Improving Dissolved Oxygen and Aquatic Life Uses in the Delaware River Estuary

Steven J. Tambini, P.E.

Executive Director

Delaware River Basin Commission

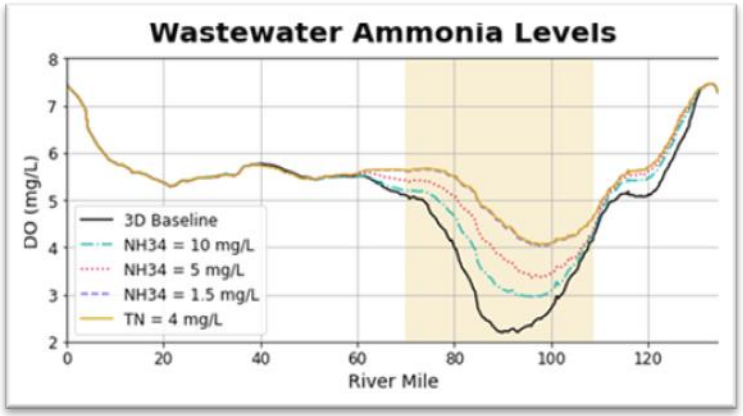
Photo: Paul Michael Bergeron

Photo: Delaware River Waterfront Corporation

NJ AWRA

Water Leadership Forum

March 22, 2023

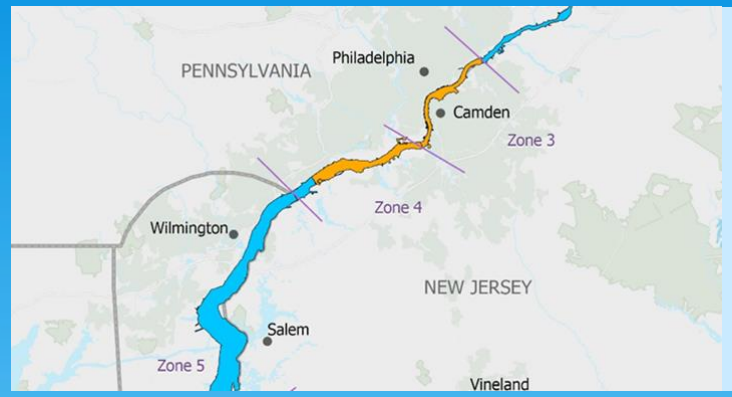


Delaware River Basin Commission

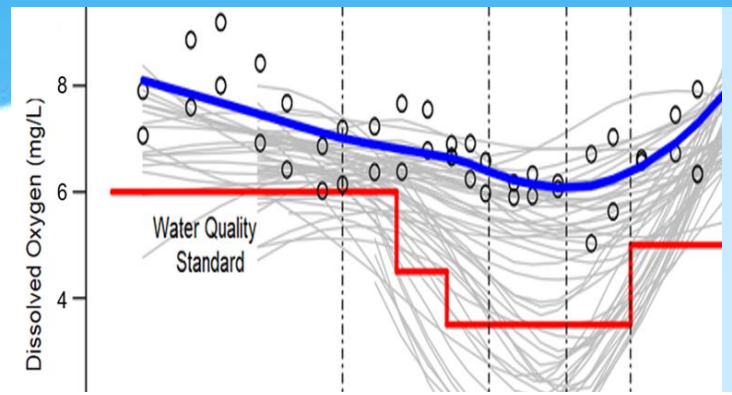
DELAWARE • NEW JERSEY

PENNSYLVANIA • NEW YORK

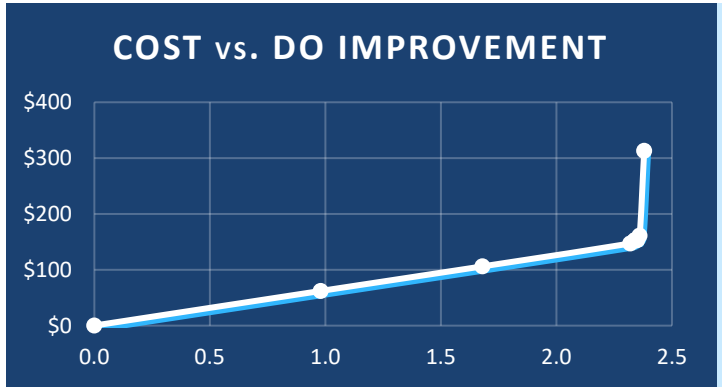
UNITED STATES OF AMERICA



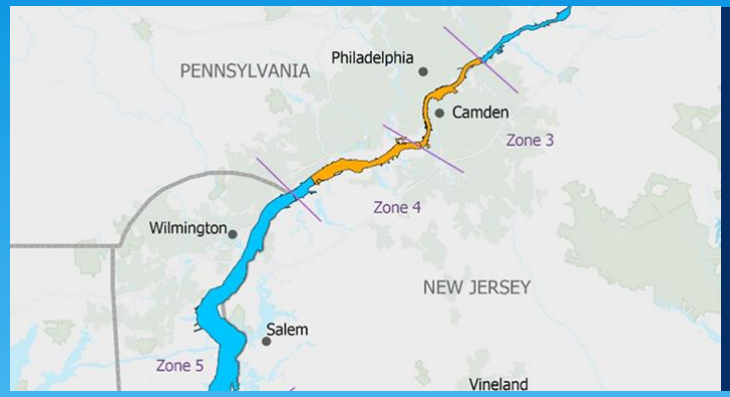
The Setting



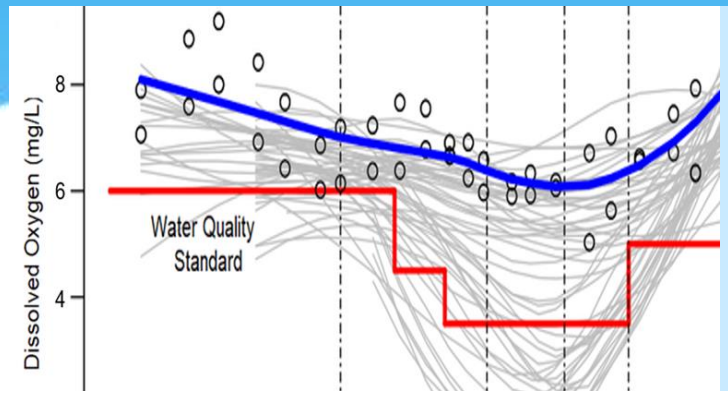
The Problem



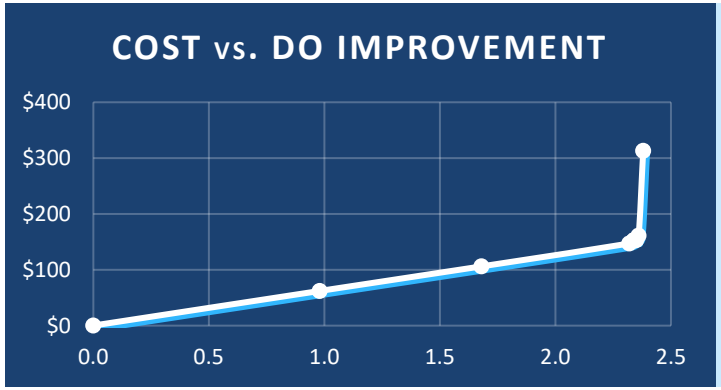
The Solution



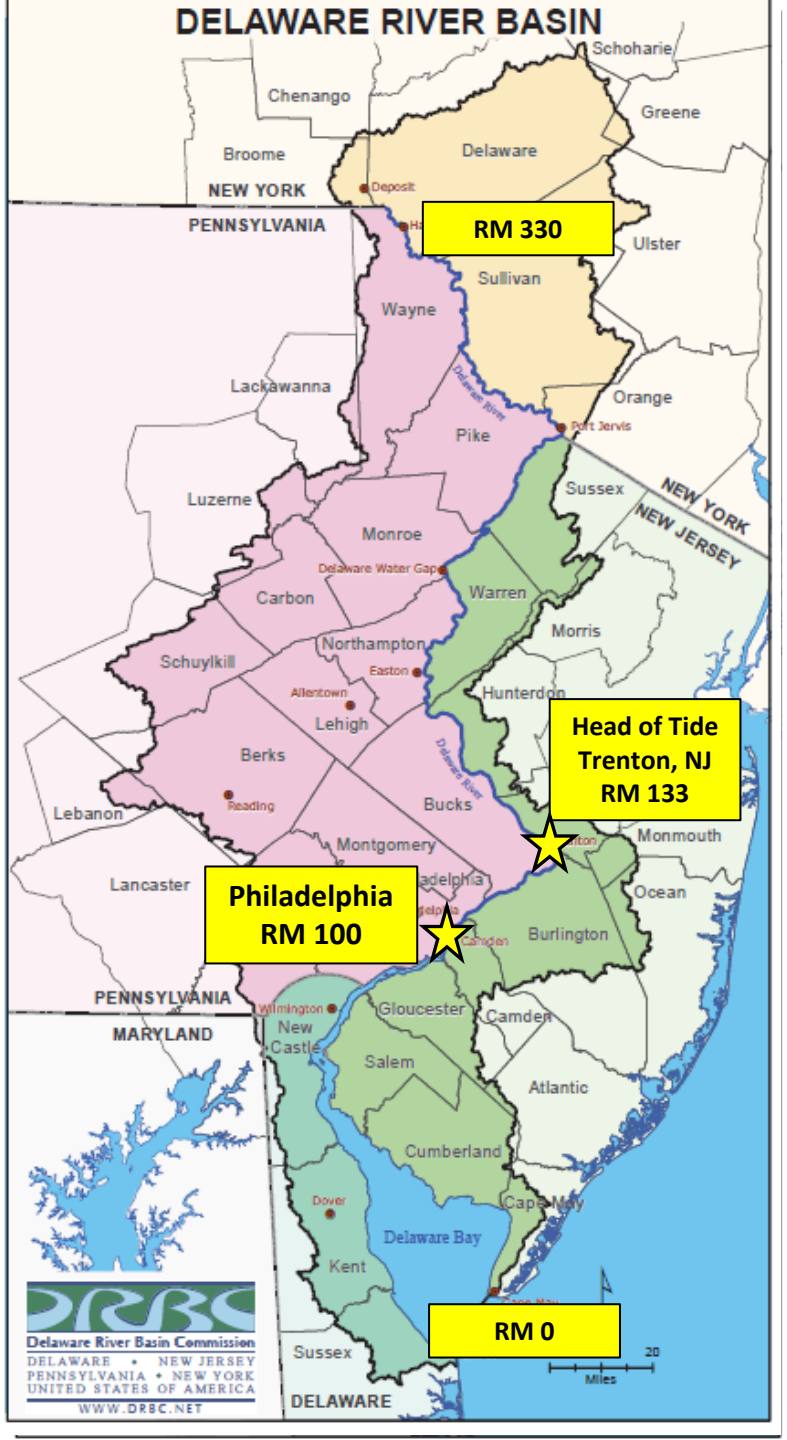
The Setting

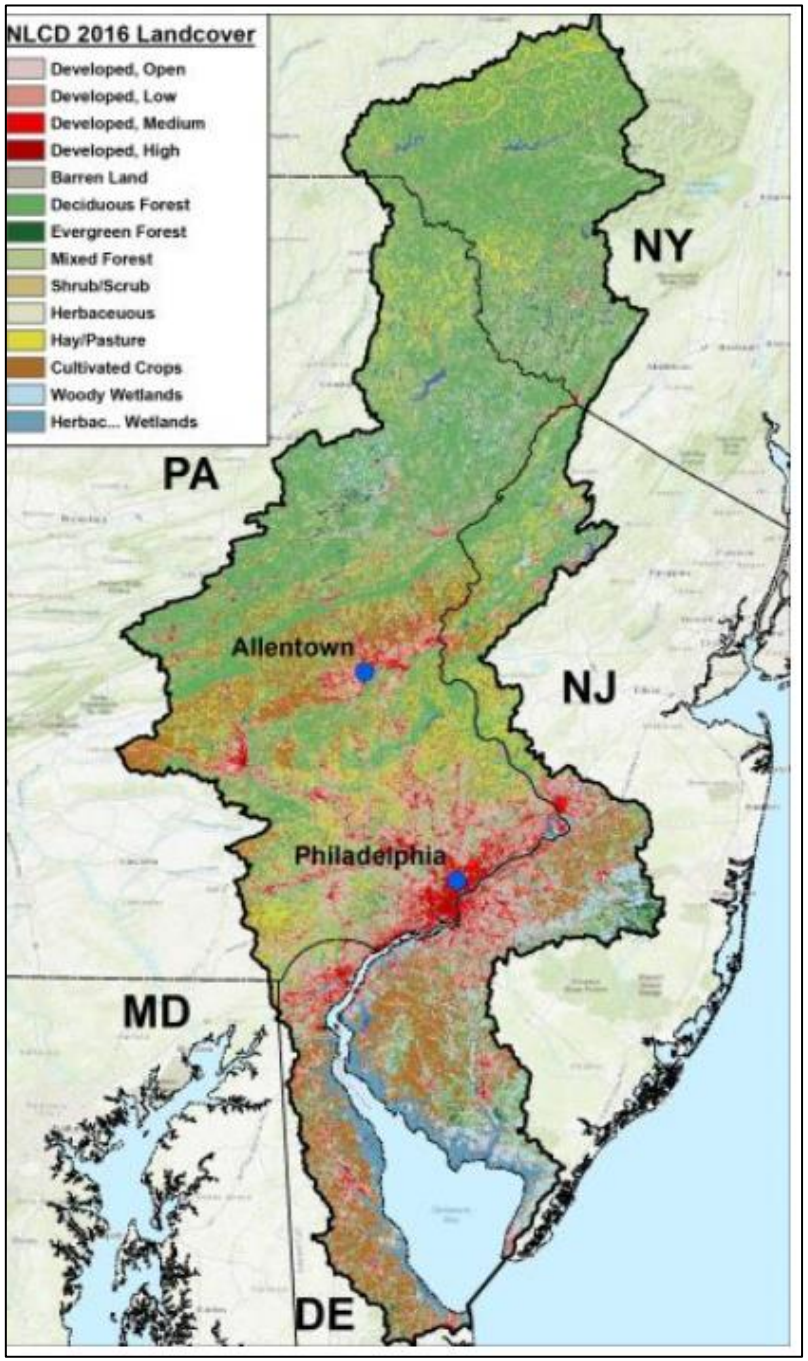


The Problem



The Solution





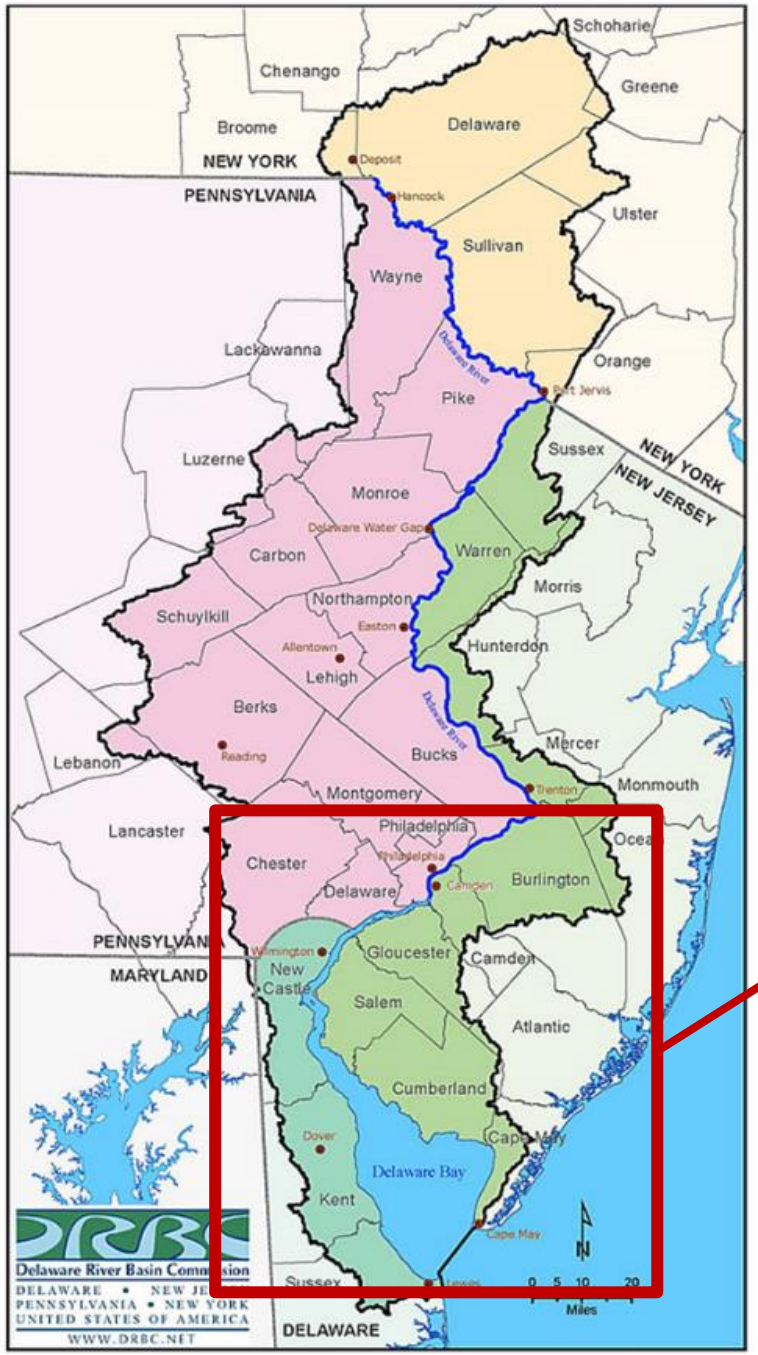
Credit: Nicholas A. Tonelli

The Benjamin Franklin Bridge is at River Mile 100:

Credit: RentPhilly.com

Credit: Laura Chamberlin, WHSRN.org

This presentation will focus on water quality in the Delaware River Estuary



The main stem Delaware River provides an interstate boundary for its entire 330 miles.

Credit: Google Maps

The Delaware River Basin Compact states that…

…The water resources of the basin are subject to the sovereign right and responsibility of the signatory parties, and it is the purpose of this Compact to provide for a joint exercise of such powers of sovereignty in the common interests of the people of the region.

Section 1.3 (b), Delaware River Basin Compact
United States: Public Law 87-328

The Delaware River Basin Commission "shall develop and effectuate plans, policies and projects relating to the water resources of the basin."

Five Equal Members:

- Delaware 
- New Jersey 
- Pennsylvania 
- New York 
- United States 

Managing, protecting, and improving the water resources of the Delaware River Basin

The water quality regulatory setting in the Basin includes two complementary foundational authorities.

DELAWARE RIVER BASIN COMPACT (1961)

Delaware River Basin Commission

DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

"The commission may assume jurisdiction to control future pollution and abate existing pollution in the waters of the basin…"

CLEAN WATER ACT (1972)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

"…restore and maintain the chemical, physical, and biological integrity of the Nation's waters."

The co-regulators in the Basin have shared water quality goals to protect aquatic life uses.

