An Overview of Numeric Nutrient Criteria (NNC) Development for Estuaries

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SAC MEETING

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Criteria Development in General

The Basics of Criteria Development

- Water Quality Criteria, aka WQC (40 CFR 131.3 (b))
  - *Elements of State water quality standards, expressed as constituent concentrations, levels or narrative statements, representing water quality that supports a particular designated use. When criteria are met, water quality will generally protect the designated use.*
  - *Can be numeric or narrative*
- States/Tribes shall adopt criteria to protect designated uses into their WQS (CWA 303(c)(1))
  - Designated uses for Albemarle include Class SC and potentially others (see map)
  - Designated uses for the Chowan River include Class C and potentially others (see map)

The Basics of Criteria Development, cont'd.

- When North Carolina moves forward with any criteria adoptions, their record must show that the criteria selected protects the designated use(s).
  - This is simpler when the state is adopting one of EPA's 304(a) criteria recommendations.
  - Site specific criteria development, while bound by the big picture guidelines of EPA's regulations, are by nature, unique and thus require additional upfront development work.
    - ***An advance thank you to DWR and the other SAC members!***

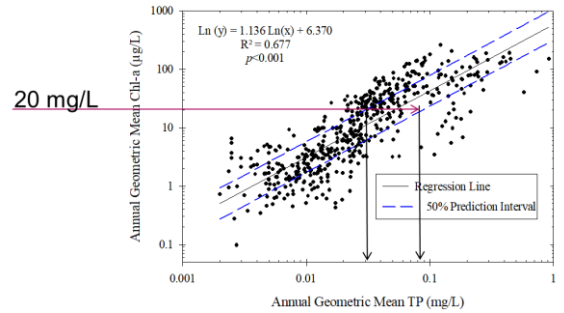
What's different for NUTRIENT criteria development?

- They can be more challenging to develop!
  - While we know TP and TN influence the response indicators, ecosystem complexities can make it harder to find precise relationships
  - Do laboratory/mesocosm/literature relationships hold up in real systems?
  - How do we agree on the level that is protective of designated uses?
    - We can't consider feasibility/cost at this step.
    - More on what it means to be protective of a designated use later…

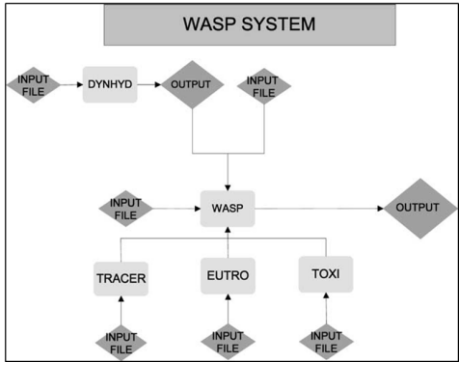
Technical Approaches

- How are numeric nutrient criteria derived?
  - Empirical stressor-response
  - Reference condition
  - Scientific literature and expert judgment
  - Mechanistic models
  - Multiple lines of evidence

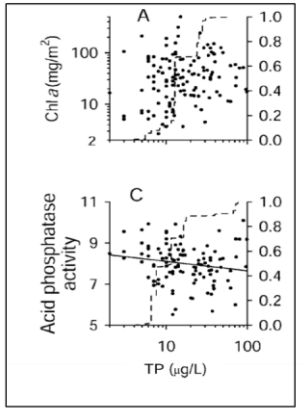
Empirical Models: TP in Lakes



•Mechanistic modeling



•Scientific literature



• Stevenson et al. 2008

Traditional NNC Development

- PARAMETERS
  - The Big 4: Chlorophyll a, TP, TN, and Secchi depth
  - DO, pH, turbidity, light penetration, macrophytes, algal toxins, seagrass, and more!

- COMPONENTS
  - Magnitude (typically concentration based, but can be load based)
  - Duration (usually over a month or seasonal period)
  - Frequency (e.g. shall not exceed, 1-in-3, or 10% exceedance rate)

Estuary	Total Phosphorus	Total Nitrogen	Chlorophyll a
(a) Clearwater Harbor/St. Joseph Sound	Annual geometric mean values not to be exceeded more than once in a three year period. Nutrient and nutrient response values do not apply to tidally influenced areas that fluctuate between predominantly marine and predominantly fresh waters during typical climatic and hydrologic conditions.		
1. St.Joseph Sound	0.05 mg/L	0.66 mg/L	3.1 µg/L
2. Clearwater North	0.05 mg/L	0.61 mg/L	5.4 µg/L
3. Clearwater South	0.06 mg/L	0.58 mg/L	7.6 µg/L
(b) Tampa Bay	Annual totals for nutrients and annual arithmetic means for chlorophyll a, not to be exceeded more than once in a three year period. Nutrient and nutrient response values do not apply to tidally influenced areas that fluctuate between predominantly marine and predominantly fresh waters during typical climatic and hydrologic conditions.		
1. Old Tampa Bay	0.23 tons/million cubic meters of water	1.08 tons/million cubic meters of water	9.3 µg/L
2. Hillsborough Bay	1.28 tons/million cubic meters of water	1.62 tons/million cubic meters of water	15.0 µg/L
3. Middle Tampa Bay	0.24 tons/million cubic meters of water	1.24 tons/million cubic meters of water	8.5 µg/L

Criteria Components:

