Reflections on Water Quality Criteria Attainment

Peter Tango and Qian Zhang

with contributions from Laura Free and Richard Tian

Status & Trends Workgroup Meeting

June 13, 2017

Chesapeake Bay Program

Science. Restoration. Partnership.

Outline

- **Water Quality Criteria**
- Current Attainment Indicator
- "Attainment Deficit" Concept
- "Beyond Capacity" Concept
- Potential Next Steps

Chesapeake Bay Program
Science. Restoration. Partnership.

Water Quality Criteria

TABLE 6. Summary of Published Water Quality Criteria Addenda and Their Guidance and Documentation Revising and Updating the Original USEPA (2003a) Water Quality Criteria.

Water Quality Criteria Addendum	Guidance and Documentation Revising and Updating the Original USEPA (2003a) Ambient Water Quality Criteria
USEPA (2004a)	• Temperature-based criteria to protect endangered short-nosed sturgeon • Site-specific DO criteria derivation guidance • Method for delineating upper and lower pycnocline boundaries • Water quality criteria attainment alternatives for the shallow water bay grass designated use • Numerical chlorophyll *a* criteria applications in Chesapeake Bay tidal waters
USEPA (2004b)	• Revisions, decisions, and rationales for Chesapeake Bay management segment schemes
USEPA (2007a)	• Refinements to spatial interpolation and statistical aspects of measuring water quality criteria attainment assessment • Recommendations for further development of spatial interpolation and statistical aspects of measuring water quality criteria attainment assessment • Refinement to procedures assessing DO, water clarity, and chlorophyll *a* criteria • Additions to procedures for assessing DO, water clarity, and chlorophyll *a* criteria • Recommended methods for using shallow water high-frequency continuous monitoring water quality data in criteria assessment • Document 303(d) list decision-making framework for water quality criteria attainment assessments
USEPA (2007b)	• Scientific bases to support numerical chlorophyll *a* criteria applicable to Chesapeake Bay and its tidal tributaries • Recommended procedures for assessing attainment of HAB-based numerical chlorophyll *a* criteria
USEPA (2008)	• Refinements to the Chesapeake Bay and tidal tributary management segment scheme • Refinements to previously published DO, water clarity, and chlorophyll *a* attainment assessment procedures • Additions to procedures for DO, water clarity, and chlorophyll *a* attainment assessment procedures • Chlorophyll *a* criteria assessment procedures
USEPA (2010a, b)	• Refinements to procedures for defining Chesapeake Bay designated uses • Refinements and additions to previously published procedures for deriving biologically based reference curves • Recommendations for applications of biologically based reference curves for DO criteria assessments • Refinements to procedures and recommendations for assessing chlorophyll *a* criteria

Note: DO, dissolved oxygen; HAB, harmful algal bloom.

Source: Tango and Batiuk (2013)

Water Quality Criteria
Dissolved Oxygen

TABLE 1. Chesapeake Bay Water Quality Criteria (from USEPA, 2003a).

Designated Use	Criteria Concentration/Duration	Protection Provided	Temporal Application
Migratory fish spawning and nursery use	Seven-day mean ≥6 mg/l (tidal habitats with 0-0.5 salinity)	Survival/growth of larval/juvenile tidal-fresh resident fish; protective of threatened/endangered species	February 1-May 31
	Instantaneous minimum ≥5 mg/l	Survival and growth of larval/juvenile migratory fish; protective of threatened/endangered species	
	Open water fish and shellfish designated use criteria apply		June 1-January 31
Shallow water bay grass use	Open water fish and shellfish designated criteria apply		Year-round
Open water fish and shellfish use[1]	30-day mean ≥5.5 mg/l (tidal habitats with ≤0.5 salinity)	Growth of tidal-fresh juvenile and adult fish; protective of threatened/ endangered species	Year-round
	30-day mean ≥5 mg/l (tidal habitats with >0.5 salinity)	Growth of larval, juvenile, and adult fish and shellfish; protective of threatened/endangered species	
	Seven-day mean ≥4 mg/l	Survival of open water fish larvae	
	Instantaneous minimum ≥3.2 mg/l	Survival of threatened/endangered sturgeon species[1]	
Deep water seasonal fish and shellfish use	30-day mean ≥3 mg/l	Survival and recruitment of bay anchovy eggs and larvae	June 1-September 30
	One-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	
	Open water fish and shellfish designated use criteria apply		October 1-May 31
Deep-channel seasonal refuge use	Instantaneous minimum ≥1 mg/l	Survival of bottom-dwelling worms and clams	June 1-September 30
	Open water fish and shellfish designated use criteria apply		October 1-May 31

[1]At temperatures considered stressful to shortnose sturgeon (*Acipenser brevirostrum*) (>29°C) dissolved oxygen concentrations above an instantaneous minimum of 4.3 mg/l will protect survival of this list sturgeon species.

Source: Tango and Batiuk (2013)

Water Quality Criteria
Water Clarity/SAV

TABLE 2. Options for Measuring Attainment of the Chesapeake Bay Shallow Water Designated Use.

Measure of Attainment	Option
Submerged aquatic vegetation acres only	The single best year of SAV acreage mapped through the bay-wide aerial survey in the past three years passes attainment of water clarity standards if the acreage in a management segment is equal to or higher than the segment-specific SAV restoration goal target
Water clarity acres only	If a segment does not pass its SAV acreage goal with aerial survey data, and there are available water quality mapping data, achievement of a water clarity criteria acreage necessary to support the SAV acreage goal can be assessed. Water clarity acres can be assessed regardless of whether or not SAV is present. Water clarity acre goals are 2.5× the SAV goal acres in a Chesapeake Bay management segment
Integrated measure of submerged aquatic vegetation and water clarity acres	A combination assessment of mapped SAV and water clarity acreage that, taken together, meets acreage goals

Note: SAV, submerged aquatic vegetation.

TABLE 3. Chesapeake Bay Water Clarity Criteria.

		Water Clarity Criteria as Secchi Depth								
		Water Clarity Criteria Application Depths								
		0.25	0.50	0.75	1.0	1.25	1.50	1.75	2.0	
Salinity Regime	Water Clarity as Percent Light Through Water (%)	Secchi Depth (meters) for Above Criteria Application Depths								Temporal Application
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

Source: Tango and Batiuk (2013)

Water Quality Criteria
Chlorophyll-a (recommended)

TABLE 5. Chesapeake Bay Chlorophyll *a* Derivations Toward Numerical Criteria (summarized from USEPA, 2007b).

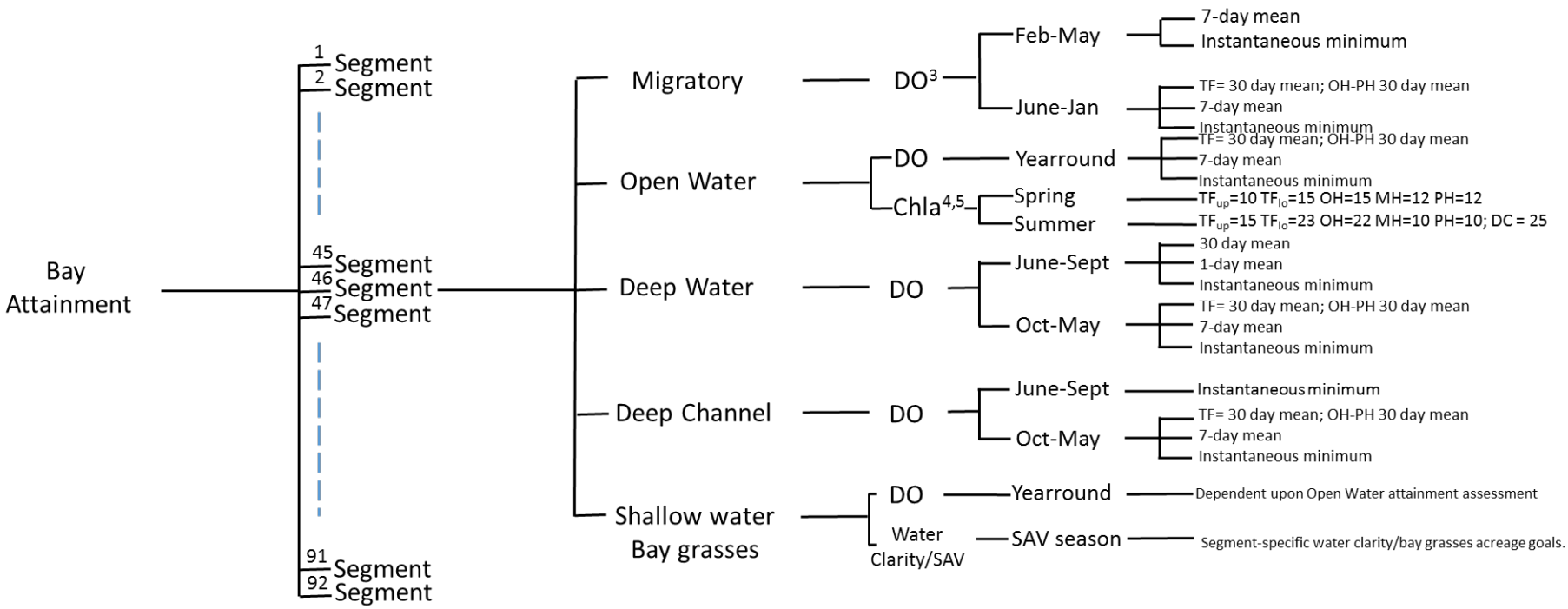
Method	Season	Salinity Zone	Criteria	Application
Historical reference DO	Spring	OH	18	90th percentile of a log normal distribution
		MH	8	
		PH	4	
	Summer	OH	46	90th percentile of a log normal distribution
		MH	23	
		PH	5	
DO impairment	Annual	TF-OH-MH-PH	10-15	Mean, deep water
			30	Mean, shallow water
Water clarity reference condition	SAV growing season	TF-OH	43, 11, N/A	Seasonal means for restoration targets of clarity are 0.5-, 1.0-, and 2.0-m depths, respectively
		MH-PH	39, 16, 3	
HAB impairment	Summer	TF-OH	27.5	90th percentile of a log normal distribution

Note: TF, tidal fresh; OH, oligohaline; MH, mesohaline; PH, polyhaline; DO, dissolved oxygen; SAV, submerged aquatic vegetation; HAB, harmful algal bloom.

