Lake and Wetland Monitoring Program

2007 Annual Report

By

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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 39 Kansas lakes and wetlands during 2007. Eight of the lakes surveyed were large federal impoundments, 13 were State Fishing Lakes (SFLs) or other water bodies on state managed lands, 15 were city and county lakes, and three were wetland areas.

Of the 39 lakes and wetlands surveyed, 49% indicated trophic state conditions comparable to their historic mean water quality conditions. Another 28% indicated improved water quality conditions, over mean historic condition, as evidenced by a lowered lake trophic state. The remaining 23% 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 59% of the lakes surveyed during 2007. Nitrogen was identified as the primary limiting factor in 26% 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) (13%), or hydrological conditions (<3%). Although no lakes surveyed in 2007 were primarily light limited, 13% had small-to-moderate secondary influences from turbidity.

There were a total of 125 documented exceedences of Kansas numeric and narrative water quality criteria, or Environmental Protection Agency (EPA) water quality guidelines, in the lakes surveyed during 2007. Of these 125 exceedences, 39% pertained to the aquatic life use and 61% 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 71 lakes received UAA surveys during 2007.

Twenty-one lakes and wetlands (55% of those surveyed for pesticides) had detectable levels of at least one pesticide in their main bodies during 2007. Atrazine, or its degradation byproducts, were detected in 20 of these water bodies, once again making atrazine the most commonly documented pesticide in Kansas lakes. The highest observed atrazine concentration during 2007 lake and wetland sampling was 24.0 ug/L. A total of four different pesticides, and one pesticide degradation byproduct, were found in lakes during 2007.

Table of Contents

Page

Tables

Figures

Page

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 or 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 2007 Monitoring Activities

Staff of the KDHE Lake and Wetland Monitoring Program visited 39 Kansas lakes and wetlands during 2007. Eight of these water bodies are large federal impoundments last sampled in 2004 or as part of special projects, 13 are State Fishing Lakes (SFLs) or lakes on other state managed lands, 15 are city/county lakes (CLs and Co. lakes, respectively), and three are wetlands. Eighteen of the 39 lakes (46%) presently serve as either primary or back-up municipal or industrial water supplies. One new lake (Harveyville City Lake) was added back into the network for 2007. In addition to regular network surveys, 71 lake use attainability analyses (UAAs) were completed in 2007.

General information on the lakes surveyed during 2007 is compiled in Table 1. Figure 1 depicts the locations of the lakes surveyed in 2007. Figure 2 depicts the locations of all currently active sites within the Lake and Wetland Monitoring Program. Additionally, a total of nine 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 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.

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 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 2007.

Lake	Basin	Authority	Water Supply	Last Survey
Banner Creek Lake	Kansas/Lower Republican	City	yes	2003
Big Hill Lake	Verdigris	Federal	yes	2004
Bone Creek Lake	Marais des Cygnes	County	yes	2006
Butler Co. SFL	Walnut	State	no	2003
Cedar Creek Reservoir	Marais des Cygnes	County	yes	2006
Chanute Santa Fe Lake	Neosho	City	no	2003
Chase Co. SFL	Neosho	State	no	2003
Elk City Lake	Verdigris	Federal	yes	2004
Fall River Lake	Verdigris	Federal	yes	2004
Fort Scott City Lake	Marais des Cygnes	City	yes	2003
Harveyville City Lake	Marais des Cygnes	City	yes	1996
Herington Reservoir	Smoky Hill/Saline	City	yes	2003
Jamestown WMA	Kansas/Lower Republican	State	no	2004
Kirwin Lake	Solomon	Federal	no	2004
Lake Parsons	Neosho	City	yes	2004
Lake Warnock	Missouri	City	no	2006
Lone Star Lake	Kansas/Lower Republican	County	no	2003
Lovewell Lake	Kansas/Lower Republican	Federal	no	2004
Marais des Cygnes WMA	Marais des Cygnes	State	no	2004
Mined Land Lake #4	Neosho	State	no	2006
Mined Land Lake #6	Neosho	State	no	2003
Mined Land Lake #7	Neosho	State	no	2003
Mined Land Lake #12	Neosho	State	no	2003

Lake	Basin	Authority	Water Supply	Last Survey
Mined Land Lake #17	Neosho	State	no	2003
Mined Land Lake #27	Neosho	State	no	2003
Mined Land Lake #30	Neosho	State	no	2003
Miola Lake	Marais des Cygnes	City	yes	2004
Neosho WMA	Neosho	State	no	2004
Norton Lake	Upper Republican	Federal	yes	2004
Ottawa Co. SFL	Solomon	State	no	2003
Pleasanton Reservoir	Marais des Cygnes	City	yes	2003
Polk Daniels SFL	Verdigris	State	yes	2003
Pony Creek Lake	Missouri	City	yes	2003
Richmond City Lake	Marais des Cygnes	City	yes	2004
Shawnee Co. SFL	Kansas/Lower Republican	State	no	2003
Shawnee Mission Lake	Kansas/Lower Republican	City	no	2004
Toronto Lake	Verdigris	Federal	yes	2004
Waconda Lake	Solomon	Federal	yes	2004
Washington Co. SFL	Kansas/Lower Republican	State	no	2003

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, 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 39 lakes surveyed during 2007.

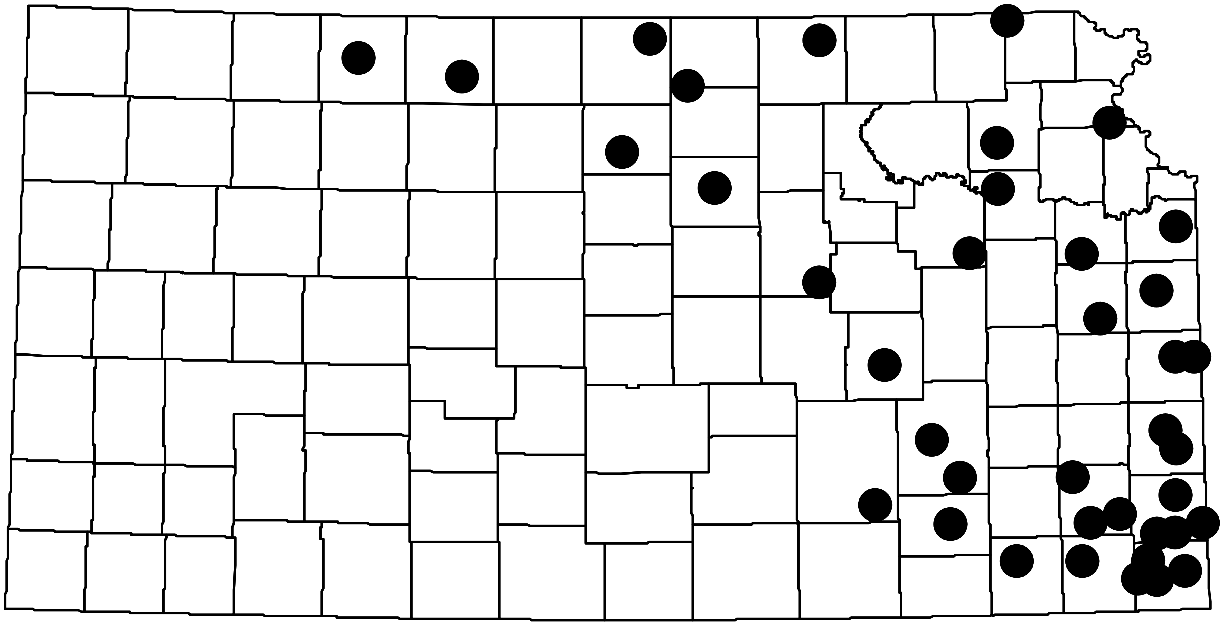
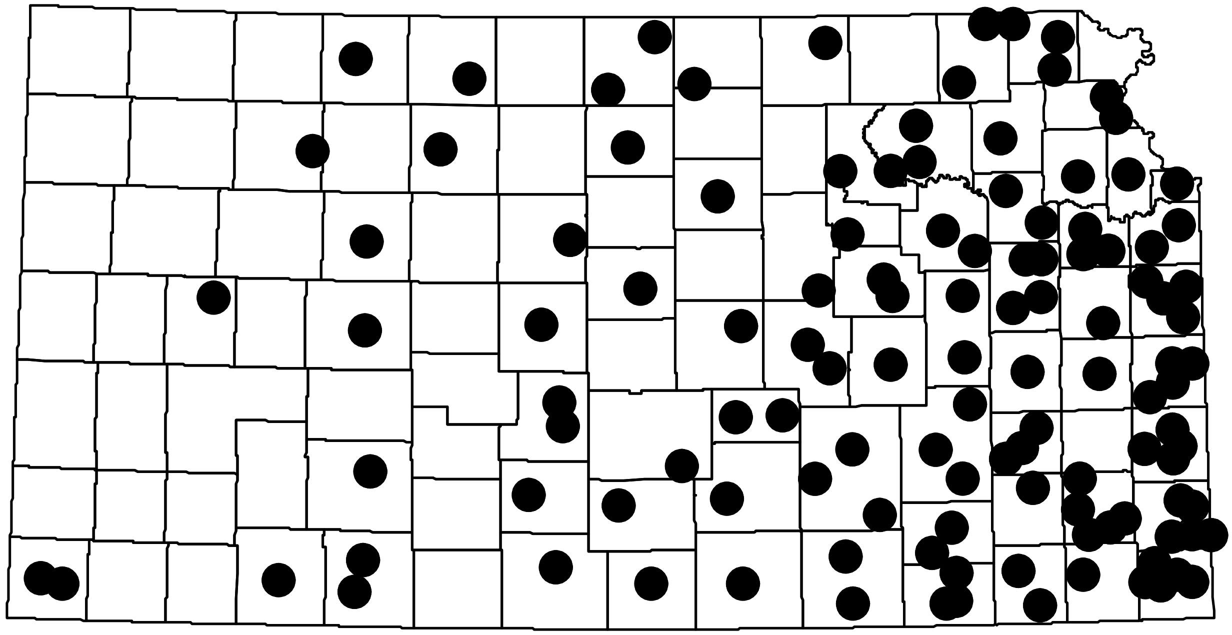


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program's network.