Magnitude

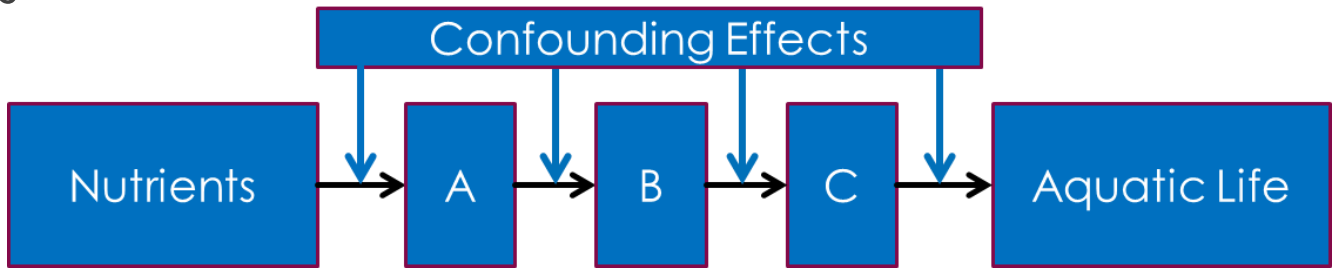
Duration

Frequency

*all concentration and loadings are magnitude, only highlighted one of each for example.

Alternative Criteria Formats

- Combined Criterion
- Biological confirmation or multi-metric component WQC take into account confounding effects



- Formats other than concentration
  - Loadings for TP/TN (It has been done! However, assessment can be more difficult.)
  - Equations

Combined Criterion vs. Independent Application

All criteria have traditionally been applied independently.

- Waterbodies are subject to multiple nutrient criteria.
- Exceeding any one water quality standard means that a waterbody must be listed as “impaired.”

	Nutrients ≤	**Nutrients >**
Chlorophyll-a ≤	Not impaired	Impaired
Chlorophyll-a >	Impaired	Impaired

What is a "Combined Criterion"?

- Combines multiple nutrient-related thresholds into a single assessment decision (e.g., total nitrogen/phosphorus, chlorophyll-a), which attempts to eliminate false positives (Type I error).
  - Exceedance of a suite of causes and responses might be more reliably associated with a high risk of losing a designated use.

SIMPLE MATRIX APPROACH

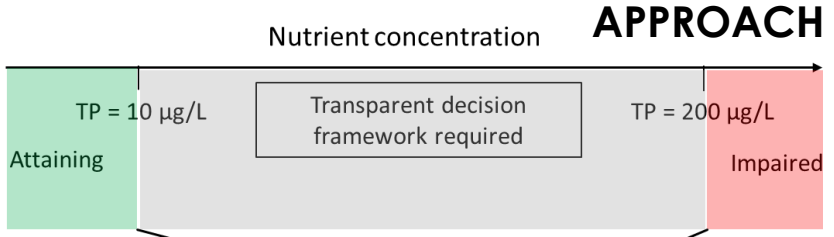
Considers a water "impaired" if causal AND any response parameter are exceeded.

	Nutrients ≤	Nutrients >
All response ≤	Not impaired	Not impaired*
Any response >	Impaired (cause not determined)	Impaired

*Site might be candidate for site-specific criteria.

RANGE APPROACH

If causal parameters are within range, response parameters are required to assess attainment.



	Nutrients < lower range	Nutrients in range	Nutrients > upper range
All response ≤	Not impaired for nutrients	Not impaired for nutrients	Impaired for nutrients
Any response >	Not impaired for nutrients*	Impaired for nutrients	Impaired for nutrients

*Site impaired for biological response condition, cause unknown.

Florida's Combined Criterion in Reg

- For streams, … The narrative nutrient criterion in paragraph 62-302.530(47)(b), F.A.C., shall be interpreted as being achieved in a stream segment where information on chlorophyll *a* levels, algal mats or blooms, nuisance macrophyte growth, and changes in algal species composition indicates there are no imbalances in flora or fauna, **and either**:

  1. the average score of at least two …SCIs … is 40 or higher, with neither of the two most recent SCI scores less than 35,

  or

  2. the nutrient thresholds …are achieved.

Florida's Combined Criterion: Floral Measures

Nuisance macrophyte growth

C of C score of <2.5 and
Frequency of occurrence of FLEPCC exotics is >25% of the total plant occurrences

Presence of algal mats

RPS rank 4-6 percent coverage >25%

Changes in algal species composition

Where thickness rank of 4-6 is 20% or greater, the biologist collects a composite sample of the dominant groups of periphyton in the stream segment for lab identification of the dominant algal taxa. If autecological information is available for the dominant taxa, this is also qualitatively evaluated.

Algal blooms and Chlorophyll a levels

A narrative statement related to "unacceptable phytoplankton bloom" and can consider autecological information for the dominant bloom species, in conjunction with the associated chlorophyll a and the persistence of the bloom, as a line of evidence when assessing imbalances of flora.

