DELAWARE CENTER FOR THE INLAND BAYS
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Developing a Hydrodynamic/Water Quality Model for the Inland Bays: Implementation Plan

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LIST OF ACRONYMS

CAST	Chesapeake Assessment Scenario Tool
CCMP	Comprehensive Conservation and Management Plan
CIB	Center for the Inland Bays
DO	Dissolved Oxygen
GEMSS	Generalized Environmental Modeling Surface Water System
HD/WQ	Hydrodynamic/Water Quality
HEM3D	Hydrodynamic Eutrophication Model 3-D
HSPF	Hydrological Simulation Program-Fortran
NEP	National Estuary Program
NOAA	National Oceanic and Atmospheric Administration
RFI	Request for Information
ROMS	Regional Ocean Modeling System
SPARROW	SPAtially Referenced Regression On Watershed attributes model
STAC	Scientific and Technical Advisory Committee
TMDL	Total Daily Maximum Load
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WASP	Water Quality Analysis Simulation Program
WiCCED	Water in the Changing Coastal Environment of Delaware

INTRODUCTION

In 2017, the Delaware Center for the Inland Bays (CIB) finalized an updated Environmental Monitoring Plan for the Inland Bays. The purposes of the plan are: (a) to guide monitoring and research to track the status and trends of key environmental indicators used to assess the chemical, physical, and biological integrity of the estuary and surrounding study area; and (b) to evaluate whether the goals of the Inland Bays Comprehensive Conservation and Management Plan (CCMP) are being met. The CIB's Scientific and Technical Advisory Committee (STAC) is responsible for ensuring the implementation of this plan and tracking progress.

Of primary importance in the plan are prioritized recommendations for new monitoring programs, or enhancement of existing programs. These recommendations were based upon critical data gaps (including emerging issues), the availability of new environmental monitoring methods or technologies, and/or changes needed to make programs sustainable over the long term. They were the result of facilitated panel discussions held with stakeholders/partners and the STAC on July 29, 2015 and September 18, 2015, respectively. Additional input was provided through written questionnaires, follow-up STAC meeting discussions, and reviews by the U.S. Environmental Protection Agency (USEPA).

Among the highest priority recommendations is the development of a predictive, coupled watershed, hydrodynamic/water quality (HD/WQ) model for the Inland Bays that uses current and high-frequency data. Update of watershed nutrient loading, estuarine water quality, and hydrodynamic models for the Inland Bays is a specific objective included in both the 2012 CCMP Addendum (Water Quality Management - Objective 1, Actions A, B and C) and the draft CCMP revision that is currently under development by the CIB and its partners (Healthy Bay Ecosystems - Objective 1, Actions 1, 2, and 3). A number of other actions may be facilitated or supported through use of these updated models (Table 1).

In 2018 and 2019, a standing CCMP/Monitoring Subcommittee of the STAC met to discuss priorities and potential approaches for developing new models for the Inland Bays. Several meetings of the full STAC were devoted to presentations from practitioners who have developed models of various types for estuarine systems. This white paper is the result of these meetings and discussions. It synthesizes the STAC's collective view of the requirements for an updated HD/WQ model of the Inland Bays and how its development can most practicably be accomplished.

THE NEED FOR MODELS

Multiple presentations from modeling practitioners to the STAC made clear the need for, and best uses of, updated and maintained models of the Inland Bays system. Professor Dominique DiToro of the University of Delaware, in particular, summarized well the usefulness of good models for understanding how the estuary functions and for making predictions about the outcomes of management actions. Models are data analysis tools; comparison of expected and observed distributions of monitoring data provides invaluable information about the system. He emphasized that:

- Models are needed to demonstrate that funding for management actions is spent in the most effective manner. That is, predictions can be made about the types and locations of practices that will result in the greatest pollutant load reductions to particular water bodies per dollar spent. In fact, decades of work to reduce nutrient loads to the Bays have not produced the sought after reductions in eutrophication. Using well-calibrated models to guide our investments will likely improve the outcomes. The newly formed Inland Bays CCMP Implementation Committee, a standing committee of the CIB Board, has identified development of an updated watershed nutrient loading as a top priority for its work in Fiscal Years 2020 and 2021.

