Chlorophyll *a* Criteria Considerations for High Rock Lake

June 2017

OVERVIEW

In looking back through the materials, the following slide from February 2016 seems to do a good job summarizing the goals we have discussed. These goals were used to guide my analysis of various chlorophyll *a* values available for our consideration.

Water Quality Goal(s) as Defined in Rule	Refined WQ Goal(s)
AQUATIC LIFE	
HRL should support a healthy and diverse population of fish, benthos, and wildlife.	HRL should support a Healthy and Diverse population of fish and benthos that are safe for Human Consumption **Diverse biological population that is safe for human consumption**
Protection of HRL to allow for the safe consumption of fish species	
HRL should maintain an aesthetic quality that does not interfere with any of the above uses.	
WATER SUPPLY	
HRL should be suitable for use as a water supply source	HRL should be free from cyanotoxins and excessive algal growth **Potentially harmful (toxic or excessive) algal bloom prevention**
HRL should not contain substances that cause taste and odor issues that are untreatable	
RECREATION	
Protection of HRL to allow for full-body contact recreation including swimming	HRL should provide water of adequate clarity that is free from excessive algae and algal toxins and is desirable for recreation **Waters desirable and safe for recreation**
Protection of HRL to allow for incidental or infrequent body contact recreation through boating, wading, or other activities	
HRL should maintain an aesthetic quality that does not interfere with any of the above uses	

This document outlines the chlorophyll *a* magnitude ranges that appear to be best associated with each goal/use in the table above. Duration and frequency are also addressed, but since the decision for a final criterion to be protective of all of the designated uses for High Rock Lake (HRL) involves many moving pieces, I have stopped short of identifying a single value so that we may discuss as a group at our next meeting. Several questions for the group are also included so everyone can be thinking on certain aspects in advance.

In Appendix A, I have consolidated the range of values discussed over the past two years, as part of our documentation and consideration of different endpoints. There has been a mix of literature based and case specific examples in our discussions and we could consider these multiple pieces of evidence as we select a protective criterion endpoint for chlorophyll *a* for HRL. Therefore, the discussion is best described as an approach considering various lines of evidence and best professional judgement. However, the lines of evidence are a mix of others' findings regarding stressor-response relationships, existing healthy water quality conditions, field observations, literature-based findings, and site specific information from HRL, which reflect the other methods possible for criteria development.

After selecting a final chlorophyll *a* criterion for HRL, I anticipate that modeling can be utilized to develop the corresponding total nitrogen and total phosphorus criteria (as concentrations and loadings). Selecting both formats is beneficial for use in multiple implementing programs moving forward, as they address multiple needs.

MAGNITUDE

Process

For each designated use, I have taken the endpoints identified in Appendix A and put them in order of increasing chlorophyll *a* ranges or specific values, paired with the respective qualitative descriptions. The result is an arrangement of chlorophyll *a* concentrations from least impacted/least effect/desired designated use (hereinafter referred to as "positive endpoints") to most impacted/adverse effect/contrary designated use (hereinafter referred to as "negative endpoints"). To document my decisions on whether the endpoint was positive or negative, I have used a green and red coloring scheme to indicate the positive and negative endpoint determinations, respectively. The resulting proposed magnitude range/values, for each designated use, reflect what is generally associated with positive endpoints from Appendix A.

Aquatic Life Endpoints

When considering which qualitative descriptions listed as aquatic life value(s) in Appendix A should be considered positive, I kept in mind the goals identified on page 1, which for aquatic life states "HRL should support a healthy and diverse population of fish and benthos that are safe for human consumption" and "diverse biological population that is safe for human consumption." All numeric values given are in µg/L.

