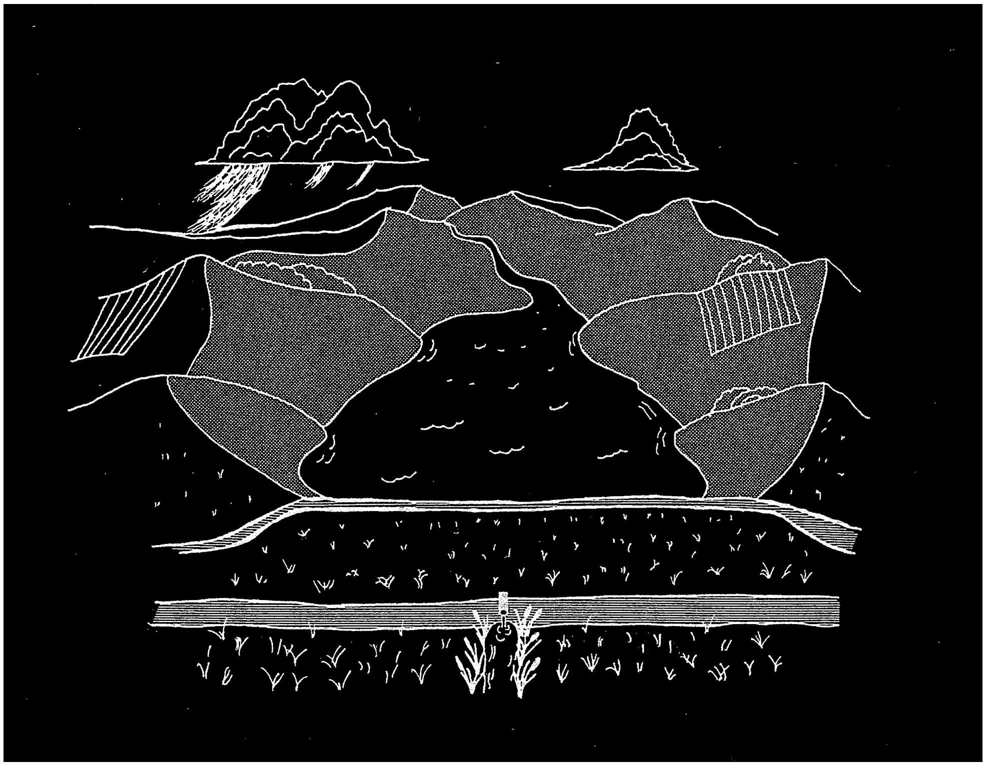
LAKE AND WETLAND

MONITORING PROGRAM

2010 ANNUAL REPORT



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Lake and Wetland Monitoring Program

2010 Annual Report

(Intended primarily for intra-agency and inter-agency use)

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 38 Kansas lakes and wetlands during 2010. Eight of the sampled waterbodies are large federal impoundments, nine are State Fishing Lakes (SFLs), twelve are city and county lakes, two are state wetland areas, and one is owned by a non-governmental organization. In addition to these 32 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), Memorial Park Lake (a.k.a. Veteran's Park Lake) in Great Bend was sampled as part of a fishkill/blue-green algae bloom investigation, Horsethief Canyon Lake (Hodgeman Co.) and Lake Jewell (City of Jewell, Jewell Co.) were sampled as part of Use Attainability Analysis (UAA) surveys, and Jetmore City Lake and Fossil Lake (Hodgeman and Russell Counties, respectively) were surveyed based on opportunity. These last two lakes were part of the program monitoring network in the past, but had been replaced due to prolonged low water or dry conditions. Both lakes seemed to have refilled prior to 2010, and were given limited examinations for comparison to past data.

Of the 32 lakes and wetlands originally scheduled for surveys, 59.4% exhibited trophic state conditions comparable to their previous period-of-record water quality conditions. Another 9.4% exhibited improved water quality conditions, compared to their previous period-of-record,

as evidenced by a lowered lake trophic state. The remaining 31.2% exhibited degraded water quality, as evidenced by elevated lake trophic state conditions. Phosphorus was identified as the primary factor limiting phytoplankton growth in 37.5% of the lakes and wetlands surveyed during 2010, nitrogen was identified as the primary limiting factor in 43.8% of the lakes and wetlands, while four lakes (12.5%) were identified as primarily light limited due to higher inorganic turbidity. The remaining two lakes were determined to be limited by hydrologic conditions.

There were a total of 26 lakes and wetlands surveyed in 2010, out of 32 originally scheduled (81%), that had trophic state conditions sufficiently elevated to cause impairment of one or more designated uses. Of these, 17 lakes and wetlands (53%) 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 inorganic parameters, were relatively few in number during 2010, accounting for only 8.4% of total water quality standards exceedences.

Twenty-four lakes (75% of those surveyed for pesticides) had detectable levels of at least one pesticide during 2010. Atrazine, or its degradation byproducts, were detected in all 24 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 11.0 ug/L. A total of five different pesticides, and two pesticide degradation byproducts, were found in lakes during 2010.

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INTRODUCTION

Development of the Lake and Wetland Monitoring Program

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

Program activities originally centered around a small sampling network comprised mostly of federal lakes, with sampling stations at numerous locations within each lake. In 1985, based on the results of statistical analyses conducted by KDHE, the number of stations per lake was reduced to a single integrator station within the main body of each impoundment. This, and the elimination of parameters with limited interpretive value, allowed expansion of the lake network to its present 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 2010 Monitoring Activities

Staff of the KDHE Lake and Wetland Monitoring Program visited 32 Kansas lakes and wetlands during 2010. Eight of these waterbodies are large federal impoundments last sampled in 2007, nine are State Fishing Lakes (SFLs), twelve are city/county lakes (CLs and Co. lakes, respectively), two are state wetland areas, and one is operated by a non-governmental organization. Sixteen of the 32 lakes (50%) 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, six lakes were sampled for special projects: Atchison Co. Lake was surveyed for a lake sedimentation study initiated by the KWO, Memorial Park Lake (Veteran’s Lake) in Great Bend was surveyed as part of a fishkill/blue-green algae investigation, Lake Jewell and Horsethief Canyon Lake were surveyed as part of UAA surveys, and Jetmore City Lake and Fossil Lake were inactive network sites visited in 2010 to assess their condition after refilling post-drought.

General information on the lakes surveyed during 2010 is compiled in Table 1. Figure 1 depicts the locations of all lakes surveyed in 2010. 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).

Table 1. General information pertaining to lakes surveyed during 2010.

Lake	Basin	Authority	Water Supply	Last Survey
Augusta Santa Fe Lake	Walnut	City	yes	2006
Banner Creek Lake	Kansas/Lower Republican	County	yes	2007
Big Hill Lake	Verdigris	Federal	yes	2007
Butler Co. SFL	Walnut	State	no	2007

Lake	Basin	Authority	Water Supply	Last Survey
Centralia Lake	Kansas/Lower Republican	City	no	2009
Cowley Co. SFL	Lower Arkansas	State	no	2005
Elk City Lake	Verdigris	Federal	yes	2007
Eureka City Lake	Verdigris	City	yes	2005
Fall River Lake	Verdigris	Federal	yes	2007
Goodman SFL	Upper Arkansas	State	no	2006
Harvey Co. East Lake	Walnut	County	no	2006
Jamestown WMA	Kansas/Lower Republican	State	no	2007
Jewell Co. SFL	Solomon	State	no	2003
Kirwin Lake	Solomon	Federal	no	2007
Lake Scott	Smoky Hill/Saline	State	no	2006
Lovewell Lake	Kansas/Lower Republican	Federal	no	2007
Lyon Co. SFL	Marais des Cygnes	State	no	2006
Madison City Lake	Verdigris	City	yes	2006
Marais des Cygnes WMA	Marais des Cygnes	State	no	2007
Mission Lake	Kansas/Lower Republican	City	yes	2009
Montgomery Co. SFL	Verdigris	State	no	2005
Murray Gill Lake	Verdigris	NGO	yes	2005
Neosho WMA	Neosho	State	no	2007
Norton Lake	Upper Republican	Federal	yes	2007
Olpe City Lake	Neosho	City	no	2006
Ottawa Co. SFL	Solomon	State	no	2007
Sabetha City Lake	Missouri	City	yes	2006
Sedan North City Lake	Verdigris	City	yes	2005
Sedan South City Lake	Verdigris	City	yes	2005
Toronto Lake	Verdigris	Federal	yes	2007
Waconda Lake	Solomon	Federal	yes	2007
Yates Center New Lake	Verdigris	City	yes	2006

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).

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).

Figure 1. Locations of the 38 lakes surveyed during 2010. Solid circles are the 32 network lakes and wetlands surveyed, while the open circles are the six supplemental lakes surveyed for other projects (Atchison Co. Lake, Memorial Park Lake, Lake Jewell, Horsethief Canyon Lake, Jetmore City Lake, and Fossil Lake).

