# Phase I Nutrient Criteria and Research Proposals

APNEP Nutrients Workgroup
July 6, 2016

## Contents



## Background and procedural standing

The APNEP Nutrients Workgroup has met since August 2014 to evaluate nutrient criteria for Albemarle Sound. This work is guided by the N.C. Nutrient Criteria Development Plan (NCDP), mutually agreed to by the state of North Carolina and the Environmental Protection Agency.

An initial set of research inquiries has been completed on the group's behalf. The workgroup has also met routinely to review the results of these inquiries and to discuss many varying aspects and implications of criteria development related to Albemarle Sound.

In light of the complexities inherent in developing criteria, workgroup members were asked to formulate and explain response criteria proposals for the broader workgroup's consideration. Members were also asked to identify new research recommendations as knowledge gaps became evident. A similar exercise is planned for causal criteria in September.

The independent proposals contained herein are provided to facilitate discussion at the workgroup's July 20, 2016 meeting. Criteria and research proposals (or elements of proposals) will be discussed and consensus will be sought where possible, with areas of persistent disagreement also documented. Recommendations agreed upon by the workgroup will initially

be documented in the meeting notes and ultimately in the Phase I report to be completed according to the NCDP.

## pH

### pH Criteria Proposal 1

Field profiles of pH and dissolved oxygen should be measured when possible at sample sites in addition to secchi depth. NC DMF and NC DWR routinely measure pH and dissolved oxygen. Protocols could be adjusted to ensure a profile is collected when secchi depth does not meet a certain criteria.

Rationale: pH levels are regularly above the current freshwater standard of 9 or saltwater standard of 8.5 standard units when a phytoplankton bloom is occurring. It is well accepted science that high pH levels are indicative of a bloom. pH is an easy indicator that can be used to assess whether poor water clarity is occurring as a result of excess phytoplankton production. We will make the assumption that excess phytoplankton production is occurring as a result of eutrophication. Thus, if we can detect phytoplankton blooms we can detect regions of the Albemarle that may be receiving excess nutrients.

Harmful algal blooms can cause hypoxia and anoxia in the estuary. This can have negative impacts on important fisheries. The current state standards for dissolved oxygen (instantaneous minimum value not less than 4 mg/L) can be used to determine if is occurring in a certain location, but provisions for areas designated as swamp waters where hypoxia and anoxia occur naturally should be noted.

### pH Criteria Proposal 2

Existing standards. The current set of standards include several parameters related to nutrient effects for the protection of aquatic life. These parameters have a long history of implementation and should be maintained. There is a long potential list of attributes that could be impacted by excess levels of nutrients, and I believe these are best addressed through narrative statement that can be evaluated within the context of future learnings on the overall health of different waterbodies and the range of conditions consistent with natural systems.

### pH Criteria Proposal 3

pH of between 6.8 and 8.5, expressed as a 90th percentile.

pH is an important nutrient-related response variable because excessive algal/plant growth can increase pH during periods of photosynthesis. Excessively high pH can adversely affect aquatic life by causing electrolytic imbalances, damaging sensitive tissues, and increasing the toxicity of other substances (e.g., ammonia, cyanide).

NC's existing pH criterion for class SB waters states that pH "shall be normal for the waters in the area, which range between 6.8 and 8.5. Although the water quality standard text includes numeric values, NC DWR (2007) describes the pH criterion as a narrative criterion. NC's pH criterion is very similar to the range promulgated by USEPA for marine waters (6.5 – 8.5), which can be traced to the USEPA Red Book (1976) and Gold Book (1986). The USEPA

recommendations are primarily on the typical range of pH in marine waters, rather than extensive studies of the effects of pH on marine/estuarine life.

The pH criterion has no averaging period or explicit duration component, and so is treated conservatively as an instantaneous criterion. In reality, neither the USEPA Red and Gold Books nor its referenced documents present any technical information that indicate that short-term occurrences of pH in the 8.5 to 9.0 range would adversely affect estuarine life, unless very high concentrations of pH-dependent toxins (e.g., ammonia, cyanide) were present. Accordingly, the pH criterion is better expressed/used as a percentile (e.g., 90th) of longer-term datasets rather than an instantaneous value. This is already done to some extent because NC (along with EPA and most if-not-all states) assesses waters for pH compliance using the 10-percent rule.

### pH Criteria Proposal 4

After review the scientific literature for estuarine systems similar to the Albemarle Sound, I recommend that we retain the current NC pH standard of – "pH: Shall be normal for the waters in the area, which generally shall range between 6.8 and 8.5". The Albemarle sound is not classified as swamp waters therefore the exception for lower pH does not apply here.

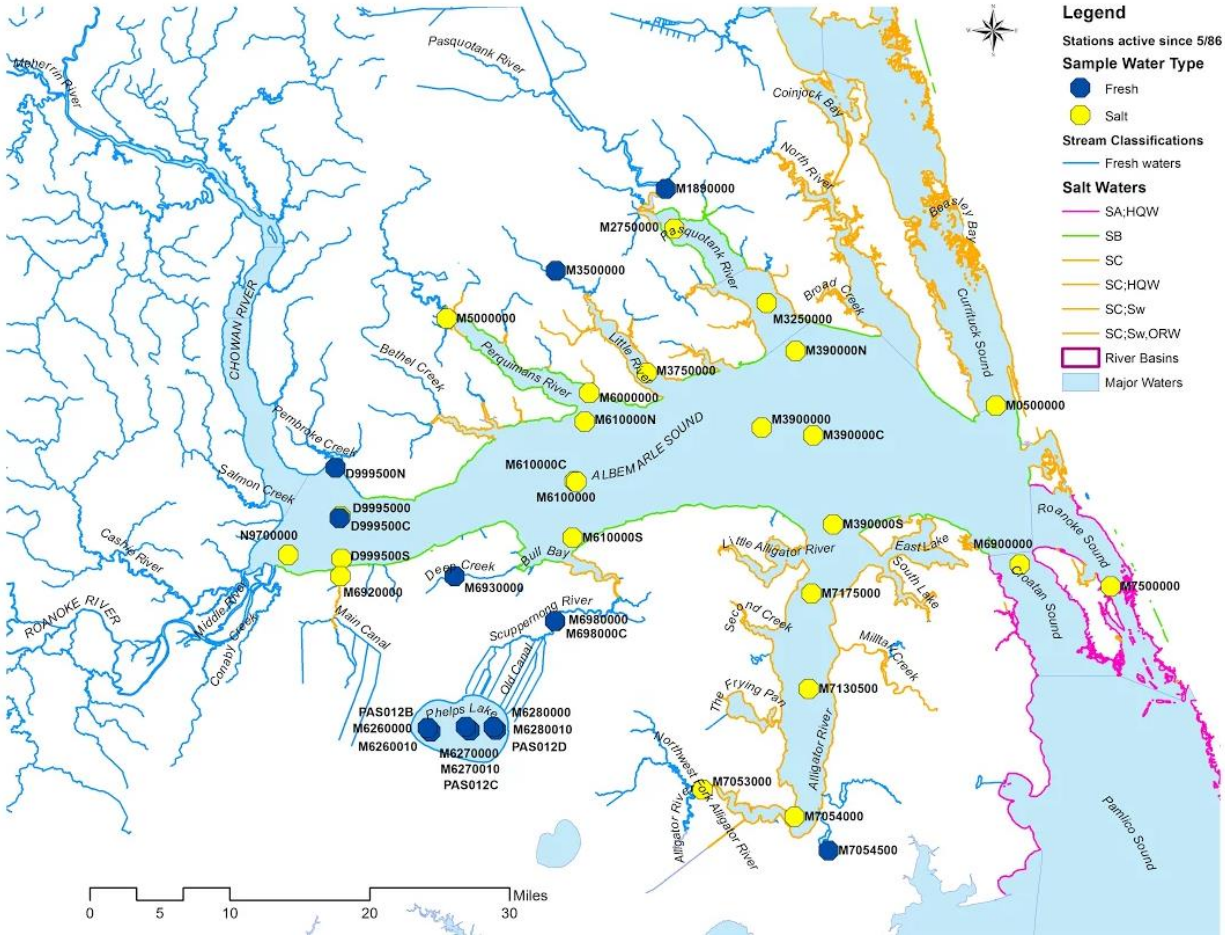
| Designated Uses | Thresholds | Protection Provided | Reference material |
|---|---|---|---|
| **Aquatic Life – Fish – Adults**<br>**Fish – Juvenile and Larval stages** | 6-9.0<br>6-8.5 | Growth and survival of Adult, juvenile and larval stage fish. | EPA, 1986;<br>Wolff et al. 1988;<br>pH TM, 2004 |
| **Aquatic Life – Mollusk** | 7-8.5 | (at low pH – shell dissolution) | Wolff et al. 1988 |
| **Aquatic Life – SAVs** | ≤ 9.0 | High pH can results in limited carbon uptake in seagrasses. | Greve and Biner 2004; Van der Heide et al. 2008 |