Annual geometric mean chlorophyll concentrations > 3.2 µg/L

Florida's Combined Criterion: Assessment Matrix

	Attains Nutrient Thresholds for Both TN and TP (3 Years of Data)			Nutrient Threshold Attainment Inconclusive for Either TN or TP (< 3 Years of Data)			At Least One Nutrient Threshold Not Attained (3 Years of Data)		
	SCI Attains (2 Samples)	**SCI Inconclusive (<2 Samples)**	**SCI Not Attained (1 or 2 Samples)**	**SCI Attains**	**SCI Inconclusive**	**SCI Not Attained**	**SCI Attains**	**SCI Inconclusive**	**SCI Not Attained**
Attains Floral Measures (2 Sampling Events)	Attains .531(2)(c) Cat. 2	Attains .531(2)(c) Cat. 2	Attains .531(2)(c) Cat. 2	Attains .531(2)(c) Cat. 2	Cannot Conclude .531(2)(c) Assessment Cat. 3b	Cannot Conclude .531(2)(c) Assessment Cat. 3b	Attains .531(2)(c) Cat. 2	Cannot Conclude .531(2)(c) Assessment Cat. 4d (Study & 303(d) List)	.531(2)(c) Not Attained Cat. 5 (Verified & 303(d) List)
Floral Measures Inconclusive (<2 Sampling Events)	Cannot Conclude .531(2)(c) Assessment Cat. 3b or 3c(Planning List)	Cannot Conclude .531(2)(c) Assessment Cat. 3b or 3c(Planning List)	Cannot Conclude .531(2)(c) Assessment Cat. 3b or 3c(Planning List)	Cannot Conclude .531(2)(c) Assessment Cat. 3b or 3c(Planning List)	Cannot Conclude .531(2)(c) Assessment Cat. 3b or 3c(Planning List)	Cannot Conclude .531(2)(c) Assessment Cat. 4d (Study & 303(d) List)	Cannot Conclude- .531(2)(c) Assessment Cat. 4d (Study & 303(d) List)	Cannot Conclude .531(2)(c) Assessment Cat. 4d (Study & 303(d) List)	.531(2)(c) Not Attained Cat. 5 (Verified & 303(d) List)
Any One Floral Measure Not Attained (2 Sampling Events)	.531(2)(c) Not Attained Cat. 5 (Verified & 303(d) List)	.531(2)(c) Not Attained Cat. 5 (Verified & 303(d) List)	.531(2)(c) Not Attained Cat 5 (Verified & 303(d) List)	.531(2)(c) Not Attained Cat. 5 (Verified & 303(d) List)	.531(2)(c) Not Attained Cat/ 5 (Verified & 303(d) List)	.531(2)(c) Not Attained Cat. 5 (Verified & 303(d) List)	.531(2)(c) Not Attained Cat. 5 (Verified & 303(d) List)	.531(2)(c) Not Attained Cat. 5 (Verified & 303(d) List)	.531(2)(c) Not Attained Cat. 5 (Verified & 303(d) List)

Combined Criterion: Guiding Principles

September 2013 – the "Guiding Principles" were released to provide a framework for states currently pursuing or considering a combined approach for developing and implementing numeric nutrient criteria that:

- Protect the designated use
  - Exceedance of criteria triggers action before adverse conditions that will require restoration
- Protect downstream waters
  - Ensures attainment and maintenance of water quality standards downstream
- Include numeric nutrient targets
  - Facilitates permitting and total maximum daily loads
- Are scientifically defensible

Lessons Learned

- Combined criteria provide states with flexibility within the context of quantifiable variability.
  - Combining causal and response variables requires knowing both well and having numeric thresholds for both.
  - Focus on a set of sensitive responses (e.g., algal assemblage, primary productivity).
  - Criteria must protect applicable uses.
- Focus on clear decision frameworks that are transparent and reproducible.

EPA's Estuarine and Coastal Marine Waters Guidance Manual

(EPA-822-B-01-003)

Outline of Recommended Process for Estuarine Criteria Development

THE E&C MANUAL EMPHASIZES THE IMPORTANCE OF REFERENCE CONDITIONS TO ADDRESS NUTRIENT PROBLEMS IN A TIMELY MANNER. THEY SERVE AS A USEFUL INITIAL MEASURE FOR IDENTIFYING NUTRIENT LOADS THAT COULD CAUSE IMPAIRMENTS. STATISTICAL AND COMPUTER-BASED MODELING CAN IMPROVE SITE SPECIFIC ESTIMATES OF THE LOAD AND RESPONSE RELATIONSHIPS.

