Analysis of Total Microcystins versus Chlorophyll *a* from Lakes Sampled by the National Lakes Assessment 2007 and 2012

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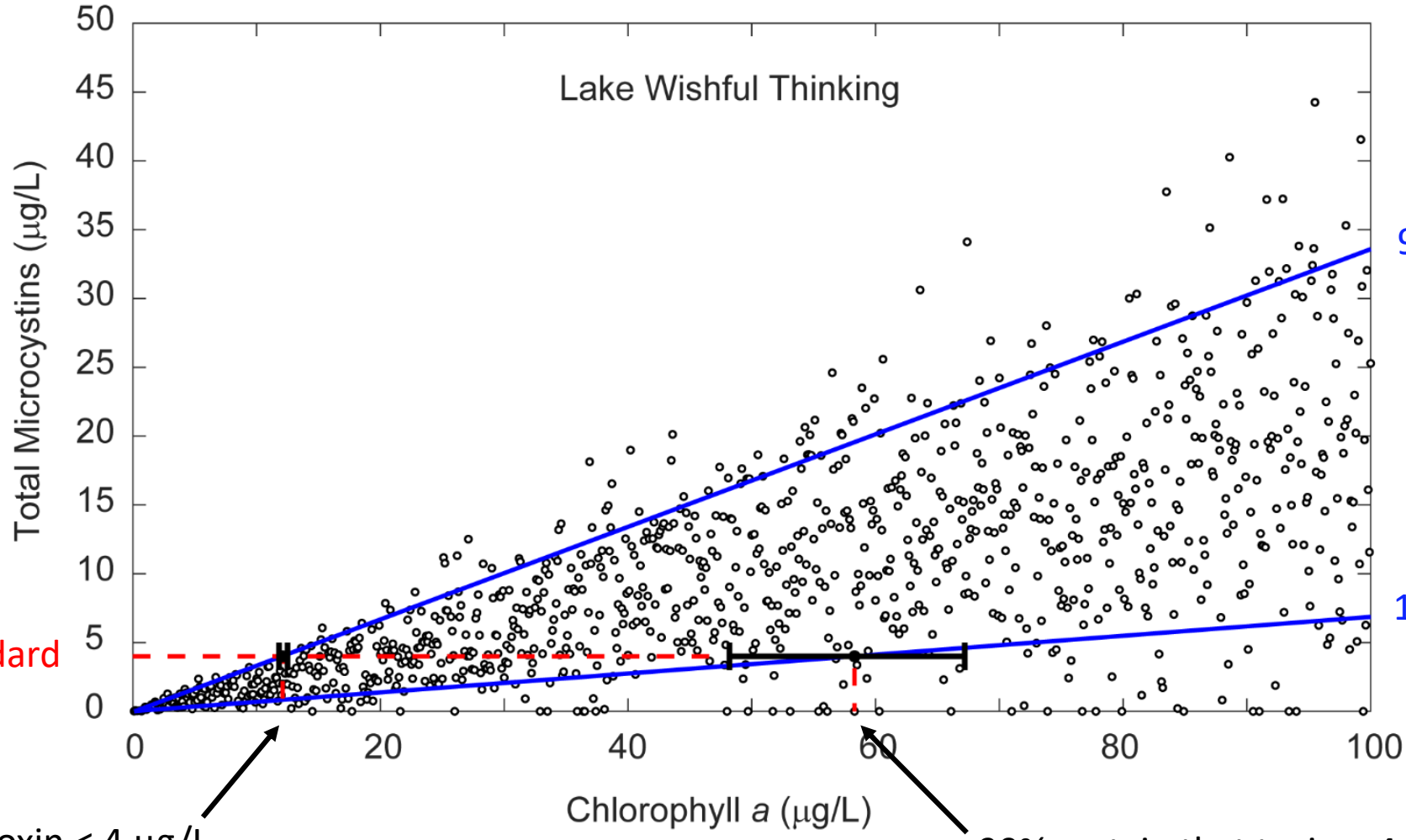
NC Nutrient Criteria Development Plan
Scientific Advisory Council
3 December 2018
Raleigh, NC

Use of Quantile Regressions to Set Chlorophyll *a* Standard Based on Risk of Recreational Cyanotoxin Exposure



90% quantile

10% quantile

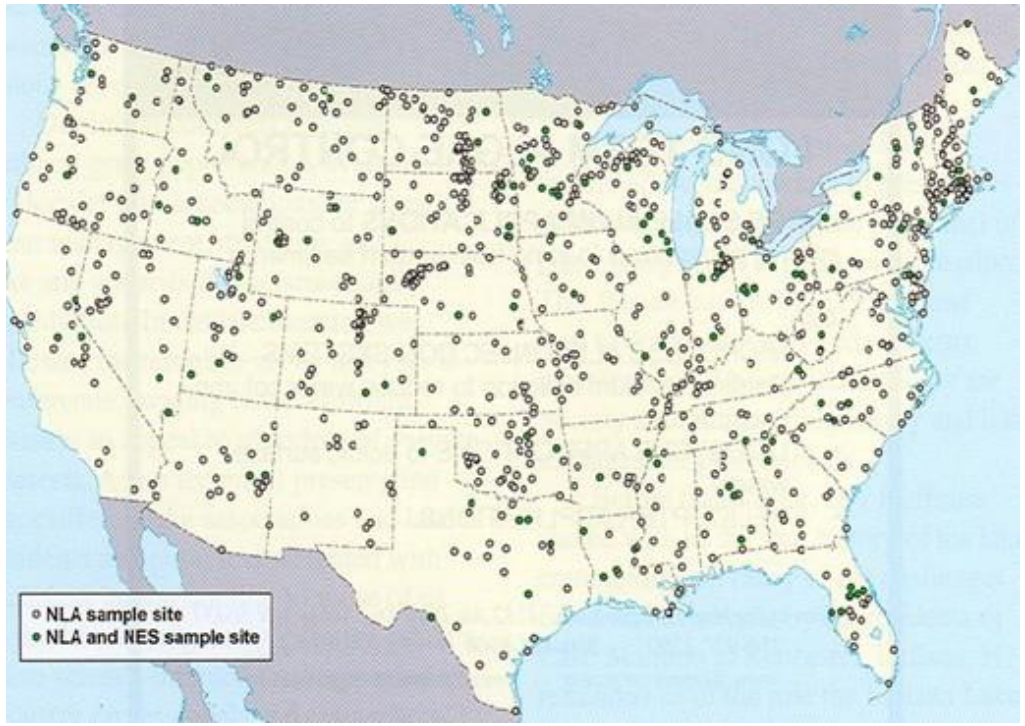
4 μg/L recreational standard

90% certain that toxin < 4 μg/L

90% certain that toxin > 4 μg/L

Used chlorophyll *a* and total microcystin data from the 2007 and 2012 National Lake Assessments

2007

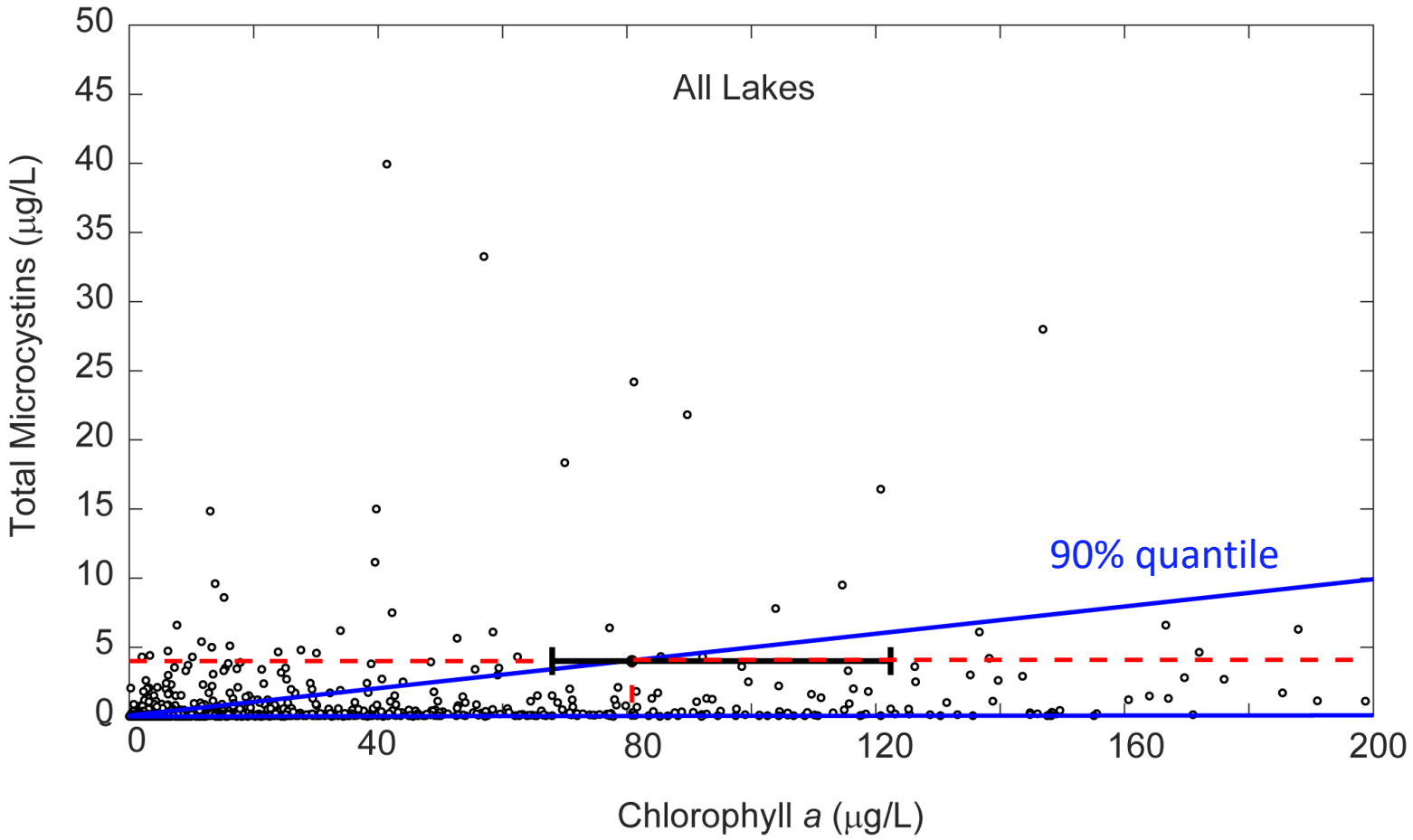


2012

1) ~1040 lakes each assessment with ~400 lakes sampled in both years
2) Sampled at lake center and at a littoral station

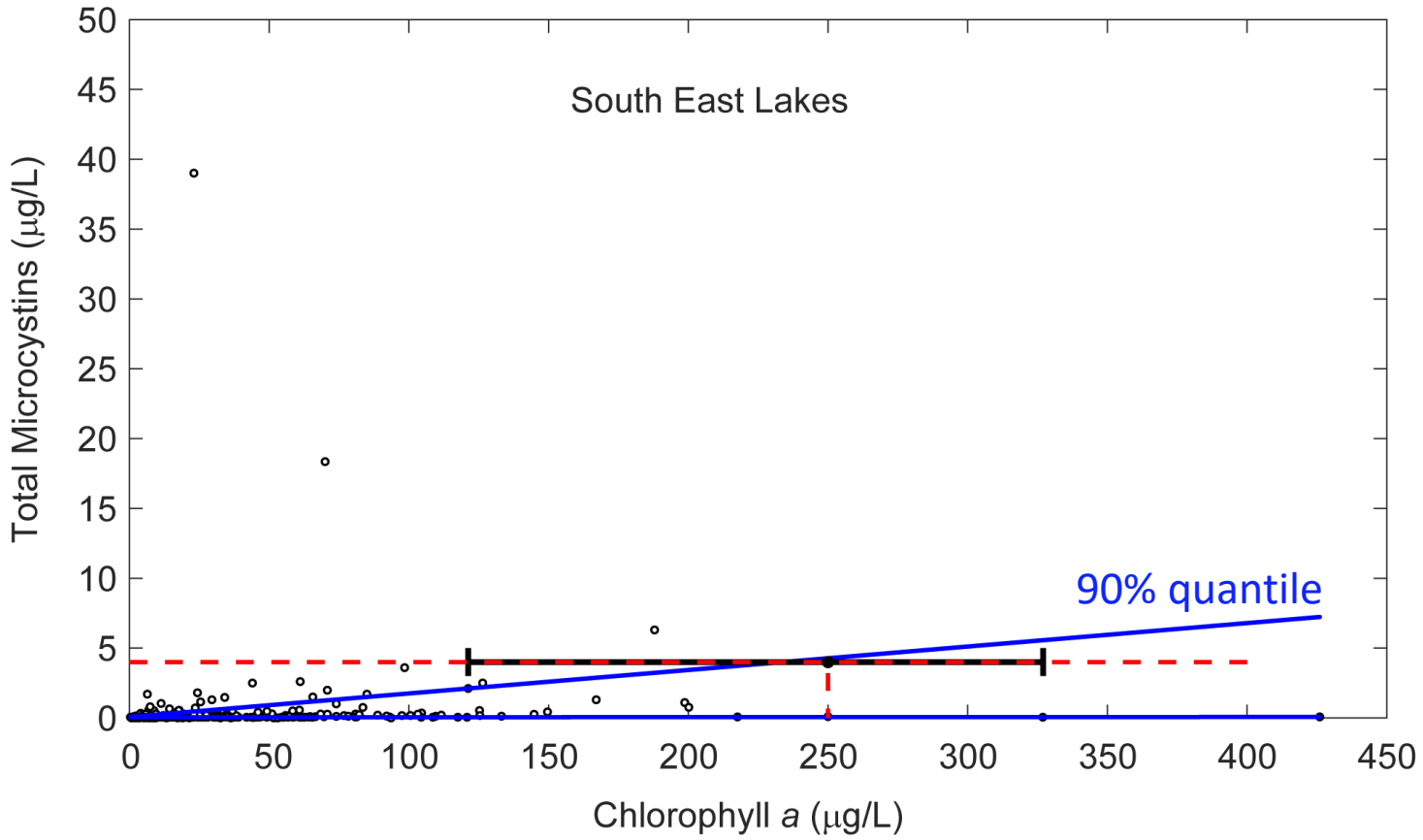
Selected data from states in the Southeast US (EPA region 4 states plus VA, AR, and LA)