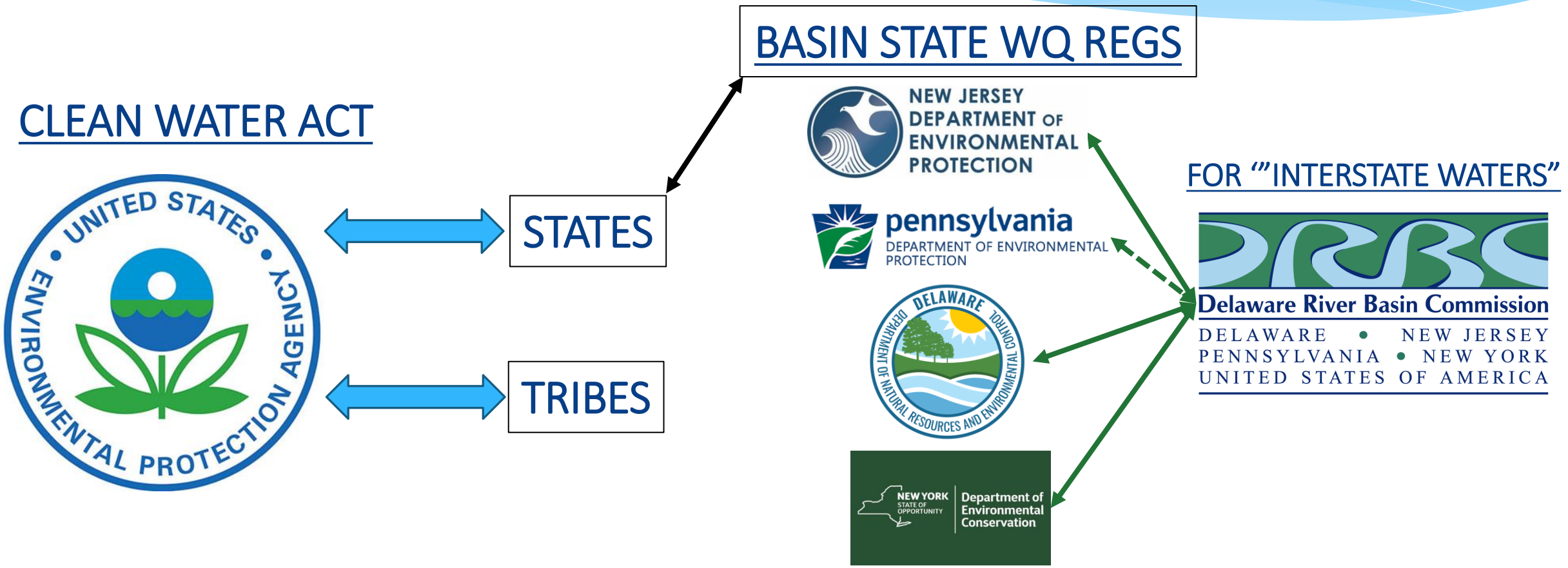
DRBC uses to be protected include: "…wildlife, fish and other aquatic life…"

American shad
Robert S. Michelson

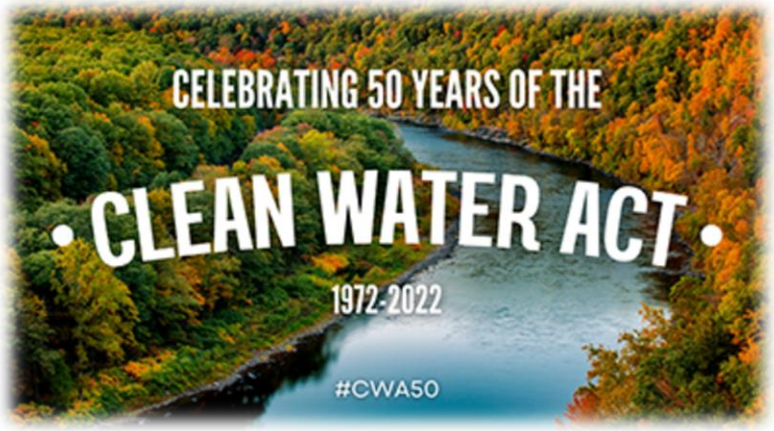
EPA goals include: "…fishable waters…" "…for the protection and propagation of fish, shellfish, and wildlife…"

NOAA

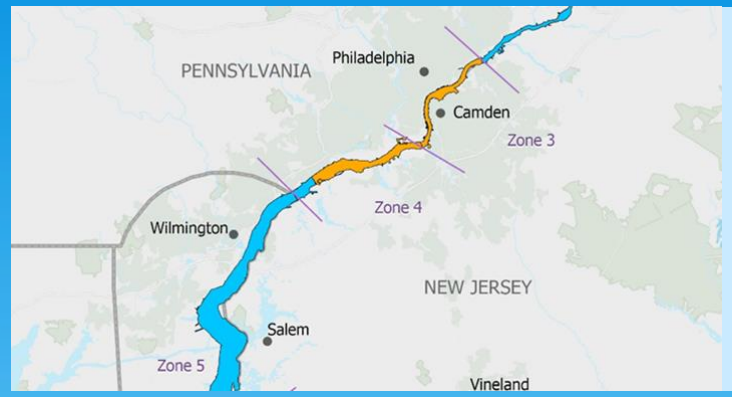
The basin states regulations “refer or defer” to DRBC for management of WQ in “interstate” waters



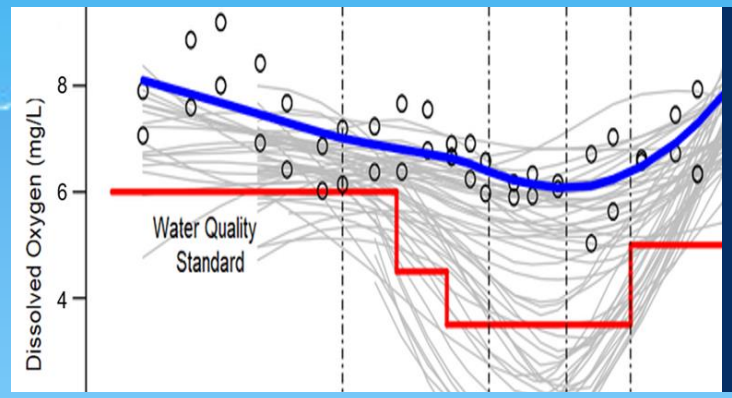
We will use the Clean Water Act terms in this presentation.



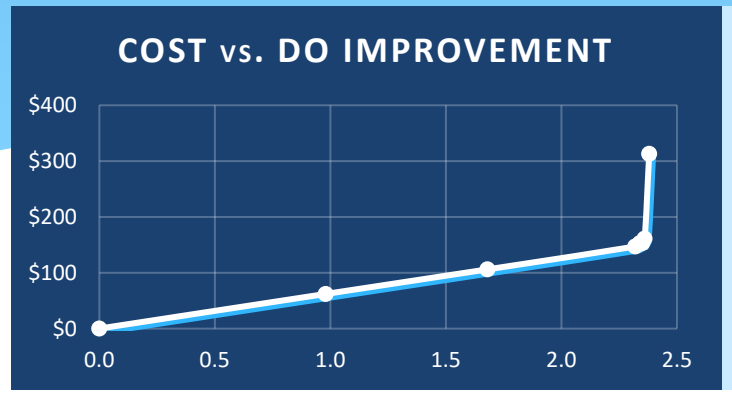
- Water Quality Standards
  - Designated Uses
  - Water Quality Criteria
  - Antidegradation



The Setting



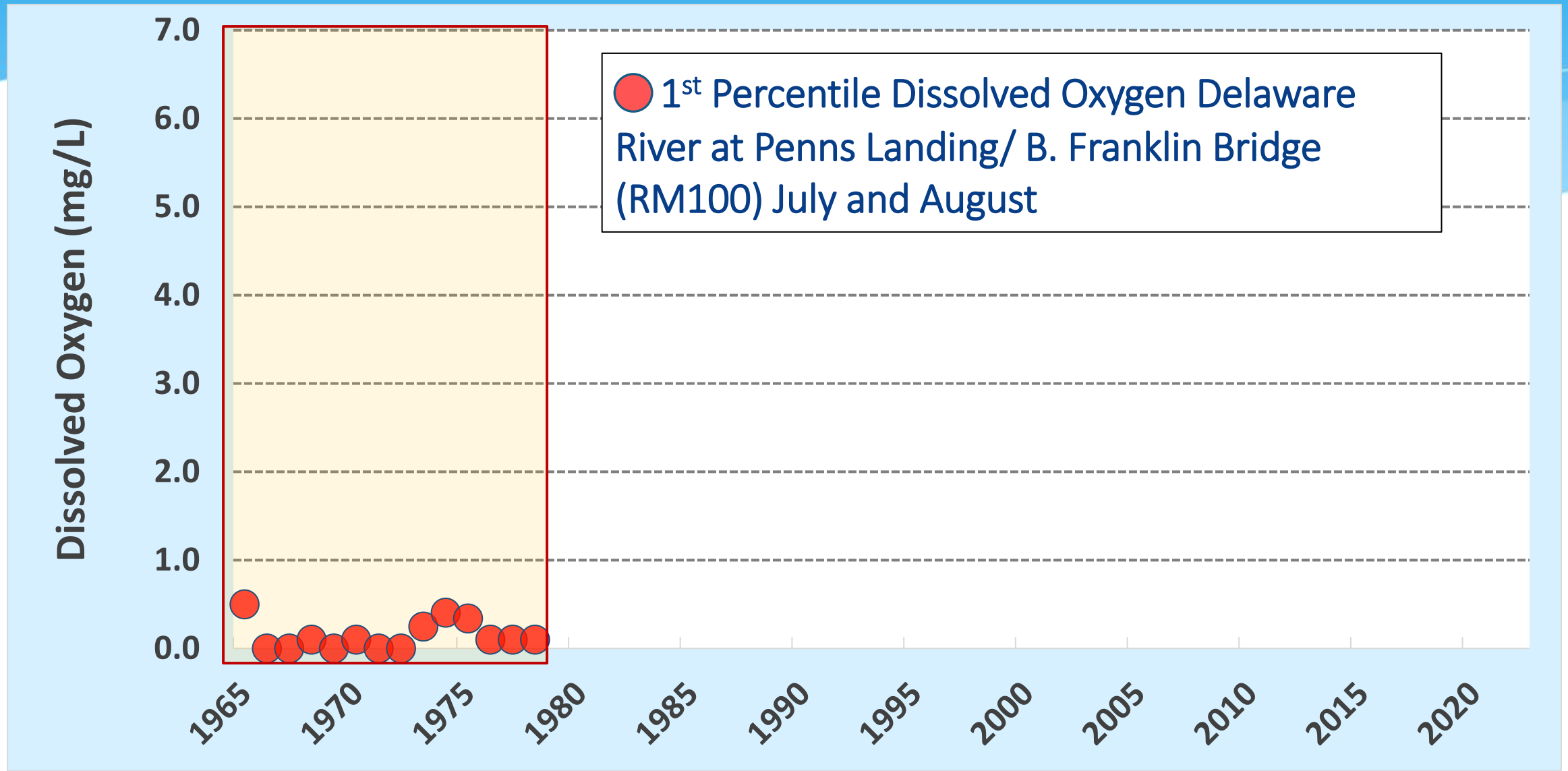
The Problem



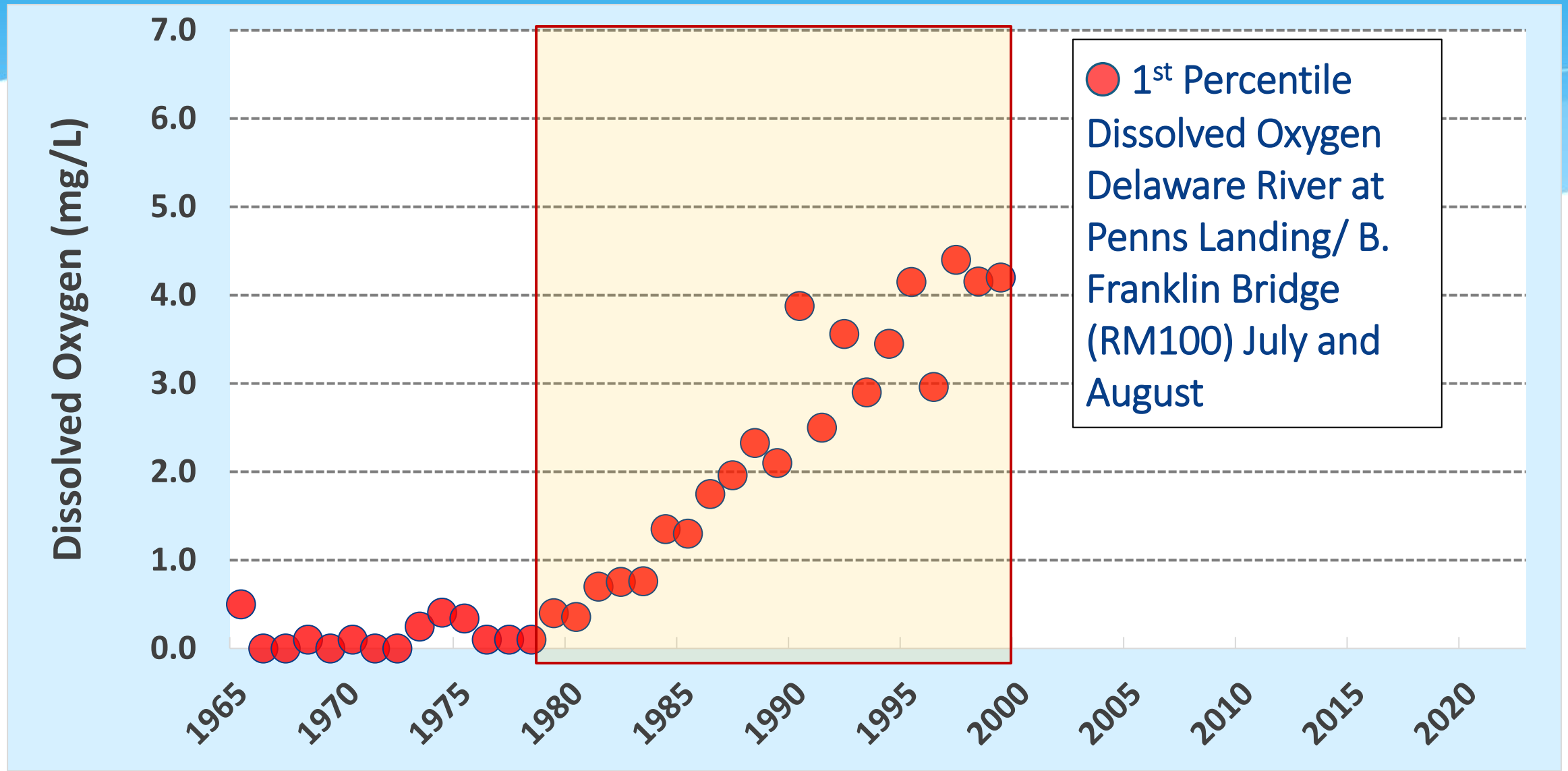
The Solution

Before DRBC regulations and the CWA dissolved oxygen concentrations in the summer at Philadelphia in the Delaware River Estuary were at, or near, zero.

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

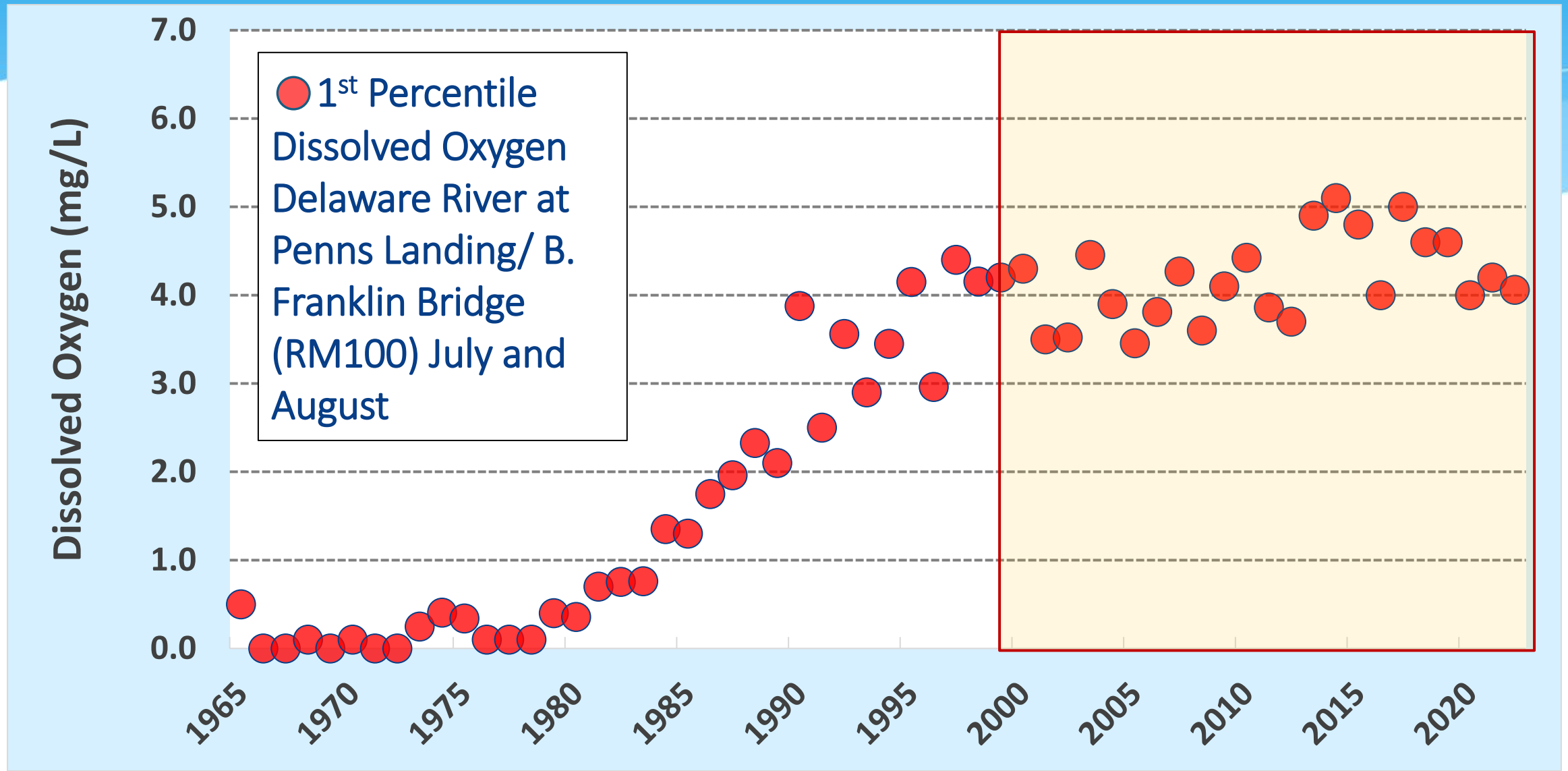


DRBC WQ regulations, the CWA, and significant infrastructure investments resulted in significant improvement in summer dissolved oxygen concentrations.



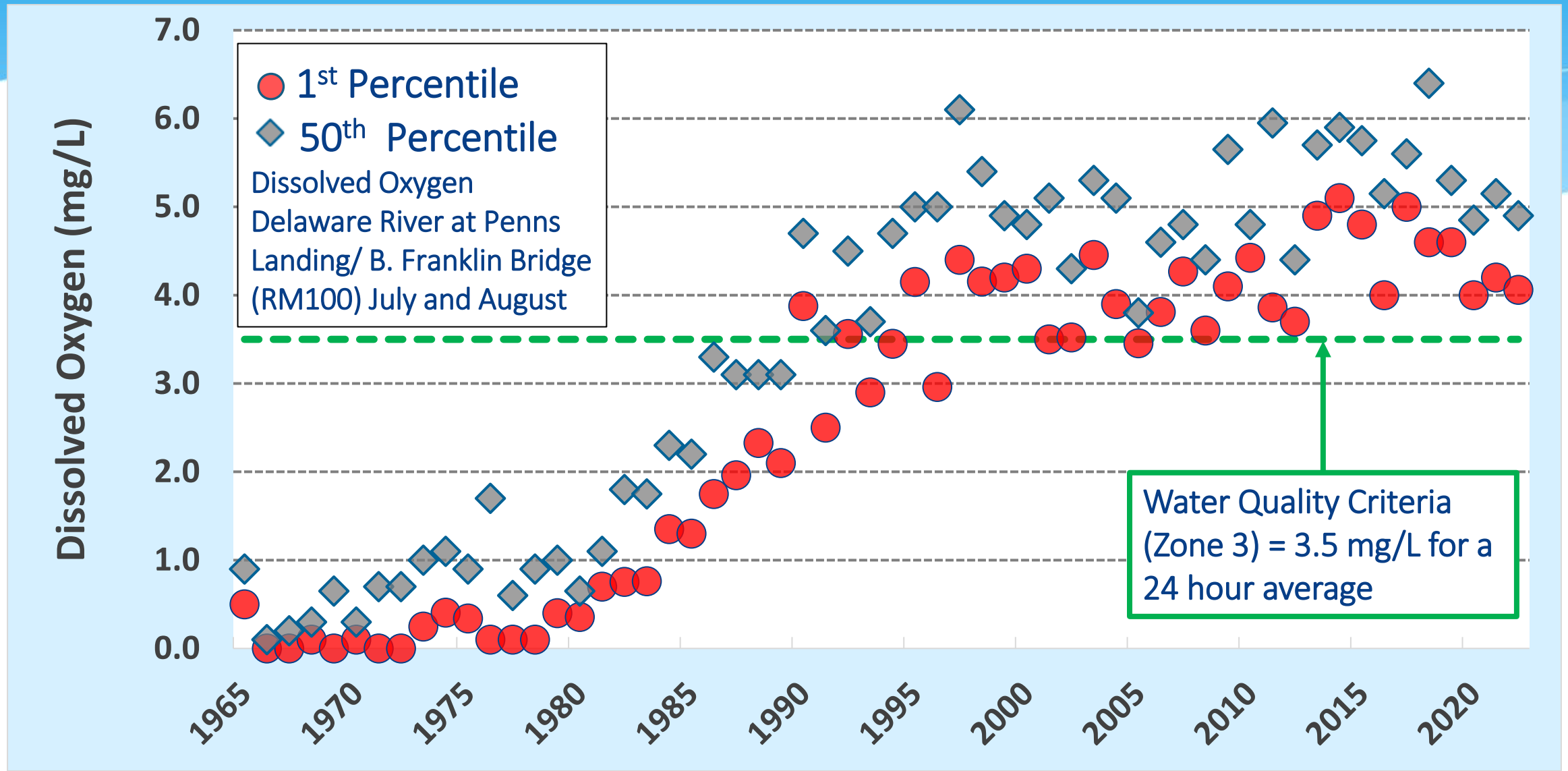
There has been limited improvement in the minimum (1st percentile) dissolved oxygen since about 2000.

