Lake County Average TSI phosphorus (TSIp) ranking 2000-2019.

53	Seven Acre Lake	0.0460	59.36
54	Turner Lake	0.0460	59.36
55	Willow Lake	0.0460	59.36
56	Waterford Lake	0.0470	59.67
57	East Meadow Lake	0.0480	59.97
58	Lucky Lake	0.0480	59.97
59	Old Oak Lake	0.0490	60.27
60	College Trail Lake	0.0500	60.56
61	Summerhill Estates Lake	0.0514	60.96
62	Big Bear Lake	0.0514	60.96
63	West Meadow Lake	0.0530	61.40
64	Beaver Lake	0.0532	61.46
65	Lucy Lake	0.0550	61.94
66	Acorn Lake	0.0564	62.30
67	Lake Christa	0.0580	62.70
68	Owens Lake	0.0580	62.70
69	Briarcrest Pond	0.0580	62.70
70	Honey Lake	0.0586	62.85
71	Crooked Lake	0.0604	63.29
72	Redhead Lake	0.0608	63.38
73	St. Mary's Lake	0.0608	63.38
74	Duck Lake	0.0610	63.43
75	Lake Charles	0.0618	63.62
76	Lake Lakeland Estates	0.0620	63.66
77	Lake Naomi	0.0620	63.66
78	Lake Catherine	0.0620	63.66
79	Liberty Lake	0.0630	63.89
80	North Tower Lake	0.0630	63.89
81	Werhane Lake	0.0630	63.89
82	Countryside Glen Lake	0.0640	64.12
83	Davis Lake	0.0650	64.34
84	Leisure Lake	0.0650	64.34
85	Channel Lake	0.0680	65.00
86	Buffalo Creek Reservoir 1	0.0680	65.00
87	Mary Lee Lake	0.0680	65.00
88	Potomac Lake	0.0714	65.70
89	Timber Lake (South)	0.0720	65.82
90	Lake Helen	0.0720	65.82
91	Grandwood Park Lake	0.0720	65.82
92	ADID 203	0.0730	66.02
93	Fish Lake	0.0730	66.02
94	Hastings Lake	0.0746	66.33
95	Deer Lake Meadow Lake	0.0755	66.50
96	Broberg Marsh	0.0780	66.97
97	Echo Lake	0.0790	67.16
98	Countryside Lake	0.0800	67.34
99	Lake Nippersink	0.0800	67.34
100	Woodland Lake	0.0800	67.34
101	Redwing Slough	0.0822	67.73
102	Tower Lake	0.0830	67.87
103	Lake Antioch	0.0850	68.21
104	Grand Ave Marsh	0.0870	68.55
105	North Churchill Lake	0.0870	68.55

Lake County Average TSI phosphorus (TSIp) ranking 2000-2019.

106	White Lake	0.0874	68.61
107	Pistakee Lake	0.0880	68.71
108	Lake Fairview	0.0890	68.88
109	Rivershire Pond 2	0.0900	69.04
110	South Churchill Lake	0.0900	69.04
111	McGreal Lake	0.0910	69.20
112	Deer Lake	0.0940	69.66
113	Eagle Lake (S1)	0.0950	69.82
114	International Mine and Chemical Lake	0.0950	69.82
115	Valley Lake	0.0950	69.82
116	McDonald Lake 1	0.0952	69.85
117	Buffalo Creek Reservoir 2	0.0960	69.97
118	Fox Lake	0.1000	70.56
119	Nippersink Lake - LCFP	0.1000	70.56
120	Sylvan Lake	0.1000	70.56
121	Petite Lake	0.1020	70.84
122	Longview Meadow Lake	0.1020	70.84
123	Lake Marie	0.1030	70.98
124	McDonald Lake 2	0.1050	71.26
125	Dunn's Lake	0.1070	71.53
126	Lake Forest Pond	0.1070	71.53
127	Long Lake	0.1070	71.53
128	Grass Lake	0.1090	71.80
129	Des Plaines Lake	0.1090	71.80
130	Spring Lake	0.1100	71.93
131	Kemper 2	0.1100	71.93
132	Bittersweet Golf Course #13	0.1100	71.93
133	Osprey Lake	0.1110	72.06
134	Rollins Savannah 1	0.1116	72.14
135	Bluff Lake	0.1120	72.19
136	Middlefork Savannah Outlet 1	0.1120	72.19
137	Lochanora Lake	0.1120	72.19
138	Round Lake Marsh North	0.1130	72.32
139	Lake Matthews	0.1180	72.94
140	Taylor Lake	0.1180	72.94
141	Island Lake	0.1210	73.31
142	Columbus Park Lake	0.1230	73.54
143	Lake Holloway	0.1320	74.56
144	Fischer Lake	0.1380	75.20
145	Slocum Lake	0.1500	76.40
146	Lakewood Marsh	0.1510	76.50
147	Pond-A-Rudy	0.1510	76.50
148	Forest Lake	0.1540	76.78
149	Bresen Lake	0.1580	77.15
150	Middlefork Savannah Outlet 2	0.1590	77.24
151	Grassy Lake	0.1610	77.42
152	Salem Lake	0.1650	77.78
153	Half Day Pit	0.1690	78.12
154	Rollins Savannah 2	0.1746	78.59
155	Lake Louise	0.1810	79.11
156	Lake Eleanor	0.1810	79.11
157	Lake Farmington	0.1850	79.43

Lake County Average TSI phosphorus (TSIp) ranking 2000-2019.

