Chesapeake Bay TMDL 2017 Mid-Point Assessment

Recommendations on Incorporating Climate-Related Data Inputs and Assessments: Selection of Sea Level Rise Scenarios and Tidal Marsh Change Models

Climate Resiliency Workgroup
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Background

The Chesapeake Bay Program (CBP) partnership is in the midst of 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.

Recognizing the need to gain a better understanding of 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.

A major component of the Midpoint Assessment is enhancing the CBP partnership's decision support tools, including the Chesapeake Bay Watershed Model (CBWM) and the Chesapeake Bay Water Quality Sediment Transport Model (CBWQSTM). 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.

CBP Midpoint Assessment Decision- Making Structure

A number of CBP Workgroups and coordinating bodies are involved with defining the scientific and technical aspects of climate change for integration into the CBWM and CBWQSTM modeling efforts. 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.

The CBP Scientific and Technical Advisory Committee (STAC) is also providing input as well as conducting an independent review of the Midpoint Assessment. Related to climate change, STAC sponsored a workshop, "The Development of Climate Projections for Use in Chesapeake Bay Program Assessments" on March 7-8, 2016 and is scheduled to conduct an independent peer review of the Phase 6 CBWM and the approach being taken to model the effects of climate change in late summer or early Fall 2016.

The Climate Resiliency Workgroup (CRWG) has also undertaken specific tasks associated with providing guidance on scientific and technical considerations related to the integration of climate effects in the Midpoint Assessment modeling efforts.[1] The CRWG's 2016-2018 Workplan includes a Key Action to, "Inform approach to factor climate change considerations into the 2017 Chesapeake Bay TMDL Midpoint Assessment." The CRWG will be providing additional guidance to support policy and decision-making processes related to Phase III Watershed Implementation Plans (WIPS)[2].

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 CBWQSTM 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 4-5, 2016
Review of CBP climate modeling approach and initial formulation of options for Phase III WIP incorporation	WQGIT	October 24-25, 2016
EPA releases draft expectations for Phase III WIPS	EPA	January, 2017
Final calibration of Phase 6 model, including all climate change components	Modeling Workgroup	January – March, 2017
Partnership decisions on how to factor	WQGIT, Management	January - March, 2017

[1] CBP CRWG Workplan (2016-2018) Performance Target: Conduct a review of approach to factor climate change considerations into the 2017 Chesapeake Bay TMDL Midpoint Assessment (Entity: CRWG; Modeling Workgroup; STAC)

[2] CBP CRWG Workplan (2016-2018) Performance Target: Conduct an assessment of research needs to support future policy dialog related to the integration of climate change considerations into the Water Quality Management Strategy (Entity: CRWG).

climate change into Phase III WIPs	Board (MB) and Principle Staff Committee (PSC)	
Partnership fatal flaw review of final Phase 6 model	CBP	March – May, 2017
EPA releases final expectations for Phase III WIPS	EPA	April, 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

CRWG Recommendations for Climate-Related Data Inputs and Assessments

This document outlines the CRWG's recommendations related to two specific climate-related data inputs and assessments to inform the Midpoint Assessment modeling effort: sea level rise projections and future tidal wetland loss assessments.[3] 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 (precipitation, temperature, evapotranspiration and the application of modeling techniques and methodologies for CBP assessments.

The STAC Workshop on the "Development of Climate Projections for Use in Chesapeake Bay Program Assessments" included a presentation by Dr. Tal Ezer, Center for Coastal and Physical Oceanography at Old Dominion University, on the "Causes, Trends, and Future Sea level Rise Projections" and a presentation on the "Loss of Coastal Marshes to Sea Level Rise" by Dr. Molly Mitchell, Virginia Institute of Marine Science, Center for Coastal Resources Management[4]. However, clear recommendations for 2025 and 2050 sea level rise projections and the methodology for assessing sea level rise induced tidal wetland loss were not included in the workshop findings. Recognizing this information gap, the STAC Workshop draft findings recommend the following:

> "Convene a group of sea level rise researchers and resource experts to reach agreement on sea level rise estimates to apply; how to best approach simulating effects of sea level rise on living resources and wetlands; and the range of sea level rise scenarios to run."