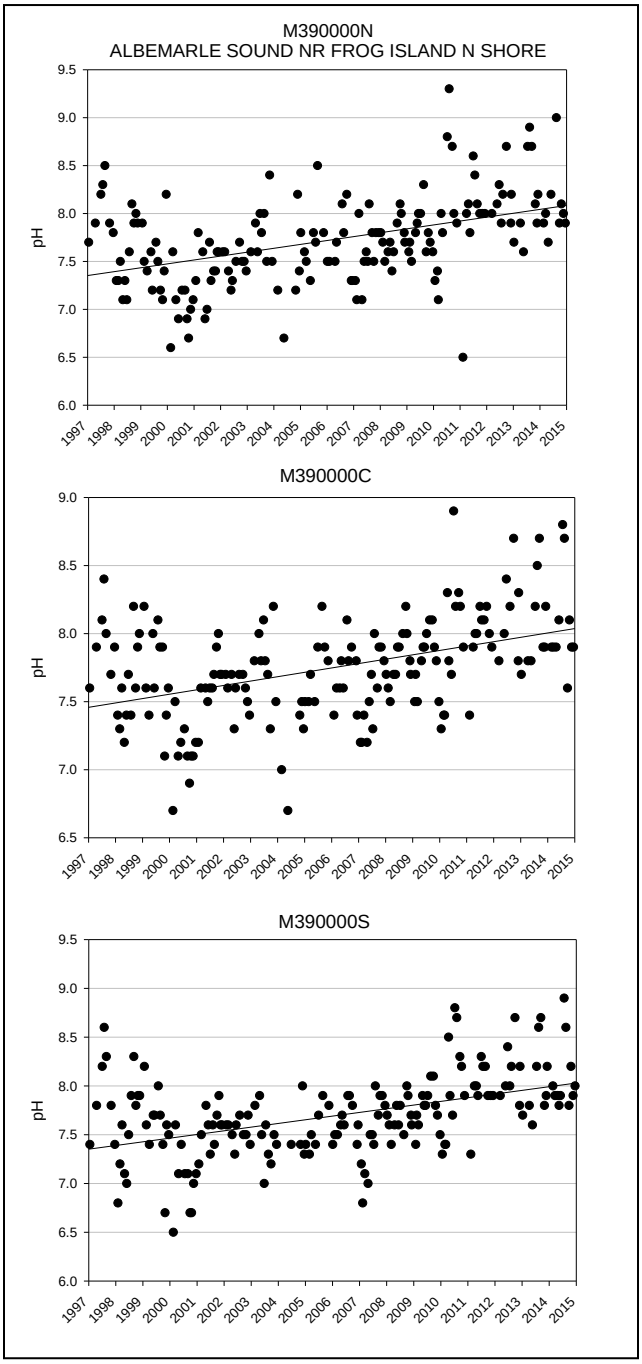
Give that the ambient monitoring frequency in the Albemarle Sound is generally occurs once per month, the use of the present 10% standard violation assessment is recommended.

Rationale: The recommended pH range appears the be protective of most species likely found in the Albemarle Sounds System. The range of 6.5 to 8.5 is generally accepted to represent safe levels for the protection of fresh and marine species and is reflected in other Eastern Atlantic state saltwater criteria (EPA, 1997).

There is currently a 2016 IR pH impairment in Albemarle Sound [AU# 30c1; Portion at Mouth of Pasquotank River, ~29,000 acres]. At stations M390000N, 19.6 % of the samples exceed the pH standard of 8.5 (96.3% confidence). Two other stations have elevated pH exceedances (M390000C and M390000S).

| Station Number | % pH > 8.5 | % Confidence |
|---|---|---|
| **M390000N** | 19.6 | 96.3 |
| **M390000C** | 10.6 | 48.7 |
| **M390000S** | 14.3 | 78.5 |
| **M610000N** | 2.0 | 3.7 |
| **M610000C** | 0 | |
| **M610000S** | 2.0 | 0.46 |
| **D999500N** | 0 | |
| **D999500C** | 0 | |
| **D999500S** | 0 | |



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Technical Memorandum Robertson-Bryan, Inc. *pH Requirements of Freshwater Aquatic Life*. May 2004.

Wolff, E.W., Seager, J., Cooper, V.A. and ORR, J. 1988. *Proposed environmental quality standards for list II substances in water. pH.* WRc report TT 259.

## Dissolved Oxygen

### DO Criteria Proposal 1

Field profiles of pH and dissolved oxygen should be measured when possible at sample sites in addition to secchi depth. NC DMF and NC DWR routinely measure pH and dissolved oxygen.

Protocols could be adjusted to ensure a profile is collected when secchi depth does not meet a certain criteria.

Rationale: pH levels are regularly above the current freshwater standard of 9 or saltwater standard of 8.5 standard units when a phytoplankton bloom is occurring. It is well accepted science that high pH levels are indicative of a bloom. pH is an easy indicator that can be used to assess whether poor water clarity is occurring as a result of excess phytoplankton production. We will make the assumption that excess phytoplankton production is occurring as a result of eutrophication. Thus, if we can detect phytoplankton blooms we can detect regions of the Albemarle that may be receiving excess nutrients.

Harmful algal blooms can cause hypoxia and anoxia in the estuary. This can have negative impacts on important fisheries. The current state standards for dissolved oxygen (instantaneous minimum value not less than 4 mg/L) can be used to determine if is occurring in a certain location, but provisions for areas designated as swamp waters where hypoxia and anoxia occur naturally should be noted.

### DO Criteria Proposal 2

Existing standards. The current set of standards include several parameters related to nutrient effects for the protection of aquatic life. These parameters have a long history of implementation and should be maintained. There is a long potential list of attributes that could be impacted by excess levels of nutrients, and I believe these are best addressed through narrative statement that can be evaluated within the context of future learnings on the overall health of different waterbodies and the range of conditions consistent with natural systems.