158	ADID 127	0.1890	79.74
159	Lake Napa Suwe	0.1940	80.11
160	Loch Lomond	0.1960	80.26
161	Patski Pond	0.1970	80.33
162	Dog Bone Lake	0.1990	80.48
163	Redwing Marsh	0.2070	81.05
164	Stockholm Lake	0.2082	81.13
165	Bishop Lake	0.2160	81.66
166	Ozaukee Lake	0.2200	81.93
167	Kemper 1	0.2220	82.06
168	Hidden Lake	0.2240	82.19
169	Oak Hills Lake	0.2790	85.35
170	Fairfield Marsh	0.3260	87.60
171	ADID 182	0.3280	87.69
172	Manning's Slough	0.3820	89.88
173	Slough Lake	0.3860	90.03
174	Rasmussen Lake	0.4860	93.36
175	Albert Lake, Site II, outflow	0.4950	93.62
176	Flint Lake Outlet	0.5000	93.76
177	Almond Marsh	1.9510	113.40
	Average	***0.1040***	***65.0***

Lake County Secchi Disk Clarity Ranking, 2000-2019.

RANK	LAKE NAME	SECCHI AVE	TSIsd
1	Lake Carina	16.96	36.31
2	Windward Lake	14.28	38.79
3	Sterling Lake	13.84	39.24
4	Round Lake	12.97	40.18
5	Cedar Lake	12.55	40.66
6	Druce Lake	11.86	41.47
7	Pulaski Pond	11.69	41.68
8	West Loon Lake	11.55	41.85
9	Gages Lake	10.42	43.33
10	Lake Zurich	10.40	43.37
11	Indpendence Grove	10.31	43.49
12	Ames Pit	9.97	43.97
13	Davis Lake	9.65	44.44
14	Harvey Lake	9.47	44.72
15	Little Silver Lake	9.42	44.79
16	Old School Lake	9.40	44.82
17	Lake Kathryn	9.39	44.84
18	Lake Miltmore	9.28	45.01
19	Dugdale Lake	9.22	45.10
20	Dog Training Pond	9.04	45.39
21	Banana Pond	8.85	45.69
22	Sand Lake	8.83	45.72
23	Deep Lake	8.83	45.72
24	Stone Quarry Lake	8.81	45.76
25	Wooster Lake	8.74	45.87
26	Lake of the Hollow	8.74	45.87
27	Cross Lake	8.18	46.83
28	Bangs Lake	8.02	47.11
29	Briarcrest Pond	8.00	47.15
30	Heron Pond	7.87	47.39
31	Sand Pond (IDNR)	7.42	48.23
32	Highland Lake	7.42	48.23
33	Lake Leo	7.31	48.45
34	Schreiber Lake	7.25	48.57
35	Nielsen Pond	7.23	48.61
36	Honey Lake	7.17	48.73
37	Lake Minear	7.13	48.81
38	Lake Helen	6.43	50.30
39	Sun Lake	6.33	50.52
40	Lake Barrington	6.12	51.01
41	Waterford Lake	6.11	51.03
42	Timber Lake (North)	6.03	51.22
43	Cranberry Lake	5.94	51.44
44	Lake Fairfield	5.89	51.56
45	Third Lake	5.78	51.83
46	Owens Lake	5.30	53.08
47	Lake Linden	5.28	53.14
48	Valley Lake	5.05	53.78
49	McGreal Lake	5.04	53.81
50	Old Oak Lake	4.85	54.36

Lake County Secchi Disk Clarity Ranking, 2000-2019.

51	Grays Lake	4.59	55.16
52	Peterson Pond	4.51	55.41
53	Timber Lake (South)	4.46	55.57
54	Crooked Lake	4.39	55.79
55	Mary Lee Lake	4.35	55.93
56	Butler Lake	4.35	55.93
57	Little Bear Lake	4.35	55.93
58	Deer Lake	4.20	56.45
59	Seven Acre Lake	4.18	56.51
60	Hastings Lake	4.18	56.51
61	Lambs Farm Lake	4.17	56.54
62	Lake Naomi	4.05	56.96
63	Hook Lake	3.95	57.32
64	Turner Lake	3.92	57.43
65	North Tower Lake	3.89	57.54
66	Leisure Lake	3.85	57.69
67	Summerhill Estates Lake	3.84	57.73
68	Acorn Lake	3.84	57.73
69	Salem Lake	3.77	58.00
70	Lake Fariview	3.75	58.07
71	Duck Lake	3.71	58.23
72	Countryside Glen Lake	3.64	58.50
73	Beaver Lake	3.64	58.50
74	Fish Lake	3.57	58.78
75	Taylor Lake	3.52	58.99
76	Lochanora	3.52	58.99
77	Bishop Lake	3.47	59.19
78	Lake Lakeland Estates	3.41	59.44
79	Lake Holloway	3.40	59.49
80	Stockholm Lake	3.38	59.57
81	Crooked Lake	3.35	59.70
82	East Loon Lake	3.30	59.92
83	Lucky Lake	3.22	60.27
84	Diamond Lake	3.17	60.50
85	Liberty Lake	3.16	60.54
86	International Mining and Chemical Lake	3.08	60.91
87	Long Lake	3.05	61.05
88	Lake Christa	3.01	61.24
89	Lucy Lake	2.99	61.34
90	Lake Charles	2.95	61.53
91	Lake Catherine	2.9	61.78
92	St. Mary's Lake	2.79	62.34
93	Channel Lake	2.77	62.44
94	Werhane Lake	2.71	62.76
95	Fischer Lake	2.70	62.81
96	Bresen Lake	2.69	62.86
97	East Meadow Lake	2.61	63.30
98	Buffalo Creek Reservoir 1	2.60	63.35
99	Countryside Lake	2.58	63.46
100	Big Bear Lake	2.58	63.46
101	Kemper Lake 1	2.56	63.58

Lake County Secchi Disk Clarity Ranking, 2000-2019.