Quantile regression of Total Microcystins on Chlorophyll *a* for All Lakes in the National Lakes Assessment (2007 & 2012)



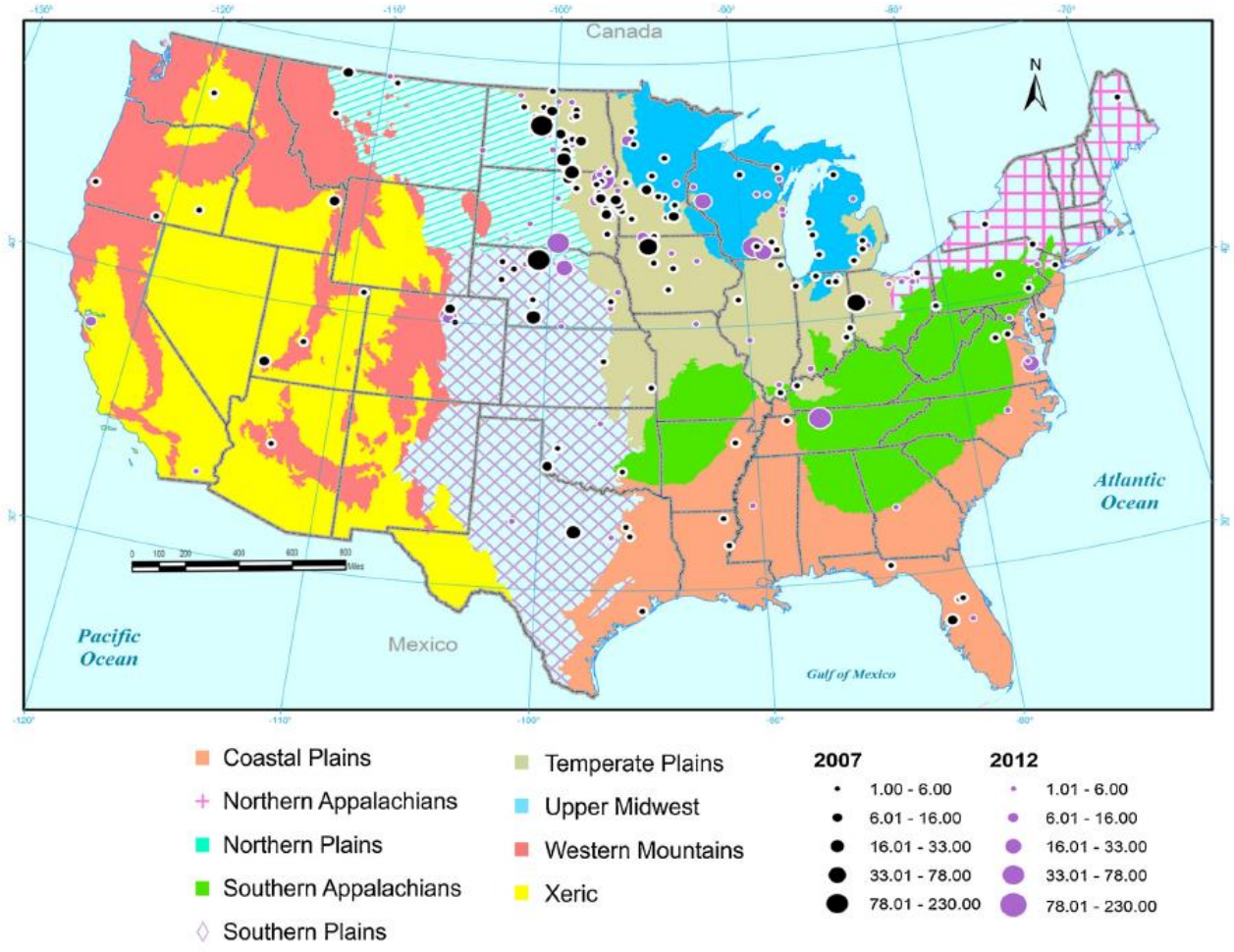
90% of samples should have less than 4 µg/L total microcystins when chl-a is < 78 µg/L (90% CI is 69-123)

Quantile regression of Total Microcystins on Chlorophyll *a* for Southeast Lakes in the National Lakes Assessment (2007 & 2012)



90% of samples should have less than 4 µg/L total microcystins when chl-a is < 230 µg/L

Southeast Lakes Are Generally Low in Microcystins
National Lakes Assessment (2007 & 2012)



Beaver et al. Harmful Algae 2018

Conclusions

National Lakes Assessment data indicates that microcystin higher than the recreational exposure advisory level of 4 μg/L is rare and relation to chlorophyll *a* is weak

With all lakes, 90% of samples should have less than 4 μg/L microcystin when chlorophyll *a* < 80 μg/L (90% CI: 70-120)

With only SE lakes, 90% of samples should have less than 4 μg/L microcystin when chlorophyll *a* < 250 μg/L

Tying a chlorophyll *a* standard to microcystin would probably lead to levels of phytoplankton biomass that would result in impairment for reasons other than toxins

Brown AND Caldwell

North Carolina Nutrient Science Advisory Council

Proposal: Framework for Deriving Site-Specific Chlorophyll-*a* Criteria

…with Pilot Application to High Rock Lake

Clifton F. Bell | December 2, 2018

Guiding Principles

Brown AND Caldwell

Desired Characteristics of the Framework

- Produces site-specific criteria that are protective of designated uses.
- Reduces assessment/management errors
  - Type I – False finding of impairment
  - Type II – False finding of attainment
- Considers both literature and lake-specific information.
- Not overly burdensome for DWR to apply.

Importance of Site-Specific Flexibility

- Not all water bodies experience the same effects at the same chlorophyll-a concentrations.
- Relatively wide spread in target values by use.
- From NCDP: “DWR is committed to evaluating nutrients and developing nutrient criteria on a site-specific basis.”
- This doesn’t mean we can’t constrain the range of appropriate values.

Threshold-Based vs. Continuum of Risk

Hard Threshold-Based

- Swimmers require Secchi depth of x, which occurs at CHLa of y_1.
- Microcystin exceeds threshold x at CHLa threshold y_2
- … etc.
- *CHLa target based on controlling (most stringent) linkage.*

Imprecise Continuum of Risk

- Some people's aesthetic enjoyment probably decreases with CHLa above y.
- Other lakes show increasing risk of toxin exceedances when CHLa exceeds y.
- … etc.
- *Choose a CHLa target based on partially subjective judgment of risk*.

My Take on Hard Threshold-Based vs. Imprecise Continuum of Risk

- Hard threshold basis is preferred ideal.
  - Discomfort with defining impairment as risk of impairment.
- Continuum of risk may be practical reality.
  - Data limitations.
  - Lack of established thresholds for some indicators.
  - Literature is relevant.
- **Proposed framework…**
  - Uses continuum-of-risk concepts (screening range).
  - Seeks confirmation of impairments within screening range.
  - Allows threshold approach within the screening range.

Proposed Framework for Deriving Site-Specific CHLa Criteria

Brown AND Caldwell

Steps of the Proposed Framework

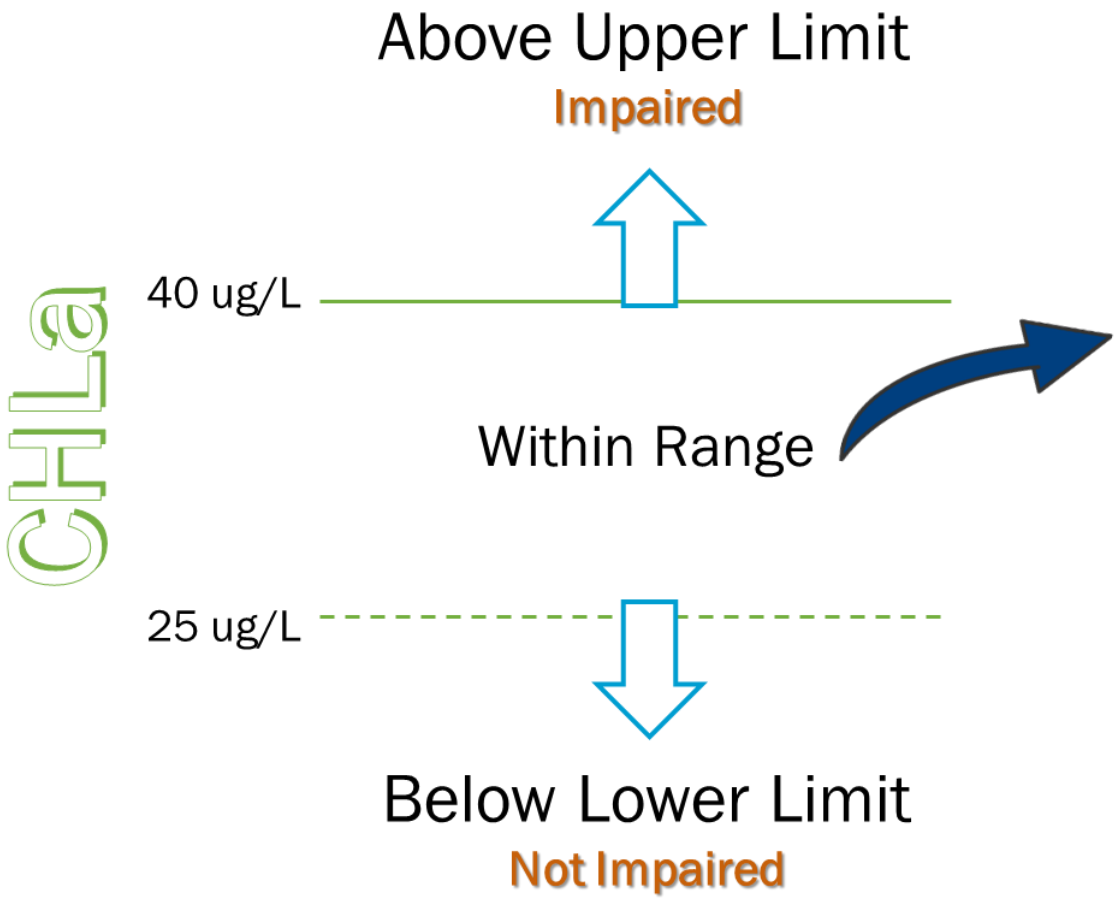
1. Apply CHLa- based screening range.

2. Perform narrative assessment for nutrient-related impairments.

3. Apply decision guidelines for determining impairment status of water bodies within screening range.

4. Apply decision guidelines for setting site-specific criteria within screening range.

Step 1: Apply CHLa- based screening range as first step in determining impairment status.



Narrative Evaluation:

- Fishery status
- Algal toxins
- Fish kills
- Water treatment issues
- *Etc.*

Step 2: Perform narrative assessment for nutrient-related impairments.

Facilitate this step with working list of indicators

- Primary indicators:
  - More direct indicator of use attainment
  - Well-established threshold or criterion exists
- Secondary indicators:
  - Less direct indicator of use attainment
  - Well-established threshold or criterion does not exist

Examples of Indicators: Aquatic Life

Use Category	Indicator	Primary or Secondary Indicator	Narrative or Numeric Indicator	Threshold(s) or Bases for Evaluation
Aquatic Life	DO conc.	P	Num.	4-5 mg/L (NC criteria)
	DO satur.	S	Num.	250-300% (based on sci. lit. of O_2-only gas bubble disease)
	pH	P	Num.	9.0 (NC criteria)
	Algal toxins	P	Num.	Various thresholds
	%Cyanobact.	S	Num.	% biovolume, % count (%biovolume more useful for judging zooplankton support)
	Fishery status	P	Narr.	Characterization based on NC WRC sampling
	Fish kills	P	Narr.	Occurrence & frequency
	Fish abnorm.	S	Narr.	Some might be related to nutrients (e.g., signs of gas bubble disease)

Examples of Indicators: Public water supply

Use Category	Indicator	Primary or Secondary Indicator	Narrative or Numeric Indicator	Threshold(s) or Bases for Evaluation
Public water supply	Algal toxins	P	Num.	Various thresholds
	T&O-causing compounds	S	Num.	Various thresholds
	Algal-related treatability challenges	P	Narr.	Severity & frequency

Examples of Indicators: Recreation

Use Category	Indicator	Primary or Secondary Indicator	Narrative or Numeric Indicator	Threshold(s) or Bases for Evaluation
Recreation	Algal toxins	P	Num.	Various thresholds
	Secchi depth	S	Num.	0.5 – 1.0 m
	Nuisance blooms; mats or extensive scums	P	Narr.	Severity & frequency

Step 2: Perform narrative assessment for nutrient-related impairments. (cont.)

Category #1: Indicator shows use clearly not met.

Category #2: Indicator does not directly show impairment, but suggests elevated risk of impairment.

Category #3: Indicator supports finding of use attainment.

