Developing Numeric Chlorophyll a Criteria Through Science, Enhanced Monitoring, and a Collaborative Stakeholder Partnership

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September 24, 2025

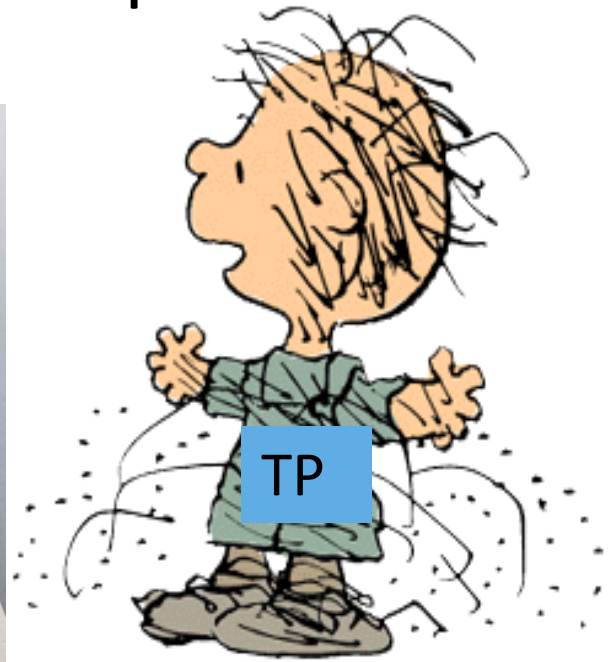
Why chlorophyll-a criteria?

Nutrients are messy!

DEQ

Nutrients are messy!

Time lags between nutrients and ecological responses



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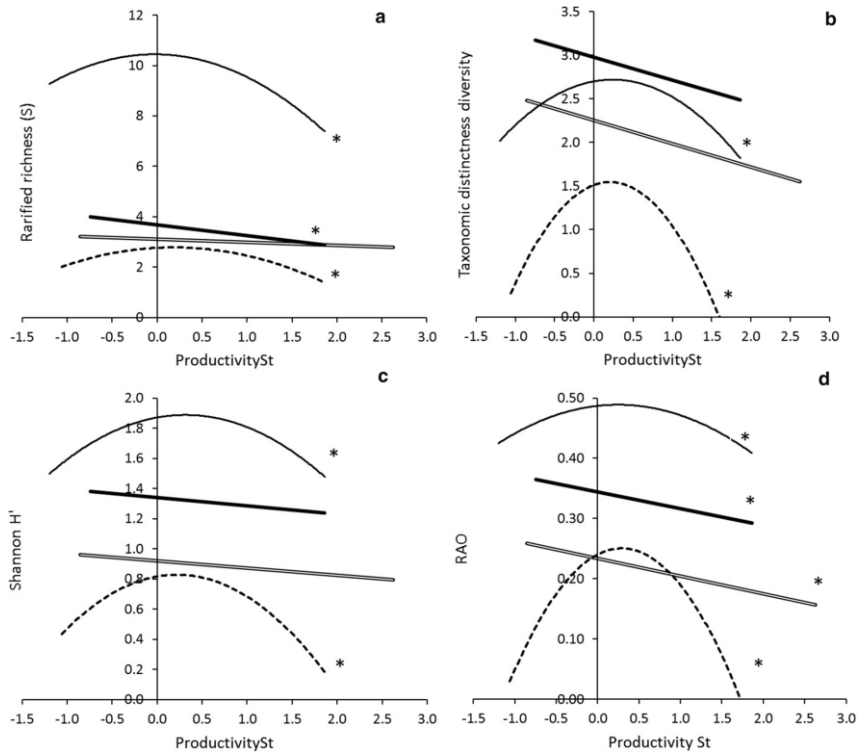
Nutrients are messy!

Nonlinearity in ecological responses to nutrients



Koperski, 2021

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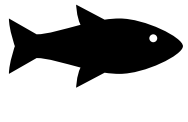
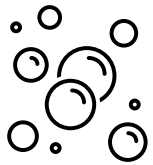
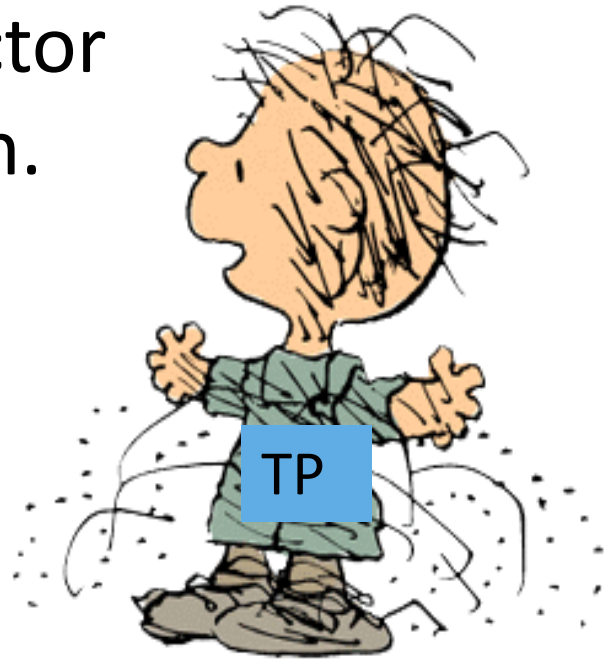
Nutrients are messy!

Nutrients aren’t the only limiting factor or predictor variable for algal growth.



H+





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Advantages of Chlorophyll Criteria

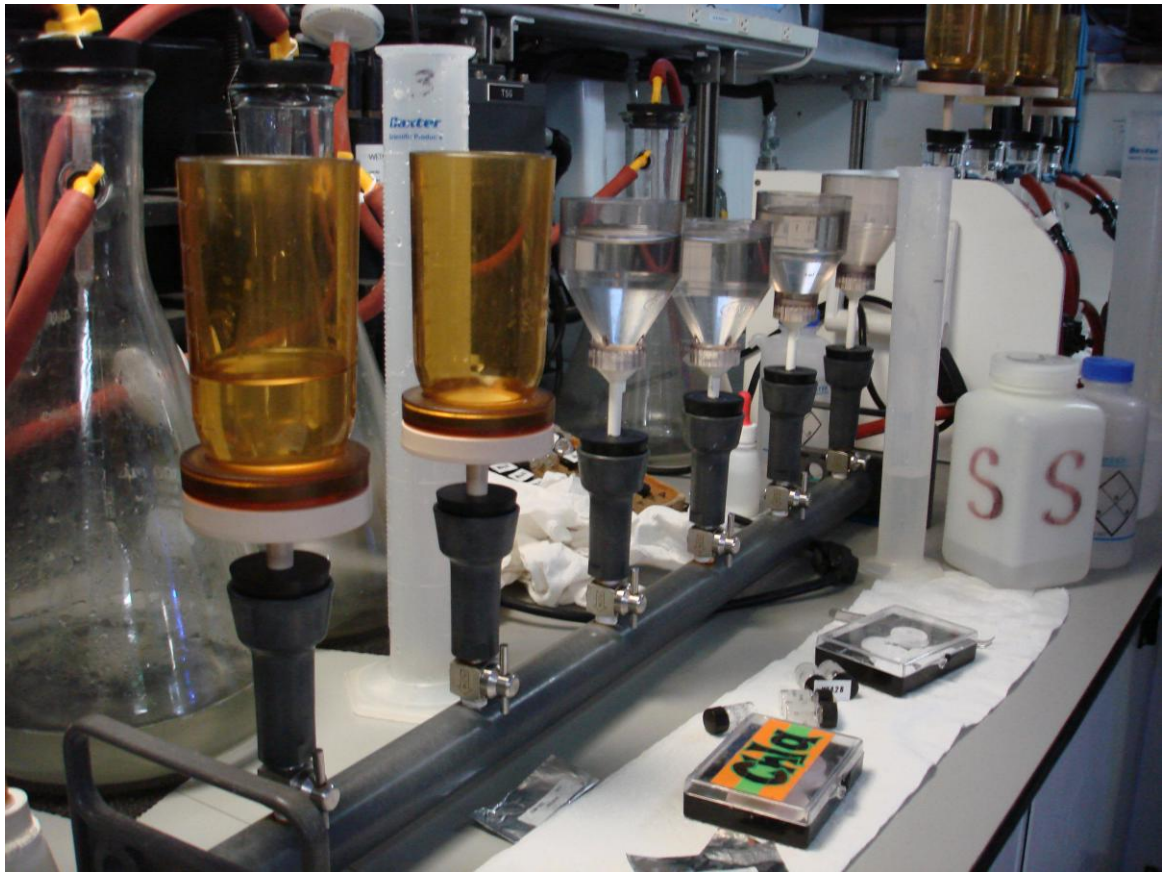
When algal blooms are occurring, chlorophyll-a concentrations are usually high too.

Advantages of Chlorophyll Criteria

Reducing the frequency and persistence of algal blooms is a great management goal because algal blooms are a visible indicator of pollution.

Advantages of Chlorophyll Criteria

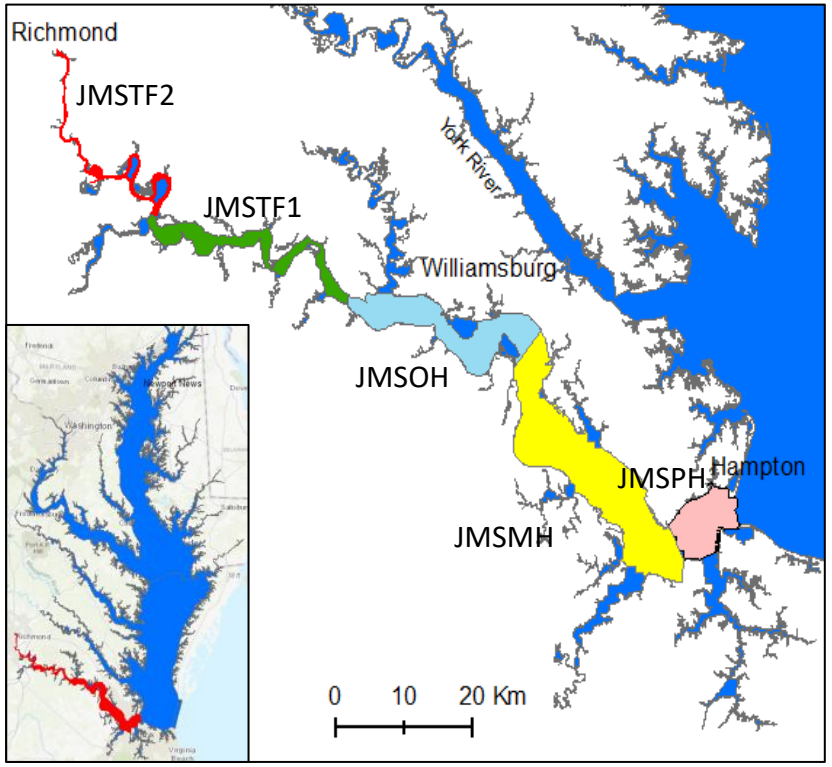
Chlorophyll concentration is a cheap, relatively easy-to-collect parameter.



James River – Virginia's Largest River

Photo credit: Vogelbein/VIMS

Photo credit: Vogelbein/VIMS



"Hey, at least the dissolved oxygen concentration isn't that bad!" - phytoplankton living in the tidal James

Original Chlorophyll-A Criteria for the Tidal James

- In 1999, EPA listed the tidal James River as impaired because of its algal blooms while the other tidal tribs in Virginia were listed as impaired due to low DO.

- DEQ worked with the EPA-Chesapeake Bay Program Office to develop the chlorophyll criteria for the tidal James.

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Stated Goal: Balanced phytoplankton community with low abundance of nuisance/unpalatable taxa

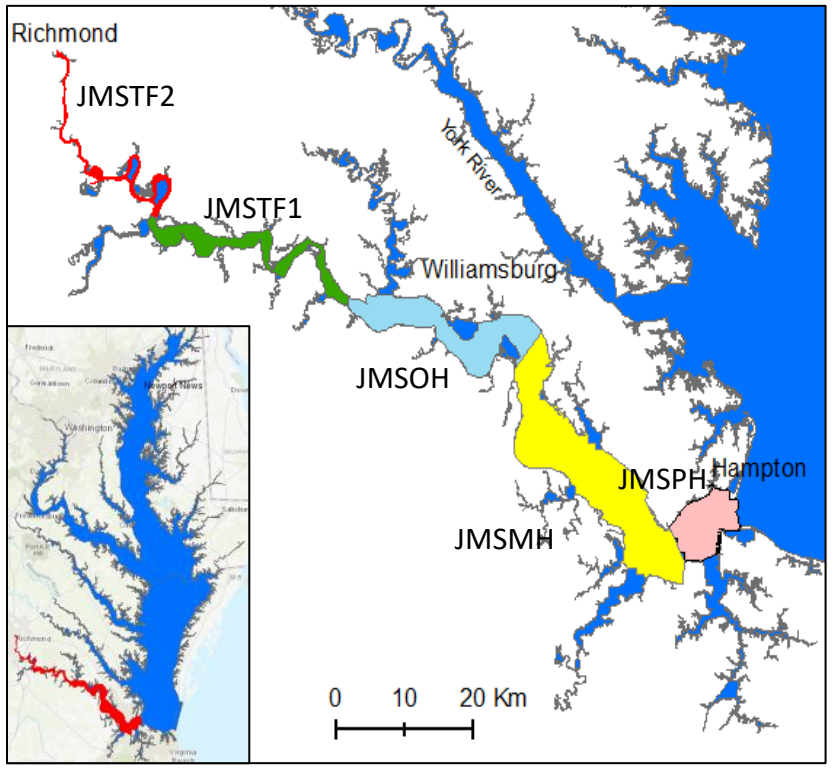
Implicit Goal: “Good fish food”

A Reference-Based Approach Was Used

Steps of the reference-based approach for chlorophyll criteria:

1. Find a waterbody that is considered to be in a “least impaired” condition. Make sure this waterbody is similar to the one you’re developing criteria for.
2. Determine the distribution of chlorophyll concentrations in this reference waterbody. Select a percentile that you think makes the most sense for your waterbody.
3. Adopt this percentile as the criterion for your waterbody and manage the nutrient concentrations around this target.

2005 Chlorophyll Criteria for the Tidal James River



bb. The following site specific numerical chlorophyll a criteria apply March 1 through May 31 and July 1 through September 30 as seasonal means to the tidal James River (excludes tributaries) segments JMSTF2, JMSTF1, JMSOH, JMSMH, JMSPH and are implemented in accordance with subsection D of 9VAC25-260-185 .