- Models provide information to guide monitoring efforts and interpret monitoring data. Models can help target monitoring efforts and eliminate unnecessary stations or identify areas of the estuary that need better coverage. When observed water quality concentrations fail to agree with predicted values, we learn something significant about the functioning of the system and may indicate that the model is not properly calibrated. Although monitoring provides data on current water quality status and past trends, predictions about future status cannot be made based upon monitoring alone. A well calibrated model can be used for predicting future conditions and those future conditions may happen only if all other conditions in the model prediction scenario remain constant.
- Models help us to understand the chemical mass balance in the estuary and the physical, geochemical, and biological processes that influence nutrient fluxes. Unless the mass balance is well understood, then the outcome of remediation practices cannot be predicted.
- Models can be used to better understand the relationship between nutrient loads and water column concentrations.

BACKGROUND ON INLAND BAYS MODELING & RELATED MONITORING

The first state-of-the-art water quality modeling program implemented in Delaware's Inland Bays was calibrated using data collected from 1988-1990 (Cerco et al., 1994). This tool included a mechanistic sediment flux model; it even included a benthic algal model due to the shallow nature of the bays (Cerco and Seitzinger, 1997). In 2004, Entrix, Inc., and J.E. Edinger Associates developed a Total Maximum Daily Load (TMDL) model for the Inland Bays (Entrix and JEEAI, 2004). The model is a fully coupled 1-dimensional watershed and 3-dimensional HD/WQ model called the Generalized Environmental Modeling Surface Water System (GEMSS). That model was used primarily to calculate water quality constituents such as nitrogen, phosphorus (particulate/dissolved, inorganic/organic) and dissolved oxygen (DO). It was calibrated using data collected from 1998-2000.

Since 2004, there has been a significant increase in understanding of nutrient loading from the watershed and how the Bays respond to nutrient loads, as documented in Hydrological Simulation Program-Fortran (HSPF) models of watershed loading (Gutierrez-Magness, 2006) and a HD/WQ model (Brady, 2014). Advances in monitoring, as documented by studies that used high-frequency data collection (Tyler, 2004; Ullman and Andres, 2004-2010) have also occurred.

The HSPF and process models represent large and fairly expensive data collection and modeling efforts. They were calibrated from watershed-specific baseflow and storm flow data and provide edge-of-stream nutrient and sediment loads on daily time steps. This is exactly the type of input needed to improve HD/WQ modeling capabilities. The tool also has the capability to model the ecosystems response to a changing climate.

Ullman and Andres (2004-2010) operated an automated on-site laboratory at the Millsboro Pond outlet that determined physical and nutrient values every six hours for nearly six years. As the Millsboro Pond outlet is the single largest input of water and nutrients to the Indian River, these data are critical for accurately determining the impact of nutrient inputs. Tyler (2001) and Tyler et al. (2009) found significant diel DO swings at multiple locations in the Bays from operation of automated, high-frequency DO monitoring sensors. Diel hypoxia and anoxia is arguably the greatest uncertain water quality threat to Delaware's Inland Bays, with multiple fish kills attributable to hypoxia occurring most years, and likely significant impacts on the cycling of nutrients between bottom sediment and the water column. Substantial research efforts have also demonstrated reduced growth rates and behavioral avoidance of hypoxia by juvenile estuary dependent fishes that rely on the Bays for essential fish habitat.

