Monitoring Chesapeake Bay:

Recent guidance and investments for dissolved oxygen, SAV, water clarity, and chlorophyll *a*

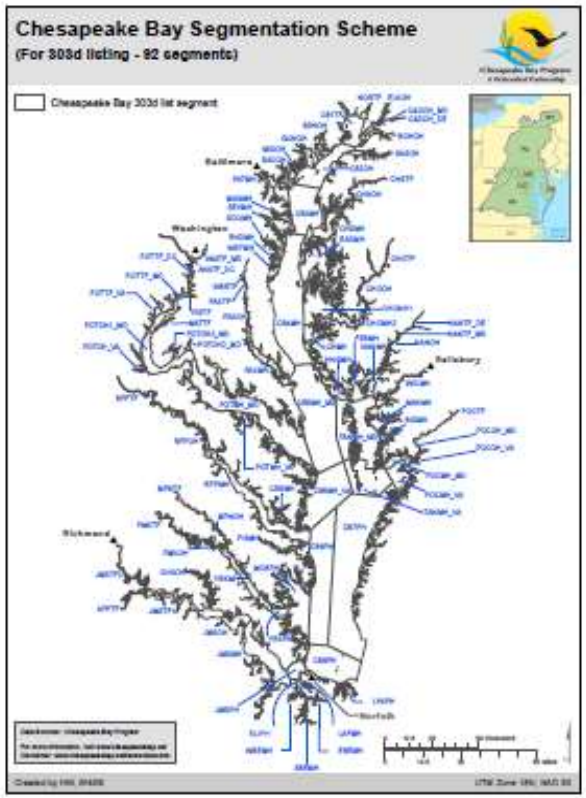
Shallow water focus

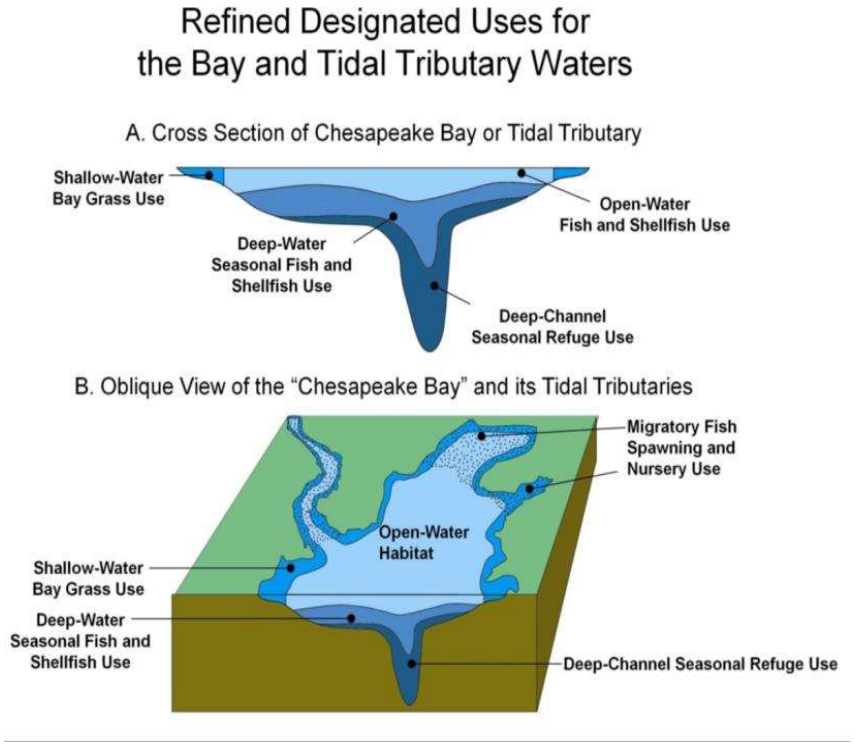
Peter Tango
USGS@CBPO
MD-DE-DC Water Science Center
CBP STAC Meeting 6/13/2023

Outline

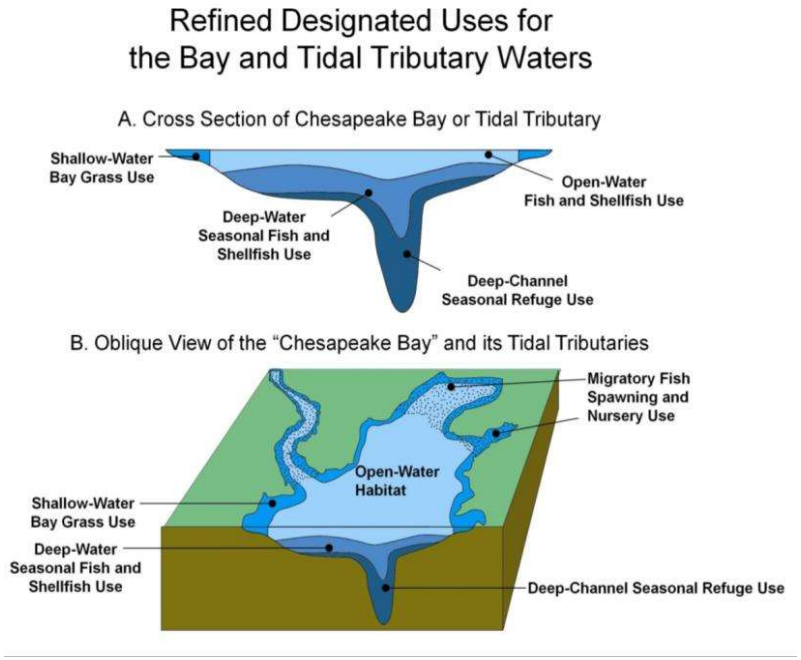
- Brief background on criteria, assessment, shallow water habitat
- Monitoring Chesapeake Bay: Guidance and investments
  - Dissolved oxygen
  - SAV
  - Water clarity
  - Chlorophyll
- Next steps

Clean Water Act Water Quality Standards Monitoring and Assessment Issue: A segment must meet **all criteria** in **all applicable designated uses** for a decision on delisting in State water quality standards





USEPA Criteria assessment guidance –



USEPA (2003):

- For dissolved oxygen and chlorophyll a criteria assessment,
  - **Open Water habitat is shore to shore.**
  - **Shallow water is not a separate assessment zone.**

- For SAV/Water clarity **–**
  - **Shallow water is the designated use for bay grass.**

USEPA Criteria assessment guidance -

FRAMING THE ASSESSMENT OF OPEN-WATER SHORT DURATION DISSOLVED OXYGEN CRITERIA

Assessing the full array of open-water short duration dissolved oxygen criteria builds on the recognition that even within an individual open water designated use segment, there are different habitat zones which have different dissolved oxygen dynamics and characteristics—e.g., diurnal cycles in dissolved oxygen concentrations in shallow water habitats vs. relatively constant dissolved oxygen concentrations over extended periods of times in deeper habitats. By matching up assessment procedures with the dissolved oxygen dynamics and the life stages often present in these different sub-segments of an overall open-water designated use segment may be assessed using different assessment procedures while at the same time still ensuring full protection of the open-water designated use.

USEPA 2017 language

Rationale for Sub-segmenting Open-Water Designated Use Segments into Zones

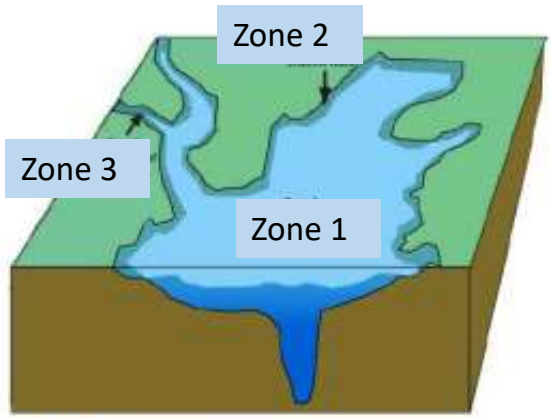
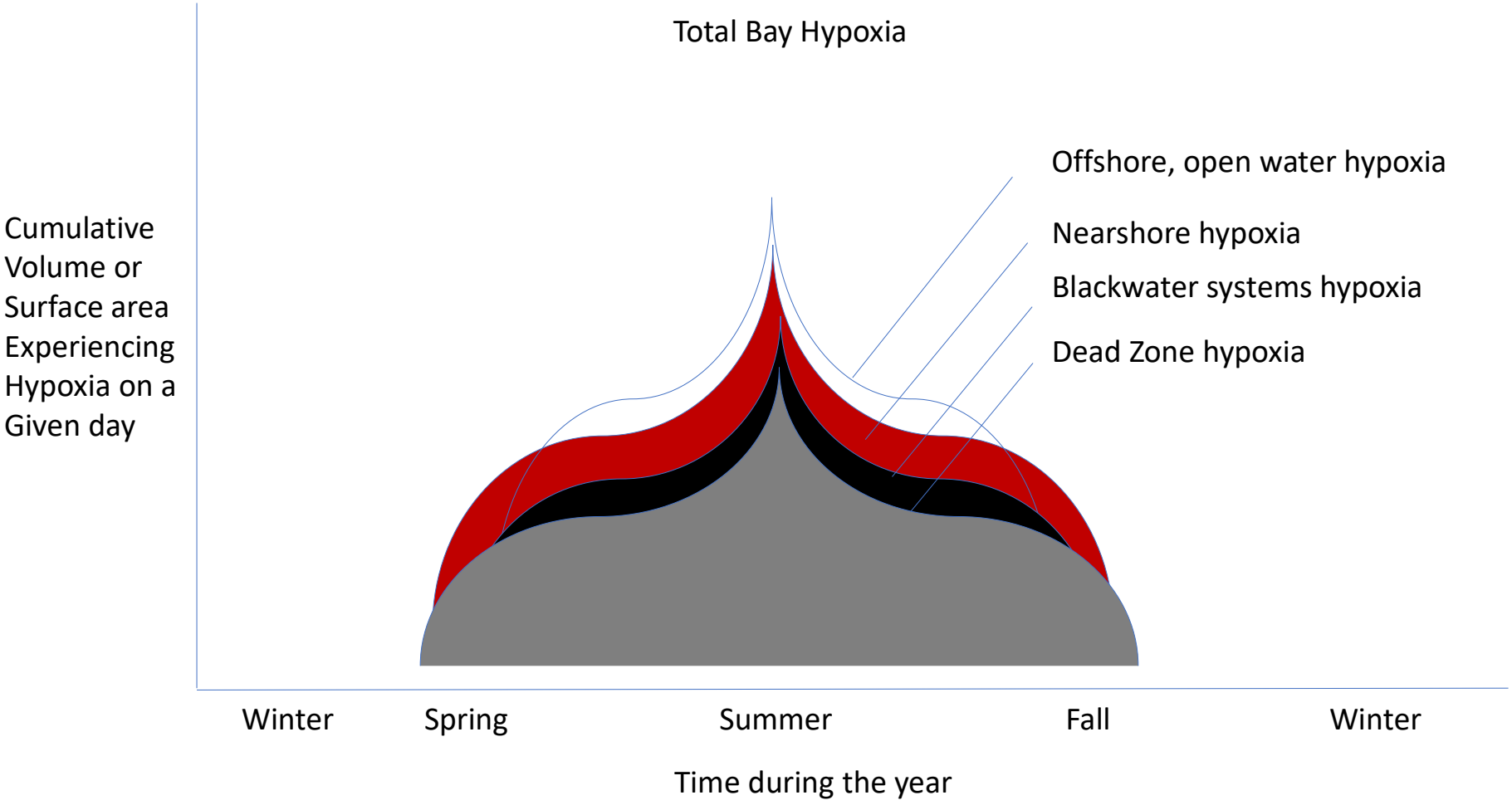


Figure II-4. Applying the concept of three zones to Chesapeake Bay open-water habitats.

