Lake and Wetland Monitoring Program

2004 Annual Report

By

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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 2004. Ten of the lakes surveyed were large federal impoundments, 11 were State Fishing Lakes (SFLs) or units within the Mined Land Lakes Recreation Area, 14 were city and county lakes, and three were state or federally owned and managed wetland areas.

Of the 38 lakes and wetlands surveyed, 60% indicated trophic state conditions comparable to their historic mean water quality conditions. Another 24% indicated improved water quality conditions, over mean historic condition, as evidenced by a lowered lake trophic state. The remaining 16% indicated degraded water quality, over historic mean condition, as evidenced by elevated lake trophic state conditions. Phosphorus was identified as the primary factor limiting phytoplankton growth in 45% of the lakes surveyed during 2004. Nitrogen was identified as the primary limiting factor in 18% of the lakes, while <8% were identified as primarily light limited. The remaining lakes and wetlands appeared limited by combinations of nutrients or nutrients and light availability (27%), or biological interactions (<3%) (i.e., grazing pressure).

There were a total of 181 documented exceedences of Kansas numeric and narrative water quality criteria, or Environmental Protection Agency (EPA) water quality guidelines, in the lakes surveyed during 2004. Of these 181 exceedences, 30% pertained to the aquatic life use and 70% concerned consumptive and recreational uses. Fully 66% involved uses previously designated in the Kansas Surface Water Register. Approximately 34% were for uses that had not been formally designated or verified by use attainability analyses.

Nineteen lakes and wetlands (50% of those surveyed for pesticides) had detectable levels of at least one pesticide in their main bodies during 2004. Atrazine, or its degradation byproduct deethylatrazine, were detected in 18 of these water bodies (95%), once again making atrazine the most commonly documented pesticide in Kansas lakes. The highest detected atrazine concentration during 2004 lake and wetland sampling was 16.0 ug/L. A total of five different pesticides, and one pesticide degradation byproduct, were found in lakes during 2004.

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INTRODUCTION

Development of the Lake and Wetland Monitoring Program

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

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

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

Overview of the 2004 Monitoring Activities

Staff of the KDHE Lake and Wetland Monitoring Program visited 38 Kansas lakes and wetlands during 2004. Ten of these water bodies are large federal impoundments last sampled in 2001 or as part of special projects, 10 are State Fishing Lakes (SFLs), 14 are city/county lakes (CLs and Co. lakes, respectively), three are wetlands, and one a unit in the Mined Land Lakes Recreation Area. Fifteen of the 38 lakes (39.5%) serve as either primary or back-up municipal or industrial water supplies. Rimrock Park Lake (a.k.a. Homer's Pond) was sampled in 2004 as a follow-up to an earlier Clean Lakes Program project, while Wilson Lake was sampled again in 2004 at the request of the Kansas Water Office (KWO). Rock Creek Lake and Sabetha City Lake were cycled back into the network to collect more recent data for Total Maximum Daily Load (TMDL) work.

General information on the lakes surveyed during 2004 is compiled in Table 1. Figure 1 depicts the locations of the lakes surveyed in 2004. Figure 2 depicts the locations of all currently active sites within the Lake and Wetland Monitoring Program. Additionally, a total of six lakes, streams, and/or ponds were investigated as part of the Taste and Odor/Algae Bloom Technical Assistance Program.

Created lakes are usually termed "reservoirs" or "impoundments," depending on whether they are used for drinking water supply or for other beneficial uses, respectively. In many parts of the country, smaller lakes are termed "ponds" based on arbitrary surface area criteria. To provide consistency, this report uses the term "lake" to describe all non-wetland bodies of standing water within the state. The only exception to this is when more than one lake goes under the same general name. For example, the City of Herington has jurisdiction over two larger lakes. The older lake is referred to as Herington City Lake while the newer one is called Herington Reservoir in order to distinguish it from its sister waterbody.

METHODS

Yearly Selection of Monitored Sites

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

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, 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 fecal coliform bacteria samples, are collected at 0.5 meters depth at the primary sampling point (KDHE, 2005).

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

Table 1. General information pertaining to lakes surveyed during 2004.

Lake	Basin	Authority	Water Supply	Last Survey
Atchison Co. SFL	Missouri	State	no	2001
Barber Co. SFL	Lower Arkansas	State	no	2000
Big Hill Lake	Verdigris	Federal	yes	2001
Bourbon Co. SFL	Marais des Cygnes	State	no	2001
Brown Co. SFL	Missouri	State	no	2001
Elk City Lake	Verdigris	Federal	yes	2001
Fall River Lake	Verdigris	Federal	yes	2001
Harvey Co. West Lake	Lower Arkansas	County	no	2000
Hillsdale Lake	Marais des Cygnes	Federal	yes	2003
Jamestown WMA	Kansas/Lower Republican	State	no	2000
Kirwin Lake	Solomon	Federal	no	2001
Lake Afton	Lower Arkansas	County	no	2000
Lake Anthony	Lower Arkansas	City	no	2000
Lake Miola	Marais des Cygnes	City	yes	2000
Lake Parsons	Neosho	City	yes	2000
Lake Wabaunsee	Kansas/Lower Republican	County	yes	2001
Leavenworth Co. SFL	Kansas/Lower Republican	State	no	2001
Louisburg SFL	Marais des Cygnes	State	yes	2000
Lovewell Lake	Kansas/Lower Republican	Federal	no	2001
Marais des Cygnes WMA	Marais des Cygnes	State	no	2000
Mined Land Lake 44	Neosho	State	no	1999
Neosho Co. SFL	Neosho	State	no	2001

Lake	Basin	Authority	Water Supply	Last Survey
Neosho WMA	Neosho	State	no	2000
Norton Lake	Upper Republican	Federal	yes	2001
Osage Co. SFL	Marais des Cygnes	State	no	2001
Pratt Co. Lake	Lower Arkansas	County	no	2000
Richmond City Lake	Marais des Cygnes	City	yes	2000
Rimrock Park Lake	Kansas/Lower Republican	City	no	1994
Rock Creek Lake	Marais des Cygnes	City	yes	1990
Sabetha City Lake	Missouri	City	yes	1989
Shawnee Mission Lake	Kansas/Lower Republican	City	no	2001
Sheridan Co. SFL	Soloman	State	no	2000
Strowbridge Reservoir	Kansas/Lower Republican	City	yes	2001
Toronto Lake	Verdigris	Federal	yes	2001
Waconda Lake	Solomon	Federal	yes	2001
Wilson Co. SFL	Verdigris	State	no	2000
Wilson Lake	Smoky Hill/Saline	Federal	no	2003
Wyandotte Co. Lake	Missouri	County	no	2001

Since 1992, macrophyte surveys have been conducted at each of the smaller lakes (<300 acres) within the KDHE Lake and Wetland Monitoring Program network. These surveys entail the selection and mapping of 10 to 20 sampling points, depending on total surface area and lake morphometry, distributed in a regular pattern over the lake surface. At each sampling point, a grappling hook is cast to rake the bottom for submersed aquatic plants. This process, combined with visual observations at each station, confirms the presence or absence of macrophytes at each station. If present, macrophyte species are identified and recorded on site. Specimens that cannot be identified in the field are placed in labeled plastic bags, on ice, for identification at the KDHE Topeka office. Presence/absence data, and taxon specific presence/absence data, are used to calculate spacial coverage (percent distribution) estimates for each lake (KDHE, 2005).

Taste and Odor/Algae Bloom Program

In 1989, KDHE initiated a formal Taste and Odor/Algae Bloom Technical Assistance Program.

Technical assistance concerning taste and odor incidences in water supply lakes, or algae blooms in lakes and ponds, may take on varied forms. Investigations are generally initiated at the request of water treatment plant personnel, or personnel at the KDHE district offices. While lakes used for public water supply are the primary focus, a wide variety of samples related to algae, odors, and fishkills, from both lakes and streams, are accepted for analysis.

Figure 1. Locations of the 38 lakes surveyed during 2004. The star indicates the location of Rimrock Park Lake, which is not part of the ambient network.