For this reason, the CIB requested an independent assessment of the DO calculation in the GEMSS model (Brady, 2014). Damien Brady also presented a summary of his assessment to the STAC at its February 2019 meeting. While the report focuses on DO, it notes that improvements in the understanding of nutrient loading and biogeochemical cycling will also be necessary to improve future model formulations. It is of course important to note that the original model was a tool to establish nutrient TMDLs that would provide protection of the Inland Bays under average conditions. The conclusions of this assessment were:

- Bay hydrodynamics have significantly changed since the Cerco et al. (1994) and Entrix and JEEAI (2004) GEMMS modeling efforts and will continue to change with rising sea level and modification to the Indian River Inlet. Volumetric flow through the inlet has changed drastically over the years and is a major driver of nutrient flushing from Rehoboth and Indian River Bays.
- The model simulates physical parameters such as tide and temperature well. However, GEMSS is not effective at simulating diel DO cycling (especially in the Indian River and tributaries).
- Calibration and validation used datasets only from 1998-2000, and 1998 was a particularly wet year. We now have 19 additional hydrographs (along with long term discharge data at Millsboro Pond and water quality data, though collected less frequently) to incorporate into the model. Furthermore, the calibration and validation datasets included few to no substantive continuous DO records. Assessing performance of the GEMMS in relation to diel-cycling hypoxia is difficult, and was not the original intent of that modeling effort.
- The model needs to incorporate sediment fluxes of nitrogen and phosphorus; it also does not incorporate any rate information such as respiration and primary productivity.

DO data collected since 2001 contain DO fluctuations from 0% to >200% saturation in the headwaters of major creeks/tributaries, and the model output shows no such fluctuations. Brady's explanation for this is either: (1) diel-cycling hypoxia only became a significant feature of the water quality in Delaware's Inland Bays in 2001; or (2) the monitoring program only became robust enough to detect diel-cycling hypoxia in 2001. In either case, changes to Bay hydrodynamics, proliferation of data and understanding of important processes since 2001 strongly argues for re-visiting the modeling framework for the Bays. In his report, Brady provided specific recommendations for future accurate simulations of diel-cycling hypoxia.

Brady's recommendations carry additional importance with consideration of recent research on sediment-water column interactions in Barnegat Bay (Wilson and DePaul, 2016; Paudel et al., 2017), Chesapeake Bay (Cornwell et al., 2016), and elsewhere. These studies build upon a long history of sediment-water column research showing that hypoxic and anoxic conditions exacerbate release of phosphorus from sediments and alter how sediments process nitrogen. The studies conclude that loads of nutrients from sediment-water column interactions in some poorly flushed coastal bays are on the same order of magnitude as watershed-delivered loads. Similar studies have not yet been completed for the Delaware Inland Bays. Sawyer et al. (2013) and Russoniello et al. (2016) have demonstrated in studies of the Inland Bays the importance of understanding watershed hydrology and groundwater-surface water exchange for identifying sources of nutrients and critical targets for management. Coupling these types of physics-based models to geochemical models would advance understanding and predictive capacity to the next level.

Finally, the CIB is currently seeking funds through the U.S. Army Corps of Engineers to collect updated data on the bathymetry of and tidal flow through the Indian River Inlet. The most recent previous tidal prism calculation was 2004. Inlet bathymetry has no doubt changed significantly in response to removal of the old Route 1 bridge, completed in 2013. The inlet is the largest single source of water flux in and out of the Bays. This information is critical to predicting impacts of long-term sea level rise on water flow and salinity in the Bays as well as storm events.

EVALUATION OF MODEL NEEDS & OPTIONS

The CIB organized and hosted a series of presentations and panel discussions by regional modeling experts for CIB staff, STAC members, and other interested parties between May 2018 and April 2019 (Table 2). In addition, the then STAC chair, Scott Andres of the Delaware Geological Survey, and other subcommittee members held meetings with other modeling experts who could not attend STAC meetings.

These meetings and presentations clarified what models are, how they are best used, and identified several potential service providers. More importantly, experts described how models are instrumental for quantifying how the estuary works, a trait that tests our understanding of estuarine processes and permits forecasting of outcomes of management and mitigation activities. Dr. Dominic DiToro's statement accurately captured the current situation -- "…without a modeling tool, you are just guessing."

