Lake and Wetland Monitoring Program

2006 Annual Report

By

C. Edward Carney

October 2007

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 35 Kansas lakes and wetlands during 2006. Eight of the lakes surveyed were large federal impoundments, seven were State Fishing Lakes (SFLs) or other water bodies on state managed lands, 18 were city and county lakes, and two were federal wetlands.

Of the 35 lakes and wetlands surveyed, 66% indicated trophic state conditions comparable to their historic mean water quality conditions. Another 23% indicated improved water quality conditions, over mean historic condition, as evidenced by a lowered lake trophic state. The remaining 11% indicated degraded water quality, over historic mean condition, as evidenced by elevated lake trophic state conditions. Phosphorus was identified as the primary factor limiting phytoplankton growth in 57% of the lakes surveyed during 2006. Nitrogen was identified as the primary limiting factor in 17% of the lakes, while none were identified as primarily light limited. The remaining lakes and wetlands appeared limited by combinations of nutrients (nitrogen and phosphorus) (20%), or carbon availability (3%) due to extreme nutrient enrichment and algal production. Primary limiting factors could not be identified in one lake (3%), but may be related to biological interactions.

There were a total of 114 documented exceedences of Kansas numeric and narrative water quality criteria, or Environmental Protection Agency (EPA) water quality guidelines, in the lakes surveyed during 2006. Of these 114 exceedences, 30% pertained to the aquatic life use and 70% concerned consumptive and recreational uses. Efforts to complete lake and wetland use attainability analyses (UAAs) for the Kansas Surface Water Register continue, with 2009 as the present goal for completion. A total of 72 lakes received UAA surveys during 2006.

Nineteen lakes and wetlands (56% of those surveyed for pesticides) had detectable levels of at least one pesticide in their main bodies during 2006. Atrazine, or its degradation byproducts, were detected in all 19 of these water bodies, once again making atrazine the most commonly documented pesticide in Kansas lakes. The highest detected atrazine concentration during 2006 lake and wetland sampling was 2.2 ug/L. A total of three different pesticides, and two pesticide degradation byproducts, were found in lakes during 2006.

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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 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 122 sites scattered throughout all the major drainage basins and physiographic regions of Kansas. The network remains dynamic, with lakes occasionally being dropped from active monitoring and/or replaced with more appropriate sites throughout the state.

In 1989, KDHE initiated a Taste and Odor/Algae Bloom Technical Assistance Program for public drinking water supply lakes. This was done to assist water suppliers in the identification and control of taste and odor problems in finished drinking water that result from pollution, algae blooms, or natural ecological processes.

Overview of the 2006 Monitoring Activities

Staff of the KDHE Lake and Wetland Monitoring Program visited 35 Kansas lakes and wetlands during 2006. Eight of these water bodies are large federal impoundments last sampled in 2003 or as part of special projects, seven are State Fishing Lakes (SFLs) or lakes on other state managed lands, 18 are city/county lakes (CLs and Co. lakes, respectively), and two are federal wetlands. Twenty of the 35 lakes (57%) presently serve as either primary or back-up municipal or industrial water supplies. A total of three new lakes were added to the program as of 2006 (Cedar Creek Reservoir, Lake Warnock, and Mined Land Lake #4). In addition to regular network surveys, 72 lake use attainability analyses (UAAs) were completed in 2006.

General information on the lakes surveyed during 2006 is compiled in Table 1. Figure 1 depicts the locations of the lakes surveyed in 2006. Figure 2 depicts the locations of all currently active sites within the Lake and Wetland Monitoring Program. Additionally, a total of eight lakes, streams, and/or ponds were investigated as part of the Taste and Odor/Algae Bloom Technical Assistance Program.

Artificial lakes are usually 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 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.

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. Up 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 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 2006.

Lake	Basin	Authority	Water Supply	Last Survey
Augusta Santa Fe Lake	Walnut	City	yes	2003
Blue Mound City Lake	Marais des Cygnes	City	yes	2005
Bone Creek Lake	Marais des Cygnes	County	yes	2005
Cedar Bluff Lake	Smoky Hill/Saline	Federal	yes	2003
Cedar Creek Lake	Marais des Cygnes	City	yes	2002
Cedar Creek Reservoir	Marais des Cygnes	County	yes	New
Centralia Lake	Kansas/Lower Republican	City	yes	2002
Clinton Lake	Kansas/Lower Republican	Federal	yes	2003
Gardner City Lake	Kansas/Lower Republican	City	yes	2002
Geary Co. SFL	Smoky Hill/Saline	State	no	2002
Goodman SFL	Upper Arkansas	State	no	2002
Harvey Co. East Lake	Walnut	County	no	2002
Kanopolis Lake	Smoky Hill/Saline	Federal	yes	2003
Lake Crawford	Marais des Cygnes	State	no	2002
Lake Scott	Smoky Hill/Saline	State	no	2002
Lake Shawnee	Kansas/Lower Republican	City	no	2003
Lake Warnock	Missouri	City	no	New
Lyon Co. SFL	Marais des Cygnes	State	no	2002
Madison City Lake	Verdigris	City	yes	2002
Miami Co. SFL	Marais des Cygnes	State	no	2003
Milford Lake	Kansas/Lower Republican	Federal	yes	2003
Mined Land Lake #4	Neosho	State	no	2002

Lake	Basin	Authority	Water Supply	Last Survey
Mission Lake	Kansas/Lower Republican	City	yes	2002
Moline City Lake #2	Verdigris	City	yes	2002
Olpe City Lake	Neosho	City	no	2002
Perry Lake	Kansas/Lower Republican	Federal	yes	2003
Pratt County Lake	Lower Arkansas	County	no	2004
Quivera Big Salt Marsh	Lower Arkansas	Federal	no	2003
Quivera Little Salt Marsh	Lower Arkansas	Federal	no	2003
Sabetha City Lake	Missouri	City	yes	2005
Thayer New City Lake	Verdigris	City	yes	2002
Tuttle Creek Lake	Kansas/Lower Republican	Federal	yes	2003
Webster Lake	Solomon	Federal	no	2003
Wilson Lake	Smoky Hill/Saline	Federal	yes	2004
Yates Center New City Lake	Verdigris	City	yes	2002

Since 1992, macrophyte surveys have been conducted at each of the smaller lakes (<300 acres) within the KDHE Lake and Wetland Monitoring Program network. These surveys entail the selection and mapping of 10 to 20 sampling points, 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 at each station, 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, for identification at 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 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 the primary focus, a wide variety of samples related to algae, odors, and fishkills, from both lakes and streams, are accepted for analysis.

Figure 1. Locations of the 35 lakes surveyed during 2006.