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 39 lakes surveyed during 2007, 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 2007 surveys was 28.2 ug/L (very eutrophic), while the median chlorophyll-a was 10.2 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. 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 $\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 30.01 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):

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

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 2007. 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 39 lakes this year was 147,379 cells/mL (median = 10,616 cells/mL).

Table 4 presents biovolume data for the 39 lakes surveyed in 2007. 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 30.98 ppm (median = 5.95 ppm).

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

during 2007. 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	2007 TSI/Class	Previous Trophic Class Period of Record Mean
Banner Creek Lake	53.8 SE	SE
Big Hill Lake	52.4 SE	SE
Bone Creek Lake	43.4 M	M
Butler Co. SFL	71.6 H	H
Cedar Creek Reservoir	51.2 SE	M
Chanute Santa Fe Lake	67.0 H	H
Chase Co. SFL	44.5 M	M
Elk City Lake	64.9 H	E
Fall River Lake	53.3 SE	SE
Fort Scott City Lake	53.3 SE	SE
Harveyville City Lake	47.2 M	SE
Herington Reservoir	55.9 E	VE
Jamestown WMA	80.2 H	H
Kirwin Lake	59.1 E	VE
Lake Parsons	56.7 E	A
Lake Warnock*	90.1 H(H)	H
Lone Star Lake	59.3 E	E
Lovewell Lake	65.6 H	VE
Marais des Cygnes WMA	57.2 E	H
Mined Land Lake #4	45.3 M	M
Mined Land Lake #6	48.3 M	H
Mined Land Lake #7*	36.1 OM(M)	OM
Mined Land Lake #12	40.3 M	OM

Lake	2007 TSI/Class	Previous Trophic Class Period of Record Mean
Mined Land Lake #17	48.7 M	OM
Mined Land Lake #27*	36.9 OM(M)	OM
Mined Land Lake #30	41.5 M	OM
Miola Lake	65.0 H	E
Neosho WMA	54.2 SE	H
Norton Lake	51.4 SE	E
Ottawa Co. SFL*	60.0 VE(VE)	VE
Pleasanton Reservoir	57.7 E	E
Polk Daniels SFL	54.8 SE	E
Pony Creek Lake	61.2 VE	VE
Richmond City Lake	49.3 M	SE
Shawnee Co. SFL	51.2 SE	SE
Shawnee Mission Lake	50.8 SE	M
Toronto Lake	57.7 E	SE
Waconda Lake	42.6 M	E
Washington Co. SFL	42.9 M	E

Trends in Trophic State

Table 5 summarizes changes in trophic status for the 39 lakes surveyed during 2007. Nine lakes (23.1%) displayed increases in trophic state, compared to their historic mean condition, while eleven lakes (28.2%) displayed improved trophic states. Stable conditions were noted in 19 lakes (48.7%).

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 newly re-added to the network, Harveyville City Lake had data from past surveys.

Only four lakes (Lake Warnock, Mined Land Lakes #7 and #27, and Ottawa Co. SFL) had macrophyte communities dense enough to cause an adjustment of trophic state designation to be considered. For Lake Warnock and Ottawa Co. SFL, no adjustment was deemed necessary. Therefore, only the Mined Land Lakes were actually adjusted due to macrophyte biomass, and those adjustments were very minor.

Table 3. Algal communities observed in the 39 lakes surveyed during 2007. 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**
Banner Creek Lake	49,487	7	89	4	<1
Big Hill Lake	62,937	0	99	0	1
Bone Creek Lake	2,426	91	0	4	5
Butler Co. SFL	182,007	0	96	4	0
Cedar Creek Reservoir	11,561	5	94	1	<1
Chanute Santa Fe Lake	122,787	6	89	4	1
Chase Co. SFL	6,143	0	94	0	6
Elk City Lake	60,323	20	79	<1	<1
Fall River Lake	11,592	1	93	4	2
Fort Scott City Lake	37,674	3	95	<2	<1
Harveyville City Lake	8,868	28	56	10	6
Herington Reservoir	6,017	3	63	33	1
Jamestown WMA	3,830,621	<1	98	1	<1
Kirwin Lake	15,750	30	56	12	2
Lake Parsons	5,513	5	69	22	4
Lake Warnock	746,141	0	97	3	<1
Lone Star Lake	50,054	12	87	1	0
Lovewell Lake	140,616	0	100	0	<1
Marais des Cygnes WMA	9,513	55	16	18	11
Mined Land Lake #4	1,260	15	0	33	52
Mined Land Lake #6	5,198	32	48	12	8
Mined Land Lake #7	3,560	28	69	2	1

	Cell Count	Percent Composition			
Mined Land Lake #12	284	55	0	0	45
Mined Land Lake #17	4,316	25	0	66	9
Mined Land Lake #27	5,355	9	91	0	0
Lake	**(cells/mL)**	**Green**	**Blue-Green**	**Diatom**	**Other**
Mined Land Lake #30	10,301	11	88	1	0
Miola Lake	88,767	2	97	1	0
Neosho WMA	9,261	37	57	6	0
Norton Lake	4,347	55	0	42	3
Ottawa Co. SFL	23,720	48	24	22	6
Pleasanton Reservoir	82,089	9	84	7	0
Polk Daniels SFL	10,616	36	0	63	1
Pony Creek Lake	73,710	<2	89	9	<1
Richmond City Lake	5,576	31	41	27	1
Shawnee Co. SFL	24,161	<1	98	2	<1
Shawnee Mission Lake	9,041	15	66	14	5
Toronto Lake	20,601	2	89	9	<1
Waconda Lake	4,410	11	85	1	3
Washington Co. SFL	1,166	38	0	8	54

Of the 16 lakes receiving macrophyte surveys (14 full surveys and two limited observational surveys), 13 (81% of those surveyed, 33% of all lakes in 2007) 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*), 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 observed abundance of aquatic plants during 2007, seven water bodies appeared to merit further assessment of the macrophyte community trophic classification. Three of these were assessed as eutrophic communities (Mined Land Lakes #7 and #27, and Washington Co. SFL), two as very eutrophic communities (Mined Land Lake #4 and Pony Creek Lake), and two on the threshold between eutrophic and very eutrophic (Lake Warnock and Ottawa Co. SFL), based on only the macrophyte community data. Four of these seven lakes also had dense enough plant beds to merit consideration of an adjustment to their overall trophic classification, although only two of those actually were adjusted higher (Table 2).

Table 4. Algal biovolumes calculated for the lakes surveyed during 2007. 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**
Banner Creek Lake	6.417	36	27	28	9
Big Hill Lake	5.217	0	81	0	19
Bone Creek Lake	1.655	82	0	1	17
Butler Co. SFL	63.325	0	83	17	0
Cedar Creek Reservoir	4.443	3	90	4	3
Chanute Santa Fe Lake	33.475	4	65	12	19
Chase Co. SFL	1.920	0	60	0	40
Elk City Lake	26.461	22	72	3	3
Fall River Lake	5.950	2	65	22	11
Fort Scott City Lake	5.716	4	75	9	12
Harveyville City Lake	2.544	8	43	24	25
Herington Reservoir	8.318	<1	19	67	14
Jamestown WMA	182.193	6	53	29	12
Kirwin Lake	12.526	19	14	52	15
Lake Parsons	9.087	1	40	44	15
Lake Warnock	661.879	0	93	6	1
Lone Star Lake	12.797	24	67	9	0
Lovewell Lake	29.445	0	93	0	7
Marais des Cygnes WMA	9.911	22	3	37	38
Mined Land Lake #4	2.117	5	0	8	87

	Biovolume	Percent Composition			
Mined Land Lake #6	3.347	10	14	11	65
Mined Land Lake #7	0.603	29	43	22	6
Mined Land Lake #12	1.138	26	0	0	74
Mined Land Lake #17	3.544	7	0	37	56
Mined Land Lake #27	0.674	20	80	0	0
Lake	**(ppm)**	**Green**	**Blue-Green**	**Diatom**	**Other**
Mined Land Lake #30	1.206	18	74	8	0
Miola Lake	26.227	10	77	13	0
Neosho WMA	6.626	26	67	7	0
Norton Lake	4.953	12	0	66	22
Ottawa Co. SFL	14.126	22	8	37	33
Pleasanton Reservoir	10.265	23	65	12	0
Polk Daniels SFL	6.909	11	0	86	3
Pony Creek Lake	16.402	3	78	17	2
Richmond City Lake	3.439	30	13	55	2
Shawnee Co. SFL	4.593	1	89	9	<1
Shawnee Mission Lake	4.393	10	37	23	30
Toronto Lake	10.656	2	62	34	2
Waconda Lake	2.017	9	30	1	60
Washington Co. SFL	1.637	6	0	8	86

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	5	12.8
Improved One Class Ranking	6	15.4
Stable	19	48.7

Degraded One Class Ranking	7	17.9
Degraded ≥ Two Class Rankings	2	5.2
Total	39	100.0

* = One of these lakes (Lake Parsons) 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.