The Chesapeake Bay Model is often cited in discussions of potential modeling approaches for the Delaware Inland Bays. The Chesapeake Bay Program's integrated suite of modeling tools includes an airshed model, a land use change model, a Phase 6 Watershed Model (the Chesapeake Assessment Scenario Tool, or CAST), and an estuary model that predicts the effects that calculated pollutant loads will have on water quality. The development and ongoing improvement of the Chesapeake models is led by a collaborative working group consisting of multi-state, federal, academic, and private partners, stakeholders and experts. The suite of tools can be accessed online for free for use by local and regional planners. The high cost and complexity of the Chesapeake Bay Model has been raised by some as a reason to avoid similar effort in the Inland Bays. However, the Chesapeake Bay and its 64,000-square-mile watershed is a very different system from the Inland Bays' shallow, poorly flushed coastal lagoons, and the level of effort required to model them is not directly comparable.

Olivia Devereux (KCI Technologies) and Mark Nardi (USGS) discussed with the STAC, for example, how CAST and the USGS's Sparrow model both include information that could be used to inform a terrestrial and management model for the Inland Bays that determines the nitrogen, phosphorus, and sediment loads delivered to the edge of small streams and to the Bays. The Inland Bays tool would simply use data from Sparrow and CAST, rather than work like or be add-ons to those existing models.

Modeling tools developed for other shallow, eutrophic mid-Atlantic coastal lagoons that connect to the ocean only through narrow inlets probably provide more relevant comparisons for what could be accomplished for the Delaware Inland Bays. Modeling projects conducted for NEP partners in Barnegat Bay, New Jersey and the Coastal Bays of Maryland not only demonstrate successful model-derived quantitative assessments of management practices and resulting changes in their estuaries, but their models and associated monitoring projects also can provide key data that can be used to fill in data gaps currently present in the Inland Bays. In short, not having data on local processes up front should not derail work to create similar tools for the Inland Bays; though adequate water quality monitoring data will still be necessary to calibrate and validate models.

A Hydrological Simulation Program-Fortran (HSPF) framework was used to model watershed hydrological and nutrient transport processes of the Maryland Coastal Bays watershed (Maryland Department of the Environment and Virginia Institute of Marine Science (VIMS), 2013), for the purpose of developing TMDLs. In addition, a Hydrodynamic Eutrophication Model 3-D (HEM3D) was developed by VIMS and used as a tool to simulate the dynamics of physical-biological-chemical processes in the receiving bay waters, using the nutrient loads generated by the HSPF watershed model (Wang et al., 2013). The HEM3D modeling system was calibrated and compared very well with intensive water quality data collected during 2001- 2004. The predicted daily mean DO from the HEM3D was further adjusted to incorporate the diel cycle of DO using a statistical analysis developed for the Maryland Coastal Bays (Perry, 2012). A continuous water quality monitoring network established in these bays (http://eyesonthebay.dnr.maryland.gov/) provided data for calibration and validation.

In New Jersey, USGS partners recently worked with the NJ Department of Environmental Protection to couple a hydrodynamic model, the Regional Ocean Modeling System (ROMS), with the USEPA's Water Quality Analysis Simulation Program (WASP) in a comprehensive analysis of water quality in the Barnegat Bay-Little Egg Harbor estuary (Defne et al., 2017). The need for a comprehensive understanding of the relation between watershed land use and water quality in the bay required a bay-wide monitoring effort supported by an advanced modeling approach. Model development relied upon data and results from a number of studies, including sea floor mapping, continuous stage and discharge measurements, water quality monitoring, sediment characterization and chemistry, light attenuation, sediment oxygen demand and sediment nutrient flux, phytoplankton characterization, and wetlands denitrification research. Data collection was facilitated by a well-supported continuous water quality monitoring network established in Barnegat Bay. The model is being used to develop a TMDL for the estuary, to test a variety of water quality management scenarios, and to provide input to other ecosystem models.

