ENVIRONMENTAL APPENDIX
NEW YORK BIGHT ECOLOGICAL MODEL (NYBEM) TECHNICAL NOTE

NEW JERSEY BACK BAYS
COASTAL STORM RISK MANAGEMENT
FEASIBILITY STUDY

PHILADELPHIA, PENNSYLVANIA

APPENDIX F.9

August 2021

NJBB
NEW JERSEY BACK BAYS STUDY

U.S. Army Corps of Engineers
Philadelphia District

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ERDC TN-EMRRP-DRAFT
June 2021

Developing a Multi-Ecosystem Conceptual Model for the New York Bight

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OVERVIEW: A suite of conceptual and quantitative ecological models are being developed to articulate and quantify mechanisms of environmental effects associated with proposed coastal storm risk management actions in the New York Bight ecosystem. Mediated modeling processes were applied to develop these ecological models; agency professionals, state and local partners, and other entities were engaged iteratively through a series of workshops and dialogs. This technical note describes the process for and value of developing conceptual \models in parallel with the planning process for projects at large spatial scales with many stakeholders. Specifically, the goals and outcomes of four workshops are presented; these collectively led to an overarching conceptual model for the regional ecosystem as well as process-based conceptual models to guide quantitative model development. From this project, we identify lessons learned and best practices that are transferrable to other locations and models.

BACKGROUND: In response to Superstorm Sandy and associated Congressional directives (PL 113-2), the North Atlantic Coast Comprehensive Study (USACE 2015) identified nine focus areas with populations vulnerable to coastal flooding risk. This paper focuses on two large-scale coastal storm risk management (CSRM) feasibility studies led by the U.S. Army Corps of Engineers (USACE). The New Jersey Back Bays (NJBB) study is investigating 900 mi^2 of land and water areas along with 3,400 mi of shoreline spanning a significant portion of New Jersey's Atlantic coastline. The New York-New Jersey Harbor & Tributaries Study (HATS) is examining 2,100 mi^2 and comprises parts of 25 counties in the two states. Objectives of these studies include issues such as: (a) reduction of coastal storm damage risks to communities, public infrastructure, important societal resources, and the environment, (b) improvement of a community's ability to recover from storm surge damages, (c) enhancement of human health and safety by improving performance of critical infrastructure and natural features during and after storm surge events, and (d) enhancement of coastal resilience with nature-based features.

The complexity of these projects includes many potential actions across a large spatial scale, which is leading to non-traditional methods of environmental assessment. The USACE is considering a

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diversity of measures for mitigating flood risks, including: structural actions (e.g., levees, floodwalls, storm surge barriers), non-structural measures (e.g., buy-outs, elevation of structures, flood-proofing), and natural and nature-based features (e.g., wetland creation, reefs for breakwaters). Project performance, environmental outcomes, and public acceptability of these measures are important constraints on plan selection, and recommendations must be in compliance with environmental laws and regulations. Given these challenges, the USACE studies are applying a programmatic approach to compliance with the National Environmental Policy Act (NEPA)7. A programmatic NEPA review followed by a tiered NEPA review is appropriate when such an approach provides a framework for agencies to help public officials make timely decisions based on an understanding of the environmental consequences at key decision points for complex studies with diverse environmental effects. The programmatic NEPA review process may defer issues for subsequent tiers of review. Site- or project-specific impacts might not be fully evaluated at initial tiers of review when the decision to act on a site development or its equivalent is yet to be made (CEQ 2014). In the context of these studies, “Tier 1” and “Tier 2” Environmental Impact Statements will be generated at the conclusion of the USACE Planning Process (i.e., integrated with the Feasibility Report) and in Pre-Construction Engineering and Design, respectively. The tiered assessment is informed with sequentially more accurate and precise information as the USACE planning process proceeds through the Alternatives Milestone Meeting (AMM), Tentatively Selected Plan (TSP), and Agency Decision Milestone (ADM).

These large-scale, complex projects (i.e., nearly 3,000 mi^2 project area) led to unique planning and assessment challenges (e.g., direct vs. indirect effects, multiple ecosystem types). The New York Bight Ecological Model (NYBEM, “nigh-bem”) is being iteratively developed in order to inform the tiered environmental impact assessment process for the NJBB and HATS feasibility studies, specifically effects on regional ecosystems and the associated resident taxa. The objectives of this technical note are: (1) to describe the process used to iteratively develop a suite of large-scale, broadly applicable conceptual models in the New York Bight and (2) to identify lessons learned and best practices for developing regional ecological models in other systems.

NEW YORK BIGHT ECOLOGICAL MODEL (NYBEM): When used in complex management decisions with many partners, environmental and ecological modeling often benefit from approaches that emphasize transparency, increase user input during development, and clearly communicate model assumptions and limitations (Voinov and Bousquet 2010). Here, a general five-step modeling process is being followed that applies best practices in ecological model development (Grant and Swannack 2008). First, general relationships among essential ecosystem components are formally *conceptualized* to tell the story of “how the system works” (Fischenich 2008). Second, the model is *quantified* using a formal structure of functional relationships, algorithms, and parameters. Third, models are *evaluated* relative to underlying scientific theory, numerical accuracy, and usability, which often entails techniques such as code checking, verification, and sensitivity analyses. Fourth, a model is *applied* to a given management question, scenario, or assessment. Fifth, a strategy is developed and executed to *communicate* model development and application to technical and non-technical audiences. This process has been applied numerous times to select, adapt, or develop ecological models for USACE and non-

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7 https://www.federalregister.gov/documents/2014/12/23/2014-30034/final-guidance-for-effective-use-of-programmatic-nepa-reviews

USACE studies (McKay et al. 2019, Herman et al. 2019), and the framework is intended to draw heavily from existing knowledge, data, and tools.

USACE policy (EC-1105-2-412, USACE 2011) defines models as “a representation of a system for a purpose,” and thus, specifying a modeling objective and domain is often a foundational step in the modeling process. **Here, our modeling objective is to articulate the mechanisms and magnitude of environmental effects of proposed coastal storm risk management actions in the New York Bight Ecosystem**. However, this model (like many models) is being developed in a constrained environment with limited time and resources. The following concsiderations also guided the scope and development of ecological models for the New York Bight ecosystem:

- Models should describe the relative environmental effects of large-scale CSRM alternatives, which can inform the feasibility process and NEPA assessments. However, any modeling suite must be directly responsive to changes in hydrologic conditions associated with proposed actions, although other changes in the ecosystem may be underway (e.g., reduced nutrient loading from enhanced wastewater treatment).