The CRWG met in person on May 23, 2016; and again via conference call on June 20, 2016 to review and recommend CBWQSTM model data inputs related to sea level rise projections (2025, 2050) and the methodology to assess tidal wetland loss and associated nutrient and sediment load reductions. CRWG findings and recommendations related to these two data considerations for integration into the CBWQSTM are provided below.

[3] Note: Addendums to this document may be added in the future as additional CRWG recommendations related to climate data and information needs of the Midpoint Assessment are developed.

[4] To view presentations, click on embedded hyperlink and or visit: http://www.chesapeake.org/stac/workshop.php?activity_id=258

Relative Sea Level Rise Projections (2025, 2050)

Background

Capt. Emil Petruncio, USN, PhD, Chair, US Naval Academy Oceanography Department and Robert E. Kopp, Ph.D., Rutgers University presented to the CRWG on May 23, 2016[5]. Capt. Petruncio presented, "Sea Level Rise Trends and Projections for the Chesapeake Bay" and Dr. Kopp, presented, "Probabilistic Sea Level Rise Projections for the Chesapeake Bay Region." Both Dr. Kopp and Capt. Petruncio are recognized national experts on climate change and sea level rise science. A summary of their key findings is provided below:

- Most global mean sea level rise (SLR) is accounted for by thermal expansion (30-55%), glacial loss (15-35%), and storage of ground water. Local SLR must account for ocean dynamics, redistribution of land ice mass, and vertical land movement.
- The geographic variability in the rate of sea level change (1992-2010) is evident in satellite altimetry data.
- There is spatial variability in Chesapeake Bay projections as the rates are uniformly higher than global mean due primarily to glacial-isostatic adjustment, and secondarily to ocean dynamics and ice-sheet fingerprints Variability within region fairly small (~1 mm/yr), dominated by effects of groundwater withdrawal
- The rate of SLR in the Mid-Atlantic exceeds the global average computed from tide gauge records (1.7 mm/yr), mostly due to vertical land movement (VLM) associated with glacial isostatic adjustment.
- In the Chesapeake Bay area, sea-level uncertainty is dominated by the contributions of the Antarctic ice sheet and ocean dynamics.
- Recent Sea Level Studies relevant to the Chesapeake Bay include: Updating Maryland's Sea Level Rise Projections(2013)[i]; IPCC 5th Assessment Report(2013)[ii]; USACE Guidance (2014)[iii]; USACE. Sea Level Rise Curve Calculator(2014)[iv]; and the National Climate Assessment(2014)[v].
- Recent papers, written by Kopp et. al,[vivii viii]provide more recent and reliable projections of sea level rise projections. To make these projections relevant to the CB, assumptions for vertical land motion and dynamic processes must be factored in.
- SLR will be more rapid and consequential after 2050, but as the Kopp et al. paper shows, this will depend on the emissions pathway.
- The recently released DoD Coastal Assessment Regional Scenario Working Group (CARSWG) Study (2016)[ix] provides plausible, scientifically credible future scenarios with regard to sea level and extreme water levels to assist decision makers and others in making robust choices to manage their risks.
- Global Mean Sea Level Rise Scenarios considered by the CARSWG (1992-2100), include: Highest (2.0m); High (1.5m); Medium (1.0m); Low (.5m); and Lowest (0.2m). The highest and lowest curves are based on the scenarios which NOAA developed for the 2014 National Climate Assessment. NOAA expressed high confidence that future global MSL would not fall outside the range of these bounding scenarios (0.2 and 2.0m).
- Highest and Lowest CARSWG scenarios adjusted for approximate Maryland VLM (1.5 mm/yr) include: 0.1-0.3m by 2025; 0.2-0.7m by 2050.

[5] To view presentations, click on embedded hyperlink and or visit: http://www.chesapeakebay.net/groups/group/climate_change_workgroup

- Comparison of Mean Sea Level Trend in Annapolis Tide Gauge Data to CARSWG Highest and Lowest Scenarios (Adjusted for MD VLM) The lower bound for sea level rise scenarios should be based on historical trends dating back at least 50 years, as shorter record lengths (such as satellite altimetry measurements) may be affected by interannual/decadal variability.
- For Interannual Variability (IAV) for scenarios extending to 2035 or less, CARSWG recommends computing two standard deviations of the detrended annual MSL residuals, and adding this value to the computed range of MSL rise. This is considered to be a conservative estimate of the variability that results from interannual/decadal oscillations (ENSO, NAO, etc.), which are significant for scenarios extending 20 years or less. This is a site specific correction, but for Chesapeake Bay, it increases MSL by approximately 0.11m / 4 inches.
- Dr. Kopp presented a summary of projections (Baltimore, MD and Sewells, VA) for years 2020, 2030, 2050 and 2100.

