Preliminary Estimate of Climate Change Influence On Chesapeake 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 <u>despite</u> 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: +7.3% (RCP* 4.5)

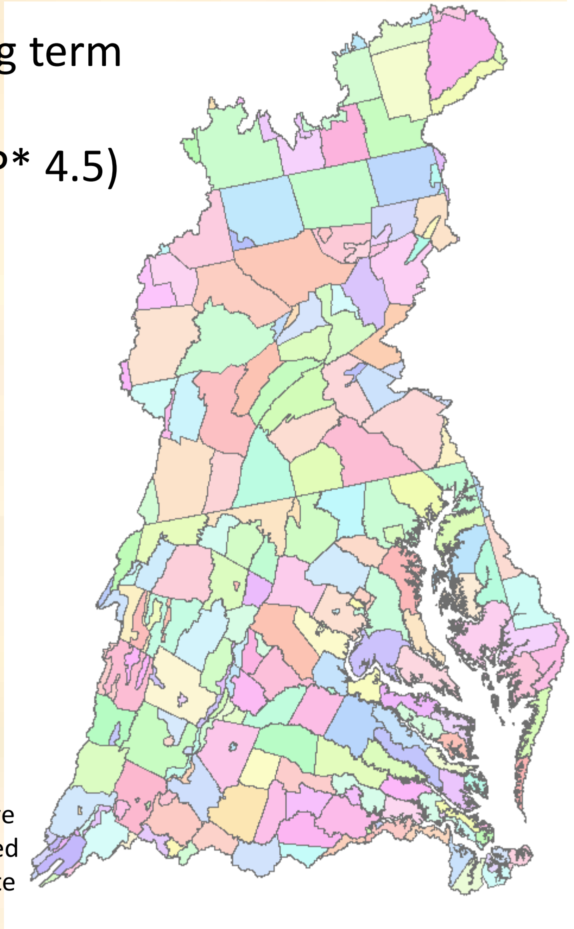
Temperature: RCP 4.5

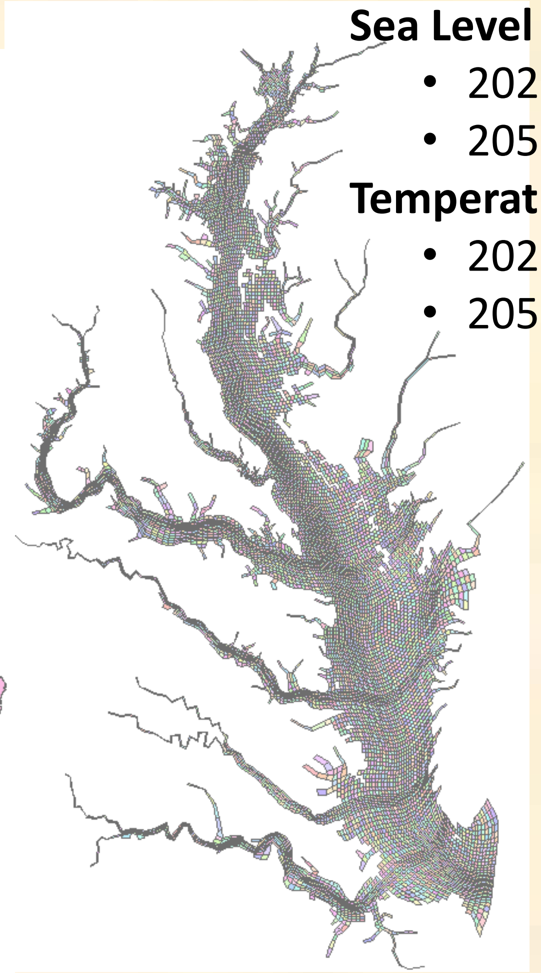
- 2025: +1.05 ^oC
- 2050: +2.08 ^oC

CO_2 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 ^oC
- 2050: +1.86 ^oC

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

**Based upon guidance provided by the Climate Resiliency Workgroup

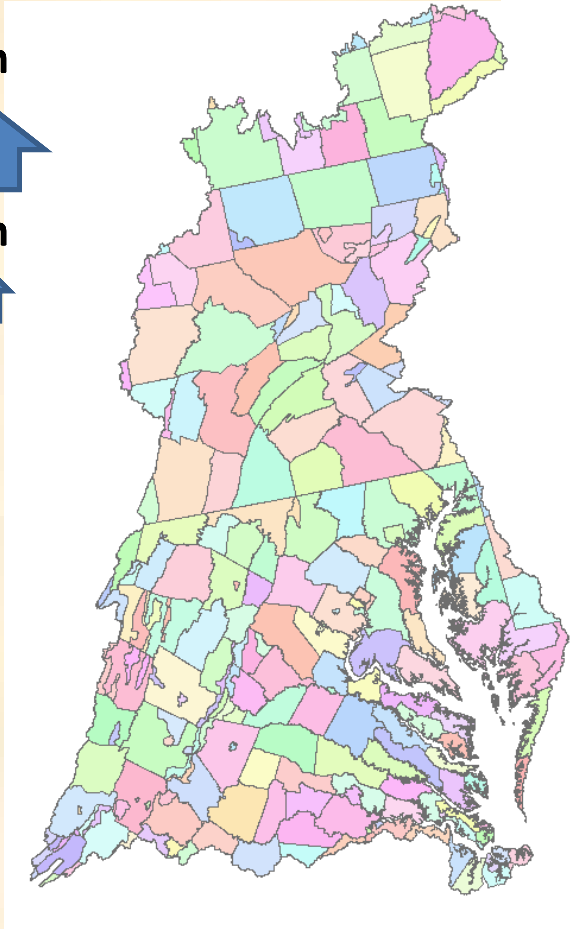
Keeping Score

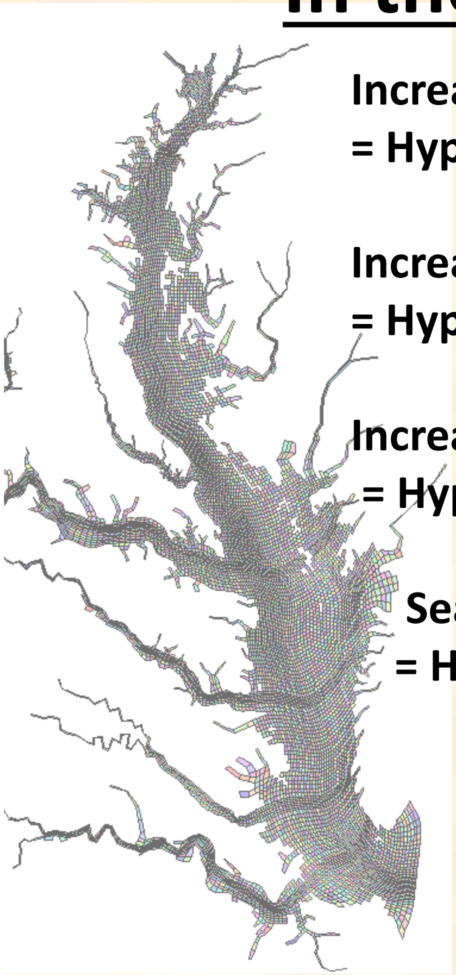
In the Watershed

Increased Precipitation Volume = Hypoxia

Increased Precipitation Intensity = Hypoxia

Increase in Temp and Evapotranspiration = Hypoxia





In the Estuary