- Models must be able to forecast environmental effects over long project planning horizons (50-100 years) based on physical changes to ecosystems resulting from both background processes (e.g., sea level rise) and project alternatives (e.g., change in tidal regime from storm surge barriers).

- Models should assess environmental effects by ecosystem type (e.g., marine deepwater vs. estuarine intertidal) to inform mitigation actions.

- Models should capture direct effects of actions at infrastructure locations (e.g., the footprint of a floodwall) as well as indirect effects induced off-site from infrastructure (e.g., change in migratory pathways associated with a storm surge barrier).

- Models should be adaptable to new information and data as project planning proceeds.

- Models should provide a consistent approach for environmental assessment, which can assist with communication of cumulative effects of recommended alternatives across the region (i.e., “roll-up” impacts into a few summary outputs for USACE decision-makers).

A model’s domain defines not only its spatial limits, but also bounds the ecosystems included. The NYBEM’s domain was defined using four sequentially smaller filters. First, the USFWS (1997) defines the ecosystems of the New York Bight as the “open ocean region south of Long Island and east of New Jersey, known as the New York Bight proper” and all associated upstream estuaries, waters, and lands. Given the scope of USACE’s studies, seaward extent is limited to ecosystems above a 20 m depth contour (i.e., the USFWS definition of “nearshore”), which defines an area of 13,420 mi^2. Second, USACE project areas further limited the model by removing upland and coastal ecosystems beyond the project boundaries (e.g., Eastern Long Island). Third, the region is highly developed, and prior human activities form the baseline for assessing future impacts of USACE activities; thus, developed areas are removed from the model domain. Figure 1 shows the application of these three spatial filters, which ultimately reduced the focal area for models to 1,720 mi^2.

The final element defining the NYBEM domain was not spatial, but instead conceptual. A key focus of the model is assessment of indirect effects of proposed actions on aquatic ecosystems. Impacts to upland and riparian systems (e.g., dunes, scrub-shrub) are better understood from prior projects in the region (e.g., beach nourishment projects). Additionally, these systems are likely to experience fewer indirect impacts, and other impact assessment methodologies are generally available for assessing direct impacts. As such, the NYBEM focuses on aquatic ecosystems, which we define as any ecosystem with elevations below mean higher high water.

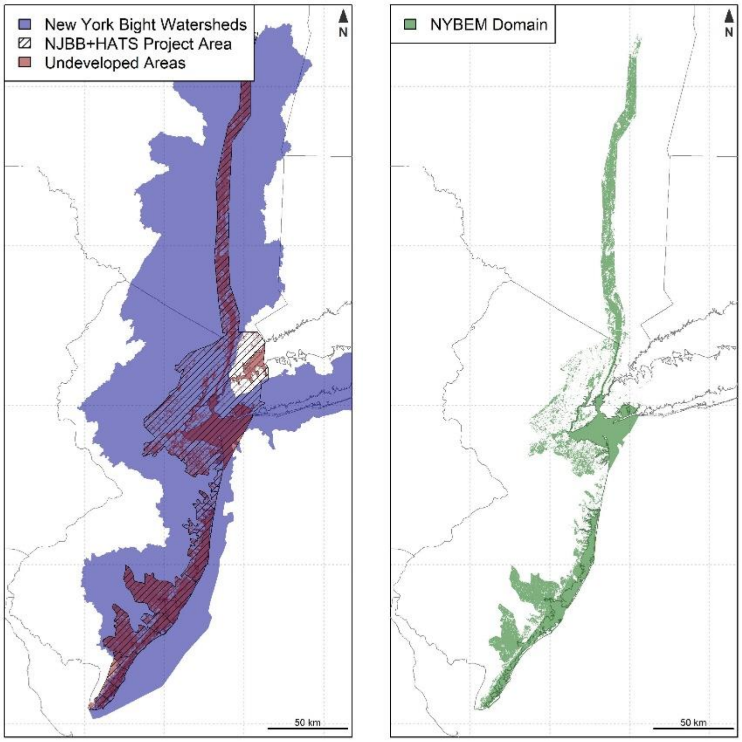


Figure 1. Geographic scope of the New York Bight study area: (left) spatial filters applied to define the New York Bight ecosystem and (right) the spatial domain of the NYBEM.

NYBEM CONCEPTUALIZATION: In this section, we describe the methods and techniques used to develop conceptual models of this system. The general strategy was to conduct a series of workshops with increasingly larger teams. Each workshop generated ideas, synthesized data and modeling resources, identified critical uncertainties, and evaluated progress to date. Between meetings, workshop outcomes were compiled and synthesized with scientific literature and other resources (e.g., data, models) to inform and refine the path of model development. This mediated modeling approach has been shown to be an efficient means of engaging interested parties and breaking down common misconceptions about ecological modeling (Herman et al. 2019).

Four workshops were held to develop conceptual models for the New York Bight ecosystem. Workshop-1 and Workshop-2 were largely internal to USACE and focused on “big picture” issues surrounding model development (e.g., type of outcomes, overall development strategy). Workshop-3 and Workshop-4 engaged large external audiences and focused on process-oriented models leading to quantitative models. The following sections describe each workshop’s goals, process, and outcomes, which are summarized in Table 1 relative to a structured approach to conceptual model development (Fischenich 2008). Notably, we focus on the process of conceptual model development, rather than system-specific aspects of the models themselves. All development drew from existing conceptual modeling best practices (e.g., Fischenich 2008, Casper et al. 2010, Fischenich and Barnes 2014) as well as the authors' collective experiences (e.g., Grant and Swannack 2008, McKay and Pruitt 2012, Herman et al. 2019).

Workshop-1: The initial phase of model development focused exclusively on the New Jersey Back Bays (NJBB) project. The first workshop was small in scope, including only NJBB team members and conducted over a 2-hour meeting (January 2019). The meeting goals were to develop a preliminary list of model components along with a general understanding of key processes models would include. The conceptual modeling process and associated examples from other ecosystems were briefly described. Attendees then brainstormed key drivers, processes, and outcomes that should be included by writing each model component on a separate slip of paper. This activity facilitated collection of ideas as well as dialog among team members about the ecosystem function. Ideas were then grouped into themes. For instance, tidal prism, depth, velocity, and salinity were lumped together as "hydrodynamic change." The grouping process allowed the team to identify processes modeled quantitatively (e.g., hydrodynamic change modeled by engineering teams) as well as data gaps that would need to be addressed either through data collection, modeling, or qualitative assessment. Preliminary ideas were refined and synthesized into a simple, color-coded box-and-arrow format (Figure 2). Although small in scope, a preliminary conceptual model provided a clear starting point for dialog among team members and communication with external parties.