USEPA (2017): Options for subsegmenting Open Water habitat for criteria assessment

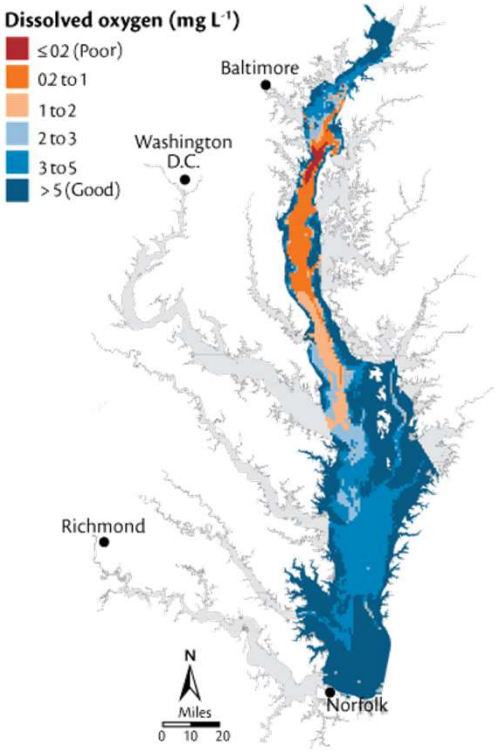
- For dissolved oxygen criteria assessment, **shallow water is one of 3 zones** that may be used to subsegment water quality assessments

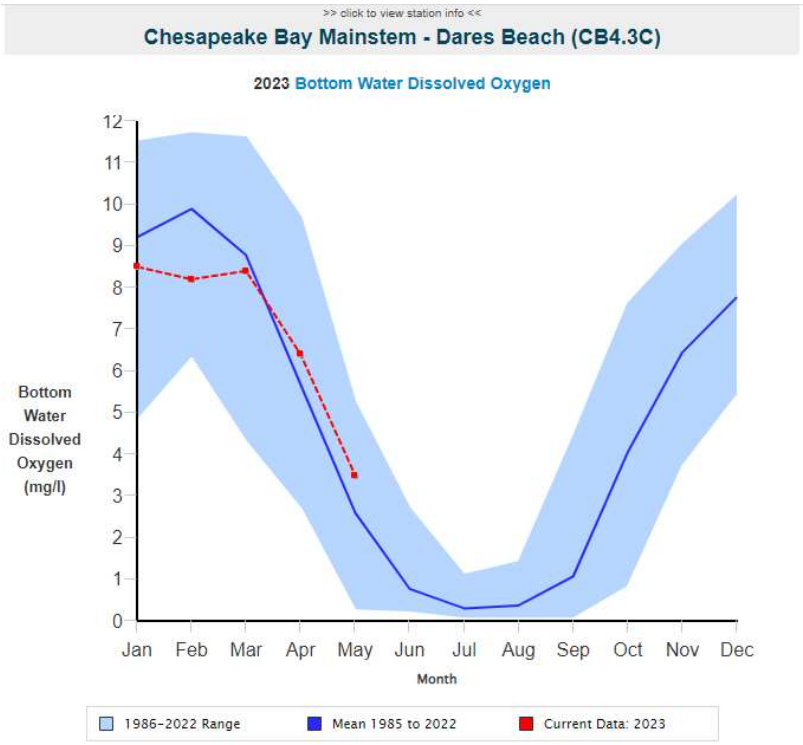
- Zone 1: Open water
- Zone 2: Shallow water
- Zone 3: Tributaries of tributaries (aka “triblets”)


Total Bay Hypoxia
Offshore, open water hypoxia
Nearshore hypoxia
Blackwater systems hypoxia
Dead Zone hypoxia
Cumulative Volume or Surface area Experiencing Hypoxia on a Given day
Winter
Spring
Summer
Fall
Winter
Time during the year

8/12/14 PT

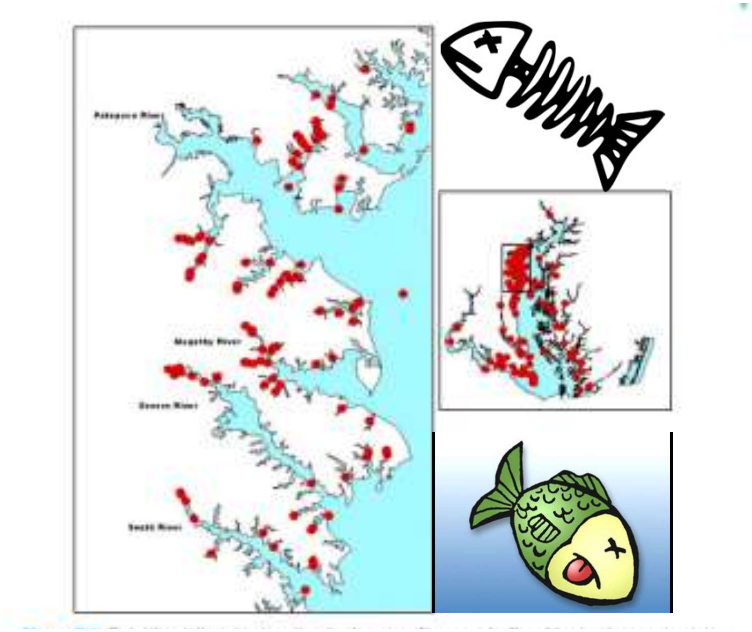
The deep water seasonal hypoxia is important - loss of thermal refuge, forage, nutrient cycling feedbacks…





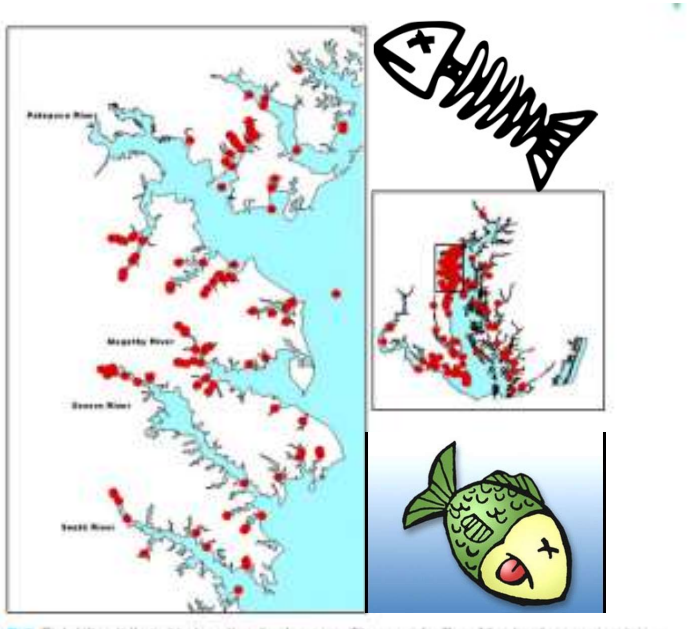
Eyes on the Bay, MD DNR 2023

… but fish die in shallow water



Fish kills attributed to hypoxia,
MD Chesapeake Bay, 1987-2001

… but fish die in shallow water with diel hypoxia.



Fish kills attributed to hypoxia,
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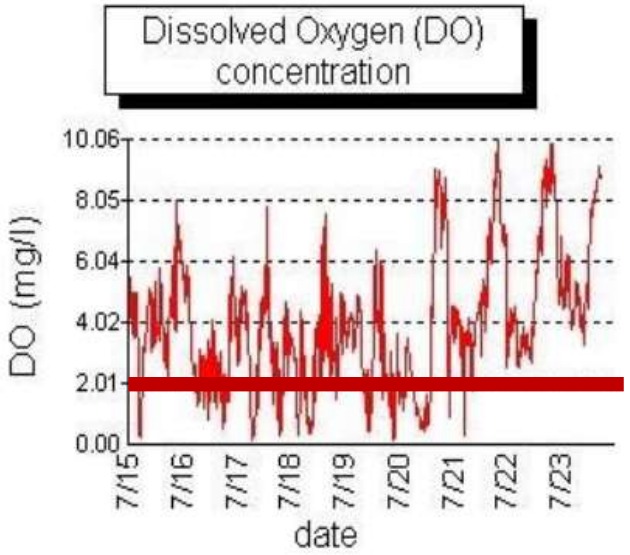
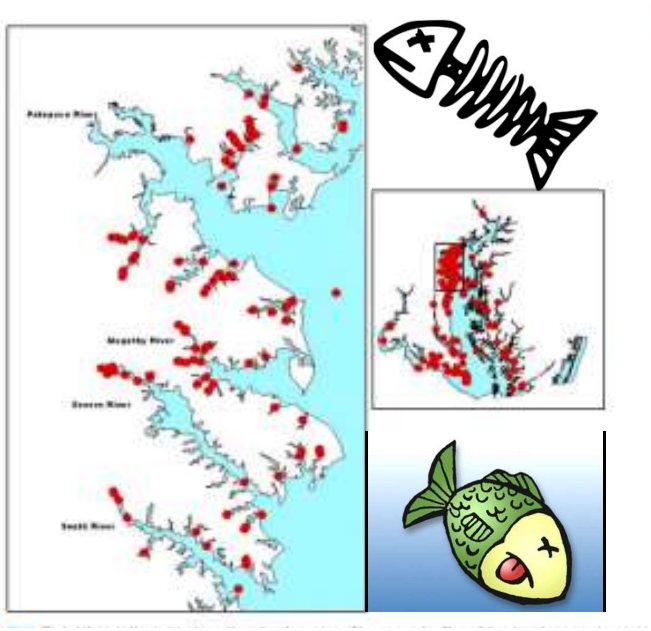


1 week example of diel dissolved oxygen swings from 0 to 9+ mg/L
Severn River, Ben Oaks

… but fish die in shallow water with diel hypoxia.

Measurement and managing both habitats is important



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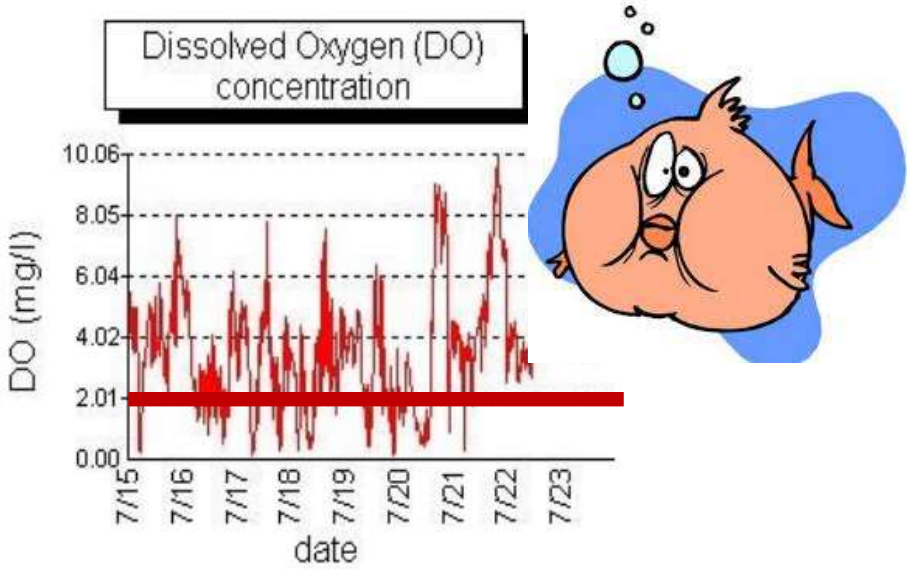


1 week example of diel dissolved oxygen swings from 0 to 9+ mg/L
Severn River, Ben Oaks