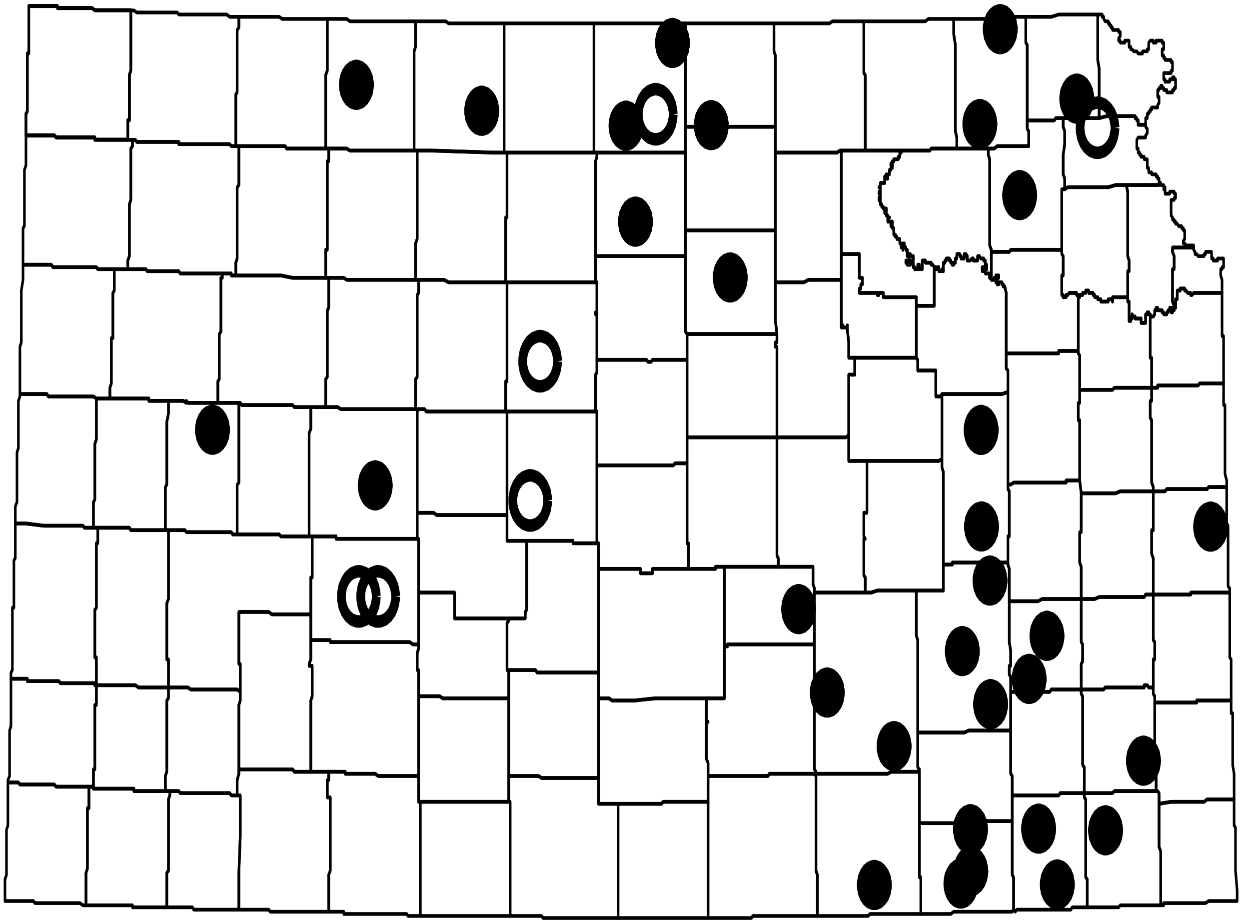
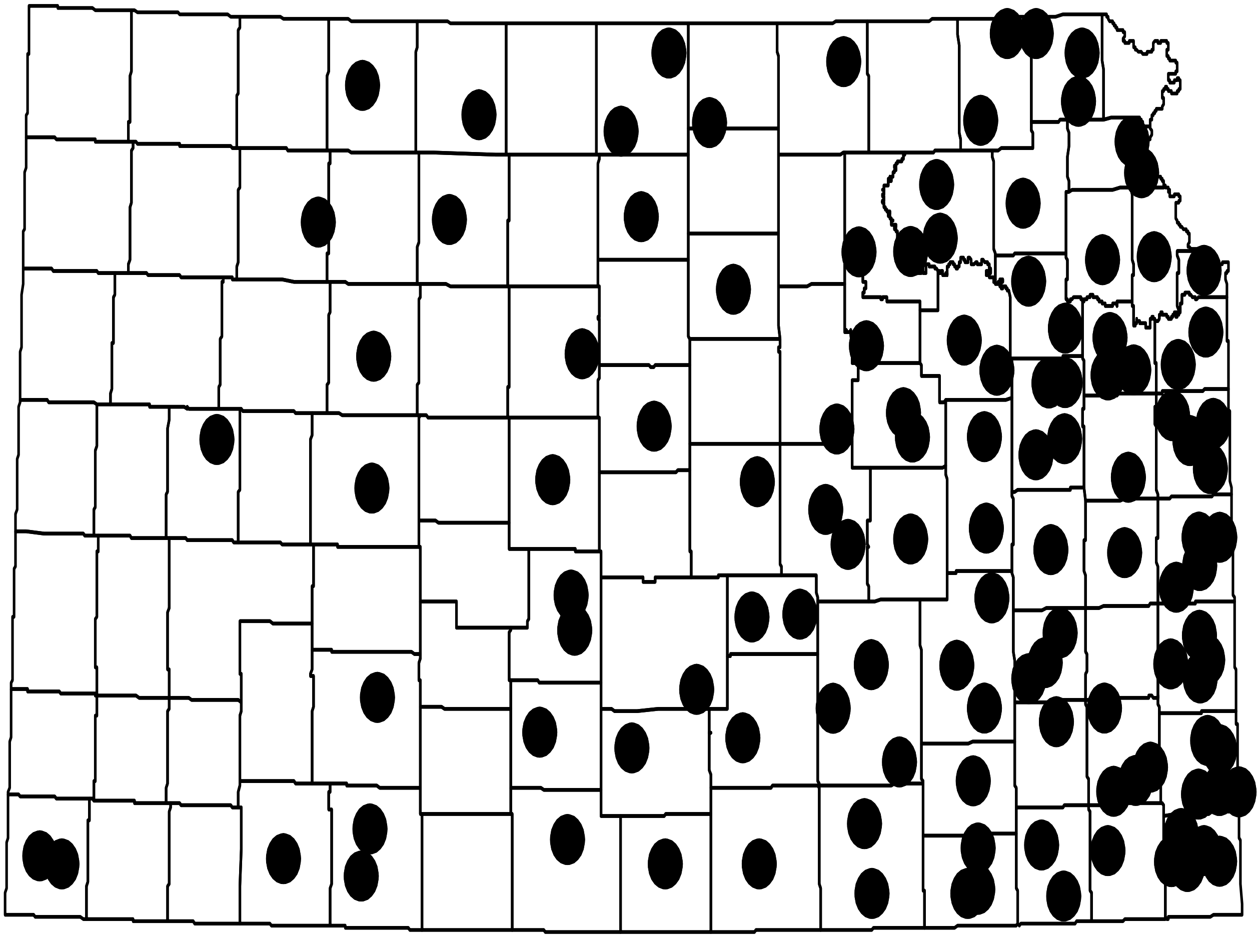


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program network.



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 32 network lakes surveyed during 2010, 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 2010 surveys was 31.56 ug/L (hypertrophic). The median chlorophyll-a was 20.13 ug/L (very eutrophic). Both values are much higher than observed in most 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 ≥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) to a generally lesser degree, 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):

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

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 2010. 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 32 lakes this year was 65,768 cells/mL (median = 26,775 cells/mL), significantly higher than in most recent years.

Table 4 presents biovolume data for the 32 lakes surveyed in 2010. 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 27.057 ppm (median = 13.954 ppm).

Table 2. Current and past TSI scores, and trophic state classification for the lakes surveyed during 2010. Trophic class abbreviations used previously apply. Macrophytes accounted for a significant portion of primary production in four 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	2010 TSI/Class	Previous Trophic Class Period-of-Record Mean
Augusta Santa Fe Lake	48.1 Arg	E
Banner Creek Lake	63.6 VE	E
Big Hill Lake	60.0 VE	SE
Butler Co. SFL	67.5 H	H
Centralia Lake	76.5 H	H
Cowley Co. SFL	60.3 VE(VE)	E
Elk City Lake	62.7 VE	E
Eureka City Lake	60.7 VE	E
Fall River Lake	45.6 Arg	SE
Goodman SFL	53.4 SE	E
Harvey Co. East Lake	73.5 H	H
Jamestown WMA	78.5 H	H
Jewell Co. SFL	60.1 VE	VE
Kirwin Lake	56.6 E	VE
Lake Scott	71.4 H	H
Lovewell Lake	68.1 H	VE
Lyon Co. SFL	45.5 M(SE)	M
Madison City Lake	52.4 SE	SE
Marais des Cygnes WMA	74.8 H	H
Mission Lake	37.8 Arg	E
Montgomery Co. SFL	59.5 E	H
Murray Gill Lake	40.0 M	M
Neosho WMA	66.9 H	H
Norton Lake	58.9 E	E
Olpe City Lake	51.2 Arg	E

Lake	2010 TSI/Class	Previous Trophic Class Period-of-Record Mean
Ottawa Co. SFL	70.4 H	H
Sabetha City Lake	70.3 H	H
Sedan North City Lake	56.1 E(E)	SE
Sedan South City Lake	48.7 M	M
Toronto Lake	35.3 Arg	SE
Waconda Lake	61.5 VE	E
Yates Center New Lake	52.3 SE(SE)	SE

Trends in Trophic State

Table 5 summarizes changes in trophic status for the 32 lakes surveyed during 2010. Ten lakes (31.2%) displayed increases in trophic state, compared to their historic mean condition, while only three lakes (9.4%) displayed improved trophic state condition. Stable conditions were noted in 19 lakes and wetlands (59.4%).

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.

Four lakes (Cowley Co. SFL, Lyon Co. SFL, Sedan North City Lake, and Yates Center New 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 trophic state assignment based on phytoplankton data. For Lyon Co. SFL, 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.

