

Preliminary Estimate of Climate Change Impact On Water Quality Attainment

Modeling Workgroup Meeting
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Chesapeake Bay Program
Science. Restoration. Partnership



Overview

- To compare estimated Base (calibration 1991-2000) and WIP2 scenarios under 1995 climate conditions to Base and WIP2 scenarios under 2025 climate conditions of sea level, watershed flows, temperature, and watershed loads.
- Investigate why decreased hypoxia is estimated under 2025 temperature, precipitation, and sea level despite higher estimated watershed loads.
- Using the Base Scenario, examine the influence separate elements of estimated 2025 conditions have on Bay hypoxia:
 - changes in sea level (SL)
 - watershed flows (Q)
 - temperature (T)
 - all combined SL, T, and Q
 - all combined SL, T, and Q along with increased 2025 watershed loads.



Overview (*continued*)

- Increases in sea level rise and watershed flow both increase estuarine gravitational circulation which in turn decreases estimated hypoxia in the Chesapeake under estimated 2025 conditions of sea level and watershed flows.
- On one hand, increased 2025 temperatures ameliorates the estimated increased precipitation in the watershed through evapotranspiration, but also increases stratification and hypoxia in the tidal Bay.
- This is a work in progress using the Beta 3 Watershed Model and the Beta 4 WQSTM to provide the best estimate available today of 2025 conditions compared to the 1995 TMDL conditions. We need to run the analysis on the final Watershed and WQSTM models.



Model Climate Inputs Were Developed with STAC Workshop and Climate Resiliency Workgroup Guidance

Precipitation Volume

- 2025: +3.1% (long term trends)
- 2050: +6.2% (RCP* 4.5)

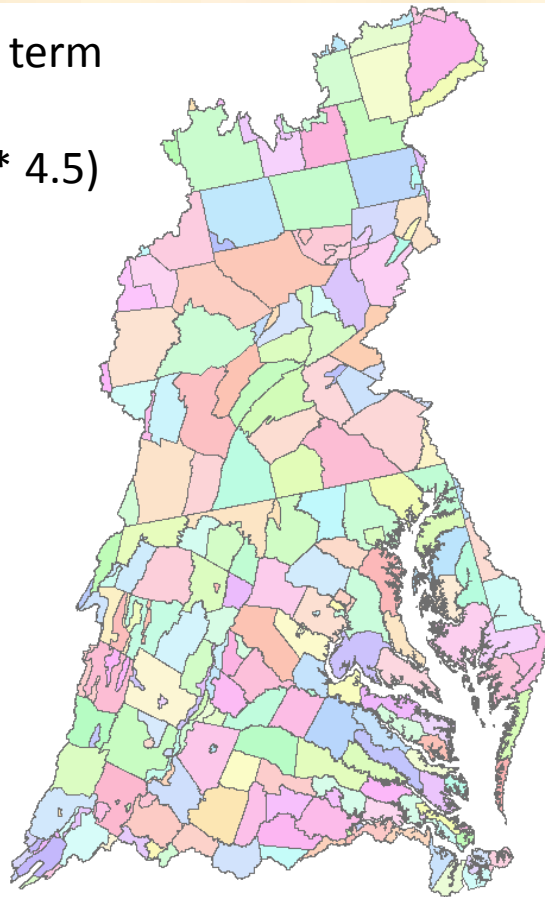
Temperature: RCP 4.5

- 2025: +1.1 °C
- 2050: +1.94 °C

CO₂ Concentration:

Meinhausen et al., 2011

- 2025: 427 ppm
- 2050: 487 ppm

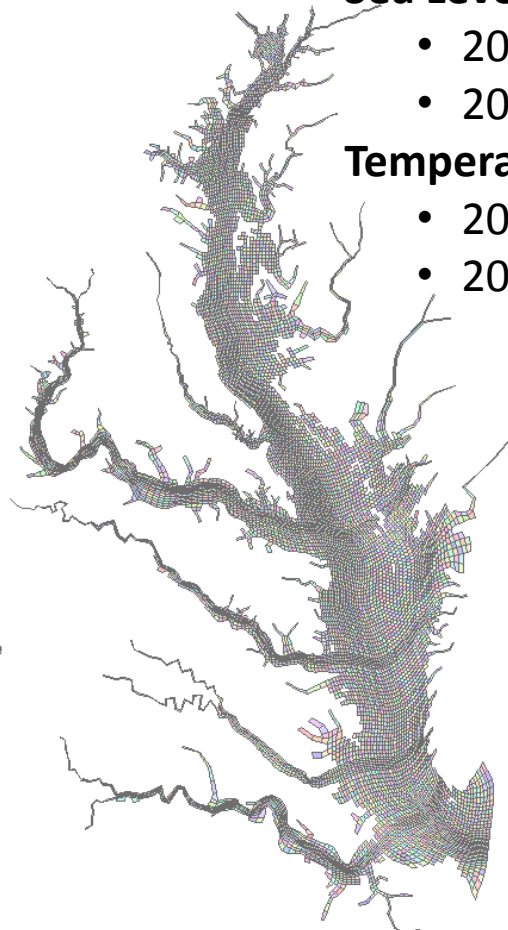


Sea Level Rise: CRWG**

- 2025: +0.3 m
- 2050: +0.5 m

Temperature: RCP 4.5

- 2025: +0.95 °C
- 2050: +1.86 °C



**Based upon guidance provided by the Climate Resiliency Workgroup

*RCP 4.5 signifies a specific Representative Concentration Pathway scenario as defined by the Intergovernmental Panel on Climate Change



Keeping Score

In the Watershed

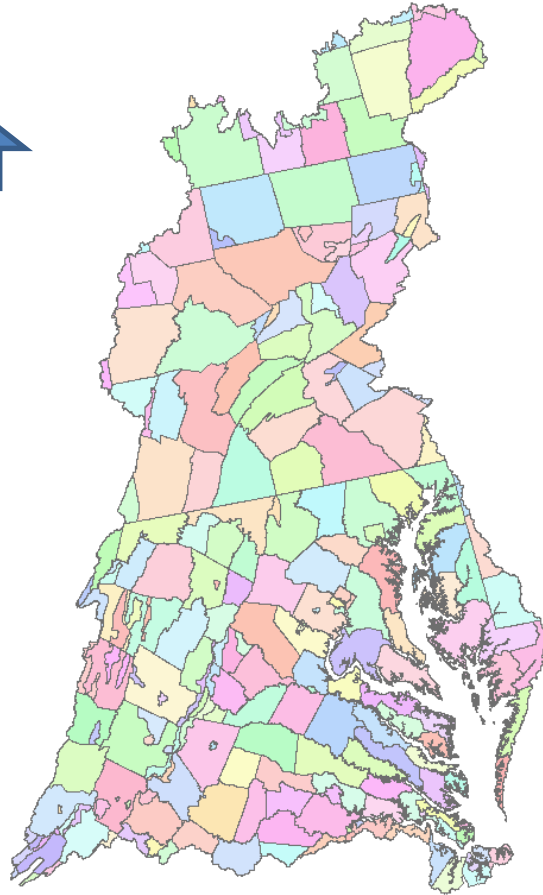
Increased Precipitation
Volume = Hypoxia