For each habitat, all space is equally important for the assessment accounting

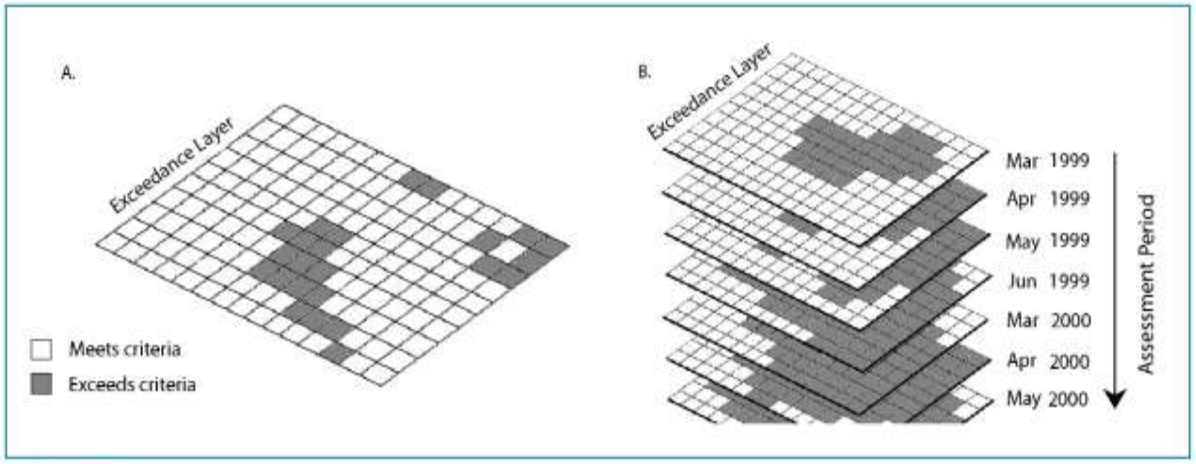
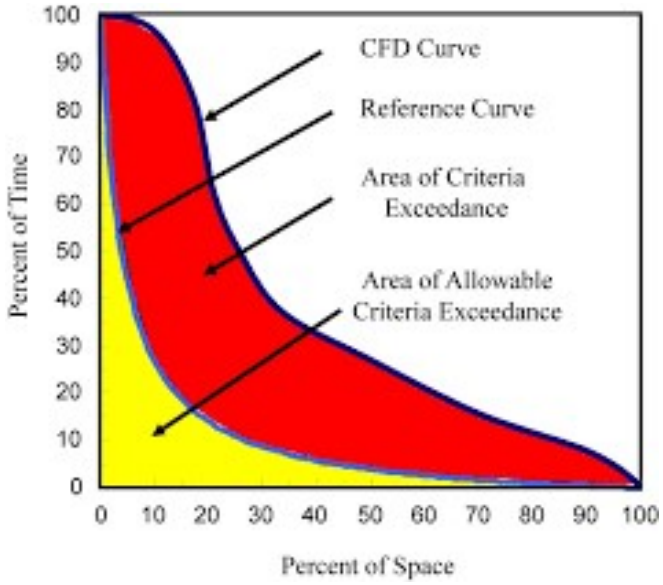


Figure VI-4. For a given sampling event, cells that exceed the criterion are determined by comparing the interpolator estimated water quality value in each cell (e.g., chlorophyll *a*) to the appropriate criterion value (a) as in Figure VI-3. The same process is repeated for each sampling event through the assessment period (b).

USEPA (2003): Criteria assessment accounting



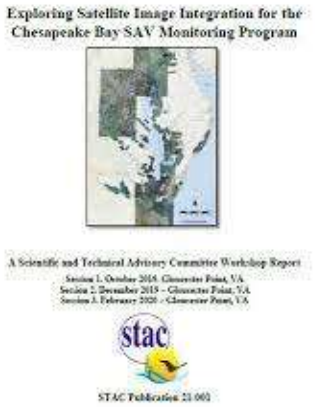
USEPA (2003): The CFD Attainment Test

Monitoring Chesapeake Bay: Guidance and investments

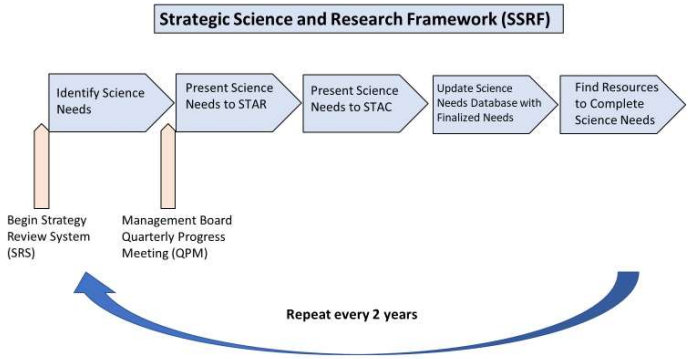
Guidance on the future of CBP monitoring programs

Approximately decadal deep dive **monitoring program reviews**

Topical Workshops with recommendations



CBP **Science Needs Database**
Program-wide data base of science, research and monitoring needs



Targeted research

JGR: Oceans Vol 118

Combining observations and numerical model results to improve estimates of hypoxic volume within the Chesapeake Bay, USA

Aaron J. Bever,[1,2] Marjorie A. M. Friedrichs,[1] Carl T. Friedrichs,[1] Malcolm E. Scully,[3] and Lyon W. J. Lanerolle[4]

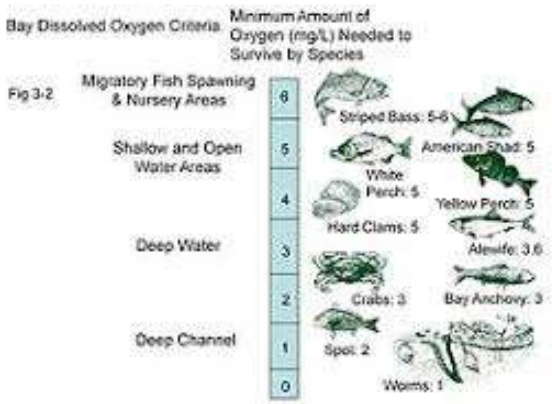
Received 15 March 2013; revised 10 July 2013; accepted 25 July 2013.

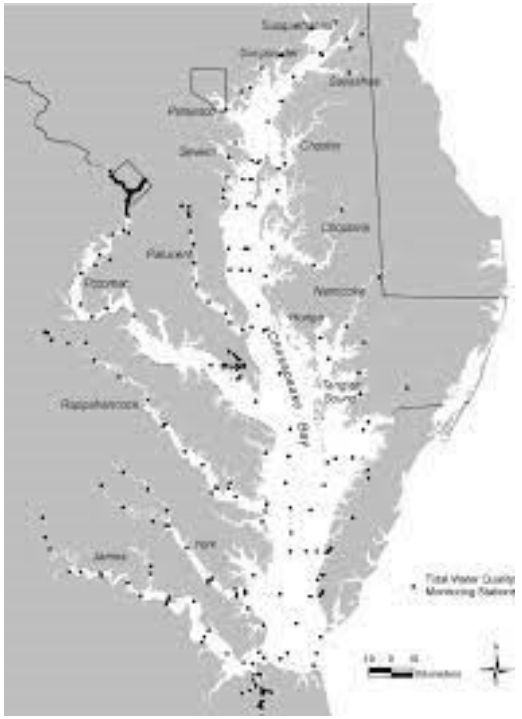
> Environ Monit Assess. 2022 Nov 29;195(1):163. doi: 10.1007/s10661-022-10725-1.

A hydrodynamic model-based approach to assess sampling approaches for dissolved oxygen criteria in the Chesapeake Bay

Dong Liang [1], Jeremy M Testa [2], Lora A Harris [2], Walter R Boynton [2]

Chesapeake Bay Dissolved oxygen monitoring





Targeted Research: Colleagues (Bever et al.) have published work examining *monitoring designs towards improving estimates of hypoxic volume, efficiencies* – program guidance

JGR Oceans

2013

Regular Article | Open Access

Combining observations and numerical model results to improve estimates of hypoxic volume within the Chesapeake Bay, USA

Aaron J. Bever ✉, Marjorie A. M. Friedrichs, Carl T. Friedrichs, Malcolm E. Scully, Lyon W. J. Lanerolle

First published: 02 August 2013 | https://doi.org/10.1002/jgrc.20331 | Citations: 45

JGR Oceans

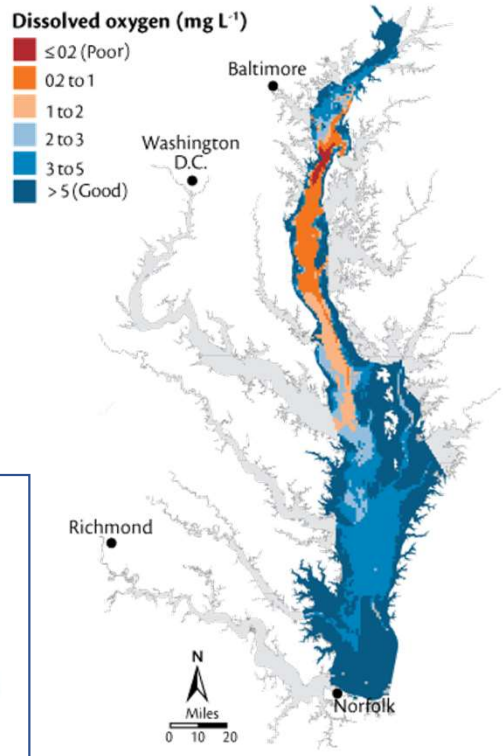
2018

Research Article | Open Access

Estimating Hypoxic Volume in the Chesapeake Bay Using Two Continuously Sampled Oxygen Profiles

Aaron J. Bever ✉, Marjorie A. M. Friedrichs, Carl T. Friedrichs, Malcolm E. Scully

First published: 27 August 2018 | https://doi.org/10.1029/2018JC014129 | Citations: 8

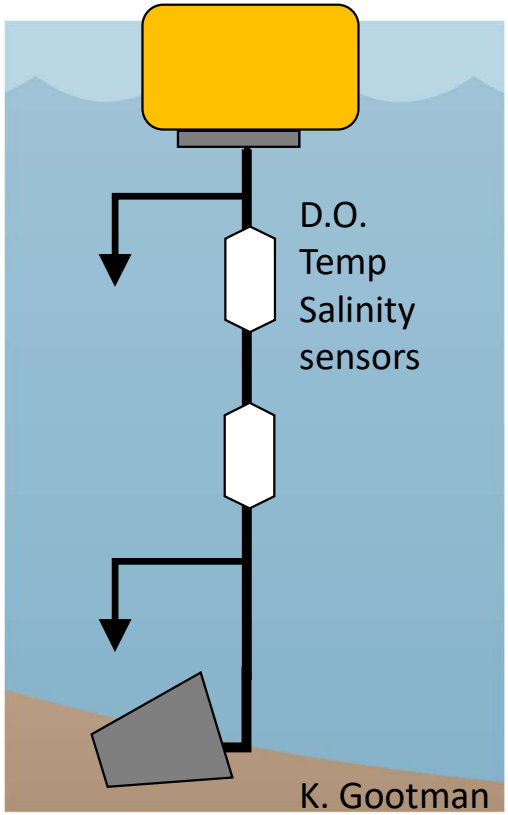


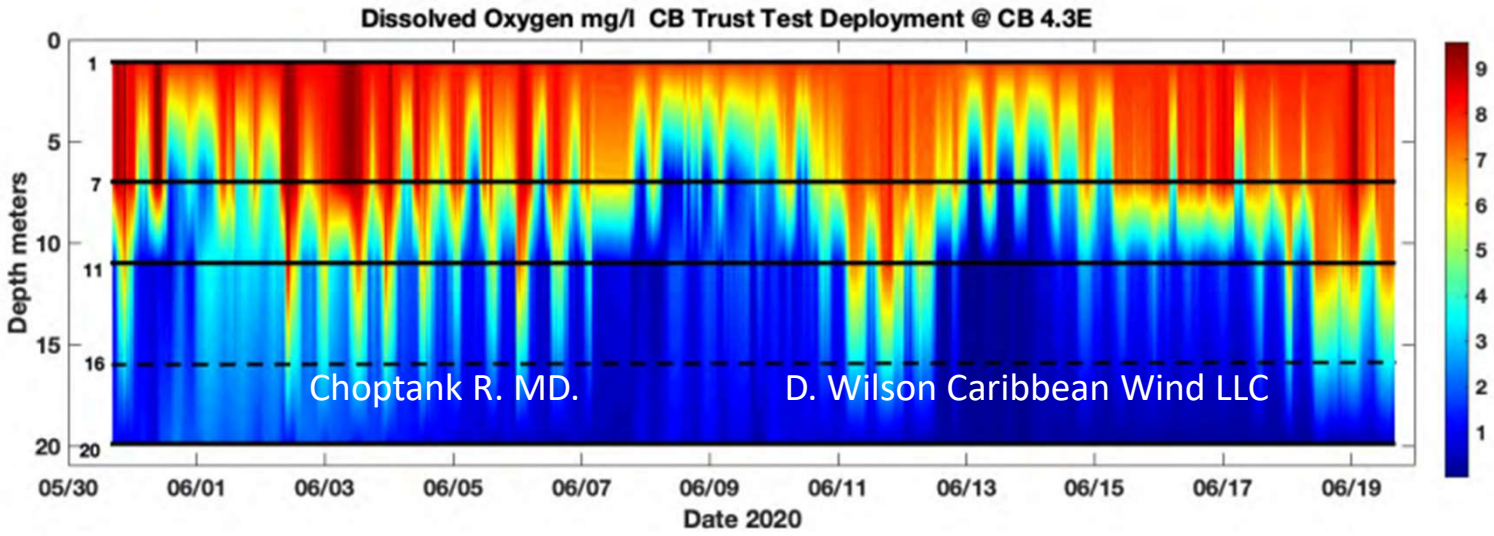
Research translated to investment…

Open Water Habitat: New vertical sampling arrays

Science and decision-support needs: Address gaps in water quality criteria attainment assessments