Table 6. Macrophyte community structure in the 16 lakes surveyed for macrophytes during 2007. 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**
Butler Co. SFL	<5%	No species observed.
Chanute Santa Fe Lake	<5%	No species observed.
Chase Co. SFL	<7%	No species observed.
Lake Warnock	80%	80% *Ceratophyllum demersum* 80% *Myriophyllum spicatum* 80% *Najas guadalupensis* 80% *Potamogeton pectinatus*
Mined Land Lake #4	80%	80% *Nymphaea sp.* 30% *Nuphar sp.*
Mined Land Lake #6	80%	80% *Najas guadalupensis*
Mined Land Lake #7	70%	70% *Myriophyllum spicatum* 60% *Najas guadalupensis* 60% *Potamogeton illinoensis* 40% *Chara vulgaris* 40% *Potamogeton pectinatus* 10% *Ceratophyllum demersum*
Mined Land Lake #12 (limited survey)	>90%	Access blocked by plant beds near boat ramp. Lake nearly full of plants. Abundant *Myriophyllum spicatum.*
Mined Land Lake #27	93%	93% *Chara zeylanica* 73% *Myriophyllum spicatum* 47% *Ceratophyllum demersum* 47% *Najas guadalupensis*

Lake	**% Total Cover**	**% Species Cover and Community Composition**	
		47%	*Potamogeton illinoensis*
Mined Land Lake #30	67%	67%	*Chara globularis*
Neosho WMA (limited survey)	>90%		Abundant mixed species community. First time macrophytes ever observed here.
Ottawa Co. SFL	87%	87%	*Ceratophyllum demersum*
		87%	*Myriophyllum spicatum*
		87%	*Najas guadalupensis*
		87%	*Nelumbo sp.*
		87%	*Potamogeton crispus*
		87%	*Potamogeton nodosus*
		87%	*Potamogeton pectinatus*
Pleasanton Reservoir	20%	20%	*Najas guadalupensis*
		5%	*Potamogeton illinoensis*
Pony Creek Lake	40%	40%	*Ceratophyllum demersum*
		40%	*Najas guadalupensis*
		40%	*Potamogeton nodosus*
		40%	*Potamogeton pectinatus*
Shawnee Co. SFL	75%	75%	*Potamogeton nodosus*
Washington Co. SFL	67%	67%	*Myriophyllum spicatum*
		53%	*Ceratophyllum demersum*
		7%	*Potamogeton illinoensis*

None of the lakes surveyed in 2007 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.

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. Mined Land Lake #12 and Ottawa Co. SFL, however, have a very high portion of total lake volume filled with submersed macrophyte beds. In these two somewhat rare situations, the extent of macrophyte beds likely does impair some recreational uses.

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 (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, this phenomenon is called “lake turnover.” Table 7 presents data related to thermal stratification in the 39 lakes surveyed in 2007 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 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 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.

Table 7. Stratification status of the 39 water bodies surveyed during 2007. 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
nner Creek Lake	08-07-2007	1.25	0.64	6.0-7.0	10.5	
g Hill Lake	07-30-2007	1.25	0.62	5.0-7.0	13.0	
ne Creek Lake	07-17-2007	1.68	0.75	2.0-4.0	14.0	
tler Co. SFL	07-30-2007	1.20	1.98	3.0-5.0	5.0	
dar Creek Reservoir	08-13-2007	2.08	0.63	2.0-4.0	15.0	
anute Santa Fe Lake	08-14-2007	1.69	0.83	2.0-5.0	9.0	
ase Co. SFL	07-09-2007	0.70	0.73	3.0-4.0	11.0	
k City Lake	09-04-2007	n.a.	n.a.	unknown	11.0	storms and wind
l River Lake	09-04-2007	0.50	0.14	not stratified	7.5	
rt Scott City Lake	08-13-2007	1.54	0.69	4.0-7.0	13.0	
rveyville City Lake	08-21-2007	n.a.	n.a.	unknown	6.0	no boat ramp
rington Reservoir	08-06-2007	n.a.	n.a.	unknown	9.0	too windy
nestown WMA	06-26-2007	n.a.	n.a.	not stratified	1.0	wetland
rwin Lake	06-25-2007	n.a.	n.a.	unknown	8.0	too low for boat acces
ke Parsons	07-30-2007	n.a.	n.a.	unknown	5.5	storms and lightning
ke Warnock	08-20-2007	n.a.	n.a.	unknown	3.5	see note below
ne Star Lake	07-10-2007	0.73	0.98	2.0-4.0	11.0	
vewell Lake	06-26-2007	0.38	1.06	3.0-7.0	9.5	

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
arais des Cygnes WMA	06-18-2007	n.a.	n.a.	unknown	2.0	wetland
ned Land Lake #4	07-17-2007	2.60	1.76	2.0-4.0	9.0	
ned Land Lake #6	07-16-2007	n.a.	n.a.	unknown	5.5	too low for boat acces
ned Land Lake #7	07-17-2007	2.71	1.17	3.0-5.0	9.0	
ned Land Lake #12	07-17-2007	n.a.	n.a.	unknown	6.0	boat ramp blocked
ned Land Lake #17	07-16-2007	n.a.	n.a.	unknown	15.0	boat ramp not useabl
ned Land Lake #27	07-16-2007	1.95	0.88	3.0-6.0	11.0	
ned Land Lake #30	07-16-2007	1.42	0.42	4.0-6.0	19.0	
ola Lake	07-25-2007	1.50	1.09	3.0-5.0	8.0	
osho WMA	08-14-2007	n.a.	n.a.	not stratified	1.0	wetland
rton Lake	06-25-2007	0.20	0.38	not stratified	6.0	
tawa Co. SFL	06-20-2007	0.83	1.90	1.0-3.0	3.5	
easanton Reservoir	08-13-2007	2.21	1.14	3.0-5.0	7.0	
lk Daniels SFL	07-30-2007	n.a.	n.a.	unknown	8.0	see note below
ny Creek Lake	08-15-2007	1.10	0.69	6.0-7.0	10.0	
chmond City Lake	07-25-2007	n.a.	n.a.	unknown	9.0	see note below
awnee Co. SFL	08-07-2007	1.56	0.83	4.0-6.0	9.0	
awnee Mission Lake	08-28-2007	n.a.	n.a.	unknown	10.0	too low for boat acces
ronto Lake	09-04-2007	0.30	1.36	not stratified	5.5	
aconda Lake	06-25-2007	n.a.	n.a.	unknown	15.0	too windy
ashington Co. SFL	06-19-2007	1.00	1.38	3.0-4.0	5.0	

Note: Although not as pronounced a problem as during 2006, there were still a number of lakes in 2007 which had their profile data collection omitted for various reasons including low water, mud or plant choked boat ramps, windy conditions, lightning in the vicinity, or logistical decisions. Polk Daniels SFL had profile data collection omitted in order to complete planned work at another site before sunset, Richmond City Lake had profile data omitted because the city no longer allows gas motors on the lake, and Lake Warnock was included in a trip to collect UAA samples from a number of small lakes without boat access. Given the previous low water conditions at Lake Warnock, attempting profile data collection in 2007 was deemed questionable. Fully 59.0% of lakes in 2007 had profile data collected (as compared to only 46% in 2006), while 15.4%

of lakes had profile data uncollected by design. The remaining 25.6% did not have profile data collected due to one or more of the reasons listed above.

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 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, 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 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 39 lakes surveyed in 2007, the calculated euphotic-to-mixed depth ratios suggest that light penetrated throughout the mixed zone in just over half of them (mean = 4.87, median = 1.03). 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 = 137 cm; non-algal turbidity: mean = 0.65 m^{-1}, median = 0.36 m^{-1}) (Walker, 1986). Table 8 presents data for 2007 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 or conditions return to historic norms for precipitation and runoff. So far in late 2007 and early 2008, weather and precipitation seem to be returning towards historic levels.

Table 8. Water clarity metrics for the 39 lakes surveyed in 2007. 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**
Banner Creek Lake	10.65	147	0.414	1.02
Big Hill Lake	9.25	186	0.306	0.81
Bone Creek Lake	3.70	270	0.278	1.09
Butler Co. SFL	65.25	82	<0.001	0.94
Cedar Creek Reservoir	8.18	163	0.409	0.88
Chanute Santa Fe Lake	40.85	102	<0.001	0.76
Chase Co. SFL	4.15	137	0.626	1.06
Elk City Lake	33.00	34	2.116	0.41
Fall River Lake	10.15	58	1.470	0.88
Fort Scott City Lake	10.10	154	0.397	0.92
Harveyville City Lake	5.45	170	0.452	1.66
Herington Reservoir	13.20	58	1.394	0.80
Jamestown WMA	156.95	12	4.410	26.28
Kirwin Lake	18.30	150	0.209	1.03
Lake Parsons	14.30	80	0.893	1.29

Lake	**Chlorophyll-a (ug/L)**	**Secchi Disk Depth (cm)**	**Non-Algal Turbidity (m^{-1})**	**Euphotic to Mixed Depth Ratio**
Lake Warnock	432.80	36	<0.001	0.36
Lone Star Lake	18.70	121	0.359	0.86
Lovewell Lake	35.45	112	0.007	0.70
Marais des Cygnes WMA	15.15	60	1.288	4.27
Mined Land Lake #4	4.50	216	0.350	0.96
Mined Land Lake #6	6.10	200	0.348	1.35
Mined Land Lake #7	1.75	292	0.299	1.05
Mined Land Lake #12	2.70	350	0.218	1.45
Mined Land Lake #17	6.35	180	0.397	0.66
Mined Land Lake #27	1.90	390	0.209	0.96
Mined Land Lake #30	3.05	280	0.281	0.68
Miola Lake	33.50	117	0.017	0.90
Neosho WMA	11.10	≥100	≤0.723	≥129.90
Norton Lake	8.40	79	1.056	1.27
Ottawa Co. SFL	20.05	86	0.662	1.97
Pleasanton Reservoir	15.90	160	0.228	1.28
Polk Daniels SFL	11.80	220	0.160	1.30
Pony Creek Lake	22.80	134	0.176	0.90
Richmond City Lake	6.75	166	0.434	1.21
Shawnee Co. SFL	8.15	133	0.548	1.13
Shawnee Mission Lake	7.85	190	0.330	1.16
Toronto Lake	15.90	47	1.730	1.05
Waconda Lake	3.40	250	0.315	0.85
Washington Co. SFL	3.50	48	1.996	1.24

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 2007 sampling season. Eleven of the 39 lakes surveyed for *E. coli* bacteria in 2007 (28%) had measurable levels of *E. coli* (i.e., greater than the analytical reporting limit of 10 cfu/100mL). Although no lake in 2007 exceeded existing criteria (KDHE, 2005b), four lakes had *E. coli* counts of >90 cfu/100mL and one lake (Butler Co. SFL) came very close to the single sample criterion for primary contact recreation. The mean *E. coli* count among these 39 lakes ranges between 34 and 43 cfu/100mL (assuming the non-detects were assigned either zero values or the reporting limit, respectively) while the median value was <10 cfu/100mL.