Summary projections: Baltimore, MD

RSL rise from 2000 to:	Likely (17-83%)	1-in-20 (95%)	1-in-200 (99.5%)	Max. poss. (99.9%)
2020	4"-7" (9-17 cm)	8" (20 cm)	9" (24 cm)	10" (26 cm)
2030	6"-11" (15-27 cm)	12" (31 cm)	15" (37 cm)	16" (41 cm)
2050	11"-19" (28-48 cm)	22" (56 cm)	27" (69 cm)	31" (80 cm)
2100, RCP 8.5	26"-49" (67-124 cm)	58" (148 cm)	82" (207 cm)	116" (294 cm)
2100, RCP 2.6	17"-34" (44-85 cm)	42" (106 cm)	67" (171 cm)	95" (242 cm)

Summary projections: Sewells Point, VA

RSL rise from 2000 to:	Likely (17-83%)	1-in-20 (95%)	1-in-200 (99.5%)	Max. poss. (99.9%)
2020	5"-7" (12-19 cm)	9" (19 cm)	10" (24 cm)	11" (27 cm)
2030	7"-12" (18-30 cm)	13" (34 cm)	16" (40 cm)	17" (43 cm)
2050	13"-21" (34-53 cm)	24" (60 cm)	29" (73 cm)	33" (85 cm)
2100, RCP 8.5	30"-53" (77-134 cm)	62" (158 cm)	86" (219 cm)	121" (307 cm)
2100, RCP 2.6	21"-38" (55-96 cm)	46" (116 cm)	72" (183 cm)	101" (255 cm)

Projections through to 2050 use RCP 8.5, since difference between emissions pathways is minimal (<2") until second half of the century.

Rutgers Earth System Science & Policy Lab 21

- Dr. Kopp recommended that the CRWG take into account high emission sea level rise scenarios for 2050 in order to complete a comprehensive risk analysis. This would mean that the analysis should not be limited to only the "likely scenario but should also encompass probabilities as shown within the 99.5th percentile. Projections within these parameters (for Baltimore) would range between 13" (.3m) and 29 (.7m) for 2050.
- Capt. Petruncio presented Plausible Ranges of Maryland SLR (based on 2013 MD Update and 2016 CARSWG Guidance): MD Update (2025 – N/A; 2050 – 0.3-.07m); CARSWG Guidance (2025 - .1-.4m; 2050 - .2-.7m).

Discussion

Based on data, information and expert opinions provided by Dr. Kopp and Capt. Petruncio, the CRWG provided feedback and guidance on the range of 2025 and 2050 sea level rise scenarios/projections for input into in the Chesapeake Bay Water Quality and Sediment Transport Model (WQSTM) simulations.

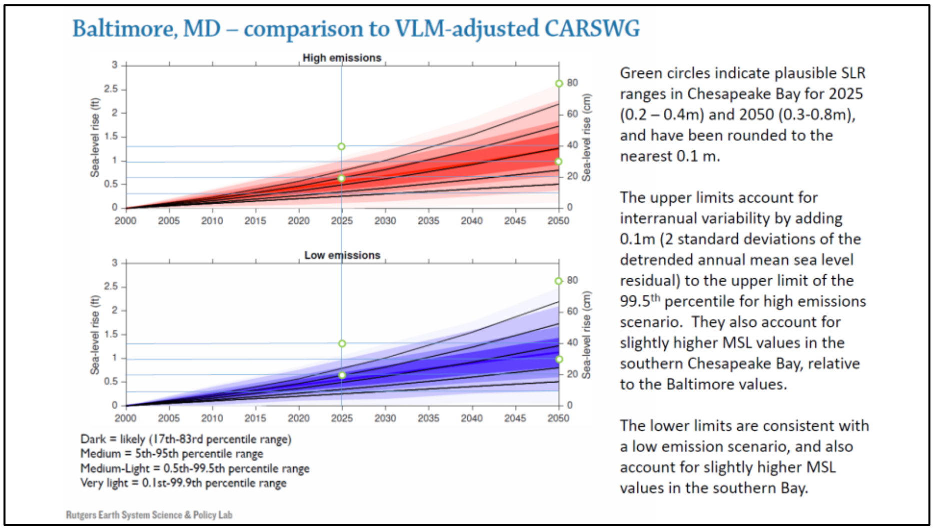
Discussion points:

