MISSOURI
DEPARTMENT OF
NATURAL RESOURCES

Rationale for Missouri Numeric Nutrient Criteria

November 2016

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1. Introduction

Nutrient pollution, or cultural eutrophication, is a pervasive and challenging issue that has impacted rivers, lakes, and oceans to varying degrees for decades. According to data queried from the US Environmental Protection Agency (EPA), approximately 20% of current stream, river, and lake impairments nationally are attributed to nutrients or the impacts of nutrient pollution[1]. Even though nutrients accounted for less than 10% percent of impairments in Missouri (MDNR 2016a), it is important to proactively develop protective procedures to guard against future degradation.

The primary mechanism of water quality impairment from nutrients is the growth of algae, which if left unchecked can result in several adverse consequences. These include reductions in dissolved oxygen caused by algal respiration and decay, unsightly blooms, reduced water transparency and, in some cases, the production of toxins by certain algae species, notably the blue-greens or cyanobacteria.

The parameters that may be used to gauge the extent of nutrient impairment can be divided into two general categories: causal and response variables. Causal variables include the two nutrients that most commonly limit algal growth, total nitrogen (TN) and total phosphorus (TP); response variables include measurements of algal growth and water clarity. The most common method of estimating algal biomass is chlorophyll-a (chlorophyll), which measures the green photosynthetic pigments produced by algae.

The relationship between nutrient inputs and algal response is often difficult to define due to the influence of environmental factors including, but not limited to, temperature, amount and intensity of sunlight, depth of water body, water mixing depth, nutrient ratios, grazing, and competition. Furthermore, hydrologic and watershed factors such as precipitation, runoff, area, residence time, and land use complicate these relationships. Hydrologic and watershed factors are significant influences in all waterbodies, but are of particular importance to the water quality of rivers and reservoirs.

The majority of Missouri's lentic systems that are used for recreation and as a drinking water supply are man-made reservoirs. These water bodies differ from natural lakes in a number of ways that influence nutrient inputs and the response of algal growth relative to those inputs. These differences include: hydrology (water residence time), coupling with the watershed, sediment load, water level fluctuations, shoreline length, and potential for erosional inputs (Kalff 2002).

An additional complicating factor in setting nutrient criteria is that suitable trophic conditions for supporting the various designated uses do not coincide, and are often at odds with each other. In particular, support of aquatic life depends in many situations on a relatively high availability of nutrients and chlorophyll to supply the food chain (Michaletz et al. 2012; Downing & Plante

[1] US Environmental Protection Agency. Assessment and Total Maximum Daily Load Tracking and Implementation System (ATTAINS). (n.d.). Retrieved September 9, 2016, from https://www.epa.gov/waterdata/assessment-and-total-maximum-daily-load-tracking-and-implementation-system-attains

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1993; Ney 1996). In contrast, suitability of lake waters for drinking water supplies is favored by lower nutrient and chlorophyll content, which reduces impacts or risks associated with increased turbidity and the production of algal toxins (Falconer, et al. 1999; Knowlton & Jones 2003).

Two nutrient compounds are regulated by existing water quality standards: total ammonia-nitrogen is regulated due to its toxicity potential to aquatic life and nitrate-nitrogen is regulated due to drinking water supply impacts. However, TN and TP criteria have only been approved for a limited set of Missouri waterbodies.

In August 2009, the Missouri Department of Natural Resources (MDNR) adopted statewide reservoir numeric nutrient criteria for TN, TP, and chlorophyll. At the time, no other state in the country had statewide lake/reservoir numeric nutrient criteria for all three parameters. Missouri's 2009 criteria development approach was based primarily on hydrological factors, including depth (as approximated by dam height), hydraulic residence time, and watershed characteristics, as these factors have been shown to significantly influence Missouri reservoir water quality (Jones et al. 2011, Jones et al. 2008b).

Although the EPA supports the adoption of nutrient criteria, particularly for both causal and response variables, they denied approval of a substantial part of the rule. In their disapproval letter, EPA (2011) concluded that the proposed criteria

1) Were not based on sound, scientific rationale because the rule package did not include the data and other necessary information to allow others to independently reproduce the values, and
2) The approach failed to demonstrate that the proposed criteria values were protective of designated uses as outlined in 40 CFR 131.6(b).

EPA (2011) suggested that when resubmitting the numeric nutrient criteria, MDNR should include any raw data and statistical analyses used to develop the values. EPA also suggested that MDNR develop a rationale using multiple lines of evidence to develop more robust set of numeric nutrient criteria, regardless of whether or not a similar, hydrologic-based approach was used.

In response to EPA objections, MDNR convened a stakeholder process to address EPA's comments and revise Missouri's reservoir numeric nutrient criteria. In September 2011, the stakeholder group met to begin discussions. The stakeholders consisted of diverse representatives from MDNR, municipalities, agricultural groups, environmental groups, consultants, and other public agencies, the Missouri Department of Conservation (MDC), the University of Missouri (MU), and EPA. Jones Aquatic Consulting, LLC, also served under contract with MDNR to provide technical input in the development of recommended criteria. Over the course of the next several years, the stakeholder group met periodically in an effort to assist MDNR in developing scientifically defensible reservoir numeric nutrient criteria.

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MDNR considered input from the stakeholder group and decided on an approach that provided for the most scientifically defensible protections for the underlying designated uses. That approach, which is detailed throughout this document, does the following:

- Targets aquatic life and drinking water protections,
- Focuses on the biological response,
- Considers ecoregional differences and existing trophic levels, and
- Supplements criteria with conservative screening values coupled with weight of evidence analysis to better support determinations of impairment.

MDNR reviewed several different sources of information to derive reservoir numeric nutrient criteria. These sources included

- Recent numeric nutrient criteria development activities in other states,
- Missouri-specific reservoir water chemistry data,
- Missouri water distribution system sampling and compliance data,
- Literature reviews, and
- Expert opinion.

This report is organized into seven sections (including this introduction). A brief description of the subsequent six sections is as follows:

Policy Considerations – This section addresses policy issues raised by EPA during the stakeholder process related to 40 CFR §§ 130.3 and 131.11.

National Overview – This section provides a national overview of reservoir nutrient criteria.

Missouri Nutrient Data – This section describes the Missouri specific reservoir nutrient and disinfection byproduct data used in this report.

Water Quality Patterns in Missouri - This section assesses relationships and patterns of Missouri reservoir data with respect to nutrients, microcystins, and disinfection byproducts.

Criteria Development - This section describes how reservoir numeric nutrient criteria were developed for aquatic life and drinking water protections.

Gray Zone Assessment Decision Framework - This section describes the screening value and weight of evidence analysis framework for further evaluating attainment when impairment status remains unclear.

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2. Policy Considerations

Throughout the stakeholder process, MDNR sought technical and policy feedback on draft reservoir nutrient criteria from EPA. MDNR shared draft criteria with EPA during the stakeholder process and in conference calls held on February 29 and March 21, 2016. Consistent with criteria recommended within this document, the draft criteria shared with EPA:

- Targeted aquatic life and drinking water protections,
- Focused on the biological response variable chlorophyll, and
- Supplemented criteria with screening values and weight of evidence analysis.

EPA commented on MDNR's draft criteria during the stakeholder process and later formalized these comments in a letter dated May 12, 2016. EPA's letter expressed that "[p]ursuant to 40 CFR §§ 130.3 and 131.11, water quality criteria must be based on a sound scientific rationale and must contain sufficient parameters to protect the designated use." MDNR's approach for addressing EPA policy issues related to 40 CFR §§ 130.3 and 131.11 are addressed below.

2.1. Protections for the Most Sensitive Use

Section 131.11(a) of the Code of Federal Regulations requires States to adopt water quality criteria to protect designated uses. For waters with multiple designated uses, the criteria shall support the most sensitive use. All reservoirs in Missouri's Water Quality Standards (WQS) regulation are designated for aquatic life protection (AQL), human health protection (HHP), whole body contact recreation (WBC), secondary contact recreation (SCR), and livestock and wildlife watering (LWW). A number of additional reservoirs are also designated for drinking water supply (DWS) (10 CSR 20-7.031). EPA has suggested that MDNR's scope of recommended designated use protections, which is currently limited to AQL and DWS, does not consider all uses and may not support the most sensitive use.

The decision to limit the scope of designated uses to AQL and DWS was made through a series of stakeholder discussions that were part of the Department's Water Protection Forum. It was decided through this forum that the focus of revised numeric nutrient criteria development would concentrate on the AQL and DWS designated uses, as sufficient data and information exist from which to establish criteria for these designated uses. Research and information continue to develop at the national level with respect to nutrient impacts and criteria for the protection of recreational uses. Missouri intends to pursue numeric nutrient criteria for recreational designated uses during a future rulemaking. This will allow studies currently underway by EPA and others on the effects of cyanotoxins on recreational uses to mature, and for the state to conduct user perception surveys of algae by the recreating public.

2.2. Criteria Parameters

EPA has long recommended states adopt both *causal indicators* (the nutrients introduced to the system – especially nitrogen and phosphorus) and *response indicators* (those measures of biotic productivity and activity reflecting the enrichment of the system including chlorophyll) for nutrient criteria (EPA 2000). MDNR's focus on the biological response variable chlorophyll has subsequently raised comments by EPA. Federal water quality standard (WQS) regulations at 40 CFR 131.11 do not explicitly specify whether both causal and response indicators are

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required, but require that "[s]uch criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use." It also requires such criteria be based on "scientifically defensible methods."

While algal biomass, as estimated by chlorophyll, is correlated to TP and TN concentrations, MDNR elected to focus on the biological response variable chlorophyll. MDNR's decision to focus on chlorophyll is based on natural variation between causal and response variables, and ultimately the designated use, as there are multiple confounding factors. The link between nutrient sources and designated uses involves multiple steps (Figure 2-1). Whereas traditional stressors are typically directly toxic, nutrient over-enrichment effects are systemic. Additionally, biological responses to nutrients can vary based on site-specific factors. For example, flushing rates, which vary between reservoirs, may limit the impact of phosphorus loading on water column concentrations, which ultimately stimulate phytoplankton production (EPA 2000). Grazing pressure and turbidity also serve as confounding factors.

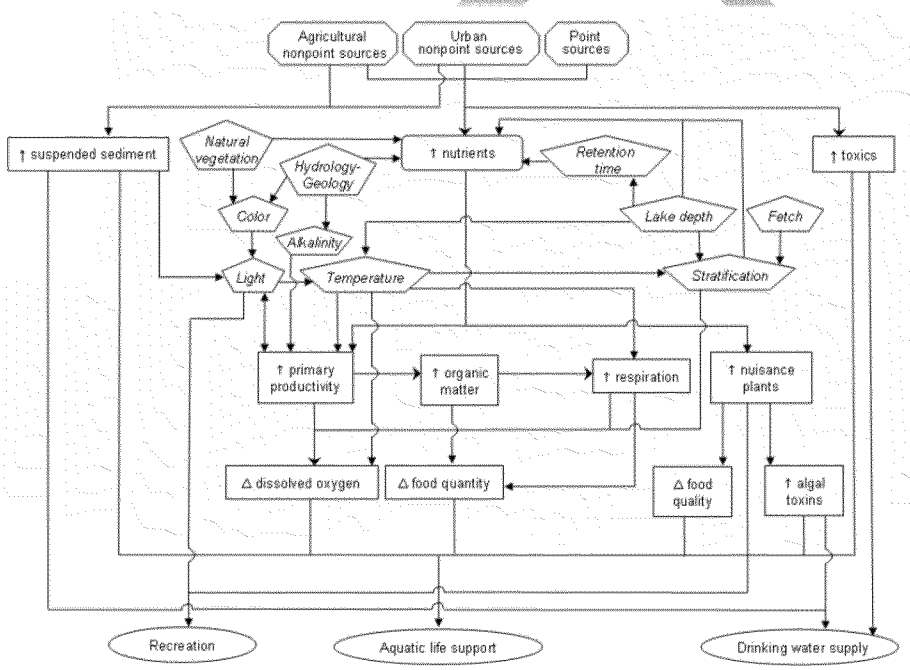

Figure 2-1. Conceptual Nutrient Model Diagram for Lakes from EPA 2010.

Chlorophyll is also more closely related than TN and TP to those factors that directly impact aquatic life and drinking water designated uses, such as low dissolved oxygen and algal toxins. Additionally, since chlorophyll integrates the effects of TN and TP, it effectively serves as a site-specific indicator of trophic conditions. For these reasons Missouri has chosen to focus on the biological response variable chlorophyll.

2.3. Purpose of Screening Values

MDNR is recommending the use of conservative screening values for TN, TP and chlorophyll to supplement chlorophyll criteria in evaluating use attainment. While not criteria, screening values can be used to define the "gray zone" where impairment status remains unclear without

a further weight-of-evidence evaluation. Results of this "gray zone" assessment can be used to identify reservoirs that are either impaired or those that should receive additional measures to prevent impairments from occurring. EPA's primary comment regarding the use of screening values is that this appears to offer no protection beyond that provided under the state's long-standing general (narrative) water quality criteria. Specifically, EPA suggested that screening values are reactive rather than protective, since actual impairments are required prior to listing as impaired.

Screening values are not intended to be used as criteria pursuant to the requirements of 40 CFR §§ 130.3 and 131.11. Rather, screening values are more similar to other numeric thresholds, such as sediment probable effect levels, that are included in Missouri's listing methodology document (LMD) but are not criteria. Screening values are intended to supplement chlorophyll criteria and provide additional protections to Missouri reservoirs as follows:

- Screening values provide a quantitative metric for flagging reservoirs in need of additional evaluation. Reservoir impairments that might otherwise go unnoticed are more likely to be identified and corrective measures can be taken earlier. This process also reduces the likelihood of false positive impairment decisions that would direct Missouri's limited resources away from restoration priorities.
- Screening values are set at levels considerably lower than the criteria identified as protective of aquatic life and drinking water supply.
- Exceedance of screening values will also trigger a weight of evidence analysis to identify reservoirs that are impaired or expected to become impaired over the next five-year time horizon. As appropriate, these reservoirs may be assigned to Category 5 of MDNR's Assessment, Listing, and Reporting categories (MDNR 2016a) to have a TMDL completed. Alternatively, these reservoirs may be assigned to Categories 4B or 5 Alt, which could trigger evaluation of appropriate, multi-disciplinary watershed management actions that can be implemented over time to prevent degradation of water quality. MDNR will collaborate with other state agencies and stakeholders to establish these actions.

Further information and details on screening values is provided in **Section** Error! Reference source not found..

2.4. Protections for a Wide Variety of Biota

Missouri's designated aquatic life use definitions include protections for a "wide variety" of biota and federal regulations at Section 131.11(a) require that criteria protect the designated use. Like other states such as Virginia, MDNR has taken the approach that the status of the recreational fishery can be considered as an indicator of the reservoir's suitability for aquatic life (Virginia Water Resources Research Center 2005). However, EPA commented during the stakeholder process that this approach may not be protective of a "wide variety" of biota. Based on EPA feedback, MDNR conducted a closer evaluation of nutrient impacts on aquatic biota including mussels and non-sport fish species (see **Section 6**). MDNR findings indicate that the

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health of sport fish populations can be interpreted as an indicator of overall ecosystem health and the presence a "wide variety" of aquatic biota, as defined in the existing regulations.

2.5. Drinking Water Protections

MDNR's draft drinking water supply criteria were based on protections against microcystins, which is the most common known set of toxins produced by cyanobacteria within algal blooms (Falconer et al. 1999). EPA commented that the proposed drinking water criteria and suggested MDNR consider:

- available scientific reports addressing the effects of eutrophication on the prevalence of disinfection byproducts (DBPs) and taste/odor producing compounds in finished drinking water, and
- the potential effects of algal toxins on sensitive human subpopulations (e.g., children under six years of age).

Based on EPA's comments, extensive additional analyses were conducted on Missouri specific DBP data. However, no reliable quantifiable link between chlorophyll and DBPs could be identified. The development of DBPs in water treatment plants has been directly linked to dissolved organic carbon (DOC), but results of studies attempting to link chlorophyll, DBPs and DOC have been mixed. DOC levels and composition in Missouri reservoirs are generally controlled by hydrology and watershed characteristics, rather than algal biomass.

In response to EPA's comment about protecting sensitive human subpopulations (e.g., children under six years of age), MDNR's is recommending chlorophyll criteria based EPA's recommended ten-day health advisory (HA) value for microcystins for bottle-fed infants and young children of pre-school age. Furthermore, targeted protections are based on the raw water supply and do not take into account removal during the treatment process. This provides an extra level of protection as drinking water supply is defined in Missouri's water quality standards as "Maintenance of a raw water supply which ***will yield potable water after treatment by public water treatment facilities***" (emphasis added).