### DO Criteria Proposal 3

For Phase 1, retain NC's existing DO criterion for SB waters, but express it as a having a one-hour average duration.

DO is the most direct nutrient-related response variable for measuring potential impacts to aquatic life. This is because DO-related impacts can be acute and severe (e.g., fish kills), and affect multiple life stages. Based on available information, the Albemarle appears to be relatively well-aerated and not DO-impaired.

North Carolina's water quality standards for SB waters include a DO criterion of "not less than 5.0 mg/L, except that swamp waters, poorly flushed tidally influenced streams or embayments, or estuarine bottom waters may have lower values if caused by natural conditions." The 5.0 mg/L criterion is not accompanied by an averaging period in the standards text, and so is currently interpreted in the most conservative manner - as an instantaneous minimum. (In contrast, NC's DO criterion for non-trout freshwaters is a daily average of 5.0 mg/L and an instantaneous minimum of 4.0 mg/L).

To evaluate the protectiveness of NC's existing DO criterion, it is useful to compare it to the Chesapeake Bay's DO criterion that were refined in the 2000s to reflect different estuarine aquatic life uses (USEPA, 2003). The comparison is relevant because the Bay criteria was based on an extensive literature review of and risked-based modeling of various organisms and life stages that are also likely to be present in the Albemarle Sound. NC's standard 5 mg/L criterion is identical to the Chesapeake Bay criterion for the migratory fish spawning and

nursery use, which is intended to promote the "survival and growth of larval/juvenile migratory fish" and protect threatened/endangered species. That criterion applies from February 1 to May 31, corresponding to spawning/nursery season. At other times of the year, the open water instantaneous minimum of 3.2 mg/L applies in the Chesapeake Bay open waters, in conjunction with a 7-day mean criterion of 4 mg/L and a 30-day mean criterion of 5 mg/L. Based on this comparison, it appears that NC's existing DO criterion is fully protective of all aquatic life uses. However, it is likely somewhat overprotective outside of spawning/nursery periods.

Significantly, the Chesapeake Bay Program's Criteria Assessment Protocol Work Group has recently concluded that the "instantaneous minimum" duration should be revised as a one-hour average concentration not to be exceeded (USEPA, 2015). This is because all the literature studies from which the criterion was derived used 2-hour or longer durations. Although a two-hour duration is scientifically appropriate, a one-hour approach will retain an additional level of conservatism.

### DO Criteria Proposal 4

Standard 5 mg/L

Sampling: 6-10 samples collected (at least one monthly) during the growing season (April-September) at 10-15 stations (half lower river stations, half open sound stations) similar to distribution conducted by USGS in summer 2012.

Data reporting-summary every year to include mean, median, and S.D., minimum and maximum values for 1. open water sites and 2. lower river sites

Violation (does not meet intended use)- occurrence of any sample less than 5 mg/L

### DO Criteria Proposal 5

Conceptual recommendation (for discussion):

1. Keep the current standard
2. Alternative approach
    - Magnitudes identified from literature and case studies include:
        - 6 mg/L (potential aquatic diversity impacts)
        - 5 mg/L, February-May (anadromous fish protection)
        - 3.2 mg/L at T≤29°C and 4.3 mg/l at T>29°C) (sturgeon protection)
    - Duration, frequency, spatial extent and seasonal application to be considered further in concert with specific fish species habitat requirements.
    - Consider subsurface as well as surface DO criteria
    - Depressed DO measurements determined to be the result of a tropical storm, hurricane, or nor'easter may be omitted from the assessment for this parameter.
    - Present methodology allowing lower DO pursuant to natural conditions remains.

Rationale

*Chesapeake Bay and Albemarle Sound Aquatic Life Similarities*

Given the significant financial and intellectual resources dedicated to research and policy development in the Chesapeake Bay, their work appears to be a helpful model from which to

build. The aquatic species in need of protection from a DO standard are also very similar in many respects.

The most oxygen-sensitive fish species identified in Chesapeake Bay, including striped bass, American shad, white perch, and yellow perch, are also present in Albemarle Sound. Atlantic sturgeon, an anadromous and endangered fish, are also present in both water bodies. While severe instances of hypoxia can result in fish kills, lack of oxygen can also have sublethal effects including depletion of available fish habitat. A comprehensive source of additional supporting documentation for the Chesapeake Bay, with applicability to Albemarle Sound fish species, is the 2003 EPA document entitled "Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity, and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries. This resource provides a comprehensive overview of the strengths and limitations of various DO criteria approaches in Chapter 3.

The table below summarizes the Chesapeake Bay's dissolved oxygen criteria recommendations:

| **Designated Use** | **Criteria/Duration** | **Protection Provided** | **Temporal Application** |
|---|---|---|---|
| Open-water fish and shellfish use | 30-day mean ≥ 5.5 mg/l (0-0.5 ppt salinity) | Growth of tidal-fresh juvenile and adult fish; protective of threatened and endangered species | Year-round |
| | 30-day mean ≥ 5 mg/l (>0.5 ppt salinity) | Growth of larval, juvenile and adult fish and shellfish; protective of threatened and endangered species | |
| | 7-day mean ≥ 4 mg/l | Survival of open-water fish larvae | |
| | Instantaneous Minimum ≥ 3.2 mg/l (at T≤29°C) Instantaneous Minimum ≥ 4.3 mg/l (at T>29°C) | Survival of threatened/endangered sturgeon species | |
| Migratory fish spawning and nursery fish | 7-day mean ≥ 6 mg/l (0-0.5 ppt salinity) | Survival/growth of larval/juvenile tidal-fresh resident fish; protective of threatened and endangered species | February 1 – May 31 |
| | Instantaneous Minimum ≥ 5 mg/l | Survival/growth of larval/juvenile migratory fish; protective of threatened and endangered species | |
| Deep-water | 30 day mean ≥ 3 mg/l | Survival and recruitment of bay anchovy eggs and larvae. | June 1 – September 30 |
| | 1 day mean ≥ 2.3 mg/l | Survival of open-water juvenile and adult fish | |
| | Instantaneous Minimum ≥ 1.7 mg/l | Survival of bay anchovy eggs and larvae. | |
| Deep-channel | Instantaneous Minimum ≥ 1.7 mg/l | Survival of bottom dwelling organisms | June 1 – September 30 |

In addition to the extensive research conducted for the Chesapeake Bay, in Albemarle Sound dissolved oxygen levels below 6 mg/L have been correlated with reduced distribution of striped bass and spot populations (Ellis et al. 2009, Deaton pers. comm. 2016.) A range of 5-6 mg/L is also identified as being protective of striped bass populations in Chesapeake Bay, though the chart above reflects a compromise value.

*North Carolina monitoring limitations*

Water quality monitoring in Albemarle Sound is presently conducted monthly, with significant logistical and financial hurdles to increasing its spatial intensity or frequency. In contrast, Chesapeake Bay criteria are predicated on a more intensive monitoring scheme. Therefore, North Carolina has more limited options regarding the frequency/duration components that can be recommended as criteria.

