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JUL 14 2016

Ref: 8EPR-EP

Lauren Evans, Chair
Water Quality Control Commission
4300 Cherry Creek Drive South
Denver, CO 80222-1530

Re: EPA Action on Revisions to Regulation #31 Regarding Nutrients

Dear Ms. Evans:

The U.S. Environmental Protection Agency (EPA) has completed its review of certain revisions to the Basic Standards and Methodologies for Surface Waters (Regulation #31) regarding nutrients. The revisions that are the subject of today's EPA action were adopted by the Colorado Water Quality Control Commission (Commission) on June 11, 2012, with an effective date under state law of September 30, 2012. The submission letter included an opinion of the Attorney General certifying that the standards were duly adopted pursuant to State law. Receipt of the revised standards on June 19, 2012 initiated the EPA's review pursuant to Section 303(c) of the Clean Water Act (CWA or the Act).

The EPA commends the Water Quality Control Division (Division) and the Commission for the progress achieved toward controlling nutrients in Colorado waters. These water quality standards provisions will support protection of high quality waters and restoration of impaired waters. In addition, although not water quality standards and therefore not subject to review by the EPA, the EPA applauds the requirements in Regulation #85, which include technology-based effluent requirements and monitoring requirements for both ambient waters and discharges. The EPA appreciates the thoughtful, long-term approach taken by the State to address an important and challenging statewide water quality issue.

CLEAN WATER ACT REVIEW REQUIREMENTS

CWA § 303(c)(2) requires States and authorized Indian Tribes to submit new and revised water quality standards to EPA for review. The EPA is required to review and approve or disapprove the revised standards pursuant to CWA § 303(c)(3). The Region's goal has been, and will continue to be, to work closely and collaboratively with States and authorized Tribes throughout the standards revision process so that submitted revisions can be approved by the EPA.

TODAY'S ACTION

The EPA is approving some revisions and taking no action on other revisions to Regulation #31. The major revisions and the EPA's actions are briefly summarized in Table 1 and the bulleted paragraphs below. In addition, for each of the new and revised standards that the EPA is acting on today, Enclosures 1 and 2 provide more detailed discussion of the adopted revisions and the rationale for the EPA's action.

Table 1
Summary of EPA's Action on the Revisions to Regulation #31

Section	Description	EPA Action	Rationale
31.9(1)(c)	Critical low flows	Approved	Enclosure 1
31.13(1)(d)(i)	Direct use water supply (DUWS) sub-classification	Approved	Enclosure 1
31.17(b), (c)	TP and TN Interim Values for Rivers/Streams	No Action	Enclosure 1
31.17(d)	Chlorophyll-a Interim values • Streams/Rivers • Lakes/Reservoirs • DUWS Sub-classification	 Approved Approved Approved	 Enclosure 1 Enclosure 1 Enclosure 1
31.17(h)	Site-specific flexibility	Approved	Enclosure 1
31.17(e),(f),(g)	Phased Application Provisions	No Action	Enclosure 1
31.17(b), (c)	TP and TN Interim Values for Lakes/Reservoirs	Approved, with recommendations	Enclosure 2

- 31.9(1)(c). Critical Low Flows
  EPA is approving this new provision, which identifies a critical low flow general policy for purposes of calculating water quality-based effluent limits (WQBELs) for nutrients.

- 31.13(1)(d)(i). Direct Use Water Supply (DUWS) Sub-classification
  EPA is approving this new provision, which establishes a use sub-classification for Direct Use Water Supply (DUWS) lakes and reservoirs.

- 31.17(b) and (c). Rivers and Streams – TP and TN Interim Values
  EPA is not acting on these provisions.

- 31.17(d). Chlorophyll-a Interim Values
  EPA is approving the chlorophyll-a interim values for rivers/streams (recreation use), lakes/reservoirs (aquatic life and recreation uses) and the DUWS sub-classification (water supply use).

- 31.17(h). Site-Specific Flexibility
  EPA is approving this new provision, which establishes that the Commission has authority to adopt, before and after May 31, 2022, site-specific standards either more or less stringent than interim values.

- 31.17(e), (f), and (g). Phased Application Provisions
  EPA is not acting on these new provisions.

- 31.17(b) and (c). Lakes and Reservoirs – TP and TN Interim Values
  The EPA is approving the total phosphorus (TP) and total nitrogen (TN) interim values for lakes and reservoirs (hereafter "lakes"). The approval action is based on EPA's finding that the interim values are appropriate for protection of lakes with relatively low chl-a yield, per unit of TP or TN, but may not be protective of lakes where a strong algal response to nutrient pollution can be expected (i.e., environmental conditions are favorable for algal growth). EPA understands that Colorado follows a two-step process to assign numeric standards to lakes, and that the interim values (step 1) become legally binding numeric standards for navigable waters only after they are applied to individual segments (step 2) and EPA approves the segment-specific application decisions. In step 2, pursuant to 31.17(h), the Commission has flexibility to apply numeric standards different than the interim values. When determining the appropriate numeric standards for individual segments, Colorado should consider that many different site-specific (including non-nutrient) factors can suppress/limit algal growth (but such influences are not always present), and refinements to the interim values may be necessary in order to be protective. Enclosure 2 provides the rationale for EPA's action and recommendations regarding application of TP and TN numeric standards to individual lake and reservoir segments.[1]

Today's letter applies only to water bodies in the State of Colorado, and does not apply to waters that are within Indian Country, as defined in 18 U.S.C. § 1151. Today's letter is not intended as an action to approve or disapprove water quality standards applying to waters within Indian Country. The EPA, or authorized Indian Tribes, as appropriate, will retain responsibilities for water quality standards for waters within Indian Country.

ENDANGERED SPECIES ACT REQUIREMENTS

The water quality standards provisions addressed in today's EPA action do not actually set water quality standards for individual water bodies, and thus have no effect on Endangered Species Act (ESA) listed or proposed endangered or threatened species or critical habitat. As a result, for the provisions approved today, no consultation with the U.S. Fish and Wildlife Service is required. The EPA anticipates that the Agency will conduct ESA Section 7 consultation where appropriate after these interim values (or other values) are adopted during the basin review process and the EPA is reviewing the state water quality standards pursuant to CWA Section 303(c).

[1] The EPA may not support/approve numeric nutrient criteria based upon methods similar to those used by Colorado in states that do not follow a similar 2-step adoption process.

CONCLUSION

EPA Region 8 acknowledges the investment of the Division and the Commission in adopting new water quality standards provisions into Regulation 31 that will guide future triennial reviews of Colorado's various basin-specific WQS regulations. We look forward to working with the State to make further progress on controlling nutrient pollution. Questions may be directed to David Moon at (303) 312-6833 or Tina Laidlaw at (406) 457-5016.

Sincerely,

Martin Hestmark
Assistant Regional Administrator
Office of Ecosystems Protection
and Remediation

Enclosures (2)

ENCLOSURE 1:
RATIONALE FOR THE U.S. EPA REGION 8 ACTION ON REVISIONS TO THE BASIC STANDARDS AND METHODOLOGIES FOR SURFACE WATERS

This enclosure addresses certain new and revised provisions of Regulation #31 adopted by the Water Quality Control Commission (Commission) on June 11, 2012. New/revised provisions addressed below are as follows:

- 31.9(1)(c). Critical low flows.
- 31.13(1)(d)(i). Direct use water supply (DUWS) sub-classification.
- 31.17(a). Overview.
- 31.17(b) and (c). Total phosphorus and total nitrogen interim values for rivers and streams.
- 31.17(d). Chlorophyll-a interim values.
- 31.17(e). Use of phosphorus and chlorophyll-a interim values prior to May 31, 2022.
- 31.17(f). Use of nitrogen interim values prior to May 31, 2022.
- 31.17(g). Use of phosphorus, nitrogen and chlorophyll-a interim values after May 31, 2022.
- 31.17(h). Site-specific flexibility.

APPROVED REVISIONS

31.9(1)(c). Flow Considerations.

New section 31.9(1)(c) identifies critical low flows for purposes of calculating water quality-based effluent limitations (WQBELs) for nutrients to be included in CWA National Pollutant Discharge Elimination System (NPDES) permits.

> Section 31.9:
> (1) Water quality standards shall apply at all times; provided, that in developing effluent limitations or other requirements for discharge permits, the Division shall normally define critical flow conditions using the following low-flow values:
> (c) Total phosphorus and total nitrogen limitations: the annual median of the daily average flows with a 1 in 5 year recurrence interval.

The EPA's water quality standards (WQS) regulation explains that "States may, at their discretion, include in their State standards, policies generally affecting their application and implementation, such as mixing zones, low flows and variances. Such policies are subject to the EPA's review and approval." (40 CFR § 131.13)

The revision to Colorado's "low flows" general policy identifies river and stream low flows, for use in calculating nutrient WQBELs, which are consistent with the adopted interim values. That is, the duration and frequency provisions of the specified low flows match the duration and frequency provisions of the interim values. The EPA concludes that use of the specified low flows will result in water quality-based effluent limits (WQBELs) or other permit requirements that are consistent with achieving the interim values.

In cases where segment-specific numeric standards are adopted that have duration and/or frequency provisions different than those incorporated into the interim values, Section 31.9(1)(c) allows the flexibility to use

appropriate low flows that are consistent with the site-specific numeric standards (i.e., "the Division shall normally define critical flow conditions using the following low-flow values"). The revision to Section 31.9 is approved.

31.13(1)(d)(i). Domestic Water Supply.