Source: Tango and Batiuk (2013)

Water Quality Criteria
Full Assessment

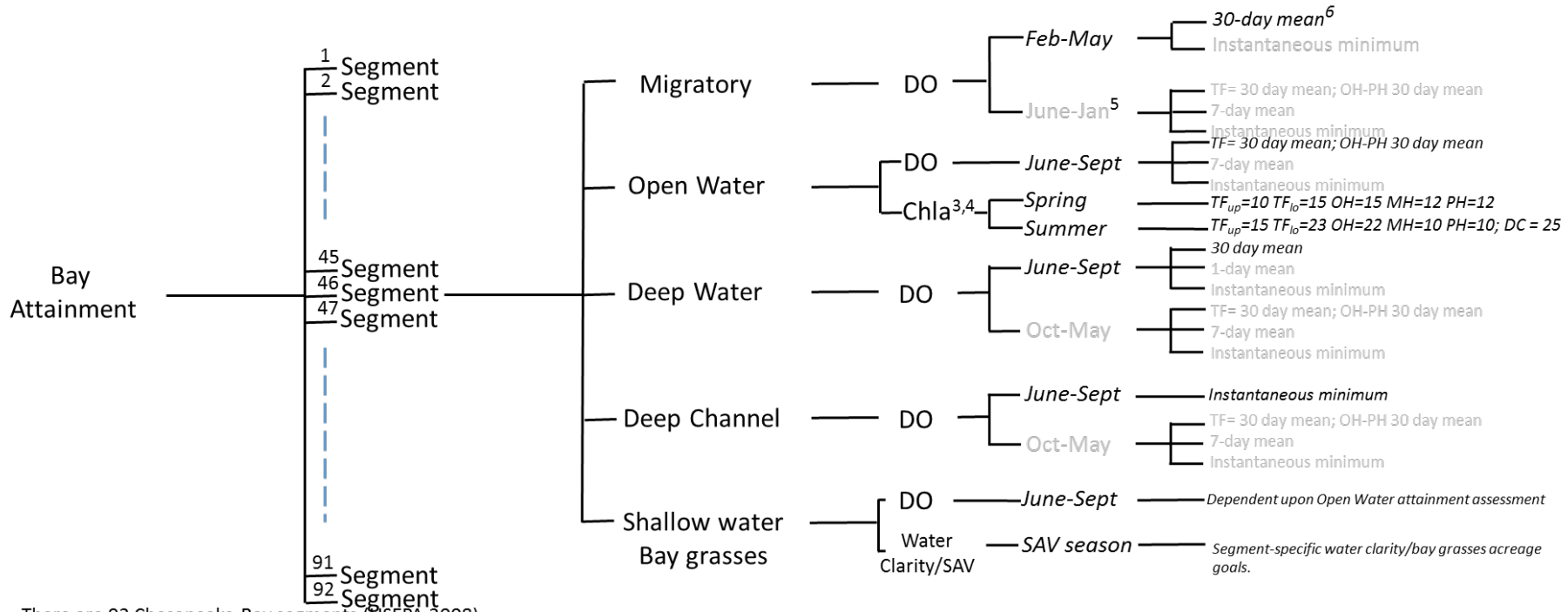
FULL Water Quality Standards Attainment Assessment for Chesapeake Bay Dissolved Oxygen, Water Clarity and Chlorophyll a



1. There are 92 Chesapeake Bay segments (USEPA 2008)
2. Designated uses are segment specific. Not all designated uses apply to each Chesapeake Bay segment
3. DO = dissolved oxygen. Thresholds are listed in USEPA 2003, Executive summary, Table 1,
4. Salinity zone-specific thresholds on the James River, VA: TF_{up}=Tidal Fresh upper segment, TF_{lo}=Tidal Fresh lower segment, OH=Oligohaline, MH=Mesohaline, PH=Polyhaline. DC= Washington District of Columbia.
5. The James River chlorophyll a criteria are assessed for attainment of a geometric mean measure of the water quality.

Water Quality Criteria
Indicator Assessment

INDICATOR Water Quality Standards Attainment Assessment for Chesapeake Bay DO, Water Clarity and Chlorophyll a



1. There are 92 Chesapeake Bay segments (USEPA 2008)
2. Designated uses are segment specific. Not all designated uses apply to each Chesapeake Bay segment.
3. Salinity zone-specific thresholds on the James River, VA: TF_{up}=Tidal Fresh upper segment, TF_{lo}=Tidal Fresh lower segment, OH=Oligohaline, MH=Mesohaline, PH=Polyhaline. DC= Washington District of Columbia.
4. The James River chlorophyll *a* criteria are assessed for attainment of a geometric mean measure of the water quality.
5. Gray text are elements of the full water quality standards attainment not included in the indicator calculations.
6. USEPA (2003) does not have a 30-day mean Feb-May DO threshold. The decision for the indicator used a 30-day mean of 6 mg/l as Feb-May DO threshold, same as the 7-day mean.

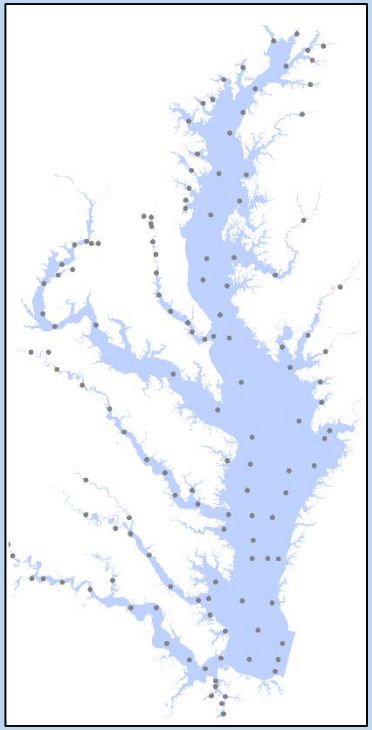
Outline

- Water Quality Criteria
- Current Attainment Indicator
- "Attainment Deficit" Concept
- "Beyond Capacity" Concept
- Potential Next Steps

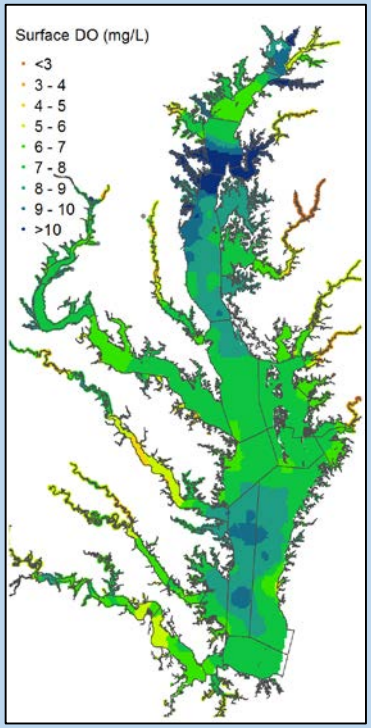
Chesapeake Bay Program
Science. Restoration. Partnership.

Water Quality Criteria Assessment

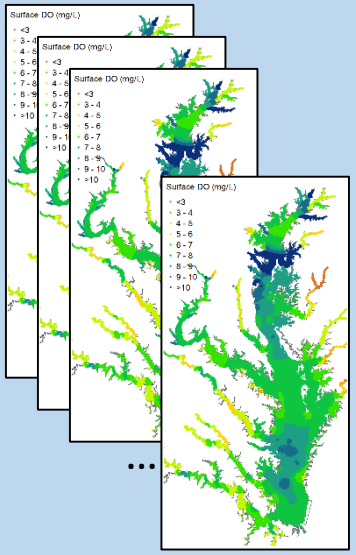
Bi-weekly to Monthly observations



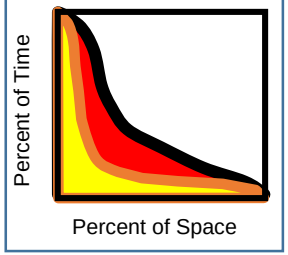
Monthly interpolations



Combine interpolations for a specific season, over 3-year period (DO and Chl-a)



Construct CFD



Yes/no each segment in this 3-year period

Water Quality Criteria Assessment

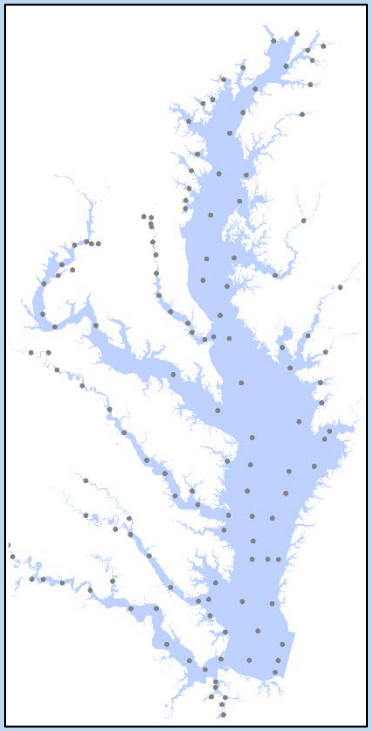
1. Collect data at ~175 long-term water quality monitoring locations.

- generally 2/mo May-September 1/mo at other times
- Average if >1 data in a given month.

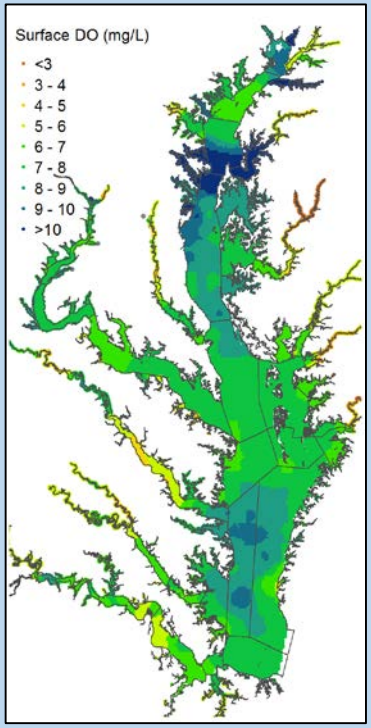
2. Spatially interpolate the monthly data across each of the 92 segments using the following method.

- Vertically interpolate for a sampling cruise (first or second) (grid resolution: 1 m)
- Horizontal interpolation of a cruise (grid resolution: 1 km^2).
- If 2 or more cruises in a month, average interpolations within that month.
- Apportion results by designated uses.

Bi-weekly to Monthly observations



Monthly interpolations



Source: Tango and Batiuk (2013)

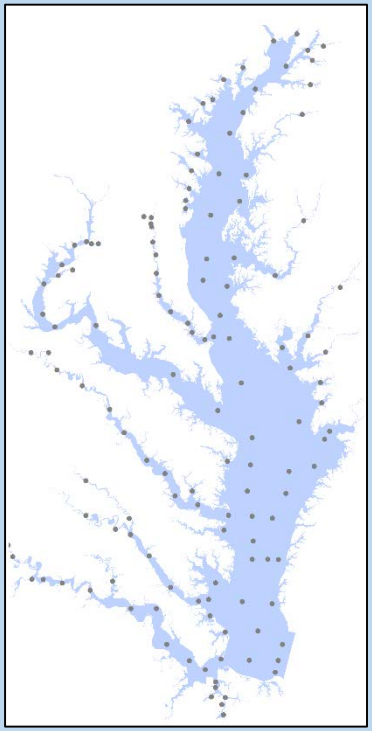
Water Quality Criteria Assessment

Parameters Involved

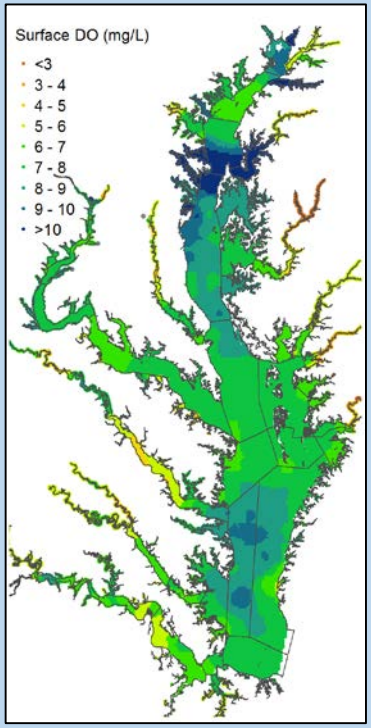
- DO in mg/L
- SAV acreage
- in vivo fluorescence and chlorophyll a measurements (ug/L).
- Secchi depth (m)
- salinity (unitless)
- water temperature (T oC)

→ Salinity and water temperature are necessary to compute the vertical density structure of the water column, which is translated into designated use layers for open water, deep water, and deep channel boundaries of the DO attainment assessments.

