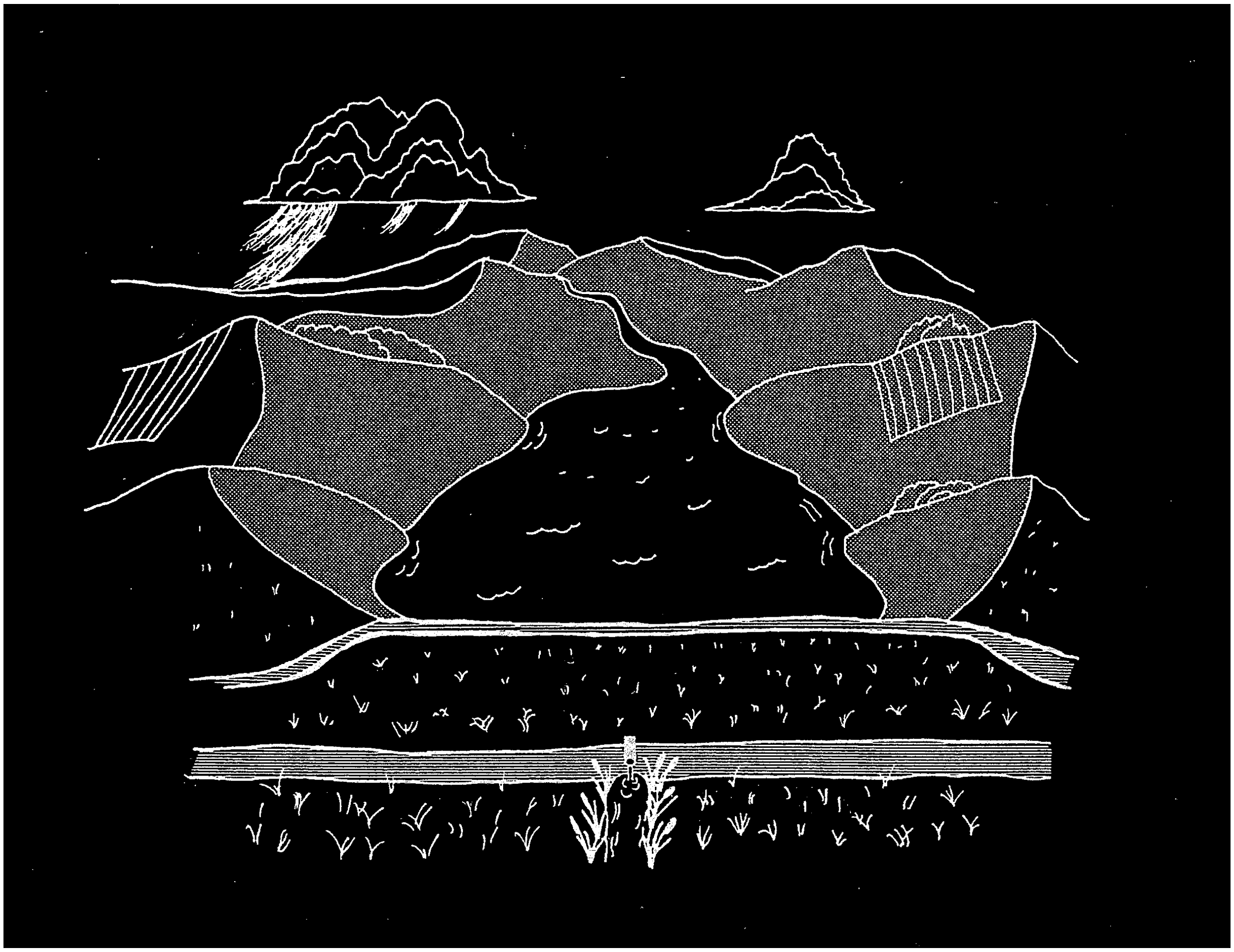
LAKE AND WETLAND

MONITORING PROGRAM

2009 ANNUAL REPORT



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Lake and Wetland Monitoring Program

2009 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 36 Kansas lakes and wetlands during 2009. Eight of the sampled waterbodies were large federal impoundments, 11 were State Fishing Lakes (SFLs) or other water bodies on state managed lands, 10 were city and county lakes, three were state and federal wetland areas, and two were small federally managed lakes on the Cimarron National Grasslands. In addition to these 34 lakes and wetlands, surveyed as part of a pre-established monitoring schedule, Atchison County Lake was sampled at the request of the Kansas Water Office (KWO) and Memorial Park Lake (a.k.a. Veteran's Park Lake) in Great Bend was sampled as part of a fishkill investigation.

Of the 34 lakes and wetlands originally scheduled for surveys, 41.2% exhibited trophic state conditions comparable to their previous period-of-record water quality conditions. Another 29.4% exhibited improved water quality conditions, compared to their previous period-of-record, as evidenced by a lowered lake trophic state. The remaining 29.4% exhibited degraded water quality, as evidenced by elevated lake trophic state conditions. Phosphorus was identified as the primary factor limiting phytoplankton growth in 53% of the lakes and wetlands surveyed during 2009, nitrogen was identified as the primary limiting factor in 17% of the lakes and wetlands, while two lakes (6%) were identified as primarily light limited due to higher inorganic turbidity. The remaining lakes and wetlands were determined to be limited by combinations of nutrients (nitrogen and phosphorus) or by other, unidentified, factors.

There were a total of 26 lakes and wetlands surveyed in 2009 (76%) that had trophic state conditions sufficiently elevated to cause impairment of one or more designated uses. Of these, 19 lakes and wetlands (56%) had trophic state conditions sufficient to create moderate-to-severe water quality problems in multiple designated uses. Additional water quality criteria exceedences, related to heavy metals and pesticides, salinity, or other physicochemical conditions, were relatively few in number during 2009, accounting for only 9% of total water quality standards exceedences.

Seventeen lakes (52% of those surveyed for pesticides) had detectable levels of at least one pesticide during 2009. Atrazine, or its degradation byproducts, were detected in all 17 of these water bodies, once again making atrazine the most commonly documented pesticide in Kansas lakes. The highest observed atrazine concentration during lake and wetland sampling was 4.4 ug/L. A total of six different pesticides, and one pesticide degradation byproduct, were found in lakes during 2009.

Table of Contents

Page

Tables

Page

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

Overview of the 2009 Monitoring Activities

Staff of the KDHE Lake and Wetland Monitoring Program visited 34 Kansas lakes during 2009. Eight of these waterbodies were large federal impoundments last sampled in 2006 or as part of special projects, 11 were State Fishing Lakes (SFLs) or lakes on other state managed lands, 10 were city/county lakes (CLs and Co. lakes, respectively), three were state or federal wetland areas, and two were smaller lakes located in the Cimarron National Grasslands. Sixteen of the 34 lakes (47%) presently serve as either primary or back-up municipal or industrial water supplies, have an existing municipal water supply allocation, or have public water supply wells along their shores. In addition to these regular network surveys, two lakes were sampled for special projects: Atchison Co. Lake was surveyed for a lake sedimentation study initiated by the KWO, while Memorial Park Lake in Great Bend was surveyed as part of a fishkill investigation.

General information on the lakes surveyed during 2009 is compiled in Table 1. Figure 1 depicts the locations of all lakes surveyed in 2009. Figure 2 depicts the locations of all currently active sites within the Lake and Wetland Monitoring Program network.