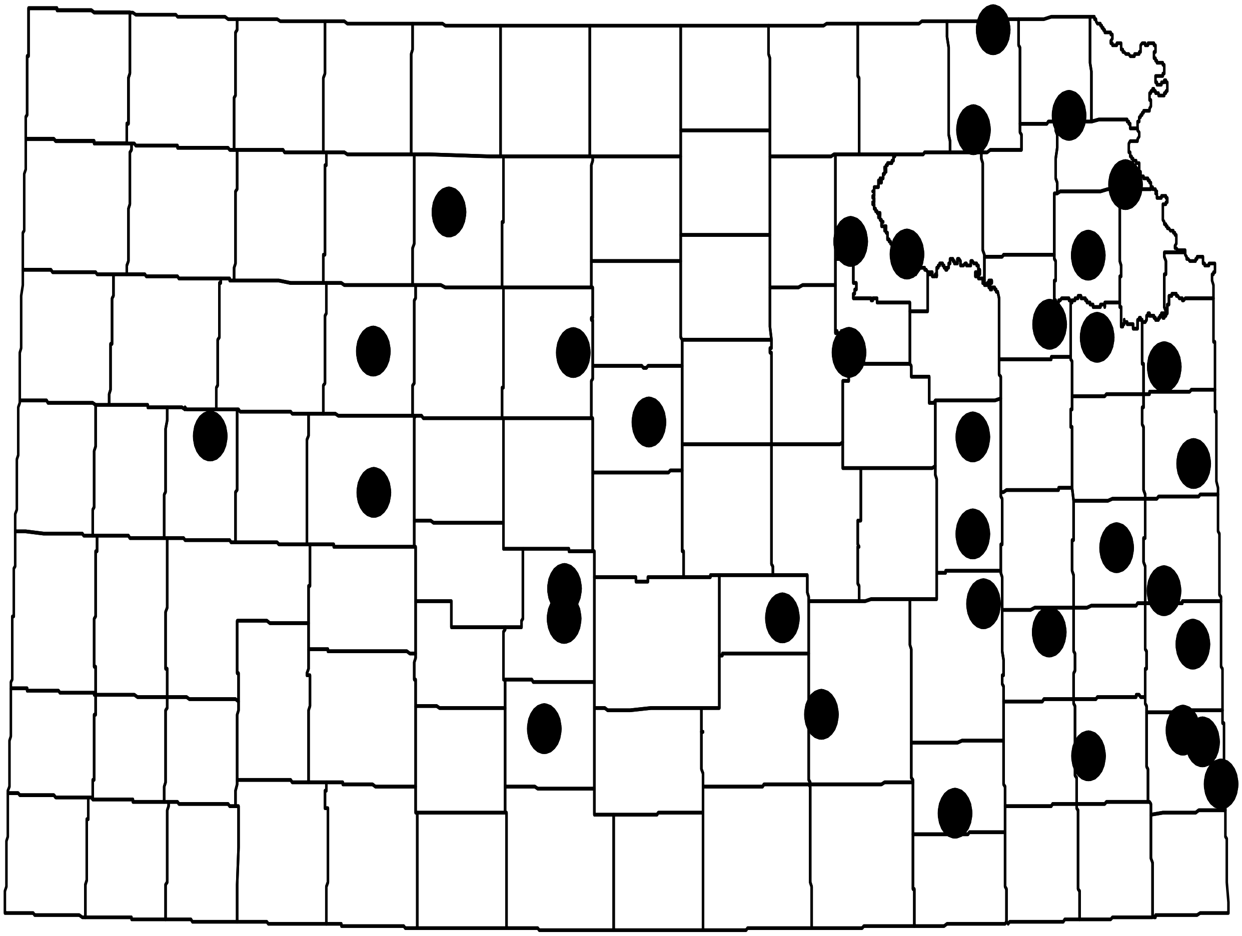
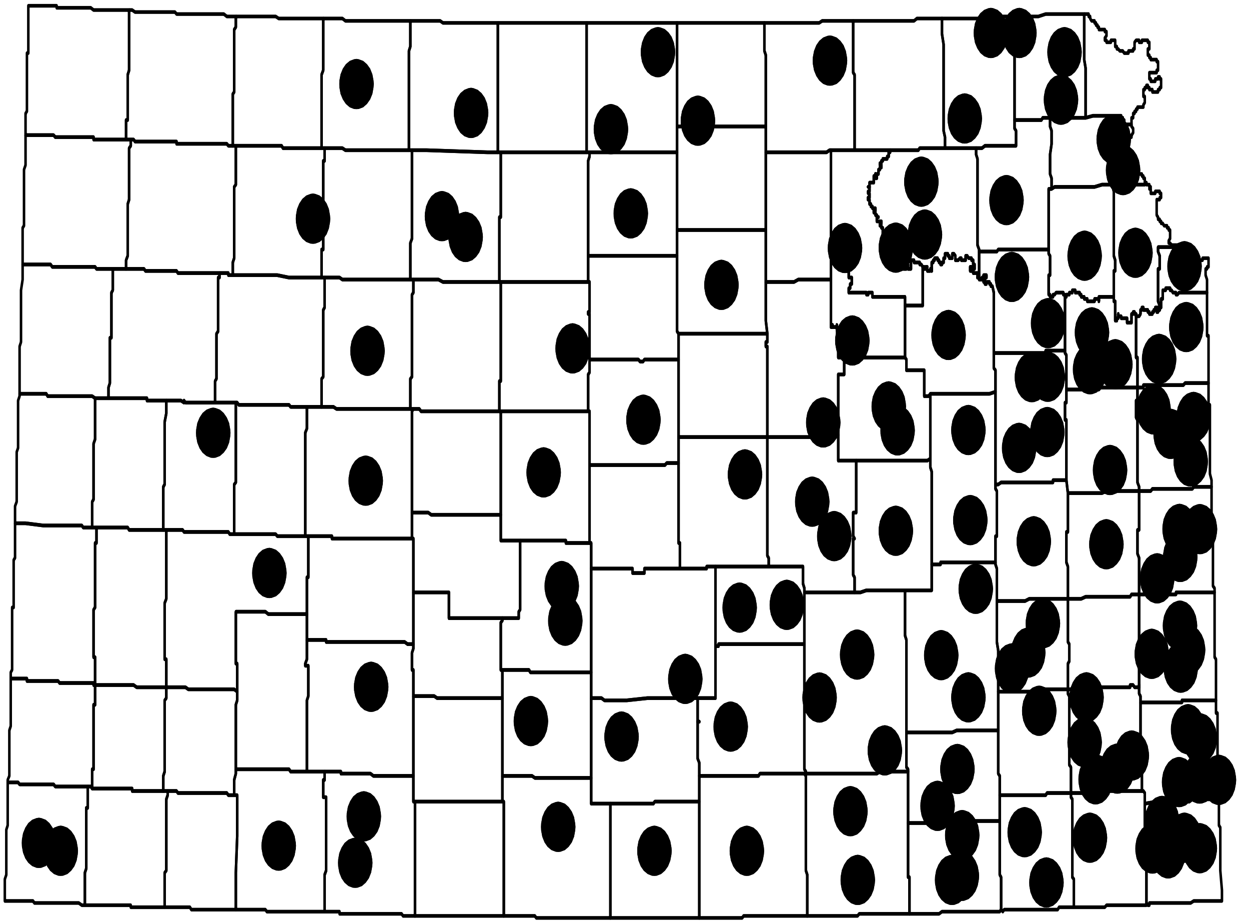


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program's network.