Bi-weekly to Monthly observations



Monthly interpolations



Water Quality Criteria Assessment

3. Determine the compliance status of each cell in the segment volume.

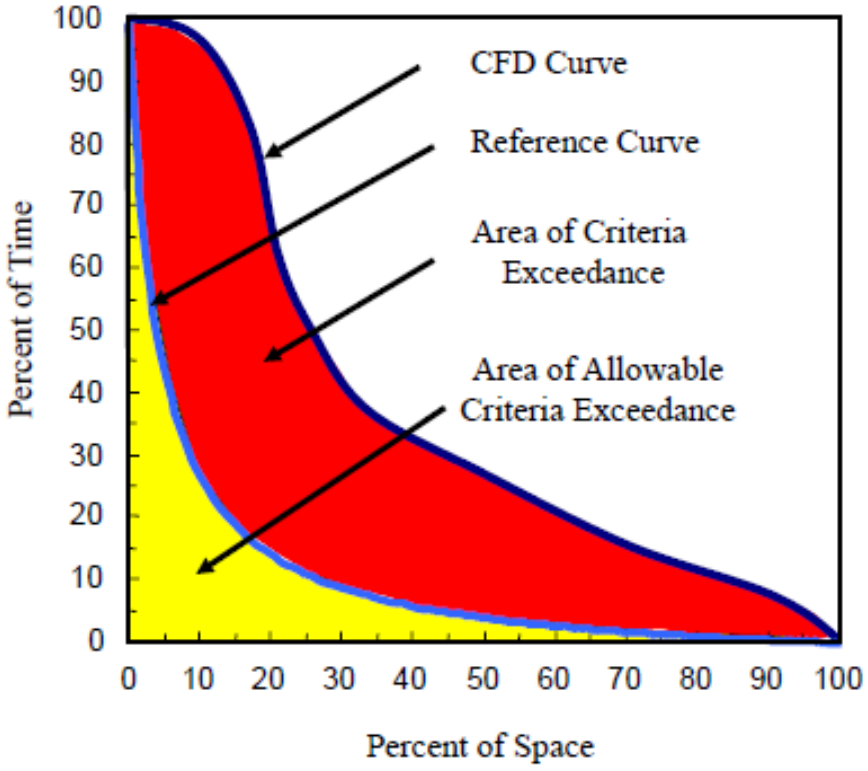
4. Produce a percent compliance matrix with sample period and percent space in compliance.

5. Rank the percent compliance in space from greatest to lowest values and assign percent of time associated with the compliance values.

6. Plot ranked percent space (x-axis) against percent time (y-axis).

7. Evaluate compliance against the reference curve.

For 1 specific segment



Source: Tango and Batiuk (2013)

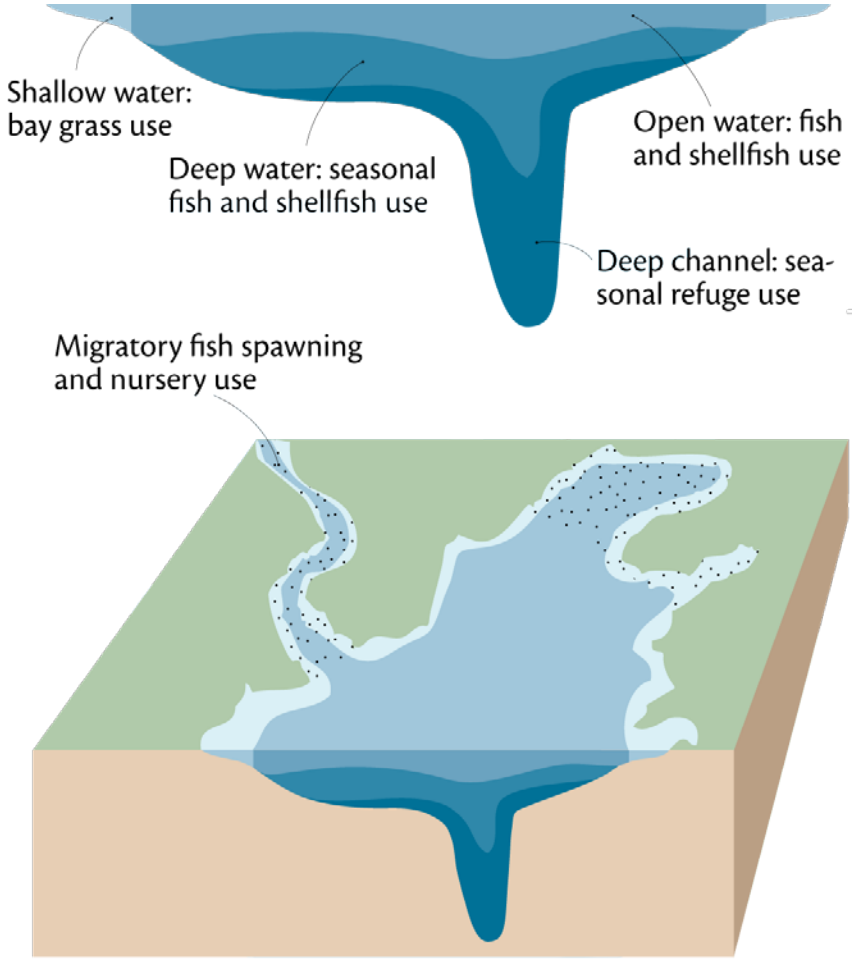
Water Quality Criteria Attainment Indicator

Single combined indicator

A Bay-wide fractional attainment indicator computed on a surface-area basis for all designated uses

- Equal weight of the three criteria for each segment
- Surface area-weighting (considering relative size)

Criteria	Designated Use	Threshold	Number of Applicable Segments
Dissolved Oxygen	Open Water (OW)	30-day mean, June-September	92
	Deep Water (DW)	30-day mean, June-September	18
	Deep Channel (DC)	Instantaneous, June-September	10
Chlorophyll-a	Open Water (OW)	Chlorophyll-a concentrations	7
SAV and or Water Clarity	Shallow Water (SW)	Segment-specific water clarity and bay grass acreage goals	79 (91/104 split)



Conceptual diagram illustrating the designated use areas in Chesapeake Bay to help determine threshold values needed for different indicators when reporting water clarity, and other water-quality indices.
Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Longstaff, B.J., T.J.B. Carruthers, W.C. Dennison, T.R. Lookingbill, J.M. Hawkey, J.E. Thomas, E.C. Wicks, and J. Woerner (eds) (2010) Integrating and applying science: A handbook for effective coastal ecosystem assessment. IAN Press, Cambridge, Maryland.

Water Quality Criteria Attainment Indicator

The attainment indicator presently uses **a subset** of the criteria otherwise necessary for a complete accounting of the three WQ criteria categories.

1. DO Criterion

- **Assumption**: the attainment of the **30-day mean** dissolved oxygen criterion can serve as an "umbrella" assessment to the remaining criteria applicable.
- Migratory Fish and Spawning Nursery: applied the **6 mg/L** 7-day mean DO criterion as if it were a 30-day mean to represent protections.
- Open-Water: **5 mg/L** 30-day mean DO criteria.
- Deep-Water: **3 mg/L** 30-day mean DO criteria.
- Deep-Channel: **1 mg/L** instantaneous minimum DO criteria.

2. Shallow-Water SAV Criterion

When water clarity assessment data are available, the shallow-water bay grasses designated use is considered in attainment if:

1. sufficient acres of SAV are observed within the segment; **and/or**
2. enough acres of shallow-water habitat meet the applicable water clarity criteria to support restoration of the desired SAV acreage for that segment.

Water Quality Criteria Attainment Indicator

3. Chlorophyll criterion

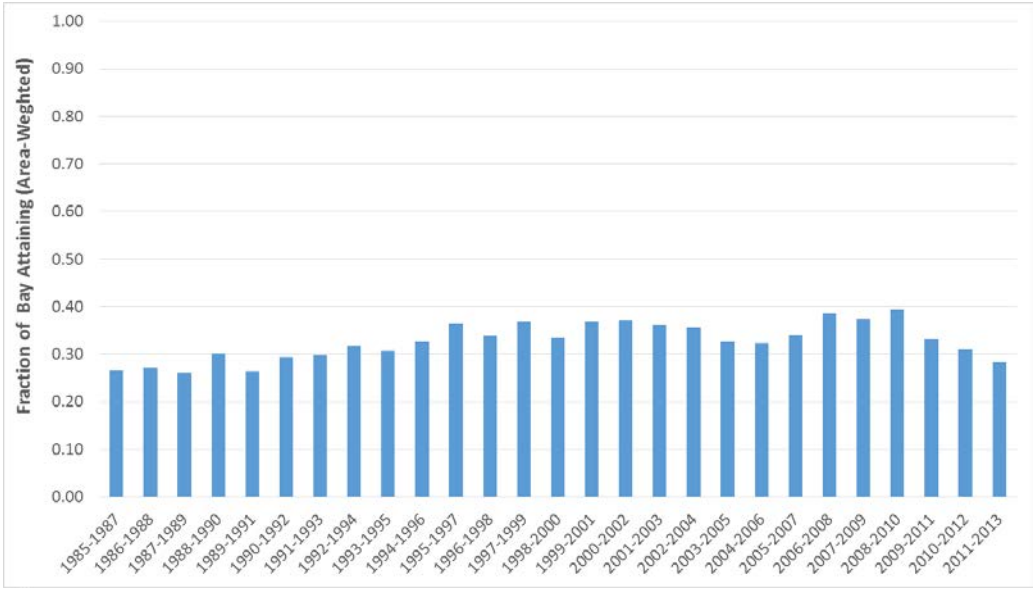
- Applied to the open-water designated use for:
  - James River segments: Criteria attainment assessed during spring (Mar1-May31) and summer (Jun1-Sep30) seasons; both seasons must be meeting the standards for the segment to be in attainment.
  - District of Columbia's Upper Potomac River and Anacostia River segments: Criteria attainment only assessed during the summer (Jun1-Sep30) season.