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

METHODS

Yearly Selection of Monitored Sites

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

Sampling Procedures

At each lake, a boat is anchored over the inundated stream channel near the dam. This point is referred to as Station 1, and represents the area of maximum depth. Duplicate water samples are taken by Kemmerer sample bottle at 0.5 meters below the surface for determination of basic inorganic chemistry (major cations and anions), algal community composition, chlorophyll-a, nutrients (ammonia, nitrate, nitrite, Kjeldahl nitrogen, total organic carbon, and total and ortho phosphorus), and total recoverable metals/metalloids (aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, vanadium, and zinc). Duplicate water samples are also taken at 0.5 to 1.0 meters above the lake substrate for determination of inorganic chemistry, nutrients, and metals/metalloids within the hypolimnion. In addition, a single pesticide sample, and duplicate *Escherichia coli* bacteria samples, are collected at 0.5 meters depth at the primary sampling point (KDHE, 2010).

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, 2010). 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 Kansas (KDHE) Health and Environmental Laboratory (KHEL).

Table 1. General information pertaining to lakes surveyed during 2009.

Lake	Basin	Authority	Water Supply	Last Survey
Barber Co. SFL	Lower Arkansas	State	no	2004
Blue Mound City Lake	Marais des Cygnes	City	yes	2006
Cedar Bluff Lake	Smoky Hill/Saline	Federal	yes	2006
Cedar Valley Lake	Marais des Cygnes	City	yes	2006
Centralia Lake	Kansas/Lower Republican	City	yes	2006
Cheyenne Bottoms	Lower Arkansas	State	no	2006
Cimarron Lake	Cimarron	Federal	no	2005
Clark Co. SFL	Cimarron	State	no	2005
Clinton Lake	Kansas/Lower Republican	Federal	yes	2006
Douglas Co. SFL	Kansas/Lower Republican	State	no	2008
Ford County Lake	Upper Arkansas	County	no	2005
Gardner City Lake	Kansas/Lower Republican	City	yes	2006
Geary Co. SFL	Smoky Hill/Saline	State	no	2006
Kanopolis Lake	Smoky Hill/Saline	Federal	yes	2006
Kingman Co. SFL	Lower Arkansas	State	no	2005
Lake Meade	Cimarron	State	no	2005
Lake Shawnee	Kansas/Lower Republican	City	no	2006
Mallard Lake	Cimarron	Federal	no	1992
Marion County Lake	Neosho	County	yes	2005

Lake	Basin	Authority	Water Supply	Last Survey
McPherson Co. SFL	Smoky Hill/Saline	State	no	2005
Miami Co. SFL	Marais des Cygnes	State	no	2006
Milford Lake	Kansas/Lower Republican	Federal	yes	2006
Mission Lake	Kansas/Lower Republican	City	yes	2006
Mound City Lake	Marais des Cygnes	City	yes	2005
Perry Lake	Kansas/Lower Republican	Federal	yes	2006
Pottawatomie Co. SFL #1	Kansas/Lower Republican	State	yes	2005
Pottawatomie Co. SFL #2	Kansas/Lower Republican	State	no	2005
Pratt County Lake	Lower Arkansas	County	no	2006
Quivera Big Salt Marsh	Lower Arkansas	Federal	no	2006
Quivera Little Salt Marsh	Lower Arkansas	Federal	no	2006
St. Jacob’s Well	Cimarron	State	no	2005
Tuttle Creek Lake	Kansas/Lower Republican	Federal	yes	2006
Webster Lake	Solomon	Federal	yes	2006
Wilson Lake	Smoky Hill/Saline	Federal	yes	2006

Since 1992, macrophyte surveys have been conducted at each of the smaller lakes (<250 acres) within the KDHE Lake and Wetland Monitoring Program network. These surveys entail the selection and survey of 10-to-20 sampling stations, depending on total surface area and lake morphometry. Stations are distributed in a grid pattern over the lake surface. At each sampling point, a grappling hook is cast to rake the bottom for submersed aquatic plants. This process, combined with visual observations, confirms the presence or absence of macrophytes at each station. If present, macrophyte species are identified and recorded on site. Specimens that cannot be identified in the field are placed in labeled plastic bags, on ice, and transported to the KDHE Topeka office. Presence/absence data, and taxon specific presence/absence data, are used to calculate spacial coverage (percent distribution) estimates for each lake (KDHE, 2010).

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 events in water supply lakes, or algae blooms in lakes and ponds, may take on varied forms. Investigations related to tastes and odors in finished drinking water are generally initiated at the request of water treatment plant personnel, or personnel at the KDHE district offices. Although lakes used for public water supply are a primary focus, a wide variety of samples related to algae, odors, and fishkills, from both lakes and streams, are accepted for analysis. Complaint investigations unrelated to taste and odor events in drinking water may be initiated for a variety of reasons, with the majority arising as complaints or concerns received from the general public.

Figure 1. Locations of the 36 lakes surveyed during 2009. Solid circles are the 34 network lakes and wetlands surveyed, while the open circles are the two lakes surveyed for other projects (Atchison Co. Lake and Memorial Park Lake).