5-24 → adopted lake criteria in Alabama, Florida, and Georgia lakes/reservoirs that have considered fishery resource or have general fish and wildlife designated use (most of which have chlorophyll in the 15-20 µg/L range)

10-15/10-15/20/20 → healthy fish population/ not necessarily detrimental to black bass and crappie/ black crappie fisheries peak/growth of crappie and largemouth increased

25/25/35 → Nevada growing season average/warmwater fisheries only (Dillon)/VA warmwater lake high end adopted, shares ecoregion with North Carolina

40-60/40/40 → fertilization to achieve chlorophyll *a* for production of bass and sunfish/trophy fish more abundant in eutrophic lakes/South Carolina and Nevada instantaneous chlorophyll

60/60 → VA fertilized lakes adopted value/white crappie fisheries peak

60-70 → ponds managed for fishing not recreation

Aquatic Life Endpoint Summary: Based on the above positive and negative designated use endpoints, chlorophyll *a* values between 15-35 µg/L were consistently determined to represent positive endpoints for aquatic life, whereas, and the value of 40 µg/L represented a mix of positive and negative endpoints. The range between 40 and 70 was generally determined to be negative because it represented fertilized, or more narrowly managed, waterbodies. For this analysis, the decision to include categories related to sport or trophy fish related endpoints as positive, when not otherwise characterized as managed or fertilized, was done to give

consideration to warmwater fish species that occur in the reservoir. The duration and frequency considerations which are associated with these magnitude values will be discussed later.

Follow-up Discussion for the Group:

- Coldwater aquatic life endpoints from previous meetings were not included in this summary. Is the SAC comfortable with that decision or should those values be inserted into the analysis?

Water Supply Endpoints

When considering which qualitative descriptions listed as water supply values in Appendix A should be considered positive, the goals stated for that use on page 1 were considered. Although the goal use states "HRL should be free from cyanotoxins and excessive algal growth" and "potentially harmful (toxic or excessive) algal bloom prevention," the majority of the information identified as water supply endpoints focuses on the algae abundance or a non-specific reference to health effects. We should consider the information described in the Follow-up Discussion questions as a way to address the toxic component of this goal further as it relates to chlorophyll *a* concentrations. All numeric values given are in µg/L.

5-20/0-30 → adopted drinking water use lake criteria in Alabama, Colorado, and Georgia/ chlorophyll *a* in this range was associated with a 9.3% dominance of blue greens

9-10/10 → taste and odor problems become noticeable/low probability of adverse health effects

15 → to keep geosmin <5 ng/L

15-20 → water supply use impaired

30/30/30-40 → represents shift in average unit density of blue greens/ increased risk of algae related health problems/ chlorophyll *a* in this range was associated with a 46.4% dominance of blue greens

>40/50 → (61.5% blue greens dominate)/moderate risk of health effects

20-80 → consumptive uses severely impaired in Kansas lakes

Water Supply Endpoint Summary: Based on the above positive and negative designated use endpoints, chlorophyll *a* values between 5-20 µg/L were determined to represent positive endpoints for water supply. While there are some negative endpoints within that range, I decided that the wording was more subjective (such as noticeable and WS use impaired). There was not much information between chlorophyll a concentrations of 20 and 30 µg/L, but if the HRL specific analysis from Jing's August 2015 presentation was considered, that could provide potentially positive endpoint information. Chlorophyll *a* concentrations of 30 µg/L or greater tended to be more consistently associated with negative quantitative endpoints and less subjective descriptions.

Follow-up Discussion for the Group:

- Should we incorporate the April 2016 information on probability of exceeding microcystin-LR concentrations?

- Should the 9.3% blue greens information be characterized as a positive or negative endpoint? Would it be one characterization for water supply and a different characterization for recreation? In this analysis, it was chosen to be positive for both uses because it seemed like the change point based on the information provided for HRL and has relevance to both designated uses.

Recreation Endpoints

When considering which qualitative descriptions listed as recreation values in Appendix A should be considered positive, the goals stated for the recreation use on page 1 were considered. Many of these examples are aesthetic or more subjective categories (such as good vs fair vs poor). However, data from Jing's August 2015 presentation identifying the blooms levels and shift in abundance of blue greens at given chlorophyll *a* increments provides additional site specific information, with quantification, to consider among the more general literature work. As outlined on page 1, "HRL should provide water of adequate clarity that is free from excessive algae and algal toxins and is desirable for recreation" and "waters desirable and safe for recreation." Similar to the water supply goals, there is limited information on toxins, particularly specific to HRL, although the toxin appears to be at low levels where studied. While separate state efforts are likely to address any possible toxin guidelines for the waters of North Carolina, the blue green related endpoints could be considered as representing a quantification of lower vs higher risks of potential for toxin-production, as opposed to a known threshold. All numeric values given are in µg/L.