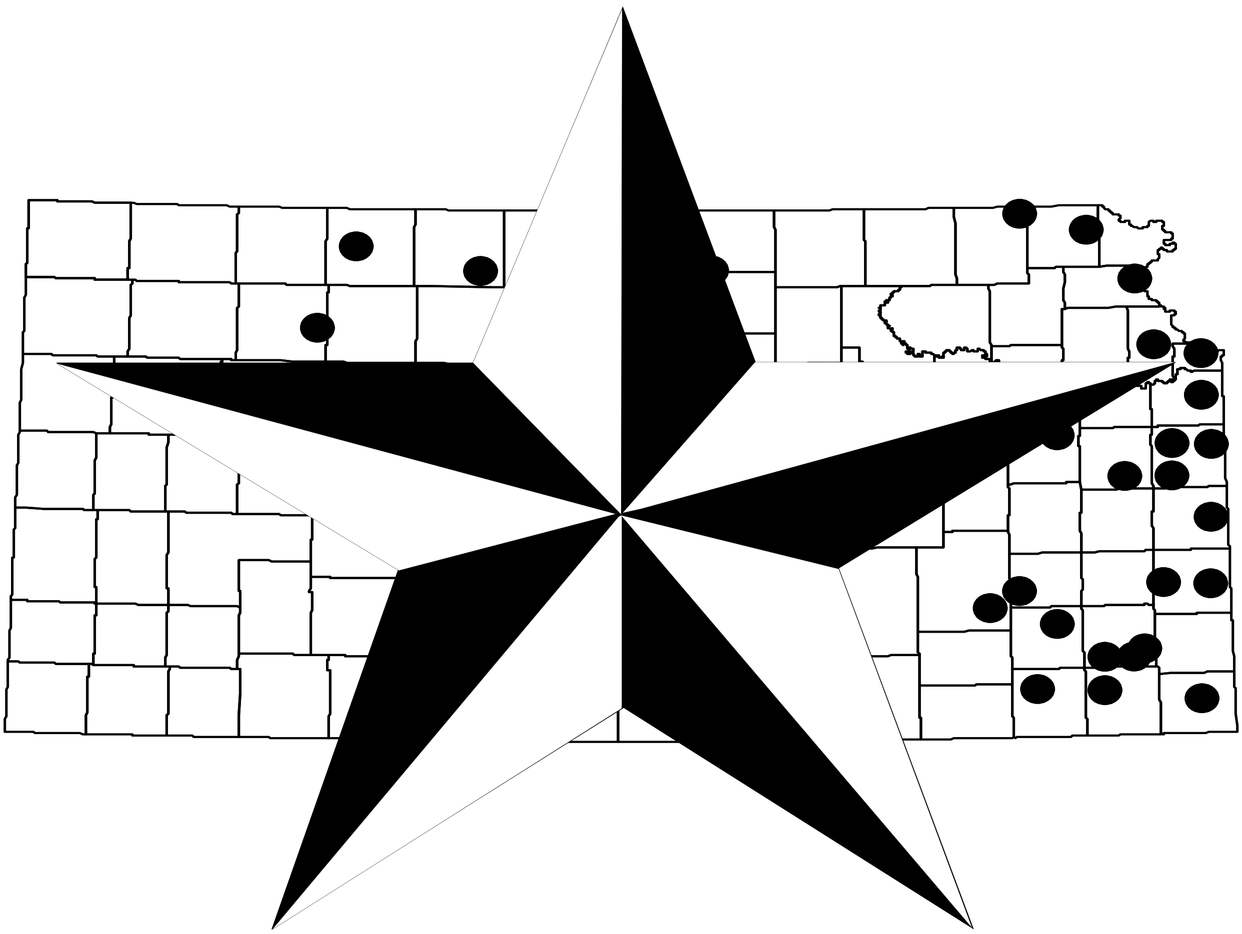
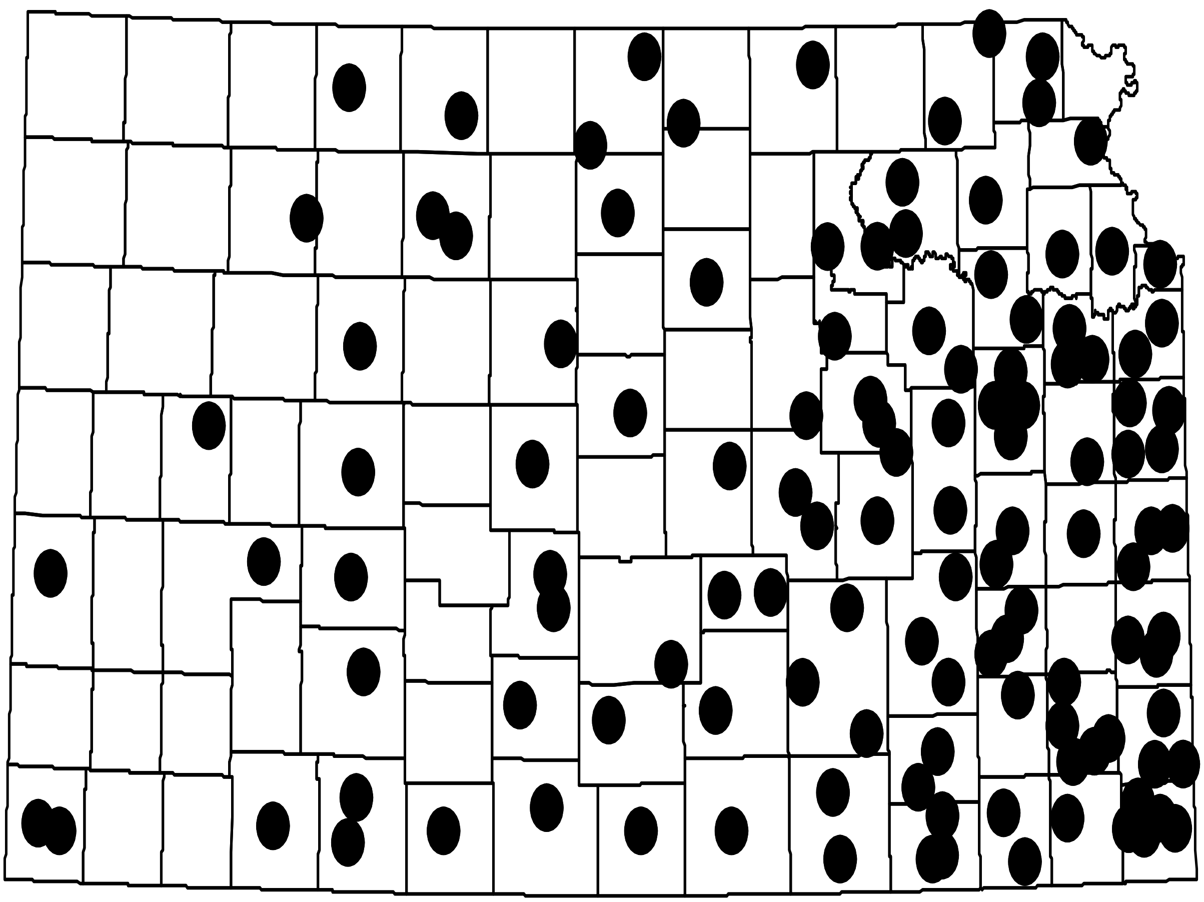


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program's network.



RESULTS AND DISCUSSION

Lake Trophic State

The Carlson Chlorophyll-a Trophic State Index (TSI) provides a useful tool for the comparison of lakes in regard to general ecological functioning and level of productivity (Carlson, 1977). Table 2 presents TSI scores for the 38 lakes surveyed during 2004, previous TSI mean scores for those lakes with past data, and an indication of the extent that lake productivity is dominated by submersed and floating-leaved vascular plant communities (macrophytes). Since chlorophyll-a TSI scores are based on the planktonic algae community, production due to macrophyte beds is not reflected in these scores. The system used to assign lake trophic state, based on TSI scores, is presented below. Trophic state classification is adjusted for macrophytes where percent areal cover (as estimated by percent presence) is greater than 50%, and visual bed volume and plant density clearly indicate that macrophyte productivity contributes significantly to overall lake primary production.

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

> OM = A lake with a low level of planktonic algae. Such lakes also lack significant amounts of suspended clay particles in the water column, giving them a relatively high level of water clarity. Chlorophyll-a concentration averages no more than 2.5 ug/L.

TSI score of 40-49 = mesotrophic (M)

> M = A lake with only a moderate planktonic algal community. Water clarity remains relatively high. Chlorophyll-a ranges from 2.51 to 7.2 ug/L.

TSI score of 50-63 = eutrophic (E)

> E = A lake with a moderate-to-large algae community. Chlorophyll-a ranges from 7.21 to 30.0 ug/L. This category is further divided as follows:

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

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

H = A lake with a very large phytoplankton community. Chlorophyll-a averages more than 30.0 ug/L. This category is further divided as follows:

TSI = 64-69.9 = lower hypereutrophic Chlorophyll-a ranges 30.01 to 55.99 ug/L,
TSI = $\geq$70 = upper hypereutrophic Chlorophyll-a values $\geq$56 ug/L.

TSI score not relevant = argillotrophic (A)

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

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

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

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 2004. 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 38 lakes this year was 101,391 cells/mL (median = 29,185 cells/mL).

Table 4 presents biovolume data for the 38 lakes surveyed in 2004. 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 33.4 ppm (median = 11.3 ppm).

Table 2. Current and past TSI scores, and trophic state classification for the lakes surveyed during 2004. Trophic class abbreviations used previously apply. An asterisk appearing after the lake name indicates that the lake was dominated, at least in part, by macrophyte production. In such a case, the trophic class is adjusted, and the adjusted trophic state class given in parentheses. Previous TSI scores are based only on algal chlorophyll TSI scores.

Lake	2004 TSI/Class	Previous Trophic Class Period of Record Mean
Atchison Co. SFL*	70.2 H(H)	H
Barber Co. SFL	54.1 SE	SE
Big Hill Lake	55.4 E	SE
Bourbon Co. SFL	56.0 E	E
Brown Co. SFL*	74.9 H(H)	H
Elk City Lake	62.9 VE	E
Fall River Lake	53.1 SE	SE
Harvey Co. West Lake	67.9 H	H
Hillsdale Lake$	61.6 VE	E
Hillsdale Lake Sta. 1 (Main Body)	62.1 VE	E
Hillsdale Lake Sta. 2 (Big Bull Creek Arm)	59.8 E	E
Hillsdale Lake Sta. 3 (Little Bull Creek Arm)	62.8 VE	E
Jamestown WMA	88.0 H	H
Kirwin Lake	50.7 SE	VE
Lake Afton	61.3 VE	VE
Lake Anthony	61.2 VE	H
Lake Miola	54.6 SE	SE
Lake Parsons	43.4 A	A
Lake Wabaunsee	67.2 H	SE
Leavenworth Co. SFL	55.7 E	E
Louisburg SFL	55.4 E	E

Lake	2004 TSI/Class	Previous Trophic Class Period of Record Mean
Lovewell Lake	67.3 H	VE
Marais des Cygnes WMA Mined Land Lake 44	64.3 H 49.9 M	H SE
Neosho Co. SFL	71.1 H	H
Neosho WMA	64.4 H	H
Norton Lake	58.4 E	E
Osage Co. SFL	47.5 M	SE
Pratt Co. Lake	73.2 H	H
Richmond City Lake	53.7 SE	SE
Rimrock Park Lake (mean of 5 surveys)	58.2 E	H
Rock Creek Lake	51.2 SE	E
Sabetha City Lake*	71.9 H(H)	H
Shawnee Mission Lake	47.7 M	M
Sheridan Co. SFL	59.5 E	VE
Strowbridge Reservoir	62.1 VE	E
Toronto Lake[x]	52.8 SE/A	SE/A
Waconda Lake	51.8 SE	E
Wilson Co. SFL	59.8 E	E
Wilson Lake	32.4 OM	M
Wyandotte Co. Lake	53.0 SE	SE

$ = Hillsdale Lake's whole lake TSI is the mean of three individual stations within the lake.
x = Toronto Lake traditionally hovers at the threshold of these two trophic state classes.

Trends in Trophic State

Table 5 summarizes changes in trophic status for the 38 lakes surveyed during 2004. Six lakes (15.8%) displayed increases in trophic state, compared to their historic mean condition, while nine lakes (23.7%) displayed improved trophic states. Stable conditions were noted in 23 lakes (60.5%).

One lake, Lake Wabaunsee, stood out as having a large change in conditions since the last survey conducted. Although Lake Wabaunsee was hypereutrophic during the 2004 survey, there is the distinct possibility the survey coincided with an infrequent algae bloom and was not reflective of the typical summer trophic condition. Future surveys will help determine the overall representativeness of the 2004 data for this lake.

Table 3. Algal communities observed in the 38 lakes surveyed during 2004. The “other” category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate groups of algae.