Increased Precipitation
Intensity = Hypoxia



Increase in Temp and
Evapotranspiration
= Hypoxia



In the Estuary

Increased WS Loads
= Hypoxia



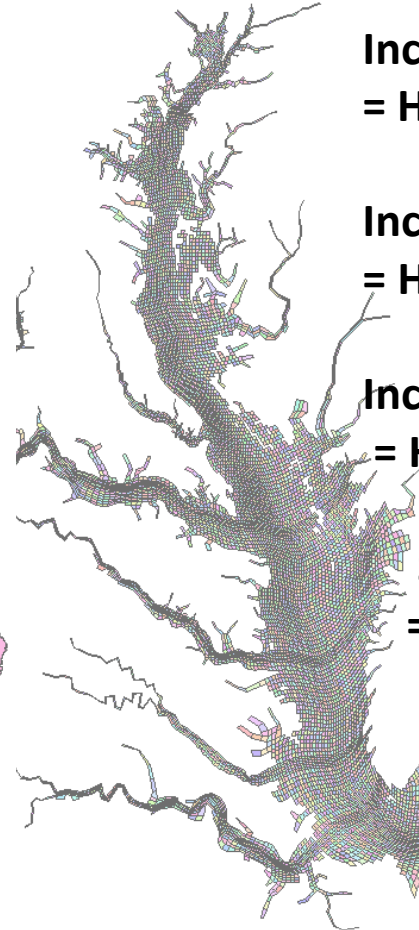
Increased WS Flows
= Hypoxia



Increased Temperature
= Hypoxia

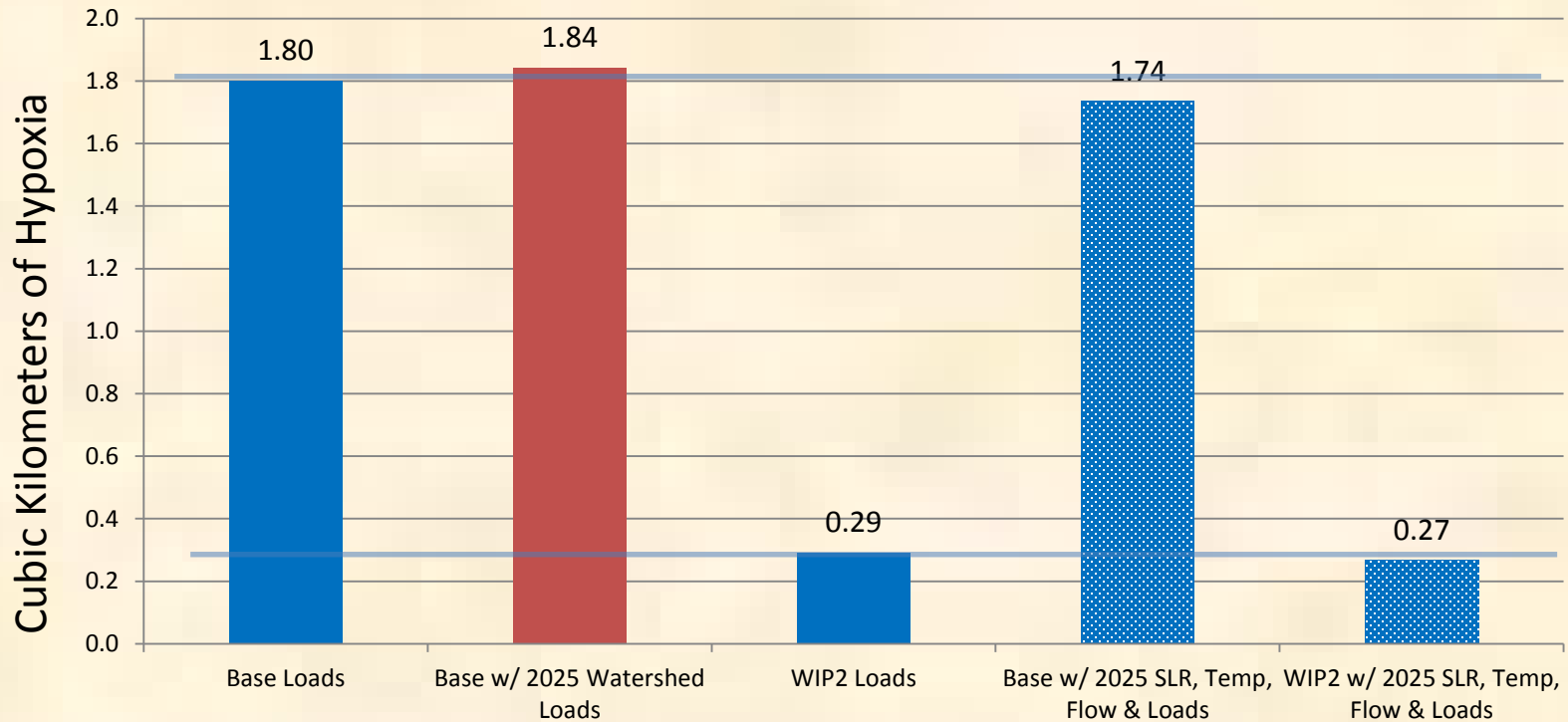


Sea Level Rise
= Hypoxia





Why does hypoxia decrease under estimated under 2025 temperature, precipitation, and sea level despite higher estimated watershed loads?

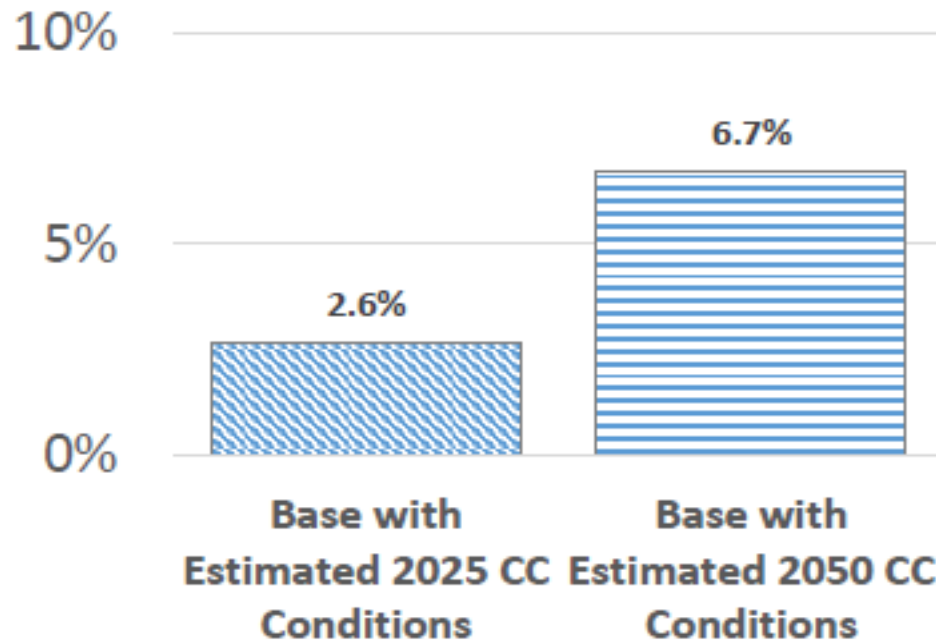


DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

solid blue = key scenario, solid red = sensitivity scenario, stippled blue = 2025 climate scenario



Watershed flow increases under estimated 2025 and 2050 climate change conditions compared to 1995 conditions.

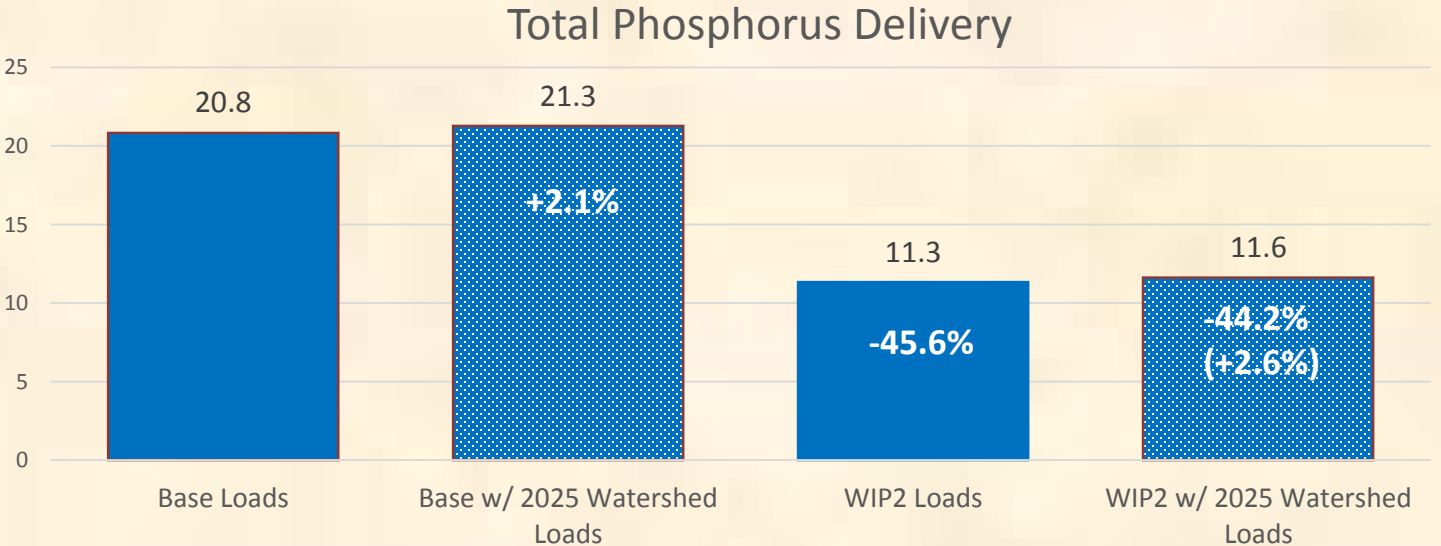
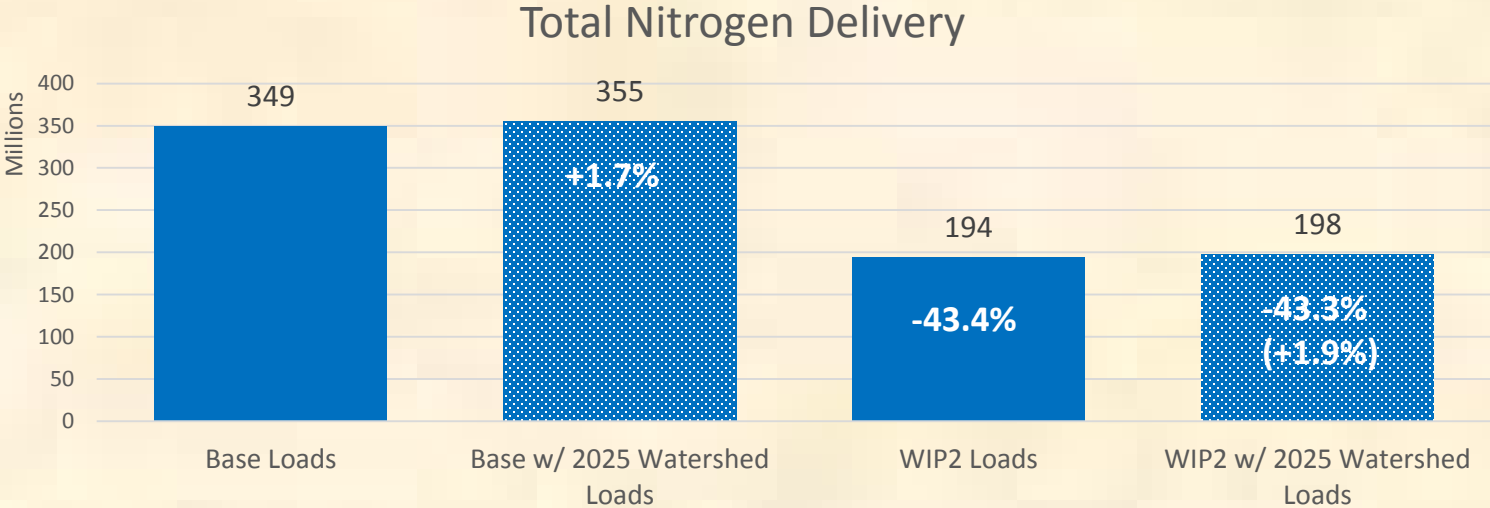


Flows under 2025 conditions increase because of increased precipitation throughout the watershed as estimated from 87 year of precipitation records (Karen Rice, personal communication). Increases in watershed temperatures of about 1°C decrement the increased precipitation somewhat because of increased evapotranspiration (estimated with Hargreaves-Samani method).



Watershed loads increase under estimated 2025 climate conditions compared to 1995 conditions.

Percent change from Base Loads except for (% change in WIP loads under 2025 conditions).