Use in model calibration and verification



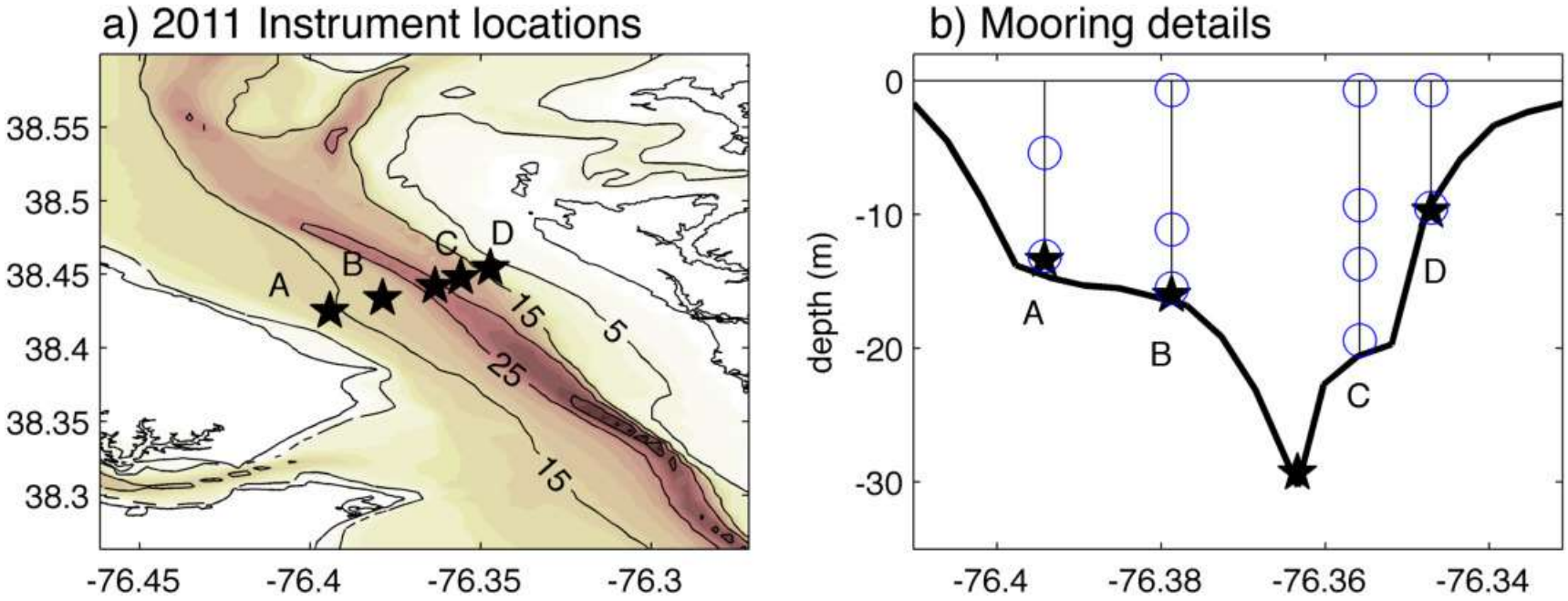


- Dissolved oxygen, **10 minute water column data**.
- 1 month in 2020, 20-meter water column depth

- **Hypoxia Collaborative** established in 2020 to build out network (NOAA, EPA, USGS led)

Sensor distribution and sampling design considerations: lateral?

E.g., Scully, M. 2016. Mixing of dissolved oxygen in Chesapeake Bay driven by the interaction between wind-driven circulation and estuarine bathymetry. JGR Oceans



USGS science for a changing world

Chesapeake Bay Program
A Watershed Partnership

Targeted Research: Nearshore and offshore monitoring of hypoxia

Segment dependent influence of nearshore/offshore monitoring combinations affect D.O. criteria assessment accuracy and bias

Maryland Department of Natural Resources

MARYLAND CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

ECOSYSTEMS PROCESSES COMPONENT (EPC)

LEVEL ONE REPORT No. 33
INTERPRETIVE REPORT
(July 1984 – December 2015)

Final Report

PREPARED FOR:

Maryland Department of Natural Resources
Tidewater Ecosystems Assessment
580 Taylor Avenue, D-2
Annapolis, MD 20401

December, 2016

J.M. Testa	Co-Principal Investigator
L.A. Harris	Co-Principal Investigator
W.R. Boynton	Co-Principal Investigator
C.L.S. Hodgkins	Senior Faculty Research Assistant
J.L. Humphrey	Senior Faculty Research Assistant
M.C. Day	Senior Faculty Research Assistant
D. Liang	Research Assistant Professor

Initial Investigation into the Next Phase of Water Quality Monitoring for Criteria Assessment in Maryland Coastal Waters 2-1

2016

Environ Monit Assess. 2022 Nov 29;195(1):163. doi: 10.1007/s10661-022-10725-1.

A hydrodynamic model-based approach to assess sampling approaches for dissolved oxygen criteria in the Chesapeake Bay

Dong Liang [1], Jeremy M Testa [2], Lora A Harris [2], Walter R Boynton [2]

Affiliations + expand

PMID: 3

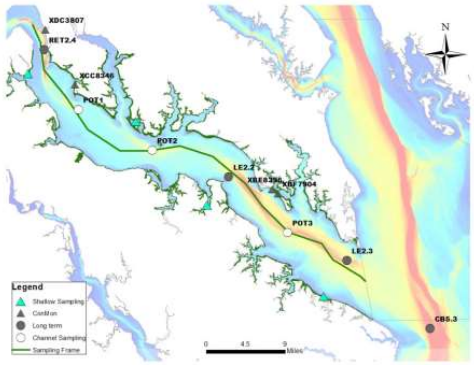


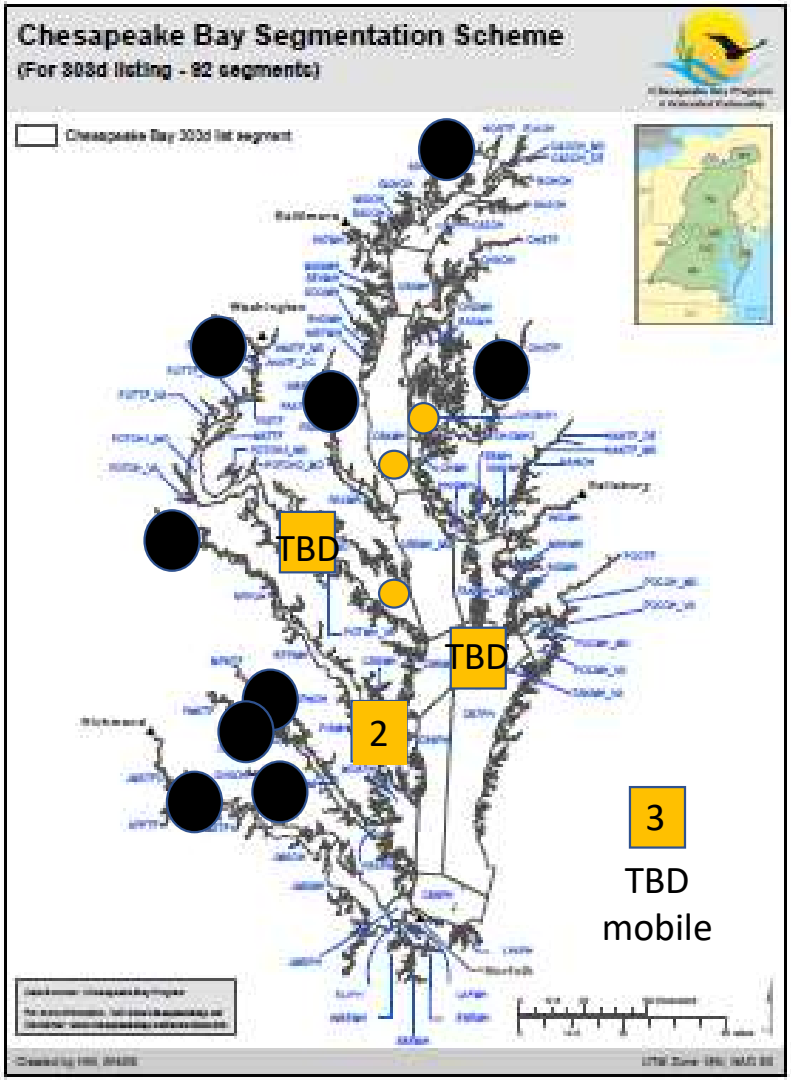
Figure 2-1. Long term fixed stations and ConMon stations in POTMH, sampling frames for channel and shallow monitoring, and four channel and four shallow stations sampled from the frames.

2022

Addressing high temporal frequency data needs issues by expanding monitoring and assessment capacity (PSC Report)

- NOAA supports 3 vertical sensor arrays (2023)
- 7 more vertical array deployments planned by 2025
- Tidal/Nontidal boundary – river input water quality continuous monitors

***Tidal Bay arrays located with input from monitoring, analysis, fisheries, and modeling workgroups



2022: New 4-D water quality interpolation is under development (Bay Oxygen Research Group):

Simulator components

Long term temporal patterns

Smoothly varying change from observations aided by deterministic relationships with continuously available information (flow, wind, temperature, dynamic model output, etc)

Key data example: Long-term fixed network

+

Spatial structure

Spatial autocorrelation; anisotropy in depth direction; deterministic relationships to other spatial data (bathymetry, satellite images, etc)

Key data example: Dataflow

+

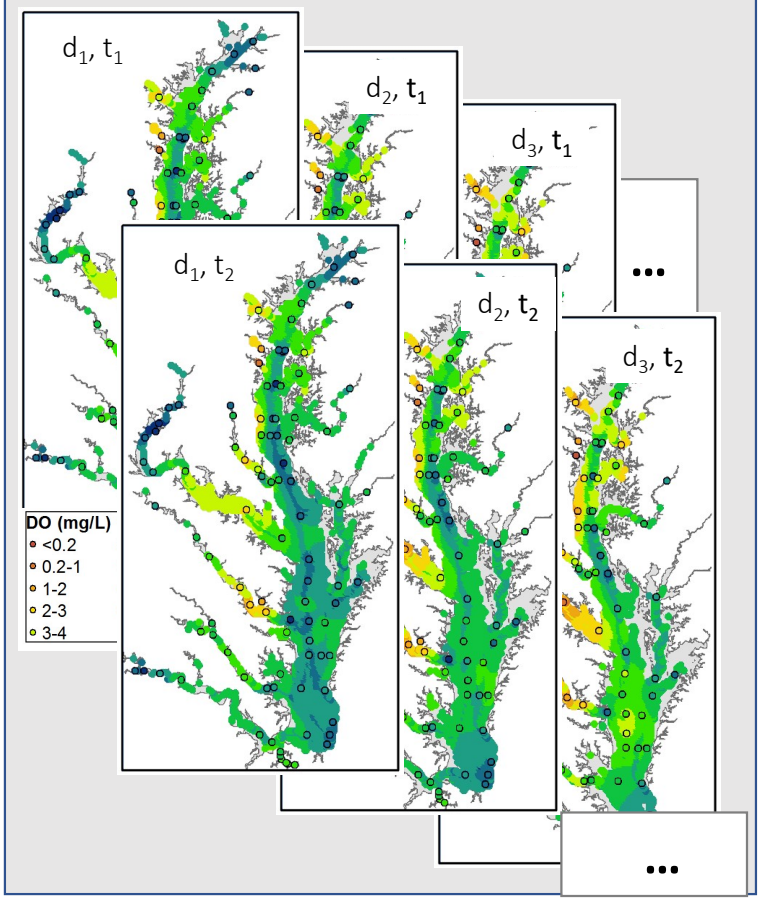
Short term temporal variability

Daily & tidal cycling, temporal autocorrelation, etc

Key data example: Conmon

Space-time interpolation with GAMs

"4d" Spatial & temporal estimates of DO



Source: R. Murphy

Where we are heading: Assessment of all Bay oxygen water quality criteria for 2025

A new analysis system, built on an expanded data collection effort, is envisioned that will allow assessment of all water quality criteria. Figure 1 shows the flow of information in the proposed system.