Designated Use	Chlorophyll a µ/l	Chesapeake Bay Program Segment	Temporal Application
Open water	10	JMSTF2	March 1 - May 31
	15	JMSTF1	
	15	JMSOH	
	12	JMSMH	
	12	JMSPH	
	15	JMSTF2	July 1 - September 30
	23	JMSTF1	
	22	JMSOH	
	10	JMSMH	
	10	JMSPH	

There was not much opposition to these criteria at the time of their adoption even though they were quite ground-breaking.

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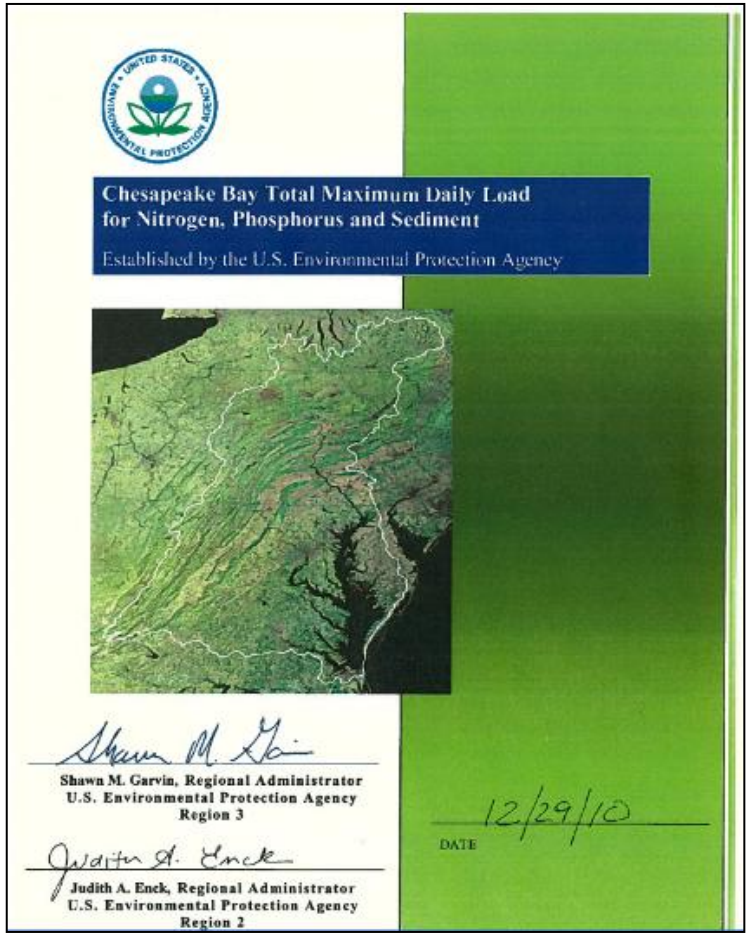

BIGGEST TMDL OF ALL TIME!!

For most of the ChesBay + tidal tribs, DO criteria were the TMDL endpoint

For the tidal James, chlorophyll criteria were the TMDL endpoint.

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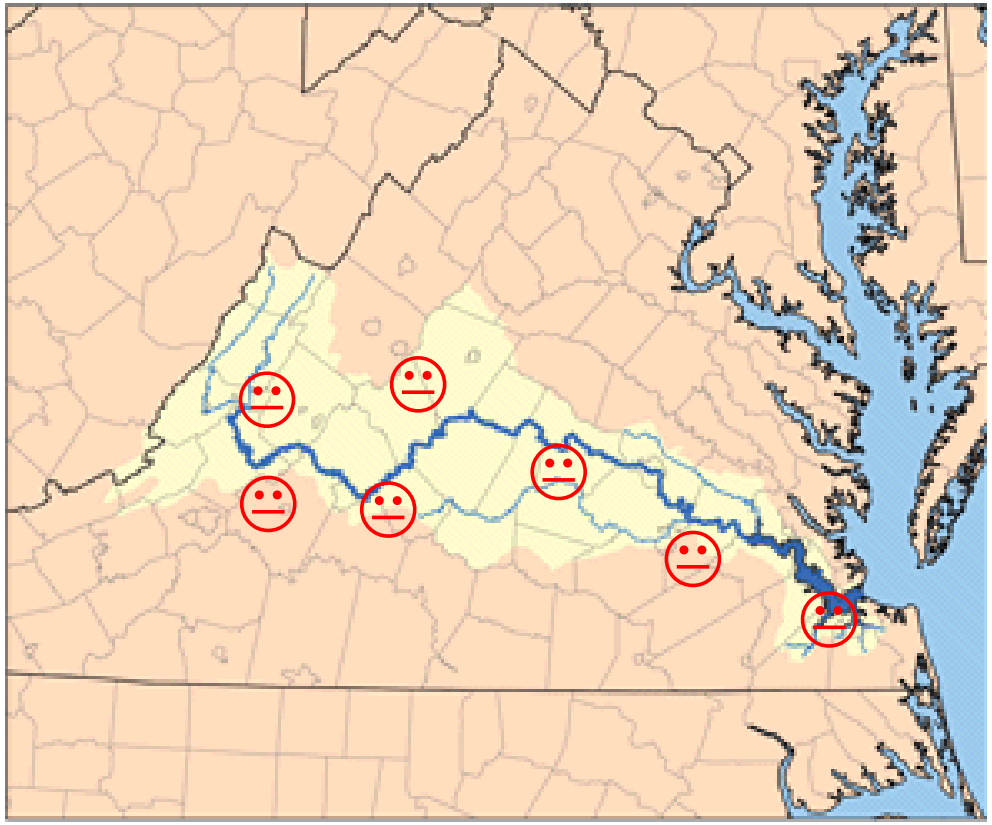
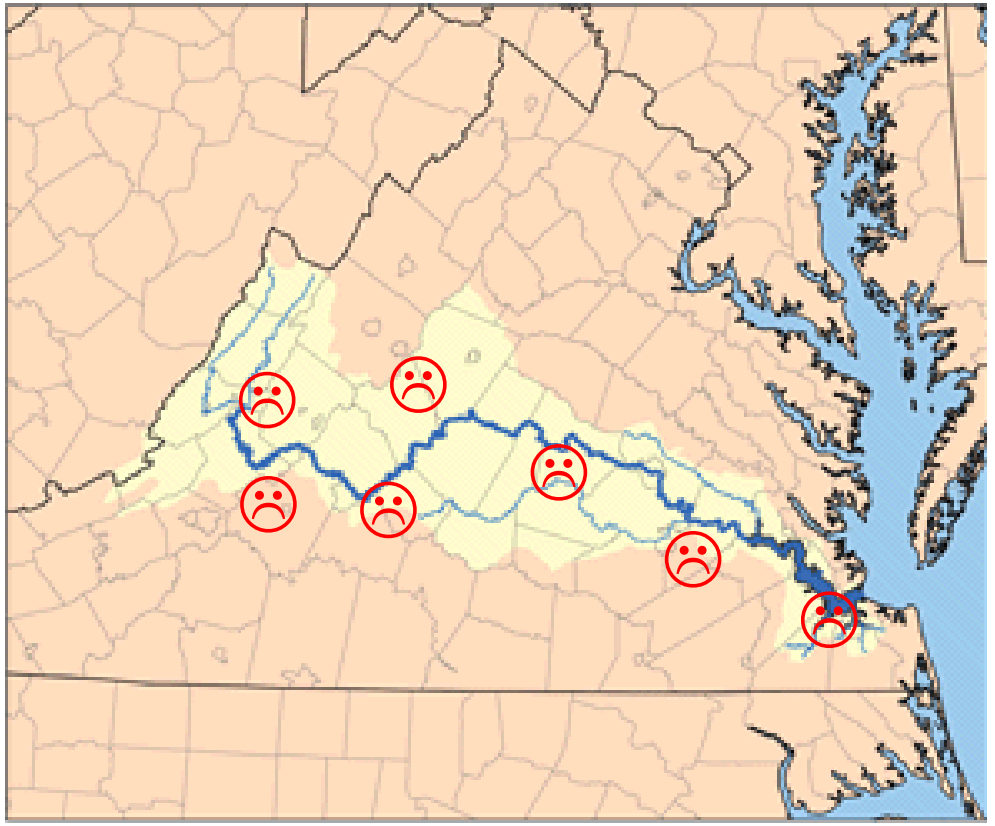
Regulated Entities in the James River Basin Before and After the Bay TMDL



Before



After

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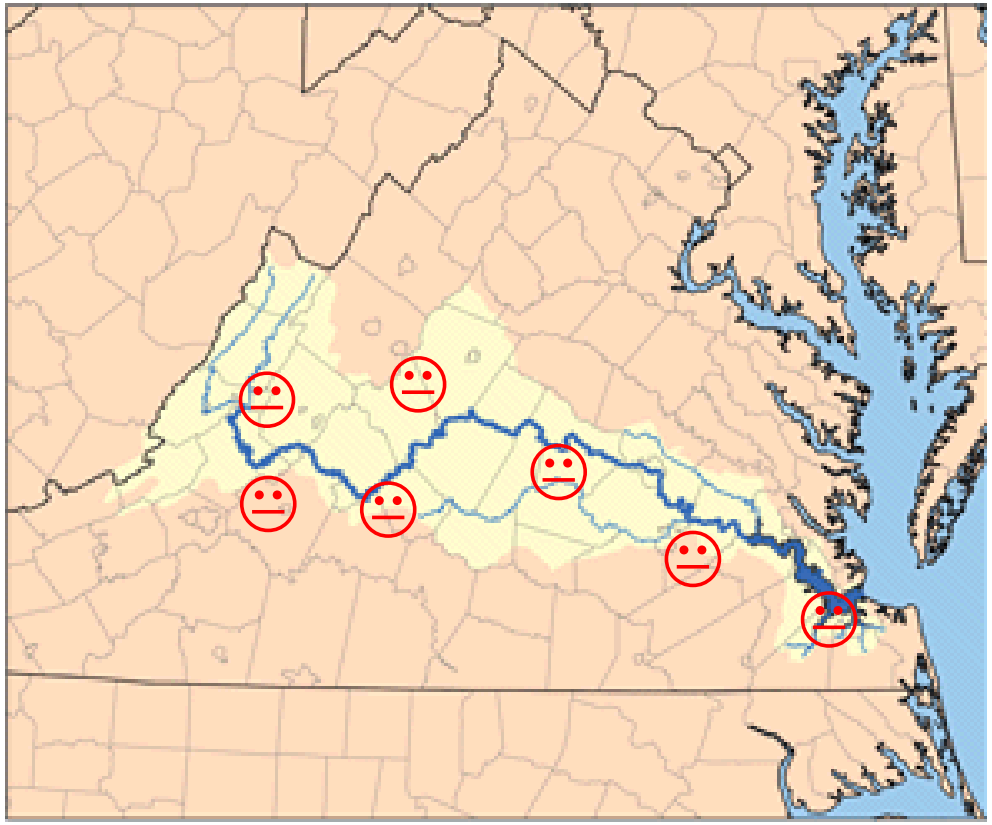
Regulated Entities in the James River Basin Before and After the Bay TMDL



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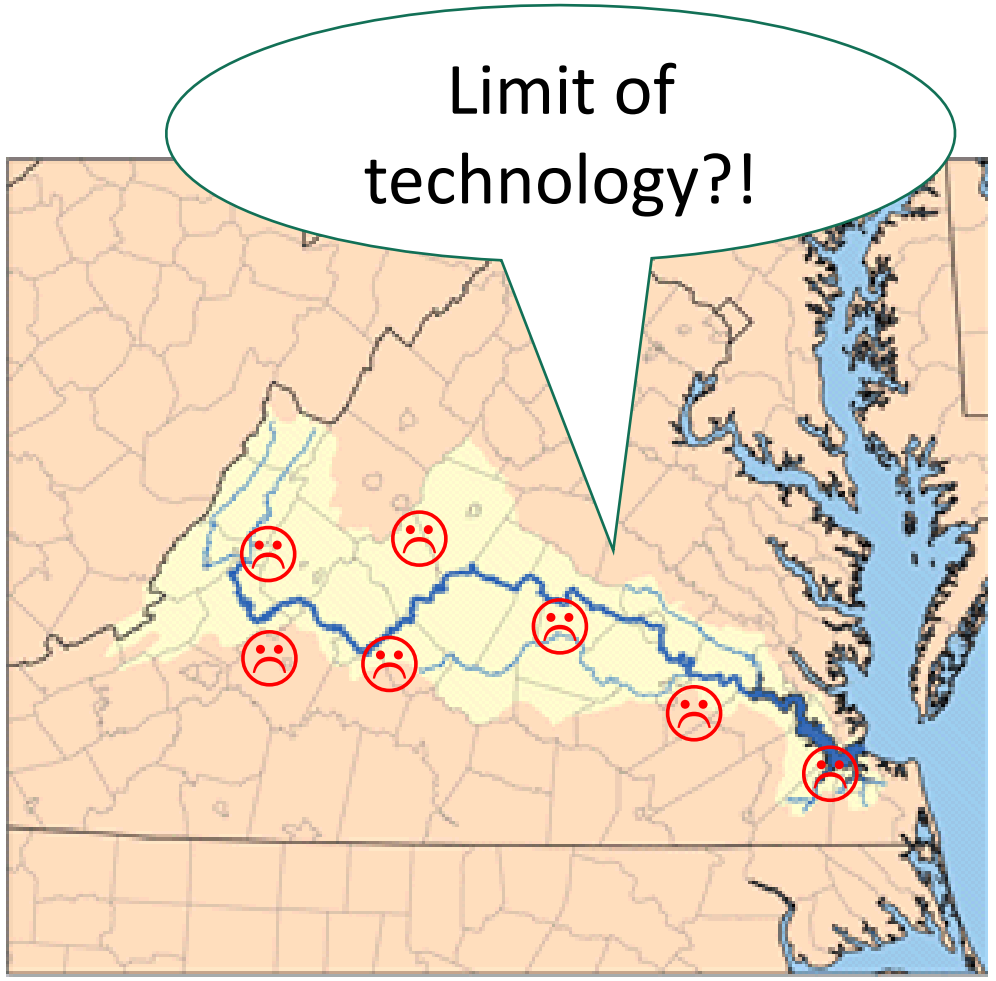

After

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James River Chlorophyll Study

The sticker shock of the Bay TMDL on the James River significant dischargers was the impetus behind the James River Chlorophyll Study initiated in 2011.

Study goals:

1. Establish the scientific basis of the criteria and recommend alternative criteria, if deemed necessary.
2. Develop an improved water quality model for determining load reductions.