*Surface DO*

A protective approach for setting DO criteria suggests a value of 6 mg/L would be appropriate for surface waters. However, the fish being protected by this surface standard are mobile and can tolerate minor and infrequent deviations from it, particularly if other suitable habitat is nearby. Evidence from the Chesapeake Bay also indicates the critical nature of spring spawning and early summer migration events for many anadromous and endangered fish species found in both water bodies.

*Sub-surface DO*

A sub-surface DO standard is also recommended for consideration to protect bottom-dependent species in Albemarle Sound. While Albemarle Sound does not typically show strong stratification, benthic DO criteria can help ensure that criteria and aquatic life uses are appropriately aligned. The temperature-dependent values identified for protection of sturgeon in the Chesapeake Bay appear adequate to support most if not all benthic species in Albemarle Sound, though more work is recommended.

Criteria in Albemarle Sound should also be protective of fish that primarily utilize benthic habitat. Sturgeon in particular typically feed on benthic organism and reside or migrate near the bottom of rivers and estuaries. As described in Chesapeake Bay documentation, acceptable DO levels for these species are temperature dependent; their metabolic rate and associated oxygen requirements increase with water temperature.

A survey of benthic species occurring in Albemarle Sound was conducted in 1997 with support from NOAA. Species identified during that survey include an array of invertebrate species including small worms, insect larvae, and amphipods. Evaluation of the Chesapeake Bay approach and independent searches for the oxygen requirements of these species provided little specific information. However, the limited information available suggested that these organisms are generally well-adapted to low-oxygen environments.

The Atlantic rangia clam (*Rangia cunneata*) is also commonly found in Albemarle Sound. According to a review of the Atlantic rangia's life history conducted by the Texas Coastal Fisheries Division, populations have been known to survive in waters where DO levels are routinely below 2 mg/L. However, a USGS study has correlated the absence of Atlantic rangia with hypoxia in Lake Pontchartrain, indicating some sensitivity to low oxygen environments.

There is some debate as to whether the clams are native to North Carolina, but they do appear to have some ecological benefits. They are non-selective filter feeders that generally consume algae and diatoms, the source of potential nutrient-related impairments. The Texas review also indicates that juvenile clams are a food source for important fishery and forage species also present in North Carolina like spot, croaker, pin fish, flounder, and blue crabs.

*State of the Sound regarding DO*

A review of Albemarle Sound monitoring data suggests its waters typically meet the present DO standard. Open sound monitoring stations reflect median values between 8 and 9.3 mg/L and 25$^{th}$ percentile ranges of 6.8 to 8 mg/L, well above the 6 mg/L proposed.

The SB/SC tributaries have slightly lower DO values. Two stations (M6920000, M7053000) often reflect values that are significantly lower than the proposed and present standards (25$^{th}$ percentile, 3.675 and 2.8 mg/L, respectively). One station is no longer monitored, and the second is slated for investigation to determine if low DO values are the result of natural conditions. Neither site is presently listed as impaired. Median DO values in the remaining tributary stations range from 7.4 to 9.2, and 25$^{th}$ percentile values range from 6 to 7.9.

Descriptive DO statistics provided in the Tetra Tech report (tables 1 and 2) provide some additional insights regarding DO levels. For example, the 25$^{th}$ percentile values for all tributary and sound proper DO measurements are 6.6 and 7.8 mg/L, respectively (Table 1).

*Relationship to Nutrients*

Workgroup discussions and Tetra Tech analyses indicate that the relationship between DO levels and nutrient inputs may be influenced by presently unstudied additional factors. For example, nutrients and DO levels are positively correlated in open sound sites, indicating that wind mixing and spatial dynamics may influence this relationship more strongly than the presence of nutrients. On the other hand, the estuarine tributaries show a negative correlation between nutrients and DO, a relationship more consistent with general conceptual models of eutrophication.

These findings have important implications in the consideration of causal nutrient criteria and in the design of restoration strategies should persistent DO violations in Albemarle Sound become apparent in the future.

### DO Research Proposal 1

During Phase 2, consider whether NC's existing DO criterion should be lowered to 3.2 mg/L outside spawning/nursery periods, and the 5 mg/L criterion used as a 30-day average outside spawning/nursery periods. This research can be primarily literature-based.

### DO Research Proposal 2

Engage with fisheries biologists and fisheries management experts to refine DO recommendations. A species-by-species evaluation of the spatial and temporal habitat utilization within Albemarle Sound (or statewide estuaries) should be considered, particularly for fish species that have already been identified as being particularly sensitive to low DO. The results of historic DMF fish surveys could be utilized for this purpose.

### DO Research Proposal 3

Impacts of the abovementioned variables [climate, episodic events, nutrient inputs, limiting nutrients] on optical habitat conditions for SAVs and DO conditions for benthic flora and fauna. Approach: Observational data on above parameters in conjunction with aerial SAV coverage and DO conditions (at established NCDENR Ambient monitoring locations).

## Clarity

### Clarity Criteria Proposal 1

Current Secchi depth measurements should be used as the first response criteria. Data on light penetration as measured by secchi disc were abundant in the Albemarle Sound database with 1,583 measurements located throughout the estuary (Figure 1, Moorman and others, 2014). Approximately 84% of these secchi disc measurements were taken by the NCDMF as a part of fish surveys conducted from 1970 to the present. Other sources of secchi disk data are the USGS, VADEQ, USEPA NRS, NCDWR AMS and APNEP Citizens Monitoring Program with each program contributing < 5 % of the total secchi disk measurements. Examination of the map of secchi disc measurements shows good coverage along the margins of the estuary with gaps in the middle of the estuary. Additionally, resources should be allocated to consistently and routinely analyze secchi data. This could easily be accomplished with a script that routinely grabs and analyzes data from the water quality portal. Results from routine analyses can be used to frequently analyze the status of various embayments in the estuary.

Rationale (including, if possible, whether areas subject to the recommendation appear to be meeting their designated uses):

Nutrient enrichment of lakes and estuaries across the Nation is widespread. Nutrient enrichment can stimulate excessive plant and algal growth and cause a number of undesirable effects that impair aquatic life and recreational activities and can also result in economic effects. One of the largest concerns related to nutrient enrichment is the occurrence of harmful algal blooms. Harmful algal blooms can cause a number of effects that are undesirable to both estuarine ecology and human health. Our recommendations provide a simple field protocol for assessing if a harmful algal bloom is occurring. This rapid protocol will enable us to detect undesirable impacts from nutrient enrichment quickly. The first step of our rapid detection protocol is to measure water clarity by recording secchi depth. Water clarity is an important response variable because good water clarity is required in order to maintain SAV. SAV is an important indicator of water quality, helps maintain nutrient and sediment balances, and provides food and habitat for important species such as migratory birds, fish, and crabs, but monitoring SAV in the Albemarle Sound is both difficult and time consuming. Poor water clarity impacts the amount of available light for SAV growth which has been linked to declines in SAV and reduce water quality.

Secchi depths based on either an Albemarle specific guideline for SAV or a guideline adopted from the Chesapeake Bay or another water body should be adopted. Secchi depth data is readily accessible, has few qa/qc issues, has been prioritized as an indicator by other regional planning

organizations such as the Albemarle-Pamlico National Estuary Program and the Eastern North Carolina South East Virginia Ecoteam (U.S. Department of Interior), and is an excellent indicator of estuarine water clarity.