New Section 31.13(1)(d)(i) establishes a use sub-classification for Direct Use Water Supply (DUWS) lakes and reservoirs. Any entity (e.g., a drinking water provider) may propose application of the new sub-classification to a lake or reservoir. The provision identifies two situations eligible for a DUWS sub-classification:

31.13(1)(d)(i)

(B) Direct use water supply lakes and reservoirs (DUWS) are those water supply lakes and reservoirs where:

(I) There is a plant intake located in the lake or reservoir or a man-made conveyance from the lake or reservoir that is used regularly to provide raw water directly to a water treatment plant that treats and disinfects raw water, or

(II) The Commission, based on evidence in the record, determines that the reservoir will meet the criteria in 31.13(1)(d)(i)(B)(I) in the future.

The EPA's water quality standards regulation allows States the discretion and flexibility to establish sub-categories of designated uses (40 CFR § 131.10(c)). In this case, the use classification provides Colorado (and Colorado drinking water providers) with an additional source water protection tool that will assist with maintaining and restoring water quality in lakes and reservoirs used as water supplies. The new provision is approved.

31.17(a).

New Section 31.17(a) contains only non-substantive introductory information. It discusses how Section 31.17 is organized. Section 31.17(a) is approved.

31.17(d). Chlorophyll-a Interim Values

Section 31.17(d) identifies chlorophyll-a interim values.[1] The EPA is approving the chlorophyll-a interim value for rivers and streams (cold and warm), which is based on protection of recreation uses, the interim value for the DUWS sub-classification, which is based on protection of human health, and the interim values for lakes and reservoirs (cold and warm), which are based on protection of recreation and aquatic life uses.

[1] "Interim values" may be considered for application to specific water bodies during triennial review of the basin-specific Colorado WQS regulations. The Statement of Basis and Purpose explains that the Commission labeled these values "interim" to emphasize its intent to undertake further review of the evolving science regarding nutrients before applying numerical nutrient standards broadly to surface waters throughout Colorado.

Table 1 - Chlorophyll-a Interim Values		
Waterbody Type	**Value**	**DUWS**
Lakes and Reservoirs, cold, > 25 acres	8 µg/L[a]	5 µg/L[c]
Lakes and Reservoirs, warm > 25 acres	20 µg/L[a]	
Lakes and Reservoirs, ≤ 25 acres	RESERVED	
Rivers and Streams cold	150 mg/m^2 [b]	
Rivers and Streams warm	150 mg/m^2 [b]	

[a] Summer (July 1-September 30) average chlorophyll a (µg/L) in the mixed layer of lakes (median of multiple depths), allowable exceedance frequency 1-in-5 years.
[b] Summer (July 1 – September 30) maximum attached algae, not to exceed.
[c] March 1-November 30 average chlorophyll-a (µg/L) in the mixed layer of lakes (median of multiple depths), allowable exceedance frequency 1-in-5 years.

The interim values are supported by the technical rationale developed by the Water Quality Control Division, which is described in the following documents submitted to the Commission during the rulemaking process: (1) proponent's pre-hearing statement, (2) responsive pre-hearing statement, and (3) rebuttal statement. Briefly, the WQCD rationale can be summarized as follows.

Rivers and Streams

The chlorophyll-a interim value for rivers and streams (150 mg/m^2, not to be exceeded) is for protection of recreation uses, and is based on a user perception survey conducted by Montana Department of Environmental Quality (MT DEQ) (Suplee et al. 2009). The purpose of the MT DEQ survey was to identify a threshold of benthic algal abundance (using chlorophyll-a as a surrogate measure) above which users are discouraged from recreating in a river or stream. The premise of the approach is that when algal abundance becomes excessive, the visual appearance of the stream (i.e., its color or "greenness") discourages recreation and impairs recreation designated uses. A key conclusion of the survey was that streams are considered "desirable" for recreation when chlorophyll-a levels are less than or equal to 150 mg/m^2. This threshold provides the basis for the interim value adopted by Colorado. Additional supporting information is included in the documents submitted by the WQCD (e.g., proponent's pre-hearing statement, Exhibit 11).

Direct Use Water Supplies

The chlorophyll-a interim value for the DUWS sub-classification (5 µg/L) is for protection of human health, and is based on achieving acceptable levels of disinfection by-products (DBPs) (trihalomethanes, haloacetic acids) in finished drinking water. The premise of the approach is that limiting algal abundance (using chlorophyll-a as a surrogate measure) reduces the precursors to DBP formation (dissolved organic carbon or DOC) in the ambient source water, which in turn reduces the concentration of DBPs in finished drinking water (Walker 1983). Detailed information on the approach followed to derive the interim value can be found in the documents submitted by the WQCD (e.g., proponent's pre-hearing statement, Exhibit 10). Generally, the approach included several elements:

- A distribution system dissolved organic carbon (DOC) target (3.0 mg/L) was determined from the maximum contaminant level (MCL) for trihalomethanes (TTHMs) and haloacetic acids (HAA5) using the median yield (µg DBP/mg DOC) for Colorado drinking water systems.

- An ambient DOC target (4.0 mg/L) was determined assuming 25% drinking water treatment removal efficiency, based on data for situations where lakes have low specific UV absorbance (SUVA) total organic carbon.
- An ambient chlorophyll-a target of 4 µg/L (expressed as a median of the annual averages) was calculated from the ambient DOC target, and then adjusted to an 80th percentile of the annual averages ambient target (5 µg/L chl-a), consistent with the allowable exceedance frequency.
- The final result is a chlorophyll-a interim value of 5 µg/L, as an average of March through November measurements. December through February measurements are not included for several reasons (e.g., the difficulty of winter sampling). The value may be exceeded once in five years.

Lakes and Reservoirs

The chlorophyll-a interim values for cold lakes (8 µg/L) and warm lakes (20 µg/L) are supported by the technical rationale described in the rulemaking documents submitted by the WQCD (e.g., Exhibit 13 of the proponent's pre-hearing statement). Such interim values are intended to protect both recreation and aquatic life uses, and were derived based on observed relationships between chlorophyll-a and a suite of water quality indicators (pH, water clarity, bloom frequency) with consideration of other risks such as cyanobacteria abundance, toxin exposure, and hypolimnetic dissolved oxygen.

The WQCD chose the Organization for Economic Cooperation and Development (OECD) boundary between mesotrophic and eutrophic conditions (8 µg/L chlorophyll-a) as the interim value for cold lakes (OECD 1982). The Division demonstrated that this value poses little risk of water quality impacts. For warm lakes, despite interest from stakeholders in setting the chlorophyll-a goal at the OECD boundary between eutrophic and hypereutrophic conditions (25 µg/L), the WQCD proposed a lower value (20 µg/L) in order to minimize the risk of water quality impacts for parameters such as pH, clarity, bloom frequency, and cyanobacteria abundance. The WQCD supporting analysis makes a compelling demonstration that chl-a summer averages above 20 µg/L put aquatic life and recreation uses at risk. For example, the Division showed that exceedance of the pH standard is likely when chlorophyll-a exceeds about 16 µg/L. In addition, the WQCD estimated that choosing 25 µg/L instead of 20 µg/L chlorophyll-a would double the expected bloom frequency (instantaneous chlorophyll-a > 30 µg/L).

The EPA concurs that the aquatic life and recreation risks associated with summer average chl-a concentrations above 20 µg/L are problematic and would place aquatic life and recreations uses at risk, and that it is important to regulate lake nutrient concentrations so that the 20 µg/L interim value is achieved. The EPA's review of the TP and TN interim values for lakes is discussed in Enclosure 2.

In developing the interim chlorophyll-a values, the WQCD considered the year-to-year variability in summer average chlorophyll-a concentrations that can be expected (Knowlton and Jones 2006). Using data from well-studied systems (i.e., reservoirs where five or more summer average chlorophyll-a concentrations are available) the Division developed a relationship between 80th percentile and 50th percentile chlorophyll-a summer average concentrations for Colorado lakes (Proponent's Pre-Hearing Statement, Exhibit 13, Figure 62). The estimations in their analysis provide a useful indication of the long-term median (or typical) summer average concentrations that need to be achieved in order to assure attainment of the (80th percentile) interim values.

Instantaneous chlorophyll-a concentrations exceeding 30 µg/L typically are considered to put beneficial water uses at risk. Both the EPA's review and the WQCD supporting analysis indicate that the warm lakes interim value will not completely eliminate the occurrence of such algal blooms in warm Colorado lakes and reservoirs. Where

the distribution of chlorophyll-a summer averages matches the interim value, blooms greater than 30 µg/L chlorophyll-a would be unlikely in a typical lake-year, but likely in the most productive lake-years. For example:

- The 80th percentile interim value (20 µg/L) relates to a long-term median or typical summer average of 12.94 µg/L chl-a, which in turn relates to a summer maximum concentration of ~23 µg/L (Figure 1).
- Where summer average chl-a equals or exceeds the interim value (20 µg/L chl-a), summer maxima approaching or exceeding ~40 µg/L can be expected (Figure 1).
- The WQCD estimated that at the 20 µg/L chlorophyll-a interim value for warm lakes, algal blooms (chl-a > 30 µg/L) would be observed in about 4 days each summer, on the average (Exhibit 13 of the proponent's pre-hearing statement, page 98).

The EPA concludes that the 20 µg/L chlorophyll-a interim value for warm lakes, though not without some risk, reasonably minimizes the risk to recreation and aquatic life uses, and is consistent with the discretion afforded to States under the CWA and the EPA's implementing regulations.

