KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

BUREAU OF WATER

WATER QUALITY STANDARDS WHITE PAPER

CHLOROPHYLL-A CRITERIA FOR PUBLIC WATER SUPPLY LAKES OR RESERVOIRS

JANUARY 10, 2011

CHLOROPHYLL-A NUTRIENT CRITERIA

ISSUE

Should Kansas adopt chlorophyll-a criteria for public water supply lakes?

It is the mission of the Kansas Department of Health and Environment (KDHE) to protect the health and environment of all Kansans by promoting responsible choices. One facet of this mission is the setting of water quality standards based on the best science available.

CURRENT CRITERIA

- **Narrative Criteria**
  - KAR 28-16-28e(b)(7) - *Taste-producing and odor-producing substances of artificial origin shall not occur in surface waters at concentrations that interfere with the production of potable water by conventional water treatment processes, that impart an unpalatable flavor to edible aquatic or semiaquatic life or terrestrial wildlife, or that result in noticeable odors in the vicinity of surface waters.*
- **Domestic Water Supply Use**
  - KAR 28-16-28e(c)(3)(D) - *The introduction of plant nutrients into surface waters designated for domestic water supply use shall be controlled to prevent interference with the production of drinking water.*

BACKGROUND

What is Chlorophyll-a?

Chlorophyll-a is the most common photosynthetic pigment found in all plants, algae, and cyanobacteria. It converts sunlight and carbon dioxide into organic compounds like carbohydrates while generating byproducts such as oxygen (photosynthesis). Chlorophyll-a is often used as a means to measure the productivity of plants and algae in a waterbody.

Lakes or reservoirs are valuable natural resources that also possess tremendous economic value. They provide enjoyment as well as many beneficial uses such as flood control, recreation, aquatic life support, domestic water supply, irrigation, and industrial water sources. In Kansas, there are 21 federal reservoirs and 63 state or locally owned reservoirs that are used as water supply. Most of these reservoirs were built from the 1940s through the 1980s. They have become an integral part of the Kansas water supply system. It is estimated that more than 67% of Kansans depend on treated surface waters from public drinking water suppliers (PWS) and many of these suppliers rely solely on reservoir water for their sources.

By nature, lakes or reservoirs act as settling ponds and will gradually be filled up with silt even in pristine environments. Human activities tend to speed up the aging process of these man-made lakes. A huge challenge facing Kansans today is that many reservoirs are experiencing significant problems caused by sedimentation and/or eutrophication (nutrient enrichment). Some of the consequences of sedimentation and eutrophication include loss of water storage capacity, loss of beneficial uses such as recreational activities and aquatic life support, and taste and odor problems for drinking water suppliers.

A few of the reservoirs have already undergone expensive restoration operations such as dredging to restore their full or partial usefulness. For some reservoirs like the John Redmond Lake, the estimated cost to restore the reservoir is so astronomical that options are still being evaluated and debated by stakeholders. Mission Lake near Horton was recently being dredged to restore its water storage capacity. The cost for dredging this relatively small reservoir (71 acres of conservation pool) is estimated at close to $6.6 million.

Excessive algal growth due to eutrophication can have undesirable and/or detrimental effects on drinking water suppliers and end users. These effects include taste and odor problems, increased levels of cyanotoxins such as microcystins, higher levels of trihalomethane (THM) precursors, and increased turbidity levels in source water. Certain algal species known to produce the musty, earthy, fishy, or grassy odors are often the culprits of taste and odor problems in eutrophic waters. Nutrient enrichment can cause undesirable species such as cyanobacteria to dominate in a waterbody. Cyanotoxins produced by cyanobacteria or blue green algae are very toxic and potentially lethal to animals and humans even in small quantities. There are two main types of cyanotoxins, (1) hepatotoxins such as microcystins that can cause serious damage to the liver; (2) and neurotoxins that can cause death in animals. Carcinogenic THMs are byproducts of the chlorination process. Rapid algal growth increases the levels of organic matter which are precursors to THMs in the water; thus increasing the levels of THMs in finished drinking water. Higher algal growth may also force drinking water treatment facilities to use more chlorine for disinfection and further exacerbate the THM problems.