Lake	Cell Count (cells/mL)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Atchison Co. SFL	343,224	0	100	<1	0
Barber Co. SFL	6,741	26	0	64	10
Big Hill Lake	38,304	1	98	1	<1
Bourbon Co. SFL	8,442	36	51	13	0
Brown Co. SFL	302,369	<1	98	1	1
Elk City Lake	26,271	75	5	5	15
Fall River Lake	11,529	9	75	14	2
Harvey Co. West Lake	322,718	3	96	1	0
Hillsdale Lake (mean)	26,397	10	74	10	6
Hillsdale Lake Sta. 1	12,915	7	67	17	9
Hillsdale Lake Sta. 2	22,491	15	72	9	4
Hillsdale Lake Sta. 3	43,785	9	83	4	<4
Jamestown WMA	980,753	4	78	17	1
Kirwin Lake	4,883	44	34	17	5
Lake Afton	11,340	10	19	69	<2
Lake Anthony	43,817	6	84	0	10
Lake Miola	25,137	13	83	2	2
Lake Parsons	4,788	1	88	9	2
Lake Wabaunsee	200,718	<1	100	<1	<1
Leavenworth Co. SFL	11,183	13	25	44	18
Louisburg SFL	31,973	3	95	1	1

Lake	Cell Count (cells/mL)	Percent Composition Greens	Blue-Greens	Diatoms	Other
Lovewell Lake	178,196	10	89	1	<1
Marais des Cygnes WMA	40,572	32	56	5	7
Mined Land Lake 44	70,277	<1	99	<1	<1
Neosho Co. SFL	263,498	4	95	<1	<1
Neosho WMA	53,298	28	54	11	7
Norton Lake	41,675	41	56	0	3
Osage Co. SFL	5,387	2	89	7	2
Pratt Co. Lake	337,050	8	87	3	2
Richmond City Lake	17,640	44	21	33	2
Rimrock Park Lake (5 surveys over summer)	34,575	44	50	6	<1
Rock Creek Lake	11,655	20	66	13	1
Sabetha City Lake	192,938	5	64	28	3
Shawnee Mission Lake	8,663	22	72	6	0
Sheridan Co. SFL	25,358	63	25	4	8
Strowbridge Reservoir	62,370	5	80	14	1
Toronto Lake	7,403	3	0	96	1
Waconda Lake	19,845	3	91	5	1
Wilson Co. SFL	69,174	1	97	2	<1
Wilson Lake	630	79	0	21	0
Wyandotte Co. Lake	12,065	14	85	<1	<1

As shown in Table 6, of the 22 lakes receiving macrophyte surveys (20 full surveys and 2 limited observational surveys), 14 (64% of those surveyed, 37% of all lakes in 2004) had detectable amounts of submersed plant material. In these lakes, the most common plant species were pondweeds (*Potamogeton spp.*), water naiad (*Najas guadalupensis*), coontail (*Ceratophyllum demersum*), parrot feather (*Myriophyllum spicatum*), and various species of stonewort algae (*Chara spp.*).

Using trophic state data for macrophytes in the literature (Schneider and Melzer, 2003; Lehmann and LaChavanne, 1999; Sladecek, 1973), combined with abundance of aquatic plants in the lakes during 2004, four water bodies appeared to merit further assessment of the macrophyte community trophic classification. Two of these were assessed as eutrophic (Osage Co. SFL and Sabetha City Lake) and two as very eutrophic (Atchison and Brown Co. SFLs), based on only the macrophyte community. No lakes merited having their trophic classification adjusted upwards based on the observed abundance and diversity of the macrophytic community during 2004 (Table 2).

Table 4. Algal biovolumes calculated for the lakes surveyed during 2004. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate forms of algae. Biovolume units are calculated in mm^3/L, and expressed as parts-per-million (ppm).

Lake	Biovolume (ppm)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Atchison Co. SFL	51.969	0	100	<1	0
Barber Co. SFL	6.774	6	0	32	62
Big Hill Lake	9.696	5	85	9	1
Bourbon Co. SFL	10.035	6	13	81	0
Brown Co. SFL	99.482	<1	64	6	30
Elk City Lake	21.250	51	1	15	33
Fall River Lake	6.666	6	26	49	19
Harvey Co. West Lake	38.855	10	80	10	0
Hillsdale (mean)	17.587	11	21	21	47
Hillsdale Lake Sta. 1	17.848	7	10	28	55
Hillsdale Lake Sta. 2	15.326	20	26	17	37
Hillsdale Lake Sta. 3	19.586	6	26	19	49
Jamestown WMA	514.883	2	29	67	2
Kirwin Lake	3.365	19	23	36	22
Lake Afton	16.101	3	3	90	4
Lake Anthony	14.889	4	24	0	72
Lake Miola	7.857	9	55	8	28
Lake Parsons	1.600	4	52	32	12

	Biovolume	Percent Composition			
Lake	(ppm)	Green	Blue-Green	Diatom	Other
Lake Wabaunsee	35.003	1	94	3	2
Leavenworth Co. SFL	8.361	3	6	53	38
Louisburg SFL	7.961	3	80	4	13
Lovewell Lake	43.626	20	56	23	1
Marais des Cygnes WMA	22.893	24	20	11	45
Mined Land Lake 44	3.681	4	58	6	32
Neosho Co. SFL	59.573	5	82	2	11
Neosho WMA	23.299	14	24	15	47
Norton Lake	13.812	29	26	0	45
Osage Co. SFL	1.852	8	50	26	16
Pratt Co. Lake	75.888	10	54	18	18
Richmond City Lake	4.904	34	15	23	28
Rimrock Park Lake (5 surveys over summer)	10.639	40	34	19	7
Rock Creek Lake	4.436	14	27	54	5
Sabetha City Lake	66.783	3	36	42	19
Shawnee Mission Lake	2.239	22	54	24	0
Sheridan Co. SFL	12.028	39	11	10	40
Strowbridge Reservoir	18.786	4	50	40	6
Toronto Lake	5.592	1	0	91	8
Waconda lake	6.758	2	38	55	5
Wilson Co. SFL	13.517	3	85	5	7
Wilson Lake	0.419	28	0	72	0
Wyandotte Co. Lake	5.248	6	78	<1	15

Table 5. Trends over time, based on a comparison to mean historic condition, for lake trophic state classification, for lakes surveyed during 2004.

Change in Trophic State Class	Number of Lakes	Percent Total

Compared to Historic Mean		
Improved Two Class Rankings	2	5.3
Improved One Class Ranking	7	18.4
Stable	23	60.5
Degraded One Class Ranking	5	13.2
Degraded Two Class Rankings	0	0
Degraded Three Class Rankings	1	2.6
Total	38	100.0

Table 6. Macrophyte community structure in the 22 lakes surveyed for macrophytes during 2004. Macrophyte community refers only to the submersed and floating-leaved aquatic plants, not emergent shoreline plants. The percent areal cover is the abundance estimate for each documented species (Note: due to overlap in cover, the percentages under community composition may not equal the total cover).

Lake	**% Total Cover**	**% Species Cover and Community Composition**
Atchison Co. SFL	73%	73% *Ceratophyllum demersum* 73% *Najas guadalupensis* 73% *Potamogeton nodosus* 73% *Potamogeton pectinatus*
Barber Co. SFL	<7%	no species observed
Bourbon Co. SFL	7%	7% *Chara zeylanica* 7% *Najas guadalupensis* 7% *Potamogeton pectinatus*
Brown Co. SFL	80%	80% *Potamogeton pectinatus* 73% *Ceratophyllum demersum* 73% *Najas guadalupensis* 73% *Potamogeton nodosus* 7% *Nelumbo sp.*
Harvey Co. West Lake	20%	20% *Marsilea vestita* (sparse) 20% *Potamogeton illinoensis* (sparse)
Lake Afton	<5%	no species observed
Lake Anthony	<5%	no species observed
Lake Miola	10%	5% *Nymphaea sp.* 5% *Potamogeton gramineous*
Lake Wabaunsee	<5%	no species observed

Lake	% Total Cover	% Species Cover and Community Composition
Leavenworth Co. SFL	15%	15% *Ceratophyllum demersum* 15% *Najas guadalupensis*
Louisburg SFL	25%	25% *Nymphaea sp.*
Mined Land Lake 44	40%	40% *Potamogeton illinoensis*
Neosho Co. SFL	<7%	no species observed
Osage Co. SFL	40%	40% *Najas guadalupensis* 10% *Chara zeylanica*
Pratt Co. Lake	<10%	<10% *Najas guadalupensis* (trace)
Richmond City Lake	40%	40% *Potamogeton pectinatus*
Rock Creek Lake	<7%	no species observed
Sabetha City Lake (limited survey)	80%	80% *Potamogeton pectinatus*
Shawnee Mission Lake (limited survey)	<5%	no species observed
Sheridan Co. SFL	<7%	no species detected
Strowbridge Reservoir	15%	15% *Potamogeton pectinatus*
Wilson Co. SFL	10%	10% *Chara zeylanica* 5% *Najas guadalupensis*

None of the lakes surveyed in 2004 appeared to have algal limitation due to macrophyte community influences. Overall, Kansas Lakes are impaired more by a lack of macrophyte habitat than by an overabundance. In general, presence of a robust (and usually diverse) macrophyte community reflects lower levels of human impact in our lakes. However, the lakes with the most macrophyte abundance in 2004 also have significant human impacts, contrasting with this historic general observation.

Lake Stratification

Stratification is a natural process that may occur in any standing (lentic) body of water, whether that body is a natural lake, pond, artificial reservoir, or wetland pool (Wetzel, 1983). It occurs when sunlight (solar energy) penetrates into the water column. Due to the thermal properties of water, high levels of sunlight (combined with calm winds during the spring-to-summer months) cause layers of water to form with differing temperatures and densities. The cooler, denser layer (the hypolimnion) remains near the bottom of the lake while the upper layer (the epilimnion) develops a higher ambient temperature. The middle layer (the metalimnion) displays a marked drop in temperature with depth (the thermocline), compared to conditions within the epilimnion and hypolimnion. Once these layers of water with differing temperatures form, they tend to remain stable and do not easily mix with one another. This formation of distinct layers impedes, or precludes, the atmospheric reaeration of the hypolimnion, at least for the duration of the summer (or until ambient conditions force mixing). In many cases, this causes hypolimnetic waters to become depleted of oxygen and unavailable as habitat for fish and other forms of aquatic life. Stratification eventually breaks down in the fall when surface waters cool. Once epilimnetic waters cool to temperatures comparable to hypolimnetic waters, the lake will mix completely once again. Typically occurring in the fall, this phenomenon is called "lake turnover." Table 7 presents data related to thermal stratification in the 38 lakes surveyed in 2004, as well as calculated euphotic-to-mixed depth ratio.