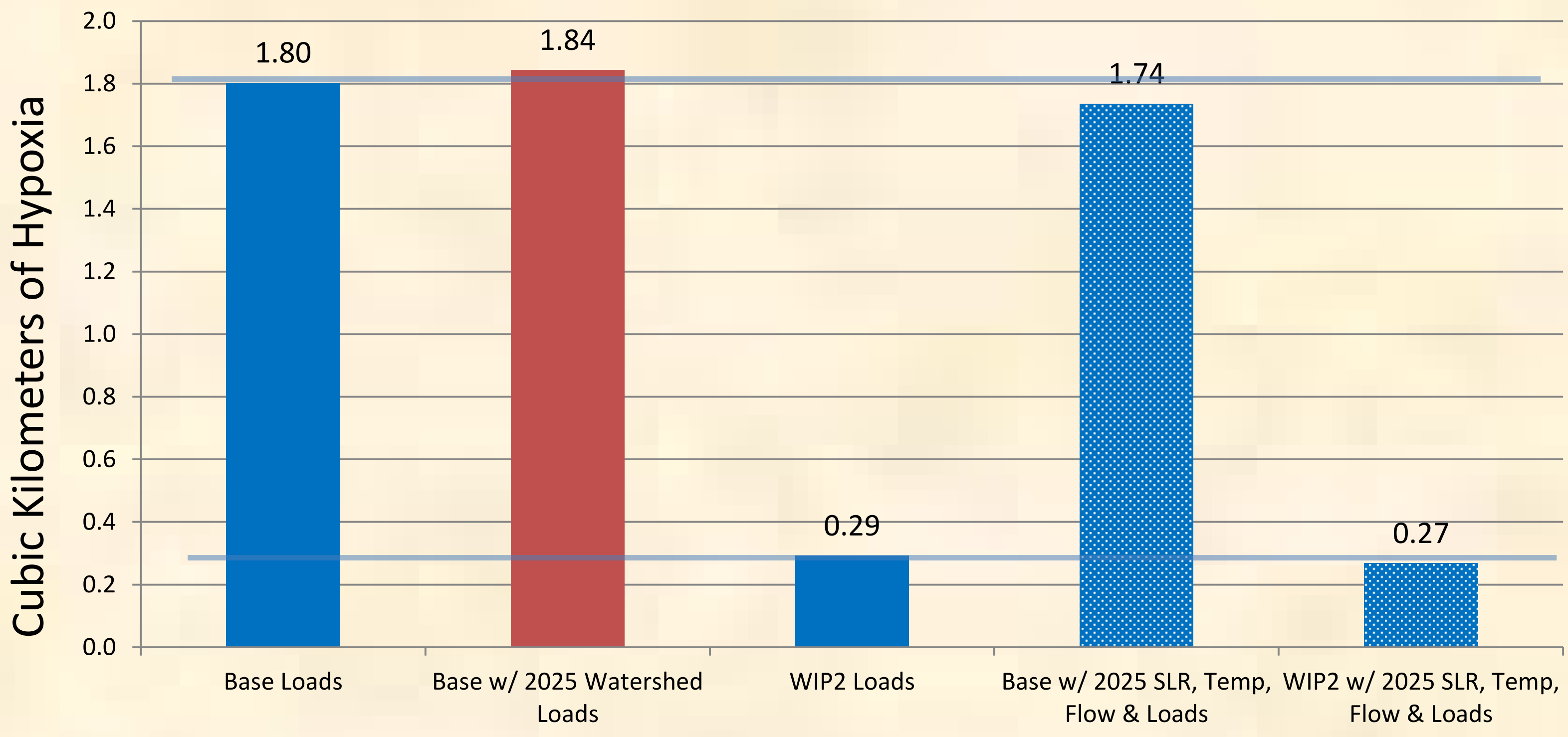
Increased WS Loads = Hypoxia

Increased WS Flows = Hypoxia

Increased Temperature = Hypoxia

Sea Level Rise = Hypoxia

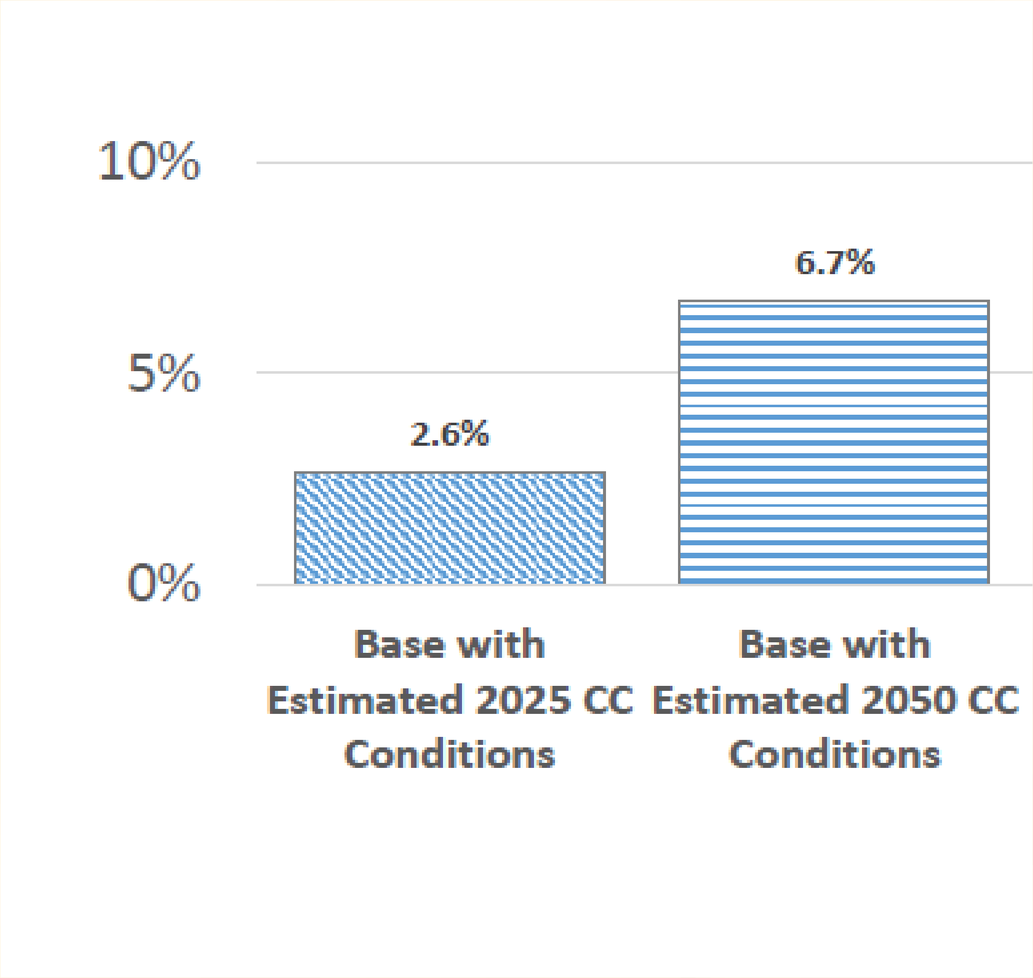
Why does hypoxia decrease under estimated under 2025 temperature, precipitation, and sea level despite higher estimated watershed loads?



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.

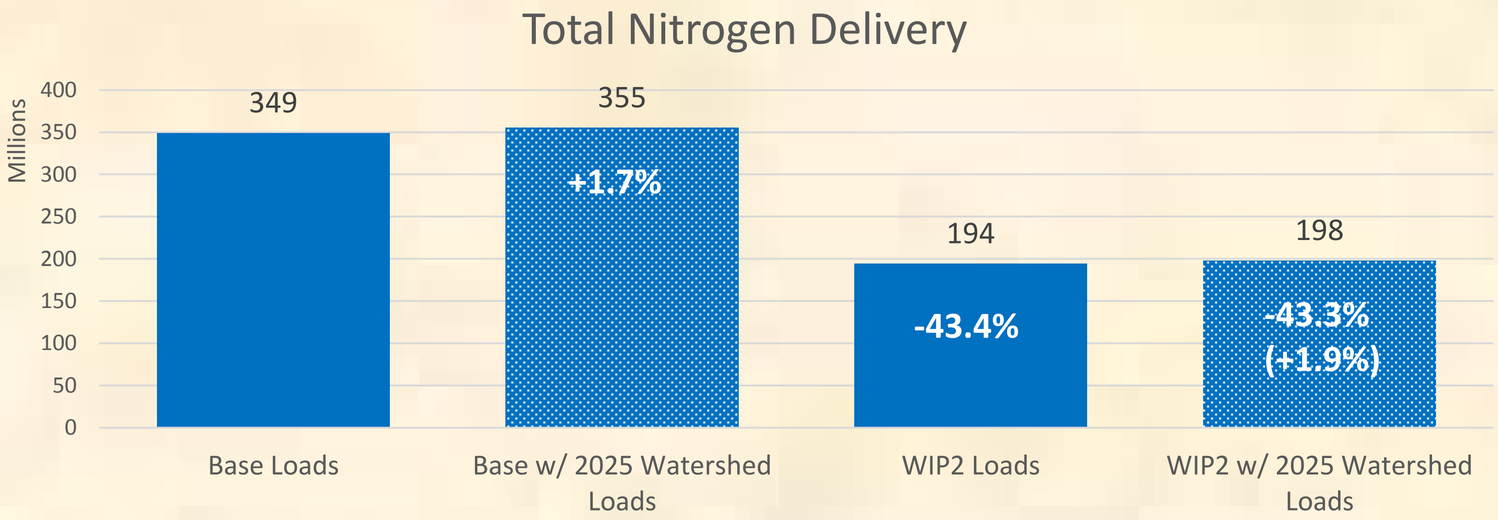


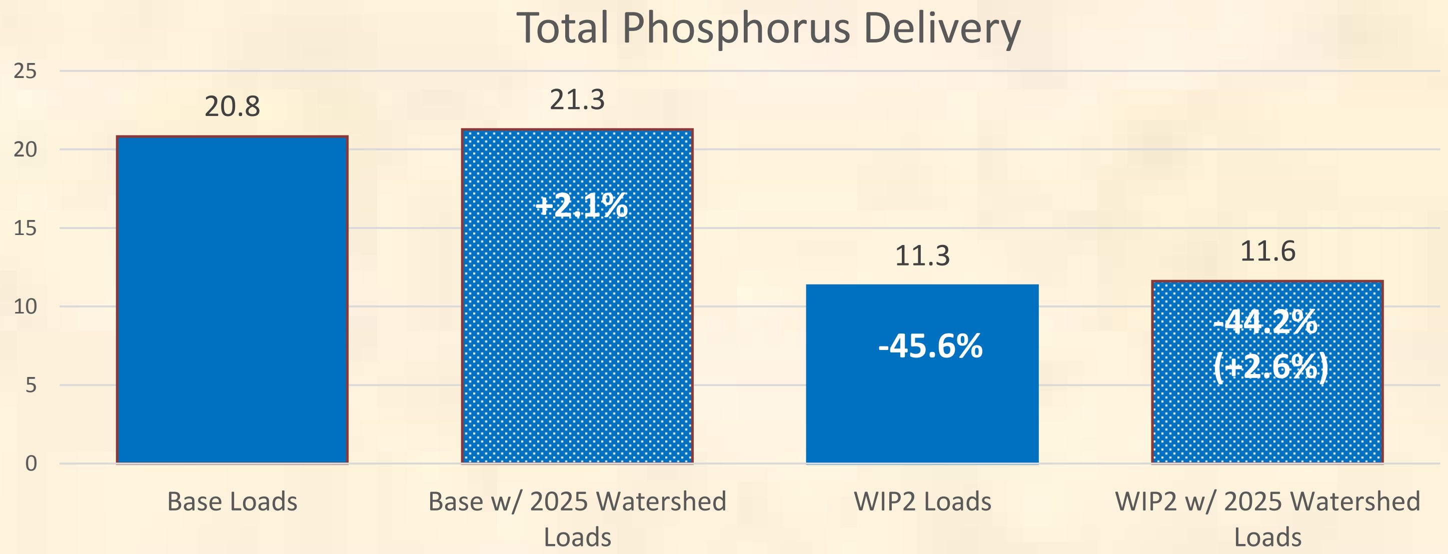
Flows under 2025 conditions increase because of increased precipitation throughout the watershed as estimated from 87 year of precipitation records (Karen Rice, personal communication). Increases in watershed temperatures of about 1^0 C decrement the increased precipitation somewhat because of increased evapotranspiration (estimated with Hargreaves-Samani method).