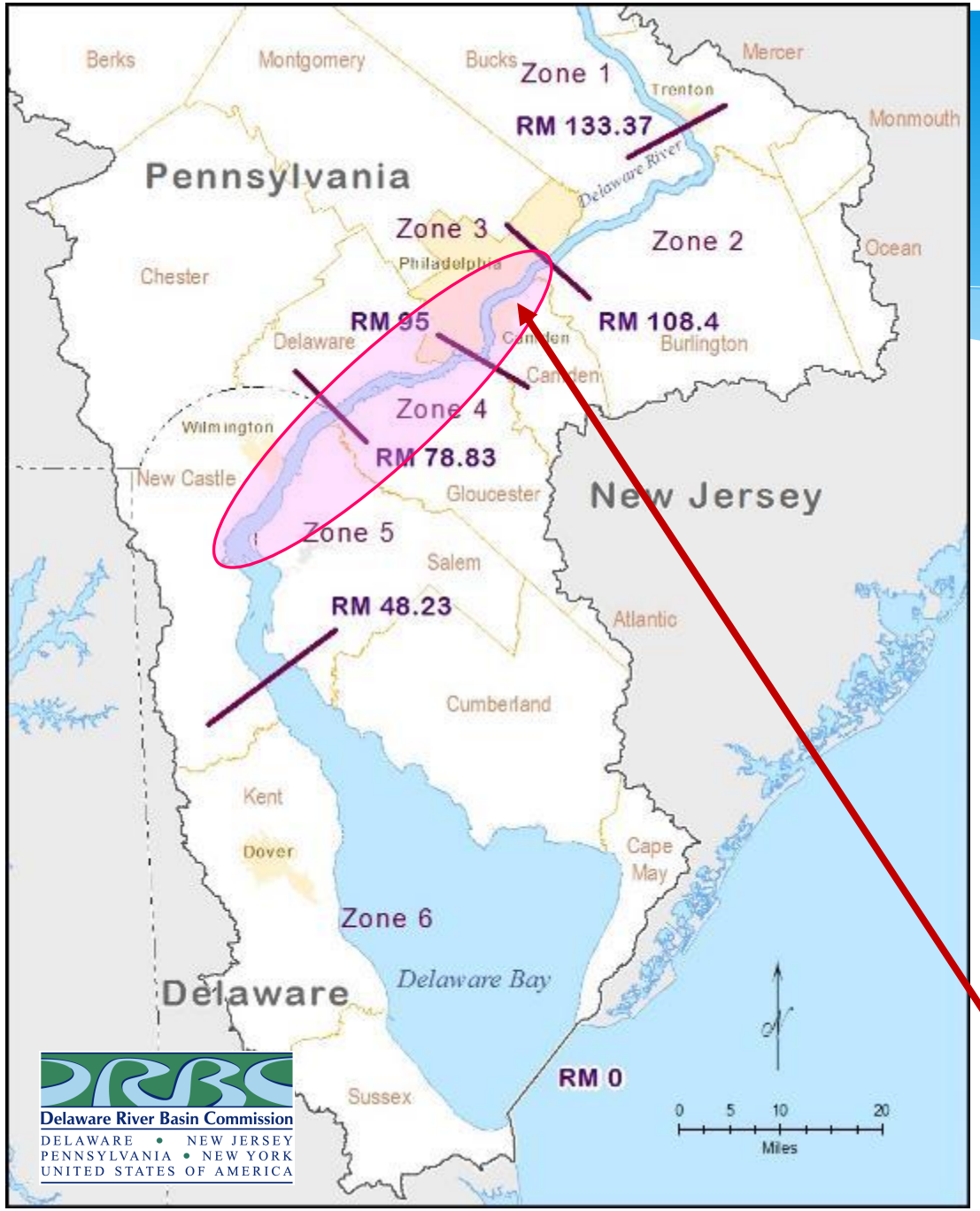
Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA



DO concentrations are currently above the minimum water quality criteria.

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA





The main stem Delaware River is separated into several water quality management and assessment "zones"

Water Quality Assessment Units:

Zone 1: Non-tidal (Upstream from Trenton)

Estuary:

Zone 2 - 5: Tidal Delaware River Estuary

Zone 6: Delaware Bay

River Miles:

RM 0.0 = Atlantic Ocean

RM 70 = City of Wilmington

RM 100 = B. Franklin Bridge, Philadelphia / Camden

RM 133 = "Head of Tide", Trenton, NJ

Water quality aquatic life designated uses and WQ criteria to protect those uses differ throughout the Estuary.

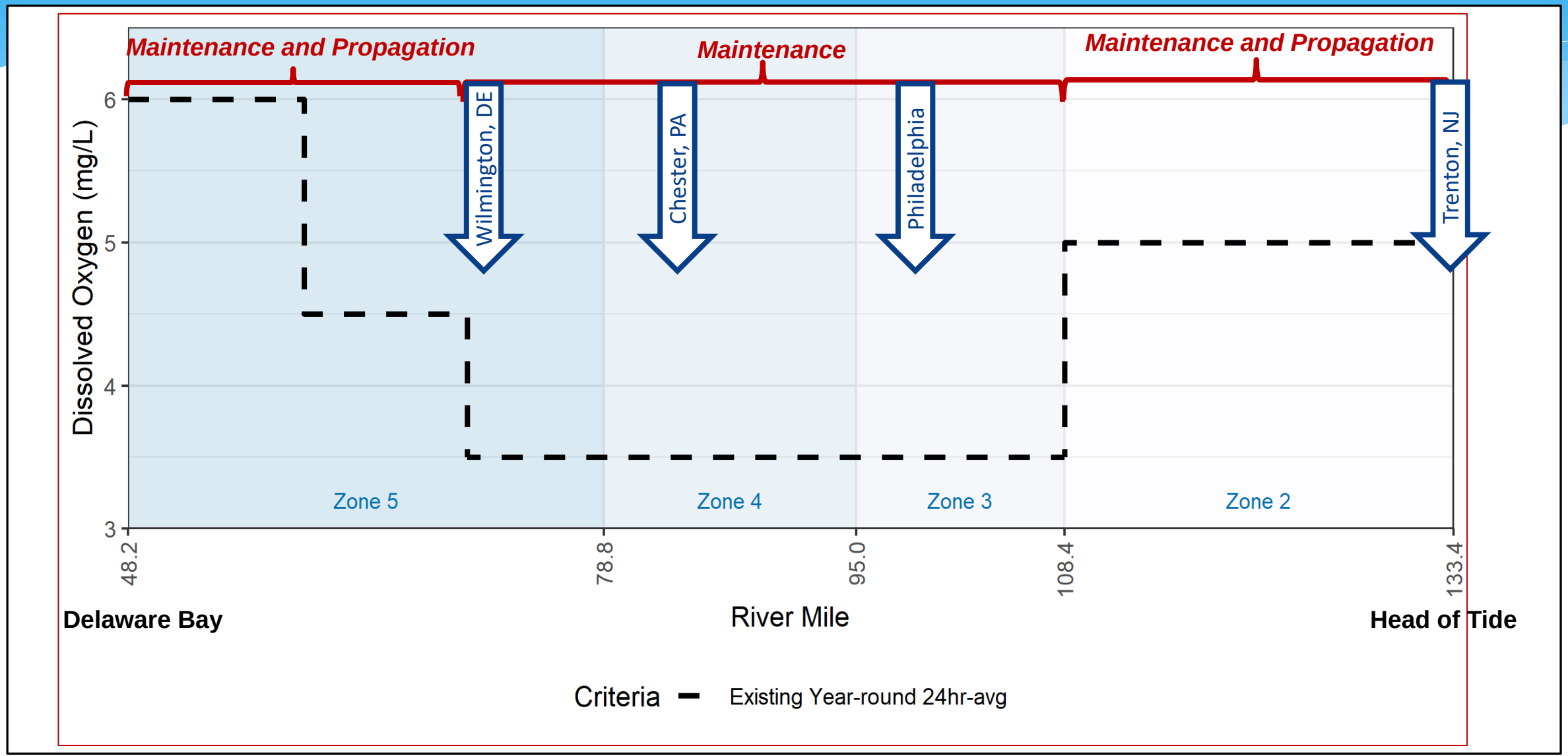
Urbanized portion of Delaware Estuary or Fish maintenance area (FMA)

The Delaware Bay

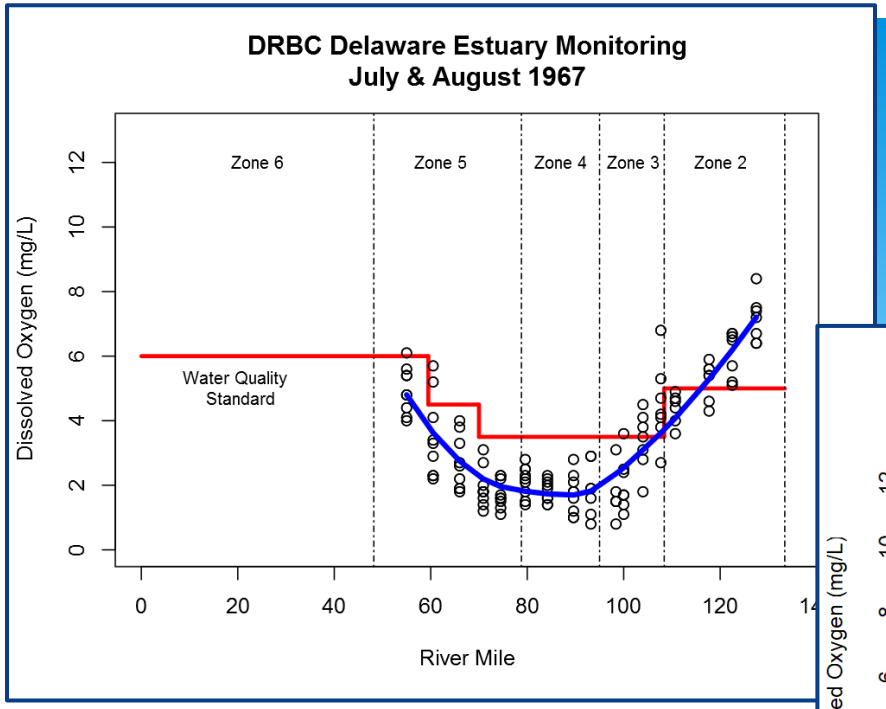
Zone	River Mile	Aquatic Life Use	Migratory Fishes	24-hour average D.O. Criteria
2	108.4 – 133.4	**maintenance** and **propagation** of resident fish and other aquatic life	**passage** of anadromous fish	5.0 mg/l
3	95 – 108.4	**maintenance** of resident fish and other aquatic life	**passage** of anadromous fish	3.5 mg/l
4	78.8 – 95	**maintenance** of resident fish and other aquatic life	**passage** of anadromous fish	3.5 mg/l
5	70 – 78.8	**maintenance** of resident fish and other aquatic life	**passage** of anadromous fish	3.5 mg/l
	48.2 – 70	**maintenance** and **propagation** of resident fish and other aquatic life	**passage** of anadromous fish	4.5 – 6.0 mg/l
6	0 – 48.2	**maintenance** and **propagation** of resident fish and other aquatic life **maintenance** and **propagation** of shellfish	**passage** of anadromous fish	6.0 mg/l

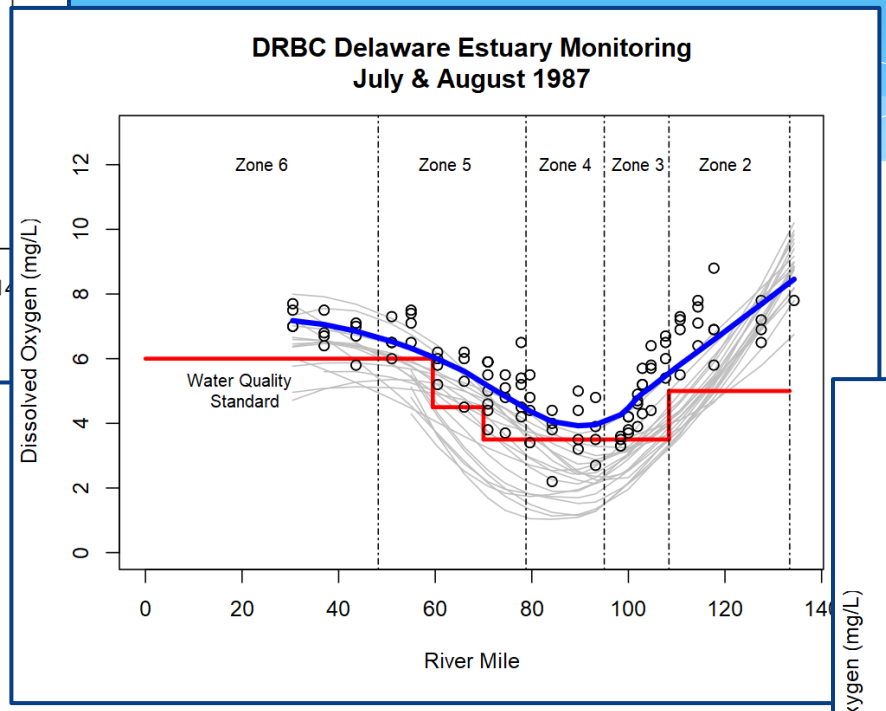
Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

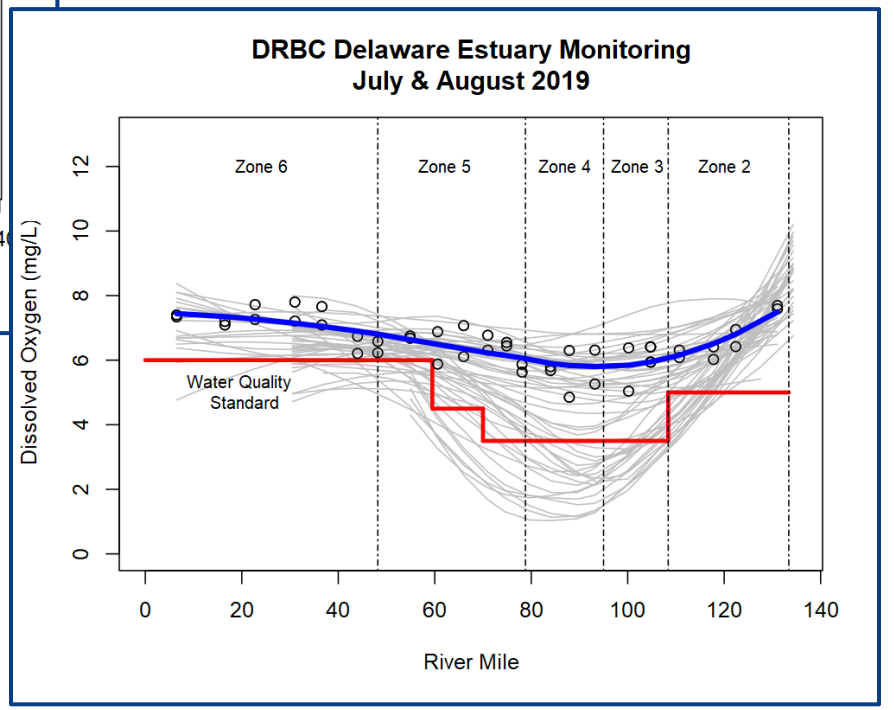
The “Fish Maintenance Area” (FMA) includes the “urban Estuary” from RM 70 to RM 108.



WQ criteria are being met, but a DO sag still exists.



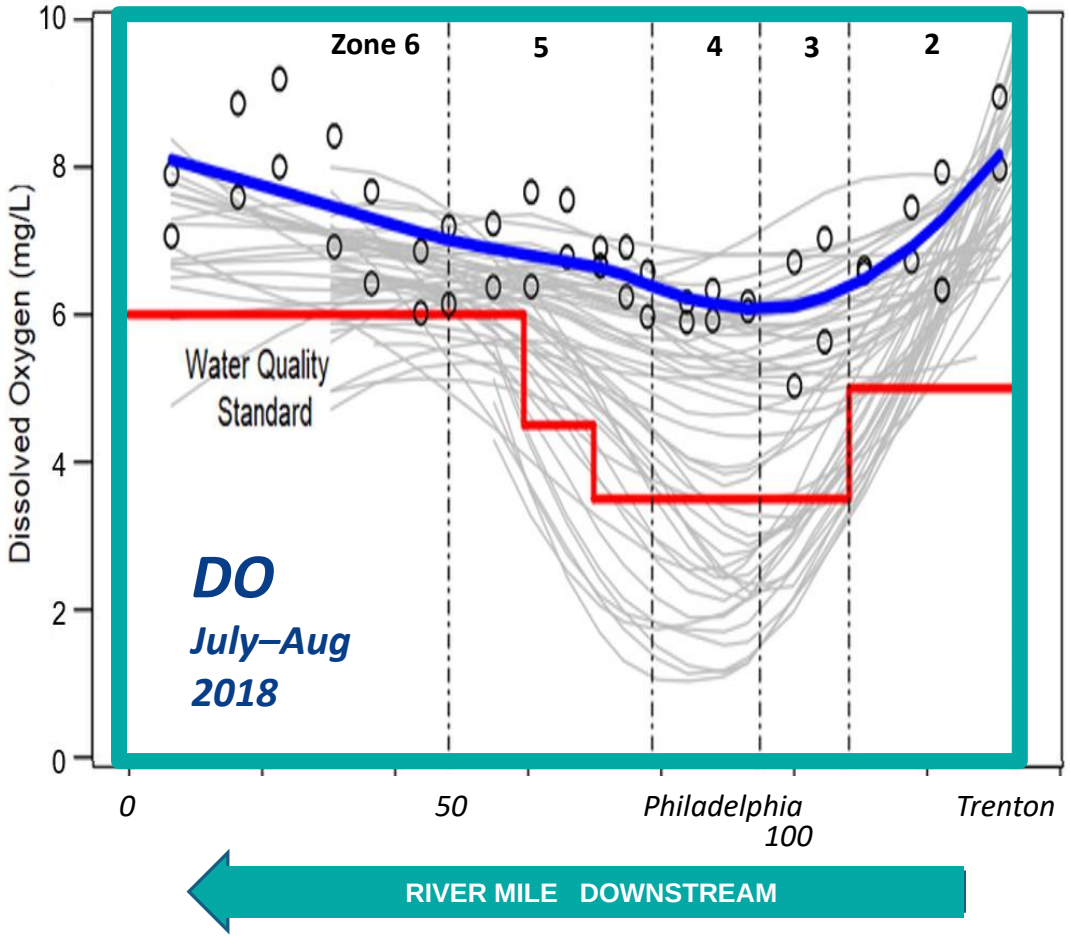


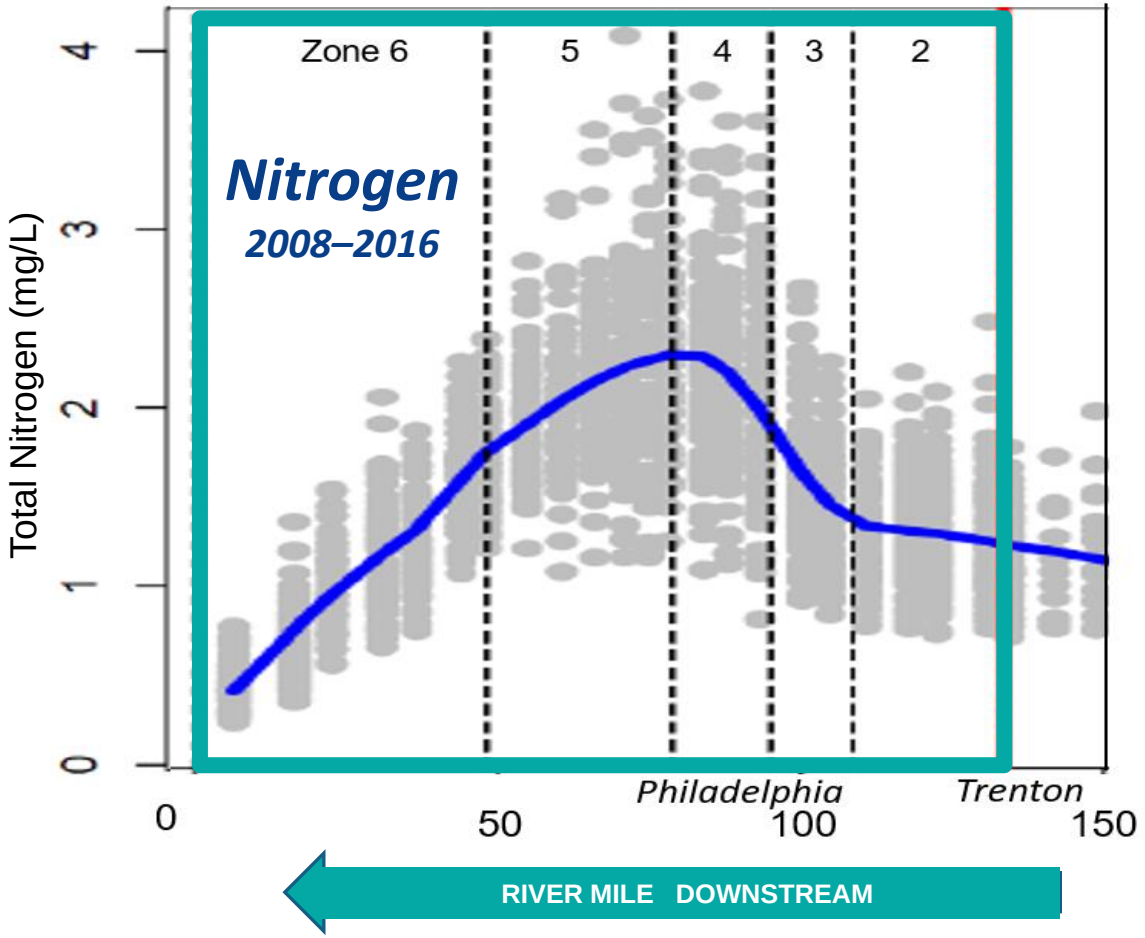


Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Nitrogen levels are highest in the urban estuary where DO levels are lowest