Table 7. Stratification status of the 38 water bodies surveyed during 2004. The term "n.a." indicates that boat access, wind conditions or other threatening weather, shallowness, or equipment problems prevented the collection of profile data or made said collection superfluous.

ke	Date Sampled (M-D-Yr)	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)	Euphotic/Mixed Depth Ratio*
chison Co. SFL	08-02-2004	1.75	1.19	1.0-3.0	10.5	0
rber Co. SFL	06-28-2004	0.67	1.35	4.0-5.0	6.5	1
g Hill Lake	07-13-2004	0.73	0.58	6.0-7.0	14.0	0
urbon Co. SFL	07-26-2004	0.94	0.71	4.0-6.0	9.5	1
own Co. SFL	07-20-2004	1.50	2.45	1.0-3.0	4.5	0
k City Lake	08-09-2004	0.85	1.09	5.0-7.0	11.0	0
l River Lake	08-09-2004	0.70	0.74	none	6.0	1
rvey Co. West Lake	06-29-2004	n.a.	n.a.	n.a.	2.0	3
lsdale Lake Sta. 1	07-08-2004	0.13	0.55	8.0-9.0	13.5	0
lsdale Lake Sta. 2	07-08-2004	n.a	n.a.	n.a.	9.5	0
lsdale Lake Sta. 3	07-08-2004	n.a.	n.a.	n.a.	8.5	0
nestown WMA	06-08-2004	0.00	0.00	none	1.5	6
rwin Lake	06-14-2004	n.a.	n.a.	n.a.	10.0	0
ke Afton	06-28-2004	0.09	0.10	none	5.5	1

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)	Euphotic/Mixed Depth Ratio*
ke Anthony	06-28-2004	0.40	1.60	none	3.0	0
ke Miola	06-21-2004	0.75	0.94	4.0-7.0	10.0	1
ke Parsons	07-12-2004	0.60	0.38	none	5.5	1
ke Wabaunsee	08-16-2004	0.25	0.59	7.0-9.0	12.5	0
avenworth Co. SFL	08-02-2004	0.05	0.48	none	10.5	1
uisburg SFL	06-21-2004	0.89	0.71	3.0-5.0	10.0	1
vewell Lake	06-14-2004	0.13	0.65	none	9.0	0
rais des Cygnes WMA	07-19-2004	n.a.	n.a.	n.a.	1.5	16
ned Land Lake 44	07-27-2004	1.36	0.65	4.0-6.0	11.5	0
osho Co. SFL	07-12-2004	1.14	1.56	1.0-3.0	7.5	0
osho WMA	07-12-2004	n.a.	n.a.	n.a.	1.0	19
rton Lake	06-15-2004	n.a.	n.a.	n.a.	5.0	1
age Co. SFL	08-11-2004	0.90	0.72	5.0-7.0	10.5	1
tt Co. Lake	06-29-2004	0.33	2.80	none	3.0	1
chmond City Lake	07-19-2004	1.75	0.95	2.0-4.0	8.5	1
nrock Park Lake	5 surveys June - Sept.	n.a.	n.a.	n.a.	3.8	1
ck Creek Lake	07-26-2004	0.40	0.84	none	5.5	1
betha City Lake	08-17-2004	n.a.	n.a.	n.a.	3.0	1
awnee Mission Lake	08-03-2004	1.46	0.65	3.0-7.0	13.5	1
eridan Co. SFL	06-15-2004	0.17	0.57	none	4.0	1
owbridge Reservoir	08-11-2004	0.44	0.68	5.0-7.0	8.5	0
ronto Lake	08-09-2004	0.60	0.66	none	5.5	1
aconda Lake	06-14-2004	0.11	0.09	none	10.5	0
lson Co. SFL	08-18-2004	0.71	0.53	5.0-7.0	12.0	0
lson Lake	05-15-2004	0.00	n.a.	none	18.0	0
vandotte Co. Lake	06-22-2004	0.81	0.65	7.0-8.0	13.5	0

* = Ratios greater than unity suggest either clearer lakes or very shallow and well mixed water bodies. Ratios much less than 0.7 indicate lakes with inorganic turbidity, self shaded conditions due to abundant phytoplankton, or deep lakes with lower turbidity. Ratios greater than unity indicate that light penetrates through the entire mixed layer of the lake. When used with other metrics, this ratio can add greatly to an overall understanding of a lake's physical ecology. For a further explanation of euphotic depth, refer to the discussion on page 20.

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

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

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

The temperature decline rate, however, must also be considered in relation to the particular lake and the shape of the temperature-to-depth relationship. The sharper the discontinuity in the data plot, the stronger the level of thermal stratification. Gradual declines in temperature with depth, through the entire water column, and indistinct discontinuities in data plots are more indicative of weaker thermal stratification. The strength of the oxycline, based on water column decline rate and the shape of the data plot, is also used to estimate stratification in lakes. A strong oxycline might be seen by mid-summer in lakes with weak thermal stratification if the lakes are not prone to wind mixing, or in the case of dense macrophyte beds.

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

<u>Fecal Coliform Bacteria</u>

Since 1996, bacterial sampling has taken place at the primary water quality sampling station at each lake. While many Kansas lakes have swimming beaches, many 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, 2003), 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. Sampling of swimming beaches is also often conducted by lake managers to document water quality where people are concentrated in a small area. These managers are in the best position to collect samples frequently enough to determine compliance with applicable regulations at these swimming beaches (KDHE, 2003).

Given the rapid die-off of fecal coliform bacteria in the aquatic environment, due to protozoan predation and a generally hostile set of environmental conditions, high fecal coliform 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. A single set of bacterial samples collected from the open, deep water, environment is normally considered representative of whole-lake bacterial water quality at the time of the survey. This environment is also less prone to short lived fluctuations in bacterial counts than are swimming beaches and other shoreline areas.

Table 8 presents the bacterial data collected during the 2004 sampling season. Fifteen lakes, out of the 38 lakes surveyed for fecal coliform bacteria, had fecal coliform bacterial counts greater than the analytical reporting limit. Although no lake in 2004 likely exceeded existing criteria (KDHE, 2003) as a geometric mean, three lakes had suspiciously high and unexpected fecal coliform counts. These three lakes are Norton Lake, Sabetha City Lake, and Jamestown WMA. All three sets of data were collected from locations other than a boat out in the open water (due to low water levels or lack of useable boat ramps), so sample location may have had some influence. In the case of Jamestown WMA (wetland), there have been past bacteria detections with higher than expected values (KDHE, 2002a).

Table 8. Fecal coliform bacterial counts (mean of duplicate samples) from the 38 lakes and wetlands surveyed for fecal coliform bacteria during 2004. 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/100 mL of lake water."

Lake	Site Location	Fecal Coliform Count
Atchison Co. SFL	open water	<10
Barber Co. SFL	open water	<10
Big Hill Lake	open water	<10
Bourbon Co. SFL	open water	<10
Brown Co. SFL	open water	<10
Elk City Lake	open water	<10
Fall River	open water	<10
Harvey Co. West Lake	open water	85
Hillsdale Lake	open water	<10
Jamestown WMA	open water	570
Kirwin Lake	off dam	35
Lake Afton	open water	<10
Lake Anthony	open water	30
Lake Miola	open water	<10
Lake Parsons	open water	<10
Lake Wabaunsee	open water	15
Leavenworth Co. SFL	open water	<15

Lake	Site Location	Fecal Coliform Count
Louisburg SFL	open water	15
Lovewell Lake	open water	15
Marais des Cygnes WMA	open water	65
Mined Land Lake 44	open water	<10
Neosho Co. SFL	open water	35
Neosho WMA	open water	<10
Norton Lake	off pier near dam	255
Osage Co. SFL	open water	15
Pratt Co. Lake	open water	30
Richmond City Lake	open water	<10
Rimrock Park Lake (5 surveys over summer)	off dam	88
Rock Creek Lake	open water	<10
Sabetha City Lake	off pier near dam	215
Shawnee Mission Lake	open water	<10
Sheridan Co. SFL	open water	110
Strowbridge Reservoir	open water	<10
Toronto Lake	open water	<10
Waconda Lake	open water	<10
Wilson Co. SFL	open water	<10
Wilson Lake	not sampled	no data
Wyandotte Co. Lake	open water	<10

Limiting Nutrients and Physical Parameters

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

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

Nutrient ratios are commonly considered in determining which major plant nutrients are limiting factors in lakes. These ratios take into account the relative needs of algae for the different chemical elements versus availability in the environment. Typically, total nitrogen/total phosphorus (TN/TP) mass ratios above 10-12 indicate increasing phosphorus limitation. Conversely, TN/TP ratios of less than 7-10 indicate increasing importance of nitrogen. Ratios of 7-to-12 indicate that both nutrients, or neither, may limit algal production (Wetzel, 1983; Horne and Goldman, 1994). It should also be kept in mind, when determining limiting factors, that highly turbid lakes typically have lower nutrient ratios, but may still have phosphorus limitation due to availability (e.g., particle adsorption) issues (Jones and Knowlton, 1993).

Table 9 presents limiting factor determinations for the lakes surveyed during 2004. These determinations reflect the time of sampling (chosen to reflect average conditions during the summer growing season to the extent possible) but may be less applicable to other times of the year. Conditions during one survey may also differ significantly from conditions during past surveys, despite efforts to sample during times representative of "normal" summer conditions. If such a situation is suspected, it is noted in Table 9 or elsewhere in the report.

As indicated in Table 9, phosphorus was the primary limiting factor identified for lakes surveyed in 2004. Seventeen of the 38 lakes (45%) were determined to be primarily limited by phosphorus. Seven lakes (18%) were determined to be primarily nitrogen limited. Three lakes were primarily light limited (8%). Another ten lakes (17%) were co-limited by phosphorus and nitrogen or limited by combinations of nutrients and/or light availability. Algal production in one lake (<3%) was determined to be primarily limited by grazing pressure from zooplankton. Although zooplankton are not routinely assessed quantitatively, there did appear to be more copepods present in the water sample from this lake than would be considered typical. Mean TN/TP ratio was 18.1 for the lakes surveyed in 2004 (median = 13.7).

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

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

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

Non-algal turbidity values $<0.4\ m^{-1}$ tend to indicate very low levels of suspended silt and/or clay, while values >1.0 m^{-1} indicate that inorganic particles are important in creating turbidity. Values between 0.4 and 1.0 m^{-1} describe a range where inorganic turbidity assumes greater influence on water clarity as the value increases, but would not assume a significant limiting role until values exceed 1.0 m^{-1}.

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

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

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

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

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

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

Table 9. Limiting factor determinations for the 38 lakes surveyed during 2004. NAT = non-algal turbidity, TN/TP = nitrogen-to-phosphorus ratio, Z_{mix} = depth of mixed layer, Chl-a = chlorophyll-a, and SD = Secchi depth. N = nitrogen, P = phosphorus, C = carbon, Fe = iron, and L = light. Shading = calculated light attenuation coefficient times mean lake depth.