Gopal Bhatt, December 2016 Quarterly Review

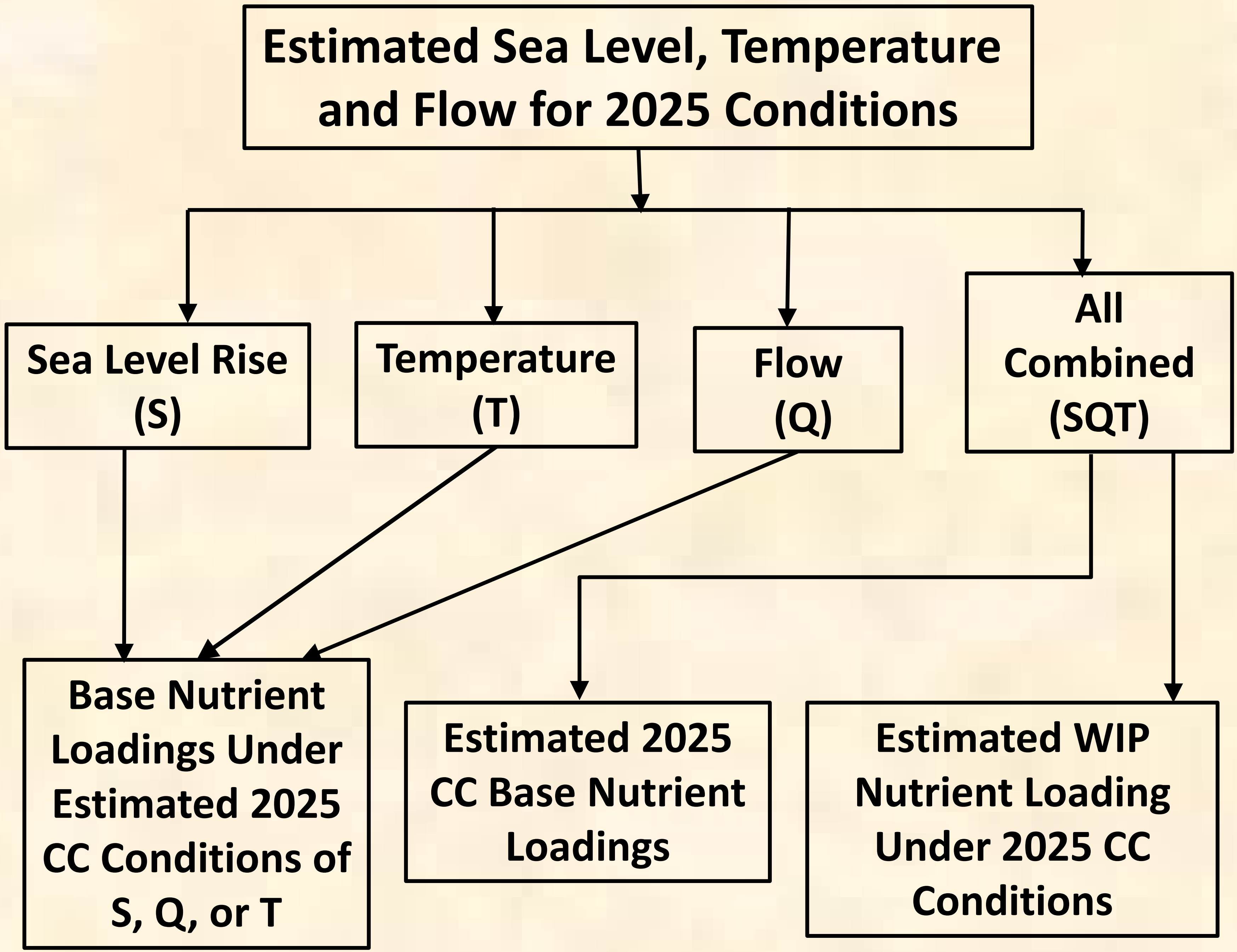
Watershed loads increase under estimated 2025 climate conditions compared to 1995 conditions.

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

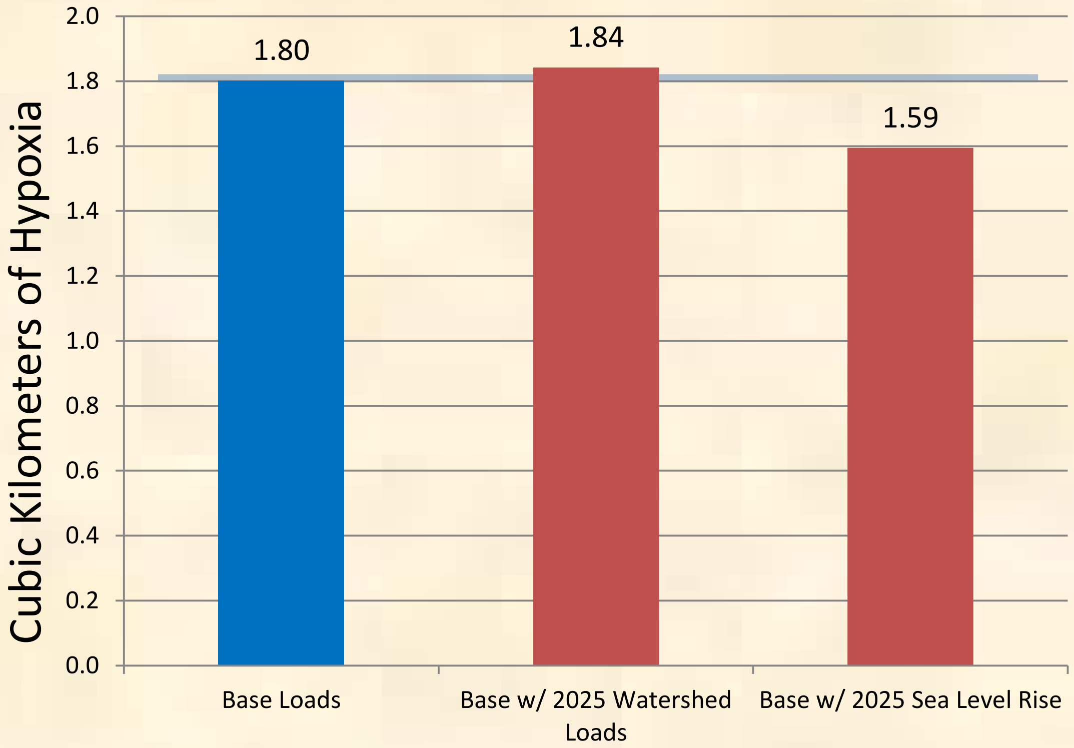




Gopal Bhatt, December 2016 Quarterly Review


Estimated Sea Level, Temperature and Flow for 2025 Conditions
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)

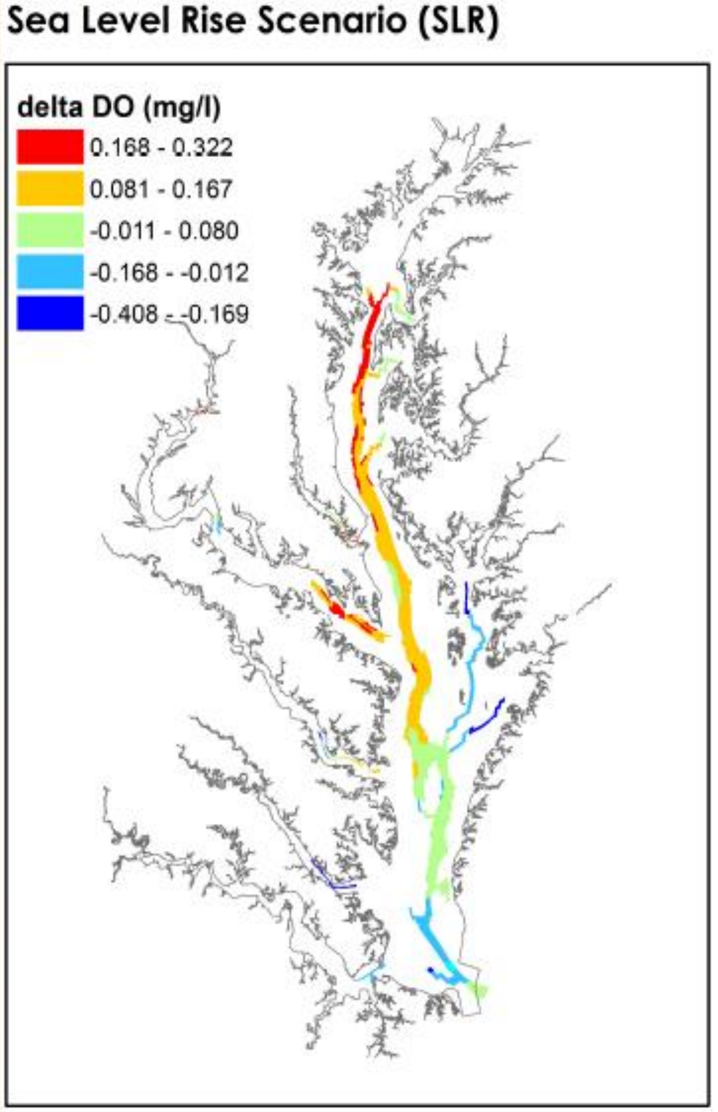


Sea level rise increases bottom water dissolved oxygen because of increased estuarine circulation, increased ventilation of Bay deep waters by oxygenated ocean waters, and in some areas decreased stratification.

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

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



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

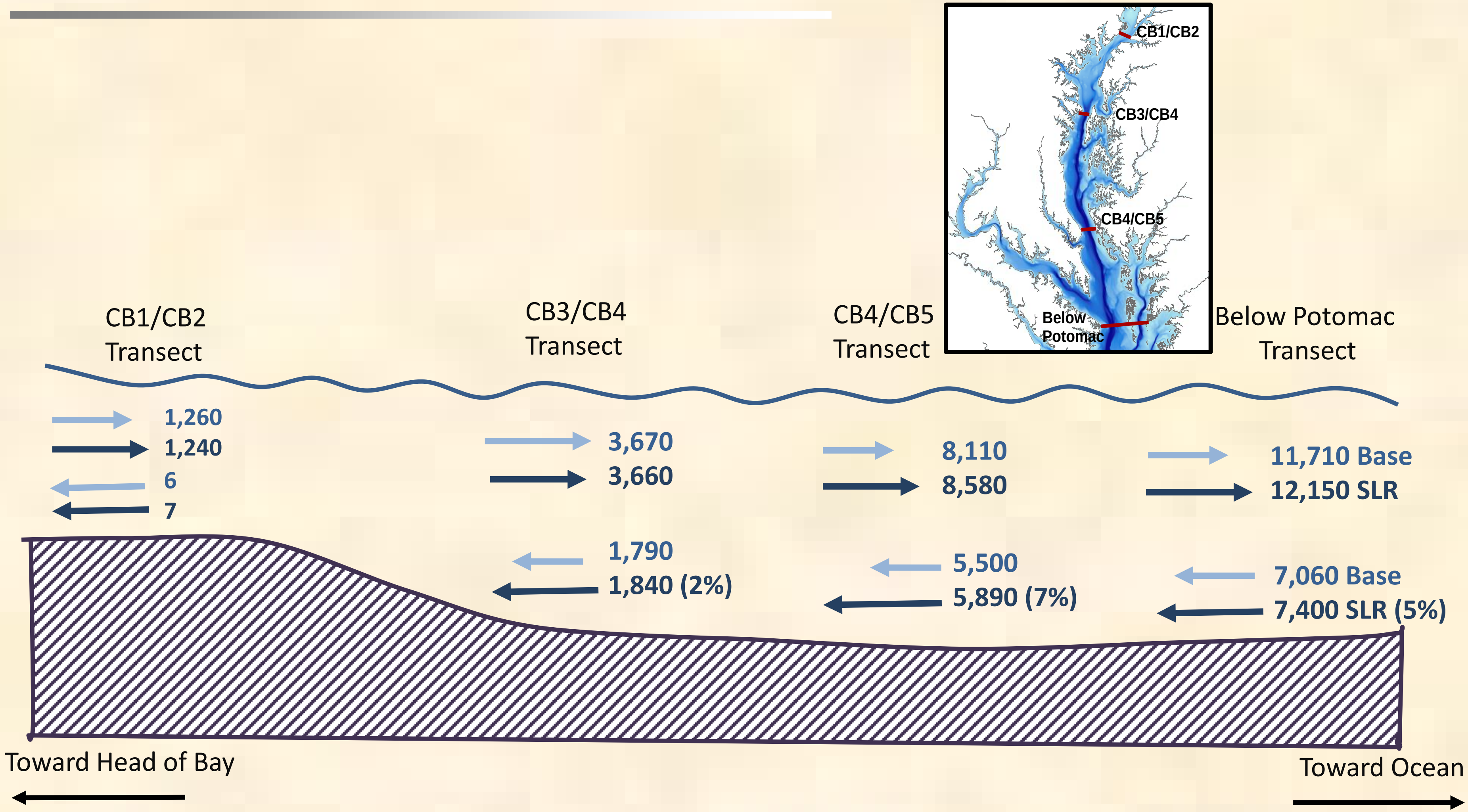
The estimated change from the base (1991 to 2000) condition in Chesapeake hypoxia due to 2050 estimated sea level rise conditions ranges from 0.3 mg/l to -0.4 mg/l.