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 35 lakes surveyed during 2006, 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 2006 surveys was 34.2 ug/L (hypereutrophic), while the median chlorophyll-a was 13.2 ug/L (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. Chlorophyll-a concentration averages no more than 2.5 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 7.2 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 30.0 ug/L. This category is further divided as follows:

TSI = 50-54 = slightly eutrophic (SE)	Chlorophyll-a ranges 7.21 to 12.0 ug/L,
TSI = 55-59 = fully eutrophic (E)	Chlorophyll-a ranges 12.01 to 20.0 ug/L,
TSI = 60-63 = very eutrophic (VE)	Chlorophyll-a ranges 20.01 to 30.0 ug/L.

TSI score of ≥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 30.01 to 55.99 ug/L,
TSI = $\geq$70 = upper hypereutrophic	Chlorophyll-a values $\geq$56 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 may only 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 2006. 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 35 lakes this year was 131,746 cells/mL (median = 23,342 cells/mL).

Table 4 presents biovolume data for the 35 lakes surveyed in 2006. 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 31.47 ppm (median = 9.38 ppm).

Table 2. Current and past TSI scores, and trophic state classification for the lakes surveyed during 2006. 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	2006 TSI/Class	Previous Trophic Class Period of Record Mean
Augusta Santa Fe Lake	64.2 H	E
Blue Mound City Lake	56.2 E	E
Bone Creek Lake	47.5 M	M
Cedar Bluff Lake	45.7 M	E
Cedar Creek Lake	59.7 E	E
Cedar Creek Reservoir	47.4 M	new to network
Centralia Lake	46.0 M	H
Clinton Lake	55.9 E	E
Gardner City Lake	56.1 E	E
Geary Co. SFL	56.8 E	E
Goodman SFL	53.6 SE	E
Harvey Co. East Lake	72.7 H	H
Kanopolis Lake	52.1 SE	SE
Lake Crawford	58.9 E	E
Lake Scott	66.9 H	H
Lake Shawnee	66.3 H	VE
Lake Warnock	76.2 H	H
Lyon Co. SFL*	43.4 M(SE)	M
Madison City Lake	50.3 SE	SE
Miami Co. SFL	80.8 H	H
Milford Lake	51.2 SE	SE
Mined Land Lake #4	28.4 OM	OM

Lake	2006 TSI/Class	Previous Trophic Class Period of Record Mean
Mission Lake	62.0 VE	E
Moline City Lake #2	36.1 OM	M
Olpe City Lake	50.4 SE	E
Perry Lake	58.8 E	E
Pratt Co. Lake	68.8 H	H
Quivera Big Salt Marsh	87.2 H	H
Quivera Little Salt Marsh	74.4 H	H
Sabetha City Lake	55.7 E	H
Thayer New City Lake*	48.5 M(SE)	M
Tuttle Creek Lake	54.2 SE	A
Webster Lake	66.9 H	E
Wilson Lake	43.0 M	M
Yates Center New City Lake*	46.3 M(SE)	SE

Trends in Trophic State

Table 5 summarizes changes in trophic status for the 35 lakes surveyed during 2006. Four lakes (11.4%) displayed increases in trophic state, compared to their historic mean condition, while eight lakes (22.9%) displayed improved trophic states. Stable conditions were noted in 23 lakes (65.7%).

For the purposes of this analysis, the new lake (Cedar Creek Reservoir) was assumed to have been mesotrophic for its short period of record since it was filled only a few years back. 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. Although Lake Warnock and Mined Land Lake #4 are new to the sampling network, both had past data from other ambient surveys.

Only three lakes (Lyon Co. SFL, Thayer New City Lake, and Yates Center New City Lake) had macrophyte communities dense enough to justify adjusting trophic state designations. Despite these upward adjustments, all three lakes still indicated nearly ideal water quality conditions.

Table 3. Algal communities observed in the 35 lakes surveyed during 2006. The “other” category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate groups of algae.

Lake	Cell Count (cells/mL)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Augusta Santa Fe Lake	4,883	16	0	15	70
Blue Mound City Lake	33,170	16	83	1	<1
Bone Creek Lake	16,475	3	93	3	<1
Cedar Bluff Lake	9,135	22	39	37	2
Cedar Creek Lake	28,098	14	78	6	<2
Cedar Creek Reservoir	13,010	9	86	2	2
Centralia Lake	7,277	14	85	<1	0
Clinton Lake	19,215	6	90	3	1
Gardner City Lake	50,715	1	97	2	0
Geary Co. SFL	78,939	1	97	2	<1
Goodman SFL	21,578	15	82	3	1
Harvey Co. East Lake	533,831	<1	95	4	<1
Kanopolis Lake	7,308	65	32	<1	3
Lake Crawford	13,010	27	56	12	6
Lake Scott	123,449	<1	99	<1	<1
Lake Shawnee	70,371	4	94	2	<1
Lake Warnock	622,724	1	98	<1	0
Lyon Co. SFL	2,993	9	74	17	0
Madison City Lake	31,185	4	94	<2	<1
Miami Co. SFL	1,036,004	1	99	0	0
Milford Lake	23,342	<1	99	<1	0

	Cell Count	**Percent Composition**			
Mined Land Lake #4	945	80	0	20	0
Mission Lake	35,973	33	64	4	<1
Moline City Lake #2	1,323	11	79	6	4
Olpe City Lake	18,396	2	96	<1	<1
Lake	**(cells/mL)**	**Greens**	**Blue-Greens**	**Diatoms**	**Other**
Perry Lake	44,195	<2	90	9	<1
Pratt Co. Lake	304,700	10	88	1	<1
Quivera Big Salt Marsh	852,012	62	36	2	<1
Quivera Little Salt Marsh	343,980	11	87	1	<1
Sabetha City Lake	22,145	14	80	<1	6
Thayer New City Lake	42,179	3	96	<1	0
Tuttle Creek Lake	1,985	7	0	90	3
Webster Lake	187,425	9	90	<1	<1
Wilson Lake	1,670	77	12	7	4
Yates Center New City Lake	7,466	4	94	1	1

As shown in Table 6, of the 19 lakes receiving macrophyte surveys (15 full surveys and four limited/estimated observational surveys), eight (42% of those surveyed, 23% of all lakes in 2006) had detectable amounts of submersed plant material. In these lakes, the most common plant species were pondweeds (*Potamogeton spp.*), water naiad (*Najas guadalupensis*), coontail (*Ceratophyllum demersum*), Eurasian water milfoil (*Myriophyllum spicatum*), and various species of stonewort algae (*Chara* and *Nitella spp.*).

Using trophic state data for macrophytes in the literature (Schneider and Melzer, 2003; Lehmann and LaChavanne, 1999; Sladecek, 1973), combined with abundance of aquatic plants in the lakes during 2006, five water bodies appeared to merit further assessment of the macrophyte community trophic classification. Three of these were assessed as eutrophic communities (Blue Mound City Lake, Lyon Co. SFL, and Yates Center New City Lake), one as a very eutrophic community (Thayer New City Lake), and one on the threshold between eutrophic and very eutrophic (Lake Warnock), based on only the macrophyte community data. Three of the five lakes merited having their overall trophic classification adjusted upwards based on the observed abundance, diversity, and trophic characteristics of the macrophytic community during 2006

(Table 2). Of note, concerning 2006 macrophyte data, was the relatively sudden and prolific appearance of *Myriophyllum spicatum*, a nuisance species, in Yates Center's primary water supply lake.