Workshop-2: The second workshop expanded the scope to include the New York / New Jersey Harbor and Tributaries Study (HATS). This one-day meeting included USACE representatives from multiple offices (March 2019). The initial meeting intent was to construct conceptual models for each ecological outcome in the conceptual model from Workshop-1. For instance, a conceptual model would be built of notable drivers and physical processes affecting imperiled shorebirds like piping plover. Initial discussions focused on developing a comprehensive list of ecological outcomes that would require conceptual models, which identified more than 25 potential topics (e.g., different taxa, multiple environmental regulations). This list was prohibitively large for subsequent numerical model development, and the focus of the workshop was rescoped around ecosystem types to reduce dimensionality and complexity of the modeling problem and structure a feasible path forward for development.

Three overarching systems were identified for model development: (1) ocean-facing, nearshore systems, (2) bayside, estuarine systems, and (3) network connectivity for the entire ecosystem. Systems were distinguished based on differences in physical processes such as wave energy and storm surge exposure and likely effects of proposed management alternatives. Nearshore and estuarine systems were subsequently divided into seven ecosystem types based on tidal ranges (deepwater, subtidal, intertidal) and salinity (marine, estuarine, freshwater). The team addressed a parallel set of issues for each system, including: representative taxa using this habitat, sub-types of habitat (e.g., hard- and soft-bottom areas of estuarine subtidal systems), representative management actions, construction vs. operational impacts, indirect effects (e.g., changes in circulation), intermediate processes a model would need to capture, and existing data and modeling resources. The goal was not to comprehensively address these subjects, but instead provide a preliminary listing to spur literature search after the meeting.

A major outcome was a decision to pursue two different modeling philosophies to address these three systems (i.e., habitat models for nearshore and estuarine systems and a network modeling approach to connectivity). For the nearshore and estuarine systems, a common approach was adopted based on quantity and quality of habitat. “Index” models (Swannack et al. 2012) were originally developed for species-specific habitat applications (e.g., slider turtles), but the general approach has also been adapted to guilds (e.g., salmonids), communities (e.g., floodplain vegetation), and ecosystem processes (e.g., the Hydrogeomorphic Method). An index-based modeling approach was proposed for multiple reasons. First, index models provide a clear link to physical changes associated with futures with and without proposed management actions. Second, index-based models align well with a phased model development approach where models expand to include new data sources. Third, index-based models are familiar to USACE decision-makers from diverse applications in other regions where multiple habitat types were assessed simultaneously, such as Louisiana coastal restoration (EWG 2006) and Mobile Harbor expansion (Berkowitz et al. 2020). Fourth, the combination of habitat quality and quantity provides a consistent metric across ecosystem types (i.e., “habitat units”). Finally, these models readily build from existing data and models. For instance, an estuarine intertidal model would draw from regional sources such as the Sea Level Affecting Marshes Model (SLAMM; Clough et al. 2016), the marsh resilience to sea level rise model (MARS, Raposa et al. 2016), and the New England Marsh model (McKinney et al. 2009).

A second modeling philosophy would be applied to assess system-wide connectivity for organism movement. For NYBEM, connectivity focuses on organismal outcomes; for instance, closure gates and storm surge barriers have the potential to disrupt animal movement between different habitat patches required during an organism’s life cycle. An analytical approach would build from connectivity models from conservation planning and freshwater systems, which include quantity and quality of habitat patches scaled by movement rates around structures.

Following the meeting, an overarching conceptual model was developed to communicate the strategy for NYBEM development. The goal of this model was to rapidly communicate the approach to assessing CSRM effects on regional ecosystems. A graphic designer was engaged iteratively to summarize these features and create an appropriate conceptual model (Figure 3). Notably, this model utilized an existing database of ecologically relevant images developed by the University of Maryland (https://ian.umces.edu/imagelibrary/). Workshop-2 ultimately solidified the general scope and direction for future model development.

Workshop-3: The third workshop drew on interagency expertise to continue building a more refined conceptual and quantitative view of the New York Bight ecosystem. This workshop engaged more than 40 subject matter experts from federal, state, and local agencies as well as non-profit and academic partners for a six-hour meeting (June 2019). Workshop-3 sought to develop preliminary, ecosystem-specific conceptual models of ongoing processes. The goals of these models were to present a detailed, process-oriented view of the mechanisms of impact in a given ecosystem type with the ultimate aim of developing quantitative models.

Table 1. Overview of the NYBEM conceptual model development process via four workshops presented relative to the seven steps of conceptual model development proposed by Fischenich (2008).

Development Step	**Workshop-1: USACE Philadelphia District Team**	**Workshop-2: USACE Philadelphia and New York District Teams**	**Workshop-3: Interagency Team for Model Development**	**Workshop-4: Interagency Team for Model Refinement**
1. State the model objectives.	Articulate preliminary issues and mechanisms of environmental impacts.	Develop an overarching approach to assessment of CSRM effects on regional ecosystems.	Develop preliminary, ecosystem-specific conceptual models of ongoing processes in the New York Bight.	Refine proposed ecosystem-specific conceptual and quantitative models of the New York Bight.
2. Bound the system of interest.	New Jersey Back Bays (NJBB) project area	Regional coastal ecosystems of New York and New Jersey	Tidally-influenced, aquatic ecosystems of the New York Bight	Tidally-influenced, aquatic ecosystems of New York Bight
3. Identify critical model components within the system.	Team members wrote down components on separate pieces of paper.	More than 25 focal ecological outcomes were identified and grouped into eight system types.	Attendees were given opportunity to add processes and outcomes through a series of posters.	Any omitted model components were added by attendees.
4. Articulate relationships among model components.	Components were grouped into logical categories (e.g., hydrodynamic effects).	Important drivers and processes were identified for each system along with management issues (e.g., construction effects).	Attendees then proposed conceptual models of each ecosystem type.	Relationships within proposed models were refined based on attendee input.
5. Represent the conceptual model.	Groupings were refined and rendered in Microsoft PowerPoint.	Partnered with graphic designer to develop a model with broad communication appeal.	Workshop input was synthesized with literature to develop “fact sheets” for each ecosystem-specific conceptual model.	Conceptual models were refined and further documented in model development reports (intended for USACE certification).
6. Describe the expected pattern of behavior.	Project effects act on intermediate physical processes to ecological outcomes & compliance issues.	The overarching conceptual model provided a “quick” reference for communication with the public and technical audiences.	Models were drawn from existing descriptions of ecosystem function and processes (including other conceptual models for the region).	Model logic was recorded, including issues such as why a variable was (or was not) incorporated into numerical models.
7. Test, review, and revise.	Model presented in project “interim” report	The model was subsequently presented and revised at future workshops.	Model “fact sheets” were presented at Workshop-4 to verify the attendees’ input was captured.	Submitted for peer-review as part of USACE certification.

