Chlorophyll-based Water Quality Criteria for Protecting Aquatic Life Designated Uses

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Eutrophication: A Long-standing Water Quality Issue (U.S. and Globally)

A wealth of scientific information linking nutrient inputs to changes in ecosystem structure and function.

But key questions remain:

- How do we set nutrient caps?
- How much N, P, CHLa is too much?
- How to link water quality targets with designated uses?

Getting Started

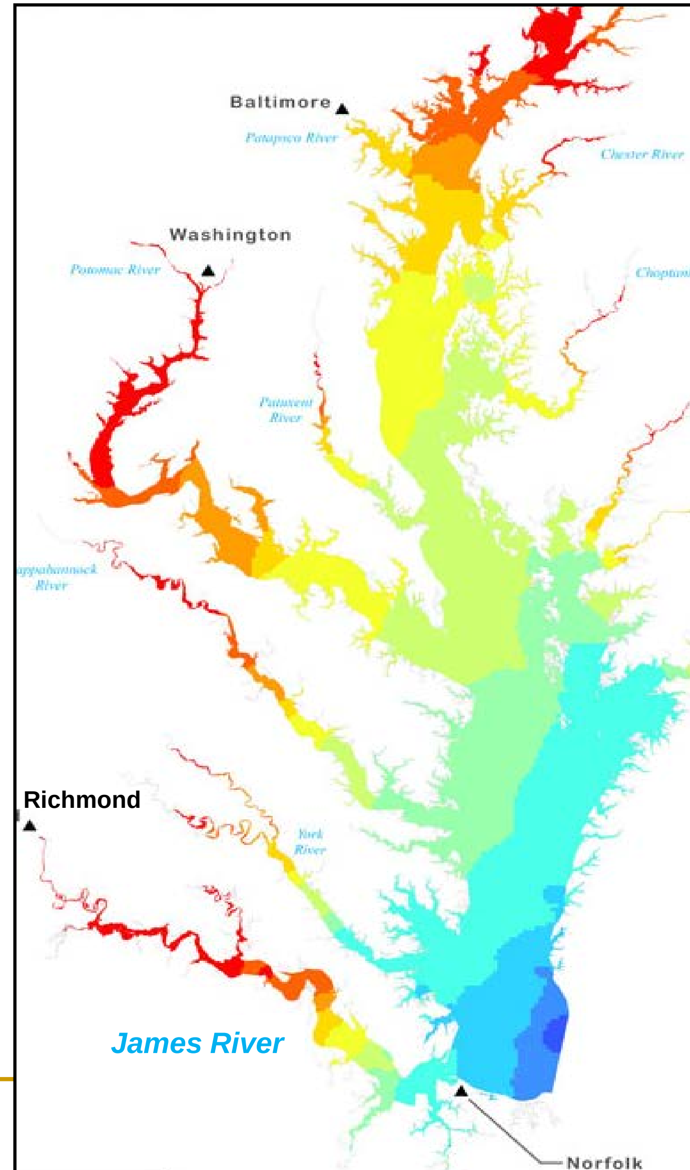
- Why CHLa criteria?
- Case Study: James River Estuary
- Approaches to developing CHLa criteria
- Data needs
- Data analysis
- Results and lessons learned

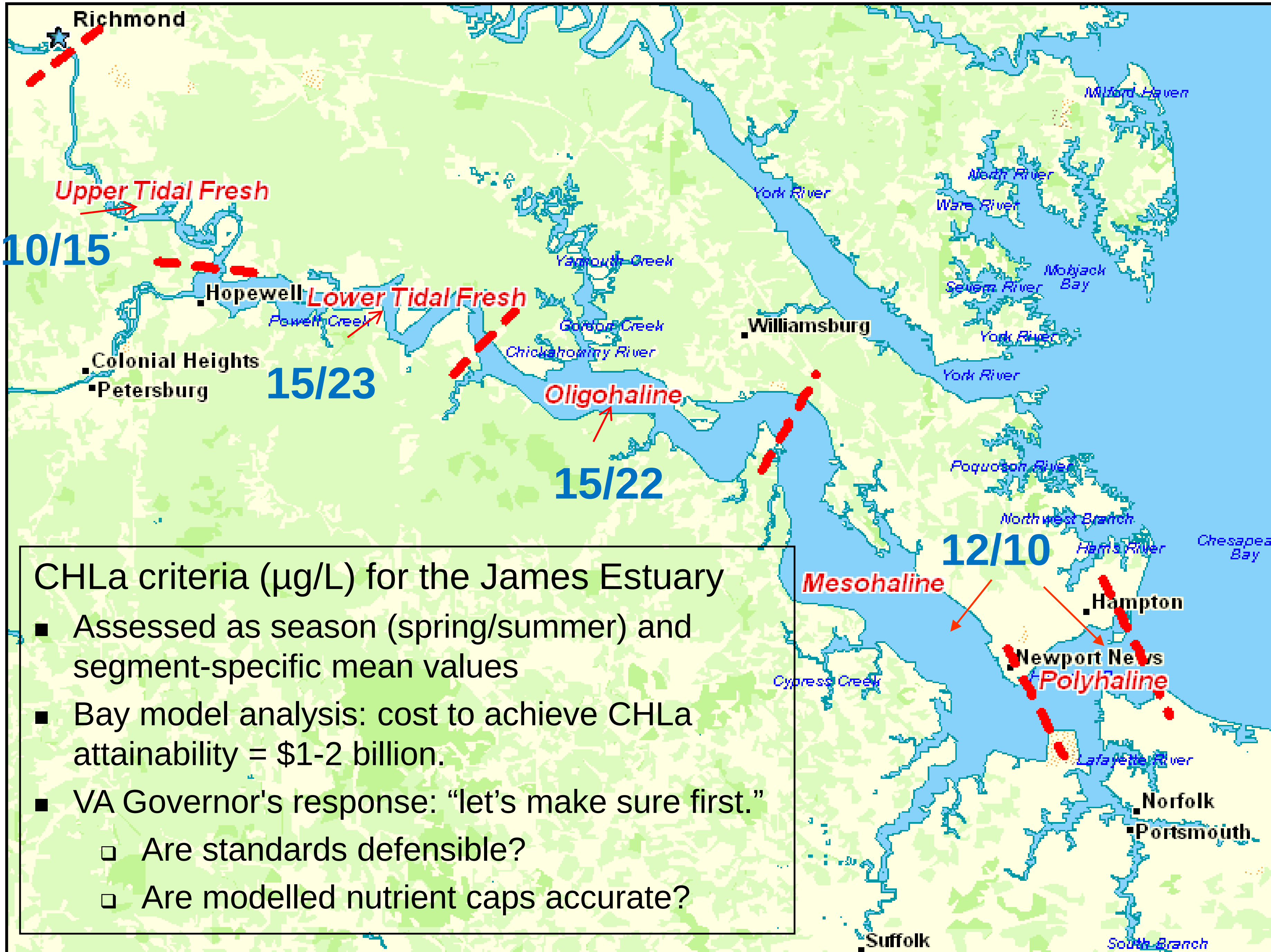
Regulatory Toolbox for Managing Eutrophication