PRIORITIZATION OF MODEL GOALS & KEY MANAGEMENT QUESTIONS TO BE ADDRESSED

Development of a well-calibrated, predictive model or models for the Inland Bays will require significant data, funding and time. Thus it is important that the effort be focused by clarifying and prioritizing overall goals for and key management questions to be addressed by the tool(s).

The key management questions for the Inland Bays are driven by a complex interrelated set of water quality issues. These include eutrophication in many bay segments, diel-cycling hypoxia in the upper reaches of the Indian River and other tidal tributaries, sediment-water column nutrient and oxygen exchange, focused (stream) and diffuse (groundwater and atmospheric) inputs of nutrients, and changes in hydrodynamics and inlet bathymetry. These questions are not new, and, despite investments of hundreds of millions of dollars in many types of pollution abatement practices and the efforts of countless people, long-term monitoring data show mixed success in improving water quality. Do we know the impacts of maintenance dredging activities on flow patterns and nutrient concentrations? Can we predict, for example, how the removal of the point source at Rehoboth Beach Wastewater Treatment Plant will impact nutrient and phytoplankton dynamics and concentrations in Rehoboth Bay over the next 10 years? Can we quantify the direct links between changes to the Rehoboth Beach wastewater discharge, annual fluctuations in watershed and ocean inputs, and observed changes to Bay water quality? Currently, experts can only say it appears that changes to the Rehoboth Beach wastewater discharge have improved water quality. With the lack of clear understanding and assessment tools, the complex web of government incentives for pollution abatement and economic development built over the past 20 years serves to perpetuate the status quo.

The CIB seeks to disrupt this inertia by establishing and supporting the partnerships necessary to construct, operate, and maintain two types of modeling tools for the Inland Bays: (1) a nutrient loading tool for the Rehoboth Bay, Indian River Bay, and Little Assawoman Bay watersheds; and (2) a fully coupled HD/WQ simulation tool for Rehoboth and Indian River Bays and their tidal tributaries.

Although subcommittee members agreed that updated modeling tools to be used for assessing and prioritizing management responses to critical water quality issues in the Bays are a high priority, there was no consensus that either the watershed loading or HD/WQ model had a greater priority. From a practical standpoint, each of these modeling projects can proceed independently of the other.

There are many potential approaches and types of model tools, with varying cost and time implications. Thus, defining and prioritizing goals and key questions to be answered is critical to the success of this effort. Following all of the presentations and panel discussions, the STAC subcommittee identified the following prioritized list of criteria for the model(s) to be developed for the Inland Bays:

A. Model(s) must predict the impacts of changes in nutrient loadings on water quality in the Bays and their tributaries, including effective simulation of diel-cycling hypoxia. This includes understanding impacts of past and future land use change and wastewater loadings.

B. Model(s) must predict the most effective types and locations of best management practices and management actions to reduce nutrient loads to the Bays.

C. Model(s) should serve to understand the effects of the Indian River tidal prism volume on water quality and flooding endpoints.

D. Model(s) should serve to understand effects of climate change (sea level rise, extreme events, increased salinity, warming) on water quality parameters.

E. Model(s) should serve to predict where habitats will be most impacted by climate change, including sea level rise and pollutant impacts.

Project priorities should be commensurate with the objectives and actions of the CCMP. This means that the most relevant timescale for predictions is on the order of five to ten years, rather than many decades.

POTENTIAL MODELING APPROACHES

The model for the estuary will be a fully coupled HD/WQ simulator. The watershed loading model could be a process-based numerical simulator, such as HSPF, or an analytic/spreadsheet tool such as SPARROW. Rather than prescribing specific computer codes or modeling approaches, prospective service providers should be solicited through Request(s) for Information (RFIs) and asked to describe the methods with which they would conduct the studies, how their methods have been successful in other estuaries or watersheds, estimated costs, and how their individual organizations are suited to work with the CIB and its partners on modeling projects. Selection of providers and tolls will consider criticality, expedience, and costs.

