Lake and Wetland Monitoring Program

2008 Annual Report

By

C. Edward Carney

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As the state's environmental protection and public health agency, KDHE promotes responsible choices to protect the health and environment for all Kansans.

Through education, direct services and the assessment of data and trends, coupled with policy development and enforcement, KDHE will improve health and quality of life. We prevent illness, injuries and foster a safe and sustainable environment for the people of Kansas.

Bureau of Environmental Field Services
Division of Environment
Kansas Department of Health & Environment

Executive Summary

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program surveyed the water quality conditions of 31 Kansas lakes and wetlands during 2008. Eight of the lakes surveyed are large federal impoundments, 13 are State Fishing Lakes (SFLs) or other water bodies on state managed lands, and 10 are city and county lakes. In addition, another 31 public lakes were surveyed as part of Use Attainability Analysis (UAA) work.

Of the 31 lakes and wetlands surveyed, 58% indicated trophic state conditions comparable to their mean period-of-record water quality conditions. Another 26% indicated improved water quality conditions, over mean period-of-record conditions, as evidenced by a lowered lake trophic state. The remaining 16% indicated degraded water quality, over past mean conditions, as evidenced by elevated lake trophic state conditions. Phosphorus was identified as the primary factor limiting phytoplankton growth in 52% of the lakes surveyed during 2008. Nitrogen was identified as the primary limiting factor in 29% of the lakes, while three lakes (9.7%) were identified as primarily light limited. The remaining lakes appeared limited by combinations of nutrients (nitrogen and phosphorus).

There were a total of 19 lakes surveyed in 2008 that had trophic state conditions elevated enough to cause impairment of one or more uses (61% of total surveyed). Of these, 14 lakes had trophic state conditions sufficient to create moderate-to-severe water quality problems (45% of total surveyed). Additional water quality criteria exceedences, related to heavy metals and pesticides, salinity, or other physicochemical conditions, were few in number during 2008.

Twenty lakes (67% of those surveyed for pesticides) had detectable levels of at least one pesticide in their main bodies during 2008. Atrazine, or its degradation byproducts, were detected in all 20 of these water bodies, once again making atrazine the most commonly documented pesticide in Kansas lakes. The highest observed atrazine concentration during lake and wetland sampling was 5.5 ug/L. A total of four different pesticides, and one pesticide degradation byproduct, were found in lakes during 2008.

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INTRODUCTION

Development of the Lake and Wetland Monitoring Program

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program was established in 1975 to fulfill the requirements of the 1972 Clean Water Act (Public Law 92-500) by providing Kansas with background water quality data for water supply and recreational impoundments, determining regional and time trends for those impoundments, and identifying pollution control and/or assessment needs within individual lake watersheds.

Program activities originally centered around a small sampling network comprised mostly of federal lakes, with sampling stations at numerous locations within each lake. In 1985, based on the results of statistical analyses conducted by KDHE, the number of stations per lake was reduced to a single integrator station within the main body of each impoundment. This, and the elimination of parameters with limited interpretive value, allowed expansion of the lake network to its present 121 sites scattered throughout all the major drainage basins and physiographic regions of Kansas. The network remains dynamic, with lakes occasionally being added to or dropped from active monitoring, or replaced with more appropriate sites throughout the state.

Overview of the 2008 Monitoring Activities

Staff of the KDHE Lake and Wetland Monitoring Program visited 31 Kansas lakes during 2008. Eight of these water bodies are large federal impoundments last sampled in 2005 or as part of special projects, 13 are State Fishing Lakes (SFLs) or lakes on other state managed lands, and 10 are city/county lakes (CLs and Co. lakes, respectively). Sixteen of the 31 lakes (52%) presently serve as either primary or back-up municipal or industrial water supplies. In addition to regular network surveys, 31 lake use attainability analyses (UAAs) were completed in 2008.

General information on the lakes surveyed during 2008 is compiled in Table 1. Figure 1 depicts the locations of the lakes surveyed in 2008. Figure 2 depicts the locations of all currently active sites within the Lake and Wetland Monitoring Program.

Artificial lakes are often termed “reservoirs” or “impoundments,” depending on whether they are used for drinking water supply or for other beneficial uses, respectively. In many parts of the country, smaller lakes are termed “ponds” based on arbitrary surface area criteria. To provide consistency, this report uses the term “lake” to describe all lentic, non-wetland, bodies of standing water within the state. The only exception to this is when more than one lake goes under the same general name. For example, the City of Herington has jurisdiction over two larger lakes. The older lake is referred to as Herington City Lake while the newer one is called Herington Reservoir in order to distinguish it from its sister waterbody. While it is recognized that the vast majority of lentic waters in Kansas are of artificial origin, use of the term "lake" also emphasizes that our artificial lentic waterbodies provide most (if not all) of the functions and beneficial societal uses supported by natural lakes. For a significant number of Kansas lakes, except for the presence of a constructed dam, there are more physical similarities to natural systems than differences (i.e., volume/depth ratio, point of discharge, watershed/lake area ratio, etc.).

METHODS

Yearly Selection of Monitored Sites

Since 1985, the 24 large federal lakes in Kansas have been arbitrarily partitioned into three groups of eight. Each group is normally sampled only once during a three year period of rotation. Around 25-to-30 smaller lakes are sampled each year in addition to that year's block of eight federal lakes. These smaller lakes are chosen based on three considerations: 1) Are there recent data available (within the last 3-4 years) from KDHE or other programs?; 2) Is the lake showing indications of pollution that require enhanced monitoring?; or 3) Have there been water quality assessment requests from other administrative or regulatory agencies (state, local, or federal)? Several lakes have been added to the network due to their relatively unimpacted watersheds. These lakes serve as ecoregional reference, or "least impacted," sites (Dodds et al., 2006).

Sampling Procedures

At each lake, a boat is anchored over the inundated stream channel near the dam. This point is referred to as Station 1, and represents the area of maximum depth. Duplicate water samples are taken by Kemmerer sample bottle at 0.5 meters below the surface for determination of basic inorganic chemistry (major cations and anions), algal community composition, chlorophyll-a, nutrients (ammonia, nitrate, nitrite, Kjeldahl nitrogen, total organic carbon, and total and ortho phosphorus), and total recoverable metals/metalloids (aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, vanadium, and zinc). Duplicate water samples are also taken at 0.5 to 1.0 meters above the lake substrate for determination of inorganic chemistry, nutrients, and metals/metalloids within the hypolimnion. In addition, a single pesticide sample, and duplicate *Escherichia coli* bacteria samples, are collected at 0.5 meters depth at the primary sampling point (KDHE, 2005).

At each lake, measurements are made at Station 1 for determination of temperature and dissolved oxygen profiles, field pH, photosynthetically active radiation (PAR) extinction, and Secchi disk depth. All samples are preserved and stored in the field in accordance with KDHE quality assurance/quality control protocols (KDHE, 2005). Field measurements, chlorophyll-a analyses, and algal taxonomic determinations are conducted by staff of KDHE's Bureau of Environmental Field Services. All other analyses are carried out by the KDHE Health and Environmental Laboratory (KHEL).

Table 1. General information pertaining to lakes surveyed during 2008.