Lake	**TN/TP**	**NAT**	**Z_{mix}*NAT**	**Chl-a*SD**	**Chl-a/TP**	**Z_{mix}/SD**	**Shading**	**Factors**
Atchison Co. SFL	23.8	<0.010	<0.010	51.46	0.943	3.880	7.92	P
Barber Co. SFL	15.1	0.487	1.319	14.48	0.283	2.067	3.55	P>N
Big Hill Lake	26.1	0.330	1.569	19.53	0.573	3.066	6.90	P
Bourbon Co. SFL	13.2	0.187	0.622	25.63	0.453	1.732	4.20	P>N
Brown Co. SFL	23.1	<0.010	<0.010	86.57	1.103	1.984	5.14	P
Elk City Lake	10.3	1.365	5.733	13.25	0.552	8.574	9.68	(P=N)>L
Fall River Lake	6.8	1.244	2.988	6.67	0.195	3.586	3.90	N
Harvey Co. West Lake	15.6	1.102	0.662	20.16	0.345	1.335	1.96	P≥N
Hillsdale Lake (whole lake)	15.0	<0.010	<0.010	42.51	0.648	2.725	7.93	P
Hillsdale Lake Sta. 1	13.5	<0.010	<0.010	46.47	0.592	2.609	7.97	P
Hillsdale Lake Sta. 2	14.8	0.096	0.357	33.49	0.555	2.194	5.32	P
Hillsdale Lake Sta. 3	17.1	<0.010	<0.010	48.06	0.822	1.881	5.07	P
Jamestown WMA	6.7	<0.010	<0.010	104.37	0.512	0.298	1.98	N>C
Kirwin Lake	17.3	0.473	1.841	11.63	0.080	2.595	4.99	Grazing Pressure
Lake Afton	6.2	0.762	1.833	17.14	0.127	3.206	4.21	N
Lake Anthony	6.3	5.317	7.581	3.84	0.084	8.387	5.70	L>N

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Lake Miola	29.8	0.468	1.604	15.31	0.464	2.599	4.64	P
Lake Parsons	8.5	2.288	5.121	1.55	0.025	5.328	4.31	L
Lake Wabaunsee	12.2	<0.010	<0.010	40.50	0.580	4.013	7.85	P>N
Leavenworth Co. SFL	14.3	0.185	0.654	25.41	0.423	1.792	4.46	P>N
Louisburg SFL	28.0	0.431	1.479	16.88	0.341	2.560	4.67	P
Lovewell Lake	15.8	0.221	0.786	33.11	0.713	4.566	7.49	P
Marais des Cygnes WMA	10.6	1.223	0.154	15.55	0.230	0.252	0.67	N≥P
Mined Land Lake 44	8.1	0.524	2.741	10.22	0.180	3.682	7.63	N
Neosho Co. SFL	15.2	<0.010	<0.010	45.52	0.520	3.508	6.12	P
Neosho WMA	8.2	2.343	0.209	10.02	0.174	0.279	0.69	N
Norton Lake	12.6	1.239	2.426	10.26	0.137	3.262	3.58	N≥P
Osage Co. SFL	7.9	0.315	1.141	12.32	0.200	1.649	4.09	N
Pratt Co. Lake	9.2	<0.010	<0.010	51.02	0.499	2.160	4.03	N≥P
Richmond City Lake	23.4	0.451	1.396	14.77	0.480	2.213	4.01	P
Rimrock Lake (5 surveys)	10.8	0.896	1.443	12.68	0.313	2.113	2.74	N≥P
Rock Creek Lake	12.0	1.000	2.058	6.81	0.155	2.480	3.03	N≥P
Sabetha City Lake	2.2	<0.010	<0.010	41.39	0.071	1.476	2.72	N>C
Shawnee Mission Lake	15.2	0.234	0.947	15.24	0.198	1.529	4.55	P≥N
Sheridan Co. SFL	18.6	1.902	2.236	8.04	0.241	2.798	2.78	N≥P

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Strowbridge Reservoir	14.2	0.397	1.229	24.45	0.601	3.161	5.15	P
Toronto Lake	4.3	1.934	4.223	4.42	0.091	4.747	4.21	L>N
Waconda Lake	103.0	0.419	2.445	13.66	0.870	3.714	9.14	P
Wilson Co. SFL	10.9	0.102	0.387	33.12	0.370	2.253	5.46	P=N
Wilson Lake	72.5	0.583	3.402	1.96	0.120	3.577	8.18	P
Wyandotte Co. Lake	34.9	0.383	1.551	15.66	0.438	2.549	5.32	P

Criteria Table

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

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

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

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

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

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

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

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

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

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

In addition to the preceding metrics, an approach developed by Carlson (1991) was employed to test the limiting factor determinations made from the suite of metrics utilized in this, and previous, reports. The approach uses the Carlson trophic state indices for total phosphorus, chlorophyll-a, Secchi depth, and the newer index for total nitrogen. Index scores are calculated for each lake, then metrics are calculated for $TSI_{(Secchi)}$-$TSI_{(Chl\text{-}a)}$ and for $TSI_{(TP\ or\ TN)}$-$TSI_{(Chl\text{-}a)}$. 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, while a negative difference indicates that larger particles (zooplankton, algal colonies) exert more importance for a lake's light regime. In the case of the metric dealing with nutrients, a positive difference indicates the nutrient in question may not be the limiting factor, while a negative difference strengthens the assumption that the particular nutrient limits algal production and biomass. Differences of more than 5 units were used as the threshold for determining if the deviations were significantly different from zero. This approach generally produced the same determinations as those derived from the original suite of metrics. It clearly identified those lakes with extreme turbidity or those with 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 for our region.

In identifying the limiting factors for lakes, primary attention was given to the metrics calculated from 2004 data. However, past Secchi depth and chlorophyll-a data were also considered for comparative purposes. Additionally, mean and maximum lake depth were taken into account when ascribing the importance of non-algal turbidity. Lakes with fairly high non-algal turbidity may have little real impact from that turbidity if the entire water column rapidly circulates (Scheffer, 1998).

Surface Water Exceedences of State Surface Water Quality Criteria

Most numeric and narrative water quality criteria referred to in this section are taken from the Kansas Administrative Regulations (K.A.R. 28-16-28b through K.A.R. 28-16-28f), or from EPA water quality criteria guidance documents (EPA, 1972, 1976; KDHE, 2003) for ambient waters and finished drinking water. Copies of the Standards may be obtained from the Bureau of Water, KDHE, 1000 Southwest Jackson Ave., Suite 420, Topeka, Kansas 66612.

Tables 11, 12, and 13 present documented exceedences of surface water quality criteria and goals during the 2004 sampling season. These data were generated by computerized comparison of the 2004 Lake and Wetland Monitoring Program data to the state surface water quality standards and other federal guidelines. Only those samples collected from a depth of $\leq$3.0 meters were used to document standards violations, as a majority of those samples collected from below 3.0 meters were from hypolimnetic waters. In Kansas, lake hypolimnions generally constitute a small percentage of total lake volume and, while usually having more pollutants present in measurable quantities, compared to overlying waters, do not generally pose a significant water quality problem for the lake as a whole.

Criteria for eutrophication and turbidity in the Kansas standards are narrative rather than numeric. However, lake trophic state does exert a documented impact on various lake uses, as does inorganic turbidity. The system on the following page (Table 10) has been developed over the last fifteen years to define how lake trophic status influences the various designated uses of Kansas lakes (EPA, 1990; NALMS, 1992). Trophic state/use support expectations are compared with the observed trophic state conditions to determine the level of use support at each lake. The report appendix from the 2002 annual program report presents a comparison of these trophic class based assessments, as well as turbidity based assessments, versus risk based values (KDHE, 2002b). In general, the risk based thresholds compare fairly well with the assessment system presently in use.

With respect to the aquatic life support use, eutrophication, high pH, and low dissolved oxygen within the upper 3.0 meters comprised the primary water quality concerns during 2004 (Table 11). Eighteen lakes exhibited trophic states high enough to impair long or short term aquatic life support. Ten lakes had low dissolved oxygen conditions within the top 3.0 meters of the water column. Four lakes had pH levels high enough to impact aquatic life support. Three lakes exhibited chronic turbidity sufficient to impact long term community structure and function.

Eutrophication exceedences are primarily due to excessive nutrient inputs from lake watersheds. Dissolved oxygen problems are generally due to advanced trophic state, which causes rapid oxygen depletion below the thermocline, but are also observed in lakes that do not exhibit excessive trophic state conditions. In these cases, the low dissolved oxygen levels likely result from shallow stratification conditions. Lakes with elevated pH are also reflective of high trophic state and algal or macrophytic production.

There were 41 exceedences of water supply criteria and/or guidelines during 2004 (Table 12). The majority (63%) were for eutrophication related conditions. Of these 41 exceedences, only fourteen (34%) occurred in lakes that currently serve as public water supplies. Irrigation use criteria were exceeded in 16 lakes, one of which currently is designated for irrigation supply. The other 15 lakes are pending use attainability analyses for irrigation use. Livestock watering criteria were exceeded in 16 lakes, all of which are pending use attainability analyses for that use. Human health (food procurement use) criteria showed no exceedences for lakes surveyed in 2004.

Table 13 lists 26 lakes with trophic state/turbidity conditions high enough to impair contact recreational uses. Eighteen of the lakes surveyed had high enough trophic state or turbidity to impair secondary contact recreation during 2004.

In all, there were 181 exceedences of numeric or narrative criteria, water quality goals, or EPA guidelines documented in Kansas lakes during 2004. Approximately 30.4% of these exceedences related to aquatic life support, 40.3% related to consumptive uses of water, and 29.3% related to recreational uses. A total of 66% occurred in lakes designated for the indicated uses, while 34% occurred in lakes where uses have not yet been verified through use attainability analyses. Eutrophication, turbidity, high pH, or low dissolved oxygen accounted for 91% of documented water quality impacts in 2004. Only about 3% of the impacts were linked to pesticides or heavy metals and metalloids.

Table 10. Lake use support determination based on lake trophic state.

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

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

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

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

Table 11. Chemical and biological parameters not complying with chronic and acute aquatic life support (ALS) criteria in lakes surveyed during 2004. DO = dissolved oxygen, EN = eutrophication or high nutrient load, and TN = high turbidity and nutrient load. Only those lakes with some documented water quality problem are included in Tables 11, 12, and 13.

	Chronic ALS					**Acute ALS**	
Lake	**EN***	**TN***	**pH***	**DO***	**Atrazine**	**EN***	**DO***
Atchison Co. SFL	X		X	X		X	X
Brown Co. SFL	X			X		X	X
Elk City Lake	X					X	
Harvey Co. West Lake	X					X	
Hillsdale Lake	X					X	
Jamestown WMA	X		X		X	X	
Lake Afton	X					X	
Lake Anthony	X	X		X		X	
Lake Parsons	X	X					
Lake Wabaunsee	X					X	
Louisburg SFL				X			
Lovewell Lake	X					X	
Marais des Cygnes WMA	X					X	
Neosho Co. SFL	X			X		X	
Neosho WMA	X					X	
Pratt Co. Lake	X		X	X		X	
Richmond City Lake				X			
Rock Creek Lake				X			
Sabetha City Lake	X		X	X		X	X
Strowbridge Reservoir	X					X	
Toronto Lake	X	X		X			

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

oxygen conditions occur at some point during this 24 hour cycle.

Table 12. Exceedence of human use criteria and/or EPA guidelines within the water column of lakes surveyed during 2004. EN = high trophic state/nutrients or turbidity/nutrient loads. Only lakes with documented exceedences are included within the table. An "X" indicates that the exceedence occurred for a presently designated use. An "(X)" indicates that the exceedence occurred where the indicated use has not yet been verified by use attainability analyses.