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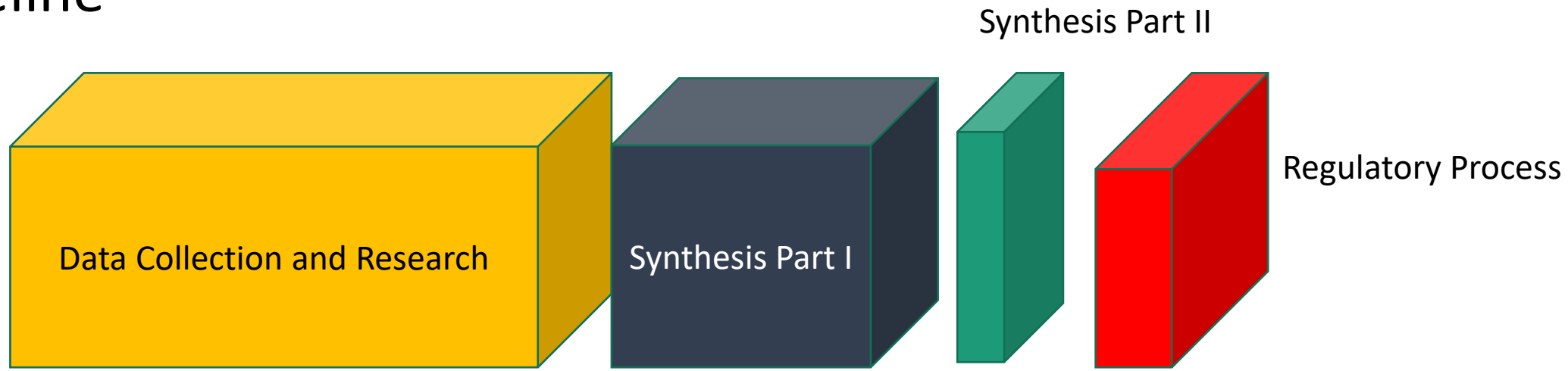
James River Chlorophyll Study

Timeline



The players

Contracted Research Labs

DEQ+ Scientific Advisory Panel

DEQ

DEQ + Regulatory Advisory Panel

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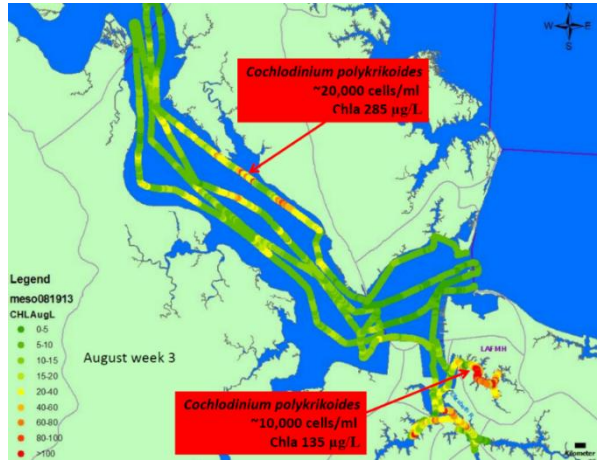
James River Chlorophyll Study

Three years of the study were devoted to data collection

Weekly water quality sampling throughout the upper estuary to supplement monthly sampling

Temporally and spatially-intensive monitoring throughout the estuary



Enhanced phytoplankton monitoring

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James River Chlorophyll Study

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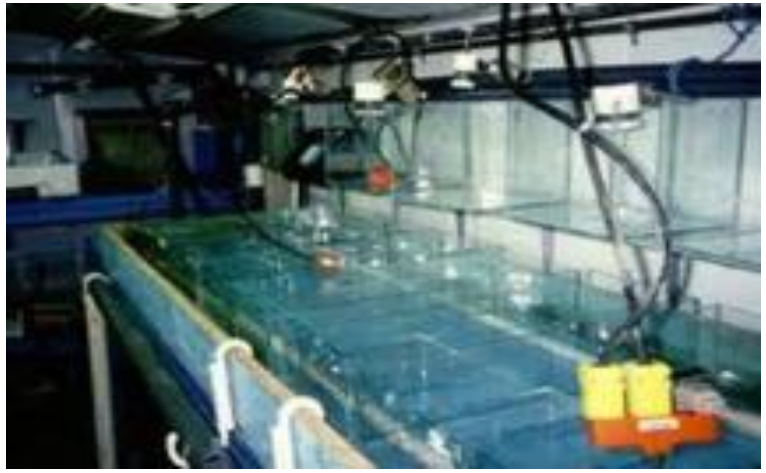
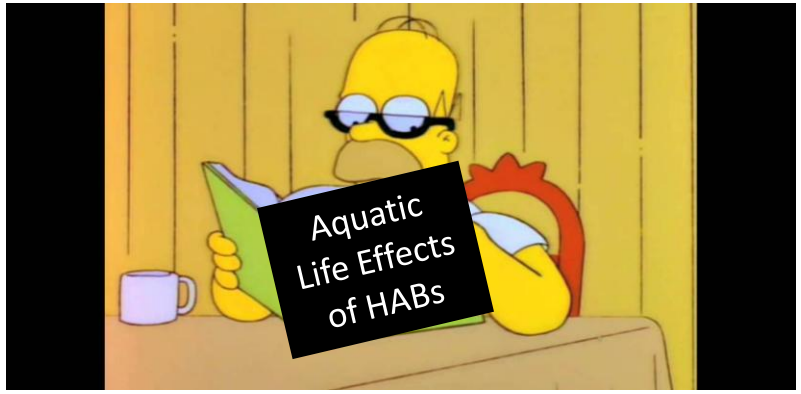


HAB toxicity tests with a variety of test subjects



HAB lit review

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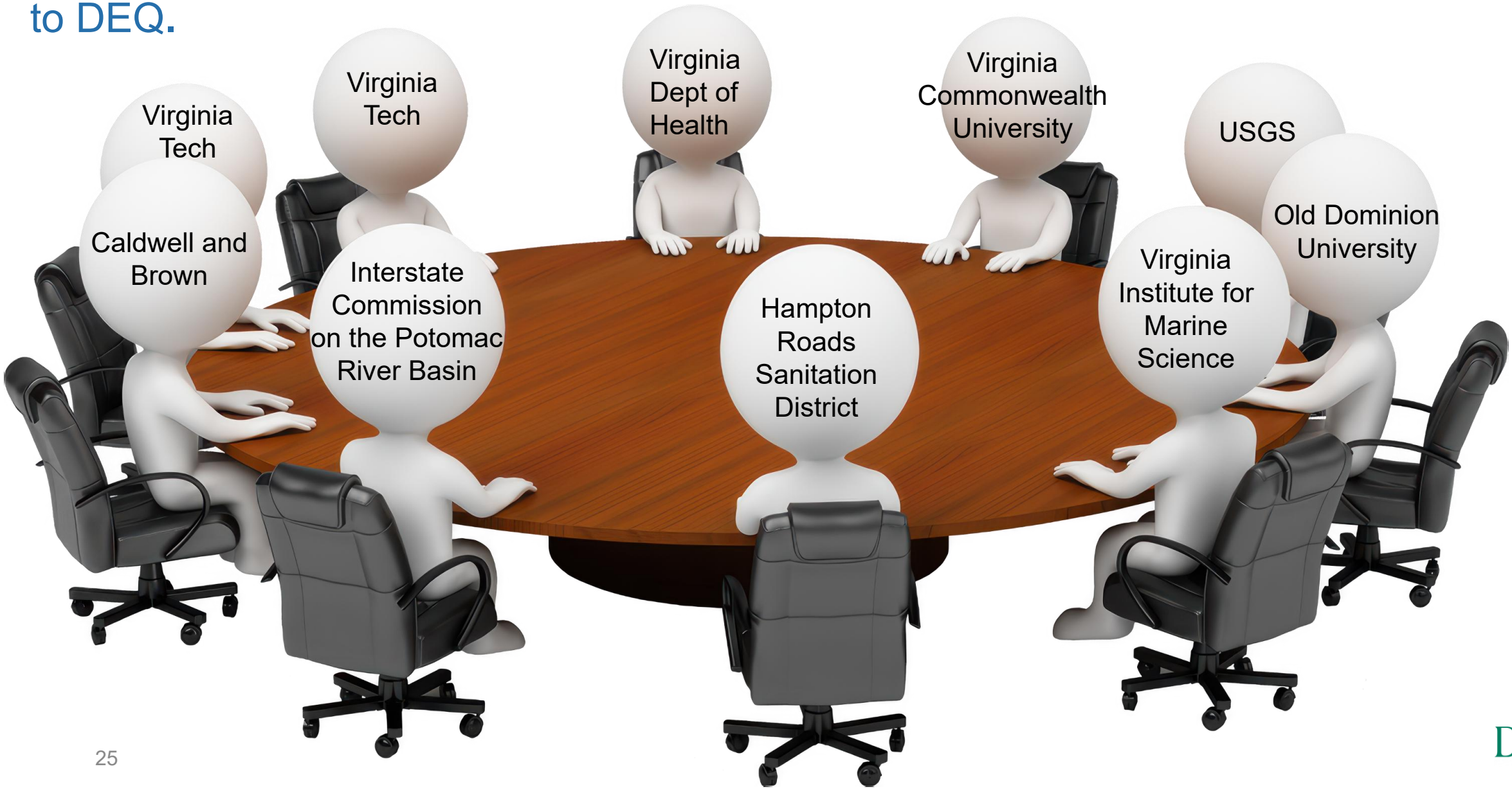
James River Chlorophyll Study Scientific Advisory Panel

The SAP met for two years to make sense of the data and make recommendations to DEQ.



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James River Chlorophyll Study

SAP findings:

Empirical relationships between chlorophyll and multiple response variables are evident in the available datasets.

- Microcystin concentration
- Cell density of toxic dinoflagellate *Cochlodinium polykrikoides*
- DO/pH
- Water clarity

James River Chlorophyll Study

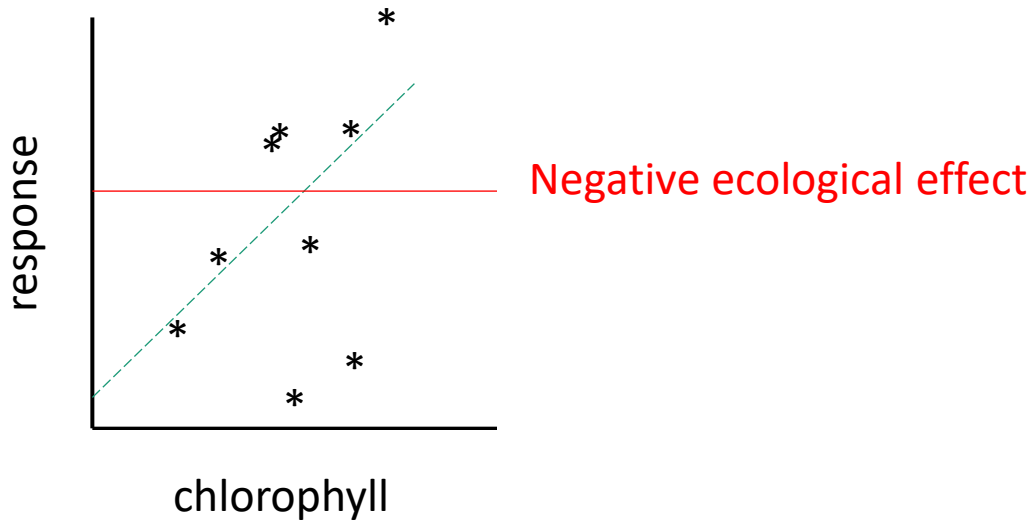
SAP findings:

These responses make for more defensible endpoints than phytoplankton community structure since their “harmfulness” to aquatic life is clearer.

Most of the SAP members advocated effects-based criteria rather than reference-based criteria.

The “How To” of Effects-Based Criteria

1. Identify the harmful ecological and water quality effects you want to minimize.
2. Use empirical relationships between chlorophyll and response variables to determine at what chlorophyll concentration we should expect to see effects, on average.
3. Set the criterion to be equal to the lowest “effect” threshold.



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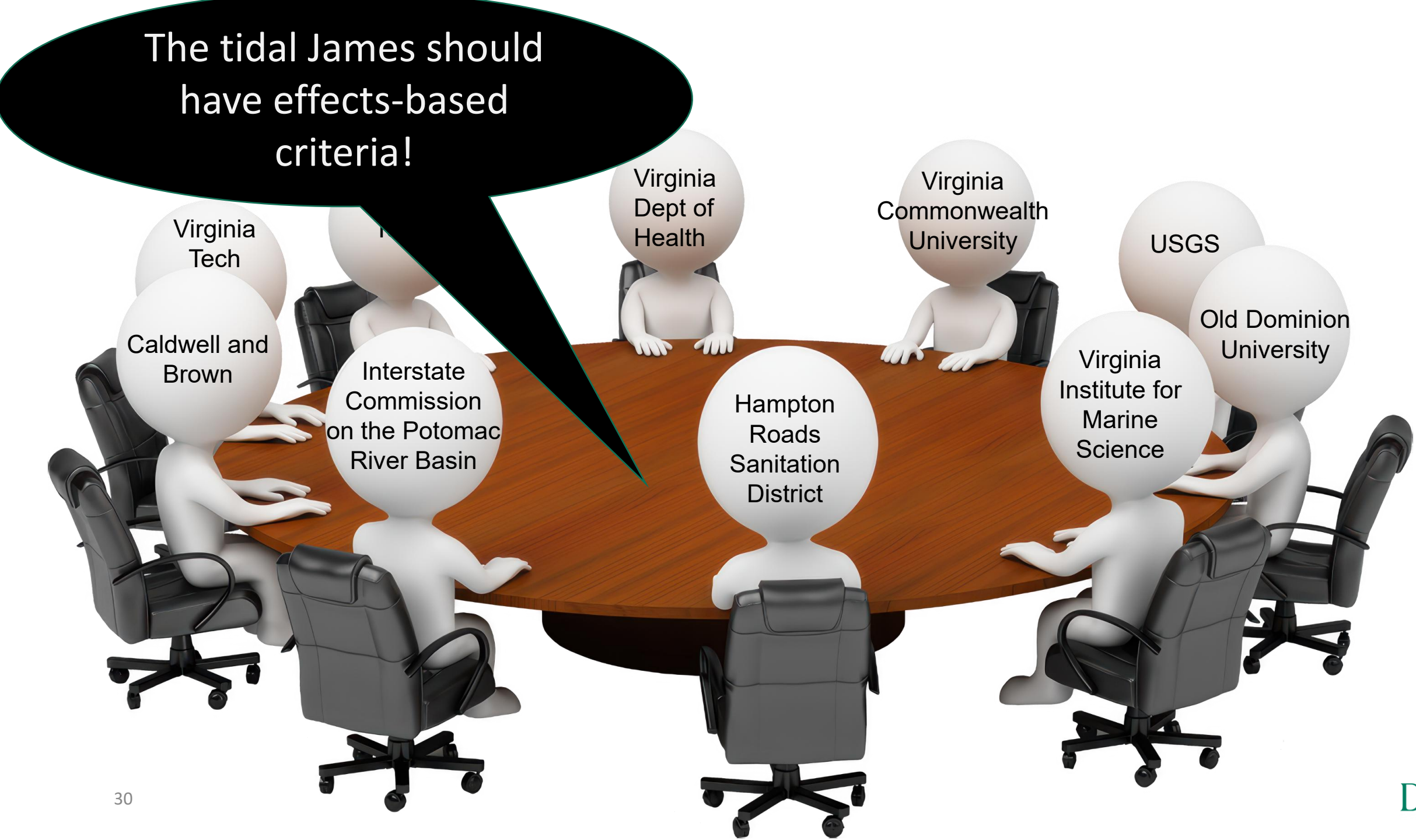
Advantages of Effects-Based Criteria Over Referenced-Based Criteria

- Effects-based criteria do not require the identification of “least impaired” sites.
- Effects-based criteria can be based solely on local datasets.
- The management targets are clearer with effects-based criteria.
- Protection against harmful effects is a more attainable goal than restoring an aquatic life assemblage (like phytoplankton) to an ideal state.