1+2+3. Single combined indicator

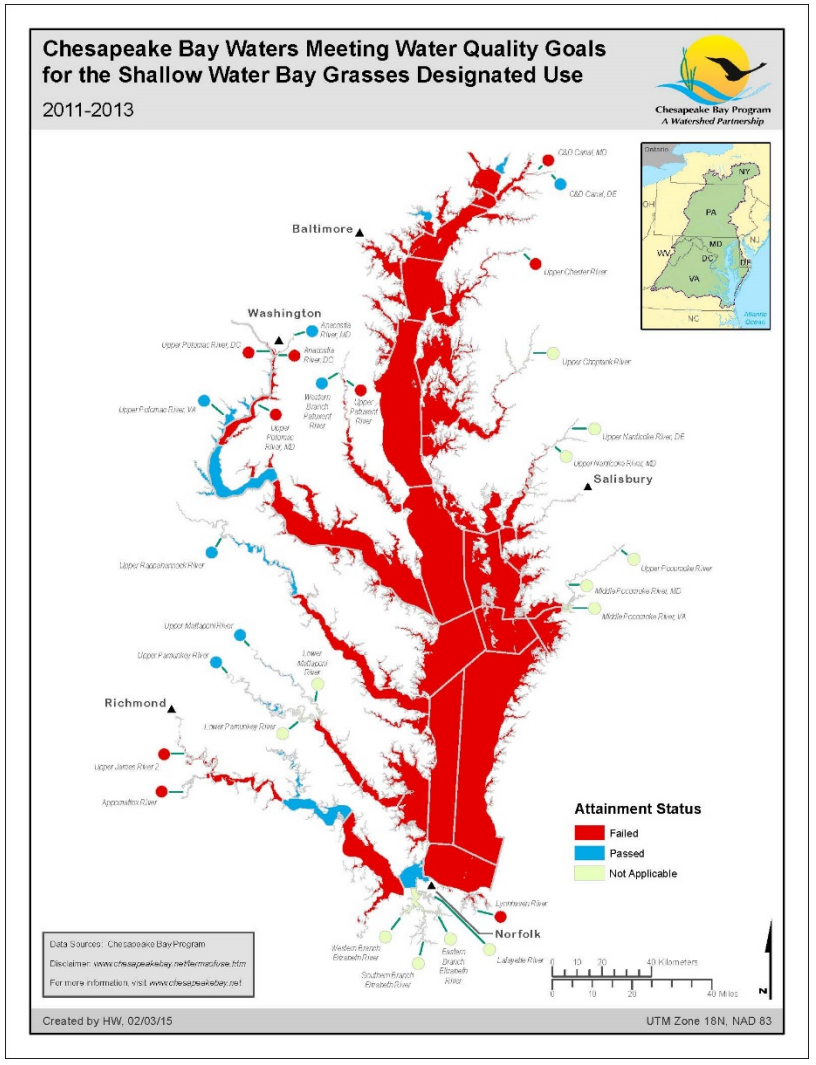
- Summarized for every applicable designated use and criteria contained within each of the 92 segments.
- A Bay-wide fractional attainment indicator:
  - **Equal weight of the three criteria for each segment**
  - **Surface area-weighting** (considering segments' relative size)

Water Quality Criteria Attainment Indicator

Area-Weighted Fraction of Bay In Attainment for Each 3-year Period

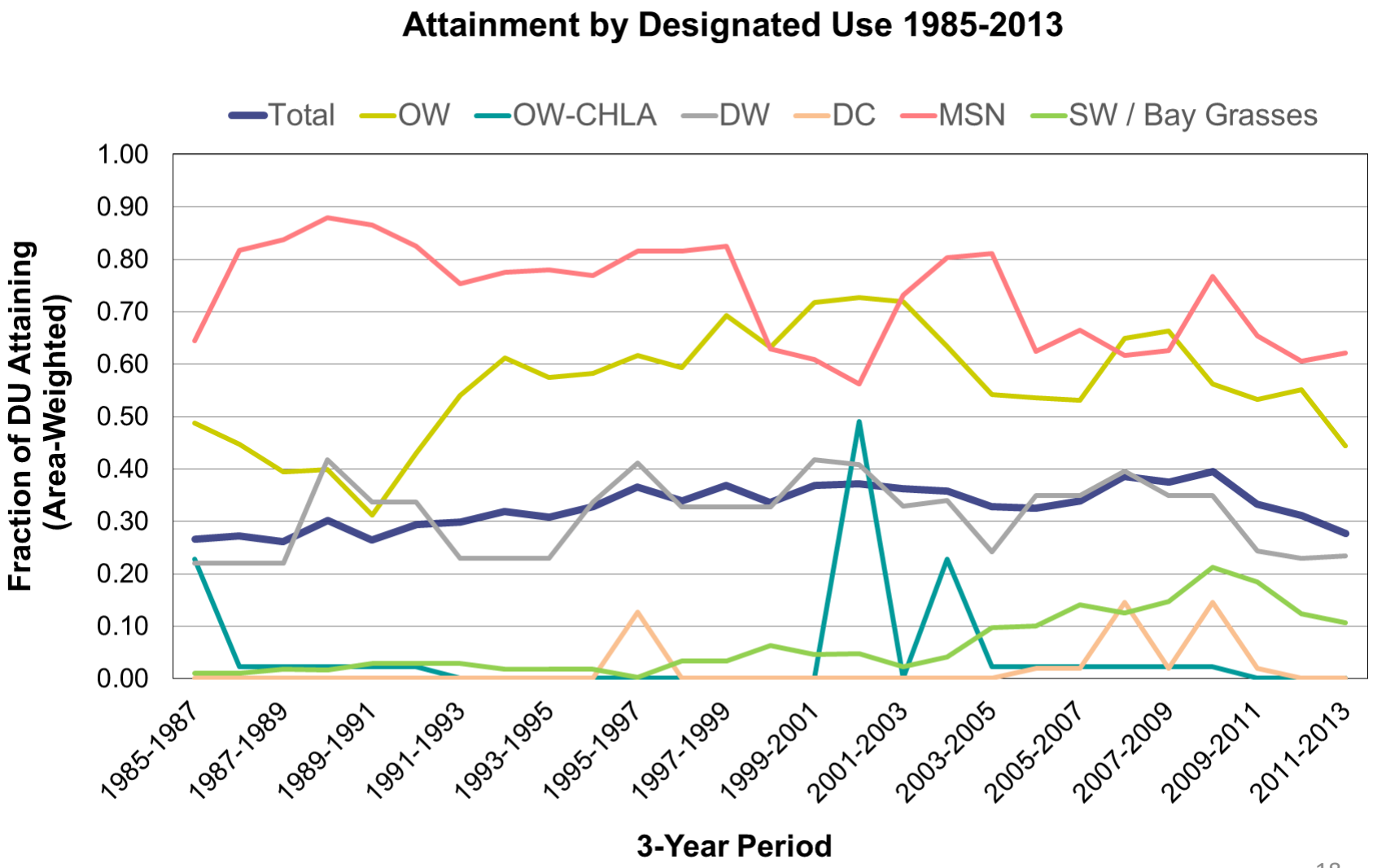


Single 3-year Period Pass/Fail for Shallow Water Segments →



Water Quality Criteria Attainment Indicator

By Designated Use



Outline

- Water Quality Criteria
- Current Attainment Indicator
- **"Attainment Deficit" Concept**
- "Beyond Capacity" Concept
- Potential Next Steps

Chesapeake Bay Program
Science. Restoration. Partnership.

Percent to Attainment

If not at attainment, is it getting closer?

- Single Segment Attainment
  - Is criteria met? Yes/No
  - Either 0 or 1
- Single Segment Percent to Attainment (or Deficit)
  - How close is the segment to attainment?
  - Percent to attainment = 100% – percent segment out of attainment (%)
    - For DO and Chlorophyll DUs, this is both spatial and temporal (CFD Curves)
    - SW based on acreage goal
  - Are they getting closer to or farther away from attainment in each segment?
  - Previous work led by Mindy Ehrich

Segment X Open Water DO

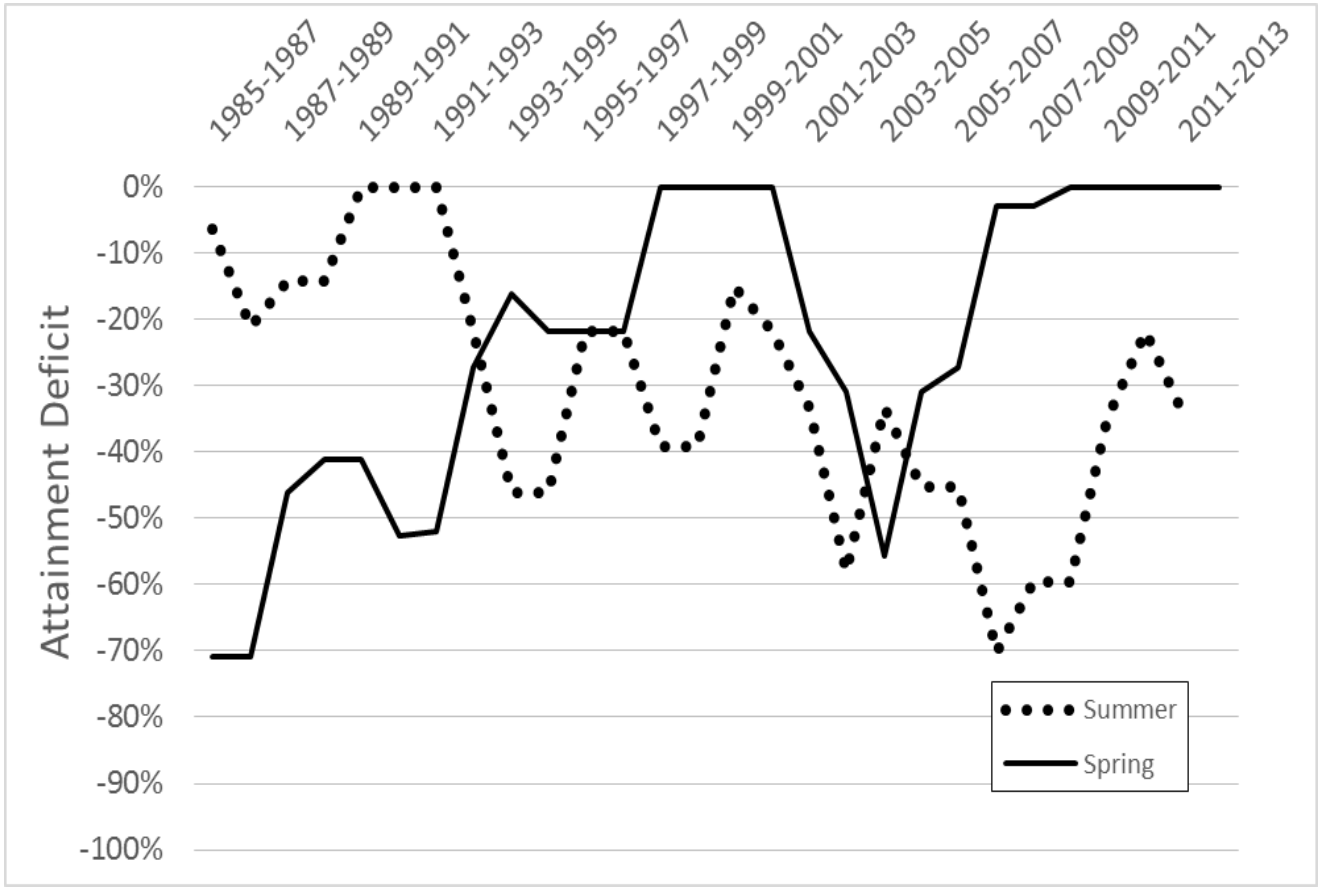
Years	Attainment	Percent to Attainment
1985-1987	Y	0
1986-1988	Y	0
1987-1989	Y	0
1988-1990	Y	0
1989-1991	Y	0
1990-1992	Y	0
1991-1993	Y	0
1992-1994	N	-2.94
1993-1995	N	-9.03
1994-1996	N	-9.04

Percent to Attainment

If not at attainment, is it getting closer?