Table 9. *E. coli* bacterial counts (mean of duplicate samples) from the 39 lakes and wetlands surveyed for *E. coli* bacteria during 2007. 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
Banner Creek Lake	open water	<10
Big Hill Lake	open water	<10
Bone Creek Lake	open water	<10
Butler Co. SFL	open water	887

Lake	Site Location	*E. Coli* Count
Cedar Creek Reservoir	open water	<15
Chanute Santa Fe Lake	open water	<10
Chase Co. SFL	open water	<10
Elk City Lake	off dam	<26
Fall River Lake	open water	<10
Fort Scott City Lake	open water	<10
Harveyville City Lake	off dam	<10
Herington Reservoir	off dam	<10
Jamestown WMA	off dam	93
Kirwin Lake	off dam	10
Lake Parsons	off dam	110
Lake Warnock	off dam	20
Lone Star Lake	open water	<10
Lovewell Lake	open water	10
Marais des Cygnes WMA	open water	<10
Mined Land Lake #4	open water	<10
Mined Land Lake #6	off dam	<10
Mined Land Lake #7	open water	<10
Mined Land Lake #12	off dam	<10
Mined Land Lake #17	off dam	<10
Mined Land Lake #27	open water	<10
Mined Land Lake #30	open water	<10
Miola Lake	open water	<10
Neosho WMA	open water	10
Norton Lake	open water	<15
Ottawa Co. SFL	open water	10
Pleasanton Reservoir	open water	161
Polk Daniels SFL	off dam	<10

Lake	Site Location	*E. Coli* Count
Pony Creek Lake	open water	<10
Richmond City Lake	off dam	15
Shawnee Co. SFL	open water	<10
Shawnee Mission Lake	off dam	<10
Toronto Lake	open water	<10
Waconda Lake	off dam	20
Washington Co. SFL	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 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 2007. 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 2007 season, one lake (Washington Co. SFL) may have had some lingering impacts from recent rains.

As indicated in Table 10, phosphorus was the primary limiting factor identified for lakes surveyed in 2007. Twenty-three of the 39 lakes (59.0%) were determined to be primarily limited by phosphorus. Ten lakes (25.6%) were determined to be primarily nitrogen limited. No lakes were primarily light limited in the 2007 season, although 13% of them indicated some secondary level of influence with respect to light availability. Another five lakes (12.8%) were co-limited by phosphorus and nitrogen. One lake seemed primarily limited by recent hydrological conditions. Mean TN/TP ratio was 27.2 for the lakes surveyed in 2007 (median = 21.9). Interquartile ranges for TN/TP ratios were 27.3-to-47.8 for phosphorus limited lakes, 5.9-to-8.8 for nitrogen limited lakes, and 12.3-to-13.6 for lakes co-limited by phosphorus and nitrogen.

Table 10. Limiting factor determinations for the 39 lakes surveyed during 2007. 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**
Banner Creek Lake	59.0	0.414	1.462	15.66	1.065	2.402	4.62	P
Big Hill Lake	77.0	0.306	1.456	17.21	0.925	2.555	6.36	P
Bone Creek Lake	62.0	0.278	1.147	9.99	0.370	1.529	4.51	P
Butler Co. SFL	6.5	<0.001	<0.010	53.51	0.544	2.510	4.90	N
Cedar Creek Reservoir	56.7	0.409	2.058	12.47	0.447	2.930	5.71	P
Chanute Santa Fe Lake	11.1	<0.001	<0.010	41.67	0.571	3.151	6.13	N>P
Chase Co. SFL	13.6	0.626	2.271	5.69	0.189	2.648	4.47	(P=N)>L
Elk City Lake	11.4	2.116	8.890	11.22	0.410	12.356	11.94	(N≥P)=L
Fall River Lake	25.6	1.470	4.432	5.89	0.308	5.197	5.26	P≥L
Fort Scott City Lake	30.4	0.397	1.577	15.55	0.449	2.581	5.24	P
Harveyville City Lake	37.0	0.452	1.092	9.06	0.274	1.420	2.76	P
Herington Reservoir	7.9	1.394	4.481	7.66	0.145	5.542	5.81	N≥L
Jamestown WMA	5.9	4.410	0.109	18.83	0.177	0.207	0.96	N>C
Kirwin Lake	5.9	0.209	0.670	27.45	0.070	2.136	4.49	N

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Lake Parsons	12.3	0.893	1.997	11.44	0.193	2.797	3.54	P=N
Lake Warnock	17.1	<0.001	<0.010	155.81	1.519	3.960	13.24	P=N
Lone Star Lake	18.1	0.359	1.302	22.63	0.360	2.998	5.49	P
Lovewell Lake	16.3	0.007	0.025	39.70	0.645	3.331	6.82	P>N
Marais des Cygnes WMA	8.0	1.288	0.774	9.09	0.112	1.001	1.40	N>P
Mined Land Lake #4	38.0	0.350	1.564	9.72	0.450	2.066	5.28	P
Mined Land Lake #6	34.5	0.348	1.059	12.20	0.277	1.524	3.43	P
Mined Land Lake #7	39.5	0.299	1.333	5.11	0.175	1.528	4.80	P
Mined Land Lake #12	24.0	0.218	0.715	9.45	0.270	0.937	3.22	P
Mined Land Lake #17	50.0	0.397	2.404	11.43	0.635	3.365	9.23	P
Mined Land Lake #27	45.5	0.209	1.063	7.41	0.190	1.305	5.60	P
Mined Land Lake #30	43.0	0.281	1.897	8.54	0.305	2.411	10.20	P
Miola Lake	29.0	0.017	0.051	39.20	1.136	2.543	5.11	P
Neosho WMA	4.3	<0.723	<0.018	>11.10	0.065	<0.025	<0.19	N
Norton Lake	9.1	1.056	2.537	6.64	0.060	3.041	3.59	N>P
Ottawa Co. SFL	5.4	0.662	0.943	17.24	0.065	1.658	2.45	N
Pleasanton Reservoir	29.6	0.228	0.616	25.44	0.649	1.692	3.59	P
Polk Daniels SFL	21.9	0.160	0.475	25.96	0.445	1.352	3.55	P
Pony Creek Lake	13.3	0.176	0.605	30.55	0.383	2.560	5.24	P≥N

Lake	**TN/TP**	**NAT**	**Z_{mix}*NAT**	**Chl-a*SD**	**Chl-a/TP**	**Z_{mix}/SD**	**Shading**	**Factors**
Richmond City Lake	61.5	0.434	1.394	11.21	0.675	1.936	3.82	P
Shawnee Co. SFL	42.5	0.548	1.762	10.84	0.815	2.417	4.12	P
Shawnee Mission Lake	16.4	0.330	1.132	14.92	0.204	1.806	4.06	P>N
Toronto Lake	11.8	1.730	3.778	7.47	0.250	4.646	4.38	(N>P)≥L
Waconda Lake	43.1	0.315	1.647	8.50	0.151	2.092	6.40	P
Washington Co. SFL	17.4	1.996	4.108	1.68	0.021	4.288	3.70	Hydrology>P

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

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 $TSI_{(Secchi)}-TSI_{(Chl\text{-}a)}$ and for $TSI_{(TP\text{ or }TN)}-TSI_{(Chl\text{-}a)}$. 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 2007 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 2007 sampling season. These data were generated by computerized comparison of the 2007 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 ≤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 eighteen 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 compare fairly well with the assessment system presently in use.

With respect to the aquatic life support use, eutrophication, high pH, and low dissolved oxygen comprised the primary water quality concerns during 2007 (Table 12). Sixteen lakes exhibited trophic states high enough to impair long or short term aquatic life support. Eleven lakes had low dissolved oxygen conditions within the top 3.0 meters of the water column. Two lakes had pH levels high enough to impact aquatic life support (>8.5 S.U.), while one lake had low pH (<6.5 S.U.).

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, 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. Lakes with elevated pH are also reflective of high trophic state and algal and/or macrophytic production.

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

There were 18 lakes with exceedences of water supply criteria and/or guidelines during 2007 (Table 13). The majority were for eutrophication related conditions. Irrigation use criteria were exceeded in nine lakes and livestock watering criteria were exceeded in 12 lakes.

Table 14 lists 17 lakes with trophic state/turbidity conditions high enough to have impaired contact recreational uses. The trophic state of nine lakes was high enough to have impaired secondary contact recreation during 2007.

In all, there were 125 exceedences of numeric or narrative criteria, water quality goals, or EPA guidelines documented in Kansas lakes during 2007. Approximately 39% of these exceedences related to aquatic life support, 36% related to consumptive uses of water, and 25% related to recreational uses. Eutrophication, high pH, or low dissolved oxygen accounted for 79% of documented water quality impacts in 2007. Only about 7% of the impacts were linked to pesticides or heavy metals and metalloids. Exceedences listed in this report section, and in Tables 12-14, apply to lakes and/or wetlands where Use Attainability Analyses (UAAs) have shown the affected use to be either existing or attainable.

Pesticides in Kansas Lakes, 2007

Detectable levels of at least one pesticide were documented in the main body of 21 lakes sampled in 2007 (55% 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. Four different pesticides, and one pesticide degradation byproduct, were noted in 2007. Of these five compounds, atrazine and picloram 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 81% of the total number of pesticide detections, and atrazine and/or its degradation byproducts were detected in 20 of the lakes with pesticides. In addition to atrazine, four lakes had detectable levels of metolachlor (Dual). One lake had detectable levels of acetochlor (Harness or Surpass) and one lake had detectable levels of picloram (Tordon). Five lakes had detectable quantities of deethylatrazine.

In all cases, the presence of these pesticides was directly attributable to agricultural activity, although the picloram detection in Richmond City Lake may have been due to brush control activity as well. Atrazine levels in two lakes surveyed in 2007 exceeded 3.0 ug/L. Three lakes were of concern due primarily to the number of pesticides detected. These included Herington Reservoir, Jamestown WMA, and Pony Creek Lake (Table 15).