	Water Supply					**Irrigation**	**Livestock Water**
Lake	**EN**	**Cl**	**SO_4**	**As**	**Atrazine**	**EN**	**EN**
Atchison Co. SFL	(X)					(X)	(X)
Barber Co. SFL			(X)				
Big Hill Lake	X						
Bourbon Co. SFL	(X)						
Brown Co. SFL	(X)			(X)		(X)	(X)
Elk City Lake	X					(X)	(X)
Harvey Co. West Lake	(X)					(X)	(X)
Hillsdale Lake	X					(X)	(X)
Jamestown WMA	(X)	(X)	(X)		(X)	(X)	(X)
Kirwin Lake			(X)				
Lake Afton	(X)					(X)	(X)
Lake Anthony	(X)					(X)	(X)
Lake Parsons	X						
Lake Wabaunsee	X					(X)	(X)
Leavenworth Co. SFL	(X)						
Louisburg SFL	X						
Lovewell Lake	(X)					X	(X)
Marais des Cygnes WMA	(X)					(X)	(X)
Mined Land Lake 44			(X)				
Neosho Co. SFL	(X)					(X)	(X)
Neosho WMA	(X)					(X)	(X)

	Water Supply					Irrigation	Livestock Water
Norton Lake	X						
Pratt Co. Lake	(X)					(X)	(X)
Lake	**EN**	**Cl**	**SO_4**	**As**	**Atrazine**	**EN**	**EN**
Rimrock Park Lake	(X)						
Sabetha City Lake	X			X		(X)	(X)
Sheridan Co. SFL	(X)			(X)			
Strowbridge Reservoir	X					(X)	(X)
Toronto Lake	X						
Waconda Lake			X				
Wilson Co. SFL	(X)						
Wilson Lake		(X)	(X)				

Table 13. Exceedences of numeric and narrative recreational guidelines for lakes surveyed during 2004. Primary contact recreation refers to recreation where ingestion of lake water is likely. Secondary contact recreation involves a low likelihood of accidental ingestion of lake water. EN = high trophic state and nutrient loads and TN = high turbidity and nutrient loads. FC = fecal coliform count. An "X" indicates that a use attainability study has been completed and/or the use was previously designated for that lake. An "(X)" indicates that the use has not been verified through a formal use attainability analysis. Only lakes with impairments are listed.

	Primary Contact Recreation			**Secondary Contact Recreation**	
Lake	**EN**	**TN**	**FC***	**EN**	**TN**
Atchison Co. SFL	X			X	
Big Hill Lake	X				
Bourbon Co. SFL	X				
Brown Co. SFL	X			X	
Elk City Lake	X			X	
Harvey Co. West Lake	X			X	
Hillsdale Lake	X			X	
Jamestown WMA	(X)		(X)	X	
Lake Afton	X			X	
Lake Anthony	X	X		X	X
Lake Parsons	X	X		X	X
Lake Wabaunsee	X			X	
Leavenworth Co. SFL	X				
Louisburg SFL	X				
Lovewell Lake	X			X	
Marais des Cygnes WMA	(X)			X	
Neosho Co. SFL	X			X	
Neosho WMA	(X)			X	

	Primary Contact Recreation			Secondary Contact Recreation	
Norton Lake	X		X		
Pratt Co. Lake	X			X	
Rimrock Park Lake	X				
Lake	**EN**	**TN**	**FC***	**EN**	**TN**
Sabetha City Lake	X		X	X	
Sheridan Co. SFL	X				
Strowbridge Reservoir	X			X	
Toronto Lake	X	X		X	X
Wilson Co. SFL	X				

* = For a strict comparison to recreational water quality standards, fecal coliform data must be collected on five separate days during a 30 day period. However, three lakes had unusually high counts in their open water zone at the time of their surveys. Such counts from the open water do constitute a water quality impact that should be considered in any overall assessment of these water bodies. This will be the last year the Lake and Wetland Program utilizes fecal coliform counts, as state water quality standards will move to the use of E. coli as the indicator organism for recreation.

Pesticides in Kansas Lakes, 2004

Detectable levels of at least one pesticide were documented in the main body of 19 lakes sampled in 2004 (51% of lakes surveyed for pesticides). Wilson Lake was not surveyed for pesticides, owing to the nature of the requested survey (Kansas Water Office requested a May survey related to a water supply study) and the past lack of pesticide detections. Table 14 lists these lakes and the pesticides that were detected, along with the level measured and the analytical quantification limit. Five different pesticides, and one pesticide degradation byproduct, were noted in 2004. Of these five compounds, atrazine and alachlor currently have numeric criteria in place for aquatic life support and/or water supply uses (KDHE, 2003).

Atrazine continues to be the pesticide detected most often in Kansas lakes (KDHE, 1991). Atrazine, and the atrazine degradation byproduct deethylatrazine, accounted for 70% of the total number of pesticide detections, and atrazine and/or deethylatrazine were detected in 18 out of 19 lakes. In addition to atrazine, five lakes had detectable levels of metolachlor (Dual), one had detectable levels of alachlor (Lasso), four had detectable levels of acetochlor (Harness or Surpass), and one had detectable levels of prometon (Pramitol). Eight lakes had detectable quantities of the atrazine degradation byproduct deethylatrazine.

In almost all cases, the presence of these pesticides was directly attributable to agricultural activity. Only Jamestown WMA exceeded applicable numeric criteria, but several represent concerns based on numbers and amounts of pesticides present in the water column. Based on the number of different pesticides detected; Big Hill Lake, Jamestown WMA, and Lake Parsons are of most concern. In terms of total maximum concentrations, Atchison Co. SFL and Jamestown WMA are of most concern. Of these, Big Hill Lake and Lake Parsons are active water supply lakes.

Table 14. Pesticides levels documented during 2004 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, alachlor = 0.1 ug/L, acetochlor = 0.1 ug/L, and prometon = 0.3 ug/L. Only those lakes with detectable levels of pesticides are reported.

Lake	Pesticide					
	Atrazine	**Deethyl-atrazine**	**Metolachlor**	**Alachlor**	**Acetochlor**	**Prometon**
Atchison Co. SFL	2.80	0.52				
Big Hill Lake	1.30	0.35	0.61		0.13	
Brown Co. SFL	0.95			0.14		
Elk City Lake	0.30					
Hillsdale Lake	1.20	0.41				
Jamestown WMA	16.00	2.30	2.60		0.28	
Lake Afton	0.83		0.48			
Lake Parsons	0.42	0.34	0.81		0.31	
Louisburg SFL	1.40					
Lovewell Lake	1.10	0.38				
Mined Land Lake 44	1.60					
Norton Lake	0.44					
Osage Co. SFL	0.44					
Richmond City Lake	1.60				0.18	
Rimrock Park Lake						0.37
Sabetha City Lake	1.90	0.39				
Strowbridge Reservoir	0.71					
Waconda Lake	1.00	0.35				

	Pesticide					
Wilson Co. SFL	1.00		0.26			

<u>Discussion of Nonpoint Sources of Pollution for Selected Lakes</u>

Six lakes were chosen for further discussion, based on the number and type of observed surface water quality impacts. A water body was chosen if 1) three, or more, parameters exceeded their respective chronic aquatic life support criteria/guidelines, 2) more than two parameters exceeded applicable acute aquatic life support criteria/guidelines, or 3) more than two parameters exceeded irrigation, water supply, livestock watering, or recreational criteria. Possible causes and sources of these documented water quality problems are considered below.

Atchison Co. SFL is a modest sized (66 acres) lake in northeast Kansas. Water quality problems in 2004 revolved around excessive eutrophication and algal production. Although a fairly deep lake, with a watershed/lake area ratio of only 30, the watershed is composed of over 60% row crop and has little buffering capacity due to the relatively small watershed.

Jamestown WMA is a 1,265 acre wetland complex located in north-central Kansas. Water quality problems in 2004 included excessive eutrophication, excessive algal production, and fairly high atrazine detections. With a moderately high watershed/lake area ratio of 70, combined with >70% cropland in the watershed, nutrient enrichment and pesticides in runoff are commonly observed water quality impairments.

Lake Anthony is a 155 acre recreational lake located in south-central Kansas. Water quality problems in 2004 included eutrophication and sediment resuspension. With a watershed composed of >80% cropland, and a watershed/lake area ratio of 82, high nutrient and sediment loads are expected. However, Lake Anthony’s primary water quality determining factor is sediment resuspension due to the shallow nature of the lake, combined with the physical quality of the soils in that part of Kansas.

Pratt Co. Lake is a moderate sized (51 acres) recreational lake in south-central Kansas. Water quality problems in 2004 included eutrophication and high algal production. Pratt Co. Lake is somewhat unusual in Kansas in that it is “off set” from a stream (In this case, the South Fork Ninnescah River). The lake receives overflow from the river during higher flows. Abundant cropland and at least one wastewater treatment discharge lie upstream from the vicinity of the lake.

Sabetha City Lake is a 112 acre recreational and water supply lake in northeast Kansas. Water quality problems in 2004 revolved around eutrophication and high algal production. The lake has a long history of algae blooms and taste & odor problems. Although the watershed/lake area ratio is a moderate 48, over 90% of the watershed is in row crop production and animal feedlots.

Toronto Lake is a 2,800 acre multi-purpose Federal lake in southeast Kansas. Water quality problems in 2004 included chronic (historically) high turbidity and nutrient enrichment. Although probably <30% of the watershed is in crop production, that land is primarily along the main inflow to the lake. Combined with a large watershed/lake ratio of 158, and the shallow conditions that prevail in Toronto lake, water quality impacts from high turbidity and nutrients are not unexpected.

<u>Taste and Odor/Algal Bloom Investigations During 2004</u>

From January 1, 2004, to January 1, 2005, six investigations were undertaken within the auspices of the KDHE Taste & Odor/Algae Bloom Program. The results of these investigation are discussed below. One of the investigations dealt with a fishkill, two were related to massive algae blooms, two were primarily aesthetic complaints, and one concerned unusual conditions in a wastewater treatment lagoon.

On January 14, 2004, in response to a citizen complaint, staff from the KDHE Southcentral District Office collected algae samples from a small urban lake in Arkansas City, Kansas. The lake had a massive blue-green algae bloom (13.7 million cells per mL in the bloom proper, an estimated 1-2 million cells per mL in the open water) composed of *Oscillatoria rubescens* (also known as *Planktothrix rubescens*). This bloom gave the lake an unusual and visually disturbing red-brown appearance, prompting the calls from the public. This particular blue-green algae is reported more commonly in winter and spring, whereas blooms associated with most other cyanophyte species occur in the summer or early fall. City staff indicated they intended to close the lake to recreation until the bloom passed.