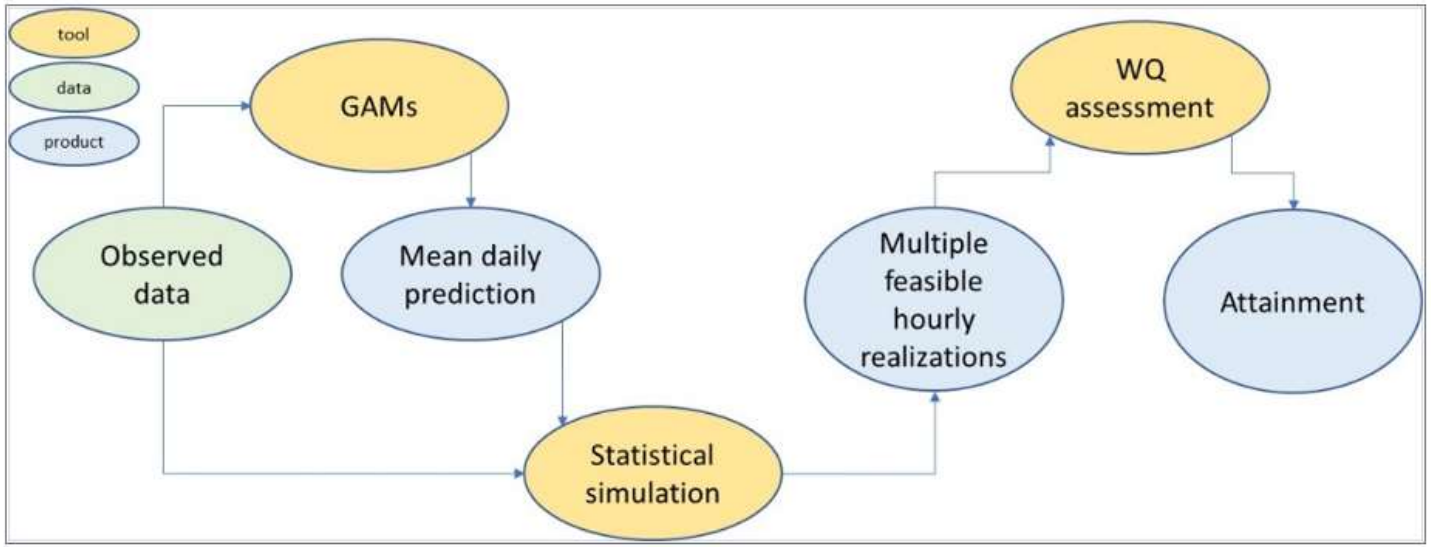


Figure 1: Interpolation and attainment assessment system

Source: G. Shenk

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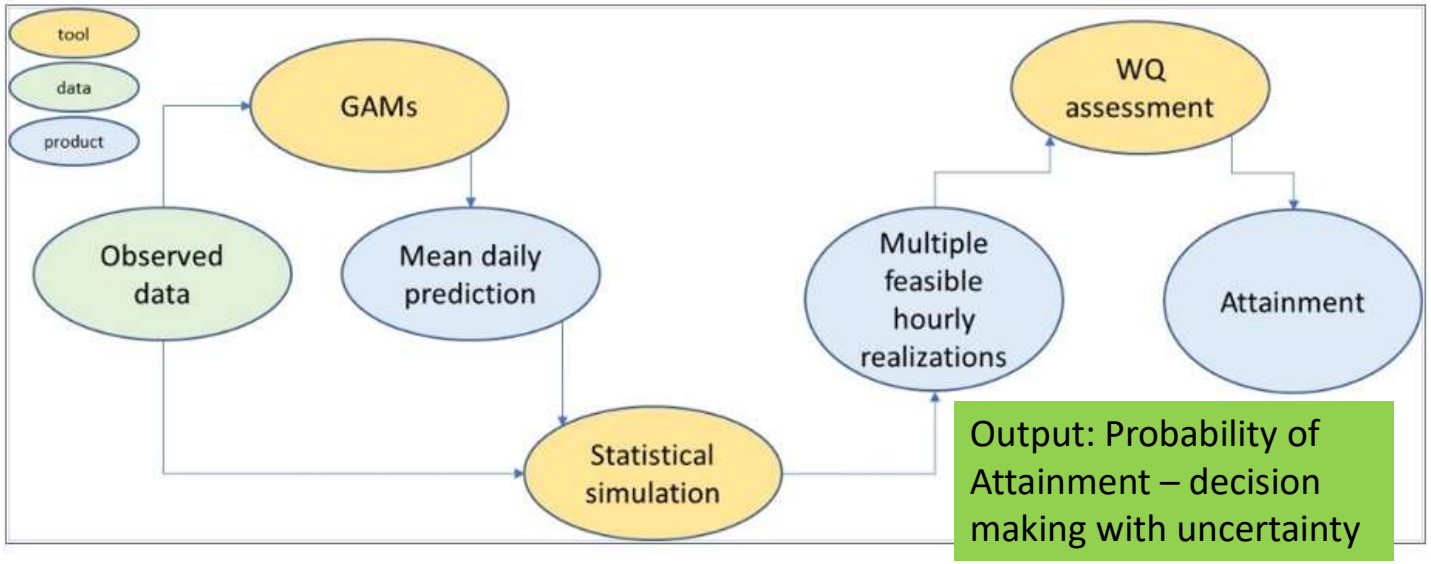

Output: Probability of Attainment – decision making with uncertainty

Figure 1: Interpolation and attainment assessment system

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Where we are heading: Assessment of all Bay oxygen water quality criteria for 2025

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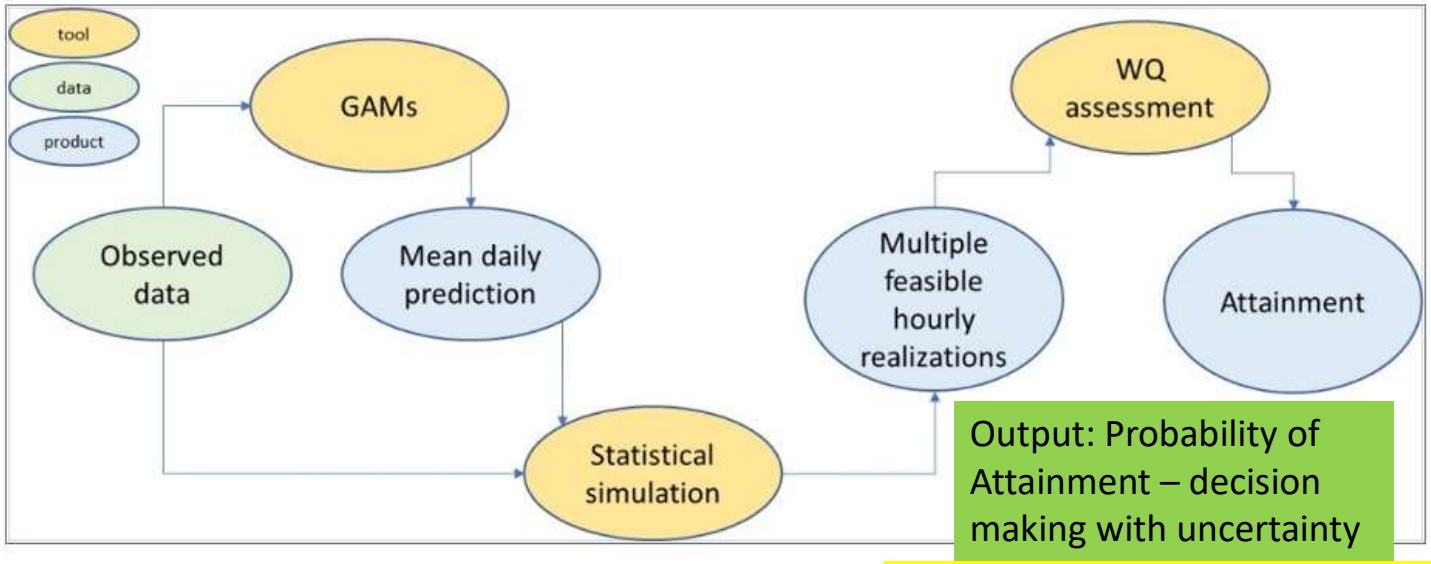
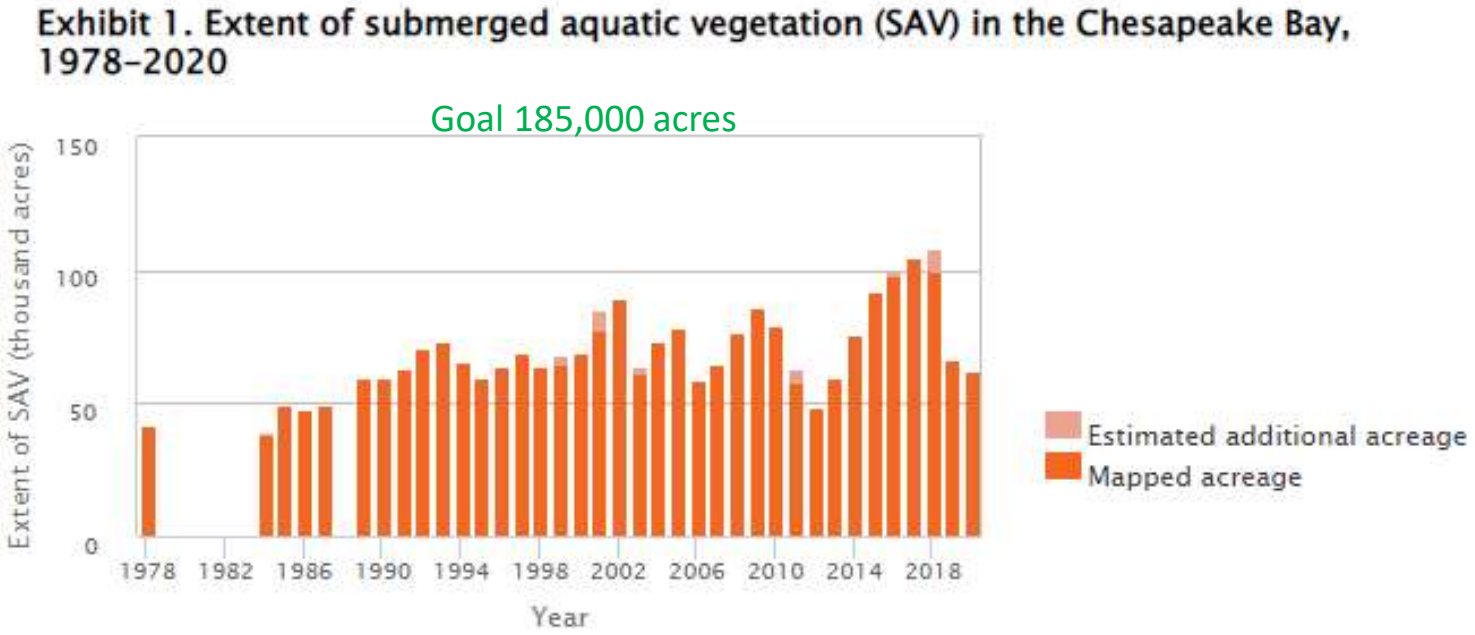


Figure 1: Interpolation and attainment assessment system

Output: Probability of Attainment – decision making with uncertainty

See also "Conditional Attainment" USEPA (2017)

Chesapeake Bay SAV

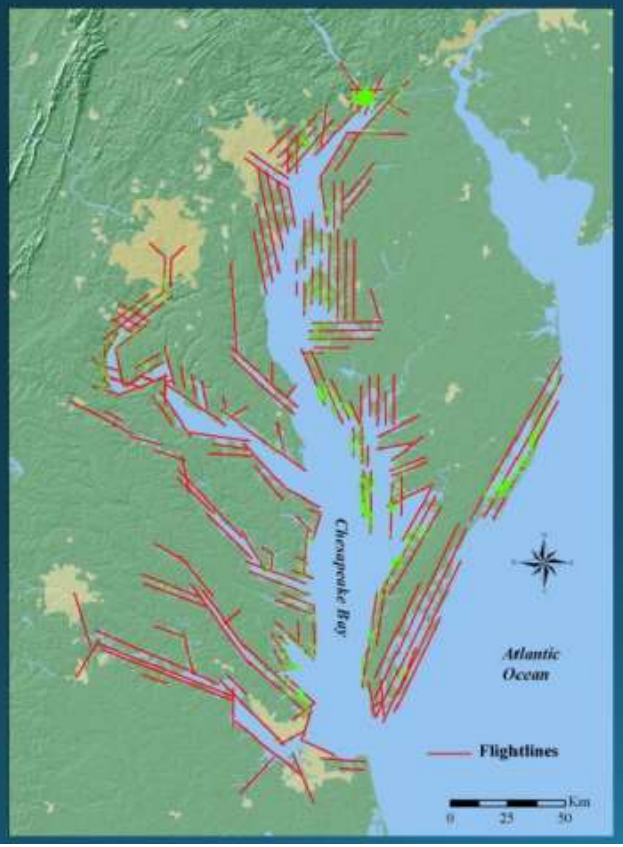


CBP 2021

Chesapeake Bay
Annual SAV Monitoring
Program
1974 to Present

Landry, B., P. Tango, C. Bisland, M. Coffer, W. Dennison, V. Hill, C. Lebrasse, J. Li., R. Orth, C. Patrick, B. Schaeffer, P. Witman, D. Wilcox, and R. Zimmerman. 2021. Exploring Satellite Image Integration for the Chesapeake Bay SAV Monitoring Program –A STAC Workshop, 1-45. Edgewater Maryland: STAC.