Lake	Basin	Authority	Water Supply	Last Survey
Atchison Co. SFL	Missouri	State	no	2004
Bourbon Co. SFL	Marais des Cygnes	State	no	2004
Brown Co. SFL	Missouri	State	no	2004
Cheney Lake	Lower Arkansas	Federal	yes	2005
Council Grove City Lake	Neosho	City	yes	2005
Council Grove Lake	Neosho	Federal	yes	2005
Douglas Co. SFL	Kansas/Lower Republican	State	no	2002
El Dorado Lake	Walnut	Federal	yes	2005
Harvey Co. West Lake	Lower Arkansas	County	no	2004
Hillsdale Lake	Marais des Cygnes	Federal	yes	2005
John Redmond Lake	Neosho	Federal	yes	2005
Lake Afton	Lower Arkansas	City	no	2004
Lake Anthony	Lower Arkansas	City	no	2004
Lake Crawford	Marais des Cygnes	State	yes	2006
Lake Wabaunsee	Kansas/Lower Republican	City	yes	2004
Leavenworth Co. SFL	Kansas/Lower Republican	State	no	2004
Louisburg SFL	Marais des Cygnes	State	yes	2004
Marion Lake	Neosho	Federal	yes	2005
Melvern Lake	Marais des Cygnes	Federal	yes	2005
Mined Land Lake #44	Neosho	State	no	2004
Neosho Co. SFL	Neosho	State	no	2004

Lake	Basin	Authority	Water Supply	Last Survey
Osage Co. SFL	Marais des Cygnes	State	no	2004
Pomona Lake	Marais des Cygnes	Federal	yes	2005
Rock Creek Lake	Marais des Cygnes	City	yes	2004
Sheridan Co. SFL	Solomon	State	no	2004
Strowbridge Reservoir	Kansas/Lower Republican	City	yes	2004
Wellington City Lake	Lower Arkansas	City	yes	2005
Wilson Co. SFL	Verdigris	State	no	2004
Winfield City Lake	Walnut	City	yes	2005
Woodson Co. SFL	Verdigris	State	no	2005
Wyandotte Co. Lake	Missouri	County	no	2004

Since 1992, macrophyte surveys have been conducted at each of the smaller lakes (<250 acres) within the KDHE Lake and Wetland Monitoring Program network. These surveys entail the selection and survey of 10 to 20 sampling stations, depending on total surface area and lake morphometry, distributed in a regular pattern over the lake surface. At each sampling point, a grappling hook is cast to rake the bottom for submersed aquatic plants. This process, combined with visual observations, confirms the presence or absence of macrophytes at each station. If present, macrophyte species are identified and recorded on site. Specimens that cannot be identified in the field are placed in labeled plastic bags, on ice, and transported to the KDHE Topeka office. Presence/absence data, and taxon specific presence/absence data, are used to calculate spacial coverage (percent distribution) estimates for each lake (KDHE, 2005).

Taste and Odor/Algae Bloom Program

In 1989, KDHE initiated a formal Taste and Odor/Algae Bloom Technical Assistance Program. Technical assistance concerning taste and odor incidences in water supply lakes, or algae blooms in lakes and ponds, may take on varied forms. Investigations related to tastes and odors in finished drinking water are generally initiated at the request of water treatment plant personnel, or personnel at the KDHE district offices. While lakes used for public water supply are a primary focus, a wide variety of samples related to algae, odors, and fishkills, from both lakes and streams, are accepted for analysis. Complaint investigations, not related to taste and odor events in drinking water, may be initiated from a variety of sources, although the majority begin as complaints or concerns from the general public.

Figure 1. Locations of the 31 lakes surveyed during 2008.

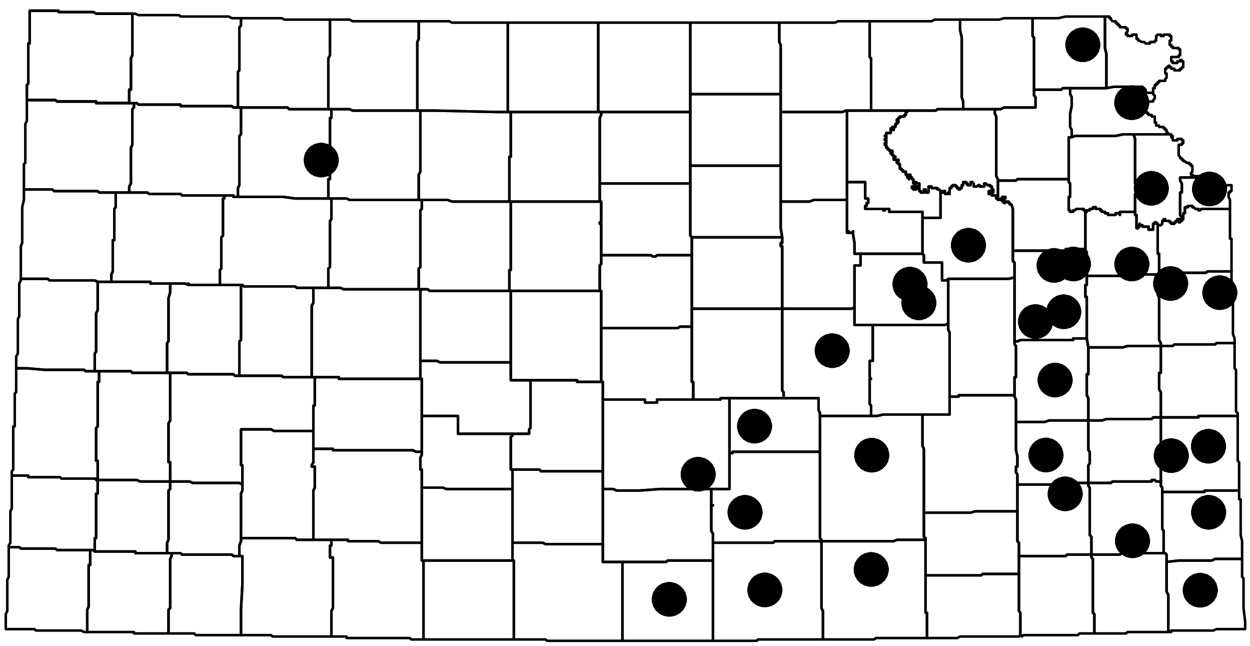
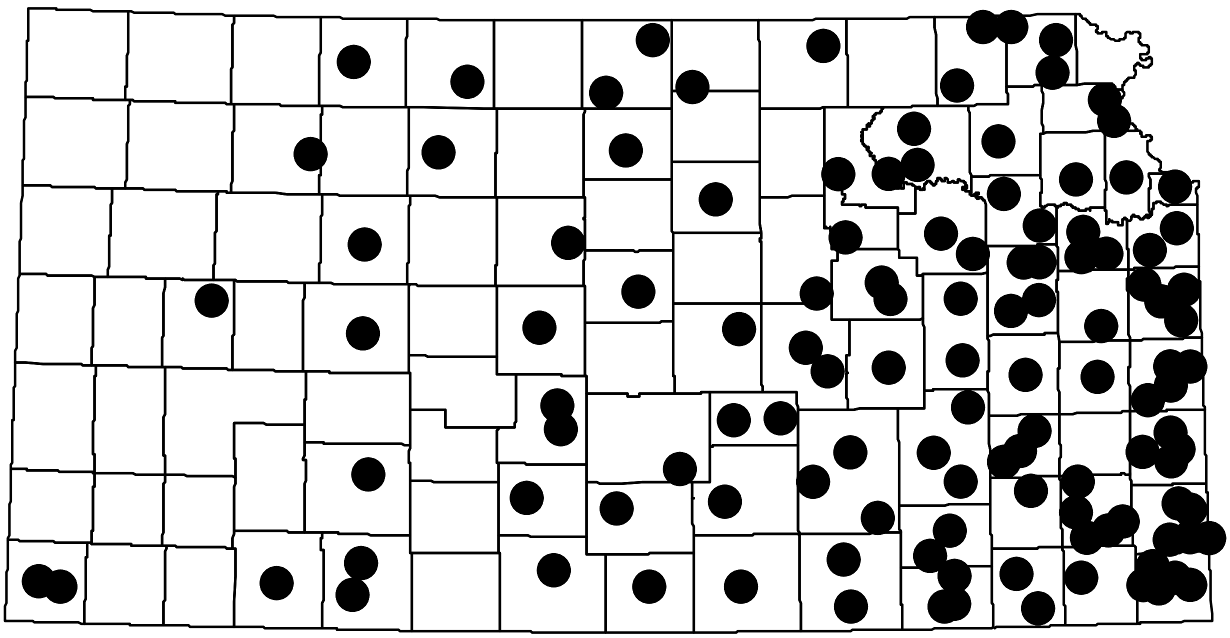


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program's network.



RESULTS AND DISCUSSION

Lake Trophic State

The Carlson Chlorophyll-a Trophic State Index (TSI) provides a useful tool for the comparison of lakes in regard to general ecological functioning and level of productivity (Carlson, 1977). Table 2 presents TSI scores for the 31 lakes surveyed during 2008, previous TSI mean scores for those lakes with past data, and an indication of the extent that lake productivity is dominated by submersed and floating-leaved vascular plant communities (macrophytes). Since chlorophyll-a TSI scores are based on the planktonic algae community, production due to macrophyte beds is not reflected in these scores. The system used to assign lake trophic state, based on TSI scores, is presented below. Trophic state classification is adjusted for macrophytes where percent areal cover (as estimated by percent presence) is greater than 50%, and visual bed volume and plant density clearly indicate that macrophyte productivity contributes significantly to overall lake primary production. Mean chlorophyll-a for the 2008 surveys was 21.0 ug/L (very eutrophic), while the median chlorophyll-a was 10.9 ug/L (slightly eutrophic).

