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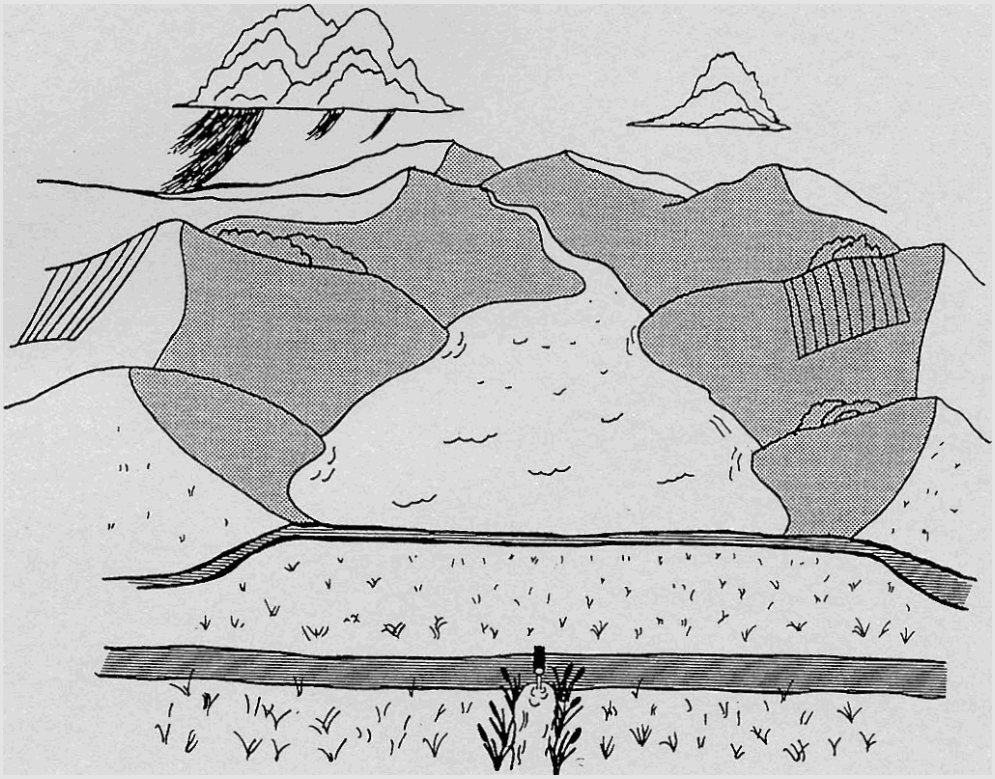

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APPENDIX A: Lake Trophic State Visual Assessments and Lake Reference Condition

INTRODUCTION

The last few years have seen a nationwide movement to accelerate the development of lake/reservoir eutrophication standards. EPA has now developed ecoregional nutrient criteria that the states will be expected to use as guidance for developing their own nutrient criteria, or face having them promulgated by EPA on their behalf (EPA, 1998). There is fairly unanimous scientific opinion that higher lake trophic state does correspond with increasing levels of lake use impairment (e.g.; EPA, 1990; NALMS, 1992, KDHE, 1998a; KDHE, 1998b). A number of states currently have narrative eutrophication criteria in their water quality standards, and several states and Canadian provinces have developed numeric eutrophication criteria (EPA, 1990; NALMS, 1992). A study published in 1989 indicated that about 60% of the states indicate they have a need for numeric eutrophication criteria (Johnson, 1989). A number of recent studies have also indicated a strong connection between increasing lake trophic state and loss of economic revenues from lakes (e.g.; Boyle, et. al., 1997; Jobin, 1997; Pretty et al., 2003).

Kansas has had a narrative eutrophication criterion in its water quality standards for many years. For the last four 305(b) reporting cycles, lake trophic state classification has been used to apply this narrative criterion in assessments of lake use impairment. The validity and value of using non-regulatory numeric criteria to implement a regulatory narrative criterion has been recognized by experts in the area of eutrophication management (Heiskary and Walker, 1988; NALMS, 1992) and is encouraged by the EPA in many of their guidance documents. Table 10 compiles the system that has been used and referenced in recent KDHE documents (KDHE, 1998a, 1998b, 1999, 2000, 2001). This system has been derived largely from the standards developed in other states, incorporating those ideas and concepts that are best suited to our geographic region.