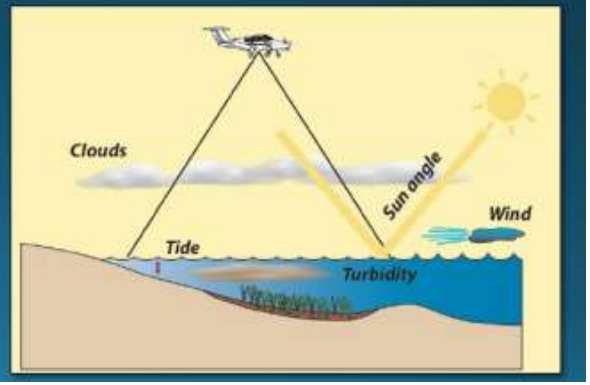
Acquisition of Aerial Imagery

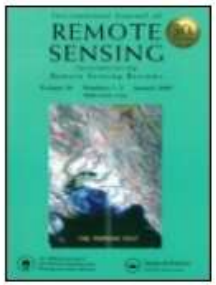


Aerial multispectral digital imagery is acquired from flight lines flown over the entire bay

Flights require low wind, minimal cloud cover, low tide, low turbidity, low sun angle.

VIMS and Air Photographics staff monitor these conditions 24/7





Taylor & Francis

International Journal of Remote Sensing

ISSN: 0143-1161 (Print) 1366-5901 (Online) Journal homepage: https://www.tandfonline.com/loi/tres20

Barriers to adopting satellite remote sensing for water quality management

Blake A. Schaeffer, Kelly G. Schaeffer, Darryl Keith, Ross S. Lunetta, Robyn Conmy & Richard W. Gould

To cite this article: Blake A. Schaeffer, Kelly G. Schaeffer, Darryl Keith, Ross S. Lunetta, Robyn Conmy & Richard W. Gould (2013) Barriers to adopting satellite remote sensing for water quality management, International Journal of Remote Sensing, 34:21, 7534-7544, DOI: 10.1080/01431161.2013.823524

To link to this article: https://doi.org/10.1080/01431161.2013.823524

Barriers? Survey says…

- Cost
- Programmatic support
- Product accuracy
- Data continuity

Satellite-based estuarine SAV assessment has arrived!

Journal of Environmental Management
Volume 337, 1 July 2023, 117669

Research article

Providing a framework for seagrass mapping in United States coastal ecosystems using high spatial resolution satellite imagery

Megan M. Coffer [a b], David D. Graybill [a], Peter J. Whitman [a], Blake A. Schaeffer [c], Wilson B. Salls [c], Richard C. Zimmerman [d], Victoria Hill [d], Marie Cindy Lebrasse [a e], Jiang Li [f], Darryl J. Keith [g], James Kaldy [h], Phil Colarusso [i], Gary Raulerson [j], David Ward [k], W. Judson Kenworthy [l]

Highlights

- Satellite imagery was used to map seagrass at eleven United States coastal sites.
- Satellite and reference data agreed best in continuous seagrass, worst in patchy.
- Methods transferable across varying ecological, atmospheric, and aquatic conditions.
- Study shows consistent, operational approach for large-scale seagrass mapping.
- Instructional videos provided to acquire, process, and classify satellite imagery.

M. Coffer et al. 2023

Proof of concept across diverse systems

Satellite-based SAV estuarine assessment has arrived!

Historical aerial SAV Monitoring model

- 1 snapshot per year per transect
- During the peak growing season
- Sub 1m-sq

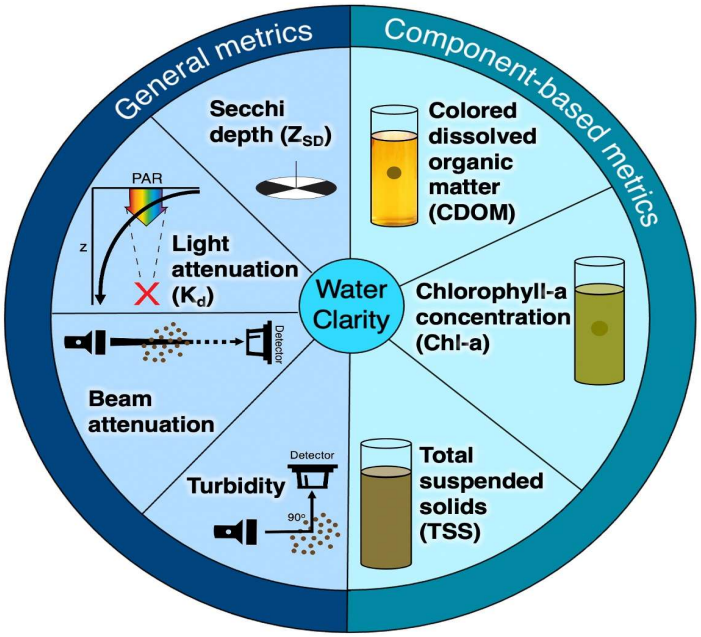
Dove Planetscope data collection model

- Daily to subdaily imaging over the bay
- Yearround
- Sub 4m-sq

Coming soon! Chesapeake Bay regional scale test of satellite-based SAV assessment

- Monitoring program review recommendations
  - Included SAV pilot of satellite-based monitoring over the mesohaline reaches of the bay
  - Included requirement for comparison and calibration with aerial based monitoring results
  - Receiving EPA support in 2023 for a 2-year study.

Chesapeake Bay Water Clarity

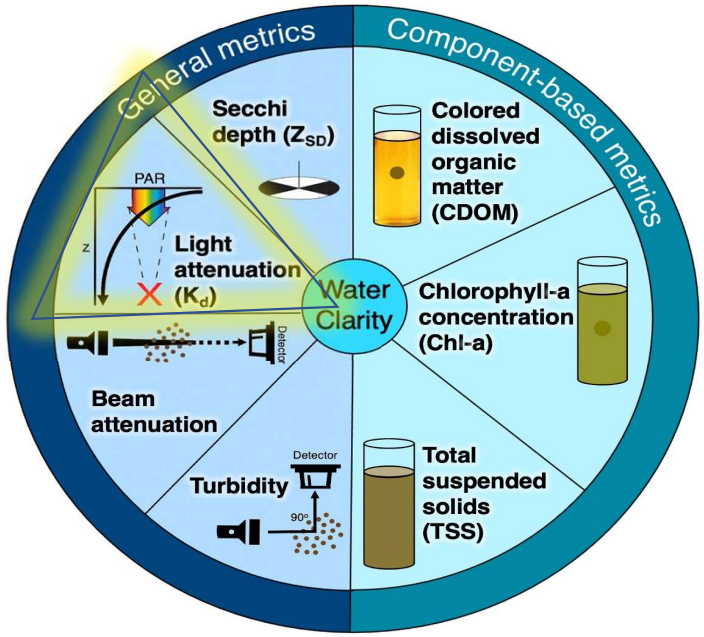



LIMNOLOGY AND OCEANOGRAPHY
LETTERS
ASLO
Open Access
Essay | Open Access
Clarifying water clarity: A call to use metrics best suited to corresponding research and management goals in aquatic ecosystems
Jessica S. Turner Kelsey A. Fall. Carl T. Friedrichs
First published: 16 December 2022 | https://doi.org/10.1002/lol2.10301 | Citations: 1

General and Component-based metrics of water clarity.

Chesapeake Bay Water Clarity

Kd



LIMNOLOGY AND OCEANOGRAPHY LETTERS ASLO Open Access

Essay | Open Access

Clarifying water clarity: A call to use metrics best suited to corresponding research and management goals in aquatic ecosystems

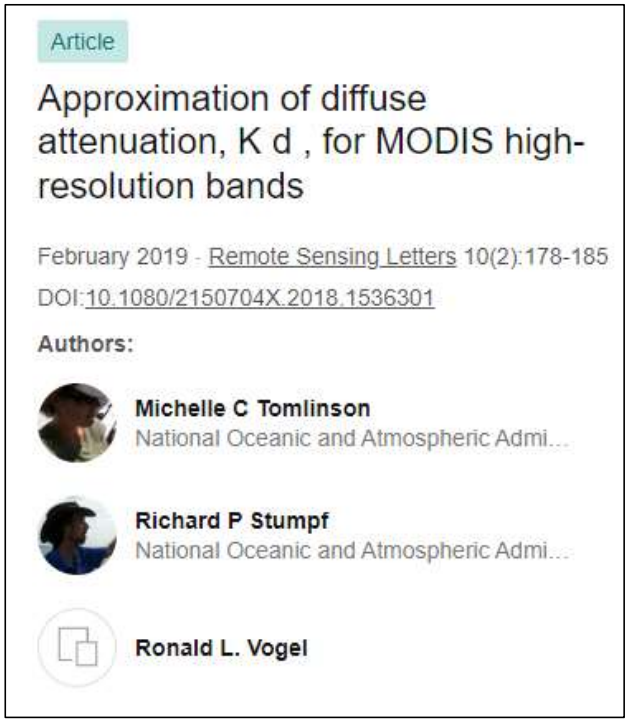
Jessica S. Turner, Kelsey A. Fall, Carl T. Friedrichs

First published: 16 December 2022 | https://doi.org/10.1002/lol2.10301 | Citations: 1

General and Component-based metrics of water clarity.

Baywide kd characterization with satellite imaging has been achieved.

However, not yet ready for primetime monitoring program adoption.



Article

Approximation of diffuse attenuation, K d , for MODIS high-resolution bands

February 2019 · Remote Sensing Letters 10(2):178-185

DOI:10.1080/2150704X.2018.1536301

Authors:

Michelle C Tomlinson
National Oceanic and Atmospheric Admi...

Richard P Stumpf
National Oceanic and Atmospheric Admi...