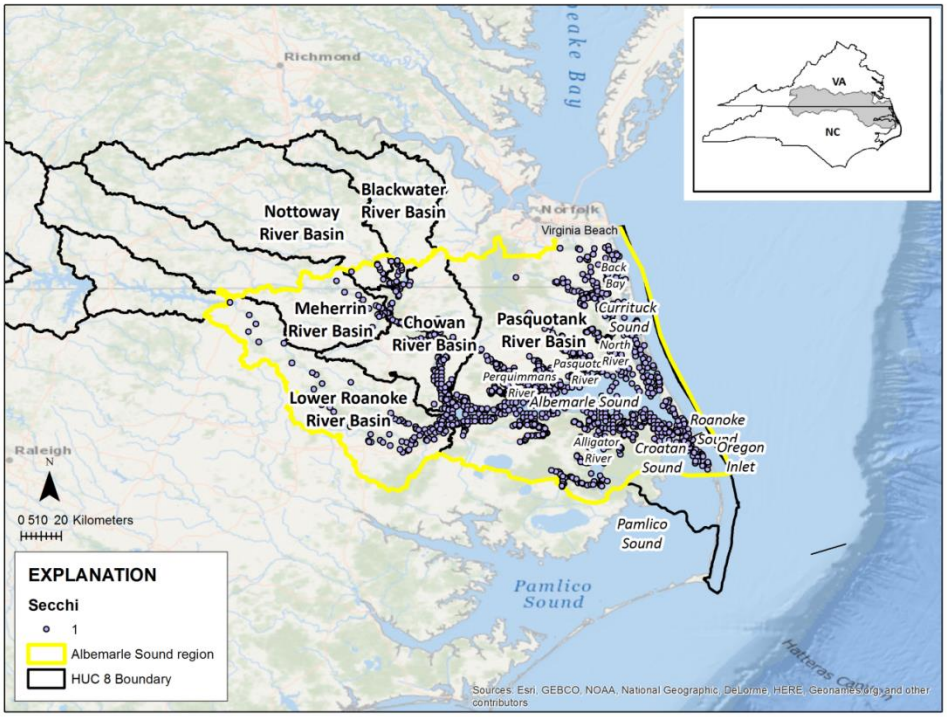


Figure 1. Distribution of sites with secchi disc depth measurements in the USGS Albemarle Sound region database (Moorman et al. 2014).

### Clarity Criteria Proposal 2

*Magnitude:* 13% light through water, as determined by either Secchi depth or a PAR (photosynthetically active radiation) meter. Secchi depth magnitude criteria would be applied by varying depths analogous to Chesapeake Bay approach.

*Duration and frequency:* Seasonal application, April 1 through October 31. Other duration and frequency determinations subject to further inquiry.

*Spatial extent:* Application only in waters less than 3m deep throughout Albemarle Sound study area. Degree of spatial averaging under consideration.

Rationale: There appears to be merit in a clarity standard protective of sensitive submerged aquatic vegetation habitats (SAV) in Albemarle Sound. The linkage between a clarity standard and impacts to submerged aquatic vegetation (aquatic life use) have been thoroughly researched by the Chesapeake Bay Program, and oligohaline species in the Chesapeake Bay are commonly found in Albemarle Sound. A comprehensive source of additional supporting documentation this approach can be found in the 2003 EPA document entitled "Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity, and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries.

The Chesapeake Bay approach is summarized in this table, as referenced in the aforementioned document:

**Table VI-2.** Summary of Chesapeake Bay water clarity criteria for application to shallow-water bay grass designated use habitats.

| Salinity Regime | Water Clarity Criteria as Percent Light-through-Water | Water Clarity Criteria as Secchi Depth | | | | | | | | Temporal Application |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Water Clarity Criteria Application Depths | | | | | | | | |
| | | 0.25 | 0.5 | 0.75 | 1.0 | 1.25 | 1.5 | 1.75 | 2.0 | |
| | | Secchi Depth (meters) for above Criteria Application Depth | | | | | | | | |
| Tidal-fresh | 13 % | 0.2 | 0.4 | 0.5 | 0.7 | 0.9 | 1.1 | 1.2 | 1.4 | April 1 - October 31 |
| Oligohaline | 13 % | 0.2 | 0.4 | 0.5 | 0.7 | 0.9 | 1.1 | 1.2 | 1.4 | April 1 - October 31 |
| Mesohaline | 22 % | 0.2 | 0.5 | 0.7 | 1.0 | 1.2 | 1.4 | 1.7 | 1.9 | April 1 - October 31 |
| Polyhaline | 22 % | 0.2 | 0.5 | 0.7 | 1.0 | 1.2 | 1.4 | 1.7 | 1.9 | March 1 - May 31, September 1 - November 30 |

[1]Based on application of Equation IV-1, PLW = $100\exp(-K_dZ)$, the appropriate PLW criterion value and the selected application depth are inserted and the equation is solved for $K_d$. The generated $K_d$ value is then converted to Secchi depth (in meters) using the conversion factor $K_d = 1.45/\text{Secchi depth}$.

Presently, there are some challenges associated with solely using DWR ambient monitoring sites to evaluate uses associated with SAV. Most ambient monitoring stations are at the mouths of the estuarine tributaries and along the center line of the Sound, far from the coastline in deeper water. In contrast, SAV is unlikely to grow at depths greater than 3 meters and is most dense in shallow water along the coastline. Furthermore, if criteria are limited to the growing season, only 6 samples per year at each ambient monitoring site would be collected. This low sampling rate limits criteria options related to duration, frequency, and statistical confidence.

However, in any given year many other organizations may be collecting data in Albemarle Sound, including the N.C. Division of Marine Fisheries, APNEP, USGS, and university researchers. So long as quality control measures are in place, utilization of routinely collected Secchi and PAR data from these sources could also be used for assessment purposes along with DWR data.

Conceptually, shore parallel grids could be established along the estuarine border, extending from shore to the 3-meter depth contour. The separation of individual grids would be informed by hydrology and projected data intensity. All clarity data collected within a grid during the growing season could be evaluated together, with appropriate data requirements and confidence safeguards to be determined.

### Clarity Research Proposal 1

Use historic secchi and pH data from all sources to determine if water clarity has changed through time and what parts of the Albemarle may or may have impaired levels of water clarity. Use this information to determine which areas of the Albemarle may or may not be impaired. If water clarity impairments are determined from the secchi and pH data, the sources of those impairments should be investigated further.

### Clarity Research Proposal 2

Establish historical spatial coverage of sea grasses in the Albemarle Sound, including areas in which the non-light factors and rising sea level provide suitable habitat.

### Clarity Research Proposal 3

Bio-optical model: During Phase 2, develop and calibrate a biooptical model similar to that employed by Biber and others (2008), for exploring whether alternative CHLa criteria would be needed to protect SAV in the Sound. This activity should explore whether water clarity near the Sound's SAV beds would be sensitive to CHLa, versus largely controlled by other sources of turbidity, and the degree to which the other sources of turbidity are natural vs. controllable. SAV-based chlorophyll-a (or water clarity) criteria should have a spatial component based on historical SAV distribution (see related research recommendation below), and should considered natural interannual variability. It would be cautioned against adopting chlorophyll/clarity criteria that require the entire Sound to have higher clarity than reflected in the historical SAV depth/distribution.