0-10/0-25/14/<1-10/10/0-30 → no problems/clear no blooms/excellent to good/excellent to good/mild-low probability of health effects/ chlorophyll *a* in this range was associated with a 9.3% dominance of blue greens

5-24 → adopted recreation use lake criteria in Alabama, Florida, Georgia, and Colorado

10-15/6-15/10-20/15-20/20 → fair/ noticeable and observable levels to moderate/scums/ considered impaired for contact recreation/recreation based low levels found with levels of algal toxin

15/25-100/20-25/20-30/32/30/30/30→ poor / no swimming due to concerns for human health/ represents shift in average unit density of blue greens/ good to acceptable/nuisance/acceptable to marginal/moderate blooms

>30/30-40 → very poor/chlorophyll *a* in this range was associated with a 46.4% dominance of blue greens

>40/50 → chlorophyll *a* in this range was associated with a 61.5% dominance of blue greens/moderate probability of short term health effects

>30/30-80/100-200/5,000/40-60 and 20-80 → severe nuisance/severe algal scums and uses impaired/dense colonies and scums/high risk of long term health effects/ nuisance to severe nuisance

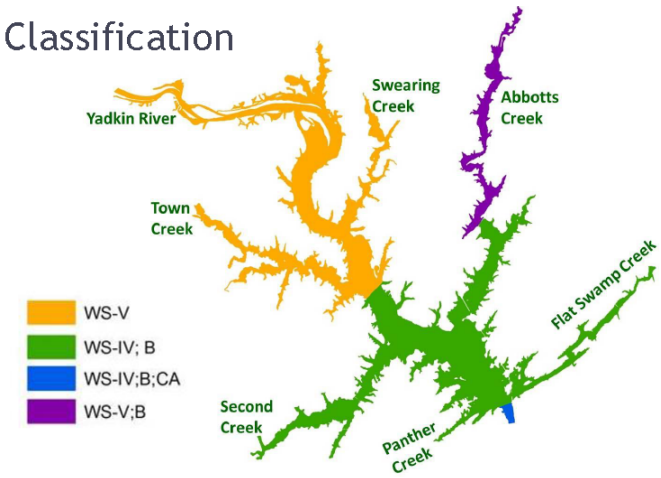
Recreation Endpoint Summary: Based on the above positive and negative designated use endpoints, chlorophyll *a* values up to 15 µg/L represent generally positive endpoints for recreation, however, there is a mix of positive and negative endpoints between 15 and 30 µg/L. Chlorophyll *a* concentrations greater than 30 µg/L tended to be more consistently associated with negative quantitative endpoints and less subjective descriptions.

Final Magnitude Summary

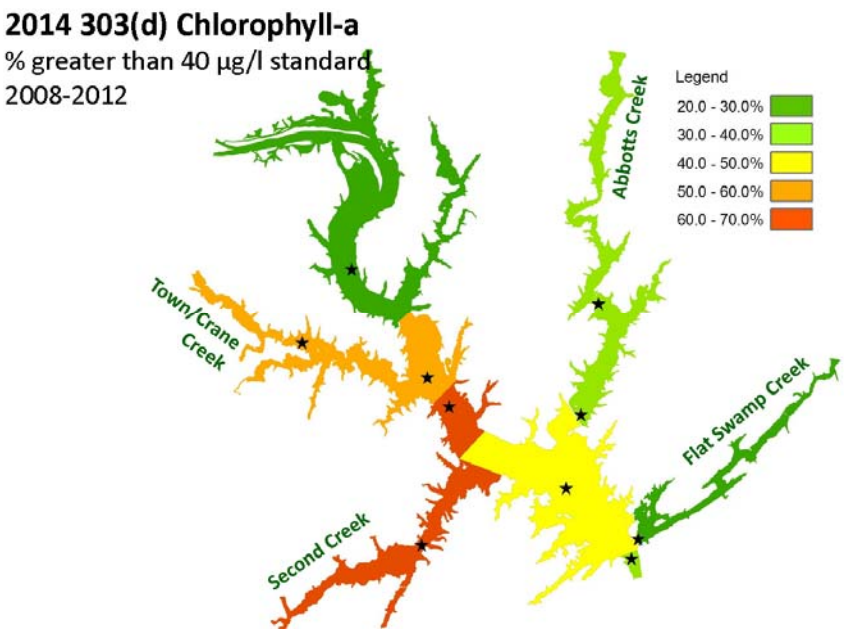
Based on the extensive information available to us, ranked according to the positive/negative endpoint characterization I have provided, chlorophyll *a* ranges of 15-35 µg/L, 5-20 µg/L, and 15-30 µg/L, appear to reflect protective endpoints, for aquatic life, water supply, and recreation designated uses, respectively. As described in more detail below, a criterion applied to unique segments of the lake, not as a lake wide average, would seem useful. Lastly, narrowing the ranges to a specific criterion should be based on the consideration of the duration components discussed below and follow up discussions on the questions posed throughout this document.