Estimated Sea Level, Temperature and Flow for 2025 Conditions

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graph TD; A[Estimated Sea Level, Temperature and Flow for 2025 Conditions] --> B[Sea Level Rise (S)]; A --> C[Temperature (T)]; A --> D[Flow (Q)]; A --> E[All Combined (SQT)]; B --> F[Base Nutrient Loadings Under Estimated 2025 CC Conditions of S, Q, or T]; C --> F; C --> G[Estimated 2025 CC Base Nutrient Loadings]; D --> F; D --> G; D --> H[Estimated WIP Nutrient Loading Under 2025 CC Conditions]; E --> H;
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**Sea Level Rise
(S)**

**Temperature
(T)**

**Flow
(Q)**

**All
Combined
(SQT)**

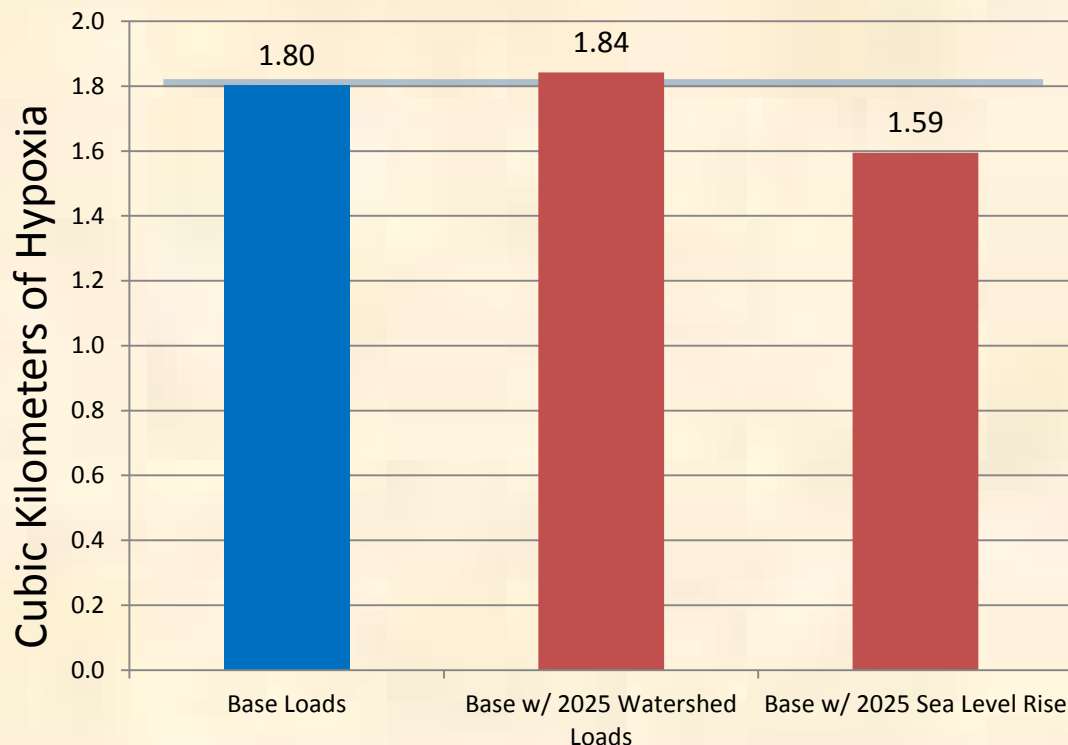
**Base Nutrient
Loadings Under
Estimated 2025
CC Conditions of
S, Q, or T**

**Estimated 2025
CC Base Nutrient
Loadings**

**Estimated WIP
Nutrient Loading
Under 2025 CC
Conditions**



Hypoxic volume (DO <1 mg/l) in Chesapeake Mainstem (Model estimate in summer 1991-2000)



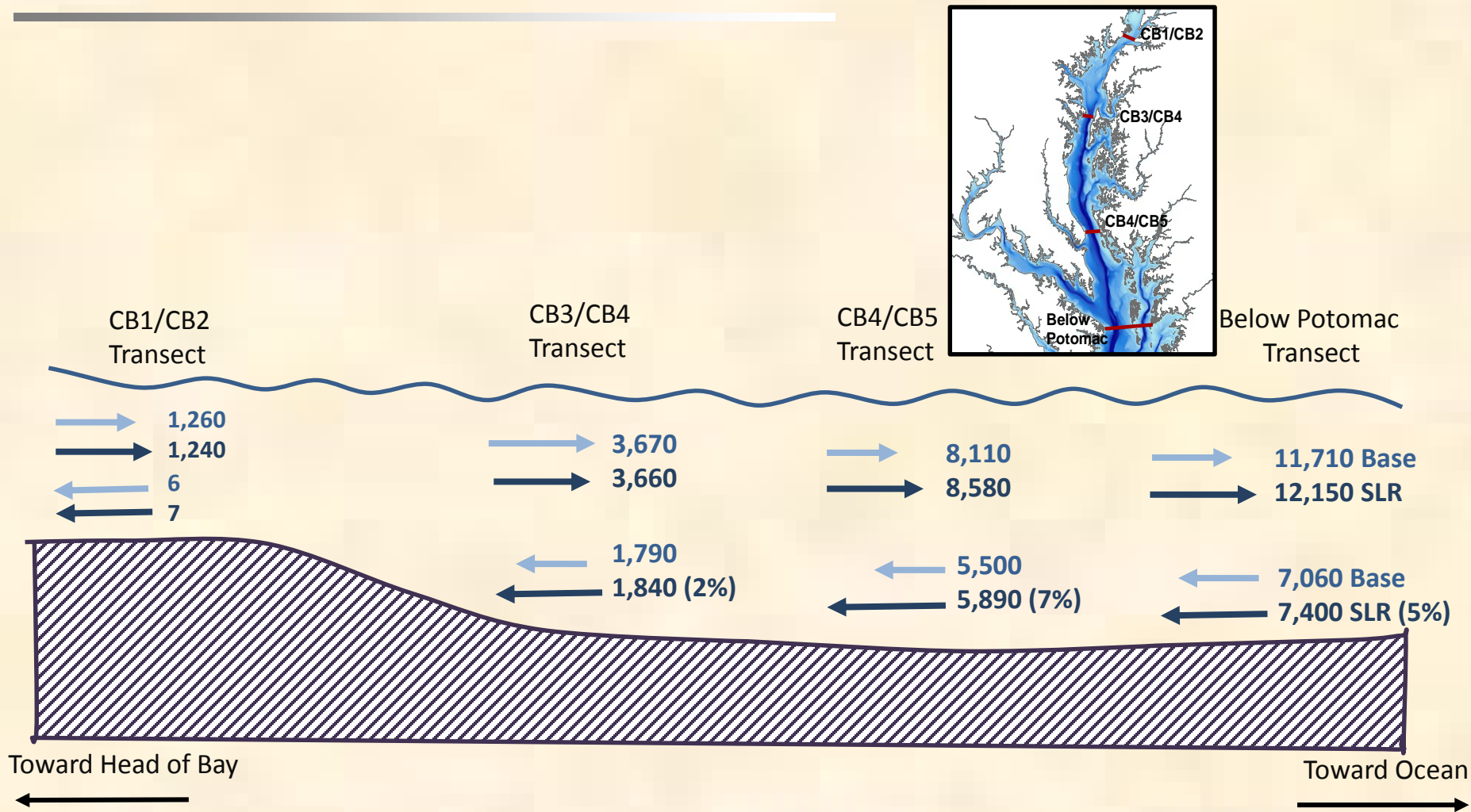
Sea level rise increases bottom water dissolved oxygen because of increased estuarine circulation, increased ventilation of Bay deep waters by oxygenated ocean waters, and in some areas decreased stratification.

DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

solid blue = key scenario, solid red = sensitivity scenario, stippled blue = 2025 climate scenario



Cross-transect water mass fluxes (m^3/s) : Base Case versus Sea Level Rise Scenario

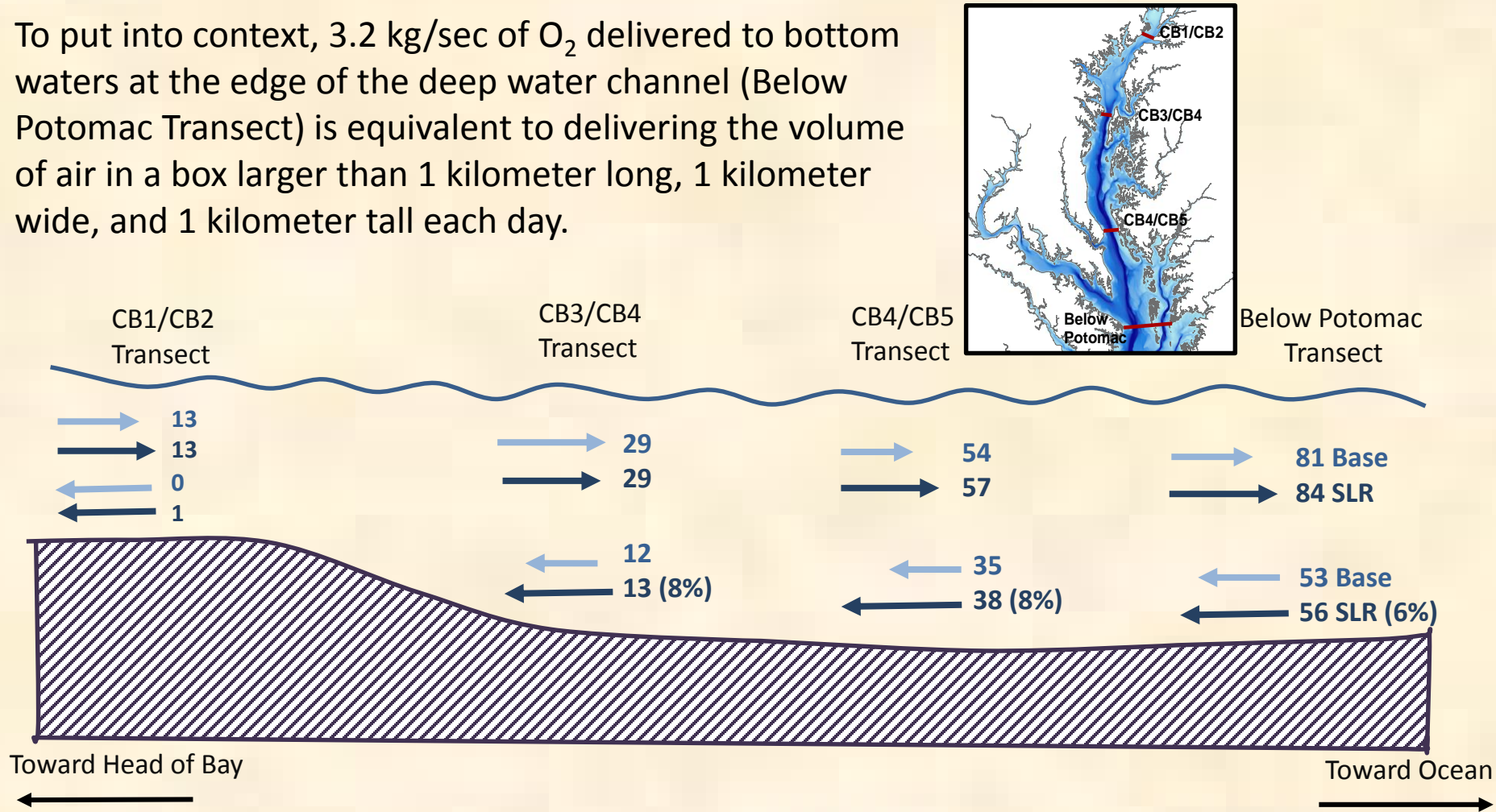


Base = Beta 4 Calibration. SLR = 0.3m Sea Level Rise Scenario representing relative Chesapeake sea level rise from 1995 to 2025. Units in mean cubic meters per second (m^3/s) for 1991 to 2000 hydrodynamics.