Ronald L. Vogel

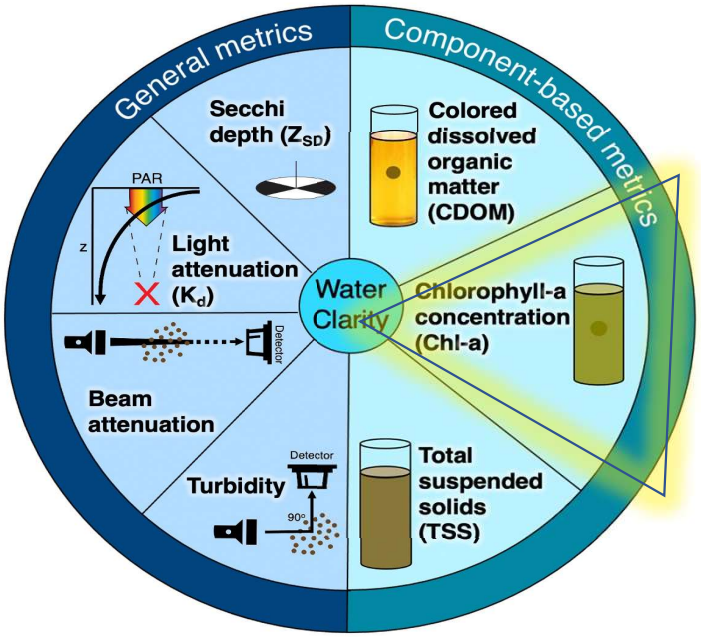
2022 Advanced Monitoring Workshop

(DRAFT - *Do not cite recommendations at this time*)

*Water clarity – Preview snippets of **DRAFT** STAC report Recommendations*

- *Research and Monitoring* – Establishing a network of calibration and verification sites for kd measures
- *Research* – Evaluation of newer satellites for improving assessment accuracy and spatial resolution is needed
- *Research* – Research is needed to tune existing algorithms for interpreting satellite-based data, or creating new algorithms that improve on accuracy over existing algorithm characterizations of satellite-based data

Chesapeake Bay Chlorophyll *a*



CHLA

LIMNOLOGY AND OCEANOGRAPHY LETTERS ASLO Open Access

Essay | Open Access

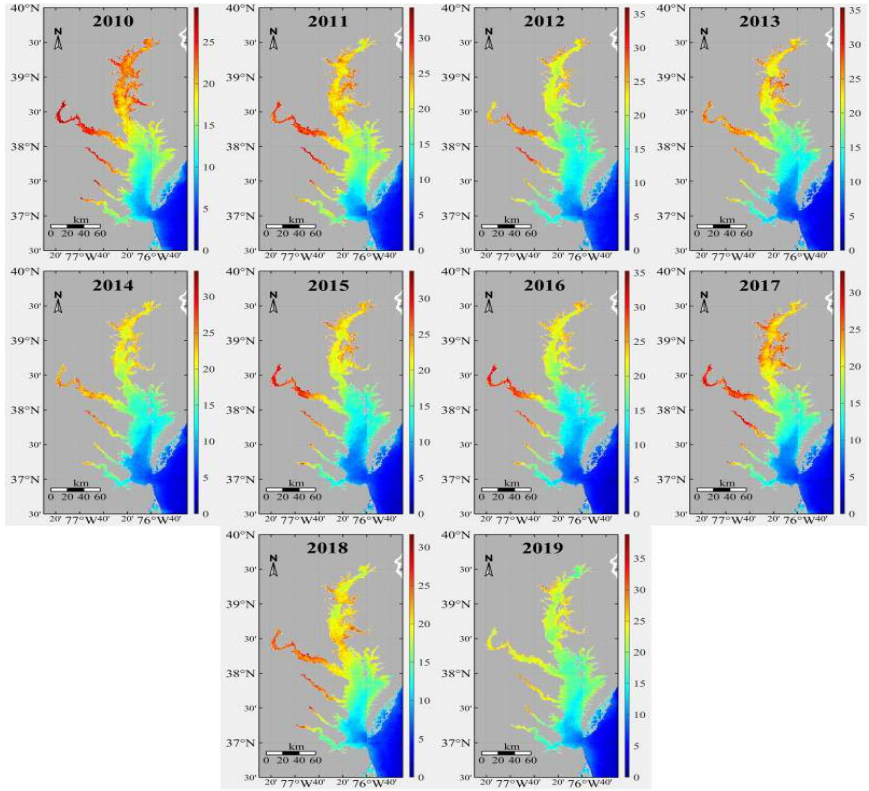
Clarifying water clarity: A call to use metrics best suited to corresponding research and management goals in aquatic ecosystems

Jessica S. Turner, Kelsey A. Fall, Carl T. Friedrichs

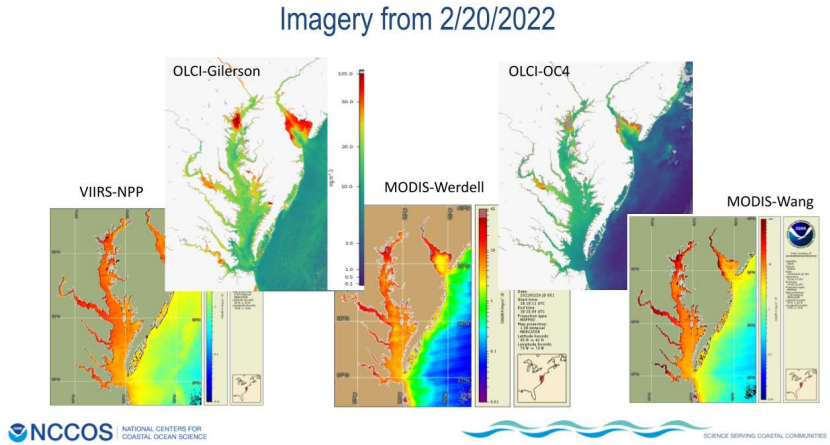
First published: 16 December 2022 | https://doi.org/10.1002/lol2.10301 | Citations: 1

General and Component-based metrics of water clarity.

We are swimming in a sea of chlorophyll (data and products)



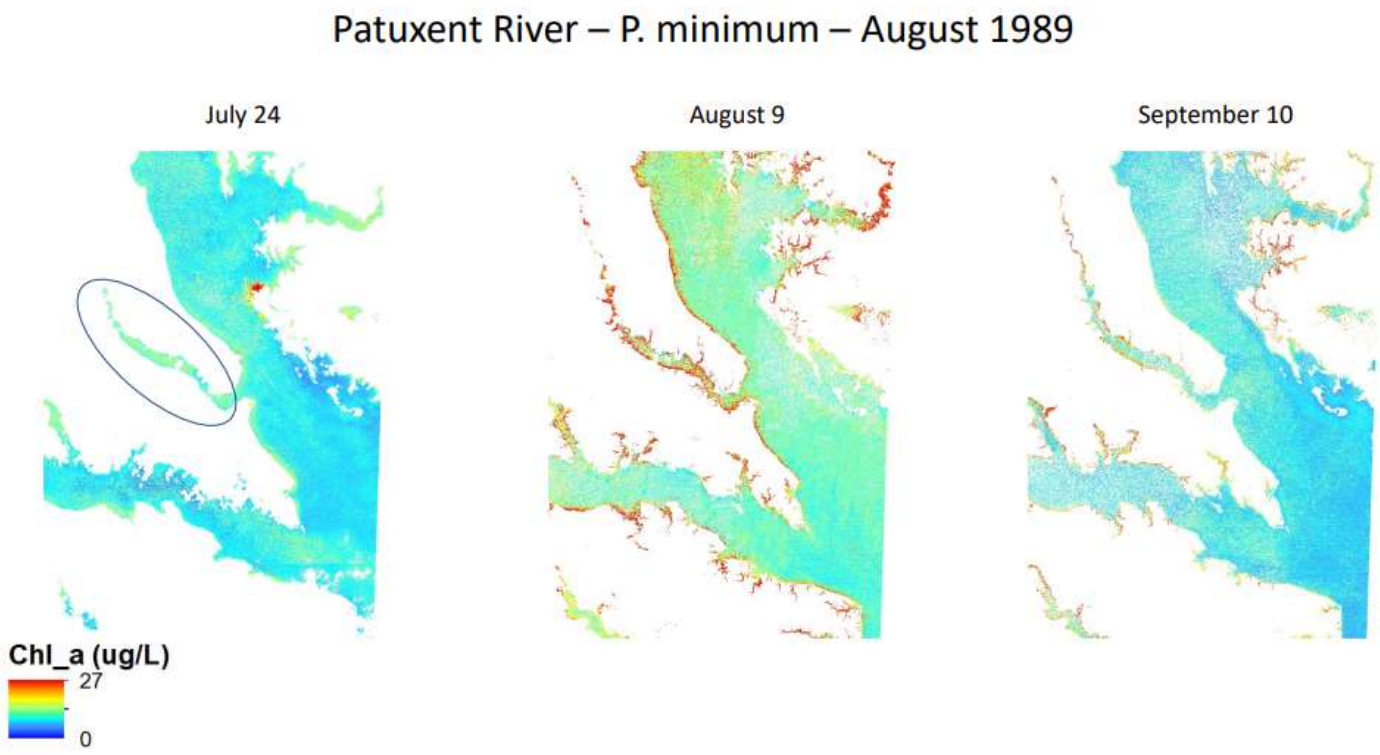
He et al. 2021 11 yr CHLA time series



NCCOS: R. Stumpf, M. Tomlinson and colleagues:
5 algorithms evaluated on chla for Chesapeake Bay

38 year satellite-based time series for CHLA for Chesapeake Bay (publication work underway)

A machine-learning model trained to estimate surface chlorophyll-a concentrations from Landsat data was applied to tidal Chesapeake Bay tidal waters from 1985-2021



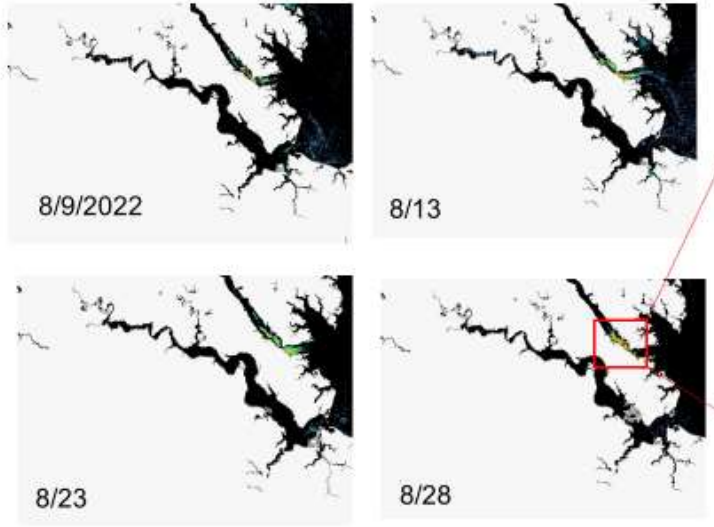
Creating a time-series of chlorophyll-*a* at a 30-meter scale.

Ongoing developments of new chlorophyll related products from NCCOS and others. Examples: Daily 300m vs 5-day 20 m

NCCOS Assists Response to HAB in the Lower Chesapeake Bay

NCCOS NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE

Sentinel 3 Fluorescence algorithm (RBD) from EUMETSAT processed at NCCOS, 300 m every day



Sentinel 2 provides 20 m imagery every 5 days

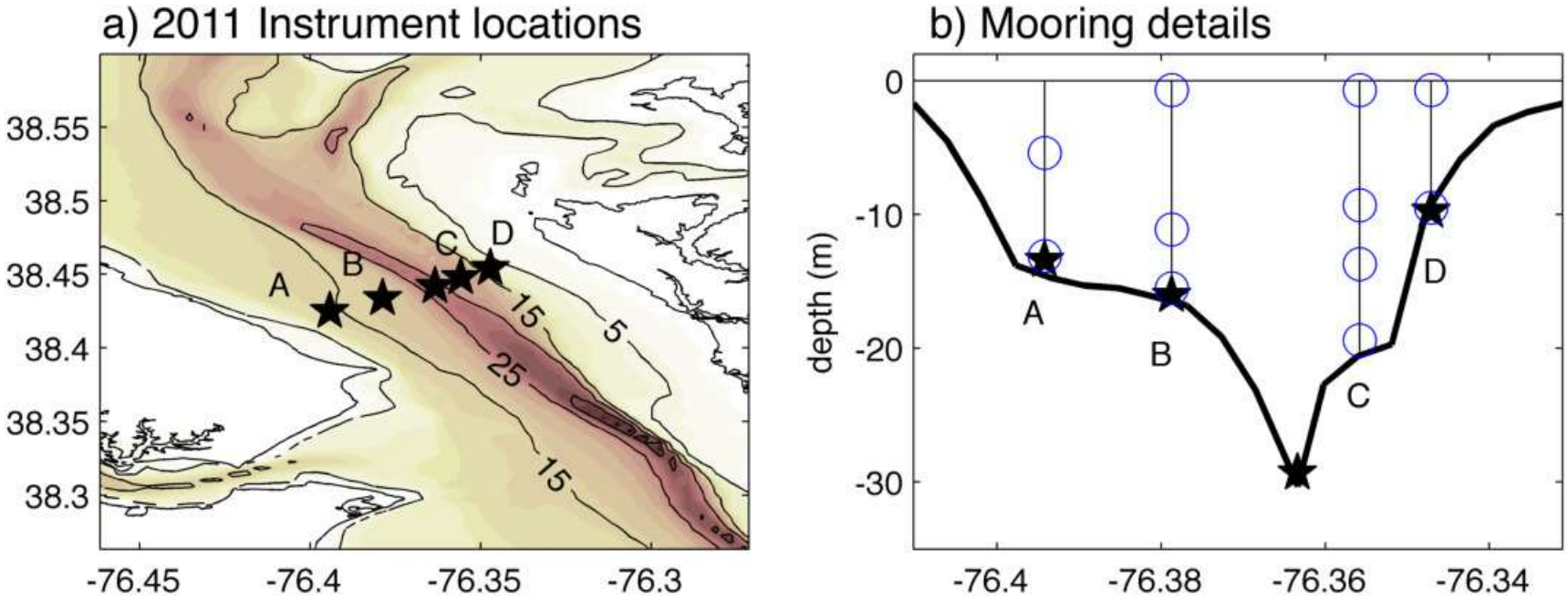
False color image from EO Browser at European Space Agency (ESA)
https://apps.sentinel-hub.com/eo-browser/