Table 3. Algal communities observed in the 32 lakes surveyed during 2010. 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**
Augusta Santa Fe Lake	4,064	18	61	16	5
Banner Creek Lake	151,295	<1	97	2	0
Big Hill Lake	36,099	4	84	12	<1
Butler Co. SFL	28,539	3	74	23	<1
Centralia Lake	229,714	0	100	0	0
Cowley Co. SFL	33,327	0	100	0	0
Elk City Lake	10,112	8	28	60	4
Eureka City Lake	20,412	3	87	10	<1
Fall River Lake	2,268	20	54	23	3
Goodman SFL	5,891	49	0	43	8
Harvey Co. East Lake	555,597	<2	98	<1	0
Jamestown WMA	136,553	2	50	38	10
Jewell Co. SFL	25,389	16	80	0	4
Kirwin Lake	28,161	8	92	<1	0
Lake Scott	76,955	2	94	3	<1
Lovewell Lake	125,780	<1	99	<1	0
Lyon Co. SFL	4,694	11	84	3	2
Madison City Lake	16,506	33	58	7	2
Marais des Cygnes WMA	262,458	9	87	1	3
Mission Lake	1,638	14	44	36	6
Montgomery Co. SFL	57,362	4	95	<1	<1
Murray Gill Lake	4,694	8	84	8	0
Neosho WMA	33,107	63	11	20	6
Norton Lake	13,797	41	37	18	4
Olpe City Lake	6,836	17	71	12	0

	Cell Count	Percent Composition			
Lake	**(cells/mL)**	**Green**	**Blue-Green**	**Diatom**	**Other**
Ottawa Co. SFL	76,514	57	5	36	2
Sabetha City Lake	61,079	56	16	13	15
Sedan North City Lake	5,261	21	36	23	20
Sedan South City Lake	15,278	11	78	11	0
Toronto Lake	693	30	51	15	4
Waconda Lake	61,268	6	91	3	<1
Yates Center New Lake	12,900	17	65	6	12

Of the 14 lakes receiving macrophyte surveys, seven (50%) 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 watermilfoil (*Myriophyllum spicatum*), and various species of stonewort algae (*Chara* and *Nitella spp.*). Banner Creek Lake was too large for a routine macrophyte survey, but was subjected to a limited observational survey. Shoreline macrophyte beds were very common, perhaps translating to a frequency of 40-to-50% of stations if a full survey had been feasible. Two other lakes (Augusta Santa Fe Lake and Mission Lake) were subjected to limited shoreline macrophyte surveys due to high inorganic turbidity.

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 2010, four water bodies appeared to merit further assessment of the macrophyte community trophic classification. Two were assessed as eutrophic communities (Cowley Co. SFL and Lyon Co. SFL), while two were assessed as slightly eutrophic communities (Sedan North City Lake and Yates Center New Lake) based on <u>only</u> the macrophyte community data. Actual adjustments to trophic state classification were made only to Lyon Co. SFL, but bed density was not extreme and the need for considering adjustments based on macrophytes could be considered marginal (Table 2).

The previous survey at Yates Center New Lake (2006) discovered a dramatic increase in the nuisance Eurasian watermilfoil (*Myriophyllum spicatum*). Prior to 2010, the lake was treated using the selective aquatic herbicide fluridone. Fluridone can be made selective on dicot (broadleaf) plants by controlling the dose. Most native macrophytes in Kansas are monocot species. The 2010 survey detected no *Myriophyllum spicatum* or *Ceratophyllum demersum* (both dicot species), but found a significant increase in more beneficial species, including stoneworts (*Chara zeylanica*) and the rare native pondweed *Potamogeton amplifolius* (largeleaf pondweed). These preliminary results suggest the treatment was a success, and it will be of interest to watch this lake in the future to determine how long it will remain free of Eurasian watermilfoil.

Table 4. Algal biovolumes calculated for the lakes surveyed during 2010. 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**
Augusta Santa Fe Lake	2.393	19	21	44	16
Banner Creek Lake	21.638	<1	76	23	0
Big Hill Lake	13.597	<2	59	22	17
Butler Co. SFL	34.047	<2	29	68	1
Centralia Lake	107.050	0	100	0	0
Cowley Co. SFL	15.731	0	100	0	0
Elk City Lake	20.008	<1	3	92	4
Eureka City Lake	14.920	2	44	53	<1
Fall River Lake	1.864	3	18	64	15
Goodman SFL	4.983	17	0	64	19
Harvey Co. East Lake	76.479	2	82	16	0
Jamestown WMA	156.298	<1	15	43	41
Jewell Co. SFL	13.818	6	78	0	16
Kirwin Lake	9.259	5	91	4	0
Lake Scott	37.148	1	67	23	9
Lovewell Lake	40.205	1	97	2	0
Lyon Co. SFL	0.948	10	43	22	25
Madison City Lake	5.242	21	36	29	14
Marais des Cygnes WMA	92.204	9	48	3	40
Mission Lake	1.058	4	13	61	22
Montgomery Co. SFL	14.089	4	85	8	3
Murray Gill Lake	0.812	13	74	13	0

	Biovolume	**Percent Composition**			
Neosho WMA	33.487	15	2	75	8
Norton Lake	11.044	32	14	41	13
Olpe City Lake	5.599	4	64	32	0
Lake	**(ppm)**	**Green**	**Blue-Green**	**Diatom**	**Other**
Ottawa Co. SFL	51.864	17	1	70	12
Sabetha City Lake	51.347	13	4	28	55
Sedan North City Lake	4.510	5	4	14	77
Sedan South City Lake	3.024	7	86	7	0
Toronto Lake	0.997	4	7	45	44
Waconda Lake	15.879	5	69	24	2
Yates Center New Lake	4.267	7	47	9	37

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	1	3.1
Improved One Class Ranking	2	6.3
Stable	19	59.4
Degraded One Class Ranking	9	28.1
Degraded ≥ Two Class Rankings	1	3.1
Total	32	100.0

* = For the purposes of this comparison, argillotrophic is considered equivalent to eutrophic, which is also the assessment protocol for nutrient related impairments for argillotrophic systems.

Table 6. Macrophyte community structure in the 14 lakes surveyed for macrophytes during 2010. 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**	
Augusta Santa Fe Lake*	<10%		No species observed
Banner Creek Lake*	40-50%	40-50%	*Ceratophyllum demersum*
		40-50%	*Najas guadalupensis*
		40-50%	*Potamogeton nodosus*
		40-50%	*Potamogeton pectinatus*
Butler Co. SFL	20%	20%	*Potamogeton nodosus*
Cowley Co. SFL	33%	33%	*Myriophyllum spicatum*
		27%	*Ceratophyllum demersum*
		27%	*Potamogeton nodosus*
		13%	*Najas guadalupensis*
		7%	*Chara vulgaris*
Goodman SFL	<10%		No species observed
Harvey Co. East Lake	<7%		No species observed
Lake Scott	87%	87%	*Myriophyllum spicatum*
Lyon Co. SFL	73%	73%	*Najas guadalupensis*
		73%	*Potamogeton nodosus*
		60%	*Chara zeylanica*
Mission Lake*	<10%		No species observed
Montgomery Co. SFL	7%	7%	*Chara globularis*
Olpe City Lake	<10%		No species observed
Sedan North City Lake	60%	33%	*Chara zeylanica*
		27%	*Ceratophyllum demersum*
		20%	*Najas guadalupensis*
		7%	*Chara braunii*
		7%	*Nitella flexilis*

Lake	**% Total Cover**		**% Species Cover and Community Composition**
		7%	*Potamogeton illinoensis*
Sedan South City Lake	<7%		No species observed
Yates Center New Lake	75%	60%	*Chara zeylanica*
		60%	*Potamogeton amplifolius*
		55%	*Najas guadalupensis*
		40%	*Potamogeton illinoensis*
		20%	*Potamogeton nodosus*

None of the lakes surveyed in 2010 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, and is a common feature in many of our reference quality systems. 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 2010 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 32 lakes surveyed in 2010. 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.

Table 7. Stratification status of the 32 water bodies surveyed during 2010. 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
gusta Santa Fe Lake	07-26-2010	n.a.	n.a.	none likely	3.0	shallow, wind
nner Creek Lake	08-23-2010	0.94	0.89	4.0-7.0	10.0	
g Hill Lake	06-14-2010	n.a.	n.a.	unknown	16.0	storms
tler Co. SFL	07-26-2010	0.33	1.30	2.0-3.0	3.0	
ntralia Lake	08-23-2010	0.58	1.08	3.0-4.0	8.5	
wley Co. SFL	07-20-2010	1.63	0.89	3.0-4.0	9.0	
k City Lake	06-14-2010	n.a.	n.a.	unknown	8.0	storms
reka City Lake	07-06-2010	n.a.	n.a.	unknown	8.0	storms
l River Lake	06-14-2010	n.a.	n.a.	none likely	7.5	storms, high water
odman SFL	08-09-2010	n.a.	n.a.	none likely	2.5	shallow
rvey Co. East Lake	07-26-2010	0.33	1.80	2.0-3.0	5.0	
nestown WMA	07-12-2010	n.a.	n.a.	none	1.0	
well Co. SFL	07-12-2010	n.a.	n.a.	unknown	7.0	storms
rwin Lake	08-16-2010	n.a.	n.a.	unknown	15.0	wind
ke Scott	08-09-2010	n.a.	n.a.	unknown	4.5	
vewell Lake	08-16-2010	n.a.	n.a.	unknown	9.0	wind
on Co. SFL	08-02-2010	1.64	0.91	4.0-5.0	8.0	
dison City Lake	07-06-2010	n.a.	n.a.	unknown	10.0	storms
rais des Cygnes WMA	06-08-2010	n.a.	n.a.	none	2.0	
ssion Lake	08-24-2010	0.00	0.05	none	4.5	

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
ontgomery Co. SFL	07-19-2010	3.00	1.82	2.0-3.0	6.5	
urray Gill Lake	07-19-2010	1.71	0.63	3.0-4.0	15.0	
osho WMA	06-09-2010	n.a.	n.a.	none	1.0	
rton Lake	08-16-2010	n.a.	n.a.	unknown	12.0	wind
pe City Lake	08-02-2010	n.a.	n.a.	unknown	5.0	wind
tawa Co. SFL	07-12-2010	n.a.	n.a.	none likely	3.5	wind
petha City Lake	08-03-2010	n.a.	n.a.	none likely	2.0	shallow
dan North City Lake	07-20-2010	2.30	0.92	2.0-3.0	5.5	
dan South City Lake	07-20-2010	2.17	1.02	2.0-3.0	6.0	
ronto Lake	06-14-2010	n.a.	n.a.	none likely	5.5	storms, high water
aconda Lake	08-16-2010	n.a.	n.a.	unknown	14.0	wind
tes Center New Lake*	07-06-2010	n.a.	n.a.	unknown	9.5	storms

* = Yates Center New Lake was surveyed July 6, 2010, for all chemical, all physical, and most biological parameters. A second survey was scheduled for August 30, 2010, so that a macrophyte survey could be conducted, and to obtain a second set of phytoplankton data.

