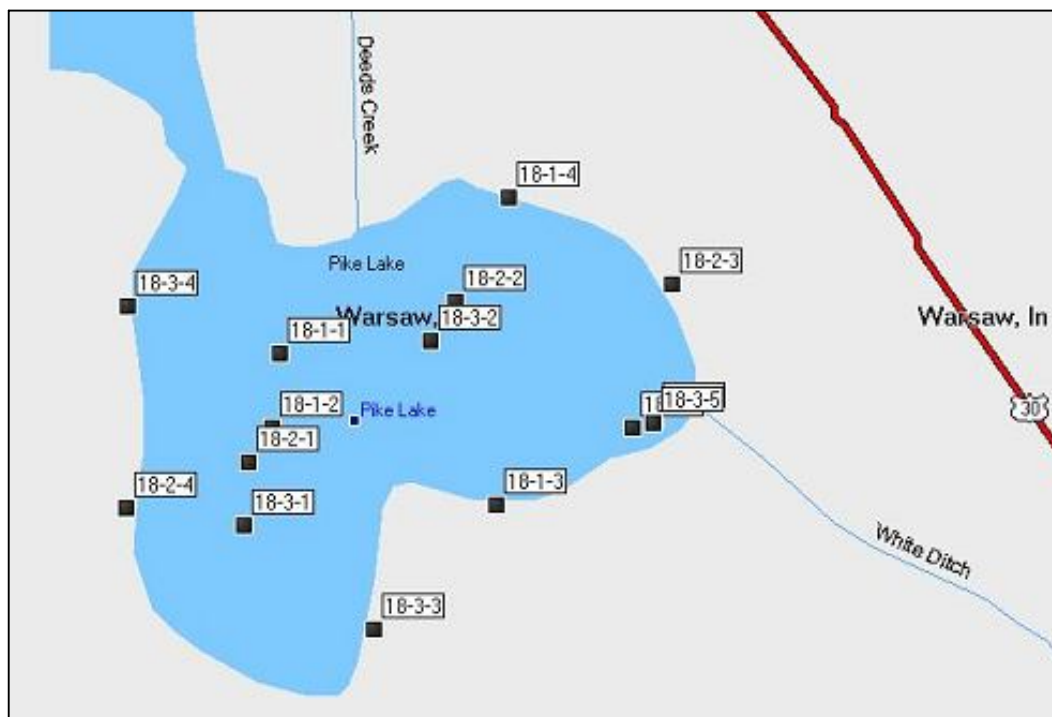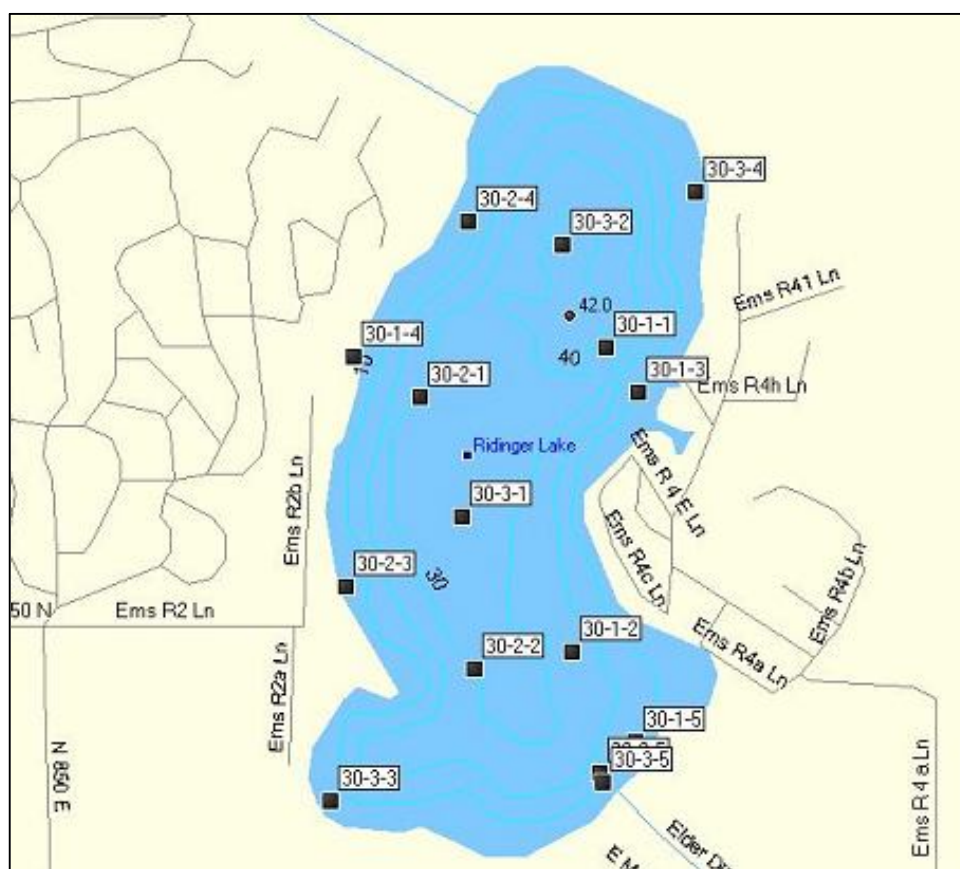