Table 12. Chemical and biological parameters not complying with chronic and acute aquatic life support (ALS) criteria in lakes surveyed during 2007. DO = dissolved oxygen, EN = eutrophication or high nutrient load, T = turbidity, Cu = copper, and Atz = atrazine. Only those lakes with some documented water quality problem are included in Tables 12, 13, and 14.

	Chronic ALS					**Acute ALS**			
Lake	**EN***	**T***	**pH***	**Cu**	**Atz**	**EN***	**T***	**DO**	**pH***
Butler Co. SFL	X					X			
Cedar Creek Reservoir								X	X
Chanute Santa Fe Lake	X					X		X	
Elk City Lake	X	X				X	X		
Herington Reservoir	X								
Jamestown WMA	X	X			X	X	X		
Kirwin Lake	X								
Lake Parsons	X								
Lake Warnock	X				X	X			X
Lone Star Lake	X							X	
Lovewell Lake	X					X			
Marais des Cygnes WMA	X							X	
Mined Land Lake #4			X					X	X
Mined Land Lake #7								X	
Miola Lake	X					X		X	
Ottawa Co. SFL	X					X		X	
Pleasanton Reservoir	X			X				X	
Pony Creek Lake	X					X			
Toronto Lake	X	X						X	
Washington Co. SFL		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 2007. EN = high trophic state/nutrients, SO_4 = sulphate, Atz = atrazine, and As = arsenic. Only lakes with documented exceedences are included within the table. UAAs have been completed for all lakes surveyed in 2007.

	Water Supply				**Irrigation**	**Livestock Water**		**Food Procurement**
Lake	**EN**	**SO_4**	**Atz**	**As**	**EN**	**EN**	**SO_4**	**As**
Butler Co. SFL	X				X	X		
Chanute Santa Fe Lake	X				X	X		
Elk City Lake	X				X	X		
Herington Reservoir	X							
Jamestown WMA	X		X	X	X	X		
Kirwin Lake	X			X				
Lake Parsons	X							
Lake Warnock	X		X	X	X	X		X
Lone Star Lake	X							
Lovewell Lake	X				X	X		
Marais des Cygnes WMA	X							
Mined Land Lake #4		X						
Mined Land Lake #7							X	
Mined Land Lake #17							X	
Mined Land Lake #30							X	
Miola Lake	X				X	X		
Ottawa Co. SFL	X				X	X		
Pleasanton Reservoir	X							
Pony Creek Lake	X				X	X		
Toronto Lake	X							
Waconda Lake		X						

Table 14. Exceedences of numeric and narrative recreational guidelines for lakes surveyed during 2007. 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 2007. Only lakes with impairments are listed.

	Primary Contact Recreation			**Secondary Contact Recreation**	
Lake	**EN**	**TN**	***E. coli***	**EN**	**TN**
Butler Co. SFL	X		(X)[*]	X	
Chanute Santa Fe Lake	X			X	
Elk City Lake	X	X		X	X
Herington Reservoir	X				
Jamestown WMA	X	X		X	X
Kirwin Lake	X				
Lake Parsons	X				
Lake Warnock	X			X	
Lone Star Lake	X				
Lovewell Lake	X			X	
Marais des Cygnes WMA	X				
Miola Lake	X			X	
Ottawa Co. SFL	X			X	
Pleasanton Reservoir	X				
Pony Creek Lake	X			X	
Toronto Lake	X	X			
Washington Co. SFL		X			

* = Although the *E. coli* count for Butler Co. SFL did not surpass the single sample criterion for primary contact recreation, it came close to exceeding this value. Given the unusual nature of high bacterial counts in Kansas lakes, this is flagged here. In the case of Butler Co. SFL, the likely source of *E. coli* is a confined animal feeding operation located just upstream in the watershed.

Table 15. Pesticides levels documented during 2007 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 picloram = 0.8 mg/L. Only those lakes with detectable levels of pesticides are reported.

		Pesticide			
Lake	**Atrazine**	**Deethylatrazine**	**Metolachlor**	**Acetochlor**	**Picloram**
Banner Creek Lake	0.57				
Big Hill Lake	0.50				
Bone Creek Lake	0.52				
Fall River Lake	0.35				
Herington Reservoir	0.50	0.40	0.90	0.11	
Jamestown WMA	24.00	2.30	3.10		
Kirwin Lake	0.92				
Lake Parsons	0.35				
Lake Warnock	5.70	0.55			
Lone Star Lake	1.80				
Lovewell Lake	1.90		0.59		
Marais des Cygnes WMA	0.82				
Mined Land Lake #30	0.79				
Miola Lake	0.61				
Neosho WMA	0.71				
Norton Lake	1.30				
Polk Daniels SFL	0.69				
Pony Creek Lake	2.90	0.45	1.10		
Richmond City Lake					0.81
Waconda Lake	0.88				

	Pesticide				
Washington Co. SFL	1.50	0.41			

Taste and Odor/Algal Bloom Investigations During 2007

From January 1, 2007, to January 1, 2008, nine investigations were undertaken within the auspices of the KDHE Taste & Odor/Algae Bloom Program. The results of these investigations are discussed below. Three of the investigations dealt with fishkills, two concerned taste and odor problems in drinking water, three were in response to various types of aesthetic complaint, and one was due to continuing algal blooms and an animal kill complaint at a lake.

On May 31, 2007, Montgomery Co. Environmental Health Department staff submitted algae samples related to an aesthetic complaint at Tow Lake. The lake had a distinct orange-brown appearance with an oily surface scum. Samples contained a moderate population of euglenoid algae, plus an abundance of orange colored detrital matter. Larger pieces of the detrital matter looked much like exuviae from some aquatic insect. The overall sheltered and stagnant conditions at the lake were offered as the ultimate cause of the aesthetic problems, with the detrital matter as the most likely source of the color reported.

On June 12, 2007, algae samples were submitted regarding taste and odor problems in drinking water from Banner Creek Lake near Holton, Kansas. The particular taste and odor complaints were for earthy/musty odor in the finished water and a bitter taste. Algae samples indicated a large blue-green algae bloom (148,000 cells/mL), composed mostly of *Microcystis aeruginosa*. Chlorophyll-a levels were in the 27-32 ug/L range. Banner Creek Lake was later surveyed as part of the 2007 ambient field work and is discussed elsewhere in this report. By August, the bloom appeared to have passed and the lake looked close to its historic norm.

In early July, 2007, Marion Lake was again in the public eye related to blue-green algae blooms. This time, however, the main concern was the reported illness/death of dogs after they immersed in, and drank from, Marion Lake. Although algae samples collected July 9, 2007, indicated only low-to-moderate blue-green algae communities, veterinary toxicologists at Kansas State University concluded that blue-green algal toxicosis appeared "to be the likely cause of death" after conducting a necropsy on the frozen carcass of the one dog that died.

On July 23, 2007, samples were collected from Washington Creek downstream of Lone Star Lake in relation to a complaint about copper colored and black colored areas in the stream, accompanied by a fishkill. The algae samples submitted contained only a small mixed-species algae community, which was unlikely to have caused the reported conditions. Dissolved oxygen was low in the stream at the time of the fishkill, and may have been due to stagnant conditions.

On July 24, 2007, samples were collected by KDHE Salina Office staff regarding a massive blue-green algae bloom and fishkill at Herington City Lake near Herington, Kansas. Samples were collected from several locations in the lake, which ranged from 50-220 ug/L chlorophyll-a, and were composed mostly of *Aphanizomenon flos-aqua*, with a smaller contribution from *Anabaena sp.* ELISA tests for microcystins indicated concentrations in the areas where algae were collecting might be in the >10-15 ug/L range. Algal cell counts in the lee areas of the lake were >200,000,000 cells/mL. Chlorophyll-a levels in these lee areas approached an amazing 150,000 ug/L. A health advisory was posted for Herington City Lake until the bloom had dissipated and did not return.

A fishkill was reported in Deer Creek, within the city of Topeka, on July 26, 2007. Algae samples indicated a community composed primarily of the Chrysophyte algae *Dinobryon sp.*, with a smaller contribution of large euglenoids and cryptophyte algae. Chlorophyll-a levels were 35-44 ug/L, indicating a fairly large algal biomass.

On September 14, 2007, an algae bloom was reported at the Trianon apartment complex lake in Topeka, Kansas. The sample was a monoculture of *Anabaena sp.*, with cell counts of 5,900,000 cells/mL and chlorophyll-a levels of around 2,700 ug/L. ELISA tests indicated microcystins were <0.5 ug/L and, fortunately, no fishkill resulted from the bloom.

On September 25, 2007, KDHE Wichita Office staff were called to a complaint in Harvey Co. regarding a spill in Sand Creek. Sand Creek was pink-to-red in color. Algae samples indicated the color was due to very small particulate matter, but not due to algae. The particulate matter was later determined to be bacterial and from a hog lagoon that had been de-watered upstream of the complaint site. Bacteria of a vivid pink color have been observed in hog lagoons in the past, and can serve as a diagnostic field characteristic for problems resulting from hog lagoon discharges.

On November 13, 2007, samples were submitted by the general manager of Public Wholesale Water Supply District #13, from a brand new water supply lake near Mound City, Kansas. The lake had been filled in June, 2007, and brought on-line as a water supply. Taste and odor problems had plagued PWWSD#13 since. The algae samples from November 13 had a moderate community of the blue-green algae *Coelosphaerium sp.*, with chlorophyll-a in the range of 22-32 ug/L. The general manager was informed that the lake might be experiencing a productivity spike or “trophic upsurge” common to newly filled artificial lakes, which occurs as inundated soils come to equilibrium with overlying waters (EPA, 1990). He was also advised that future problems would depend on the characteristics within the lake’s watershed, with taste and odor problems to be expected if the watershed was composed mostly of urban areas and/or cropland (see the Appendix in this report). If the lake’s watershed was mainly grassland and woods, problems might be expected to lessen after the initial spike in productivity passed.