TSI score of 0-39 = oligo-mesotrophic (OM)

> OM = A lake with a low level of planktonic algae. Such lakes also lack significant amounts of suspended clay particles in the water column, giving them a relatively high level of water clarity. These lakes often have robust submersed macrophyte communities. Chlorophyll-a concentration averages no more than 2.50 ug/L.

TSI score of 40-49 = mesotrophic (M)

> M = A lake with only a moderate planktonic algal community. Water clarity remains relatively high. Chlorophyll-a ranges from 2.51 to 7.20 ug/L.

TSI score of 50-63 = eutrophic (E)

> E = A lake with a moderate-to-large algae community. Chlorophyll-a ranges from 7.21 to 29.99 ug/L. This category is further divided as follows:

TSI = 50-54 = slightly eutrophic (SE)	Chlorophyll-a ranges 7.21 to 11.99 ug/L,
TSI = 55-59 = fully eutrophic (E)	Chlorophyll-a ranges 12.00 to 19.99 ug/L,
TSI = 60-63 = very eutrophic (VE)	Chlorophyll-a ranges 20.00 to 29.99 ug/L.

TSI score of $\geq$64 = hypereutrophic (H)

> H = A lake with a very large phytoplankton community. Chlorophyll-a averages more

than 30.0 ug/L.   This category is further divided as follows:

TSI = 64-69.9 = lower hypereutrophic	Chlorophyll-a ranges 30.00 to 55.99 ug/L,
TSI = $\geq$70 = upper hypereutrophic	Chlorophyll-a values $\geq$56.00 ug/L.

TSI score not relevant = argillotrophic (A)

A = In a number of Kansas lakes, high turbidity due to suspended clay particles restricts the development of a phytoplankton community. In such cases, nutrient availability remains high, but is not fully translated into algal productivity or biomass due to light limitation. Lakes with such high turbidity and nutrient levels, but lower than expected algal biomass, are called argillotrophic (Naumann, 1929) rather than oligo-mesotrophic, mesotrophic, etc. These lakes may have chronically high turbidity, or they may experience sporadic (but frequent) episodes of dis-equilibrium following storm events that create "over flows" of turbid runoff on the lake surface. Frequent wind resuspension of sediments, as well as benthic feeding fish communities (e.g., common carp), can create these conditions as well. Argillotrophic lakes also tend to have very small, or nonexistent, submersed macrophyte communities. Mean chlorophyll-a concentration does not exceed 7.2 ug/L as a general rule.

All Carlson chlorophyll TSI scores are calculated by the following formula, where C is the phaeophytin corrected chlorophyll-a level in ug/L (Carlson, 1977):

$$TSI = 10(6-(2.04-0.68\log_e(C))/\log_e(2)).$$

The composition of the algal community (structural feature) often gives a better ecological picture of a lake than relying solely on a trophic state classification (functional feature). Table 3 presents both total algal cell count and percent composition of several major algal groups for the lakes surveyed in 2008. Lakes in Kansas that are nutrient enriched tend to be dominated by green or blue-green algae, while those dominated by diatom communities may not be so enriched. Certain species of green, blue-green, diatom, or dinoflagellate algae may contribute to taste and odor problems in finished drinking water, when present in large numbers in water supply lakes and streams. The mean algal cell count among the 31 lakes this year was 56,895 cells/mL (median = 8,064 cells/mL).

Table 4 presents biovolume data for the 31 lakes surveyed in 2008. When considered along with cell counts, biovolume data are useful in determining which algae species or algae groups actually exert the strongest ecological influence on a lake. The mean algal biovolume among lakes this year was 17.13 ppm (median = 5.93 ppm).

Table 2.	Current and past TSI scores, and trophic state classification for the lakes surveyed

during 2008. Trophic class abbreviations used previously apply. An asterisk appearing after the lake name indicates that the lake was dominated, at least in part, by macrophyte production. In such a case, the trophic class is adjusted, and the adjusted trophic state class given in parentheses. Previous TSI scores are based only on algal chlorophyll TSI scores.

Lake	2008 TSI/Class	Previous Trophic Class Period-of-Record Mean
Atchison Co. SFL*	72.8 H(H)	H
Bourbon Co. SFL	60.8 VE	E
Brown Co. SFL*	76.7 H(H)	H
Cheney Lake	56.2 E	A
Council Grove City Lake	47.2 M	SE
Council Grove Lake	43.7 A	A
Douglas Co. SFL	42.9 M	VE
El Dorado Lake	68.1 H	A
Harvey Co. West Lake	70.4 H	H
Hillsdale Lake	58.5 E	E
John Redmond Lake	49.3 A	E
Lake Afton	52.6 SE	VE
Lake Anthony	48.5 A	VE
Lake Crawford	55.4 E	E
Lake Wabaunsee	52.7 SE	SE
Leavenworth Co. SFL	50.9 SE	E
Louisburg SFL	58.5 E	E
Marion Lake	65.9 H	E
Melvern Lake	47.2 M	SE
Mined Land Lake #44	51.0 SE	SE
Neosho Co. SFL	70.9 H	H
Osage Co. SFL	51.7 SE	SE
Pomona Lake	49.0 A	A

Lake	2008 TSI/Class	Previous Trophic Class Period-of-Record Mean
Rock Creek Lake	61.2 VE	E
Sheridan Co. SFL	54.4 SE	VE
Strowbridge Reservoir	59.4 E	E
Wellington City Lake	44.0 A	A
Wilson Co. SFL	61.6 VE	E
Winfield City Lake	54.0 SE	SE
Woodson Co. SFL	47.6 M	M
Wyandotte Co. Lake	43.9 M	SE

Trends in Trophic State

Table 5 summarizes changes in trophic status for the 31 lakes surveyed during 2008. Five lakes (16.2%) displayed increases in trophic state, compared to their historic mean condition, while eight lakes (25.8%) displayed improved trophic states. Stable conditions were noted in 18 lakes (58.0%).

When lakes deviated from a past argillotrophic mean status, the trophic state was compared against the eutrophic class, which is similar to the approach for determining impairments due to argillotrophic conditions.

Only two lakes (Atchison Co. SFL and Brown Co. SFL) had macrophyte communities dense enough to consider the need for an adjustment of trophic state designation. In both cases, no adjustment was performed as both lakes were already classed as hypereutrophic based on phytoplankton levels.

Table 3. Algal communities observed in the 31 lakes surveyed during 2008. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled, flagellated, groups of algae.

Lake	Cell Count (cells/mL)	Percent Composition			
		Green	**Blue-Green**	**Diatom**	**Other**
Atchison Co. SFL	306,621	<1	99	<1	0
Bourbon Co. SFL	58,275	3	93	3	<1
Brown Co. SFL	400,050	0	100	0	0
Cheney Lake	23,279	5	91	<2	2
Council Grove City Lake	8,001	15	82	1	2
Council Grove Lake	2,111	35	34	21	10
Douglas Co. SFL	8,064	7	93	0	0
El Dorado Lake	4,820	2	36	0	62
Harvey Co. West Lake	347,288	7	93	<1	<1
Hillsdale Lake	37,863	<2	94	4	0
John Redmond Lake	5,387	4	69	27	0
Lake Afton	1,985	63	0	32	5
Lake Anthony	4,410	76	0	14	10
Lake Crawford	10,962	31	67	0	2
Lake Wabaunsee	10,836	34	62	<2	<2
Leavenworth Co. SFL	3,024	48	0	34	18
Louisburg SFL	48,636	0	>99	0	<1
Marion Lake	60,921	<1	92	7	1
Melvern Lake	1,071	12	59	12	17
Mined Land Lake #44	1,512	6	0	21	73
Neosho Co. SFL	286,146	1	99	<1	<1
Osage Co. SFL	7,592	5	93	0	2

	Cell Count	Percent Composition			
Pomona Lake	9,167	8	83	7	<2
Rock Creek Lake	28,130	22	64	11	3
Sheridan Co. SFL	2,615	0	0	36	64
Lake	**(cells/mL)**	**Green**	**Blue-Green**	**Diatom**	**Other**
Strowbridge Reservoir	14,585	2	81	16	1
Wellington City Lake	4,725	92	0	0	8
Wilson Co. SFL	51,755	<2	98	0	<1
Winfield City Lake	5,796	18	76	0	6
Woodson Co. SFL	6,647	10	85	<3	<3
Wyandotte Co. Lake	1,481	0	43	0	57

Of the 10 lakes receiving macrophyte surveys (two full surveys and eight limited observational surveys), three (30% of those surveyed, 10% of all lakes in 2008) had detectable amounts of submersed plant material (Table 6). In these lakes, the most common plant species were pondweeds (*Potamogeton spp.*), water naiad (*Najas guadalupensis*), and coontail (*Ceratophyllum demersum*). Eurasian water milfoil (*Myriophyllum spicatum*), and various species of stonewort algae (*Chara* and *Nitella spp.*), although typically common throughout the state, were not observed during 2008's constrained macrophyte survey activity.