### Clarity Research Proposal 4

Historical SAV distribution: Revisit available information on the historical depth and distribution of SAV in Albemarle Sound. Determine if aerial photography allows better determination on the SAV depth/distribution in previous decades. Also identify areas where SAV is unlikely to grow due to natural conditions (waves, substrate, etc.). Use this information to help set reasonable long-term average goals for the spatial extent of SAV and water clarity in Albemarle Sound.

### Clarity Research Proposal 5

Drawing upon a previous USGS survey, evaluate data availability and spatial and temporal characteristics of Secchi depth and PAR meter monitoring from various professional sources, including DWR, DMF, USGS, and others. This information can help estimate monitoring intensity, which can be used to hone duration, frequency, and spatial extent recommendations for this parameter.

### Clarity Research Proposal 6

Evaluate and select an appropriate light partitioning model capable of distinguishing between CDOM, chlorophyll *a*, and TSS influences on clarity. The degree to which these parameters contribute to a clarity impairment would influence a recovery strategy. On appropriate spatial scales, determine secondary benchmark values for CDOM, chlorophyll *a*, and TSS. If the clarity standard is not met, exceedances of these secondary benchmarks would be used to diagnose and potentially regulate the specific source(s) of the clarity impairment. Benchmark values would also need to be evaluated in light of (potential) chlorophyll *a* and TSS stand-alone criteria protective of other uses.

## TSS

### TSS Criteria Proposal 1

(conceptual, for discussion):

- 30 mg/L TSS using standard assessment methods in Albemarle Sound proper and estuarine tributaries except Alligator River (90%, 10% confidence, minimum of 10 samples).
- 35 mg/L TSS using standard assessment methods in Alligator River.

Rationale: This criterion would be comparable to widely prescribed standards across many water quality agencies (Table 1). It is proposed to be protective from an anti-degradation perspective, with no TSS future impairments expected unless levels become elevated from the historical baseline.

Historically, TSS levels in Albemarle Sound have not been a primary concern. Median TSS values are at or below 10 mg/L for all stations within the study area. The 90th percentile value is <30 mg/L at 19 of 20 stations, with the sole excursion being a station in the Alligator River with a 90th percentile value at 32.5. 17 of 20 stations have a 90th percentile value of <25 mg/L.

Approximately 75% of TSS results over 30 mg/L were from the 1970's and 1980's, with only around 25% being from the 1990's and 2000's. Few data points have been collected since 2010. The average 90th percentile TSS value for Albemarle Sound stations is 18.025 mg/L. The average 90th percentile value for open sound stations is 16.93 mg/L and for the estuarine tributaries is 19.12 mg/L.

Figure 1: Components of Turbidity and Total Suspended Solids

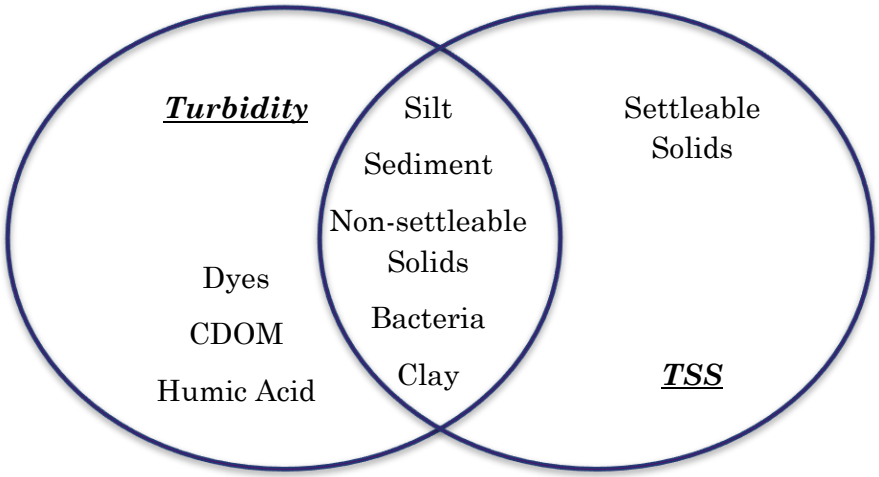

Table 1: Preliminary survey of TSS standards

| Location | Turbidity Criterion | TSS Criterion | Timeframe | Notes |
|---|---|---|---|---|
| North Carolina | 10/25 NTU | 20 mg/L | Not to exceed | Turbidity criteria for trout/non-trout waters.<br>TSS criterion for HQW/effluent anti-deg |
| Vermont | 10/25 NTU | -- | Not to exceed | Dependent on water classification, cold/warm water fisheries |
| Louisiana | 25/50 NTU | -- | Not to exceed | Freshwater/estuarine lakes<br>(Jen note – this is opposite of other standards, marine usually lower) |
| Worldwide | -- | <40 mg/L /<br><10 mg/L | Varies | Freshwater / marine averages |
| Minnesota | --<br>*(previously 25 NTU)* | 10 mg/L /<br>25 mg/L<br>(plus others) | April – September, not to exceed more than 10% of the time over multiple years | Coldwater fisheries and drinking water / warm, indigenous fish and recreation. Others (up to 100 mg/L) are based on classification and specific water bodies.<br>(Jen note – median MN stormwater runoff TSS is 58 mg/L) |
| Washington | 5 NTU over background | 30 mg/L* | Not to exceed | Turbidity = 25 NTU effluent limit<br>* New effluent limit going into effect 1/1/17 |
| Australia | Ecosystem health – see notes | -- | Used as "triggers" | <10 NTU = healthy<br>10-20 NTU = fair<br>>20 NTU = poor |
| Hawaii | -- | 10 mg/L<br>30 mg/L<br>55 mg/L | Geomean NTE<br><10% NTE<br><2% NTE | Unsure of the time period for the geomean? |
| Utah | -- | 35 mg/L | NTE 30 day average | Cold water |
| | -- | 58 mg/L | NTE per day maximum | Cold water |
| | -- | 90 mg/L | NTE 30 day average | Warm water |
| | -- | 263 mg/L | NTE per day maximum | Warm water |
| North Dakota | -- | 30 mg/L | NTE 30 day average | Cold water |
| | -- | 58 mg/L | NTE per day maximum | Cold water |
| South Dakota | -- | 30 mg/L | NTE 30 day average | Cold water |
| | -- | 58 mg/L | NTE per day maximum | Cold water |
| | -- | 150 mg/L | NTE 30 day average | Warm water |
| | -- | 263 mg/L | NTE per day maximum | Warm water |
| Newfoundland | -- | 25 mg/L above background | Not to exceed | Effluent regulatory limit is 30 mg/L |
| Michigan | -- | "Shall not be injurious to designated use" | Narrative | Wastewater effluent = 30 mg/L monthly average, 45 mg/L weekly average |
| Delaware Bay | -- | 20 mg/L | May-October, minimum 10 samples | Some confusing caveat about confidence, etc. |
| EPA Aquatic Life | -- | "Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life." | | |

### TSS Research Proposal 1

Seek internal and external financial or logistical support to resume TSS sampling at appropriate stations in Albemarle Sound. Corroborate historical measurements with new samples to evaluate potential trends. TSS samples may also be necessary to inform proposed clarity criteria.

### TSS Research Proposal 2

Conduct further literature research regarding the impacts of TSS on estuarine aquatic life uses. Should the values above be determined to have no significant effects on aquatic life uses, the reference approach utilized may be protective of Albemarle Sound's designated uses.