As an added measure of protection, MDNR is also recommending screening values for drinking water supplies. Recommended screening values are based on a chlorophyll level of 10 µg/L, which has been linked, albeit inconsistently, to the occurrence of algal blooms and taste and odor issues. The screening and associated weight of evidence approach also takes into account other factors such as concentrations of microcystin and cylindrospermopsin algal toxins and DBPs in drinking water systems during the critical periods of the second and third quarter, which is more conservative than the 4-quarter average currently used for purposes of Safe Drinking Water Act compliance monitoring.

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3. National Overview

Missouri conducted a review of lake nutrient criteria from around the country to help development of recommended criteria. Although EPA has stressed the need for adoption of numeric nutrient criteria on several occasions over the past few decades, currently only half of the states have either partial or statewide EPA-approved criteria (**Table 3-1**). Of those states with EPA-approved criteria, most include criteria for chlorophyll and/or TP. Only eight states have EPA approved criteria for TN.

EPA-approved lake nutrient criteria in a number of states target the response variable chlorophyll as the primary indicator of nutrient enrichment. States that have adopted lake or reservoir chlorophyll criteria as part of a response variable approach are described below.

- Alabama – Alabama applies chlorophyll criteria on a lake-specific basis, but lacks TP or TN criteria as described in the Alabama Administrative Code.

  > "The response to nutrient input may vary significantly lake-to-lake, and for a given lake year-to-year, depending on a number of factors such as rainfall distribution and hydraulic retention time. For this reason, lake nutrient quality targets necessary to maintain and protect existing uses, expressed as chlorophyll *a* criteria, may also vary lake-to-lake. Because the relationship between nutrient input and lake chlorophyll *a* levels is not always well-understood, it may be necessary to revise the criteria as additional water quality data and improved assessment tools become available" (AAC 335-6-10.11).

- Maryland – Maryland applies chlorophyll criteria to their Public Water Supply reservoirs, but has no reservoir criteria for TP or TN (COMAR 26.08.02.03-3).

- Minnesota – In Minnesota, an exceedance of TP ***and either*** the chlorophyll or Secchi disk transparency standard is required to indicate an impaired condition (Minnesota Administrative Rules 7050.0222).

- North Carolina – North Carolina applies chlorophyll criteria to Class C lakes and reservoirs, but has no criteria for TP or TN (15A NCAC 02B .0200).

- Oregon – Oregon applies chlorophyll criteria to all natural lakes to protect for nuisance phytoplankton growth. Lake TP criteria are currently limited to Clear Lake (Oregon Administrative Rules 340-041-0019).

- Texas – Texas applies site-specific chlorophyll criteria to reservoirs. TP and TN criteria do not apply (Texas Water Quality Standards §307.10).

- Virginia – Virginia applies site-specific chlorophyll criteria to reservoirs. TP criteria only apply if the reservoir received algicide treatment during the monitoring and assessment period (9 VAC 25-260-187).

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Table 3-1. States with EPA Approved Lake Nutrient Criteria.

State	Distribution	Chlorophyll (µg/ L)	TP (µg/ L)	TN (µg/ L)
Alabama	Partial	5-27	--	--
Arizona	Partial	30-50	115-160	1,600-1,900
California	Partial	0.6-1.5	8-300	100-4,000
Colorado	Statewide*	8-20	25-83	426-910
Florida	Statewide	6-20	10-160	510-2,230
Georgia	Partial	5-27	0.5-5.5 lbs/acre-ft/yr	3,000-4,000
Illinois	Partial	--	50	--
Maryland	Partial	10-30	--	--
Minnesota	Statewide	3-30	12-90	--
Missouri	Partial	1.5-11	7-31	200-616
Nebraska	Partial	8-10	40-50	800-1,000
Nevada	Partial	5-45	25-330	250-1,000
New Jersey	Statewide	--	50-100	--
New Mexico	Partial	--	100	--
North Carolina	Statewide	15-40	--	--
Oklahoma	Partial	10	14-17	--
Oregon	Statewide†	10-15	241 lbs/yr	--
Rhode Island	Statewide	--	25	--
South Carolina	Partial	10-40	20-90	350-1,500
Tennessee	Partial	18	--	--
Texas	Partial	5-20	--	--
Vermont	Partial	--	10-54	--
Virginia	Partial	10-60	10-40	--
West Virginia	Statewide	10-20	30-40	--
Wisconsin	Statewide	--	5-40	--

Source: https://www.epa.gov/nutrient-policy-data/state-development-numeric-criteria-nitrogen-and-phosphorus-pollution

*Colorado labeled these values "interim" to emphasize its intent to undertake further review of the evolving science regarding nutrients before applying numerical standards broadly to surface waters throughout the state (EPA letter dated July 14, 2016 regarding EPA Action on Revisions to Regulation #31 Regarding Nutrients).

†Chlorophyll criteria apply statewide and TP criteria applies only to Clear Lake.

Other states have also adopted a response variable approach with additional weight of evidence procedures. For example, Arizona applies a weight of evidence approach contingent on chlorophyll values for identifying violations of narrative nutrient standards for lakes and reservoirs (**Table 3-2**).

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Table 3-2. Arizona Weight of Evidence Approach for Identifying Violations of the Narrative Nutrient Standard for Lakes/Reservoirs.

Primary Decision Criteria	Weight of Evidence Supporting Criteria
1. The mean chlorophyll result is above the upper value in the threshold range	None needed.
2. The mean chlorophyll result is within the range, **and**	The mean blue-green result is at or above either blue-green threshold.
3. The mean chlorophyll result is within the threshold range, and there is additional evidence o f nutrient-related impairments **such as**	Exceedances of DO or pH, **or** Fish kills attributed to DO or pH exceedances or ammonia toxicity, **or** Fish kills or other aquatic organism mortality attributed to algal toxicity, **or** Secchi depth below the lower threshold value, **or** Nuisance algal blooms present in the lacustrine portion of the lake or reservoir, **or** The upper threshold for TKN, TP, or TN is exceeded.
4. The mean chlorophyll result is within or below the range, but the lake is a shallow lake (mean depth less than 4m), **and**	Submerged aquatic vegetation is greater than 50% of the aerial extent of the lake bottom, **and** there is greater than 5 mg/L swing in diel (24-hr) DO measured within the photic zone (depth of light penetration supporting algal or plant growth).

Source: Adapted from R18-11-108.03 – Narrative Nutr ient Criteria for Lakes and Reservoirs.
Note: EPA has not acted on R18-11-108.03.

Similar to Arizona, Maine has proposed a weight of evidence approach based on response indicators for its lakes and reservoirs (Chapter 58 3 Nutrient Criteria for Surface Waters (06-096 CMR 583 – Draft 6/12/2012). Under the Maine approa ch, compliance is determined by TP and any number of response variables including chloroph yll, Secchi depth, patches of bacteria and fungi, pH, dissolved oxygen, and aquatic life crite ria. An affirmative impairment decision would require exceedances of both the TP criterion and a response variable. This approach is not dissimilar to other states that take a response var iable approach such as those previously described.

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4. Missouri Nutrient Data

Missouri used a robust dataset comprised of nutrient related measurements from over 200 reservoirs throughout the state to support the development of reservoir nutrient criteria. This dataset includes over 32,000 records of chlorophyll and nutrient data, making it one of the largest datasets used for criteria derivation. The data originated from various University of Missouri (MU) programs and special studies, but most notably from the Lakes of Missouri Volunteer Monitoring Program (LMVP) and the Statewide Lake Assessment Program (SLAP). The MU Limnology Laboratory, within the School of Natural Resources, oversees both of these programs, which are funded under CWA Section 319.

Both LMVP and SLAP collect water samples from Missouri's reservoirs for a variety of nutrient related measurements including algal chlorophyll, total nitrogen, total phosphorus, volatile and nonvolatile solids, and transparency (Secchi depth). The number of monitored reservoirs has varied over time, but LMVP samples approximately 66 reservoirs between four and eight times each year, whereas SLAP samples approximately 75 reservoirs four times each summer. SLAP employs students as field technicians to collect water samples and make field measurements while LMVP relies on citizen volunteers. Laboratory analyses for both programs are performed by the MU Limnology Laboratory. Monitoring protocols also differ between the two programs with respect to the length of the monitoring season, number of samples collected within the season, and the number of sites on individual water bodies. However, most all the data were collected during the summer growing season (May through September). Data collected outside of the summer growing season were not included in the database.

The Missouri dataset also includes microcystins (known algal toxins) samples from approximately 160 different Missouri reservoirs. The vast majority of the microcystins data were collected from 2004 through 2006 through different programs managed by the MU Limnology Laboratory. Microcystin and nutrient data from EPA's National Lake Assessment (NLA) were also evaluated.

In addition to data from MU and NLA, MDNR assessed disinfection byproduct (DBP) data collected as part of Missouri's Safe Drinking Water Program. The DBP dataset included both total trihalomethanes (TTHM) and total haloacetic acids (HAA5) data collected from 39 public water suppliers that use reservoirs as source water. The DBP dataset also included alkalinity and total organic carbon (TOC) data collected from drinking water intakes. Reservoirs used as source water were identified and linked to the DBP data in a database to facilitate analysis with the nutrient dataset. These data were supplemented with additional DBP data collected in 2004 as part of a special study by MU. In the study, MU collected TTHM forming potential (THMFP), dissolved organic carbon (DOC), UV_{254}, specific ultra-violet absorbance (SUVA), and chlorine demand at 76 reservoirs across the state during one summer.

Data from the MU Limnology Laboratory, the NLA, and MDNR's Safe Drinking Water program were compiled into a database for analysis. Data from the MU Limnology Laboratory was limited to sample sites located near the reservoir dam and excluded sites located in reservoir arms. Reservoirs were attributed in the database for geographic coordinates, size, Missouri WBID, and ecoregion. The dataset included over 67,000 records from over 200 Missouri

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reservoirs spanning approximately 15 years (1999-20 14). The DBP data included over 32,000 records spanning approximately 11 years (2004-2015).

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5. Water Quality Patterns in Missouri

Data from the nutrient database were reviewed to characterize water quality conditions and patterns with respect to nutrients, chlorophyll, microcystin, and DBPs across the state of Missouri. Unless otherwise noted, analyses were limited to data collected during the summer growing season (May through September) and years with at least four samples. Results from this evaluation are presented in the sections that follow.

5.1. Ecoregional Trophic Levels

Trophic state refers to the biological production, both plant and animal life, that occur in a lake or reservoir. All trophic classification is based on a division of the trophic continuum, of which there is no clear delineation of divisions (Carlson 1977). Reservoirs with low nutrient concentrations and low levels of algal production are referred to as oligotrophic, while water-bodies with high nutrient levels and productivity are termed eutrophic. Mesotrophic reservoirs fall in between oligo- and eutrophic on this continuum. Hypereutrophic reservoirs fall on the extreme high end of this continuum, and are characterized by excessive nutrients and are extremely productive in terms of algal growth. In these systems algal blooms may be frequent and severe. These blooms can lead to oxygen deficits when the bloom dies off and bacterial decomposition of the organic matter is maximized. Low oxygen concentrations can in turn negatively affect the aquatic life within the reservoir, causing reduced reproduction or lethality depending on the duration and intensity of dissolved oxygen decrease. Trophic state thresholds proposed by Jones et al. (2008a) for Missouri reservoirs are presented below in **Table 5-1**.

Table 5-1. Trophic State Thresholds for Missouri Reservoirs from Jones et al. 2008a. Values in parentheses represent the range of chlorophyll values reported for each trophic category worldwide (Nurenburg 1996).

Trophic State	Upper Limit of Chlorophyll for Trophic State (µg/L)
Oligotrophic	3 (2 – 4.3)
Mesotrophic	9 (5 – 10)
Eutrophic	40 (18 – 40)
Hypereutrophic	>40

The trophic state classification of eutrophic should not be confused with the concept of cultural eutrophication. Eutrophic is one of the four categories used by scientists and lake managers to place a water body within the productivity gradient. These categories are meant to be descriptive but not subjective in nature. Cultural eutrophication, on the other hand, is the process in which a water body becomes more productive due to human influences within the watershed. When cultural eutrophication causes a harmful change in water quality, it is considered to be undesirable. Also, cultural eutrophication can occur in all water bodies including oligotrophic systems.

There is a relationship between geographic location and the occurrence of trophic conditions in Missouri reservoirs (Jones & Knowlton 1993, Jones et al. 2008a, Jones et al. 2009). Reservoirs in the northern and western parts of the state (Central Dissected Plains and Osage Plain ecoregion) tend to be more eutrophic and hypereutrophic, while reservoirs in the Ozark Highlands ecoregion are generally mesotrophic and oligotrophic. Reservoirs in the Ozark

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Border ecoregion have a range of trophic states tha t are generally lower than the Plains ecoregion, but higher than the Ozark Highlands (Jon es et al. 2008a). Regional patterns are apparent when evaluating long-term average chloroph yll concentrations calculated from the updated Missouri dataset (Figure 5-1). These regio nal differences in water quality reflect geological, topographical and cultural land use dif ferences across the state (Jones et al. 2008a, Jones et al. 2008b).

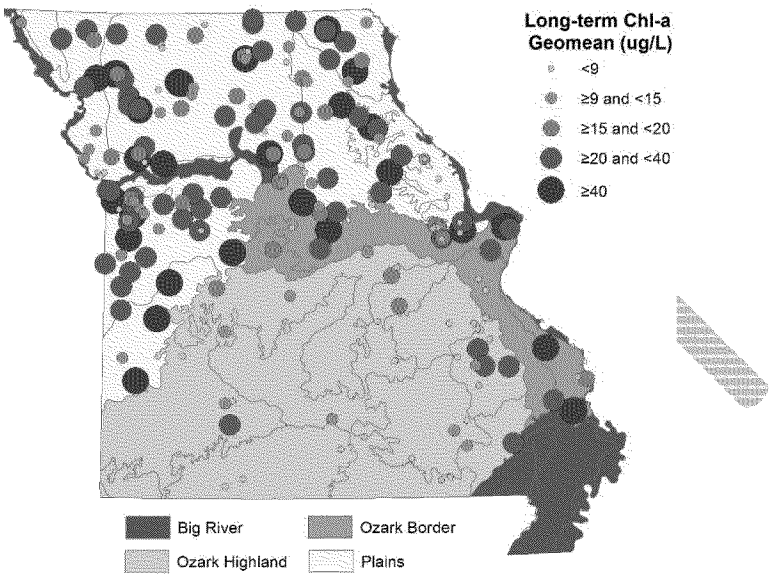

Figure 5-1. Long-Term Chlorophyll Geometric Means f or Missouri Reservoirs.

Regional differences in trophic conditions are also apparent when seasonal average data are evaluated (Figure 5-2). In the Plains ecoregion, the interquartile range (25th to 75th percentile) of growing season chlorophyll levels are within the eutrophic zone of 10 to 40 µg/L. Growing season chlorophyll levels in the Ozark Border ecore gion are less than those found in the Plains ecoregion, as the interquartile range includes both the mesotrophic and eutrophic zones. Growing season chlorophyll levels are lowest on the Ozark Highlands where the median value of 5.8 µg/L is in the mesotrophic zone, with the in terquartile range spanning from the oligotrophic to eutrophic zones.

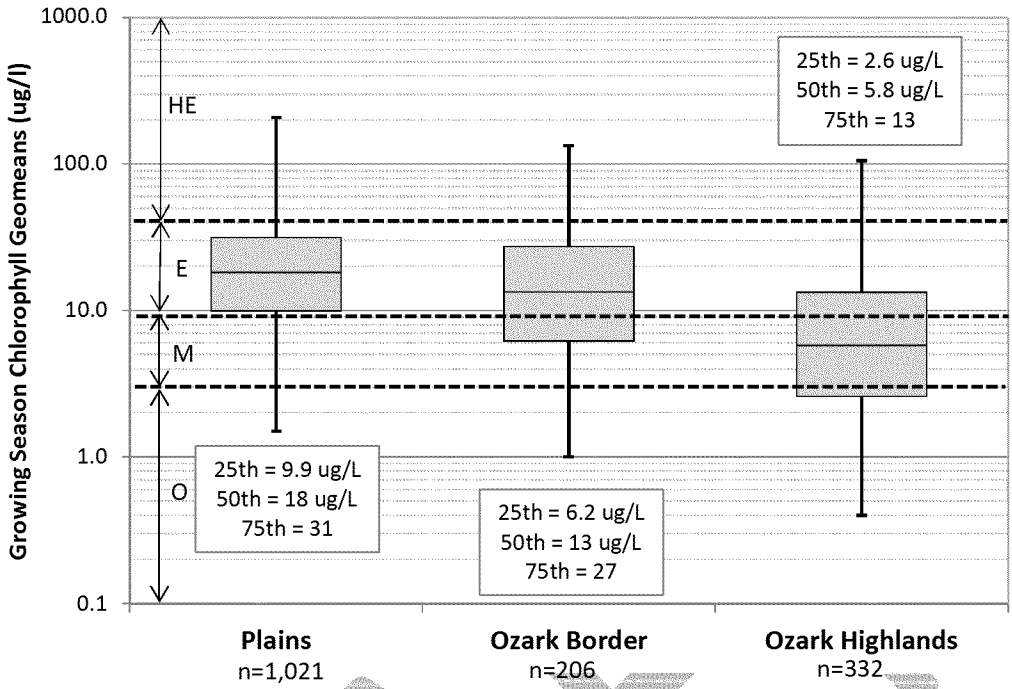

Figure 5-2. Distribution of Growing Season Chlorophyll Geometric Means by Ecoregion for Missouri Reservoirs.