The 2008 season presented a number of difficulties which, although often experienced separately, are seldom dealt with in combination. Specifically, six additional lakes had been planned for macrophyte surveys, but combinations of high winds, lake maintenance activities, and persistent outboard motor problems resulted in the decision to forego this work. In seven other instances, these same difficulties restricted the level of macrophyte survey work to limited shoreline surveys..

Using trophic state data for macrophytes in the literature (Schneider and Melzer, 2003; Lehmann and LaChavanne, 1999; Sladecek, 1973), combined with observed abundance of aquatic plants during 2008, two water bodies appeared to merit further assessment of the macrophyte community trophic classification. Both were assessed as very eutrophic communities (Atchison and Brown Co. SFLs), based on only the macrophyte community data. Neither lake merited adjustment of their overall trophic classification, as both of these lakes were classed as hypereutrophic based on phytoplankton levels (Table 2).

Table 4. Algal biovolumes calculated for the lakes surveyed during 2008. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled, flagellated, forms of algae. Biovolume units are calculated in mm^3/L, and expressed as parts-per-million (ppm).

Lake	**Biovolume (ppm)**	**Percent Composition**			
		Green	**Blue-Green**	**Diatom**	**Other**
Atchison Co. SFL	71.521	1	91	8	0
Bourbon Co. SFL	15.147	2	87	9	<2
Brown Co. SFL	122.430	0	100	0	0
Cheney Lake	8.232	3	51	22	24
Council Grove City Lake	3.593	7	82	1	10
Council Grove Lake	1.255	17	13	44	26
Douglas Co. SFL	1.575	7	93	0	0
El Dorado Lake	40.495	<1	<1	0	99
Harvey Co. West Lake	52.999	17	73	2	8
Hillsdale Lake	10.927	1	64	35	0
John Redmond Lake	3.532	2	21	77	0
Lake Afton	5.316	11	0	85	4
Lake Anthony	3.310	39	0	35	26
Lake Crawford	7.291	9	82	0	9
Lake Wabaunsee	4.959	15	67	9	9
Leavenworth Co. SFL	4.085	7	0	60	33
Louisburg SFL	10.305	0	94	0	6
Marion Lake	29.814	<1	37	57	6
Melvern Lake	3.205	1	4	28	67

Lake	Biovolume (ppm)	Percent Composition Green	Blue-Green	Diatom	Other
Mined Land Lake #44	4.054	<1	0	5	95
Neosho Co. SFL	57.136	1	96	<1	2
Osage Co. SFL	4.516	3	29	0	68
Pomona Lake	3.630	6	41	46	7
Rock Creek Lake	15.806	20	22	31	27
Sheridan Co. SFL	6.386	0	0	18	82
Strowbridge Reservoir	12.089	1	29	68	2
Wellington City Lake	1.532	61	0	0	39
Wilson Co. SFL	16.494	3	91	0	6
Winfield City Lake	5.925	3	15	0	82
Woodson Co. SFL	2.609	5	68	4	23
Wyandotte Co. Lake	0.920	0	11	0	89

Table 5. Trends over time in trophic state classification, based on comparisons to mean historic condition.

Change in Trophic State Class Compared to Historic Mean*	Number of Lakes	Percent Total
Improved ≥ Two Class Rankings	3	9.7
Improved One Class Ranking	5	16.1
Stable	18	58.0
Degraded One Class Ranking	3	9.7
Degraded ≥ Two Class Rankings	2	6.5
Total	31	100.0

* = Five of these lakes (Cheney Lake, Council Grove Lake, El Dorado Lake, Pomona Lake, and Wellington City Lake) had historic mean trophic state classifications of argillotrophic. In such cases, the presently observed trophic class is compared to the eutrophic class, which is similar to the assessment protocol for nutrient related impairments for argillotrophic systems.

Table 6. Macrophyte community structure in the 10 lakes surveyed for macrophytes during 2008. Macrophyte community refers only to the submersed and floating-leaved aquatic plants, not emergent shoreline plants. The percent areal cover is the abundance estimate for each documented species based on frequency of detection. An asterisk following the lake name indicates that only a limited shoreline survey was conducted. (Note: due to overlap in cover, the percentages under community composition may not equal the total cover.)

Lake	**% Total Cover**	**% Species Cover and Community Composition**
Atchison Co. SFL	60%	60% *Ceratophyllum demersum* 53% *Potamogeton crispus* 27% *Potamogeton pectinatus* 7% *Najas guadalupensis* 7% *Potamogeton nodosus*
Bourbon Co. SFL*	10%	10% *Najas guadalupensis*
Brown Co. SFL	67%	40% *Potamogeton pectinatus* 33% *Ceratophyllum demersum* 20% *Najas guadalupensis* 20% *Nelumbo sp.* 20% *Potamogeton crispus* 13% *Potamogeton nodosus*
Harvey Co. West Lake*	<10%	No species observed
Lake Afton*	<5%	No species observed
Lake Anthony*	<7%	No species observed
Neosho Co. SFL*	<10%	No species observed
Rock Creek Lake*	<10%	No species observed
Sheridan Co. SFL*	<10%	No species observed
Woodson Co. SFL*	<10%	No species observed

None of the lakes surveyed in 2008 appeared to have experienced algal limitation due to macrophyte community influences. In general, Kansas lakes are impaired more by a lack of macrophyte habitat than by an overabundance of aquatic plants. Presence of a robust and diverse macrophyte community normally reflects lower levels of human impact in our lakes. However, some species (*Ceratophyllum demersum*, *Potamogeton crispus*, or *Myriophyllum spicatum*) may attain nuisance proportions as a result of human activities. Dominance by other species that are native, or at least benign naturalized species (*Najas guadalupensis*, other *Potamogeton spp.*, or *Chara/Nitella spp.*), generally implies a higher level of ecosystem health.

It should be noted that the method utilized in KDHE surveys does not measure bed density in a quantitative manner. Even with fairly high percent presence values, it is rare for bed densities to approach any threshold that would be identified as an impairment. None of the lakes surveyed in 2008 supported bed densities capable of exerting a negative influence on any beneficial lake use.

<u>Lake Stratification and Water Clarity</u>

Stratification is a natural process that may occur in any standing (lentic) body of water, whether that body is a natural lake, pond, artificial reservoir, or wetland pool (Wetzel, 1983). It occurs when sunlight (solar energy) penetrates into the water column. Due to the thermal properties of water, high levels of sunlight (helped by periods of calm winds during the spring-to-summer months) cause layers of water to form with differing temperatures and densities. The cooler, denser layer (the hypolimnion) remains near the bottom of the lake while the upper layer (the epilimnion) develops a higher ambient temperature. The middle layer (the metalimnion) displays a marked drop in temperature with depth (the thermocline), compared to conditions within the epilimnion and hypolimnion. Once these layers of water with differing temperatures form, they tend to remain stable and do not easily mix with one another. This formation of distinct layers impedes, or precludes, the atmospheric reaeration of the hypolimnion, at least for the duration of the summer (or until ambient conditions force mixing). In many cases, this causes hypolimnetic waters to become depleted of oxygen and unavailable as habitat for fish and some other forms of aquatic life. Stratification eventually breaks down in the fall when surface waters cool. Once epilimnetic waters cool to temperatures comparable to hypolimnetic waters, the lake will mix completely once again. Typically occurring in the fall, and sometimes within only 1 to 2 days, this phenomenon is called "lake turnover." Table 7 presents data related to thermal stratification in the 31 lakes surveyed in 2008 while Table 8 presents data related to water clarity and the light environment within the water column.