The treatment cost for dealing with issues caused by excessive algal growth can be very high and sometimes prohibitive for small communities. For the city of Wichita, an $8.5 million ozone facility was constructed at Cheney Reservoir to control taste and odor problems. In Kansas, there have been a few incidences where drinking water treatment plants were forced to shut down during moderate to severe algal blooms due to their inability to adequately treat the source water. For example, massive algal blooms have triggered shutdown of drinking water intakes in Cheney Reservoir, Clinton Reservoir, and Marion Reservoir in the past decade. It has been widely recognized that prevention is one of the most cost-effective ways for dealing with nutrient related problems for lakes and reservoirs.

The danger of toxic algal blooms has been brought front and center to the public's awareness due to a series of widely publicized lake closures during the summer of 2010. A total of 9 lakes (including 2 unclassified lakes) were issued public health advisory or warning alerts due to high levels of cyanobacteria and/or microcystins. Since this is the first year these public health alerts have been issued by KDHE for lakes affected by toxic algal blooms, the public may be surprised to know the occurrence or severity of such events. Six out of the 7 classified lakes are known to be impaired by nutrients and five lakes already have TMDLs[1] developed for eutrophication. The problems have been exacerbated this year by a very wet spring (significant nutrient runoff) followed by an extremely hot and dry summer. These are the ideal incubation conditions for algae.

Direct counting of algal communities under microscopes is a time-consuming and labor-intensive process. The high levels of expertise required for algal counting often make the tests very expensive and the results prone to errors and biases. A good practical alternative for assessing algal biomass is the measurement of chlorophyll-a in the water.

Chlorophyll-a is the most common photosynthetic pigment found in all plants, algae, and cyanobacteria. It converts sunlight and carbon dioxide into organic compounds like carbohydrates while generating byproducts such as oxygen. The concentration of chlorophyll-a provides a good assessment of the primary production or algal activities in a waterbody. The direct causes of algal blooms are often associated with increased total phosphorous (TP) and/or total nitrogen (TN) levels in a waterbody. TP and TN are referred as the causal or contributing variables of nutrient enrichment by EPA[2]. Chlorophyll-a is referred to as a response variable. For Kansas reservoirs, TP is most often the limiting factor for algal productions. Thus, excess TP inputs are more likely the main culprit of algal blooms for many reservoirs in Kansas. While TN and TP concentrations can vary widely in producing an algal response of 10 μg/L chlorophyll-a, taste and odor problems begin occurring once chlorophyll-a values reach 10 μg/L.

For lakes or reservoirs, the intensity of algal response measured by chlorophyll-a is determined not only by the levels of TP and/or TN, but also by factors such as water turbidity, sunlight, water depth, temperature, seasons, etc. Algal blooms are more likely to occur from late Spring through early Fall when there are elevated temperatures and ample sunlight. Chlorophyll-a is a measurement of response by the algal communities to all the chemical, physical, and biological conditions in a waterbody. It is regarded as a reliable indicator of the eutrophic conditions in lakes or reservoirs. Different lakes or reservoirs with similar chemical parameters but different physical conditions can have very different algal responses. Appropriate TP and/or TN levels can be set specifically for each lake or reservoir through lake modeling and the TMDL process.

Since chlorophyll-a is used in photosynthesis, the samples for chlorophyll-a are to be collected in the photic zone (top-most layer where sunlight can reach) of a waterbody. For lakes or reservoirs that stratify, the top layer or epilimnion should coincide with the photic zone of the waterbody in most lakes or reservoirs.

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[1] Total Maximum Daily Load

[2] US Environmental Protection Agency

Currently, Kansas has only narrative criteria for nutrients. Adopting site-specific numeric criteria for chlorophyll-a will be useful for the protection of public water supply (PWS) lakes or reservoirs. To assure that the criteria can achieve the intended goal of protecting PWS lakes or reservoirs, a 10% margin of safety could be incorporated into the proposed criteria. It is anticipated the proposed value would be the lesser of 9 µg/L (10 µg/L with a 10% margin of safety) or a long-term average. The 10% margin of safety has been successfully applied to TMDLs for nearly a decade in Kansas and has been seen as a reasonable offset to uncertainties when dealing with water quality issues.

The long-term average would be the running average of a minimum of 4 samples over a 10 year period following the standard KDHE sampling protocols for lakes. KDHE will also solicit and evaluate additional data from external sources such as the Army Corps of Engineers, USGS, Kansas Biological Survey, etc. Any available external data may be incorporated into the long-term average calculation if deemed appropriate. The numeric criteria for chlorophyll-a will facilitate earlier detection and 303(d)[3] listing of the impairment, as well as timely TMDL development. The ultimate goal is to encourage earlier involvement and actions by stakeholders to protect the PWS lakes or reservoirs that are threatened or impaired by eutrophication.