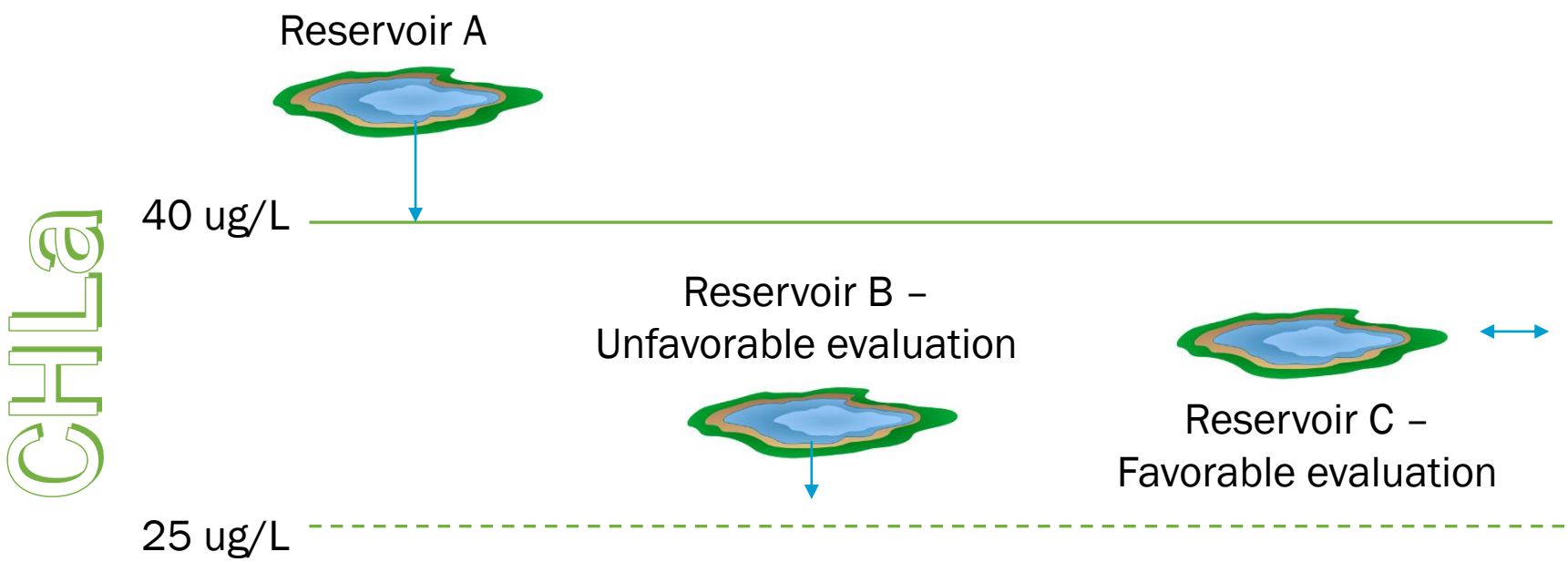
Step 3: Apply decision guidelines for determining impairment status of water bodies within screening range.

- Finding of impairment based on red primary indicators.
- Finding of attainment based on:
  - No red indicators
  - No more than 50% yellow indicators
- “Indeterminate” or “insufficient information” is a valid outcome.

Step 4: Apply decision guidelines for determining site-specific criteria

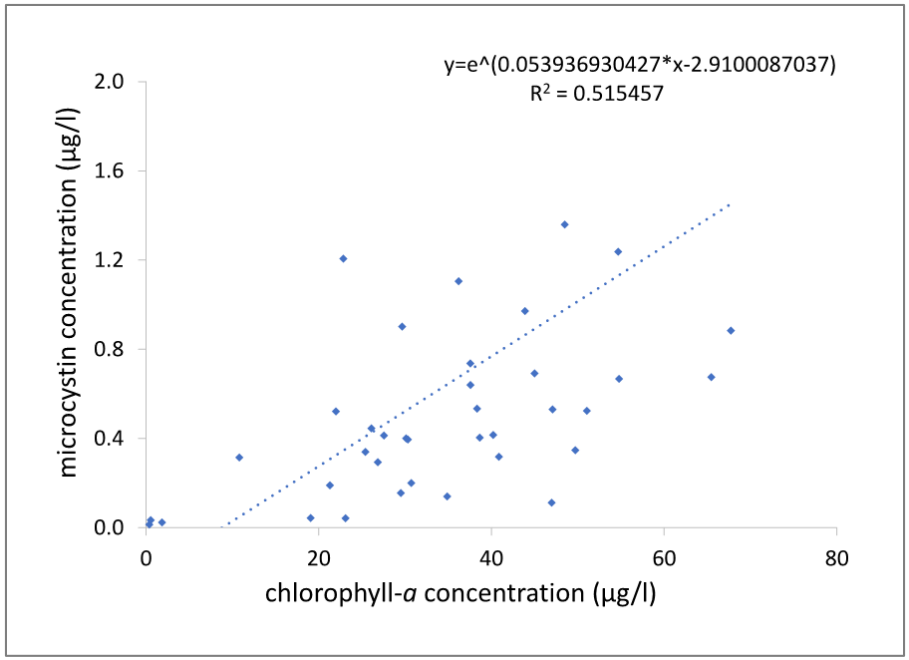
Existing CHLa	Does not Fail Narrative Assessment	Fails Narrative Assessment
Above screening range	• Criterion is upper end of screening range, barring special demonstration.	• Set criteria within screening range. • Prof. judgment based on severity and existing CHLa levels • Use CHLa-indicator linkages if available.
Within screening range	• Antidegradation policy applies • Option for criteria based on existing condition, considering variability • Use CHLa-indicator linkages if available.	• Bottom of screening range is default • Default can be overridden by CHLa-indicator linkages if available.
Below screening range	• Criterion is bottom end of screening range, barring special demonstration. • Antidegradation policy applies	• Case-by-case • Use CHLa-indicator linkages if viable.

Conceptual Approach for Setting Site-Specific Chlorophyll-a Goals

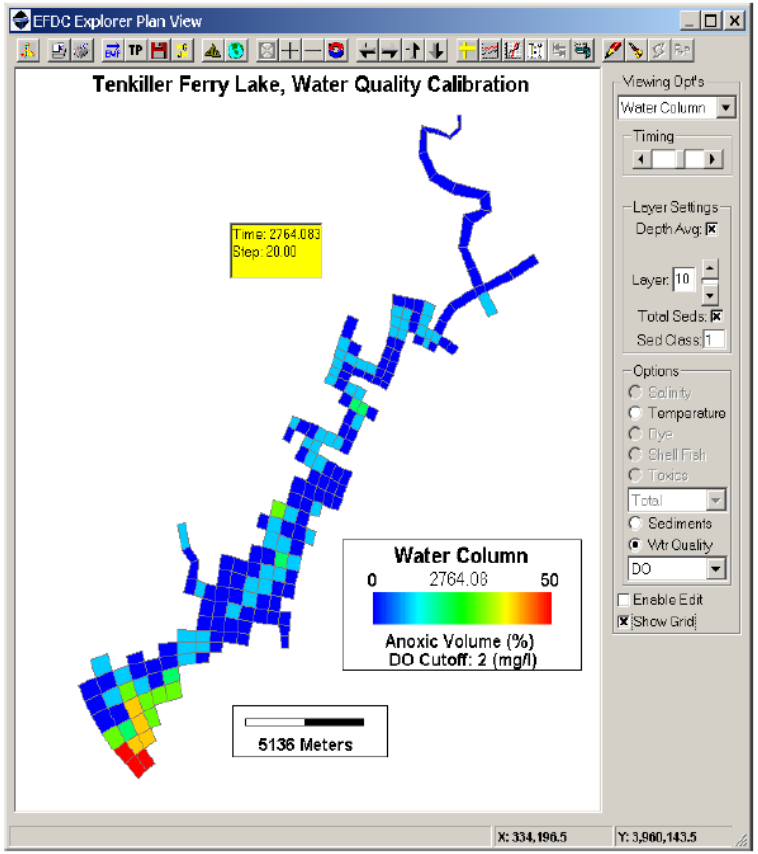


Use CHLa-indicator relations as data/resources allow.

Empirical



Deterministic models (if available)



Revisiting Desired Characteristics of Framework w.r.t. Proposal

- ✓Produces site-specific criteria that are protective of designated uses.
- ✓Reduces assessment/management errors
  - ✓Type I – False finding of impairment
  - ✓Type II – False finding of attainment
- ✓Considers both literature and lake-specific information.
- ✓Not overly burdensome for DWR to apply.

Text Example Using 2016 IR Data, 25-40 ug/L Tier Approach

Effect	Proportion of Stations
Flip from non-attainment to attainment	2.5%
Flip from non-attainment to requiring narrative evaluation	13.9%
Flip from attainment to requiring narrative evaluation	7.8%
Stays in non-attainment	17.2%
Stays in attainment	58.7%

Expressing the Chlorophyll-a Criteria & Screening Range

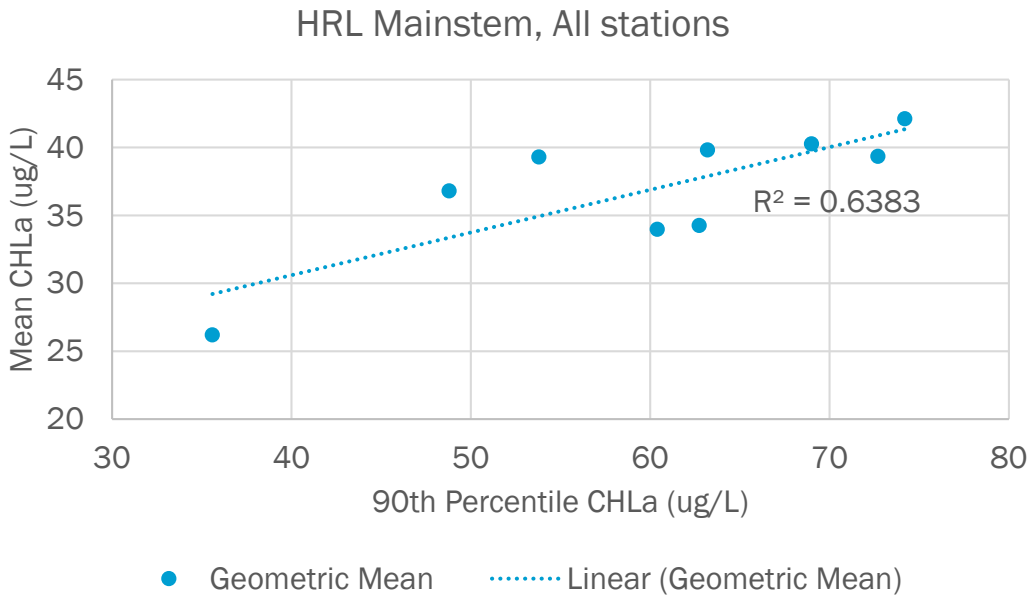
Brown AND Caldwell

Recommended Temporal Components of Chlorophyll-*a* Criteria

- April-October geometric mean chlorophyll-*a*
- Allowable exceedance frequency: 1 in 3 years.

Basis for Geometric Mean Recommendation

- A measure of overall trophic status to protect against a variety of effects over different time scales.
- Geomean is measure of central tendency for log-normal or asymmetric variables (USEPA, 2012)
- Precedents (e.g., Florida, Virginia, Missouri)



Basis of 1-in-3 year Allowable Frequency

- Consider natural variability and data representativeness
- Limit Type I assessment errors to ~10%, ala FDEP
  - Implicitly assumes criteria magnitude should be achieved in most (80%) years, not just as long-term average (50%).

Rationale for not including a statistical test

- Concern about making it too hard to list or delist lakes
- By averaging 10+ data, the result is never based on 1-2 measurements.
  - Difference from not-to-exceed criteria
- 1-in-3 approach has statistical foundation
- Screening range + narrative assessment increases confidence in result.
  - Upper end of range reduces risk of type I errors
  - Lower end of range reduces risk of type II errors
  - Narrative assessment provides additional confidence

Literature Most Useful for Informing the Lower End of the Range

- Recreational Uses:
  - A wide variety of CHLa targets based on region, user expectations, and whether nuisance forms occur.
    - Impairments identified at CHLa as low as 5 ug/L (Hoyer and others, 2004) to as high as 40 ug/L (Nevada DEP, 2008)
    - Most values in 15-30 ug/L range
  - Some subjective judgments:
    - Users of many southeastern warmwater reservoirs would not expect CHLa values in the lower end of this range
    - If nuisance forms are not prevalent, higher values may be acceptable

Literature Most Useful for Informing the Lower End of the Range (cont.)

- Public Water Supply:
  - Similar wide range at which taste and odor or algal toxins can (but don't necessarily) exceed problem thresholds.
  - Impairments identified at values ranging from 10 mg/L (Carney, 1998) to 30 ug/L (Heath and others, 1998)
  - Southeastern water utilities routinely treat water from highly-productive reservoirs.

Literature Most Useful for Informing the Lower End of the Range (cont.)

- Warmwater fisheries use:
  - A higher CHLa range (20 – 60+) but still wide.
  - Some studies indicate reductions in fish productivity with CHLa reduction.
  - Not clear at what CHLa level this would occur.