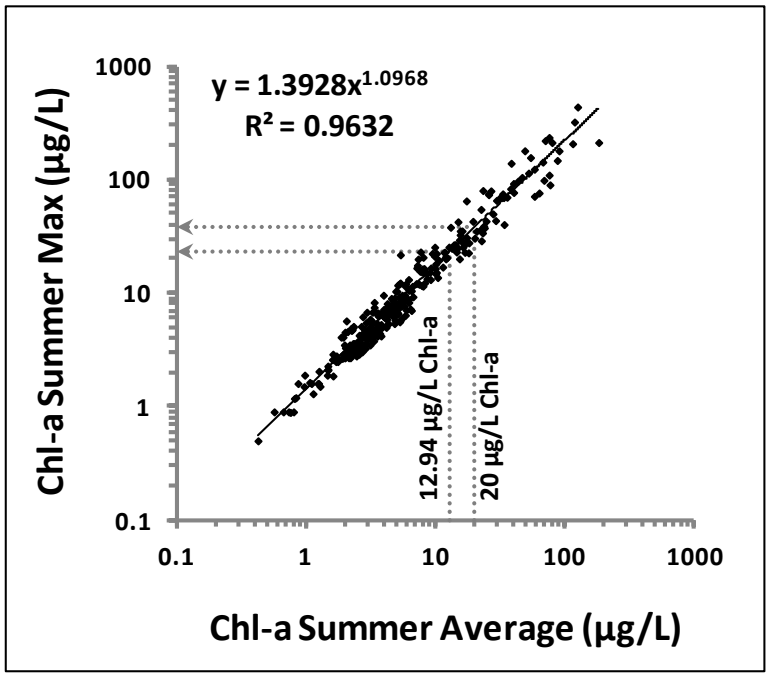

Figure 1. Summer maximum vs summer average chlorophyll-a in Colorado lakes

EPA Action

Based on review of the WQCD technical rationale and all comments/documents submitted to the WQCC during the rulemaking process, the EPA has concluded that the chlorophyll-a interim values are consistent with the EPA's water quality standards regulation:

> "States must adopt those water quality criteria that protect the designated use. Such criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use. (40 CFR § 131.11(a)(1))."

The EPA has concluded that the 150 mg/m^2 interim value will be protective of recreation use classifications assigned to rivers and streams, the 5 µg/L interim value will be protective of direct use water supply use classifications, the 8 µg/L interim value will be protective of recreation and aquatic life use classifications assigned to cold lakes and reservoirs, and the 20 µg/L interim value will be protective of recreation and aquatic life use classifications assigned to warm lakes and reservoirs. Accordingly, the EPA has concluded that these interim values are consistent with § 131.11(a)(1) of the EPA's water quality standards regulation. The interim values are approved.

<u>31.17(h). Site-Specific Flexibility to Consider Alternatives to the Interim Values.</u>

New Section 31.17(h) establishes that the Commission has authority to adopt, before and after May 31, 2022, site-specific standards either more or less stringent than interim values. Similarly, the EPA's water quality standards regulation allows States the latitude and discretion to adopt numeric standards based on site-specific conditions (40 CFR § 131.11(b)(1)(ii)). Accordingly, the new provision is approved.

PROVISIONS THE EPA IS NOT ACTING ON TODAY

- 31.17(b) and (c). Total phosphorus and total nitrogen interim values for rivers and streams.
- 31.17(e). Use of phosphorus and chlorophyll-a interim values prior to May 31, 2022.
- 31.17(f). Use of nitrogen interim values prior to May 31, 2022.
- 31.17(g). Use of phosphorus, nitrogen and chl-a interim values after May 31, 2022.

REFERENCES

Knowlton, M.F., and J.R. Jones. 2006. Natural variability in lakes and reservoirs should be recognized in setting nutrient criteria. Lake and Reserv. Manage. 22(3):161-166.

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Suplee, M.W, V. Watson, M. Teply, and H. McKee. 2009. How green is too green? Public opinion of what constitutes undesirable algal levels in streams. Journal of the American Water Resources Association 45(1): 123-140.

Walker, W.W. 1983. Significance of eutrophication in water supply reservoirs. Journal of the American Water Works Association 75: 38-42.

ENCLOSURE 2:
TP AND TN INTERIM VALUES FOR LAKES AND RESERVOIRS

This enclosure explains the rationale for the EPA's approval of the total phosphorus (TP) and total nitrogen (TN) interim values for lakes and reservoirs adopted by the Water Quality Control Commission (Commission) on June 11, 2012. The discussion below is organized as follows:

I. Background Information
II. Derivation of Colorado's TP and TN Interim Values
III. EPA's Review of the TP and TN Interim Values
IV. EPA's Action
V. Recommendations for the Application of TP and TN Standards in Colorado's Basin-Specific WQS Rules
VI. References

I. BACKGROUND INFORMATION

Anthropogenic Eutrophication of Lakes

The natural process of eutrophication has been defined as the "alteration of the production of a lake along a continuum in the direction from low to high values, that is, from oligotrophy to eutrophy" (Wetzel 2001). Accordingly, acceleration of the eutrophication process by human activity (e.g., nutrient pollution) is often referred to as anthropogenic (or cultural) eutrophication. Nutrient pollution of lakes can affect recreation, aquatic life, water supply (taste and odor, toxins), and other uses. Such effects can diminish the perceived value of a water body, and cause economic impacts, including decreased property values and loss of income for businesses that depend on water recreation (Smith 2003). Where such problems develop, recommended restoration methods have included reduction of external loading of phosphorus (Schindler 2008) and nitrogen (Paerl and Otten 2012, U.S. EPA 2015).

The risk and negative consequences of anthropogenic eutrophication, including high chlorophyll-a levels, is reviewed in Exhibit 13 of the WQCD pre-hearing statement (CDPHE 2011), submitted by the Division during the nutrient water quality standards rulemaking process.[1]

Algae blooms are problematic because they are aesthetically unpleasant, and because they affect the safety of water recreation (e.g., in swimming areas). Nutrient pollution and algal blooms also pose risks to aquatic life uses. Such problems can include loss of transparency, elevated pH, shifts in species composition, increased algal size (i.e., diameter, which may affect edibility by zooplankton), toxin production, and reduced yields of desirable finfish and shellfish (Smith 2003). Following blooms, decomposition can result in oxygen depletion and fish kills (Barica 1993).

High chlorophyll levels typically mean a less diverse phytoplankton assemblage, with an elevated risk that total biomass will be dominated by cyanobacteria (Watson et al. 1997, Downing et al. 2001).[2] Cyanobacteria can

[1] Chlorophyll-a is a commonly used surrogate measure of algal biomass.
[2] Cyanobacteria are also known as Cyanophyta or blue-green algae. Although photosynthetic, they are bacteria, not algae. In lakes, as the eutrophication process advances, the percentage of biomass contributed by cyanobacteria increases. Cyanobacteria is a large and diverse phylum, with each species having different habitat requirements and characteristics.

affect water uses in a variety of ways ranging from aesthetic concerns (unsightly appearance or odor), to skin irritations/allergic effects during recreational exposure, to more serious health impacts when humans or animals ingest water with high concentrations of cyanotoxins (WHO 2003). Although some species of cyanobacteria can fix nitrogen from the atmosphere, dominance by cyanobacteria does not necessarily mean a preponderance of nitrogen-fixers, as such species require specific environmental conditions to be successful (Havens et al. 2003, Lewis et al. 2008). Similarly, not all species of cyanobacteria are capable of producing toxins, and multiple factors influence the risk of toxin production (Dokulil and Teubner 2000, Dolman et al. 2012).

During Colorado's rulemaking process, the Division used their analysis linking chlorophyll-a to pH and other water quality impacts to caution against a warm lakes chlorophyll-a value higher than 20 µg/L, as suggested by some stakeholders, and clearly demonstrated why it is critical that TP and TN values are selected that achieve the chlorophyll-a value of 20 µg /L.

See Enclosure 1 for discussion of the EPA's rationale for approving the chlorophyll-a interim values for lakes and reservoirs.

II. DERIVATION OF COLORADO'S TP AND TN INTERIM VALUES

To derive interim values for TP and TN for application to lakes (Table 1), the Water Quality Control Division (WQCD or the Division) first identified 80th percentile (of the summer averages) interim values for chlorophyll-a (see previous section). An "80th percentile" means the summer average concentration that must be attained in 4 out of 5 years. Different 80th percentile chl-a values were selected for cold lakes (8 µg/L) and warm lakes (20 µg/L). In Step 2, an empirical relationship, using data from well-studied lakes, was used to convert each 80th percentile interim chl-a value to a 50th percentile chl-a target, i.e., a long-term median of the summer averages (CDPHE 2011, Figure 62).

Table 1
Interim Values for Colorado Lakes and Reservoirs (µg/L)

Use	Parameter	Step 1 Chl-a Int. Value (80th %tile of summer avgs)	Step 2 Chl-a Target (median of summer avgs)	Step 3 TP/TN Targets (median of summer avgs)	Step 4 TP/TN Int Values (80th %tile of summer avgs)
COLD LAKES	Chl-a	8 →	5.25		
Aq. Life and Recreation	TP			19.8 →	25
	TN			358 →	426
WARM LAKES	Chl-a	20 →	12.94		
Aq. Life and Recreation	TP			65.9 →	83
	TN			744 →	910

To translate the median summer average chl-a targets to median summer average TP and TN targets (Step 3), the Division compiled summer averages from all Colorado lakes and derived (log-log) chl:TP and chl:TN empirical response relationships. The chl-a vs TP regression was based on 282 sets of summer averages (54 lakes) and the chl-a vs TN regression was based on 121 sets of summer averages (30 lakes). Summer averages were included where at least 3 summer (July – September) measurements of both parameters were available. The empirical models are shown in Figure 1, and discussed in CDPHE 2011, pp. 60-63. The comparison shows that the smaller

set of TN summer averages (spanning roughly 1 order of magnitude) occupy a more narrow range than the TP summer averages (spanning roughly 2 orders of magnitude). The chl-a vs TN regression has steeper slope and somewhat higher correlation. Because they are based on data from both cold and warm lakes (combined), the Figure 1 equations apply to both cold and warm lakes, and were used by the Division to calculate the TP and TN targets corresponding to each chl-a target concentration.