	(USACE 2019a) for public input.			

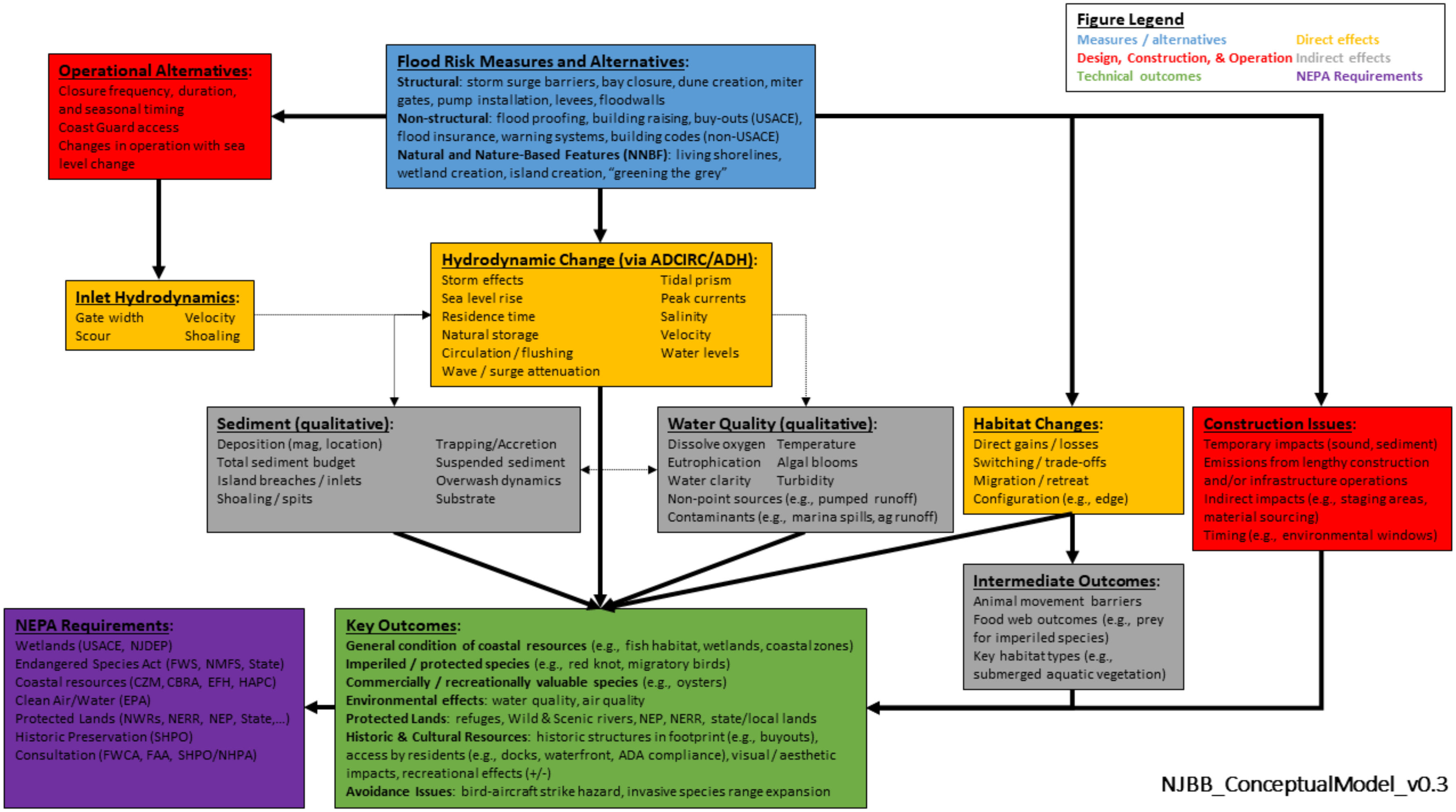


Figure 2. Preliminary NJBB conceptual model from Workshop-1.