Criteria	Strengths	Limitations
Dissolved Oxygen	Long history; extensive data linking low DO to adverse impacts on biota.	Application limited to stratified waters with chronic hypoxia (e.g., lakes, some estuaries).
Nutrients	Directly linked to loads, and to factors controlling algal abundance.	The yield of algal biomass (per unit load) is highly variable across systems, therefore nutrient effects are highly variable.
Chlorophyll	Directly related to algal biomass, and therefore to deleterious effects.	Is there a scientific basis for deriving defensible criteria (i.e., linking CHLa to water clarity, HABs, etc.)?

Case Study: James River Estuary

- James River: southern-most and 3rd largest tributary of Chesapeake Bay.
- Fluvial and tidal mixing precludes stratification and chronic hypoxia.
- Season- and segment-specific CHLa criteria established by VA DEQ in 2005.





CHLa criteria (µg/L) for the James Estuary

- Assessed as season (spring/summer) and segment-specific mean values
- Bay model analysis: cost to achieve CHLa attainability = $1-2 billion.
- VA Governor's response: “let’s make sure first.”
    - Are standards defensible?
    - Are modelled nutrient caps accurate?

James River CHLa Study

- 5-year (2013-2017), $3 million study administered by VA DEQ. Three components:
  - The Number – defining criteria values
  - The Method – how these values are applied
  - The Model – translating CHLa targets to nutrient caps
- Question: Are current numeric CHLa criteria for the tidal James scientifically defensible?
  - Specifically, will criteria be protective of aquatic life designated uses at attainment?

What constitutes ‘protective’?

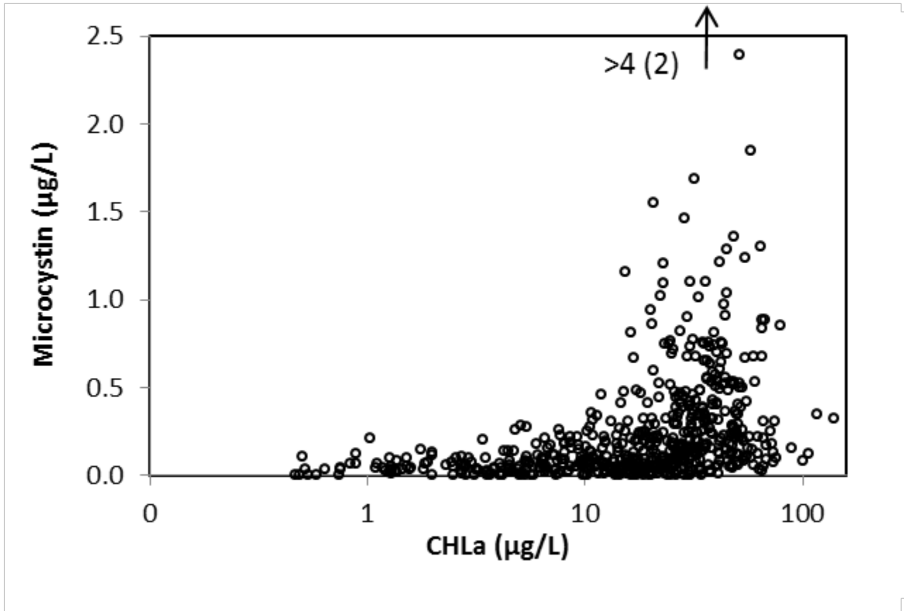
Approaches to Developing CHLa Criteria

Approach	Data Needs	Challenges
Reference	Establish target CHLa based on historical or spatial reference systems.	If historical data unavailable, can we find reference sites? Is our goal to restore all systems to reference conditions?
Anti-degradation	Establish current CHLa conditions for the system.	Are standards based on current CHLa protective (or over-protective)?
Effects-based	Establish quantitative relationships between CHLa and deleterious effects.	Deriving NOEFL for CHLa - How much CHLa is too much?