SELECTED AVAILABLE DATA

The ecoregional criteria developed by EPA were set at values that are equivalent to the 25th percentiles of all the data (possibly including all seasons) in the ecoregion. The EPA's aggregated chlorophyll-a ecoregional summary table and map for Kansas lakes and reservoirs are shown below in Table 1 and Figure 1. Because of the inherent problems associated with the data and analytical methods, EPA expected states and tribes to use them as starting points to develop more precise and region-specific criteria. The actual delineation of Level III ecoregions for Kansas is shown in Figure 2. As depicted by Figures 1 and 2, the Level III ecoregions "Western High Plains" and "Central Great Plains" were aggregated into Region (V). The Level III ecoregions "Southwestern Tablelands", "Flint Hills", and "Central Oklahoma /Texas Plains" were aggregated into Region IV.

Table 1. Summary of EPA's Aggregrate Ecoregion Values for Chlorophyll-a for Kansas Lakes & Reservoirs

Parameter	**IV**	**V**	**VI**	**IX**
Chlorophyll-a (µg/L)	2.0	2.3	8.6	4.9

[3] Impaired Water List, Section 303(d) of the Clean Water Act

Figure 1. EPA's Aggregate Ecoregions for Kansas

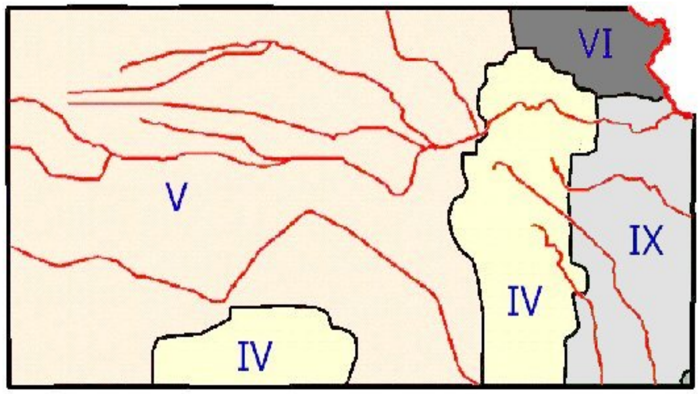
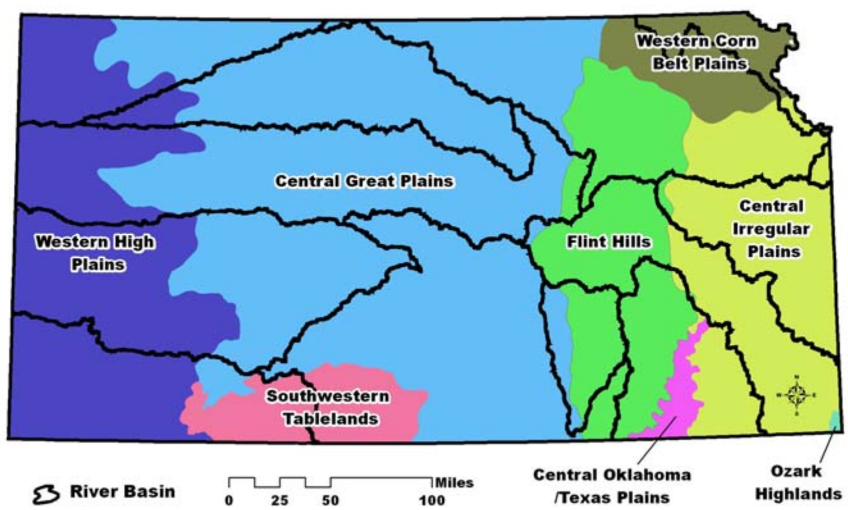


Figure 2. Level III Ecoregion Map in Kansas



The EPA Region VII Regional Technical Assistance Group (RTAG) undertook the task of developing regional nutrient criteria for Kansas, Missouri, Nebraska, and Iowa. The group proposed a single set of benchmarks (or criteria) for lakes and reservoirs in the region. The benchmark for chlorophyll-a is listed in Table 2. The general consensus of state natural resources agencies in Kansas is that one set of TN and TP values can not represent accurately the vast differences in the region. These benchmarks may indeed represent high quality waters but may also be over-protective in many areas if adopted as criteria.