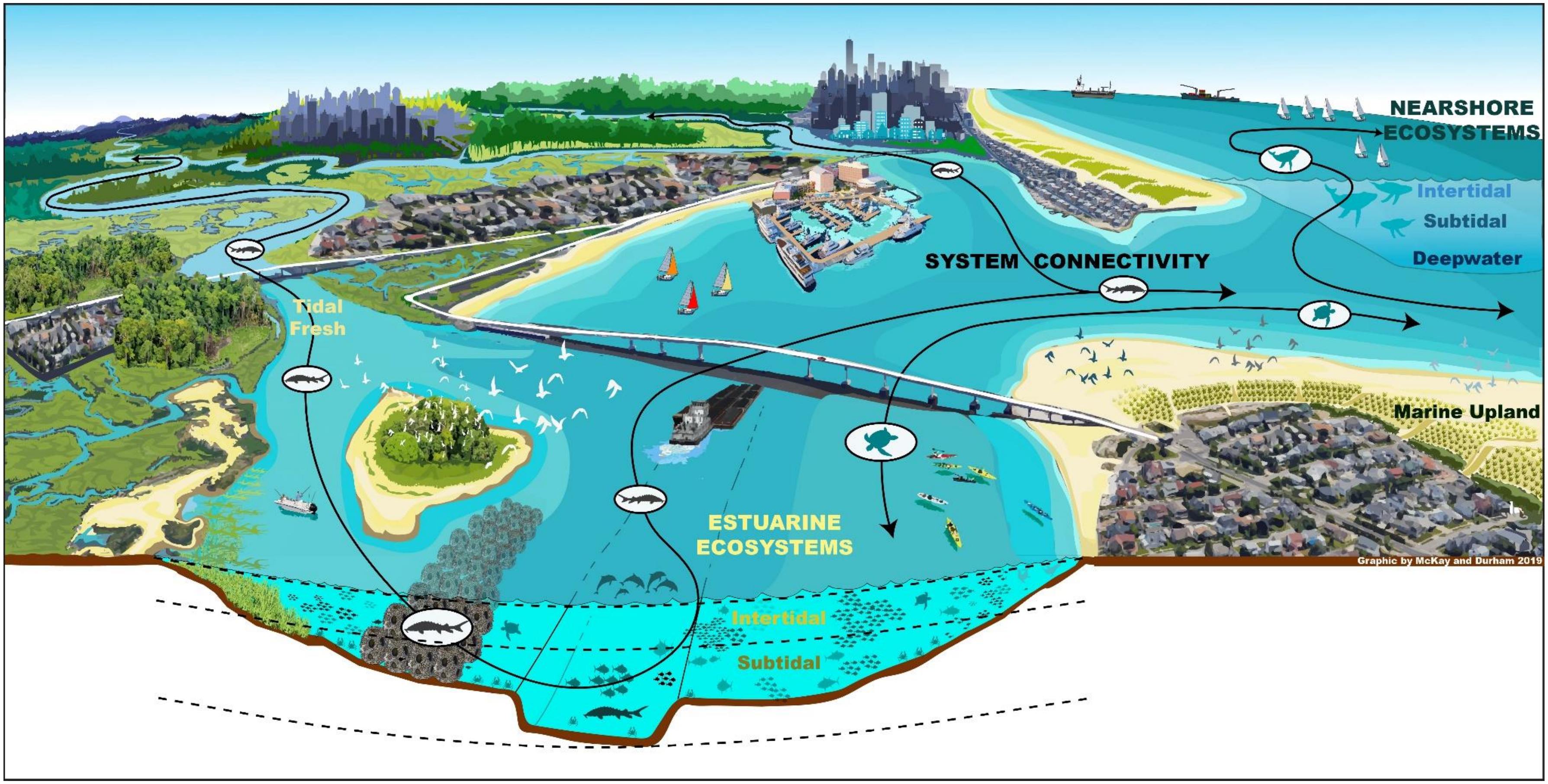


Figure 3. Overarching conceptual model of the New York Bight for communicating general functions of regional ecosystems and the scope of future model development. This model was developed in partnership with a graphic designer following a rescoping of model development at Workshop-2. The model also serves as a communication tool for subsequent development at Workshops 3 and 4.

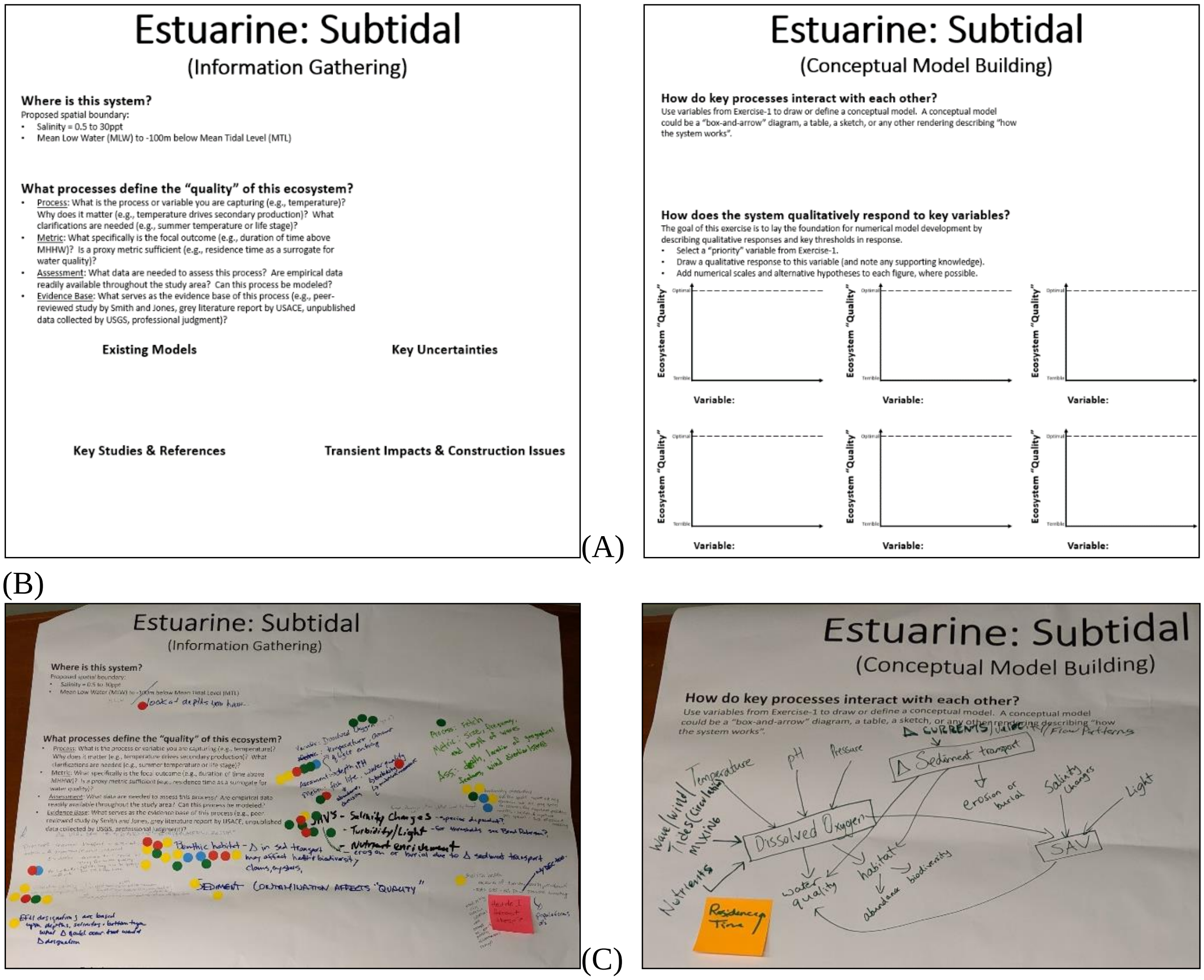
Attendees were provided background on the intent of the NYBEM and theory of conceptual model building. After initial discussion of the overarching strategy, the workshop proceeded with two major exercises structured around "posters" addressing each ecosystem (Figure 4A and Figure 4B). Posters were designed as participatory activities to facilitate dialog and elicit input from the large audience. Specifically, the posters were structured around common steps in conceptual and numerical model development (Fischenich 2008, Herman et al. 2019). In the morning, posters were used to identify model components for an ecosystem type and collect additional resources and "leads" (i.e., to literature, modeling, data, or personnel assets). Attendees were encouraged to circulate among posters, discuss input with other participants, and add their content and suggestions directly. Participants then "voted" on the most important topics (in their view) at each poster by placing stickers near notes and entries. After lunch, morning posters were hung nearby, and a new poster was introduced to guide attendees through construction of a conceptual model for each system. No constraints were placed on model development, and multiple formats were encouraged (e.g., box-and-arrow, schematics). Participants were also encouraged to draw qualitative responses of ecosystem quality to select driving variables (e.g., quality increases as percent fine sediment decreases). Four facilitators floated between posters to prompt small, self-organized groups through the process.