Table 4. Algal biovolumes calculated for the lakes surveyed during 2006. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate 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**
Augusta Santa Fe Lake	29.193	<1	0	11	89
Blue Mound City Lake	5.334	34	53	8	5
Bone Creek Lake	3.581	3	79	9	9
Cedar Bluff Lake	7.746	6	9	72	13
Cedar Creek Lake	9.930	21	43	18	17
Cedar Creek Reservoir	2.123	16	53	5	25
Centralia Lake	1.729	29	70	1	0
Clinton Lake	12.010	3	64	22	11
Gardner City Lake	10.718	10	78	12	0
Geary Co. SFL	9.311	5	65	27	3
Goodman SFL	6.574	23	43	26	8
Harvey Co. East Lake	81.638	<1	73	10	17
Kanopolis Lake	7.524	53	6	<1	40
Lake Crawford	12.520	26	16	32	27
Lake Scott	36.016	2	90	2	6
Lake Shawnee	30.680	2	85	12	1
Lake Warnock	118.388	2	94	4	0
Lyon Co. SFL	1.464	23	30	47	0
Madison City Lake	5.977	6	81	6	7

	Biovolume	Percent Composition			
Miami Co. SFL	203.966	2	98	0	0
Milford Lake	6.435	<1	95	4	0
Mined Land Lake #4	0.221	67	0	33	0
Mission Lake	28.553	76	16	7	<2
Moline City Lake #2	0.554	5	37	31	27
Olpe City Lake	4.171	3	83	5	9
Lake	**(ppm)**	**Green**	**Blue-Green**	**Diatom**	**Other**
Perry Lake	33.001	1	23	71	4
Pratt Co. Lake	41.663	41	44	6	9
Quivera Big Salt Marsh	209.793	50	28	14	8
Quivera Little Salt Marsh	111.403	10	50	33	7
Sabetha City Lake	9.382	24	31	3	43
Thayer New City Lake	3.255	16	83	1	0
Tuttle Creek Lake	10.053	1	0	97	2
Webster Lake	41.657	12	79	3	6
Wilson Lake	2.387	10	2	3	85
Yates Center New City Lake	2.400	2	56	1	41

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	8.6
Improved One Class Ranking	5	14.3
Stable	23	65.7
Degraded One Class Ranking	2	5.7

Degraded ≥ Two Class Rankings	2	5.7
Total	35	100.0

* = One of these lakes (Tuttle Creek Lake) had a historic mean trophic state classification 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. In the case of Cedar Creek Reservoir, it was assumed that the historic trophic status has not changed over time. Cedar Creek Reservoir was constructed only a few years ago and, therefore, has no historic water quality data.

Table 6. Macrophyte community structure in the 19 lakes surveyed for macrophytes during 2006. 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. (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**	
Augusta Santa Fe Lake	<5%		no species observed
Blue Mound City Lake	87%	80% 80% 80% 13%	*Chara zeylanica* *Najas guadalupensis* *Potamogeton nodosus* *Nelumbo sp.*
Cedar Creek Reservoir (limited survey)	<5%		no species observed
Gardner City Lake	<10%		no species observed
Geary Co. SFL	13%	13% 13%	*Ceratophyllum demersum* *Najas guadalupensis*
Goodman SFL	<10%		no species observed
Harvey Co. East Lake	<5%		no species observed
Lake Crawford (limited survey)	<5%		no species observed
Lake Scott (limited survey)	85%	85%	*Myriophyllum spicatum* (beds much less dense than in past surveys)
Lake Warnock	70%	70% 70% 70% 70%	*Ceratophyllum demersum* *Myriophyllum spicatum* *Najas guadalupensis* *Potamogeton pectinatus*
Lyon Co. SFL	87%	87% 87% 60%	*Najas guadalupensis* *Potamogeton nodosus* *Potamogeton illinoensis*

Lake	**% Total Cover**		**% Species Cover and Community Composition**
Madison City Lake	<5%		no species observed
Miami Co. SFL	<5%		no species observed
Mission Lake (limited survey)	<10%	trace	*Ceratophyllum demersum*
Moline City Lake #2	<10%		no species observed
Olpe City Lake	<10%		no species observed
Pratt Co. Lake	<10%		no species observed
Thayer New City Lake	40%	40%	*Najas guadalupensis*
		27%	*Potamogeton nodosus*
Yates Center New City Lake	70%	65%	*Myriophyllum spicatum*
		35%	*Najas guadalupensis*
		30%	*Potamogeton illinoensis*
		25%	*Ceratophyllum demersum*
		10%	*Potamogeton amplifolius*

None of the lakes surveyed in 2006 appeared to have algal limitation due to macrophyte community influences. Overall, Kansas lakes are impaired more by a lack of macrophyte habitat than by an overabundance. In general, presence of a robust (and usually diverse) macrophyte community reflects lower levels of human impact in our lakes.

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 reported in Table 6, it is rare for bed densities to approach any threshold that would be identified as an impairment.

Lake Stratification and Water Clarity

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 (combined with 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, this phenomenon is called “lake turnover.” Table 7 presents data related to thermal stratification in the 35 lakes surveyed in 2006 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 explosive 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 our 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 the depth profiles taken in each lake for temperature and dissolved oxygen concentration. 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 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 estimate 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.

Table 7. Stratification status of the 35 water bodies surveyed during 2006. 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
gusta Santa Fe Lake	06-26-2006	0.00	0.40	none	3.0	
ue Mound City Lake	07-12-2006	n.a.	n.a.	unknown	6.0	no boat ramp
ne Creek Lake	07-12-2006	1.50	0.78	6.0	13.0	
dar Bluff Lake	06-12-2006	n.a.	n.a.	unknown	15.0	too low for boat acces
dar Creek Lake	07-31-2006	n.a.	n.a.	unknown	10.5	windy conditions
dar Creek Reservoir	07-12-2006	1.43	0.50	3.0-4.0	15.0	
ntralia Lake	07-17-2006	0.64	0.94	3.0-4.0	8.0	
nton Lake	06-19-2006	0.60	0.96	8.0-9.0	11.0	
rdner City Lake	08-21-2006	1.23	0.66	5.0-6.0	12.5	
ary Co. SFL	08-07-2006	1.18	0.68	5.0-6.0	11.5	
odman SFL	08-14-2006	n.a.	n.a.	unknown	2.0	
rvey Co. East Lake	06-27-2006	0.00	1.73	none	3.0	
nopolis Lake	06-13-2006	n.a.	n.a.	unknown	6.5	too low for boat acces
ke Crawford	07-12-2006	n.a.	n.a.	none	13.0	too low for boat acces
ke Scott	08-14-2006	n.a.	n.a.	unknown	4.0	
ke Shawnee	08-01-2006	0.14	0.20	below 7.0	14.0	windy conditions