Lake turnover can cause fishkills, aesthetic problems, and taste and odor problems in finished drinking water if the hypolimnion comprises a significant volume of the lake. This is because such a sudden mixing combines oxygen-poor, nutrient-rich, hypolimnetic water with epilimnetic water lower in nutrients and richer in dissolved oxygen. Lake turnover can result in temporary accelerated algal growth, lowering of overall lake oxygen levels, and sudden fishkills. It also often imparts objectionable odors to the lake water and tastes and odors to finished drinking water produced from the lake. Thus, the stratification process is an important consideration in lake management.

The "enrichment" of hypolimnetic waters (with nutrients, metals, and other pollutants) during stratification results from the entrapment of materials that sink down from above, as well as materials that are released from lake sediments due to anoxic conditions. The proportion of each depends on the strength and duration of stratification, existing sediment quality, and inflow of materials from the watershed. For the majority of the larger lakes in Kansas, built on major rivers with dependable flow, stratification tends to be intermittent (polymictic), or missing, and the volume of the hypolimnion tends to be small in proportion to total lake volume. These conditions tend to lessen the importance of sediment re-release of pollutants in the largest Kansas lakes, leaving watershed pollutant inputs as the primary cause of water quality problems.

Presence or absence of stratification is determined by depth profile measurements for temperature and dissolved oxygen concentration taken in each lake. Table 7 presents these data. Mean temperature decline rates (for the entire water column) greater than 1.0 ^{o}C/m are considered evidence of stronger thermal stratification, although temperature changes may be less pronounced during the initiation phase of stratification. Lakes with strong thermal stratification will be more resistant to mixing of the entire water column pending the cooling of epilimnetic waters in autumn.

The temperature decline rate, however, must also be considered in relation to the particular lake and the shape of the plotted temperature-to-depth relationship. The sharper the discontinuity in the data plot, the stronger the level of thermal stratification. Gradual declines in temperature with depth, through the entire water column, and indistinct discontinuities in data plots are more indicative of weaker thermal stratification. The strength of the oxycline, based on water column dissolved oxygen decline rate and the shape of the data plot, is also used to characterize stratification in lakes. A strong oxycline might be seen by mid-summer in lakes with weak thermal stratification, if the lakes are not prone to wind mixing, or even in the case of dense macrophyte beds in shallow unstratified lakes. In lakes with dense macrophyte beds, dissolved oxygen may be very high in the overlying water on a sunny day but decline to almost zero just beneath the canopy.

Euphotic depth, or the depth to which light sufficient for photosynthesis penetrates the water column, can be calculated from relationships derived from Secchi depth and chlorophyll-a data (Scheffer, 1998). This report presents the ratio of calculated euphotic depth to calculated mixing depth. Mixing depth is the maximum depth to which wind circulation (and thermal stratification) should reach typically. The metric supplies a means to interpret light and production relationships in a lake, provided other factors, such as depth and thermal stratification, are also considered simultaneously. For instance, a very high ratio may mean a lake is exceptionally clear, or may mean it is very shallow and well mixed. A very low value likely means the lake is light limited due to inorganic turbidity or self-shaded due to high algal biomass near the surface.

Table 7. Stratification status of the 31 water bodies surveyed during 2008. The term "n.a." indicates that boat access, wind conditions or other threatening weather, shallowness, or equipment problems prevented the collection of profile data or made said collection superfluous.

ke	Date Sampled (M-D-Yr)	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)	Comments
chison Co. SFL	06-30-2008	1.55	1.16	3.0-4.0	10.0	
urbon Co. SFL	08-11-2008	1.11	0.80	4.0-6.0	10.0	
own Co. SFL	08-04-2008	1.13	2.43	2.0-3.0	4.5	
eney Lake	08-25-2008	n.a.	n.a.	unknown	12.0	wind
uncil Grove City Lake	06-16-2008	n.a.	n.a.	unknown	12.5	wind and storms
uncil Grove Lake	06-16-2008	0.17	0.47	not stratified	10.0	
uglas Co. SFL	07-15-2008	n.a.	n.a.	unknown	10.0	wind and boat motor
Dorado Lake	08-25-2008	n.a.	n.a.	unknown	15.5	wind
rvey Co. West Lake	06-23-2008	n.a.	n.a.	not stratified	2.0	shallow
lsdale Lake	07-31-2008	0.42	0.52	8.0-9.0	14.0	
n Redmond	07-28-2008	n.a.	n.a.	not stratified	2.5	wind
ke Afton	07-21-2008	n.a.	n.a.	unknown	6.0	wind and boat motor
ke Anthony	07-21-2008	n.a.	n.a.	not stratified	3.5	wind and boat motor
ke Crawford	08-11-2008	n.a.	n.a.	unknown	13.0	wind and boat motor

ke	Date Sampled (M-D-Yr)	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)	Comments
ke Wabaunsee	07-09-2008	0.77	0.72	5.0-7.0	11.5	
avenworth Co. SFL	07-15-2008	n.a.	n.a.	unknown	14.0	wind and boat motor
uisburg SFL	08-25-2008	n.a.	n.a.	unknown	6.5	boat motor
rion Lake	07-30-2008	n.a.	n.a.	unknown	8.5	wind
elvern Lake	07-28-2008	n.a.	n.a.	unknown	15.0	wind
ned Land Lake #44	08-11-2008	n.a.	n.a.	unknown	13.5	boat motor
osho Co. SFL	08-11-2008	n.a.	n.a.	unknown	8.0	storms and boat moto
age Co. SFL	06-17-2008	1.10	0.86	4.0-6.0	11.0	
mona Lake	07-28-2008	n.a.	n.a.	unknown	15.0	wind
ck Creek Lake	08-11-2008	n.a.	n.a.	unknown	5.0	boat ramp not useable
eridan Co. SFL	07-07-2008	1.10	1.56	2.0-3.0	5.0	
owbridge Reservoir	06-17-2008	0.19	1.01	4.0-6.0	9.0	
ellington City Lake	07-21-2008	n.a.	n.a.	unknown	5.0	wind and boat motor
lson Co. SFL	07-16-2008	n.a.	n.a.	unknown	12.0	wind and boat motor
nfield City Lake	08-25-2008	n.a.	n.a.	unknown	12.5	wind
oodson Co. SFL	08-25-2008	n.a.	n.a.	unknown	14.0	wind and boat motor
yandotte Co. Lake	08-05-2008	1.30	0.51	5.0-7.0	16.0	

Note: There were a number of lakes in 2008 which had their profile data collection omitted for various reasons including windy conditions, lightning in the vicinity, or mechanical problems. In a novel turn, Rock Creek Lake could not be safely accessed due to aggressive bee colonies at the boat ramp.

The calculated euphotic-to-mixed depth ratios suggest that light penetrated throughout the mixed zone in about half of the 31 lakes surveyed in 2008 (mean ratio = 0.93, median ratio = 1.03). This indicates that most of these lakes are not expected to have significant light limitation concerns as sunlight can reach essentially throughout the epilimnion. This is also borne out by Secchi depth and calculated non-algal turbidity data (Secchi depth: mean = 115 cm, median = 105 cm; non-algal turbidity: mean = 0.79 m^{-1}, median = 0.47 m^{-1}) (see Walker, 1986). Table 8 presents water clarity data for the lakes sampled in 2008.

Table 8. Water clarity metrics for the 31 lakes surveyed in 2008. See the section on limiting factors for a more detailed description of non-algal turbidity and its application in lake assessment.