The tidal James should have effects-based criteria!
Virginia Tech
Caldwell and Brown
Interstate Commission on the Potomac River Basin
Virginia Dept of Health
Hampton Roads Sanitation District
Virginia Commonwealth University
Virginia Institute for Marine Science
USGS
Old Dominion University

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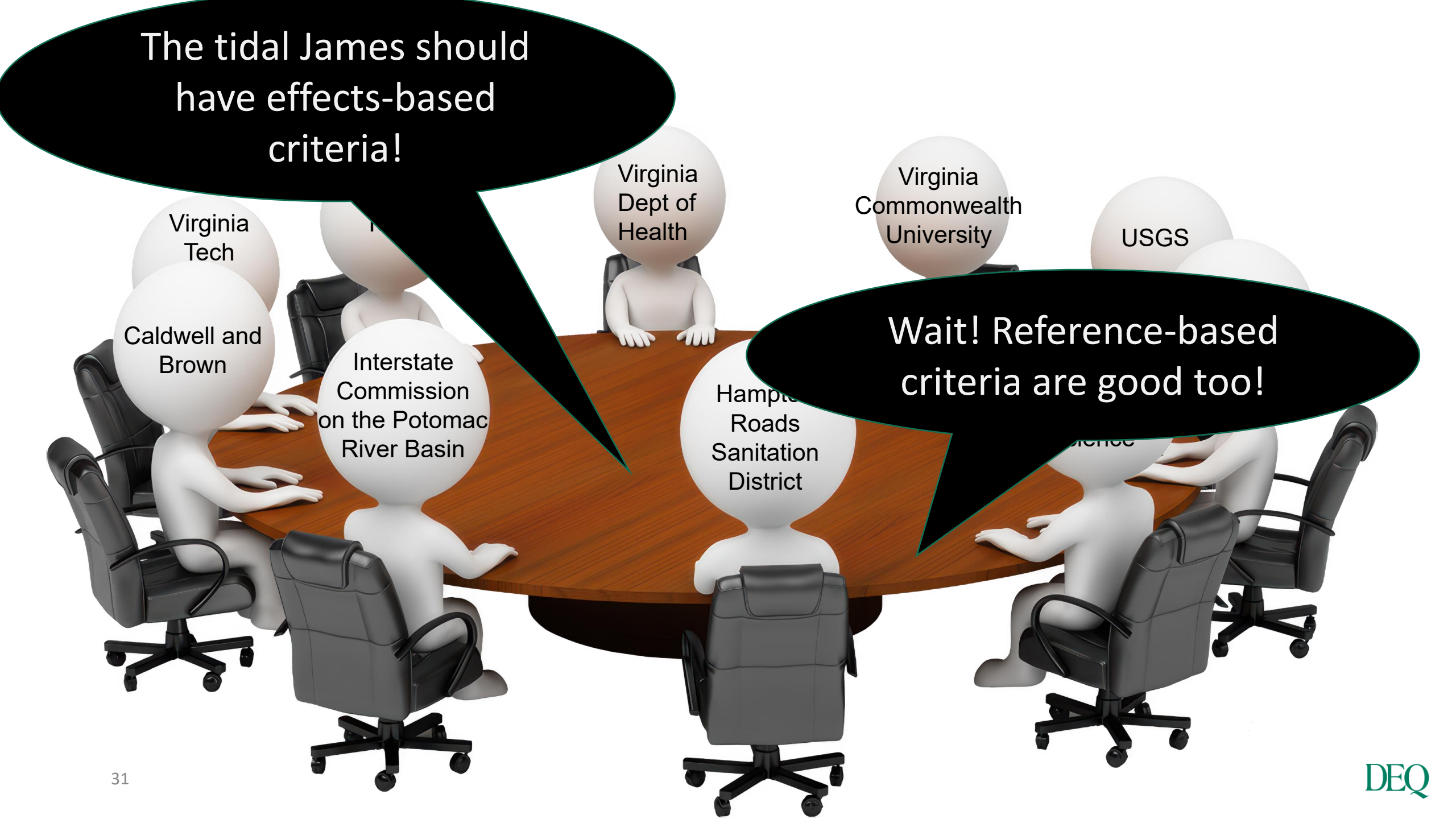
The tidal James should have effects-based criteria!
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Hampton Roads Sanitation District
Virginia Commonwealth University
USGS
Wait! Reference-based criteria are good too!

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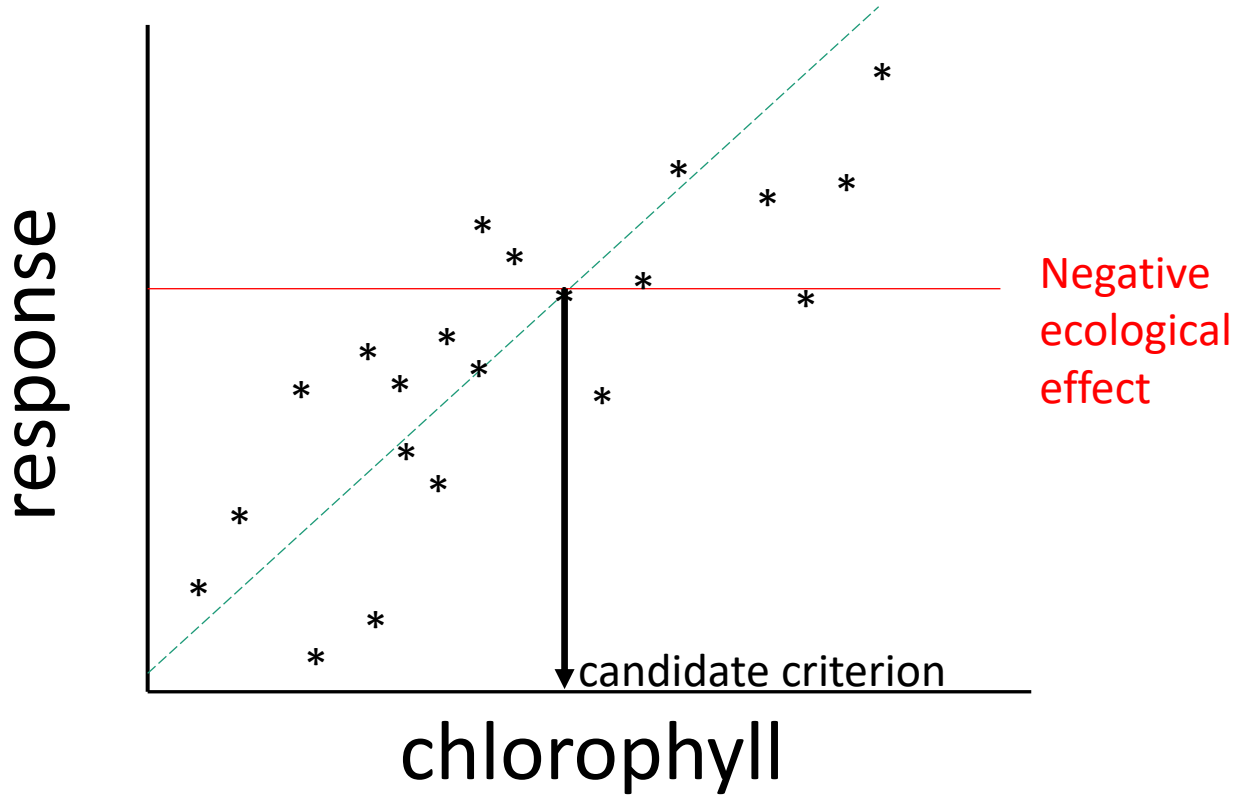
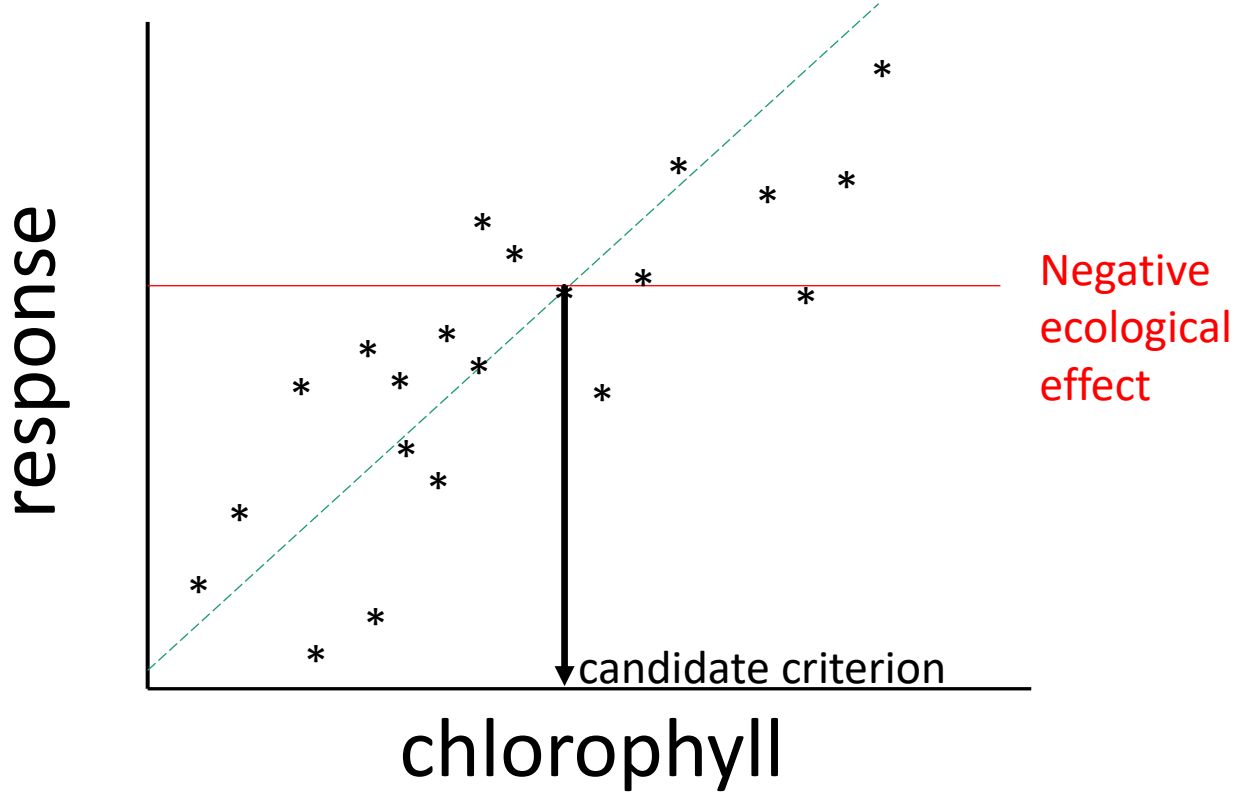
A “Pure” Effects-Based Approach Has Its Weaknesses



No extrapolation is required to come up with a criterion, which makes the criterion defensible.

DEQ

A “Pure” Effects-Based Approach Has Its Weaknesses



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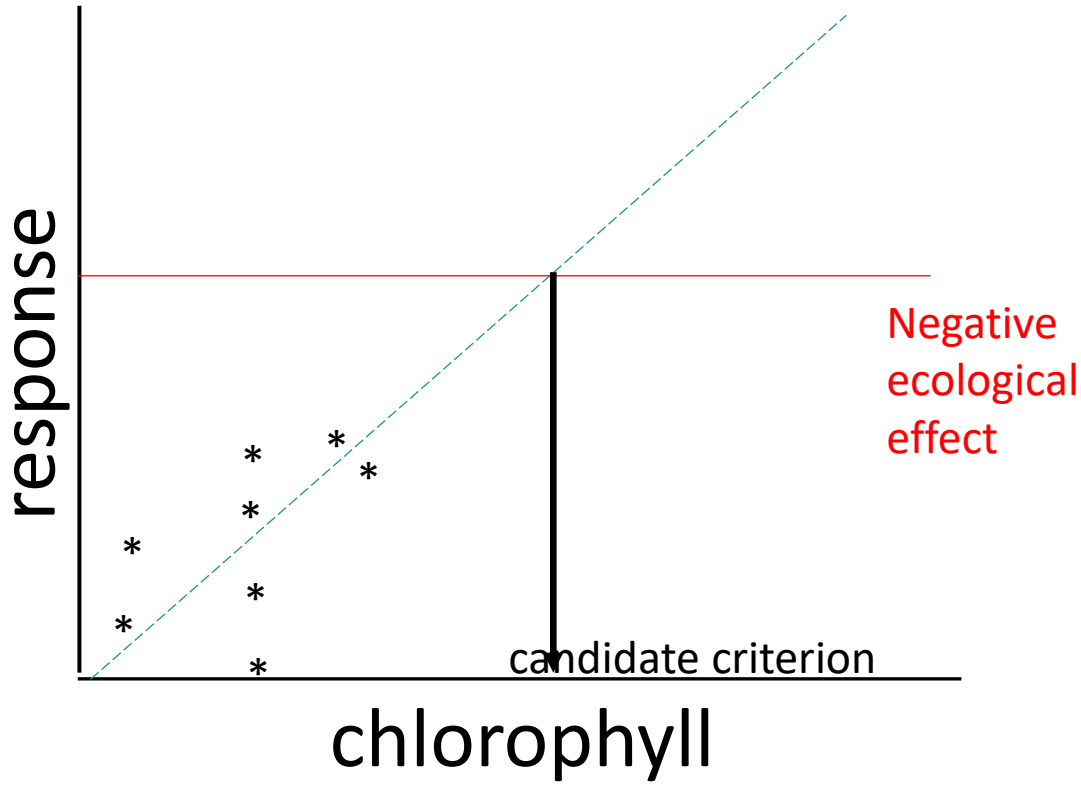
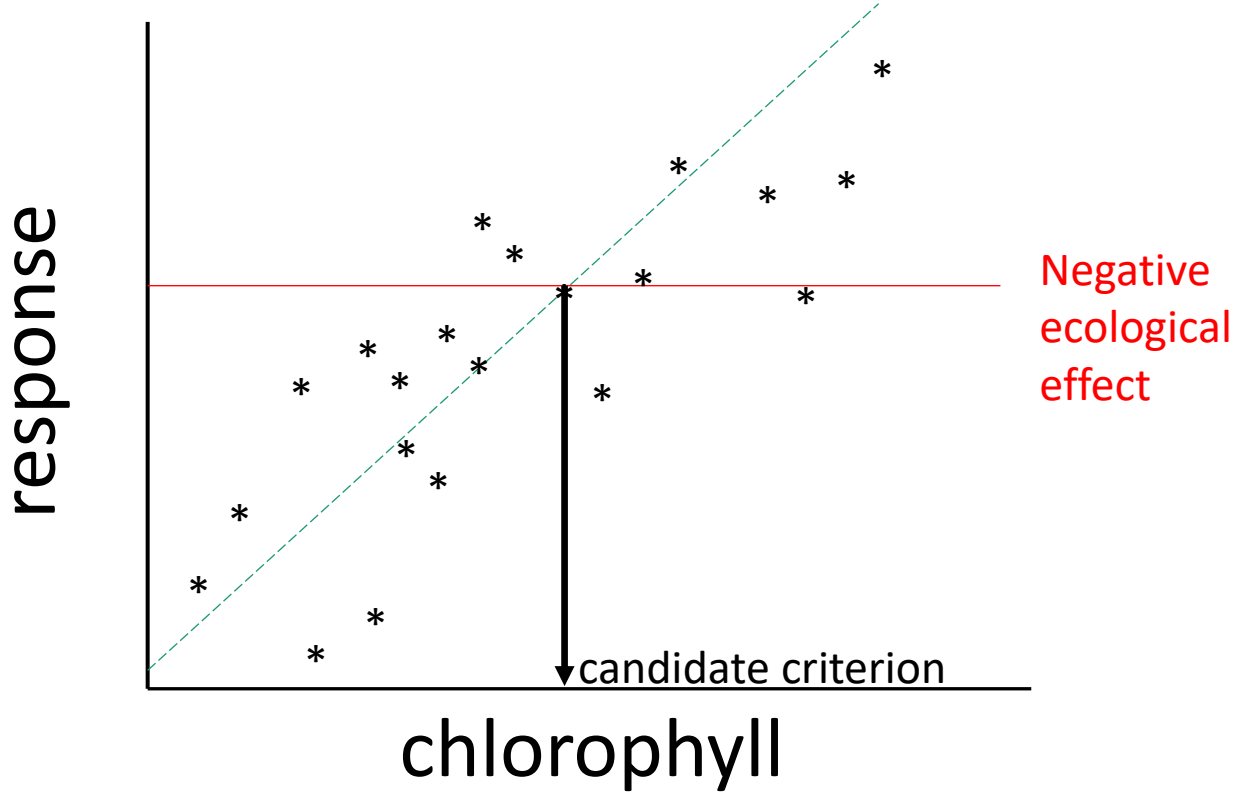