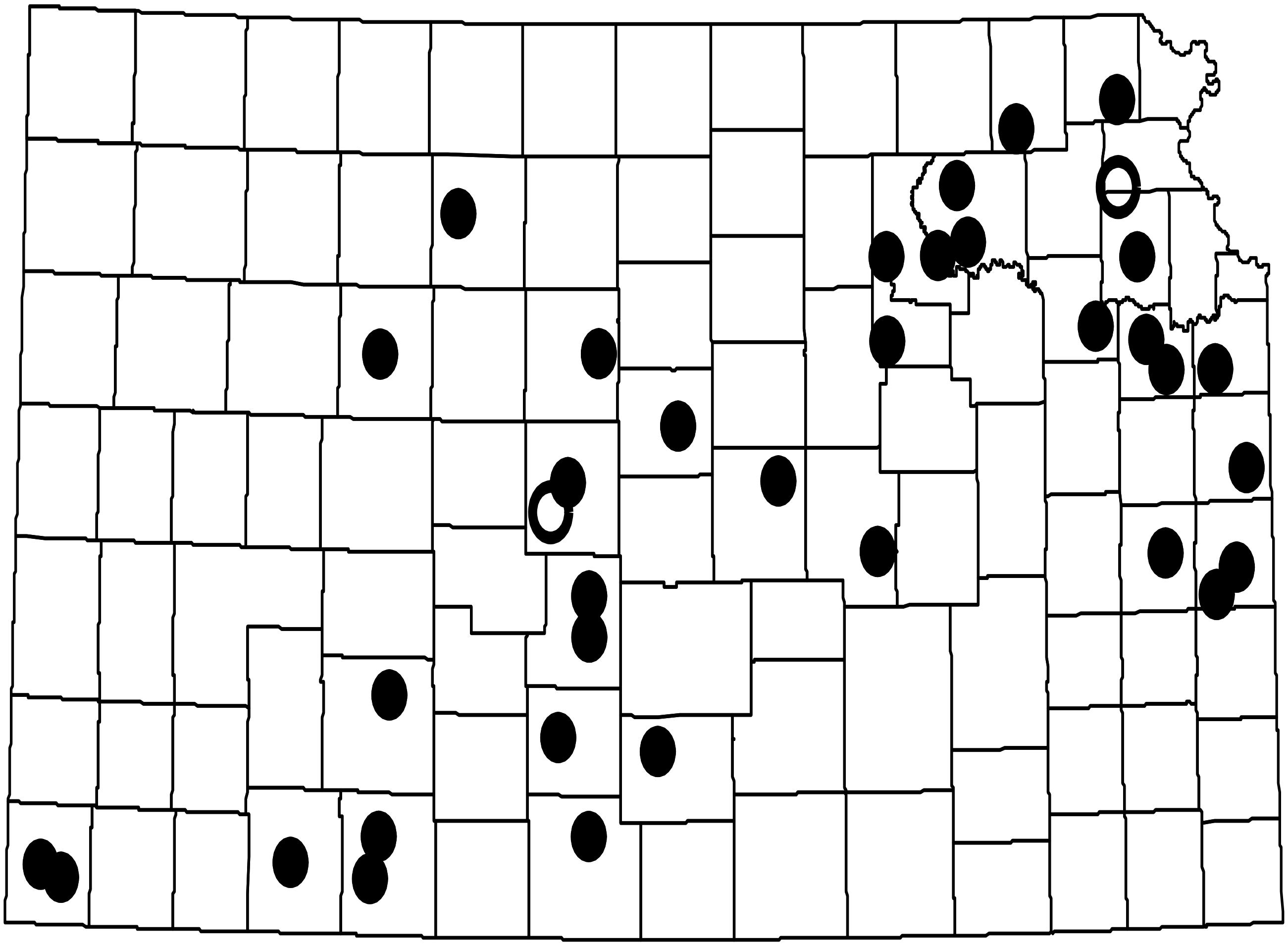
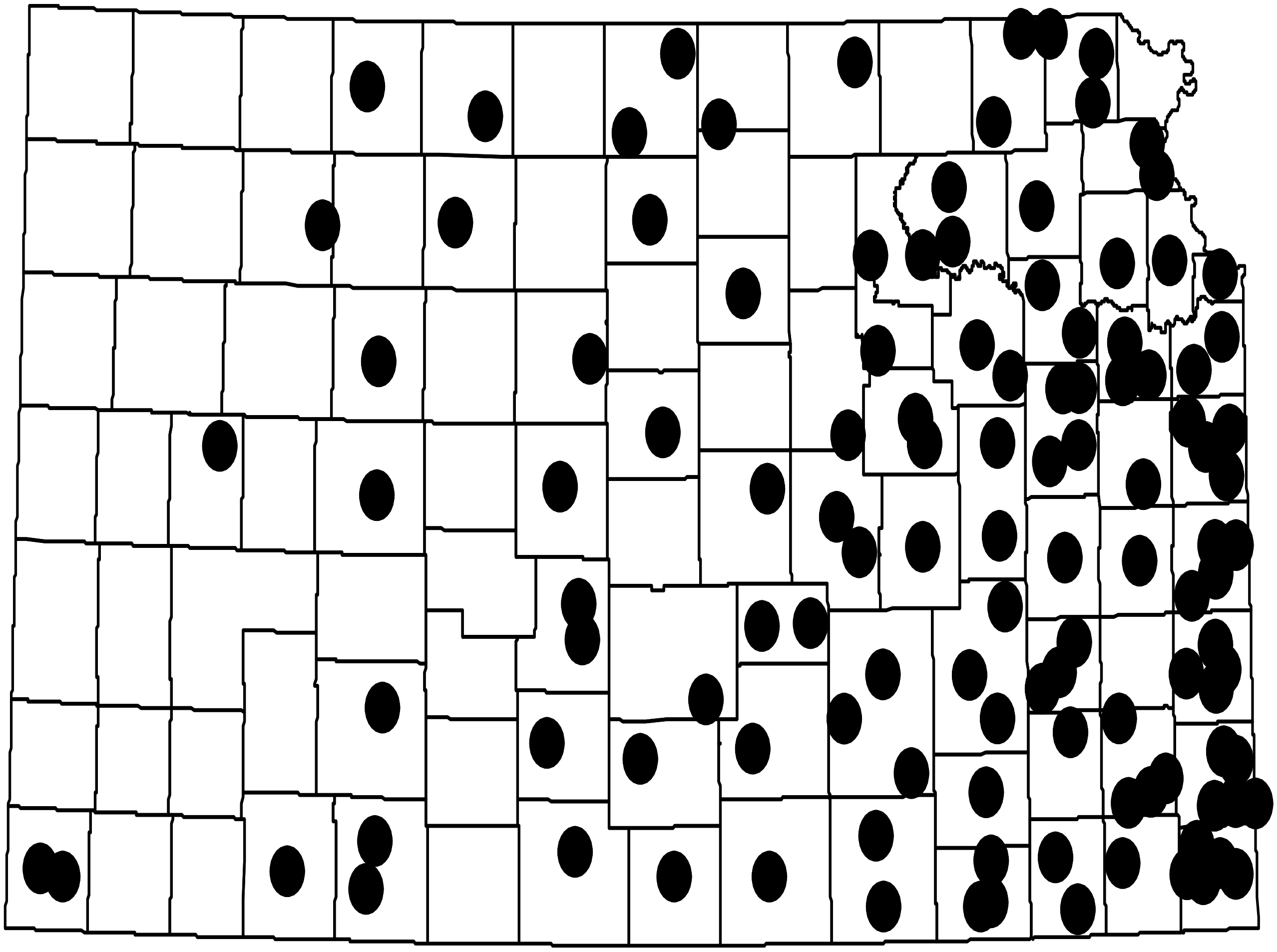


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program's network.



RESULTS AND DISCUSSION

<u>Lake Trophic State</u>

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 34 network lakes surveyed during 2009, 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 where visual bed volume and plant density clearly indicate that macrophyte productivity contributes significantly to overall lake primary production. Mean chlorophyll-a for the 2009 surveys was 39.20 ug/L (hypertrophic). The median chlorophyll-a was 25.40 ug/L (very eutrophic). Both values are much higher than observed in recent years.

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

> OM = A lake with a low level of planktonic algae. Such lakes also lack significant amounts of suspended clay particles in the water column, giving them a relatively high level of water clarity. These lakes often have robust submersed macrophyte communities. Chlorophyll-a concentration averages no more than 2.60 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 2.61 to 7.20 ug/L.

TSI score of 50-63 = eutrophic (E)

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

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

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

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

than 30.00 ug/L. This category is further divided as follows:

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

TSI score not relevant = argillotrophic (A)

A = In a relatively small number of Kansas lakes (4% of public lakes at the last accounting), 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). These lakes typically have chronically high turbidity. Frequent wind resuspension of sediments, as well as benthic feeding fish communities (e.g., common carp), contribute to these chronic conditions. During periods of calm winds, these lakes may temporarily become hypereutrophic as light limitation is relaxed due to settling of suspended solids. Argillotrophic lakes also tend to have very small, or nonexistent, submersed macrophyte communities. Mean chlorophyll-a concentration does not exceed 7.20 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 2009. 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 34 lakes this year was 103,866 cells/mL (median = 49,771 cells/mL), significantly higher than in recent years.

Table 4 presents biovolume data for the 34 lakes surveyed in 2009. 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 37.172 ppm (median = 17.704 ppm).