Lake	**Chlorophyll-a (ug/L)**	**Secchi Disk Depth (cm)**	**Non-Algal Turbidity (m^{-1})**	**Euphotic to Mixed Depth Ratio**
Atchison Co. SFL	73.90	82	<0.001	0.53
Bourbon Co. SFL	21.80	166	0.057	0.95
Brown Co. SFL	110.00	118	<0.001	0.85
Cheney Lake	13.60	76	0.976	0.64
Council Grove City Lake	5.45	240	0.280	1.10
Council Grove Lake	3.80	41	2.344	0.56
Douglas Co. SFL	3.50	223	0.361	1.27
El Dorado Lake	46.05	59	0.544	0.38
Harvey Co. West Lake	58.15	61	0.186	3.11
Hillsdale Lake	17.30	143	0.267	0.66
John Redmond Lake	6.75	49	1.872	3.37
Lake Afton	9.45	44	2.036	0.97
Lake Anthony	6.25	29	3.292	1.31
Lake Crawford	12.60	139	0.404	0.87
Lake Wabaunsee	9.55	193	0.279	1.04
Leavenworth Co. SFL	7.95	178	0.363	0.95
Louisburg SFL	17.20	67	1.063	1.03
Marion Lake	36.70	54	0.934	0.61
Melvern Lake	5.45	157	0.501	0.75
Mined Land Lake #44	8.00	150	0.467	0.65
Neosho Co. SFL	61.10	66	<0.001	0.63
Osage Co. SFL	8.65	182	0.333	1.07
Pomona Lake	6.55	69	1.286	0.56

Lake	Chlorophyll-a (ug/L)	Secchi Disk Depth (cm)	Non-Algal Turbidity (m^{-1})	Euphotic to Mixed Depth Ratio
Rock Creek Lake	22.65	59	1.129	1.16
Sheridan Co. SFL	11.35	105	0.669	1.59
Strowbridge Reservoir	18.90	101	0.518	0.93
Wellington City Lake	3.95	36	2.679	0.80
Wilson Co. SFL	23.75	108	0.332	0.76
Winfield City Lake	10.85	114	0.606	0.86
Woodson Co. SFL	5.65	172	0.440	0.97
Wyandotte Co. Lake	3.90	292	0.245	1.03

Fecal Indicator Bacteria

Since 1996, bacterial sampling has taken place at the primary water quality sampling station at each lake monitored by KDHE. For several years prior to 1996, sampling took place at swimming beaches or boat ramp access areas. While many Kansas lakes have swimming beaches, many others do not. However, presence or absence of a swimming beach does not determine whether or not a lake supports primary contact recreational use. Primary contact recreation is defined as "recreation during which the body is immersed in surface water to the extent that some inadvertent ingestion of water is probable" (KDHE, 2005b), which includes swimming, water skiing, wind surfing, jet skiing, diving, boating, and other similar activities. The majority of Kansas lakes have some form of primary contact recreation taking place during the warmer half of the year. Also, sampling of swimming beaches is often conducted by lake managers to document water quality where people are concentrated in a small area on specific days. These managers are in the best position to collect samples frequently enough to determine compliance with applicable regulations at these swimming beaches (KDHE, 2005b).

Given the rapid die-off of fecal bacteria in the aquatic environment, due to protozoan predation and a generally hostile set of environmental conditions, high bacterial counts should only occur in the open water of a lake if there has been 1) a recent pollution event, or 2) a chronic input of bacteria-laced pollution. For the purposes of this report, a single set of bacterial samples collected from the open, deep water, environment is considered representative of whole-lake bacterial water quality at the time of the survey. This environment is less prone to short-lived fluctuations in bacterial counts (expressed as colony forming units, or "cfu," per 100 mL of water) than swimming beaches and other shoreline areas.

Table 9 presents the bacterial data collected during the 2008 sampling season. Seven of the 30 lakes surveyed for *E. coli* bacteria in 2008 (23%) had measurable levels of *E. coli* (i.e., greater than the analytical reporting limit of 10 cfu/100mL). Although no lake in 2008 exceeded existing criteria (KDHE, 2005b), one lake had *E. coli* counts of >100 cfu/100mL. This higher count was likely attributable to wind resuspension of shoreline sediments (Lake Anthony). The mean *E. coli* count among these 30 lakes ranged between 20 and 29 cfu/100mL (assuming the non-detects were assigned either zero values or the reporting limit, respectively), whereas the median value was <10 cfu/100mL.

Table 9. *E. coli* bacterial counts (mean of duplicate samples) from the lakes surveyed for *E. coli* bacteria during 2008. Note: These samples were collected during the week, not during weekends when recreational activity would be at peak levels. All units are in "number of cfu/100mL of lake water."

Lake	Site Location	*E. Coli* Count
Atchison Co. SFL	open water	26
Bourbon Co. SFL	open water	31
Brown Co. SFL	open water	<10
Cheney Lake	off pier near dam	<10
Council Grove City Lake	off dam	<10
Council Grove Lake	open water	<10
Douglas Co. SFL	off pier near dam	<10
El Dorado Lake	off pier near dam	<10
Harvey Co. West Lake	off pier	<10
Hillsdale Lake	open water	<10
John Redmond	off pier near dam	<15
Lake Afton	off dam	<10
Lake Anthony	off dam	295
Lake Crawford	samples not collected	samples not collected
Lake Wabaunsee	open water	<10
Leavenworth Co. SFL	off pier near dam	<10
Louisburg SFL	off pier near dam	<10
Marion Lake	off pier near dam	75

Lake	Site Location	*E. Coli* Count
Melvern Lake	off pier near dam	<10
Mined Land Lake #44	off dam	<15
Neosho Co. SFL	off pier near dam	81
Osage Co. SFL	open water	<10
Pomona Lake	off pier near dam	<10
Rock Creek Lake	off pier near dam	92
Sheridan Co. SFL	open water	<15
Strowbridge Reservoir	open water	<15
Wellington City Lake	off pier near dam	10
Wilson Co. SFL	off pier near dam	<10
Winfield City Lake	off pier near dam	<10
Woodson Co. SFL	off dam	<10
Wyandotte Co. Lake	open water	<10

Limiting Nutrients and Physical Parameters

The determination of which nutrient, or physical characteristic, "limits" phytoplankton production is of primary importance in lake management. If certain features can be shown to exert exceptional influence on lake water quality, those features can be addressed in lake protection plans to a greater degree than less important factors. In this way, lake management can be made more efficient.

Common factors that limit algal production in lakes are the level of available nutrients (phosphorus and nitrogen, primarily) and the amount of light available in the water column for photosynthesis. Less common limiting factors in lakes, and other lentic water bodies, include available levels of carbon, iron, and certain trace elements (such as molybdenum or vitamins), as well as grazing pressure on the phytoplankton community, competition from macrophytes and/or periphyton, water temperature, and hydrologic flushing rate.

Nutrient ratios are commonly considered in determining which major plant nutrients are limiting factors in lakes. These ratios take into account the relative needs of algae for the different chemical elements versus availability in the environment. Typically, total nitrogen/total phosphorus (TN/TP) mass ratios above 12 indicate increasing phosphorus limitation, with phosphorus limitation fairly certain at ratios above 18. Conversely, TN/TP ratios of less than 10 indicate increasing importance of nitrogen. Ratios of 10-to-12 generally indicate that both nutrients, or neither, may limit algal production (Wetzel, 1983; Horne and Goldman, 1994). It should also be kept in mind, when evaluating limiting factors, that very turbid lakes typically have lower nutrient ratios (due to elevation of phosphorus concentration, relative to nitrogen, in suspended clay particles) but may still experience phosphorus limitation due to biological availability (e.g., particle adsorption) issues (Jones and Knowlton, 1993).

Table 10 presents limiting factor determinations for the lakes surveyed during 2008. These determinations reflect the time of sampling (chosen to reflect average conditions during the summer growing season to the extent possible) and may be less applicable to other times of the year. Conditions during one survey may also differ significantly from conditions during past surveys, despite efforts to sample during representative summer weather conditions. If such a situation is suspected, it is noted in Table 10 or elsewhere in this report.

As indicated in Table 10, phosphorus was the primary limiting factor identified for lakes surveyed in 2008. Sixteen of the 31 lakes (51.6%) were determined to be primarily limited by phosphorus. Nine lakes (29.0%) were determined to be primarily nitrogen limited. Three lakes were primarily light limited in the 2008 season (9.7%), and another five (16.1%) indicated some secondary level of influence with respect to light availability. Another three lakes (9.7%) were co-limited by phosphorus and nitrogen. Mean TN/TP ratio was 19.5 for the lakes surveyed in 2008 (median = 15.8). Interquartile ranges for TN/TP ratios were 19.2-to-27.5 for phosphorus limited lakes, 7.8-to-10.7 for nitrogen limited lakes, and 11.8-to-14.4 for lakes co-limited by phosphorus and nitrogen.

Table 10a. Limiting factor determinations for the 31 lakes surveyed during 2008. NAT = non-algal turbidity, TN/TP = nitrogen-to-phosphorus ratio, Z_{mix} = depth of mixed layer, Chl-a = chlorophyll-a, and SD = Secchi depth. N = nitrogen, P = phosphorus, C = carbon, and L = light. Shading = calculated light attenuation coefficient times mean lake depth.