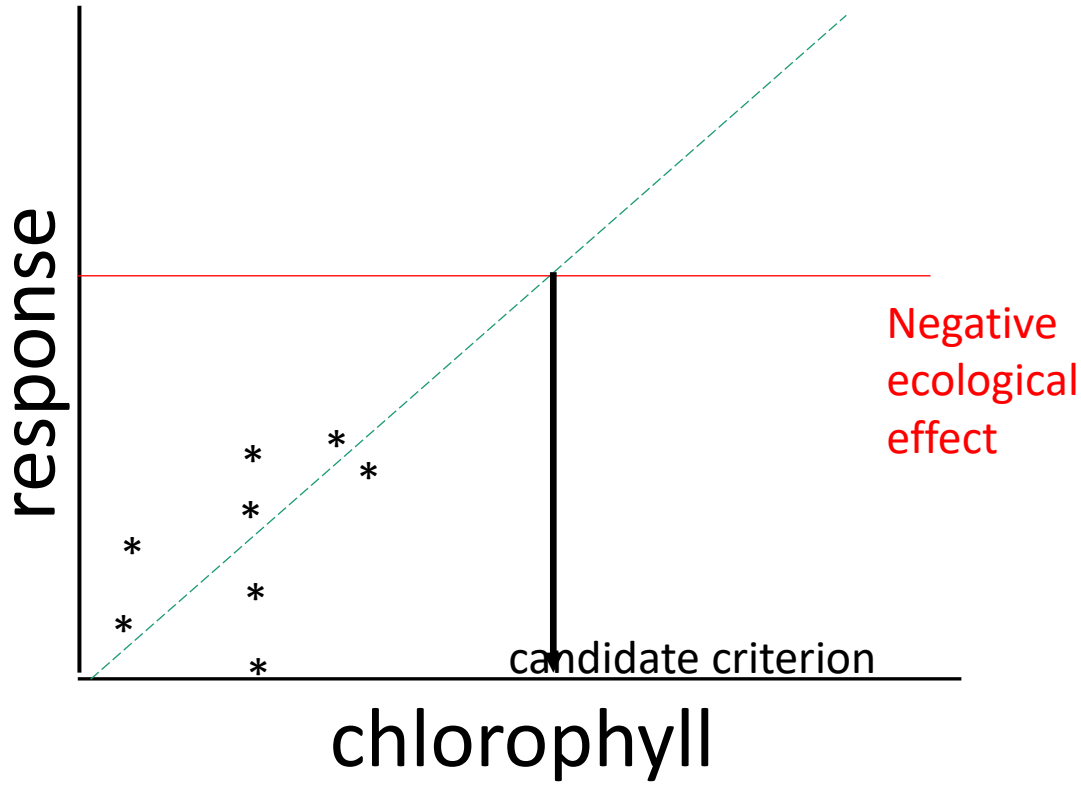
Extrapolation is required. The criterion is not as defensible.

DEQ

A “Pure” Effects-Based Approach Has Its Weaknesses



Successful implementation of this criterion will result in lower chlorophyll concentrations.



Chlorophyll concentrations will be allowed to increase with this criterion.

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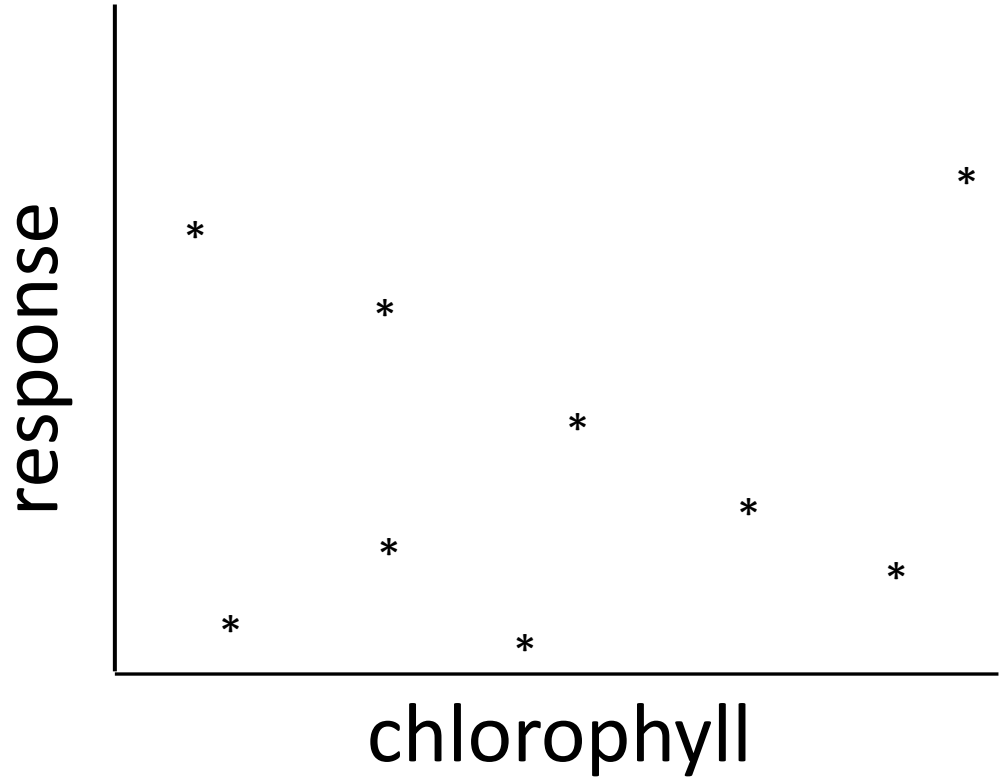
A “Pure” Effects-Based Approach Has Its Weaknesses

Also, what do we do when we can’t find statistically significant relationships between chlorophyll and response variables in our data?



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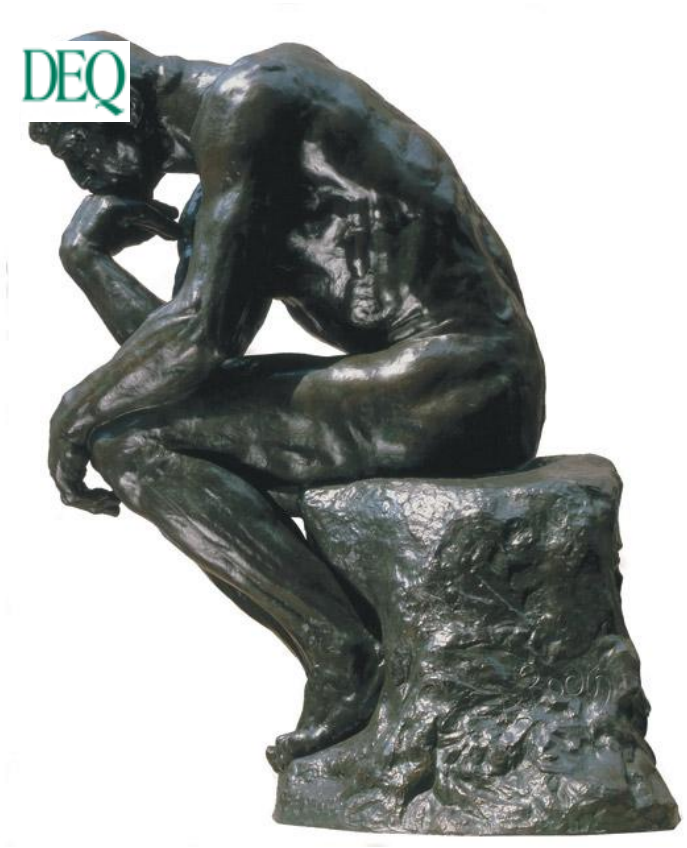
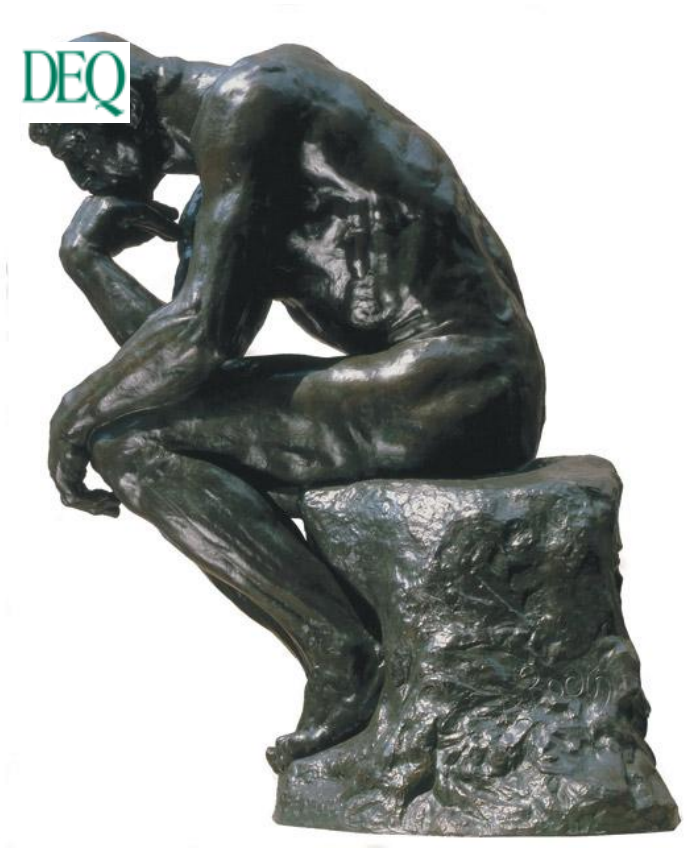
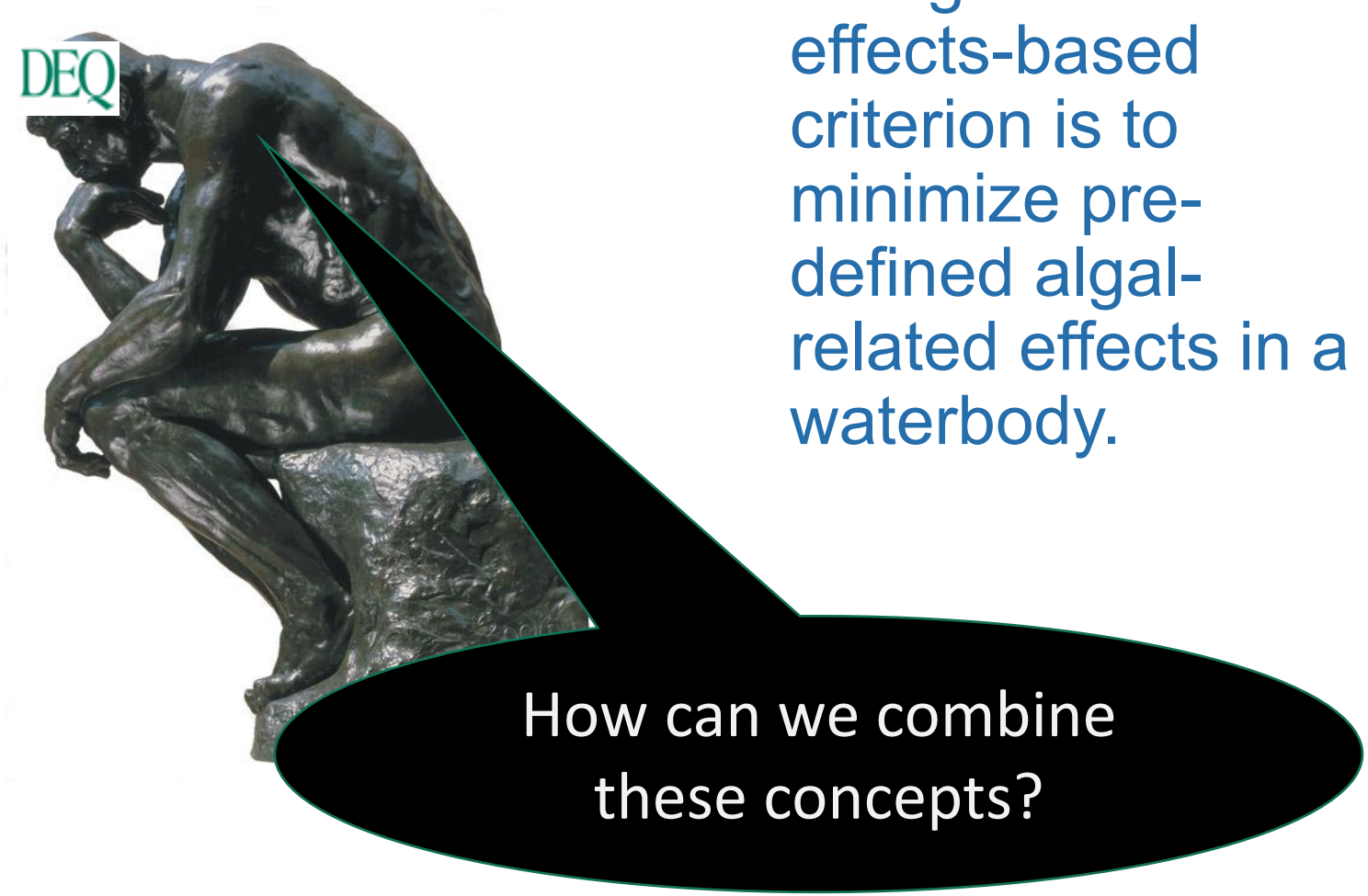

DEQ

The goal of a reference-based criterion is to make a degraded waterbody similar to a reference waterbody in terms of its trophic state.