Service providers for these projects would likely be universities, research institutes, the consulting industry, or the federal government (USGS, NOAA). Several potential providers participated in the meetings, presentations, and panel discussions organized by the STAC. They would be invited to submit proposals that would be fairly competed with those of other practitioners.

The HD/WQ model project cycle is anticipated to be up to five years, with two to three years for model development and reporting, followed by two years of maintenance and updates. The watershed loading model project cycle is anticipated to be two years or less. Both projects will require input from CIB staff, STAC members, and partner agencies and organizations. Potential funding sources for the work still need to be identified.

The STAC subcommittee identified the following list of additional criteria for modeling approaches and tasks:

- Model(s) will have long-term usefulness and would be validated and updated as appropriate with new data generated by environmental monitoring programs and research (annually or biennially).
- Model(s) should be easily updated. Living/breathing modules could be replaced in future as new approaches or updates become available.
- Code used should be open source and proposed by potential service provider(s).
- Model scenarios must be able to be easily run in a cost-effective manner.
- A model maintenance agreement must be included as part of the contract.

It is recommended that the CIB be responsible for contracting and managing the service provider. The CIB would also be responsible for coordinating partners. The CCMP Implementation Committee will play a key role in both areas. The STAC is the obvious group to coordinate exchange of technical information, interact with the service provider on technical issues, and review the findings of the work.

DEFINITION OF DATA GAPS & A PLAN FOR COLLECTION OF DATA REQUIRED FOR MODEL CALIBRATION

In contrast to other nearby estuaries (i.e., Chesapeake, Barnegat Bay) the Delaware community of scientists and engineers is very small, and problems of data access are minimal. It should be understood that any competent service provider will know what data they need to do their work and already know where to acquire and make those data usable in their project. Providers that have worked in Delaware before will likely know who to ask questions about data. When necessary, CIB and STAC will be the points of contact for coordinating access to data and pointing the model service provider to the most appropriate contacts for answering questions.

The background section of this document and the Environmental Monitoring Plan identify the most important historic datasets available for development and calibration of a HD/WQ model. Nearly all of these datasets are available online for download or can easily be acquired by contacting the project managers. CIB staff will contribute data from the high-frequency DO observing systems that they now operate. Ongoing research by Project WiCCED (https://projectwicced.org/about/) investigators may be available for a modeling project. Several STAC members are members of Project WiCCED, and installation of at least two continuous monitoring sondes in the Inland Bays is planned under that project.

The choice of a watershed nutrient loading model platform will dictate which data are needed for that tool. FirstMap (https://firstmap.delaware.gov/) houses the vast majority of geospatial data on land cover, topography, hydrography, etc. for either model platform.

The subcommittee has identified several important data and research gaps but did not reach consensus on priorities. Several presentations and panel discussions among regional experts concluded that data gaps do not preclude modeling work, and that model results will assist in prioritizing work to fill data and research gaps, though keeping in mind adequate water quality monitoring data is still necessary for model calibration and validation. Thus, these research needs are not expected to delay initiation of or progress on model development. Model development can proceed using existing local and regional data and then be updated with new data and research findings in the future; this is an iterative process.

The key data and research gaps identified, with time and cost estimates to fill them, are:

- Exchange of nutrients and oxygen between bottom sediment and the water column and the role of benthic algae (2.5 years and $150-500K estimate from Jeff Cornwell).
- Diel cycling of dissolved oxygen in the upper Indian River and tributaries. Better spatial coverage of high-frequency measurements is needed. Chlorophyll a data may be important in tributaries as well. (3 to 5 years; and $250K estimated installation cost, plus $80-100K annual maintenance, based upon estimates for five continuous monitoring stations).
- Changes in hydrodynamics due to changes in the bathymetry of the Indian River Inlet (1 year, $50-80K estimate from USACE).
- Additional stream gages are desirable for the watershed loading model. Currently only two are in place (Millsboro Pond and Beaver Dam Creek). Re-activation of stations at Bundicks Branch, Swan Creek, and Blackwater Creek that supported the GEMMS and HSPF models would provide information about how changes in the watershed over the past 20 plus years have impacted hydrology and nutrient loading. Annual operational costs currently are approximately $16K per station. Installation costs can range from a few hundred to a few thousand dollars per station.