Lake	**TN/TP**	**NAT**	**Z_{mix}*NAT**	**Chl-a*SD**	**Chl-a/TP**	**Z_{mix}/SD**	**Shading**	**Factors**
Atchison Co. SFL	25.6	<0.010	<0.010	60.60	1.164	4.184	8.81	P
Bourbon Co. SFL	18.8	0.057	0.197	36.19	0.681	2.067	4.95	P
Brown Co. SFL	9.1	<0.010	<0.010	129.80	0.550	1.580	5.48	N
Cheney Lake	11.1	0.976	4.378	10.34	0.179	5.904	7.93	N=L
Council Grove City Lake	25.9	0.280	1.092	13.08	0.279	1.622	4.38	P
Council Grove Lake	6.7	2.344	9.848	1.56	0.025	10.247	8.85	L
Douglas Co. SFL	53.0	0.361	1.238	7.81	0.350	1.538	3.70	P
El Dorado Lake	10.7	0.544	2.902	27.17	0.439	9.049	14.69	N
Harvey Co. West Lake	14.4	0.186	0.112	35.47	0.447	0.985	1.92	P=N
Hillsdale Lake	69.5	0.267	1.334	24.74	1.730	3.496	8.01	P
John Redmond	5.3	1.872	1.397	3.31	0.045	1.523	1.66	N>L
Lake Afton	4.2	2.036	4.897	4.16	0.045	5.465	4.73	N=L

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Lake Anthony	4.7	3.292	4.693	1.81	0.019	4.916	3.67	L
Lake Crawford	17.4	0.404	1.607	17.51	0.365	2.859	5.54	P>N
Lake Wabaunsee	10.0	0.279	1.039	18.43	0.265	1.927	4.56	N>P
Leavenworth Co. SFL	19.3	0.363	1.499	14.15	0.353	2.319	5.19	P>N
Louisburg SFL	25.5	1.063	2.721	11.52	0.521	3.822	4.45	P
Marion Lake	7.8	0.934	3.163	19.82	0.272	6.270	7.64	N>L
Melvern Lake	26.0	0.501	2.618	8.56	0.273	3.331	7.27	P
Mined Land Lake #44	22.8	0.467	2.675	12.00	0.372	3.822	8.88	P
Neosho Co. SFL	15.8	<0.010	<0.010	40.33	0.633	4.507	7.30	P≥N
Osage Co. SFL	17.7	0.333	1.209	15.74	0.247	1.993	4.43	P>N
Pomona Lake	26.4	1.286	6.723	4.52	0.312	7.579	9.66	P=L
Rock Creek Lake	11.8	1.129	2.323	13.36	0.360	3.489	3.96	P=N
Sheridan Co. SFL	8.9	0.669	1.376	11.92	0.103	1.960	2.90	N
Strowbridge Reservoir	23.0	0.518	1.664	19.09	0.367	3.182	5.02	P
Wellington City Lake	5.3	2.679	7.253	1.42	0.016	7.520	5.72	L
Wilson Co. SFL	13.1	0.332	1.265	25.65	0.389	3.526	6.32	P=N
Winfield City Lake	11.8	0.606	2.359	12.37	0.241	3.415	5.58	N≥P
Woodson Co. SFL	30.7	0.440	1.817	9.72	0.263	2.400	5.06	P
Wyandotte Co. Lake	50.5	0.245	1.079	11.39	0.390	1.509	4.87	P

Table 10b. Criteria used to classify lakes based on the various metrics applied in this report (cf., Walker, 1986; Scheffer, 1998).

Expected Lake Condition	**TN/TP**	**NAT**	**Z_{mix}*NAT**	**Chl-a*SD**	**Chl-a/TP**	**Z_{mix}/S**
Phosphorus Limiting	>12				>0.40	
Nitrogen Limiting	<7				<0.13	
Light/Flushing Limited		>1.0	>6	<6	<0.13	
High Algae-to-Nutrient Response		<0.4	<3	>16	>0.40	
Low Algae-to-Nutrient Response		>1.0	>6	<6	<0.13	
High Inorganic Turbidity		>1.0	>6	<6		
Low Inorganic Turbidity		<0.4	<3	>16		
High Light Availability			<3	>16		
Low Light Availability			>6	<6		

In addition to nutrient ratios, the following six metrics (see Table 10b) are applied in determining the relative roles of light and nutrient limitation for lakes in Kansas (cf., Walker, 1986; Scheffer, 1998).

1) Non-Algal Turbidity = $(1/SD)-(0.025m^2/mg*C)$,

where SD = Secchi depth in meters and C = chlorophyll-a in mg/m^3.

Non-algal turbidity values <0.4 m^{-1} tend to indicate very low levels of suspended silt and/or clay, whereas values >1.0 m^{-1} indicate that inorganic particles are important in creating turbidity. Values between 0.4 and 1.0 m^{-1} describe a range where inorganic turbidity assumes a progressively greater influence on water clarity. However, this parameter normally would assume a significant limiting role only if values exceeded 1.0 m^{-1}.

2) Light Availability in the Mixed Layer = Z_{mix}*Non-Algal Turbidity,

where Z_{mix} = depth of the mixed layer, in meters.

Values <3 indicate abundant light within the mixed layer of a lake and a high potential response by algae to nutrient inputs. Values >6 indicate the opposite.

3) Partitioning of Light Extinction Between Algae and Non-Algal Turbidity = Chl-a*SD,

where Chl-a = chlorophyll-a in mg/m^3 and SD = Secchi depth in meters.

Values <6 indicate that inorganic turbidity is primarily responsible for light extinction in the water column and there is a weak algal response to changes in nutrient levels. Values >16 indicate the opposite.

4) Algal Use of Phosphorus Supply = Chl-a/TP,

where Chl-a = chlorophyll-a in mg/m^3 and TP = total phosphorus in mg/m^3 .

Values <0.13 indicate a limited response by algae to phosphorus; i.e., nitrogen, light, or other factors may be more important. Values above 0.4 indicate a strong algal response to changes in phosphorus level. The range 0.13-to-0.4 suggests a variable but moderate response by algae to phosphorus levels.

5) Light Availability in the Mixed Layer for a Given Surface Light = Z_{mix}/SD,

where Z_{mix} = depth of the mixed layer, in meters, and SD = Secchi depth in meters.

Values <3 indicate that light availability is high in the mixed zone and the probability of strong algal responses to changes in nutrient levels is high. Values >6 indicate the opposite.

6) Shading in Water Column due to Algae and Inorganic Turbidity = Z_{mean}*E,

where Z_{mean} = mean lake depth, in meters, and E = calculated light attenuation coefficient, in units of m^{-1}, derived from Secchi depth and chlorophyll-a data (Scheffer, 1998).

Values >16 indicate high levels of self-shading due to algae or inorganic turbidity in the water column. Values <16 indicate that self-shading of algae does not significantly impede productivity. The metric is most applicable to lakes with maximum depths of less than 5 meters (Scheffer, 1998).

In addition to the preceding metrics, an approach developed by Carlson (1991) was employed to test the limiting factor determinations made from the suite of metrics utilized in this, and previous, reports. The approach uses the Carlson trophic state indices for total phosphorus, chlorophyll-a, Secchi depth, and the newer index for total nitrogen. Index scores are calculated for each lake, then metrics are calculated for $TSI_{(Secchi)}$-$TSI_{(Chl-a)}$ and for $TSI_{(TP\ or\ TN)}$-$TSI_{(Chl-a)}$. The degree of deviation of each of these metrics from zero provides a measure of the potential limiting factors. In the case of the metric dealing with Secchi depth and chlorophyll, a positive difference indicates small particle turbidity is important (inorganic clays), while a negative difference indicates that larger particles (zooplankton, algal colonies) exert more importance on lake light regime. In the case of the metric dealing with nutrients, a positive difference indicates the nutrient in question may not be the limiting factor, while a negative difference strengthens the assumption that the particular nutrient limits algal production and biomass. Differences of more than 5 units were used as the threshold for determining if the deviations were significantly different from zero. This approach generally produced the same determinations as those derived from the original suite of metrics. It accurately identified those lakes with extreme turbidity or those with large algal colonies or large-celled algal species. However, the $TSI_{(TN)}$ scores are given less weight than the other TSI calculations because the metric was developed using water quality data from Florida lakes which may render it less representative of our region.