James River CHLa Study

- Science Advisory Panel: adopted an empirical, effects-based approach.
- Objective: link CHLa concentrations to deleterious effects on aquatic life using site-specific data.
- Data needs: paired observations of CHLa and various metrics that capture the range of deleterious effects associated with algal blooms.
  - Effects on water quality, water clarity, and algal communities.

Challenges to Data Analysis

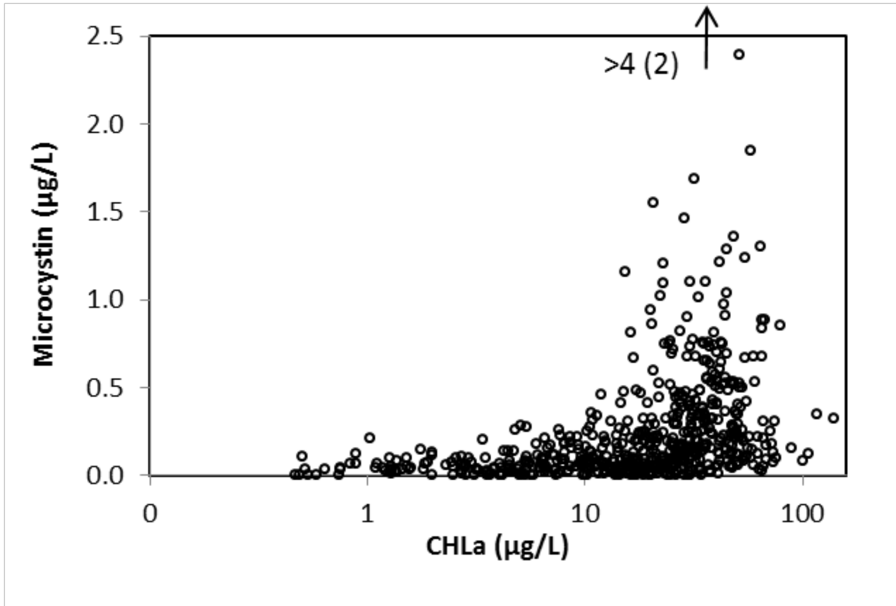


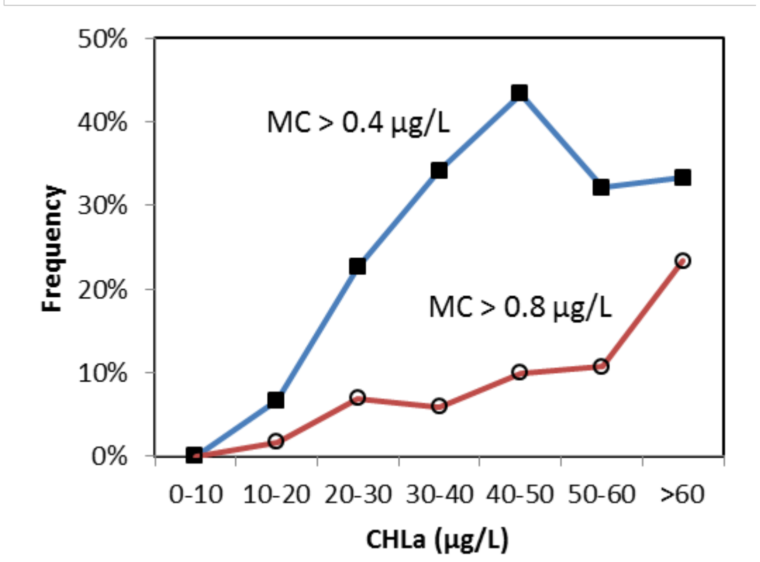
Linking CHLa with deleterious effects

Example: cyanotoxin concentrations as a function of CHLa.

The absence of elevated levels at low CHLa is informative, but at high CHLa, MC concentrations are highly variable. Models do not provide strong quantitative predictions.