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.

The calculated euphotic-to-mixed depth ratios suggest that light penetrated throughout the mixed zone in about half of the 32 lakes surveyed in 2010 (mean ratio = 4.91, median ratio = 1.02). This also implies that most of the lakes did not experience significant light limitation, because sunlight permeates most, or all, of the epilimnion. This contention is supported by the accompanying Secchi depth and calculated non-algal turbidity data (Secchi depth: mean = 96 cm, median = 83 cm; non-algal turbidity: mean = 0.86 m^{-1}, median = 0.44 m^{-1}) (see Walker, 1986), despite the fact that some lakes in 2010 had elevated turbidity due to hydrologic impacts early in the summer.

Where full light (PAR) profiles could be obtained (11 lakes), additional evidence of the general lack of light limitation was observed. Measured light extinction depth versus calculated mixed depth ratio averaged a value of 0.60 (median = 0.62), suggesting light availability was still high enough for photosynthesis to occur throughout most of the epilimnetic volume in most surveyed lakes. Table 8 presents water clarity data for the lakes sampled in 2010.

Table 8. Water clarity metrics for the 32 lakes surveyed in 2010. 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**
Augusta Santa Fe Lake	5.98	30	3.184	1.63
Banner Creek Lake	28.92	108	0.203	0.80
Big Hill Lake	20.04	127	0.286	0.57
Butler Co. SFL	43.03	89	0.048	1.97
Centralia Lake	107.43	92	<0.001	0.50
Cowley Co. SFL	20.72	136	0.217	0.98
Elk City Lake	26.55	30	2.670	0.53
Eureka City Lake	21.53	77	0.760	0.90
Fall River Lake	4.62	40	2.385	0.76
Goodman SFL	10.21	74	1.096	3.25
Harvey Co. East Lake	79.31	61	<0.001	0.80
Jamestown WMA	132.86	26	0.525	39.97
Jewell Co. SFL	20.21	142	0.199	1.18
Kirwin Lake	14.19	180	0.201	0.69
Lake Scott	64.51	60	0.054	0.96
Lovewell Lake	45.74	38	1.488	0.48
Lyon Co. SFL	4.57	186	0.423	1.39
Madison City Lake	9.29	108	0.694	0.98

Lake	**Chlorophyll-a (ug/L)**	**Secchi Disk Depth (cm)**	**Non-Algal Turbidity (m^{-1})**	**Euphotic to Mixed Depth Ratio**
Marais des Cygnes WMA	90.65	23	2.082	1.82
Mission Lake	2.09	38	2.579	1.22
Montgomery Co. SFL	19.07	146	0.208	1.27
Murray Gill Lake	2.62	261	0.318	1.06
Neosho WMA	40.74	55	0.800	81.82
Norton Lake	17.95	145	0.241	0.74
Olpe City Lake	8.21	28	3.366	0.88
Ottawa Co. SFL	57.73	71	<0.001	1.37
Sabetha City Lake	57.13	44	0.844	2.80
Sedan North City Lake	13.53	126	0.455	1.50
Sedan South City Lake	6.36	196	0.351	1.69
Toronto Lake	1.62	30	3.293	0.90
Waconda Lake	23.42	160	0.039	0.63
Yates Center New Lake	9.20	144	0.464	1.10

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 of the primary sampling location 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 2010 sampling season. Fifteen of the 32 lakes and wetlands surveyed for *E. coli* bacteria in 2010 (47%) had measurable levels of *E. coli* (i.e., greater than the analytical reporting limit of 10 cfu/100mL). Two water bodies in 2010 exceeded existing single-sample criteria (KDHE, 2005). These two were Marais des Cygnes WMA and Waconda Lake. The mean *E. coli* count among these 32 lakes ranged between 163 and 169 cfu/100mL (assuming non-detects were assigned either zero values or the reporting limit, respectively). The median *E. coli* count ranged between 0 and 10 cfu/100mL (assuming non-detects were assigned either zero values or the reporting limit, respectively).

The 2010 sampling season produced some of the highest *E. coli* counts, as well as one of the highest yearly detection rates, ever observed by the Lake and Wetland Monitoring Program. High open water bacterial counts are fairly infrequent in Kansas lakes, historically. The most obvious reason for the higher counts in 2010 is the excessive rainfall and runoff the state experienced during the spring and early summer of 2010.

Table 9. *E. coli* bacterial counts (mean of duplicate samples) from the lakes surveyed for *E. coli* bacteria during 2010. Note: These samples were collected during the week, not during weekends when recreational activity would be at peak levels. All units are in "number of cfu/100mL of lake water."

Lake	Site Location	*E. Coli* Count
Augusta Santa Fe Lake	off dam	<10
Banner Creek Lake	open water	<10
Big Hill Lake	off pier near dam	<10
Butler Co. SFL	open water	<10
Centralia Lake	open water	<10
Cowley Co. SFL	open water	<10

Lake	Site Location	*E. Coli* Count
Elk City Lake	off dam	47
Eureka City Lake	off pier near dam	97
Fall River Lake	off dam	52
Goodman SFL	off pier near dam	15
Harvey Co. East Lake	open water	10
Jamestown WMA	off dam	52
Jewell Co. SFL	off pier near dam	63
Kirwin Lake	off dam	10
Lake Scott	off pier near dam	<10
Lovewell Lake	off pier near dam	<10
Lyon Co. SFL	open water	<10
Madison City Lake	off pier near dam	<20
Marais des Cygnes WMA	open water	1785
Mission Lake	open water	69
Montgomery Co. SFL	open water	<10
Murray Gill Lake	open water	<10
Neosho WMA	open water	69
Norton Lake	off pier near dam	<10
Olpe City Lake	off pier near dam	<15
Ottawa Co. SFL	off pier near dam	42
Sabetha City Lake	off pier near dam	<10
Sedan North City Lake	open water	<10
Sedan South City Lake	open water	<10
Toronto Lake	off dam	80
Waconda Lake	off pier near dam	2795
Yates Center New Lake	off pier near dam	36

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 10a. Limiting factor determinations for the 32 lakes and wetlands surveyed during 2010. 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**
Augusta Santa Fe Lake	4.0	3.184	3.742	1.79	0.017	3.917	3.06	L>N
Banner Creek Lake	19.8	0.203	0.696	31.23	0.689	3.176	5.86	P
Big Hill Lake	27.1	0.286	1.559	25.45	0.679	4.287	9.74	P
Butler Co. SFL	10.4	0.048	0.056	38.30	0.448	1.320	2.53	N>P
Centralia Lake	9.4	<0.001	<0.001	98.84	0.316	3.367	9.30	N
Cowley Co. SFL	63.5	0.217	0.698	28.18	2.072	2.363	4.74	P
Elk City Lake	7.5	2.670	8.552	7.97	0.241	10.678	8.82	L>N
Eureka City Lake	16.1	0.760	2.262	16.58	0.507	3.863	5.15	P≥N
Fall River Lake	8.5	2.385	7.187	1.85	0.048	7.535	6.06	Hydrologic Flushing
Goodman SFL	28.1	1.096	0.987	7.56	0.255	1.217	1.63	P
Harvey Co. East Lake	9.1	<0.001	<0.001	48.38	0.417	3.374	5.75	N
Jamestown WMA	5.1	0.525	0.013	34.54	0.289	0.095	0.63	N
Jewell Co. SFL	6.6	0.199	0.539	28.70	0.094	1.906	3.87	N
Kirwin Lake	11.6	0.201	1.050	25.54	0.173	2.905	7.89	N>P
Lake Scott	11.0	0.054	0.101	38.71	0.379	3.108	4.83	N>P
Lovewell Lake	5.9	1.488	5.299	17.38	0.155	9.372	9.92	N

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Lyon Co. SFL	24.9	0.423	1.259	8.50	0.223	1.599	3.32	P
Madison City Lake	19.5	0.694	2.380	10.03	0.295	3.176	4.78	P
Marais des Cygnes WMA	7.8	2.082	1.251	20.85	0.239	2.612	3.28	N
Mission Lake	25.7	2.579	4.809	0.79	0.012	4.907	3.81	L
Montgomery Co. SFL	33.4	0.208	0.533	27.84	0.646	1.754	3.59	P
Murray Gill Lake	30.0	0.318	1.357	6.84	0.262	1.637	4.67	P
Neosho WMA	5.7	0.800	0.020	22.41	0.189	0.045	0.31	N
Norton Lake	5.2	0.241	1.081	26.03	0.092	3.095	6.87	N
Olpe City Lake	12.6	3.366	6.928	2.30	0.093	7.351	5.24	L
Ottawa Co. SFL	10.9	<0.001	<0.001	40.99	0.412	2.008	3.50	N>P
Sabetha City Lake	8.7	0.844	0.507	25.14	0.224	1.365	2.13	N
Sedan North City Lake	21.0	0.455	1.019	17.05	0.520	1.776	3.06	P
Sedan South City Lake	45.0	0.351	0.845	12.47	0.636	1.227	2.70	P
Toronto Lake	6.3	3.293	7.190	0.49	0.009	7.279	5.08	Hydrologic Flushing
Waconda Lake	9.3	0.039	0.197	37.47	0.146	3.125	8.38	N
Yates Center New Lake	23.8	0.464	1.544	13.25	0.438	2.309	4.25	P

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}/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

Table 10 presents limiting factor determinations for the lakes surveyed during 2010. 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, and for the first time in the history of this report series, nitrogen was the primary limiting factor identified for lakes surveyed. Fourteen of the 32 lakes (43.8%) were determined to be primarily limited by nitrogen. Thirteen lakes (37.5%) were determined to be primarily phosphorus limited. Four lakes were primarily light limited in the 2010 season (12.5%). Two lakes (6.2%) were limited due to hydrologic flushing due to high amounts of precipitation and runoff during the spring and early summer. Mean TN/TP ratio was 16.7 for the lakes surveyed in 2010 (median = 11.0). This is considerably lower than seen in past reports, and reflects the impacts of high precipitation and runoff on lake processes, generally, during summer 2010.