- Because there are no definitive projections of future sea level rise, the CBP should consider a range of expected and “what if” scenarios in order to manage uncertainty and assess risk.
- There is utility in providing the CBP Modeling Team with a range of sea level rise projections for 2025 and 2050, which could be used to assess not only water quality but also living resources.
- Given the wide range of projections for 2025 and 2050, the Workgroup discussed the need to consider multiple sea level rise scenarios. It was argued that considerations should not be limited to only the “most likely” scenario but to also examine the results of a worst-case scenario.
- A point was made that if modeling runs are limited (due to time or fiscal constraints), a “likely” and “worst-case scenario” are often selected.
- The selection of scenarios is considered a “risk management” decision and could require the modeling team to run multiple scenarios.
- In terms of modeling, one option would be to split the difference, using a midpoint of the current best estimates with an understanding that additional model runs could be conducted in the future. Running only a midpoint, however, would incur risk as it is equally plausible that sea level rise could be higher. Any point within the range of sea level rise projections for 2025 and 2050, as presented by Dr. Kopp and Capt. Petruncio is equally plausible.
- It is important to understand how the end goals are reached and not just simulate the end result after 20 or 50 years of SLR. Modeling every step in between can help practitioners to understand incremental changes or impacts. Bay Program models, however, are not sophisticated enough to undertake such a step change simulation.
- Understanding that SLR will likely increase at an even more rapid rate after 2050 through the end of the century, workgroup members voiced reluctance to operate within the lowest possible SLR scenario, since it reflects only a continuation of historic trends and does not factor in the projected future acceleration.
- A plausible range of both 2025 and 2050 estimates should be provided to the CBP partnership to better evaluate options in both the short term for the TMDL timeline as well as assess impacts over longer time spans.

Recommendations

- The CRWG recommends that the CBP leadership consider the application of the plausible range of sea level rise projections for CBWQSTM modeling efforts, with upper and lower limits, for the years 2025 and 2050.
- In selecting the range of scenarios, the upper bound should be consistent with a higher emissions scenario (but not the extreme upper scenario). This would result in the upper bound corresponding with the 99.5% probability, plus 0.1m to account for interannual variability.
- The lower range value should be within the “likely” range, as presented by Dr. Kopp, consistent with a lower emission scenario (RCP 2.6), but not be the extreme lower scenario which depicts historical tide gauge trend.
- Based on the considerations above, the CRWG recommends that the following range of sea level rise projections for 2025 (.2 - .4 m) and 2050 (.3-.8 m) (see graphic below) be applied in the CBWQSTM.

- Model runs using sea level rise projections of .2 and .4m for 2025 and .3 and .8 m for 2050 should be conducted to correspond with upper and lower sea level rise projection limits. The higher limit is within the 99.5% probability as recommended by Dr. Kopp and the high emission scenario (RCP 8.5) as presented in the CARSWG study. The lower limit is consistent with the low emission scenario, in accordance with the Paris Accord.



Assessing Loss of Tidal Marshes to Sea Level Rise in the Chesapeake Bay

Background

A component of the CBWQSTM modeling effort to support the Midpoint Assessment is an assessment of the effects of wetland loss on Chesapeake Bay water quality as both a source of organic matter and suspended solids to the water column and in terms of its retention of upland nutrients. Carl Cerco, USACE Engineering Research and Development Center, is the lead for this modeling effort. According to C. Cerco, to accomplish this assessment, there are three underlying information needs: 1) information on current wetland area and the nature of these wetlands; 2) projections of future wetland area and type; and 3) information on wetland functions, including what functions are being lost and the composition of eroded material from wetlands.