5.2. Nutrients

Empirical links between chlorophyll and TP have been extensively studied and are well defined (Dillon and Rigler 1974; Jones and Bachmann 1976), particularly in Missouri (Jones et al. 1998; Jones and Knowlton 2005; Jones et al. 2008a; Jones et al. 2008b), and therefore are not discussed here in detail. In Missouri reservoirs, TP accounts for 79% of the cross-system variation in chlorophyll. There is a 5-fold range of chlorophyll to TP ratios among long-term means indicating substantial variation in how the response variable, chlorophyll, relates to the causal variable, TP. Residual variation is likely due to reservoir-specific conditions including sediment influx (Jones and Knowlton 2005).

Relationships between chlorophyll, TN, and TP are evident in the Missouri data (Figure 5-3). The equations are expressed as ln-ln as this serves to normalize the data and provides the best basis for describing the relationship among these variables. The lognormal regressions yield R^2 values for TP ranging from 0.61 to 0.85 depending on the ecoregion. R^2 values for TN are slightly less, ranging from 0.56 to 0.79. Equations were generated from the regression analysis to estimate chlorophyll levels as a function of TP and TN.

Although chlorophyll data from Missouri reservoirs are strongly correlated with both TP and TN, studies suggest TN accounts for little variation and unlikely serves as the limiting nutrient. For example, Jones and Knowlton (2005) show that in stepwise multiple regressions TP accounts for 60% of chlorophyll variation, while TN accounts only for an additional 1.8% of the variation. They further note that the relatively small variation in long-term average chlorophyll to TP ratios

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suggests that if nitrogen limitation occurs, it does not frequently depress biomass below expectations based on TP.

While **Figure 5-3** indicates a relationship between chlorophyll and both TP and TN, relationships between TP, TN and designated uses is less clear. As a measure of algal biomass, chlorophyll is more directly linked to aquatic life and recreational designated uses than either TP or TN. In addition to being one step removed from designated uses, the magnitude of the prediction intervals makes it difficult to precisely predict chlorophyll levels from TN and TP. This lack of precision makes TP and TN a less useful predictor of designated use attainment.

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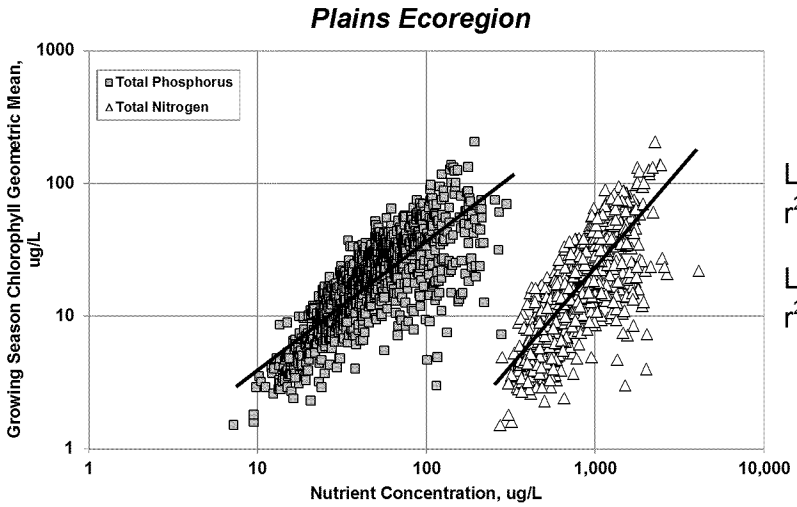
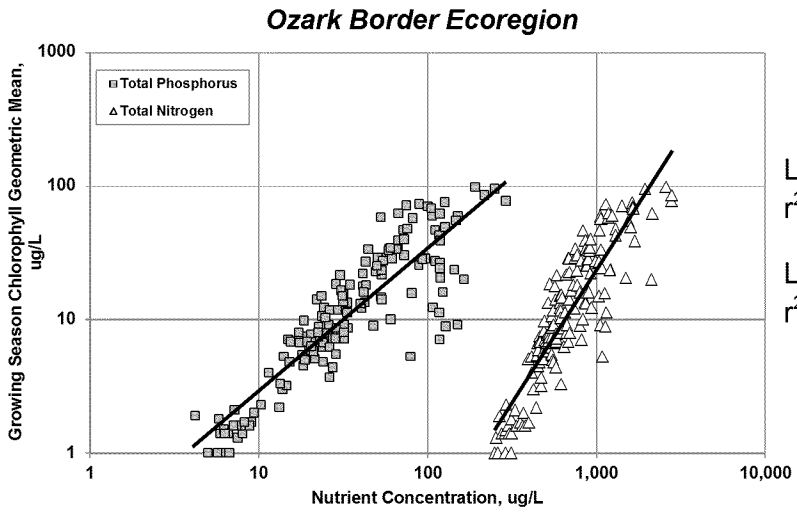


Plains Ecoregion

Ln Chlorophyll = 0.96 Ln TP – 0.85
r^2 = 0.61; n=975 (Eq. 1)

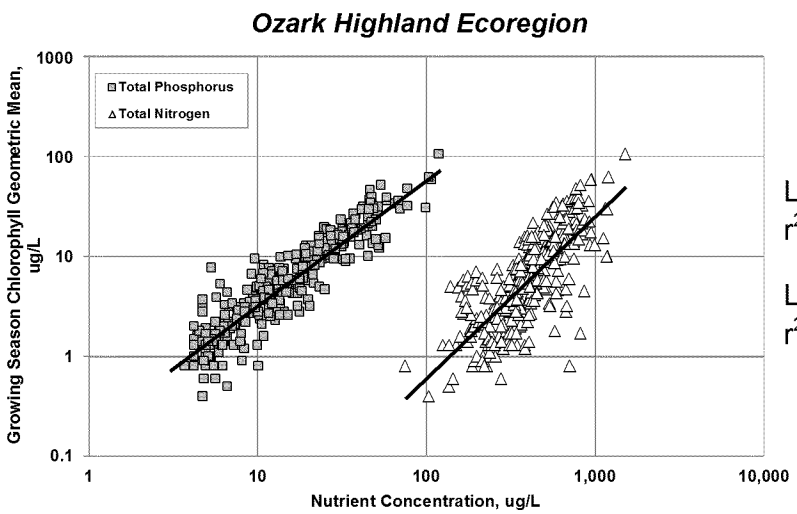
Ln Chlorophyll = 1.48 Ln TN – 7.08
r^2 = 0.56; n=976 (Eq. 2)



Ozark Border Ecoregion

Ln Chlorophyll = 1.08 Ln TP – 1.41
r^2 = 0.79; n=158 (Eq. 3)

Ln Chlorophyll = 1.99 Ln TN – 10.6
r^2 = 0.79; n=158 (Eq. 4)



Ozark Highlands Ecoregion

Ln Chlorophyll = 1.27 Ln TP – 1.70
r^2 = 0.85; n=332 (Eq. 5)

Ln Chlorophyll = 1.63 Ln TN – 8.01
r^2 = 0.58; n=332 (Eq. 6)

Figure 5-3. Relationships between Chlorophyll, Tota l Nitrogen, and Total Phosphorus in Three Missouri Ecoregions.

5.3. Temporal Variability

Scatter around the regression lines in Figure 5-3 demonstrates that factors other than nutrients influence algal response and resulting chlorophyll levels in Missouri reservoirs. These factors include physical, biological, and chemical attributes such as light limitation related to turbidity and algal self-shading, reservoir morphology, mixing status, hydraulic flushing rate [2], and zooplankton grazing (EPA 2000). In reservoirs specifically, factors related to hydrology substantially affect the variability in observed chlorophyll-nutrient relationships at any point in time.

Vollenweider (1975) showed that nutrient concentrations in reservoirs are directly related to inflow concentrations; as inflow concentrations increase, reservoir concentrations also increase. When these increases are coupled with high hydraulic flushing rates, reservoir nutrient concentrations are maximized (Welch and Jacoby 2004, **Figure 5-4**). In Missouri, in-reservoir nutrient concentrations effectively double when flushing rates increase from 0.25 to 2 times a year (Jones et al. 2008b). Jones and Knowlton (2005) further note that accounting for turbid inflow, as measured by increased non-algal seston levels, substantially decreases variability in chlorophyll-nutrient relationships. Turbidity has the effect of reducing chlorophyll:TP ratios due to poor light and high proportions of particulate, sediment-bound TP (Jones and Knowlton 2005).

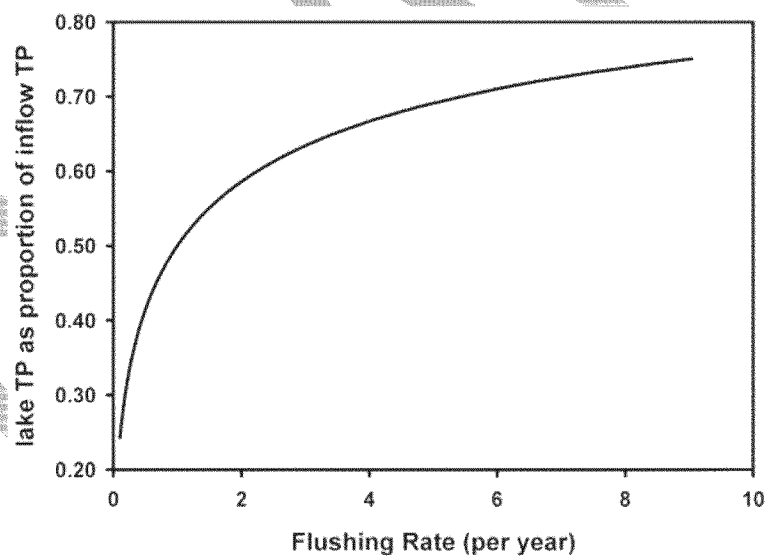


Figure 5-4. Estimated Relationship between In-Lake Total Phosphorus as a Proportion of Inflow TP to Flushing Rate from Welch and Jacoby 2004 as presented in Jones et al. 2008b.

[2] Flushing rate is the number of times that a reservoir's entire volume will be completely renewed in one year. Flushing rate is related to hydraulic residence time (reservoir volume divided by reservoir outflow). For example, a reservoir with a flushing rate of 2 would have a hydraulic residence time of 6 months.

The variability associated with these physical, biological, and chemical factors are not only apparent among reservoirs in Missouri, but also within specific reservoirs over time. For example, data collected from Lake of the Ozarks between 1999 and 2014 demonstrate the variation that can be exhibited between samples from the same reservoir (Figure 5-5). Chlorophyll results measured over the sampling period average approximately 11 µg/L but range from less than 2 to almost 45 µg/L.

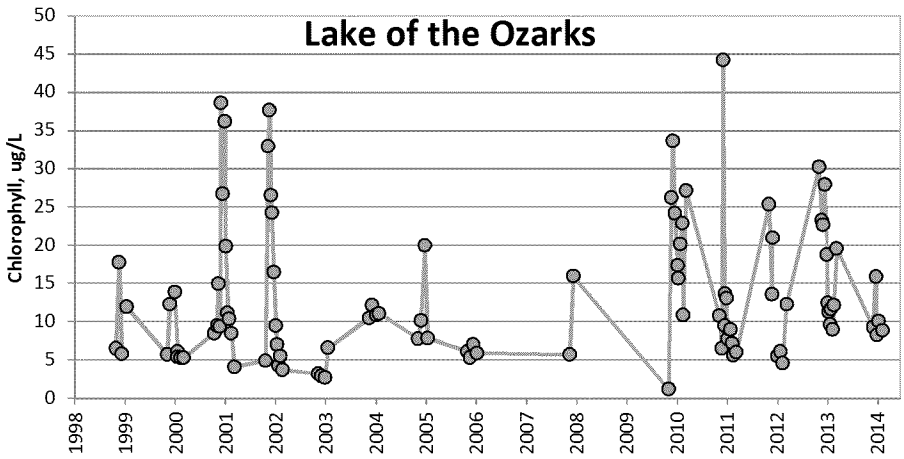


Figure 5-5. Discrete Chlorophyll Samples Collected from Lake of the Ozarks near the Dam between 1999 and 2014.

The impact of natural variability on observed chlorophyll and nutrient levels, empirical relationships, and trend detection has been studied extensively in Missouri reservoirs. Knowlton and Jones (2006a) found that seasonal average chlorophyll and nutrient levels in Missouri reservoirs can vary from year to year by a factor of 3 or more. Furthermore, they found that single season estimates incorrectly approximated long-term average values nearly 20% of the time (Knowlton and Jones 2006a). As a result of these findings, the researchers suggest using long-term average, rather than single season average concentrations, to evaluate the trophic status of reservoirs. These results demonstrate that applying criteria on an annual basis is a conservative management approach.

It is obvious from both scientific literature and the Missouri dataset that in addition to nutrients, physical, chemical, and biological factors play an important role in determining reservoir chlorophyll concentrations. These factors introduce substantial uncertainty into the process of investigating trophic status and must be considered when evaluating or applying empirical chlorophyll-nutrient relationships (Figure 5-3). To best reflect the current state of the science and our understanding of chlorophyll-nutrient relationships in Missouri reservoirs, the criteria development process must include provisions to account for uncertainty related to natural temporal variability.

5.4. Microcystins Occurrence and Levels

Microcystins are the most common, known toxins produced by cyanobacteria within algal blooms (Falconer et al. 1999). As hepatoxins, microcystins have been documented to pose

chronic and acute health risks to livestock, pets, and humans. Approximately 100 microcystin congeners exist, which vary in toxicity. Since microcystin-LR is one of the most potent cogeners and has the majority of toxicological data on adverse health effects, microcystin-LR is used a surrogate for all microcystins in health advisories (EPA 2015). The World Health Organization (WHO) has adopted a provisional guideline value for lifetime exposure of 1.0 µg/L for microcystin-LR[3] (*Id.*). More recently, the EPA has issued a Health Advisory (HA) for microcystins focused on drinking water as the primary source of exposure. The EPA recommended microcystin ten-day HA value for bottle-fed infants and young children of pre-school age is 0.3 µg/L and 1.6 µg/L for school children through adults (*Id.*). These guidelines are for treated drinking water and not the raw source water.

Microcystins have generally been found at low levels in Missouri reservoirs. These levels were compared to the health advisories for finished drinking water. Based on data collected between 2000 - 2006 from 214 reservoirs, microcystin levels were non-detect 80% of the time (1,331 non-detects out of 1,658 samples) (

Table 5-2 and Figure 5-6). Only 8% of the microcystin samples exceeded 0.3 µg/L and only 3% exceeded 1 µg/L.

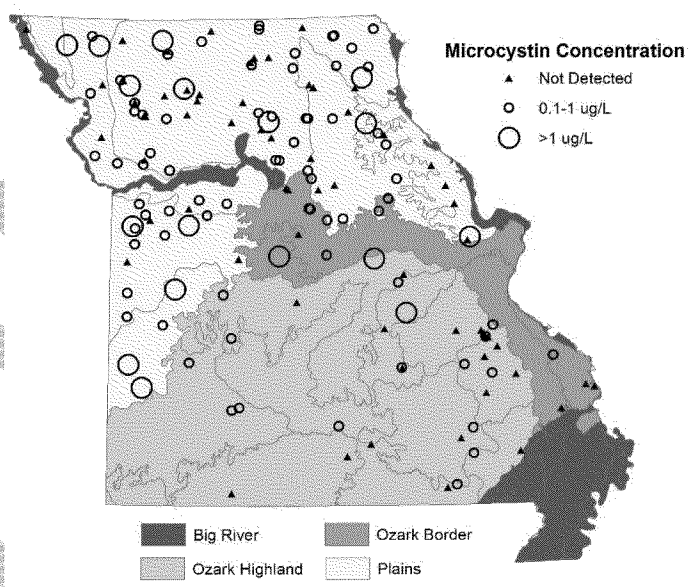


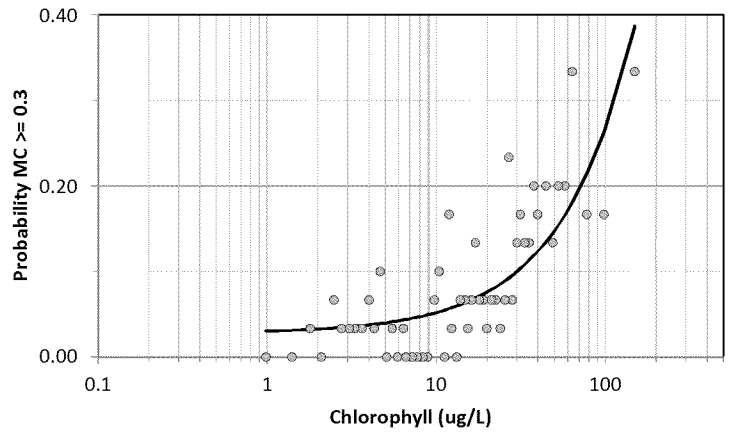
Figure 5-6. Maximum Microcystin Concentrations in Missouri Reservoirs

[3] The guideline value is based on the following assumptions: Average adult body weight (bw) is 60 kg, a provisional total daily intake (TDI) set at 0.04 µg kg^{-1}, of which a proportion (P) of 0.8 is allocated to drinking water, and water consumption of 2 L d^{-1}. It is calculated as follows: $Guideline\ \ lue = \frac{TI*bw*P}{L}$,which comes to 0.96 µg L^{-1}, and is rounded up to 1.0 µg L^{-1}.