Interquartile ranges for TN/TP ratios were 20.7-to-30.9 for phosphorus limited lakes and 6.1-to-10.2 for nitrogen limited lakes. Although the number of light limited systems is higher in 2010 than what might be considered "normal" for a given year's survey work, the flood year of 1993 still holds the record for that category. The primary impact during 2010 seems to have been more towards altered nutrient regimes rather than increased inorganic turbidity. This may be due to the timing of precipitation and runoff. In 1993, rains continued through most of the summer, while in 2010 rains ended by mid-summer and were replaced by the normal regimen of heat and dry weather.

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 $TSI_{(TP\text{ or }TN)}$-$TSI_{(Chl\text{-}a)}$. 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 5.0 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 2010 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 2010 sampling season were documented by computerized comparison of the 2010 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 plus 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 2010, 26 lakes (81%) had trophic state conditions elevated enough to impair one or more uses. Seventeen lakes (53%) had trophic state conditions elevated enough to cause moderate-to-severe impairments in a majority of uses.

Six lakes had aquatic life use impairments resulting from either elevated pH or low dissolved oxygen levels in the epilimnion (Lake Scott and Montgomery Co. SFL: pH; Butler Co. SFL, Harvey Co. East Lake, Montgomery Co. SFL, and Sedan North & South City Lakes: dissolved oxygen). These impairments were considered secondary responses to elevated trophic state and, in regards to dissolved oxygen, some exceptionally high late summer temperatures. Additionally, in five lakes (Augusta Santa Fe Lake, Fall River Lake, Mission Lake, Olpe City Lake, and Toronto Lake) high inorganic turbidity levels were sufficient to impair primary and secondary recreational uses.

Atrazine >3.0 ug/L was documented in four lakes and wetlands (Harvey Co. East Lake, Marais des Cygnes WMA, Neosho WMA, and Ottawa Co. SFL). Criteria exceedences for heavy metals, salinity related parameters, and other inorganic compounds were few, constituting only 3.9% of total criteria exceedences combined. Recreation uses accounted for 29.6% of total exceedences, while aquatic life support accounted for 32.4% and consumptive uses accounted for 38.0% of the total.

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

esignated Use	A	M	SE	E	VE	H-no BG TSI 64-70	H-no BG TSI 70+	H-with BG TSI 64+
uatic Life Support	X	Full	Full	Full	Partial	Partial	Non	Non
inking Water Supply	X	Full	Full	Partial	Partial	Non	Non	Non
mary Contact Recreation	X	Full	Full	Partial	Partial	Non	Non	Non
condary Contact Recreation	X	Full	Full	Full	Partial	Partial	Non	Non
vestock Water Supply	X	Full	Full	Full	Partial	Partial	Non	Non
gation	X	Full	Full	Full	Partial	Partial	Non	Non
oundwater Recharge	Trophic state is not generally applicable to this use.							
od 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

Pesticides in Kansas Lakes, 2010

Detectable levels of at least one pesticide were documented in the main body of 24 lakes sampled in 2010 (75.0% of lakes and wetlands surveyed for pesticides). Table 12 lists these lakes and the pesticides that were detected, along with the level measured and the analytical quantification limit. Five different pesticides, and two pesticide degradation byproducts, were noted in 2010. 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 70% of the total number of pesticide detections, and atrazine and/or its degradation byproducts were detected in all 24 lakes with pesticides. In addition to atrazine, ten lakes had detectable levels of metolachlor (Dual). Four lakes had detectable levels of acetochlor (Harness or Surpass), two lakes had detectable levels of alachlor (Lasso), and one lake had prometon (Pramitol) present. Sixteen lakes had detectable quantities of the atrazine metabolites deethylatrazine and/or deisopropylatrazine.

In all cases, the presence of these pesticides was directly attributable to agricultural activity, although prometon is often used in conjunction with brush control in parks and urban areas or around construction sites. Atrazine levels in four lakes and wetlands surveyed in 2010 exceeded 3.0 ug/L (Harvey Co. East Lake, Marais des Cygnes WMA, Neosho WMA, and Ottawa Co. SFL). Five lakes had detectable levels of more than two pesticides (Augusta Santa Fe Lake, Big Hill Lake, Elk City Lake, Mission Lake, and Ottawa Co. SFL).

Supplementary Lake Surveys in 2010

In addition to the 32 monitoring network sites originally scheduled for sampling in 2010, six 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. Memorial Park Lake (a.k.a. Veteran’s Park Lake) located in Great Bend, Kansas, was sampled as part of a continuing fishkill/blue-green algae investigation. Lake Jewell and Horsethief Canyon Lake were sampled as part of Use Attainability Analyses. Fossil Lake and Jetmore City Lake are inactive sites on the statewide monitoring network which have refilled since they were dropped from active status due to dewatered/low water conditions. Both were given limited surveys to compare to past data.

Table 12. Pesticide levels documented during 2010 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**	**Deisopropylatrazine**	**Acetochlor**	**Alachlor**	**Metolachlor**	**Prometon**
Augusta Santa Fe Lake	1.20	0.33			0.20	0.37	
Banner Creek Lake	0.67						
Big Hill Lake	1.40	0.36		0.11			0.53
Centralia Lake	1.10	1.20				0.45	
Elk City Lake	1.70	0.44		0.13		0.46	
Fall River Lake	0.41						
Goodman SFL	0.33						
Harvey Co. East Lake	5.50	0.76			0.14		
Jamestown WMA	0.89	0.30				0.31	
Jewell Co. SFL	0.52						
Kirwin Lake	1.20						
Lake Scott	1.90	0.90				1.00	
Lovewell Lake	1.20	0.34					
Madison City Lake	0.41						
Marais des Cygnes WMA	5.30	0.69					
Mission Lake	0.30			0.21		2.10	

	Pesticide						
Montgomery Co. SFL	0.36						
Lake	**Atrazine**	**Deethylatrazine**	**Deisopropylatrazine**	**Acetochlor**	**Alachlor**	**Metolachlor**	**Prometon**
Neosho WMA	3.80	0.55					
Norton Lake	1.30	0.53					
Olpe City Lake	1.50	0.39					
Ottawa Co. SFL	11.00	0.73		1.80		0.38	
Sabetha City Lake	1.40	1.90	0.59			0.55	
Toronto Lake	0.50					0.60	
Waconda Lake	1.30	0.39				0.45	

Atchison County Lake

Surveyed on August 24, 2010, Atchison Co. Lake was hypereutrophic, with a mean chlorophyll-a of 55.21 ug/L. Secchi disk depth was only 22 cm and yielded a non-algal turbidity of 3.165 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 5.4 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 165,785 cells/mL, and had a community composed of 92% blue-green species (a mixture of *Anabaena spp.*, *Microcystis aeruginosa*, and *Anabaenopsis sp.*), <2% diatoms, and 6% chlorophyte and euglenoid algae. *E. coli* counts averaged <15 cfu/100mL. Pesticides present at detectable levels included atrazine (1.60 ug/L), deethylatrazine (0.58 ug/L), metolachlor (0.56 ug/L), and acetochlor (0.18 ug/L).

Lake Jewell

Surveyed on July 12, 2010, Lake Jewell is a small city recreation lake located in the City of Jewell in North-Central Kansas. This lake was removed from the Water Register several years ago when the lake appeared to be in a state of draining and dam removal. Since that time, the city administration appears to have located funds to completely restore and renovate the dam and facilities. Therefore, the newly restored lake was subjected to a UAA survey for once again placing it in the Kansas Water Register. At the time of the survey, Lake Jewell was hypereutrophic, with a mean chlorophyll-a of 93.79 ug/L. Secchi disk depth was 74 cm and yielded a non-algal turbidity of <0.001 m^{-1}, indicative that the majority of turbidity was due to the phytoplankton community. The TN/TP ratio was 7.7 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 50,400 cells/mL, and had a community composed of 0% blue-green species, 15% chlorophytes, 76% diatoms, and about 9% cryptophyte and euglenoid algae. *E. coli* counts averaged 30 cfu/100mL. Pesticides present at detectable levels included atrazine (0.78 ug/L), deethylatrazine (0.41 ug/L), and metolachlor (0.34 ug/L).

Horsethief Canyon Lake

Horsethief Canyon Lake is a large, new, lake located just West of Jetmore, Kansas, in Hodgeman Co. The lake is still in the process of filling, but was of sufficient depth and volume to allow a UAA survey in order to place the lake in the Kansas Water Register. Surveyed on August 9, 2010, Horsethief Canyon Lake was very eutrophic, with a mean chlorophyll-a of 20.22 ug/L. Secchi disk depth was 57 cm and yielded a non-algal turbidity of 1.249 m^{-1}, indicative of moderate inorganic turbidity. The TN/TP ratio was 11.1 which, along with the suite of metrics typically applied to network sites, and the fact that the lake was still likely reaching a water quality equilibrium as it fills for the first time, the primary limiting factors at the time of the survey are believed to be a combination of nitrogen, light availability, and grazing pressure by zooplankton. At the time of the survey, the copepod community was very large, enough so to be readily visible in samples collected. The phytoplankton community contained 15,215 cells/mL, and had a community composed of 66% blue-green species (a mixture of *Anabaena spp.*), 26% diatoms, and about 8% chlorophyte, dinoflagellate, and euglenoid algae. *E. coli* counts averaged <10 cfu/100mL. Pesticides present at detectable levels included atrazine (2.20 ug/L), deethylatrazine (1.00 ug/L), and metolachlor (0.44 ug/L).