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.

Source: CERF Conference 2015

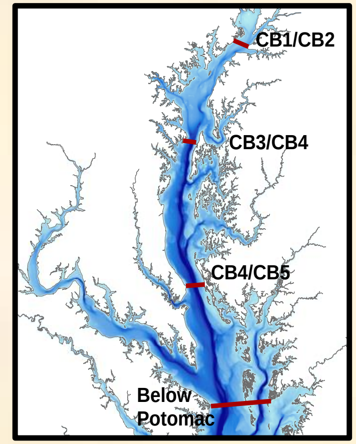
Cross-transect water mass fluxes (m^3/s) : Base Case versus Sea Level Rise Scenario

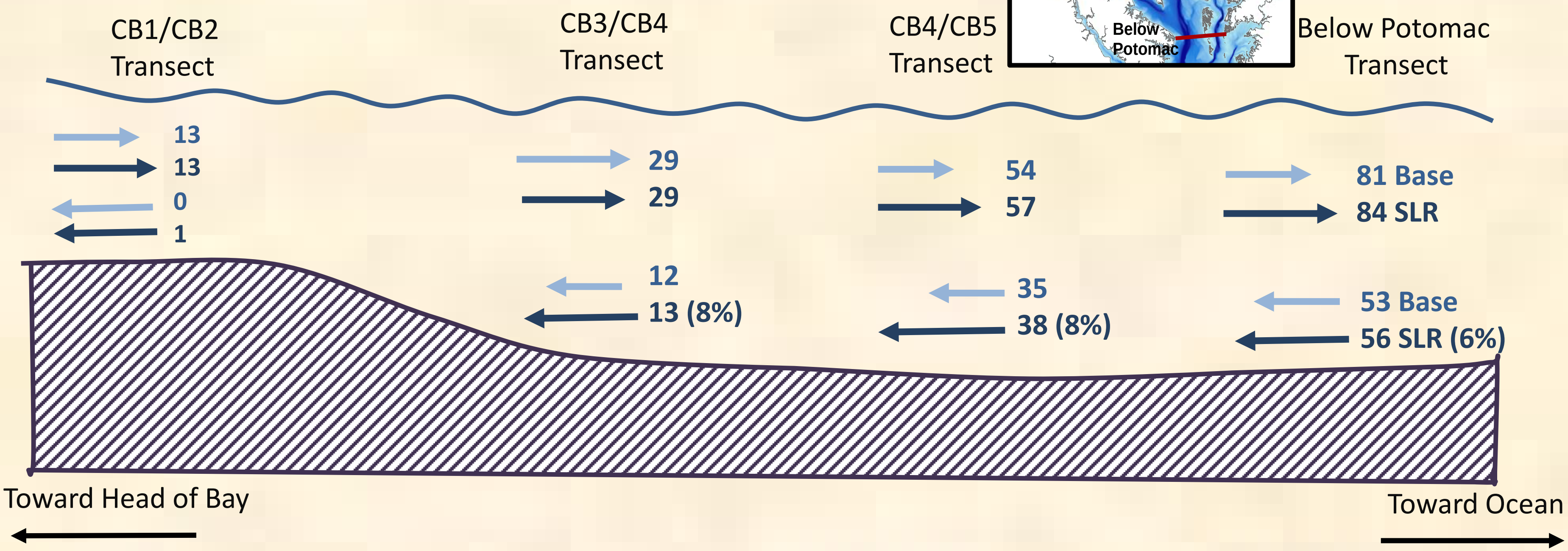


Base = Beta 4 Calibration. SLR = 0.3m Sea Level Rise Scenario representing relative Chesapeake sea level rise from 1995 to 2025. Units in mean cubic meters per second (m^3/s) for 1991 to 2000 hydrodynamics.

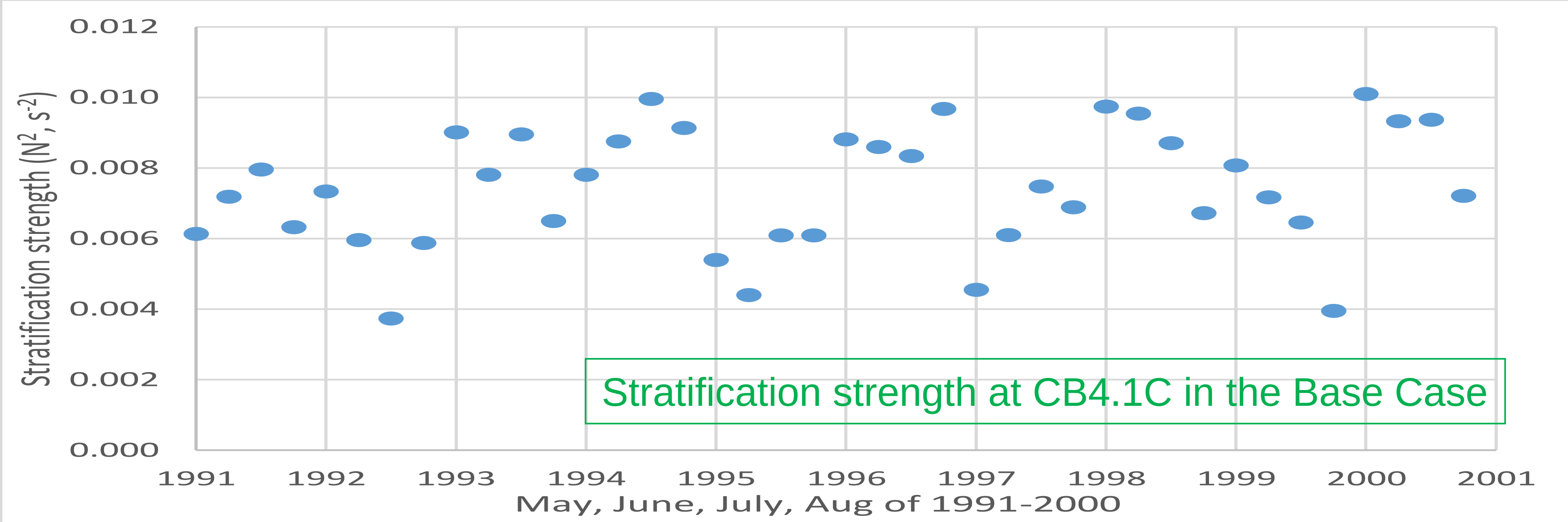
Cross-transect DO fluxes (kg/s): Base Case versus Sea Level Rise (SLR) Scenario

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.

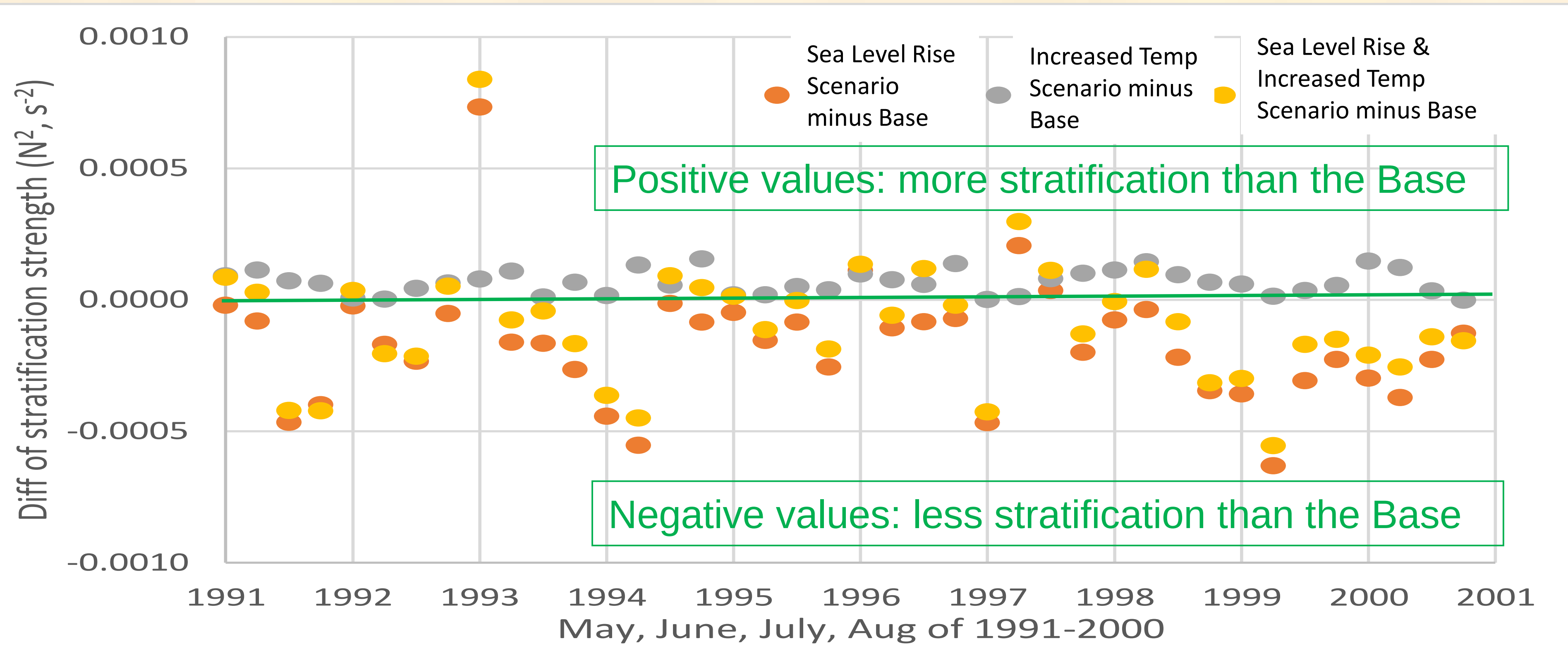




Base = Beta 4 Calibration. SLR = 0.3m Sea Level Rise Scenario representing relative Chesapeake sea level rise from 1995 to 2025. Units in mean kg DO per second (m^3/s) for 1991 to 2000 hydrodynamics.