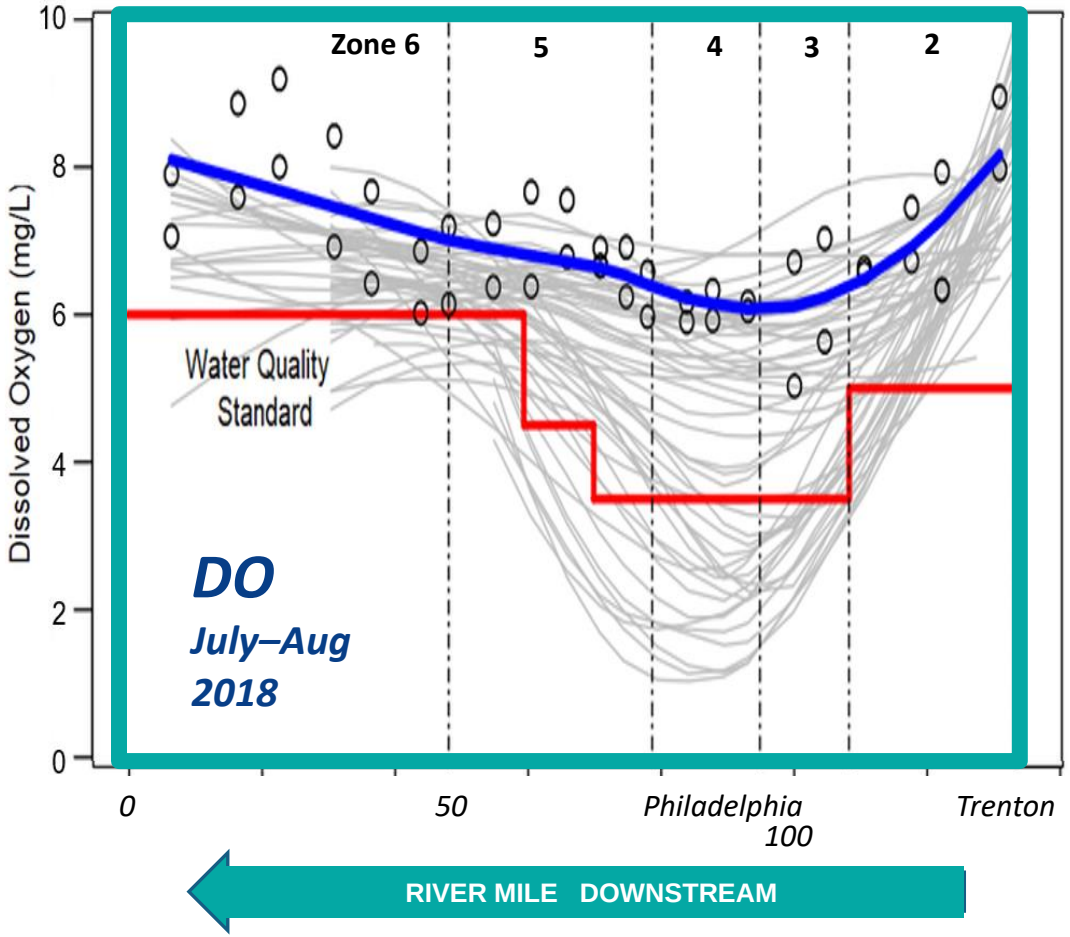
Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

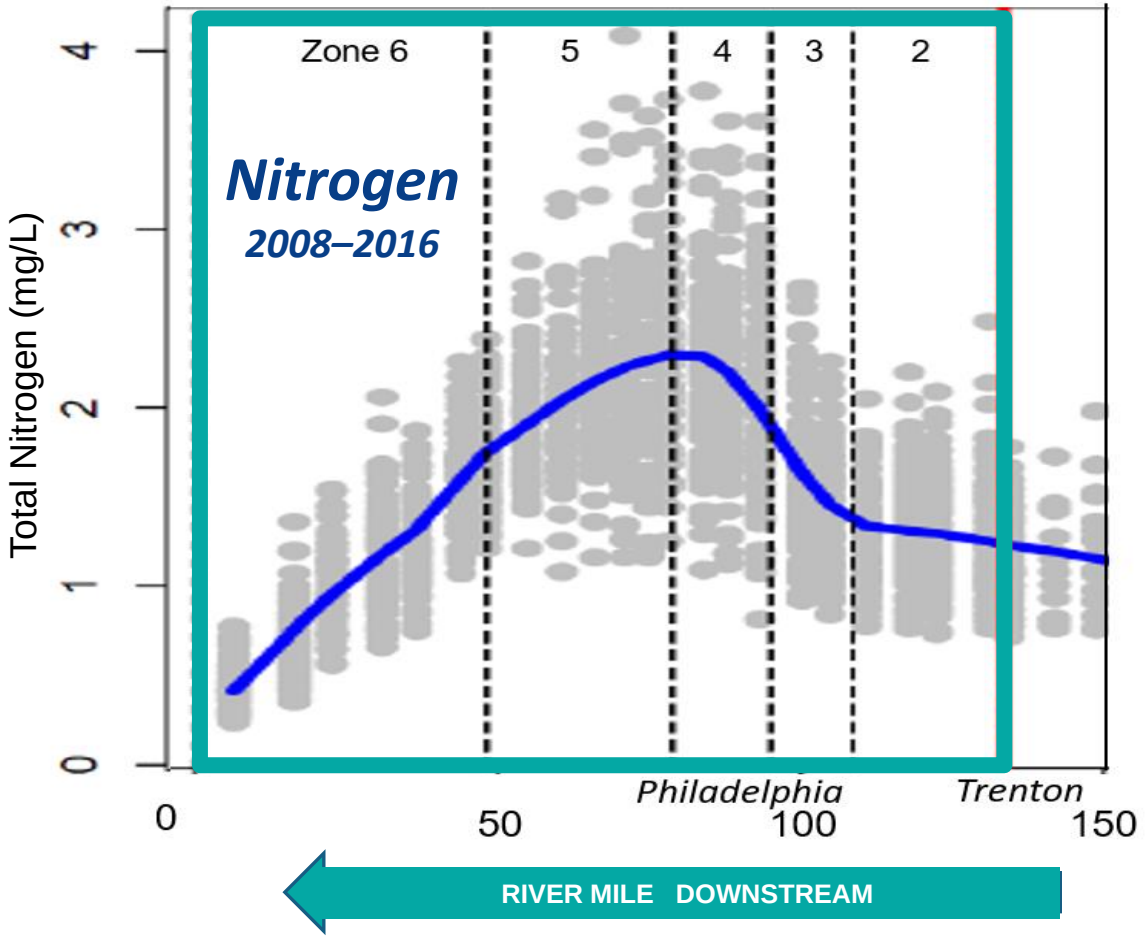




Nitrogen levels are highest in the urban estuary where DO levels are lowest

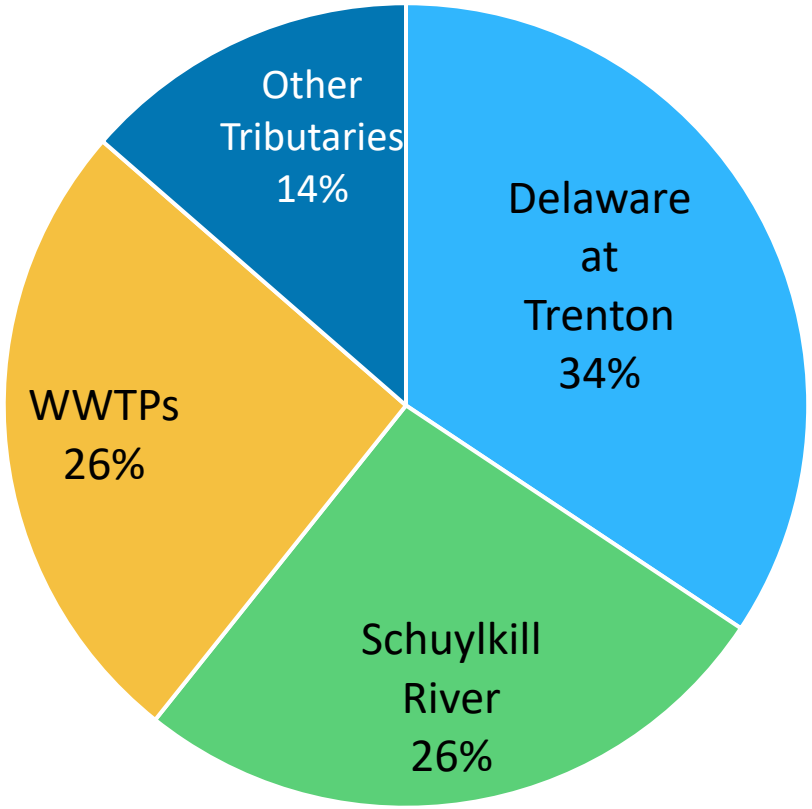
Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA



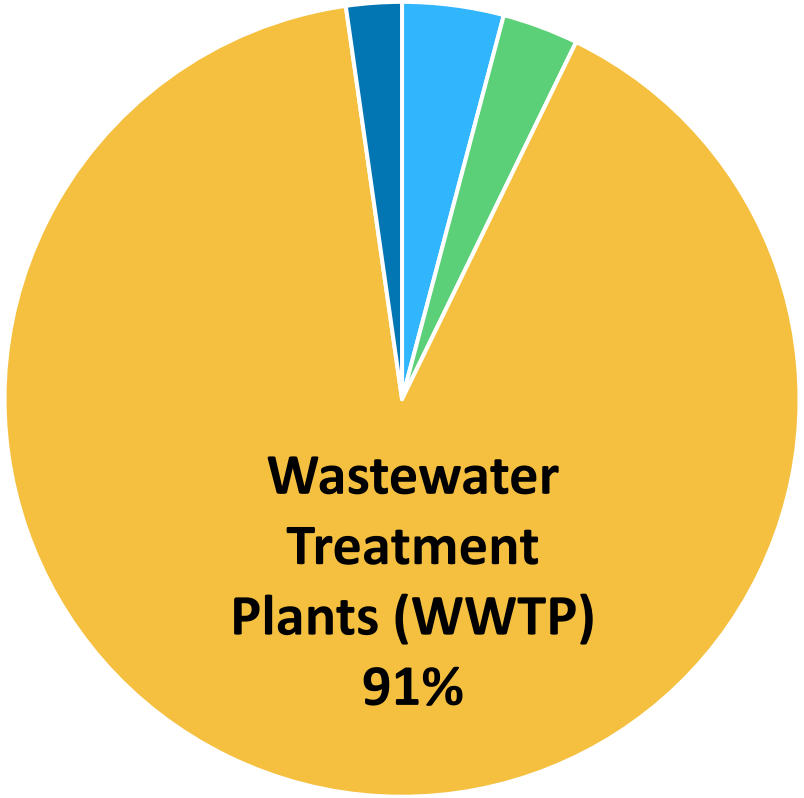


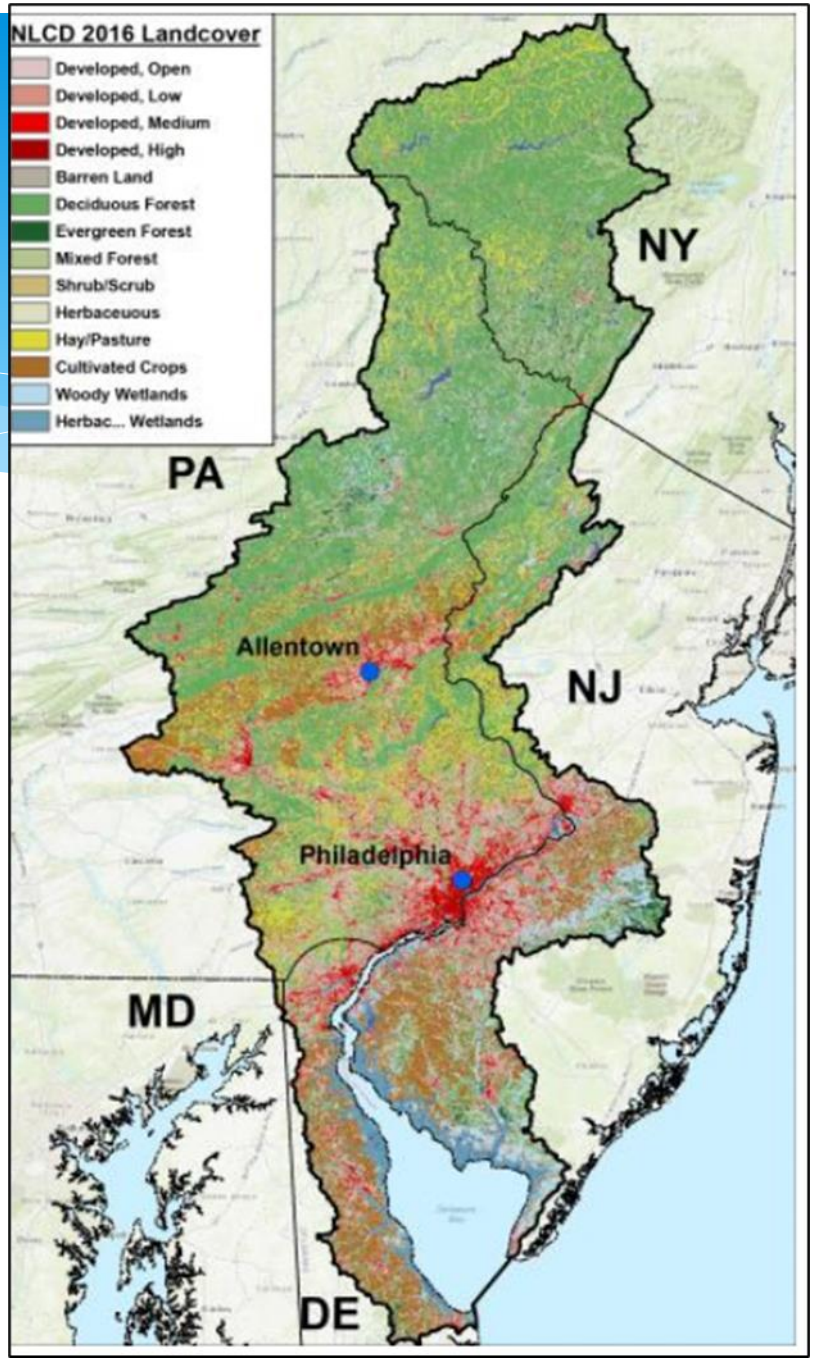
What are the sources of Nitrogen?

Total Nitrogen

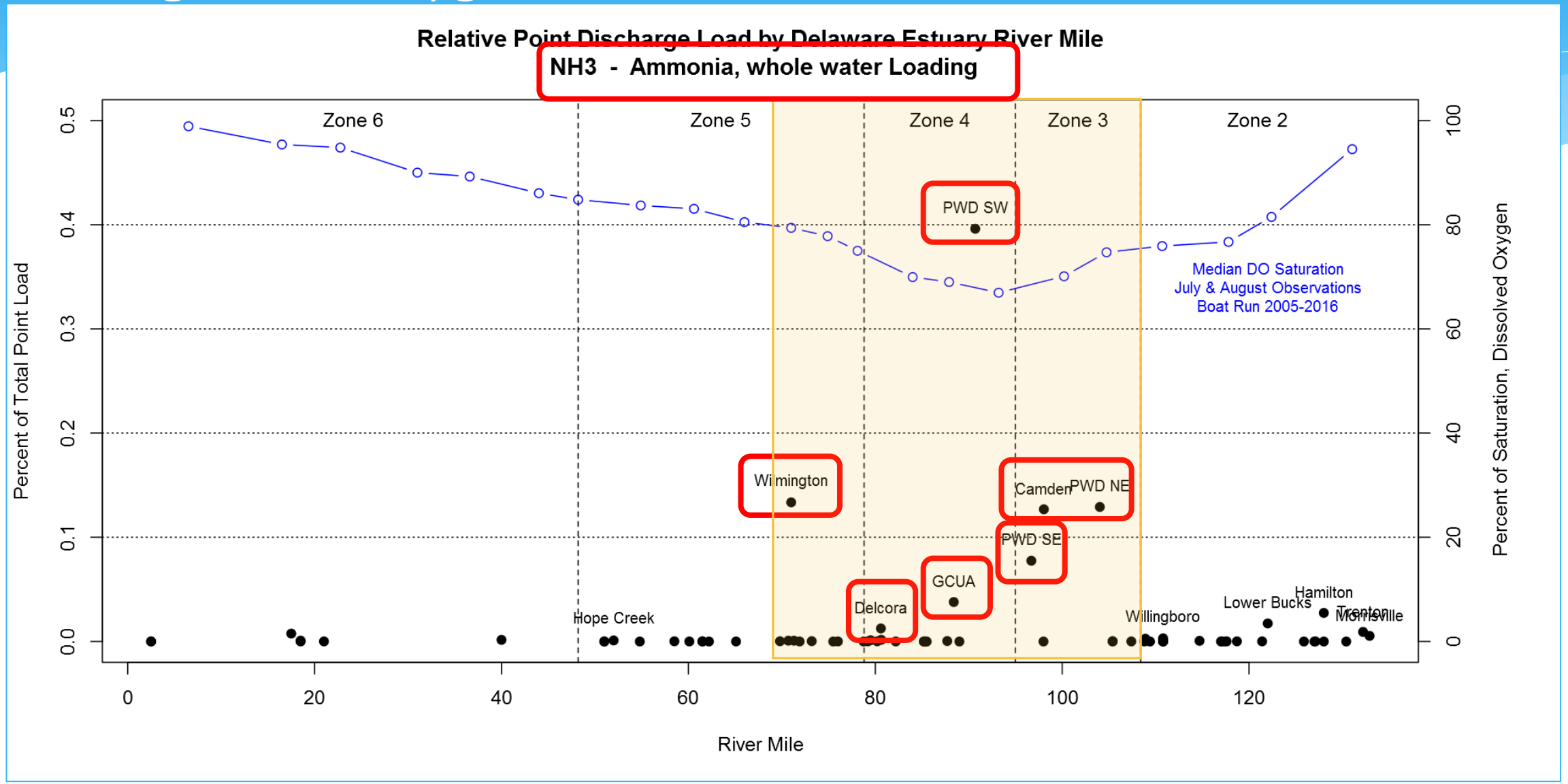


Ammonia





Carbonaceous oxygen demand has been addressed. Nitrogenous oxygen demand has not.



There are dissolved oxygen sensitive and threatened and endangered fish species in the Estuary.