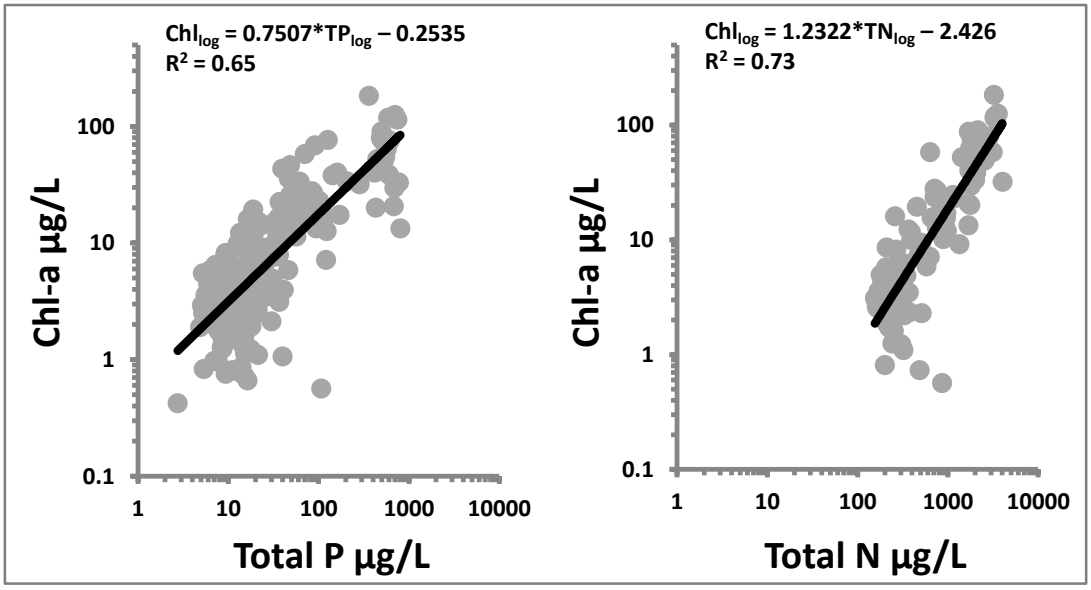

Figure 1. WQCD Chl:TP and Chl:TN empirical models (summer averages)

In the final step, another set of empirical relationships was used to convert the median summer average TP and TN targets to 80th percentile values (CDPHE 2011, Figure 63 and 64). The resulting TP and TN interim values are summer average concentrations in the mixed layer that must be attained in 4 out of 5 years.

III. EPA'S REVIEW OF THE TP AND TN INTERIM VALUES

The EPA's review considered both the derivation method used by Colorado and the level of protection provided by the interim values. In general, the EPA finds it was reasonable and appropriate for the WQCD to calculate TP and TN targets from the selected chl-a target concentrations using empirical chl:TP and chl:TN relationships. The EPA has recommended this approach, e.g., for lakes with similar algal response relationships (EPA 2010). However, in a State such as Colorado, where nutrient concentrations and physical conditions are wide ranging, algal response to nutrients varies from lake to lake. As such, the Agency maintains that predicting the expected response (across all lakes) using a single empirical response relationship does not adequately account for this variability. The EPA finds that the variability is largely a result of site-specific factors that affect (suppress or limit) algal growth, including strong nitrogen limitation (affects chl:TP response), strong phosphorus limitation (affects chl:TN response), non-algal turbidity, depth, mixing status, hydraulic residence time, and others.

Because algal response varies from lake-to-lake, the Division's method may be under-protective in productive lakes that are especially vulnerable to nutrient pollution. The EPA's review indicated that the interim values provide a reasonable basis for numeric standards in lakes with relatively low chl-a yield, per unit of TP or TN, but may not be protective of lakes where a strong algal response to nutrient pollution can be expected (i.e., environmental conditions are favorable for algal growth). Accordingly, in Section V of this enclosure, the EPA

provides recommendations for the application of numeric standards in Colorado's basin-specific WQS rules, with emphasis on warm lakes.

A Brief Overview of Factors that Affect Algal Response to Nutrients

Efforts in the 1960s and 1970s to study eutrophication included evaluation of data from northern, temperate, natural lakes where phosphorus levels are low and transparency is typically dominated by phytoplankton. Phosphorus is often a limiting factor in such lakes, and cross-lake chl-a vs TP relationships are typically linear and strongly correlated when using a log-log plot of the data (Dillon and Rigler 1974, Jones and Bachmann 1976, Carlson 1977). A cooperative worldwide project to study eutrophication across a diverse set of conditions produced chl-a vs TP plots for various geographic and limnological situations (OECD 1982). Although the study concluded that lake algal production is controlled by phosphorus in a majority of cases, it also identified lakes where algae are light limited (e.g., due to heavy silt load) and/or nitrogen limited. In deriving chl-a vs TP equations, data were excluded from lakes where algal growth was limited by factors other than phosphorus.

Walker (1982) evaluated data from U.S. reservoirs and showed that non-algal turbidity and nitrogen strongly influence the chl-a vs TP relationship. He found that when the reservoir dataset was screened to eliminate station-years with high non-algal turbidity levels (indicating light limitation) and low nitrogen/phosphorus (N/P) ratios (indicating N-limitation), the chl-a vs TP regression model was nearly identical to empirical models for phosphorus-limited northern lakes (e.g., Jones and Bachmann 1976). Walker (1984) concluded that:

> "Most of the apparent differences between lakes and reservoirs with respect to chlorophyll/phosphorus ratio are explained by simultaneous variations in other factors which influence algal growth, not by impoundment type. These factors, in turn, can be traced to watershed characteristics which control the export and partitioning of nutrients, and the generation and transport of sediment. If one attempts to apply a given phosphorus/chlorophyll regression to a collection of lakes and/or reservoirs, the model would be biased in certain systems, based upon N/P ratio, turbidity, and flushing rate, because it would not incorporate effects of limiting factors other than phosphorus. A more complex model is needed if it is to be generally applicable over the wide range of lake and reservoir conditions."

Other researchers have demonstrated that when using large compilations of data from lakes with wide-ranging physical characteristics and nutrient concentrations, a log-log plot of chl-a vs TP data can have a nonlinear or sigmoidal response pattern (Forsberg and Ryding 1980, McCauley et al. 1989, Stauffer 1991, Chow-Fraser et al. 1994, Mazumder 1994, Jones et al. 2011). McCauley et al. (1989) found that when using a linear model "chlorophyll concentration is overestimated at low phosphorus levels (2 to 50 µg/L) and underestimated at higher phosphorus levels (50 to 1000 µg/L)." Similarly, Stauffer (1991) concluded that "the sigmoidal chlorophyll *a* v. TP response curve, when fitted indiscriminately using a straight line, can lead to biased predictions concerning lake trophic state."

In sum, although nutrients are often considered to set an upper limit on algal biomass, it is well established that other factors may cause chl-a levels to be less than expected based on the phosphorus or nitrogen concentration (Brown et al. 2000, Bachmann 2001). A partial list of site factors that contribute to variation includes physical factors such as non-algal turbidity (Walker 1982, Dzialowski et al. 2011), lake depth (Phillips et al. 2008), mixing status (Mazumder 1994), and hydraulic residence time (Soballe and Kimmel 1987, Jones et al. 2008a) and biological factors such as zooplankton grazing (Lampert et al. 1986, Mazumder and Havens 1998), self-shading (Wetzel 1966), and the chlorophyll content of algae (Nicholls and Dillon 1978, Ahlgren et al. 1988). The

influence of such factors helps explain why chlorophyll levels vary substantially at any given TP or TN concentration (Knowlton and Jones 2006), and why algal response varies more in reservoirs than in natural lakes (Canfield and Bachmann 1981).

The Influence of Non-Algal Turbidity

Non-algal turbidity can result from watershed sediment delivery or in-lake processes such as wind-induced mixing and shoreline erosion. Non-algal turbidity levels are elevated more commonly in man-made lakes than in natural lakes (Canfield and Bachmann 1981) and are affected by land use (Jones et al. 2008a). Elevated non-algal turbidity levels may be a symptom of short hydraulic residence time because short residence times diminish the opportunity for particles to settle (Jones et al. 2008a). Elevated non-algal turbidity can suppress algal response to nutrients by decreasing the biologically available nutrient fraction(s) and increasing light attenuation in the water column (i.e., the photic zone is reduced and light limited growth may be induced).

Effects of non-algal turbidity (using Colorado data) are discussed below. However, the EPA also considered relevant information from other States, particularly reservoir studies. For example:

- A study of 19 reservoirs located in eastern and central Kansas concluded that "significant relationships were observed between water column chlorophyll-a and TN and TP concentrations only when reservoirs exhibiting light limitation were removed from the analyses" (Dzialowski et al. 2005).
- Similarly, a study of 7 Kansas reservoirs found that increasing levels of non-algal turbidity had a significant and progressively negative influence on algal biomass (chlorophyll-a) across a wide range of non-algal turbidity (Dzialowski et al. 2011).
- Jones et al. (2008b) provides an empirical multivariate model that predicts chl-a levels in Missouri reservoirs based on reservoir mean total phosphorus and non-algal seston concentrations ($R^2 = 0.89$). For example, if three reservoirs each have mean TP of 50 µg/L, and non-algal seston is 4, 8, and 25 mg/L, predicted reservoir mean chl-a levels are 22, 16, and 9 µg/L, respectively.

Non-Algal Turbidity Influences Algal Growth in Colorado Lakes

When secchi depth is less than expected for a given level of chlorophyll, this indicates that transparency is influenced by non-algal particles or color. Based on this concept, the component of water transparency attributable to non-algal particles and/or color in Colorado lakes was assessed by calculating secchi depth observed/expected ratios (Carlson and Havens 2005, Jones et al. 2008b).[3]

The EPA's review indicates that non-algal turbidity has a significant influence on algal growth in Colorado lakes, particularly in cold lakes. For example, using geometric mean (of the summer average) concentrations, Figure 2 compares cold lakes with high and low non-algal turbidity levels by plotting secchi depth vs chl-a (left) and chl-a vs TP (right). The comparison shows that high turbidity lakes have low levels of transparency, per unit of chl-a, and also reduced chl:TP yields. Moderate turbidity systems are not plotted in Figure 2 (but generally have intermediate secchi:chl and chl:TP performance).