Table 2. Current and past TSI scores, and trophic state classification for the lakes surveyed during 2009. Trophic class abbreviations used previously apply. Macrophytes

accounted for a significant portion of primary production in five lakes. The assigned trophic class of these waterbodies has been adjusted accordingly and appears in parentheses. Previous TSI scores are based solely on algal chlorophyll TSI scores.

Lake	2009 TSI/Class	Previous Trophic Class Period-of-Record Mean
Barber Co. SFL	48.6 M	SE
Blue Mound City Lake	54.1 SE	E
Cedar Bluff Lake	43.5 M	E
Cedar Valley Lake	75.6 H	E
Centralia Lake	67.9 H	H
Cheyenne Bottoms	68.4 H	H
Cimarron Lake	62.6 VE	E
Clark Co. SFL	66.3 H	SE
Clinton Lake	61.9 VE	E
Douglas Co. SFL	48.6 M	VE
Ford County Lake	88.4 H	H
Gardner City Lake	63.6 VE	E
Geary Co. SFL	65.0 H	E
Kanopolis Lake	59.8 E	SE
Kingman Co. SFL	69.8 H(H)	SE
Lake Meade	57.8 E	H
Lake Shawnee	62.8 VE	VE
Mallard Lake	43.9 M	E
Marion County Lake	70.2 H(H)	E
McPherson Co. SFL	62.8 VE(VE)	H
Miami Co. SFL	66.3 H	H
Milford Lake	67.4 H	SE
Mission Lake	44.3 A	E/A
Mound City Lake	55.1 E	E

Lake	2009 TSI/Class	Previous Trophic Class Period-of-Record Mean
Perry Lake	59.4 E	E
Pottawatomie Co. SFL #1	54.7 SE(E)	E**
Pottawatomie Co. SFL #2	45.8 M(SE)	M
Pratt County Lake	74.5 H	H
Quivera Big Salt Marsh	68.2 H	H
Quivera Little Salt Marsh	73.1 H	H
St. Jacob's Well	61.6 VE	H
Tuttle Creek Lake	57.6 E	A
Webster Lake	55.0 E	E
Wilson Lake	36.1 OM	M

** = Period-of-record trophic state is adjusted for Pottawatomie Co. SFL #1 by the removal of an anomalous trophic state value from 2005. This value represents an extreme outlier, and attempts to explain it have been unsuccessful to date.

Trends in Trophic State

Table 5 summarizes changes in trophic status for the 34 lakes surveyed during 2009. Ten lakes (29.4%) displayed increases in trophic state, compared to their historic mean condition, while another ten lakes (29.4%) displayed improved trophic state condition. Stable conditions were noted in 14 lakes and wetlands (41.2%).

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.

Five lakes (Pottawatomie Co. SFLs #1 and #2, Kingman Co. SFL, McPherson Co. SFL, and Marion County Lake) had macrophyte communities dense enough to at least consider the need for an adjustment of trophic state designation. In three cases, the consideration of macrophytic production did not alter the already high trophic state assignment based on phytoplankton data. For Pottawatomie Co. SFLs #1 and #2, macrophytes were felt to be abundant enough that they could warrant slight upward adjustments in trophic classification although bed densities were still only modest, at best, in both lakes.

Table 3. Algal communities observed in the 34 lakes surveyed during 2009. 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**
Barber Co. SFL	49,739	1	96	3	<1
Blue Mound City Lake	18,018	24	73	1	2
Cedar Bluff Lake	9,797	5	94	1	0
Cedar Valley Lake	167,423	4	89	5	2
Centralia Lake	199,742	0	100	0	0
Cheyenne Bottoms	108,171	9	82	8	1
Cimarron Lake	77,711	>99	0	0	<1
Clark Co. SFL	103,194	8	88	4	<1
Clinton Lake	65,772	1	98	1	<1
Douglas Co. SFL	20,066	2	97	<1	<1
Ford County Lake	1,089,144	0	100	<<1	0
Gardner City Lake	23,751	1	96	2	1
Geary Co. SFL	97,272	0	100	<<1	0
Kanopolis Lake	11,781	42	29	26	3
Kingman Co. SFL	274,208	5	92	1	2
Lake Meade	73,017	14	86	0	<1
Lake Shawnee	72,198	1	98	1	0
Mallard Lake	1,197	87	0	8	5
Marion County Lake	42,399	3	74	18	5
McPherson Co. SFL	81,680	2	96	2	<1
Miami Co. SFL	128,205	33	66	<1	<1
Milford Lake	151,893	3	96	1	0
Mission Lake	1,701	57	15	22	6
Mound City Lake	19,530	18	77	5	<1

	Cell Count	**Percent Composition**			
Perry Lake	18,869	2	86	11	1
Lake	**(cells/mL)**	**Green**	**Blue-Green**	**Diatom**	**Other**
Pottawatomie Co. SFL #1	23,972	16	78	4	2
Pottawatomie Co. SFL #2	6,174	9	87	<3	2
Pratt County Lake	306,684	10	87	3	<1
Quivera Big Salt Marsh	49,802	93	0	7	<1
Quivera Little Salt Marsh	183,267	18	78	3	1
St. Jacob’s Well	8,096	18	36	0	46
Tuttle Creek Lake	27,437	50	27	21	2
Webster Lake	17,924	28	71	<2	0
Wilson Lake	1,607	23	77	0	0

Of the 15 lakes receiving macrophyte surveys, six (40%) 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*), and various species of stonewort algae (*Chara* and *Nitella spp.*). Eurasian watermilfoil (*Myriophyllum spicatum*), although somewhat common throughout the state, was not observed during the 2009 macrophyte surveys. However, Cedar Bluff Lake, although too large for a comprehensive survey, did have established beds of Eurasian watermilfoil present. Informational signs posted at the boat ramp area warned visitors that they should check and clean plant material from their trailers and boats to avoid transporting the plant from Cedar Bluff Lake to other uninfested waterbodies.

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 2009, five water bodies appeared to merit further assessment of the macrophyte community trophic classification. Four were assessed as very eutrophic communities (Kingman Co. SFL, McPherson Co. SFL, Pottawatomie Co. SFL #1, and Marion County Lake), while one was assessed as slightly eutrophic (Pottawatomie Co. SFL #2) based on only the macrophyte community data. Actual adjustments to trophic state classification were made to the two Pottawatomie Co. SFLs, but bed density was very modest in both lakes and the need for considering adjustments based on macrophytes could be considered questionable (Table 2).