Table 5-2. Chlorophyll Levels Observed in the Missouri Dataset at Three Microcystin Concentration Thresholds.

Microcystins (µg/L)	Chlorophyll (µg/ L)		
	n	Median	Range
nd	1,331	11.4	0.6-246
0.1-0.3	187	25.3	0.7-267
≥0.3	140	33.5	1.9-201

Note: Microcystin data compiled from 214 Missouri reservoirs from 2000-2006.



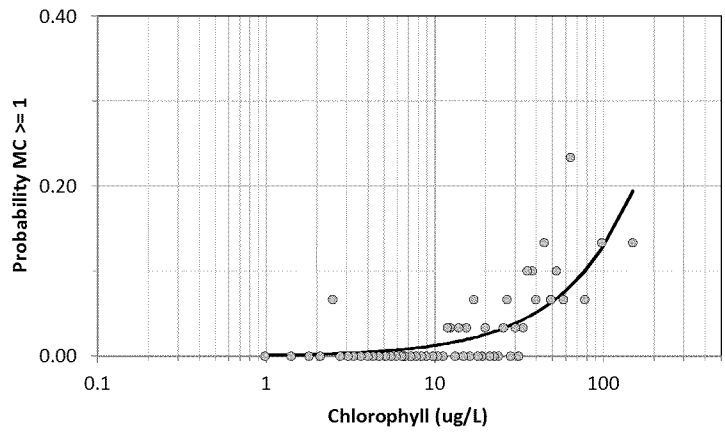


Figure 5-7. Relationship between Chlorophyll and the Probability of Microcystin Concentrations in Excess of Different Advisory Levels.

Plots of the relationship between chlorophyll and the probability of microcystin concentrations in excess of different advisory levels were compared to a range of chlorophyll levels (

Figure 5-7). A median chlorophyll concentration of approximately 30 µg/L corresponds to a 10% chance of microcystin being greater than 0.3 µg/L. The corresponding chlorophyll concentration for a 10% chance of exceedance of 1.0 µg/L is appro ximately 80 µg/L. The average probability of occurrence is based on Missouri reservoir data b inned into groups of approximately 30. Chlorophyll concentrations represent medians within the binned data groups.

EPA collected microcystin data nationally as part of their 2007 National Lake Assessment (NLA) project. NLA data collected from Missouri were limi ted, but were lower than national and regional levels (Figure 5-8,

Table 5-3). Microcystin data collected by MU were a lso lower than national NLA data and comparable to the regional levels (Figure 5-8). Na tionally, 68% of NLA microcystin samples were below the detection limit of 0.1 µg/L as compa red to 80% for Missouri data. When results below the detection limit are removed, the median m icrocystin concentration is 0.51 µg/L as compared to 0.22 µg/L for the Missouri data and 0.1 7 µg/L for the NLA Missouri dataset (Figure 5-8, **Table 5-3).**

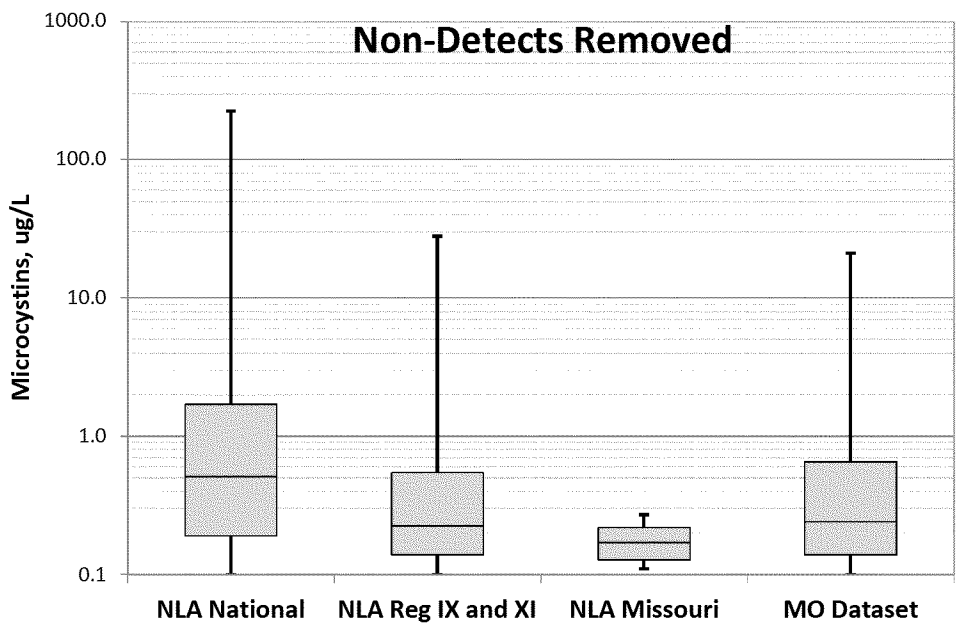


Figure 5-8. Comparison of Microcystin Concentration s (Excluding Non-Detects) Collected from EPA's National Lake Assessment and Missouri Data.

Table 5-3. Summary of EPA's National Lake Assessment and Missouri Microcystin Data (Excluding Non-Detects).

Statistic	NLA National	NAL Ecoregion IX and XI	NLA Missouri	Missouri Dataset (Non-NLA)
n (detects only)	404	74	8	337
n (total)	1,252	279	28	1,658
% Non-Detect	68%	73%	71%	80%
Minimum (ug/L)	0.10	0.10	0.11	0.10
25th Percentile (ug/L)	0.19	0.14	0.13	0.14
Median (ug/L)	0.51	0.23	0.17	0.22
75th Percentile (ug/L)	1.70	0.55	0.22	0.60
Maximum (ug/L)	225	28	0.27	21

Note: Summary statistics are based on detect data only. Detection limit is 0.1 µg/L.

5.5. Disinfection Byproduct Precursors

The presence of natural organic matter in treatment plant source waters has been a concern for utilities who strive to reduce the formation potential of DBPs during treatment, as natural organic matter contains DBP precursor compounds. Organic carbon, in both the total and dissolved forms, is frequently measured to assess the relative amount of natural organic matter. The development of DBPs in water treatment plants has been directly linked to the dissolved fraction of organic carbon found in water supplies, with factors such as pH and temperature playing a key role in creating favorable conditions for increased DBP formation. Hydrology can greatly impact the relative amounts of allochthonous (derived from external sources) and autochthonous (derived from in-lake processes) carbon in a particular reservoir system, but the relative importance of internal and external carbon sources with respect to DBPs varies with time and across lakes (Callinan et al. 2013).

In order the meet EPA's maximum contaminant level (MCL) for total regulated DBPs (TTHM and HAA5), water utilities may require enhanced coagulation processes to improve removal of organic compounds, which can consequently increase operating costs. In an effort to reduce these costs, water utilities have begun to look for opportunities to reduce influent DBP precursor compounds, such as the fraction of dissolved algal organic matter. Jack et al. (2002) found that the presence of algae and associated biological products can contribute low-aromatic hydrophilic molecules such as amino acids and sugars that can lead to increased DBP formation when exposed to chlorine or chloramines. However, studies have shown that

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relationships between algal production or chlorophy ll and DBP formation are not always strong or consistent across or within lake systems. This i s particularly evident in reservoir systems that are influenced by hydrologic factors and watershed sources of organic materials (Veum 2006).

5.5.1. Source Water DBP Formation Potential Evaluation

The 2004 MU DBP study data were used to evaluate th e extent to which chlorophyll influences DOC and TTHM formation potential (THMFP) in Missour i reservoirs. THMFP represents the maximum tendency of system organics to form THMs un der controlled conditions, such as sample temperature, chlorine dose, and pH. Since t he THMFP method conditions may not be representative of actual treatment conditions, the data produced can only serve as an indicator of THM MCL noncompliance and as such should not be directly compared to the TTHM MCL that is expressed as an annual average. Seasonal averages were calculated for all reservoirs. Predictably, average summer DOC concentrations were strongly related to THMFP concentrations during the study (c=0.81) [4]. This strong relationship is not uncommon and is t he reason that DOC is often used by water system opera tors as an inexpensive surrogate for measuring DBP formation potential. The results also demonstrate that chlorophyll concentrations were weakly related to THMFP. Media n chlorophyll was generally less than 20 µg/L across the range of THMFP concentrations, but THMFP concentrations greater than 350 µg/L were more frequently observed at chlorophyll c oncentrations exceeding 30 µg/L (**Figure 5-9**). However, THMFP varied widely across the range of individual reservoir chlorophyll values that varied from approximately 1 µg/L to almost 80 µg/L (Figure 5-9).

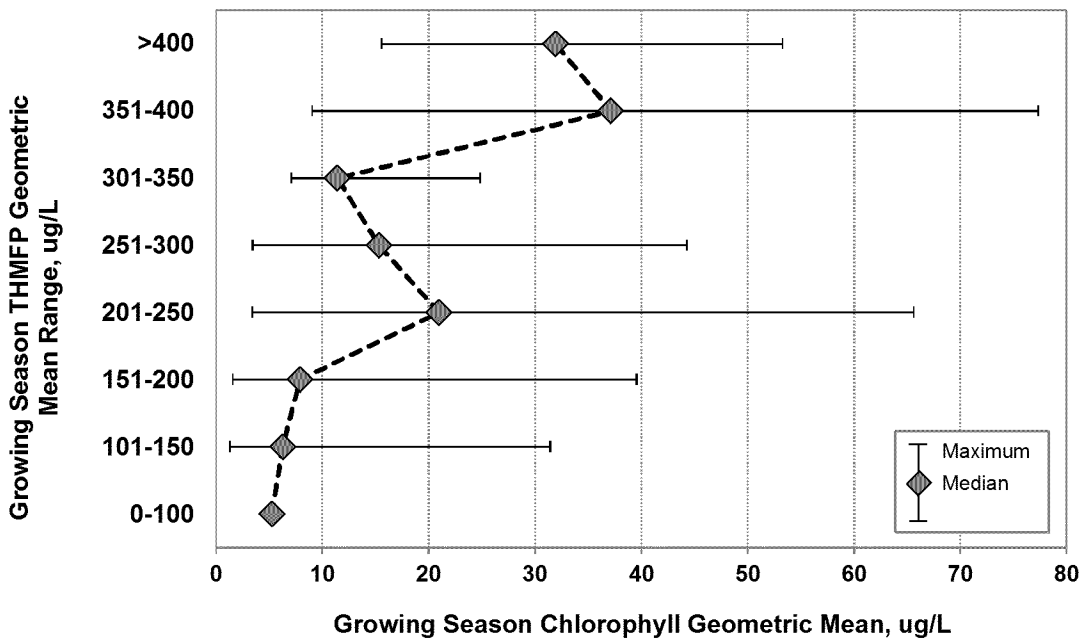

Figure 5-9. Growing Season Chlorophyll and THMFP Co ncentrations Measured in Reservoirs Sampled as Part of the 2004 MU DBP Study (Veum 2006).

[4] Correlation values were calculated to confirm the relationships between water quality variables in th is study. Correlation values were estimated using the Pearson correlation equation, abbreviated herein as "c". C orrelatoin values range from -1 to 1.

The observed relationship between chlorophyll and DOC in the 2004 MU DBP study data was also weak (Figure 5-10). Although the data show that DOC generally increased with chlorophyll concentration, individual results exhibited significant variability and generally ranged from 2 to 8 mg/L across the distribution. It is important to note that the 2004 MU DBP data were collected during a relatively wet year and may not be representative of long term conditions in Missouri reservoirs (Veum 2006). To determine if the weak relationship observed in the 2004 data were representative, the relationship between DOC and chlorophyll for all reservoir across the entire period of record (1999 – 2014) in the database were also examined. Results of this evaluation were comparable to the relationship exhibited in Figure 5-10; however the variability of individual results was greater. DOC generally ranged from 2 to 10 mg/L across the range of observed chlorophyll values for the entire period of record.

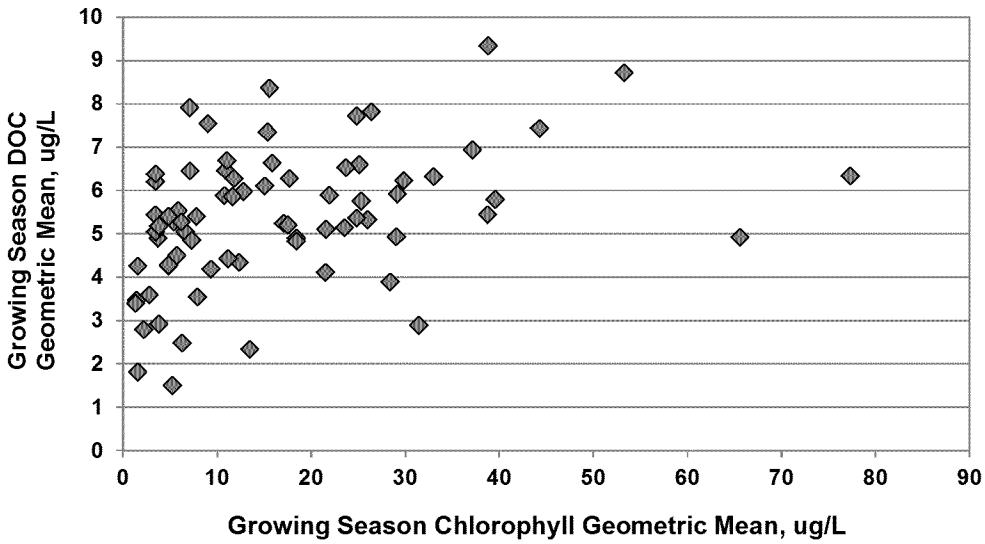

Figure 5-10. Growing Season DOC and Chlorophyll Concentrations Measured in Reservoirs Sampled as Part of the 2004 MU DBP Study (Veum 2006).

Overall, a review of the 2004 MU DBP study data showed that relationships between chlorophyll, DOC, and THMFP were generally weak and exhibited significant variability. As the MU researchers discussed, results of studies attempting to link these parameters have been mixed because every reservoir has a unique biogeochemistry that impacts precursor levels, composition, distribution, and reactivity (Veum 2006). Furthermore, studies have found that the source of carbon loading can be dominated by reservoir morphology and hydrology in many systems, while algal productivity may dominate in other systems or at different times in the same system (Chapra et al. 1997). In the MU study, Veum (2006) found that 77% of the variation observed in DOC concentrations was attributed to hydraulic flushing rate. This finding suggests that DOC levels and composition in Missouri reservoirs are generally controlled by hydrology and watershed characteristics, rather than chlorophyll.

5.5.2. SUVA as an Indicator of Algal DOC Contributions in Missouri Reservoirs

Previous studies have indicated that aromaticity of DOC, measured by SUVA, is closely related to the organic carbon production source which may impact the degree of DBP formation. Hua

et al. (2015) observed an increase in DBP formation as SUVA values increased. Nguyen et al. (2005) suggested that the small DOC compounds produced by algae have SUVA values less than 2 L/mg-m and are primarily comprised of biodegradable materials such as amino acids, sugars, and carbohydrates. High SUVA value samples of at least 3 L/mg-m consisted of large, aromatic, humic, refractory compounds. These high SUVA levels are generally indicative of carbon derived from allochthonous, or watershed, sources. A large amount of low SUVA compounds in source waters could indicate the presence of algal-derived DBP precursors, whereas a large amount of high SUVA compounds could indicate the influence of hydrologic and watershed factors on DBP precursors.