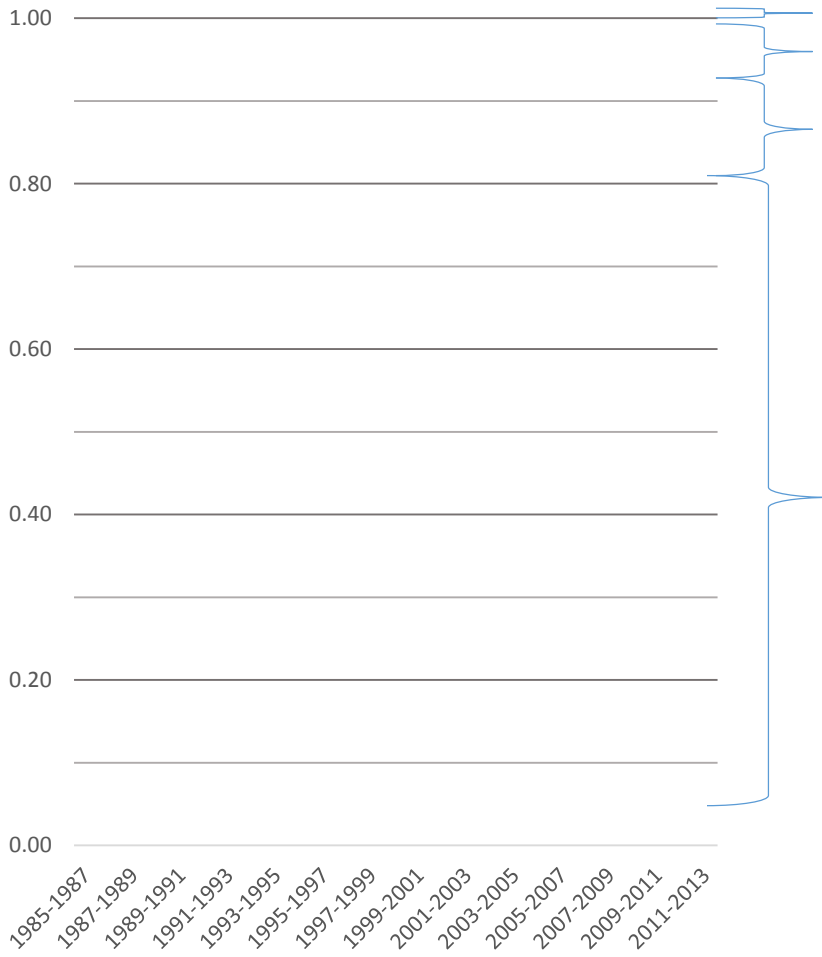
Segment **JMSPH** (Mouth of James River)

Chl-a summer and spring attainment deficits from 1985-2014



Percent to Attainment
Categorization for Dissolved Oxygen

How close to attainment is the segment?



At/Near Attainment -> Mostly/All 1.0

95-100 %-> Numerous in the 0.95-1.00 Range

80-95%-> Most values between 0.80-0.95 / High variability of values crossing multiple categories

<80%-> Numerous values less than 80%

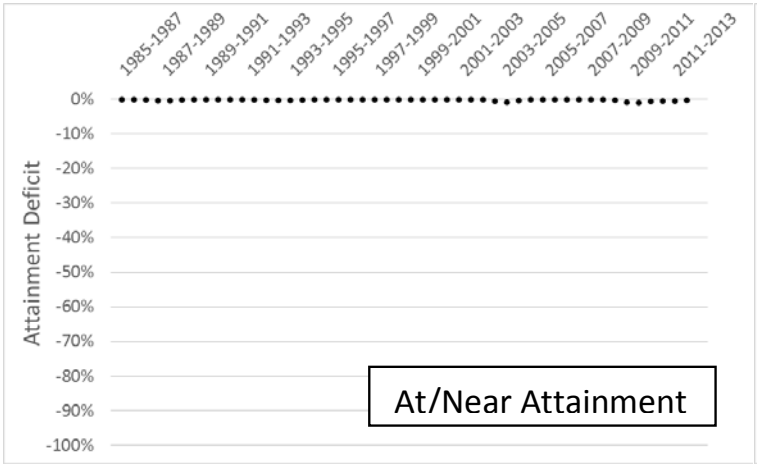
Is there any significant trend?

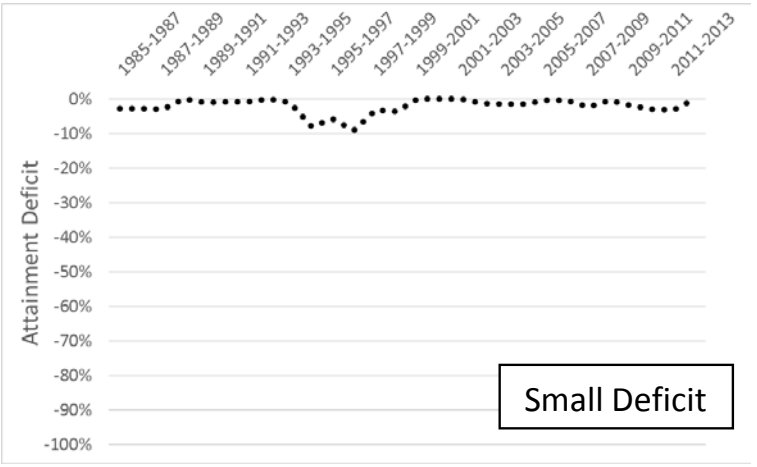
↑ - Increasing

↓ - Decreasing

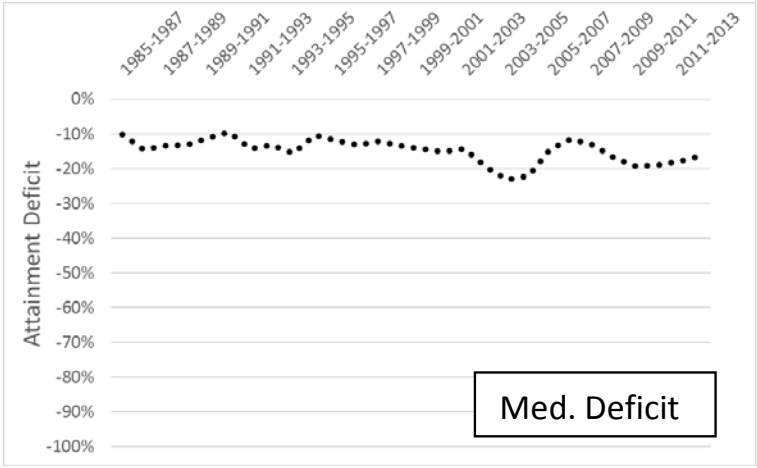
Note: The percent change is slight.