Table 4. Algal biovolumes calculated for the lakes surveyed during 2009. 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**
Barber Co. SFL	2.901	9	73	11	7
Blue Mound City Lake	4.879	27	59	1	13
Cedar Bluff Lake	1.652	20	79	<2	0
Cedar Valley Lake	94.290	5	45	13	37
Centralia Lake	39.012	0	100	0	0
Cheyenne Bottoms	35.776	7	49	37	7
Cimarron Lake	18.962	89	0	0	11
Clark Co. SFL	31.315	5	57	37	1
Clinton Lake	17.762	<1	72	22	6
Douglas Co. SFL	3.858	2	95	1	2
Ford County Lake	517.683	0	99	1	0
Gardner City Lake	17.645	<1	90	8	2
Geary Co. SFL	27.233	0	100	<<1	0
Kanopolis Lake	6.688	22	10	46	22
Kingman Co. SFL	51.845	8	55	1	36
Lake Meade	12.305	37	58	0	5
Lake Shawnee	19.380	3	82	15	0
Mallard Lake	0.450	55	0	18	27
Marion County Lake	52.528	<1	21	38	41
McPherson Co. SFL	19.805	10	75	15	<1
Miami Co. SFL	31.961	37	52	2	9
Milford Lake	33.961	2	84	14	0

	Biovolume	Percent Composition			
Mission Lake	1.864	16	3	66	15
Mound City Lake	5.857	15	61	21	3
Perry Lake	12.717	<1	45	46	9
Lake	**(ppm)**	**Green**	**Blue-Green**	**Diatom**	**Other**
Pottawatomie Co. SFL #1	6.740	11	53	18	18
Pottawatomie Co. SFL #2	1.729	8	65	13	14
Pratt County Lake	84.865	17	63	15	5
Quivera Big Salt Marsh	33.918	86	0	13	1
Quivera Little Salt Marsh	49.735	24	57	6	13
St. Jacob’s Well	6.995	4	12	0	84
Tuttle Creek Lake	11.019	34	14	30	22
Webster Lake	6.134	27	55	18	0
Wilson Lake	0.376	35	65	0	0

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	4	11.8
Improved One Class Ranking	6	17.6
Stable	14	41.2
Degraded One Class Ranking	4	11.8
Degraded ≥ Two Class Rankings	6	17.6

Total	34	100.0

* = Two of these lakes (Mission Lake and Tuttle Creek Lake) had historic mean trophic state classifications of argillotrophic (although Mission Lake borders between being eutrophic or 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 15 lakes surveyed for macrophytes during 2009. Macrophyte community refers only to the submersed and floating-leaved aquatic plants, not emergent shoreline plants. Percent areal cover is the abundance estimate for each documented species, and is based on frequency of detection. An asterisk following the lake name indicates that only a limited shoreline survey was conducted. (Note: due to overlap in cover, the percentages under community composition may not equal the total cover.)

Lake	**% Total Cover**	**% Species Cover and Community Composition**
Barber Co. SFL	<7%	No species observed
Cimarron Lake	<10%	No species observed
Ford County Lake	<10%	No species observed
Geary Co. SFL	10%	10% *Ceratophyllum demersum*
Kingman Co. SFL	73%	73% *Ceratophyllum demersum* 73% *Najas guadalupensis* 73% *Potamogeton nodosus* 73% *Potamogeton pectinatus* 53% *Nelumbo sp.* 53% *Nymphaea sp.*
Lake Meade	<7%	No species observed
Mallard Lake	<10%	No species observed
Marion County Lake	60%	60% *Najas guadalupensis* 50% *Ceratophyllum demersum* 40% *Potamogeton pectinatus* 10% *Potamogeton illinoensis* 5% *Chara zeylanica*
McPherson Co. SFL	73%	73% *Ceratophyllum demersum* 73% *Najas guadalupensis* 73% *Potamogeton nodosus*
Miami Co. SFL	<7%	No species observed
Mission Lake	<7%	No species observed
Pottawatomie Co. SFL #1	90%	90% *Ceratophyllum demersum*

Lake	**% Total Cover**	**% Species Cover and Community Composition**
		60% *Najas guadalupensis* 30% *Potamogeton pectinatus*
Pottawatomie Co. SFL #2	80%	80% *Potamogeton illinoensis* 50% *Ceratophyllum demersum*
Pratt County Lake	<10%	No species observed
St. Jacob's Well	<10%	No species observed

None of the lakes surveyed in 2009 appeared to have experienced algal limitation due to macrophyte community influences. In general, Kansas lakes are impaired more by a lack of macrophyte habitat than by an overabundance of aquatic plants. Presence of a robust and diverse macrophyte community normally reflects lower levels of human impact in our lakes. However, some species (*Ceratophyllum demersum*, *Potamogeton crispus*, or *Myriophyllum spicatum*) may attain nuisance proportions as a result of human activities. Dominance by other species that are native, or at least benign naturalized species (*Najas guadalupensis*, other *Potamogeton spp.*, or *Chara/Nitella spp.*), generally implies a higher level of ecosystem health.

It should be noted that the method utilized in KDHE macrophyte surveys only allows for qualitative estimates of bed density. Even with fairly high percent presence values, it is rare for bed densities to approach any threshold that would be identified as an impairment. None of the lakes surveyed in 2009 supported bed densities capable of exerting a negative influence on any beneficial lake use.

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, and sometimes within only 1 to 2 days, this phenomenon is called “lake turnover.” Table 7 presents data related to thermal stratification in the 34 lakes surveyed in 2009. Table 8 presents data related to water clarity and the light environment within the water column of each lake.

Lake turnover can cause fishkills, aesthetic problems, and taste and odor problems in finished drinking water if the hypolimnion comprises a significant volume of the lake. This is because such a sudden mixing combines oxygen-poor, nutrient-rich, hypolimnetic water with epilimnetic water lower in nutrients and richer in dissolved oxygen. Lake turnover can result in temporary accelerated algal growth, lowering of overall lake oxygen levels, and sudden fishkills. It also often imparts objectionable odors to 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 state’s largest lakes, leaving watershed pollutant inputs as the primary cause of water quality problems.

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

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

Euphotic depth, or the depth to which light sufficient for photosynthesis penetrates the water column, can be calculated from relationships derived from Secchi depth and chlorophyll-a data (Scheffer, 1998). This report presents the ratio of calculated euphotic depth to calculated mixing depth (Walker, 1986). Mixing depth is the maximum depth to which wind circulation (and thermal stratification) should typically occur. This metric supplies a means to interpret light and algal 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 it may mean it is very shallow and well mixed. A very low value likely means the lake is light limited due to inorganic turbidity or self-shaded due to high algal biomass near the surface.