### TSS Research Proposal 3

Consider the interrelationship between clarity and TSS criteria recommendations before finalizing these criteria.

## Turbidity

### Turbidity Criteria Proposal 1

Existing standards. The current set of standards include several parameters related to nutrient effects for the protection of aquatic life. These parameters have a long history of implementation and should be maintained. There is a long potential list of attributes that could be impacted by excess levels of nutrients, and I believe these are best addressed through narrative statement that can be evaluated within the context of future learnings on the overall health of different waterbodies and the range of conditions consistent with natural systems.

### Turbidity Criteria Proposal 2

Retain presently established statewide turbidity standard as-is.

## Phytoplankton and Cyanotoxins

### Phytoplankton and Cyanotoxins Criteria Proposal 1

If field measurements suggest water clarity is poor and pH is, samples for phytoplankton and cyanotoxins should be collected. Both of these parameters cannot be directly measured in the field, but can easily be collected and submitted to a lab. Our recommendation is that staff collect and preserve a phytoplankton sample with lugols and preserve a cyanotoxin on ice that is immediately frozen. Samples could then be analyzed for phytoplankton within a specified period of time at either the state lab or a contract lab. If cyanobacteria capable of producing toxins are present above a specified level, the cyanotoxin sample could be run for analysis. Based on our results from the Albemarle, this data is not time sensitive unless a thick, scum-forming bloom is present such as those seen on the Chowan with microcystin levels greater than 60 ppb in summer of 2013 and 2015. In these instances, samples should be immediately submitted and analyzed to determine if the bloom could be hazardous to human health. If NC DMF assists in sample collection, specific water-quality sites should be established for each area

sampled, i.e. there only needs to be 1-2 sites per an Albemarle embayment and only one sample for lab submission should be collected and submitted if multiple field measurements are taken in an area. Additionally, since the main parameter of concern is water clarity, a sample for colored dissolved organic matter could also be collected and preserved, at least initially, because natural tannins from swamp water impact water clarity.

Harmful algal blooms often occur as a result of excess nutrients in a waterbody. The number of harmful algal blooms is increasing in the United States and harmful algal blooms can have negative impacts on both human and ecosystem health. Additionally, we have detected harmful algal blooms capable of producing toxins which can be harmful to both human and ecological health in both the Chowan and Albemarle Sound.

### Phytoplankton and Cyanotoxins Research Proposal 1

Natural range of phytoplankton assemblage present in the Albemarle Sound across years and in different regions. Year-to-year variation in salinity (both higher and lower) should be factored into the characterization. If species that may form algal toxins are present, follow-up testing for presence of toxins that may affect recreational uses or aquatic life should be done.

### Phytoplankton and Cyanotoxins Research Proposal 2

CHLa and algal toxins: Collect additional algal toxin data as needed to develop an empirical relationship between CHLa and algal toxin concentrations. Include data from adjacent river segments in this analysis.

### Phytoplankton and Cyanotoxins Research Proposal 3

Algal bioassays: Perform algal bioassays to determine nutrient (N, P) and light limitations on algae from Albemarle Sound and adjacent river segments.

### Phytoplankton and Cyanotoxins Research Proposal 4

Establishing linkage of nutrient inputs (loading) to algal growth/bloom potentials in Albemarle Sound. Approach: Establishing space-time relationships between N and P inputs (dissolved and particulate inorganic and organic forms) and phytoplankton biomass and community composition at established NCDENR Ambient monitoring locations.

### Phytoplankton and Cyanotoxins Research Proposal 5

Before implementing long-term nutrient management strategies/steps, we need to know which nutrients are controlling (limiting) algal growth, especially during periods favorable for algal bloom formation. Approach: Nutrient limitation bioassays conducted on waters collected at the headwaters and from Albemarle Sound proper. These should probably be conducted at the beginning and mid-bloom periods (spring-summer) and they should be the in situ type (incubated under natural light and temperature conditions). Methodologies are available (Paerl et al., 1999, 2008; Calandrino and Paerl 2011).


- Calandrino, E. and H.W. Paerl. 2011. Determining the potential for the proliferation of the harmful cyanobacterium Cylindrospermopsis raciborskii in Currituck Sound, North Carolina. Harmful Algae 11:1-9.
- Paerl, H. W., J. D. Willey, M. Go, B. L. Peierls, J. L. Pinckney and M. L. Fogel. 1999. Rainfall stimulation of primary production in Western Atlantic Ocean waters: Roles of different nitrogen sources and co-limiting nutrients. Mar. Ecol. Progr. Ser. 176:205-214.

- Paerl, H.W., J.J. Joyner, A.R. Joyner, K. Arthur, V.J. Paul, J. M. O'Neil and C. A. Heil. 2008. Co-occurrence of dinoflagellate and cyanobacterial harmful algal blooms in southwest Florida coastal waters: A case for dual nutrient (N and P) input controls. Marine Ecology Progress Series 371:143-153.

## Chlorophyll a

### Chlorophyll Criteria Proposal 1

Chlorophyll a as indicator of plant growth at level to support fisheries but not degrade habitat for aquatic life. Since concern is for chronic overloading of nutrients leading to sustained excess algal growth in the water column of Albemarle Sound, implementation is recommended to be as a seasonal geometric mean. Refinement may be needed, but a starting point for discussion would be 25 µg/L. The growing season geometric mean would not exceed the criterion more than 1 year in three. Implementation would best be done by spatial zones – possibly three for the Albemarle Sound proper outside of the tidal portions of tributaries. Information provided at prior meetings indicates the Albemarle Sound currently meets the aquatic life designated use, including consideration of commercial and recreational fishing.

Note 1 – the need for a maximum value for Chlorophyll a should be based on demonstrated peak blooms that lower dissolved oxygen to stressful levels for fish and benthos and/or include demonstrated levels of algal toxins to concentrations of concern for recreational uses and aquatic life.

### Chlorophyll Criteria Proposal 2

For Phase 1, retain NC's existing chlorophyll-*a* criterion magnitude for SB waters (40 ug/L). Continue to effectively assess the criterion using the 10% rule, pending additional evaluation of the appropriate statistic and frequency. Spatial considerations: Pool surface layer data from all stations in assessment unit.

Rationale:

CHLa can be a useful indicator of various harmful effects (e.g., algal toxins, low water clarity, low DO) if sufficient data/tools are available to demonstrate the relationship between CHLa and the effects of concern in the system of interest. NC's exiting existing chlorophyll-a criterion for class SB waters specifies that chlorophyll-a "shall not be greater than 40 ug/L in sounds, estuaries, and other waters subject to growths of macroscopic or microscopic vegetation". The criterion has no stated averaging period, and so is used conservatively as an instantaneous minimum. In practice, NC assesses waters for chlorophyll-impairment using a 10% rule; i.e., a water body would be listed as impaired if more than 10% of the growing season samples exceeded the criterion.

Based on the data review presented to the working group, the main body of the Albemarle Sound does not appear to experience frequent exceedances of CHLa = 40 ug/L, and in general, does not show clear signs of CHLa impairment. The adjacent river segments do appear to sometimes exceed the 40 ug/L value.