Lake Papakeechie

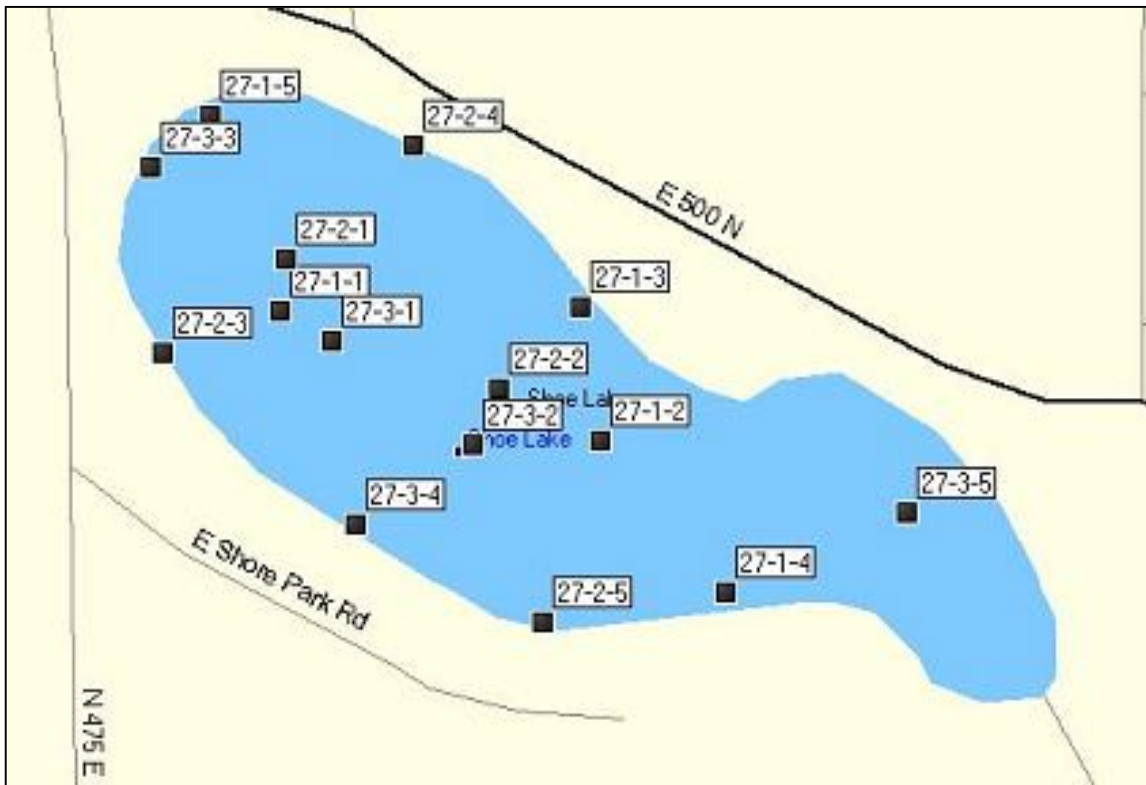# Pike Lake

Ridinger Lake