Atlantic Sturgeon

Acipenser oxyrinchus oxyrinchus

Shortnose Sturgeon

Acipenser brevirostrum

fisheries.noaa.gov

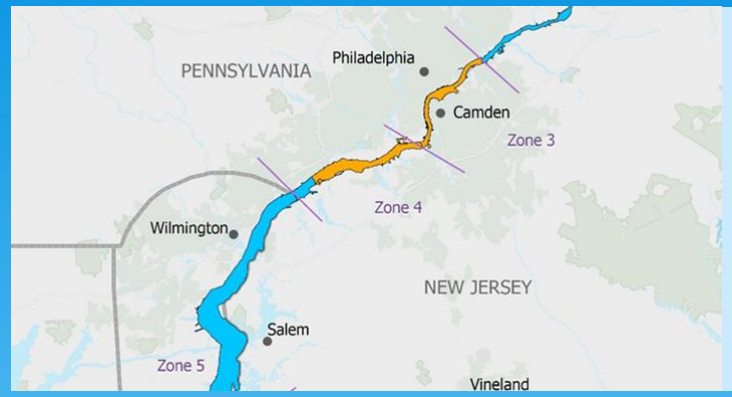
In 2017 the Commission took formal action through unanimous vote (Resolution 2017-4).

Recognizing that evidence supports further study on the inclusion of propagation as a designated use in Zones 3 and 4 and the upper portion of Zone 5 of the Delaware River Estuary.

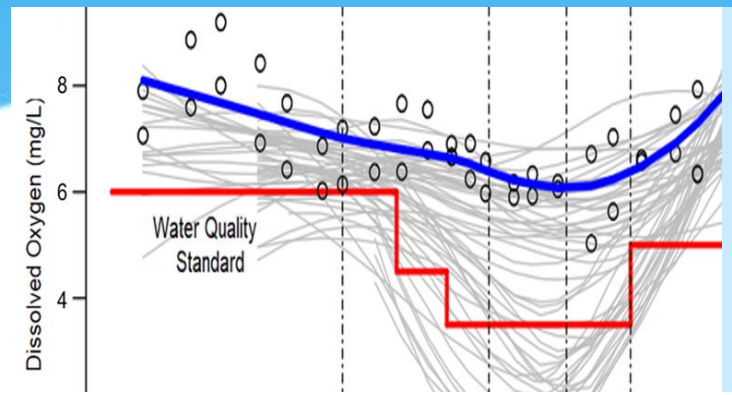
Directing the DRBC the Executive Director to initiate a rulemaking process to establish the designated uses and determine water quality criteria.

Recognizing the vital importance of determining the appropriate designated aquatic life uses of the … through a collaborative process informed by technical studies and specialized scientific and engineering expertise.

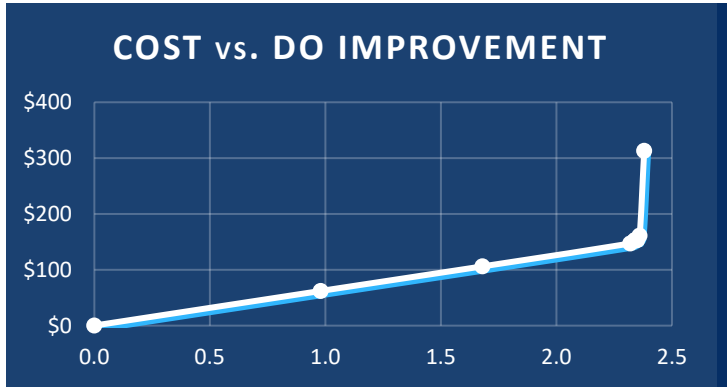
Recognizing shared goals including that water quality standards, including designated uses and water quality criteria, should be updated consistent with Clean Water Act goals as quickly as possible and practicable



The Setting



The Problem



The Solution

Objective: Reduce Pollutant Loads

Continuous Water Quality Improvement Process

WQ Assessment:

- Monitoring
- Measurement
- Compliance w/ WQS and CWA

Analysis:

- Apply science and engineering to understand problems and develop solutions.

Coordination with:

- Co-regulators
- Advisory committees
- Stakeholder community

Public:

- Outreach
- Input
- Education

New or Revised Policy:

- Regulation
- Enforcement

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Resolution 2017-4 required that DRBC perform a series of studies and an analysis of attainability before rulemaking.

Fish/DO Studies

- 6(a). Input on the **dissolved oxygen requirements of aquatic species**
- 6(b). Field studies of the occurrence, spatial and temporal distribution of the life stages of Estuary fish species
- 6(c). Input from consultations pursuant to the **Endangered Species Act** ("ESA")

Modeling Studies

- 6(d). Development and calibration of a **eutrophication model** for the Delaware River Estuary and Bay;
- 6(e). Determination of the nutrient **loadings from point and non-point sources** necessary to support key aquatic species;

Cost/Feasibility Studies

- 6(f). Evaluation of the **capital and operating costs for treatment** capable of achieving higher levels of dissolved oxygen;
- 6(g). Evaluation of the physical, chemical, biological, **social and economic factors affecting the attainment of uses**,

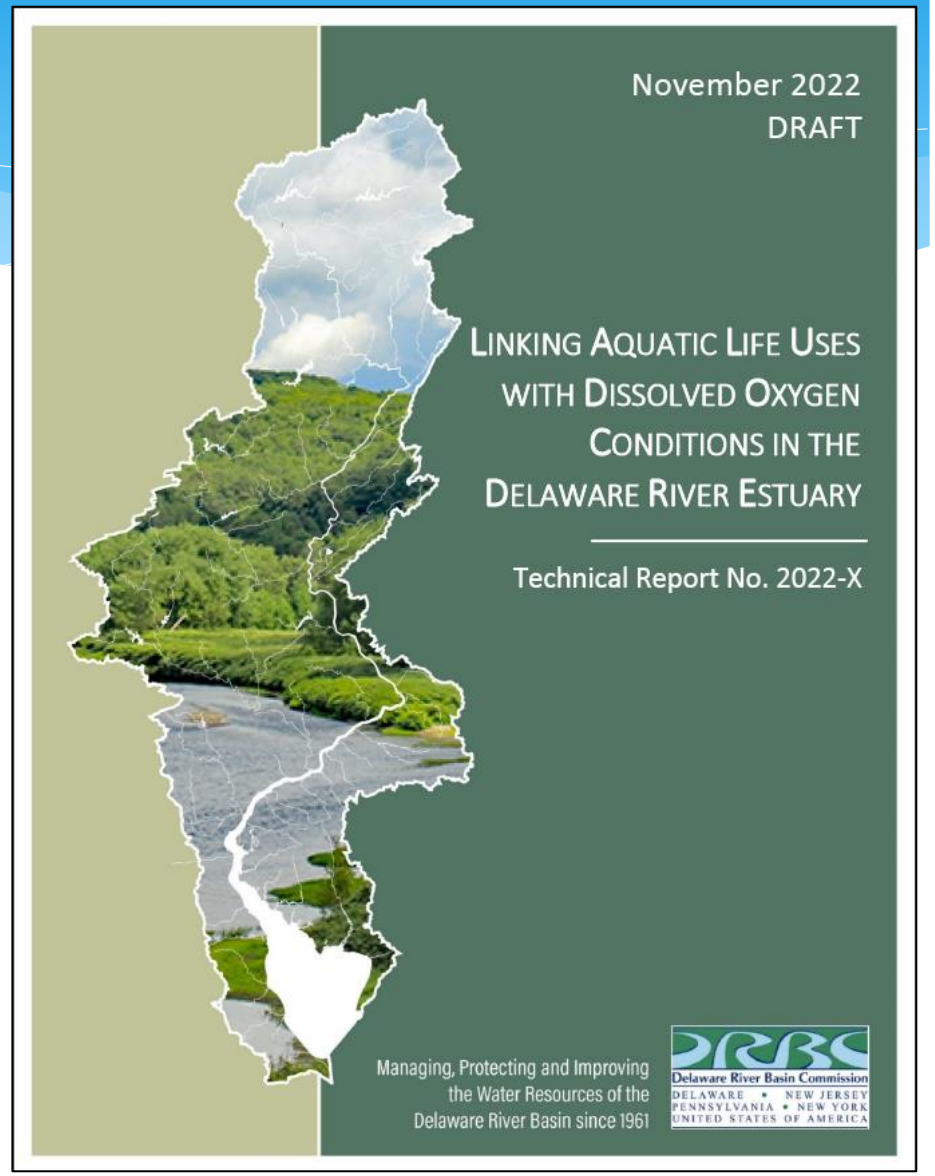
6. "Analysis of Attainability"

6(h). Preparation of a **draft report and final report** containing findings and conclusions.

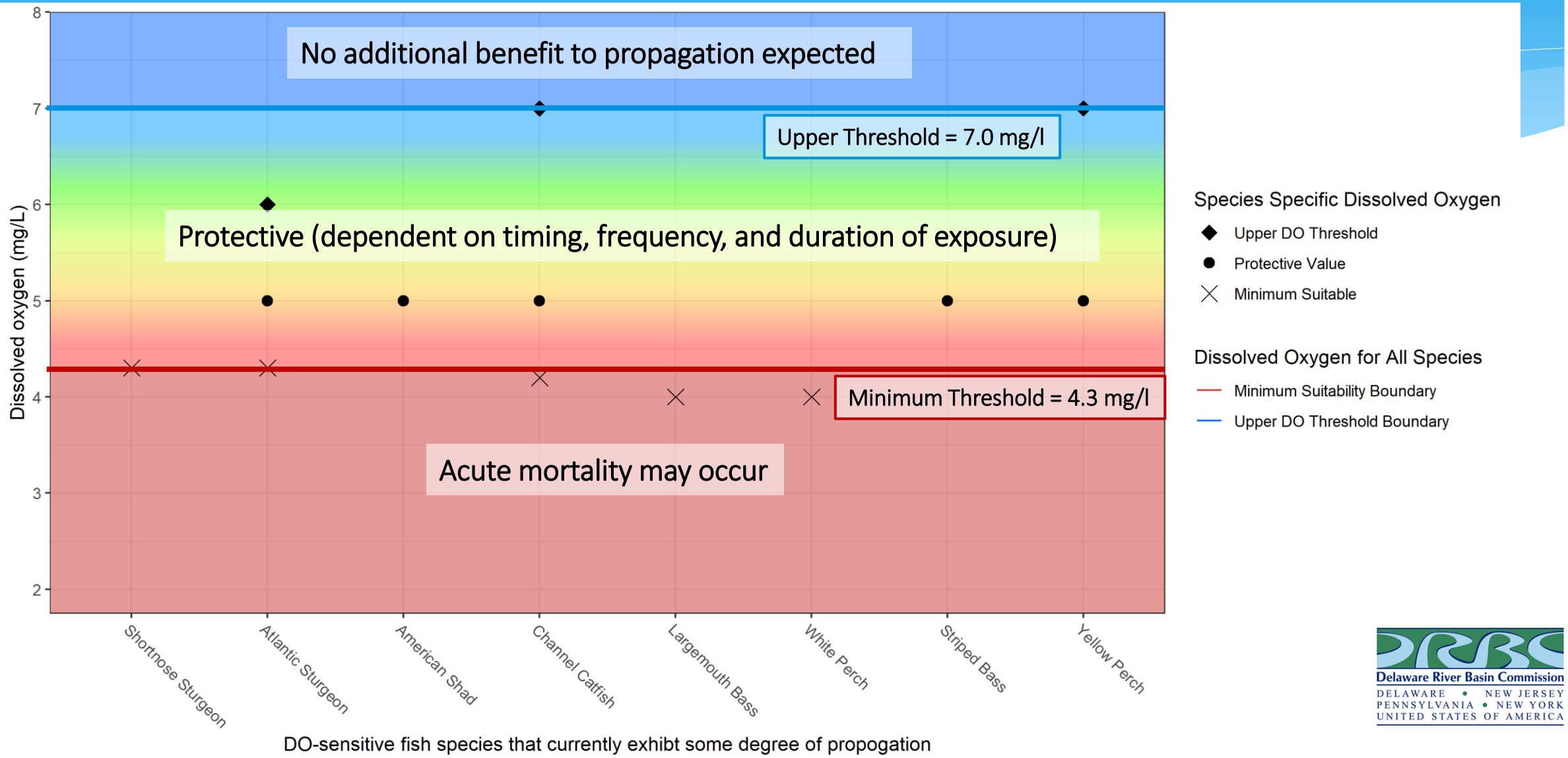
Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Aquatic life uses are strongly dependent upon dissolved oxygen (DO) levels in the water column

- Identified eight DO-sensitive species in the estuary
- Characterized occurrence and distribution of the life stages of DO-sensitive fish species
- Identified relevant research on the oxygen requirements of each at different life stages
- Determine the ranges of DO values that support propagation of DO-sensitive species



A suitability gradient was determined for DO sensitive species.

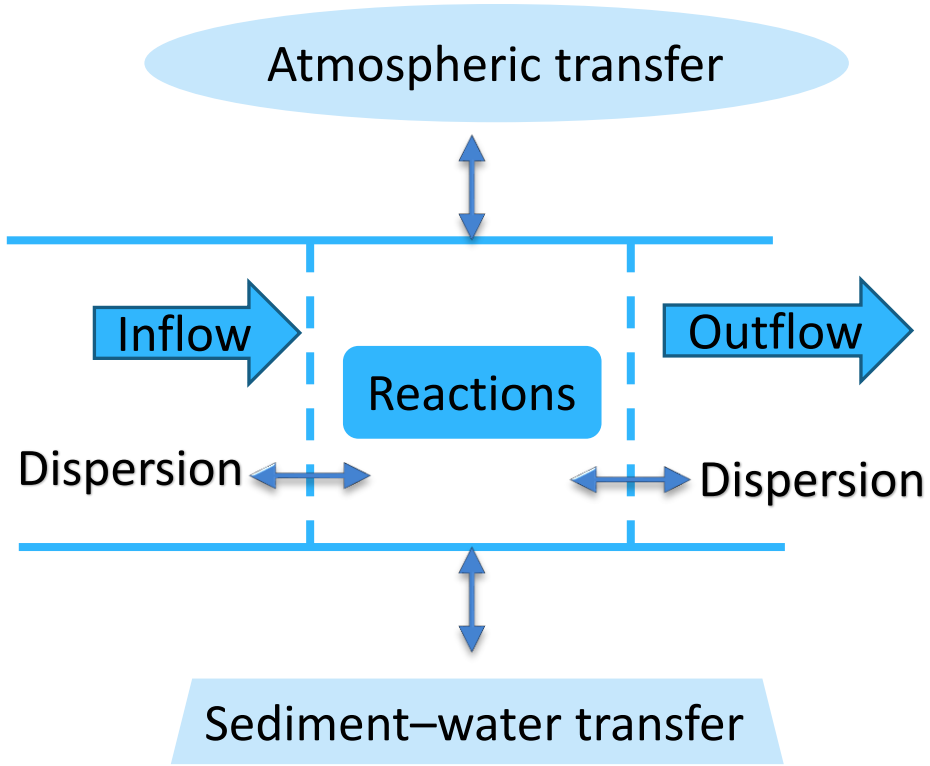


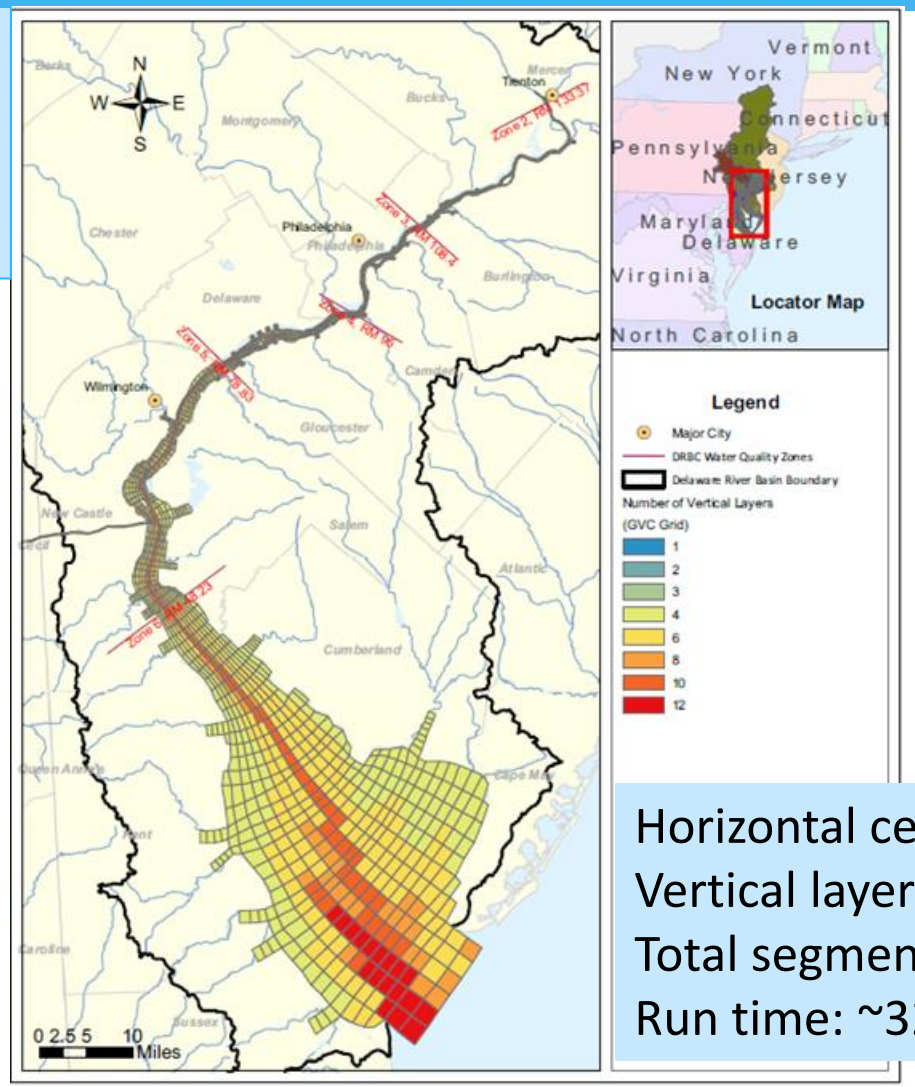
Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

DRBC developed a linked hydrodynamic and water quality model to calibrate and then simulate complex eutrophication processes in the Estuary.

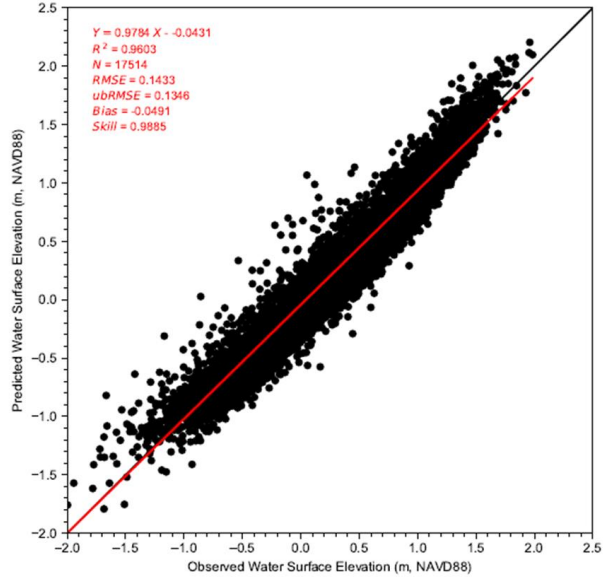
Purpose:

To determine dissolved oxygen levels that would result from various pollutant reduction scenarios.