The working group currently lacks sufficient technical information to either change the CHLa criterion, or to confirm that it is an appropriate value. Hence the need to retain it and proceed to Phase 2. However, there are several promising areas of research that could help refine this criterion in magnitude, frequency, or duration. I believe the most promising is the exploration of the relationship among CHLa, TSS, and water clarity needed to support SAV. And although algal toxin levels appear to very low in the Sound proper, additional information on the relationship between CHLa and algal toxins in the adjacent river segments could provide useful information for those types of segments. These concepts are discussed further below under the research recommendations.

*Duration/averaging considerations*: Regarding the appropriate duration/statistic for the CHLa criterion: Looking at precedents from other states and regions, CHLa criteria have most often been expressed as a seasonal average (e.g., geometric mean) rather than a not-to-exceed value. Anecdotally, NC's 1970s-era working group that recommended the 40 ug/L criterion intended it as some type of seasonal mean, but that recommendation was not reflected in the standards language (F. Westall, pers. comm., 11 Dec 2015). The lack of an averaging period is a major shortcoming of NC's existing CHLa criterion. Thus, the working group/DWR should express the CHLa criterion as seasonal geometric mean during Phase 2, coupled with any appropriate revision to the magnitude of the criterion.

*Spatial considerations*: In addition to expressing the criterion as a temporal (seasonal) mean, it is also appropriate to pool data from multiple stations within assessment segments, to reflect the integrated/averaged nature of the CHLa target. This assumes that the assessment units do not exhibit large, spatially-consistent non-uniformities in the distribution of CHLa. Assessment units should not be subdivided to represent individual stations for water bodies that are other relatively homogenous or have a well-defined geographic delineation.

*Frequency considerations*: During Phase 2, the working group should recommend an allowable frequency of exceedance of the seasonal mean CHLa criterion. Examples from other states include a 1-in-3 year (or 2-in-6) allowable exceedances (FL, WI, proposed in VA). The allowable exceedance is needed to reflect interannual variability in hydrology, temperature, and other non-controllable factors. A 1-in-3 allowable exceedance reflects the fact that CHLa criteria are best understood as reasonable long-term goals for the estuary - which should be attained in most but not necessarily all years.

### Chlorophyll Criteria Proposal 3

Chlorophyll a (contingent upon satisfying concerns posed in letter to Jim Hawhee on July 5 (link here)-the data in the DENR database currently do not appear to be correlated to nutrient concentrations. to possibly rectify this, see research recommendation below.

Continue Current Standard- 40 ug/L

Sampling: 6-10 samples collected (at least one monthly) during the growing season (April-September) at 10-15 stations (half lower river stations, half open sound stations) similar to distribution conducted by USGS in summer 2012.

Data reporting-summary every year to include mean, median, and S.D., minimum and maximum values for 1. open water sites and 2. lower river sites

Violation (does not meet intended use)-occurrence of 40 ug/Lor higher at the 90th percentile at any station or a growing season mean of 20 ug/L or above for any station

Rationale: For the chosen response variable to be useful, the response variable must be related to the causal variable(s). If the relationship can be demonstrated (see research recommendations below), then it can be effectively used to indicate environmental conditions that do or do not impair the intended use of the water. Chlorophyll a has been demonstrated to reflect nutrient loading conditions and concentrations in the world scientific literature (see examples in the link above). North Carolina already has an existing standard which should be adequate to evaluate the condition of the Albemarle Sound Drainage. It is known that harmful algae, low oxygen, frequency of fish kills occur when chlorophyll a levels are high and reflect and are correlated to high algal densities. If the data in North Carolina do not show this, the data should be analyzed as part of the proposed research project (below) and appropriate QA/QC and data collection procedures adopted.

### Chlorophyll Research Proposal 1

For chlorophyll a to be a meaningful indicator, it is imperative that a definable relationship exists between the chlorophyll a and both nitrogen and/or phosphorus. The current DWR data base should be analyzed by an independent reviewer(s) from the university system or federal agency who is knowledgeable about statistics and aquatic ecology. They must: (1) determine if a significant correlation exists between chlorophyll a and P or N at annual or summertime time steps concentrations by station, by all stations in the Albemarle Sound drainage, by open-water sound stations, river stations and (2) if a meaningful predictive regression model appeared possible with the current DEQ data set, data collection, and lab analysis procedures. If not, recommendations should be made to revise appropriate data collection and analysis procedures. This analysis need not be expensive-a report prepared for USGSin 2014 by Duke University students was very informative and well done report (http://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/8486/LocklierMcGeeZhangMPFinal.pdf?sequence=1 Even though this report found relationships between P and chlorophyll a, much as did the Tetratech report, developing a regression model to show a predictive relationship, such as that suggested here, requires a more detailed analysis.

## Other Recommendations

### Monitoring Proposal 1

Monitoring budgets grow and shrink thus we need a collaborative approach to monitoring eutrophication that is robust and responsive. Although we need accurate data on nutrient concentrations in the Albemarle Sound, directly measuring nutrients for the purpose of comparing data to a standard is difficult due to the fact that there are many species of nutrients and they are constantly transforming between various states.

Chlorophyll a has also proven to be a difficult parameter to measure and compare to a standard due to the high variability in lab results. Additionally, any response parameter that has to be analyzed at a lab data does not provide immediate results regarding estuarine health. For these reasons, we suggest a field-based approach designed to measure indicators of eutrophication such as reduced water clarity, elevated pH, and low dissolved oxygen. These are

measurements that can be collected by almost any agency interested in assessing nutrient enrichment in the Albemarle Sound and can provide for the rapid detection of harmful effects of eutrophication such as hypoxia, poor water clarity, and the production of algal toxins. All participating agencies should agree to put their data into the water-quality portal (STORET and NWIS) and round robins between agencies should be routinely conducted to ensure that data is comparable.

### Monitoring Proposal 2

In addition to NCDENR monitoring locations, establishing new monitoring sites at strategic locations?

### Duration, Frequency and Bioconfirmation Proposal

See text under response variable sections above that include specific recommendations on the duration and frequency components of criteria to be developed during Phase 2. During phase 2, it is also recommended to consider how bioconfirmation concepts could apply to the Albemarle Sound. For example, in the Chesapeake Bay, a segment is considered to be attaining its shallow water use if it meets certain water clarity criteria OR meets the SAV acreage goal.

### Prioritization Proposal

I recommend that the response criteria should be prioritized as follows:

1. A measure of water column clarity. This could be as simple as a Secchi disk reading, although in some parts of the system, the Secchi disk depth will be greater than the actual water column depth. In that case, a PAR sensor should be used. Parallel TSS, turbidity and CDOM measurements would complement clarity measurements.

2. Chlorophyll a concentration. This will allow us to assess the trophic state of the system. Whenever possible, this measurement should be linked to optical properties, N and P inputs as well as total N and total P concentrations in the water column.

3. SAV aerial coverage, using field surveys and aircraft/satellite remote sensing.

4. Link 1-3 to fin- and shellfish population dynamics and yields.

(note, we talked about DO, but its response to environmental drivers in Albemarle Sound is controlled by complex and non-linear physical-chemical interactions, whereas 1-3 are much more direct responses to these drivers, just like much of the rest of APES).

### Climate Variability Proposal

Roles of climatic/hydrologic variability and episodic events (hurricanes, droughts) in controlling nutrient/sediment inputs and biotic responses (algal primary production and bloom formation) in the Albemarle Sound. Approach: Establishing space-time relationships between nutrient inputs, freshwater discharge/water residence time and phytoplankton biomass and community compositional responses at established NCDENR Ambient monitoring locations.