Pages 6-3&4

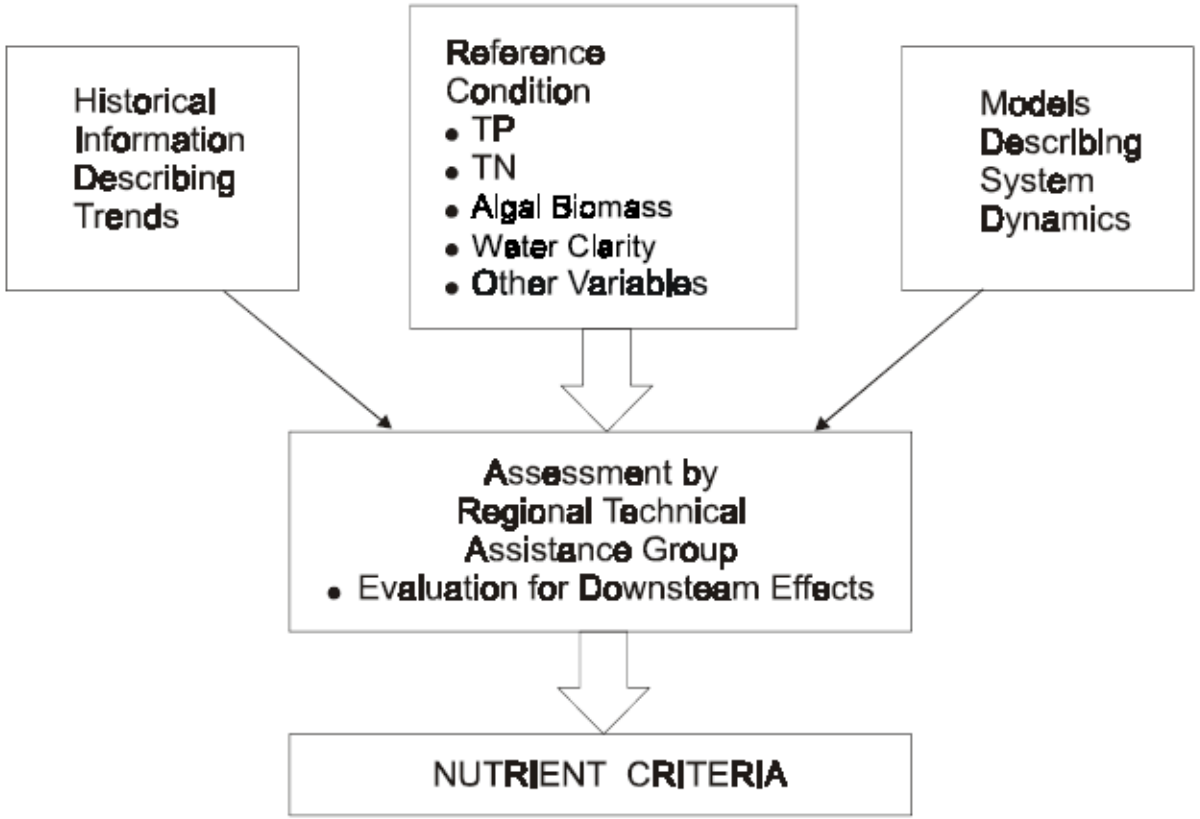


Figure 1-4. Elements of nutrient criteria development and their relationships in the process.

Chapter 6 – Determining the Reference Condition

"FISHABLE/SWIMMABLE USES" IS A TERM COMMONLY USED TO DESCRIBE THE INTERIM GOAL OF THE CLEAN WATER ACT

THE GRADIENT SHOWN IN THE GRAPHIC IS INTENDED TO HIGHLIGHT THAT NUTRIENT CRITERIA NEED NOT ONLY REPRESENT REFERENCE CONDITIONS, WHICH ARE INHERENTLY PROTECTIVE