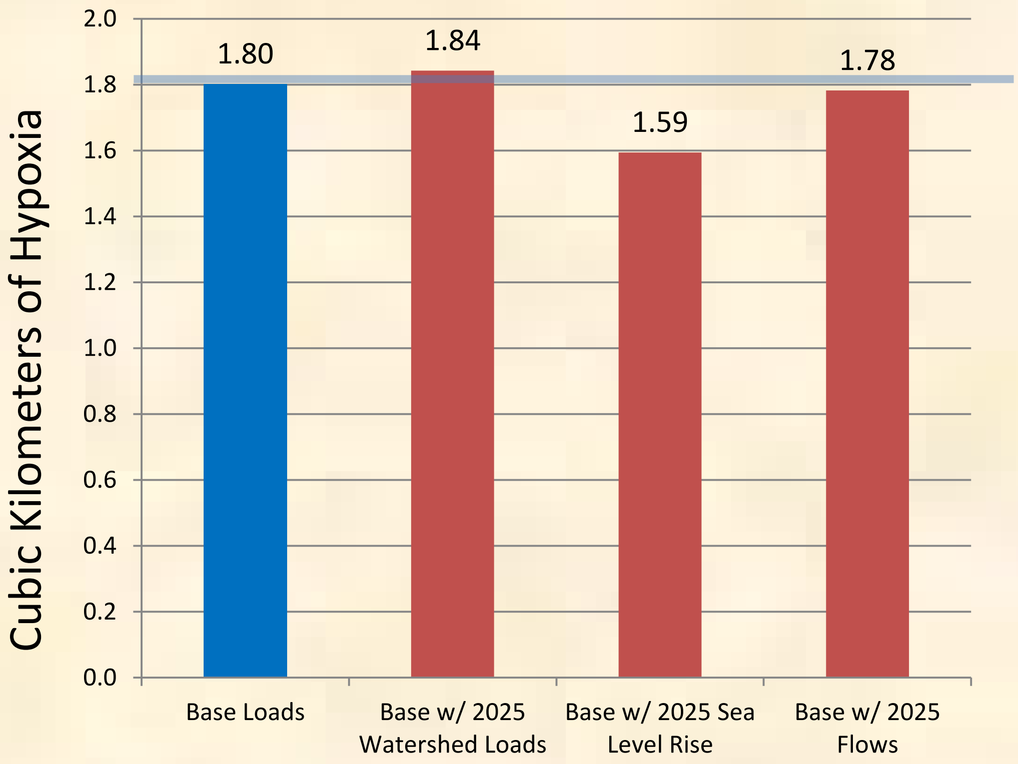


Stratification strength at CB4.1C in the Base Case
Stratification strength (N^2, s^{-2})
0.012
0.010
0.008
0.006
0.004
0.002
0.000
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
May, June, July, Aug of 1991-2000



Sea Level Rise Scenario minus Base
Increased Temp Scenario minus Base
Sea Level Rise & Increased Temp Scenario minus Base
Positive values: more stratification than the Base
Negative values: less stratification than the Base
Diff of stratification strength (N^2, s^{-2})
0.0010
0.0005
0.0000
-0.0005
-0.0010
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
May, June, July, Aug of 1991-2000

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

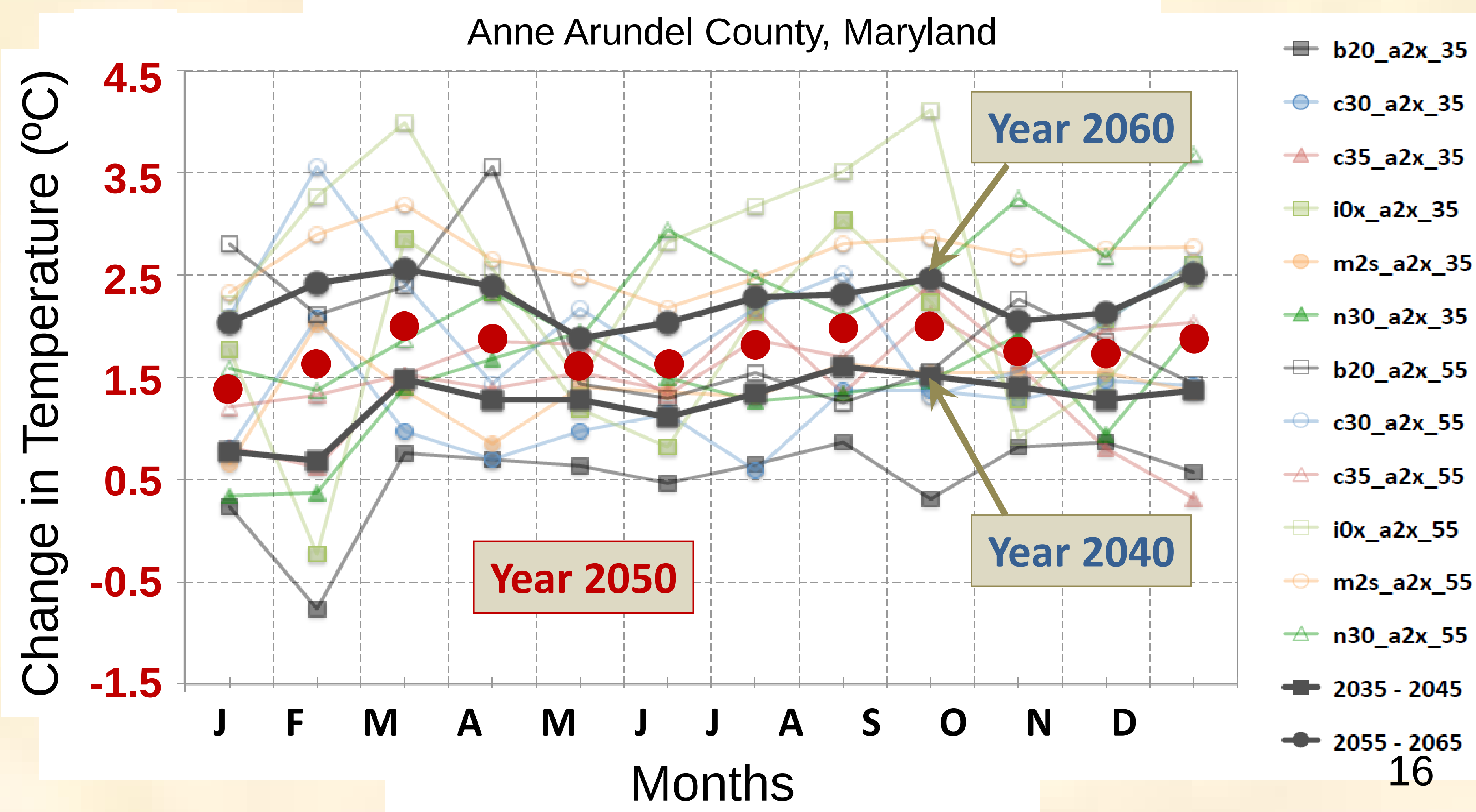


Increased fresh water flows from the watershed also increase bottom water dissolved oxygen slightly because of increased estuarine circulation, however there is also an increase in stratification.

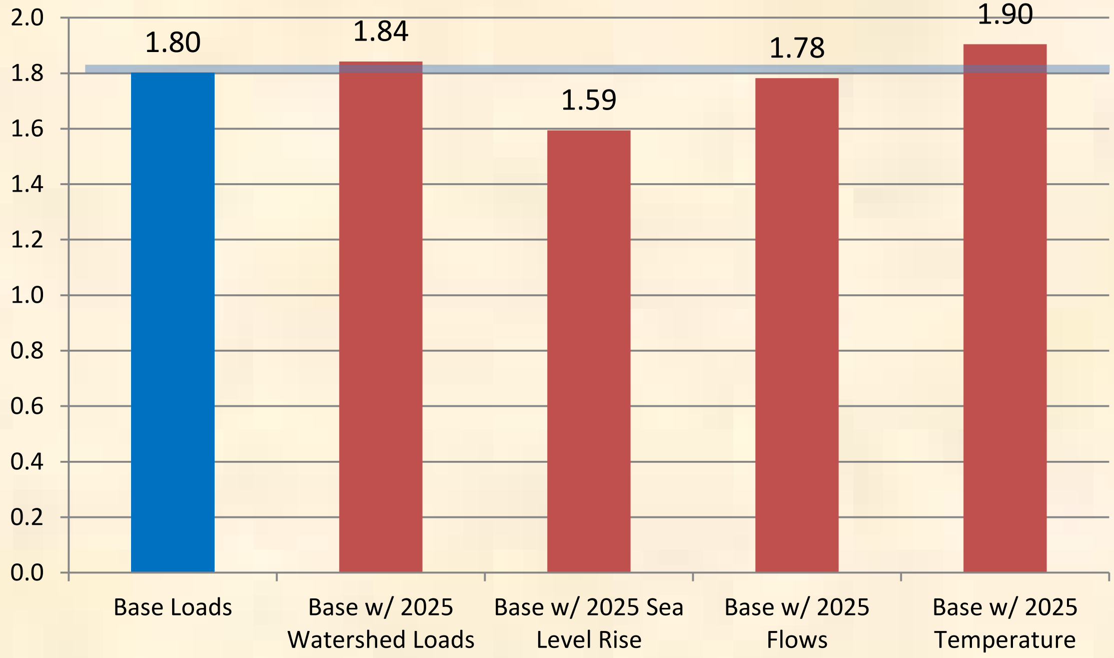
DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

2050 Temperature Increase Scenario

Projections of downscaled ***mean monthly change in temperature*** were obtained from multiple global climate models. Estimated overall increase in watershed-wide annual average temperature was 1.75˚C.