Table 2. EPA Region VII RTAG's Benchmark for Chlorophyll-a

Parameter	Benchmark
Chlorophyll-a (μg/L)	8

In Kansas, lakes and reservoirs have been categorized and assessed for eutrophication using chlorophyll-a levels for many years. The annual reports by Kansas Lake and Wetland Monitoring Program list the following categories for lake trophic state according to chlorophyll-a levels.

Table 3. Lake Trophic State Indicator Used by KDHE

Lake Trophic State	Chlorophyll-a (μg/L)
Oligo-mesotrophic	≤ 2.50
Mesotrophic	2.51-7.20
Slightly eutrophic	7.21-11.99
Fully eutrophic	12.00-19.99
Very eutrophic	20.00-29.99
Lower hypereutrophic	30.00-53.99
Upper hypereutrophic	≥56.00

The 2010 Kansas 303(d) list used 10 μg/L of chlorophyll-a as the listing criterion for domestic water supply lakes. The 2008 Kansas 305(b)[4] list used the following thresholds of chlorophyll-a for domestic water supply uses: < 10 μg/L fully supportive; 10-12 μg/L fully supportive but threatened; 12-20 μg/L partially supportive; and >20 μg/L non-supportive.

Dodds et al attempted to determine the ecoregional reference conditions for Kansas lakes and reservoirs in 2006. Three methods used were (1) reference lakes identified by best professional judgment (BPJ); (2) trisection[5] method; and (3) regression model (extrapolation). Partial results are listed below in Tables 4 and 5.

[4] Water Quality Assessment Report, section 305(b) of the Clean Water Act

[5] A statistical method that determines the median value derived from the best one-third of a data set. This value is considered by some to estimate a reference condition.

Table 4. BPJ Method Reference Values

Parameter	Median	75th Percentile	n
Chl *a* (μg · L^{-1})	8	10	58
Secchi Depth (cm)	129	155	55
Total Phosphorus (μg · L^{-1})	23	33	58
Total Nitrogen (μg · L^{-1})	625	861	47

Table 5. Trisection and Regression Model Methods Reference Values

Ecoregion	Chl *a*				Secchi Depth			
	Trisection	n	Extrapolation	n	Trisection	n	Extrapolation	n
Central Great Plains	11	18	NA		117	17	66	44
Central Irregular Plains	8	34	11	100	130	31	109	92
Flint Hills	5	9	9	26	149	9	112	25
Western Corn Belt	13	6	NA		114	5	93	14

In 2006, the State of Oklahoma adopted chlorophyll-a criteria for public and private water supply use lakes. A significant number of Oklahoma water systems have THM, total organic carbon (TOC), as well as taste and odor problems. Many of the violations may be attributed to excessive algae. A long-term average of 10 μg/L was established for chlorophyll-a for the water supply lakes. Site specific phosphorus and/or nitrogen limits are to be derived from lake models and TMDLs.

Downing et al concluded that chlorophyll-a levels above 10 μg/L can exponentially increase the likelihood of cyanobacteria dominance, thus cause more occurrences of taste and odor problems for drinking water supply reservoirs (Figure 3). Smith et al suggested the intensity and frequency of taste and odor events measured by geosmin in Cheney Lake would consistently be reduced if mean chlorophyll-a concentrations are maintained below 11 μg/L throughout the reservoir (Figure 4). While the causal parameters TP and TN can vary greatly, chlorophyll-a above 10 μg/L seems to consistently produce taste and odor problems that can plague public water supply reservoirs.

Figure 3. Chlorphyll-a and Cyanobacteria (Source: Downing et al, 2001)