Percent to Attainment
DO

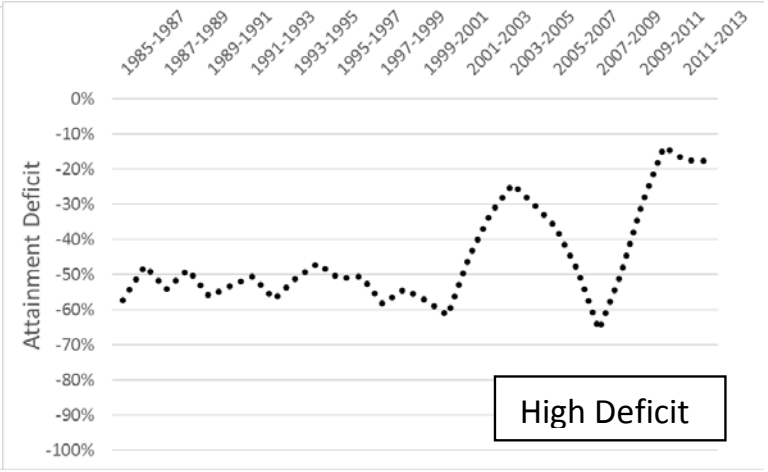




CB3MH - DC

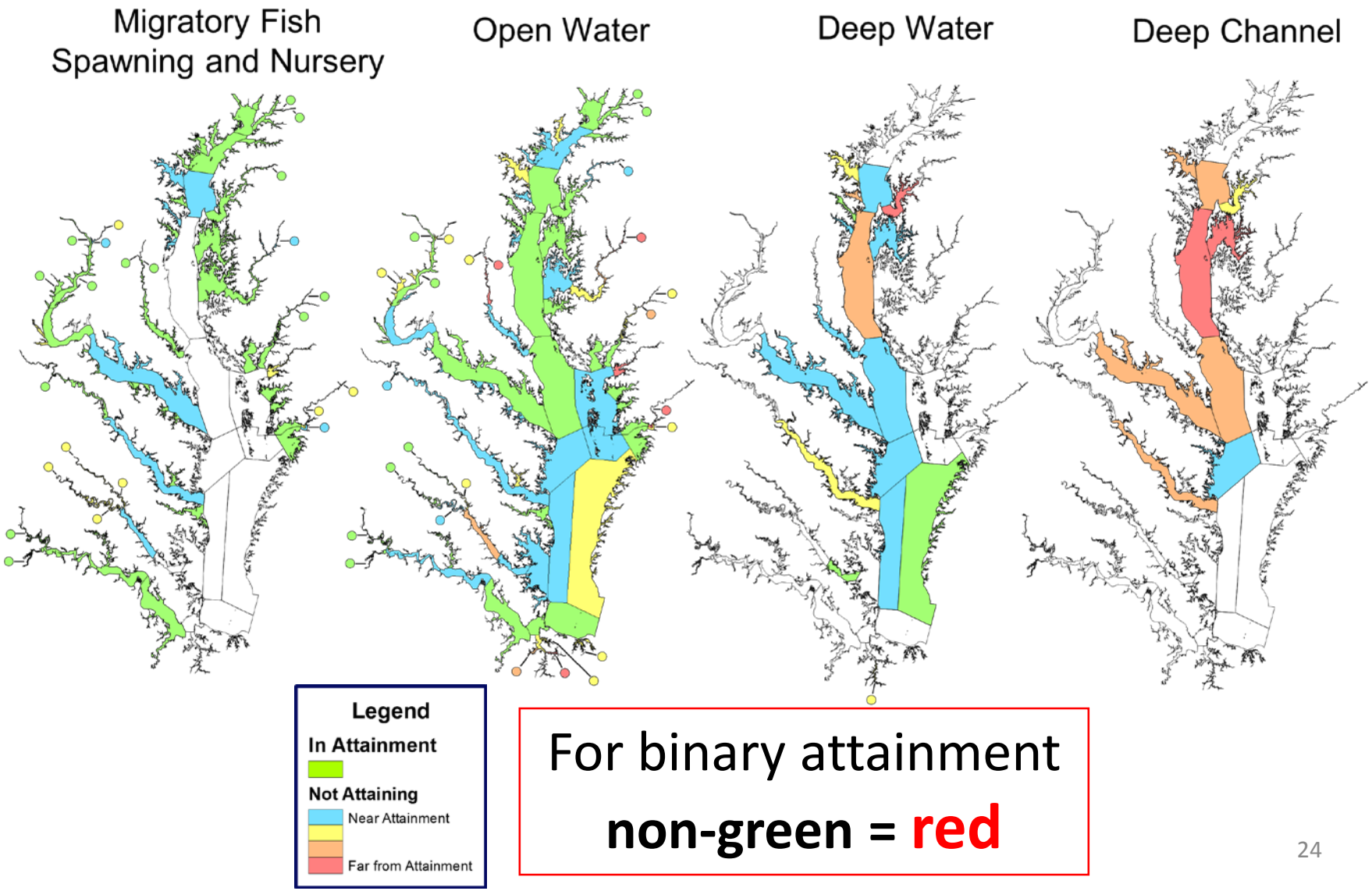


MAGMH - DW



Percent to Attainment

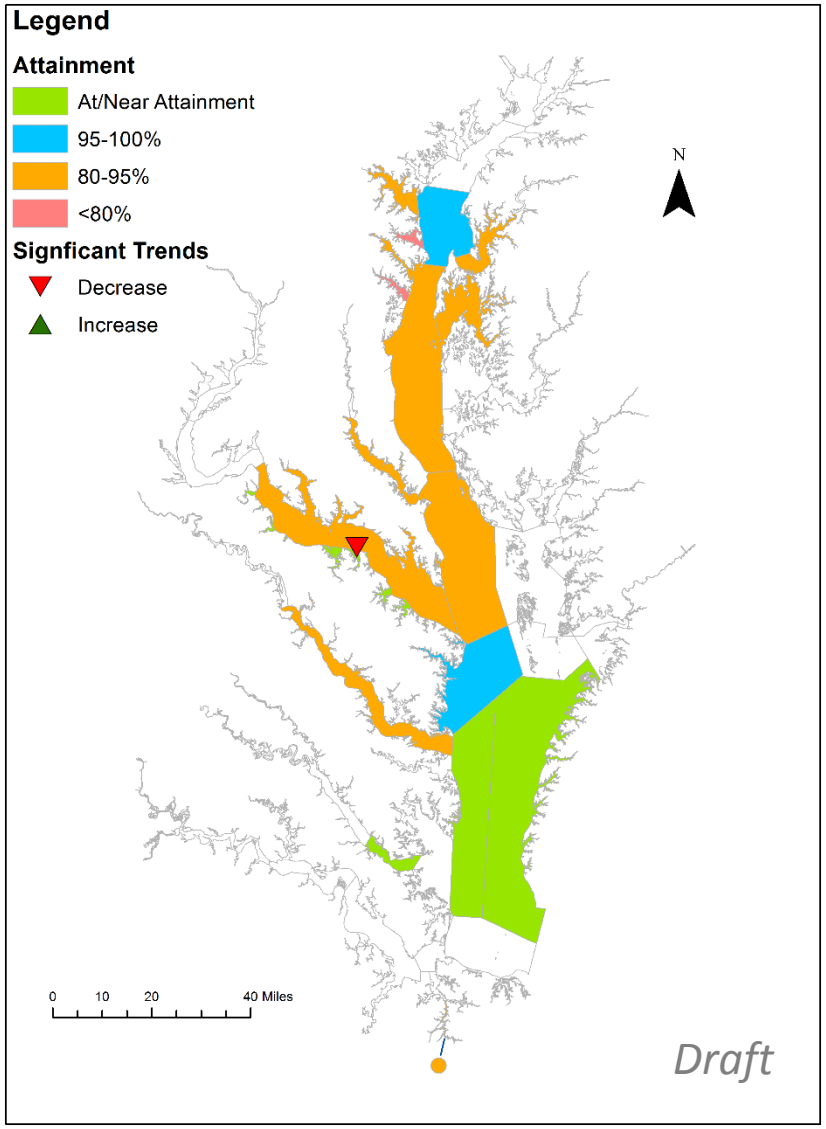
DO 2011-2013



For binary attainment

non-green = red

Percent to Attainment
Deep Water DO 1985-2013



Category	Count	Category	Count
At/Near Attainment	4	80-95%	10
95-100%	2	<80%	2

Trends	
Significant ↑	0
Significant ↓	1

- Most Deep Channel segments have not been near attainment over the time series.
- The Lower Bay is doing well.
- Mid Bay is not doing well, and the Lower Potomac River has been degrading.

Outline

- Water Quality Criteria
- Current Attainment Indicator
- "Attainment Deficit" Concept
- **"Beyond Capacity" Concept**
- Potential Next Steps

Chesapeake Bay Program
Science. Restoration. Partnership.

Beyond Capacity

If at attainment, how much buffer does it have?

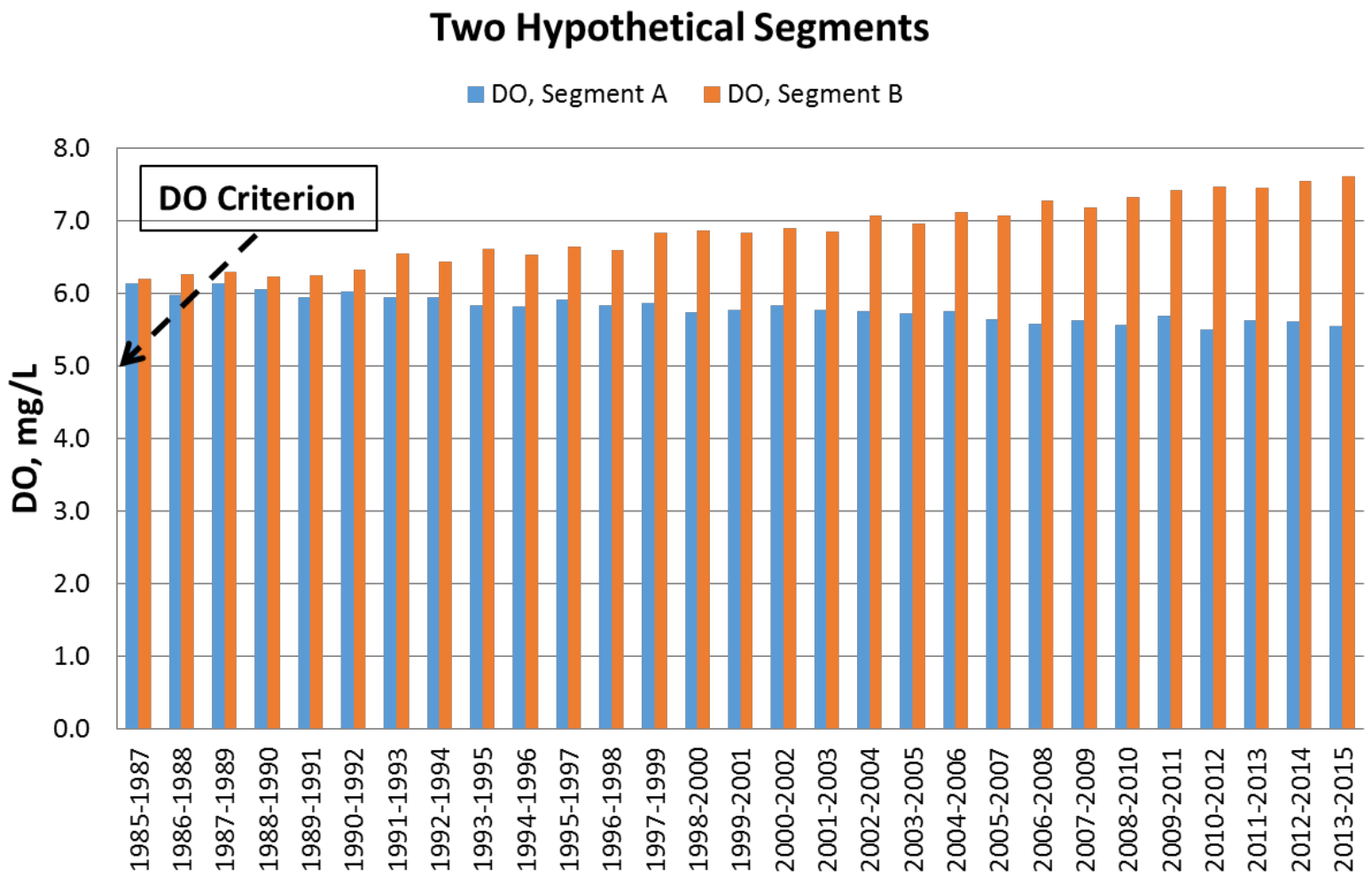
- Single Segment Attainment
  - Is criteria met? Yes/No
  - Either 0 or 1
- Single Segment Percent to Attainment
- Single Segment Beyond Capacity
  - How much buffer does the segment have?
  - Manipulating the thresholds (e.g., DO criteria) to test the "**resiliency**" of the segments with respect to a specific criterion
  - What is the max DO threshold for a segment to be classified as at attainment?
  - Examine trend in "resiliency"

PAXTF OW DO

Years	Attainment	Percent to Attainment	Beyond Attainment
1985-1987	Y	0	+?
1986-1988	Y	0	+?
1987-1989	Y	0	+?
1988-1990	Y	0	+?
1989-1991	Y	0	+?
1990-1992	Y	0	+?
1991-1993	Y	0	+?
1992-1994	N	-2.94	-2.94
1993-1995	N	-9.03	-9.03
1994-1996	N	-9.04	-9.04

