Preliminary Phase 6 Watershed Model (WSM) and Chesapeake Bay Water Quality Sediment Transport Model (WQSTM) Climate Change Assessment Procedures and Scenarios for the 2017 Midpoint Assessment

Principals' Staff Committee Briefing Document
December 13, 2016

I. Background

The Chesapeake Bay Program (CBP) partnership is undertaking a midpoint assessment of progress to ensure that the seven Chesapeake Bay watershed jurisdictions are on track to meet the 2025 Chesapeake Bay Total Maximum Daily Load (TMDL) goal. A key element of this effort is the incorporation of the latest science, data, tools, and BMP's into the partnership's decision support tools to help guide implementation and to use this new information to facilitate and optimize implementation of the jurisdictions' Watershed Implementation Plans (WIPS).

Recognizing the need for understanding the likely impacts of climate change as well as potential management solutions for the watershed, the 2014 *Chesapeake Bay Watershed Agreement*, committed the CBP partnership to take action to "increase the resiliency of the Chesapeake Bay watershed, including its living resources, habitats, public *infrastructure* and communities, to withstand adverse impacts from changing environmental and climate conditions." This new Bay Agreement goal builds on the 2010 TMDL documentation and 2009 Presidential Executive Order 13508 that called for an assessment of the impacts of a changing climate on the Chesapeake Bay water quality and living resources that is being conducted as an element of the 2017 Midpoint Assessment.

II. CBP Midpoint Assessment Decision- Making Structure

The Water Quality Goal Implementation Team (WQGIT) serves as the "lead systems integrator" for the Midpoint Assessment, working with STAR's Modeling Workgroup and the WQGIT source sector workgroups to define the scientific and technical issues to be addressed and determining the schedule for partnership briefings and policy decisions.

A major component of the Midpoint Assessment is enhancing the CBP partnership's decision support tools, including the Phase 6 Watershed Model (WSM) and the Chesapeake Bay Water Quality Sediment Transport Model (WQSTM). The incorporation of key elements of the latest science on climate change is one of more significant refinements to this modelling effort being conducted as part of the Midpoint Assessment. A number of CBP Workgroups and coordinating bodies are involved with defining the scientific and technical aspects of climate change for integration into the WSM and WQSTM modeling efforts. The CBP Scientific and Technical Advisory Committee (STAC) and the Climate Resiliency Workgroup (CRWG) have provided guidance on the climate data and information to support the Midpoint Assessment modeling effort including the following.

- A STAC sponsored workshop, "The Development of Climate Projections for Use in Chesapeake Bay Program Assessments"[1] conducted on March 7-8, 2016.

[1] See the written report for the STAC Workshop, "Development of Climate Projections for Use in Chesapeake Bay Program Assessments" (in press) for recommendations related to additional climate-related data inputs

- STAC is scheduled to conduct an independent peer review of the Phase 6 WSM and the WQSTM which includes a review of the approach being taken to model the effects of climate change. The reviews of the Phase 6 WSM and the WQSTM will take place in the fall and winter of 2016, respectively.
- The CRWG developed written recommendations on two specific climate-related data inputs and assessments, sea level rise projections and future tidal wetland loss, to inform the Midpoint Assessment modeling effort:

III. Schedule for Midpoint Assessment Climate Considerations

The timeline for the integration of climate considerations into the Midpoint Assessment and specific deliverables and key management decisions, along with responsible CBP coordinating bodies, is outlined below.

Deliverable/Decision	Decision- Making Lead(s)	Timeline
Technical Workshop on climate change projections for use in CBP assessments	STAC, STAR Modeling Workgroup	March 7-8, 2016
Recommend WQSTM model data inputs related to: sea level rise projections and tidal wetland loss assessment methodology	CBP Climate Resiliency Workgroup (CRWG)	May –August, 2016
Develop initial climate change analysis with all CBP models	CBP Modeling Team	June-July, 2016
Modeling Workgroup Quarterly Review (initial review of climate data and analysis)	STAR Modeling Workgroup	August 9-10, 2016
Independent peer review of the CBP climate change modeling approach	STAC, Modeling Workgroup	September – December, 2016
Exploration of options for incorporating climate change findings in Phase III WIPS	CBP Climate Resiliency Workgroup	September 19, 2016
Modeling Workgroup Quarterly Review (review of climate data and analysis)	STAR Modeling Workgroup	October 4,13 2016
WQGIT Climate Webinar	N/A	October 18, 2016
Review of CBP climate modeling approach and initial formulation of options for Phase III WIP incorporation	WQGIT	October 24-25, 2016
Approve WQGIT decisions concerning CBP climate modeling approach and initial formulation of options for Phase III WIP incorporation	Management Board (MB)	November, 2016
Decision on proposed climate assessment procedures and proposed range of options for factoring climate change into Phase III WIPs	Principle Steering Committee	December, 2016
Final calibration of Phase 6 Model, including all climate change components	Modeling Workgroup	January – March, 2017
Partnership decisions on how to factor climate change into Phase III WIPs	WQGIT, Management Board (MB) and	January - March, 2017