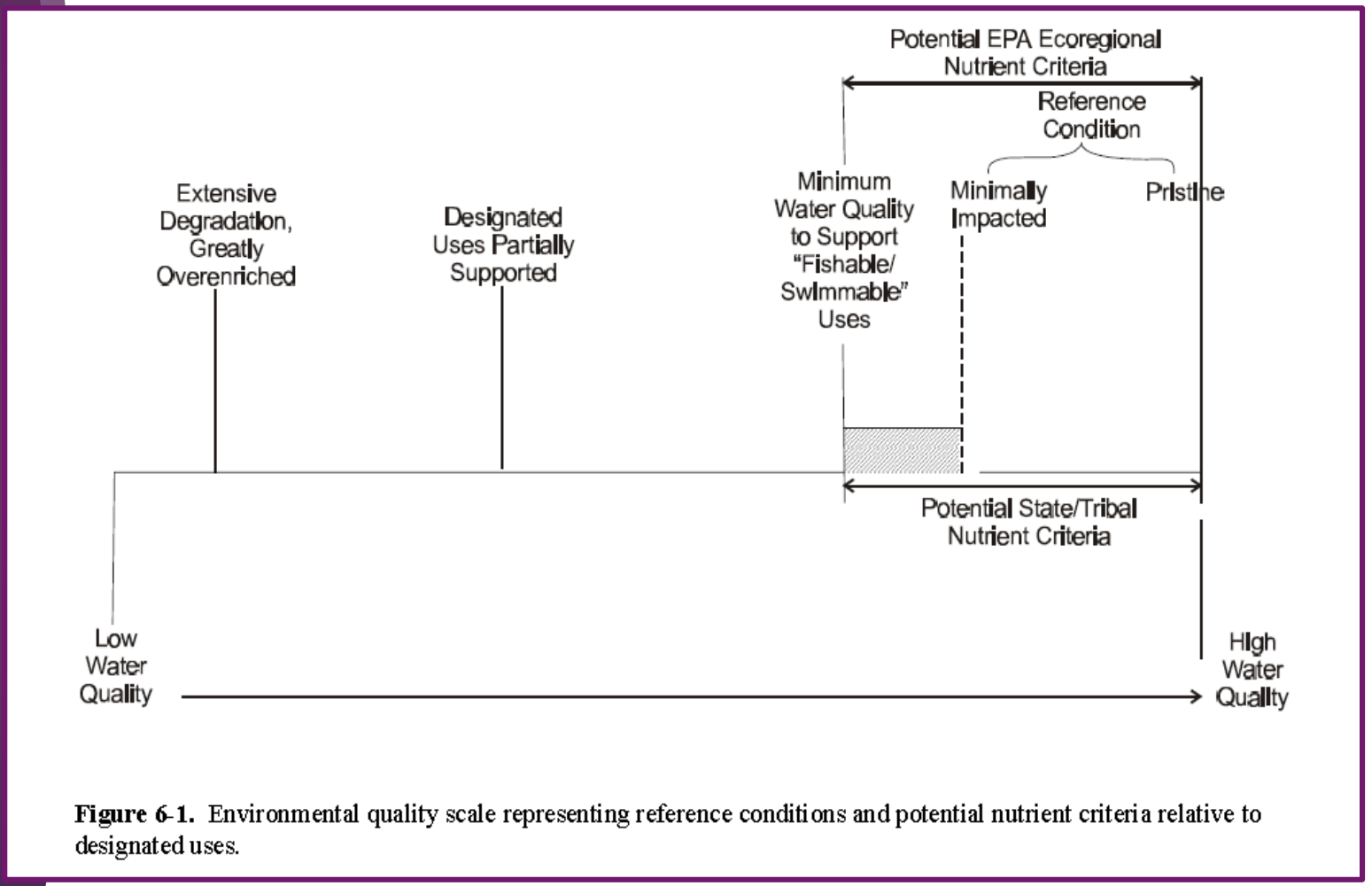


Figure 6-1. Environmental quality scale representing reference conditions and potential nutrient criteria relative to designated uses.

Chapter 6 – Determining the Reference Condition

DATA CAN EITHER BE SUMMARIZED AS MEDIANS OF THE INDICATOR ENDPOINTS OR FREQUENCY DISTRIBUTIONS

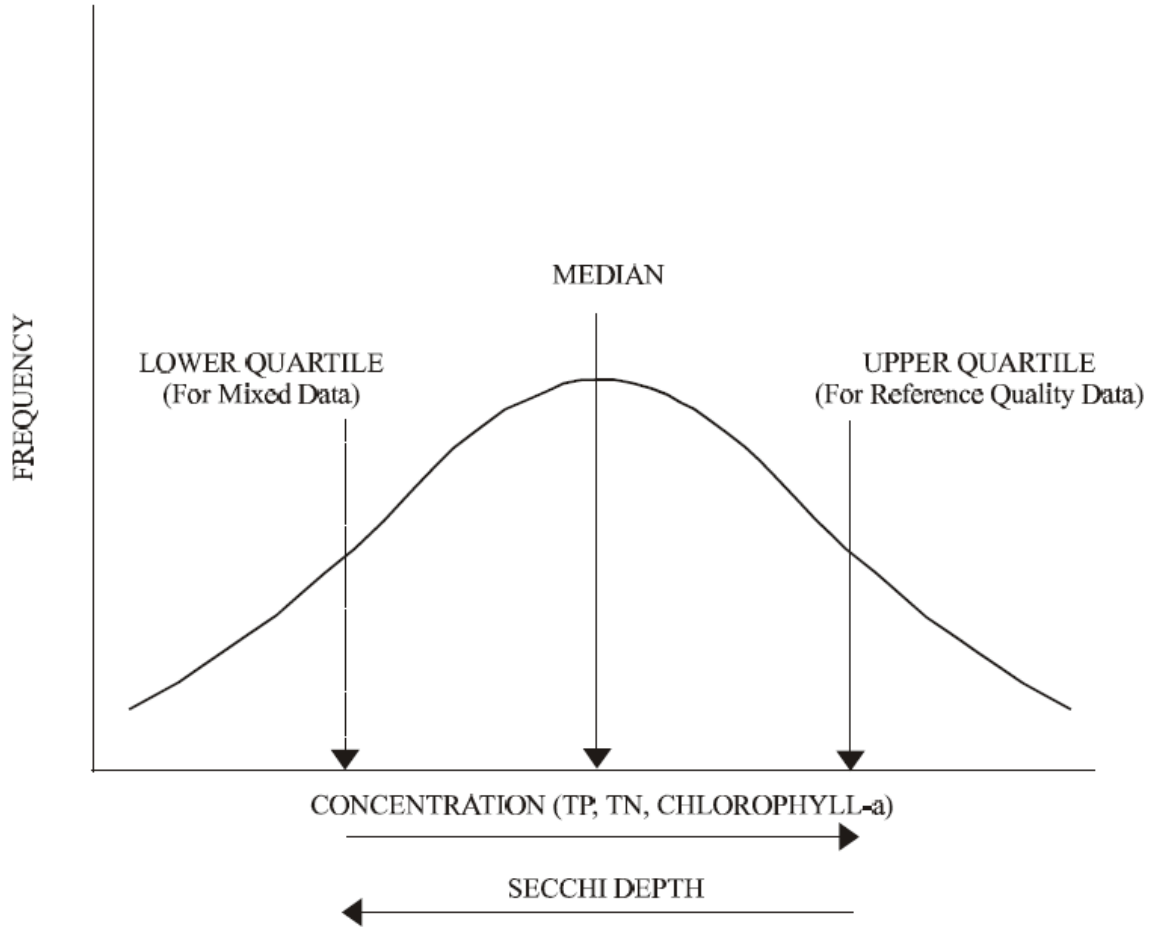


Figure 6-2. Hypothetical frequency distribution of nutrient-related variables showing quantities for reference or high-quality data and mixed data (all data incuded).