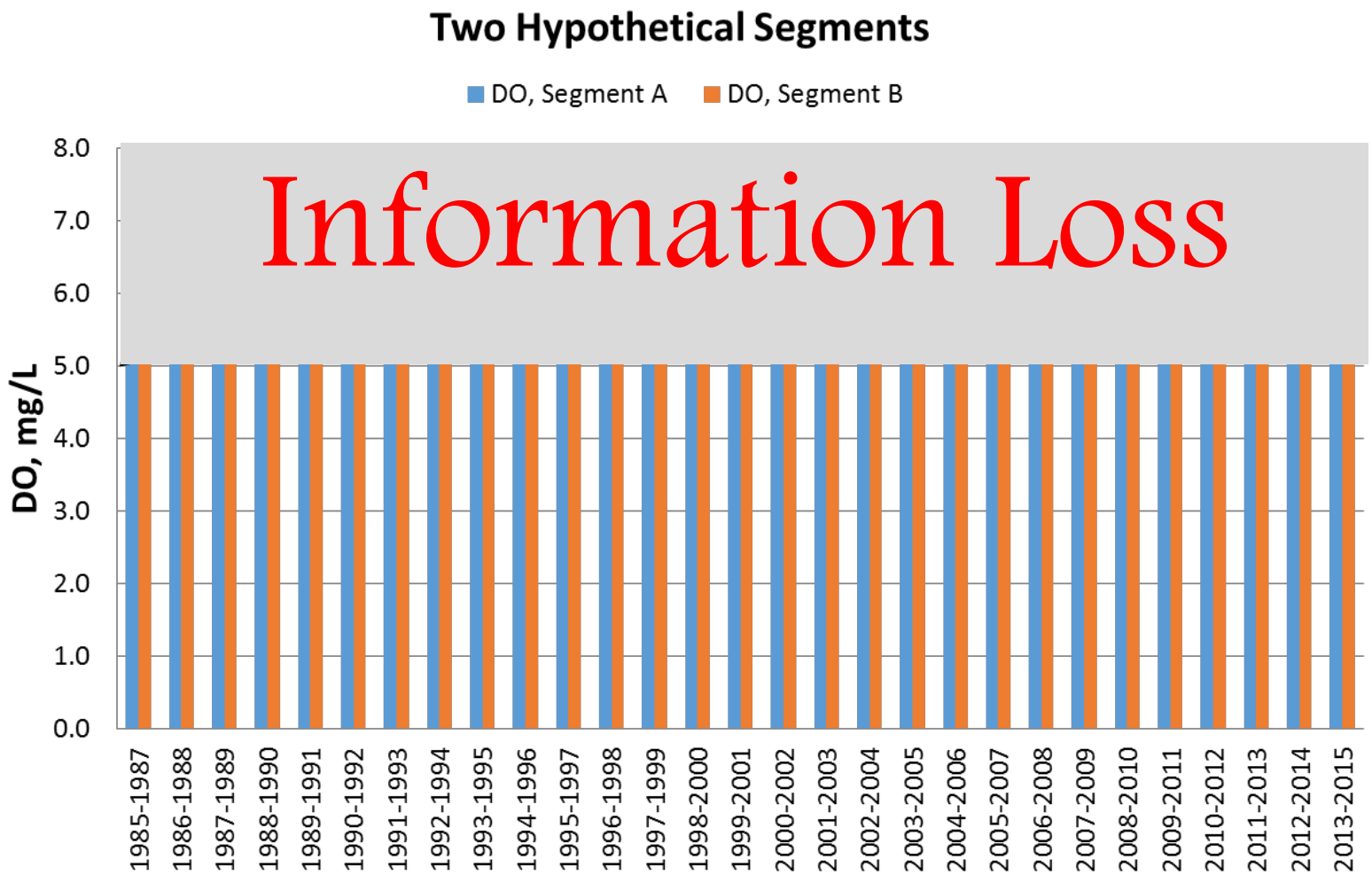
Beyond Capacity

If at attainment, how much buffer does it have?



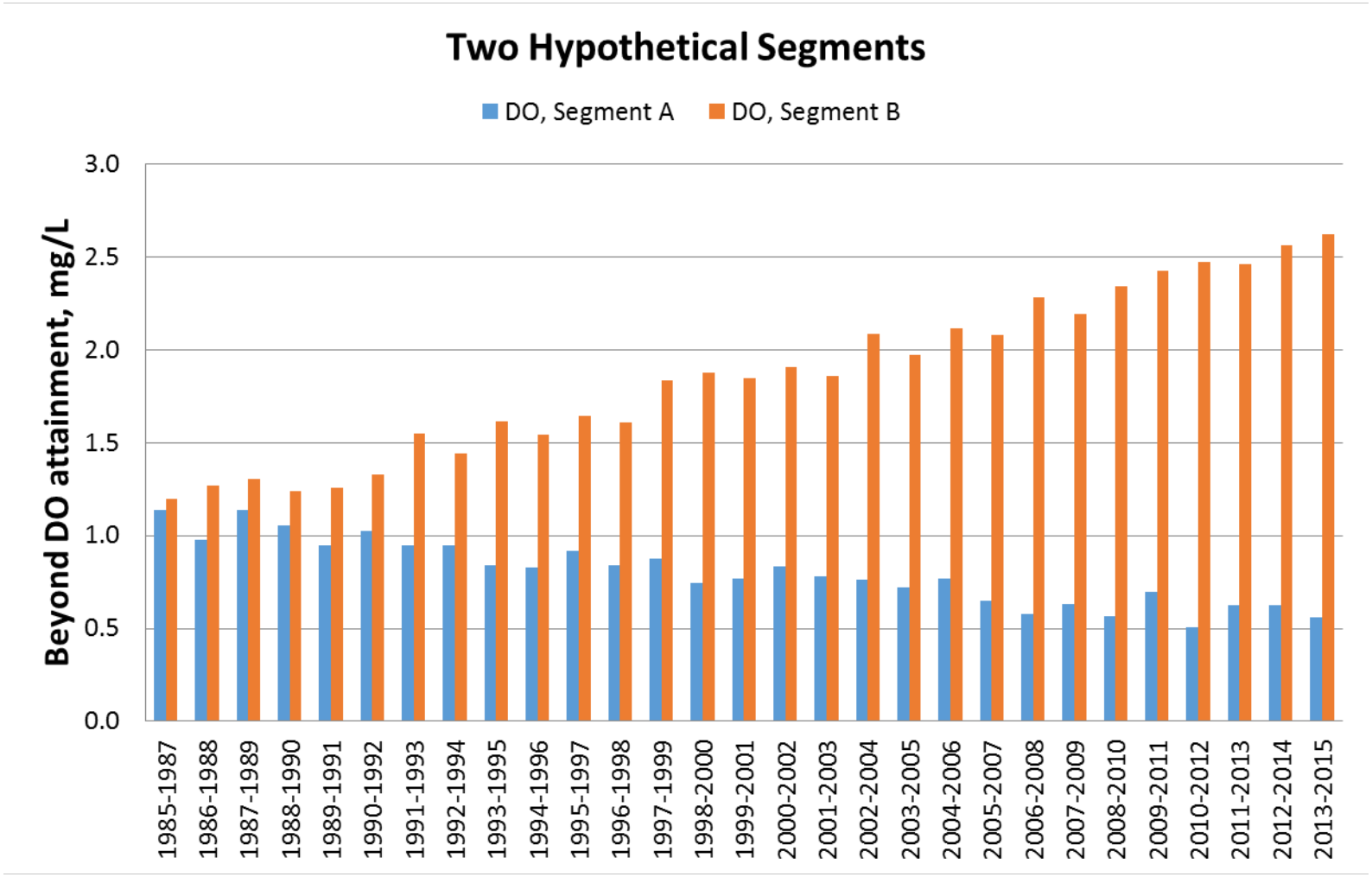
Beyond Capacity

If at attainment, how much buffer does it have?



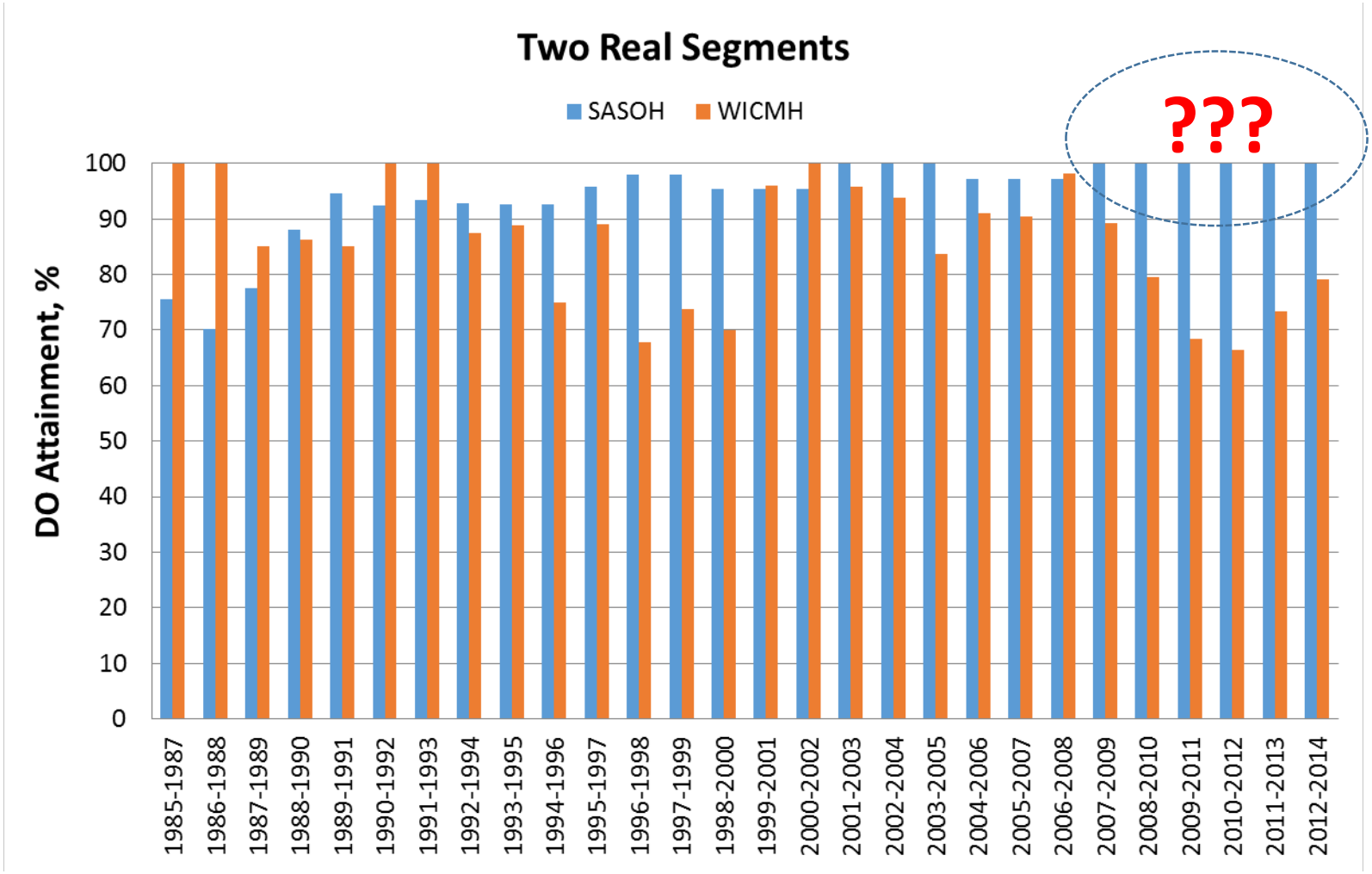
Beyond Capacity

If at attainment, how much buffer does it have?



Beyond Capacity

If at attainment, how much buffer does it have?



SASOH: Sassafras River WICMH: Wicomico River

Outline

- Water Quality Criteria
- Current Attainment Indicator
- “Attainment Deficit” Concept
- “Beyond Capacity” Concept
- **Potential Next Steps**

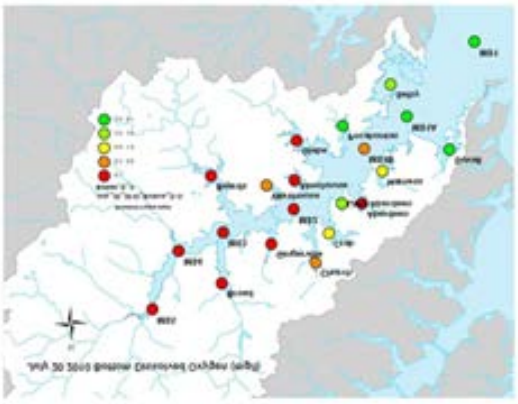
Chesapeake Bay Program
Science. Restoration. Partnership.