Figures 4C and 4D show representative outcomes of conceptual modeling exercises for estuarine, subtidal ecosystems. The morning exercise identified key variables and provided a preliminary notion of their relative importance. The afternoon exercise led to preliminary conceptual models, which served as a basis for post-workshop development. Facilitators used sticky notes to distinguish their comments and ask clarifying questions. Participants were able to expand comments and discuss other people's input. Overall, the exercises provided a useful mechanism to facilitate conceptual model development without an active facilitator.

Following the workshop, content was synthesized with recommended data, reference, model resources as well as supplemented with literature search to develop a quantitative, index-based model. For each ecosystem, a model "fact sheet" was assembled to include key resources, construction impacts, critical uncertainties, an ecosystem-specific conceptual model, a table of important variables with supporting logic, and a suite of proposed suitability index curves (the main parameterization of an index-based model). A consistent format was used for all models to provide reviewers and agency partners with a predictable mechanism for communication.

Workshop-4: The final, half-day workshop focused on revision and evaluation of conceptual and quantitative models by more than 30 interagency attendees, with ~50% attendee overlap with Workshop-3 (November 2019). Model "fact sheets" from Workshop-3 were presented as posters (Figure 5A), and attendees were encouraged to revise, edit, and propose alternative approaches (Figure 5B). Attendees were given a brief description of the modeling strategy and example "fact sheets" prior to the workshop to understand the modeling strategy and format for input.

External revision and confirmation of model structure provided a useful mechanism for informal model evaluation. Notably, all models were presented in draft format, and in fact, some models were less developed than others with specific notes and questions for attendees. The open format helped attendees understand how models were developed and ultimately enhanced "buy-in" to the modeling process by providing opportunity for input on technical details. Evaluations identified some models requiring additional development and others as relatively complete. Data gaps were also identified by developers, which participants were able to fill (e.g., a request for site contamination data was met by partners at the US Environmental Protection Agency). The informal nature of open discussion allowed developers and attendees to discuss future challenges associated with model application (e.g., How should models be applied for different operational scenarios for proposed infrastructure?). Models were subsequently revised post-workshop.



(A)

Estuarine: Subtidal

(Information Gathering)

Where is this system?
Proposed spatial boundary:
- Salinity = 0.5 to 30ppt
- Mean Low Water (MLW) to -100m below Mean Tidal Level (MTL)

What processes define the "quality" of this ecosystem?
- Process: What is the process or variable you are capturing (e.g., temperature)? Why does it matter (e.g., temperature drives secondary production)? What clarifications are needed (e.g., summer temperature or life stage)?
- Metric: What specifically is the focal outcome (e.g., duration of time above MHHW)? Is a proxy metric sufficient (e.g., residence time as a surrogate for water quality)?
- Assessment: What data are needed to assess this process? Are empirical data readily available throughout the study area? Can this process be modeled?
- Evidence Base: What serves as the evidence base of this process (e.g., peer-reviewed study by Smith and Jones, grey literature report by USACE, unpublished data collected by USGS, professional judgment)?

Existing Models

Key Uncertainties

Key Studies & References

Transient Impacts & Construction Issues

(B)

Estuarine: Subtidal

(Conceptual Model Building)

How do key processes interact with each other?
Use variables from Exercise-1 to draw or define a conceptual model. A conceptual model could be a "box-and-arrow" diagram, a table, a sketch, or any other rendering describing "how the system works".

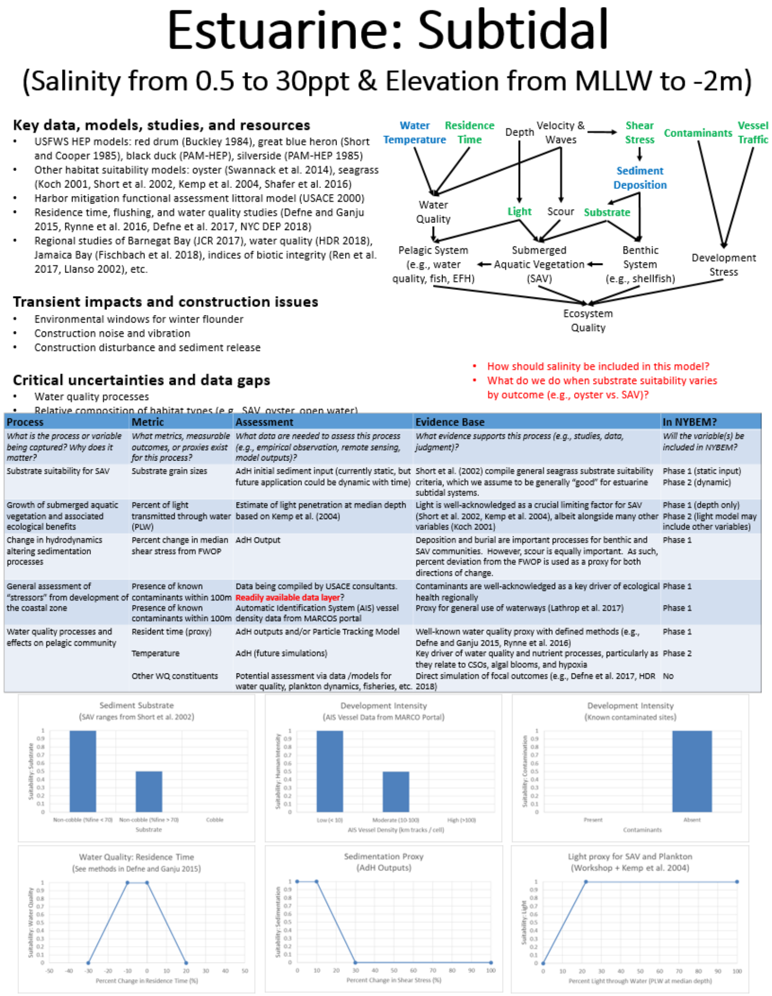
How does the system qualitatively respond to key variables?
The goal of this exercise is to lay the foundation for numerical model development by describing qualitative responses and key thresholds in response.
- Select a "priority" variable from Exercise-1.
- Draw a qualitative response to this variable (and note any supporting knowledge).
- Add numerical scales and alternative hypotheses to each figure, where possible.