Chapter 7 – Nutrient and Algal Criteria Development

- **Guidance for Interpreting and Applying Criteria**

A critical step in the criteria development process is to assess how realistically criteria can be implemented into standards that are accepted by the public. **It should be realized that today's designated uses are not those that would be applicable in many estuaries at the turn of the century or in some cases even several decades ago.** Many estuaries have lost important fisheries that may not be easily recovered if at all. For example, sturgeon are rare in many estuaries today when they were abundant decades ago in several east coast estuaries. It is doubtful that the nutrient relationship for sturgeon growth and survival is adequately known except for obvious factors such as hypoxia. **The RTAG should make some judgements about designated uses as exemplified by the sturgeon example that significantly improves nutrient-based degraded water quality in terms of "fishable and swimmable" but maintains an important degree of realism.**

Chapter 7 – Nutrient and Algal Criteria Development

- **Do the Criteria Protect Designated Uses?**

Section 303(c) of the CWA as amended (Public Law 92-500 [1972], 33 U.S.C. 1251, et seq.) requires all States and authorized Tribes to establish designated uses for their waters. **EPA's interpretation of the CWA requires that wherever attainable, standards should provide for protection and propagation of fish, shellfish, and wildlife and provide for recreation in and on the water (section 101(a)).** Note: this is the secondary goal of the Act; the primary goal being the protection and restoration of the physical, chemical, and biological integrity of the Nation's waters, and zero discharge of pollution. Other uses identified in the Act include industrial, agricultural, and public water supply. However, no waters may be designated to be used as repositories for pollutants (see 40 CFR 131.10(a)). **Each waterbody must have criteria that protect and maintain the designated use of that water.**

Pages 7-10 to 7-11 of the E&C Manual provides some narrative qualitative descriptors of aspects to be protected by various uses.

Chapter 7 – Nutrient and Algal Criteria Development

- ***Example from page 7-10:***

Fisheries

Developing criteria to protect a specific fishery may be somewhat difficult because in open estuarine and coastal waters fish species shift with seasonal migrations and salinity changes. However, basic response variables such as available DO and turbidity can be incorporated to protect all seasonal fish and crustacean communities and resident molluscan populations. Consultation with fisheries managers, the recreational public, and commercial fishermen should help resolve any issues of targeted species management through nutrient abatement. Although our knowledge of the dynamics of change in the biota as a function of eutrophication requires further development, there is sufficient evidence to conclude that eutrophication will bring species changes. If an area has an existing aquatic life use, then that use must be maintained. (See 40 CFR §131.12(a) (1).) Eutrophication will cause some species to change in relative abundance and cause others to disappear; therefore, nutrient enrichment may be incompatible with the maintenance of a specific biota. The ultimate extension of this concept is in the use classification of outstanding natural resource waters.

How would the SAC members define the needs (aka the designated uses) which should be protected in Albemarle Sound?

Chapter 9 – Use of Models in Nutrient Criteria Development

- This chapter addresses both empirical and mathematical models. More text is devoted to mathematical models, because "they are capable of addressing many more details of underlying processes when properly calibrated and validated."
- There is a lot of information on models in this chapter!

- EPA also produced the document, "Using Stressor-Response Relationships to Derive Numeric Nutrient Criteria (EPA-820-S-10-001)," in November 2010, based on the updated information learned during the prior decade working with states on nutrient criteria.

Specific Examples of Existing Work in Region 4

SABET Project → An Approach to Develop NNC for GA and SC Estuaries

A TASK FORCE REPORT TO THE EPA, GA EPD, AND SC DHEC

SABET → GASCET

- SABET effort was renamed GASCET (GA/SC Estuary Taskforce). EPA Region 4 convened GASCET to adapt the previously applied approaches in Florida and Chesapeake Bay to create a unique framework appropriate for the ecology of the Georgia and South Carolina coast.
- The effort identified candidate criteria development approaches 1) Reference conditions, (2) stressor-response relationships (regression models), and (3) water quality simulation modeling; and evaluated their potential applicability to coastal waters in the two states. The data will be analyzed to determine if there is a biological response in estuarine waters to nutrient concentrations, and aid in nutrient criteria development.
- https://epd.georgia.gov/sites/epd.georgia.gov/files/related_files/site_page/TSD%20NNC%20SABET%2002-17-16.pdf

Summary of GA/SC Estuaries

- Georgia and South Carolina's estuaries are characterized by their high turbidity, widely varying residence times associated with high tidal amplitudes, lack of seagrasses, high ratios of tidal wetland to estuary surface area, and relatively low coastal anthropogenic land use.
- They generally can be classified into:
  - Piedmont riverine systems (headwaters above the fall line, with large inflow),
  - Blackwater systems (headwaters in the coastal plain with significant terrestrial contributions of organic matter), and
  - Coastal embayments (ocean-dominated systems with only freshwater contributions from land stormwater runoff and subterranean (e.g., shallow water aquifer) sources).
- Conceptual models of estuarine eutrophication established for other U.S. estuaries are often based upon hypoxia below the pycnocline, production dominated by phytoplankton, and seagrass endpoints – none of which apply well to Georgia and South Carolina's estuaries, which tend to be well-mixed, mediated by heterotrophs, and have light-limited phytoplankton production.