Data Analysis

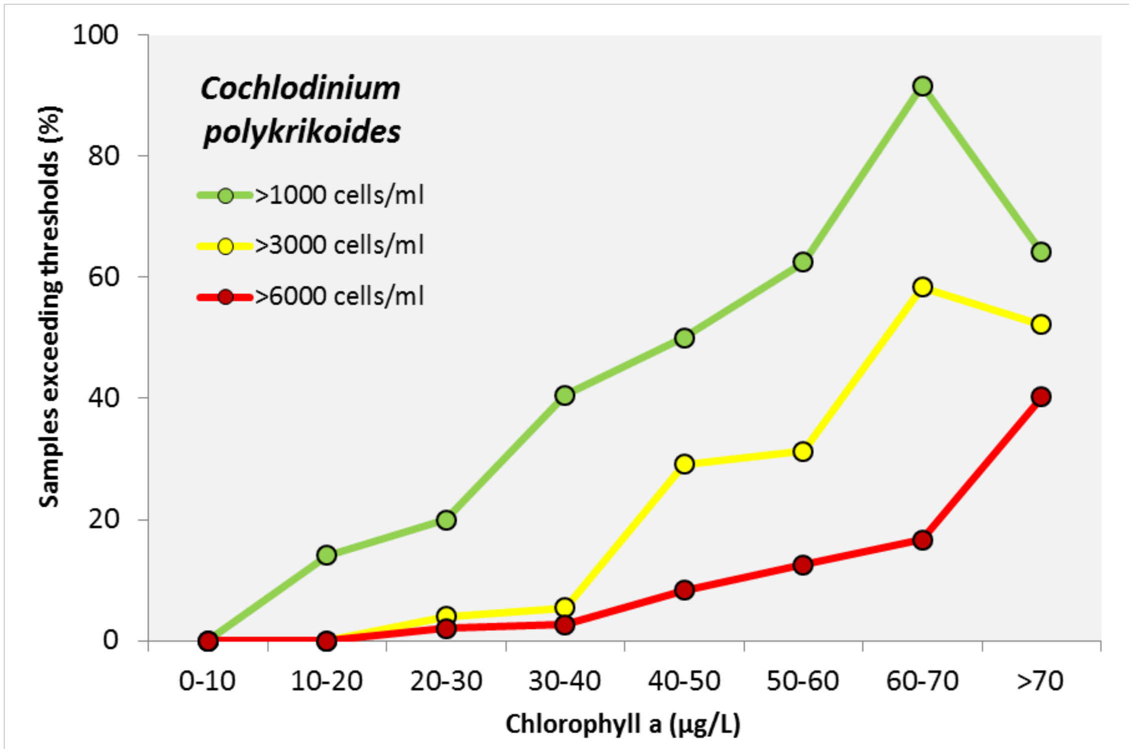




But, the probability of exceeding specified thresholds for microcystin can be modeled as a function of CHLa.

A probability-based approach was adopted to assess risk to aquatic life designated uses over a range of CHLa conditions. The shape of this function is used to forecast deleterious effects at attainment.

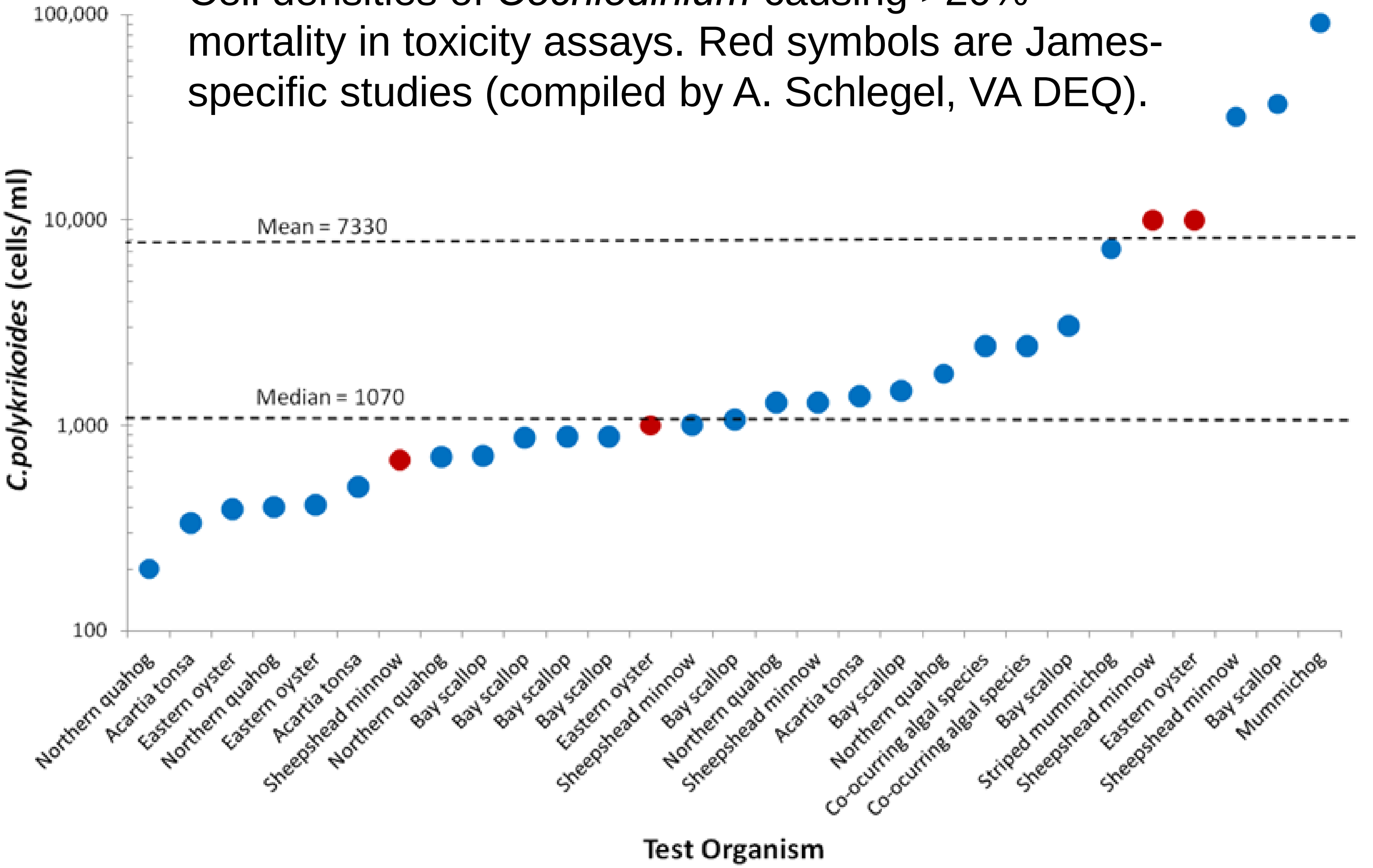
HABs: Lower James



Frequency of exceeding specified cell density thresholds of *Cochlodinium* in relation to CHLa. MH and PH data for July-September 2011-2013 from Todd Edgerton (ODU) and Will Hunley (HRSD).