On April 29, 2004, in response to a fishkill at Lake Anthony (Harper Co.), an investigation was performed by the KDHE Southcentral District Office. Based on water samples collected as part of this investigation, total algal cell count in the lake was determined to be only 21,000 cells/mL and composed of a mixture of green algae, cryptophytes, and euglenoids. During the week preceding the fishkill, the lake experienced heavy rain and hail. The investigation concluded the runoff event and/or the associated nutrient/organic load it brought to the lake was the proximal cause of the fishkill.

Marion Lake (Marion Co., Kansas) experienced a series of massive blue-green algae blooms during 2004, similar to those that had occurred during the summer of 2003. The 2004 blooms continued into late summer, although the magnitude seemed to lessen by August. Principal species included *Microcystis aeruginosa*, *Aphanizomenon flos-aqua*, and *Anabaena spp.* (mostly believed to be *A. spiroides* and *A. circinalis*). *Anabaena spp.* were the most prominent blue-greens present. This was the second year of extreme algae blooms in Marion Lake, causing a great deal of concern among local citizens and management agencies.

On August 5, 2004, algae samples were collected by staff of the Kansas Department of Wildlife and Parks (KDWP) from Lake Meade State Park, where a massive blue-green algae bloom was in progress. These samples were transferred to KDHE-BEFS staff for processing. *Microcystis aeruginosa* was determined to be the principle blue-green species present in the lake, with cell counts ranging from 887,000 cells/mL in the more upwind areas to 116 million cells/mL on the downwind side of the lake (chlorophyll-a at that location was 17,800 ug/L). With such a large population of a species with a known toxin producing potential (semi-quantitative immunoassay tests for microcystins ranged in value from >0.5 to around 3.0 ug/L), it was recommended that KDWP staff close the beach to contact recreation activities and campers be advised to avoid skin contact with bloom material.

On August 25, 2004, staff from the KDHE Southwest District Office conducted an inspection for the Holcomb, Kansas, wastewater treatment facility. During the inspection, they took pictures of a strange red growth in the water column and collected samples of it for taxonomic analysis. Staff at the city and treatment facility were concerned by the odd coloration and questioning whether it might represent a problem with the facility. Examination of the samples indicated a large mixed blue-green algae community (as might be expected in a sewage lagoon during August) plus a large population of the zooplankton *Diaphanosoma sp.* The red coloration in the water was the result of the red coloration being generated in the zooplankter's carapaces. Many zooplankton will produce such coloration in situations where dissolved oxygen becomes scarce during each diel cycle, as might happen in a very enriched setting such as a sewage lagoon. The phenomenon represented no problem to the treatment system process, but provided an interesting set of photographs for use by KDHE staff in presentations and educational settings.

On September 8, 2004, staff from the Southcentral District Office investigated a small residential lake in Wichita, Kansas, as part of a complaint called in by a citizen. The lake was reported to have a brown scum, with an oily appearance, giving the impression of a contaminant spill. By the time KDHE staff arrived, most of the brown scum had disappeared but samples of the material were collected from what remained. Microscopic examination revealed little algae, but a great deal of microscopic organic detritus, grass pollen, and what appeared to be tiny egg cases from an unknown macroinvertebrate. Given the lack of keys for egg cases of aquatic insects and other macroinvertebrates, further identification was not possible.

CONCLUSIONS

The following conclusions are based on the lake monitoring data collected during 2004.

1) Trophic state data indicated that only 16% of the lakes surveyed in 2004 had degraded, compared to their historic mean condition (i.e., their trophic state had increased). About

60% showed stable conditions over time, while 24% showed improved trophic state condition. Most of the improvement in trophic state can be attributed to the impact of prolonged drought, and lowered inputs of nutrients in runoff, on nutrient limited systems.

2) Over 75% of the documented water quality impairments in these lakes were associated with high lake trophic status and nutrient enrichment. Other significant problems included low dissolved oxygen and high pH, chloride, sulphate, and high turbidity.

3) Approximately half of the lakes surveyed by KDHE had detectable levels of agricultural pesticides in 2004. As noted in previous years, atrazine was the most frequently detected pesticide. Only one detection in 2004 was above applicable water quality criteria.

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LAKE DATA AVAILABILITY

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

APPENDIX A

Time Trends Among Kansas Lakes

Except for the many small oxbow and sinkhole lakes scattered across the state, most lakes in Kansas are artificial phenomena, created by placing dams across streams and obstructing the natural patterns of surface flow. Regardless of their origins, lakes supply tremendous benefits to our society in the form of recreation and provision of water for domestic consumption and livestock watering, irrigation, and aesthetic enjoyment. Lakes often enhance the quality of life and/or local property values, and provide for many other benefits such as fire protection, the creation of aquatic habitat, and fisheries (Boyle et al., 1997; Jobin, 1997; KDHE, 1998a, 1998b, 1998c, 2003).

Lake building in Kansas began in the last half of the 1800s, although the lack of mechanized earth moving equipment limited the number and size of water bodies. By the early 1900s, only a handful of smaller lakes had been created (Stene, 1946), all of which were less than 200 acres in individual surface area. The oldest artificial lakes in Kansas are probably on the order of 130 years, given that a number were constructed across the state by the railroads as they expanded in the 1870s and after. The oldest lakes within the KDHE Lake and Wetland Monitoring Program network are about 100 years in age. After World War I, and the advent of mechanized earth moving equipment, lake building became somewhat of a growth industry, peaking during the Federal dam building period of the 1950s to early 1980s in Kansas, but still ongoing for smaller watershed impoundments.

One of the longer term goals of the KDHE Lake and Wetland Monitoring Program is to be able to analyze lake water quality data for time trends. Due to the size of the state, the number of lakes versus resources and staff, and the need to collect data for other ends, the analysis of time trends has been a secondary activity until now. Although delineation of time trends is still problematic for individual water bodies (due to the modest data sets for some lakes in the network), the collective examination of network lakes for trends in water quality is statistically feasible and clearly worthwhile from a lake management perspective. One advantage of having a population of predominantly artificial lakes is that the age of each can be pinpointed, thereby facilitating the analysis of the impact exerted by the passage of time

Given that nutrient pollution and eutrophication are the greatest threats to lakes and their support of beneficial uses in Kansas (NALMS, 1992; Smith et al., 2002; KDHE, 2004), and that eutrophication is a process that should (in theory at least) increase over time as pollutants are retained by a lake (Wetzel, 1983; Horne and Goldman, 1994), we attempt to answer the question of how the passage of time and changes in watershed condition influence lake water quality in Kansas.

The Larger Federal Lakes

In recent years, the Kansas Water Office (KWO), has become increasingly concerned about sedimentation and water quality degradation in the Federal lakes used as public water supplies in the state. One specific aspect of this concern is the influence of lake age on sedimentation and water quality. Sedimentation influences ambient water quality by either 1) increasing shallow area in a lake, resulting in increased sediment resuspension, or by 2) bringing in pollutants along with the sediment. These accumulated pollutants (e.g., phosphorus, silt and clay particles, heavy metals, etc.) then allow for degradation of water quality and trophic status over time. Given these concerns, KDHE BEFS staff were requested by the KWO, in Fall 2003, to conduct a time trend analysis of water quality in Federal lakes in the state, in order to assess whether water quality was changing along with the documented increases in sediment accumulation over time.

Kansas has 24 larger Federal lakes, constructed by either the Army Corps of Engineers (ACOE) or the Bureau of Reclamation (BOR). All 24 are a part of the KDHE sampling network and they constitute the majority of public lake surface acreage in the state (>80%) and estimated volume (>90%). Since 1985, each of these lakes has been sampled on a three year rotational schedule, so all 24 are surveyed at least once during each three year time period. This lends itself to the collective examination of time trends for our larger lake systems. Trophic state data (chlorophyll-a) were analyzed by producing a mean value for each three year cycle for each lake, covering the last 21 years. Upon initial examination, four of these lakes were recognized as having large water quality fluctuations which are believed to be strongly influenced by large shifts in water levels. Three of these four lakes are irrigation water sources, and so undergo drastic, and almost yearly, changes in water levels (Kirwin, Lovewell, and Webster Lakes). The fourth lake has undergone these abrupt water level changes over time as well, but owing to variability in rainfall in western Kansas (Cedar Bluff Lake). Due to these confounding factors, these four lakes were excluded from further time trend analyses. The results of these analyses, performed for the remaining 20 lakes, are presented in Figure A1.

Collectively, these 20 larger lakes have experienced an upward shift in trophic status over time, as indicated by the mean, median, 75^{th} percentile, and/or maximum chlorophyll-a concentrations. Trends were statistically significant for the mean, median, and 75^{th} percentile values so examined ($p < 0.05$), with R^2 values in the range of 0.90 to 0.95. Maximum values were influenced by a particularly high value in 1995 at Waconda Lake, but the inclusion of 2005 data, to complete the last time period, also produces a statistically significant upward trend over time ($p = 0.01$, and $R^2 = 0.76$).

During the past two decades, the collective trophic status of these lakes has increased from mesotrophic to the middle of the eutrophic range. Although the collective trend for these lakes is towards a higher trophic state (predicted to be hypereutrophic by around 2030) there is considerable variability among lakes. Some lakes show no change between time periods, while others show very significant upward changes from survey to survey. Is the trend due solely to lake aging? The variability among water bodies, and the modest 30 years spanning the development of these Federal lakes, would suggest that the answer is “no.” More likely, the time trend is correlated to differences and changes in watershed condition and the influx of nutrients (and other pollutants) as these changes progress. Although watershed land use data were not readily available for these 20 large lakes, estimates of “lower” or “higher” agricultural/urban influence could be assigned to these lakes (ignoring the 6 lakes in the group which are typically classed as argillotrophic due to in-lake resuspension problems that can mask watershed influences) using a statewide land cover map. Figures A2 and A3 illustrate that differences based on watershed condition do exist.

Both age and watershed land use data are readily available for smaller lakes within the KDHE sampling network. The next section examines smaller Kansas lakes for trophic state impacts associated with both the passage of time and watershed condition.

Figure A1. Collective time trends, 1985-2005, for trophic status (chlorophyll-a) for 20 Federal lakes in Kansas by three year survey cycle. Data being analyzed are the mean values for each lake and time period. Time period medians are white squares, while time period means are grey ellipses.

Figure A2. Chlorophyll-a mean data, 1985-2005, for 14 Federal lakes, versus gross watershed land use condition. White squares represent medians while grey ellipses represent mean values. N = 6 for the "Lower Ag" and N = 8 for the "Higher Ag" categories.

Figure A3. Total phosphorus mean data, 1985-2005, for 14 Federal lakes, versus gross watershed land use condition. White squares represent medians while grey ellipses represent mean values. N = 6 for the “Lower Ag” and N = 8 for the “Higher Ag” categories.