Memorial Park Lake, Great Bend

Surveyed on August 9, 2010, Memorial Park Lake (a.k.a., Veteran's Park Lake) has had a continuing history of blue-green algae blooms and fishkills, and was one of the first lakes with an algae bloom warning issued under the new Blue-Green Algae Response Protocol (finalized August 13, 2010). At the time of the survey, the lake was hypereutrophic, with a mean chlorophyll-a of 79.19 ug/L. Secchi disk depth was 51 cm and yielded a non-algal turbidity of <0.001 m^{-1}, indicating that the vast majority of lake turbidity was derived from phytoplankton rather than inorganic materials. The phytoplankton community contained 425,408 cells/mL, and had a community composed of >99% blue-green species (a mixture of *Aphanizomenon sp.*. and *Microcystis aeruginosa*). 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.

Jetmore City Lake

Jetmore City Lake has been a monitoring network site in the past, but was placed on inactive status after the drought of the early-mid 2000s dewatered the system. During a sampling trip which included nearby lakes, staff stopped to examine the current status of Jetmore City Lake. Upon finding the lake to be re-filled, apparently for some time, staff elected to conduct a limited water quality survey for comparison to past water quality data. Surveyed on August 9, 2010, Jetmore City Lake was extremely hypereutrophic, with a mean chlorophyll-a of 156.57 ug/L. Secchi disk depth was a respectable (given the amount of algae) 74 cm and yielded a non-algal turbidity of <0.001 m^{-1}, indicative that turbidity was entirely due to phytoplankton rather than inorganic materials. The phytoplankton community contained 175,833 cells/mL, and had a community composed of >99% blue-green species (a mixture of *Anabaena spp.*, *Aphanizomenon* *flos-aqua*, and *Microcystis aeruginosa*).

Fossil Lake

Fossil Lake has been a monitoring network site in the past, but was placed on inactive status after low water and limited access became issues. During a sampling trip which included nearby lakes, staff stopped to examine the current status of Fossil Lake. Upon finding the lake to be re-filled, and accessible, staff elected to conduct a limited water quality survey for comparison to past water quality data. Surveyed on August 17, 2010, Fossil Lake was hypereutrophic, with a mean chlorophyll-a of 94.59 ug/L. Secchi disk depth was only 33 cm and yielded a non-algal turbidity of 0.665 m^{-1}, indicative of minor inorganic turbidity, with the majority of turbidity due to phytoplankton biomass. The phytoplankton community contained 422,352 cells/mL, and had a community composed of 96% blue-green species (*Anabaena spp.*), with the remainder a mixture of chlorophytes, diatoms, and euglenoid algae.

CONCLUSIONS

The following conclusions are based on lake monitoring data collected during 2010.

1) Trophic state data indicated that about 31% of the lakes surveyed in 2010 had degraded water quality in comparison to historic mean conditions (i.e., their trophic state had increased). About 59% showed stable conditions over time while another 9% 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 (6.7%) of the documented water quality criteria exceedences.

3) A majority of the lakes surveyed in 2010 (75%) had detectable levels of agricultural pesticides. As noted in previous years, atrazine was the most frequently detected pesticide.

4) Elevated rainfall and runoff during the spring and early summer, followed by a sudden return to hot and dry summer conditions in Kansas, exerted some influence on lake water quality. The summer of 2010 was unusually prolific of blue-green algae blooms. Such antecedent weather conditions (abundant spring runoff followed by long periods of hot and dry conditions) are generally viewed among lake ecologists as a “perfect storm” for the creation of large and numerous blue-green algae blooms.

BIBLIOGRAPHY AND REFERENCES

Allan, J.D., Stream Ecology: Structure and Function of Running Waters. Chapman & Hall, London, Great Britain. 1995.

Brooks, E.B. and L.A. Hauser, Aquatic Vascular Plants of Kansas 1: Submersed and Floating Leaved Plants. Kansas Biological Survey, Technical Publication #7. 1981.

Carlson, R.E., A Trophic State Index for Lakes. Limnology and Oceanography, 22(2), 1977, p.361.

Carlson, R.E., Expanding the Trophic State Concept to Identify Non-Nutrient Limited Lakes and Reservoirs, Abstracts from the "Enhancing the States' Lake Monitoring Programs" Conference, 1991, pages 59-71.

Carney E., Relative Influence of Lake Age and Watershed Land Use on Trophic State and Water Quality of Artificial Lakes in Kansas. Lake and Reservoir Management, 25, 2009, pages 199-207.

Correll, D.L., The Role of Phosphorus in the Eutrophication of Receiving Waters: A Review, Journal of Environmental Quality, 27(2), 1998, p. 261.

Davies-Colley, R.J., W.N. Vant, and D.G. Smith, Colour and Clarity of Natural Waters: Science and Management of Optical Water Quality. Ellis Horwood Limited, Chichester West Sussex, Great Britain. 1993.

Dodds, W.K., E. Carney, and R.T. Angelo, Determining Ecoregional Reference Conditions for Nutrients, Secchi Depth, and Chlorophyll-a in Kansas Lakes and Reservoirs. Lake and Reservoir Management, 22(2), 2006, pages 151-159.

EPA, Ecological Research Series, Water Quality Criteria 1972. National Academy of Sciences/National Academy of Engineering. 1972.

EPA, Quality Criteria for Water. United States Environmental Protection Agency, Washington, D.C. 1976.

EPA, The Lake and Reservoir Restoration Guidance Manual, Second Edition. United States Environmental Protection Agency, Office of Water, Washington, D.C., EPA-440/4-90-006. 1990.

EPA, Fish and Fisheries Management in Lakes and Reservoirs: Technical Supplement to The Lake and Reservoir Restoration Guidance Manual. United States Environmental Protection Agency, Water Division, Washington, D.C., EPA-841-R-93-002. 1993.

EPA, National Strategy for the Development of Regional Nutrient Criteria. United States Environmental Protection Agency, Office of Water, Washington, D.C., EPA 822-R-98-002. 1998a.

EPA, Lake and Reservoir Bioassessment and Biocriteria Technical Guidance Document. United States Environmental Protection Agency, Office of Water, Washington, D.C., EPA 841-B-98-007. 1998b.

EPA, Nutrient Criteria Technical Guidance Manual: Lake and Reservoirs. United States Environmental Protection Agency, Office of Water, Washington, D.C., EPA 822-B00-001. 2000.

Heiskary, S.A. and W.W. Walker, Jr., Developing Phosphorus Criteria for Minnesota Lakes. Lake and Reservoir Management, 4(1), 1988, p. 7.

Horne, A.J. and C.R. Goldman, Limnology, Second Edition. McGraw Hill Publishing, Inc., New York. 1994.

Hynes, H.B.N., The Ecology of Running Waters. University of Toronto Press. 1970.

Jones, J.R. and M.F. Knowlton, Limnology of Missouri Reservoirs: An Analysis of Regional Patterns. Lake and Reservoir Management, 8(1), 1993, p. 17.

KDHE, Atrazine in Kansas, Second Edition. 1991.

KDHE, Division of Environment Quality Management Plan, Part III: Lake and Wetland Water Quality Monitoring Program Quality Assurance Management Plan. 2010.

KDHE, Kansas Surface Water Quality Standards. Kansas Administrative Regulations

28-16-28b through 28-16-28f. 2005.

KDHE, Kansas Wetland Survey: Water Quality and Functional Potential of Public Wetland Areas. 2002a.

KDHE, Lake and Wetland Monitoring Program Annual Report. 2002b.

KDHE, A pH Survey of The Mined Land Lakes Area. 1993.

KDHE, A Primer on Taste and Odor Problems in Water Supply Lakes. 1998a.

KDHE, A Primer on Lake Eutrophication and Related Pollution Problems. 1998b.

KDHE, A Primer on Protection and Restoration of Lake Resources. 1998c.

Lehmann, A. and J.B. LaChavanne, Changes in the Water Quality of Lake Geneva Indicated by Submerged Macrophytes. Freshwater Biology, 42, 1999, p. 457.

Naumann, E., The Scope and Chief Problems of Regional Limnology. Int. Revue ges. Hydrobiol, Vol. 21. 1929.

North American Lake Management Society (NALMS), Developing Eutrophication Standards for Lakes and Reservoirs. NALMS Lake Standards Subcommittee, Alachua, Florida. 1992.

Palmer, C.M., Algae In Water Supplies: An Illustrated Manual on the Identification, Significance, and Control of Algae in Water Supplies. U.S. Department of Health, Education, and Welfare, Public Health Service Publication No. 657. 1959.

Reckhow, K.H., S.W. Coffey, and C. Stow, Technical Release: Managing the Trophic State of Waterbodies. U.S. Soil Conservation Service. 1990.

Scheffer, M., Ecology of Shallow Lakes. Chapman & Hall Publishing, New York. 1998.

Schneider, S. and A. Melzer, The Trophic Index of Macrophytes (TIM) - A New Tool for Indicating the Trophic State of Running Waters. International Review of Hydrobiology, 88(1), 2003, p. 49.

Sculthorpe, C.D., The Biology of Aquatic Vascular Plants. Koeltz Scientific Books, West Germany. 1967.

Sladecek, V., System of Water Quality from the Biological Point of View. Arch. Hydrobiol. Beih. Ergben. Limnol, 7(I-IV), 1973, p.1.

Smeltzer, E. and S.A. Heiskary, Analysis and Applications of Lake User Survey Data. Lake and Reservoir Management, 6(1), 1990, p. 109.

Stene, E.O., How Lakes Came to Kansas. Transactions of The Kansas Academy of Science, 49(2), 1946, p. 117.

Thornton, K.W., B.L. Kimmel, and F.E. Payne, Reservoir Limnology: Ecological Perspectives. Wiley Inter-Science, John Wiley & Sons, Inc., New York. 1990.

Walker, W.W., Jr., Empirical Methods for Predicting Eutrophication in Impoundments; Report 4, Phase III: Applications Manual. Technical Report E-81-9, United States Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 1986.

Wetzel, R.G., Limnology, Second Edition. Saunders College Publishing, New York. 1983.