(precipitation, temperature, evapotranspiration and the application of modeling techniques and methodologies for CBP assessments.

	Principle Staff Committee (PSC)	
Partnership fatal flaw review of final Phase 6 Model	CBP	March – May, 2017
Release of final Phase 6 Model	Modeling Workgroup	June, 2017
EPA releases draft Phase III WIPS Planning Targets	EPA	June, 2017
EPA releases final Phase III WIP Planning Targets	EPA	December, 2017

IV. Phase 6 WSM and WQSTM Climate Change Analysis

In 2012, the CBP partnership identified climate change as one of the key priorities of the Bay TMDL's Midpoint Assessment. As a result, the partnership developed the tools and procedures to quantify the effects of climate change on watershed flows and pollutant loads, storm intensity, increased estuarine temperatures, sea level rise, and ecosystem influences, including loss of tidal wetland attenuation with sea level rise, as well as other ecosystem influences in the Chesapeake Bay watershed. Current modeling efforts, as discussed above, are underway to frame a range of future climate change scenarios based on estimated 2025 and 2050 conditions.

A. STAC Recommendations

- For the 2017 Midpoint Assessment, use historical (~100 years) trends to project precipitation to 2025 as opposed to utilizing an ensemble of future projections from GCMs. Shorter term climate change projections using GCMs have large uncertainties because climate models are structured to look further out and at much larger scales.
- Looking forward, the 2050 timeframe is more appropriate for selecting and incorporating a suite of global climate scenarios and simulations to provide long-term projections for the management community, and an ongoing adaptive process to incorporate climate change into decision-making as implementation moves forward.
- Beyond the 2017 Midpoint Assessment, it is recommended that the CBP use 2050 projections for best management practice (BMP) design, efficiencies, effectiveness, selection, and performance – given that many of the BMPs implemented now could be in the ground beyond 2050.

B. *Methodology*

The current calibration of the Phase 6 WSM is *Beta* 3. The Phase 6 WSM will be further refined with a *Beta* 4 calibration in December 2016, and a final calibration in April 2017. Therefore, the current Phase 6 WSM scenarios should be seen as preliminary, initial estimates that will be improved on. For the 2025 and 2050 climate scenarios, estimated attainment of water quality standards under 2025 and 2050 watershed loads, temperatures, hydrodynamics, tidal wetland attenuation, and sea level rise will be quantified. The work is currently underway.

The general methodology for the Phase 6 Beta 3 application to climate change analysis is to apply the CBP ten-year average hydrology of 1991 to 2000 used in the 2010 TMDL and adjust the rainfall and temperature hourly time series with factors derived from observed long term trends for 2025conditions, or from General Circulation Models (GCMs) downscaled to the Chesapeake region for 2050 conditions. The year 1995 serves as the midpoint of the 1991 to 2000 hydrology used to represent the period of hydrology that the 2010 Chesapeake TMDL was based on. Projecting forward from 1995 by 30 years to 2025, or by 55 years to 2050 provides the relative difference needed for application of precipitation and temperature from the downscaled GCMs.

For the year 2025, the relative change in precipitation was derived from trends estimated from an 87 year record of precipitation in the Chesapeake watershed (Karen Rice and Jason Lynch, personal communication). The estimated temperature difference from 1995 to 2025 was developed by taking the median of 32 general circulation models (GCMs), chosen to align with the guidance set forth in the U.S. Climate Resilience Toolkit.