Table 7. Stratification status of the 34 water bodies surveyed during 2009. The term “n.a.” indicates that limited boat access, high wind conditions, other threatening weather, shallow water, or equipment problems either 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
rber Co. SFL	07-28-2009	1.58	1.33	3.0-5.0	6.5	
ue Mound City Lake	06-29-2009	n.a.	n.a.	unknown	6.0	lacks boat ramp
dar Bluff Lake	07-14-2009	0.65	0.63	9.0-11.0	15.0	
dar Valley Lake	08-10-2009	0.21	0.86	not stratified	8.5	
ntralia Lake	08-19-2009	n.a.	n.a.	unknown	8.5	wind
eyenne Bottoms	06-15-2009	n.a.	n.a.	not stratified	1.0	shallow
marron Lake	06-16-2009	n.a.	n.a.	unlikely	2.0	shallow
ark Co. SFL	07-28-2009	0.60	0.84	7.0-9.0	11.0	
nton Lake	08-10-2009	0.00	0.14	not stratified	12.0	
uglas Co. SFL	07-20-2009	1.78	0.81	3.0-5.0	10.0	
rd County Lake	06-15-2009	n.a.	n.a.	unlikely	2.5	shallow
rdner City Lake	07-20-2009	1.33	0.85	5.0-6.0	12.5	
ary Co. SFL	07-22-2009	1.18	0.70	4.0-6.0	12.0	
nopolis Lake	07-13-2009	0.11	0.29	not stratified	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
ngman Co. SFL	07-27-2009	n.a.	n.a.	unlikely	2.0	shallow
ke Meade	06-16-2009	n.a.	n.a.	unlikely	3.0	shallow
ke Shawnee	06-22-2009	1.08	0.70	5.0-7.0	14.0	
llard Lake	06-16-2009	n.a.	n.a.	unlikely	1.5	shallow
rion County Lake	07-27-2009	0.83	1.01	2.0-4.0	9.5	
Pherson Co. SFL	07-27-2009	0.83	1.68	2.0-4.0	6.5	
ami Co. SFL	07-07-2009	n.a.	n.a.	unlikely	2.0	shallow
lford Lake	06-23-2009	0.38	0.73	15.0-16.0	18.0	
ssion Lake	08-04-2009	n.a.	n.a.	unlikely	4.0	storms, shallow
ound City Lake	06-29-2009	1.67	1.17	3.0-4.0	6.5	
rry Lake	08-11-2009	0.18	0.51	not stratified	12.0	
ttawatomie Co. SFL #1	08-03-2009	0.40	1.62	2.0-5.0	5.5	
ttawatomie Co. SFL #2	08-03-2009	1.35	0.75	3.0-5.0	10.5	
tt County Lake	07-27-2009	n.a.	n.a.	unlikely	2.0	shallow
ivera Big Salt Marsh	06-15-2009	n.a.	n.a.	unlikely	1.0	shallow
ivera Little Salt Marsh	06-15-2009	n.a.	n.a.	unlikely	1.5	shallow
Jacob’s Well	06-16-2009	n.a.	n.a.	unknown	5.5	lacks boat ramp
ttle Creek Lake	06-23-2009	n.a.	n.a.	unknown	19.0	high heat index
ebster Lake	07-14-2009	0.58	0.57	4.0-7.0	13.0	
lson Lake	07-13-2009	0.43	0.38	10.0-12.0	22.0	

The calculated euphotic-to-mixed depth ratios suggest that light penetrated throughout the mixed zone in over half of the 34 lakes surveyed in 2009 (mean ratio = 4.72, median ratio = 1.12). This also implies that most of the lakes did not experience significant light limitation, because sunlight permeates the entire epilimnion. This contention is supported by the accompanying Secchi depth and calculated non-algal turbidity data (Secchi depth: mean = 117 cm, median = 114 cm; non-algal turbidity: mean = 0.614 m^{-1}, median = 0.293 m^{-1}) (see Walker, 1986).

Where full light (PAR) profiles could be obtained (19 lakes), additional evidence of the general lack of light limitation was observed. Measured light extinction depth versus calculated mixed depth ratio indicated a mean value of 1.64 and a median value of 1.54, suggesting light availability was high enough for photosynthesis to occur throughout the epilimnion in most surveyed lakes. Table 8 presents water clarity data for the lakes sampled in 2009.

Table 8. Water clarity metrics for the 34 lakes surveyed in 2009. See the section on limiting factors for a more detailed description of non-algal turbidity and its application in lake assessment.

Lake	**Chlorophyll-a (ug/L)**	**Secchi Disk Depth (cm)**	**Non-Algal Turbidity (m^{-1})**	**Euphotic to Mixed Depth Ratio**
Barber Co. SFL	6.30	171	0.427	1.46
Blue Mound City Lake	11.00	86	0.888	1.28
Cedar Bluff Lake	3.75	246	0.313	0.84
Cedar Valley Lake	98.10	88	<0.001	0.52
Centralia Lake	44.78	60	0.547	0.66
Cheyenne Bottoms	47.50	29	2.261	59.58
Cimarron Lake	26.30	47	1.470	3.52
Clark Co. SFL	38.30	142	<0.001	0.70
Clinton Lake	24.45	98	0.409	0.62
Douglas Co. SFL	6.30	219	0.299	1.21
Ford County Lake	363.40	31	<0.001	0.64
Gardner City Lake	29.00	147	<0.001	0.76
Geary Co. SFL	33.60	109	0.077	0.69
Kanopolis Lake	19.70	148	0.183	0.87
Kingman Co. SFL	54.74	47	0.759	2.91
Lake Meade	16.00	72	0.989	2.33
Lake Shawnee	26.75	162	<0.001	0.74
Mallard Lake	3.90	56	1.688	4.59
Marion County Lake	56.70	135	<0.001	0.68
McPherson Co. SFL	26.65	118	0.181	1.12
Miami Co. SFL	38.35	90	0.152	4.01
Milford Lake	42.50	146	<0.001	0.43

Lake	**Chlorophyll-a (ug/L)**	**Secchi Disk Depth (cm)**	**Non-Algal Turbidity (m^{-1})**	**Euphotic to Mixed Depth Ratio**
Mission Lake	4.05	30	3.232	1.17
Mound City Lake	12.15	129	0.471	1.34
Perry Lake	18.80	132	0.288	0.71
Pottawatomie Co. SFL #1	11.75	189	0.235	1.68
Pottawatomie Co. SFL #2	4.70	139	0.602	1.12
Pratt County Lake	88.45	52	<0.001	1.67
Quivera Big Salt Marsh	46.30	24	3.009	54.23
Quivera Little Salt Marsh	76.30	34	1.034	4.82
St. Jacob's Well	23.60	145	0.100	1.39
Tuttle Creek Lake	15.65	78	0.891	0.47
Webster Lake	12.10	245	0.106	0.82
Wilson Lake	1.75	338	0.252	0.74

Fecal Indicator Bacteria

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

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

Table 9 presents the bacterial data collected during the 2009 sampling season. Thirteen of the 33 lakes surveyed for *E. coli* bacteria in 2009 (39%) had measurable levels of *E. coli* (i.e., greater than the analytical reporting limit of 10 cfu/100mL). Although no lake in 2009 exceeded existing criteria (KDHE, 2005), one lake had *E. coli* counts of >100 cfu/100mL. This higher count may have been attributable to septic systems and lateral fields along the shore (Gardner City Lake). The mean *E. coli* count among these 33 lakes ranged between 19 and 25 cfu/100mL (assuming non-detects were assigned either zero values or the reporting limit, respectively). The median *E. coli* count was <10 cfu/100mL.

Table 9. *E. coli* bacterial counts (mean of duplicate samples) from the lakes surveyed for *E. coli* bacteria during 2009. 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
Barber Co. SFL	open water	<10
Blue Mound City Lake	off pier near dam	15
Cedar Bluff Lake	open water	<10
Cedar Valley Lake	open water	<10
Centralia Lake	samples not collected	samples not collected
Cheyenne Bottoms	Pool #1 outlet	<10
Cimarron Lake	off dam	<10
Clark Co. SFL	open water	<10
Clinton Lake	open water	<10
Douglas Co. SFL	open water	<10
Ford County Lake	off pier near dam	16
Gardner City Lake	open water	174
Geary Co. SFL	open water	52
Kanopolis Lake	open water	<10

Lake	Site Location	*E. Coli* Count
Kingman Co. SFL	off pier near dam	15
Lake Meade	off pier near dam	10
Lake Shawnee	open water	<10
Mallard Lake	off dam	<10
Marion County Lake	open water	<10
McPherson Co. SFL	open water	<10
Miami Co. SFL	off pier near dam	<10
Milford Lake	open water	<10
Mission Lake	off pier near dam	75
Mound City Lake	open water	20
Perry Lake	open water	<10
Pottawatomie Co. SFL #1	open water	<10
Pottawatomie Co. SFL #2	open water	<10
Pratt County Lake	off pier near dam	26
Quivera Big Salt Marsh	main pool outlet	68
Quivera Little Salt Marsh	main pool outlet	92
St. Jacob’s Well	discharge area	43
Tuttle Creek Lake	off pier near dam	10
Webster Lake	open water	<10
Wilson 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 vanadium), as well as grazing pressure on the phytoplankton community, competition from macrophytes and/or periphyton, water temperature, and hydrologic flushing rate.