Model–data comparison of water surface elevation at NOAA Philadelphia



Horizontal cell: 1876
Vertical layer: 10 in nav. Channel
Total segments: 11,490
Run time: ~32-hr in 3D

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

State Variables and Processes Applied to Delaware Estuary Model

Dissolved Constituents

Gases

- **DISOX: dissolved oxygen**

Inorganic Nutrients

- NH-34: ammonia nitrogen
- NO3O2: nitrate nitrogen
- D-DIP: inorganic phosphate
- IN-SI: inorganic silica

Organic nutrients

- CBODU1: ultimate CBOD from stream
- CBODU2: ultimate CBOD from PS
- CBODU3: refractory CBOD
- ORG-N: dissolved organic nitrogen
- ORG-P: dissolved organic phosphorus
- ORG-SI: dissolved organic silica

Particulate Constituents

Phytoplankton Biomass

- PHYTO1: spring marine diatom community
- PHYTO2: summer freshwater diatom community
- PHYTO3: summer marine diatom community

Detritus

- DET-C: detrital carbon
- DET-N: detrital nitrogen
- DET-P: detrital phosphorus
- DET-SI: detrital silica

Other Solids

- TOTDE: particulate detrital organic material (dw)
- SOLID: inorganic solid

Major Processes Simulated

Chemical Processes

- **Oxidation of CBOD**
- **Nitrification of ammonia to nitrate**
- Dissolution and Mineralization
- **Sediment oxygen demand**

Physical Processes

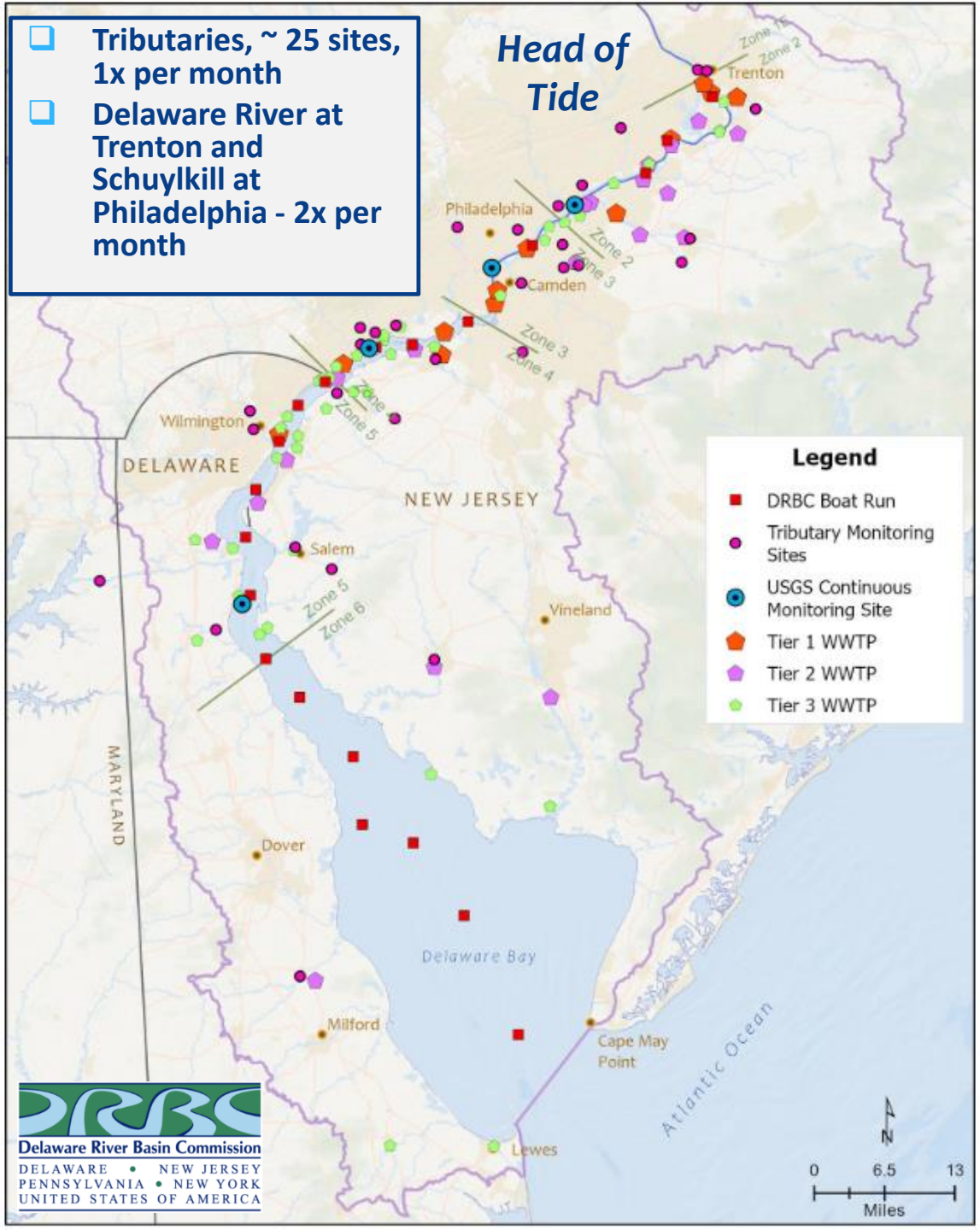
- Settling
- **Reaeration (influx and efflux)**
- Sorption

Biological Processes

- **Photosynthesis**
- **Respiration**
- Phytoplankton growth and death
- Uptake

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

- Tributaries, ~ 25 sites, 1x per month
- Delaware River at Trenton and Schuylkill at Philadelphia - 2x per month



DRBC initiated extensive monitoring during the 2018-2019 eutrophication model calibration period

Analytical Parameter	Units	Filtration	Sample Type
Total Phosphorus (TP)	mg/L as P	Unfiltered	24-hour composite
Total Kjeldahl Nitrogen (TKN)	mg/L as N	Unfiltered	24-hour composite
Nitrate Nitrogen (NO3-N)	mg/L as N	Unfiltered	24-hour composite
Nitrite Nitrogen (NO2-N)	mg/L as N	Unfiltered	24-hour composite
20-day Biochemical Oxygen Demand (BOD_{20})	mg/L	Unfiltered	24-hour composite
5-day Carbonaceous Biochemical Oxygen Demand ($CBOD_5$)*	mg/L	Unfiltered	24-hour composite
Chemical Oxygen Demand (COD)	mg/L	Unfiltered	24-hour composite
Total Organic Carbon (TOC)	mg/L	Unfiltered	24-hour composite
Dissolved Organic Carbon (DOC)*	mg/L	0.45 µm filter	24-hour composite
Total Suspended Solids (TSS)	mg/L	Unfiltered	24-hour composite
Soluble Reactive Phosphorus (SRP)	mg/L as P	0.45 µm filter	24-hour composite
Ammonia Nitrogen (NH3-N)	mg/L as N	0.45 µm filter	24-hour composite
Discharge Flow	MGD	N/A	daily average
Water Temperature	°C	N/A	24-hour mean
Dissolved Oxygen	mg/L	N/A	24-hour mean
pH	1-14 S.U.	N/A	24-hour mean
Specific Conductance or TDS	µS/cm or mg/L	N/A	24-hour mean

Nationally recognized model experts provided guidance for DRBC staff through out the modeling process.

Name	Organization	Service
Carl Cerco	U.S. Army Corps of Engineers (Retired)	Panel Members
Bob Chant	Rutgers University	
Steve Chapra	Tuffs University	
Tim Wool	U.S. EPA Region 4 (Retired)	
Vic Bierman	LimnoTech	Consultant to DRBC
Scott Hinz	LimnoTech	

Conclusions:

1. Model is scientifically defensible over a wide range of environmental conditions in the Delaware Estuary.
2. Model is appropriate for its intended use to determine the improvement in dissolved oxygen condition that would result from specific reductions to point and nonpoint source loadings

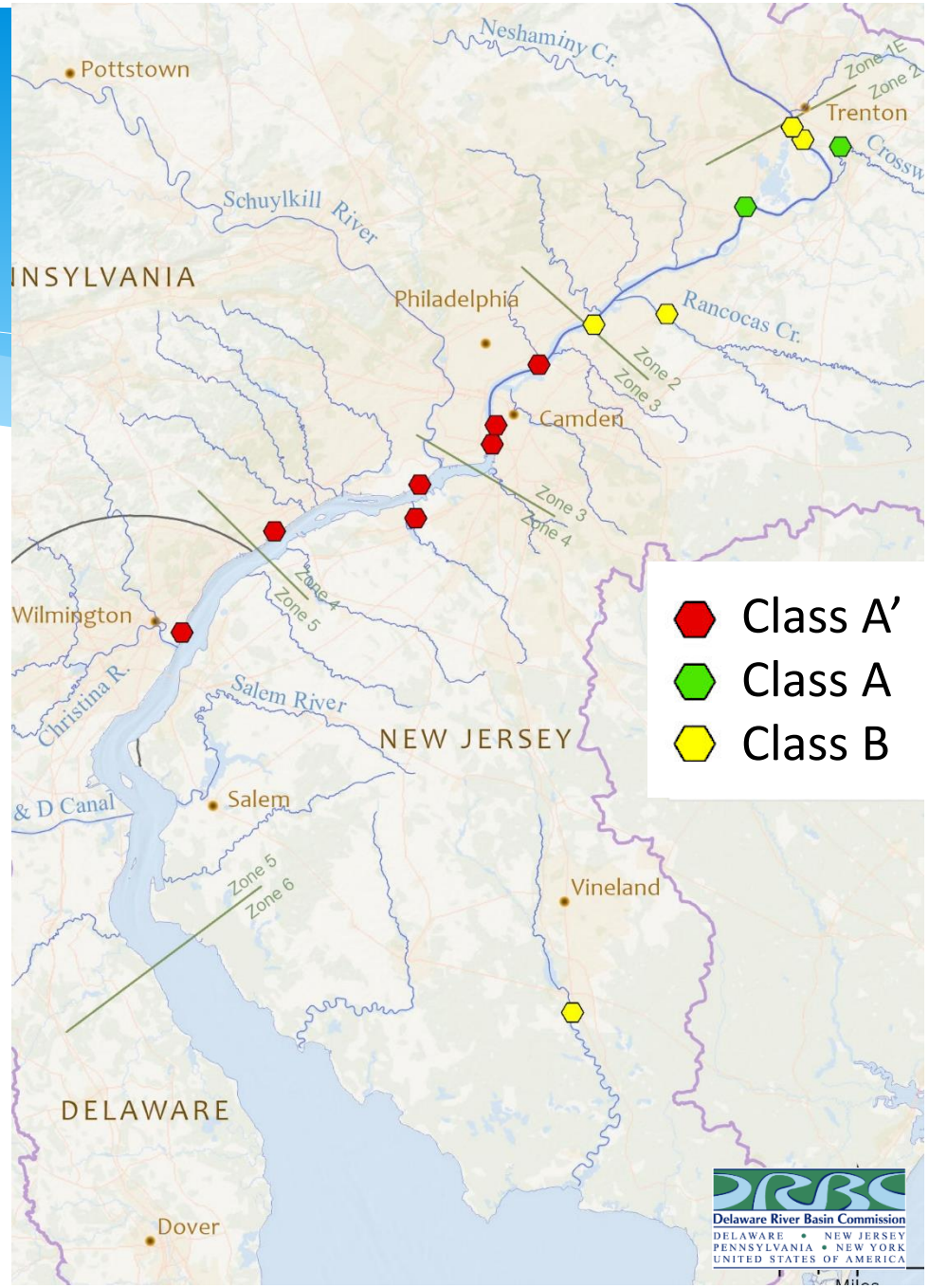
The model tells us what factors have the most impact on dissolved oxygen improvements.

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

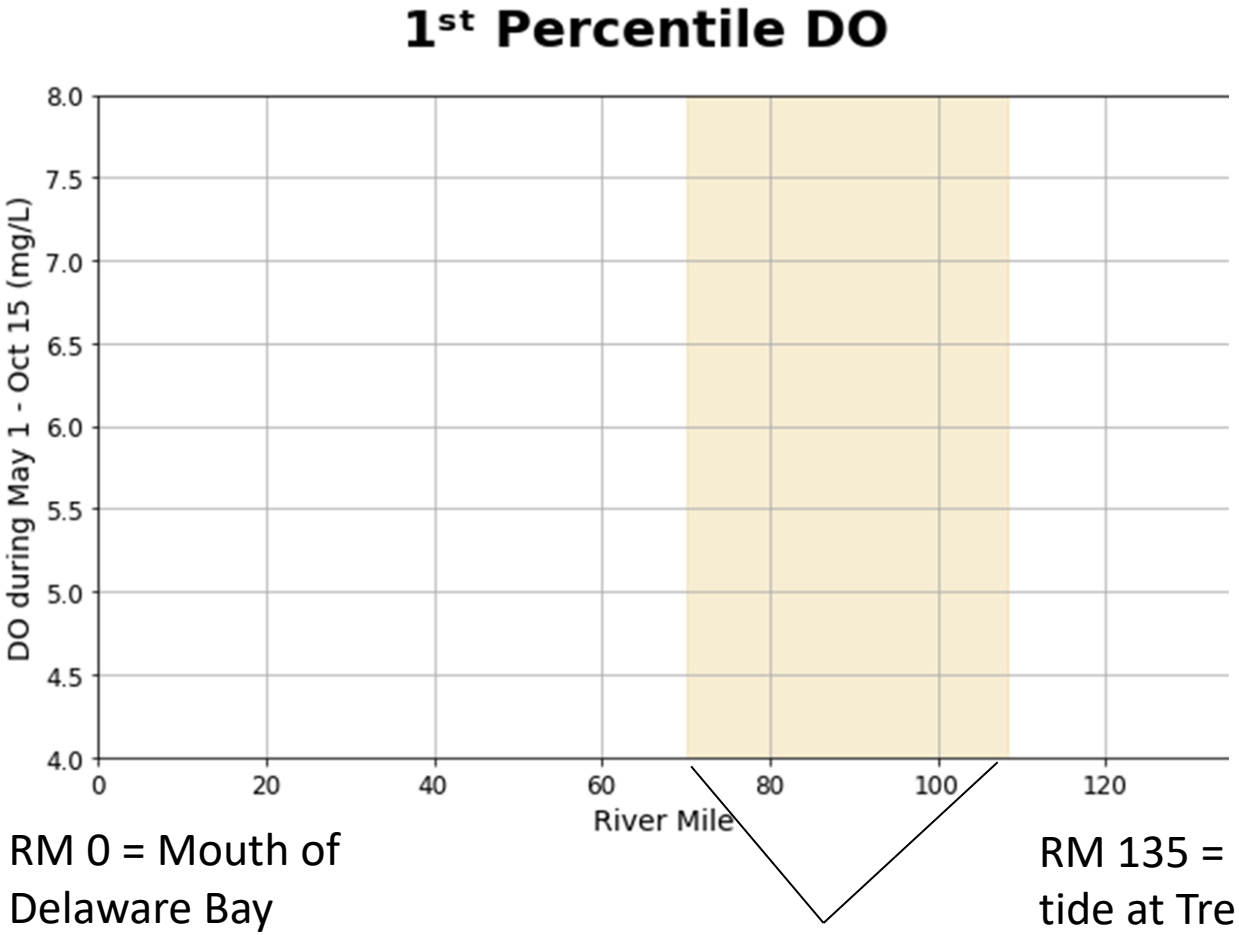
Factors that can most improve DO in the FMA	Factors that can slightly improve DO in the FMA	Factors that cannot measurably improve DO in the FMA
▪ Summer (May–Oct) ammonia loads from specific point-source discharges ▪ Carbon loads from Delaware River at Trenton (high % of total flow)	▪ Combined sewer overflows (CSOs) ▪ DO concentration in treated effluent from the largest point-source discharges ▪ Carbon loads from Schuylkill River	▪ Nutrient (C, N, P) loads from tributaries, except C loads from Delaware River at Trenton and Schuylkill River ▪ Winter (Nov–Apr) ammonia, CBOD, and TN from all point-source discharges ▪ Summer (May–Oct) ammonia loads from many point-source discharges ▪ Direct stormwater runoff into the Delaware Estuary

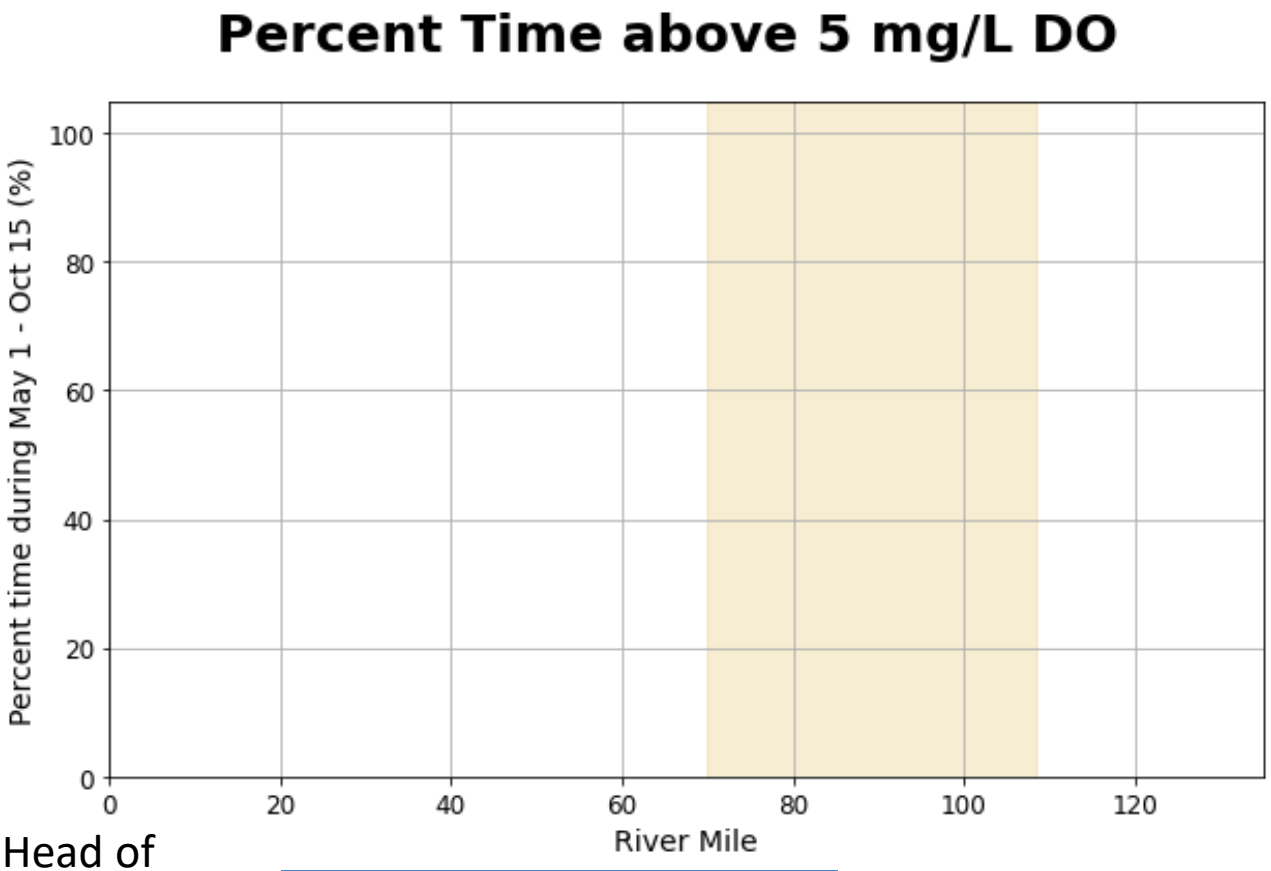
Discharges by Class – 67 total

Class	Discharge Name	Zone	River Mile	Permitted Flow (MGD)	Effluent Ammonia (mg/L)
A' (7)	PWD Northeast	3	103.9	210	4.4
	Camden County MUA	3	97.9	80	17.3
	PWD Southeast	3	96.7	112	8.6
	PWD Southwest	4	90.7	200	19.0
	Gloucester County UA	4	89.9	27	23.9
	DELCORA	4	80.4	70	3.8
	City of Wilmington	5	71.6	134	9.5
A (2)	Hamilton TWP WPCF	2	128.4	16	27.0
	Lower Bucks JMA	2	121.9	10	19.7
B (58)	Morrisville BMA	2	132.5	7	9.7
	Trenton SU	2	131.8	20	5.4
	Willingboro WPCP	2	111.4	5	1.4
	Cinnaminson SA	2	108.7	2	16.0
	…	…	…	…	…



How does ammonia reduction from an individual discharge impact low DO in the FMA?