For the year 2050, a 32 member ensemble of GCM's downscaled to Chesapeake watershed were developed from two different CO_2 emission scenarios called representative concentration pathways (RCPs), shown in Figure 1. The socio-economic assumptions and associated concentration levels of RPC 4.5 assumes that an increase in average global radiative forcing will reach 4.5 Wm^{-2} by the year 2100, and is considered to be a moderate future climate condition compared to RCP 8.5. Conditions under RCP 8.5 assume little to no reduction in greenhouse gas emissions over time leading to high greenhouse gas concentration levels and significant radiative forcing of 8.5 Wm^{-2} by the year 2100. The RCP 2.6 scenario (which is not currently included in this analysis) assumes greater initiatives set forth for the reduction of greenhouse gas emissions, resulting in a globally averaged radiative forcing of 2.6 Wm^{-2} by the year 2100.

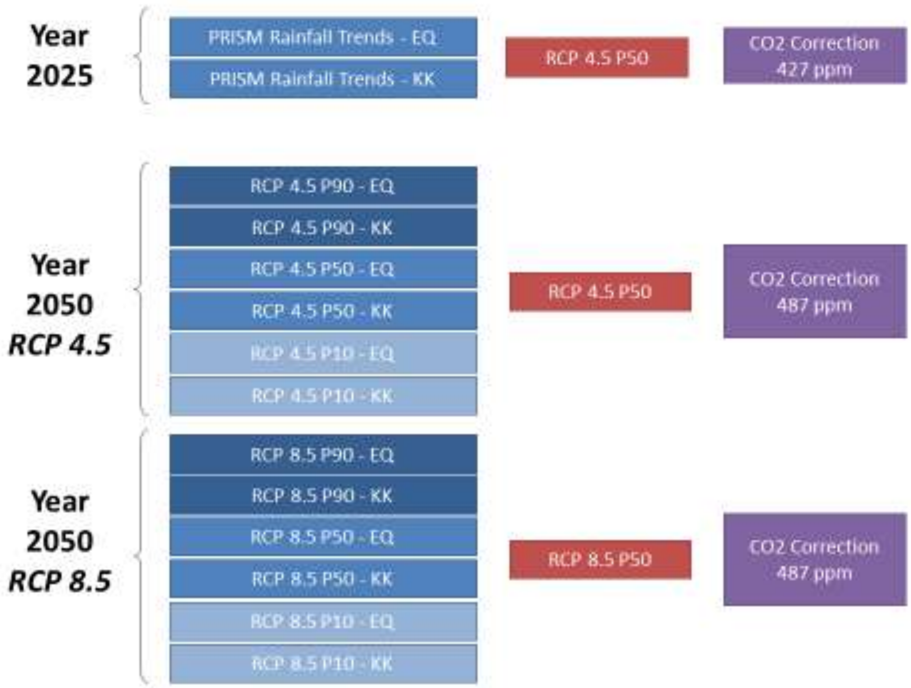

Figure 1. The 14 climate scenarios now being developed for the 2025 and 2050 future conditions (with RCP 2.6 scenarios to be added). All scenarios have either the estimated increased precipitation volume added evenly throughout the time series of precipitation events (EQ) or increased volume assigned to different percentiles of precipitation events as described by Groisman, Pavel Ya, et al (2004). The 2050 scenarios were developed by determining the median, 10th percentile, and 90th percentile of altered precipitation volumes from an ensemble of downscaled GCMs defined by the guidance presented in the U.S. Climate Resilience Toolkit.

Several different approaches to estimate evapotranspiration will be examined including Hamon, Hargreaves, Penman–Monteith and others will be examined. Where practicable, the CO_2 correction for stomatal resistance as described by Butcher et al., 2016 will be applied.

C. Climate Projections and Scenarios (GMC, RCP's, LASSO Tool, Historical Trends)

1. STAC Recommendations:

- For any 2050 assessment, use an ensemble or multiple global climate model approach, selecting model outputs that bound the range of key climate variables (e.g., temperature, precipitation) for the Chesapeake Bay region. Use multiple scenarios covering a range of projected emissions (RCP 4.5 and 8.5 are a reasonable range to select and are currently being utilized for Fourth National Climate Assessment). Include the 2 °C emissions reduction pathway (RCP 2.6) as well as more "business as usual" assumptions.
- Select an existing system to access GCM downscaled scenario data (such as 'LASSO' described in more detail in Section II) in lieu of conducting a tailored statistical climate downscaling process for the Chesapeake Bay watershed.
- The Program should carefully consider the representation of evapotranspiration in watershed model calibration and scenarios because the calculation method for evapotranspiration has a strong influence on the strength and direction of future water balance change.