CRITERIA DEVELOPMENT AND SEGMENTATION

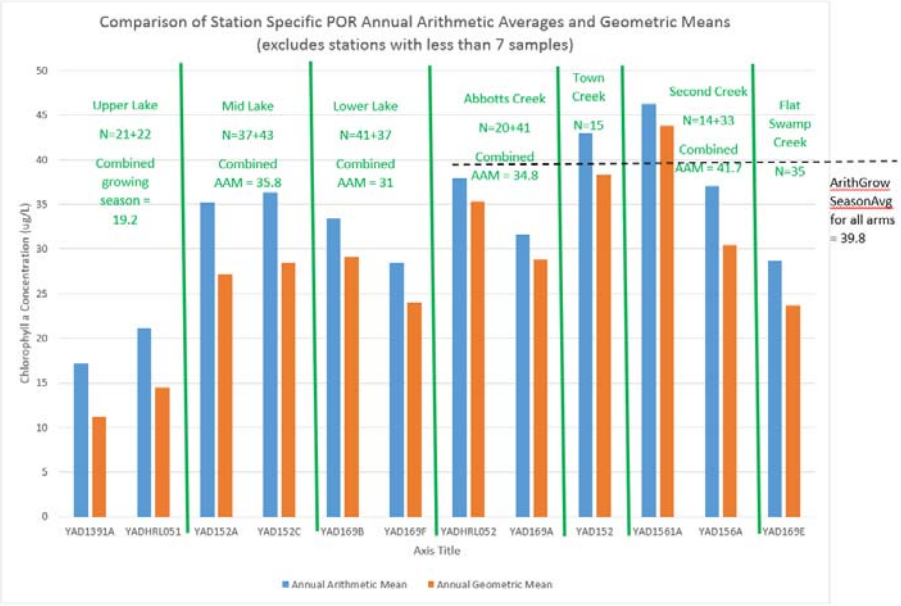
Before getting into the duration and frequency component discussions, I wanted to touch on some other critical elements of criterion development. If we were to consider different criteria based on the different uses in the lake there would not seem to be much difference since all segments are listed for water supply (WS), fishing, and recreation related uses. Perhaps NC staff can discuss whether the distinction of WS-IV, WS-V, or CA have different designated use related expectations compared to the other WS classifications which are not applicable here. [Graphic from May 2015 SAC meeting slides.]



A more likely possible segmentation is dividing the lake into homogenous sections to better capture any expected differences in response based on physical differences or other considerations. [Graphic from May 2015 SAC meeting slides.] Fortunately, the number and location of stations for HRL on the mainstem and in the arms, along with the model, will help us determine where that makes sense. Using this graphic as an example of how different segments react, it would be important to consider assessing the lake's compliance with a chlorophyll *a* concentration in multiple segments, and not as a lake wide average.



The following graphic shows various computations, as another way to visualize station specific differences in chlorophyll *a* concentrations, along with green lines separating out different areas of the lake which have been discussed in the past. The first two stations tend to be lower, but based on past conversations the local conditions in that portion of the lake are the likely reason for a lower chlorophyll *a* expression.