102	Bluff Lake	2.51	63.86
103	Broberg Marsh	2.50	63.92
104	Antioch Lake	2.48	64.03
105	Island Lake	2.32	65.00
106	Tower Lake	2.31	65.06
107	Buffalo Creek Reservoir 2	2.30	65.12
108	Woodland Lake	2.28	65.25
109	Rivershire Pond 2	2.23	65.57
110	College Trail Lake	2.18	65.89
111	Loch Lomond	2.17	65.96
112	Redhead Lake	2.16	66.03
113	Pistakee Lake	2.15	66.09
114	Des Plaines Lake	2.14	66.16
115	Echo Lake	2.11	66.36
116	Eagle Lake (S1)	2.10	66.43
117	West Meadow Lake	2.07	66.64
118	Forest Lake	2.04	66.85
119	Grand Ave Marsh	2.03	66.92
120	Columbus Park Lake	2.03	66.92
121	Grassy Lake	2.00	67.14
122	Petite Lake	2.00	67.14
123	Sylvan Lake	1.98	67.28
124	Bittersweet Golf Course #13	1.98	67.28
125	Deer Lake Meadow Lake	1.83	68.42
126	Spring Lake	1.78	68.82
127	Kemper Lake 2	1.77	68.90
128	Fourth Lake	1.77	68.90
129	Nippersink Lake	1.73	69.23
130	Lake Louise	1.68	69.65
131	Willow Lake	1.63	70.09
132	Slough Lake	1.63	70.09
133	Rasmussen Lake	1.62	70.17
134	Lake Farmington	1.62	70.17
135	Half Day Pit	1.60	70.35
136	Lake Marie	1.56	70.72
137	White Lake	1.53	71.00
138	Longview Meadow Lake	1.51	71.19
139	Lake Matthews	1.48	71.48
140	Rollins Savannah 1	1.38	72.51
141	Fox Lake	1.28	73.57
142	Dunn's Lake	1.22	74.26
143	Lake Eleanor	1.16	74.99
144	Lake Napa Suwe	1.06	76.29
145	Osprey Lake	1.03	76.70
146	Manning's Slough	1.00	77.13
147	Dog Bone Lake	0.94	78.02
148	Redwing Marsh	0.88	78.97
149	Flint Lake Oulet	0.83	79.82
150	Fairfield Marsh	0.81	80.17
151	Slocum Lake	0.81	80.17
152	Oak Hills Lake	0.79	80.53

Lake County Secchi Disk Clarity Ranking, 2000-2019.

153	McDonald Lake 1	0.79	80.53
154	Grass Lake	0.78	80.71
155	Lake Nippersink	0.77	80.90
156	South Churchill Lake	0.73	81.67
157	Lake Forest Pond	0.71	82.07
158	Rollins Savannah 2	0.66	83.03
159	ADID 127	0.66	83.12
160	North Churchill Lake	0.61	84.26
161	Hidden Lake	0.56	85.54
162	McDonald Lake 2	0.53	86.28
163	Ozaukee Lake	0.51	86.84
	average	***4.35***	***60.37***

Appendix C:
Methods for Field Data Collection and Laboratory Analyses

Water Sampling and Laboratory Analyses

Two water samples were collected once a month from May through September. Sample locations were at the deepest point in the lake (see sample site map), three feet below the surface, and 3 feet above the bottom. Samples were collected with a horizontal Van Dorn water sampler. Approximately three liters of water were collected for each sample for all lab analyses. After collection, all samples were placed in a cooler with ice until delivered to the Lake County Health Department lab, where they were refrigerated. Analytical methods for the parameters are listed in Table A1. Except nitrate nitrogen, all methods are from the Eighteenth Edition of <u>Standard Methods</u>, (eds. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1992). Methodology for nitrate nitrogen was taken from the 14th edition of Standard Methods. Dissolved oxygen, temperature, conductivity and pH were measured at the deep hole with a Hydrolab DataSonde® 4a. Photosynthetic Active Radiation (PAR) was recorded using a LI-COR® 192 Spherical Sensor attached to the Hydrolab DataSonde® 4a. Readings were taken at the surface and then every two feet until reaching the bottom.

Plant Sampling

In order to randomly sample each lake, mapping software (ArcMap 9.3) overlaid a grid pattern onto an aerial photo of Lake County and placed points 60 or 30 meters apart, depending on lake size. Plants were sampled using a garden rake fitted with hardware cloth. The hardware cloth surrounded the rake tines and is tapered two feet up the handle. A rope was tied to the end of the handle for retrieval. At designated sampling sites, the rake was tossed into the water, and using the attached rope, was dragged across the bottom, toward the boat. After pulling the rake into the boat, plant coverage was assessed for overall abundance. Then plants were individually identified and placed in categories based on coverage. Plants that were not found on the rake but were seen in the immediate vicinity of the boat at the time of sampling were also recorded. Plants difficult to identify in the field were placed in plastic bags and identified with plant keys after returning to the office. The depth of each sampling location was measured either by a hand-held depth meter, or by pushing the rake straight down and measuring the depth along the rope or rake handle. One-foot increments were marked along the rope and rake handle to aid in depth estimation.