From the Report

The conceptual model presented here for Georgia and South Carolina's estuaries describes pathways by which nitrogen and phosphorus can affect ecosystem structure (chlorophyll *a*, benthic index of biotic integrity) and function (dissolved oxygen and ecosystem primary production rates). These effects are diagrammed in **Figure 2-5**, representing pools as boxes and fluxes as arrows.

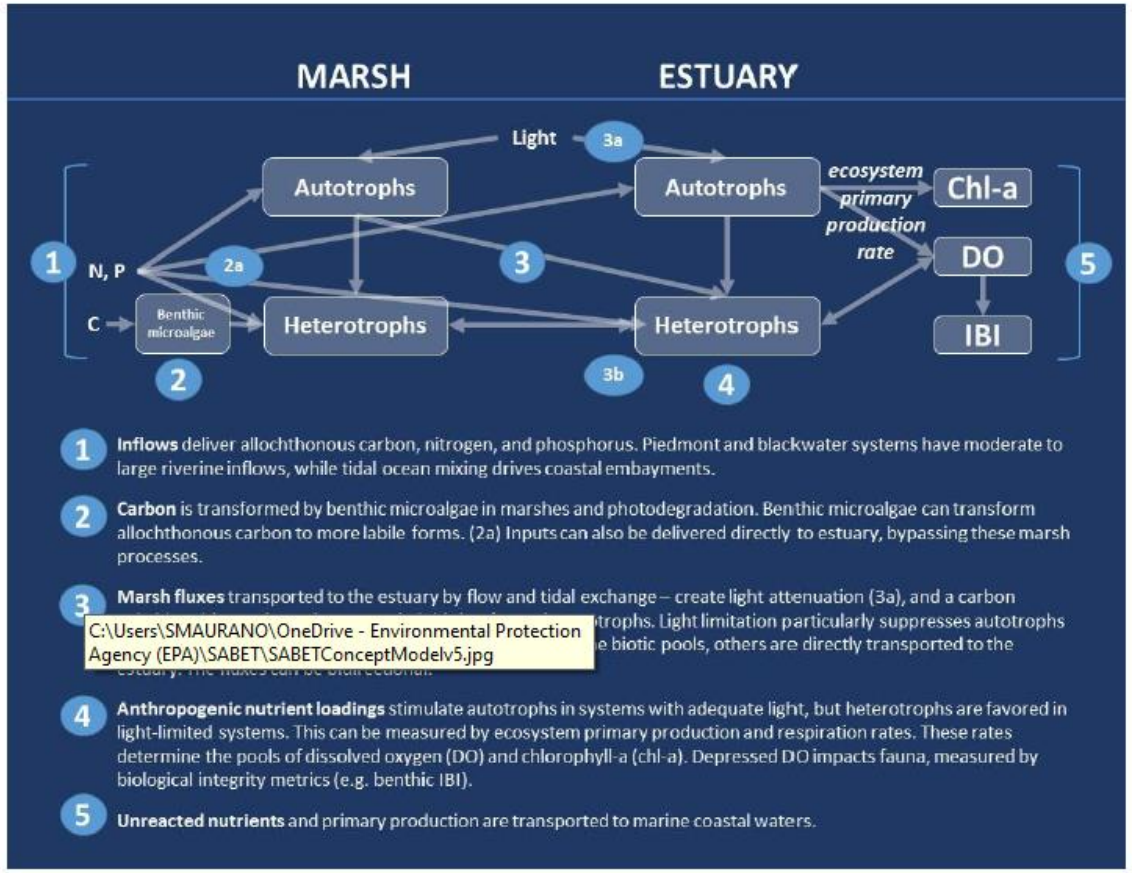


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Figure 2-5. Conceptual model for effects of nitrogen and phosphorus on Georgia and South Carolina's estuaries.

From the Report

Other endpoints included: invertebrates, fish, clarity, DO, Chla, TP, and TN

There are numerous endpoints that can, at a minimum, be qualitatively related to nutrients (e.g., Bricker et al. 2008). For example, endpoints selected by the State of Florida included phytoplankton, macroalgae, epiphytes, seagrass, benthic macroinvertebrate and fish indices, HABs, and coral (US EPA 2010). For Georgia and South Carolina, seagrass and coral endpoints are not applicable, and therefore not considered. Thus, the major measurement endpoints considered for Georgia and South Carolina, and linkage to, or effects of, nutrients are summarized in **Table 2-2**.

Table 2-2. Measurement endpoints for evaluating the magnitude and effects of nutrients, including advantages and disadvantages.

	Importance	Linkage to, or Effects of, Nutrients	Advantages	Disadvantages
Phytoplankton	• Primary producers and important component of marine food web • Excess growth affects clarity, DO, habitat, aesthetics, and overall food web productivity.	• Nutrients are key limiting factors for algal growth rates and assemblage composition.	• Responsive to nutrients, well-established basis for use as indicator • Biomass data in estuarine waters are routinely monitored and data are generally abundant	• Other factors can interfere with evaluating stressor-response relationships • Differences in field sample and taxonomic methods may increase uncertainty • Field-collected biomass data in coastal (offshore) waters are limited • Most estuaries lack species composition models developed for nutrient response, but data for incorporation in to models are emerging.
Harmful Algal Blooms	• Often associated with toxins leading to faunal kills, shellfish contamination, economic effects, decline in aesthetic value, environmental and ecological damage.	• HAB species may be less studied.	• Foul odor and reduced aesthetics can lead to public awareness.	• Data exist in the SC coastal zone for HABs

From the Report

Discussion of strengths and weaknesses of each criteria development approach

Table 3-1. Strengths, weaknesses, indications (situations where approach is most applicable), and contraindications (situations where another approach may be needed) for each of the three categories of criteria development described.