RM 0 = Mouth of Delaware Bay

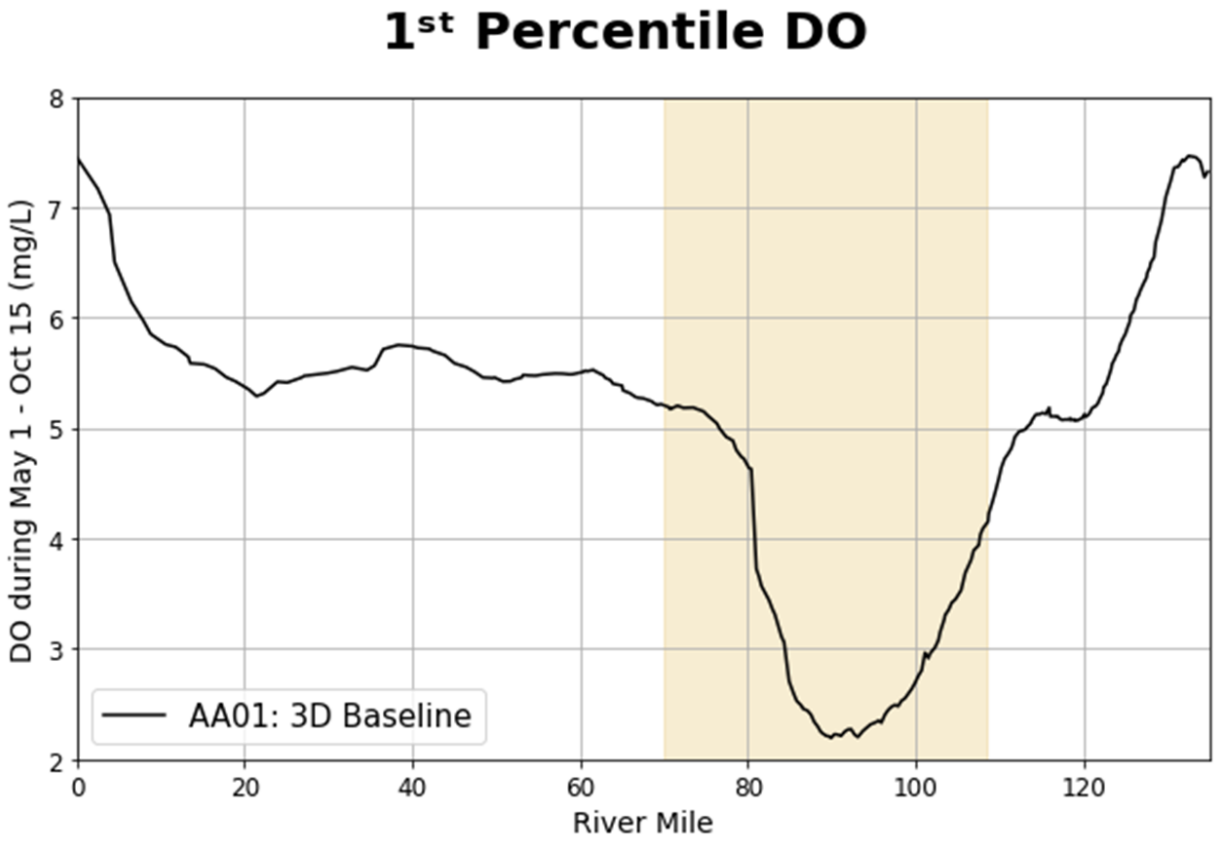
RM 135 = Head of tide at Trenton, NJ

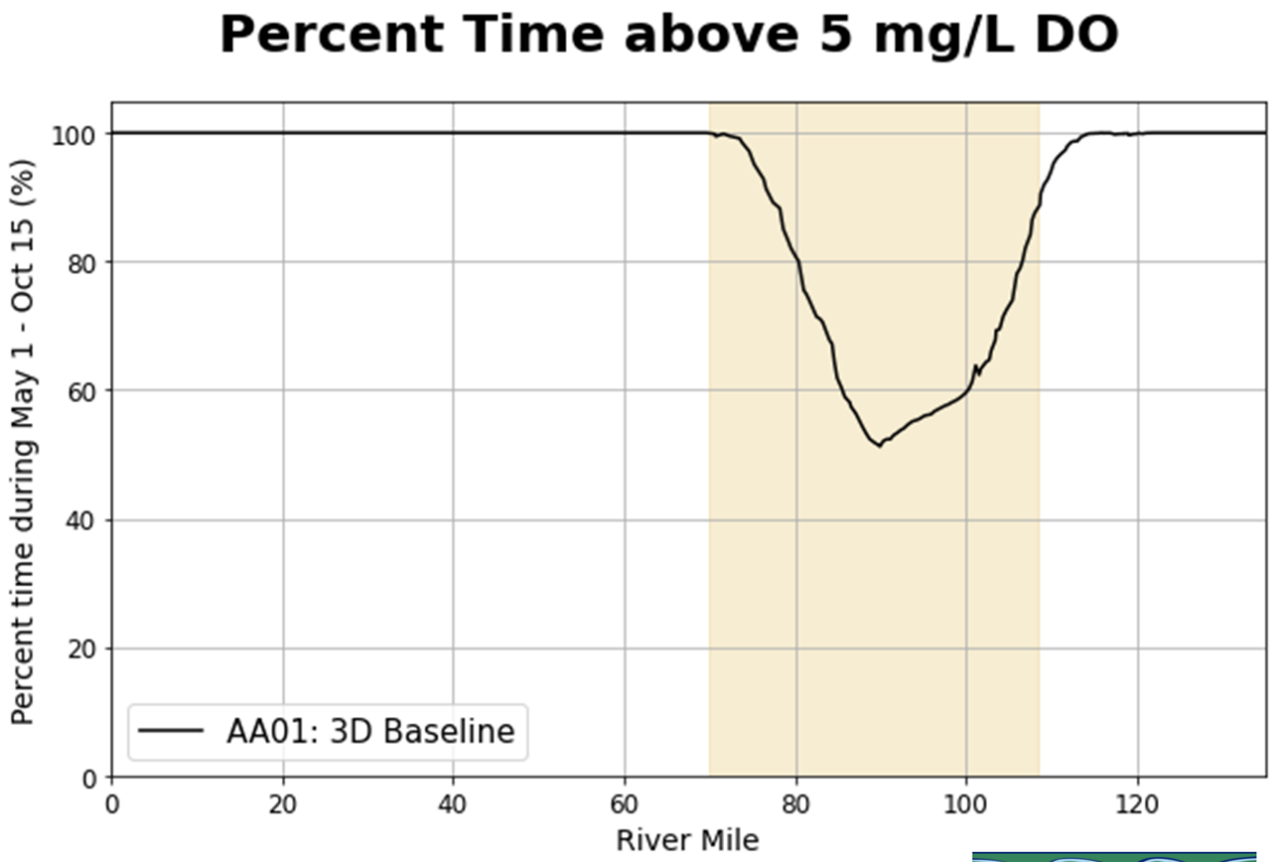
Fish Maintenance Area: RM 70–108.4

For both metrics: Higher is better!

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

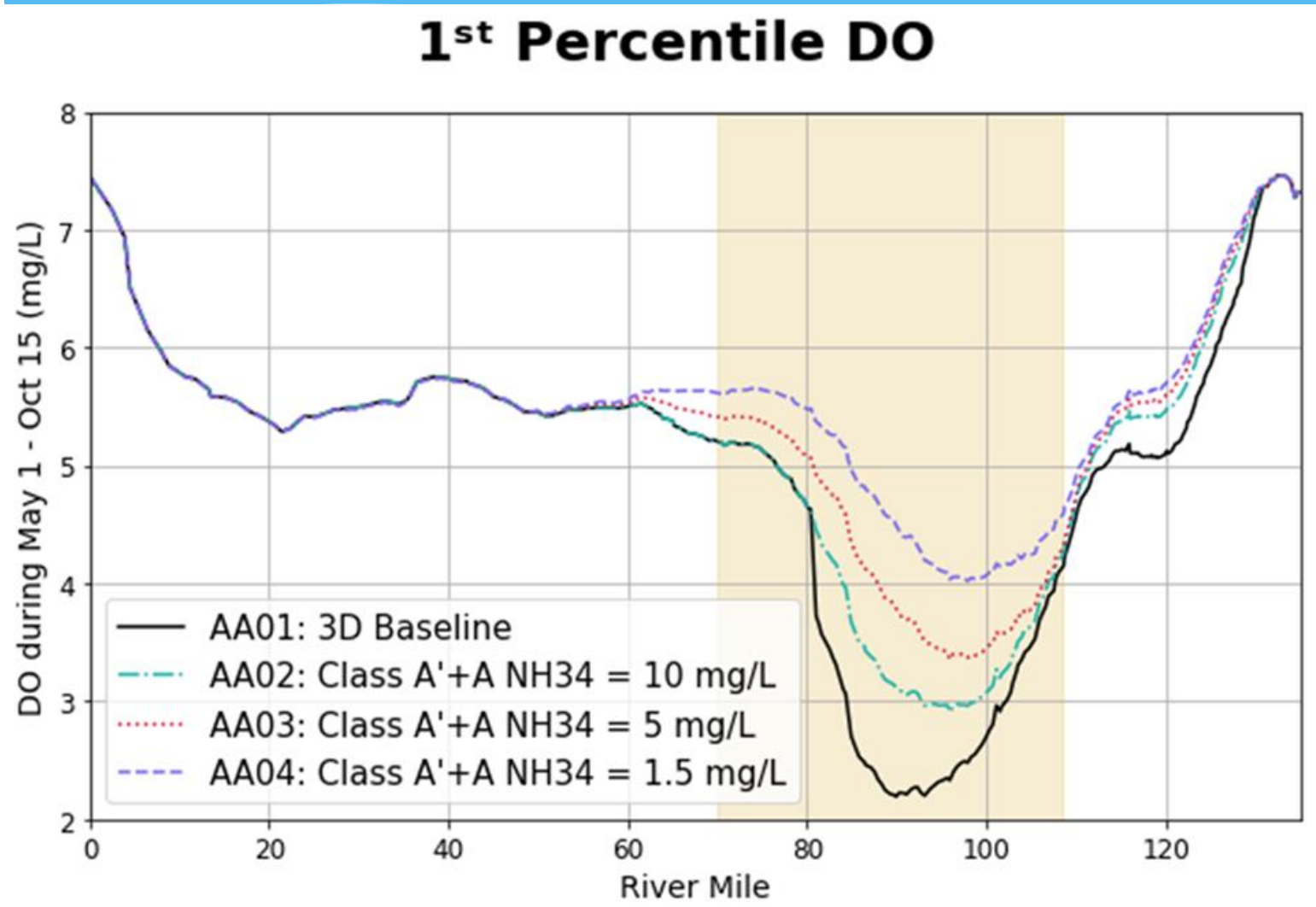
Baseline design condition represents protection of existing water quality and uses





Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

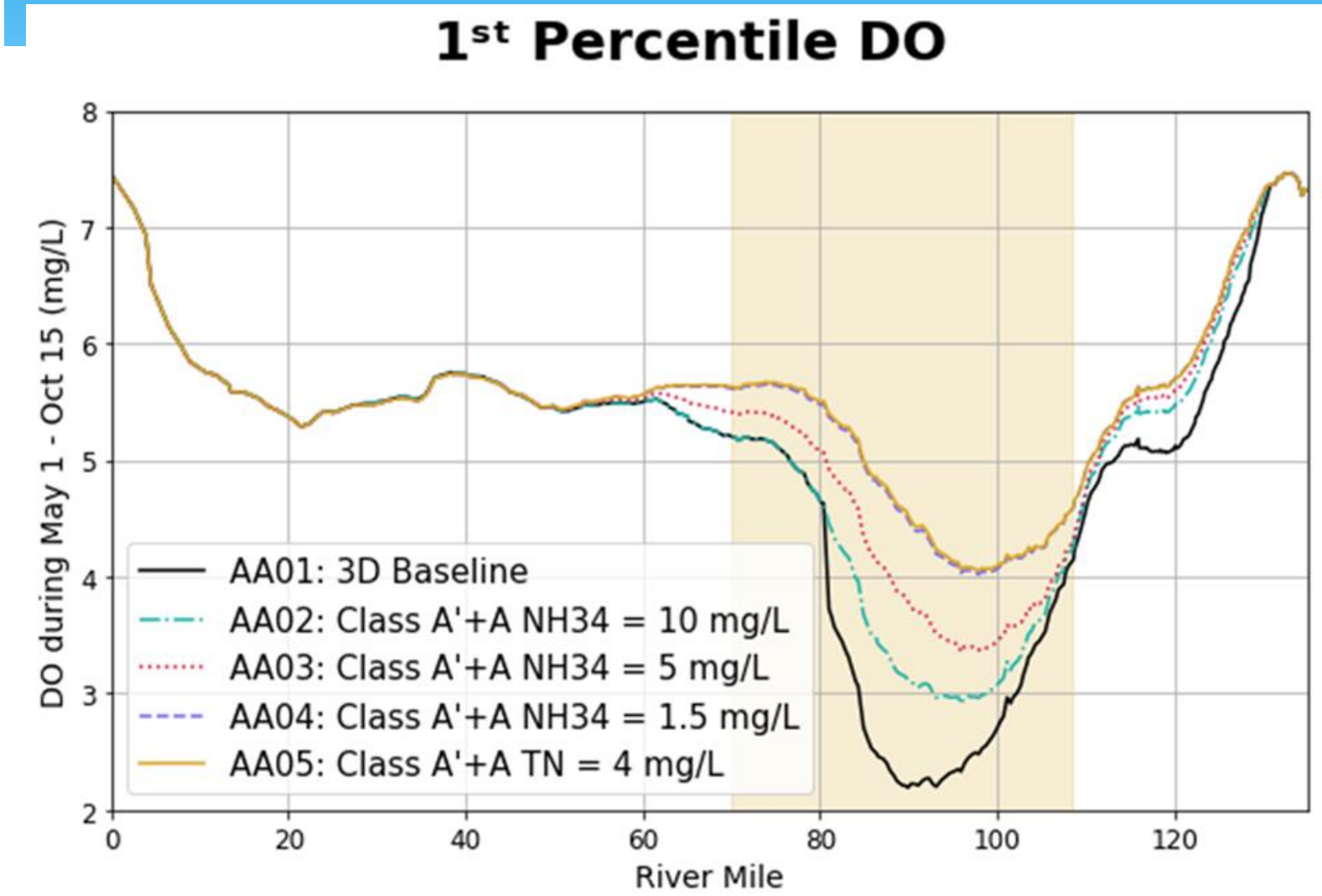
Bringing minimum DO above 4 mg/L requires reducing effluent ammonia from Class A' dischargers to 1.5 mg/L



Class	Discharge Name	Zone
A' (7)	PWD Northeast	3
	Camden County MUA	3
	PWD Southeast	3
	PWD Southwest	4
	Gloucester County UA	4
	DELCORA	4
	City of Wilmington	5

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

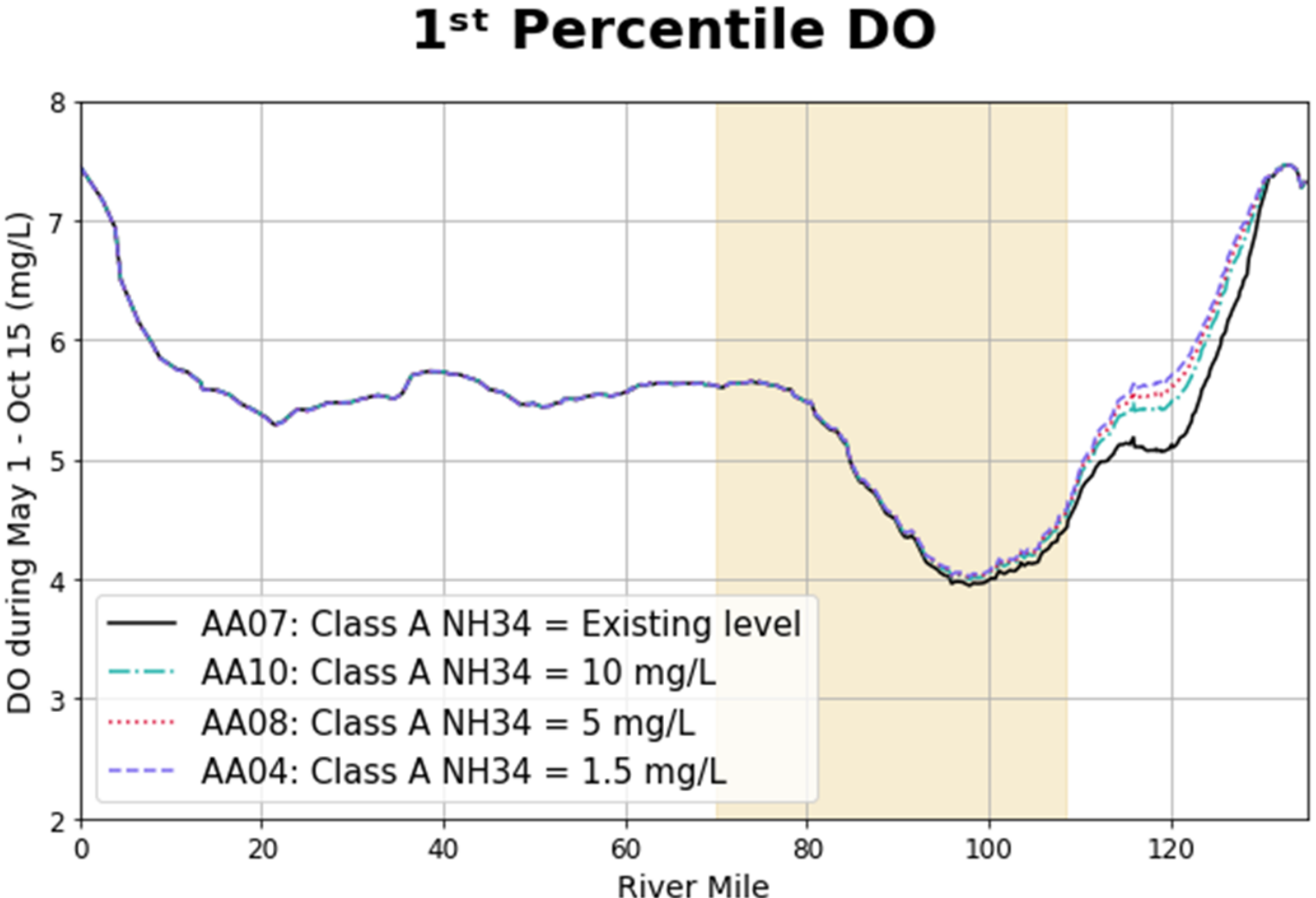
Reducing total nitrogen (TN) brings no additional benefit to improve minimum DO.

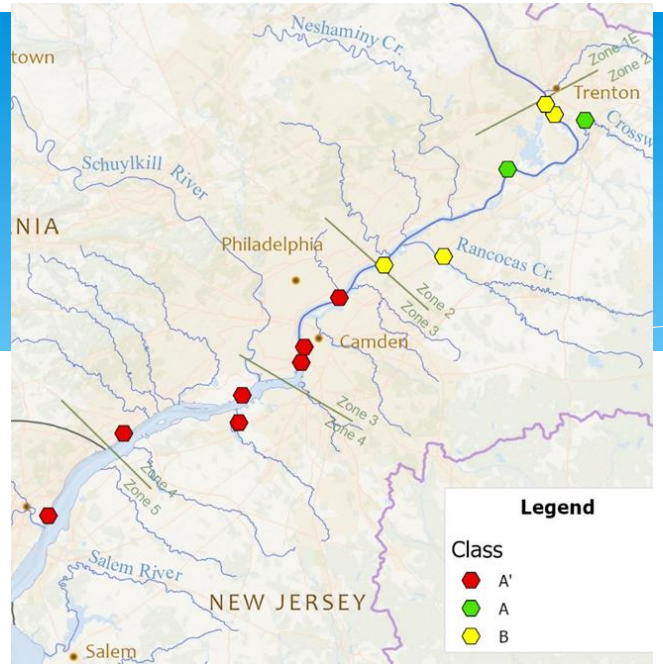


Class	Discharge Name	Zone
A' (7)	PWD Northeast	3
	Camden County MUA	3
	PWD Southeast	3
	PWD Southwest	4
	Gloucester County UA	4
	DELCORA	4
	City of Wilmington	5

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

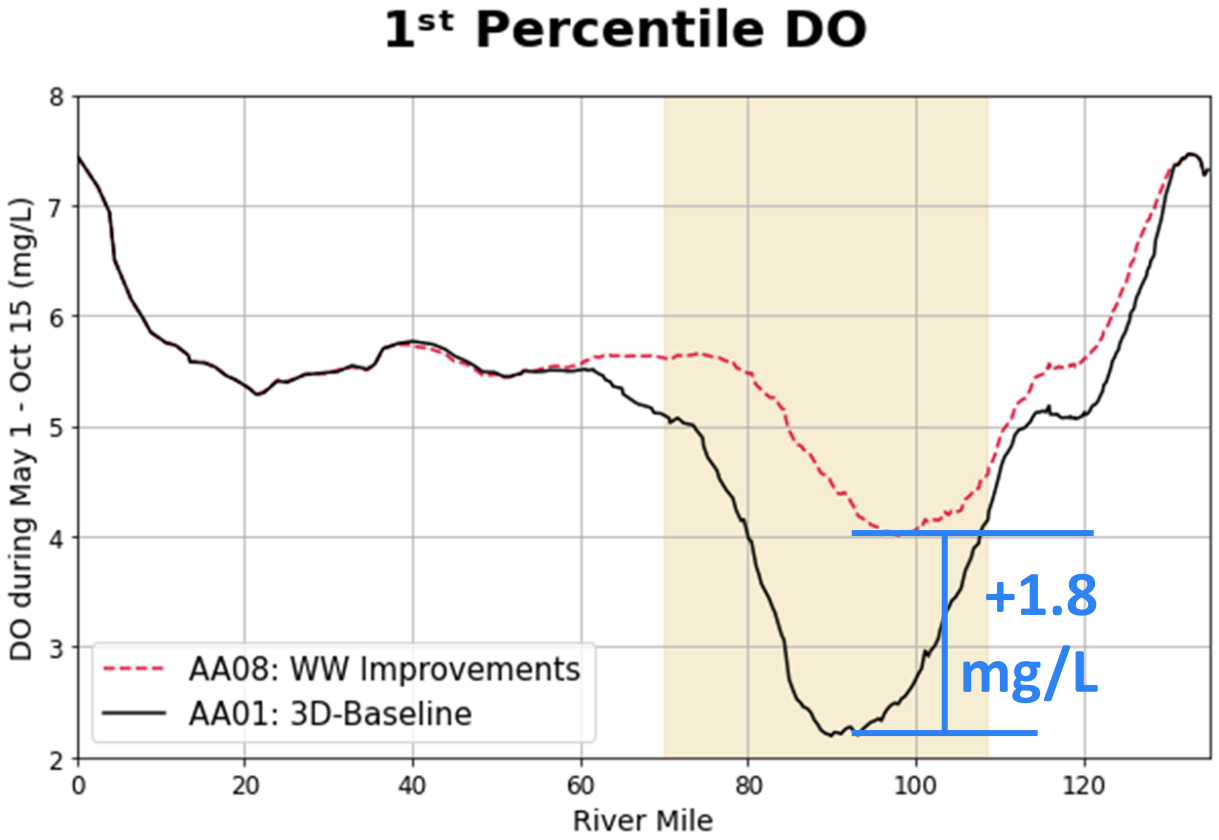
DO is less sensitive to Class A ammonia levels, but ammonia reduction does have an impact.