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 Warnock	07-18-2006	1.00	2.85	1.5	2.5	
on Co. SFL	08-22-2006	1.00	0.93	6.0-7.0	7.5	
dison City Lake	08-08-2006	1.50	0.89	3.0-5.0	9.5	
ami Co. SFL	08-21-2006	n.a.	n.a.	unknown	1.5	
lford Lake	07-05-2006	0.22	0.40	15.0-16.0	19.0	
ned Land Lake #4	09-05-2006	n.a.	n.a.	unknown	9.0	
ssion Lake	07-18-2006	n.a.	n.a.	unknown	4.0	storms in area
line City Lake #2	08-29-2006	n.a.	n.a.	unknown	5.0	too low for boat acces
pe City Lake	08-08-2006	0.33	0.50	none	4.0	
rry Lake	06-19-2006	0.64	0.90	8.0-9.0	12.0	
tt Co. Lake	08-15-2006	n.a.	n.a.	unknown	2.0	
ivera Big Salt Marsh	08-15-2006	n.a.	n.a.	none	1.0	
ivera Little Salt Marsh	08-15-2006	n.a.	n.a.	none	1.5	
betha City Lake	07-17-2006	n.a.	n.a.	unknown	2.5	
ayer New City Lake	08-29-2006	n.a.	n.a.	unknown	7.0	too low for boat acces
ttle Creek Lake	07-05-2006	0.08	0.14	none	19.0	
ebster Lake	06-12-2006	n.a.	n.a.	unknown	7.0	too low for boat acces
lson Lake	06-12-2006	n.a.	n.a.	unknown	16.0	too low for boat acces
tes Center New City ke	08-30-2006	0.75	0.78	6.0-7.0	8.5	

Note: A comparison to past annual reports may give the reader the impression that 2006 had a larger than typical number of lakes without profile data collected. This was, indeed, the case. The summer of 2006 presented a number of sampling difficulties in the form of very low water levels that rendered boat ramps unuseable, as well as a few surveys with windy conditions. Under normal circumstances, rescheduling of some of these trips may have been feasible, but due to the volume of site visits to non-network lakes, for use attainability analysis (UAA) surveys, and the continuation of drought conditions, a number of these lakes simply had to be surveyed without the collection of depth profile data for temperature and dissolved oxygen. Roughly 46% of surveyed lakes had profile data collected in 2006. Another 31% did not have profile data collected by plan (lake is normally too shallow to collect profile data, the visit was primarily for UAA analysis, the lake is small and lacks a boat ramp, etc.). The remaining lakes (23%) had profile data collection omitted because of conditions found once staff were on-site. Under such circumstances, maximum depth was estimated based on the maximum depth measured during past surveys, minus the estimated difference between current and normal pool elevations.

Euphotic depth, or the depth to which light sufficient for photosynthesis penetrates, 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, which is the depth to which wind circulation and 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.

For the 35 lakes surveyed in 2006, the calculated euphotic-to-mixed depth ratio suggests that light penetrates throughout the mixed zone in over half of them (mean = 1.68, median = 1.23). This suggests that most of these lakes should not have significant light limitation concerns as sunlight can reach essentially throughout the epilimnion and, in many cases, into the thermocline zone. This is also borne out by Secchi depth and calculated non-algal turbidity data (Secchi depth: mean = 148 cm, median = 119 cm; non-algal turbidity: mean = 0.58 m^{-1}, median = 0.39 m^{-1}) (Walker, 1986). Table 8 presents data for 2006 concerning water clarity measures. Over the last few years, with the continuation of drought conditions, staff have observed higher general water clarity in Kansas lakes, as well as significant increases in specific lakes. Future years should provide some very interesting data, whether the drought continues as currently indicated or conditions return to historic norms for precipitation and runoff.

Table 8. Water clarity metrics for the 35 lakes surveyed in 2006. See the section on limiting factors for a more in-depth 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**
Augusta Santa Fe Lake	30.65	28	2.805	1.35
Blue Mound City Lake	13.60	120	0.493	1.38
Bone Creek Lake	5.60	282	0.215	1.06
Cedar Bluff Lake	4.65	350	0.169	0.88
Cedar Creek Lake	19.50	80	0.763	0.78
Cedar Creek Reservoir	5.55	241	0.276	1.00
Centralia Lake	4.80	155	0.525	1.33
Clinton Lake	13.20	171	0.255	0.86
Gardner City Lake	13.50	163	0.276	0.94
Geary Co. SFL	14.55	121	0.463	0.90
Goodman SFL	10.50	51	1.698	4.13
Harvey Co. East Lake	73.25	54	<0.100	1.40
Kanopolis Lake	8.95	100	0.776	1.17
Lake Crawford	17.95	119	0.392	0.79
Lake Scott	40.65	39	1.548	1.07
Lake Shawnee	38.05	115	<0.100	0.62
Lake Warnock	104.90	62	<0.100	1.23
Lyon Co. SFL	3.70	245	0.316	1.55
Madison City Lake	7.50	98	0.833	0.97
Miami Co. SFL	167.85	26	<0.100	1.48
Milford Lake	8.15	242	0.209	0.69
Mined Land Lake #4	0.80	550	0.162	1.84
Mission Lake	24.50	52	1.311	1.35
Moline City Lake #2	1.75	500	0.156	2.44
Olpe City Lake	7.55	37	2.514	1.30

Lake	**Chlorophyll-a (ug/L)**	**Secchi Disk Depth (cm)**	**Non-Algal Turbidity (m^{-1})**	**Euphotic to Mixed Depth Ratio**
Perry Lake	17.75	157	0.193	0.75
Pratt Co. Lake	49.30	64	0.330	3.35
Quivera Big Salt Marsh	322.40	17	<0.100	6.02
Quivera Little Salt Marsh	86.80	33	0.860	7.79
Sabetha City Lake	12.90	81	0.912	3.27
Thayer New City Lake	6.20	250	0.245	1.58
Tuttle Creek Lake	11.10	147	0.403	0.60
Webster Lake	40.40	70	0.419	0.78
Wilson Lake	3.55	200	0.411	0.78
Yates Center New City Lake	4.95	167	0.475	1.29

Fecal Indicator Bacteria

Since 1996, bacterial sampling has taken place at the primary water quality sampling station at each lake monitored by KDHE. 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. 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 than swimming beaches and other shoreline areas.

Table 9 presents the bacterial data collected during the 2006 sampling season. Eleven lakes, out of the 34 lakes surveyed for *E. coli* bacteria (32%), had counts greater than the analytical reporting limit (Mined Land Lake #4 was not sampled for *E. coli* bacteria). Although no lake in 2006 exceeded existing criteria (KDHE, 2005b), three lakes had *E. coli* counts of 100-200 cfu/100mL . The mean *E. coli* count among these 34 lakes ranges between 18 and 25 cfu/100mL (assuming the non-detects are zero values, or the reporting limit, respectively) while the median value is <10 cfu/100mL.