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

Table 10 presents limiting factor determinations for the lakes surveyed during 2009. These determinations reflect the time of sampling (chosen to reflect average conditions during the summer growing season, sometimes called the “critical period” in lake water quality assessment, to the extent possible) and may be less applicable to other times of the year. Conditions during one survey may also differ significantly from conditions during past surveys, despite efforts to sample during representative summer weather conditions. If such a situation is suspected, it is noted in Table 10 or elsewhere in this report.

As indicated in Table 10, phosphorus was the primary limiting factor identified for lakes surveyed in 2009. Eighteen of the 34 lakes (53.0%) were determined to be primarily limited by phosphorus. Six lakes (17.6%) were determined to be primarily nitrogen limited. Two lakes were primarily light limited in the 2009 season (5.9%). Another seven lakes (20.6%) were co-limited by phosphorus and nitrogen. One lake (2.9%) defied determination of a primary limiting factor. Mean TN/TP ratio was 20.4 for the lakes surveyed in

2009 (median = 17.1). Interquartile ranges for TN/TP ratios were 19.2-to-36.2 for phosphorus limited lakes, 7.8-to-11.3 for nitrogen limited lakes, and 12.5-to-15.7 for lakes co-limited by phosphorus and nitrogen.

Table 10a. Limiting factor determinations for the 34 lakes surveyed during 2009. 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**
Barber Co. SFL	44.6	0.427	1.157	10.77	0.307	1.583	3.13	P
Blue Mound City Lake	24.5	0.888	2.135	9.46	0.301	2.796	3.58	P
Cedar Bluff Lake	45.9	0.313	1.636	9.23	0.153	2.126	6.45	P*
Cedar Valley Lake	14.0	<0.001	<0.001	86.33	1.078	3.520	8.91	P>N
Centralia Lake	19.9	0.547	1.695	26.87	0.702	5.163	7.04	P
Cheyenne Bottoms	7.5	2.261	0.056	13.78	0.102	0.086	0.42	N
Cimarron Lake	21.5	1.470	0.883	12.36	0.348	1.278	1.70	P
Clark Co. SFL	18.7	<0.001	<0.001	54.39	0.594	2.682	6.83	P
Clinton Lake	21.4	0.409	1.836	23.96	0.604	4.579	8.11	P
Douglas Co. SFL	51.5	0.299	1.026	13.80	0.630	1.566	3.87	P
Ford County Lake	11.8	<0.001	<0.001	112.65	0.727	2.905	8.31	N>P
Gardner City Lake	15.2	<0.001	<0.001	42.63	0.574	2.648	6.38	P>N
Geary Co. SFL	19.5	0.077	0.295	36.62	0.851	3.493	6.92	P
Kanopolis Lake	12.4	0.183	0.683	29.16	0.346	2.521	5.48	P≥N

Lake	**TN/TP**	**NAT**	**Z_{mix}*NAT**	**Chl-a*SD**	**Chl-a/TP**	**Z_{mix}/SD**	**Shading**	**Factors**
Kingman Co. SFL	13.5	0.759	0.456	25.73	0.406	1.278	2.05	N≥P
Lake Meade	17.4	0.989	1.162	11.52	0.219	1.632	2.14	P≥N
Lake Shawnee	20.0	<0.001	<0.001	43.34	0.552	2.548	6.60	P
Mallard Lake	19.4	1.688	1.014	2.18	0.084	1.073	1.30	Unknown
Marion County Lake	14.1	<0.001	<0.001	76.55	0.567	2.463	6.84	P>N
McPherson Co. SFL	9.6	0.181	0.464	31.45	0.254	2.170	4.08	N>P
Miami Co. SFL	11.5	0.152	0.092	34.52	0.433	0.668	1.49	P≥N
Milford Lake	7.1	<0.001	<0.001	62.05	0.224	4.113	14.03	N
Mission Lake	5.9	3.232	5.348	1.22	0.016	5.515	4.01	L
Mound City Lake	16.8	0.471	1.207	15.67	0.316	1.985	3.42	P≥N
Perry Lake	39.0	0.288	1.290	24.82	0.561	3.399	7.09	P
Pottawatomie Co. SFL #1	19.1	0.235	0.527	22.21	0.309	1.184	2.73	P
Pottawatomie Co. SFL #2	14.6	0.602	2.065	6.53	0.149	2.468	4.19	N≥P
Pratt County Lake	12.5	<0.001	<0.001	45.99	0.590	1.732	3.19	N≥P
Quivera Big Salt Marsh	13.3	3.009	0.075	11.11	0.165	0.103	0.46	N>P
Quivera Little Salt Marsh	8.6	1.034	0.296	25.94	0.325	0.841	1.62	N
St. Jacob’s Well	26.6	0.100	0.223	34.22	0.441	1.543	3.30	P
Tuttle Creek Lake	13.6	0.891	5.349	12.21	0.075	7.698	12.83	L>(N=P)
Webster Lake	27.6	0.106	0.502	29.65	0.285	1.940	6.28	P

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Wilson Lake	55.5	0.252	1.629	5.92	0.175	1.912	8.79	P*

* = Metrics, and on-site observations, suggest some additional, unidentified, factor was present in Cedar Bluff and Wilson Lakes during these surveys. Possible factors may include grazing by zooplankton, or a temporary impact from recent rains. Such temporary weather-related impacts were fairly common during 2009 as the summer had many precipitation events.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Values <0.13 indicate a limited response by algae to phosphorus (i.e., nitrogen, light, or other factors may be more important). Values above 0.4 indicate a strong algal response to changes in phosphorus level. The range 0.13-to-0.40 suggests a variable but moderate response by algae to fluctuating 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 $TSI_{(TP\ or\ TN)}$-$TSI_{(Chl\text{-}a)}$. 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 5.0 units were used as the threshold for determining if deviations were significantly different from zero. This approach generally reproduced determinations 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 2009 data, including consideration of any lingering effects from the previous 1-2 weeks weather. However, past Secchi depth, nutrient, 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 experience little real impact from that turbidity if the entire water column rapidly circulates and is exposed to sunlight at frequent intervals (Scheffer, 1998).

Exceedences of State Surface Water Quality Criteria

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

Exceedences of surface water quality criteria and guidelines during the 2009 sampling season were documented by computerized comparison of the 2009 Lake and Wetland Monitoring

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

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

Eutrophication exceedences are primarily due to excessive nutrient inputs from lake watersheds. Dissolved oxygen problems are generally due to advanced trophic state, which causes rapid oxygen depletion below the thermocline. Lakes with elevated pH are also reflective of high trophic state and algal and/or macrophytic production. In 2009, 26 lakes (76%) had trophic state conditions elevated enough to impair one or more uses. Nineteen lakes (56%) had trophic state conditions elevated enough to cause moderate-to-severe impairments in a majority of uses.