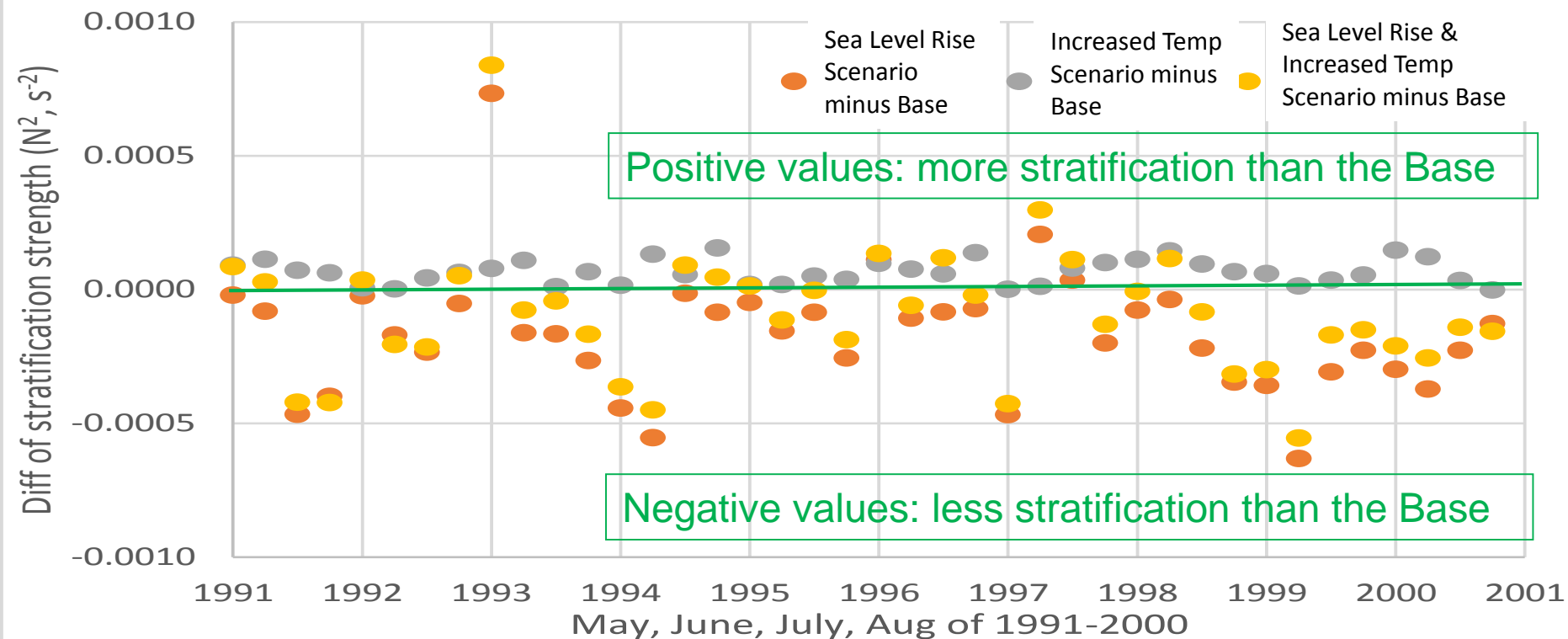
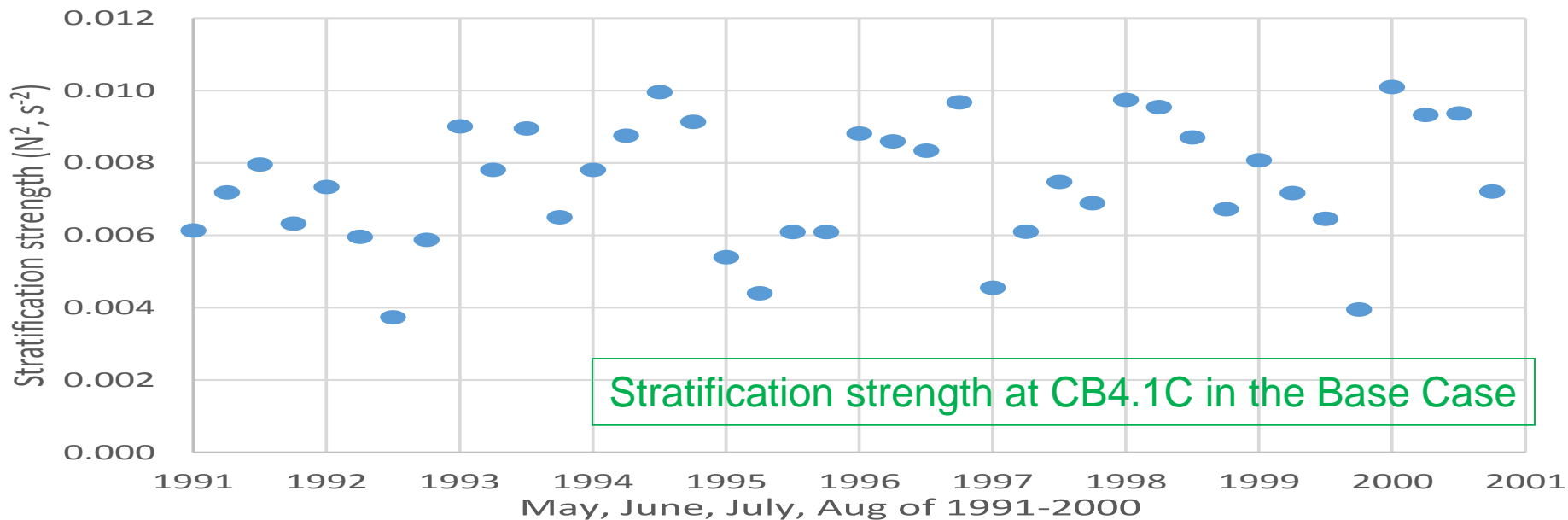


Cross-transect DO fluxes (kg/s): Base Case versus Sea Level Rise (SLR) Scenario

To put into context, 3.2 kg/sec of O_2 delivered to bottom waters at the edge of the deep water channel (Below Potomac Transect) is equivalent to delivering the volume of air in a box larger than 1 kilometer long, 1 kilometer wide, and 1 kilometer tall each day.

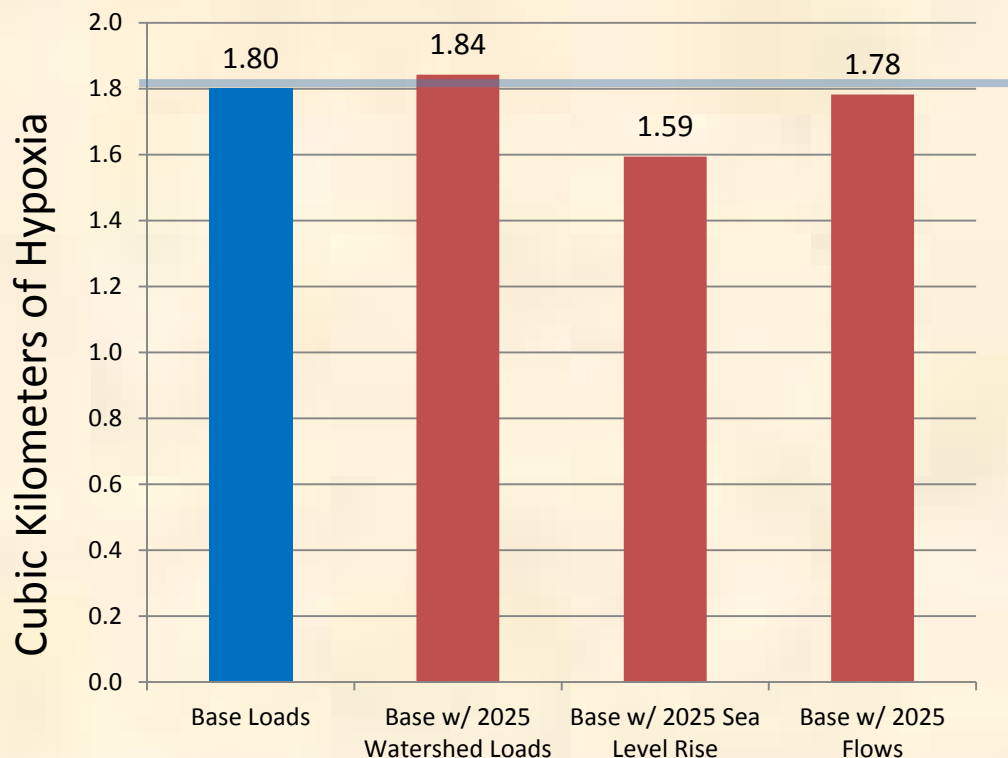


Base = Beta 4 Calibration. SLR = 0.3m Sea Level Rise Scenario representing relative Chesapeake sea level rise from 1995 to 2025. Units in mean kg DO per second (m^3/s) for 1991 to 2000 hydrodynamics.






Hypoxic volume (DO <1 mg/l) in Chesapeake Mainstem (Model estimate in summer 1991-2000): 2025 Estimates

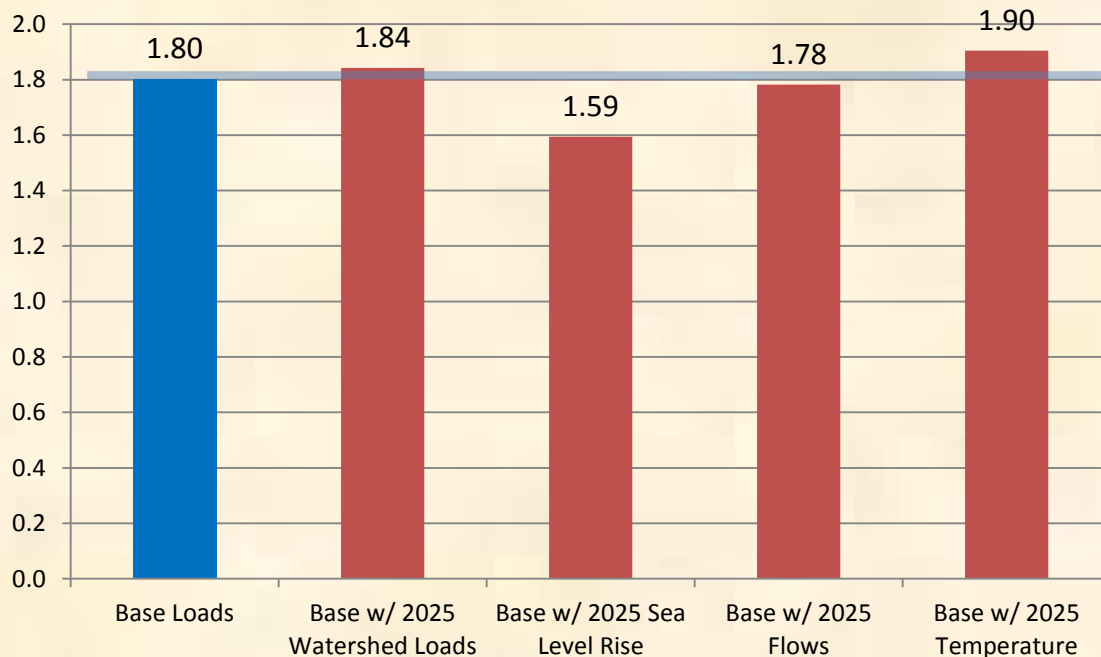


Increased fresh water flows from the watershed also increase bottom water dissolved oxygen slightly because of increased estuarine circulation, however there is also an increase in stratification.

DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.



Hypoxic volume (DO <1 mg/l) in Chesapeake Mainstem (Model estimate in summer 1991-2000): 2025 Estimates



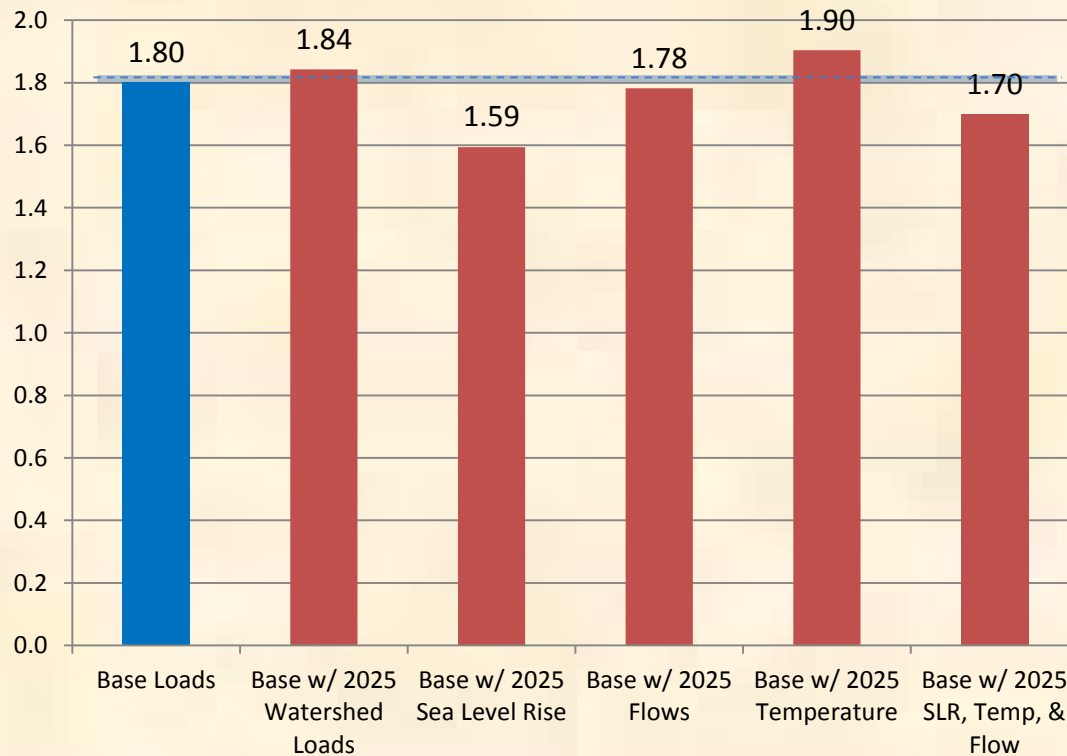
Estimated 2025 increased temperature in tidal waters increases temperature of both the surface and bottom waters but overall increases stratification.

DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

solid blue = key scenario, solid red = sensitivity scenario, stippled blue = 2025 climate scenario



Hypoxic volume (DO <1 mg/l) in Chesapeake Mainstem (Model estimate in summer 1991-2000): 2025 Estimates



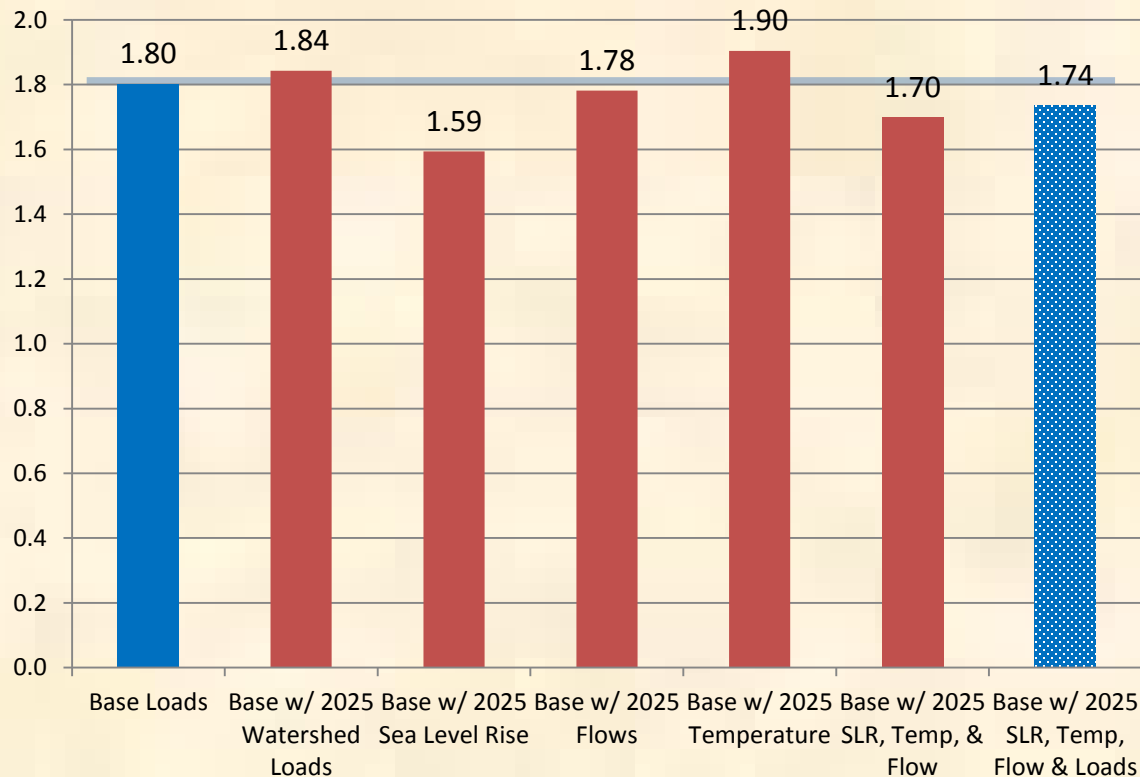
Combining all the estimated physical property changes of sea level, watershed flow, and temperature has an overall change of a 6 percent reduction in tidal water hypoxia.

DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

solid blue = key scenario, solid red = sensitivity scenario, stippled blue = 2025 climate scenario



Hypoxic volume (DO <1 mg/l) in Chesapeake Mainstem (Model estimate in summer 1991-2000): 2025 Estimates



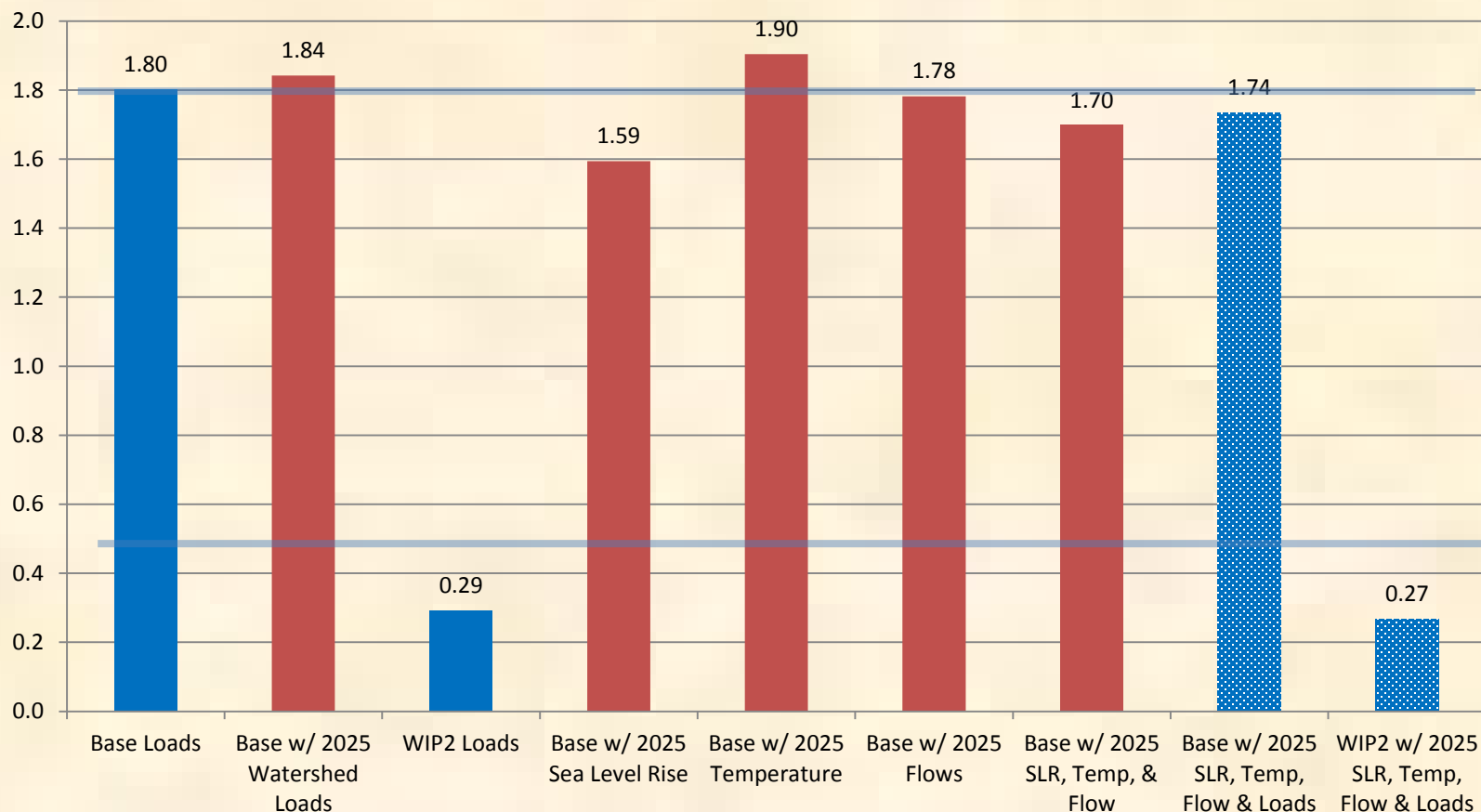
DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