Shoreline Assessment

<u>Shoreline Assessment Protocol</u>

Each lake was divided into reaches in ArcGIS based on nearshore landuse. For each reach, a shoreline assessment worksheet was filled out in the field focusing on shoreline conditions (land use, slope, erosion, buffer, etc) that describe the overall reach segment of the lake.

A GPS Trimble unit was used to collect the degree of shoreline erosion along the entire length of the lake. The degree of shoreline erosion was categorically defined as none, slight, moderate, or severe. Below are brief descriptions of each category.

Table 1: Degree of Shoreline Erosion

Category	Description
None	Includes man-made erosion control such as rip-rap and sea wall.
Slight	Minimal or no observable erosion; generally considered stable; no erosion control practices will be recommended with the possible exception of small problem areas noted within an area otherwise designated as "slight". Beaches have been included as "slight" erosion.
Moderate	Recession is characterized by past or recently eroded banks; area may exhibit some exposed roots, fallen vegetation or minor slumping of soil material; erosion control practices may be recommended although the section is not deemed to warrant immediate remedial action.
Severe	Recession is characterized by eroding of exposed soil on nearly vertical banks, exposed roots, fallen vegetation or extensive slumping of bank material, undercutting, washouts or fence posts exhibiting realignment; erosion control practices are recommended and immediate remedial action may be warranted.

Lateral recession rates were calculated on a per reach basis based on the IL EPA stream methodology, defining lateral recession into four main categories (slight, moderate, severe, and very severe). Descriptions of each category are defined in the Table 2.

Table 2: Lateral Recession Rate Categories

Lateral Recession Rate	Description	Description
0.01 – 0.05	Slight	Some bare bank but active erosion not readily apparent. Some rills but no vegetation overhanging. No exposed tree roots.
0.06 – 0.2	Moderate	Bank mostly bare with some rills and vegetation overhanging.
0.3 – 0.5	Severe	Bank is bare with rills and severe vegetative overhang. Many exposed tree roots and some fallen trees and slumps or slips. Some changes in cultural features such as fence corners missing and realignment of roads or trails. Channel cross-section becomes more U-shaped as opposed to V-shaped.
0.5+	Very Severe	Bank is bare with gullies and severe vegetative overhang. Many fallen trees, drains and culverts eroding out and changes in cultural features as above. Massive slips or washouts common. Channel cross-section is U-shaped and streamcourse or gully may be meandering.

Shoreline Buffer Condition

Lakeshore buffer condition was assessed using a qualitative methodology that considered an area up to 25 feet inland from the shoreline for each reach. The assessment was done by viewing high resolution 2014 aerial images in ArcGIS. A 25 foot buffer was chosen based on research that indicates a 25-foot vegetated buffer is the minimum effective width for in-lake habitat maintenance (a 15 foot buffer is the minimum effective width for bank stability). Criteria used for category assignment are shown in table below.

Table 3: Shoreline Buffer Condition Categories

Category	Criteria	Percentage
Good	Unmowed grasses & forbs + tree trunks + shrubs	≥70%
	and impervious surfaces	≤5%
Fair	Unmowed grasses & forbs + tree trunks + shrubs	≥50% and <70%
	and Impervious surface	≤10%
Poor	Unmowed grasses & forbs +tree trunks + shrubs	<50%
	and Impervious surface	≥50%

Wildlife Assessment

Species of wildlife were noted during visits to each lake. When possible, wildlife was identified to species by sight or sound. However, due to time constraints, collection of quantitative information was not possible. Thus, all data should be considered anecdotal.
Some of the species on the list may have only been seen once, or were spotted during their migration through the area.

Table A1. Analytical methods used for water quality parameters.

Parameter	***Method***
Temperature	Hydrolab DataSonde® 4a or YSI 6600 Sonde®
Dissolved oxygen	Hydrolab DataSonde ®4a or YSI 6600 Sonde®
Nitrate and Nitrite nitrogen	USEPA 353.2 rev. 2.0 EPA-600/R-93/100 Detection Limit = 0.05 mg/L
Ammonia nitrogen	SM 18th ed. Electrode method, #4500 NH_3-F Detection Limit = 0.1 mg/L
Total Kjeldahl nitrogen	SM 18th ed, 4500-N_{org} C Semi-Micro Kjeldahl, plus 4500 NH_3-F Detection Limit = 0.5 mg/L
pH	Hydrolab DataSonde® 4a, or YSI 6600 Sonde® Electrometric method
Total solids	SM 18th ed, Method #2540B
Total suspended solids	SM 18th ed, Method #2540D Detection Limit = 0.5 mg/L
Chloride	SM 18th ed, Method #4500C1-D
Total volatile solids	SM 18th ed, Method #2540E, from total solids
Alkalinity	SM 18th ed, Method #2320B, patentiometric titration curve method
Conductivity	Hydrolab DataSonde® 4a or YSI 6600 Sonde®
Total phosphorus	SM 18th ed, Methods #4500-P B 5 and #4500-P E Detection Limit = 0.01 mg/L
Soluble reactive phosphorus	SM 18th ed, Methods #4500-P B 1 and #4500-P E Detection Limit = 0.005 mg/L
Clarity	Secchi disk
Color	Illinois EPA Volunteer Lake Monitoring Color Chart
Photosynthetic Active Radiation (PAR)	Hydrolab DataSonde® 4a or YSI 6600 Sonde®, LI-COR® 192 Spherical Sensor

Appendix D:
Interpreting Your Lake's Water Quality Data

Lakes possess a unique set of physical and chemical characteristics that will change over time. These in-lake water quality characteristics, or parameters, are used to describe and measure the quality of lakes, and they relate to one another in very distinct ways. As a result, it is virtually impossible to change any one component in or around a lake without affecting several other components, and it is important to understand how these components are linked.