Table 9. *E. coli* bacterial counts (mean of duplicate samples) from the 34 lakes and wetlands surveyed for *E. coli* bacteria during 2006. 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
Augusta Santa Fe Lake	open water	15
Blue Mound City Lake	off dam	<20
Bone Creek Lake	open water	<10
Cedar Bluff Lake	off dam	20
Cedar Creek Lake	off dam	<10
Cedar Creek Reservoir	open water	52
Centralia Lake	open water	<10
Clinton Lake	open water	<10
Gardner City Lake	open water	<10
Geary Co. SFL	open water	<10
Goodman SFL	off dam	111
Harvey Co. East Lake	open water	<10
Kanopolis Lake	off dam	20
Lake Crawford	off dam	10
Lake Scott	off dam	<10
Lake Shawnee	open water	<10
Lake Warnock	open water	10
Lyon Co. SFL	open water	<10
Madison City Lake	open water	<10

Lake	Site Location	*E. Coli* Count
Miami Co. SFL	off dam	<10
Milford Lake	open water	<10
Mined Land Lake #4	not sampled for bacteria	no data
Mission Lake	off dam	<10
Moline City Lake #2	off dam	<10
Olpe City Lake	open water	<25
Perry Lake	open water	<10
Pratt Co. Lake	off dam	<10
Quivera Big Salt Marsh	open water	145
Quivera Little Salt Marsh	open water	81
Sabetha City Lake	off dam	129
Thayer New City Lake	off dam	<10
Tuttle Creek Lake	open water	<10
Webster Lake	off dam	<10
Wilson Lake	off dam	15
Yates Center New City 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 10-12 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 indicate that both nutrients, or neither, may limit algal production (Wetzel, 1983; Horne and Goldman, 1994). It should also be kept in mind, when determining limiting factors, that highly turbid lakes typically have lower nutrient ratios, but may still have 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 2006. These determinations reflect the time of sampling (chosen to reflect average conditions during the summer growing season to the extent possible) but 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 times representative of "normal" summer conditions. If such a situation is suspected, it is noted in Table 10 or elsewhere in the report. For the 2006 season, three lakes (Centralia Lake, Goodman SFL, and Yates Center New City Lake) may have had some lingering impacts from recent rains, but the impacts are believed to be relatively small.

Table 10. Limiting factor determinations for the 35 lakes surveyed during 2006. 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, Fe = iron, and L = light. Shading = calculated light attenuation coefficient times mean lake depth.

ke	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
gusta Santa Fe Lake	5.6	2.805	3.297	8.58	0.161	4.197	3.70	N
ue Mound City Lake	27.4	0.493	1.186	16.32	0.439	2.004	3.32	
ne Creek Lake	47.0	0.215	0.886	15.79	0.560	1.464	4.61	
dar Bluff Lake	47.2	0.169	0.886	16.28	0.216	1.494	6.20	
dar Creek Lake	16.8	0.763	2.693	15.60	0.291	4.414	6.06	P
dar Creek Reservoir	79.5	0.276	1.180	13.38	0.555	1.772	4.95	
ntralia Lake	34.0	0.525	1.562	7.44	0.119	1.919	3.48	
nton Lake	28.8	0.255	1.070	22.57	0.471	2.457	5.73	
rdner City Lake	22.7	0.276	1.051	22.01	0.370	2.336	5.12	

ake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
ary Co. SFL	39.1	0.463	1.678	17.61	0.633	2.998	5.24	
odman SFL	32.1	1.698	1.020	5.36	0.214	1.178	1.45	
rvey Co. East Lake	11.9	0.021	0.024	39.56	0.431	2.176	3.56	P
nopolis Lake	8.9	0.776	2.187	8.95	0.122	2.818	3.92	
ke Crawford	11.6	0.392	1.556	21.36	0.399	3.340	6.13	P
ke Scott	16.0	1.548	2.561	15.85	0.280	4.242	4.40	P
ke Shawnee	21.8	<0.010	<0.010	43.76	1.171	3.590	7.89	
ke Warnock	10.3	<0.010	<0.010	65.04	0.456	1.896	4.06	P
on Co. SFL	74.5	0.316	0.898	9.07	0.370	1.161	2.96	
dison City Lake	30.0	0.833	2.857	7.35	0.283	3.500	4.83	
ami Co. SFL	11.7	<0.010	<0.010	43.64	0.377	2.311	4.05	(P≥N)
lford Lake	5.3	0.209	1.258	19.72	0.060	2.481	8.79	
ned Land Lake #4	86.5	0.162	0.454	4.40	0.080	0.510	2.50	Unknown
ssion Lake	13.5	1.311	2.168	12.74	0.293	3.182	3.48	P
line City Lake #2	68.0	0.156	0.322	8.75	0.175	0.412	1.89	
pe City Lake	15.6	2.514	4.159	2.79	0.084	4.472	3.62	(N>P)
rry Lake	60.0	0.193	0.867	27.87	1.109	2.858	6.73	
tt Co. Lake	11.3	0.330	0.198	31.55	0.379	0.939	1.78	N
ivera Big Salt Marsh	16.7	<0.010	<0.010	54.81	0.576	0.525	2.17	C>(P>
ivera Little Salt Marsh	20.5	0.860	0.144	28.64	0.362	0.505	1.26	P
betha City Lake	7.9	0.912	0.821	10.45	0.065	1.112	1.62	N
ayer New City Lake	33.8	0.245	0.663	15.50	0.276	1.083	2.90	
ttle Creek Lake	4.9	0.403	2.418	16.32	0.058	4.085	10.11	
ebster Lake	20.7	0.419	1.179	28.28	0.367	4.025	5.86	
lson Lake	71.5	0.411	2.239	7.10	0.355	2.722	7.16	
tes Center New City Lake	20.4	0.475	1.472	8.27	0.141	1.855	3.58	

Criteria Table (cf., Walker, 1986; Scheffer, 1998).

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

As indicated in Table 10, phosphorus was the primary limiting factor identified for lakes surveyed in 2006. Twenty of the 35 lakes (57.1%) were determined to be primarily limited by phosphorus. Six lakes (17.2%) were determined to be primarily nitrogen limited. No lakes were primarily light limited in the 2006 season. Another seven lakes (20.0%) were co-limited by phosphorus and nitrogen. Algal production in one wetland (2.9%) was determined to be primarily limited by carbon due to extreme nutrient enrichment, while the primary limiting factors for one lake could not be determined (2.9%). Mean TN/TP ratio was 29.5 for the lakes surveyed in 2006 (median = 20.7). Interquartile ranges for TN/TP ratios were 22.5-to-50.4 for phosphorus limited lakes, 5.4-to-8.7 for nitrogen limited lakes, and 11.5-to-14.0 for lakes co-limited by phosphorus and nitrogen.

In addition to nutrient ratios, the following six metrics 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, while 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 greater influence on water clarity as the value increases, but would not assume a significant limiting role until values exceed 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 2006 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).

Surface Water 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.