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

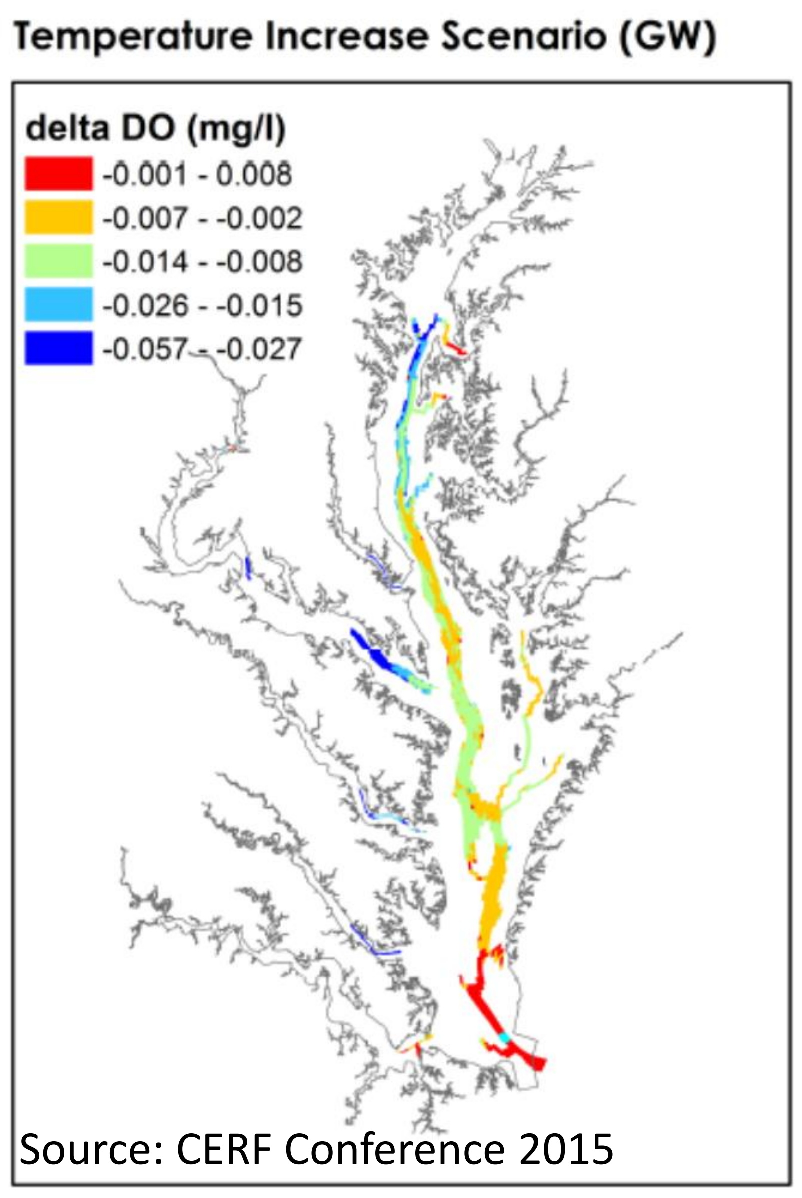


Estimated 2025 increased temperature in tidal waters increases temperature of both the surface and bottom waters but overall increases stratification.

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

Estimated 2050 Temperature Increases on Bottom DO



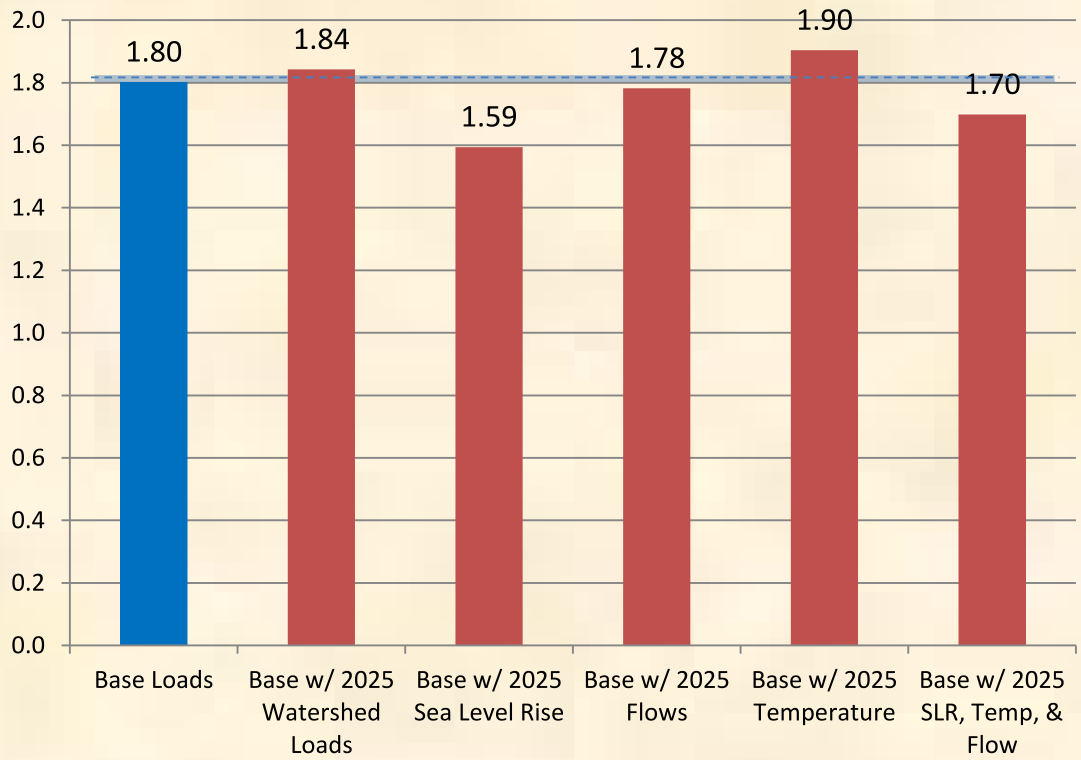
The influence of an 2050 estimated temperature increase on Chesapeake hypoxia is small.

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.

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

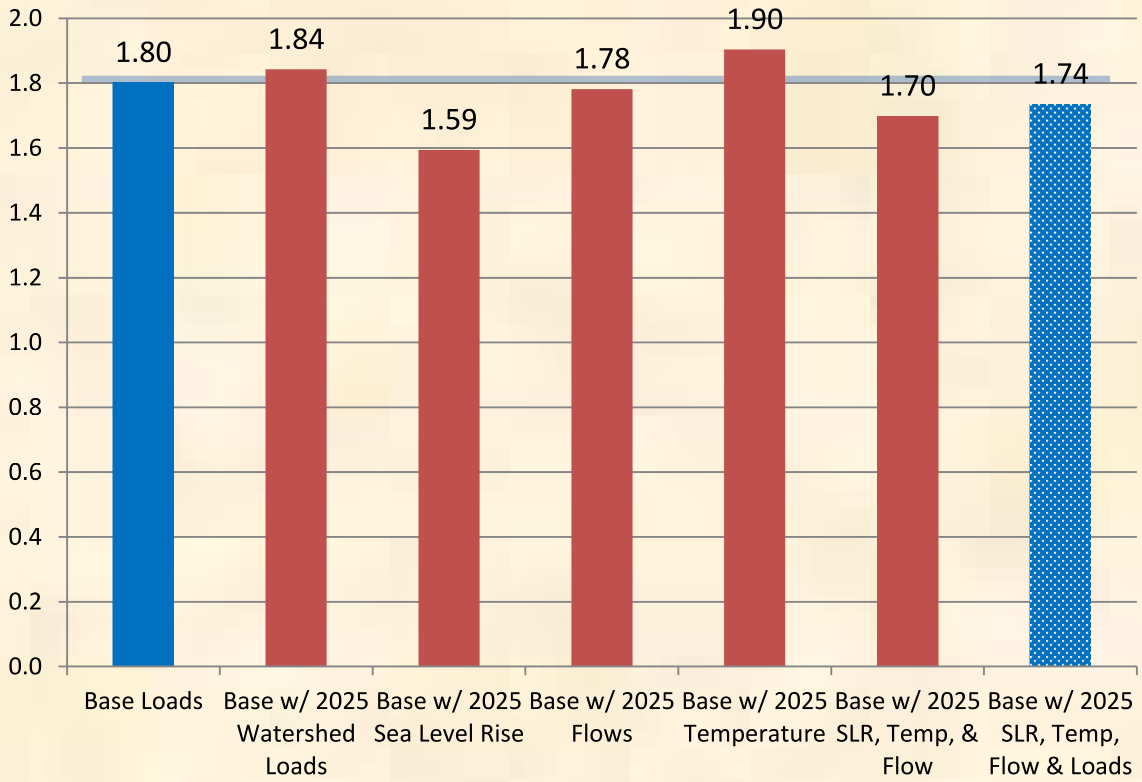


Combining all the estimated physical property changes of sea level, watershed flow, and temperature has an overall change of a 6 percent reduction in tidal water hypoxia.