	Strengths & Weaknesses	Most Applicable When	Least Applicable When
Reference Condition Approaches	*Strengths* • Simple, direct and understandable; provides information to quantify criteria. *Weaknesses* • Need quantitative data to characterize the reference condition that reflects support of the designated use.	• Substantial water quality data are available and the estuary is minimally impacted by nitrogen and phosphorus sources. • Substantial water quality data are available from a historical period when the estuary was minimally impacted by nutrients. • The estuary is very similar to another estuary to which one of the above conditions applies	• The estuary is impacted by nitrogen and phosphorus sources and is likely impaired by nutrients. • Little or no data are available from a historical period when the estuary was not minimally impacted by nutrients. • The estuary is considered relatively unique.
Stressor-Response Relationships (Regression Models)	*Strengths* • Easy to understand and visualize; uncertainty may be quantified, provides linkage between criteria and aquatic life uses, can quantify relationships between different criteria values. *Weaknesses* • Regressions can be affected by covariates; may not address additive or interacting effects of more than one causal factor.	• Extensive data are available, spanning multiple years and spanning a range of nutrient loading rates and water quality response. • Simple regression relationships exist and quantify relationships between nutrient loading and/or nutrient concentrations and water quality responses. • Response is consistent across many estuaries.	• Little or no data are available • Complex relationships between nutrients and water quality responses involve multiple interacting causes, including physical- biological coupling. • Key ecological processes and interactions are different or unique compared to other estuaries.
Water Quality Simulation Models	*Strengths* • Can provide detailed simulation results for many variables, addressing magnitude, frequency and duration; addresses physical-biological coupling. *Weaknesses* • May not address important ecological processes; many unknown model parameters including boundary conditions; may not be valid for unobserved conditions.	• Important ecosystem processes are well-understood • Available data are from process studies or other isolated studies, rather than consistent monitoring over multiple years. • Interactions are complex, involve physical-biological interactions, or are spatially structured. • Relatively little site-specific data are available.	• Mechanisms governing interaction among nutrient sources, water quality, and biological responses are not well understood. • Critical inputs to model are completely unknown (e.g., large open boundaries) • Linkages between possible model outputs and use attainment are not well-defined. • Adequate data are not available as model input.

Florida's Estuarine NNC

Florida – Marine Criteria

- Florida's criteria include chlorophyll *a* criteria for coastal waters and TP, TN, and chlorophyll *a* criteria for estuarine waters. Note: Loading values not shown in this summary.
  - TP: Ranges from 0.019 to 0.86 mg/L
  - TN: Ranges from 0.24 to 1.29 mg/L
  - Chl *a*: Ranges from 1.1 to 15 µg/L
  - Generally annual geometric means, although duration/frequency/format more variable than other waterbody types
- Estuarine Waters Methodology:
  - Healthy Conditions (based on location and/or time period) using Distribution Approach
- WQBEL and TMDL Methodologies:
  - Site specific work adopted as WQS, typically adopted as loading values

Case Study: Reference Period Approach in Estuaries

- Coastal lagoon estuary
- Minimally disturbed condition
  - No 303(d) listings for nutrients or dissolved oxygen
- Long-term data set available
  - Spatial and temporal representativeness

Case Study: Reference Period Approach in Estuaries (continued)

- All data available from 1974–2009 were reviewed
  - Nutrient assessment endpoints were evaluated **[seagrass, DO concentration, and chl a concentration]**
  - Used data from years when no nutrient-related impairments were identified

Case Study: Reference Period Approach in Estuaries (continued)

- Where at least 8 years of data were available, the state selected the upper 80 percent prediction limit of the spatially averaged annual geometric means as a criteria magnitude annual geometric mean, with a frequency and duration of not more than one year exceeding the limit in a 3 yr period.
  - For datasets with less than 8 years of data, but at least 30 total samples, an alternative statistical method was used. The upper 90 percent prediction limit of the individual samples was chosen as a criterion to be expressed as a single sample value not to be exceeded in more than 10 percent of samples.
  - In two systems with significant freshwater inflows at times and wide variations in residence time, a salinity surrogate was used. Then a linear regression was calculated. TP and TN criteria developed as salinity dependent equation.
  - For segments where these approaches weren't possible, modeling was done.

Lessons Learned

- Definition of *reference condition* varies; however in all cases:
  - Reference conditions should support designated uses
  - It need not mean pristine
  - High quality data are developed through application of data quality objectives
  - Objective data screens are used to define reference and arrive at a final data set for deriving criteria
- States have concerns with applying the reference condition approach when there are not many uncompromised sites. There are solutions for regions with heavily impacted sites.
- Selecting the percentile of the reference condition data set is dependent upon the data, and the amount of uncertainty one has that it accurately reflects the reference condition.
- The reference condition approach is scientifically defensible when supported with appropriate rationales and data.

Nutrient Criteria Development Exercise