Relationships between DOC, chlorophyll, and THMFP were weak and suggest that hydrology and watershed factors impact DOC more than chlorophyll in Missouri reservoirs. SUVA results collected during the 2004 MU DBP study were reviewed to further evaluate the role that algal-derived DOC may have on DBP formation. In the dataset, 66% of SUVA values were greater than 2 L/mg-m, indicating that the majority of DBP precursors measured in Missouri reservoirs originate from allochthonous, or watershed-derived, sources rather than algal sources. DOC samples with SUVA values below 2 L/mg-m samples were also examined to determine if the relationship between DOC and chlorophyll is stronger in low aromatic samples (Saunders et al. 2015). The 2004 MU DBP data demonstrate that there is a weak and variable relationship between low SUVA (< 2 L/mg-m) DOC and chlorophyll (**Figure 5-11**) and further support the previous conclusions that hydrology and watershed factors are likely the most important source of DOC in Missouri reservoirs.

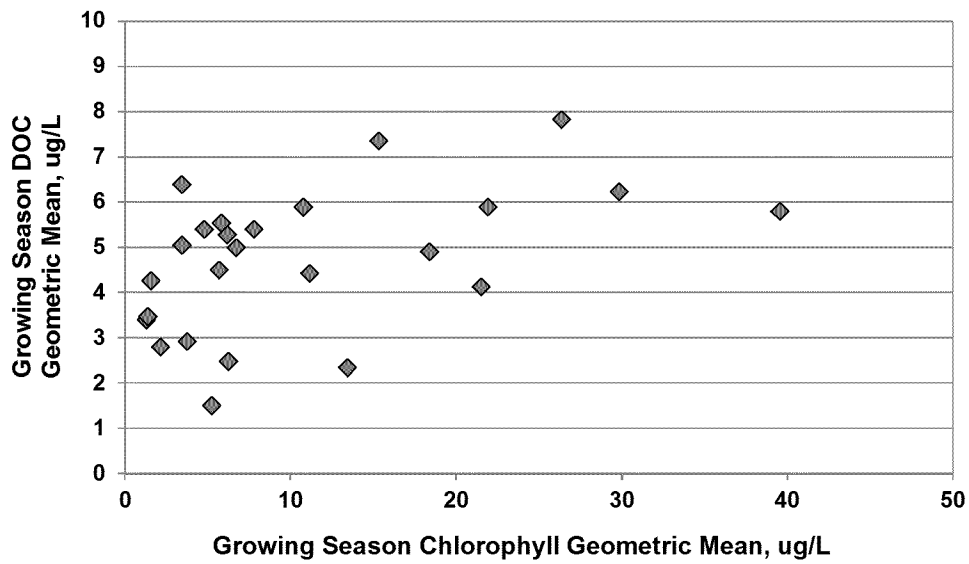

Figure 5-11. Growing Season DOC and Chlorophyll concentrations for Reservoirs with SUVA < 2 L/mg-m.

5.5.3. Disinfection Byproducts in Missouri Drinking Water Systems

The Public Drinking Water Branch of MDNR publishes an Annual Compliance Report on the state's public water systems. The reports are provided to comply with statutory obligations

mandated by the Federal Safe Drinking Water Act, including the Stage 1 and 2 Disinfectants and Disinfection Byproducts Rule (DBPR). Any public water system that violates MCLs for TTHM and HAA5 are reported in the annual report.

A public drinking water system is defined by MDNR as a system that provides water through piping or other constructed conveyances for human consumption to at least 15 service connections, or serves an average of at least 25 people for at least 60 days each year (MDNR 2015a). The three types of public water systems are:

1. Community systems include towns, water districts, subdivisions, mobile home parks and residential facilities such as nursing homes or prisons.
2. Nontransient noncommunity systems serve the same people every day, but not in a residential setting; schools and factories are good examples.
3. Transient noncommunity systems serve different people daily, such as restaurants, resorts and rest stops. These smaller systems are typically in rural areas where it is not feasible to hook up to a city source or water district.

According to the 2015 Annual Compliance Report, there are a total of 2,732 public water systems in Missouri, of which 1,427 are community, 1,089 are transient noncommunity, and 216 are nontransient noncommunity. In terms of source water, the percent of population served by Missouri's public drinking water systems is broken down as follows (MDNR 2015a).

- Missouri River: 47%
- Groundwater: 39%
- Mississippi River: 1%
- Other Surface Water (includes reservoirs and rivers): 12%

There is no exclusive category for reservoirs, but based on the "Other Surface Water" category, reservoirs serve as source water for less than 12% of Missouri's population. MDNR's 2015 census of public water systems identifies 58 source water reservoirs serving 41 systems, the majority of which are located in northern Missouri (MDNR 2015b).

The 2004 through 2014 Annual Compliance Reports were reviewed to identify TTHM and HAA5 MCL violations for systems that use reservoirs as source water. In that time, the number of systems that had DBP MCL violations was between 3 and 14 systems per year. Collectively however, there were a total of 26 different public water systems with reservoir source water that had MCL violations over the 11 year period of time.

As described previously, algal-derived DOC may contribute to DBP formation in drinking water system source waters. Chlorophyll, DOC, and DBPs were not strongly related in the 2004 MU DBP study data. However, the 2004 study only measured DBP forming potential of raw reservoir water. It did not measure actual DBPs that occurred in the drinking water system. To evaluate whether or not reservoir chlorophyll levels were related to drinking water system DBPs, ambient chlorophyll were reviewed for reservoirs that did and did not experience MCL violations

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between 2004 and 2014 (Figure 5-12). Median summer chlorophyll levels were approximately 19 µg/L and 16 µg/L for the reservoirs with and without MCL violations, respectively. For both groups, chlorophyll ranged from approximately 3 µg/ L to at least 60 µg/L. A statistical evaluation of the data indicates that the two distributions are not different from each other (Mann-Whitney U test, $p<0.05$). These results further support the previous conclusions that strong relationships between chlorophyll and DBPs are not apparent in Missouri reservoir systems.

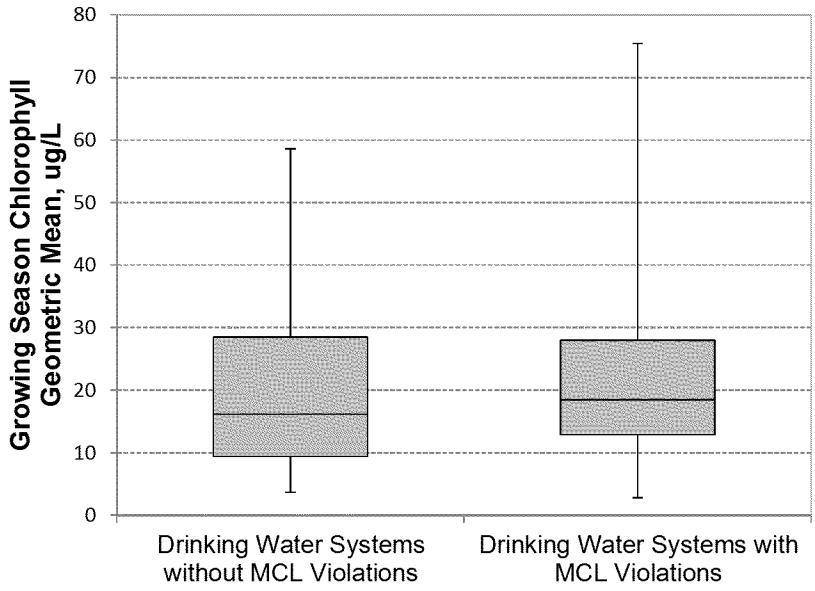

Figure 5-12. Comparison of Growing Season Geometric Mean Chlorophyll Values Measured in Reservoirs with and without MCL Violations between 2004 and 2014. A statistical evaluation of the two distributions indicates that they are not different from each other (Mann-Whitney U test, $p<0.05$).

Long-term chlorophyll levels were also assessed for individual systems to evaluate whether or not patterns or trends were apparent for systems based on the number of DBP MCL violations between 2004 and 2014. For reservoirs of drinking water systems that have had no MCL violations, long-term chlorophyll concentrations ranged from 14 µg/L at Mark Twain Lake to 35 mg/L at Lake Mahoney (**Figure 5-13**). Long-term chlorophyll concentrations of reservoirs with at least one MCL violation ranged from 4.5 µg/L at Bethany City Old Reservoir to 45 µg/L at Lamar Lake. In these data, there is no clear relationship between chlorophyll and DBP MCL violations because violations were distributed across a wide range of chlorophyll values. Additionally, Smithville Reservoir serves as source water for two separate drinking water systems; one has had three MCL violations and the other has had none. Collectively, these findings demonstrate that other environmental and treatment system operation-related factors likely have a greater impact on DBP formation than does algal biomass.

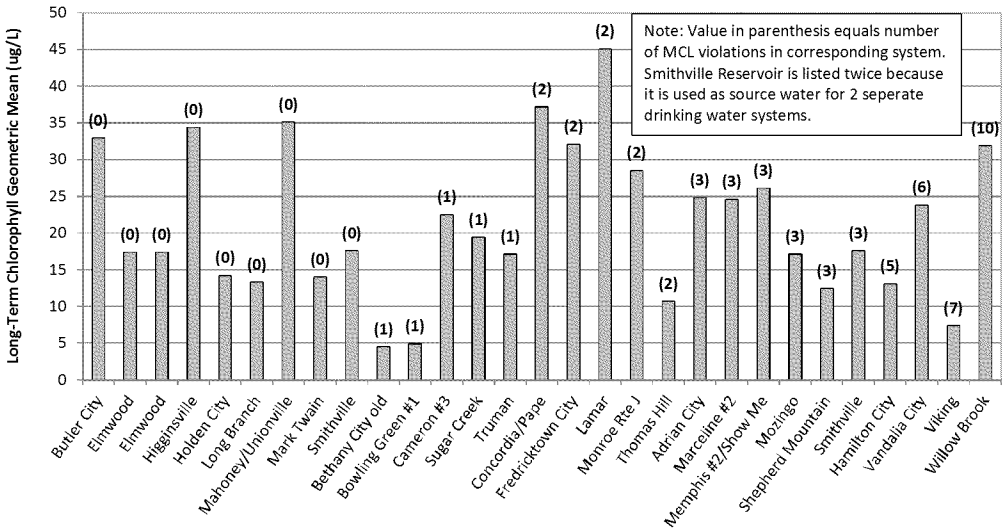

Figure 5-13. Long-Term Chlorophyll Concentrations in Drinking Water System Reservoirs and the Corresponding Number of DBP MCL Violations for Each System between 2004 and 2014.

Drinking water distribution system DBP data were al so paired with source water chlorophyll levels to further evaluate potential relationships. The DBP data were averaged based on the maximum observed HAA5 and TTHM values observed in t he 2nd and 3rd quarter for each year with available data. The 2nd and 3rd quarter data were chosen because they include the summer growing season, when chlorophyll would be most like ly to contribute to DBP formation. Where chlorophyll data were available from corresponding source water reservoirs, the averaged DBP data were plotted against the geometric mean of the summer chlorophyll levels (

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Figure 5-14). Results of this evaluation further indicate that there is no clear relationship between source water chlorophyll and DBPs. While algal biomass can contribute to DBPs, this lack of a relationship could be due to confounding factors such as other sources of DOC. Allochthonous DOC from the watershed tends to be more refractory, resisting bacterial breakdown compared to the labile DOC produced by algae which decompose quickly. Also, operational practices used by the different treatment plants can add variability to the production of DBPs relative to DOC levels.

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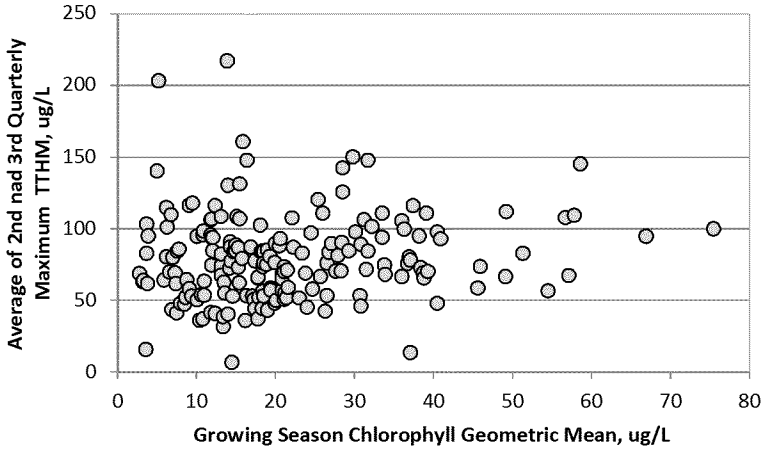

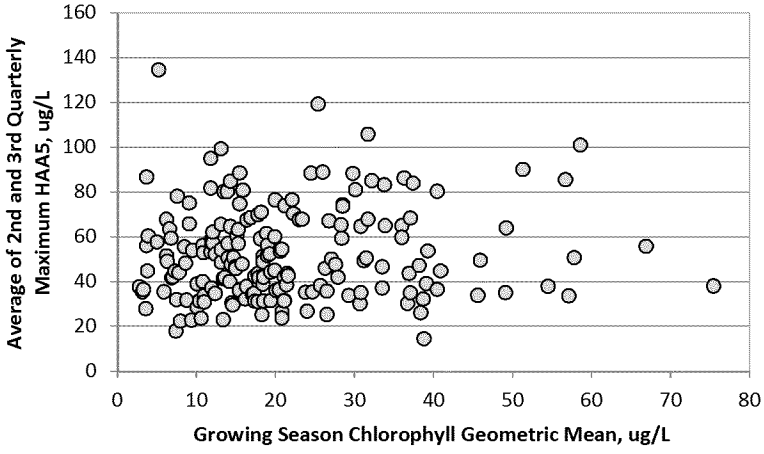

Figure 5-14. Relationship between the Average of 2n d and 3rd Quarter Maximum HAA5 and TTHM and Growing Season Geometric Mean Chlorophyll Conce ntrations in Source Water Reservoirs.

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6. Criteria Development

Establishing scientifically defensible reservoir nutrient criteria is challenging from a technical perspective, which is why progress has been limited since 1998 when EPA initiated the push for states to develop criteria. Aside from the complexities associated with variability in man-made reservoirs described earlier, nutrients are inherently non-toxic. In fact, phosphorus and nitrogen are nutrients that are essential for the growth and development of organisms. Unlike traditional toxics, lower levels of nutrients do not necessarily result in better attainment of designated uses. Furthermore, data are also currently insufficient to develop nutrient criteria for all designated uses in Missouri. For example, limited data are available that adequately link reservoir nutrient concentrations to risks associated with human health protection and fish consumption. Additionally, appropriate criteria for the protection of recreational uses are relatively subjective and have not yet been fully studied in Missouri. Further input is being sought from the public to determine what degree of water clarity is desired for suitability of this use.

EPA recommends the reference condition approach for setting criteria (EPA 2010). Reference conditions represent a "baseline that should protect the inherent beneficial uses of the nation's waters" (EPA 2000). The rationale being that reference conditions "help to set the upper bounds of what can be considered the most natural and attainable lake conditions for a specific region" (*Id.*). However, use of reference conditions is better suited for natural lakes than man-made reservoirs because Missouri's reservoirs were built long after large scale land-cover changes had already occurred on the landscape. Reservoirs are highly managed for purposes that may or may not be well aligned with expectations for a pristine, natural lake. Furthermore, nutrients in reservoirs are driven by human decisions such as dam height and watershed size, which depend on where the dam is built within the river drainage.

Where reference sites cannot be identified, EPA suggests using the lower 25th percentile of data from a representative sampling of the entire population of lakes in an ecoregion (EPA 2000). However, this approach inherently assumes that all reservoirs are capable of achieving the same nutrient levels regardless of differences in factors such as watershed characteristics and flushing rates. It also presupposes that there is a link between designated uses and the 25th percentile value, which is not scientifically defensible and would not address EPA's previous rationale rejecting the 2009 Missouri criteria. Additionally, it raises questions of policy as it effectively implies that 75 percent of lakes are impaired.

Given these issues, Missouri is recommending a tailored approach that focuses on the stressor-response relationships. Specifically, the Department has selected that chlorophyll serve as the basis for establishing nutrient criteria. Chlorophyll is the most common method of estimating the abundance of algae in a water body. Chlorophyll is also directly related to a number of factors such as low dissolved oxygen and algal toxins that directly impact aquatic life and drinking water designated uses. Additionally, limiting criteria to chlorophyll focuses efforts on the parameter that directly relates to impairments. This limits the challenges and uncertainties associated with implementing criteria based on causal indicators, which are strongly influenced by natural factors that increase variability and uncertainty.

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Although reservoir nutrient criteria are limited to chlorophyll, the Department recognizes that TN and TP data can serve a useful role in protecting Missouri reservoirs from cultural eutrophication. Therefore, as described in **Section** Error! Reference source not found., TN and TP screening values will be used to supplement chlorophyll criteria in identifying impairments.

Limiting reservoir nutrient criteria to chlorophyll is not a unique approach and has been adopted by other states. For instance, nutrient criteria for Virginia's reservoirs are limited to chlorophyll, unless the reservoir received algaecide treatment. Where causal variables are applied as criteria, other states apply stipulations. For example, Minnesota requires an exceedance of ***both*** TP and chlorophyll. Similarly, Maine has proposed a decision framework whereby an exceedance of TP does not trigger an impairment decision unless there is additional evidence of impairment as measured by other indicators like chlorophyll or dissolved oxygen.