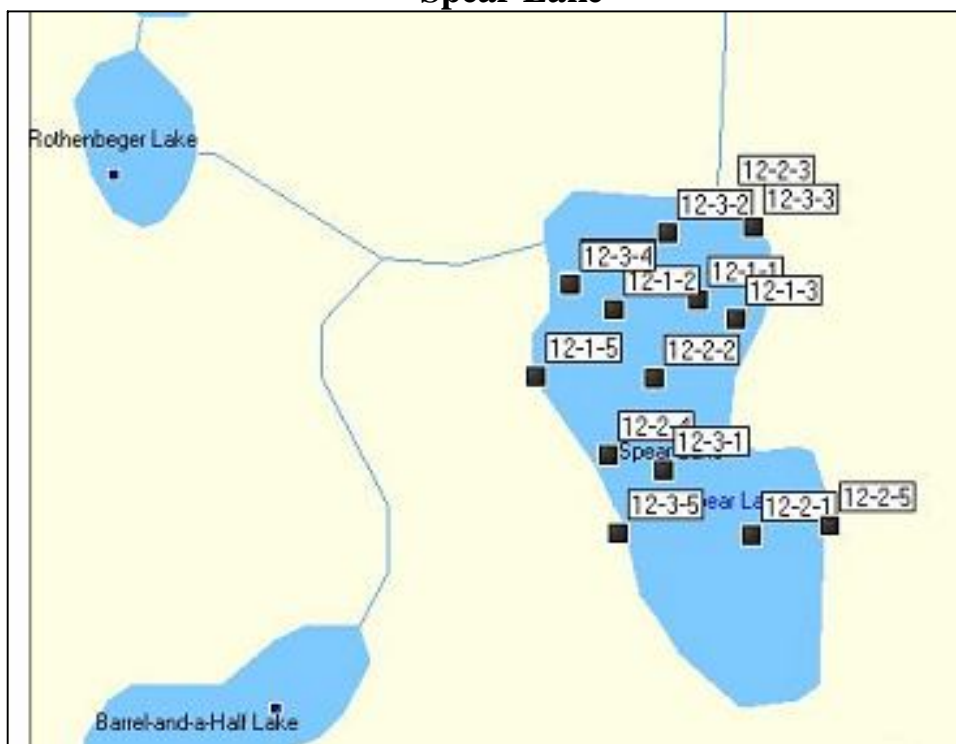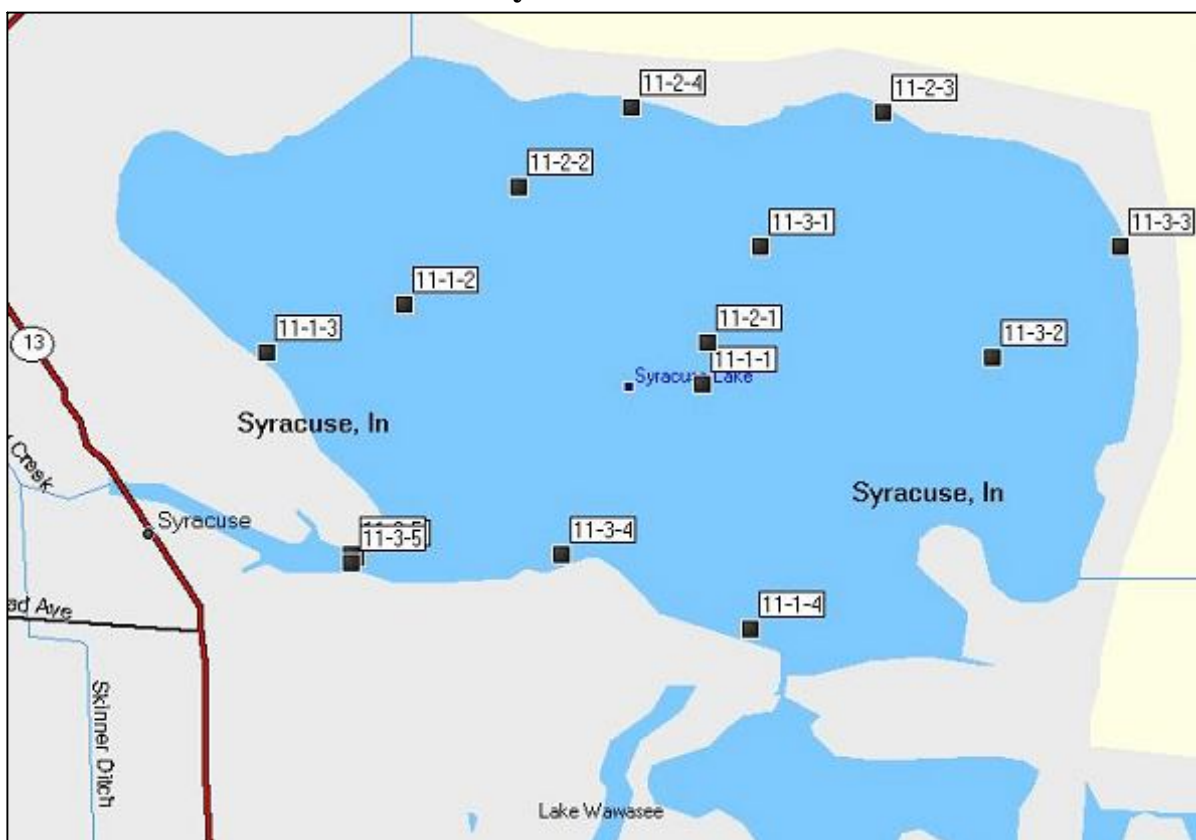## Rock Lake