In 1998, KDHE staff began a project to collect data that might provide refined threshold levels for determining lake use impairments based on trophic state and water clarity. The 1998 annual report presented the results of that first effort. During 1999-2002, data collection efforts continued and the combined data has been presented each year in annual program reports. Continuing in that same manner, the combined 1998-2002 data are analyzed and presented in this report. This represents the conclusion of this special project, results of which should prove valuable to all concerned with eutrophication and nutrient related water quality problems.

METHODS

During the summers of 1998-2002, KDHE attempted to verify the suitability of the numeric guidelines presented in Table 10 for assessing lake use impairment by eutrophication. The methodology was developed for use in Minnesota, where lake conditions are described in terms of the frequency, or risk of, nuisance conditions (Heiskary and Walker, 1988). The reader is referred

to that article for an in-depth discussion of procedures. The basic method involves 1) *a-priori* assessments of lake use support, based on visual inspection, 2) correlating visual assessment data with analytical data for trophic state parameters (nutrients, chlorophyll-a, Secchi depth, and non-algal turbidity), 3) conducting a frequency analysis of the data, and 4) using that frequency analysis to develop criteria based on perceived risk levels (<1%, 10%, 25%, etc.).

Three lake uses were assessed for the study conducted in 1998-2002. These were primary contact recreation, secondary contact recreation (formerly designated non-contact recreation), and aesthetic use. This "aesthetic" use should be applied, not only to strict aesthetic uses, but also to other very nutrient sensitive uses such as water supply, or to assessment of the physical appearance of the water. Kansas water quality standards do not recognize an "aesthetic" use for surface waters, unlike some neighboring states such as Nebraska. Nevertheless, the aesthetic quality of lakes does exert an impact on other types of use support and even property values (Boyle, et al., 1997). In Kansas, many housing projects have used their location near a lake to attract buyers. Lowered water quality in these lakes does have an impact on property buyers and property values. "Aesthetic" assessment of the water, for this study, looked for a presence or absence of an overtly visible algae community and inorganic turbidity. Visible "presence" of an algae community should reflect support for water supply uses too because water supply impairments can occur at very low algal biomass (Smith, et al., 2002). While the model for this effort (Heiskary and Walker, 1988) used frequency analysis to derive phosphorus criteria, KDHE chose to derive primary criteria for algal biomass, water clarity, and total phosphorus. The first two criteria should be utilized as the primary indicators of lake use support, although total phosphorus criteria will be of primary importance in both TMDL work and in describing downstream impacts.

While the Minnesota approach utilized only a single visual assessment, focusing on the level of "green" observed in the water, KDHE's study involved two separate assessments, "green" and "brown." These visual assessments relate to impairments resulting from elevated lake trophic state (algal biomass) and reduced levels of water clarity, respectively. In Kansas (and throughout much of the world), traditional water clarity measures, such as Secchi depth and nephelometric turbidity, are influenced more by soil-derived inorganic turbidity than by algae (Davies-Colley, et al., 1993). Given that soil erosion is a major problem in many Kansas watersheds, the use of two visual assessments was deemed valuable. Approximately 7% of Kansas lakes experience chronic inorganic turbidity of sufficient magnitude that it interferes with the normal nutrients-to-algal biomass process. Although impacted by nutrient loads in a different fashion, constituting a distinct sub-population of lakes, they still are impacted and need a method for assessing impacts.

Staff of the Lake and Wetland Monitoring Program conducted visual assessments at each waterbody surveyed during the summers of 1998-2002. This resulted in 3,012 total observational scores being included in the values generated for this report. At each site, staff would first measure Secchi depth. The visual assessments were conducted by examining the color of the water upon the white quarters of the Secchi disk, at the shallower of a depth of one-half the measured Secchi depth or one meter. After examining the color of the water in this manner, plus assessing the overall appearance of the water column, "green" and "brown" scores were assessed by each staff member for each of the three

use categories. The make-up of the field crew was believed to provide a decent cross-section of viewpoints, in that half of those involved had grown up in an urban setting in eastern Kansas while the other half had grown up in a rural western Kansas environment. While this study did not involve a random cross section of the general public, it did provide a valid data base for water quality standards development based on the recommendations of other entities involved in such efforts (Smeltzer and Heiskary, 1990; NALMS, 1992). Assigned scores rarely differed among field staff by more than one unit, demonstrating a general uniformity of perception among informed observers regardless of background. Fully 96% of scores matched exactly, or differed by only one point on a scale of one-to-ten.