(C)

(D)

Figure 4. Methods for conceptual model development at Workshop-3. Posters for information gather in morning session (A) and conceptual model building in afternoon session (B). Attendee input on model components and relative ranking via sticker exercise using morning poster (C) and preliminary rendering of conceptual model using afternoon poster (D).

Future Development: Workshops 1-4 focused on model scoping, identification of a modeling strategy, development of ecosystem-specific conceptual models, and evaluation of proposed numerical models, respectively. Deep engagement with external audiences has benefitted NYBEM development, particularly given the complexity and scope of the NJBB and HATS. Potential opportunities for future engagement could include: (a) External review of formal model documentation; (b) Presentation of model application to future without project conditions, which would provide an alternative mechanism for evaluation; (c) Development of a second "phase" of models to align with project planning needs of the tiered NEPA process; and (D) Development of an interactive, web-based platform for sharing model results.



Estuarine: Subtidal

(Salinity from 0.5 to 30ppt & Elevation from MLLW to -2m)

Key data, models, studies, and resources

- USFWS HEP models: red drum (Buckley 1984), great blue heron (Short and Cooper 1985), black duck (PAM-HEP), silverside (PAM-HEP 1985)
- Other habitat suitability models: oyster (Swannack et al. 2014), seagrass (Koch 2001, Short et al. 2002, Kemp et al. 2004, Shafer et al. 2016)
- Harbor mitigation functional assessment littoral model (USACE 2000)
- Residence time, flushing, and water quality studies (Defne and Ganju 2015, Rynne et al. 2016, Defne et al. 2017, NYC DEP 2018)
- Regional studies of Barnegat Bay (JCR 2017), water quality (HDR 2018), Jamaica Bay (Fischbach et al. 2018), indices of biotic integrity (Ren et al. 2017, Llanso 2002), etc.

Transient impacts and construction issues

- Environmental windows for winter flounder
- Construction noise and vibration
- Construction disturbance and sediment release

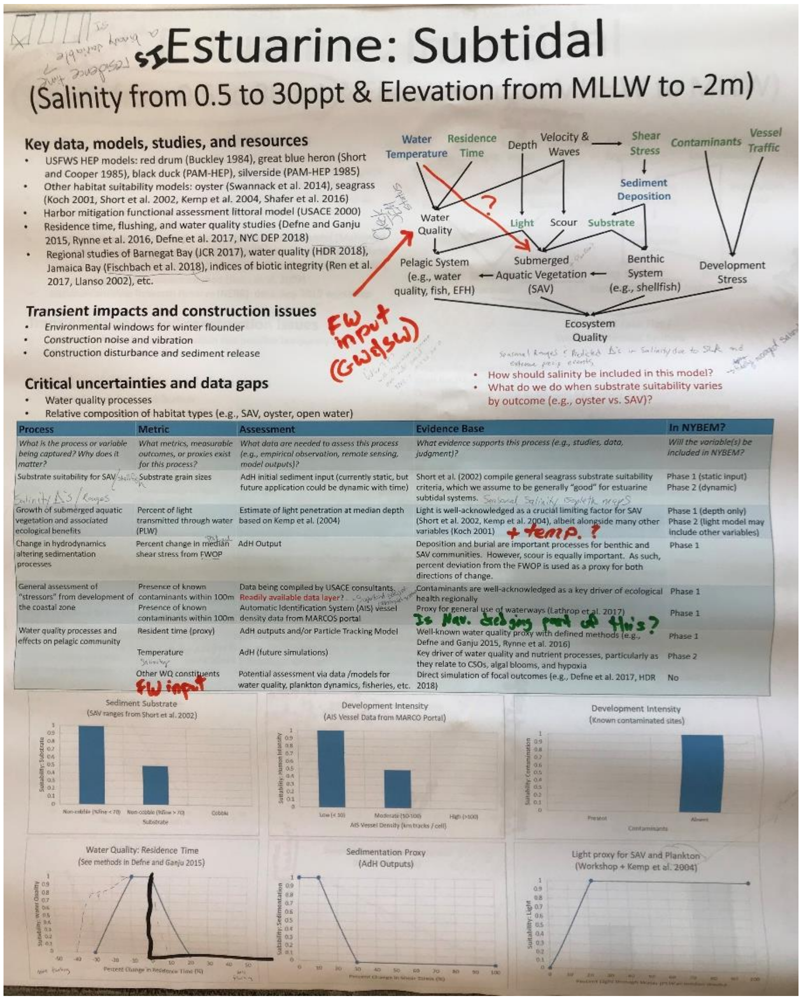
Critical uncertainties and data gaps

- Water quality processes
- Relative composition of habitat types (e.g., SAV, oyster, open water)

- How should salinity be included in this model?
- What do we do when substrate suitability varies by outcome (e.g., oyster vs. SAV)?

Process	Metric	Assessment	Evidence Base	In NYBEM?
What is the process or variable being captured? Why does it matter?	*What metrics, measurable outcomes, or proxies exist for this process?*	*What data are needed to assess this process (e.g., empirical observation, remote sensing, model outputs)?*	*What evidence supports this process (e.g., studies, data, judgment)?*	*Will the variable(s) be included in NYBEM?*
Substrate suitability for SAV	Substrate grain sizes	AdH initial sediment input (currently static, but future application could be dynamic with time)	Short et al. (2002) compile general seagrass substrate suitability criteria, which we assume to be generally "good" for estuarine subtidal systems.	Phase 1 (static input) Phase 2 (dynamic)
Growth of submerged aquatic vegetation and associated ecological benefits	Percent of light transmitted through water (PLW)	Estimate of light penetration at median depth based on Kemp et al. (2004)	Light is well-acknowledged as a crucial limiting factor for SAV (Short et al. 2002, Kemp et al. 2004), albeit alongside many other variables (Koch 2001)	Phase 1 (depth only) Phase 2 (light model may include other variables)
Change in hydrodynamics altering sedimentation processes	Percent change in median shear stress from FWOP	AdH Output	Deposition and burial are important processes for benthic and SAV communities. However, scour is equally important. As such, percent deviation from the FWOP is used as a proxy for both directions of change.	Phase 1
General assessment of "stressors" from development of the coastal zone	Presence of known contaminants within 100m	Data being compiled by USACE consultants. Readily available data layer?	Contaminants are well-acknowledged as a key driver of ecological health regionally	Phase 1
	Presence of known contaminants within 100m	Automatic Identification System (AIS) vessel density data from MARCOS portal	Proxy for general use of waterways (Lathrop et al. 2017)	Phase 1
Water quality processes and effects on pelagic community	Resident time (proxy)	AdH outputs and/or Particle Tracking Model	Well-known water quality proxy with defined methods (e.g., Defne and Ganju 2015, Rynne et al. 2016)	Phase 1
	Temperature	AdH (future simulations)	Key driver of water quality and nutrient processes, particularly as they relate to CSOs, algal blooms, and hypoxia	Phase 2
	Other WQ constituents	Potential assessment via data /models for water quality, plankton dynamics, fisheries, etc.	Direct simulation of focal outcomes (e.g., Defne et al. 2017, HDR 2018)	No