Discussion

The CWRG was asked to provide guidance and feedback on item #2 as noted above; and more specifically, to evaluate and provide recommendations on methodologies to estimate loss of tidal marshes in 2025 and 2050 due to factors associated with sea level rise. The CRWG held two meetings focused on exploring methodologies and developing recommendations related to the information need for projections of future wetland area and type. To inform the CRWG discussions, the following technical presentations[6] were provided to the Workgroup:

[6] To view presentations, click on embedded hyperlink and or visit: http://www.chesapeakebay.net/groups/group/climate_change_workgroup

- 2017 Midpoint Assessment Modeling Needs: Simulating Sea Level Rise, Tidal Marsh Loss and Changes in Watershed Loads (Carl Cerco, USACE ERDC; Ping Wang, VIMS; Gopal Bhatt, Penn State and Lewis Linker, U.S. EPA Chesapeake Bay Program)
- The Chesapeake Bay Sentinel Site Cooperative: A regional collaborative network to monitor sea level change impacts and build coastal resilience (Sarah Wilkins, CBSSC Coordinator)
- Loss of Coastal Marshes to Sea Level Rise, Molly Mitchell (VIMS Center for Coastal Resources Management)
- Feedback Processes Governing Tidal Wetland Vulnerability to Sea Level Rise, J. Patrick Megonigal (Smithsonian Environmental Research Center)
- Application of SLAMM to Estimate N removal services in tidal wetlands (Jennifer Bryan and Lora Harris, UMCES)
- NOAA Sea Level Rise Viewer Demo: Method for Mapping Wetland Conversion due to SLR (Quentin Stubbs, USGS/CBP)

Discussion points:

- Lora Harris and Jennifer Bryan's research demonstrated that different sea level rise scenarios influence estimates of nitrogen removal.
- Abrupt land elevation changes (e.g., shelfs or benches) and slope are two important geophysical factors to consider in assessing the potential for future wetland migration. The slope of the land behind today's marsh is a key factor in determining the potential intertidal land area available for landward migration of marshes. A bench will stop upward wetland migration until water levels overtop it and marsh grasses can recolonize the newly inundated land. These facts support the need for high resolution land elevation imagery to make projections of future marsh migration due to sea level rise.
- There are two available data products that could be used to establish a baseline of current wetland area in the Chesapeake Bay (USDOI's National Wetland Inventory (NWI) and NOAA's Coastal Change Analysis Program (CCAP)); and two readily available modeling tools/methodologies that can be used to assess future wetland change (gain/loss) due to sea level rise in the Chesapeake Bay.
- Marsh change modeling runs have been conducted in the Chesapeake by the National Wildlife Foundation (2008)[x] and the Maryland Department of Natural Resources (2012)[xi] using the Sea Level Affecting Marsh Model and by NOAA's Office for Coastal Management using the Digital Coast Sea Level Rise Marsh Impacts and Migration Tool.[xii]
- NWF ran SLAMM v5 using a 30-meter Digital Elevation Model (DEM); Maryland DNR ran SLAMM v6.01 using a 10-meter DEM; and the NOAA Marsh Tool uses a 10-meter DEM. The NWF and Maryland DNR SLAMM modeling preselected sea level rise projections for 2025, 2050 and 2100. The NOAA tool, allows analysis of marsh loss to sea level rise in one-foot (1,2,3,4,5) foot increments.
- Many other marsh studies have been conducted in the Chesapeake Bay at more localized or smaller regional scales; however, these studies do not support immediate data need for a current acreage number and projection of future area under varying sea level rise scenarios.
- Although SLAMM data is available, there are limitations to using modeling outputs to project future marsh loss. SLAMM modeling does not take into account current shoreline

“hardening” (seawalls) or future land use changes, which could impact a marsh’s ability to migrate inland. In these cases, SLAMM could over estimate future marsh gain on the upland side.
- Recent published papers on wetland loss methodologies indicate that assessing loss/gain is a complicated process. For example, Matt Kirwan, VIMS, published a study in Nature Climate Change[xiii] that argues that models, such as SLAMM, substantially overestimate marsh loss due to sea-level rise compared to dynamic models that account for biophysical feedback processes. E. Lentz et. al[xiv], also in Nature Climate Change asserts that inundation models can over predict lands likely to submerge.
- Despite the limitations of these data sets and models, they represent thebest available information at this time.