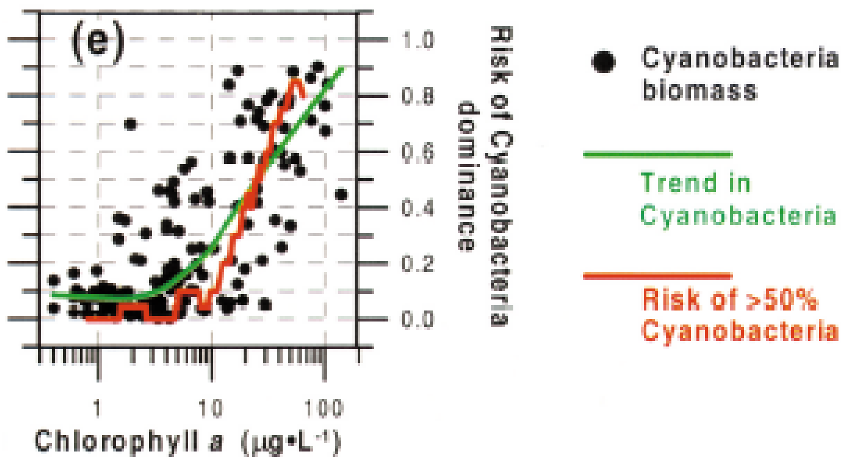
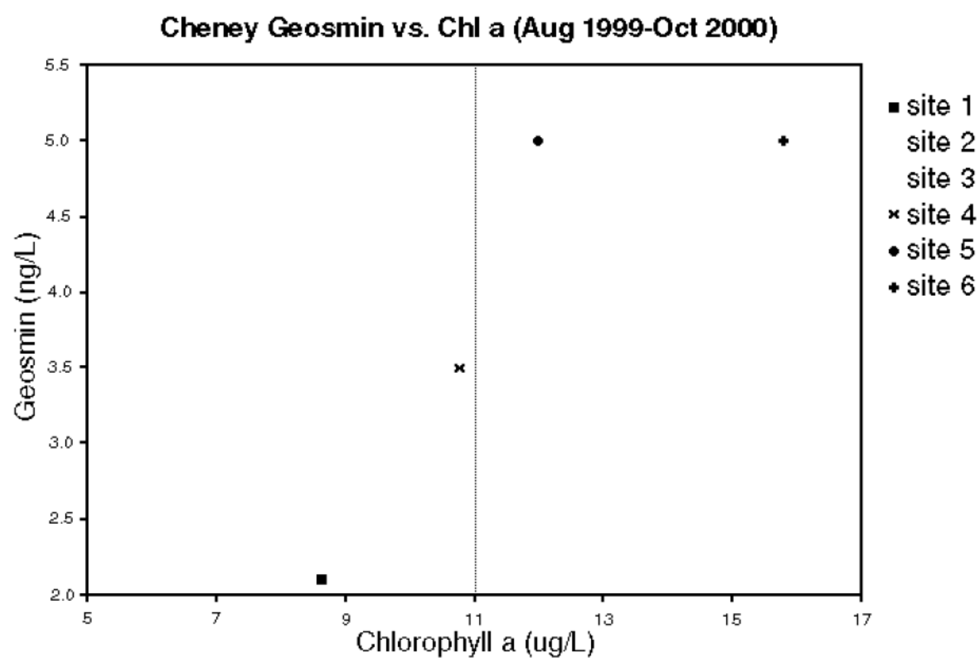


Figure 4. Cheney Lake Geosmin vs. Chlorophyll-a (Source: Smith et al 2001)



SUMMARY

Problems caused by eutrophication are a major concern for drinking water treatment facilities and end users. The cost of treatment can be extremely high depending on the severity of eutrophication. A good and cost-effective way of addressing the problems is the protection of source water from nutrient enrichment in lakes or reservoirs. Studies have shown that maintaining chlorophyll-a levels below 10 μg/L in lakes or reservoirs can prevent or significantly reduce the occurrence of taste and odor problems. Appropriate targets of the causal factors of algal growth (measured by chlorophyll-a) such as TP and/or TN can be set on a case-by-case basis for impaired lakes.

OPTIONS

A few options to consider during this review process include:

- Maintain only the current narrative nutrient criteria
- Add chlorophyll-a criteria for public water supply lakes or reservoirs – the lower of 10 μg/L (with no margin of safety) or the long-term average of chlorophyll-a concentration
- Add chlorophyll-a criteria for public water supply lakes or reservoirs – the lower of 9 μg/L (10 μg/L with a 10% margin of safety) or the long-term average of chlorophyll-a concentration
- Adopt RTAG's benchmark for chlorophyll-a (8 μg/L) as the criterion

Impact Considerations: Since most of the PWS reservoirs or lakes are located in rural areas, few wastewater dischargers lie above those lakes and reservoirs. Therefore, nonpoint sources are likely the major contributors of nutrients to these PWS reservoirs or lakes. The cost for controlling nutrient inputs from the non-point sources will depend on the size of the watershed, current management practices, and severity of the existing problem. However, the cost may be mitigated by cost-sharing programs available through the State Conservation Commission or the US Department of Agriculture's Natural Resources Conservation Service programs. Reduction in nutrient loads will likely reduce the operating costs of drinking water plants since fewer chemicals are needed to treat the water. In the long run, a local community may save a significant amount of money by not having to upgrade the drinking water plant in order to deal with nutrient enrichment issues. The benefits to the drinking water plants, consumers, and local communities will offset, and may outweigh the cost associated with nutrient reduction. Furthermore, adoption of criteria may provide warning to public water suppliers of threatening conditions developing in their source water, allowing for more orderly contingency planning to maintain service.