2. **CRWG Recommendations (SLR):** Apply a plausible range of sea level rise projections for WQSTM modeling efforts, with upper and lower limits, for the years 2025 and 2050. Specifically, the CRWG recommended that the following range of sea level rise projections for 2025 (.2 - .4 m) and 2050 (.3-.8 m) be applied in the WQSTM.

3. Climate Variables (Sea level Rise, Temperature, Precipitation)

1. 2025 Run

SLR: 0.3 m
Temp: 32 member ensemble of downscaled GCMs (U.S. Climate Resilience Toolkit). Estimated average annual temperature increase of 1.08^{o} C applied as monthly means to the base temperature time series.
Precip: 87 year historical record of precipitation (Karen Rice, personal communication). Rainfall increase of 1.29 inches (+3.11%)
ET: Range determined by Hamon and Hargreaves method with stomatal resistance correction (Butcher et al., 2016).
CO_2: 427 ppm (an increase of 64 ppm)

2. 2050 Run

SLR: 0.5 m
Temp: 32 member ensemble of downscaled GCMs (U.S. Climate Resilience Toolkit). Estimated average annual temperature increase of 2.13^{o} C applied as monthly means to the base temperature time series.

Precip: 32 member ensemble of downscaled GCMs (U.S. Climate Resilience Toolkit). Rainfall increase of 3.05 inches (+7.34%)
ET: Range determined by Hamon and Hargreaves method with Stomatal resistance correction (Butcher et al., 2016).
CO_2: 487 ppm (an increase of 124 ppm)

V. Preliminary Results:

For 2025:

Influence of Estimated 2025 Watershed Nutrient and Sediment Loads

The range of the influence of estimated watershed loads in future climate change conditions using the observed (87 year) increase of precipitation volume (Karen Rice) and a century of observed precipitation intensity (Karl and Knight) depends on the evapotranspiration method chosen. Depending on the evapotranspiration method used the estimated 2025 range of nutrient (total nitrogen and total phosphorus), and sediment loads are 0 percent to 2 percent and 0 percent to 5 percent, respectively.

For 2050:

Influence of Estimated 2050 Estuarine Temperature Increases on Bottom DO

The influence of a 2050 estimated temperature increase on Chesapeake hypoxia is small, with an estimated increase in Chesapeake hypoxia ranging from 0.008 to – 0.06 mg/l. With the increased temperatures from watershed discharge, ocean inflow and estuarine warming the hypoxia increases are due to the increase in vertical stratification due to the increased thermocline, reduced oxygen saturation levels, and increased respiration. By extension, estimated 2025 temperature increases will also have slight influence on water quality standard achievement.

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

The influence of a 2050 estimated sea level rise on Chesapeake hypoxia is also relatively small. The estimated change from the base hydrology (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 hypoxia are due to increased ventilation of deep Chesapeake waters by well oxygenated ocean waters, and also because of changes in vertical stratification.

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.

VI. CBP Modeling Workgroup Next Steps:

October – December 13, 2016 Modeling Quarterly Review

- Explore Hamon, Hargreaves, Penmen-Monteith and other evapotranspiration methods, including ensemble methods, for Phase 6 climate change analysis.
- Complete 2025 CH3D Hydrodynamic Model of an estimated 0.3 m 2025 sea level rise.

- Develop other sea level rise CH3D model runs as directed by the WQGIT.
- Complete Phase 6 WSM *Beta* 4 calibration.
- Complete WQSTM calibration to *Beta* 3.

December 2016 – March 2017
- Begin *Beta* 5 calibration of the Phase 6 WSM.
- Begin calibration of WQSTM to *Beta* 4.
- Apply improved evapotranspiration methods to Phase 6 analysis of climate change influence on Chesapeake water quality.
- Develop a range of climate change scenarios and analysis as directed by the WQGIT and other CB decision making groups.

March 2017 – May 2017
- Begin final review of Phase 6 suite of modeling tools.
- Complete final Phase 6 WSM
- Complete final WQSTM
- Continue to examine a range of climate change scenarios and line of analysis as needed and directed by the WQGIT and other CB decision making groups.