Table A1 presents the system for assigning green scores, while Table A2 presents the system for assessing brown scores. In each case, a score of three is meant to represent the onset of minor use impairment (i.e., partial impairment) while a score of five is meant to represent the onset of significant use impairment (i.e., non-support). Only the green or brown quality of the water column was taken into account in assigning scores. The effects of water depth on primary contact recreation, shoreline condition on aesthetic appeal of the lake, lack of a boat ramp on boating, and other such factors were not considered in this exercise.

The frequency/risk potential approach was applied to both sets of scores, for all three uses. The water quality parameters of chlorophyll-a and Secchi depth were used in association with the green visual scores based on a high level of correlation between green visual scores and measured parameters. In a similar fashion, Secchi depth and calculated non-algal turbidity were used in association with brown visual scores based on a high correlation level between brown visual scores and these parameters. Total phosphorus was also examined, in comparison to both green and brown scores, as the original Minnesota study had done. For both brown and green scores, the strength of correlation with total phosphorus was less than for Secchi depth or chlorophyll-a, respectively, but still significant.

The "use hesitation" descriptions in tables A1 and A2 can also be viewed in the following manner. These descriptions apply to either scale, green or brown.

Slight hesitation	Would probably participate in the use at the given location, even if there are other lakes with better water quality nearby, but with reduced enjoyment.
Definite hesitation	Would participate in the use at the current location reluctantly, if at all, even if there were no other lakes nearby with better water quality. If other lakes were near, with better water quality, participation in the use would be moved to the new location despite extra costs in travel or time.
Strong hesitation	Would not participate in the given use at the current location under any circumstances, regardless of any lack of other lakes with better water quality.

Table A1. "Green" score descriptors for primary and secondary contact recreational uses, and for aesthetics and other sensitive uses. Even scores allowed for maximum flexibility in allowing individuals to interpolate between descriptions. Hesitation about recreating in a given waterbody is based only on the appearance of the water, in terms of algae or "green-ness." Other factors, such as waterbody depth or presence of facilities, were not part of the assessment.

Score	Aesthetic Appearance & Sensitive Uses	Primary Contact Recreation	Secondary Contact Recreation
1	Beautiful, no problems.	Beautiful, no problems.	Beautiful, no problems.
2			
3	Not clear. Some algae and color visible.	Slight hesitation about swimming in or contacting water.	Slight hesitation about wading or general recreation.
4			
5	Definite or strong green algae color.	Definite hesitation about swimming in or contacting water.	Definite hesitation about wading. Some reduced general recreation quality.
6			
7	Very strong green algae color.	Strong hesitation about swimming in or contacting water.	Strong hesitation about wading. Quality of general recreation definitely impaired.
8			
9	Extreme green algae color. Scums and/or odors evident.	Primary contact recreational use enjoyment impossible due to algae levels.	Wading and recreation enjoyment almost impossible due to algae.
10			

Table A2. "Brown" score descriptors for primary and secondary contact recreational uses, and for aesthetics and other sensitive uses. Even scores allowed for maximum flexibility in allowing individuals to interpolate between descriptions. Hesitation about recreating in a given waterbody is based only on the appearance of the water, in terms of turbidity or "brown-ness." Other factors, such as waterbody depth or presence of facilities, were not part of the assessment.