Adding now the estimated 2025 watershed loads due to increase flows and combining all the estimated physical property changes of sea level, watershed flow, and temperature has an overall change of a 3 percent reduction in tidal water hypoxia compared to the Base Loads.

solid blue = key scenario, solid red = sensitivity scenario, stippled blue = 2025 climate scenario



Hypoxic volume (DO <1 mg/l) in Chesapeake Mainstem (Model estimate in summer 1991-2000): 2025 Estimates

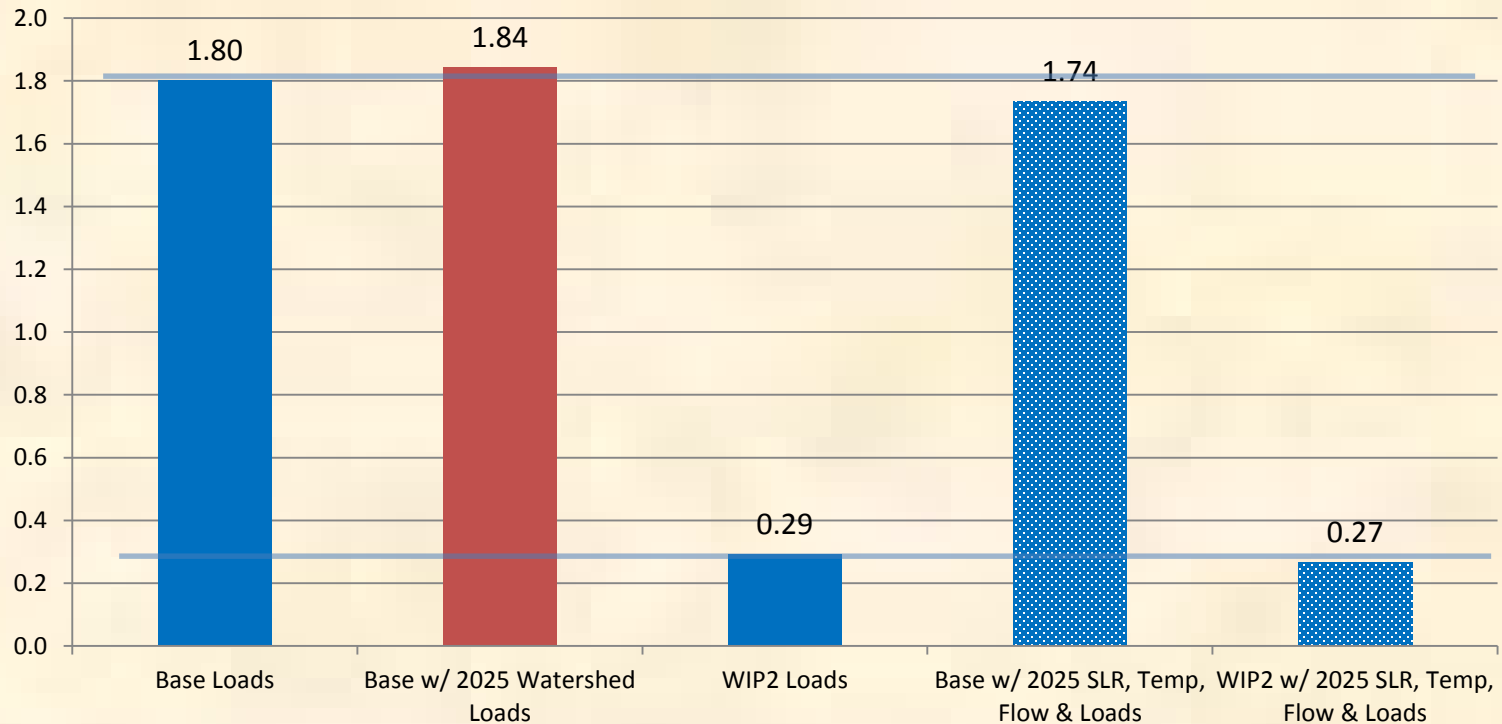


DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

solid blue = key scenario, solid red = sensitivity scenario, stippled blue = 2025 climate scenario



Why does hypoxia decrease under estimated under 2025 temperature, precipitation, and sea level despite higher estimated watershed loads? A: Mostly due to sea level rise.

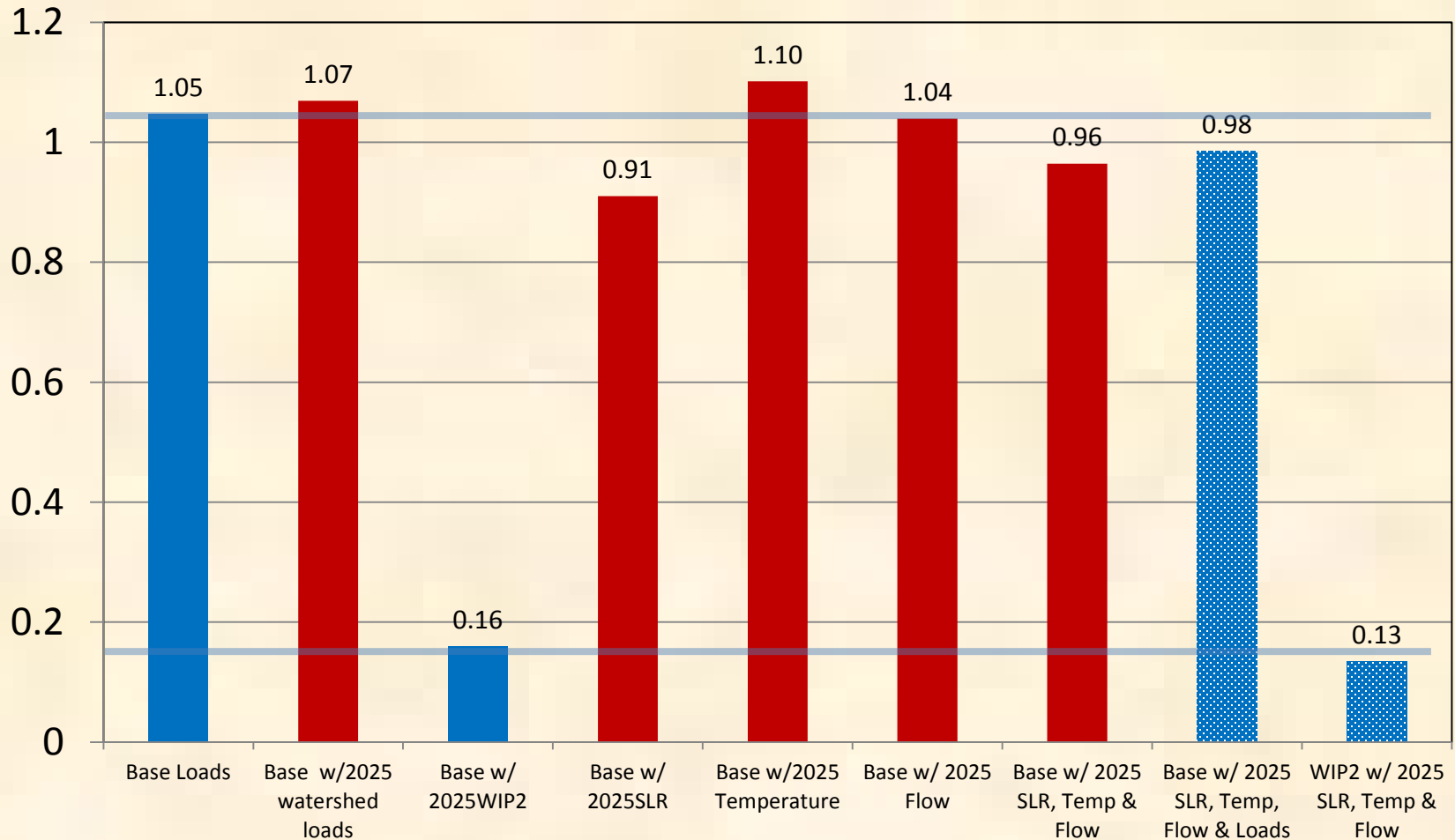


DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

solid blue = key scenario, solid red = sensitivity scenario, stippled blue = 2025 climate scenario



Hypoxic volume (DO <1 mg/l) in CB4MH (Model estimate in summer 1991-2000)