WHO. Guidelines for Safe Recreational Water Environments, Volume 1: Coastal and Fresh Waters. World Health Organization. 2003.

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.

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Appendix: STREAM PHYTOPLANKTON AND TROPHIC STATE DATA 2003-2010, WITH A COMPARISON TO LAKES FOR 2003-2010

The recent EPA push towards numeric nutrient criteria, for the protection of the beneficial uses assigned to lakes and streams, has provided added value to the mass of water quality data collected over the last few decades by various KDHE programs. The KDHE Lake and Wetland Monitoring Program has collected all manner of nutrient and trophic state data since the inception of the program in 1975. The KDHE Stream Chemistry Monitoring Program has collected nutrient data from stream and river locations across the state since the 1960s. However, one segment of that water quality database that had not been previously collected in Kansas pertains to the sestonic algae communities of running, or lotic, systems.

In 2003, a selected sub-set of the stream chemistry monitoring sites were subjected to the collection of samples for determining sestonic chlorophyll-a and algal community taxonomic composition. This sub-set picked sites from those believed to be nutrient impacted, as well as sites felt to be relatively unimpacted by nutrient pollution, with considerable overlap between the two categories. Each year since, the sub-set has changed to accommodate rotational sampling sites, as well as include streams and rivers where site-specific phytoplankton information was of interest. After eight years of data collection, the trophic condition of streams and rivers in Kansas is described herein, as well as compared to trophic data from lentic waterbodies (lakes and wetlands) for the same time period.

Streams versus Lakes

That standing (lentic) and flowing (lotic) waterbodies differ markedly in some ecological processes and in community structure has been known for a long while (Hynes, 1970; Wetzel, 1983; Horne and Goldman, 1994; Allan, 1995). Over the years, the belief that streams and rivers can’t support sestonic algae communities (due to extremely short retention times) has given way to an understanding that many flowing waterbodies do generate and maintain planktonic algae communities. However, the physical and hydrological differences between the two types of waterbody would still be expected to influence the development of any sestonic community, in terms of magnitude and composition.

Tables A1 through A4 summarize the data from 2003-2010 for algal cell count and biovolume for both lakes and streams. Figures A1 and A2 present the difference between lake and stream communities graphically, while Figures A3 through A6 divide cell count and biovolume among major phytoplankton groups. It should be noted that biovolume equates to biomass if it is assumed algal cells approximate the density of water.

Table A1. Lake algal cell count statistics for 2003-2010, based on 280 lake surveys. Units are in cells/mL.

	Cell Count (cells/mL)	% Chlorophyte (Greens)	% Cyanophytes (Blue-Greens)	% Diatoms	% Others
Maximum	13,207,950	99	100	96	74
90th Percentile	203,618	55	98	28	11
75th Percentile	61,544	27	93	13	4
Median	19,877	9	82	3	1
25th Percentile	6,718	2	44	1	1
10th Percentile	2,728	1	0	0	0
Minimum	284	0	0	0	0
Mean	135,384	18	66	10	5

Table A2. Stream algal cell count statistics for 2003-2010, based on 935 stream surveys. Units are in cells/mL.

	Cell Count (cells/mL)	% Chlorophyte (Greens)	% Cyanophytes (Blue-Greens)	% Diatoms	% Others
Maximum	1,088,010	100	97	100	88
90th Percentile	37,838	84	58	75	15
75th Percentile	9,513	67	15	56	7
Median	2,835	47	0	28	1
25th Percentile	882	25	0	11	0
10th Percentile	378	10	0	4	0
Minimum	63	0	0	0	0
Mean	19,307	46	14	35	5

Table A3. Lake biovolume/biomass statistics for 2003-2010, based on 280 lake surveys.

	Biovolume Biomass (ppm or mg/L)	% Chlorophyte (Greens)	% Cyanophytes (Blue-Greens)	% Diatoms	% Others
Maximum	4323.812	89	100	97	99
90th Percentile	59.948	33	90	61	50
75th Percentile	25.590	17	75	35	27
Median	9.347	7	48	13	11
25th Percentile	4.150	2	14	4	2
10th Percentile	1.722	1	0	0	0
Minimum	0.221	0	0	0	0
Mean	43.874	13	45	23	19

Table A4. Stream biovolume/biomass statistics for 2003-2010, based on 935 stream surveys.

	Biovolume Biomass (ppm or mg/L)	% Chlorophyte (Greens)	% Cyanophytes (Blue-Greens)	% Diatoms	% Others
Maximum	416.471	100	95	100	99
90th Percentile	28.135	54	19	94	50
75th Percentile	8.023	33	2	84	24
Median	2.621	16	0	62	5
25th Percentile	0.874	7	0	29	0
10th Percentile	0.381	3	0	9	0
Minimum	0.025	0	0	0	0
Mean	11.877	23	6	56	16

Figure A1. Algal cell count by waterbody type, 2003-2010. Whiskers are the 90th and 10th percentiles, black box is the interquartile range, white box is the median, and white circle is the mean.

Figure A2. Algal biovolume (biomass) by waterbody type, 2003-2010. Whiskers are the 90th and 10th percentiles, black box is the interquartile range, white box is the median, and white circle is the mean.

Figure A3. Lake algal community composition (cell count), 2003-2010. Whiskers are the 90th and 10th percentiles, black box is the interquartile range, white box is the median, and white circle is the mean.

Figure A4. Stream algal community composition (cell count), 2003-2010. Whiskers are the 90th and 10th percentiles, black box is the interquartile range, white box is the median, and white circle is the mean.

Figure A5. Lake algal community composition (biovolume/biomass), 2003-2010. Whiskers are the 90th and 10th percentiles, black box is the interquartile range, white box is the median, and white circle is the mean.

Figure A6. Stream algal community composition (biovolume/biomass), 2003-2010. Whiskers are the 90th and 10th percentiles, black box is the interquartile range, white box is the median, and white circle is the mean.

The previous tables and graphs support a number of observations, that other texts and articles have described elsewhere around the world, regarding differences between lakes and streams in Kansas (Hynes 1970; Allan, 1995). Among these are that (1) Kansas lakes can be expected to generate a larger planktonic algae community than streams, generally, although (2) sometimes streams and rivers can also exhibit very large phytoplankton communities. Also, (3) Kansas lakes tend to have a phytoplankton community dominated by blue-green species, although diatoms and other large flagellate species can sometimes provide significantly to the biomass, and (4) streams and rivers will tend to be dominated by green and diatom algae, although diatoms are most often the primary contributor to total biomass. Blue-green algae tend to rarely dominate stream and river communities at large biomass (5), unlike lakes.

Seasonality Within Streams and Rivers

Stream sampling takes place all year while lake and wetland sampling is limited to the summer "critical" time period where recreational and water supply uses are at their highest level of use. Therefore, seasonality can be examined with regards to stream trophic state condition. For the purposes of a seasonal analysis, chlorophyll-a is used as a substitute for algal biomass, much as is traditional for lake ecological analysis. Also examined are total phosphorus (TP: a primary nutrient driving trophic state development), total nitrogen (TN: a primary nutrient driving trophic state development), and total suspended solids (TSS: estimate of solids in the water column and of clarity).

Tables A5 through A8 present data for the trophic state variables for the 2003-2010 period. Figures A7 through A10 present those trophic state variables graphically. Sample numbers were fairly uniform between seasons (Winter = 216, Spring = 253, Summer = 225, Fall = 241), with winter and summer being slightly lower due to some lost sampling opportunities due to dry/pooled streams or to ice cover.

Kruskal-Wallace tests indicate that there were no significant ($p>0.05$) seasonal differences for either total phosphorus or total nitrogen in Kansas streams and rivers. However, there were seasonal differences for algal biomass ($p<0.001$) and TSS ($p<0.001$). Algal biomass, as measured by chlorophyll-a, tended to be higher in the spring and summer and lower in the winter. Total suspended solids followed the same pattern. In this way, streams and rivers would seem to also experience the traditional growing season as the "critical" sampling period when biomass and potential impacts are highest, as do lakes.

Table A5. Stream chlorophyll-a data for 2003-2010, based on 935 stream surveys. All values are in units of ug/L.

	Winter	Spring	Summer	Fall
Maximum	63.40	535.15	270.55	305.95
90th Percentile	15.45	74.55	73.89	39.75
75th Percentile	7.63	23.45	24.00	17.45

	Winter	Spring	Summer	Fall
Median	3.75	5.95	8.80	5.10
25th Percentile	1.80	2.55	2.90	1.75
10th Percentile	0.85	1.30	1.62	1.05
Minimum	<0.30	<0.30	0.50	0.30
Mean	6.58	27.73	26.99	17.63

Table A6. Stream total phosphorus data for 2003-2010, based on 935 stream surveys. All values are in units of ug/L.

	Winter	Spring	Summer	Fall
Maximum	4,684	4,329	3,710	4,853
90th Percentile	1,040	732	857	763
75th Percentile	350	355	367	383
Median	119	92	142	117
25th Percentile	30	33	49	41
10th Percentile	<20	<20	27	26
Minimum	<20	<20	<20	<20
Mean	403	302	329	381

Table A7. Stream total nitrogen data for 2003-2010, based on 935 stream surveys. All values are in units of ug/L.

	Winter	Spring	Summer	Fall
Maximum	20,408	23,431	14,075	21,461
90th Percentile	5,517	4,126	4,097	3,700

	Winter	Spring	Summer	Fall
75th Percentile	2,997	2,394	2,310	2,394
Median	1,349	1,253	1,289	1,168
25th Percentile	473	524	571	503
10th Percentile	<250	<250	<250	<250
Minimum	<250	<250	<250	<250
Mean	2,496	1,933	1,923	2,013

Table A8. Stream total suspended solids data for 2003-2010, based on 935 stream surveys. All values are in units of mg/L.

	Winter	Spring	Summer	Fall
Maximum	168	644	396	392
90th Percentile	41	107	131	66
75th Percentile	21	56	83	41
Median	12	23	39	21
25th Percentile	<10	11	14	10
10th Percentile	<10	<10	<10	<10
Minimum	<10	<10	<10	<10
Mean	19	45	58	31

Figure A7. Stream seasonal chlorophyll-a data, 2003-2010. Whiskers are the 90th and 10th percentiles, black box is the interquartile range, and white box is the median.