NEXT STEPS

The STAC recommends to the CIB the following actions:

1. Submit this document to the CIB Board of Directors for consideration at its March 2020 meeting.
2. Share this document with the CCMP Implementation Committee. Coordinate with the IC on

watershed loading model development.

3. Develop and distribute Request(s) for Information to model service providers to determine feasibility, interest, and/or available capabilities to develop and maintain watershed loading and HD/WQ models for the Inland Bays. Responses will provide information on practitioners available, timelines, and costs.
4. Identify potential funding sources for each component of the work (e.g., watershed loading model, hydrodynamic model, water quality model, research to address data gaps). At least one STAC meeting or workshop in 2020 should be devoted to this.
5. Develop a detailed funding strategy and timeline for development of both models. This strategy must include a plan and funding to allow future updates to the model(s). The STAC subcommittee and CIB staff will work together to develop this plan.

The STAC will be responsible for developing Requests for Proposals, reviewing responses, and ensuring that the selection process is transparent and neutral.

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Table 1. Delaware Inland Bays CCMP actions directly or potentially addressed through use of updated watershed, hydrodynamic, and/or water quality models. Table 1A lists actions in the 2012 Addendum. Relevant actions included in the draft CCMP revision being prepared by the CIB are listed in Table 1B, next page.

Table 1A - 2012 CCMP Addendum Actions

Focus Area: Nutrient Management
Objective 1, Action E1: Conduct watershed specific analysis to determine nutrient loading to the Bays from developed lands under different management practices.
Focus Area: Wastewater Management
Objective 3, Action E: Develop a nutrient budget for wastewater to determine existing and projected total wastewater loads to receiving waters.
Objective 3, Action F: Research the attenuation of nutrients and contaminants released from different types of on-site wastewater systems along flowpaths to receiving waters.
Focus Area: Water Quality Management
Objective 1, Action A: Update the Inland Bays estuarine water quality and hydrodynamic model.
Objective 1, Action B: Update the Inland Bays watershed nutrient loading model.
Objective 1, Action C: Utilize updated estuarine and watershed models to evaluate if existing TMDLs are adequate to achieve water quality standards for nitrogen and phosphorus.
Objective 2, Action B: Revise PCS goals as needed, incorporating any revisions to the TMDLs.
Objective 5, Action D: Examine dead-end canals to determine if any could benefit from low-cost solutions to increase flushing.
Objective 6, Action C: Develop recommendations to improve efficacy of monitoring efforts to detect trends.
Focus Area: Managing Living Resources and Their Habitat
Objective 1, Action B: Map areas of the Bays that have habitat characteristics supportive of the reestablishment of bay grass species that have been identified as suitable candidates for restoration.
Objective 2, Action B: Identify candidate sites for the creation and restoration of wetlands.
Objective 5, Action B1: Create additional hard bottom areas suitable for oyster recruitment or planting of oyster spat.
Focus Area: Planning for Climate Change
Objective 1, Action B: Conduct a sea level rise vulnerability analysis specific to the Inland Bays watershed that includes potential impacts to both green and gray infrastructure.
Objective 1, Action D: Model the distribution of tidal wetlands under different sea level rise scenarios to guide land use and protection decisions that maximize future tidal wetland extent.