And while not specifically addressed up to this point in my write up, Appendix A does include details from past presentations on the computations Bill and Clifton have provided for various station specific or lake wide analyses. I think this is helpful information to have for our consideration as we fine tune the conclusions resulting from the designated use specific endpoint analyses, but found it important to start first with endpoint selection, before getting too far into the analysis of the current concentrations of the lake. Once we determine the location(s) for deriving criteria we can re-do any of the graphics/analyses to reflect any splitting of the lake

into segments, as well as use information based on our discussions on duration and frequency in those recalculations.

DURATION

For the discussion on duration, I have summarized the known durations associated with the chlorophyll *a* values/ranges identified as positive endpoints.

The criteria in Alabama's lakes (between 5 and 24µg/L) are expressed as growing season averages, using either the April through September (Tennessee River lakes) or April through October (all other lakes) and Georgia, with the same criteria magnitude range, uses the April through October growing season average, also.

Florida's lake criterion of 20µg/L is based on an annual geometric mean and North Carolina and South Carolina are currently adopted as shall not exceed values of 40µg/L. In contrast, Nevada uses a growing season average of 25µg/L, with an instantaneous max of 40µg/L, and Virginia's warmwater lakes have a growing season average chlorophyll *a* of 35µg/L.

Based on Jing's presentation in August 2015, the instantaneous chlorophyll *a* of 30 µg/L seems to be the point where the average instantaneous bloom densities are significantly different than values of 10 or 20 µg/L. Instantaneous values of chlorophyll *a* between 0-30µg/L had blue greens dominating less than 10% of the sample, whereas instantaneous values between 30-40 µg/L had blue greens dominating about 46% of the sample, and above 40 µg/L the percentage was 61.5.

Lastly, I wanted to look at what durations were known for the literature values, but was not able to complete that analysis for this version of the document. I intend to provide an update with the results of what I am able to locate for the literature based work associated with positive endpoints which have been previously discussed above.

<u>Final Duration Summary</u>

Positive endpoints included both instantaneous and longer term average based responses and both provide useful endpoints for different aspects of designated use protection. Therefore, the duration summary reflects a refinement from the magnitude summary of the respective designated use chlorophyll *a* concentrations.

Aquatic Life: Growing Season Average of 15-35 µg/L

Drinking Water: Growing Season Average of 5-20 µg/L

Recreation: Growing Season Average of 15-25 µg/L

Additionally, it seems that instantaneous concentrations between 30-40 µg/L are associated with positive endpoints. Additional analysis could be completed to confirm whether September and October are similar enough to determine whether the growing season is defined as through September or October. At this point, I do not have a preference for arithmetic vs geometric mean.

Follow-up Discussion for the Group:

- If a growing season average is selected, would the SAC suggest any additional protections to address the non-growing season, either narrative or numerically?
    - In a location with more defined seasons, as is the case in North Carolina, it is appropriate to consider growing season. To address any concerns about non-growing season loadings, with modeling, it is possible to determine what annual TN/TP loads and concentrations would support the seasonal chlorophyll a criterion, to ensure conditions are met throughout the year to meet the critical response time period.
- Do we have enough information to also consider an instantaneous value?

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.

Final Frequency Summary

The use of 1-in-3 frequency for chlorophyll *a* given could be considered in conjunction with a growing season average for the duration component. The state of Florida's implementation document provides additional detail on how they implement a 1-in-3 criterion in permitting. Similar considerations are taken for the TMDL development when the target is based on a 1-in-3 criterion.

Follow-up Discussion for the Group:

- What frequency would the state be able to monitor HRL, moving forward? This may further inform whether the 1-in-3 is the best option for the chlorophyll *a* criterion or an alternative frequency may be more appropriate.
- Possibly more for the CIC group, but in general how is follow up monitoring done after a TMDL is completed? What role does management strategies have in the implementation of newly developed criteria and TMDL?