Establishing Thresholds of Concern

Cell densities of *Cochlodinium* causing >20% mortality in toxicity assays. Red symbols are James-specific studies (compiled by A. Schlegel, VA DEQ).



General Approach

- Define metrics and thresholds of concern (e.g., DO < 5 mg/L; pH > 9). Identify metrics showing statistically significant relationships with CHLa.
- Calculate the probability of exceeding thresholds for observations pooled within CHLa ranges (e.g., 0-10, 10-20 µg/L).
- Derive combined probability of exceeding threshold at a given CHLa, and probability of occurrence for that CHLa over a range of mean CHLa values.
- Assess risk of threshold exceedance over a range of mean CHLa. Where should criteria fall along this curve?

Combined Probability Approach

Risks to designated uses were quantified as a function of two probabilities:

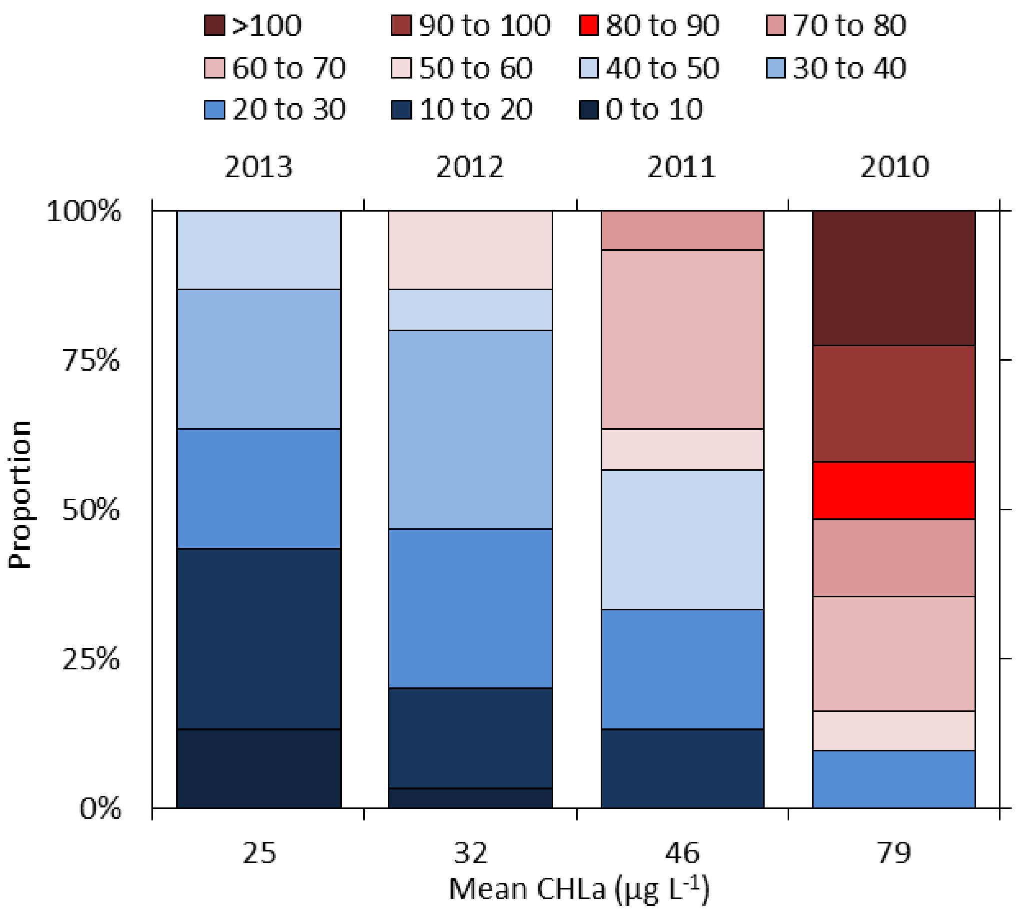
1) The probability of threshold exceedance in a given CHLa range and
2) The likelihood of occurrence of CHLa values in that range

Example

CHLa	p (DO<5)	p (CHLa)	p (combined)
0-30	1%	50%	0.5%
31-60	10%	35%	3.5%
61-90	50%	15%	7.5%