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)

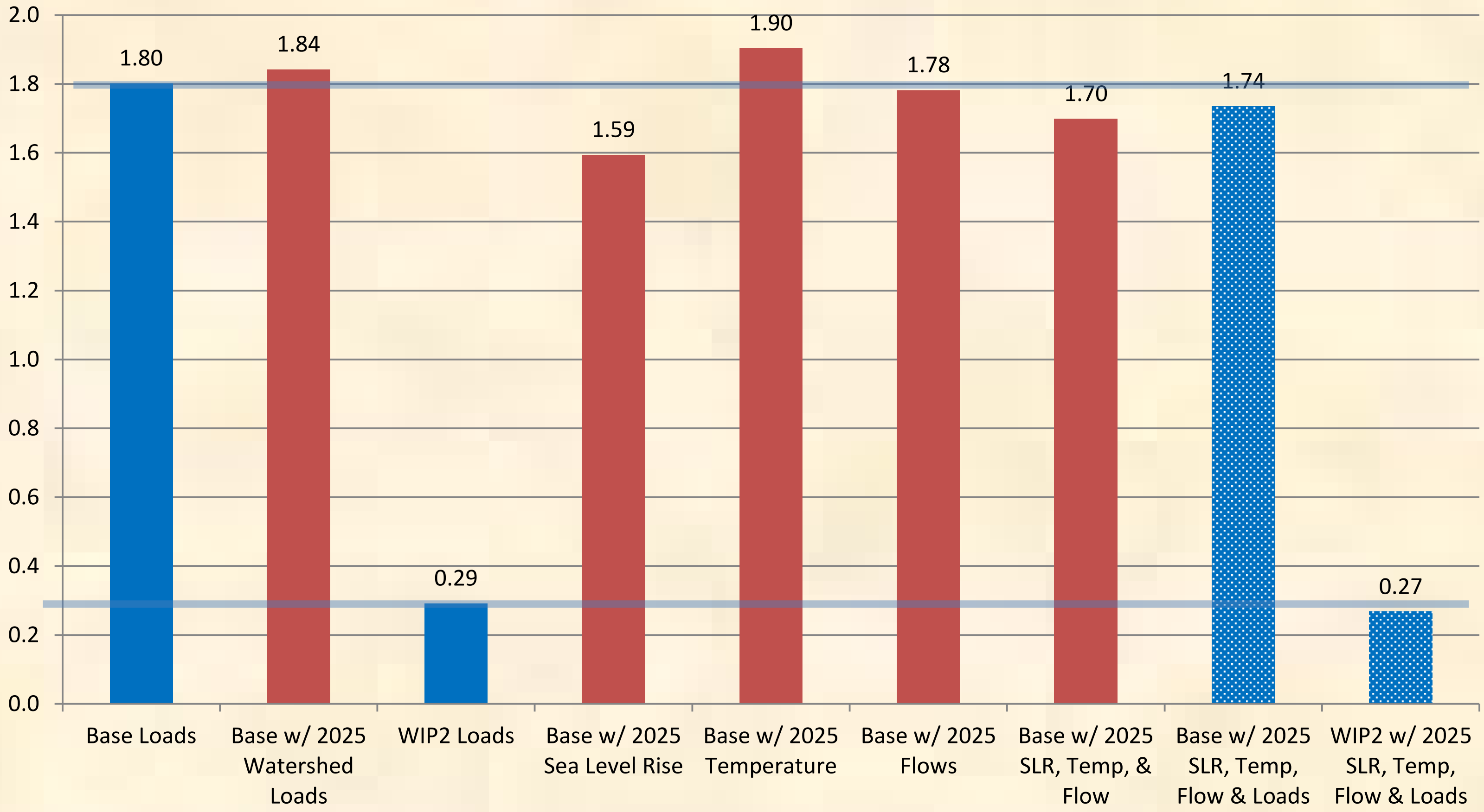


DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

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

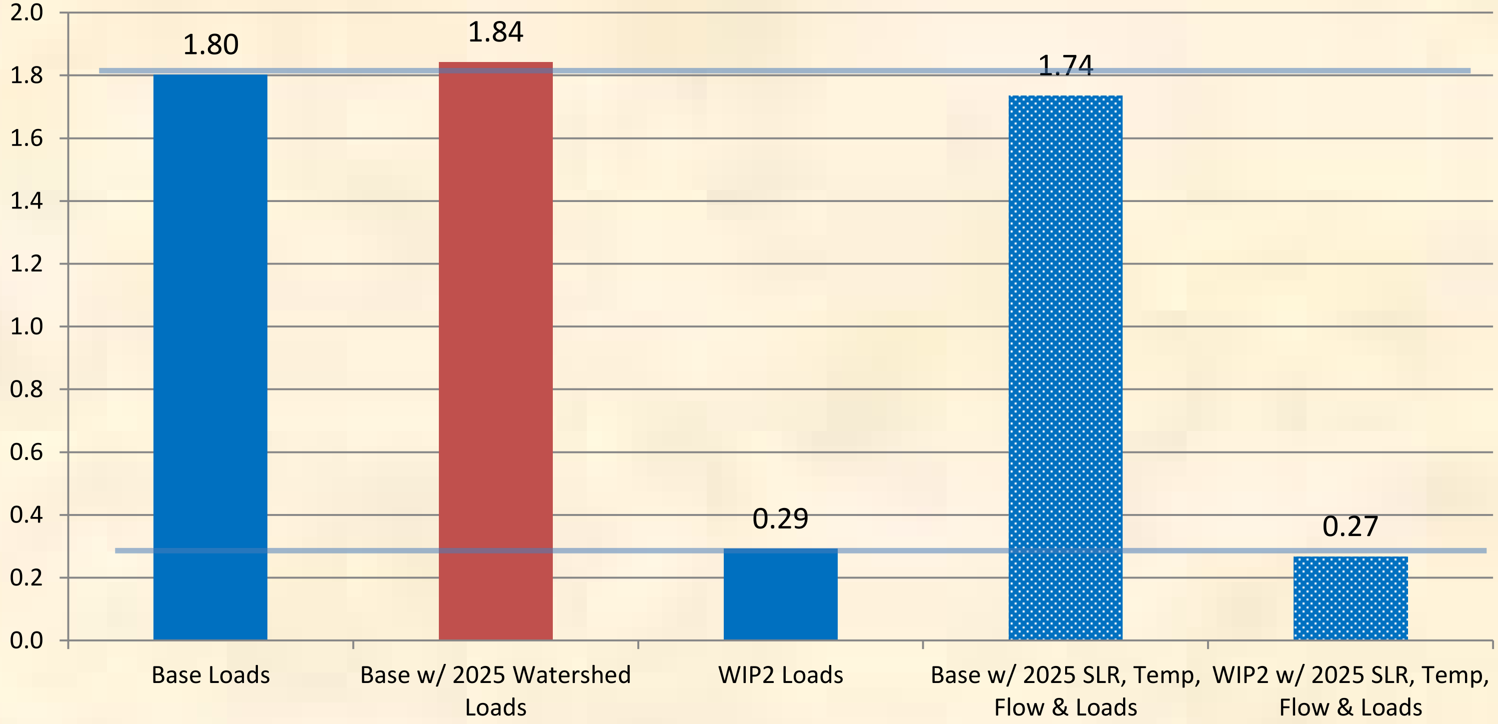
Hypoxic volume (DO <1 mg/l) in Chesapeake Mainstem (Model estimate in summer 1991-2000)



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

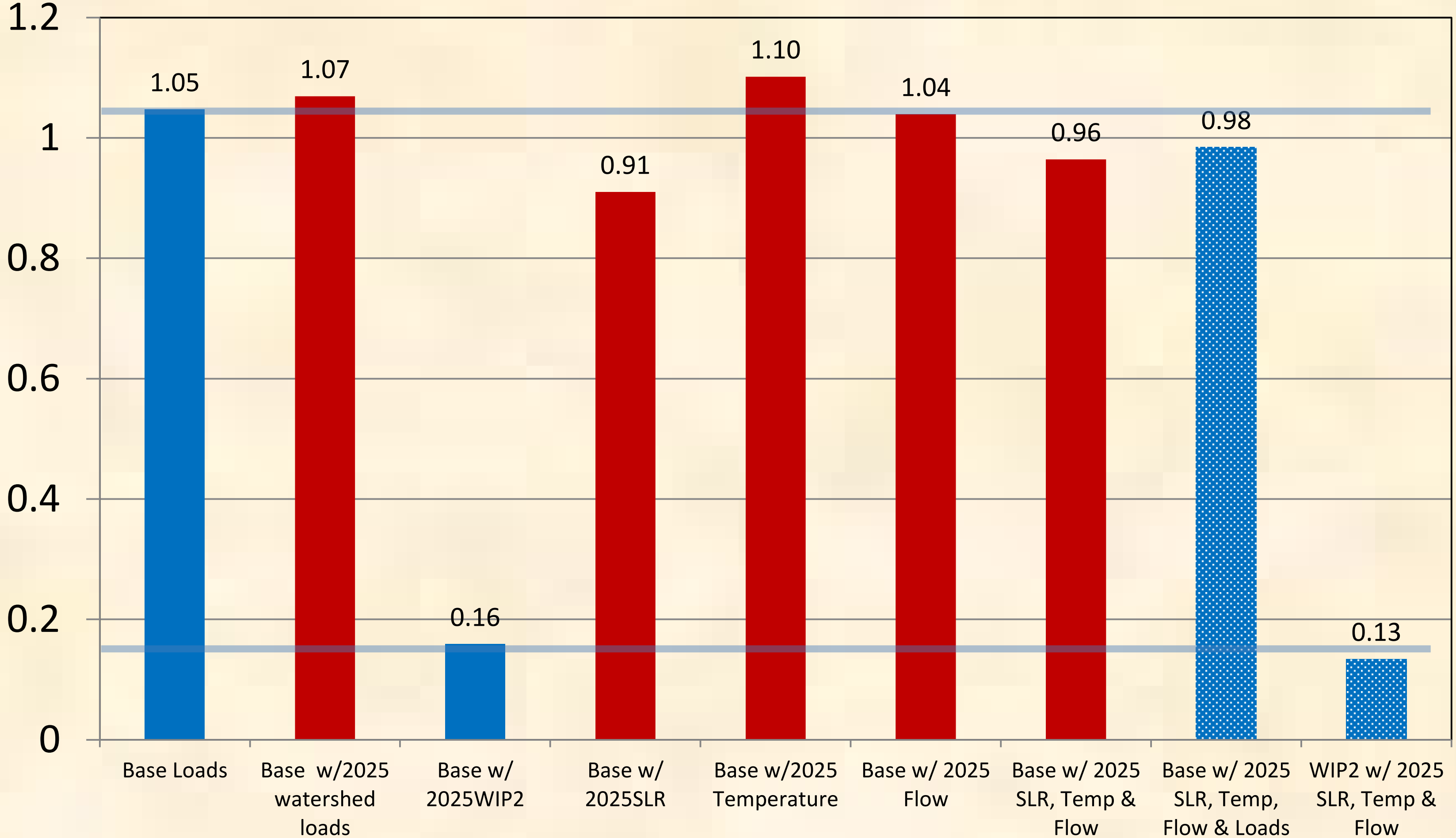
Why does hypoxia decrease under estimated under 2025 temperature, precipitation, and sea level despite higher estimated watershed loads? A: Mostly due to sea level rise.