[3] Levels of non-algal turbidity and/or color were assessed by calculating secchi depth observed/expected ratios (secchi O/E) using the secchi depth vs chl-a relationship in Carlson (1977). This method compares the observed secchi depth to the predicted secchi depth (at observed chl-a). High secchi O/E values (~ 1.0 and higher) indicate that transparency is dominated by phytoplankton, while low secchi O/E values (~ 0.5 and less) indicate elevated non-algal turbidity.

USGS studies lend further support to the conclusion that some man-made reservoirs in the Colorado dataset have very high levels of non-algal turbidity (Elliot and Gyetvai 1999, Stevens and Sprague 2003, Kuhn et al. 2003, Ortiz 2004). For example, Elliot and Gyetvai (1999) evaluated bank erosion and sediment transport in Elkhead Creek, above and below the reservoir, and the formation of a large delta at the northeastern (upstream) end of the reservoir. Between 1982 and 1993, the delta was reported to increase an average of 2.3 acres per year. Elkhead Reservoir is one of the "high turbidity" lakes included in Figure 2.

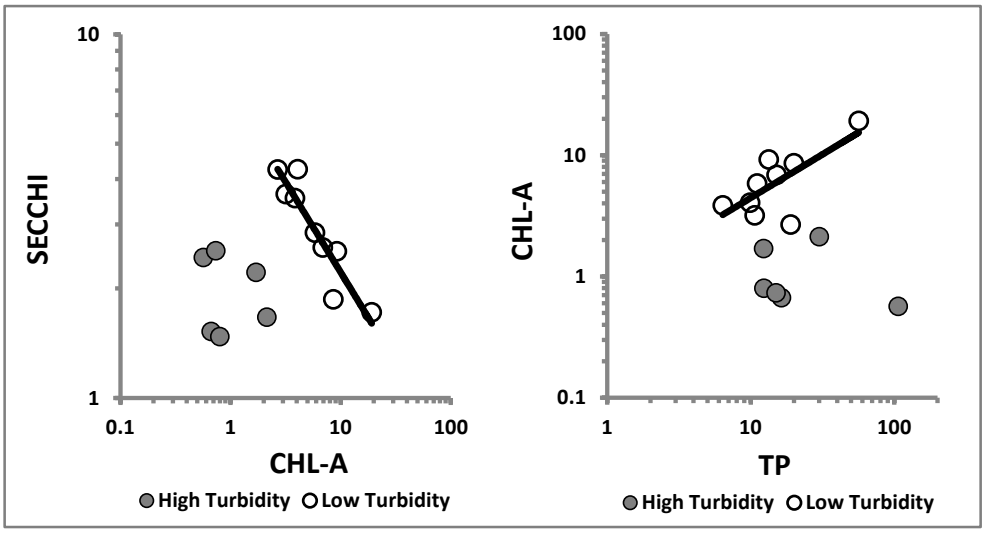

Figure 2. Cold lakes (geometric means). Comparison of lakes with high vs. low levels of non-algal turbidity and/or color (inferred).[4,5]

The influence of non-algal turbidity was also evaluated using multiple linear regression analyses. Correlation of a $Chl_{log} = f(TP_{log})$ model was found to be weak with cold summer grabs ($R^2 = 0.21$, n = 927) and cold summer averages ($R^2 = 0.29$, n = 145). However, with the addition of a $(\text{secchi O/E})_{log}$ term ($p < 0.01$), model correlation was significantly improved with both grabs ($R^2 = 0.67$) and averages ($R^2 = 0.78$).[6] These results indicate that non-algal light attenuation has an important confounding influence on prediction of chl-a levels in cold Colorado lakes. For example, using summer averages, if three cold lakes each have TP of 20 µg/L and secchi O/E of 1.5 (79th percentile), 1.0 (44th percentile) and 0.5 (8th percentile) respectively, predicted chl-a levels are 9, 5, and 2 µg/L.

Comparable results were achieved using the smaller dataset of summer chl-a, TN, and secchi measurements from cold lakes (n = 346), an indication that non-algal turbidity also affects chl:TN response. Further, using the methods described in Walker (1996) and Jones and Hubbart (2011), estimated non-algal turbidity (NAT) levels proved to be significant predictors of Chl_{log} ($p < 0.01$) individually and in multiple linear regression models, though the degree of model improvement using these methods was less than with secchi O/E values.

Secchi O/E values were also calculated using National Lakes Assessment data (EPA 2009, n = 1000 July to September chl-a, secchi, TP, and TN grabs). Although model coefficients were different (compared to the

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4 Cold and warm lakes were defined based on whether a cold or warm water aquatic life designated use has been assigned.

5 Geometric mean (of the summer average) concentrations are plotted in Figure 2 to reduce the variability of the chl:TP response (Jones et al. 1998). The summer averages per lake (with measured chl-a, secchi, and TP) ranges from 1 to 20, with an average of 5 per lake.

6 The equations are $CHL_{log} = 0.512*TP_{log} + 1.13*(\text{Secchi O/E}_{log}) + 0.0596$ (927 cold lake summer grabs, $R^2 = 0.67$), and $CHL_{log} = 0.524*TP_{log} + 1.19*(\text{Secchi O/E}_{log}) + 0.0418$ (145 cold lake summer averages, $R^2 = 0.78$).

Colorado models), $Chl_{log} = f(TP_{log})$ and $Chl_{log} = f(TN_{log})$ equations were again improved by adding a (secchi $O/E)_{log}$ term ($p < 0.01$). The degree of improvement was greater using data from man-made lakes (R^2 improved from 0.46 to 0.65 for chl:TP), and less using data from natural lakes (R^2 improved from 0.72 to 0.78 for chl:TP). This suggests that non-algal turbidity has a strong influence on algal growth in lakes, and especially in the Nation's man-made lakes (similar to findings in Canfield and Bachmann 1981, Walker 1982, Jones et al. 2008b, Dzialowski et al. 2011). Nearly all of the waters in the Colorado "lakes" dataset are reservoirs.

The Influence of Single Nutrient Limitation

Resource limitation theory (based on Liebig's "law of the minimum") provides that the resource in shortest supply will limit growth. Phosphorus is an important limiting factor in freshwater lakes (Schindler 1977) and many efforts to reduce or control eutrophication have focused on decreasing inputs of phosphorus (Schindler 2008). However, experimental evidence also supports the view that nitrogen is an important limiting factor in freshwater lakes, individually or in combination with phosphorus (Elser et al. 1990, Lewis and Wurtsbaugh 2008, Sterner 2008), and that a dual control strategy is appropriate for the protection of freshwater, coastal and marine systems (Paerl 2009, Lewis et al. 2011, EPA 2015).

Colorado adopted both TP and TN interim values for lakes, based on the rationale in CDPHE (2011). The Division reasoned that control of both is justified because TP and TN levels in Colorado lakes are well correlated, and both nutrients are often important in limiting algal growth over the course of a summer growing season. Evidence for this conclusion includes nutrient enrichment studies for Colorado mountain lakes (Morris and Lewis 1988) and reviews of similar studies (Elser et al. 1990, Maberly et al. 2002, Lewis and Wurtsbaugh 2008, Lewis et al. 2011).[7] Elser et al. (1990) found that, most typically, combined N and P enrichment is required to consistently produce substantial algal response, and explained that co-limitation is "consistent with a view that both N and P are in relatively short supply, such that enrichment of one nutrient without the other produces only a brief growth enhancement until depletion of the other nutrient occurs."

In lakes where co-limitation by phosphorus and nitrogen is the natural or expected condition, the nutrient supply may become unbalanced if anthropogenic activity causes one nutrient to be present in excess. For example, "nitrogen-only" limitation may be induced in lakes where inflows are dominated by phosphorus-rich discharges from domestic wastewater treatment plants (Downing and McCauley 1992, Lewis and Wurtsbaugh 2008). The potential for phosphorus limitation or co-limitation can be minimal in such lakes, particularly where phosphorus loading from in-lake sources assures an abundant supply of bioavailable phosphorus throughout the growing season (Sprague 2002). On the other hand, "phosphorus-only" limitation can be induced in areas with heavy atmospheric deposition of nitrogen (Bergstrom and Jansson 2006, Elser et al. 2009).

[7] A "nutrient enrichment study" involves adding nutrients to lake water samples and measuring the algal response to determine whether/which nutrients limit algal growth.

Table 2
N:P Ratios (by Mass) Suggested as Indicators of Nutrient Limitation

Source	P-Only Limitation	Co-Limitation (N and P)	N-Only Limitation
Sakamoto 1966	> 17:1	17:1 to 10:1	< 10:1
Forsberg et al. 1978	> 17:1	17:1 to 10:1	< 10:1
Morris and Lewis 1988	> 25:1	25:1 to 15:1	< 15:1
Downing and McCauley 1992			< 14:1
Guildford and Hecky 2000	> 23:1		< 9:1
Dzialowski et al. 2005	> 29:1	21:1 to 9:1	< 8:1

The total nitrogen to total phosphorus (N:P) ratio can be used as an indicator of whether algal growth is likely to be P-limited, co-limited (both nutrients), or N-limited (Smith 2006). Table 2 lists N:P ratios (by mass) recommended in the literature as indicators of nutrient limitation. High ratios have been suggested as indicators of phosphorus-only limitation. Low ratios have been suggested as indicators of nitrogen-only limitation. Intermediate range N:P ratios have been suggested as indicators of co-limitation.