The goal of an effects-based criterion is to minimize pre-defined algal-related effects in a waterbody.

The goal of a reference-based criterion is to make a degraded waterbody similar to a reference waterbody in terms of its trophic state.



The goal of an effects-based criterion is to minimize pre-defined algal-related effects in a waterbody.

The Approach

Objective: Develop chlorophyll-a criteria for the five tidal James River segments that 1) minimize the frequency of harmful algal-related effects and 2) prevent degradation of current water quality conditions due to eutrophication.

Four Steps

1. Characterization of “baseline” chlorophyll central tendency and variation in space and time for each segment-season.

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Four Steps

1. Characterization of “baseline” chlorophyll central tendency and variation in space and time for each segment-season.

   - Baseline period = 2005-2013
   - Lots of continuous monitoring, Dataflow, and weekly grab sampling occurring during this period.
   - These data were used estimate the “typical” chlorophyll concentration in each segment and season.
   - Central tendency expressed as a seasonal geometric mean.
   - “Typical” seasonal spatial and temporal variation were also estimated.

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Over a Million Data Points!

DEQ

Four Steps

2. Use existing and historical monitoring datasets to model relationships between chlorophyll concentrations and various effects. Establish “effect thresholds” from these models.

- Poor water clarity
- Low dissolved oxygen
- High pH
- Microcystin concentrations (tidal fresh)
- Cochlodinium cell density (MH and PH)

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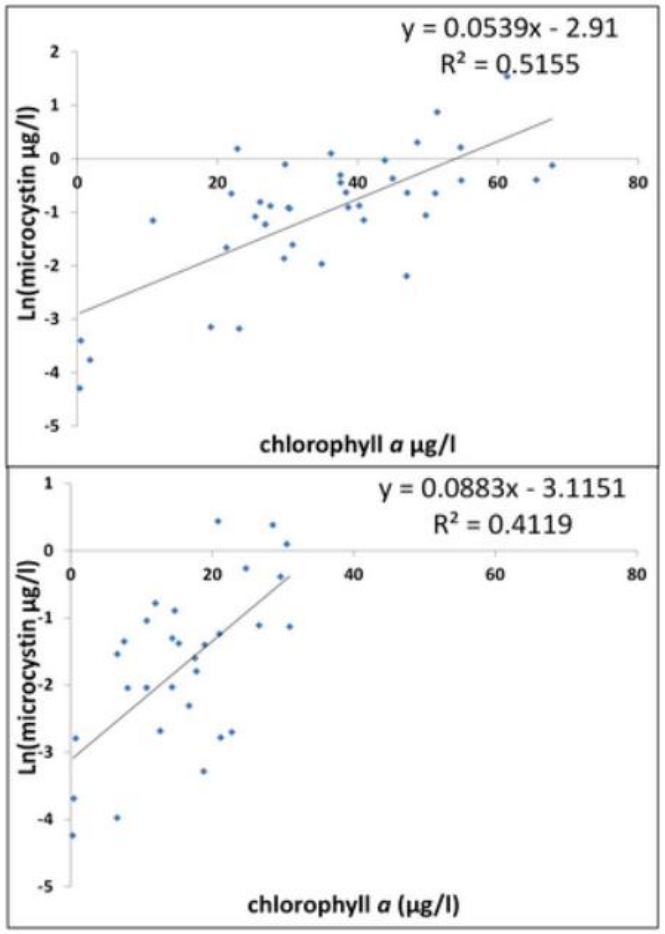
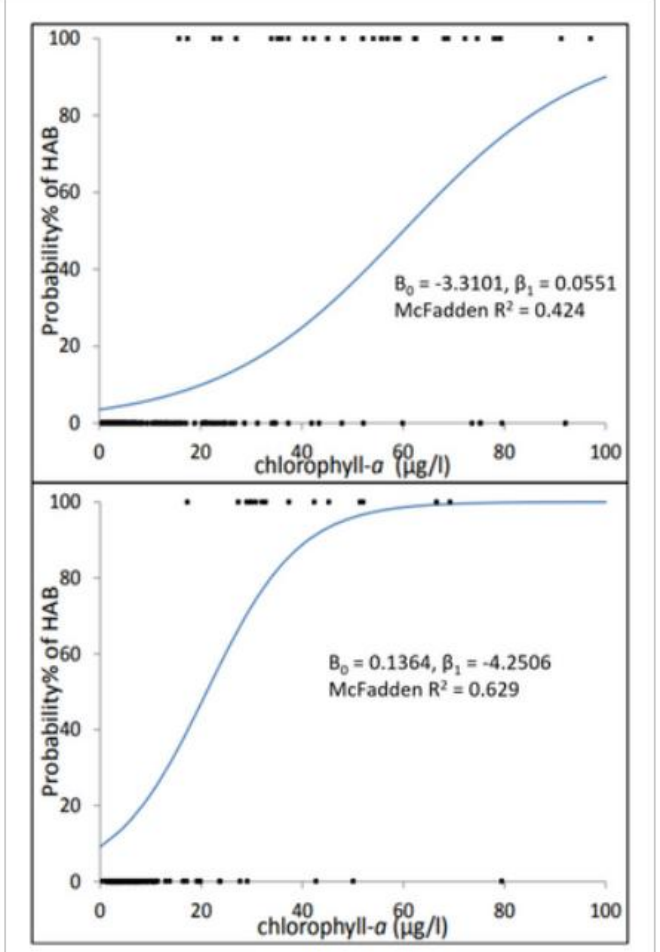
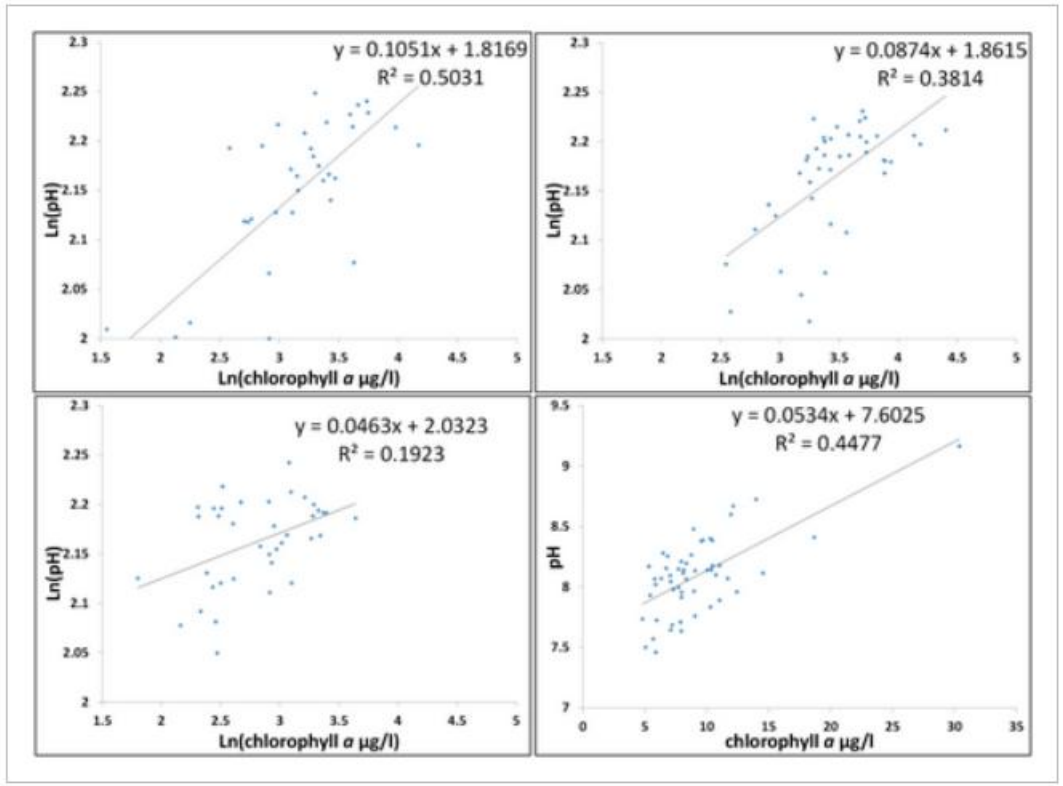
Microcystin



Cocholidinum



pH



The Approach

3. For each segment-season and effect threshold, develop a probability model using baseline metrics to predict the chlorophyll concentration that would confer an acceptable exceedance rate of the effect threshold.

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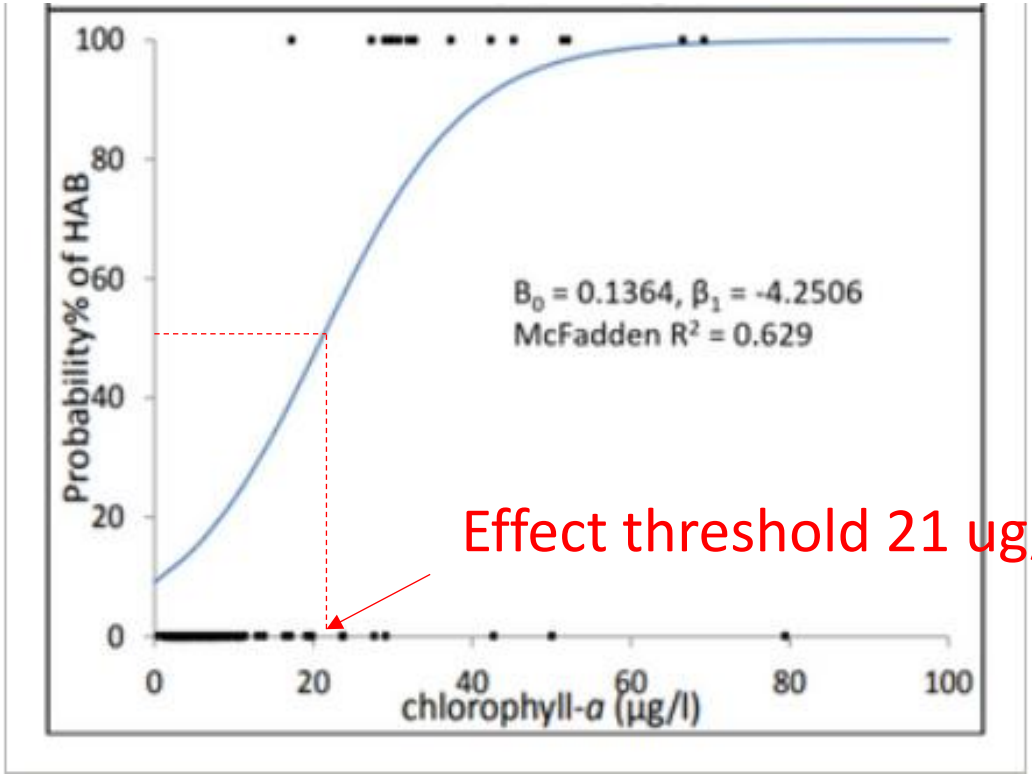
The Approach

3. For each segment-season and effect threshold, develop a probability model using baseline metrics to predict the chlorophyll concentration that would confer an acceptable exceedance rate of the effect threshold.

JMSPH-Summer

Chlorophyll – Cochlodinium Model



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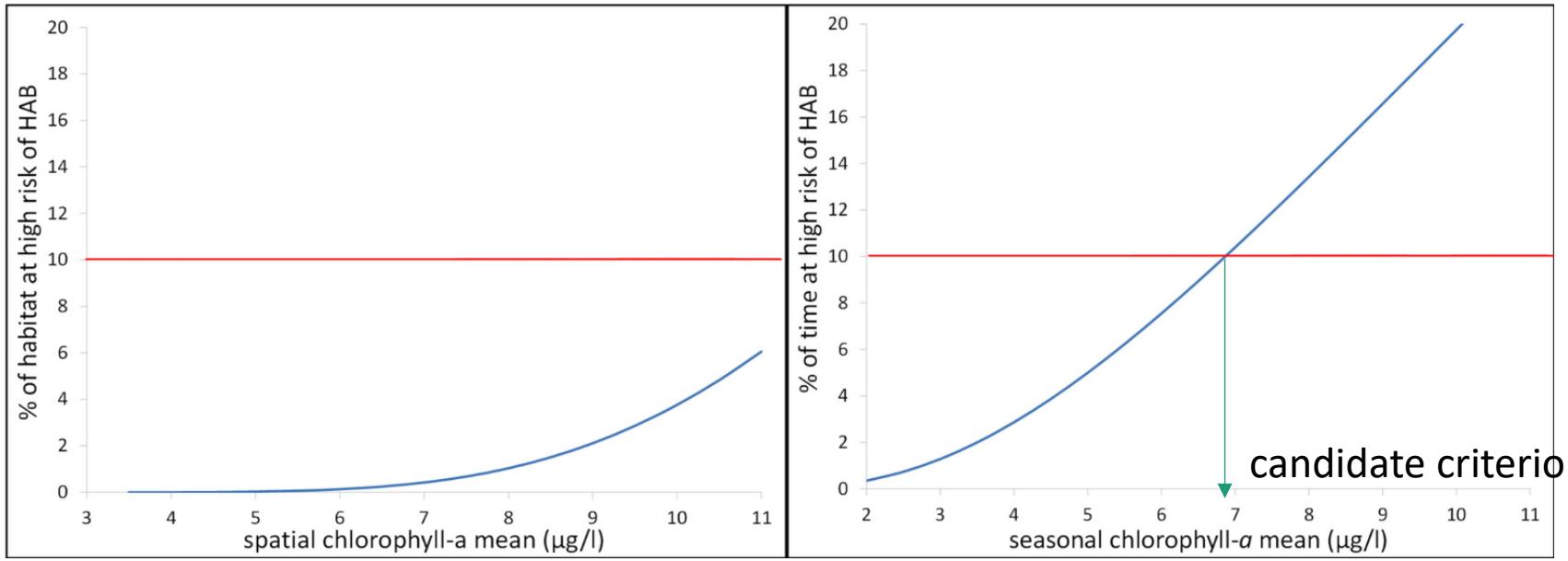
The Approach

3. For each segment-season and effect threshold, develop a probability model using baseline metrics to predict the chlorophyll concentration that would confer an acceptable risk of the effect.