Missouri's recommended approach for reservoir nutrient criteria is intended to balance technical complexities with designated use protections by:

- Developing ecoregional criteria based only on the response variable chlorophyll,
- Focusing on aquatic life and drinking water supply designated uses,
- Using conservative screening threshold values to identify reservoirs that do not exceed chlorophyll criteria but may require additional evaluations to determine if beneficial uses are not supported, and
- Applying weight-of-evidence procedures that outline specific metrics that should be evaluated when reservoirs are above the screening thresholds but below the criteria.
- Exceedance of screening values will also trigger a trend analysis of historic data to identify reservoirs that are expected to become impaired over the next five year time horizon. This trend analysis will be used to identify threatened reservoirs as impaired so that MDNR can take corrective actions.

Specific criteria recommendations and rationale for aquatic life and drinking water supply designated uses are described in the sections that follow.

6.1. Aquatic Life Use Criteria Recommendations

Missouri reservoirs are designated to one of the following AQL uses which are based on temperature and biological assemblages per 10 CSR 20-7.031(1)(C)1:

- *Warm Water Habitat (WWH) – Waters in which naturally-occurring water quality and habitat conditions allow the maintenance of a wide variety of warm-water biota.*
- *Cool Water Habitat (CLW) – Waters in which naturally-occurring water quality and habitat conditions allow the maintenance of a wide variety of cool-water biota. These waters can support a sensitive, high quality sport fishery (i.e., smallmouth bass and rock bass)*
- *Cold Water Habitat (CDH) – Waters in which naturally-occurring water quality and habitat conditions allow the maintenance of a wide variety of cold-water biota. These waters can support a naturally reproducing or stocked trout fishery and populations of other cold-water species.*

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All three levels of AQL protections include provisions for the maintenance of a "*wide variety*" of aquatic biota. However, even though the relationship between species diversity/richness and productivity is well studied in ecology, the issue is still somewhat controversial (Mittelback et al. 2001). Review of the literature indicates a lack of consistency in how, or even if, productivity influences species diversity in aquatic systems. Factors not relating to productivity that can also influence species diversity include disturbances to ecosystem, grazing and predation, spatial scale of study, niche specialization by species, dispersal, and extreme environmental conditions (Fukami and Morin 2003, Declerck et al. 2005). "Productivity" can be measured in many different ways, and in the following section the term includes: potential productivity as estimated by nutrient levels, actual measures of biomass, and rates of carbon fixation. While the various studies use different measures of productivity, they are all related to primary production.

The influence of various factors can be seen in both laboratory experiments and field studies. Fukami and Morin (2003) investigated the influence of sequence of assembly in lab experiments using microbes. Results from their experiments indicate that intra-species interactions were important in shaping the relationship between productivity and diversity. Field studies such as those done by Chase and Leibold (2002), highlight the importance of scale on the relationship between species diversity and productivity. Invertebrate and macrophyte diversity were determined for 30 ponds located within 10 drainages (3 ponds per drainage). The diversity-productivity relation for this larger group of water bodies (n=30) was humped-shaped, with the highest diversity occurring in ponds with mid-level productivity. To examine diversity at the watershed scale, researchers combined the invertebrate and macrophyte data from the 3 ponds within each drainage and found a positive relationship, with highest diversity in the most productive drainages.

The species diversity-productivity relationship has also been investigated via large scale regional surveys. Jeppesen et al. (2000) looked at the species diversity of six different aquatic biotic groups across 71 shallow Danish lakes. The different aquatic groups displayed varying patterns of diversity relative to TP concentrations, with only the submerged macrophytes showing a strong negative relationship likely due to light limitation associated with increased algal biomass. The results suggest that there is no single level of productivity that can maximize diversity across the different aquatic biotic groups. The study also indicated that even hypereutrophic conditions (TP >400 µg/L) did not lead to large scale loss of diversity across the six taxonomic groups.

A regional study encompassing 186 water bodies located within 8 states in northeast U.S. looked at diversity of benthic invertebrates, riparian birds, sedimentary diatoms, fish, planktonic crustaceans, and planktonic rotifers (Allen et al. 1999). Results showed that anthropogenic factors (human density in watershed) and measures of productivity (TP) had weak and varied influence on species diversity. For 5 of the 6 taxonomic groups, lake surface area was the strongest explanatory variable associated with species diversity (Allen et al. 1999). The authors noted that their results were consistent with those of Schindler (1987), who found assemblages were affected by only the most severe environmental perturbations.

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Surface area was also the most important factor in predicting species diversity of crustacean zooplankton in 66 North American lakes (Dodson 1992). This study found 5 factors were significantly correlated to diversity: lake surface area (r-value = 0.75), mean depth (0.60), distance to nearest lake (0.57), number of lakes within 20 km (0.56), and photosynthetic flux (0.50). These results highlight how important factors not relating to lake fertility and nutrient levels are in determining species richness in aquatic systems.

Mittelbach et al. (2001) reviewed 171 published scientific articles that investigated the diversity-productivity relationship, 55 of which dealt with aquatic systems. The authors divided the biota into three groups: fish, invertebrates and plants with 7, 28 and 20 published studies for each group, respectively (Table 6-1). A total of 19 of 55 studies (35%) showed no relation between species diversity and productivity, with only 4 of the studies (7%) having a negative relationship.

Table 6-1. Relationship between Diversity and Productivity for Three Different Aquatic Groups. Data represent information shown in Figure 4 of Mittleback et al. (2001).

Aquatic Group (# of studies)	Shape of Diversity-Productivity Relationship				
	Hump-shaped	Positive	Negative	U-Shaped	No Pattern
Fish (7)	3	2	0	0	2
Invertebrates (28)	11	2	3	2	10
Plants (20)	9	1	1	2	7
# of Studies (%)	23 (42%)	5 (9%)	4 (7%)	4 (7%)	19 (35%)

Another regional study found the diversity-productivity relationship to be complex with varying patterns for different aquatic groups as well as regional differences (Declerck et al. 2005). The authors concluded "Our results indicate that the search for a single diversity index aimed at assessing taxon richness at the level of the entire system on a regional scale is probably of low relevance" and that it might be best to "maintain a variety of lake types on a regional scale" to truly maximize aquatic diversity.

As suggested in Table 6-1, the literature generally shows that relatively higher nutrient concentrations support healthy fish communities (Knowlton & Jones 2003). Jones and Hoyer (1982) found a strong positive relationship between chlorophyll concentrations, up to 70 µg/L, and sport fish yields in Missouri and Iowa lakes. Michaletz et al. (2012) reported that growth and size structure of sport fish populations increased with measures of water fertility, due to abundance of prey in more fertile water, but there is an upper limit beyond which fish population declines. While the positive relation between reservoir fertility (TP and chlorophyll) and game fish health exists, it is often secondary to inter- and intra-species interactions, indicating these systems are both complex and dynamic. Michaletz et al. (2012) also reported that for largemouth bass and black crappie, fish size distributions had a threshold for chlorophyll of 40 to 60 µg/L, above which fish sizes declined. Additionally, largemouth bass and redear sunfish Catch Per Unit Effort (CPUE) were particularly low when TP exceeded 100 µg/L.

Downing and Plante (1993) used worldwide data to investigate the relation between lake fertility and fish production. They found a significant positive relation between fish production and both TP and chlorophyll concentrations. The results of this study, according to the authors, suggest

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that these systems operate "bottom-up"; with each trophic level in the aquatic food web being controlled by the subordinate level. The paper also notes that eutrophic lakes tend to have greater species richness, which leads to greater fish production when combined with the fertility potential of eutrophic systems.

Egertson and Downing (2004) reported that in Iowa lakes on a chlorophyll gradient of 10 to 100 µg/L, CPUE for common carp and other benthivore species went up. This appeared to be at the expense of CPUE for more desirable species, notably bluegills and black crappie. While the declines of the latter were not statistically significant, the results suggest that highly eutrophic conditions favor benthivores and disfavor piscivores, which are mainly visual feeders.

These patterns are consistent with results observed in other sport and non-sport fish populations. Ney (1996) reviewed data from reservoir studies and concluded that maximum biomass is supported at different TP levels for sport and non-sport fish communities. Using this information, Ney (1996) developed generalized relationships which suggest that sport fish biomass increases until TP concentrations near 100 µg/L; total fish biomass increases as TP approaches 300 µg/L (Figure 6-1).

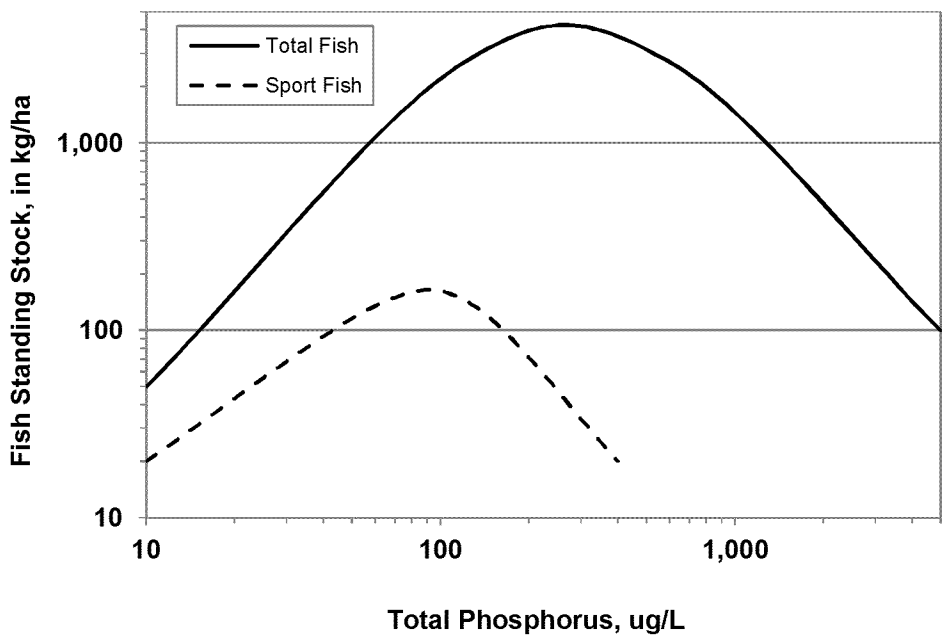

Figure 6-1. Generalized Relationship of Total and Sport Fish Standing Stock to Total Phosphorus Concentrations in Reservoirs Adapted from Ney 1996.

As has been demonstrated with fish communities, nutrient increases can also have competing positive and negative effects on other organisms, such as mussels. As nutrient levels increase, so does the abundance of mussel food sources, such as algae, bacteria, and fungi. Studies suggest that these increases create a beneficial, food-rich environment for mussel communities (Strayer et al. 2014). In cases of extreme eutrophication, changes in algal composition influence food quality and can impact habitat by reducing dissolved oxygen levels. In some instances, the

release of ammonia by decaying algae following large algal blooms can also have toxic effects on mussels (Strayer et al. 2014). Nutrient poor environments however, may influence food availability and reduce mussel growth, abundance, and fecundity.

The nutrient thresholds at which these positive and negative effects occur is largely unknown, as the data are limited and impacts tend to vary by species. However, it generally accepted that mussels exhibit a similar response pattern to increasing nutrients as do fish (Figure 6-2). Mussel abundance (and likely diversity) increases in response to increasing nutrients because food availability and quality improve. At some upper nutrient threshold, which varies by species and is influenced by habitat and other physical and chemical waterbody characteristics, mussel communities decline (Strayer et al. 2014).

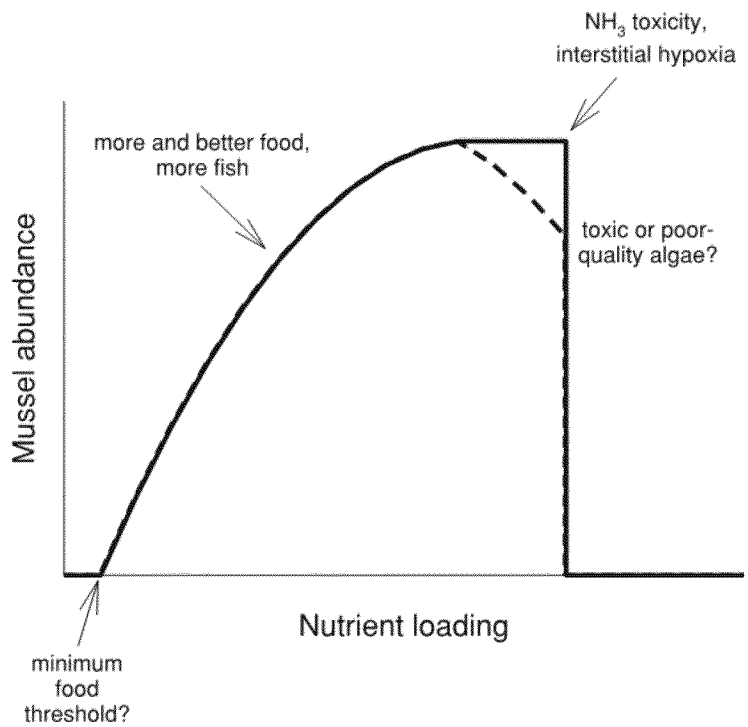

Figure 6-2. Generalized Relationships between Mussel Abundance and Nutrient Loading from Strayer et al. 2014.

As a group, mussels are some of the most imperiled aquatic organisms and reservoirs have had a negative effect on freshwater mussel diversity within the impounded drainages (Box and Mossa 1999, Watters 2000). The creation of a reservoir represents a loss of habitat, a change in sedimentation, and a shift in hydrology; all of these listed as being a greater stressor to freshwater mussels than nutrients (Richter et al 1997). Other problems for freshwater mussels associated with reservoirs include: deeper water that may not be tolerated by the mussels, cooler water temperatures in the hypolimnion which may reduce or eliminate reproduction, and the potential loss of the obligatory fish host required for mussel reproduction (Box and Mossa 1999, Watters 2000). Missouri's reservoirs are stressors on the freshwater mussel community

within the state, and there is no evidence that nutrient reductions would have any positive effect on their recovery.

Overall, the literature suggests aquatic organism biomass and diversity generally increases with trophic state, but reaches some maximum level that varies across systems and aquatic communities. The literature also suggests that species composition may change across the trophic continuum. However, as EPA (2000) has pointed out, changes in biological structure alone are not sufficient indicators of nutrient impacts:

> Unfortunately, changes in biological structure do not fit neatly into a nutrient-based classification because structural changes can occur along any environmental axis such as pH or temperature. The bioassessment of aquatic habitats has its strength in the concept that the organisms can be sensitive variables of the condition of the aquatic environment. However, unless a great deal is known about the requirements of the organisms themselves, the assessment does not necessarily indicate the nature of the disturbance. Such general variables would be of little use as variables of nutrient change if they were susceptible to change by a large number of other factors as well.

In Missouri, data which help definitively characterize the structure, function, and diversity of all aquatic biota as related to nutrients in reservoirs is limited. However, Missouri sport fish data demonstrate that most reservoirs in Missouri provide water quality and habitat suitable for a variety of fish species. The Department maintains that using sport fishery status as an indicator of aquatic life use protection is ecologically justified because sport fish are generally apex predators in reservoir systems. The apex predators (top of the food chain) do not directly utilize the energy created by and stored within the algal community. Instead, the energy created via photosynthesis by the algae is passed upward through the aquatic food web via intermediate levels. A positive relation between algal biomass and the health of the apex predators requires these intermediate levels in the food web be present and functioning properly. Most Missouri reservoirs also support naturally-reproducing sport fish communities. Therefore, the health of sport fish populations can be interpreted as an indicator of overall ecosystem health and the presence a "wide variety" of aquatic biota, as defined in the existing regulations.

Following a review of the literature and discussions with Missouri reservoir and fishery management professionals, staff from MDC and MU made recommendations for chlorophyll concentrations that would support aquatic life uses in reservoirs (Table 6-2). The MDC and MU recommendation for the Plains is conservatively set to support sport fisheries rather than maximizing sport fish harvest. Using sport fishery status as an indicator of aquatic life use protection is ecologically justified because sport fish are generally apex predators in reservoir systems. Therefore, the health of sport fish populations can be interpreted as an indicator of overall ecosystem health and the presence a "wide variety" of aquatic biota, as defined in the existing regulations.