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

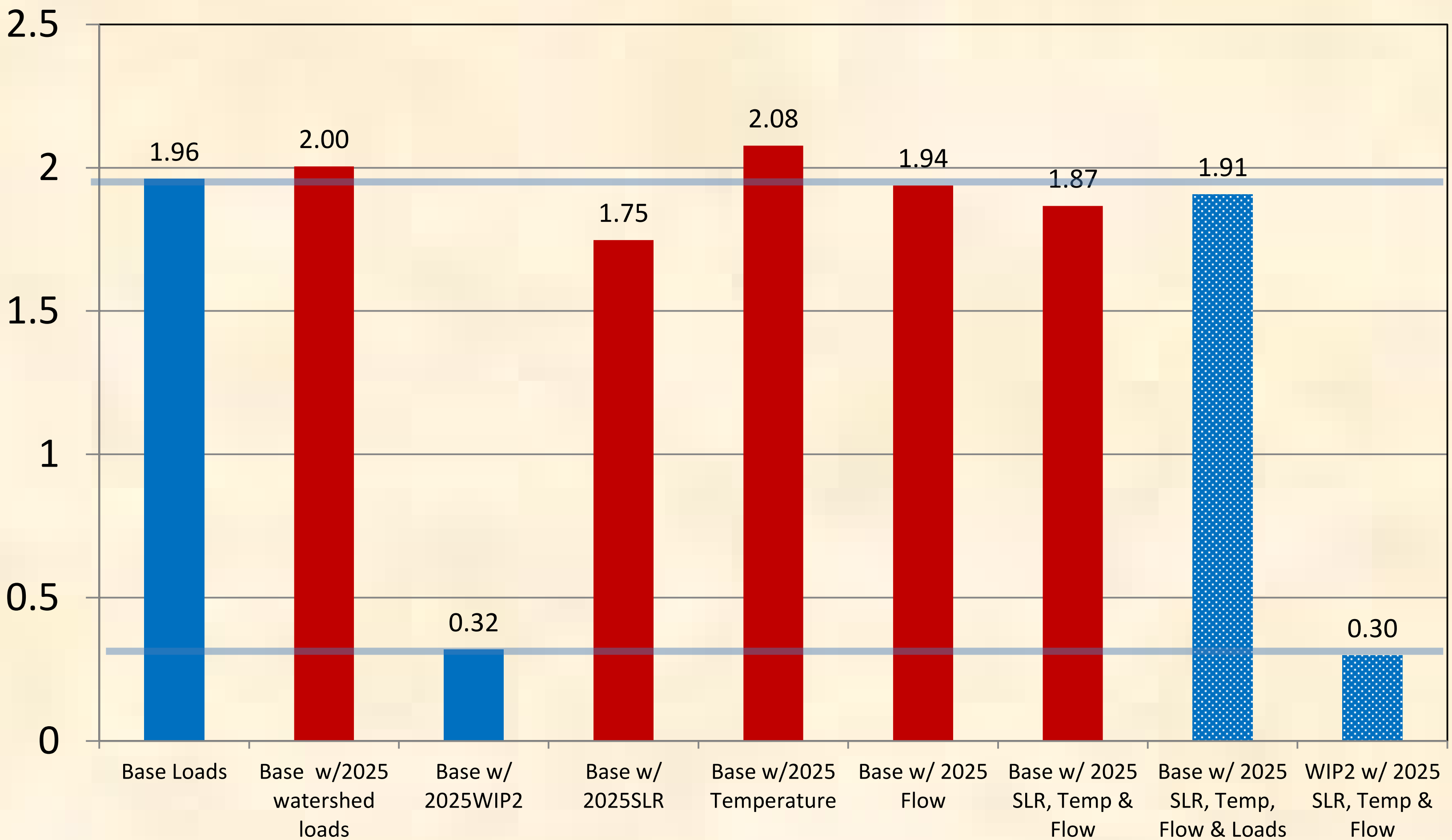
Hypoxic volume (DO <1 mg/l) in CB4MH (Model estimate in summer 1991-2000)



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)



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

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.

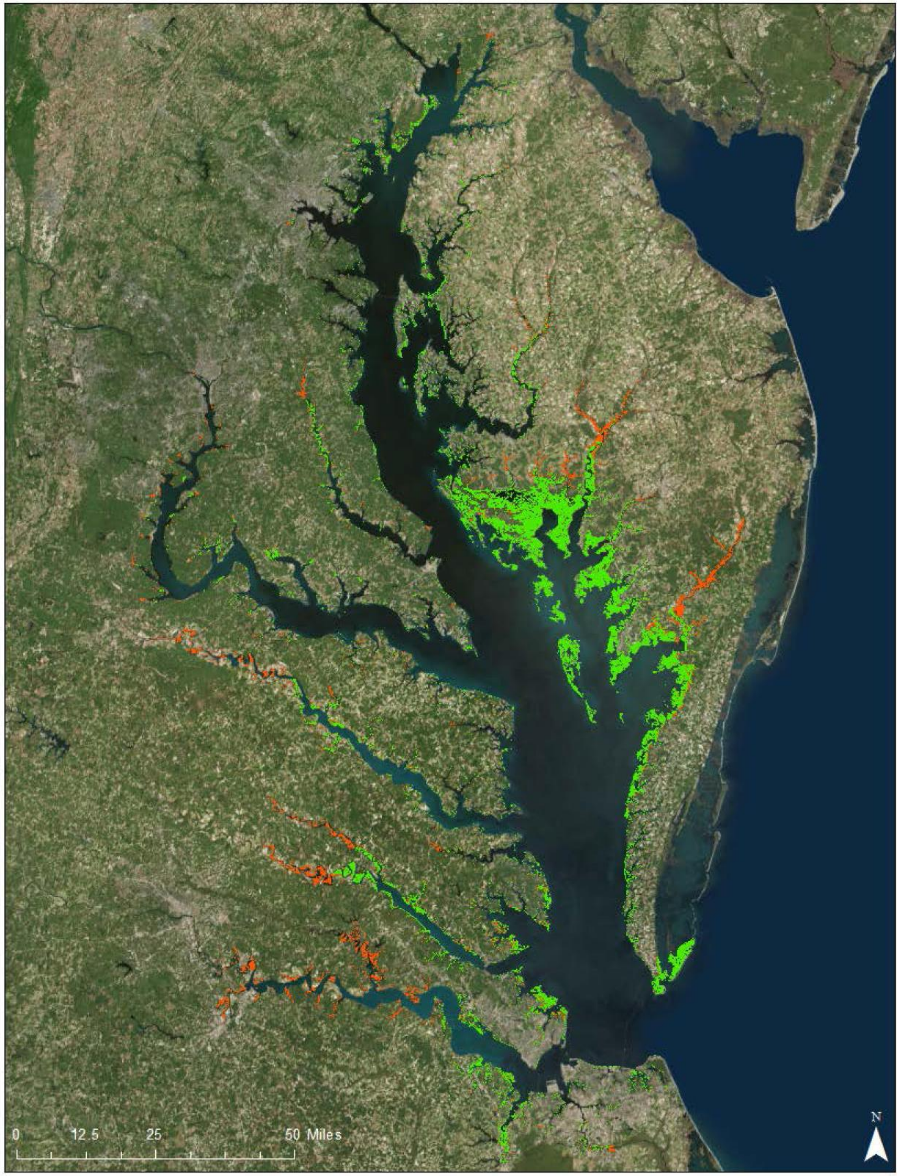
Conclusions *(continued)*

- 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.

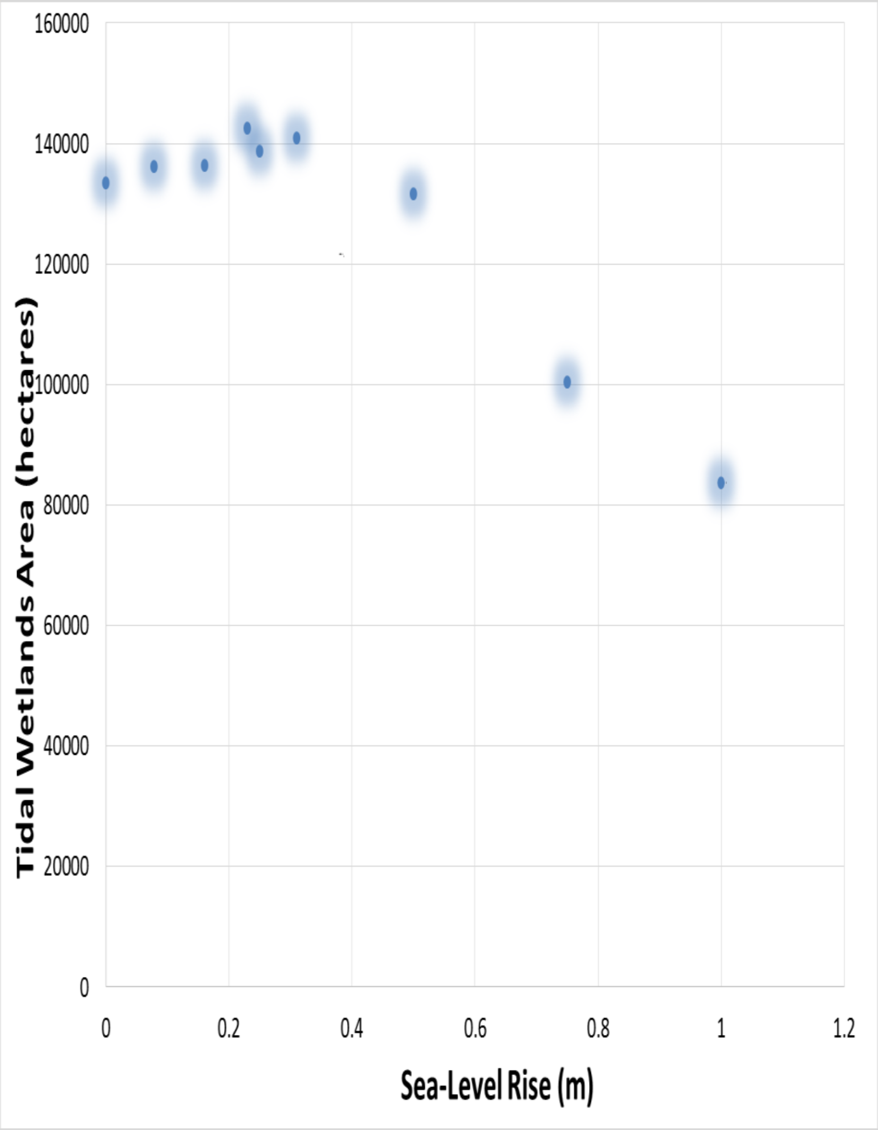
Chesapeake Bay Tidal Wetlands



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.

Source: Carl Cerco, U.S. CoE ERDC