The following pages will discuss the different water quality parameters measured by Lake County Health Department staff, how these parameters relate to each other, and why the measurement of each parameter is important. The median values (the middle number of the data set, where half of the numbers have greater values, and half have lesser values) of data collected from Lake County lakes from 2000-2010 will be used in the following discussion.

Temperature and Dissolved Oxygen:

Water temperature fluctuations will occur in response to changes in air temperatures, and can have dramatic impacts on several parameters in the lake. In the spring and fall, lakes tend to have uniform, well-mixed conditions throughout the water column (surface to the lake bottom). However, during the summer, deeper lakes will separate into distinct water layers. As surface water temperatures increase with increasing air temperatures, a large density difference will form between the heated surface water and colder bottom water. Once this difference is large enough, these two water layers will separate and generally will not mix again until the fall. At this time the lake is thermally stratified. The warm upper water layer is called the ***epilimnion***, while the cold bottom water layer is called the ***hypolimnion***. In some shallow lakes, stratification and destratification can occur several times during the summer. If this occurs the lake is described as polymictic. Thermal stratification also occurs to a lesser extent during the winter, when warmer bottom water becomes separated from ice-forming water at the surface until mixing occurs during spring ice-out.

Monthly temperature profiles were established on each lake by measuring water temperature every foot (lakes $\leq$ 15 feet deep) or every two feet (lakes > 15 feet deep) from the lake surface to the lake bottom. These profiles are important in understanding the distribution of chemical/biological characteristics and because increasing water temperature and the establishment of thermal stratification have a direct impact on dissolved oxygen (DO) concentrations in the water column. If a lake is shallow and easily mixed by wind, the DO concentration is usually consistent throughout the water column. However, shallow lakes are typically dominated by either plants or algae, and increasing water temperatures during the summer speeds up the rates of photosynthesis and decomposition in surface waters. Many of the plants or algae die at the end of the growing season. Their decomposition results in heavy oxygen consumption and can lead to an oxygen crash. In deeper, thermally stratified lakes, oxygen production is greatest in the top portion of the lake, where sunlight drives photosynthesis, and oxygen consumption is greatest near the bottom of a lake, where sunken organic matter accumulates and decomposes. The oxygen difference between the top and bottom water layers can be dramatic, with plenty of oxygen near the surface, but practically none near the bottom.

The oxygen profiles measured during the water quality study can illustrate if this is occurring. This is important because the absence of oxygen (anoxia) near the lake bottom can have adverse effects in eutrophic lakes resulting in the chemical release of phosphorus from lake sediment and the production of hydrogen sulfide (rotten egg smell) and other gases in the bottom waters. Low oxygen conditions in the upper water of a lake can also be problematic since all aquatic organisms need oxygen to live. Some oxygen may be present in the water, but at too low a concentration to sustain aquatic life. Oxygen is needed by all plants, virtually all algae and for many chemical reactions that are important in lake functioning. Most adult sport-fish such as largemouth bass and bluegill require at least 3 mg/L of DO in the water to survive. However, their offspring require at least 5 mg/L DO as they are more sensitive to DO stress. When DO concentrations drop below 3 mg/L, rough fish such as carp and green sunfish are favored and over time will become the dominant fish species.

External pollution in the form of oxygen-demanding organic matter (i.e., sewage, lawn clippings, soil from shoreline erosion, and agricultural runoff) or nutrients that stimulate the growth of excessive organic matter (i.e., algae and plants) can reduce average DO concentrations in the lake by increasing oxygen consumption. This can have a detrimental impact on the fish community, which may be squeezed into a very small volume of water as a result of high temperatures in the epilimnion and low DO levels in the hypolimnion.

Nutrients:

Phosphorus:

For most Lake County lakes, phosphorus is the nutrient that limits plant and algae growth. This means that any addition of phosphorus to a lake will typically result in algae blooms or high plant densities during the summer. The source of phosphorus to a lake can be external or internal (or both). External sources of phosphorus enter a lake through point (i.e., storm pipes and wastewater discharge) and non-point runoff (i.e., overland water flow). This runoff can pick up large amounts of phosphorus from agricultural fields, septic systems or impervious surfaces before it empties into the lake.

Internal sources of phosphorus originate within the lake and are typically linked to the lake sediment. In lakes with high oxygen levels (oxic), phosphorus can be released from the sediment through plants or sediment resuspension. Plants take up sediment-bound phosphorus through their roots, releasing it in small amounts to the water column throughout their life cycles, and in large amounts once they die and begin to decompose. Sediment resuspension can occur through biological or mechanical means. Bottom-feeding fish, such as common carp and black bullhead can release phosphorus by stirring up bottom sediment during feeding activities and can add phosphorus to a lake through their fecal matter. Sediment resuspension, and subsequent phosphorus release, can also occur via wind/wave action or through the use of artificial aerators, especially in shallow lakes. In lakes that thermally stratify, internal phosphorus release can occur from the sediment through chemical means. Once oxygen is depleted (anoxia) in the hypolimnion, chemical reactions occur in which phosphorus bound to iron complexes in the sediment becomes soluble and is released into the water column. This phosphorus is trapped in the hypolimnion and is unavailable to algae until fall turnover, and can cause algae blooms once it moves into the sunlit surface water at that time. Accordingly, many of the lakes in Lake County are plagued by dense algae blooms and excessive, exotic plant coverage, which negatively affect DO levels, fish communities and water clarity.