CONCLUSIONS

The following conclusions are based on the lake monitoring data collected during 2007.

1) Trophic state data indicated that 23% of the lakes surveyed in 2007 had degraded, compared to their historic mean condition (i.e., their trophic state had increased). About 49% showed stable conditions over time, while 28% showed improved trophic state condition. Most of the improvement in trophic state was attributable to the lingering impacts of prolonged drought (2000-2006) and, thus, lowered inputs of nutrients in runoff.

2) Over 80% 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, turbidity, and high pH. Salinity accounted for about 4% of impairments, while pesticides, heavy metals, and metalloids accounted for about 7%.

3) Over half of the lakes surveyed by KDHE had detectable levels of agricultural pesticides in 2007 (55% of lakes surveyed). As noted in previous years, atrazine was the most frequently detected pesticide.

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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.

APPENDIX: The Relationship Between Watershed Land Use and Trophic State

Using the lake water quality data set from a recent lake reference condition analysis (Dodds et al., 2006), relationships were examined between lake trophic state and the prevalence of agricultural land within watersheds. When one looks at a statewide land use map of Kansas, it is clear that most of the state is characterized by either the presence of cultivated land (human influences), or the presence of grassland (analogous to pre-settlement land use even if not free of human impact). It is common knowledge that the widespread nature of agricultural activities in Kansas makes cropland one of the most important human contributions to nutrient pollution in general. Therefore, understanding the influence of watershed disturbance and land use on lake water quality is an important goal.

The data set previously used for determining statewide lake reference condition thresholds was altered to the extent necessary to conduct this analysis. Basically, the data set was updated for those lakes with data collected since 2002, and lakes were omitted if they had significant portions of their watersheds in urban drainage, point sources, or were believed to have sediment resuspension issues. The final list included 126 lakes that include monitoring network sites, special study lakes, and lakes evaluated by UAA and other synoptic survey projects. Several lakes added to the data set are new to the sampling network. For all lakes included in the analysis, the proportion of the watersheds in cropland, or grassland, were compared and contrasted to the trophic state variables of chlorophyll-a (Chl-a) and total phosphorus (TP).

The Influence of Agricultural Land Use on Lake Water Quality and Trophic State

The amount of cropland among the 126 watersheds ranged from zero to 95%, giving a full range of watershed conditions to examine. There was a significant correlation between percent cropland in the drainage and both trophic state variables. Linear regressions on log transformed data indicated a moderately strong predictive relationship between cropland levels and both chlorophyll-a and total phosphorus. Essentially, and without considering potential influences due to in-lake characteristics, geographic locations, or land use patterns within drainages, the total amount of cropland in a watershed explained 50% of the variability in chlorophyll-a and 60% of the variability in total phosphorus.

Correlations	**P Value =**	**R =**
Chlorophyll-a vs. Cropland	<0.001	+0.707
Total Phosphorus vs. Cropland	<0.001	+0.773

$\text{Log}_{10}(\text{Chl-a}) = 0.00973*(\%\ \text{Cropland}) + 0.867$ $P < 0.001$ $R^2 = 49.6\%$

$\text{Log}_{10}(\text{TP}) = 0.0114*(\%\ \text{Cropland}) + 1.27$ $P < 0.001$ $R^2 = 59.4\%$

Figure A1 shows chlorophyll-a for the data set, divided into five different land use classes based on cropland amounts. Figure A2 provides the same graphic for total phosphorus data. For all box-plot graphs, small white squares represent the median while small white ovals represent the mean value. As is evident from Kruskal-Wallace tests, both water quality parameters show a very significant (P<0.001) upward trend with increasing agricultural influences in the watershed. Based on these graphical analyses, there would appear to be a break point, between acceptable trophic state and water quality versus impaired water quality and beneficial uses, at roughly 20-50% cropland within a watershed. The mean trophic state for the <10% group was slightly eutrophic, while the 10-30% group was eutrophic on average. This compared to the 40-60% group, where the mean trophic state was hypereutrophic.

Figure A3 presents the probabilities, based on the percent occurrence within each land use group, for a lake being mesotrophic, eutrophic (the three eutrophic sub-classes), and hypereutrophic. This graphical analysis also supports the occurrence of a break point at 20-50% cropland within a watershed. Below this range, the likelihood of having very healthy water quality and lower trophic status is high. Above this range, the likelihood of poorer water quality conditions and use impairments increases substantially.

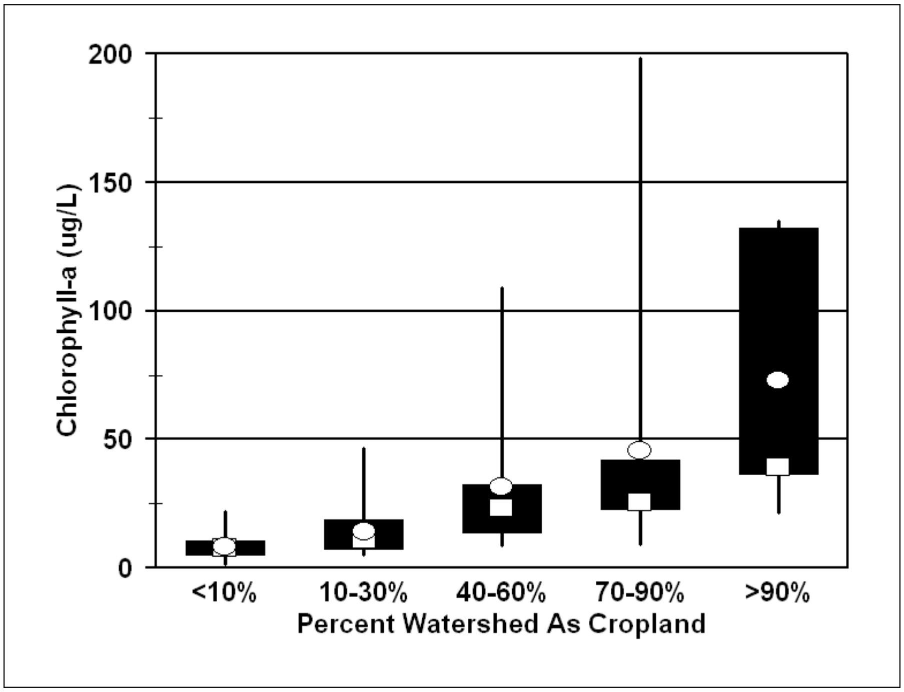


Figure A1. Mean chlorophyll-a versus watershed cropland amounts.

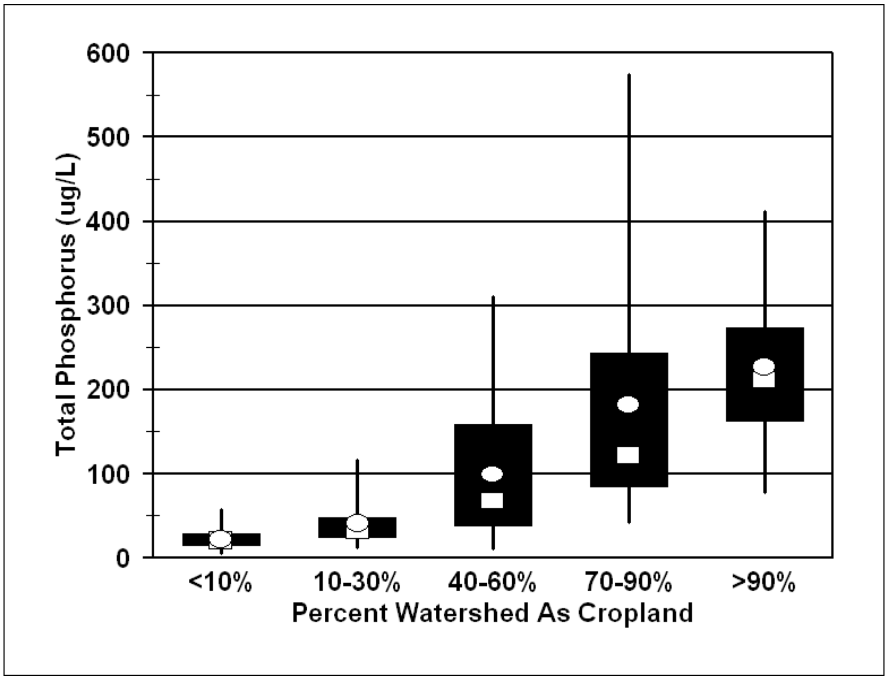
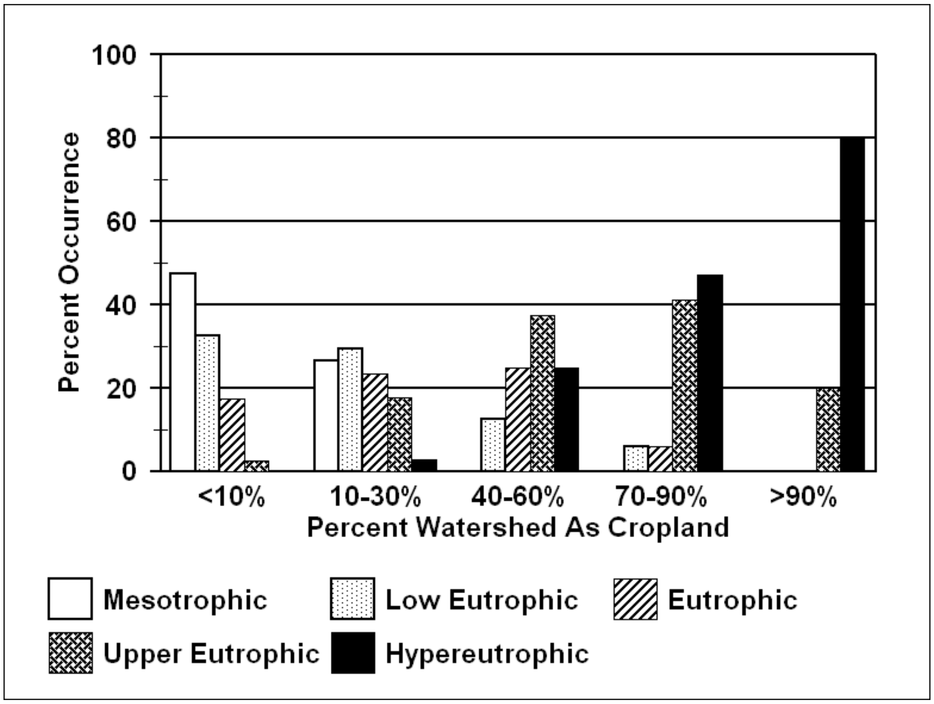


Figure A2. Mean total phosphorus versus watershed cropland amounts.