Table 1B – Draft CCMP Revision (October 2019)

Focus Area: Living with a Changing Climate
Objective 2, Action 1: Develop a Coastal Flood Monitoring System for the Inland Bays to provide a publicly-accessible, real-time tool to create flood inundation potential maps and time series of forecasted tidal predictions.
Focus Area: Clean Waters: Heathy Agricultural Landscapes
Objective 2, Action 2: Develop and implement a project plan to achieve the Agricultural Actions of the Inland Bays Pollution Control Strategy.
Focus Area: Clean Waters: Reducing Pollution from the Developed Landscape
Objective 2, Action 3: Develop a nutrient budget for wastewater to determine existing and projected loads to receiving waters and report biannually.
Objective 2, Action 6: Research the attenuation of nutrients and contaminants released from County-owned wastewater systems along flow paths to receiving waters.
Objective 3, Sub-Action 2b: Develop a plan to create stormwater retrofits to work toward a goal of treating 4,500 acres of urban and residential lands developed pre-1990.
Objective 3, Action 4: Develop a nutrient budget for stormwater to determine existing and projected loads to receiving waters and report biannually.
Focus Area: Healthy Bay Ecosystems: Protect and Restore Thriving Habitats for Abundant Fish & Wildlife
Objective 1, Action 1: Update the Inland Bays estuarine water quality and hydrodynamic model.
Objective 1, Action 2: Update the Inland Bays watershed nutrient loading model.
Objective 1, Action 3: Utilize updated estuarine and watershed models to evaluate if existing TMDLs are adequate to achieve water quality standards for nitrogen and phosphorus.
Objective 1, Action 4: Continue research on potential for reestablishing bay grasses.
Focus Area: Coordinated Land and Water Use Management
Objective 1, Sub-Action 2c: Develop an Inland Bays regional sediment management project plan for Indian River and Little Assawoman Bay.

Table 2. Record of meetings and decisions. Copies of STAC meeting agendas, notes, and presentations may be viewed at https://www.inlandbays.org/stac-meeting-agenda-notes-reports-presentationspublication-science-technical-advisory-committee-presentations/.

Date	Meeting/Decision	Agenda, Relevant Presentations
2/27/18	STAC CCMP/Model Subcommittee Scoping Meeting – CIB/STAC leadership	Develop scope of work, goals, and potential members
4/19/18	STAC Subcommittee Meeting	First meeting
7/19/18	STAC Subcommittee Leadership Meeting	Discussion of modeling needs and options
9/12/18	STAC Subcommittee Leadership Meeting	Clarified subcommittee goals
10/26/18	Full STAC Meeting	Jeremy Testa, UMCES (*Using ecosystem models to explore eutrophication, hypoxia, and acidification in estuarine ecosystems*) Joseph Zhang, VIMS (*A seamless modeling system on unstructured grids for hydrodynamics and water quality*)
2/1/19	Full STAC Meeting	Damien Brady, Univ. of ME (*Water Quality Modeling in Delaware's Inland Bays: Lessons Learned*) Dominic DiToro, Univ. of DE (*The Importance of water quality and eutrophication models in understanding the causes of improving and degrading water quality*) Jeffrey Cornwell, UMCES (*Benthic biogeochemistry in shallow coastal ecosystems: Lessons learned from East Coast estuaries*) Olivia Devereux, KCI Technologies, & Mark Nardi, USGS (*Developing a Terrestrial and Management Model*) Panel Discussion
4/1/19	STAC Subcommittee Meeting	Prioritization of model goals, approaches, and data gaps
5/10/19	Full STAC Meeting	Tye Pettay, Univ. of DE (*Improving resolution and accessibility of real-time water quality data using low-cost, high-frequency sensors maintained by citizen scientists*) Update to full STAC on subcommittee progress
7/26/19	Full STAC Meeting	Report to STAC on draft document and next steps.
8/26/19	Review of draft document by STAC and CIB Executive Director completed	---
2/13/20	Revised, final draft sent for STAC approval	---
2/17/20	STAC vote held to approve document for submission to CIB Board of Directors	---