Nutrient Limitations Influence Algal Growth in Colorado Lakes

In Colorado lakes, N:P ratios typically are higher in cold lakes (geometric mean = 20:1, n = 355 summer grabs) and lower in warm lakes (geometric mean = 10:1, n = 416 summer grabs). As shown in Figure 3 (left), N:P ratios decline sharply with rising TP in warm lakes. Similarly, the middle panel shows that:

- 65% of samples have *high* N:P (> 25:1) below 10 µg/L TP,
- 86% of samples have *low* N:P (< 10:1) above 80 µg/L TP, and
- 64% of samples have *intermediate* N:P ratios ($10 \leq N:P \leq 25$) from 10 to 80 µg/L TP, meaning that typically, the supply of nutrients is balanced and well matched to the nutritional requirements of phytoplankton (Downing and McCauley 1992).

Figure 3 (right) shows the relationship between chl-a and N:P ratios in warm Colorado lakes. Chl-a levels rise as TP and TN levels increase and N:P ratios decrease; however, this pattern does not hold in samples with the lowest N:P ratios.

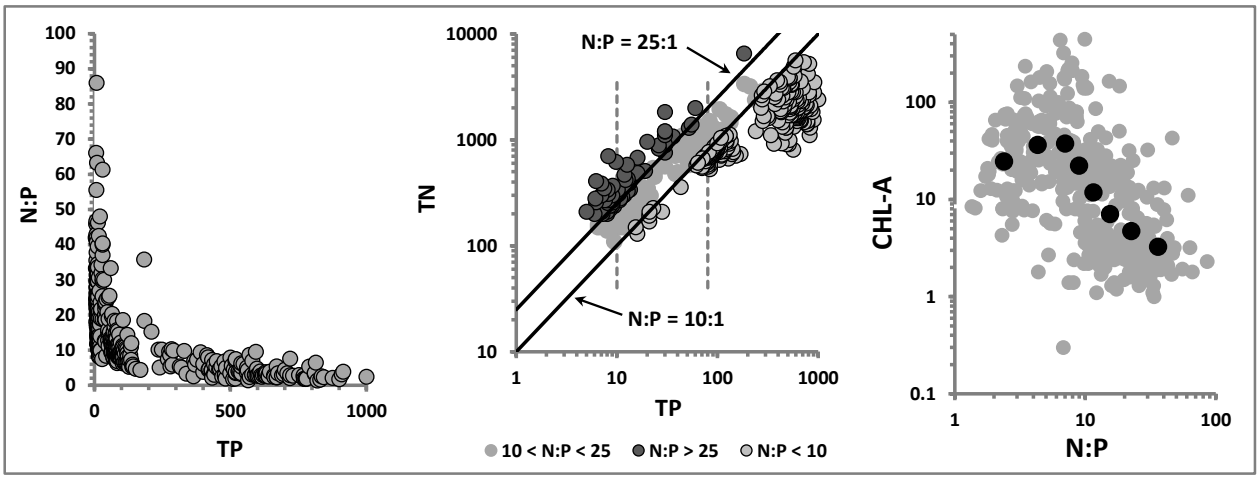

Figure 3. Warm lake summer grabs with measured chl-a, TP, and TN (n = 416).[8]

The influence of TP and TN on chlorophyll levels in warm lakes was evaluated using multiple linear regression. Only lake-years with summer average chl-a, TP, and TN were used for the analysis (n = 66). Across all lake-years, N:P ratios ranged widely from 2:1 to 50:1. Separate equations were developed for lake-years meeting several (overlapping) N:P ratio screening criteria.

The results of the multiple linear regression analysis (Table 3) indicate that:

- At high N:P (≥ 20:1, geometric mean = 26:1), only TP_{log} is a significant predictor of Chl_{log}. When Chl_{log} is regressed separately against each individual nutrient, correlation is better with TP_{log} ($R^2 = 0.66$) than TN_{log} ($R^2 = 0.49$).
- At low N:P (≤ 12:1, geometric mean = 6:1), only TN_{log} is a significant predictor of Chl_{log}. When Chl_{log} is regressed separately against each individual nutrient, correlation is better with TN_{log} ($R^2 = 0.52$) than TP_{log} ($R^2 = 0.25$).
- In the intermediate N:P range ($10 \leq N:P \leq 25$, geometric mean = 16:1), the multiple linear regression itself is highly significant, but neither phosphorus or nitrogen are significant predictors ($p > 0.1$ with both). The reason appears to be that summer average TP and TN levels are strongly correlated ($R^2 = 0.91$) and chl-a can be predicted equally well with either nutrient. For example, when Chl_{log} is regressed separately against each individual nutrient, both TP_{log} and TN_{log} are highly significant ($p < 0.01$) and their performance as predictors is nearly identical ($R^2 = 0.78$ with both).

[8] The right panel of Figure 3 plots July-September warm lake grabs (n = 416 from 43 lakes, range of 1 to 108 per lake, avg = 10 per lake). Grabs were ranked on N:P, sorted into bins (~60 samples per bin), and geometric mean N:P and chl-a values were calculated for each bin (black circles).

Table 3
Multiple Linear Regression Analysis Using Warm Lake Summer Averages@

N:P Criterion	N	R^2	Variable	Coefficient	Std. Error	t stat	Significant?
High N:P Lake-Years (≥ 20:1)	16	0.64	TP_{log}	1.6	0.63	2.6	**Yes***
			TN_{log}	-0.29	0.56	-0.52	No
			Intercept	-0.55	0.83	-0.66	
Low N:P Lake-Years (≤ 12:1)	34	0.57	TP_{log}	-0.28	0.19	-1.5	No
			TN_{log}	1.5	0.28	5.2	**Yes***
			Intercept	-2.5	0.49	-5.0	
Intermediate N:P Lake-Years (10 ≤ N:P ≤ 25)	34	0.79	TP_{log}	0.40	0.28	1.4	No
			TN_{log}	0.50	0.32	1.5	No
			Intercept	-1.0	0.47	-2.1	
All lake-years (exclude none)	66	0.83	TP_{log}	0.40	0.11	3.5	**Yes***
			TN_{log}	0.58	0.19	3.1	**Yes***
			Intercept	-1.2	0.36	-3.5	

@ All equations have the form Chl_{log} = coefficient*TP_{log} + coefficient*TN_{log} + intercept
* $p < 0.01$

Using geometric mean (of the summer average) values for warm Colorado lakes, Figure 4 shows how N:P ratios influence chl:TP and chl:TN response. For the TP plot, mean N:P ≥ 10:1 was presumed to indicate P or co-limitation, and mean N:P < 10:1 was presumed to indicate N-limitation. Similarly, for the TN plot, mean N:P ≤ 25:1 was presumed to indicate N or co-limitation, and mean N:P > 25:1 was presumed to indicate P-limitation.

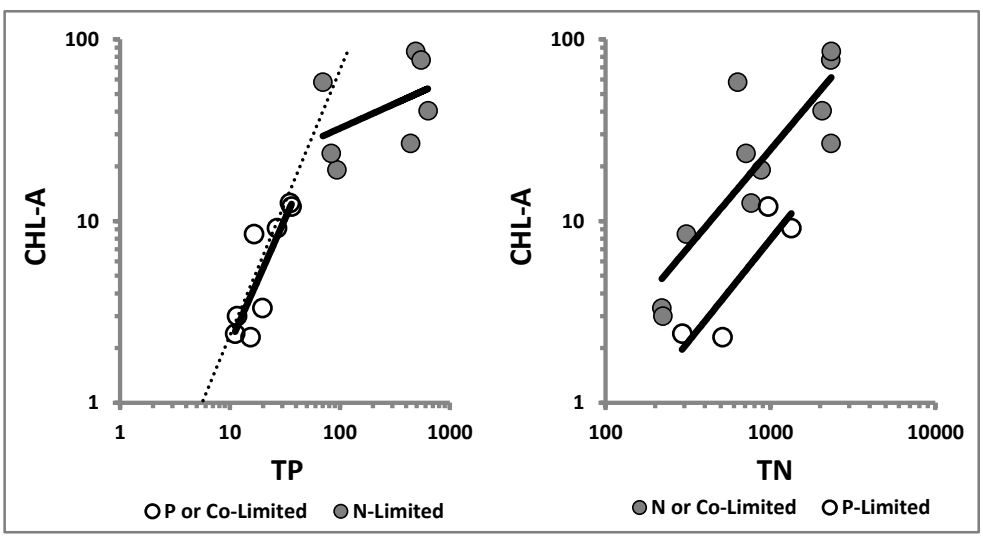

Figure 4. Warm lakes (geometric means). Comparison of P-limited, Co-limited, and N-limited lakes. The left panel also shows the line (dotted) from Jones & Bachmann (1976).[9]

[9] The comparison in Figure 4 uses geometric mean of the summer average concentrations. The number of summer averages per lake (with measured chl-a, TP and TN) ranges from 1 to 13, with an average of 4.4 per lake.

Figure 4 (left) shows that in lakes where P or co-limitation is indicated, the slope of the chl:TP response relationship is steep, similar to published empirical models for northern temperate lakes (e.g., Jones and Bachmann 1976, shown as a dotted line). However, the slope of the response flattens using data from lakes where nitrogen-only limitation is indicated. The right panel shows that in lakes where N or co-limitation is indicated, chl:TN yields are higher compared to lakes where phosphorus-only limitation is indicated.