Figure A3. Likelihood of a lake being mesotrophic, eutrophic, or hypereutrophic (on average) versus percent watershed as cropland.



The Influence of Grassland on Lake Water Quality and Trophic State

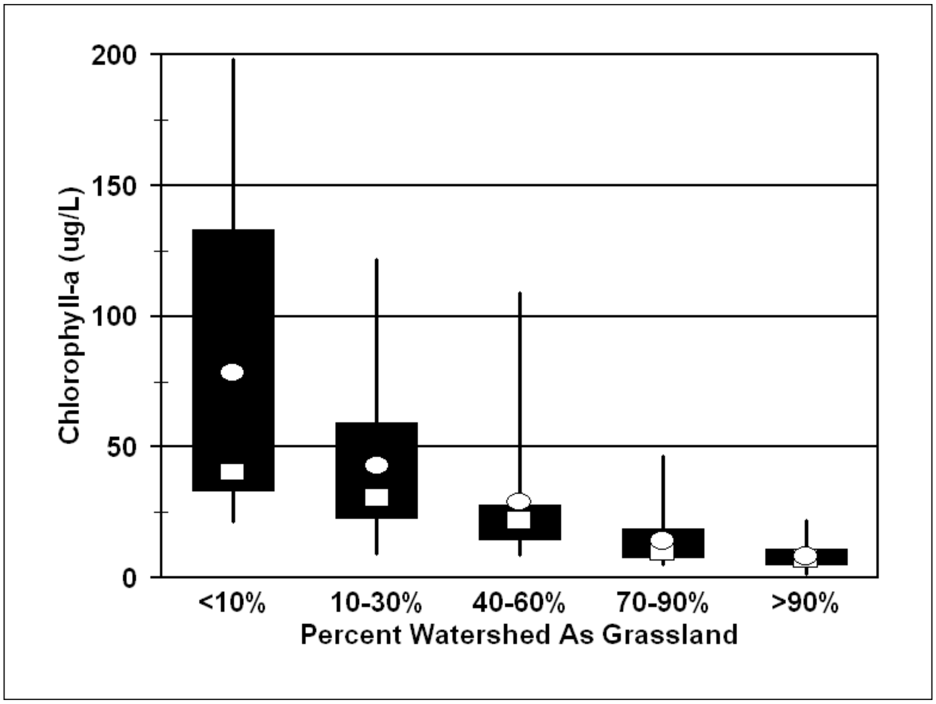
Conceivably, the amount of grassland cover within a drainage might be a better predictor of lake trophic state and water quality than the amount of human-impacted land. In this secondary analysis, the amount of grassland among the 126 watersheds ranged from zero to 100%. A significant correlation existed between percent grassland in the drainages and both trophic state variables, but the parameters were now inversely related. Linear regressions on log transformed data indicated equally predictive relationships between grassland levels and both chlorophyll-a and total phosphorus. Once again, without considering potential influences due to in-lake characteristics, geographic locations, or land use patterns within drainages, the total amount of grassland in a watershed explained 50-60% of the variability in chlorophyll-a and total phosphorus, respectively.

Correlations	**P Value =**	**R =**
Chlorophyll-a vs. Grassland	<0.001	-0.727
Total Phosphorus vs. Grassland	<0.001	-0.763

$\text{Log}_{10}(\text{Chl-a}) = -0.00965*(\%\text{ Grassland}) + 1.81$ $P < 0.001$ $R^2 = 52.4\%$

$\text{Log}_{10}(\text{TP}) = -0.0108*(\%\text{ Grassland}) + 2.35$ $P < 0.001$ $R^2 = 57.9\%$

Figure A4 divides the chlorophyll-a data set into five different land use classes based on grassland amount. Figure A5 provides the same graphic for total phosphorus data. For all box-plot graphs, small white squares represent the median while small white ovals represent the mean value. As indicated by Kruskal-Wallace tests, both water quality parameters show a very

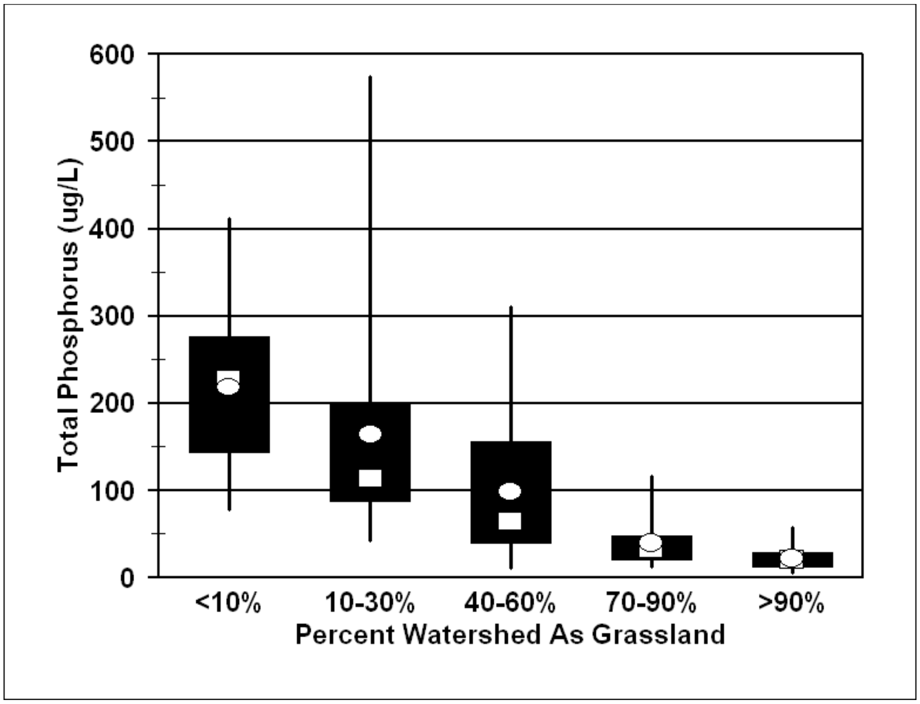


significant (P<0.001) downward trend with increasing grassland cover in the watershed. Based on these graphical analyses, there would appear to be a break point between acceptable trophic state and water quality versus impaired water quality and beneficial uses in the range of 50-80% grassland within a watershed. The mean trophic state for the >90% group was slightly eutrophic, while the 70-90% group was eutrophic, on average. In the 40-60% group, the mean trophic state was just below the hypereutrophic threshold.

Figure A6 presents the probabilities, based on the percent occurrence within each land use group, for a lake being mesotrophic, eutrophic, and hypereutrophic, versus grassland cover. This graphical analysis suggests a break point somewhere between 50-80% grassland within a watershed. Above this range, the likelihood of having healthy water quality and lower trophic status is high. Below this range, the likelihood of poorer water quality conditions and use impairments increases significantly.

Figure A4. Mean chlorophyll-a versus watershed grassland amounts.

Figure A5. Mean total phosphorus versus watershed grassland amounts.