*Resulted in NCCOS Event Response funds to support additional sampling

Next steps

- Build out the Next Generation Tidal Bay Monitoring Strategy
  - Build upon the new strategy work developed from the 2021-22 PSC Monitoring Review
    - Scenario assessments of inshore-offshore linked sampling programs
      - that consider the pairing of our new infrastructure investments with existing data collection programs for the least biased, most accurate habitat assessments.
        - GIT-funded study on detailed designs for 10%/10 yrs of bay segment assessments?
        - Grad student? Post doc?
        - RFP?
    - Scenarios that adapt to the constraints of less than optimal sampling locations
      - Avoid shipping channels
      - Limits on numbers of sensors deployed and maintained
      - Nearshore infrastructure to attach sensor units
    - New science to support adoption, integration of new data streams -
      - Create new science on living resource-habitat relationships using new spatial coverage, spatial and temporal density data available
      - Evaluate alignment of rich new data products with regulatory assessment needs
  - Ongoing research on AI/ML algorithm development, testing and tuning for efficient, effective data retrieval, data characterizing from advanced monitoring resources

Sensor distribution and sampling design considerations: lateral?



USGS science for a changing world

Chesapeake Bay Program
A Watershed Partnership

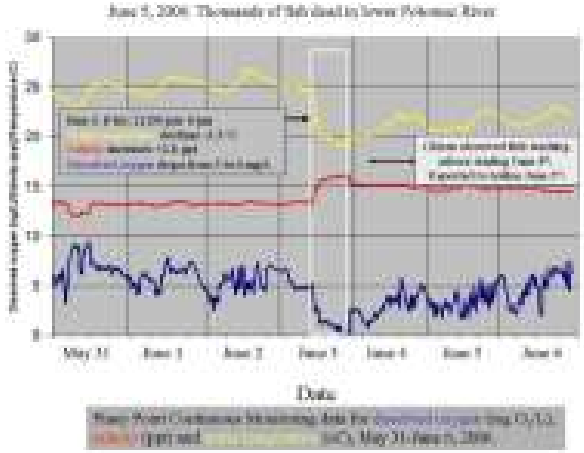
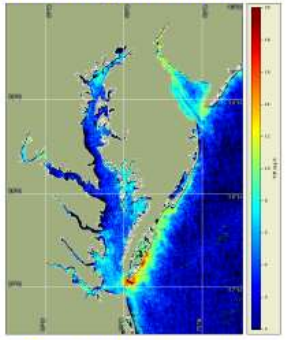


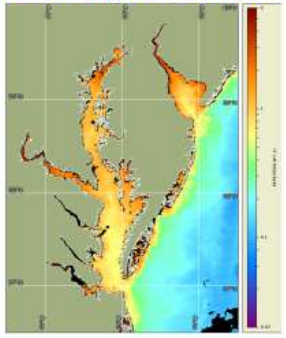
Figure B-5. Lower Potomac River Piney Point Continuous Monitoring data, Maryland Department of Natural Resources, from May 31 to June 6, 2006 shows intrusion of deeper water anoxic waters from the mainstem Chesapeake Bay. Such an intrusion affecting nearshore dissolved oxygen resources was linked with climate forcing effects of wind direction changes on June 3, 2006 and a resulting seiche of bottom waters of the adjoining mainstem Bay.

Source: Maryland Department of Natural Resources

Total Suspended Matter



Diffuse Light Attenuation



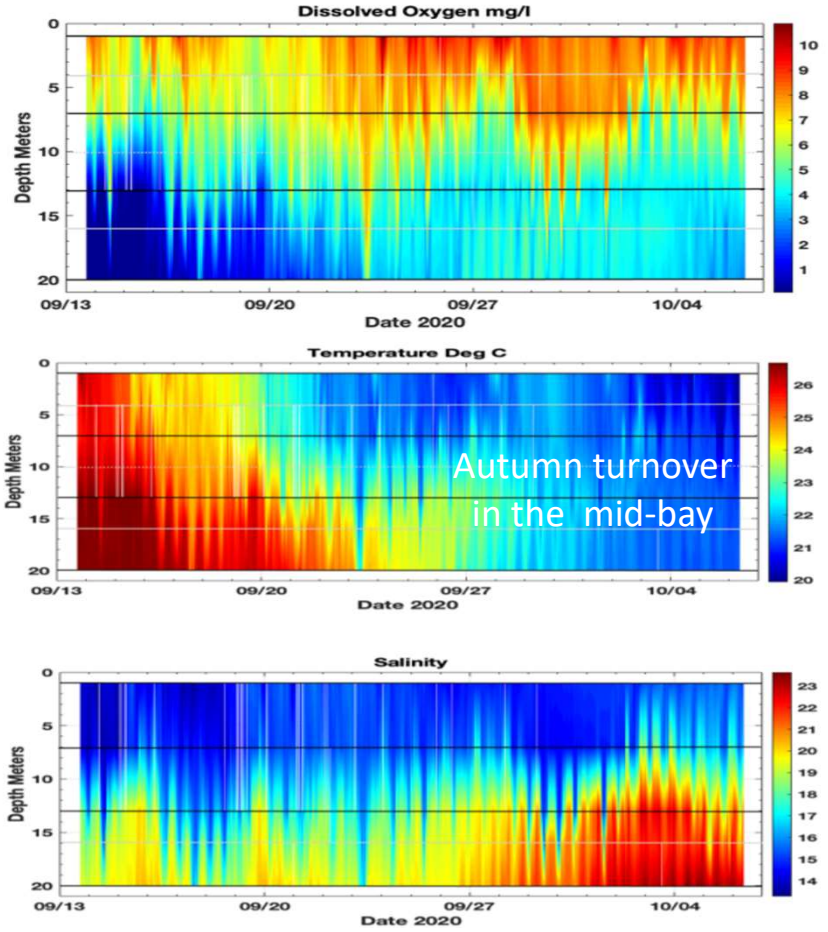
Summary: Data Considerations

- Broad geographic coverage for overview of spatial patterns
- Daily overpasses from 5 satellites
  - instruments: MODIS (1), VIIRS (2), OLCI (2)
- Overpass times:
  - OLCI: ~10:30 AM local time
  - MODIS & VIIRS: ~3:00 PM local time
- Spatial resolutions: 1 km, 750 m **coarser**
  375 m, 300 m, 250 m **finer**
- Surface measurement only (euphotic zone)
- Clouds cause gaps, mitigations possible
- Algorithms: Some algs developed with Bay in-situ data
- Validation: Accuracies published for some products
- Length of record: MODIS 2009, VIIRS 2012, OLCI 2018
  - Mission-length reprocessing needed for full records

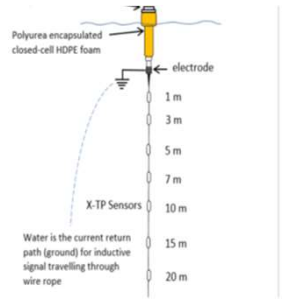
High temporal density water quality data collection for habitat conditions is needed to define habitat boundaries as well as the oxygen resource

- **Dissolved oxygen**
- **Temperature**
- **Salinity**

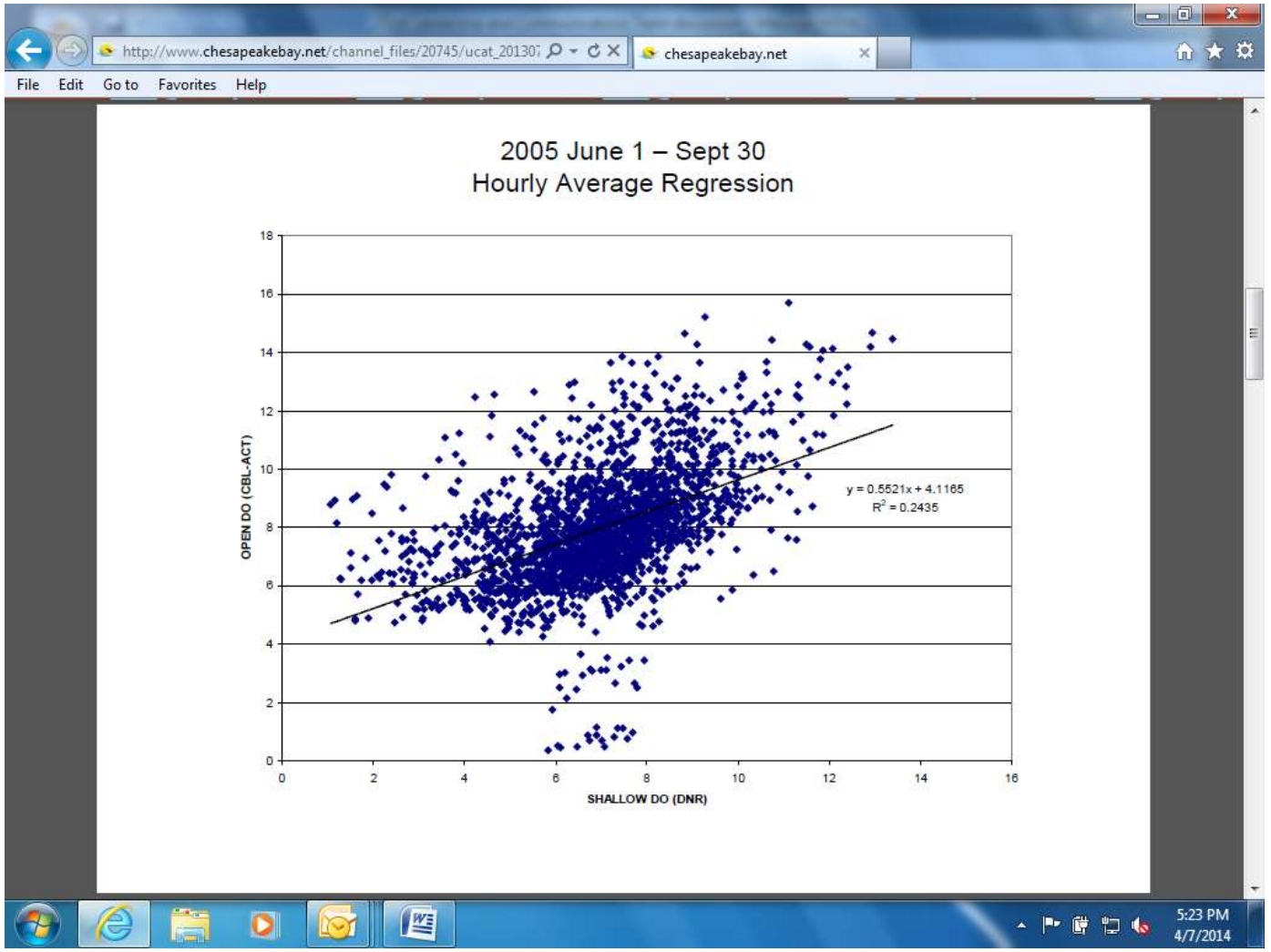
Sept-Oct 2020 mid-Bay CB4.3



~ $50K instrument with high data return on investment



D. Wilson 2020. 2019-2020 Chesapeake Bay Trust GIT-funded pilot project results


http://www.chesapeakebay.net/channel_files/20745/ucat_20130
chesapeakebay.net
File Edit Go to Favorites Help
2005 June 1 – Sept 30
Hourly Average Regression
OPEN DO (CBL-ACT)
SHALLOW DO (DNR)
y = 0.5521x + 4.1165
R2 = 0.2435
0
2
4
6
8
10
12
14
16
18
5:23 PM
4/7/2014