Score	Aesthetic Appearance & Sensitive Uses	Primary Contact Recreation	Secondary Contact Recreation
1	Beautiful, no problems.	Beautiful, no problems.	Beautiful, no problems.
2			
3	Not clear. Some turbidity and color visible.	Slight hesitation about swimming in or contacting water.	Slight hesitation about wading or general recreation.
4			
5	Definite or strong turbidity/brown color.	Definite hesitation about swimming in or contacting water.	Definite hesitation about wading. Some reduced general recreation quality.
6			
7	Very strong brown turbidity/color.	Strong hesitation about swimming in or contacting water.	Strong hesitation about wading. Quality of general recreation definitely impaired.
8			
9	Extreme brown turbidity/color.	Primary contact recreational use enjoyment impossible due to turbidity levels.	Wading and recreation enjoyment almost impossible due to turbidity.
10			

RESULTS

Combined 1998-2002 Results

"Green" Scores

Three parameters were examined in comparison to the "green" criteria scores, including total phosphorus, chlorophyll-a, and Secchi depth. In the case of Secchi depth, the criteria values discussed in this report section should be applied to lakes that lack overtly visible levels of inorganic turbidity. Table **A3** is concerned with lake trophic state (chlorophyll-a levels), Table A4 with in-lake total phosphorus, and Table A5 with Secchi depth.

Table A3. A comparison of use support versus current interpretation of lake trophic state and 1998-2002 a ***priori*** "green" data. All values are in units of ug/L, or ppb, of chlorophyll-a, rounded to the nearest full unit. The "risks" are the chlorophyll-a threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use.

Lake Use and Support Level	**Current Method (trophie state) (chlorophyll-a ppb)**	**Risk Based Criteria 1998-2002 Green Data**	
		<1%	**10%**
Aesthetic/Sensitive Uses Physical Appearance Water Supply			
Full Support	<12	<2	<7
Partial Support	<12	2-6	7-12
Non-Support	>12	>6	>12
Primary Contact Recreational Use			
Full Support	<12	<9	<10
Partial Support	12-20	9	10-23
Non-Support	>20	>9	>23
Secondary Contact Recreational Use			
Full Support	<20	<9	<21
Partial Support	20-56	9-23	21-38
Non-Support	>56	>23	>38

Table A4. A comparison of use support versus current interpretation of in-lake total phosphorus and 1998-2002 *apriori* "green" data. All values are in units of ug/L, or ppb, of total phosphorus. The "risks" are the total phosphorus threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use.

Lake Use and Support Level	Current Method (trophic state) (total phosphorus ppb)*	Risk Based Criteria 1998-2002 Green Data	
		<1%	10%
Aesthetic/Sensitive Uses Physical Appearance Water Supply			
Full Support	<25	<15	<15
Partial Support	<25	15	15-27
Non-Support	>25	>15	>27
Primary Contact Recreational Use			
Full Support	<25	<15	<22
Partial Support	25-50	15	22-50
Non-Support	>50	>15	>50
Secondary Contact Recreational Use			
Full Support	<50	<15	<48
Partial Support	50-100	15-50	48-109
Non-Support	>100	>50	>109

* = These values come from the EPA "Red Book."

Table A3 indicates that the use of the distinct trophic state classes for use impairment assessment is a valid method. The greatest discrepancies are in the threshold for non-support of secondary contact recreation, and in the full-support threshold of aesthetic appearance, where current methodology is overly high at a 10% risk level. In these two areas, the current methodology equates with a 30-to-40% and a 55-to-65% risk level, respectively.

Table A4 indicates that, in terms of in-lake total phosphorus, the values published as guidelines for lakes and streams by the EPA back in the 1970s (EPA; 1972,1976) are very representative of a 10% impairment risk level. The original EPA criteria/goals for total phosphorus were 25 ppb for lakes, 50 ppb for streams entering lakes, and 100 ppb for streams. KDHE has, historically, interpreted these for the Midwest as 25 ppb for open, deep water, 50 ppb for smaller, shallower reservoirs and upper reaches of large reservoirs, and 100 ppb for streams.

Table **A5.** A comparison of use support versus current interpretation of lake water clarity and 1998-2002 a ***priori*** "green" data. All values are in units of centimeters, or cm, of Secchi depth. The "risks" are the Secchi depth threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use. These table values should only be applied to lakes without overt inorganic turbidity.