Things to Consider

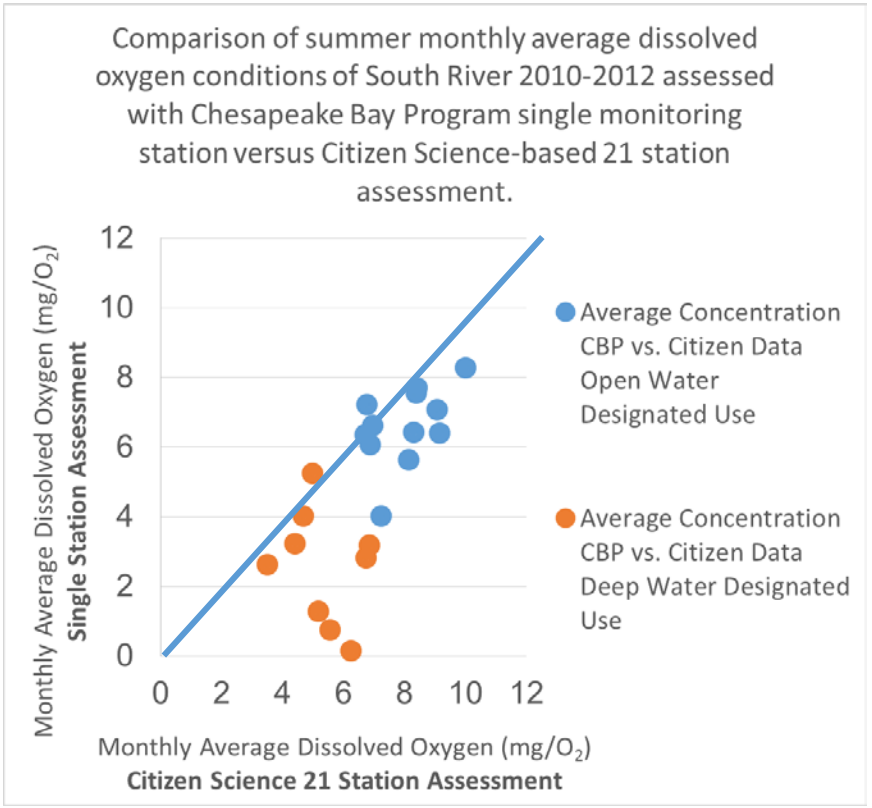
- The indicator has rules for overcoming the lack of full information on short-term criteria required for declaring a segment's full status.
- We can show the raw accounting compared to data that are missing, if the true attainment measure is wanted.
- The "**attainment deficit**" and "**beyond attainment**" quantification provides new information on water quality conditions and trends -- potentially useful for guiding decision making through more targeted allocations of resources.
  - 2 "failed" segments can be different in terms of severity.
  - 2 "passed" segments can be different in terms of resiliency (and our c**onfidence/certainty** in the attainment status).

Data Resolution
Uncertainty in Attainment Results

CBP monitoring
1-station



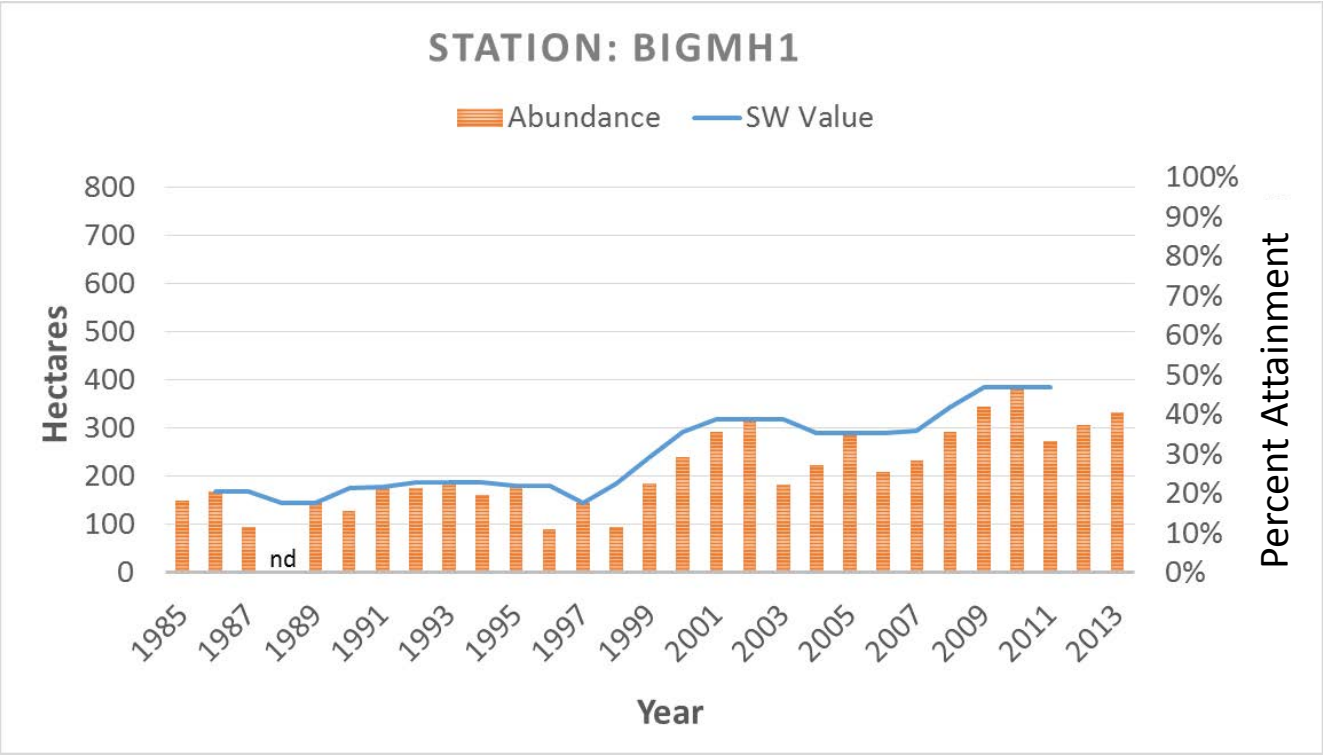
South River Federation monitoring
21-stations



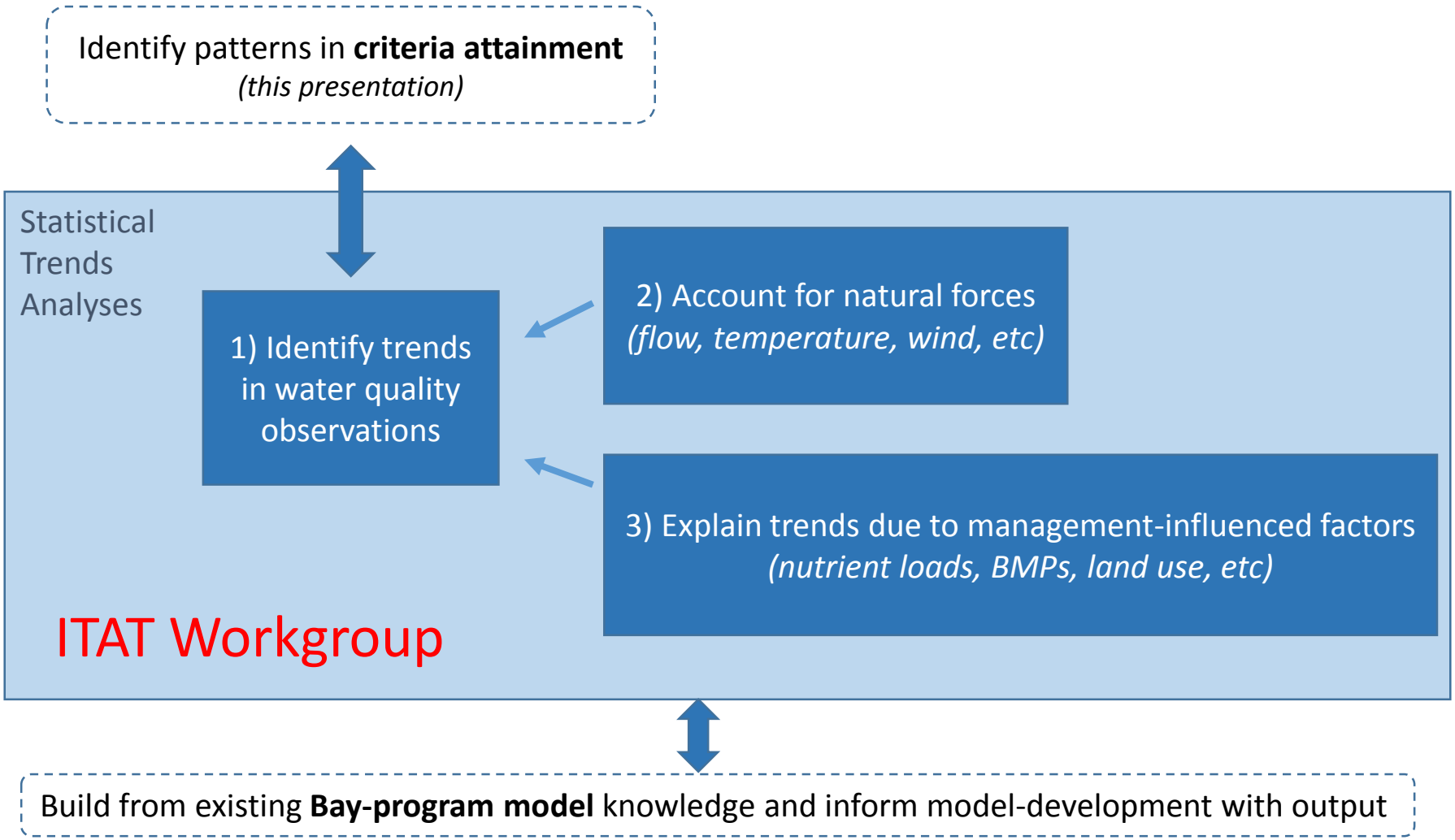
Greater spatial resolution with Cit Sci monitoring suggests that dissolved oxygen conditions are often better in South River than we see with CBP-only data.

Linking to Monitoring Data
SW/SAV example

Does the monitoring data tell the same story as the attainment values?



Linking to Watershed Factors



Potential Next Steps

Suggestion? Priority? Timeline? Workplan? Communication?

1. Develop "Beyond Capacity" by manipulating thresholds
2. Incorporate new assessment protocols for handling short-duration criterion
3. Identify and compare long-term trends in (binary) attainment, attainment deficit, and beyond capacity
4. Visualize spatial patterns in attainment (with maps)
5. Compare attainment results with findings from trend analysis of station-based data (e.g., GAMs)
6. Link results to watershed factors (on tributary basis?)
7. Evaluate segment behaviors by groups (salinity, rivers, etc)
8. Explore/test volume-based indicators (e.g., hypoxic volume)