Recommendations

- Use a multi-model approach, tied to the CRWG’s recommended range of sea level rise projections for 2025 and 2050, to gain estimates of current wetland area and projected wetland loss/gain. Use these estimates to inform watershed loads in the CBWQSTM modeling effort.
- To estimate project wetland gain/loss, analyze data results available through the National Wildlife Foundation, Sea Level Affecting Marsh Model v.5 of the Chesapeake Bay (2008) and data available through NOAA’s Office for Coastal Management Sea Level Rise Marsh Impacts and Migration Tool.
- In interpreting the data available through these two products, assess whether the sea level rise projections used for the studies were consistent with the 2025 and 2050 SLR projections (as recommended by the CRWG); or, in the case of the NOAA Marsh Tool, whether data runs could be acquired for a different SLR scenario.
- The USGS/CBP GIS Team, which is working to compile the land use/land cover data set for the Midpoint Assessment, should work with the EPA/CBP Modeling Team to ensure there is consistency among the wetland classifications included in the marsh loss modeling outputs (NWF SLAMM (2008) and the NOAA Marsh Tool) to allow for side by side comparison of results.

Next Steps

This document lays out the CRWG’s recommendations related to sea level rise projections and tidal wetland loss assessments to inform the Midpoint Assessment modeling effort. Addendums to this document may be added in the future as additional CRWG recommendations related to climate data and information needs of the Midpoint Assessment are developed.

Looking beyond the Midpoint Assessment, the CRWG will work to stay abreast of and inform on emerging climate, sea level rise and wetland science and the application of this information to CBP assessments and decision-making processes. In particular, however, the CRWG should engage with partners, including academic and governmental scientists and cooperatives such as the Chesapeake Bay Sentinel Site Cooperative, to develop recommendations for new and/or refined methods and modeling techniques (e.g., Chesapeake Atlantis Model) to better assess current acreage estimates, projections of future marsh change and impacts on living resources.

[i] Boesch, D., et. al., 2013. Updating Maryland's Sea Level Rise Projections. Maryland Commission on Climate Change, Scientific and Technical Workgroup, Baltimore, MD.

[ii] Intergovernmental Panel on Climate Change (IPCC). 2013. IPCC 5th Assessment Report.

[iii] Department of The Army, U.S. Army Corps of Engineers. 2014. Incorporating Sea Level Change in Civil Works Programs. Env. Regulation 1100-2-8162.

[iv] Department of the Army, U.S. Army Corps of Engineers 2015. Sea Level Rise Curve Calculator.

[v] US Global Change Research Program. 2014. Third National Climate Assessment.. U.S. Global Change Research Program, Washington, D.C.

[vi] Kopp, Robert, F. Simons, J. Mitrovica, A. Maloof and M. Oppenhiemer. 2009. Probabilistic assessment of sea level during the last interglacial stage. Nature: vol. 462, 863-868.

[vii] Kopp, Robert, R. Horton, C. Little, J. Mitrovica, M. Oppenheimer, D.J. Rasmussen, B. Strauss, and C. Tebaldi. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauges. Earth's Future, 2, 383-406.

[viii] Kopp, Robert., A. Kemp, K. Bitterman, B. Horton, J. Donnelly, W.R. Gehrels, C. Hay. J. Mitrovica, E. Morrow and S. Rahmstorf. 2015. Temperature Driven global sea level variability in common era. PNAS Early Edition, 1-8., DOI 10.1073/pnas 1517056113.

[ix] Hall, J.A., S. Gill, J. Obeysekera, W. Sweet, K. Knuuti, and J. Marburger. 2016. Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide. U.S. Department of Defense, Strategic Environmental Research and Development Program. 224 pp.

[x] Glick, Patty, et al.. 2008. Sea-Level Rise and Coastal Habitats in the Chesapeake Bay Region, Technical Report. National Wildlife Federation, Washington, DC.

[xi] Papiez, C. 2012. Coastal Land Conservation in Maryland: Targeting Tools and Techniques for Sea Level Rise Adaptation and Response. Maryland Department of Natural Resources, Chesapeake and Coastal Service, Annapolis, MD.

[xii] NOAA Coastal Services Center. 2012. Detailed Method for Mapping Sea Level Rise Marsh Migration. NOAA Coastal Services Center, Charleston, SC.

[xiii] Kirwin, Matt, S. Temmerman, E. Skeehan, G. Guntenspergen and S. Fagherazzi. 2016. Overestimation of marsh vulnerability to sea level rise. Nature Climate Change, volume 6. 253-260.

[xiv] Lentz, Erika, E.R. Thieler, N.Plant, S. Stippa, R. Horton and D. Gesch. 2016. Evaluation of dynamic coastal response to sea level rise modifies inundation likelihood. Nature Climate Change, DOI 10.1038/NClimate2957.