Lakes with an average phosphorus concentration greater than 0.05 mg/L are considered nutrient rich. The median near surface total phosphorus (TP) concentration in Lake County lakes from 2000-2010 was 0.065 mg/L and ranged from a non-detectable minimum of <0.010 mg/L on seven lakes to a maximum of 3.880 mg/L on Albert Lake. The median anoxic TP concentration in Lake County lakes from 2000-2010 was 0.174 mg/L and ranged from a minimum of 0.012 mg/L in Independence Grove Lake to a maximum of 3.800 mg/L in Taylor Lake.

The analysis of phosphorus also included soluble reactive phosphorus (SRP), a dissolved form of phosphorus that is readily available for plant and algae growth. SRP is not discussed in great detail in most of the water quality reports because SRP concentrations vary throughout the season depending on how plants and algae absorb and release it. It gives an indication of how much phosphorus is available for uptake, but, because it does not take all forms of phosphorus into account, it does not indicate how much phosphorus is truly present in the water column. TP is considered a better indicator of a lake's nutrient status because its concentrations remain more stable than soluble reactive phosphorus. However, elevated SRP levels are a strong indicator of nutrient problems in a lake.

Nitrogen:

Nitrogen is also an important nutrient for plant and algae growth. Sources of nitrogen to a lake vary widely, ranging from fertilizer and animal wastes, to human waste from sewage treatment plants or failing septic systems, to groundwater, air and rainfall. As a result, it is very difficult to control or reduce nitrogen inputs to a lake. Different forms of nitrogen are present in a lake under different oxic conditions. NH_4^+ (ammonium) is released from decomposing organic material under anoxic conditions and accumulates in the hypolimnion of thermally stratified lakes. If NH_4^+ comes into contact with oxygen, it is immediately converted to NO_2 (nitrite) which is then oxidized to NO_3^- (nitrate). Therefore, in a thermally stratified lake, levels of NH_4^+ would only be elevated in the hypolimnion and levels of NO_3^- would only be elevated in the epilimnion. Both NH_4^+ and NO_3^- can be used as a nitrogen source by aquatic plants and algae. Total Kjeldahl nitrogen (TKN) is a measure of organic nitrogen plus ammonium. Adding the concentrations of TKN and nitrate together gives an indication of the amount of total nitrogen present in the water column. If inorganic nitrogen (NO_3^-, NO_2^-, NH_4^+) concentrations exceed 0.3 mg/L in spring, sufficient nitrogen is available to support summer algae blooms. However, low nitrogen levels do not guarantee limited algae growth the way low phosphorus levels do. Nitrogen gas in the air can dissolve in lake water and blue-green algae can "fix" atmospheric nitrogen, converting it into a usable form. Since other types of algae do not have the ability to do this, nuisance blue-green algae blooms are typically associated with lakes that are nitrogen limited (i.e., have low nitrogen levels).

The ratio of TKN plus nitrate nitrogen to total phosphorus (TN:TP) can indicate whether plant/algae growth in a lake is limited by nitrogen or phosphorus. Ratios of less than 10:1 suggest a system limited by nitrogen, while lakes with ratios greater than 20:1 are limited by phosphorus. It is important to know if a lake is limited by nitrogen or phosphorus because any addition of the limiting nutrient to the lake will, likely, result in algae blooms or an increase in plant density.

Solids:

Although several forms of solids (total solids, total suspended solids, total volatile solids, total dissolved solids) were measured each month by the Lakes Management Staff, total suspended solids (TSS) and total volatile solids (TVS) have the most impact on other variables and on the lake as a whole. TSS are particles of algae or sediment suspended in the water column. High TSS concentrations can result from algae blooms, sediment resuspension, and/or the inflow of turbid water, and are typically associated with low water clarity and high phosphorus concentrations in many lakes in Lake County. Low water clarity and high phosphorus concentrations, in turn, exacerbate the high TSS problem by leading to reduced plant density (which stabilize lake sediment) and increased occurrence of algae blooms. The median TSS value in epilimnetic waters in Lake County was 8.1 mg/L, ranging from below the 0.1 mg/L detection limit to 165 mg/L in Fairfield Marsh.

TVS represents the fraction of total solids that are organic in nature, such as algae cells, tiny pieces of plant material, and/or tiny animals (zooplankton) in the water column. High TVS values indicate that a large portion of the suspended solids may be made up of algae cells. This is important in determining possible sources of phosphorus to a lake. If much of the suspended material in the water column is determined to be resuspended sediment that is releasing phosphorus, this problem would be addressed differently than if the suspended material was made up of algae cells that were releasing phosphorus. The median TVS value was 123.0 mg/L, ranging from 34.0 mg/L in Pulaski Pond to 298.0 mg/L in Fairfield Marsh.