OTHER QUESTIONS/ITEMS FOR GROUP DISCUSSION:

- Given the three ranges for the uses, what is the best way to weight these competing uses to derive a single criterion?
    - Can we model natural conditions to see what is lowest possible chlorophyll *a* in this modified system? It wouldn't seem appropriate to require a lower chlorophyll *a* than physically possible for the system.
    - For drinking water and recreation uses, concentrations above 30 µg/L were generally negative endpoints.
    - What data were used for the calculation of 42µg/L at YAD169F? The highest growing season arithmetic mean I saw for YAD169F was 40.2 in 2011 and the period of record growing season arithmetic average was 33.3.
    - Should we consider the average of the other ecoregion 45, piedmont lakes for a comparison?
        - Average POR of 25µg/L
        - Growing season average POR 30.8µg/L

- For Maintain Existing Use Support Approach
    - Should consideration be given to lessening water treatment costs through increased prevention of chlorophyll *a* impacts?
        - Whit Wheeler's October 2016 presentation indicated one of their treatment goals is no taste and odor calls.
- For placeholder discussion:
    - One possible TP/TN option would be to model the annual concentrations and loads necessary to meet a growing season chlorophyll *a* concentration.

APPENDIX A

Chlorophyll *a* Values and Ranges	**Endpoint/Details**	**Source**
5-24 growing season averages 20 AGM 40 instantaneous	Range of Region 4 lake chlorophyll *a* criteria	July 2015 (Lauren's ppt, pages 110,117,118 of 189 PDF notes)
35 growing season average 60 growing season average 25 growing season mean, 40 max growing season	Virginia warmwater lakes, shared ecoregions 9 and 11 with North Carolina Virginia fertilized lakes in ecoregion 9 Nevada criteria	July 27, 2007 EPA approval letter on VA's lake criteria April 2016 (Bill's ppt, page 50 of 217 PDF notes)
<30 represents mild or less blooms of blue greens (9.3% blue greens dominate) 30-40 chl a shifts from moderate to severe blooms of blue greens (46.4% blue greens dominate) >40 (61.5% blue greens dominate)	Algal Unit Density/Blooms vs. Chlorophyll *a* (based on 2008-2010 data and 2005-2010 data)	August 2015 (Jing's ppt, pages 25-26 of 94 PDF notes)
10-15/20/20 → not detrimental to black bass and crappie/ black crappie fisheries peak/growth of crappie and largemouth increased 40-60/40 → production of bass and sunfish/trophy fish 60-70/60 → managed for fishing not recreation/white crappie fisheries peak	Warmwater fisheries	April 2016 (Bill's ppt, page 50 of 217 PDF notes)
0-10/0-25/14/<1-10/10 → no problems/clear/excellent to good/excellent to good/ mild-low probability of health effects 10-20/30/10-15/15-30/6-15 → scums/good to acceptable/fair/poor/observable levels to moderate	Swimming/Aesthetics	April 2016 (Bill's ppt, pages 52-53 of 217 PDF notes)

20-30/32/25-100/50/>30 / 15-20/ → nuisance/acceptable to marginal/moderate blooms/moderate prob of short term health effects/very poor / considered impaired for contact recreation/ considered impaired for contact recreation/no swimming due to concerns for human health >30/100-200/5,000/40-60 and 20-80 → severe nuisance/dense colonies and scums/high risk of long term health effects/nuisance to severe nuisance		
9-10/10 → taste and odor problems become noticeable/low probability of adverse health effects 15-20 → water supply use impaired 30/50 → increased risk of algae related health problems/moderate risk of health effects 20-80 → consumptive uses severely impaired in Kansas lakes	Drinking Water	April 2016 (Bill's ppt, page 55 of 217 PDF notes)
10% probability – chl a 0.07-1.22 50% probability – chl a 23.36-105.84 90% probability – chl a 167.04-871.20	Chlorophyll concentrations and probabilities of exceeding microcystin-LR health advisory concentrations	April 2016 (page 217 of 217 PDF notes)
Chl a average – 25µg/L	Average of all ecoregion 45b and 45c lake photic zone samples	June 2016 (Lauren's ppt, page 20 of 77 PDF notes)
10-15µg/L healthy fish population 25µg/L warmwater fisheries only (Dillon) 25-60µg/L HRL specific values (note: geo mean using May-Sept)	Summarized chl a values and ranges from April 2016	All from June 2016 (Pages 34-35 of 77 PDF notes)

35.95-56.28µg/L HRL observations 42µg/L suitable drinking water source 15µg/L to keep geosmin <5ng/L 0-50µg/L max for aesthetics, 50 had <10% (MN users had upper ranges of 50 and 30, NY users had 16, and TX had 25) 20µg/L recreation based low level for chla associated with higher levels of algal toxin?		