10% probability of ≥ 21 ug/L

Cumulative distribution functions (inverse) composed from the baseline spatial (left) and temporal (right) variation estimates for JMSPH-summer

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The Approach

4. The final criterion for a segment-season was the lower value between two options:

- The seasonal mean concentration found to be protective of all documented effects in the segment.
- The baseline concentration for that segment-season

James River segment-season	2005 Seasonal Mean Criteria (µg/L)	2020 Seasonal Mean Criteria (µg/L)
JMSTF2 – spring	10	8
JMSTF2 – summer	15	21
JMSTF1 – spring	15	10
JMSTF1 - summer	23	24
JMSOH - spring	15	13
JMSOH – summer	22	11
JMSMH - spring	12	7
JMSMH – summer	10	7
JMSPH – spring	12	8
JMSPH - summer	10	7

James River segment-season	2005 Seasonal Mean Criteria (µg/L)	2020 Seasonal Mean Criteria (µg/L)
JMSTF2 – spring	10	**8**
JMSTF2 – summer	15	
JMSTF1 – spring	15	**10**
JMSTF1 - summer	23	
JMSOH - spring	15	**13**
JMSOH – summer	22	**11**
JMSMH - spring	12	**7**
JMSMH – summer	10	
JMSPH – spring	12	**8**
JMSPH - summer	10	

These criteria were designed to maintain baseline conditions rather than protection against specific effects because quantifiable algal-related effects were not found to occur excessively under baseline conditions.

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James River segment-season	2005 Seasonal Mean Criteria (µg/L)	2020 Seasonal Mean Criteria (µg/L)
JMSTF2 – spring	10	
JMSTF2 – summer	15	**21**
JMSTF1 – spring	15	
JMSTF1 - summer	23	**24**
JMSOH - spring	15	
JMSOH – summer	22	
JMSMH - spring	12	
JMSMH – summer	10	**7**
JMSPH – spring	12	
JMSPH - summer	10	**7**

These criteria were designed to protect against specific effects because quantifiable algal-related effects were found to occur excessively under baseline conditions. These criteria are lower than the segment-season's baseline concentration.

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Another layer of protection was added…

James River segment	Spatial Application	Magnitude (µg/L)	Duration
JMSTF2	Upstream boundary to river mile 95	--	--
JMSTF2	River mile 95 to downstream boundary	52	1-month median
JMSTF1	Upstream boundary to river mile 67	52	1-month median
JMSTF1	River mile 67 to downstream boundary	34	1-month median
JMSOH	Entire segment	--	--
JMSMH	Entire segment	59	1-day median
JMSPH	Entire segment	20	1-day median

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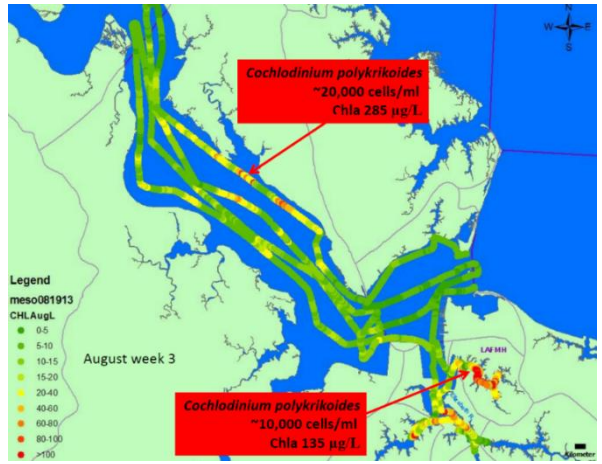
Lessons Learned

The Importance of Partnerships and Stakeholder Engagement

The Importance of Partnerships and Stakeholder Engagement



Much of the data collected under the study were generated by partnering institutions. HRSD contributed a huge amount of Dataflow data without charge to DEQ.

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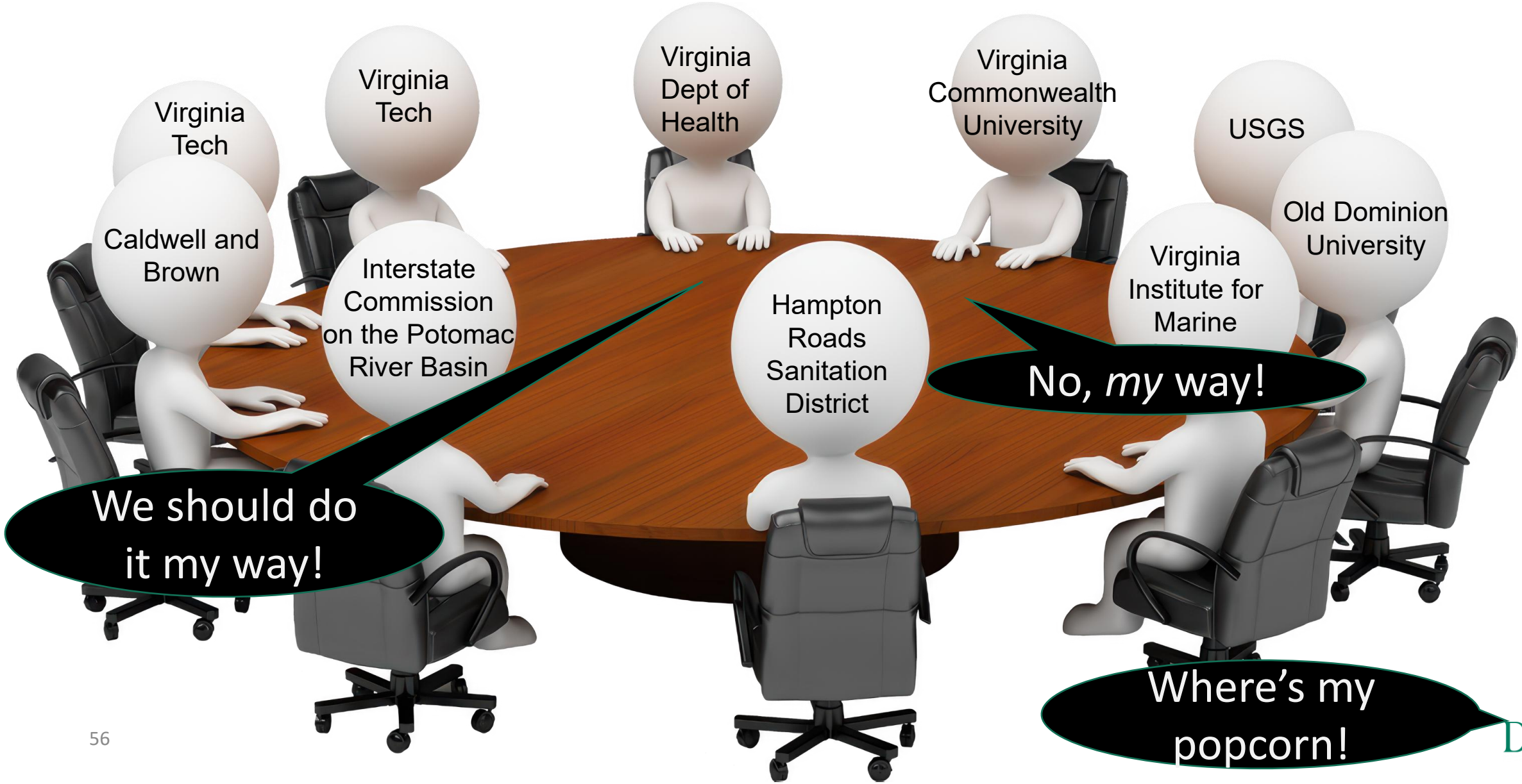
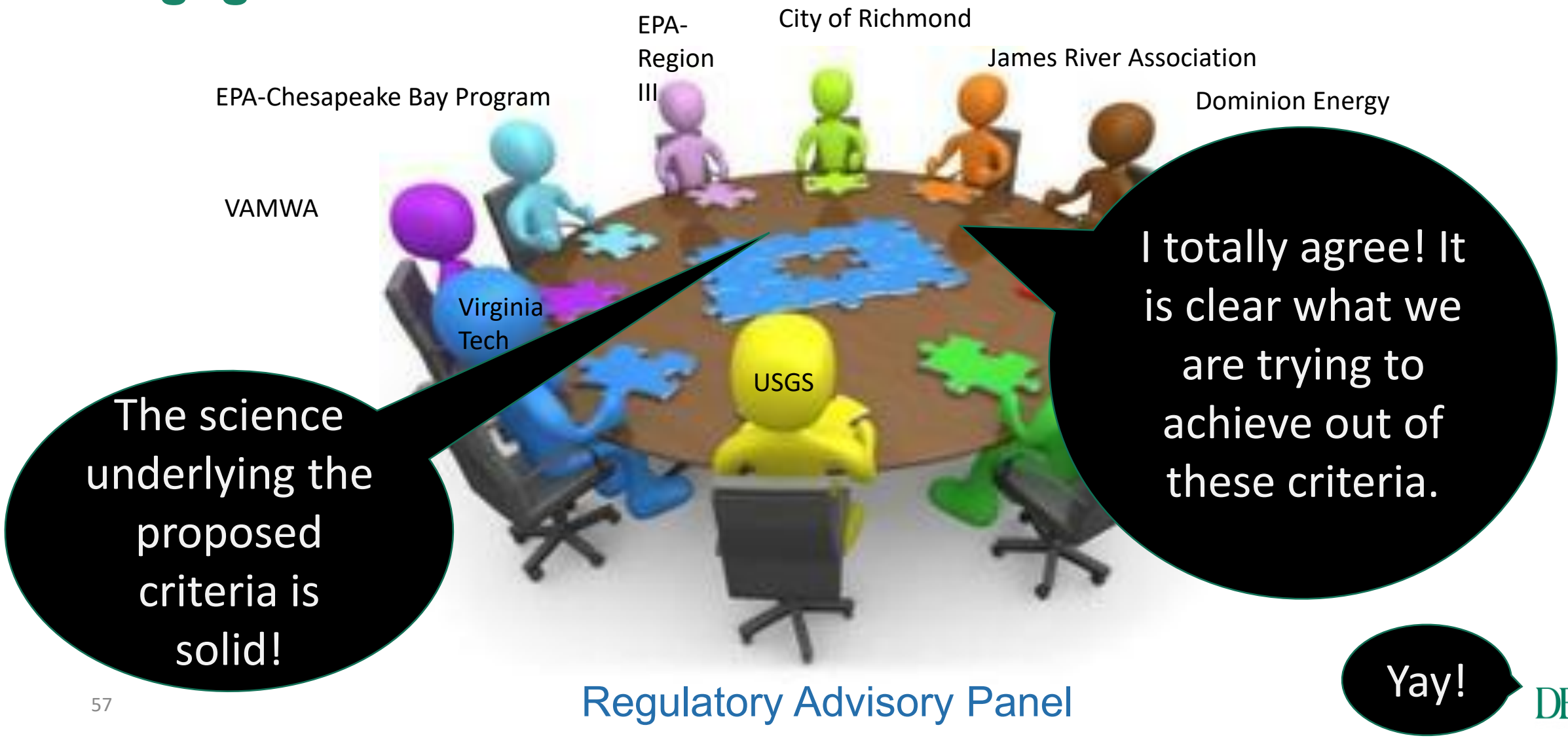
The Importance of Partnerships and Stakeholder Engagement



The Importance of Partnerships and Stakeholder Engagement



Regulatory Advisory Panel

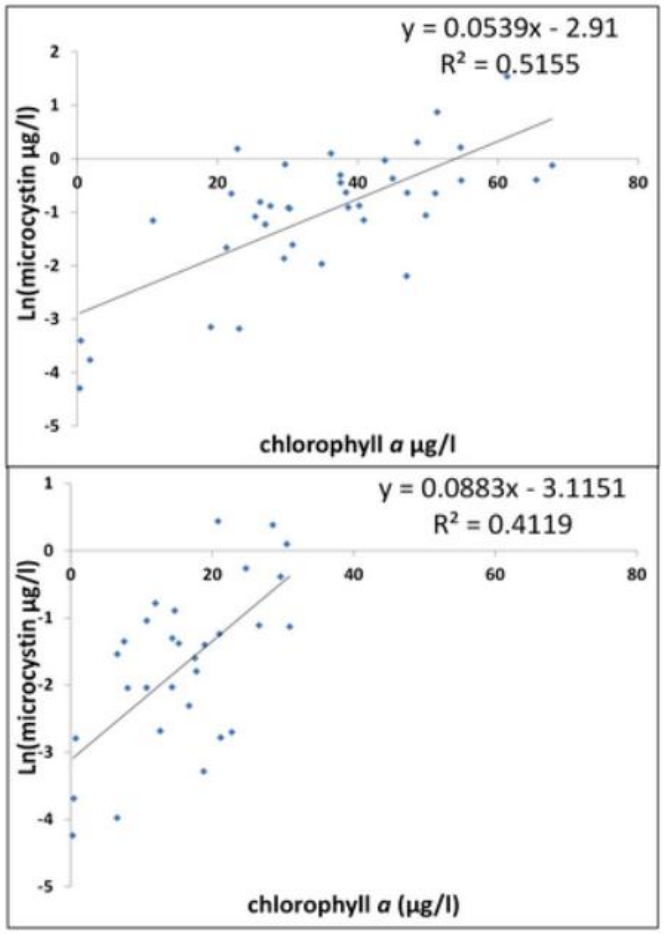
DEQ

Lessons Learned

1. The importance of partnership and stakeholder engagement
2. The importance of spatially and temporally intensive datasets