Total dissolved solids (TDS) are the amount of dissolved substances, such as salts or minerals, remaining in water after evaporation. These dissolved solids are discussed in further detail in the *Alkalinity* and *Conductivity* sections of this document. TDS concentrations were measured in Lake County lakes prior to 2004. This practice was discontinued due to the strong correlation of TDS to conductivity and chloride concentrations. Since 2004, chloride concentrations data are collected..

Water Clarity:

Water clarity (transparency) is not a chemical property of lake water, but is often an indicator of a lake’s overall water quality. It is affected by a lake’s water color, which is a reflection of the amount of total suspended solids and dissolved organic chemicals. Thus, transparency is a measure of particle concentration and is measured with a Secchi disk. Generally, the lower the clarity or Secchi depth, the poorer the water quality. A decrease in Secchi depth during the summer occurs as the result of an increase in suspended solids (algae or sediment) in the water column. Aquatic plants play an important role in the level of water clarity and can, in turn, be negatively affected by low clarity levels. Plants increase clarity by competing with algae for resources and by stabilizing sediments to prevent sediment resuspension. A lake with a healthy plant community will almost always have higher water clarity than a lake without plants. Additionally, if the plants in a lake are removed (through herbicide treatment or the stocking of grass carp), the lake will probably become dominated by algae and Secchi depth will decrease. This makes it very difficult for plants to become re-established due to the lack of available sunlight and the lake will, most likely, remain turbid. Turbidity will be accelerated if the lake is very shallow and/or common carp are present. Shallow lakes are more susceptible to sediment resuspension through wind/wave action and are more likely to experience clarity problems if plants are not present to stabilize bottom sediment.

Common Carp are prolific fish that feed on invertebrates in the sediment. Their feeding activities stir up bottom sediment and can dramatically decrease water clarity in shallow lakes. As mentioned above, lakes with low water clarity are, generally, considered to have poor water quality. This is because the causes and effects of low clarity negatively impact both plant and fish communities. Fish populations will suffer as water clarity decreases due to a lack of food and decreased ability to successfully hunt for prey. Bluegills are planktivorous fish and feed on invertebrates that inhabit aquatic plants. If low clarity results in the disappearance of plants, this food source will disappear too. Largemouth Bass and Northern Pike are piscivorous fish that feed on other fish and hunt by sight. As the water clarity decreases, these fish species find it more difficult to see and ambush prey and may decline in size as a result. This could eventually lead to an imbalance in the fish community. Phosphorus release from resuspended sediment could increase as water clarity and plant density decrease. This would then result in increased algae blooms, further reducing Secchi depth and aggravating all problems just discussed. The median Secchi depth for Lake County lakes is 2.95 feet. From 2000-2010, both Ozaukee Lake and McDonald Lake #2 had the lowest Secchi depths (0.25 feet) and West Loon Lake had the highest (23.50 feet). As an example of the difference in Secchi depth based on plant coverage, South Churchill Lake, which had no plant coverage and large numbers of Common Carp in 2003 had an average Secchi depth of 0.73 feet (over four times lower than the county average), while Deep Lake, which had a diverse plant community and few carp had an average 2003 Secchi depth of 12.48 feet (almost four times higher than the county average).

Another measure of clarity is the use of a light meter. The light meter measures the amount of light at the surface of the lake and the amount of light at each depth in the water column. The amount of attenuation and absorption (decreases) of light by the water column are major factors controlling temperature and potential photosynthesis. Light intensity at the lake surface varies seasonally and with cloud cover, and decreases with depth. The deeper into the water column light penetrates, the deeper potential plant growth. The maximum depth at which algae and plants can grow underwater is usually at the depth where the amount of light available is reduced to 0.5%-1% of the amount of light available at the lake surface. This is called the euphotic (sunlit) zone. A general rule of thumb in Lake County is that the 1% light level is about 1 to 3 times the Secchi disk depth.

Alkalinity, Conductivity, Chloride, pH:

Alkalinity:

Alkalinity is the measurement of the amount of acid necessary to neutralize carbonate ($CO_3^{=}$) and bicarbonate (HCO_3^{-}) ions in the water, and represents the buffering capacity of a body of water. The alkalinity of lake water depends on the types of minerals in the surrounding soils and in the bedrock. It also depends on how often the lake water comes in contact with these minerals. If a lake gets groundwater from aquifers containing limestone minerals such as calcium carbonate ($CaCO_3$) or dolomite ($CaMgCO_3$), alkalinity will be high. The median alkalinity in Lake County lakes (162 mg/L) is considered moderately hard according to the hardness classification scale of Brown, Skougstad and Fishman (1970). Because hard water (alkaline) lakes often have watersheds with fertile soils that add nutrients to the water, they usually produce more fish and aquatic plants than soft water lakes. Since the majority of Lake County lakes have a high alkalinity they are able to buffer the adverse effects of acid rain.

Conductivity and Chloride:

Conductivity is the inverse measure of the resistance of lake water to an electric flow. This means that the higher the conductivity, the more easily an electric current is able to flow through water. Since electric currents travel along ions in water, the more chemical ions or dissolved salts a body of water contains, the higher the conductivity will be. Accordingly, conductivity has been correlated to total dissolved solids and chloride ions. The amount of dissolved solids or conductivity of a lake is dependent on the lake and watershed geology, the size of the watershed flowing into the lake, the land uses within that watershed, and evaporation and bacterial activity. Many Lake County lakes have elevated conductivity levels in May, but not during any other month. This was because chloride, in the form of road salt, was washing into the lakes with spring rains, increasing conductivity. Most road salt is sodium chloride, calcium chloride, potassium chloride, magnesium chloride or ferrocyanide salts. Beginning in 2004, chloride concentrations are one of the parameters measured during the lake studies. Increased chloride concentrations may have a negative impact on aquatic organisms. Conductivity changes occur seasonally and with depth. For example, in stratified lakes the conductivity normally increases in the hypolimnion as bacterial decomposition converts organic materials to bicarbonate and carbonate ions depending on the pH of the water. These newly created ions increase the conductivity and total dissolved solids. Over the long term, conductivity is a good indicator of potential watershed or lake problems if an increasing trend is noted over a period of years. It is also important to know the conductivity of the water when fishery assessments are conducted, as electroshocking requires a high enough conductivity to properly stun the fish, but not too high as to cause injury or death.