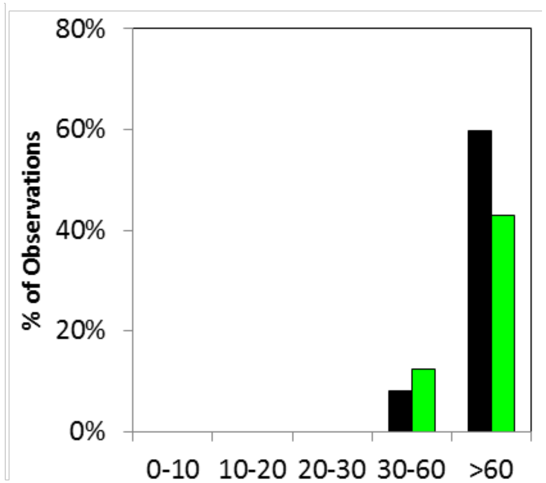
Sum = combined risk

Variation in CHLa

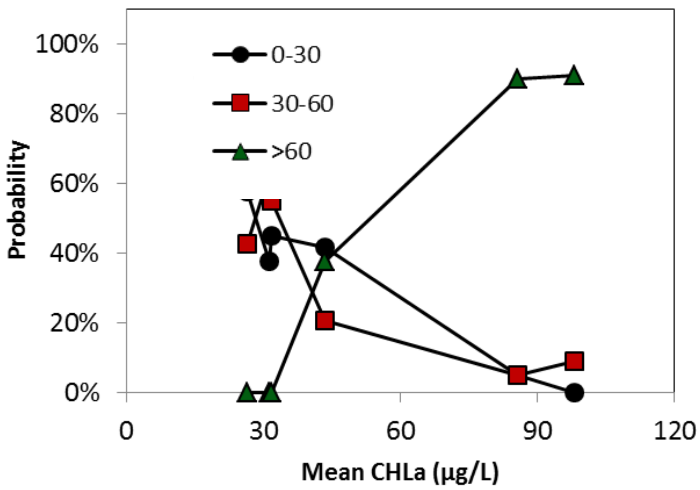


Proportional distribution of summer CHLa observations based on weekly monitoring in the tidal-fresh James.

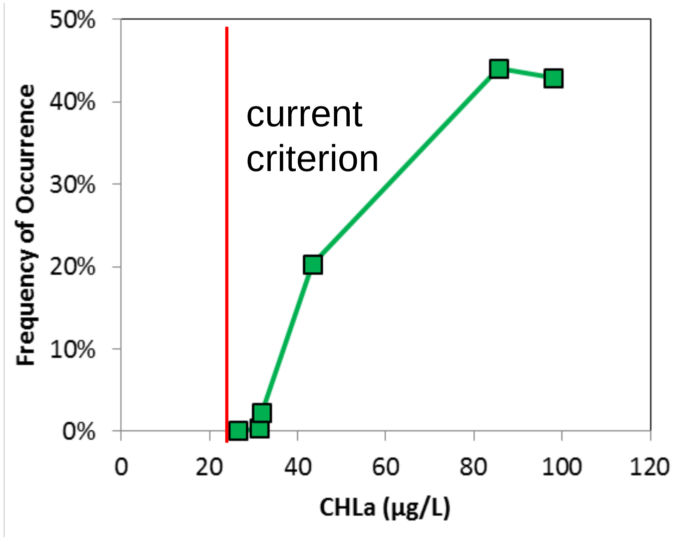
Example: Risk of Daytime pH Exceedance



A. Frequency of pH > 9 vs. CHLa



B. Frequency of CHLa > 60, etc. vs. mean CHLa



C. Combined frequency distribution: criterion is protective against daytime pH exceedance

Metrics and Data Sources

- Water quality
  - Daily minimum (10%-tile) DO < 5 mg/L
  - Daily maximum (90%-tile) pH > 9

Three years of continuous water quality monitoring data for each of the 5 salinity segments.

- Water clarity
  - Algal biomass > 10% TSS

Paired measurements of phytoplankton biomass (counts) and TSS.

- Phytoplankton
  - PIBI > 2.67 ('least degraded')

Chesapeake Bay phytoplankton Index of Biotic Integrity.

- HAB metrics
  - TF: *Microcystis* > 20k cells/mL; microcystin > 0.8 µg/L
  - OH, MH & PH: *Cochlodinium* >1,000 cells/mL

Measurements of microcystin and cell densities of *Microcystis* and *Cochlodinium*.

Metrics and Results

- Water quality
  - Daily minimum (10%-tile) DO < 5 mg/L
  - Daily maximum (90%-tile) pH > 9
- Water clarity
  - Algal biomass > 10% TSS
- Phytoplankton
  - PIBI > 2.67 (‘least degraded’)
- HAB metrics
  - TF: *Microcystis* > 20k cells/mL; microcystin > 0.8 µg/L
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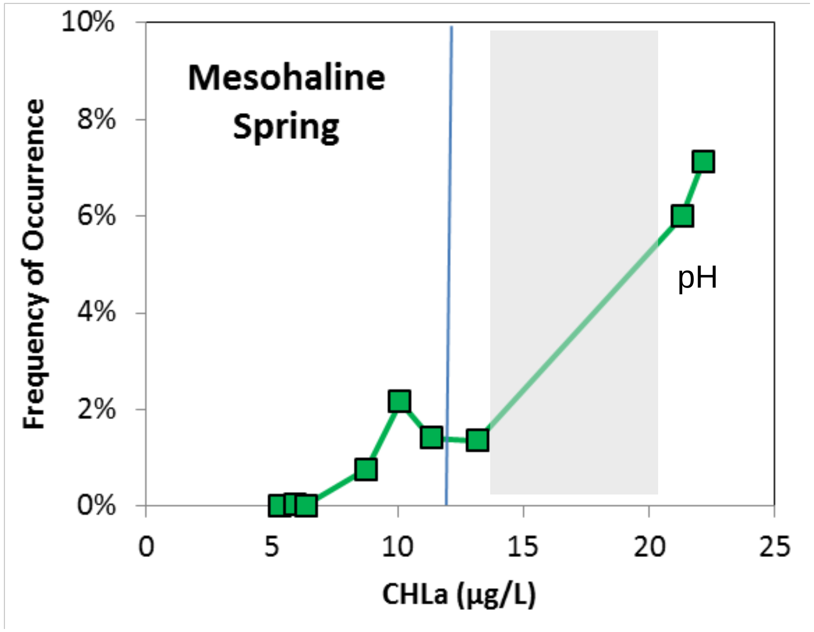
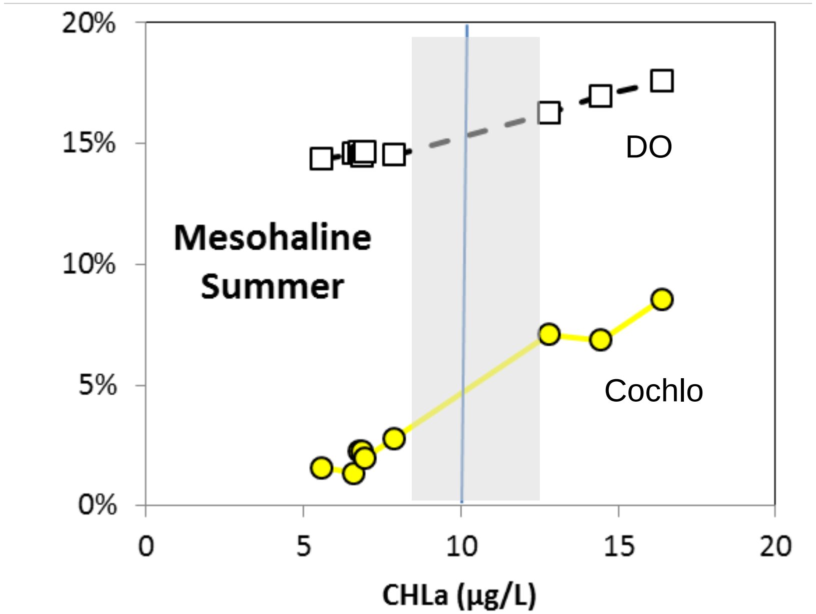
Segment	Metric	Season
TF-up	Microcystin	Summer
TF-low	pH	Spring, Summer
	Clarity	Summer
	PIBI	Spring, Summer
	Microcystin	Summer
OH	pH	Spring
	PIBI	Spring
MH	pH	Spring
	DO	Summer
	Evenness	Spring, Summer
	Cochlodinium	Summer
PH	Clarity	Spring
	Evenness	Spring, Summer
	Cochlodinium	Summer