Ney (1996) reported that sport fish biomass peaks as TP nears 100 µg/L. According to the updated Missouri dataset presented previously (Figure 5-3), 100 µg/L is approximately 36 µg/L

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chlorophyll in the Plains ecoregion. For the Plains , MDC and MU suggested a more conservative value of 30 µg/L. For the Ozark Highl ands, MDC and MU recommended a lower chlorophyll concentration of 15 µg/L, which reflects the region al pattern of reservoir fertility associated with the different physiographic regions of the state. The Ozark Border section represents a transition zone between the Plains and Ozark Highlands; therefore, MDC and MU recommended a chlorophyll criterion intermediate to the other two sections. Missouri's proposed chlorophyll criteria values are similar to EPA-appr oved criteria adopted in other states sharing Level III ecoregions with Missouri. West Virginia i s in ecoregion XI, the same as Missouri's Ozark Highlands, and has approved chlorophyll crite ria of 10-20 µg/L. North Carolina is largely comprised of ecoregions XI and IX, similar to Misso uri. North Carolina's adopted chlorophyll criteria is 15-40 µg/L, again similar to Missouri's proposed values of 15-30 µg/L.

Table 6-2. MDC and MU Aquatic Life Use Chlorophyll Criteria Recommendations.

Reservoir Ecoregion	Chlorophyll, µg/L
Plains	30
Ozark Border	22
Ozark Highlands	15

6.2. Drinking Water Criteria Recommendations

Missouri reservoirs designated for drinking water s upply are afforded the following protections per 10 CSR 20-7.031(1)(C)6:

> *Maintenance of a raw water supply which will yield potable water after treatment by public water treatment facilities.*

High levels of algal biomass in reservoirs that ser ve as public drinking water supply can give rise to several maintenance issues, including taste and odor problems, higher treatment costs, and potential health hazards. The last impact may come in the form of cyanotoxins or DBPs. These issues were evaluated based on literature stu dies and Missouri specific data in establishing chlorophyll criteria protective of dri nking water supplies. Considerations and findings are presented below.

6.2.1. Limiting Algal Blooms

One potential approach for setting criteria protect ive of drinking water supplies is to target nutrient concentrations that limit algal blooms (i. e. extreme levels of algal biomass), which can be associated with algal toxins and cause high leve ls of organic carbon that may be disinfection byproduct precursors. Algal bloom frequency is tho ught to be a better indicator of potential use impairment than trophic status alone (Heiskary and Walker 1988). Some studies have suggested that algal bloom frequency increases expo nentially when average chlorophyll levels exceed 10 µg/L (Walker 1984; Falconer et al, 1999; Downing et al. 2001). However, these findings are based on interpretations of relatively poorly defined relationships. Additionally, these studies may be more applicable to lakes than reservoirs. When investigating the probability of blue-green algal dominance in water bodies, Downing et al. (2001) purposely excluded reservoirs from their study, potentially d ue to the fact that reservoirs respond

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differently to nutrient enrichment than natural lakes. This assumption is supported by Missouri research which shows that the history and frequency of high chlorophyll events differs among individual reservoirs, likely due to system-specific constraints of chlorophyll by biotic and abiotic factors (Jones et al. 2011). Based on existing data and studies, the relationships between chlorophyll levels and algal blooms are not predictable in Missouri reservoirs for use as a basis for developing criteria.

6.2.2. Taste and Odor Issues

Another potential approach is to target chlorophyll levels that minimize compounds responsible for taste and odor issues. Two such compounds, geosmin (trans-1, 10 dimethyl-trans-9-decalol) and MIB (2-methyl isoborneol), have been associated with blue-green algae blooms (Smith et al. 2002) but relationships are likely not universal (Graham et al. 2010, Graham et al. 2012, Otten et al. 2016). Smith et al. (2002) found a relationship between geosmin and chlorophyll concentrations based on a limited dataset based on only six samples from a single reservoir (Figure 6-3). From this relationship, Smith et al. (2002) provisionally suggested that taste and odor problems would cease when chlorophyll concentrations below 10 µg/L. However, this recommendation was based on an assumed odor threshold of 5 ng/L for geosmin, which varies between studies. For example, the American Water Works Association (2006) uses a geosmin threshold of 10 ng/L, which suggests that chlorophyll values beyond the predictive range of the Smith et al. (2002) relationship may be more appropriate. Due to the uncertainty associated with these relationships, taste and odor is not considered a sufficient basis for developing chlorophyll criteria.

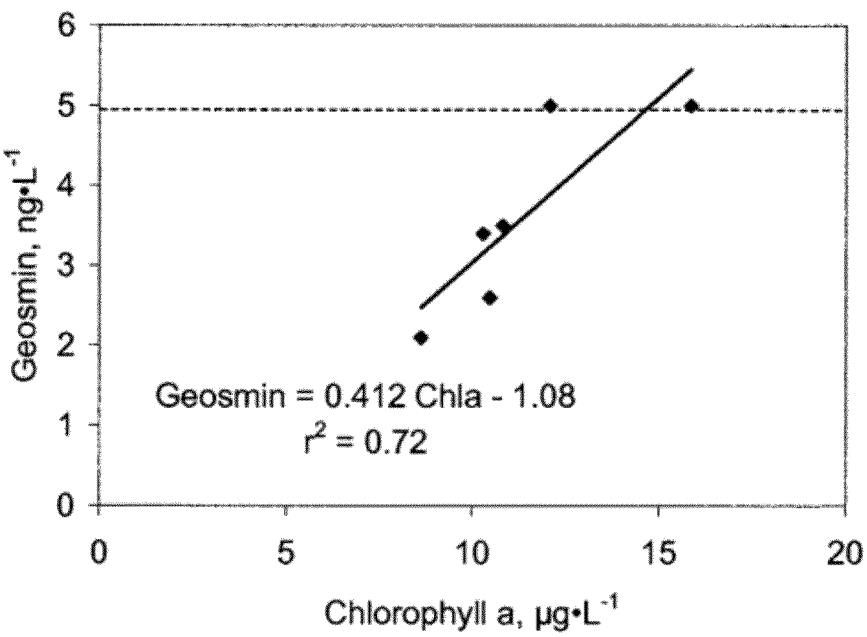

Figure 6-3. Relationship between Geosmin and Chlorophyll-a in Cheney Reservoir, USA. Taken from Smith et al. (2002).

6.2.3. Disinfection Byproducts

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As discussed in **Section 5.5** of this document, chlorophyll can contribute to DBP formation in some circumstances. However, relationships between DBPs, chlorophyll, and related variables in Missouri drinking water systems are very weak. Furthermore, there are no significant relationships between drinking water systems with reported MCL exceedances and chlorophyll or measured DBP levels and chlorophyll. As a result, these relationships cannot be used to develop scientifically defensible drinking water criteria.

During the stakeholder process, EPA suggested that MDNR review methods that have been used for establishing chlorophyll criteria based on DBPs in Colorado (Water Quality Control Division (WQCD) Pre-Hearing Statement 2011) and New York (Callinan et al. 2013). Both approaches are based on empirical data collected for individual lakes and associated distribution systems. MDNR reviewed these studies and determined that they are not appropriate for use in Missouri after making similar assessments using Missouri-specific data.

6.2.3.1. Colorado Approach

The state of Colorado (WQCD Pre-Hearing Statement 2011) evaluated the connections between DBP formation at water treatment plants and source water DOC and chlorophyll concentrations. This study was conducted to develop a quantitative relationship between lake chlorophyll levels and DBPs in distribution systems and ultimately resulted in a recommended chlorophyll criterion of 5 µg/L.

To evaluate the efficacy of TOC removal through water treatment systems, WQCD examined TOC removal efficiency in Colorado systems and compared the results to nationwide literature. Their evaluation yielded an estimated 20-30% removal of TOC for low-SUVA compounds. WQCD was also able to determine detailed treatment plant specific yield values for DBPs (ug DBP/mg DOC) in water treatment plants and correlate yield values to disinfectant type. Median disinfectant specific yield values were calculated for TTHM and HAA5 production and defined as "representative yield" values. The representative yield values were used to back calculate a "critical" DOC value to meet DBP MCLs of 80 µg/L for TTHM and 60 µg/L for HAA5.

To calculate the intake threshold DOC concentration, WQCD estimated a DOC removal efficiency of 25%. This removal efficiency yielded an estimated critical intake concentration of 4.0 mg/L DOC. Finally, WQCD converted the intake critical DOC concentration to an equivalent chlorophyll concentration by using a median ratio of 1 mg DOC per 1 µg chlorophyll, which yielded a lake chlorophyll criterion of 4.0 µg/L. This metric for converting DOC to chlorophyll was based on the observed relationship between DOC and chlorophyll in Colorado source waters. Lastly, the WQCD adjusted the chlorophyll lake criterion for the allowable frequency exceedance (once per five years), which increased the final chlorophyll criterion threshold concentration to 5.0 µg/L.

WQCD's approach is inappropriate for use in Missouri because data collected from Missouri reservoirs and drinking water systems demonstrate that comparable relationships do not exist. For example, one of the key components of WQCD's approach is using the observed relationship between lake DOC and chlorophyll to determine critical chlorophyll concentrations. However, similar relationships are not apparent in Missouri reservoir data (Figure 5-10, Figure 5-11) and exhibit significant variability across the range of observed chlorophyll. The absence of

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strong relationships in the Missouri data, coupled with the fact that there are no significant relationships between reported MCLs or measured DBP levels and chlorophyll, indicate that using DBPs to develop reservoir chlorophyll criteria is not scientifically defensible given the available data.

6.2.3.2. New York Approach

The New York State Department of Environmental Conservation (NYSDEC) proposed a chlorophyll criterion of 4-6 µg/L for water supply lakes and reservoirs (Callinan et al. 2013). The study focused on understanding contributions from autochthonous (in-lake) sources of organic matter such as algae. These contributions are typically more resistant to water treatment processes. The study compared average chlorophyll, THMFP and DOC concentrations to THMFP for 21 different source waters.

To derive a preliminary chlorophyll criterion, NYSDEC used an "off-the-shelf" simulation model from Rodriguez et al. (2000) to extrapolate from the THMFP relationships results to TTHM. The model uses a standard equation to quantify a TTHM concentration:

$$[TTHM] = 0.044(DOC)^{1.030} * (Time)^{0.262} * (pH)^{1.10} * (Dose)^{0.277} * (Temp)^{0.068}$$

The variables are defined as: TTHM (µg/L), DOC (mg/L), disinfection contact time (h), pH (between 0-14), disinfectant dosage (mg/L), and temperature (°C). To determine the "critical" DOC concentration (with the same meaning as the critical DOC concentration determined in the Colorado study), the researchers applied typical treatment system conditions to the model to solve for DOC at the TTHM MCL (80 µg/L). The system conditions modeled were as follows: residence time = 72 hours, pH = 7.8, chlorine dose = 1.0 mg/L and temperature = 20°C. The resulting critical DOC concentration from the model was 3 mg/L. NYSDEC then used observed data to link DOC to THMFP and THMFP to chlorophyll.

As with the Colorado approach, NYSDEC's approach ultimately relies on strong empirical relationships to derive chlorophyll criteria from DBP data. First, NYSDEC partially justifies their approach by demonstrating that a relationship between DOC and chlorophyll exists in New York lakes. However, the authors note that two lakes which were dominated by allochthonous inputs were significant outliers in the relationship. Based on the information currently available, most Missouri reservoirs would be considered "outliers" using the NYSDEC approach. As discussed previously, in Missouri reservoirs Veum (2006) found that 77% of the variation observed in DOC concentrations was attributed to hydraulic flushing rate and that 66% of DOC (as measured by SUVA) originated from allochthonous, or watershed-derived, sources rather than algal sources. As a result of these allochthonous inputs, relationships between DOC and chlorophyll in Missouri are weak (Figure 5-10, Figure 5-11).

Other empirical relationships used by NYSDEC to derive their criteria include relationships between DOC and THMFP and THMFP and chlorophyll. Similar to NYSDEC's data, the MU 2004 DBP study data show that average THMFP concentrations were strongly related to average summer DOC concentrations during the study (c=0.81). However, a strong relationship

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between THMFP and chlorophyll was not apparent in the Missouri data (Figure 5-9). As a result of the weak relationships in the Missouri data, the NYSDEC approach is not technically justified for developing scientifically defensible chlorophyll criteria.

6.2.4. Microcystins

Targeting protections from microcystins [5] produced by cyanobacteria provides an approach for setting chlorophyll criteria. EPA recently issued a Health Advisory (HA) for microcystins focused on drinking water as the primary source of exposure. The EPA recommended ten-day HA value for bottle-fed infants and young children of pre-school age is 0.3 µg/L and for school children through adults is 1.6 µg/L for microcystins (EPA 2015). EPA's HA levels additionally contain a margin of safety to address database uncertainties (EPA 2016).

The median level of chlorophyll in Missouri reservoirs that corresponds to microcystin levels less than EPA's most stringent HA level of 0.3 µg/L is approximately 25 µg/L (**Table** 5-2). The probability of exceeding this HA level at a chlorophyll level of 25 µg/L is less than 10% in Missouri reservoirs (**Figure** 5-7). Although relationships between chlorophyll, microcystin, geosmin, and other taste and odor compounds are generally unclear in the literature, are likely not universal across lakes, and are insufficient for developing criteria, it is interesting to note that the 10 ng/L geosmin advisory threshold used by the American Water Works Association (2008) corresponds to a chlorophyll value of approximately 28 µg/L according to the Smith et al. (2002) equation (**Figure 6-3**).

Targeting a microcystin level of 0.3 µg/L addresses EPA's concern that criteria be based on sound scientific rationale as it represents a scientifically-defensible endpoint to which reservoir chlorophyll levels can be correlated. Furthermore, targeting the lowest HA level recommended for finished drinking water as the basis for a source water chlorophyll criterion represents a proactive approach for protecting Missouri's reservoirs. While Missouri's drinking water supply beneficial use is based upon use of water supplies that *"yield potable water after treatment by public water treatment facilities"*, criteria based on source water quality prior to treatment conservatively provides an extra level of protection.

Phytoplankton community structure was analyzed for 63 Missouri reservoirs sampled during July 2003. The reservoirs ranged in chlorophyll concentration from 0.6 to 107.8 µg/L, at the time of sample collection. The distribution across the trophic gradient was fairly uniform, with 14 reservoirs having oligotrophic chlorophyll levels (<3.0 µg/L) and 8 reservoirs being in the hypereutrophic range (>40.0 µg/L) (**Table 6-3**). To provide greater detail, the eutrophic category was split into two categories: lower eutrophic (chlorophyll 9-25 µg/L) and upper eutrophic (chlorophyll 25-40 µg/L).

[5] Microcystin-LR is used as a surrogate for all microcystins.

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As expected, there was a general increase in the concentration of phytoplankton (cells/mL) across the trophic gradient (**Table 6-3**). The exception occurred between the lower and upper eutrophic categories, with the average number of phytoplankton cells per mL of sample in the upper eutrophic category being 22% less than measured in the lower eutrophic group. This decline in the cell abundance probably reflects a switch in the algal community, which has been noted in lakes and reservoirs in other regions.

Cyanobacteria abundance also increased with trophic status, with a similar decrease of around 25% between lower and upper eutrophic categories. Overall cyanobacteria dominated the phytoplankton communities in these 63 reservoirs, averaging 94% of the cell counts (range of 61% to 100%). Results indicate no trend in the proportion of cyanobacteria cells across the trophic gradient.

Table 6-3. Summary of Cyanobacteria Data Collected from Missouri Reservoirs.

Trophic Group	Chlorophyll Range (µg/L)	Average # of algal cells per mL	Average # of Cyanobacteria cells per mL	Average proportion of cyanobacteria	Average proportion of microcystin producing cyanobacteria
Oligotrophic (n=14)	<3.0	75,299	72,297	95%	<1%
Mesotrophic (n=11)	3.1 – 9.0	147,819	140,819	93%	<1%
Lower Eutrophic (n=18)	9.1 – 25.0	360,427	353,377	96%	3%
Upper Eutrophic (n=12)	25.1 – 40.0	281,500	265,670	92%	8%
Hypereutrophic (n=8)	>40.0	452,606	436,350	94%	16%

Cyanobacteria in the 63 reservoirs were classified into 14 different genera. Because microcystin is the most common toxin produced by cyanobacteria (Falconer et al. 1999), a summary of potential microcystin producing genera (Anabaena, Anabaenopsis, Aphanizomenon, Cylindrospermopsis, Microcystis, Phormidium and Planktothrix) is presented (**Table 6-3**). Microcytin producing genera tend to make up a larger portion of the phytoplankton community across the trophic gradient. On average, these genera account for <1% of all algal cells for reservoirs with <9µg/L chlorophyll. The increase for reservoirs with up to 25µg/L chlorophyll is marginal (3% on average), with microcystin producing genera averaging 16% of total cells counts for hypereutrophic reservoirs. **Figure 6-4** shows the proportion of potential microcystin producing cells versus chlorophyll concentration for the 63 reservoirs. Microcystin producing cells remain <10% of the total number of phytoplankton cells until 24 µg/L chlorophyll. Of the 21 reservoirs that had chlorophyll concentrations ≥24 µg/L, only 7 had phytoplankton communities consisted of >10% potential microcystin producing cells.