Chl-a (µg/l)	Notes
40-60	Fertilization to achieve Chl a concentrations for production of bass and sunfish (Maceina, 2001)
40	Bachman et al. 2002 confirms trophy fish are more abundant in more eutropic lakes
40	Non-trout waters (McGhee, 1983)-North Carolina
25	Warmwater fisheries only (Dillon et al, 1975)
60-70	Hyperutrophic status for managed ponds, no recreation (Lee et al, 1995)
20	Black crappie fisheries peak (Schupp and Wilson, 1993)
60	White crappie fisheries peak (Schupp and Wilson, 1993)
10-15	These Chl a levels not necessarily detrimental to black bass and crappie fisheries (Reckhow et al, 1980)
20	Growth of crappie and largemouth bass increased up to this Chl a level (Maciena, 1996)
25-40 30-50	All lakes and reservoirs besides urban (mean values for growing season) Urban lakes and reservoirs (mean values for growing season) (Arizona DEQ, 2007)
25 40	Growing Season Mean Growing season maximum (Nevada Division of Environmental Protection, 2008)-Lakes and Reservoirs in Nevada

Rationale for Lower End Recommendation

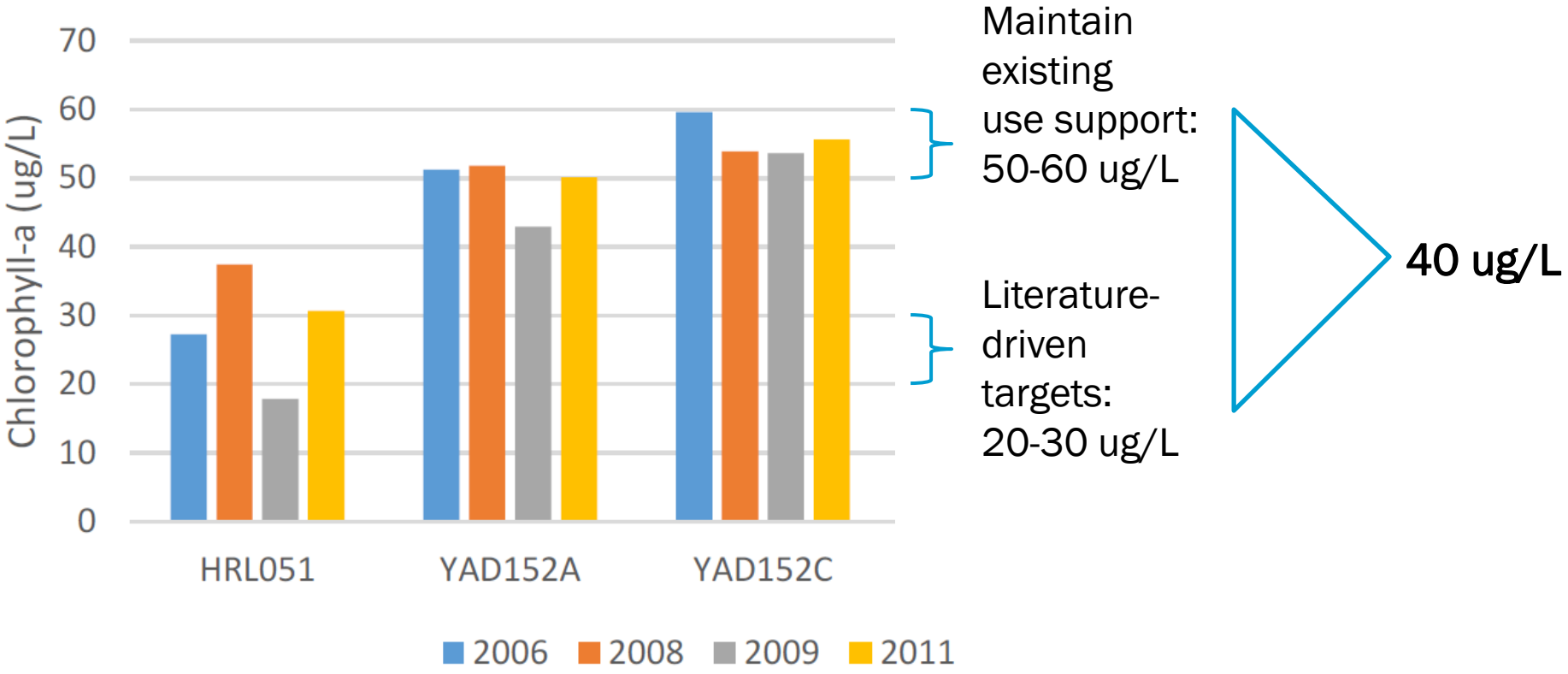
- Consider nature and uses of NC warmwater reservoirs
  - Fishing valued
  - Balance between fishing and potential aesthetic issues
- Choose a value from within the overlapping literature ranges where some use impacts have been noted
  - Recreation: 15-30 ug/L
  - Public water supply: 10-30 ug/L
  - Fishing: 20–60 ug/L

  } Overlap: 20-30 ug/L
- Set at value where we are also confident we won't adversely impact warmwater fisheries.
- → 25 ug/L

Setting the Upper End of Range

- Literature informative but less directly useful
  - Tends to characterize CHLa where use impacts can (but don't necessarily) occur
  - Fewer studies of lakes/reservoirs without problems/complaints.
- Should also be informed by highly productive lakes without clear impairments
  - "A greenish lake with good fishing".
  - High Rock Lake provides a good example

Recommendation of 40 ug/L based on balancing “maintain existing use support” concepts with literature-driven perspectives

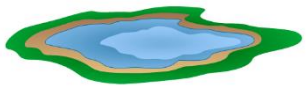


Pilot Application of Framework to High Rock Lake

Brown AND Caldwell

Step 1: Apply Screening Range

HRL up to 55 ug/L



High Rock Lake Impaired Based on CHLa alone

CHLa

40 ug/L

25 ug/L

Step 2: Perform narrative assessment for nutrient-related impairments.

Use Category	Indicator	Primary or Secondary Indicator[1]	Narrative or Numeric Indicator	Threshold(s) or Bases for Evaluation	Indicator Status under HRL's Existing CHLa Conditions[2]
Aquatic Life	DO concentration	Primary	Numeric	4-5 mg/L (NC criteria)	HRL not impaired for DO. Surface DO favorable. Bottom DO strongly affected by stratification.
	DO saturation	Secondary	Numeric	250-300% (based on sci. lit. of O_2-only gas bubble disease)	2016 monitoring showed 90th percentiles of 98% -188% with instant. max. values of 148%-265% depending on station.
	pH	Primary	Numeric	9.0	HRL currently impaired for pH. Proposed adjustments to pH monitoring method would lessen impairment but some stations (e.g., YAD152C) would still be marginal.
	Algal toxins	Primary	Numeric	Various thresholds	Algal toxins present but in low concentrations. General concern over toxin potential.
	%Cyanobact.	Secondary	Numeric	% biovolume, % count (%biovolume more useful for judging zooplankton support)	%Counts high but %biovolume adequate to support high trophic levels.
	Fishery status	Primary	Narrative	Characterization based on NC WRC sampling	Meets fishery use.
	Fish kills	Primary	Narrative	Occurrence & frequency	No nutrient-related fish kills on record.
	Fish abnormalities	Secondary	Narrative	Some might be related to nutrients (e.g., signs of gas bubble disease)	NC WRC: No signs of gas bubble disease in HRL fish.
Public water supply	Algal toxins	Primary	Numeric	Various thresholds	Algal toxins present but in low concentrations. General concern over toxin potential.
	T&O-causing compounds	Secondary	Numeric	Various thresholds	Town of Denton does not report T&O problems.
	Treatability challenges	Primary	Narrative	Occurrence & frequency	Town of Denton does not report algae-related treatability problems.
Recreation	Algal toxins	Primary	Numeric	Various thresholds	Algal toxins present but in low concentrations. General concern over toxin potential.
	Secchi depth	Secondary	Numeric	0.6 – 1.0 m	CHLa sufficiently high to reduce SD < 1.0 m and impart green color to water. Unclear how this relates to regional user expectations or actual use.
	Nuisance blooms; mats or extensive scums	Primary	Narrative	Occurrence & frequency	Algae in HRL tends to be dispersed in water column.

Step 3: Apply decision guidelines for determining impairment status of water bodies within screening range.

- Skip this step; HRL above screening range.

Step 4: Apply decision guidelines for determining site-specific criteria

Existing CHLa	Does not Fail Narrative Assessment	Fails Narrative Assessment
Above screening range	• Criterion is upper end of screening range, barring special demonstration.	• Set criteria within screening range. • Prof. judgment based on severity and existing CHLa levels • Use CHLa-indicator linkages if available.
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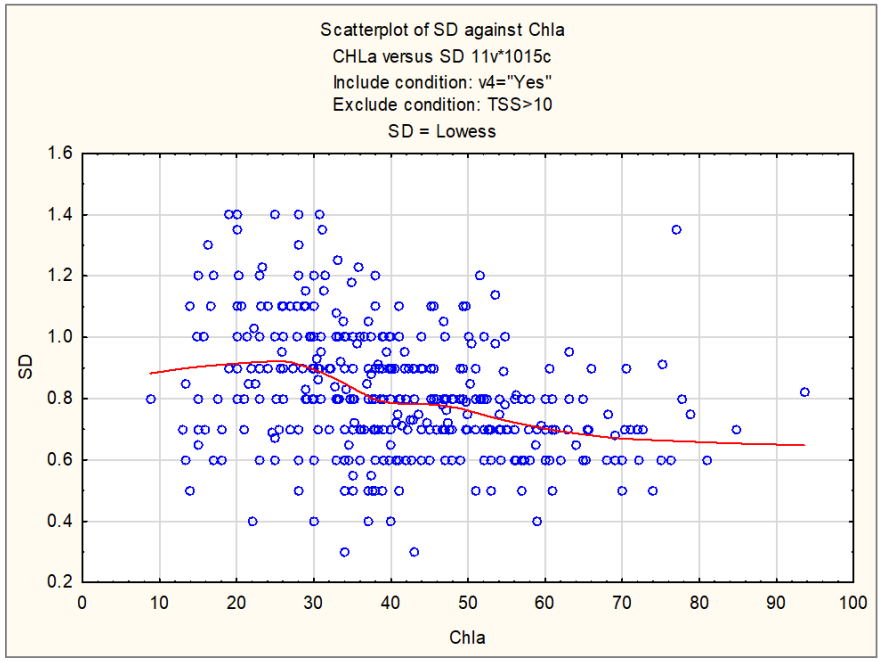
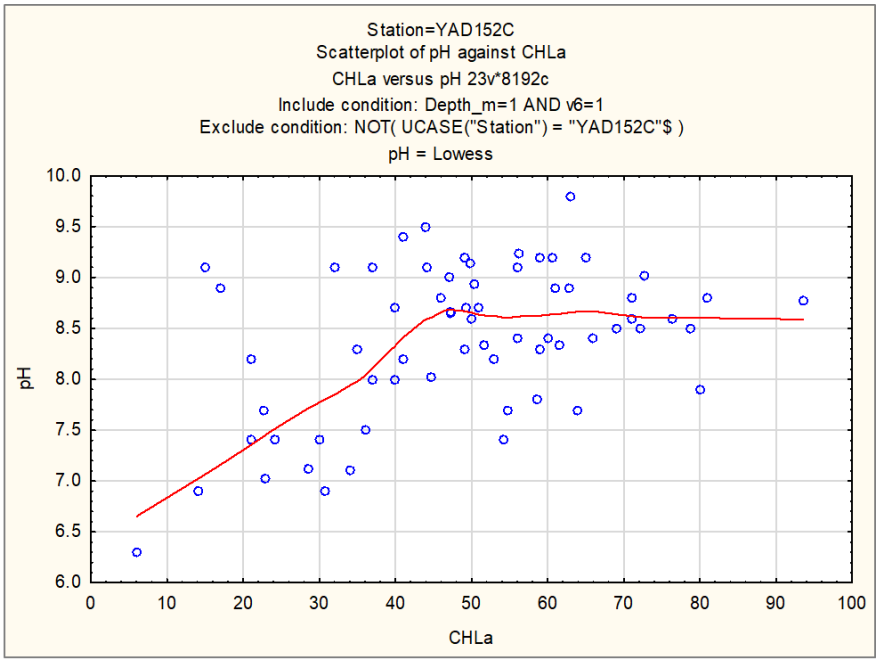
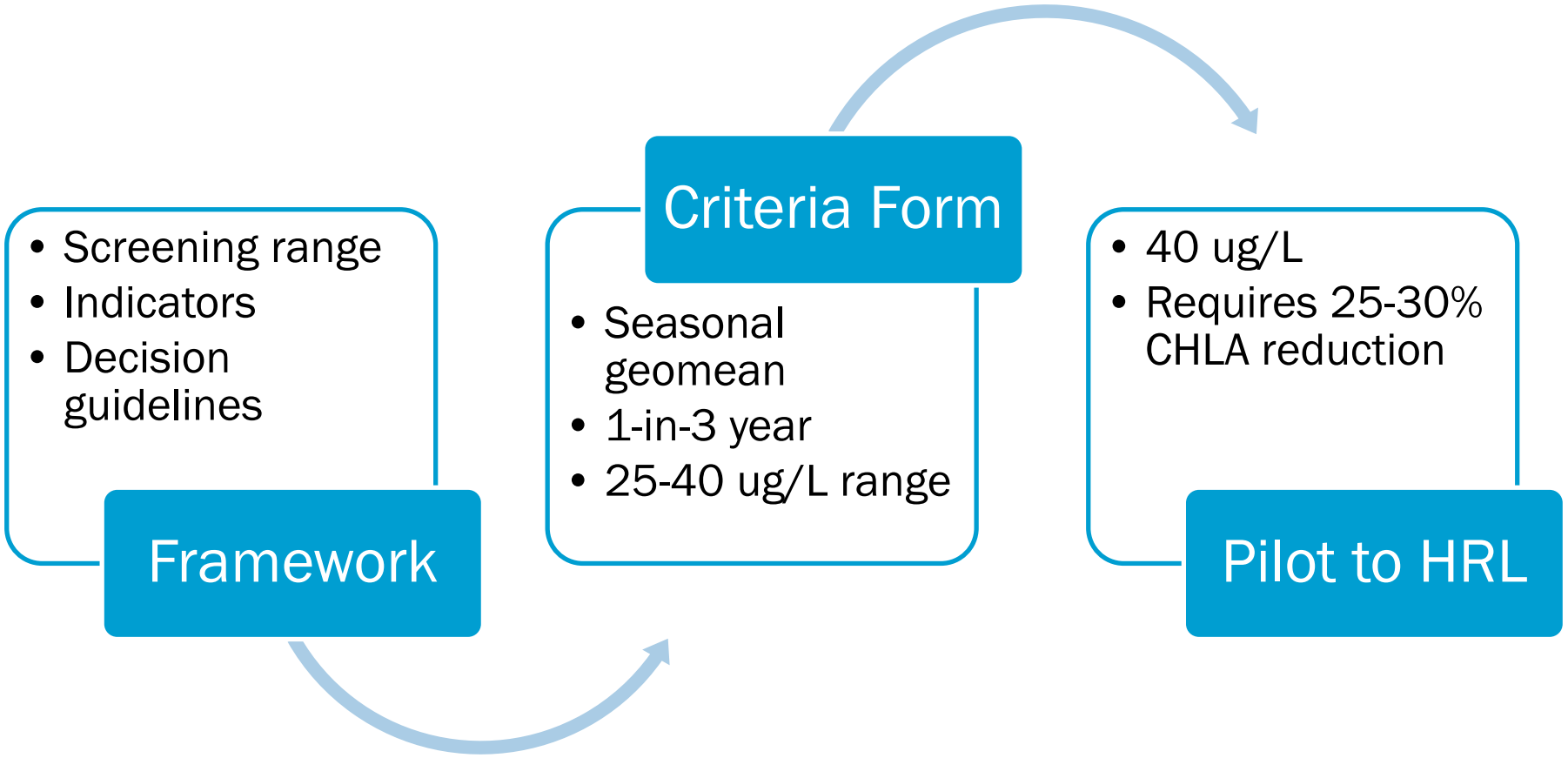
Evaluate CHLa-indicator relations





Summary


Framework
• Screening range
• Indicators
• Decision guidelines
Criteria Form
• Seasonal geomean
• 1-in-3 year
• 25-40 ug/L range
Pilot to HRL
• 40 ug/L
• Requires 25-30% CHLA reduction

Proposal for the December 2018 SAC Meeting (LP Proposal #1)

15A NCAC 02B .0211 (4) Chlorophyll a (corrected):

(a) Unless otherwise specified on a site specific basis at 15A NCAC 02B .0211(4)(b), not greater than 40 ug/l for lakes, reservoirs, and other waters subject to growths of macroscopic or microscopic vegetation not designated as trout waters, and not greater than 15 ug/l for lakes, reservoirs, and other waters subject to growths of macroscopic or microscopic vegetation designated as trout waters (not applicable to lakes or reservoirs less than 10 acres in surface area). The Commission or its designee may prohibit or limit any discharge of waste into surface waters if the surface waters experience or the discharge would result in growths of microscopic or macroscopic vegetation such that the standards established pursuant to this Rule would be violated or the intended best usage of the waters would be impaired;

(b) Site Specific Criteria for Chlorophyll a (corrected):

(i) High Rock Lake: A growing season arithmetic average (based on samples collected April 1 - October 31) of 24 µg/L should not be exceeded more than once in a three-year period. No instantaneous value shall be greater than 30 µg/L to protect against excessive dominance by blue green algae.