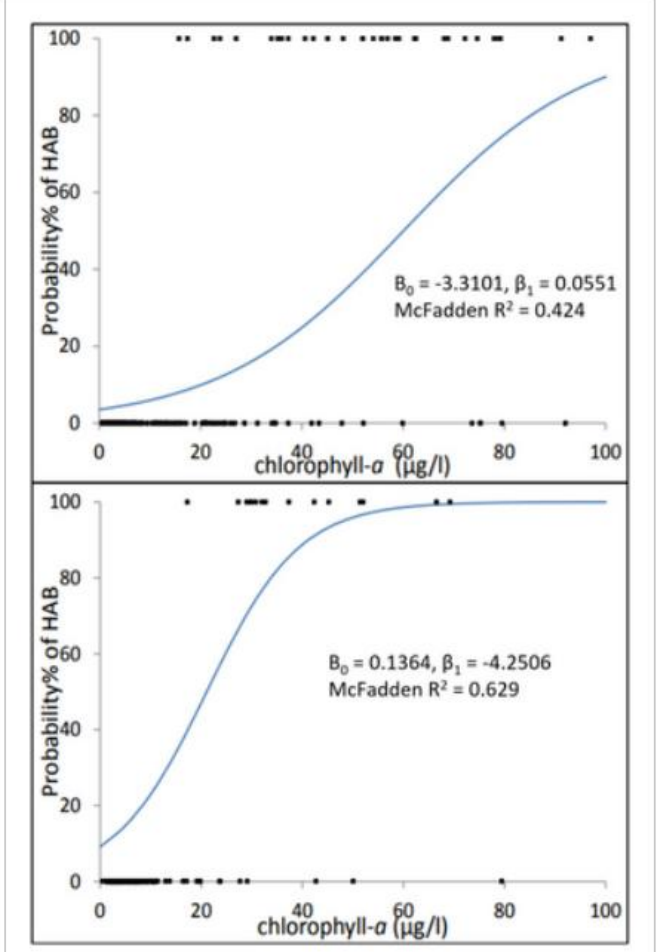
DEQ

Microcystin



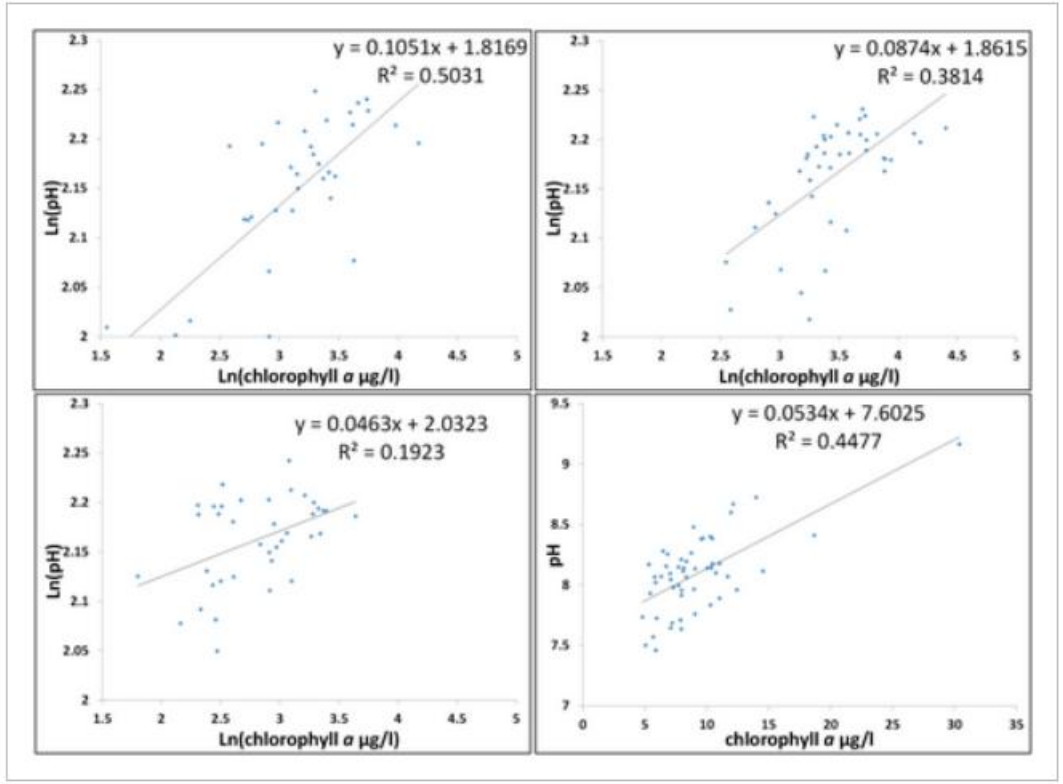
Weekly grab samples

Cocholidinum



Dataflow-faciliated grab samples

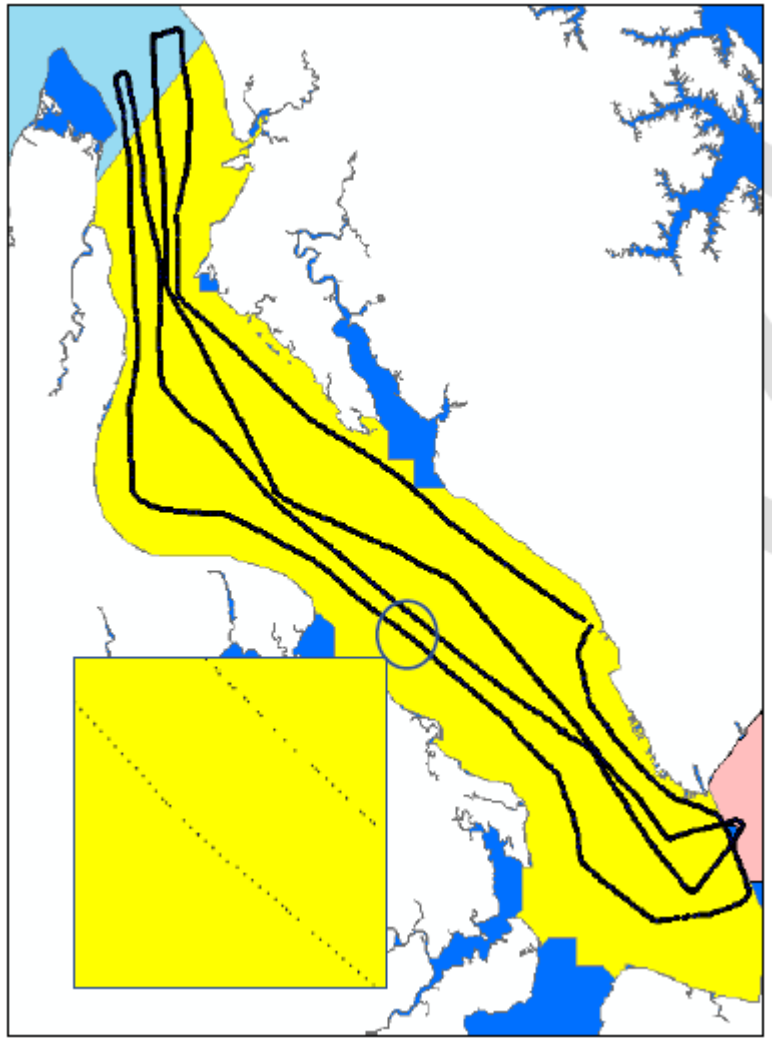
pH



ConMon data

DEQ

The Importance of Spatially and Temporally Intensive Datasets



Dataflow data enabled very refined estimates of central tendency and spatial variability, which was crucial for establishing protective baseline criteria.

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Lessons Learned

1. The importance of partnership and stakeholder engagement.
2. The importance of spatially and temporally intensive datasets.
3. In large systems, protection in space and time is important.

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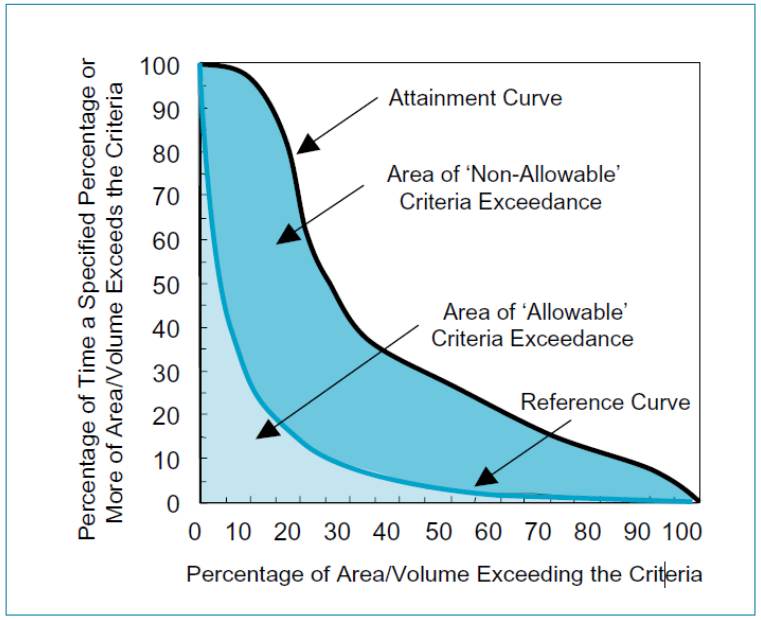
In large systems, protection in space and time is important.



DEQ decided to stop using the CFD for assessing James River chlorophyll criteria.

DEQ developed an alternative methodology that does not require spatial interpolation.

However, the concept of protecting space and time was not abandoned. It was simply baked into the criteria magnitudes rather than reserved for the assessment methodology.

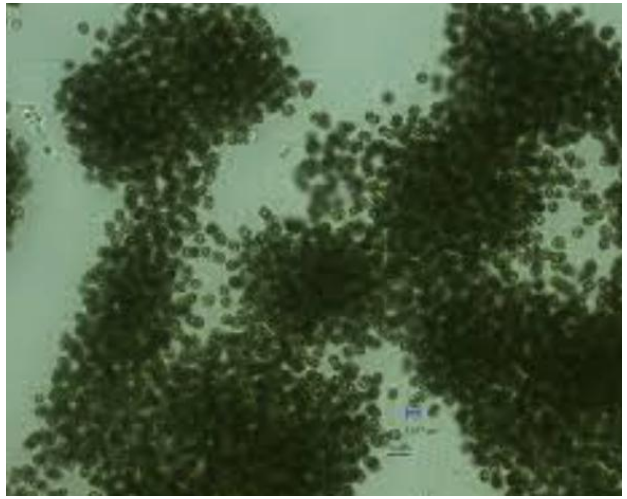
DEQ

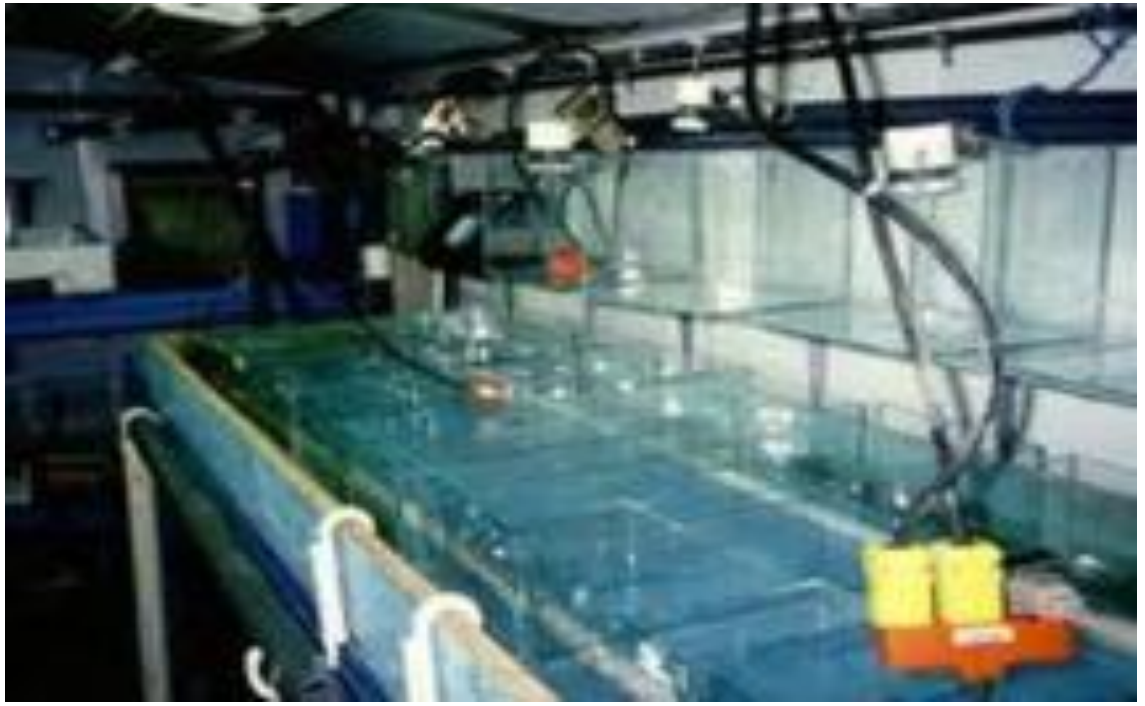
Lessons Learned

1. The importance of partnership and stakeholder engagement.
2. The importance of spatially and temporally intensive datasets.
3. In large systems, protection in space and time is important.
4. Tracking effects alongside water quality can yield powerful insights for managers.

DEQ

Tracking effects alongside water quality can yield powerful insights for managers

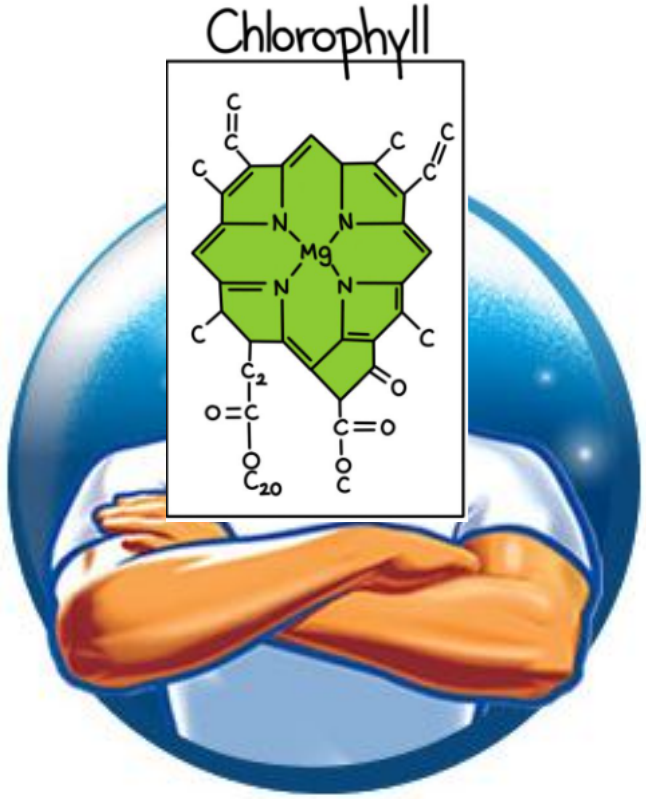




Algae don't just affect water quality parameters like DO and pH. The organisms themselves can be harmful. Toxicity tests are crucial for an effects-based criteria development process for systems where HABs have been documented.

DEQ

Chlorophyll criteria are challenging but they are an effective regulatory tool



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