Tables 12, 13, and 14 present documented exceedences of surface water quality criteria and guidelines during the 2006 sampling season. These data were generated by computerized comparison of the 2006 Lake and Wetland Monitoring Program data to the state surface water quality standards and other federal guidelines. Only those samples collected from a depth of $\leq$3.0 meters were used to document standards violations, as a majority of those samples collected from below 3.0 meters were from hypolimnetic waters. In Kansas, lake hypolimnions generally constitute a small percentage of total lake volume and, while usually having more pollutants present in measurable quantities compared to overlying waters, 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 seventeen 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 risk based values (KDHE, 2002b). In general, the risk based thresholds compare fairly well with the assessment system presently in use.

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

With respect to the aquatic life support use, eutrophication, high pH, and low dissolved oxygen within the upper 3.0 meters comprised the primary water quality concerns during 2006 (Table 12). Eleven lakes exhibited trophic states high enough to impair long or short term aquatic life support. Five lakes had low dissolved oxygen conditions within the top 3.0 meters of the water column, a condition linked to eutrophication in two of those lakes. In the other three lakes, low dissolved oxygen apparently was related more to the circumstances of stratification (i.e., a shallow thermocline mainly due to late spring/early summer heat, light, and wind conditions). Three lakes had pH levels high enough to impact aquatic life support.

Eutrophication exceedences were 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, but are also observed in lakes that do not exhibit excessive trophic state conditions. In these cases, the low dissolved oxygen levels in the upper 3.0 meters likely results from shallow stratification conditions and may not be assessed as an impairment per se (see paragraph above). Lakes with elevated pH are also reflective of high trophic state and algal and/or macrophytic production.

There were 28 exceedences of water supply criteria and/or guidelines during 2006 (Table 13). The majority (61%) were for eutrophication related conditions. Irrigation use criteria were exceeded in 10 lakes and livestock watering criteria were exceeded in 11 lakes.

Table 14 lists 19 lakes with trophic state/turbidity conditions high enough to have impaired contact recreational uses. The trophic state of 11 lakes was high enough to have impaired secondary contact recreation during 2006.

In all, there were 114 exceedences of numeric or narrative criteria, water quality goals, or EPA guidelines documented in Kansas lakes during 2006. Approximately 30% of these exceedences related to aquatic life support, 44% related to consumptive uses of water, and 26% related to recreational uses. Eutrophication, high pH, or low dissolved oxygen accounted for 86% of documented water quality impacts in 2006. Only about 5% of the impacts were linked to heavy metals and metalloids. There were no exceedences due to pesticides during 2006. Exceedences listed in this report section, and in Tables 12-14, are for designated uses where Use Attainability Analyses (UAAs) have shown the use to be either existing or attainable.

Table 12. Chemical and biological parameters not complying with chronic and acute aquatic life support (ALS) criteria in lakes surveyed during 2006. DO = dissolved oxygen, EN = eutrophication or high nutrient load, Pb = lead, Se = selenium, and Cl = chloride. Only those lakes with some documented water quality problem are included in Tables 12, 13, and 14.

	Chronic ALS			**Acute ALS**			
Lake	**EN***	**Pb**	**Se**	**EN***	**DO***	**pH***	**Cl**
Augusta Santa Fe Lake	X			X			
Cedar Creek Reservoir					X		
Centralia Lake					X		
Harvey Co. East Lake	X			X	X		
Lake Scott	X			X			
Lake Shawnee	X			X			
Lake Warnock	X			X	X		
Madison City Lake					X		
Miami Co. SFL	X			X		X	
Mission Lake	X			X			
Olpe City Lake		X					
Pratt Co. Lake	X			X			
Quivera Big Salt Marsh	X			X		X	X
Quivera Little Salt Marsh	X			X		X	X
Webster Lake	X		X	X			

* = Although there are no specific chronic versus acute criteria for these parameters, the magnitude of the excursions are used to determine whether the impact is of immediate or long term importance. Measured values for dissolved oxygen and pH can be dependent on when samples are collected during a 24 hour cycle. When nutrient pollution and eutrophication are high, one can assume higher pH and lower dissolved oxygen conditions occur at some point during this 24 hour cycle.

Table 13. Exceedence of human use criteria and/or EPA guidelines within the water column of lakes surveyed during 2006. EN = high trophic state/nutrients, SO_4 = sulphate, Cl = chloride, F = fluoride, and As = arsenic. Only lakes with documented exceedences are included within the table. UAAs have been completed for all lakes surveyed in 2006.

	Water Supply				**Irrigation**		**Livestock Water**
Lake	**EN**	**SO_4**	**Cl**	**As**	**EN**	**F**	**EN**
Augusta Santa Fe Lake	X				X		X
Blue Mound City Lake	X						
Cedar Bluff Lake		X					
Cedar Creek Lake	X						
Clinton Lake	X						
Gardner City Lake	X						
Geary Co. SFL	X						
Harvey Co. East Lake	X				X		X
Kanopolis Lake			X				
Lake Crawford	X						
Lake Scott	X						X
Lake Shawnee	X				X		X
Lake Warnock	X			X	X		X
Miami Co. SFL	X			X	X		X
Mined Land Lake #4		X					
Mission Lake	X				X		X
Perry Lake	X						
Pratt Co. Lake	X				X		X
Quivera Big Salt Marsh					X		X
Quivera Little Salt Marsh					X	X	X
Sabetha City Lake	X			X			
Webster Lake	X	X	X	X	X		X

	Water Supply				**Irrigation**		**Livestock Water**
Wilson Lake		X	X				

Table 14. Exceedences of numeric and narrative recreational guidelines for lakes surveyed during 2006. Primary contact recreation refers to recreation where ingestion of lake water is likely. Secondary contact recreation involves a low likelihood of accidental ingestion of lake water. EN = high trophic state and nutrient loads and TN = high turbidity and nutrient loads. UAAs have been completed for all lakes surveyed in 2006. Only lakes with impairments are listed.

	Primary Contact Recreation			**Secondary Contact Recreation**	
Lake	**EN**	**TN**	***E. coli***	**EN**	**TN**
Augusta Santa Fe Lake	X			X	
Blue Mound City Lake	X				
Cedar Creek Lake	X				
Clinton Lake	X				
Gardner City Lake	X				
Geary Co. SFL	X				
Harvey Co. East Lake	X			X	
Lake Crawford	X				
Lake Scott	X			X	
Lake Shawnee	X			X	
Lake Warnock	X			X	
Miami Co. SFL	X			X	
Mission Lake	X			X	
Perry Lake	X				
Pratt Co. Lake	X			X	
Quivera Big Salt Marsh	X			X	
Quivera Little Salt Marsh	X			X	
Sabetha City Lake	X				
Webster Lake	X			X	

Pesticides in Kansas Lakes, 2006

Detectable levels of at least one pesticide were documented in the main body of 19 lakes sampled in 2006 (57% of lakes surveyed for pesticides). Table 15 lists these lakes and the pesticides that were detected, along with the level measured and the analytical quantification limit. Three different pesticides, and two pesticide degradation byproducts, were noted in 2006. Of these five compounds, only atrazine currently has 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 79% of the total number of pesticide detections, and atrazine and/or its degradation byproducts were detected in all 19 of the lakes with pesticides. In addition to atrazine, five lakes had detectable levels of metolachlor (Dual) and three had detectable levels of acetochlor (Harness or Surpass). Ten lakes had detectable quantities of deethylatrazine or deisopropylatrazine.