In identifying the limiting factors for lakes, primary attention was given to the metrics calculated from 2008 data. However, past Secchi depth and chlorophyll-a data were also considered for comparative purposes. Additionally, mean and maximum lake depth were taken into account when ascribing the importance of non-algal turbidity. Lakes with fairly high non-algal turbidity may have little real impact from that turbidity if the entire water column rapidly circulates and is exposed to sunlight at frequent intervals (Scheffer, 1998).

Exceedences of State Surface Water Quality Criteria

Most numeric and narrative water quality criteria referred to in this section are taken from the Kansas Administrative Regulations (K.A.R. 28-16-28b through K.A.R. 28-16-28f) (KDHE, 2005b) or from EPA water quality criteria guidance documents (EPA, 1972, 1976) for ambient waters and finished drinking water. Copies of the Kansas regulations may be obtained from the Bureau of Water, KDHE, 1000 Southwest Jackson Ave., Suite 420, Topeka, Kansas 66612.

Exceedences of surface water quality criteria and guidelines during the 2008 sampling season were documented by computerized comparison of the 2008 Lake and Wetland Monitoring

Program data to the state surface water quality standards and applicable federal guidelines. Only those samples collected from a depth of $\leq$3.0 meters were used to document standards violations, as a majority of samples collected from below 3.0 meters were from hypolimnetic waters. In Kansas, lake hypolimnions generally constitute a small percentage of total lake volume. Although hypolimnetic waters usually have more pollutants present in measurable quantities, compared to overlying waters, they do not generally pose a significant water quality problem for the lake as a whole.

Criteria for eutrophication and turbidity in the Kansas standards are narrative rather than numeric. However, lake trophic state does exert a documented impact on various lake uses, as does inorganic turbidity. The system shown in Table 11 has been developed over the last nineteen years to define how lake trophic status influences the various designated uses of Kansas lakes (EPA, 1990; NALMS, 1992). Trophic state/use support expectations are compared with the observed trophic state conditions to determine the level of use support at each lake. The report appendix from the 2002 annual program report presents a comparison of these trophic class based assessments, as well as turbidity based assessments, versus statistically derived risk based values (KDHE, 2002b). In general, the risk based thresholds are comparable with the assessment system presently in use.

Eutrophication exceedences are primarily due to excessive nutrient inputs from lake watersheds. Dissolved oxygen problems are generally due to advanced trophic state, which causes rapid oxygen depletion below the thermocline. Lakes with elevated pH are also reflective of high trophic state and algal and/or macrophytic production. In 2008, 19 lakes (61%) had trophic state conditions elevated enough to impair one or more uses. Fourteen lakes (45%) had trophic state conditions elevated enough to cause moderate-to-severe impairments in a majority of uses.

In addition to the eutrophication/nutrient/turbidity related impairments described above, the following impairments were observed in five of the lakes surveyed in 2008:

Brown Co. SFL	Low dissolved oxygen and high pH (aquatic life support) and arsenic (water supply).
Atchison and Sheridan Co. SFLs	Low dissolved oxygen (aquatic life support).
Wellington City Lake	Lead (chronic aquatic life support).
Strowbridge Reservoir	Atrazine (chronic aquatic life support and water supply).

Table 11. Lake use support determination based on lake trophic state.

Designated Use	A	M	SE	E	VE	H-no BG TSI 64-70	H-no BG TSI 70+	H-with BG TSI 64+
Aquatic Life Support	X	Full	Full	Full	Partial	Partial	Non	Non
Drinking Water Supply	X	Full	Full	Partial	Partial	Non	Non	Non
Primary Contact Recreation	X	Full	Full	Partial	Partial	Non	Non	Non
Secondary Contact Recreation	X	Full	Full	Full	Partial	Partial	Non	Non
Livestock Water Supply	X	Full	Full	Full	Partial	Partial	Non	Non
Irrigation	X	Full	Full	Full	Partial	Partial	Non	Non
Groundwater Recharge	Trophic state is not generally applicable to this use.							
Food Procurement	Trophic state is applicable to this use, but not directly.							

BG = blue-green algae dominate the community (50%+ as cell count and/or 33%+ as biovolume)
X = use support assessment based on nutrient load and water clarity, not algal biomass

A = argillotrophic (high turbidity lake)
M = mesotrophic (includes OM, oligo-mesotrophic, class), TSI = zero-to-49.9
SE = slightly eutrophic, TSI = 50-to-54.9
E = eutrophic (fully eutrophic), TSI = 55-to-59.9
VE = very eutrophic, TSI = 60-to-63.9
H = hypereutrophic, TSI $\geq$ 64

TSI = 64 = chlorophyll-a of 30 ug/L
TSI = 70 = chlorophyll-a of 56 ug/L

Pesticides in Kansas Lakes, 2008

Detectable levels of at least one pesticide were documented in the main body of 20 lakes sampled in 2008 (67% of lakes surveyed for pesticides). Table 12 lists these lakes and the pesticides that were detected, along with the level measured and the analytical quantification limit. Four different pesticides, and one pesticide degradation byproduct, were noted in 2008. Of these five compounds, atrazine and alachlor currently have numeric criteria in place for aquatic life support and/or water supply uses (KDHE, 2005b).

Atrazine continues to be the pesticide detected most often in Kansas lakes (KDHE, 1991). Atrazine, and the atrazine degradation byproducts deethylatrazine and deisopropylatrazine, accounted for 74% of the total number of pesticide detections, and atrazine and/or its degradation byproducts were detected in all 20 lakes with pesticides. In addition to atrazine, seven lakes had detectable levels of metolachlor (Dual). Two lakes had detectable levels of acetochlor (Harness or Surpass) and one lake had detectable levels of alachlor (Lasso). Eight lakes had detectable quantities of deethylatrazine.

In all cases, the presence of these pesticides was directly attributable to agricultural activity. Atrazine levels in only one lake surveyed in 2008 exceeded 3.0 ug/L (Strowbridge reservoir). Only one lake had detectable levels of more than two pesticides (Pomona Lake).

CONCLUSIONS

The following conclusions are based on lake monitoring data collected during 2008.

1) Trophic state data indicated that 16% of the lakes surveyed in 2008 had degraded water quality in comparison to historic mean conditions (i.e., their trophic state had increased). About 58% showed stable conditions over time while almost 26% exhibited improved trophic state conditions.

2) The majority of the documented water quality impairments in these lakes were associated with high lake trophic status and nutrient enrichment. Heavy metals and pesticides accounted for a smaller than normal percentage of total exceedences (four total exceedences).

3) Over half of the lakes surveyed by KDHE had detectable levels of agricultural pesticides in 2008 (67% of lakes surveyed). As noted in previous years, atrazine was the most frequently detected pesticide.

Table 12. Pesticides levels documented during 2008 in Kansas lakes. All values listed are in ug/L. Analytical quantification limits are as follows: atrazine = 0.3 ug/L, deethylatrazine = 0.3 ug/L, metolachlor = 0.25 ug/L, acetochlor = 0.1 ug/L, and alachlor = 0.1 mg/L. Only those lakes with detectable levels of pesticides are reported.

		Pesticide			
Lake	**Atrazine**	**Deethylatrazine**	**Metolachlor**	**Acetochlor**	**Alachlor**
Atchison Co. SFL	1.35	0.42		0.12	
Brown Co. SFL	0.66	0.40			
Cheney Lake	0.89				
Council Grove Lake	1.50		0.46		
El Dorado Lake	0.40				
Hillsdale Lake	1.40	0.39	0.32		
John Redmond Lake	1.20		0.37		
Lake Afton	1.30				0.30
Louisburg SFL	0.50				
Marion Lake	1.30				
Melvern Lake	1.15				
Mined Land Lake #44	1.40	0.47	1.70		
Neosho Co. SFL	0.43				
Osage Co. SFL	1.70	0.33			
Pomona Lake	0.92	0.30	0.46	0.13	
Sheridan Co. SFL	1.00	0.36			
Strowbridge Reservoir	5.50	0.78	1.90		
Wellington City Lake	0.35		1.10		
Wilson Co. SFL	0.38				
Winfield City Lake	0.37				

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LAKE DATA AVAILABILITY

Water quality data are available for all lakes included in the Kansas Lake and Wetland Monitoring Program. These data may be requested by writing to the Bureau of Environmental Field Services, KDHE, 1000 Southwest Jackson Ave., Suite 430, Topeka, Kansas 66612-1367, or by calling 785-296-6603.