ASSUMPTIONS:

Assumption #1 – The current condition of the lake is not supporting its designated uses. Elevated pH is a widely accepted indicator of over enrichment. The downstream waters are experiencing deteriorating water quality conditions, most notably through chlorophyll a and pH listings. A condition better than the current one would be more reflective of the best usage and conditions related to the best usage desired by the state's regulations.

(1) Best Usage of Waters: aquatic life propagation and maintenance of biological integrity (including fishing and fish), wildlife, secondary recreation, agriculture, and any other usage except for primary recreation or as a source of water supply for drinking, culinary, or food processing purposes;
(2) Conditions Related to Best Usage: the waters shall be suitable for aquatic life propagation and maintenance of biological integrity, wildlife, secondary recreation, and agriculture. Sources of water pollution that preclude any of these uses on either a short-term or long-term basis shall be considered to be violating a water quality standard;

Assumption #2 (Local Literature Support) - The chlorophyll a criteria of nearby states were adopted by states and approved by EPA as representative of the concentrations associated with meeting the relevant designated use expectations (swimming, fishing, aquatic life, and drinking water sources) in each state's lakes (in most cases, manmade reservoirs). These criteria included chlorophyll a magnitudes in the range of 5-35µg/L, with varying durations and frequencies. See Assumption #3 for further refinement.

Additional information – The nearby states criteria were based on chlorophyll a levels found to be associated with a lack of: fish kills, eutrophication impacts such as low DO or elevated pH, swimming beach closures, or taste/odor/ treatment impacts for associated drinking water

facilities. The states demonstrated through either documentation of designated use support or necessary reductions through TMDL modeling to achieve other applicable water quality criteria (such as DO and pH) that all designated uses were protected.

Assumption #3 (Averaging Period and Long Term Effects) – For chlorophyll a, a response variable for nutrient enrichment, a longer term response, in the form of a seasonal average, is a beneficial way to monitor for manifestation of the longer term response to nutrients. When refining the values in Assumption #2 to only consider averaged concentrations, chlorophyll a magnitudes were narrowed to a range of 5-24 µg/L.

Assumption #4 (Final Magnitude Selection) – In order to narrow down the range of criteria values from Assumption #3 further, data from HRL was considered. Based on the data provided in the table below, there appears to be a shift in the arithmetic averages over time, indicating increased eutrophication. Prior to the 2000s, the lake experienced concentrations more typical of the values identified in the earlier assumptions. If the data from 1982 and 1990's growing seasons are averaged (n=34) the average chlorophyll is 23.4. Alternatively, the range in seasonal averages is 21.9 (n=20) to 25.6 (n=14) and an average of 23.75. These numbers represent a time before a shift occurred in the existing historical data and generally align with the upper end of the range of values from Assumption #3. In the 2000s is when the lake was first listed. Therefore, a growing season arithmetic average chlorophyll a of 24µg/l would be protective of the designated uses of the lake.

Year	Arithmetic Average of Growing Season Data (in µg/L)	Range of Single Values (in µg/L)	Notes
1982	25.6	2-45	June, July (n=14)
1990	21.9	4-41	May-Sept (n=20)
2001	38.4	3-52	July-Aug (n=15)
2002	37.6	0.5-61	June, July, Sept (n=20)
2004	34.4	3-53	June, July, Aug (n=23)
2005	39.4	13-71	April, Oct (n=20)
	*		
2006	41.6	12-71	April-Sept (n=66)
	42.3	12-71	May-Sept (n=55)
2008	39.9	17-52	April – Oct (n=10)
	42.4	33-52	May-Oct (n=9)
2009	29.2	14-54	May-July, Sept (n=5)
2011	44.7	13-86	May, July-Sept (n=55)

NOTE: Data from years 1981, 1983, 1984, 1985, 1986, 1989, 1994, and 2010 were not used because there was either no or only single month data in the growing season months.
**Data from 2005 includes only October samples, once April is removed for purposes of computing averages, so it is not shown here for the same reasons others years were not included.*

Assumption #5 (Short Term Effects) – Because there can also be shorter term, acute biological concerns, such as those relating to increased risk for cyanotoxin production, the proposal above incorporates additional language to protect against those effects. Based on the state's analysis, instantaneous chlorophyll a concentrations <30 represented "mild" or "less blooms" and corresponded

to a 9.3% blue green dominance. In contrast, the range of 30-40 corresponded to “severe blooms” and corresponded to a 46.4% blue green dominance. Therefore, this proposal concludes that the qualitative statements and percentage likelihood for blue green dominance associated with the <30 chlorophyll a value are more consistent with the goals of designated use support than the 30-40 µg/L level of chlorophyll a conclusions.

Assumption #6 (Arithmetic Average) – The proposal’s selection of an arithmetic averaging method was chosen because it aligns best with the underlying support being used to support this proposal. Alabama and Georgia use growing season averages so maintaining something comparable would be most equivalent to the local literature support values with growing season-based magnitudes.

Assumption #7 (1-in-3) – With regard to the frequency, the use of a 1-in-3 allowable excursion frequency is an established approach and is consistent with EPA’s recommendations when protecting aquatic life against long-term effects.

Proposal for the December 2018 SAC Meeting (LP Proposal #2)

15A NCAC 02B .0211 (4) Chlorophyll a (corrected):

(a) Unless otherwise specified on a site specific basis at 15A NCAC 02B .0211(4)(b), not greater than 40 ug/l for lakes, reservoirs, and other waters subject to growths of macroscopic or microscopic vegetation not designated as trout waters, and not greater than 15 ug/l for lakes, reservoirs, and other waters subject to growths of macroscopic or microscopic vegetation designated as trout waters (not applicable to lakes or reservoirs less than 10 acres in surface area). The Commission or its designee may prohibit or limit any discharge of waste into surface waters if the surface waters experience or the discharge would result in growths of microscopic or macroscopic vegetation such that the standards established pursuant to this Rule would be violated or the intended best usage of the waters would be impaired;

(b) Site Specific Criteria for Chlorophyll a (corrected):

(i) High Rock Lake: No instantaneous chlorophyll a value shall be greater than 30 µg/L to protect against excessive dominance by blue green algae.

ASSUMPTIONS:

Assumption #1 – The current condition of the lake is not supporting its designated uses. Elevated pH is a widely accepted indicator of over enrichment. The downstream waters are experiencing deteriorating water quality conditions, most notably through chlorophyll a and pH listings. A condition better than the current one would be more reflective of the best usage and conditions related to the best usage desired by the state's regulations.

> *(1) Best Usage of Waters: aquatic life propagation and maintenance of biological integrity (including fishing and fish), wildlife, secondary recreation, agriculture, and any other usage except for primary recreation or as a source of water supply for drinking, culinary, or food processing purposes;*
> *(2) Conditions Related to Best Usage: the waters shall be suitable for aquatic life propagation and maintenance of biological integrity, wildlife, secondary recreation, and agriculture. Sources of water pollution that preclude any of these uses on either a short-term or long-term basis shall be considered to be violating a water quality standard;*

Assumption #2 (Short Term Effects) – Because there can also be shorter term, acute biological concerns, such as those relating to increased risk for cyanotoxin production, the proposal above incorporates additional language to protect against those effects. Based on the state's analysis, instantaneous chlorophyll a concentrations <30 represented "mild" or "less blooms" and corresponded to a 9.3% blue green dominance. In contrast, the range of 30-40 corresponded to "severe blooms" and corresponded to a 46.4% blue green dominance. Therefore, this proposal concludes that the qualitative statements and percentage likelihood for blue green dominance associated with the <30 chlorophyll a value are more consistent with the goals of designated use support than the 30-40 µg/L level of chlorophyll a conclusions.

SPIROGYRA DIVERSIFIED
ENVIRONMENTAL SERVICES
Water Resource Management and Analytical Services

Chlorophyll *a* Magnitude Proposal
NC SAC Meeting – Dec. 3, 2018

Proposal

My discussion refers to the proposals summarized in the Template for CHL a proposals_05312018-2. Regarding the establishment of a chlorophyll *a* magnitude, I am most in agreement with the basis put forward by Bill Hall, who recommends defining a level "necessary to protect uses". Thus, the magnitude should be tied to specific types of use impairment. In the AllPresentations PowerPoint, the question was raised: "What [magnitude] do we want to use for HRL *and* other lakes in NC. I believe that conditions in HRL are anomalous from those of other NC lakes/reservoirs; thus, the use impairment approach is more appropriate for application to all NC lakes/reservoirs. Bill's proposal selects a single target level of magnitude, 40 μg/L, which, if exceeded on average within three years, would trigger an evaluation of use impairment prior to determination of any lower target. The proposal also employs an anti-degradation strategy based on TP. I would deviate from this proposal on two points: 1) expand growth season to April-Oct. 2) sample type would be a photic zone composite.

My second-choice proposal is Clifton Bell's CB2 which, again, establishes a 40 μg/L target magnitude, derived from a 25-40 μg/L range that has wide scientific support for warmwater reservoirs. The proposal includes the option of spatial assessment based on limnological categories. It also provides for recognition of existing favorable site-specific indicators (excellent fishery, lack of nuisance scums and other aesthetic concerns, low algal toxin levels). I would deviate from this proposal only in possibly raising the low end of the aforementioned range to $\geq$ 30 μg/L and expanding the high end to a value closer to the maximum level mentioned in the proposal, 55 μg/L.

Scientific Rationale

In selecting the above proposals, I have considered information from several sources. First, I will refer to information summarized in the AllPresentations PowerPoint. Slide 20 summarized chlorophyll *a* data (n = 3208) for NC Lakes, showing a wide range of values from 0.5-380 μg/L. Yet, the mean level was only 25 μg/L. Moreover, Slide 21 showed that the 75th percentile value was $\geq$ 33 μg/L. Slide 22 shows a neighboring state (South Carolina) precedent for selection of a 40 μg/L target magnitude.

Slide 32 from a 2016 presentation contains two important points to consider: 1) we may not want to go below 25 μg/L to avoid adverse impacts on the fishery, which is arguably the primary use category for HRL 2) if T & O issues are treated at the WTP, no maximum criterion is needed for the potable water use category. Slide 34 contains a reference to a chl *a* range for healthy fish populations of 25-60 μg/L. A number of scientific papers assert that chl μg/L levels below 20 μg/L are associated with declining fishery quality (Maceina and Byrne, 2001; Ney, 1996). Maceina and Byrne (2001) conclude:

> *When establishing water quality standards that result in reduced nutrient loading, fishery and water quality managers should collaborate to achieve compromises between aesthetics and fisheries.*

Ney (1996) concludes:

> *Reversal of eutrophication can have deleterious effects on reservoir fisheries. The Clean Lakes Program objectives are often too narrowly focused on enhancement of aesthetic and recreational uses with little consideration of fisheries (Lee and Jones, 1991)*

DiCenzo et al (1995) concluded that the growth and condition of largemouth and spotted bass are greater in eutrophic waters.

The above proposals also address the issue of cyanotoxin concentration for recreational use, which is arguably a secondary, albeit important use for HRL. Their proposed chl *a* magnitudes, 40 μg/L, are well within the range deemed acceptable in Slides 32 and 35 for aesthetics/recreation. Clifton's suggested low-end value of the range for incidental/infrequent contact is no lower than 30 μg/L. His lower suggested value of 20 μg/L for full body contact was derived from reservoirs with higher levels of cyanotoxins than those currently determined in HRL.

Both proposals refer to use attainment status to form the basis of criteria implementation. An acceptable chl *a* range for recreation must be broad enough to reflect the uncertainty in the relationship between chl *a* and cyanotoxin concentration. A cautious approach toward cyanotoxin considerations has broad scientific support, as reflected in the more liberal cyanotoxin recreational guidelines proposed in the latest EPA draft guidance documents (EPA Draft, 2016; EPA-AWQC Advisory, 2018).