That nitrogen-only limitation would flatten chl:TP response in Colorado lakes with high TP (and low N:P) is supported by other lines of evidence:

- *TMDLs.* The Total Maximum Daily Load completed for Barr Lake and Milton Reservoir found that the very high summer phosphorus concentrations (~ 500 µg/L) were well above levels that might potentially limit algal growth (Barr-Milton Watershed Association 2010).
- *Nutrient enrichment studies*. For example, N-limitation has been experimentally demonstrated in Cherry Creek Reservoir (Knowlton and Jones 1996, Lewis et al. 2008), where the long-term geometric mean N:P ratio is 9:1, and Barr Lake (U.S. EPA 1977), where the long-term geometric mean N:P ratio is 4:1.
- *Comparison to NLA data*. A comparison of Colorado and National Lakes Assessment data (EPA 2009) shows that geometric mean N:P ratios in Colorado lakes are 70-72% of the national average at any TP (July to September summer grabs, n = 870 Colorado samples, n = 1000 NLA samples). Results are similar when the comparison is restricted to > 10 µg/L TP samples (indicating the difference is not merely due to measurement error in low TP samples). The comparison shows that, relative to the national average, there is substantially less nitrogen in Colorado lakes (at any TP). One implication is that an N:P ratio of 10:1 corresponds to 70 µg/L TP using Colorado data, versus 150 µg/L TP using NLA data. Similarly, an N:P ratio of 25:1 corresponds to 9 µg/L TP using Colorado data, versus 19 µg/L using NLA data. This suggests that nitrogen limitation, individually or in combination with phosphorus, may be observed at lower TP levels in Colorado lakes, compared to the Nation's lakes.

<u>The Pattern of Algal Response to Nutrients Differs in Cold and Warm Colorado Lakes</u>

Colorado lakes cover a wide elevation range (from less than 4,000 feet to more than 12,000 feet). Table 4 summarizes key differences between cold and warm lakes. During the summer growing season, cold lakes are more likely to be stratified and have lower nutrient concentrations, while warm lakes are more likely to be mixed and have higher nutrient concentrations.

Table 4
Physical/Chemical Characteristics of Cold and Warm Colorado Lakes

Cold Lakes are typically:	**Warm Lakes** are typically:
Colder	Warmer
Deeper	Not as deep
Likely to be stratified	Likely to be mixed
Geomean TP = 15 µg/L (1021 summer grabs)	Geomean TP = 48 µg/L (813 summer grabs)
Geomean N:P = 20:1 (355 summer grabs)	Geomean N:P = 10:1 (416 summer grabs)

Figure 5 compares chl:TP response in cold and warm lakes. In cold systems, algal response is weak (near flat) at low to intermediate TP (< 30 µg/L TP). As discussed above, variation in non-algal turbidity appears to be an important factor that contributes to the weak response observed in cold systems. By contrast, algal response in

warm systems is steep at low TP, but becomes weak (near flat) at high TP. Multiple lines of evidence indicate that nitrogen is an important confounding factor at high TP. However, other factors such as algal self-shading (Wetzel 1966) and inorganic solids (Jones et al. 2011) may also be important. For example, using > 80 µg/L summer grabs from warm Colorado lakes, multiple linear regression shows that both TN_{log} and $(\text{secchi O/E})_{log}$ are significant predictors of Chl_{log} ($p < 0.01$). When added to the model as a 3rd term, TP_{log} is also significant ($p < 0.01$) but has a negative slope coefficient. That non-algal turbidity could exert an important influence, at least episodically, is consistent with the fact that many warm lakes are shallow enough to mix intermittently during summer (e.g., during storms), thereby re-suspending bottom deposits.

When all data are combined, the sigmoid response pattern is similar to that discussed in McCauley et al. (1989), Prairie et al. (1989), Stauffer (1991), Watson et al. (1992), Chow-Fraser et al. (1994), Mazumder (1994) and Dolman et al. (2012). Mazumder (1994) noted that "sigmoid patterns of TP-Chl relationships appear to be related to the transition from stratified to mixed systems along the TP gradient."

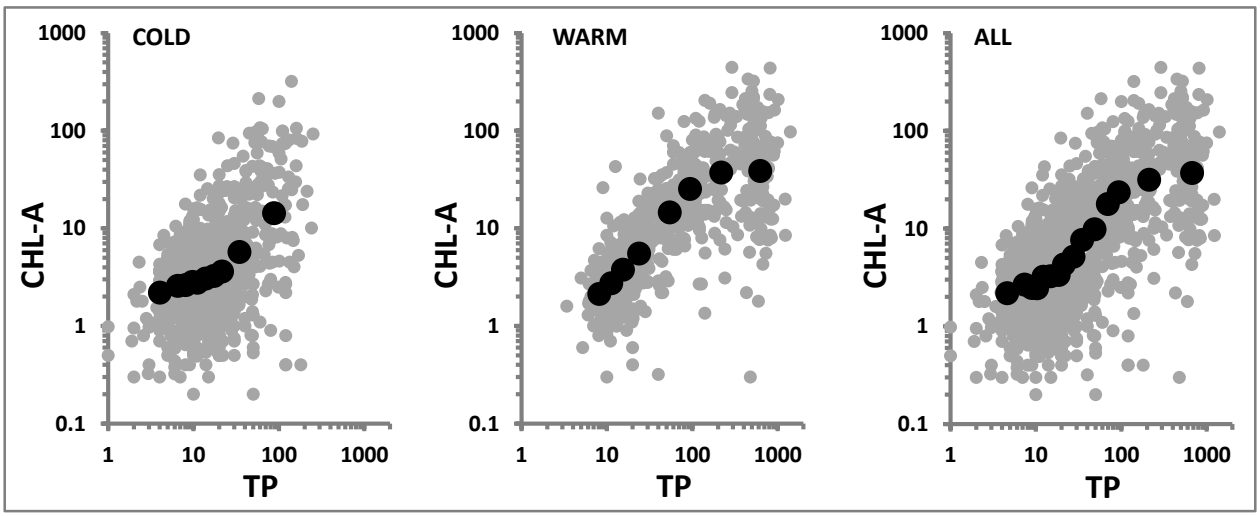

Figure 5. Summer Grabs (n = 1,834). Chl-a vs TP. Comparison of cold, warm, and all.[10]

Figure 6 uses the same method to compare chl:TN response in cold and warm lakes. In cold systems, chl-a response is again weak (near flat) at low to intermediate TN, which is consistent with the evidence that non-algal turbidity/light limitation interferes with algal response to nutrients. In warm systems, chl-a response does not weaken at high TN as it does with TP (lending further support to the conclusion that weak response at high TP is influenced by nitrogen). It is noteworthy that a number of well-sampled Colorado reservoirs with high mean summer TN and TP levels (but low mean N:P ratios, indicating nitrogen only limitation) are strongly influenced by upstream domestic wastewater treatment plant discharges. A similar (i.e., strongly linear) chl:TN response pattern, in 30 waste-receiving Swedish lakes, is described in Forsberg & Ryding (1980).

[10] Figure 5 plots July-September grabs (n =1,834 from 154 Colorado lakes, range of 1 to 133 samples per lake, avg = 12 per lake). Grabs were ranked on TP, sorted into bins (~100 samples per bin), and geometric mean TP and chl-a concentrations for each bin were calculated (black circles).

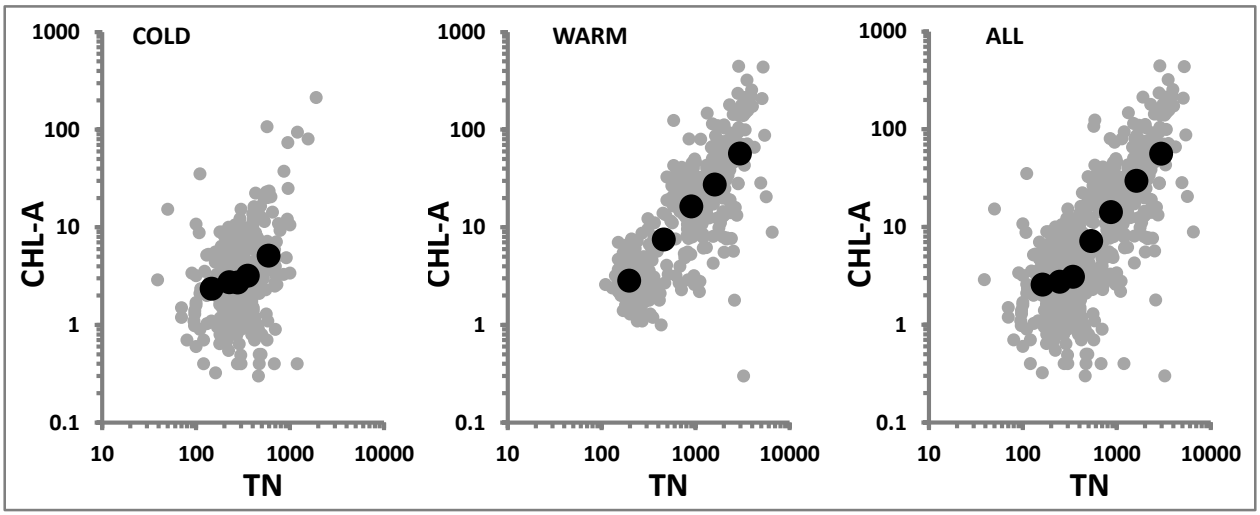

Figure 6. Summer grabs (n = 813). Chl-a vs TN. Comparison of cold, warm, and all.[11]

Productive Warm Lakes May Be Under Protected by Colorado's TP and TN Interim Values

For the reasons described above, the EPA is concerned that the TP and TN interim values for warm lakes may not always achieve the 20 µg/L chl-a objective.

To assess the range of chl-a levels likely to be observed at the warm lake interim values, cold lake summer averages were excluded, and chl:TP and chl:TN regression equations were developed using only warm lake summer averages. For the chl-a vs TN relationship, a linear log-log model was used, consistent with the observed response pattern (Figures 4 and 6). For the chl-a vs TP relationship, both nonlinear ($R^2 = 0.86$) and linear ($R^2 = 0.82$) models were developed. The nonlinear model was selected to represent central tendency because it was more accurate (higher correlation/lower standard error), more representative of the observed response pattern (Figures 4 and 5), and consistent with resource limitation theory (nitrogen is likely to limit growth in lakes with high TP and low N:P ratio). In addition, the TP_{log}, $(TP_{log})^3$, and intercept terms in the nonlinear model were highly significant ($p < 0.01$). The nonlinear chl:TP equation is similar in form to the model developed with a large compilation of data from Missouri reservoirs (Jones et al. 2011).