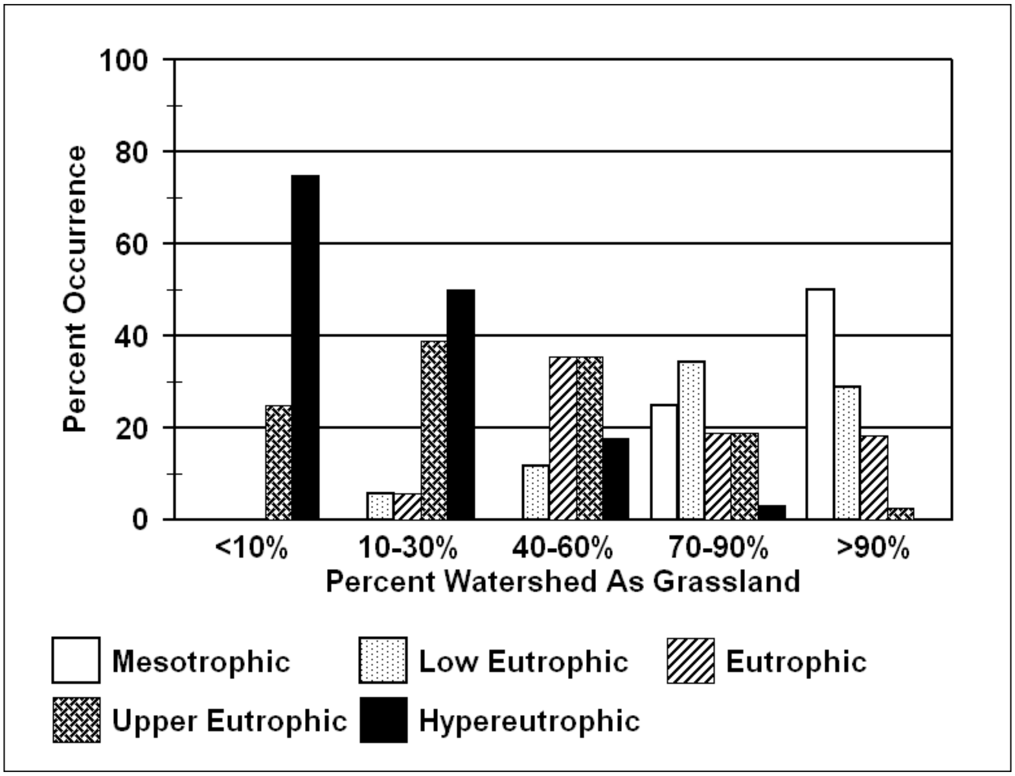


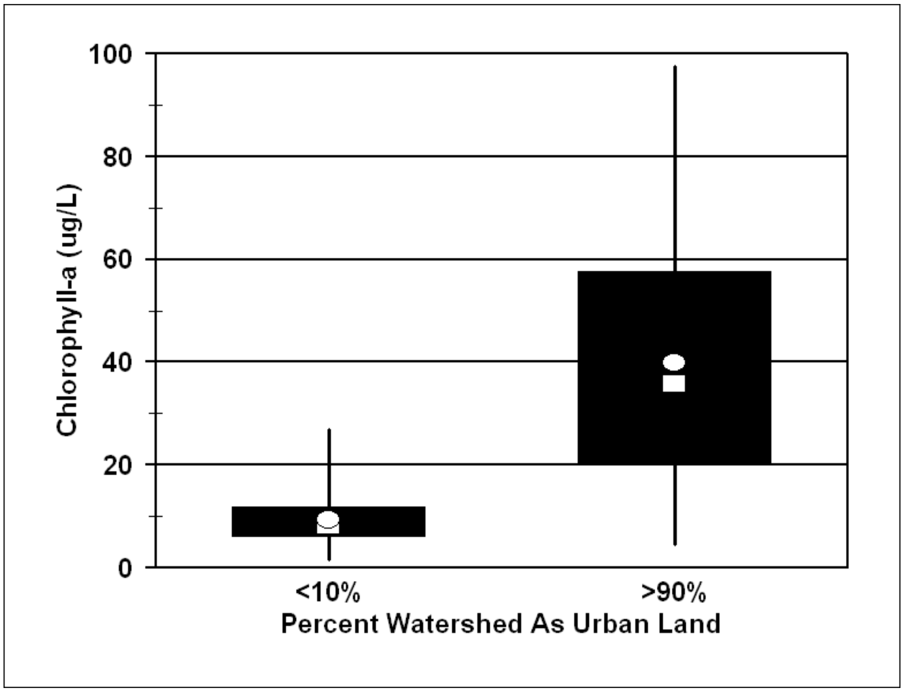
Figure A6. Likelihood of a lake being mesotrophic, eutrophic, or hypereutrophic (on average) versus percent watershed as grassland.

The Influence of Urban Land on Lake Water Quality and Trophic State

There are a much smaller number of lakes within the KDHE database which are in heavily urbanized watersheds, which makes an analysis for the effects of urban drainages somewhat more difficult. The original data set used for the previous analyses was adjusted to eliminate lakes with >20% agricultural land in their watersheds but retain all lakes with significant urban development in their drainages. The resulting data set comprised 104 lakes, which was then subjected to the same statistical and graphical analyses used for cropland and grassland dominated systems. The end results were much weaker correlations and regressions, and no strong visible trend based on the probabilities of a lake being mesotrophic, eutrophic, or hypereutrophic when comparing all five watershed categories. A large portion of the poorer statistical relationships are likely due to the skewing of watersheds in our data set to >90% and <10% urbanized watersheds. The mid-range for land use composition, present for the previous two analyses, is far smaller for addressing urban impacts.

Only the <10% urban land group was statistically different from the other four groups. The implication being that "less of a watershed in urbanized land is better," for lake water quality and trophic status, but there are significant limitations in the data set for specifically addressing urban watersheds and their impacts on lakes. It is also possible that urbanized land, even when mainly addressing residential urban land, is much more variable in terms of lake water quality impacts than are cropland types. Figure A7 presents chlorophyll-a differences between the two ends of the watershed spectrum for urban impacts. Figure A8 presents the same for total phosphorus. For all box-plot graphs, small white squares represent the median while small white ovals represent the mean value. Figure A9 presents a similar probability graphic to those given in Figures A3 and A6, but limited to the two land use groups at either end of the spectrum.

Figure A7. Mean chlorophyll-a versus watershed urban land amounts.



100
80
60
40
20
0
Chlorophyll-a (ug/L)
<10%
>90%
Percent Watershed As Urban Land

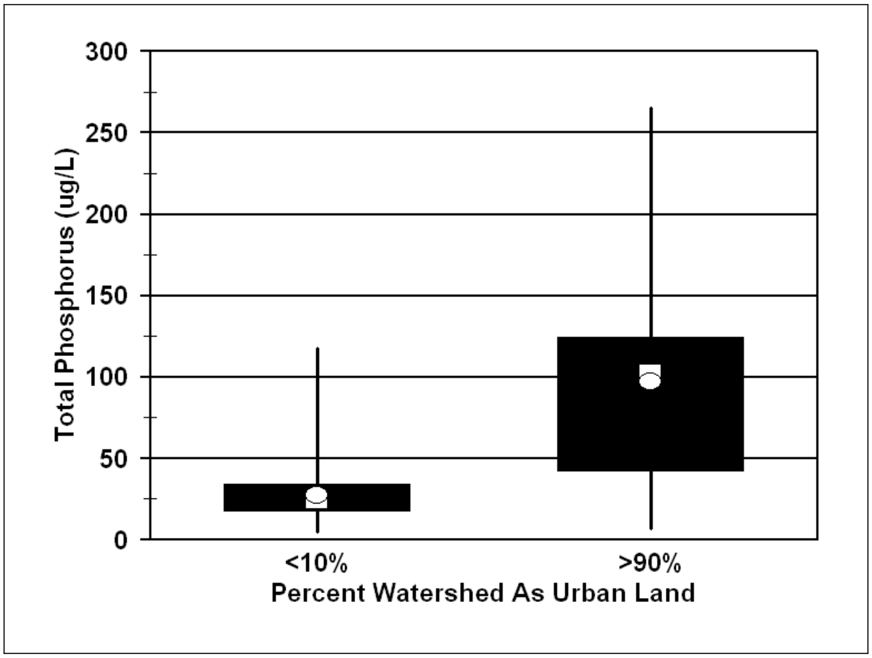
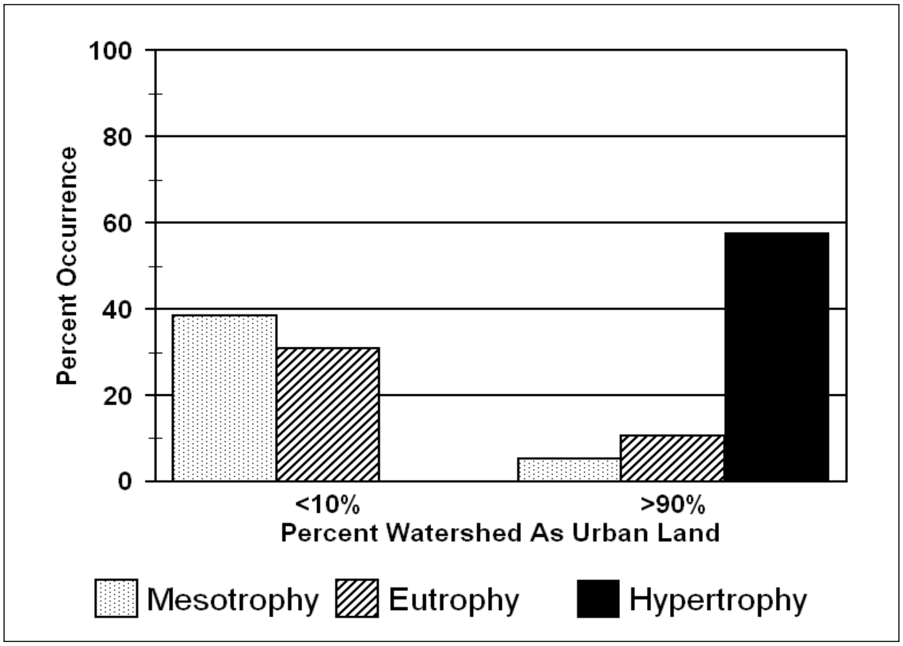


Figure A8. Mean total phosphorus versus watershed urban land amounts.

Figure A9. Likelihood of a lake being mesotrophic, fully eutrophic, or hypereutrophic (on average) versus percent urban land in watersheds.



Conclusions

Either land use category, cropland or grassland, provided equally useful predictions of lake trophic state and water quality. This is not unexpected, as lakes and watersheds with significant urban influences were purposefully excluded from the data set. Therefore, the majority of most watersheds represented were primarily composed of cropland and grassland, with much smaller contributions from other land use types.

Of more interest was the moderately strong ability of a single watershed feature to explain 50-60%
of the variability for lake trophic state variables. This suggests that watershed composition should be of primary importance in the protection and restoration of lakes in Kansas, in general, with other features (i.e., land use distribution patterns in a watershed, lake morphology, or geological/geographical differences) taking important, but secondary, roles in management plans.

Of further interest are the apparent land use thresholds identified by these analyses. Greater than 20-50% cropland, or less than 50-80% grassland, were strongly associated with trophic state conditions high enough to significantly impair beneficial uses and jeopardize the health of aquatic ecosystems.
Existing land use patterns cannot always be modified to meet water quality goals, but planning of future lakes can certainly benefit from early attention to the quality of the watershed. Fortunately, many existing lakes in Kansas occur with watersheds capable of yielding satisfactory water quality.
For those lakes exhibiting a high percentage of grassland within their watersheds, maintaining the "status quo" might be a sound water quality maintenance plan. For those lakes with more abundant agricultural land, perhaps best management practices could be preferentially sought that would maximize grassland and its water quality benefits. Specifically, grass (and wooded) buffers along streams would seem a reasonable way to protect lake water quality, provided the buffer widths for such best management practices were adequately designed, developed, and maintained.

Although there does appear to be a useful relationship between urbanized land and lake water quality, our data set did not allow as decisive an analysis as was the case for agricultural land uses or grassland. However, the same general rule of "less will be better for water quality and trophic status" still appears to hold true, just as it did for agricultural land uses.