I have served as a contractor in several studies of cyanotoxin occurrence in NC reservoirs, including studies for the US EPA, NC DWR, and NC Division of Public Health. The NC DPH study (Shehee et al, unpublished) explored the relationship between swimmer gastrointestinal complaints, cyanobacterial abundance, and cyanotoxin concentrations in Falls Lake swimming areas. Results were inconclusive. Further, I participated in an EPA-published study examining the relationship of cyanobacterial abundance and microcystin concentrations in Falls Lake

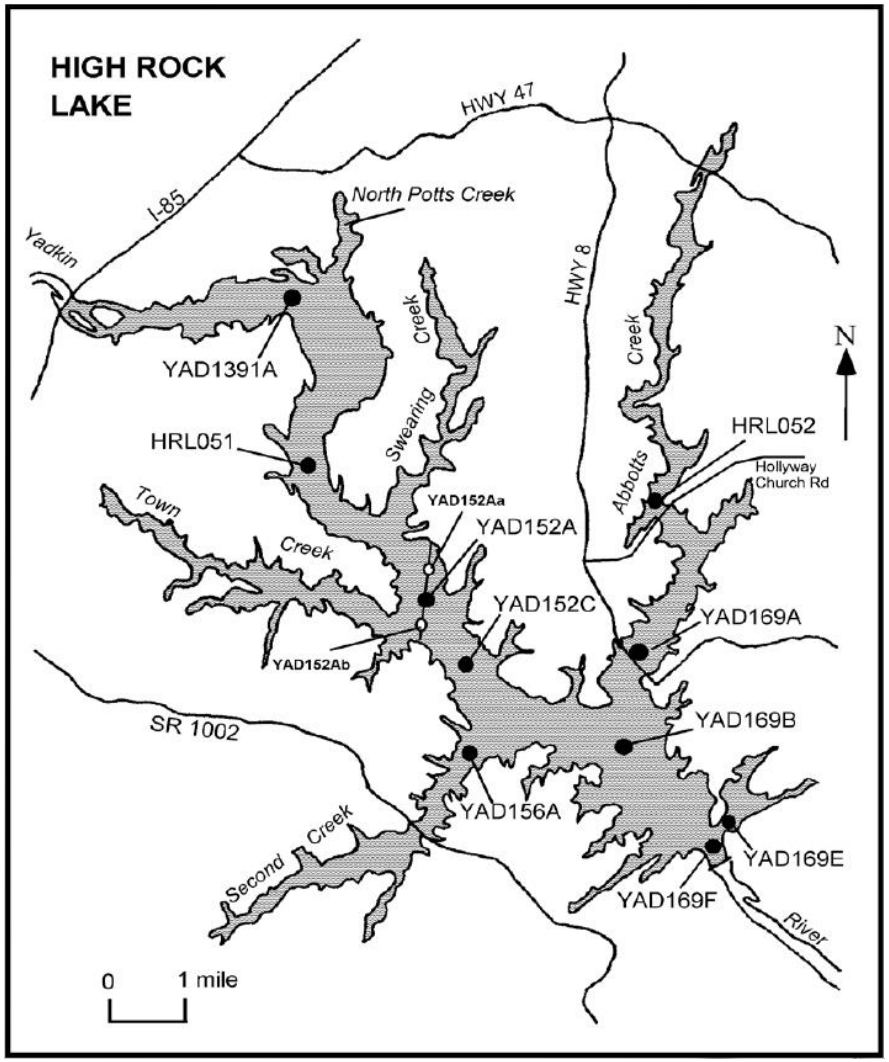
(Ehrlich et al, 2008). We found a weak correlation (R^2 = 0.11) between MCYSTS and the grouped densities of *Dolichospermum (Anabaena*) and *Aphanizomenon*.

High Rock Lake Chlorophyll a Evaluation for Key Locations

NC SAC – 12/3/18 Meeting

AquAeTer

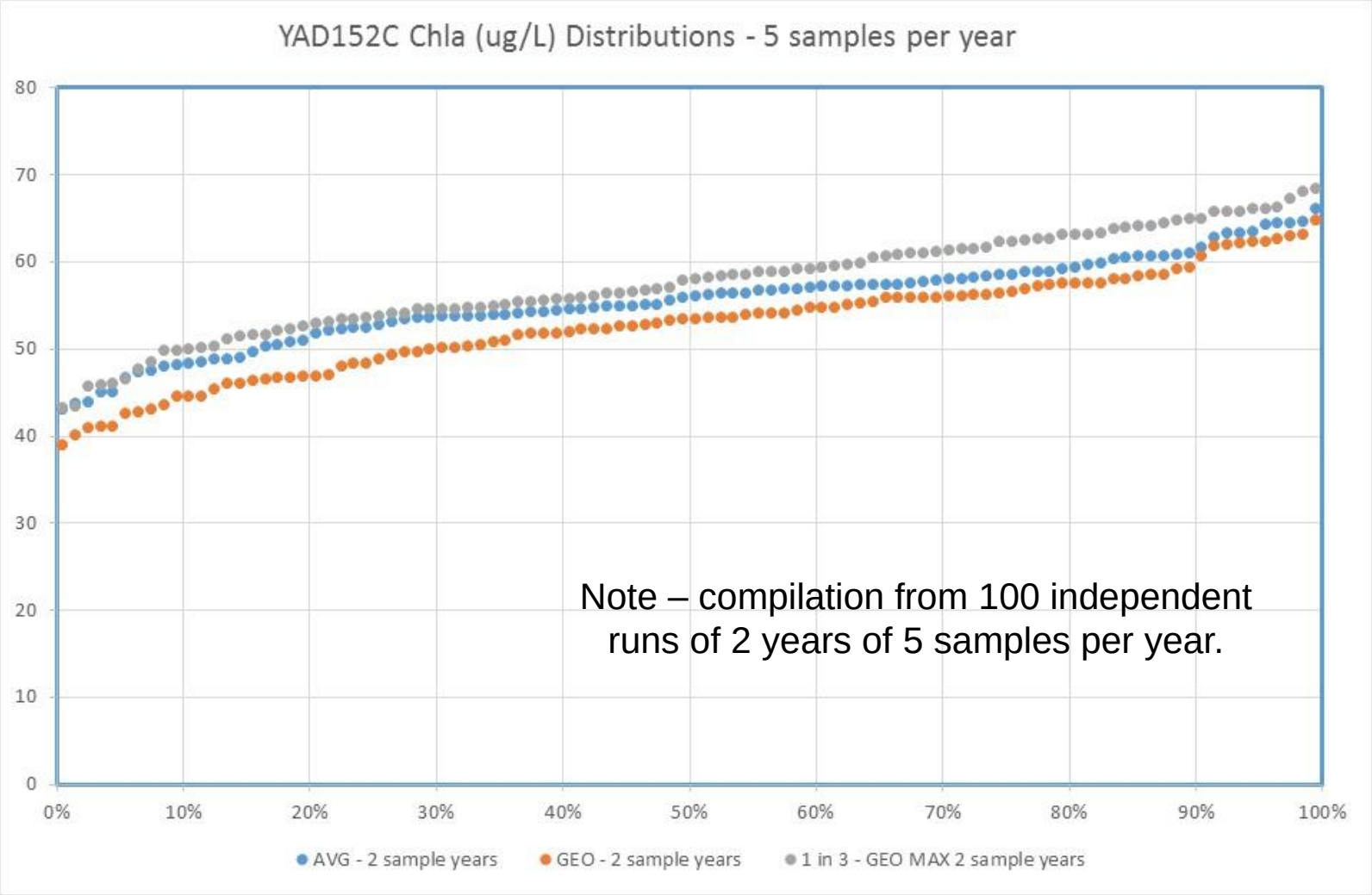
Description of Evaluation



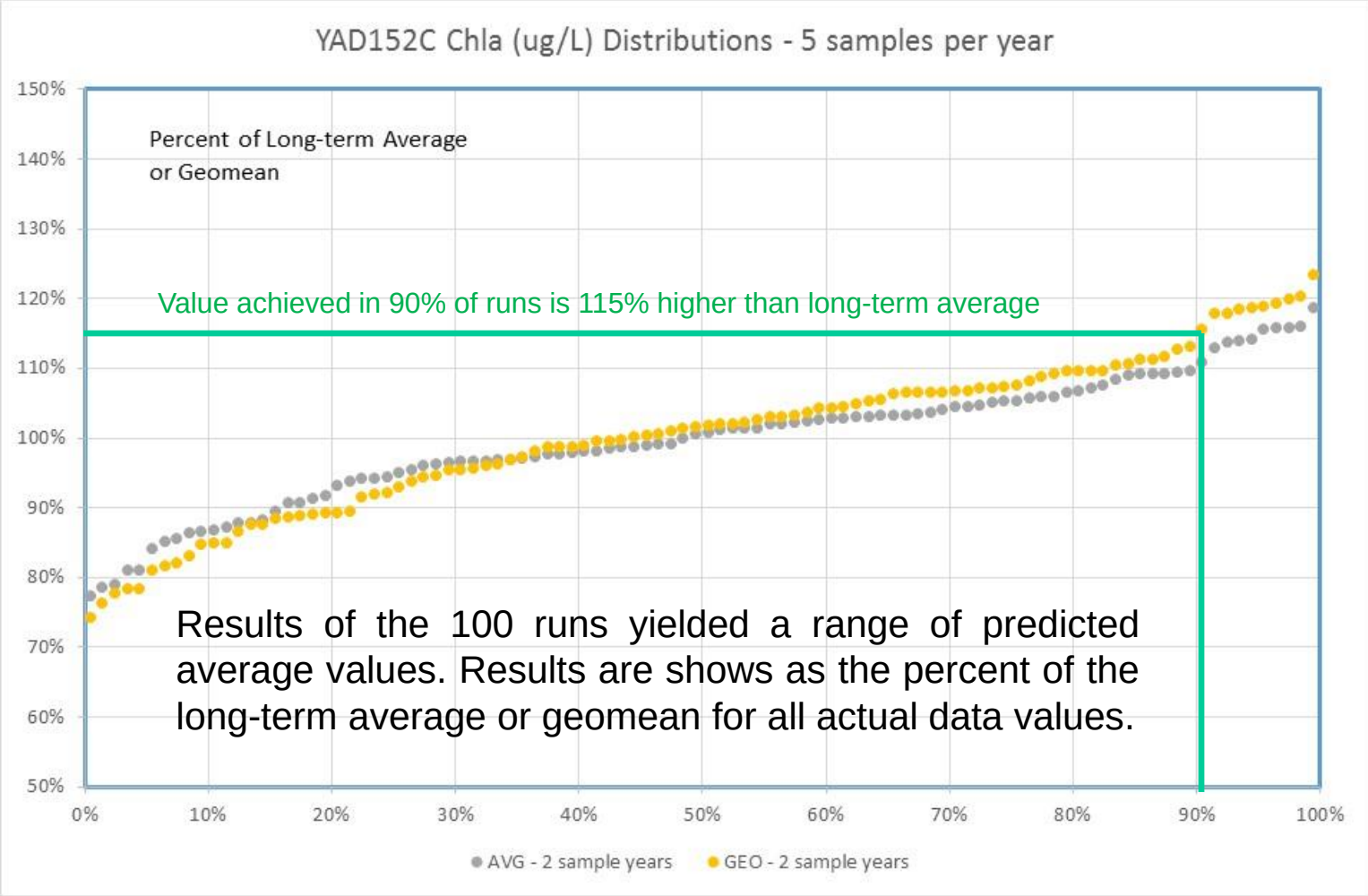
- Utilize Monte Carlo approach to evaluate average Chla for sampling 5 months for 2 years
- Data for 2006-2016 NC DWR surveys during April-October
- Pool all data from a station and randomly sample 5 times per year for 3 years
- Create 100 synthetic sample records with which to evaluate variation in arithmetic and geomean approaches
- HRL051, YAD152C, YAD169B, and YAD169A

AquAeTer

Comparison of Summary Metrics



Comparison of Summary Metrics



Note – 100 independent runs of 2 years of 5 samples per year.