Table 4. Indicator metrics showing relationships to CHLa by segment and season.

Example





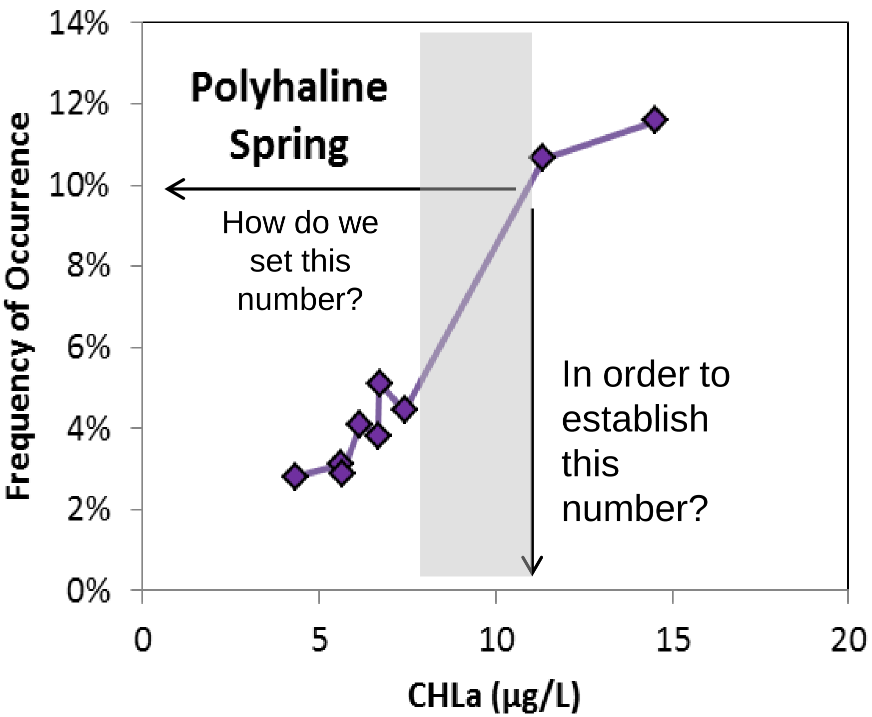
Mesohaline	Spring	Summer
Current Criteria	12	10
Metrics ($p<0.05$)	pH	DO, Cochlo
Protective Range	13-21	8-13

Assessing Protectiveness

How do we define an allowable level of threshold exceedance in order to derive a criterion from this curve?