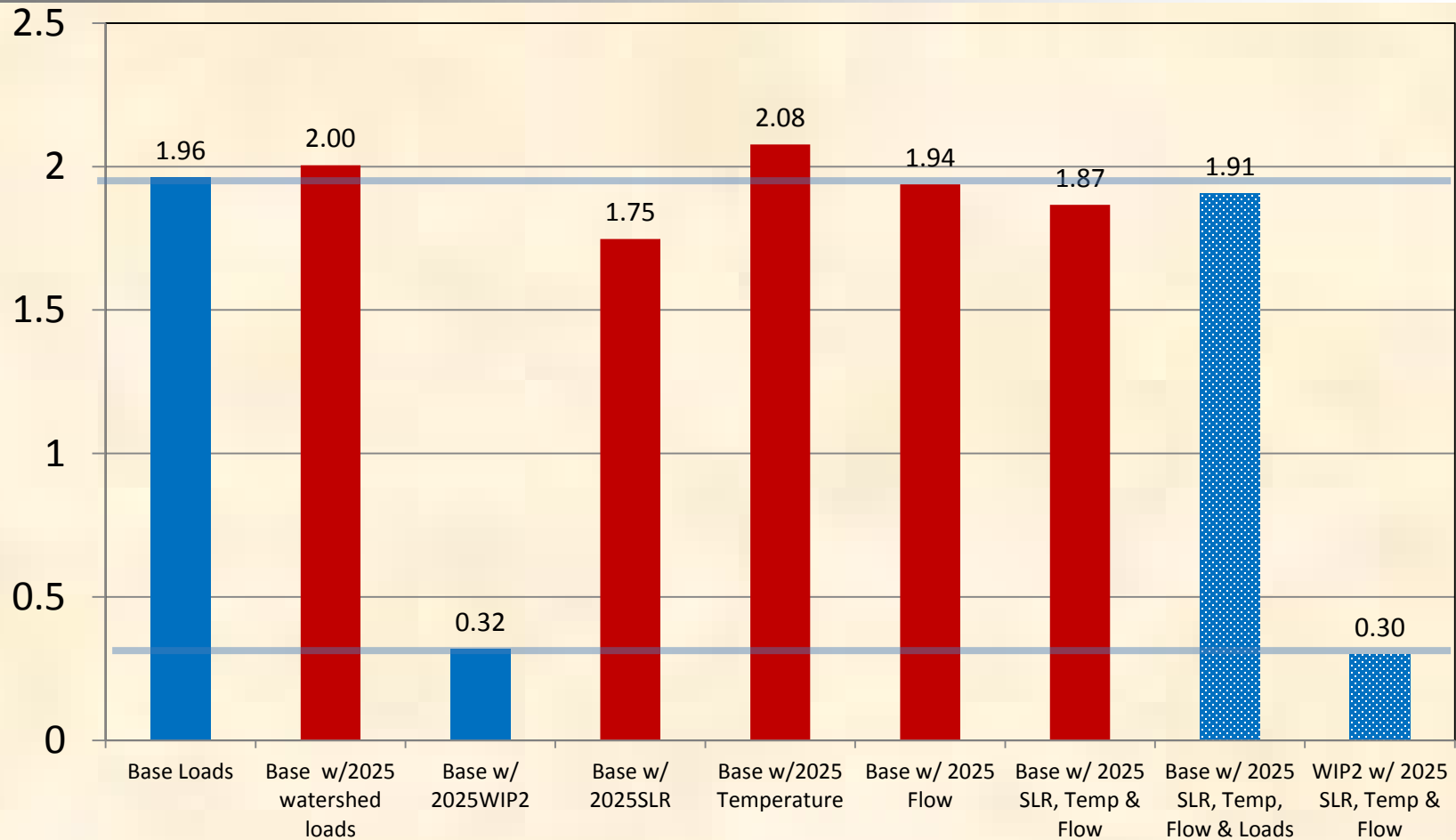


DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

solid blue = key scenario, solid red = sensitivity scenario, stippled blue = 2025 climate scenario



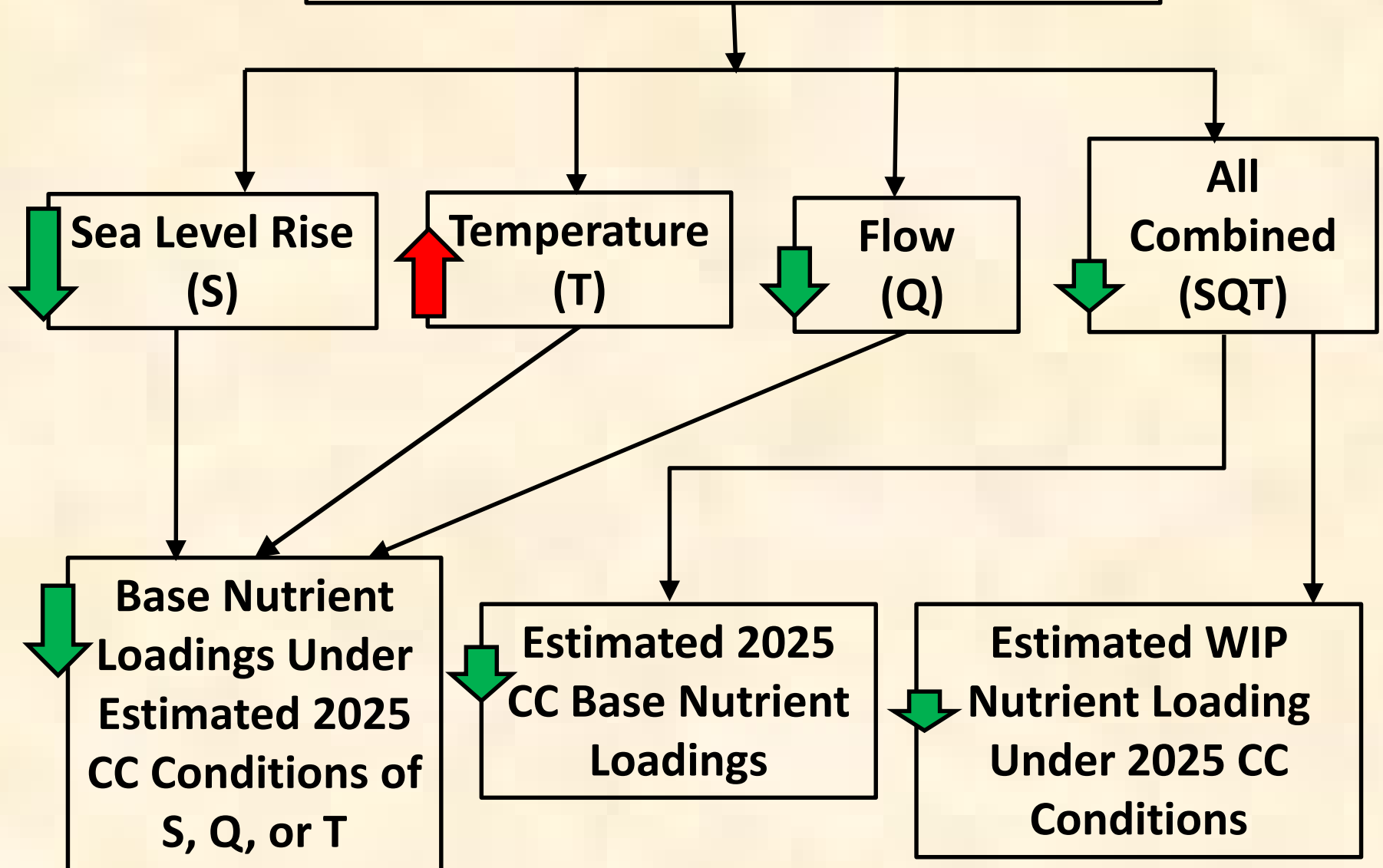
Hypoxic volume (DO <1 mg/l) in Whole Bay (Model estimate in summer 1993-1995): 2025 Estimates



DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

solid blue = key scenario, solid red = sensitivity scenario, stippled blue = 2025 climate scenario

Estimated Sea Level, Temperature and Flow for 2025 Conditions





Conclusions

- This is a work in progress using the Beta 3 Watershed Model and the Beta 4 WQSTM to provide the best estimate available today. Need to run the analysis on the final Watershed and WQSTM models.
- The CBP Modeling Workgroup is factoring into the Chesapeake Bay assessment tools the latest research on climate change with guidance from the STAC and the Climate Resiliency Workgroup.
- Influence of 2025 sea level rise is estimated to be a small but positive influence on Chesapeake hypoxia.
- Likewise, the influence of greater watershed flows (not loads) increases estuarine circulation, albeit with an increase in stratification, and overall is estimated to have a very slight positive influence on hypoxia.



Conclusions (*continued*)

- Influence of estimated 2025 temperature on Chesapeake water quality standards (WQS) is a slight but negative influence on Chesapeake hypoxia.
- Estimated influence of changes in tidal wetland attenuation is small in 2025 and 2050 because of little change in overall tidal wetland area, but accompanied by wetland type changes. However, tidal wetland losses are estimated to increase beyond 2050.
- The range of the influence of estimated watershed loads in future climate change conditions using observed (87 year) increase of precipitation volume (Karen Rice) and precipitation intensity (Karl and Knight) depends on the evapotranspiration method chosen.



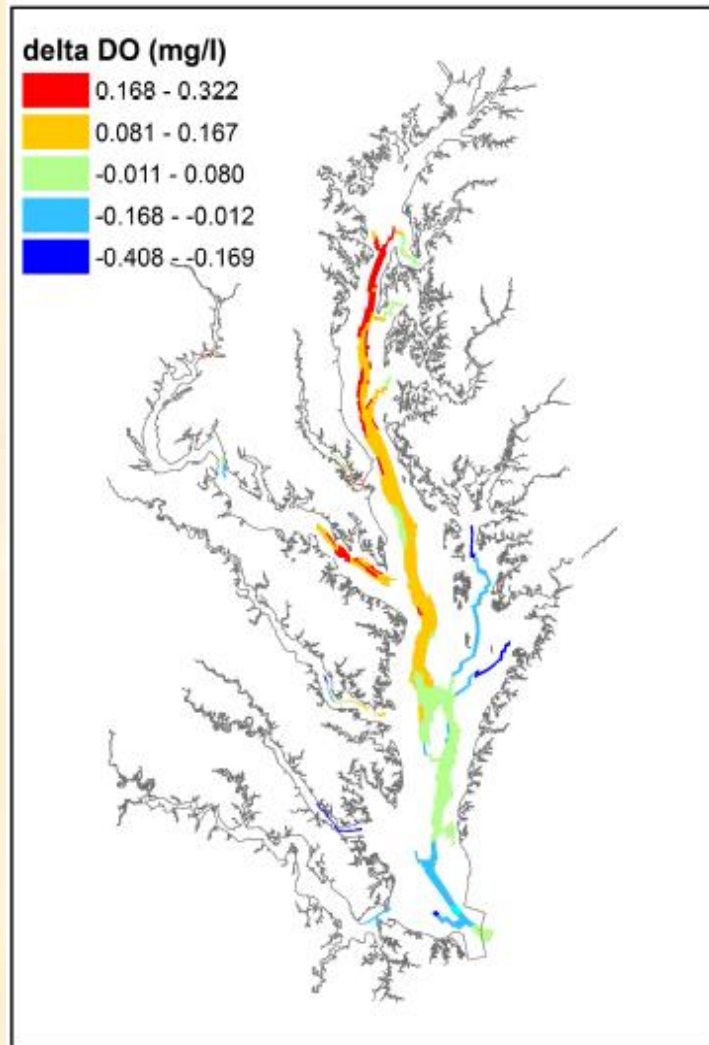
Conclusions (*continued*)

- Scientific peer reviews of the representation of climate change by the CBP models will be conducted by the CBP Scientific and Technical Advisory Committee (STAC).
- Future work is oriented toward developing a range of climate change estimates to reflect different assumptions of rainfall intensity for 2025 estimates and different future estimated greenhouse gas concentrations (Representative Concentration Pathways (RCPs)) for 2050.



Influence of Estimated 2050 Sea Level Rise (0.5 m) on Bottom DO

Sea Level Rise Scenario (SLR)



The influence of an 2050 estimated sea level rise on Chesapeake hypoxia is significant.