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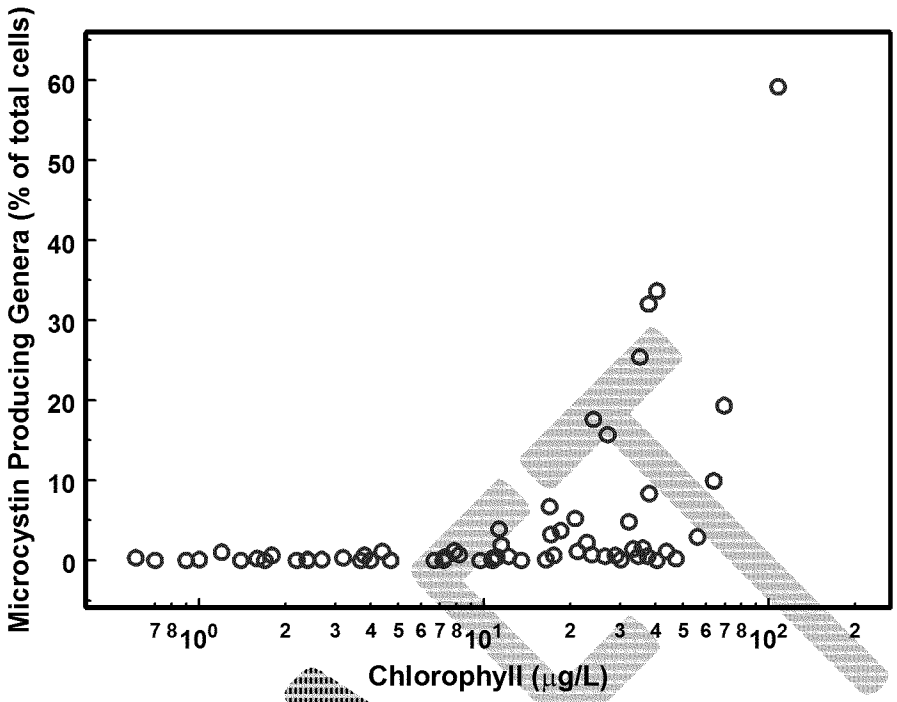

Figure 6-4. Relationship between Microcystin Produc ing Cyanobacteria Genera and Chlorophyll in Missouri Reservoirs.

6.3. Criteria Recommendation Summary

After reviewing the scientific literature, Missouri reservoir data, and criteria development activities across the country, the Department has d etermined that chlorophyll should serve as the basis for nutrient criteria in Missouri. Final recommended chlorophyll criteria vary by ecoregion and designated use (Table 6-4). The chlor ophyll criteria proposed in this document are intended to apply only to reservoirs at least 10 acres in size during normal pool conditions located outside the Big River Floodplain ecoregion. The 10 acre threshold was suggested in EPA's Nutrient Criteria Technical Guidance Manual (EPA 2000). It also reflects existing state regulations, which limit site-specific reservoir nu trient criteria to lakes larger than 10 acres outside the Big River Floodplain (10 CSR 20-7.031(5)N(2)).

Table 6-4. Final Ecoregional Chlorophyll Criteria f or Aquatic Life and Drinking Water Supply Beneficial Use Categories in Missouri.

Reservoir Ecoregion	Aquatic Life (µg/L)	Drinking Water Supply (µg/L)
Plains	30	25
Ozark Border	22	25
Ozark Highlands	15	25

Water quality criteria are expressed not only in te rms of magnitude (allowable concentration), but also in terms of duration and frequency. Durat ion refers to the time period over which exposure is to be averaged. Specifying a duration is necessary because water quality naturally

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fluctuates in response to a variety of factors. The chlorophyll criteria will be based on growing season summer average concentrations. Average growing season concentrations should be calculated as the geometric mean of a minimum of four samples per season. All samples must be collected from the reservoir surface, near the outflow end of the reservoir, and during the growing season of May through September. Criteria may be assigned at a later date to tributary arms of large reservoirs to provide additional protection.

Missouri researchers have shown that several years of data are necessary to accurately characterize reservoir chlorophyll conditions (Knowlton and Jones 2006b). Therefore, applying the criteria as single growing season, rather than long-term averages, is a conservative approach that is expected to provide sufficient protections for Missouri reservoirs. Frequency refers to how often the magnitude of the criterion may be exceeded. It is necessary to specify an allowable frequency because it is statistically impossible to project that criteria will never be exceeded. As ecological communities are naturally subjected to a series of stresses, the allowable frequency of pollutant-related stress should be set at a value that does not significantly increase the frequency or severity of all stresses combined (EPA 1994). EPA typically recommends an excursion frequency of not more than one in three years for most pollutants. MDNR is recommending the same excursion frequency for the chlorophyll criteria.

Lines of Evidence

Aquatic Life Use Criteria: 15 – 30 µg/L chlorophyll depending on region

- The Ozark Highlands are in the same ecoregion (XI) as West Virginia, where statewide chlorophyll criteria of 10 – 20 µg/L have been approved by EPA (Table 3-1).
- The majority of Missouri's reservoirs are in ecoregions IX and XI, similar to North Carolina, where statewide chlorophyll criteria of 15 – 40 µg/L have been approved by EPA (Table 3-1).
- The relationship between aquatic diversity and productivity is mixed (Table 6-1). Setting criteria at moderate chlorophyll levels (15 – 30 µg/L) is a conservative approach.
- Research on relationships between game fish health and productivity in Missouri reservoirs suggest a positive relation up to 50-70 µg/L chlorophyll. Setting chlorophyll criteria at 15 – 30 µg/L is a conservative approach.
- Ney (1996) reports sport fish biomass peaks around 100 µg/L TP, which would result in a chlorophyll concentrations of 36 µg/L in the Plains Region of Missouri.

Drinking Water Criterion: 25 µg/L chlorophyll state wide

- The median chlorophyll concentration for Missouri reservoir samples containing 0.1 – 0.3 µg/L microcystin is 25.3 µg/L (Table 5-2).
- The probability of microcystin >0.3 µg/L exceeds 0.10 at 30 µg/L (Figure 5-7).
- An extension of the geosmin-chlorophyll relation (Figure 6-3) to include a geosmin threshold of 10 ng/L (American Water Works Association 2008) translates to a chlorophyll concentration of 27 µg/L.
- Potential microcystin producing cells exceed 10% of the phytoplankton community at 24 µg/L (Figure 6-4).

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7. Gray Zone Assessment Decision Framework

The concept of a "gray zone" has been widely discussed as an approach for addressing uncertainty around predicting nutrient concentrations that adversely affect aquatic life. In April 2013, EPA convened a workshop in which experts proposed the use of a "gray zone" to define a range, above which designated uses are impaired, and below which designated uses are attained. Nutrient levels that fall within the "gray zone" would be subject to a decision framework to combat the uncertainty around the relationship between nutrient concentrations and biological response (EPA 2014). Similar approaches have been proposed in other states including Virginia (AAC 2012) and Arizona (ADEQ 2008). MDNR supports the use of this decision framework approach.

Although recommended criteria are limited to chlorophyll, MDNR is recommending the use of the causal variables TN and TP along with chlorophyll for defining the low end of the "gray zone" as part of a holistic approach to reservoir nutrient management. These values, hereinafter referred to as screening values, define the low end of the "gray zone". While not recommended as water quality criteria, screening values serve the purpose of defining the "gray zone" where impairment status is unclear without further evaluation and efforts may be needed to maintain the integrity of those waters.

Reservoirs that meet the applicable chlorophyll criteria but exceed the screening values for TP, TN, or chlorophyll fall into the "gray zone" and require a weight of evidence analysis (Figure 7-1). Screening values are similar to other numeric thresholds, like probable effect levels, that are included in Missouri's listing methodology document (LMD) but are not criteria and not solely used to make impairment decisions. Screening values help identify when a weight of evidence (WOE) analysis is needed and may be considered as part of that analysis.

7.1. Screening Value Recommendations

Recommended screening values for chlorophyll, TP, and TN are presented in Table 7-1. Screening values are based on conservative assumptions designed to facilitate early identification of potential nutrient-related impairments that might otherwise go undetected. As with the recommended water quality criteria, screening values represent growing season average conditions and should be calculated similarly.

Table 7-1. Screening Values Used to Supplement Chlorophyll Criteria Implementation.

Reservoir Ecoregion	Designated Use	Screening Value, µg /L		
		TP	TN	Chlorophyll
Plains	DWS	27	567	10
Plains	AQL	49	843	18
Ozark Border	DWS	31	642	10
Ozark Border	AQL	40	733	13
Ozark Highland	DWS	24	548	10
Ozark Highland	AQL	16	401	6

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The basis for selected screening values is described below.

- For DWS uses, chlorophyll screening values were set equal to 10 µg/L. This concentration was selected because it represents a level of chlorophyll that has been linked, albeit inconsistently, to the occurrence of algal blooms and taste and odor issues.
- For AQL uses, chlorophyll screening values were set equal to the 50 th percentile of the distribution of growing season chlorophyll data for each ecoregion (Figure 5-2).
- For both DWS and AQL uses, TP and TN screening values were back calculated using the respective chlorophyll screening value and relationships presented in Figure 5-3.

7.2. Weight of Evidence Factor Recommendations

MDNR will perform a WOE evaluation based upon quantitative analysis and expert opinion (e.g. state fishery biologists and water treatment specialists) to determine impairments. Reservoirs will be considered impaired if any of the following factors indicate designated use impairment.

Recommended weight of evidence factors for assessment of AQL uses include:

- Occurrence of fish mortality or morbidity events relating to excess algal production;
- Epilimnetic excursions from dissolved oxygen or pH criteria;
- Excessive cyanobacteria cell counts that cause detrimental impacts to the aquatic community;
- Detrimental shifts in aquatic diversity attributed to cultural eutrophication; or
- Excessive levels of mineral turbidity that consistently limit algal productivity during the period May through September.

Recommended weight of evidence factors for assessment of DWS uses include:

- Impacts on water treatment operations caused by excessive algal biomass;
- Excessive DBP formation associated with excessive algal biomass as determined by an exceedance of 80 µg/L TTHM or 60 µg/L HAA5 as an average of the Safe Drinking Water Act compliance monitoring results during the 2nd and 3rd quarters of the year; or
- Recurring algal toxins in excess of EPA's health advisory levels (0.3 µg/L for microcystins, 0.7 µg/L for cylindrospermopsin) in in the reservoir near drinking water intakes.

For both AQL and DWS uses, trend evaluations may also be used as part of a weight of evidence analysis. A critical consideration in implementing reservoir chlorophyll criteria is that the criteria protect against incremental deterioration of water bodies. Missouri's antidegradation policy already provides such protections as it requires the maintenance and protection of existing water quality. However, determining whether or water quality is deteriorating requires a trend analysis. In the case of reservoir chlorophyll levels, a trend analysis must include a rigorous statistical evaluation based on a robust dataset.

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MDNR already incorporates provisions for conducting reservoir water quality trend analyses in their bi-annual 305(b) integrated water quality report (MDNR 2016a), which is reviewed by EPA. MDNR generally uses linear regression to identify trends. Because identifying trends in reservoir water quality can be complicated by year-to-year variations, changing climate conditions, data limitations, and ecoregions, MDNR suggests tracking reservoir trends on an individual basis for management purposes.

MDNR also incorporates provisions for conducting trend analyses to identify threatened waters in the bi-annual 303(d) listing methodology document (LMD), which is also reviewed by EPA. The most recent LMD states that time trend analyses should be used to identify waters that will not meet their designated uses before the next 303(d) listing cycle (MDNR 2016b).

Recommended guidelines for conducting a trend analysis on chlorophyll levels are presented below:

- When evaluating trends, confounding, or exogenous variables, such as natural phenomena (e.g., rainfall, flushing rate and temperature) must be controlled for.
- The trend must be statistically significant. This process involves standard statistical modeling, such as least squares regression or LOcally WEighted Scatterplot Smoothing (LOWESS) analysis. To be considered statistically significant, the *p* value associated with the residuals trend analysis shall be less than 0.05.
- Impairment decisions based on trend analysis should, at a minimum, demonstrate that the slope of the projected trend line is expected to exceed the chlorophyll criterion within 5 years and that there is evidence of anthropogenic nutrient enrichment.

If the weight of evidence analysis suggests designated uses are being attained, the reservoir should be placed into Category 3A of MDNR's Assessment, Listing, and Reporting categories (MDNR 2016a). If sufficient data are not available to adequately assess use attainment using the weight of evidence factors outlined above, the reservoirs should be place into Category 3B so that these waters are prioritized for additional future monitoring. If the weight of evidence analysis demonstrates impairment, the reservoir should be placed into Category 5, 5 Alt., or 4B, as appropriate.

Table 7-2. MDNR's Assessment, Listing, and Reporting Categories.

Category	Description
Category 1	All uses fully maintained.
Category 2	At least one use has inadequate data to make a use attainment decision.
Category 2A	Available data suggest compliance with water quality standards.
Category 2B	Available data suggest noncompliance with water quality standards. High priority for additional monitoring.
Category 3	Inadequate data to make a compliance determination for all uses.
Category 3A	Available data suggest compliance with water quality standards. Lower priority for additional monitoring than 3B.
Category 3B	Available data suggest noncompliance with water quality standards. High priority for additional monitoring.
Category 4	Water quality standards are not attained but a TMDL is not required.
Category 4A	A TMDL has already been conducted.

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Category 4B	Controls other than a TMDL will correct the impairment.
Category 4C	Impairment not caused by a discrete pollutant.
Category 5	A TMDL is required.
Category 5 Alt.	An alternative restoration approach is being pursued. Low TMDL priority.

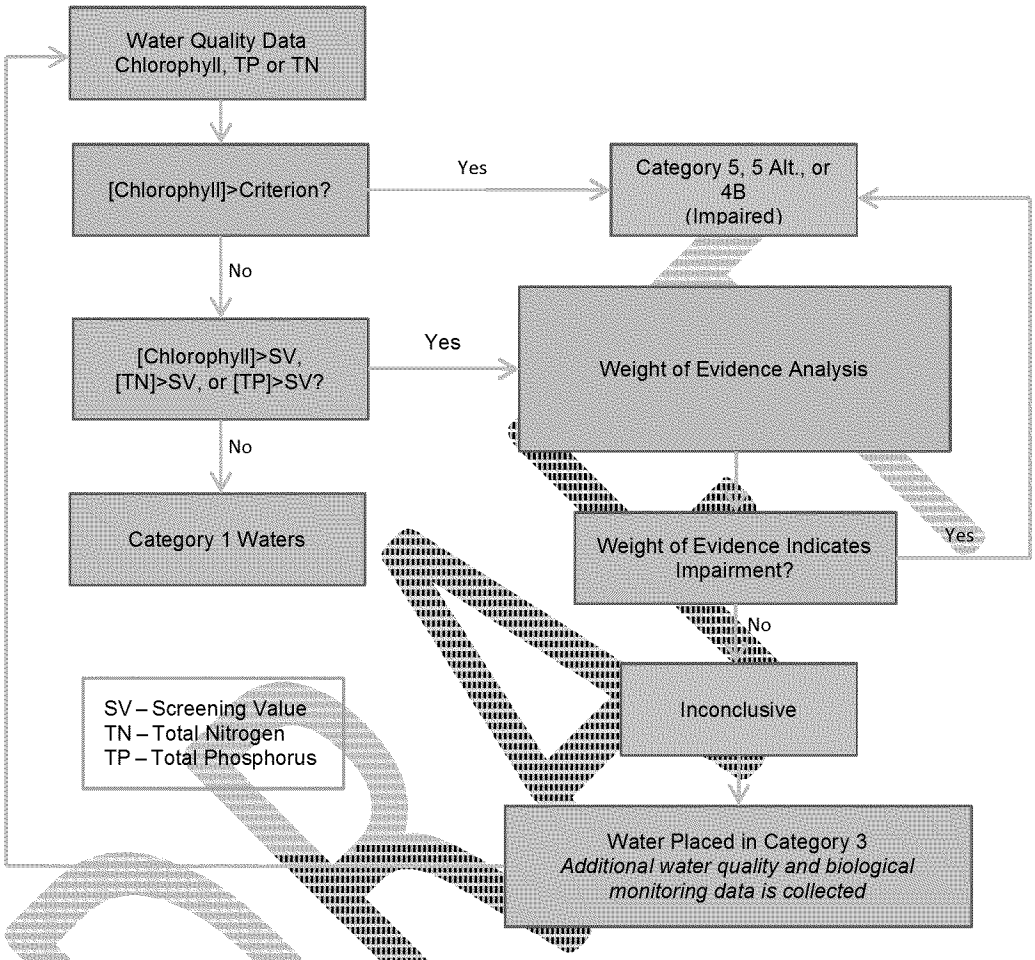

Figure 7-1. Missouri Chlorophyll Criteria and Gray Zone Decision Framework Implementation Approach.

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