Kansas Lakes of Small to Moderate Surface Area

Ninety-six smaller (non-Federal) lakes (both in the KDHE sampling network and from special projects) were sorted based on age and watershed land use composition. Starting at each end of the age spectrum, lakes were then selected based on having either a low amount of agricultural and urban land in the watershed or a high amount. Four groups of eight were selected (about one-third of the smaller lakes in the network), representing:

1) a group of younger lakes with watersheds conducive to “low” nutrient levels (New-Low),
2) a group of younger lakes with watersheds conducive to “high” levels of nutrients (New-High),
3) a group of older lakes with watersheds conducive to “low” nutrient levels (Old-Low), and
4) a group of older lakes with watersheds that were conducive to “high” nutrient levels (Old-High).

The membership of these groups were adjusted slightly to avoid lakes with known or suspected in-lake sediment suspension problems, and to make the groups as similar to each other as possible in terms of surface area, mean depth, and hydrologic retention time. Although, in the final groupings, older lakes tend to be slightly smaller in size and lakes in the “high” watershed category tend to be slightly shallower and have slightly shorter hydrologic retention times, the overlap among the groups suggests general comparability except for age and watershed land use composition. The largest discrepancy among the two primary group characteristics was that the two groups of newer lakes were somewhat dissimilar in age (Figure A4). Although that difference could not be eliminated, both groups of newer lakes are statistically different from the older lake groups in age ($p < 0.01$). The inability to close the age gap between the “newer” lake groups may reflect the fact that fewer watersheds of high quality exist today than was the case 20 to 30 years ago. Therefore, the majority of lakes built in the last 20 years have, of necessity, been in watersheds that were more highly developed. Likewise, the fact that the older lakes are slightly smaller may reflect the improvements in mechanized earth moving equipment over time, thus allowing projects of greater size since the 1950s.

Group membership, in terms of watershed land use composition, proved much easier to match. Watersheds in the “low” pollution potential groups had interquartile ranges between 1-9% agricultural or urbanized land while those in the “high” pollution potential groups had 57-81% agricultural or urban land (Figure A5). Paired groups were essentially identical, contrasting well with the opposite pair of groups.

Once the four lake groups were finalized, period of record water quality data (1985-2003) were examined. Six aspects of lake trophic state condition were examined as part of this analysis. First, chlorophyll-a, as a measure of algal biomass and production (Figure A6). Second, total phosphorus and total nitrogen, as measures of nutrient enrichment (Figures A7 and A8). Third, blue-green algae (cyanophytes) cell count, as a measure of algal nuisance potential (Figure A9). Fourth, turbidity, as a measure of water clarity (Figure A10). Fifth, Secchi disk depth, as a measure of water clarity and habitat quality for sight feeding fish (Figure A11). Sixth, macrophyte community health as measured by species richness (Figure A12), macrophytic diversity (Figure A13), and Charophyte (stonewort) abundance (Figure A14). For the macrophyte community analyses, only those lakes with past macrophyte community surveys could be utilized. Fortunately, the majority of lakes (6 to 8 out of each group) in all four groups had macrophyte community survey data to work with.

The differences and similarities among the groups provided a number of very illuminating results. In terms of chlorophyll-a, total phosphorus, total nitrogen, and blue-green algal populations, all four analyses gave very similar results. Lake age appeared to have no observable impact on water quality and trophic state, provided the watersheds were in very good condition in terms of nutrient pollution potential. Lakes in better quality drainage, regardless of age, were classed as being on, or below, the threshold between mesotrophy and eutrophy, with total phosphorus levels between 20 to 30 ug/L, total nitrogen <600 ug/L, and blue-green algae populations generally <5,000 cells/mL.

Regardless of lake age, developed watersheds gave rise to degraded water quality conditions, although a secondary age impact may be present under these conditions of high nutrient pollution potential. Lakes in poorer quality watersheds, regardless of age, ranged from the upper end of eutrophy to hypertrophy, had total phosphorus levels mostly >80-90 ug/L, total nitrogen >1,200 ug/L, and blue-green algae populations mostly >50,000 cells/mL.

Turbidity (Figure A10) data indicated that, once again regardless of age, lakes with developed watersheds had significantly higher ($p < 0.05$) turbidity than lakes with relatively undeveloped drainage. However, absolute differences in turbidity among group means were not as pronounced as for the other trophic state parameters. Water clarity, as assessed by Secchi depth (Figure A11), displayed the same trend, with much higher clarity observed in lakes in undeveloped watersheds. These lakes had Secchi depths generally >135 cm, while lakes in highly developed watersheds tended to have Secchi depths <65 cm.

Figure A4. Composition of the four lake/watershed groups in terms of lake age in years.

Figure A5. Composition of the four lake/watershed groups in terms of watershed land use composition.

Figure A6. Chlorophyll-a levels among the four lake/watershed groups. Medians are depicted by white squares, while the means are depicted by the grey ellipses.

Figure A7. Total phosphorus levels among the four lake/watershed groups. Medians are depicted by white squares, while means are depicted by the grey ellipses.

Figure A8. Total nitrogen levels among the four lake/watershed groups. Median values are depicted by white squares, while the means are depicted by the grey ellipses.

Figure A9. Blue-green algae populations among the four lake/watershed groups. Median values are depicted by white squares, while the means are depicted by the grey ellipses.

Figure A10. Water column turbidity among the four lake/watershed groups. Median values are depicted by white squares, while means are depicted by the grey ellipses.

Figure A11. Secchi disk depth among the four lake/watershed groups. Median values are depicted by white squares, while means are depicted by the grey ellipses.

Macrophyte Communities In Kansas Lakes

Macrophytes, for the purposes of the KDHE sampling network, include submersed and floating leaved vascular aquatic plants plus the macro-algae known as Charophytes or stoneworts. The macrophyte community represents a portion of a lake's trophic state that is longer lived than the phytoplankton, and takes far longer to develop and reproduce. Thus, macrophytes in lakes may be viewed as analogous to using macroinvertebrate communities to study stream ecosystems.

Kansas lakes tend to have far more examples that lack an observable macrophyte community, and thus lack the beneficial habitat they provide, than examples with robust communities. This may be for physical reasons (wind and shore erosion, steep shorelines), biological reasons (competition with phytoplankton and periphyton), or due to management activities (grass carp introductions, chemical control, or mechanical harvesting). Of the three categories, macrophyte removal as part of lake management activities is likely the greatest factor.

Despite the general public "dislike" of macrophyte beds (due to potential interference with shoreline fishing and boat propellers), these organisms provide excellent habitat for fisheries and abundant positive influences on the overall health and integrity of lakes (Sculthorpe, 1967; Wetzel, 1983; Scheffer, 1998). Of course, overabundance can be just as much a problem as a lack of macrophyte habitat. The current view tends to be that lakes and their fisheries do best when limited stands are present (Bennett, 1970) that do not exceed about 40% cover when a bass/sunfish community is the desired end for the fishery (EPA, 1993).

Three examples of macrophyte community measures are examined as part of this overall analysis of time and watershed condition versus lake trophic state. These are period of record species richness (Figure A12), period of record diversity as expressed by Shannon's diversity index (Figure A13), and the period of record abundance of the Charophyte portion of the macrophyte community (Figure A14). Charophytes have developed the reputation of being valuable in lake ecosystems for promoting and maintaining clear water and low nutrient conditions, and have been utilized increasingly in Europe as bioremediation tools in lakes (Meijer, 2001; van den Berg, 2001). Data from each lake's past macrophyte surveys were averaged and utilized in the overall statistics for each lake/watershed group. Most of the lakes used in this general analysis (28 of the 32) had been surveyed for macrophytic vegetation, thus making this additional analysis possible.

Clear differences were seen between lake groups with developed watersheds and those without. Lakes with watersheds rich in agriculture and urban land are far more likely to have no macrophyte community. Where such plant communities do exist in these lakes, they tend to be far less diverse, have fewer total species, and lack Charophytes. In contrast, lakes in undeveloped watersheds typically had robust aquatic plant communities, with about 30-40% of all stations examined in each lake having plants present, with significant portions of the diversity due to Charophytes. In the case of macrophyte communities, a time trend may also be present, with lake aging allowing for the influx of propagules and time for development. As this component of the aquatic ecosystem is longer lived, such a trend might be anticipated *a priori*.

Figure A12. Macrophyte species richness among the four lake/watershed groups. Median values are depicted by white squares, while means are depicted by the grey ellipses.

Figure A13. Macrophyte diversity among the four lake/watershed groups. Median values are depicted by white squares, while means are depicted by the grey ellipses.

Figure A14. Charophyte abundance among the four lake/watershed groups. Median values are depicted by white squares, while means are depicted by the grey ellipses.

Conclusions

1. The simple passage of time, over the roughly 100 year span represented by assessed lakes in Kansas, appears to have no observable/significant impact on lake trophic state parameters, provided watershed condition is relatively undisturbed and undeveloped. Even in these highest quality systems, one might expect age related trends to appear over several centuries. Testing of that hypothesis must, however, be left to future limnologists in the state.

2. Watershed condition appears to exert a profound impact on lake trophic state conditions, regardless of lake age. Even relatively new lakes in highly impacted watersheds typically have poor water quality and high trophic status.

3. Although not significant in a statistical sense, but visible in the previous graphics, lakes in highly impacted watersheds seemingly demonstrate secondary impacts related to aging. It is possible that the higher impacts accelerate, or compress, the eutrophication/lake aging process, thus allowing us to see the simulated effect of time in that grouping of lake/watershed systems.

4. Conversely, there are suggestions of secondary age trends in water clarity and macrophyte community development among higher quality systems. A time trend for macrophyte community development, given that macrophyte communities develop and grow over longer time frames than phytoplankton, would appear reasonable.

5. Of the two forces examined here, lake age versus watershed condition, watershed condition is clearly the more important in terms of present water quality and trophic status. This is fortunate, in that we do exert control over this factor as a society. Therefore, we have opportunity to protect and restore these aquatic systems. Because lake protection is almost always easier and less expensive than lake restoration, it is imperative that society act in the present to protect these valuable aquatic resources (and ideally during the planning process for artificial lakes). Otherwise, opportunities and benefits from many aquatic resources may be lost, and a legacy of difficult and expensive restoration activities will be our gift to future generations.

APPENDIX B

Blue-Green Algae Fact Sheet

During the summers of 2003 and 2004, several lakes in Kansas experienced extremely large blue-green algae blooms, causing a great deal of public concern over the water quality of these lakes. In Kansas, the worst (or at least the most publicly reported) blooms occurred in Marion Lake and Cheney Lake. The neighboring state of Nebraska also had widespread problems with blooms during this same time period.

Part of the response to these conditions was to develop a fact sheet that could be quickly sent to water suppliers, city staff, or the general public, providing a concise amount of information on what blue-green algae are, why blooms were occurring, what impacts and threats they may pose, and what might be done about them. This general fact sheet on blue-green algae is provided on the following pages for the reader's use and edification.