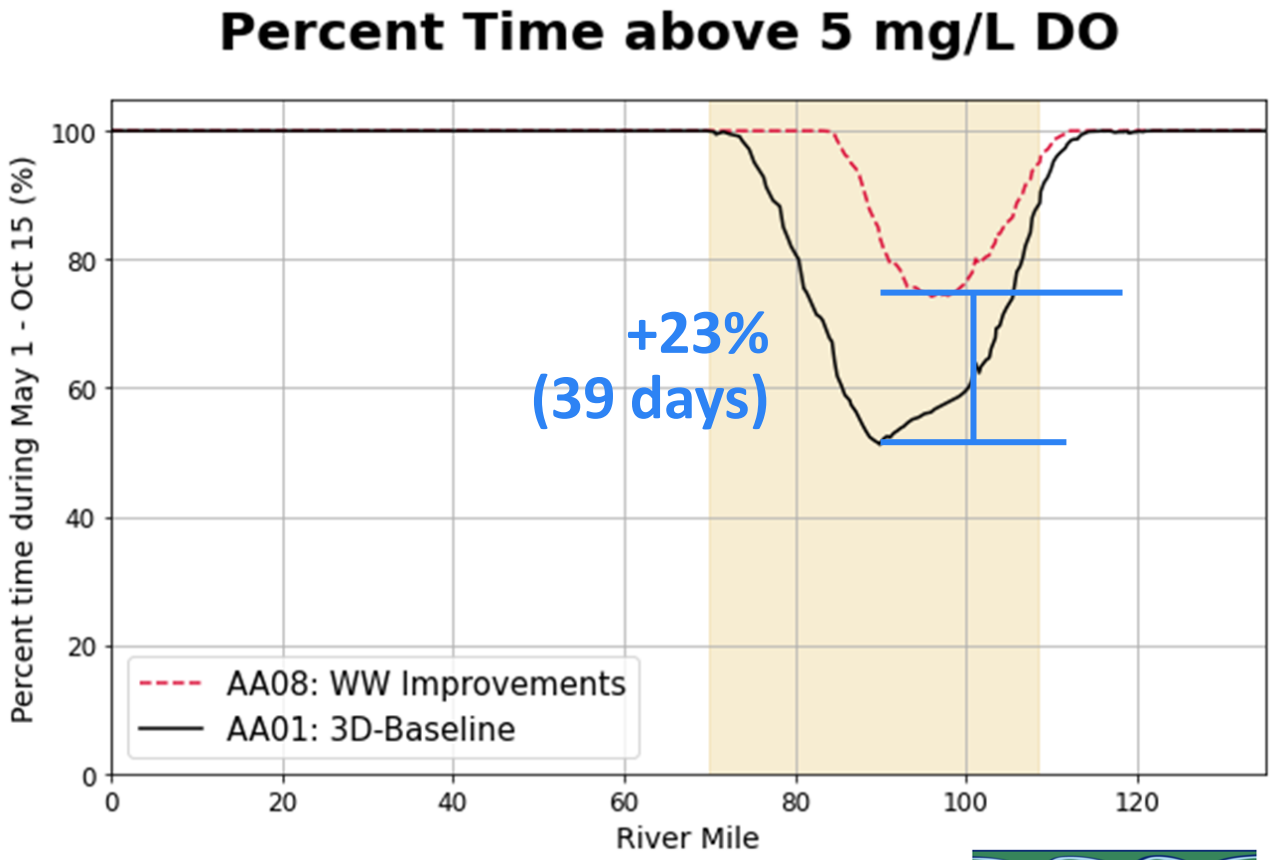




Class	Discharge Name	Zone
A' (7)	PWD Northeast	3
	Camden County MUA	3
	PWD Southeast	3
	PWD Southwest	4
	Gloucester County UA	4
	DELCORA	4
	City of Wilmington	5
A (2)	Hamilton TWP WPCF	2
	Lower Bucks JMA	2

Reducing effluent ammonia to **1.5** mg/L for Class A' dischargers and **5** mg/L for Class A discharges **improves habitat** in the urban estuary (Run AA08)





The lowest DO value in the Estuary **increases** and **moves upstream**

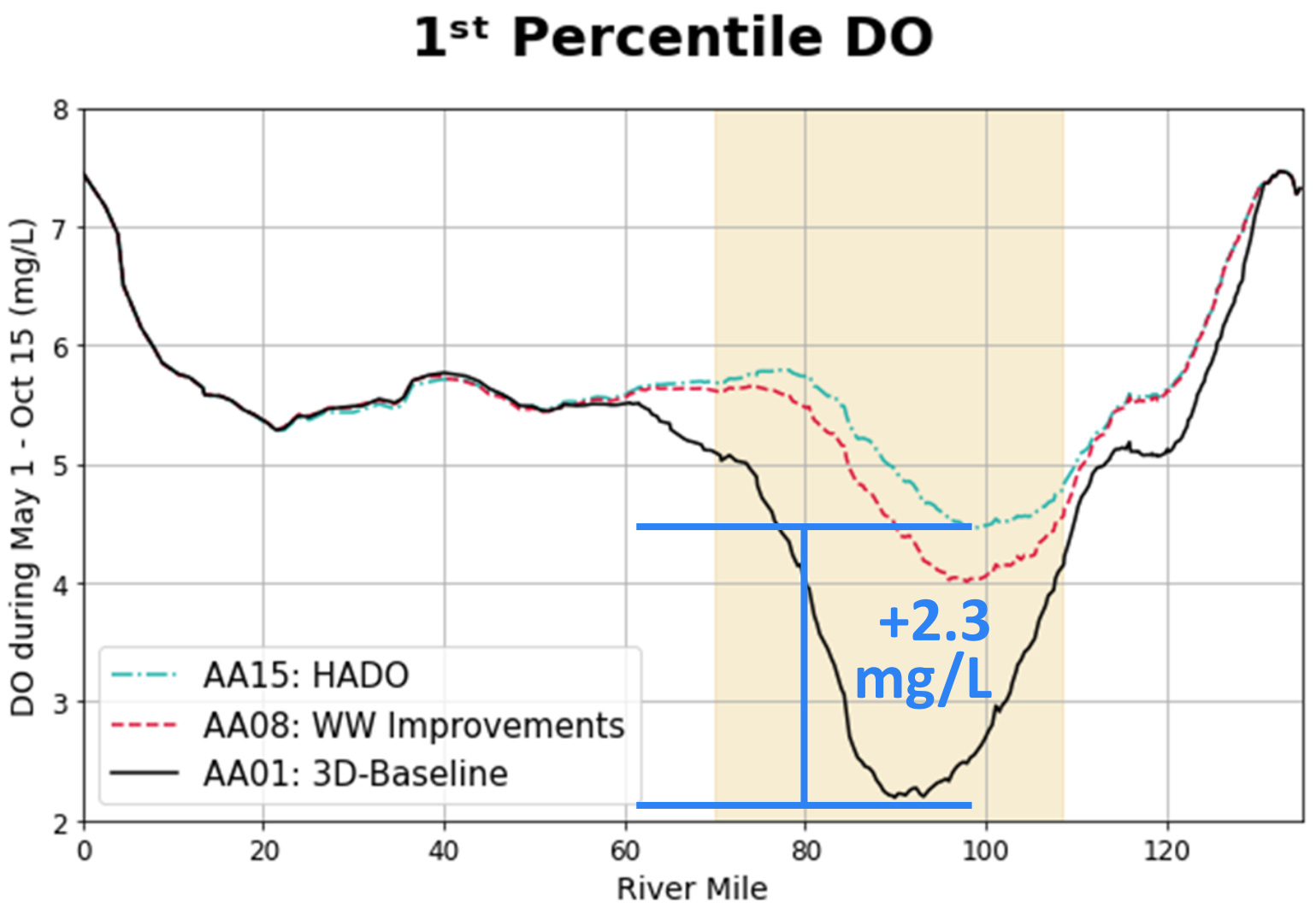
28 miles experience DO less than 5 mg/L

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

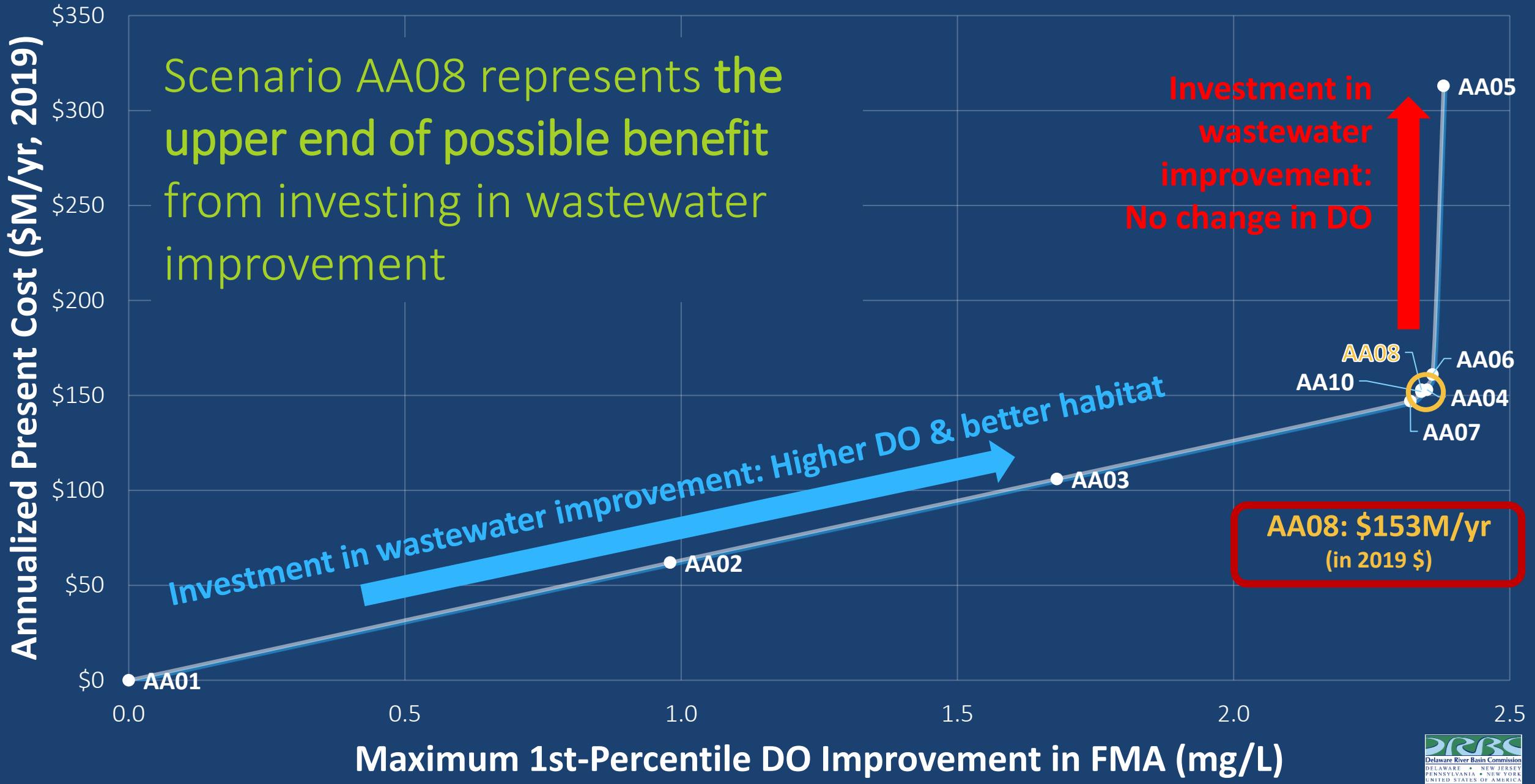
What is the highest attainable dissolved oxygen (HADO) condition in the Delaware Estuary considering all factors?

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

- Wastewater treatment:
  - ✓ 7 Class A' dischargers at ammonia = 1.5 mg/L
  - ✓ 2 Class A discharges at ammonia = 5 mg/L
- Additional factors considered:
  - ✓ CSO reductions (based on LTCPs)
  - ✓ Effluent DO
  - ✓ Seasonally variable nitrification
  - ✓ 10% Reserve Capacity



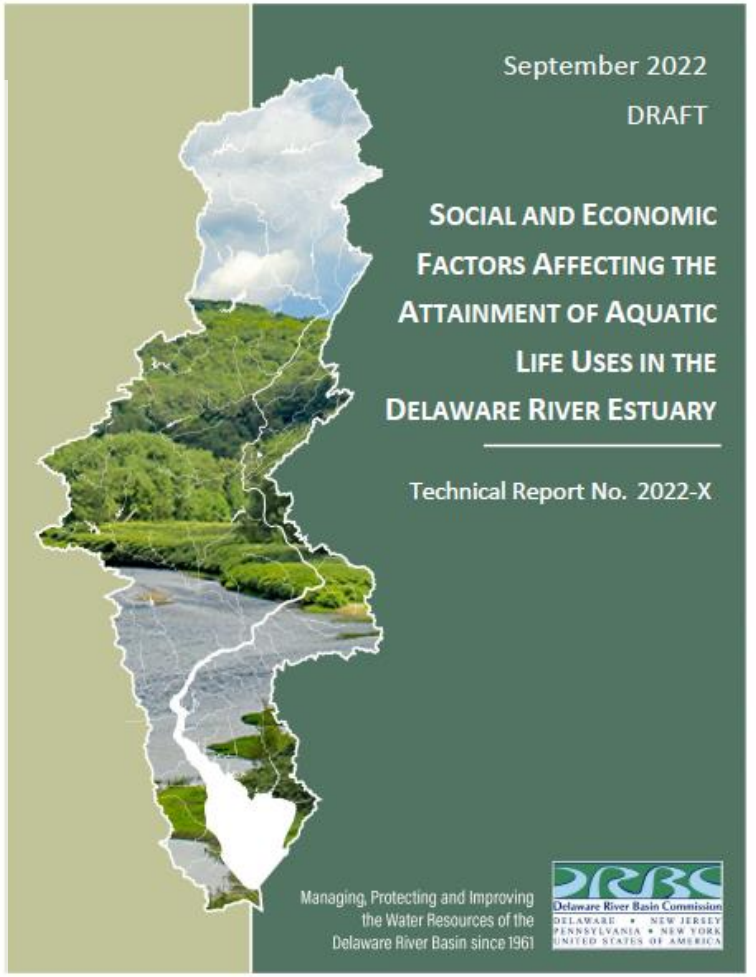
TOTAL COST vs. DISSOLVED OXYGEN IMPROVEMENT



The costs of the additional treatment will not increase the affordability burden category on households within the service areas of the affected wastewater treatment plants.

Table 8: Household affordability score

Utility Name	Baseline	Ammonia 10 mg/L	Ammonia 5 mg/L	Ammonia 1.5 mg/L	Total Nitrogen 4 mg/L
CCMUA	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden
City of Trenton	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden
DELCORA	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden
GCUA	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden
Hamilton Twp WPCF	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden
LBCJMA	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden
Morrisville	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden
PWD	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden	High Burden
Willingboro WPCF	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden
Wilmington	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden



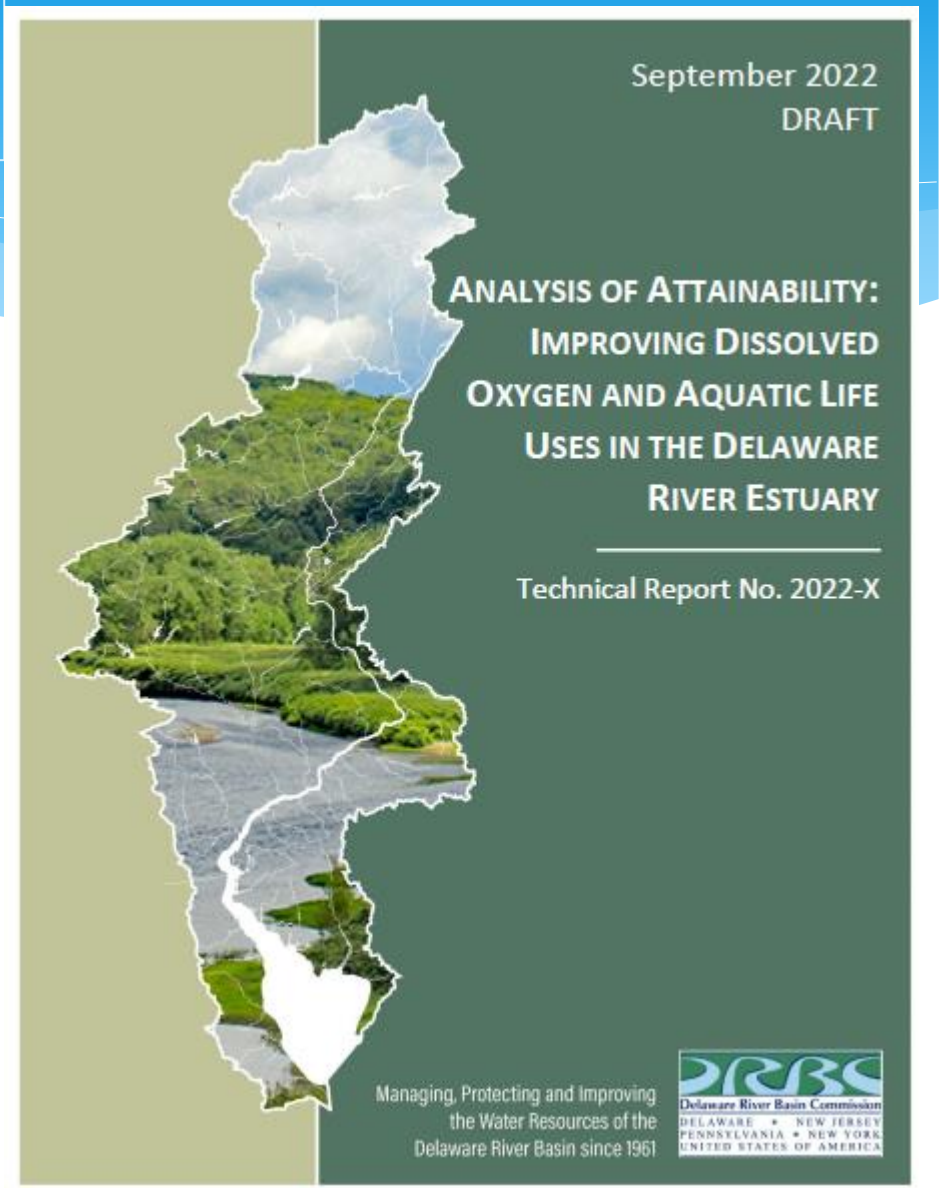
The Analysis of Attainability shows that:

Water quality supporting the aquatic life use of "fish propagation" is attainable.

Upgrading nine (9) major wastewater treatment plants will significantly improve the level of dissolved oxygen.

The costs of advanced treatment associated with the recommended scenario are significant .

The Commission should proceed with rulemaking and adopt new water quality standards.



The next steps are ongoing and involve a coordinated co-regulator process for :

- Development of revised science-based water quality standards, including revised water quality criteria.
- Rule proposals.
- Public input processes.
- Adoption of new water quality standards.

Thank you DRBC Technical Team!

Name	Title
Thomas Amidon	Manager, Water Resource Modeling
Sarah Beganskas	Water Resource Scientist
Jacob Bransky	Aquatic Biologist
Fanghui Chen	Senior Water Resource Engineer
Vince DePaul	Hydrologist (USGS)
Kristen B. Kavanagh	Deputy Executive Director
Elaine Panuccio	Water Resource Scientist
Sara Sayed	Water Resource Scientist
Namsoo Suk	Director, Science and WQ Management
John Yagecic	Manager, Water Quality Assessment
Li Zheng	Senior Water Resource Modeler