Lake Use and Support Level	**Current Method (trophic state) (Secchi Depth in cm)***	**Risk Based Criteria 1998-2002 Green Data**	
		<1%	**10%**
Aesthetic/Sensitive Uses Physical Appearance Water Supply			
Full Support	>100	>216	>216
Partial Support	>100	216	216-151
Non-Support	<100	<216	<151
Primary Contact Recreational Use			
Full Support	>70	>216	>184
Partial Support	>70	216-154	184-92
Non-Support	<70	<154	<92
Secondary Contact Recreational Use			
Full Support	no assessment value	>216	>96
Partial Support	no assessment value	216-91	96-71
Non-Support	no assessment value	<91	<71

* = These Secchi depth values have been used as goals and guidelines for Kansas lakes, based on best professional judgement and the literature.

Table A5 indicates that, in terms of water clarity, Secchi depths currently used as guidelines equate with risk levels much greater than 10%. Therefore, current guideline/water quality goals are likely under-protective of the uses. In countries and regions where water clarity is an actual regulation for swimming use, the value tends to be >100 cm, or "disk visible on the bottom substrate" (Davies-Colley, et al., 1993), which conforms roughly with the 92 and 96 cm threshold values for the 10% risk level for primary contact non-support and secondary contact full support, respectively.

"Brown" Scores

Similar analyses were conducted for the brown visual score data, concerning perceived impairment versus Secchi depth and non-algal turbidity. Table **A6** presents the values for Secchi depth, while Table **A7** presents similar data for calculated non-algal turbidity.

Table **A6.** **A** comparison of use support versus current interpretation of lake water clarity and 1998-2002 a *priori* "brown" data. All values are in units of centimeters, or cm, of Secchi depth. The "risks" are the Secchi depth threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use. These table values should only be applied to lakes with overt inorganic turbidity.

Lake Use and Support Level	**Current Method (water clarity) (Secchi Depth in cm)***	**Risk Based Criteria 1998-2002 Brown Data**	
		<1%	**10%**
Aesthetic/Sensitive Uses Physical Appearance Water Supply			
Full Support	>100	>106	>88
Partial Support	>100	**106-91**	**88-66**
Non-Support	<100	**<91**	<66
Primary Contact Recreational Use			
Full Support	**>70**	>106	>86
Partial Support	>70	**106-69**	**86-54**
Non-Support	<70	<69	<54
Secondary Contact Recreational Use			
Full Support	no assessment value	>69	>59
Partial Support	no assessment value	**69-56**	**59-37**
Non-Support	no assessment value	<56	<37

* = These Secchi depth values have been used as goals and guidelines for Kansas lakes, based on best professional judgement and the literature.

Table A7. A comparison of use support versus current interpretation of lake water clarity and 1998-2002 *a priori* "brown" data. All values are in units of "per meter," or m^{-1}, of non-algal turbidity. The "risks" are the turbidity threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use. These table values should only be applied to lakes with overt inorganic turbidity.

Lake Use and Support Level	Current Method (water clarity) (non-algal turbidity, m^{-1})*	Risk Based Criteria 1998-2002 Brown Data <1%	10%
Aesthetic/Sensitive Uses Physical Appearance Water Supply			
Full Support	<0.40	<0.50	<0.66
Partial Support	0.40-0.70	0.50-0.63	0.66-0.96
Non-Support	>0.70	>0.63	>0.96
Primary Contact Recreational Use			
Full Support	<0.70	<0.50	<0.75
Partial Support	0.70-1.00	0.50-0.87	0.75-1.12
Non-Support	>1.00	>0.87	>1.12
Secondary Contact Recreational Use			
Full Support	no assessment value	<0.63	<1.07
Partial Support	no assessment value	0.63-0.87	1.07-2.18
Non-Support	no assessment value	>0.87	>2.18

* = These non-algal turbidity values have been used as goals and guidelines for Kansas lakes, based on best professional judgement and the literature.

For both sets of data, Tables A6 and **A7,** the "guideline" values used in the past appear to provide reasonably good threshold criteria for water clarity and turbidity versus recreational and aesthetic use support. These data support the continued use of "best professional judgement" threshold values, for lakes with observable inorganic turbidity.