Since 2004 measurements taken in Lake County lakes have exhibited a trend of increasing salinity measured by chloride concentrations. The median near surface chloride concentration of

Lake County Lakes was 142 mg/L. In 2009, Schreiber Lake had the lowest chloride concentration recorded at 2.7 mg/L. The maximum average chloride measurement was at 2760 mg/L at IMC. It is important to note that salt water is denser than fresh water and so it accumulates in the hypolimnion or near the bottom of the lake, this can impact mixing of bottom waters into surface waters in lakes that experience turnover. This phenomenon could have far reaching impacts to an entire ecosystem within a lake. Further, in studies conducted in Minnesota, chloride concentrations as low as 12 mg/L have been found to impact some species of algae.

pH:

pH is the measurement of hydrogen ion (H^+) activity in water. The pH of pure water is neutral at 7 and is considered acidic at levels below 7 and basic at levels above 7. Low pH levels of 4-5 are toxic to most aquatic life, while high pH levels (9-10) are not only toxic to aquatic life they may also result in the release of phosphorus from lake sediment. The presence of high plant densities can increase pH levels through photosynthesis, and lakes dominated by a large amount of plants or algae can experience large fluctuations in pH levels from day to night, depending on the rates of photosynthesis and respiration. Few, if any pH problems exist in Lake County lakes. Typically, the flooded gravel mines in the county are more acidic than the glacial lakes as they have less biological activity, but do not usually drop below pH levels of 7. The median near surface pH value of Lake County lakes was 8.37, with a minimum average of 7.07 in Bittersweet #13 Lake and a maximum of 10.40 in Summerhill Estates Lake.

Eutrophication and Trophic State Index:

The word *eutrophication* comes from a Greek word meaning “well nourished.” This also describes the process in which a lake becomes enriched with nutrients. Over time, this is a lake’s natural aging process, as it slowly fills in with eroded materials from the surrounding watershed and with decaying plants. If no human impacts disturb the watershed or the lake, natural eutrophication can take thousands of years. However, human activities on a lake or in the watershed accelerate this process by resulting in rapid soil erosion and heavy phosphorus inputs. This accelerated aging process on a lake is referred to as cultural eutrophication. The term trophic state refers to the amount of nutrient enrichment within a lake system. *Oligotrophic* lakes are usually deep and clear with low nutrient levels, little plant growth and a limited fishery. *Mesotrophic* lakes are more biologically productive than oligotrophic lakes and have moderate nutrient levels and more plant growth. A lake labeled as *eutrophic* is high in nutrients and can support high plant densities and large fish populations. Water clarity is typically poorer than oligotrophic or mesotrophic lakes and dissolved oxygen problems may be present. A *hypereutrophic* lake has excessive nutrients, resulting in nuisance plant or algae growth. These lakes are often pea-soup green, with poor water clarity. Low dissolved oxygen may also be a problem, with fish kills occurring in shallow, hypereutrophic lakes more often than less enriched lakes. As a result, rough fish (tolerant of low dissolved oxygen levels) dominate the fish community of many hypereutrophic lakes. The categorization of a lake into a certain trophic state should not be viewed as a “good to bad” categorization, as most lake residents rate their lake based on desired usage. For example, a fisherman would consider a plant-dominated, clear lake to be desirable, while a water-skier might prefer a turbid lake devoid of plants. Most lakes in Lake County are eutrophic or hypereutrophic. This is primarily as a result of cultural eutrophication. However, due to the fertile soil in this area, many lakes (especially man-made) may have started out under eutrophic conditions and will never attain even mesotrophic conditions, regardless of any amount of money put into the management options. This is not an excuse to allow a lake to continue to deteriorate, but may serve as a reality check for lake owners attempting to create unrealistic conditions in their lakes.

The Trophic State Index (TSI) is an index which attaches a score to a lake based on its average total phosphorus concentration, its average Secchi depth (water transparency) and/or its average chlorophyll *a* concentration (which represent algae biomass). It is based on the principle that as phosphorus levels increase, chlorophyll *a* concentrations increase and Secchi depth decreases. The higher the TSI score, the more nutrient-rich a lake is, and once a score is obtained, the lake can then be designated as oligotrophic, mesotrophic or eutrophic. Table 1 (below) illustrates the Trophic State Index using phosphorus concentration and Secchi depth.

Table 1. Trophic State Index (TSI).

Trophic State	TSI score	Total Phosphorus (mg/L)	Secchi Depth (feet)
Oligotrophic	<40	≤ 0.012	>13.12
Mesotrophic	≥40<50	>0.012 ≤ 0.024	≥6.56<13.12
Eutrophic	≥50<70	>0.024 ≤ 0.096	≥1.64<6.56
Hypereutrophic	≥70	>0.096	< 1.64