Four lakes had aquatic life use impairments resulting from either elevated pH or low dissolved oxygen levels in the epilimnion (Ford and Pratt County Lakes: pH; Marion Co. Lake and McPherson Co. SFL: dissolved oxygen). These impairments were considered secondary responses to elevated trophic state. Additionally, in Mission Lake, high inorganic turbidity levels impaired primary and secondary recreational uses. Three lakes experienced exceedences of applicable irrigation criteria for fluoride (Cimarron and Mallard Lakes, and Lake Meade).

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 ≥ 64

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

Salinity related exceedences were documented in two lakes with elevated chloride levels (Kanopolis Lake and Wilson Lake), and five lakes with elevated sulphate concentrations (Barber Co. SFL, Cedar Bluff Lake, Kanopolis Lake, Webster Lake, and Wilson Lake). Atrazine exceedences were documented in two lakes (Cedar Valley Lake and McPherson Co. SFL). These water quality exceedences all related to drinking water supply criteria in lakes designated for the drinking water supply use.

Pesticides in Kansas Lakes, 2009

Detectable levels of at least one pesticide were documented in the main body of 17 lakes sampled in 2009 (51.5% of lakes surveyed for pesticides). Table 12 lists these lakes and the pesticides that were detected, along with the level measured and the analytical quantification limit. Six different pesticides, and one pesticide degradation byproduct, were noted in 2009. Of these seven compounds, atrazine and alachlor currently have numeric criteria in place for aquatic life support and/or water supply uses (KDHE, 2005).

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 57% of the total number of pesticide detections, and atrazine and/or its degradation byproducts were detected in all 17 lakes with pesticides. In addition to atrazine, eight lakes had detectable levels of metolachlor (Dual). Five lakes had detectable levels of acetochlor (Harness or Surpass), four lakes had detectable levels of alachlor (Lasso), one lake had simazine present, and one lake had metribuzin (Sencor) present. Eight lakes had detectable quantities of the atrazine metabolite deethylatrazine.

In all cases, the presence of these pesticides was directly attributable to agricultural activity, although simazine is often used in conjunction with weed control in parks and urban areas. Atrazine levels in two lakes surveyed in 2009 exceeded 3.0 ug/L (Cedar Valley Lake and McPherson Co. SFL). Seven lakes had detectable levels of more than two pesticides (Cedar Valley Lake, McPherson Co. SFL, Milford Lake, Mission Lake, Perry Lake, Quivera Little Salt Marsh, and Tuttle Creek Lake).

Supplementary Lake Surveys in 2009

In addition to the 34 monitoring network sites originally scheduled for sampling in 2009, two other lakes were the subject of special investigations. Atchison Co. Lake was added to the sampling schedule at the request of the Kansas Water Office, as part of a lake sedimentation study funded by EPA. Memorial Park Lake (a.k.a. Veteran’s Park Lake) located in Great Bend, Kansas, was sampled as part of a fishkill investigation. Due to intense local interest in the fishkill, staff were asked to conduct a lake survey by the KDHE Fishkill Coordinator.

Table 12. Pesticide levels documented during 2009 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, alachlor = 0.1 ug/L, simazine = 0.3 ug/L, and metribuzin = 0.1 ug/L. Only those lakes with detectable levels of pesticides are listed.

	Pesticide						
Lake	**Atrazine**	**Deethylatrazine**	**Metolachlor**	**Acetochlor**	**Alachlor**	**Simazine**	**Metribuzin**
Cedar Bluff Lake	0.56						
Cedar Valley Lake	3.45	0.71	0.45		0.21		
Cheyenne Bottoms	0.45						
Clinton Lake	1.30						
Douglas Co. SFL	0.48					0.54	
Ford County Lake	1.20	0.43					
Kanopolis Lake	0.77						
Lake Shawnee	2.70	0.40		0.11			
Marion County Lake	0.37						
McPherson Co. SFL	4.40	0.54	1.50	0.18			
Milford Lake	2.40	0.48	0.57	0.10			
Mission Lake	0.64	0.57	2.45	0.31			
Mound City Lake	0.46						
Perry Lake	0.89	0.62	1.10		0.12		
Quivera Little Salt Marsh	1.20		0.33		0.17		
Tuttle Creek Lake	0.69	0.83	2.80	0.80	0.26		0.10

	Pesticide						
Webster Lake	1.20		0.43				

Atchison County Lake

Surveyed on August 4, 2009, Atchison Co. Lake was hypereutrophic, with a mean chlorophyll-a of 37.50 ug/L. Secchi disk depth was only 48 cm and yielded a non-algal turbidity of 1.146 m^{-1}, indicative of considerable inorganic turbidity . Thermal stratification was not expected to be present, given a maximum lake depth of only 1.5 m. The TN/TP ratio was 7.1 which, along with the suite of metrics typically applied to network sites, indicated that nitrogen was the primary limiting factor at the time of the survey. The phytoplankton community contained 70,308 cells/mL, and had a community composed of 86% blue-green species (a mixture of *Planktothrix rubescens*, *Anabaena spp.*, *Aphanizomenon flos-aqua*, and *Microcystis aeruginosa*), 12% diatoms, and a small portion of chlorophyte, cryptophyte, and euglenoid algae. *E. coli* counts averaged 87 cfu/100mL. Pesticides present at detectable levels included atrazine (1.3 ug/L), deethylatrazine (0.94 ug/L), metolachlor (0.90 ug/L), and acetochlor (0.46 ug/L).

Memorial Park Lake, Great Bend

Surveyed on June 15, 2009, Memorial Park Lake (a.k.a., Veteran's Park Lake) was hypereutrophic, with a mean chlorophyll-a of 101.05 ug/L. Secchi disk depth was only 36 cm and yielded a non-algal turbidity of 0.252 m^{-1}, indicating that the majority of lake turbidity was derived from phytoplankton rather than inorganic materials. Thermal stratification may have been present, given a maximum lake depth of around 4.0 m, but was considered unlikely owing to abundant recent precipitation and lower spring temperatures. The TN/TP ratio was 18.1 which, along with the suite of metrics typically applied to network sites, indicated that phosphorus was the primary limiting factor at the time of the survey (both phosphorus and nitrogen were very elevated in concentration). The phytoplankton community contained 531,027 cells/mL, and had a community composed of >99% blue-green species (a mixture of *Phormidium spp.* and *Anabaena spp.*). An ELISA-based microcystin algal toxin test was conducted on an aliquot of water collected from the lake. The test was positive and indicative of a total microcystin concentration of about 3.0 ug/L. *E. coli* counts averaged <30 cfu/100mL. The pesticide simazine was present in the lake at a concentration of 3.0 ug/L.

CONCLUSIONS

The following conclusions are based on lake monitoring data collected during 2009.

1) Trophic state data indicated that 29% of the lakes surveyed in 2009 had degraded water quality in comparison to historic mean conditions (i.e., their trophic state had increased). About 41% showed stable conditions over time while another 29% exhibited improved trophic state conditions.

2) The majority of the documented water quality impairments in these lakes resulted from nutrient enrichment and elevated trophic state. Heavy metals and pesticides accounted for a small percentage (3%) of the documented water quality criteria exceedences.

3) Over half of the lakes surveyed in 2009 (52%) had detectable levels of agricultural pesticides. 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.