The regression equations for warm Colorado lakes are as follows:

(1) $CHL_{log} = 1.455*(TP_{log}) - 0.0606*(TP_{log})^3 - 1.01$ ($R^2 = 0.86$, n = 126 warm lake summer averages).
(2) $CHL_{log} = 1.195*(TN_{log}) - 2.273$ ($R^2 = 0.81$, n = 66 warm lake summer averages).

Equations (1) and (2) were used to sub-divide all lake-years into two groups with above/below average chl-a yield. As shown in Figure 7, separate regression lines were fitted to each group. This approach produces lines that are intended to bracket the most likely summer average chl-a concentrations. Although mean chl-a levels observed across all Colorado lakes will range widely, for simplicity the upper line can be used to represent lakes with above average production, and the lower line can be used to represent lakes with below average production. Figure 7 shows that at the 12.94 µg/L chl-a target, the upper/lower lines return nutrient targets ranging from 32 to

[11] Figure 6 plots July-September grabs (n = 813 samples from 91 Colorado lakes, range of 1 to 108 samples per lake, avg = 9 per lake). Grabs were ranked on TN, sorted into bins (~80 samples per bin), and geometric mean TN and chl- a concentrations were calculated for each bin (black circles).

66 µg/L TP, and from 500 to 1,060 µg/L TN. By comparison, the WQCD calculated 65.9 µg/L TP and 744 µg/L TN targets for the 12.94 µg/L chl-a target.

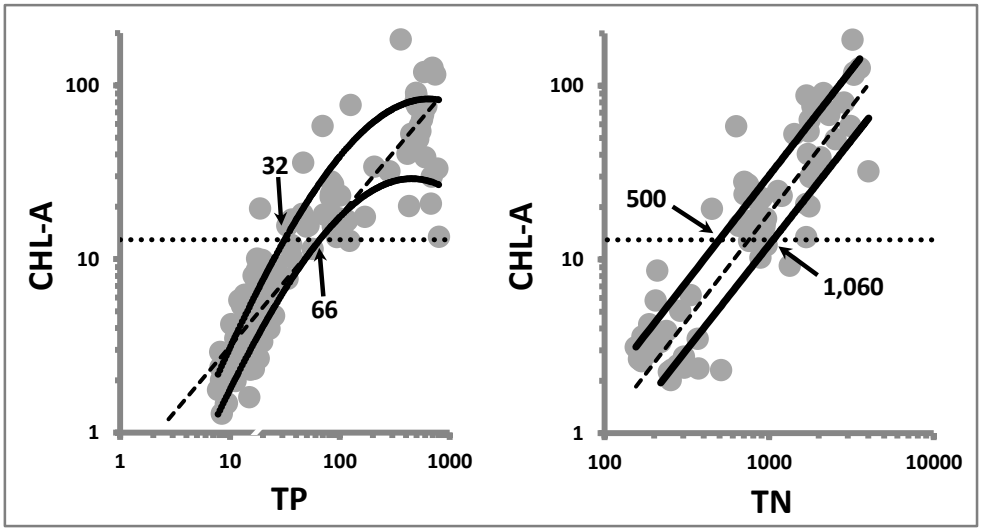

Figure 7. Warm lake summer averages. WQCD model (dashed line) compared to regression lines for lake-years where production is above average (upper) and below average (lower). The chl-a target is shown as a horizontal dotted line.

At the 65.9 µg/L TP target, predicted chl-a is 27 µg/L using the upper line in Figure 7, and 28 µg/L using the line for P-limited or co-limited lakes (Figure 4). The predicted median summer average chl-a using the WQCD line is 12.94 µg/L, an estimate that appears to be appropriate for lakes with below average algal production. For example, the lower (below average) line in Figure 7 also predicts 12.9 µg/L chl-a. Accordingly, the EPA is concerned that the WQCD model may not be representative of productive warm lakes where phosphorus is limiting or co-limiting.

At the 744 µg/L TN target, predicted chl-a is 21 µg/L using the upper line in Figure 7, and 18 µg/L using the line for N-limited or co-limited lakes (Figure 4). The predicted median summer average chl-a using the WQCD line is 12.94 µg/L, which appears to be a reasonable estimate of the central tendency response rate. However, because of the evidence that confounding factors (light limitation, strong P-limitation, etc.) suppress chl:TN response in some lakes, the EPA is again concerned that the WQCD model may not be representative of productive warm lakes where nitrogen is limiting or co-limiting.

IV. EPA'S ACTION

The EPA concludes that lake algal response to TP and TN varies widely, many site-specific factors (including non-nutrient factors) influence algal growth, and Colorado's TP and TN interim values are appropriate in lakes with relatively low chl-a yield, per unit of TP or TN), but may not be protective of lakes where a strong algal response to nutrient pollution can be expected (i.e., environmental conditions are favorable for algal growth). The EPA's review considered the fact that Colorado uses a two-step process to assign numeric standards to lakes, i.e., the interim values (step 1) become legally binding numeric standards for navigable waters only after they are applied to individual segments (step 2) and the EPA approves the segment-specific application decisions. In step 2, pursuant to 31.17(h), the Commission has flexibility to apply numeric standards different than the interim values. Given the segment-specific flexibility, the EPA finds that the TP and TN interim values for lakes

(31.17(b) and (c)) are consistent with the EPA requirement that states must adopt water quality criteria that protect designated uses based on sound scientific rationale (40 CFR § 131.11(a)(2)). Accordingly, the TP and TN interim values for lakes are approved. Below are recommendations for the application of TP and TN standards to individual segments listed in Colorado's basin-specific WQS rules.

V. RECOMMENDATIONS FOR THE APPLICATION OF TP AND TN STANDARDS IN COLORADO'S BASIN-SPECIFIC WQS RULES

The EPA's review identified several aspects of Colorado's methodology for deriving the TP and TN interim values that raise questions about whether the interim values can be relied upon to protect use classifications absent further analysis (on a site-specific or statewide basis):

1) *Confounding Factors*. Colorado's interim values were calculated using empirical models that are influenced by lakes where algal response is strongly confounded. For example, it is problematic to use data that represent low N:P situations to predict chl:TP response, or conversely, data that represent high N:P situations to predict chl:TN response. Similarly, it is problematic to use data that represent highly turbid situations to predict algal response to either nutrient. Exclusion of data from lakes with significant confounding factors would improve the reliability of threshold values derived from the empirical models.

2) *Lake Classification*. Colorado used a single chl:TP and chl:TN model to represent all Colorado lakes. The absence of lake classifications (categories) is problematic, given that nutrient concentrations and physical conditions are wide ranging, and that algal response to nutrients varies from lake to lake. In particular, the EPA's review indicates that there are important differences between cold and warm lakes. Development of separate empirical models for warm and cold lakes would improve the reliability of threshold values derived from the empirical models.

3) *Productive Lakes*. The TP interim values were calculated using an empirical model that may not represent what can be expected when phosphorus is limiting or co-limiting, and the TN interim values were calculated using an empirical model that may not represent what can be expected when nitrogen is limiting or co-limiting. In productive lakes, when the TP and TN targets are achieved, the chl-a targets may be exceeded. Completing further analyses (on a site-specific or statewide basis) would allow Colorado to establish protective threshold values for productive lakes as these lakes are not likely to be protected when threshold values derived from the Colorado general empirical models are applied.

Bear Creek Reservoir is an example of a productive Colorado lake. In 2015, based on a 2000-2013 compilation of Bear Creek Reservoir summer averages, the WQCD proposed that the site-specific 8 µg/L chl-a target relates to 16 µg/L TP (with both values expressed as median summer averages). By comparison, using the statewide model that provides the technical basis for the Regulation 31 TP interim values, 8 µg/L chl-a relates to a TP target of 35 µg/L. However, site data indicate that a 35 µg/L TP target would be too high, and yield ~15 µg/L chl-a as a median summer average (almost double the 8 µg/L chl-a target). In other words, for this reservoir, the statewide model substantially under-predicts the chl:TP response that has been observed.

Alternative (e.g., categorical) or site-specific values may be more protective for such lakes. To minimize the need for site-specific studies, the state may want to consider alternative methods to derive more protective values for these types of lakes before applying the interim values to individual segments. For example, Colorado could evaluate alternative lake classification schemes, e.g., so that segment specific values are derived for groupings of

lakes with similar physical characteristics (U.S. EPA 2010). In order to minimize the influence of lakes where strong confounding influences are present, Colorado could update the interim values using upper prediction intervals (U.S. EPA 2010). This statistical method was discussed in the Region's pre-hearing and rebuttal written comments, and was the basis for the alternative proposal submitted to the Commission by the EPA during the state's rulemaking action.

Recommendations

These TP and TN interim values for lakes are approved; however, the EPA emphasizes that the Division's analysis (CDPHE 2011) does not provide adequate scientific justification to apply the TP and TN interim values for warm lakes in the absence of additional site-specific information. The EPA recommends the following:

1) For warm lakes, the TP and TN interim values should be applied to individual segments only where a site-specific analysis demonstrates that designated uses would be protected. The EPA may disapprove new/revised water quality standards in cases where the TP or TN interim values are applied to warm lakes in the absence of a site-specific justification.

2) For warm and cold lakes, Colorado should evaluate options for developing more protective alternative values or site-specific standards that can be applied to individual segments with confidence that chl-a objectives and designated uses would be protected.

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