The estimated change from the base (1991 to 2000) condition in Chesapeake hypoxia due to 2050 estimated sea level rise conditions ranges from 0.3 mg/l to -0.4 mg/l.

Hypoxia decreases in the mid-Bay are due to increased ventilation of deep Chesapeake waters by well oxygenated ocean waters and also because of changes in vertical stratification.

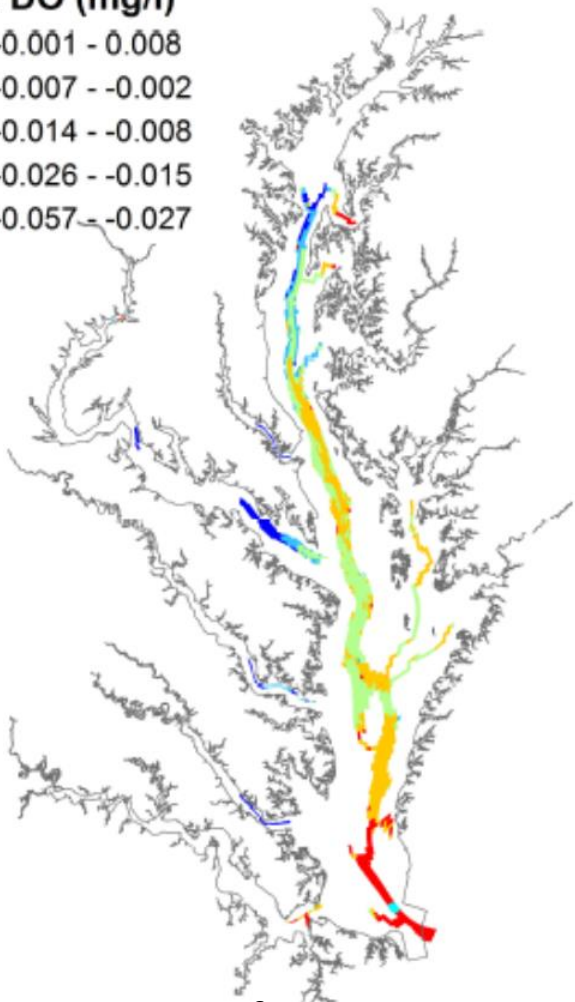
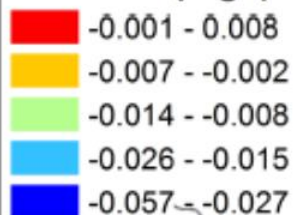
By extension, estimated 2025 (0.3 m) sea level rise increases will also have slight influence on water quality standard achievement.



Estimated 2050 Temperature Increases on Bottom DO

Temperature Increase Scenario (GW)

delta DO (mg/l)



Source: CERF Conference 2015

The influence of an 2050 estimated temperature increase on Chesapeake hypoxia is small.

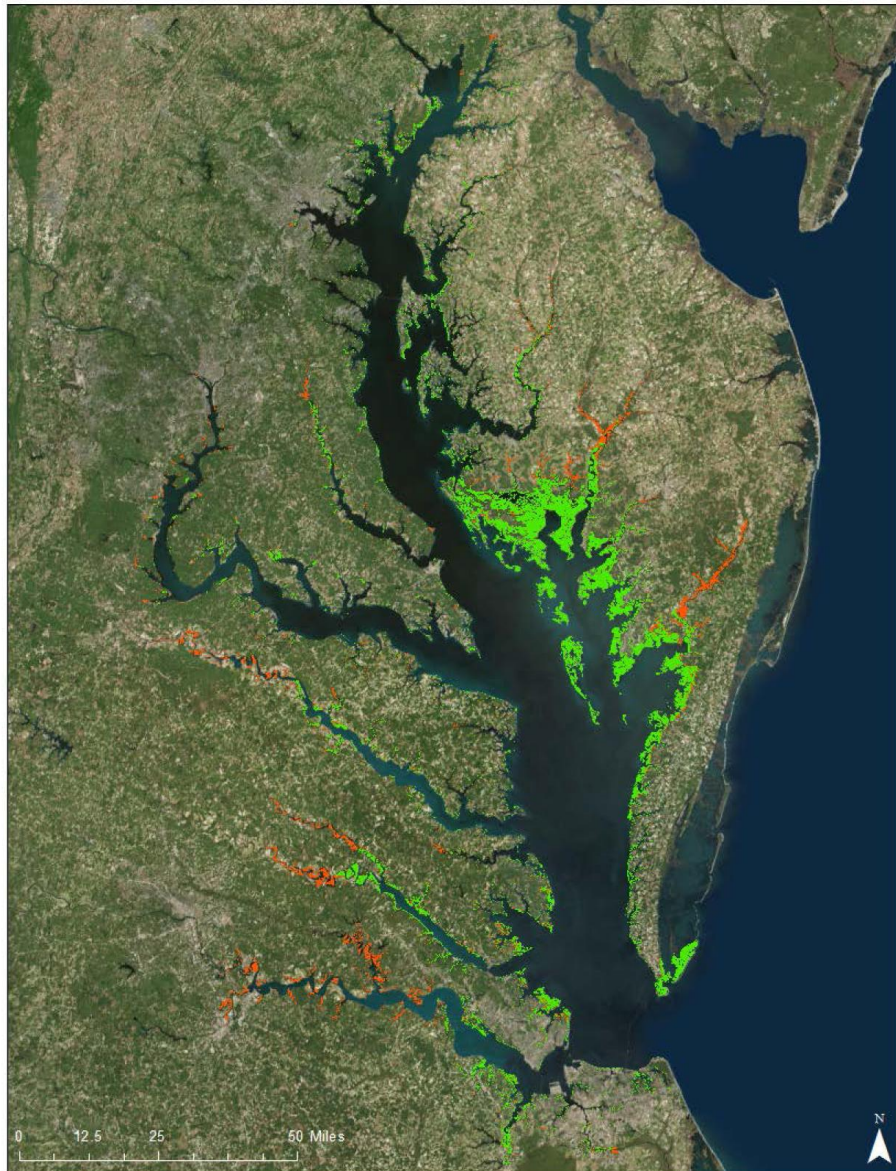
But we can measure in infinitesimal with our models. The estimated increase in Chesapeake hypoxia due to 2050 estimated temperature increases ranges from 0.008 to - 0.06 mg/l.

Hypoxia increases are due to the increase in vertical stratification due to the increased thermocline, reduced oxygen saturation levels, and increased respiration.

Estimated 2025 temperature increases will also have slight influence on water quality standard achievement.



Chesapeake Bay Tidal Wetlands

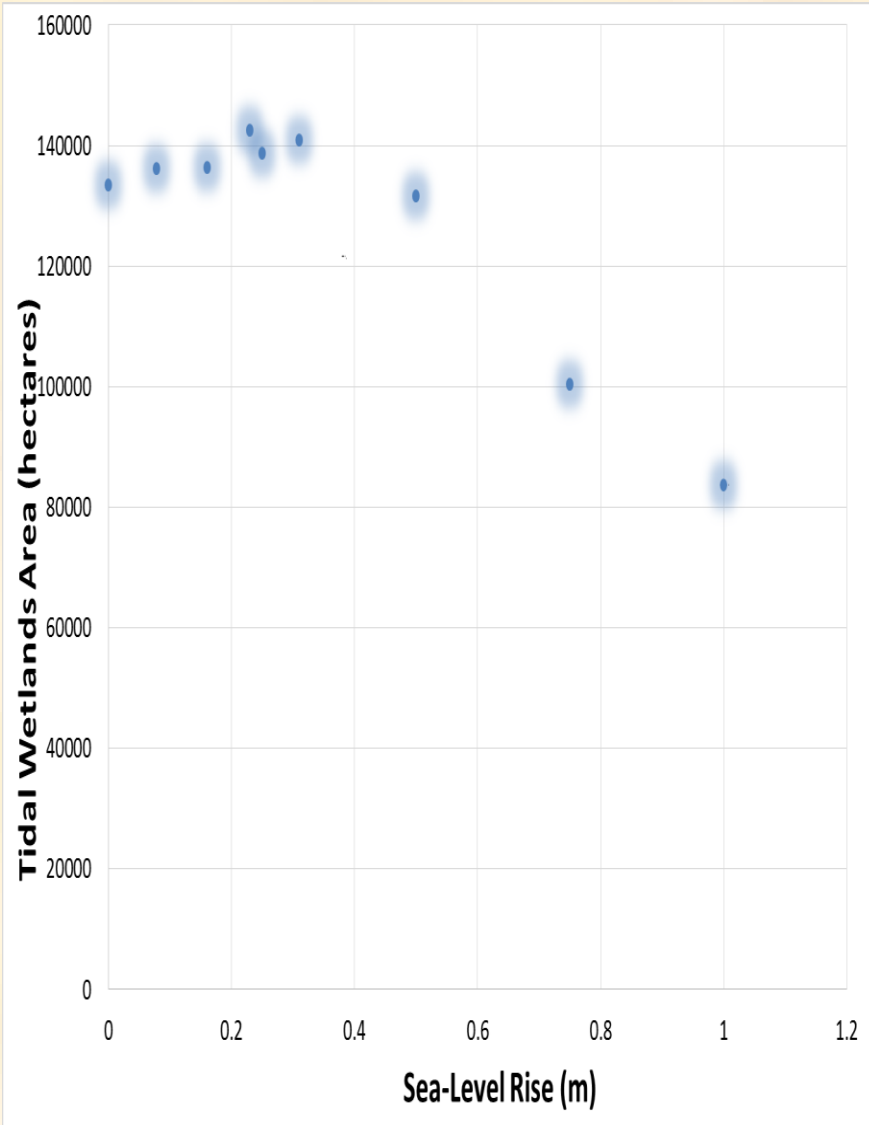


Source: Carl Cerco, U.S. CoE ERDC

- The extent from National Wetlands Inventory is determined largely from vegetation perceived via aerial photography.
- 190,000 hectares of estuarine (green) and tidal fresh (red) wetlands.
- A tidal wetlands module is now fully operational in the WQSTM. The module incorporates functions of sediment and particulate nutrient removal and burial, denitrification, and respiration. The loss of wetland function due to sea level rise and inundation will be accounted for explicitly.



Influence of Estimated 2025 (0.3 m) and 2050 (0.5m) Sea Level Rise on Tidal Wetland Attenuation



There is little change in estimated total tidal wetland area for 2025 (0.3 m) and 2050 (0.5 m) which equates to negligible changes in tidal wetland attenuation.

Long range (2100) conditions estimate tidal wetland changes to be on the order of a 40% loss in the Chesapeake which could reduce tidal wetland attenuation on the order of about 10 million pounds nitrogen and 0.6 million pounds phosphorus.