Sellers Lake
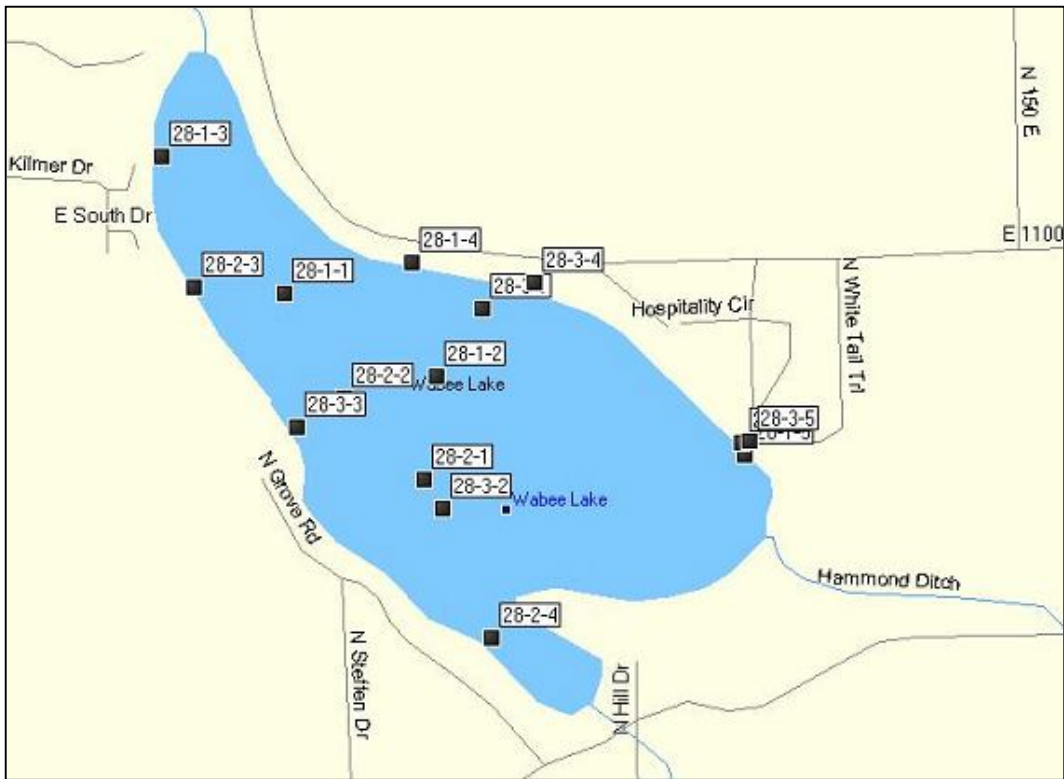
Shoe Lake

Silver Lake

Spear Lake

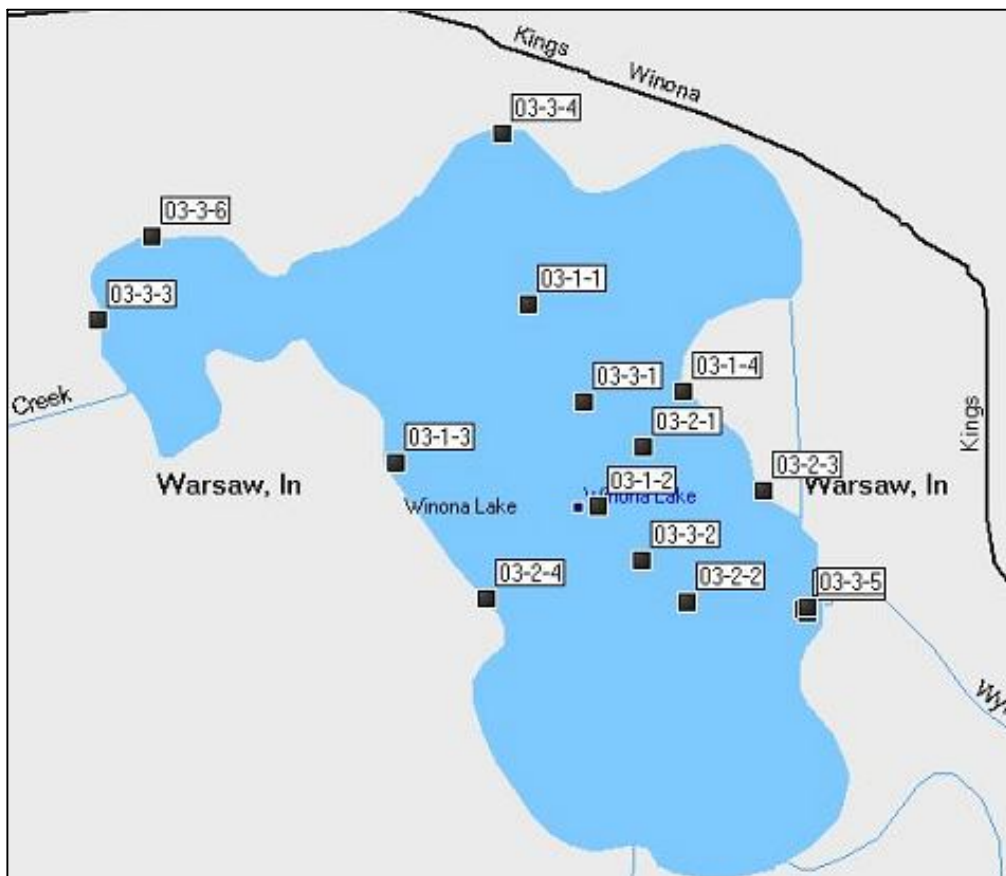## Syracuse Lake

Lake Tippecanoe

Waubee Lake

Lake Wawasee

Webster Lake

Winona Lake

Yellow Creek Lake

Appendix 2: Water Monitoring Data Sheet

Grace College Water Monitoring Data Sheet

Date: ___/___/___   Time: _____   ID Number: ___ ___-___-___

Current Weather: ☐Clear/Sunny ☐Overcast ☐Showers ☐Rain (steady) ☐Storm (heavy)

Weather Past 48 hrs: ☐Clear/Sunny ☐Overcast ☐Showers ☐Rain (steady) ☐Storm (heavy)

Lake Name: _____   Site GPS Location: _____

Field Collection by: ___Grace College Water Monitoring_____

Water Quality Measurements

A check mark indicates that a sample was taken at the site then tests were performed elsewhere. E. Coli testing was performed at the Kosc. County Health Dept. Nutrients were tested for Phosphates and Nitrate+Nitrite at the state lab. All other data was collected from sampling instruments at the site.

___Test For E. Coli

___Test For Nutrients

Turbidity: _____ NTU's

Test For Chlorophyll a: _____ total fluorescence

pH: _____ units

Lake Depth: _____ m

D.O. Measurements:

% saturation _____   Temp. _____ ° C   Depth: _____ m

% saturation _____   Temp. _____ ° C   Depth: _____ m

% saturation _____   Temp. _____ ° C   Depth: _____ m

Secchi Depth Readings: _____ ft   _____ ft   Hit Bottom: _____
down   up   Y/N

Air Temp: _____ °C

Appendix 3: Water Quality Initiative Staff Contact Information

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