REFERENCES

1. Carmichael, W. W. (1994). "The Toxins of Cyanobacteria". Scientific American, January 1994, 78-86. http://colberganimation.com/PISdemo/TExFoGassets/Articles/TheToxinsofCyanobacteria.pdf

2. Carney, E. (2009). "Lake and Wetland Monitoring Program 2008 Annual Report". Kansas Dept of Health & Environment, Topeka, Kansas.

3. Dodds, W., E. Carney, and R. T. Angelo. (2006). "Determining Ecoregional Reference Conditions for Nutrients, Secchi Depth and Chlorophyll a in Kansas Lakes and Reservoirs". Lake and Reservoir Management 22 (2):151-159. http://www.kdheks.gov/befs/download/bibliography/NutrientReferenceConditions_WKD_2006.pdf

4. Downing, J.A, S. B. Watson, and E. McCauley. (2001). "Predicting Cyanobacteria Dominance in Lakes". Canadian Journal of Fisheries and Aquatic Sciences, 58:1905-1908. http://www.public.iastate.edu/~downing/tier%202/jadpdfs/2001%20CJFAS%201905-1908.pdf

5. Jones, R. A. and G. F. Lee. (1982). "Chlorophyll – A Raw Water Quality Parameter". Research and Technology, American Water Works Association Journal, September 1982, 490-494. http://www.gfredlee.com/WSWQ/ChlorophyllRawWater.pdf

6. Kansas Department of Health and Environment. (2008). "2008 Kansas Integrated Water Quality Assessment". http://www.kdheks.gov/befs/download/2008IR_040108FINAL.pdf

7. Kansas Department of Health and Environment. (2010). "Methodology for the Evaluation and Development of the 2010 Section 303(d) List of Impaired Water Bodies for Kansas". http://www.kdheks.gov/tmdl/download/2010_303_d_Methodology_Draft.pdf

8. Kansas Water Office, Kansas State University. (2008). "Sedimentation in Our Reservoirs: Causes and Solutions". http://www.kwo.org/Reports%20&%20Publications/KWRI_Book.pdf

9. Oklahoma Water Resources Board. (2005). "Justification for Chlorophyll-a Criteria to Protect the Public and Private Water Supply Beneficial Use of Sensitive Water Supplies". http://www.owrb.ok.gov/util/rules/pdf_rul/nutrient_criteria_sws_jd.pdf

10. Smith, V. H., F. deNoyelles, D. Graham, S. J. Randtke. (2001). "A Comparative Water Quality Study of Cheney Reservoir, Kansas". Final Report to the City of Wichita Water and Sewer Department. http://www.wichita.gov/NR/rdonlyres/E617DB85-D3F6-42C9-BE95-B39E3AE8A11A/0/A_Comparative_Water_Quality_Study_of_Cheney_Reservoir_Kansas_20d.pdf

11. Smith, V. H., J. Sieber-Denlinger, F. deNoyelles, Jr., S. Campbell, S. Pan, S. J. Randtke, G. T. Blain and A. A. Strasser. (2002). "Managing Taste and Odor Problems in a Eutrophic Drinking Water Reservoir". Lake & Reservoir Management, 18(4): 319-323

12. U.S. Environmental Protection Agency. (2002). "Summary Table for the Nutrient Criteria Documents". http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/files/sumtable.pdf

13. U.S. Environmental Protection Agency Region 7 Regional Technical Assistance Group. (2008). Summary Table for Nutrient Benchmarks. http://cpcb.ku.edu/progwg/html/assets/nutrientwg/2008Denver_R7lakesstreams.pdf

14. U.S. Environmental Protection Agency. (2000). "Nutrient Criteria Technical Guidance Manual – Lakes and Reservoirs". http://www.epa.gov/waterscience/criteria/nutrient/guidance/lakes/lakes.pdf

15. Walker, W.W. (1983). "Significance of Eutrophication in Water Supply Reservoirs". Research and Technology, American Water Works Association Journal, January 1983, 38-42. http://wwwalker.net/pdf/awwa.pdf

16. Walker, W.W. (1985). "Statistical Bases for Mean Chlorophyll-a Criteria". Lake & Reservoir Management, 1985, 57-62. http://wwwalker.net/pdf/chlacrit85.pdf