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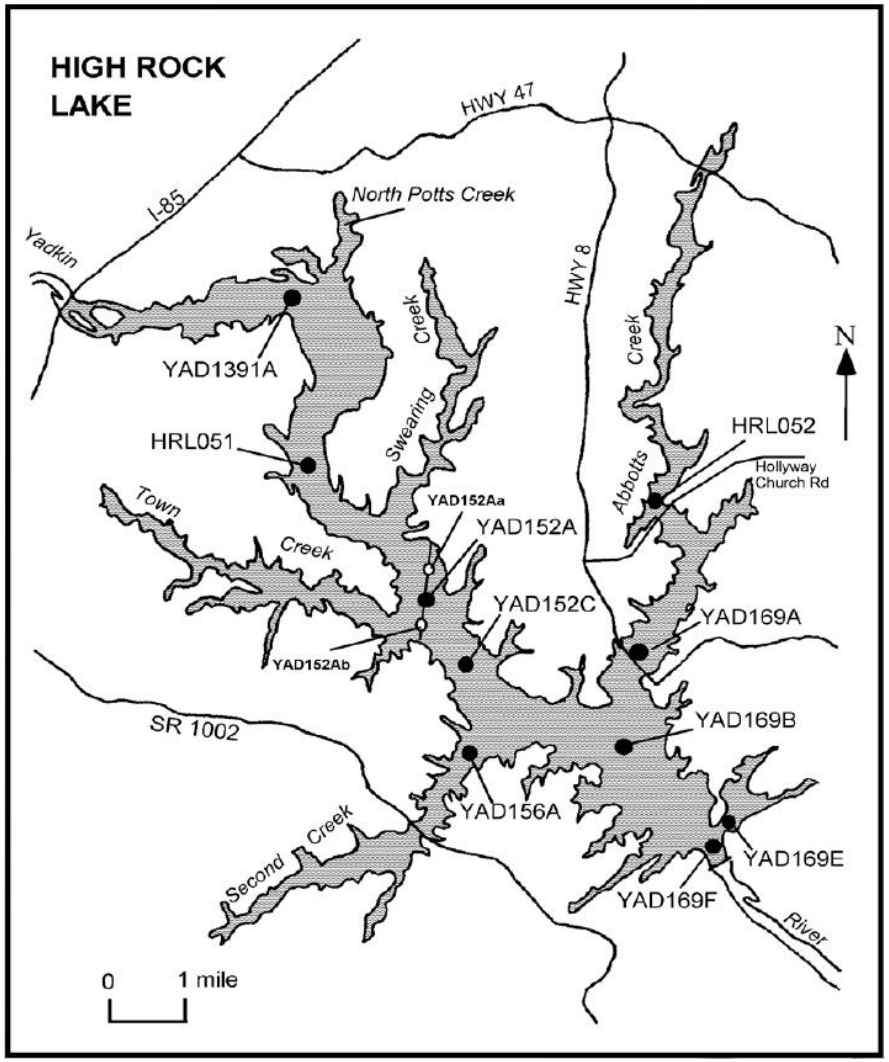
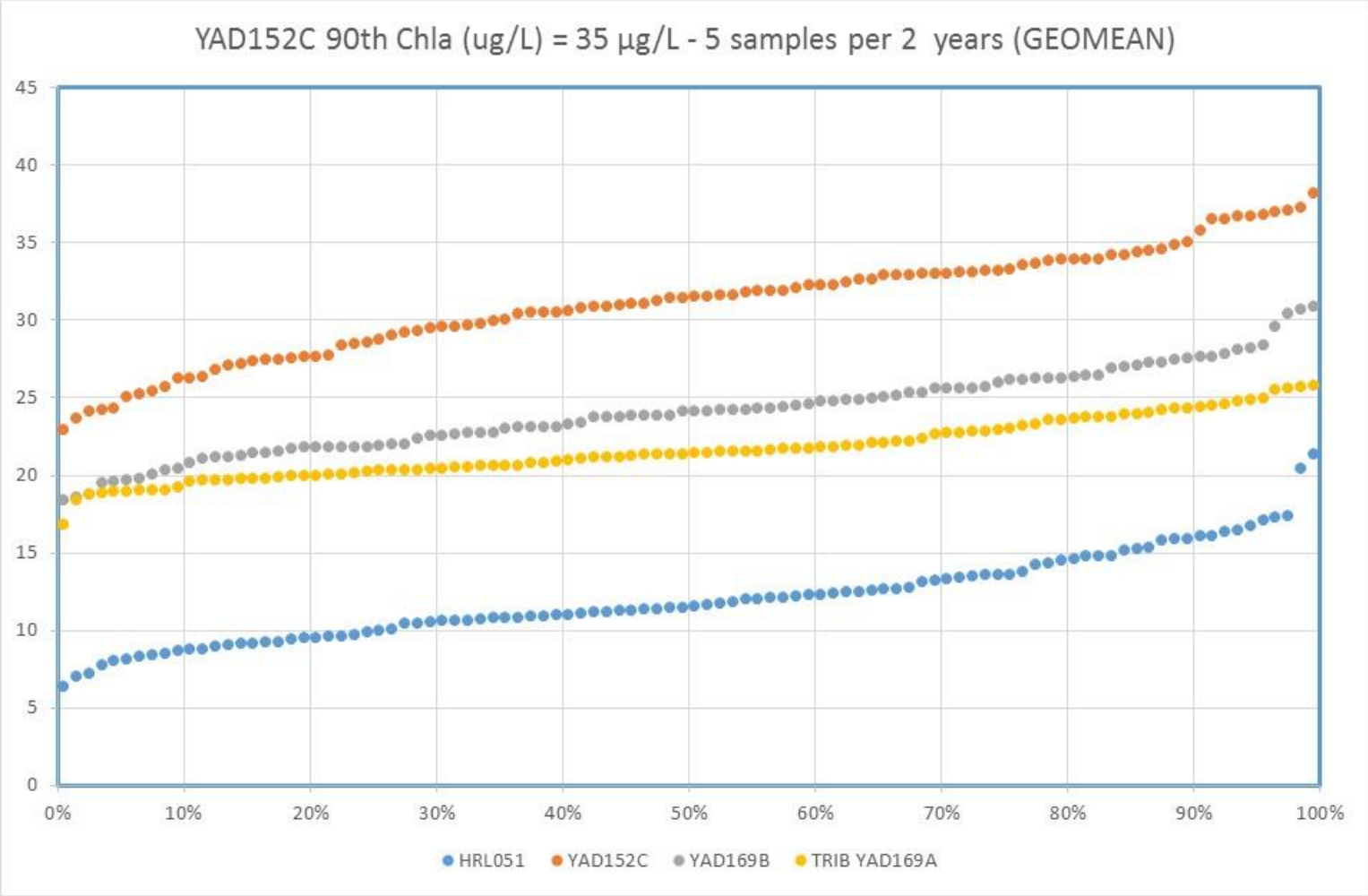
Derivation of Criterion Value



- Desired Chla for productive fishery is 20-25 µg/L
- The threshold value for which 90% of random runs would comply is about 115% of the long-term average (YAD152C)
- A Geomean of 35 µg/L would yield a long-term average value of 26 µg/L for YAD152C
- Simulated distributions for HRL051, YAD169B, and YAD169A and the ratio of the long-term Geomean for each location to YAD152C were used to predict future Chla for each location as a distribution for the Geomean of 10 samples

AquAeTer

Compliance with 35 µg/L Chla WQS



Note – based on 100 independent runs of 2 years of 5 samples per year expressed as Geomean.

AquAeTer

Presenter	CB1	CB2	LP	BH	ML	Existing WQS
Basis	Balance between (1) mostly favorable site-specific indicators (excellent fishery, lack of nuisance scums, low algal toxins, etc.) despite CHLA up to 55 ug/L; and (2) literature-based concerns at lower CHLA levels.	Balance between (1) mostly favorable site-specific indicators (excellent fishery, lack of nuisance scums, low algal toxins, etc.) despite CHLA up to 55 ug/L; and (2) literature-based concerns at lower CHLA levels.	Multiple lines of evidence: literature, with consideration of site specific information, such as HRL modeling (natural conditions ~20-25 ug/L using arithmetic average but can change with re-do of DWR plot); medium level of toxin risk; targets use protection for all uses	Level "necessary to protect uses"; it is strongly recommended that DEQ approve other use metrics to define when a use is impaired (e.g., biological index for aquatic life use; cyanotoxin concentration for recreational use; water clarity value for recreational use; drinking water use impairments (applied at potable water intake)) so that relationship between chlorophyll-a and use can be evaluated.	Support for productive sport fishery while lowering potential for future impacts to aquatic life, recreation and drinking water uses. Literature supports recreation, aquatic life and drinking water uses are achieved when Chla is 20-40 µg/L.	No change
Magnitude	40 ug/L, derived from 25-40 ug/L range for warmwater reservoirs. Upper end of range selected due to mostly favorable use indicators.	40 ug/L, derived from 25-40 ug/L range for warmwater reservoirs. Upper end of range selected due to mostly favorable use indicators.	~30 ug/L (30.6 ug/L based on medium level of cyanotoxin risk) OR To address the interest in a geo mean that is "comparable" to the above recommended magnitude, a geo mean between 16-18 represents HRL specific data from years suspected as being less enriched during record (1982 and 1990), HOWEVER computing the geo mean would be required by DWR in order to develop a confirmed/more accurate geo mean based on the modeling so the 16-18 could change.	40 µg/L; If existing water quality exceeds target, use impairment must be documented before exceedance is confirmed as nutrient criterion exceedance. Similarly, if chlorophyll-a is below 40µg/L but nutrient-related use impairment is present, will require assessment to determine a lower chl-a target based on relationship between chl-a and impairment metric.	35 µg/L to support average Chla levels throughout High Rock Lake of 20-25 µg/L.	40 ug/L
Measure	Note: I interpreted this row as redundant with "Duration/Averaging Period", which had a more clear meaning, so did not enter anything for "Measure"	Note: I interpreted this row as redundant with "Duration/Averaging Period", which had a more clear meaning, so did not enter anything for "Measure"	Seasonal (May-Oct) arithmetic avg, but open to modifying to reflect April start and different averaging (once an updated source of information is completed by DWR)	see duration	Seasonal Geomean for samples collected from the months of April-October for the assessment period.	instantaneous
Frequency	not to exceed > 1 in 3 years.	In leiu of an explicit frequency component, express as a multi-year geometric mean not be exceeded at a 90% confidence level.	not to be exceeded > once in 3 years	not to exceed once in 3 years, on average	Not to exceed value. Expression of confidence for exceedence is recommended.	not to be exceeded in 10% of samples with a 90% confidence
Duration	Geometric mean (Apr-Oct); individual years	Geometric mean (Apr-Oct); multiple years	See measure row for duration	Growing season (May-Oct) geomean	Seasonal Geomean for samples collected from the months of April-October for the assessment period.	
Spatial	Combine all data in assessment unit	Combine all data in assessment unit	Existing protocol	Given the limited amount of sampling and data (once every 5 years), sampling stations should be combined (e.g., the centerline stations 152A, 152C, 169B, and 169F could be combined to yield a single assessment for the lake). For potable water use impairment, assessment needs to be made at point of potable water intake. If HRL is assessed for downstream potable water use impairment, assessment should only consider discharge from lake (Station 169F).	Evaluate by assessment unit.	Each assessment unit is separate
# Samples	At least 3 years of data, data from at least five different months within growing season for each year	at least 10 needed for statistical analysis; data from at least 5 different months within growing season for each year; data from at least two years.	I would envision we suggest that not all months are required but some minimum monthly coverage should be suggested to prevent concerns with single grab sample in one year or missing a single month due to a hurricane for example	At least one sample in each month of the growing season. Prefer 2/month.	Minimum of 10 data points. Recommend data from two or more years.	at least 10 needed for statistical analysis[1]
Monitoring	Photic zone composite over 2X Secchi depth	Photic zone composite over 2X Secchi depth	Existing protocol	Photic zone grab at 2X Secchi depth	Photic zone grab at 2X Secchi depth	Photic zone grab at 2X Secchi depth
Notes		Could assess spatially based on limnological category of lake sections (riverine, transitional, lacustrine)	This recommendation balances the literature available with HRL specific details and increased knowledge of risk from elevated chl a levels.	Deterioration from existing conditions to be addressed using antidegradation requirements for TP.	Monte Carlo example compiled to illustrate how the not to exceed value relates to average Chla in different areas of High Rock Lake.	[1] Monitoring is during one growing season every 5 years resulting in approximately 5 samples. Where small sample sizes occur, data evaluations can go back one monitoring cycle to achieve 10 samples.

High Rock Lake Chlorophyll-a Numeric Nutrient Standard – Box Model

Indicator	Protected Use			Screening Threshold
	Aquatic Life	Recreation	Drinking Water	
Chlorophyll-a				30 µg/L (April-Oct. geometric mean)
Water Clarity		If impairs use (to be defined)		
Dissolved Oxygen	< 4.0 mg/L daily min			
pH	> 9.0 average over depth			
Algal Toxins Microcystins Cylindrospermopsin		To be defined 8 µg/L 16 µg/L	 If impairs use If impairs use	
Dissolved Organic Carbon			If impairs use	
Geosmin, etc.			If impairs use	
Biological Integrity	To be defined			

Note: All values are presented as examples

Application

1. Evaluate indicators that have established criterion concentrations to protect specific uses of lake. These indicators include Water Clarity, Dissolved Oxygen, pH, Algal Toxins, DOC, Taste & Odor, and Biological Integrity constituents. If individual indicators are achieved, nutrient-related impairment is not occurring.

2. If an individual indicator is exceeded, compare chlorophyll-a concentration to screening value.

    a. If chlorophyll-a does not exceed screening threshold, nutrient-related impairment is not presumed to be causing the observed exceedance of the indicator, subject to Step 3 below.

    b. If chlorophyll-a exceeds the screening threshold, nutrient-related impairment is presumed to be causing the observed exceedance of the indicator, subject to Step 3 below.

3. Off-Ramp

    Allow site-specific adjustment to chlorophyll-a criterion if scientifically defensible data shows that screening threshold needs to be adjusted. Revise chlorophyll-a criterion to lower value if cause of impairment is due to enrichment even though screening level is achieved. Revise chlorophyll-a criterion to higher value if data show that screening level is not necessary to achieve indicator targets.

High Rock Lake Chlorophyll-a Numeric Nutrient Standard – Flow Chart

1. Identify Protected Uses

2. Identify factors that cause impairment of Protected Uses

a. Prepare/Consult Conceptual Model relating nutrients to use impairments

b. Identify specific factors that impair specific uses

c. Identify threshold of impairment for specific factor and use

3. Determine how factor is related to chlorophyll-a concentration

a. Stressor-response evaluation (See EPA Guidance (November 2010))

   i. Classification (similar lakes)

   ii. Confounding Factors

   iii. Prediction and Confidence Intervals

b. Identify Confidence Intervals for Chlorophyll-a Criterion

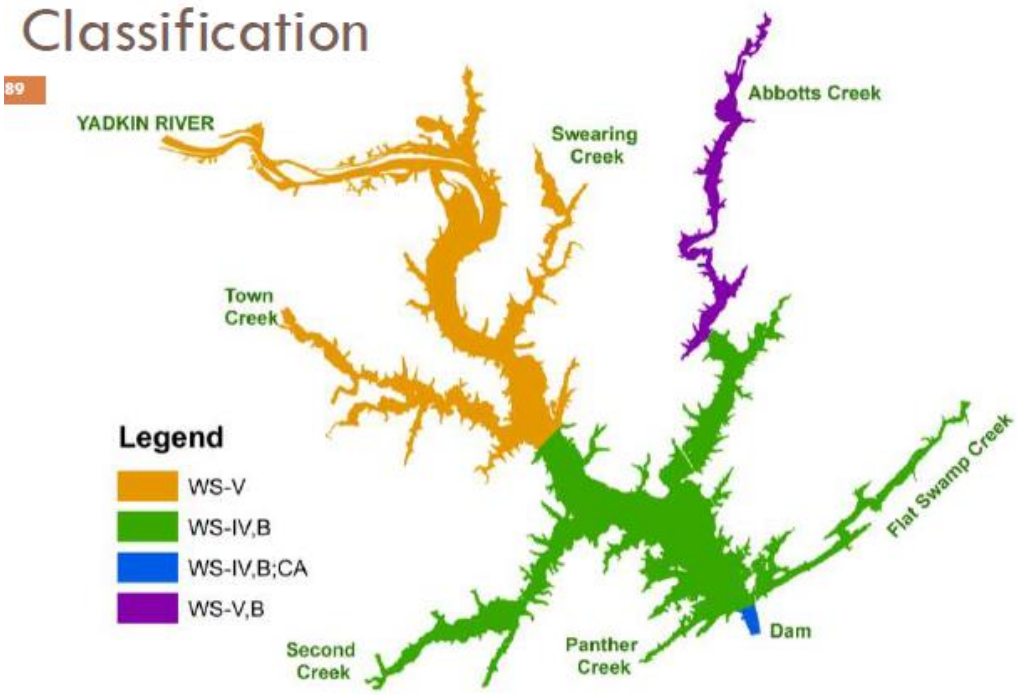
4. Set Chlorophyll-a Criterion

a. Range versus Single Value

b. Off-ramp for situations where assumptions are incorrect (chlorophyll-a criterion exceeded but associated impairment factor not exceeded)

Application of Flow Chart Proposal

1. High Rock Lake – Designated Uses (15A NCAC 02B.0101 (c))



Class B

Waters protected for all Class C uses in addition to primary recreation. Primary recreational activities include swimming, skin diving, water skiing, and similar uses involving human body contact with water where such activities take place in an organized manner or on a frequent basis.