Figure A8. Stream seasonal total phosphorus data, 2003-2010. Whiskers are the 90th and 10th percentiles, black box is the interquartile range, and white box is the median.

Figure A9. Stream seasonal total nitrogen data, 2003-2010. Whiskers are the 90th and 10th percentiles, black box is the interquartile range, and white box is the median.

Figure A10. Stream seasonal total suspended solids data, 2003-2010. Whiskers are the 90th and 10th percentiles, black box is the interquartile range, and white box is the median.

The Risk of Blue-Green Algae Impacts

With the adoption of a policy and protocol (August 13, 2010) defining blue-green algae levels, above which advisories and warnings will be issued by KDHE, discussion immediately began whether the policy would apply mainly to lakes or whether streams and rivers might also have public health alerts issued.

This analysis of phytoplankton and trophic state data intends to answer how common the issuance of advisories and warnings for possible toxic algae bloom conditions will be for the two different water body types. The KDHE policy uses two cell count levels for blue-green algae, 20,000 and 100,000 cells/mL, for issuing advisories and warnings, respectively. These numbers are derived from guidance offered up by the World Health Organization (WHO, 2003).

Table A9 presents a comparison of lakes and streams with regard to how often blue-green algae are observed in samples (i.e., "present"), how often blue-green algae are "dominant" in samples (i.e., cell count is >50% blue-green species), how often samples exceed the advisory level of 20,000 blue-green cells/mL, and how often samples exceed the warning level of 100,000 blue-green cells/mL.

<u>Lakes</u>

From the data in Table A9, it is apparent that there is a high, and nearly equal, probability of any of the four algal categories utilized here (greens, blue-greens, diatoms, and other flagellates)being found in any given sample from a lake. However, when we switch to the likelihood of dominance in the algal community, blue-green algae are far more likely to be the largest contributor to total cell count. The likelihood of a lake being dominated by chlorophyte/green algae is a distant second, with the likelihood of finding a Kansas lake with diatoms, dinoflagellates, euglenoids, or other algal types as the primary feature being only 3-4%.

Almost 50% of the time total algal cell count exceeded 20,000 cells/mL in lake samples. Lake samples exceeded 100,000 cells/mL almost one-fifth of the time, indicating abundant phytoplankton is fairly common in Kansas lakes, as described by these eight years of data.

Lake samples can reasonably be expected to exceed the blue-green algae advisory threshold of 20,000 blue-green cells/mL 42% of the time, based on this eight years of data. Therefore, a significant number of Kansas lakes might be expected to trigger this level of action during a typical Kansas summer. Roughly 16% of Kansas lakes could be expected to exceed the threshold of 100,000 blue-green cells/mL and trigger a warning.

Table A9. Comparison of lakes and streams, with regard to how frequently samples have (1) blue-green algae present (at any amount/level), (2) have blue-green algae dominant (>50% of cell count total), (3) exceed 20,000 blue-green cells/mL, or (4) exceed 100,000 blue-green cells/mL.

	Lakes (% samples)	Streams (% samples)

	Lakes (% samples)	Streams (% samples)
Chlorophytes (Greens) Present	92.9	95.6
Cyanophytes (Blue-Greens) Present	87.9	28.3
Diatoms Present	88.9	96.7
Other Algae Present	81.1	58.4
Chlorophytes Dominant	11.1	46.5
Cyanophytes Dominant	73.6	12.8
Diatoms Dominant	3.9	31.5
Other Algae Dominant	3.2	1.1
Total Algae Exceed 20,000 cells/mL	49.6	15.7
Total Algae Exceed 100,000 cells/mL	17.5	4.6
Blue-Green Algae Exceed 20,000 cells/mL	42.1	6.2
Blue-Green Algae Exceed 100,000 cells/mL	15.7	1.8

<u>Streams</u>

From the data in Table A9, it is apparent that there is an unequal probability among the four algal categories utilized here (greens, blue-greens, diatoms, and other flagellates) of being found in any given sample from a stream or river. Probabilities of green or diatom algae being present are high, the probability of blue-greens being present is a much lower 28%, and the probability of other algal groups being found is intermediate. This order is almost the same when we switch to the likelihood of dominance in the algal community. Green and diatom algae are far more likely to be the largest contributor to total cell count in streams. The likelihood of a stream being dominated by blue-green algae is only about 13%, with the likelihood of finding a Kansas stream with dinoflagellates, euglenoids, or other algal types as the primary feature is only 1-2%.

Only 16% of the time does total algal cell count exceed 20,000 cells/mL in stream and river samples. Stream and river samples exceeded 100,000 cells/mL only 5% of the time. This supports data discussed previously that indicate streams and rivers “can” have abundant phytoplankton communities, but it is a rarer phenomenon than observed in lakes.

Stream and river samples could be expected to exceed the blue-green algae advisory threshold of 20,000 blue-green cells/mL only 6% of the time, based on these eight years of data. Therefore, very few of Kansas streams and rivers might be expected to trigger this level of action during a typical Kansas year. Less than 2% of Kansas streams and rivers could be expected to exceed the threshold of 100,000 blue-green cells/mL and trigger a warning. It needs to be kept in mind that some portion of these potential exceedences could be due to wastewater or CAFO (confined animal feeding operation) lagoon discharges or releases, rather than blue-green communities generated within the stream or river itself. Such lagoons typically host very large, or even extremely large, blue-green algal communities, especially during summer, and KDHE typically investigates complaints each summer regarding receiving streams downstream of lagoons.

A majority of stream samples that made up the category of “blue-green cell count >20,000/mL” came from only five streams and rivers (Arkansas River downstream of Wichita, Kansas River, Big Blue River near the Nebraska border, Wolf River in the Missouri Basin, and Buffalo Creek near Concordia).

Of the stream and river samples that exceeded 100,000 blue-green cells/mL, and therefore would have been able to trigger a warning, the majority come from two streams (Buffalo Creek near Concordia and the Arkansas River downstream of Wichita).

Although abundant blue-green algae are fairly common in lentic waters, the same can not be said of flowing waters in Kansas. Blue-green algae problems and concerns for our streams and rivers can be expected to be minimal.

Trophic State Data for Streams and Rivers and Statistical Relationships

This final analysis summarizes selected nutrient and trophic state data for the period of record

2003-to-2010 for streams and rivers in Kansas. Table A10 provides basic descriptive statistics, while Table A11 provides information regarding linear regression models for stream trophic state variables. To facilitate the regression analyses, individual parameter values below KHEL's reporting limit were substituted with a value of one-half that limit.

Table A10. Stream and river descriptive statistics for nutrient and trophic state variables. Statistics are for the period of record with no regard to seasonality (N = 935).

Statistic	Chlorophyll-a (ug/L)	Total Phosphorus (ug/L)	Total Nitrogen (ug/L)	Total Suspended Solids (mg/L)	Total Algal Cell Count (cells/mL)
Maximum	535.15	4,853	19,143	644	1,088,010
90th %ile	45.55	731	4,006	95	39,564
75th %ile	17.49	340	2,394	50	10,537
Median	5.30	101	1,245	21	2,835
25th %ile	2.30	36	495	10	819
10th %ile	1.14	<20	<250	<10	315
Minimum	<0.30	<20	<250	<10	63
Mean	20.92	302	1,850	39	20,335

That there are differences in trophic state processes between lentic and lotic waters in Kansas becomes very apparent when comparing correlations and predictive equations developed for each water body type. Very strong regression models for total phosphorus versus chlorophyll-a for Kansas lakes have been produced (Dodds et al., 2006; Carney, 2009). In contrast, general models relating total nitrogen to chlorophyll-a in lakes statewide produce weak predictive models. R^2 values for lake total phosphorus models typically are 0.65-to-0.80, while those for lake total nitrogen models range from 0.10-to-0.40. These lake total phosphorus models always have statistical significance ($p<0.05$), while lake total nitrogen models can be either significant at the $p<0.05$ level or non significant ($p>0.05$).

Table A11. Linear regression models developed from the 2003-2010 stream and river nutrient and trophic state data. A total of 878 individual samples are included in these analyses. Chl-a = chlorophyll-a, TP = total phosphorus, and TN = total nitrogen.

Model	p	R^2
Single Variable Models		
Log(Chl-a) = (0.67*Log(TP))-0.57	<0.001	0.44
Log(Chl-a) = (0.78*Log(TN))-1.54	<0.001	0.35
Two Variable Models Log(Chl-a) = (0.54*Log(TP))+(0.22*Log(TN))-0.97	<0.001	0.46
Relationship Between Chlorophyll-a and Algal Cell Count		
Log(Chl-a) = (0.71*Log(Cell Count))-1.68	<0.001	0.76

The models presented in Table A11, for streams and rivers, suggest modest (at best) predictive ability for either phosphorus or nitrogen, although the analyses clearly indicate a relationship is present. The role of TSS remains unclear. The TSS measure would be expected to include both organic (algal and other organic material) and inorganic components. Previous graphs (Figures A7 and A10) also suggest stream TSS used in this analysis correlates to some extent with chlorophyll-a. For the purposes of modeling, a different measure of water clarity would seem preferable to TSS.

However, light limitation of sestonic algal production in streams and rivers in Kansas is likely small, due to mixing and relatively shallow stream depth and, therefore, felt to be generally unimportant in controlling the phytoplankton. Clearly, other factors besides just nutrients figure into sestonic algal production in Kansas streams and rivers, making them somewhat more complex than their lentic counterparts. In lakes, phosphorus has been shown to be a very important limiting factor, with nitrogen and light availability showing up as important secondary factors generally. For streams, light seems less important, while nutrients are important but clearly not the only primary limiting factor. Although this data set does not allow an examination of the influence of flow and flushing, that fundamental difference between streams and lakes would seem a likely feature to target in future studies.