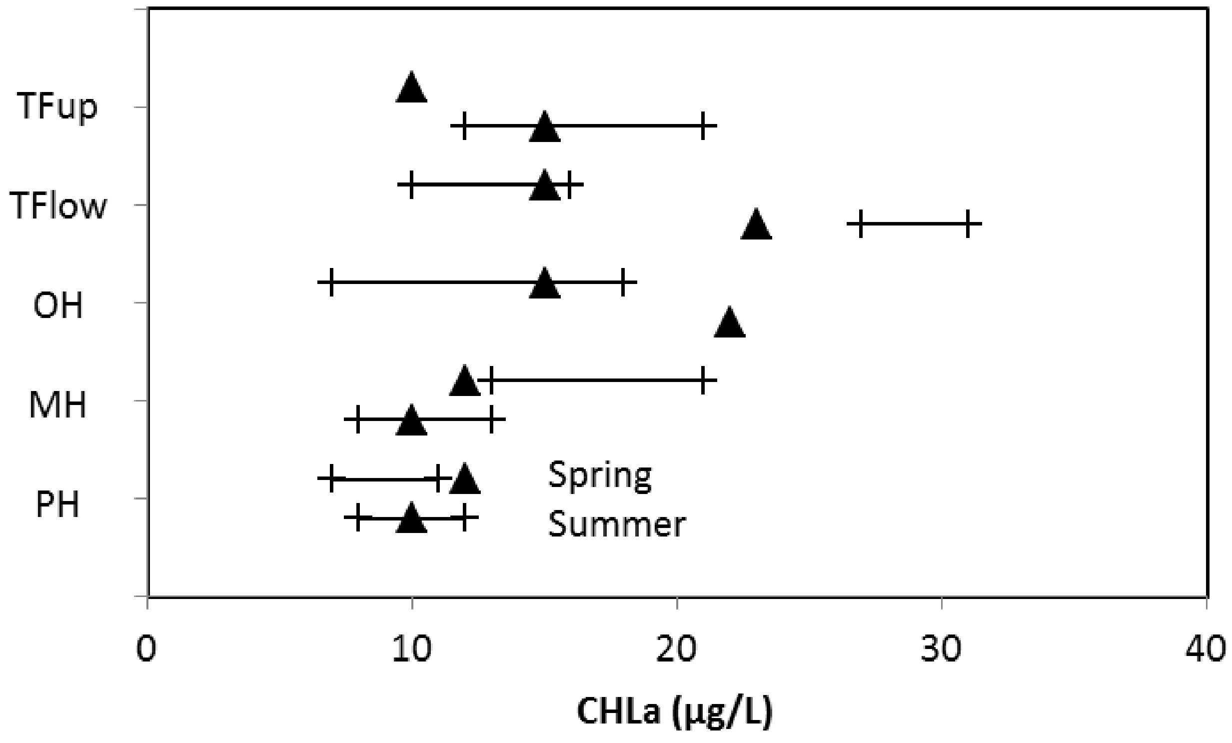
One approach is to use a fixed value for all metrics (e.g., 10%). This seems objective, or at least consistent.

However, the scientific basis for this is lacking. Can we say that a 10% exceedance of the clarity threshold is equally deleterious to a 10% exceedance of the microcystin threshold?



The gray area denotes a scientifically defensible range of potential CHLa criteria for this relationship.

Substantive Findings



Current CHLa criteria (symbols) and proposed defensible ranges (horizontal lines) by season and segment.

What Did We Accomplish?

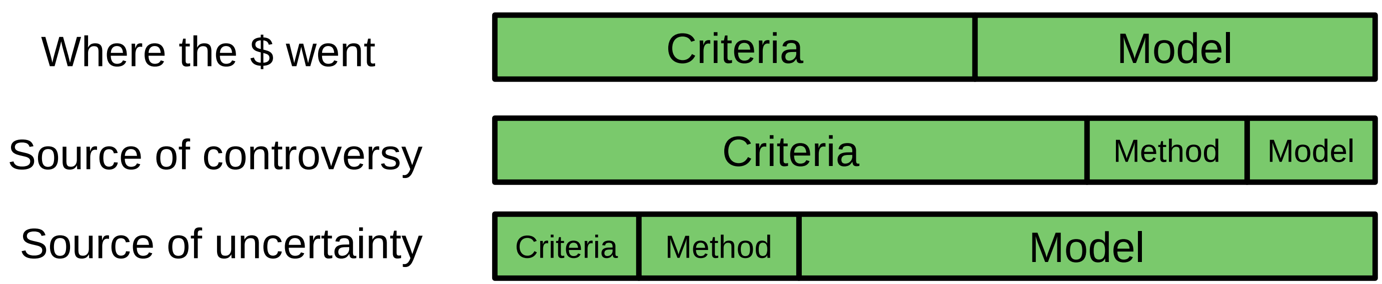
- Effects-based approach: we established empirical relationships between CHLa and deleterious effects using site-specific data.
- These relationships provided a basis for establishing CHLa criteria, either as fixed values, or as defensible ranges.
- Clear and measurable benefits: the relationships quantify the expected improvements arising from attainment (i.e., the decrease in occurrence of deleterious conditions) thereby providing a basis for communicating these benefits to stakeholders.

Challenges to Developing CHLa Criteria

- Critical need for observations during bloom events. These are rare, making it difficult to quantify effects at high end of the CHLa range.
- Data are needed for a wide range of metrics (DO, clarity, HABs, etc.). Even in eutrophic systems, few of these may have statistically significant relationships to CHLa (e.g., in our study, 18 of 50 tested). Without these, there is no basis for using CHLa to mitigate impairments.

Lessons Learned

- Stakeholders are often pre-occupied with The Number (setting criteria), but it should be recognized that how you apply this number is equally important to assessing impairment (and establishing nutrient cap).
- The model used to translate this number into a target nutrient load likely contributes a much greater level of uncertainty to this process as it depends on an assumed (forecasted) algal yield.



Transferability

- The James River CHLa criteria were derived using site-specific data, therefore it may not be appropriate to apply these criteria to other systems.
  - Example: where cyanobacteria account for a greater % of algal biomass, microcystin yield (per unit CHLa) would likely be higher, and therefore a lower criterion would be needed to assure protectiveness.
- The same approach could be used with a more generic dataset (e.g., a regional or global database of paired microcystin and CHLa measurements) to obtain generic criteria. However, this has yet to be tested.

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To obtain a copy of the report:
http://www.deq.virginia.gov/Portals/0/DEQ/Water/WaterQualityStandards/James%20River%20Chl%20A%20Study/SAP_Reports/Emp_Relationships_James_River_CHLa_Report_APR_2016.pdf?ver=2017-07-31-135641-917