Class C

Waters protected for uses such as secondary recreation, fishing, wildlife, fish consumption, aquatic life including propagation, survival and maintenance of biological integrity, and agriculture. Secondary recreation includes wading, boating, and other uses involving human body contact with water where such activities take place in an infrequent, unorganized, or incidental manner.

Water Supply IV (WS-IV)

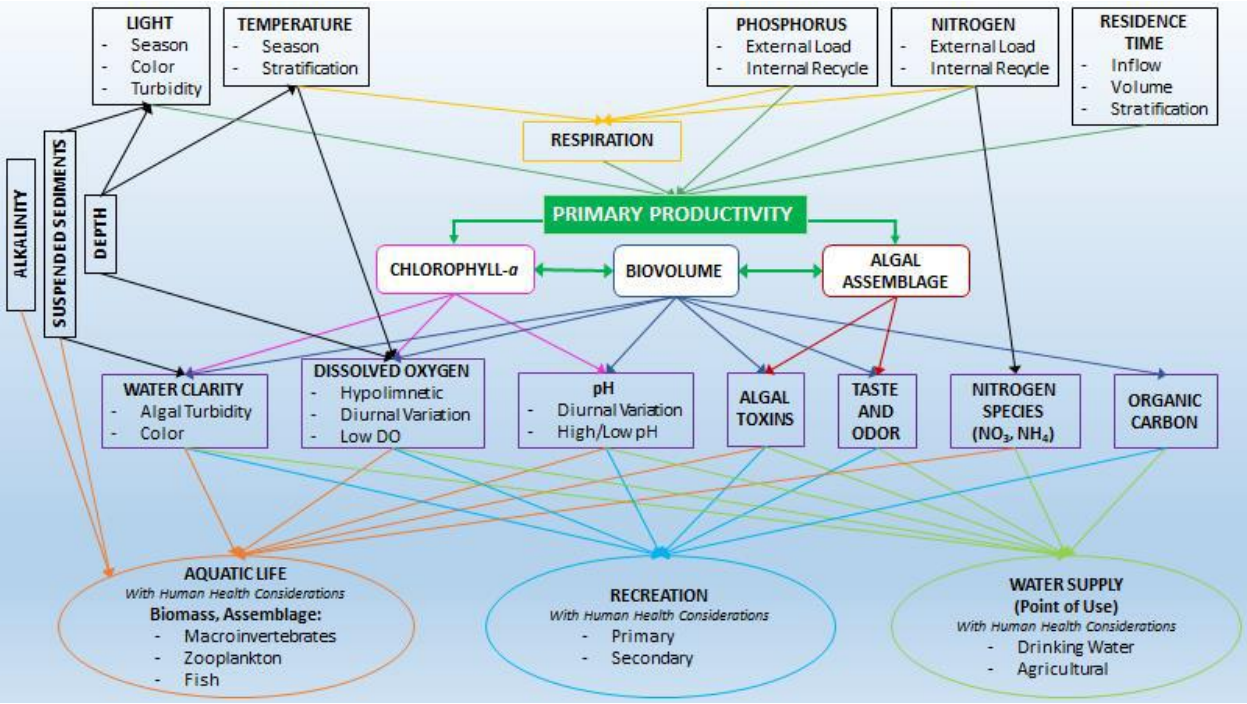
Waters used as sources of water supply for drinking, culinary, or food processing purposes where a WS-I, II or III classification is not feasible. These waters are also protected for Class C uses. WS-IV waters are generally in moderately to highly developed watersheds or Protected Areas.

Water Supply V (WS-V)

Waters protected as water supplies which are generally upstream and draining to Class WS-IV waters or waters used by industry to supply their employees with drinking water or as waters formerly used as water supply. These waters are also protected for Class C uses.

2. Factors Causing Use Impairment

2a. Conceptual Model Relating Nutrients to Use Impairment



2b. Factors related to Chlorophyll-a that impair Designated Uses

Aquatic Life Use	Recreational Use	Drinking Water Use (at point of intake)
Water clarity Dissolved Oxygen pH Algal Toxins Ammonia-N	Water clarity Dissolved Oxygen pH Algal Toxins Taste and Odor Organic Carbon	Water clarity Dissolved Oxygen pH Algal Toxins Taste and Odor Nitrogen Species Organic Carbon

2c. Impairment Thresholds

Aquatic Life (biological integrity): (15A NCAC 02B.0211 (1)) Best Usage of Waters: aquatic life propagation and maintenance of biological integrity. Biological integrity means the ability of an aquatic ecosystem to support and maintain a balanced and indigenous community of organisms having species composition, diversity, population densities and functional organization similar to that of reference conditions. (15A NCAC 02B.0202 (11))

Dissolved Oxygen (15A NCAC 02B.0211 (6)) Dissolved oxygen: not less than 6.0 mg/l for trout waters; for non-trout waters, not less than a daily average of 5.0 mg/l with a minimum instantaneous value of not less than 4.0 mg/l; swamp waters, lake coves, or backwaters, and lake bottom waters may have lower values if caused by natural conditions.

pH (15A NCAC 02B.0211 (14)) pH: shall be normal for the waters in the area, which range between 6.0 and 9.0 except that swamp waters may have a pH as low as 4.3 if it is the result of natural conditions. The SAC has proposed revised criteria for pH.

Algal Toxins (No Criteria) but see 15A NCAC 02B.0216 – WS-IV Waters; 15A NCAC 02B.0218 – WS-V Waters) (2) regarding waters, following treatment, shall be safe for drinking.

Nitrogen Species (15A NCAC 02B.0216 – WS-IV Waters) (3)(h)(i)(D) Nitrate nitrogen 10.0 mg/L. (Also applies to WS-V waters)

Taste and Odor(15A NCAC 02B.0216 – WS-IV Waters; 15A NCAC 02B.0218 – WS-V Waters) (2) the waters, following treatment required by the Division, shall meet the Maximum Contaminant Level concentrations considered safe for drinking, culinary, or food-processing purposes that are specified in the national drinking water regulations and in the North Carolina Rules Governing Public Water Supplies, 15A NCAC 18C .1500;
Dissolved Organic Carbon

Water Clarity (15A NCAC 02B.0211 (21)) Turbidity: the turbidity in the receiving water shall not exceed 50 Nephelometric Turbidity Units (NTU) in streams not designated as trout waters and 10 NTU in streams, lakes, or reservoirs designated as trout waters; for lakes and reservoirs not designated as trout waters, the turbidity shall not exceed 25 NTU; if turbidity exceeds these levels due to natural background conditions, the existing turbidity level shall not be increased.

Dissolved Organic Carbon (See drinking water regulations regarding amount of DOC allowed in potable water supplies)

3. Determine how factor is related to chlorophyll-a concentration

Examples of regression evaluations from EPA (2010) Using Stressor-response Relationships to Derive Numeric Nutrient Criteria.

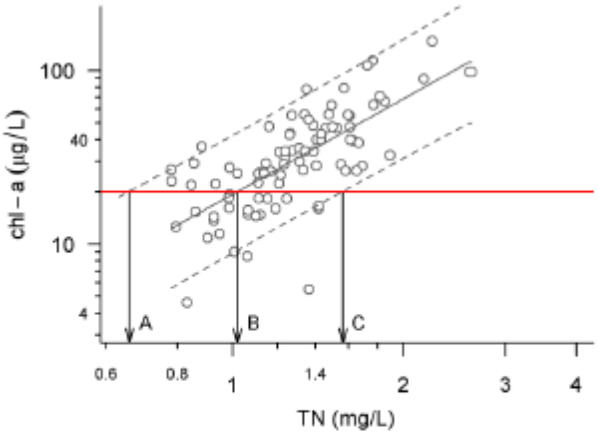


Figure 4-4. Total nitrogen (TN) versus chl *a* in one lake collected during March-August over 10 years. Solid line: linear regression fit. Dashed lines: upper and lower 90th prediction intervals. Red horizontal line: chl *a* = 20 µg/L. Note that upper prediction interval has been extended beyond the range of the data to estimate the point at which it intersects the chl *a* threshold. Arrows indicate candidate criteria associated with different prediction intervals and the mean relationship. See text for details.

(Guidance at 39)

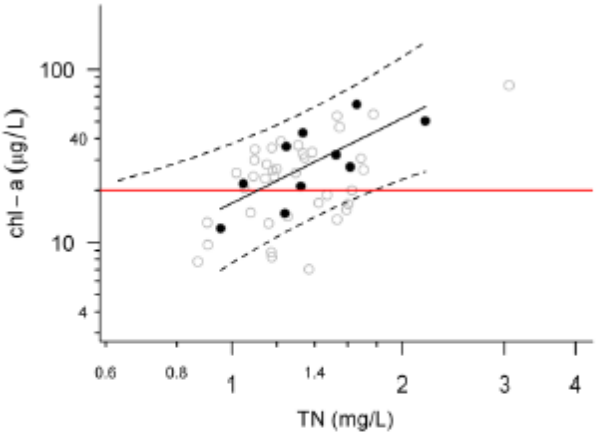


Figure 4-11. Synopic data set simulated by selecting 2 annual average values from each lake (shown as filled black circles). Open gray circles show all of the available seasonally averaged data to facilitate comparison with previous examples. Solid line shows linear regression fit to the synoptic data (filled black circles) and dashed lines show 90% prediction intervals.

(Guidance at 45)

4. Set Chlorophyll-a Criterion

a. Specify criterion concentration

   i. Set a range based on prediction interval if prediction intervals encompass all results that show compliance with target level for factor of concern.

      When assessing individual lakes, consider lake response and set chlorophyll-a criterion to threshold that meets criterion.

   ii. Set criterion to lower prediction interval if data show large amount of scatter outside of prediction intervals.

      If chlorophyll-a level in lake is below criterion, assume compliance with factor of concern. If chlorophyll-a level is above criterion, consider lake response to factor of concern and set site-specific chlorophyll-a criterion for lake.

b. Off-Ramp

   Allow site-specific adjustment to chlorophyll-a criterion if lake response does not conform to regression evaluation used to set chlorophyll-a criterion. If lake response shows that the factor of concern is exceeded even though chlorophyll-a criterion is achieved, revise criterion to lower value if necessary to achieve attainment with factor of concern/designated use. If lake response shows that the factor of concern is not exceeded even through chlorophyll-a criterion is exceeded, revise criterion to higher value.

Designated Use Management Goals & Criteria Development Approaches for HRL

				Criteria Development Approaches by Use & Indicator							
Designated Use	**SW Class**	**Definition (where defined in rule)**	**SAC Management Goal**	**DO**	**pH**	**Turbidity**	**Chlorophyll-a**	**Cyanotoxins**	**Clarity**	**TN**	**TP**
Secondary Recreation	C	Secondary recreation includes wading, boating, and other uses involving human body contact with water where such activities take place in an infrequent, unorganized, or incidental manner.	**Example**: Prevent algal surface scums.	NA	NA	Maintain current standard					
Fishing	C	Fishing means the taking of fish by sport or commercial methods as well as the consumption of fish or shellfish or the propagation of fish and such other aquatic life as is necessary to provide a suitable environment for fish.		Maintain current standard	Literature review	Maintain current standard					
Fish Consumption	C	Fishing means the taking of fish by sport or commercial methods as well as the consumption of fish or shellfish or the propagation of fish and such other aquatic life as is necessary to provide a suitable environment for fish.	**Example**: Prevent taste & odor issues in fish tissue.	NA	NA	NA					
Wildlife	C	Best Usage of Waters: aquatic life propagation and maintenance of biological integrity (including fishing and fish), wildlife, secondary recreation, agriculture, and any other usage except for primary recreation or as a source of water supply for drinking, culinary, or food processing purposes;		NA	NA	NA					
Aquatic Life including propagation, survival and maintenance of biological integrity	C	Biological integrity means the ability of an aquatic ecosystem to support and maintain a balanced and indigenous community of organisms having species composition, diversity, population densities and functional organization similar to that of reference conditions.	**Example**: Ensure that water quality is such that all aquatic, and aquatic-dependent, life that can reasonably be considered to inhabit HRL are able to maintain self-sustaining populations both with and downstream of HRL.	Maintain current standard	Literature review	Maintain current standard					
Agriculture	C	Agricultural uses include the use of waters for stock watering, irrigation, and other farm purposes		NA	NA	NA					
Primary Recreation	B	Primary recreational activities include swimming, skin diving, water skiing, and similar uses involving human body contact with water where such activities take place in an organized manner or on a frequent basis.	**Example**: Prevent algal surface scums. Prevent potentially harmful algal blooms.	NA	NA	Maintain current standard					
Water Supply IV	WS-IV	Waters used as sources of water supply for drinking, culinary, or food processing purposes where a WS-I, II or III classification is not feasible. These waters are also protected for Class C uses. WS-IV waters are generally in moderately to highly developed watersheds or Protected Areas.		NA	NA	NA					
Water Supply V	WS-V	Waters protected as water supplies which are generally upstream and draining to Class WS-IV waters or waters used by industry to supply their employees with drinking water or as waters formerly used as water supply. These waters are also protected for Class C uses.		NA	NA	NA					