In all cases, the presence of these pesticides was directly attributable to agricultural activity. None of the lakes surveyed in 2006 exceeded 3.0 ug/L of atrazine, but several lakes were of concern due to the number of pesticides detected. These include Augusta Santa Fe Lake, Cedar Creek Lake, Lake Shawnee, Mission Lake, and Tuttle Creek Lake.

Taste and Odor/Algal Bloom Investigations During 2006

From January 1, 2006, to January 1, 2007, eight investigations were undertaken within the auspices of the KDHE Taste & Odor/Algae Bloom Program. The results of these investigations are discussed below. Two of the investigations dealt with fishkills, one concerned taste and odor problems in drinking water, and five were in response to various types of aesthetic complaint.

On April 6, 2006, the KDHE Southcentral District Office responded to an inquiry about excessive algae growth in Stewart Creek near Udall, Kansas. The inquiry was specifically about the discharge from the Udall wastewater treatment facility, and whether it could be causing a perceived excessive growth of algae. Phytoplankton samples obtained by District Office staff contained a small community of mixed green and diatom species, fairly typical of Kansas streams. Filamentous algae, which turned out to be the primary concern, were described as occurring in “trace amounts” on April 6, 2006, during a site visit by KDHE District Office staff, leading them to determine there was no obvious impact from the Udall wastewater treatment facility.

Table 15. Pesticides levels documented during 2006 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, deisopropylatrazine = 0.3 ug/L, metolachlor = 0.25 ug/L, and acetochlor = 0.1 ug/L. Only those lakes with detectable levels of pesticides are reported.

Lake	**Pesticide**				
	Atrazine	**Deethyla trazine**	**Deisopropyl atrazine**	**Metolachlor**	**Acetochlor**
Augusta Santa Fe Lake	2.20	0.32		0.40	
Bone Creek Lake	0.58				
Cedar Creek Lake	1.50	0.76	0.42	0.88	
Centralia Lake	1.60	0.85	0.31		
Clinton Lake	0.95				0.10
Harvey Co. East Lake	0.64	0.35			
Kanopolis Lake	0.42				
Lake Crawford	0.54				
Lake Scott	1.40	0.43		0.27	
Lake Shawnee	1.60	0.32			0.11
Lake Warnock	1.30				
Madison City Lake	0.37				
Milford Lake	0.48	0.31			
Mission Lake	0.75	1.60		1.10	
Perry Lake	0.86				
Pratt Co. Lake	0.40				

	Pesticide				
Quivera Little Salt Marsh	0.43				
Sabetha City Lake	1.80	0.55			
Tuttle Creek Lake	1.30	0.53		1.10	0.15

On April 19, 2006, staff from the KDHE Southcentral District Office investigated a fishkill at a small lake in the Westridge housing addition in Wichita, Kansas. Samples contained a moderate sized algal community (66,000 cells/mL) composed mostly of *Aphanizomenon spp.* Although a blue-green bloom, the size of the community was not extreme. This, and the age of the fishkill when reported, made assigning a cause very uncertain.

On June 19, 2006, staff from the KDHE Northeast District Office submitted algae samples from a small lake in the Trianon Apartment complex in Topeka, Kansas, that had experienced a fishkill. Samples revealed a moderate sized community of green algae and small dinoflagellates (65,000 cells/mL). Identification of the dinoflagellate component was not possible because preservation of the sample had prompted the cells to lyse. The cause of the fishkill was named as stagnant conditions which caused dissolved oxygen sag.

On July 5, 2006, samples were received from the KDHE Southcentral District Office as part of a complaint investigation at a residential lake (a storm water retention lake in a west Wichita, Kansas, housing development). The organism of concern turned out to be a vascular aquatic plant, *Najas guadalupensis*, rather than phytoplankton.

On July 20, 2006, staff from the KDHE Northeast District Office submitted samples from an investigation on Bull Creek near Paola, Kansas. Algae samples revealed a surface bloom of *Euglena sp.*, which covered the stream with a bright red scum. Historically, these red surface scums have been indicative of stagnant, low flow, conditions in streams, particularly those with any degree of nutrient enrichment.

On August 17, 2006, almost exactly a year since its last major bloom, Miami Co. SFL was reported to have a severe algae bloom in progress. Staff from the KDHE Northeast District Office submitted samples, supplemented the following week by the scheduled survey of Miami Co. SFL as part of routine lake sampling activities. The August 17, 2006, samples contained an extremely large blue-green community composed of *Anabaena sp.* and *Microcystis aeruginosa*. Although an extremely large bloom, no fishkill was reported for the lake. However, a recreational advisory was issued by KDHE as a precautionary measure.

On September 6, 2006, a taste and odor problem was reported for Carbondale, Kansas, which uses Strowbridge Reservoir as its primary water supply source. KDHE Central Office staff collected an algae sample from the lake on September 7, 2006, which contained a very large, mixed, blue-green algae community (639,000 cells/mL). Given the type and size of the algae community, it was believed to be the cause of the taste and odor problems in the finished drinking water.

On September 18, 2006, a citizen complaint was received by the Governor's Office, which was then routed to KDHE for a response. The complaint concerned the perceived excessive growth of a particular plant at Winfield City Lake. However, the name of the plant given by the complainant did not correspond to any known species (*Sarbina sp.*). After multiple attempts to contact the complainant, a site visit was performed by the KDHE Stream Chemistry Monitoring Program staff while working in the Winfield area. Their survey of Winfield City Lake found no plants growing along the shorelines in any excessive amounts. Months after the investigation, the original complainant contacted staff and indicated the organism of concern was actually *Spartina sp.*, a fairly common grass associated with ditches and moister soils, and not with any actual plant growth in the lake proper. As this complaint seemed more related to a dispute over maintenance practices on city property, the complainant was referred to local city agencies.

CONCLUSIONS

The following conclusions are based on the lake monitoring data collected during 2006.

1) Trophic state data indicated that 11% of the lakes surveyed in 2006 had degraded, compared to their historic mean condition (i.e., their trophic state had increased). About 66% showed stable conditions over time, while 23% showed improved trophic state condition. Most of the improvement in trophic state can be attributed to the lingering impacts of prolonged drought (during 2000-2006) and, thus, lowered inputs of nutrients in runoff on nutrient limited systems.

2) Over 85% of the documented water quality impairments in these lakes were associated with high lake trophic status and nutrient enrichment. Other significant problems included low dissolved oxygen and high pH. Salinity and fluoride accounted for about 9% of impairments, while heavy metals and metalloids accounted for about 5%.

3) Over half of the lakes surveyed by KDHE had detectable levels of agricultural pesticides in 2006 (56% of lakes surveyed). As noted in previous years, atrazine was the most frequently detected pesticide.

4) General water clarity of Kansas lakes appears to have improved over the last few years.

Several years of continued summer drought conditions appear to be the most likely cause (see paragraph 1, above). This general observation was recently corroborated by staff of the Kansas Biological Survey (personal communication with Dr. Jerry deNoyelles, KBS, during the Fall of 2006).

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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.