(A)



SI Estuarine: Subtidal

(Salinity from 0.5 to 30ppt & Elevation from MLLW to -2m)

residence time a binary variable

Key data, models, studies, and resources

- USFWS HEP models: red drum (Buckley 1984), great blue heron (Short and Cooper 1985), black duck (PAM-HEP), silverside (PAM-HEP 1985)
- Other habitat suitability models: oyster (Swannack et al. 2014), seagrass (Koch 2001, Short et al. 2002, Kemp et al. 2004, Shafer et al. 2016)
- Harbor mitigation functional assessment littoral model (USACE 2000)
- Residence time, flushing, and water quality studies (Defne and Ganju 2015, Rynne et al. 2016, Defne et al. 2017, NYC DEP 2018)
- Regional studies of Barnegat Bay (JCR 2017), water quality (HDR 2018), Jamaica Bay (Fischbach et al. 2018), indices of biotic integrity (Ren et al. 2017, Llanso 2002), etc.

Transient impacts and construction issues

- *Environmental windows for winter flounder*
- Construction noise and vibration
- Construction disturbance and sediment release

Critical uncertainties and data gaps

- Water quality processes
- Relative composition of habitat types (e.g., SAV, oyster, open water)

Seasonal Ranges & Predicted Δ's in Salinity due to SLR and extreme precip events

- How should salinity be included in this model?
- What do we do when substrate suitability varies by outcome (e.g., oyster vs. SAV)?

Process	Metric	Assessment	Evidence Base	In NYBEM?
What is the process or variable being captured? Why does it matter?	*What metrics, measurable outcomes, or proxies exist for this process?*	*What data are needed to assess this process (e.g., empirical observation, remote sensing, model outputs)?*	*What evidence supports this process (e.g., studies, data, judgment)?*	*Will the variable(s) be included in NYBEM?*
Substrate suitability for SAV/shellfish Salinity Δ's / Ranges	Substrate grain sizes	AdH initial sediment input (currently static, but future application could be dynamic with time)	Short et al. (2002) compile general seagrass substrate suitability criteria, which we assume to be generally "good" for estuarine subtidal systems. Seasonal Salinity [illegible] ranges	Phase 1 (static input) Phase 2 (dynamic)
Growth of submerged aquatic vegetation and associated ecological benefits	Percent of light transmitted through water (PLW)	Estimate of light penetration at median depth based on Kemp et al. (2004)	Light is well-acknowledged as a crucial limiting factor for SAV (Short et al. 2002, Kemp et al. 2004), albeit alongside many other variables (Koch 2001) + temp. ?	Phase 1 (depth only) Phase 2 (light model may include other variables)
Change in hydrodynamics altering sedimentation processes	Percent change in median shear stress from FWOP	AdH Output	Deposition and burial are important processes for benthic and SAV communities. However, scour is equally important. As such, percent deviation from the FWOP is used as a proxy for both directions of change.	Phase 1
General assessment of "stressors" from development of the coastal zone	Presence of known contaminants within 100m	Data being compiled by USACE consultants. Readily available data layer?	Contaminants are well-acknowledged as a key driver of ecological health regionally	Phase 1
	Presence of known contaminants within 100m	Automatic Identification System (AIS) vessel density data from MARCOS portal	Proxy for general use of waterways (Lathrop et al. 2017) Is Nav. dredging part of this?	Phase 1
Water quality processes and effects on pelagic community	Resident time (proxy)	AdH outputs and/or Particle Tracking Model	Well-known water quality proxy with defined methods (e.g., Defne and Ganju 2015, Rynne et al. 2016)	Phase 1
	Temperature Salinity	AdH (future simulations)	Key driver of water quality and nutrient processes, particularly as they relate to CSOs, algal blooms, and hypoxia	Phase 2
	Other WQ constituents FW input	Potential assessment via data /models for water quality, plankton dynamics, fisheries, etc.	Direct simulation of focal outcomes (e.g., Defne et al. 2017, HDR 2018)	No

(B)

Figure 5. Example of methods for ecosystem-specific conceptual model refinement from Workshop-4 for the estuarine, subtidal ecosystem: (A) pre-workshop poster summarizing the conceptual model and proposed quantitative model and (B) refinements, edits, and ideas submitted by interagency attendees.

LESSONS LEARNED: In this section, we present lessons learned in NYBEM development that are transferrable to other projects (regardless of scale). Readers are also encouraged to consult other guidance on conceptual modeling best practices (e.g., Fischenich 2008, Casper et al. 2010, McKay and Pruitt 2012, Fischenich and Barnes 2014).

Value of conceptual models for different purposes: Conceptual models often target multiple audiences; for instance, Fischenich (2008) identifies ten common uses of conceptual models throughout the life cycle of an ecosystem restoration project. Here, multiple conceptual models were developed to meet different project needs related to rapid communication of overarching system function (Figure 3) as well as technical details of ecosystem-specific conceptual models to guide quantitative tool development (Figure 5). Throughout the project, conceptual models served as a crucial tool for building shared understanding, communicating with interdisciplinary audiences, and structuring thinking about environmental effects of CSRM projects.

Significance of transparency in model building: Workshop-based model development often increases transparency for complex technical issues (Herman et al. 2019). Mediated modeling methods break down silos between disciplines and organizations as participants work together to build models. Furthermore, workshops serve as a means to broader team building, open dialog about technical issues, and productive engagement. Mediated modeling methods are a valuable part of a broader strategy for model communication, which also relies on adequate documentation, effective data visualization, and transparent sharing of data and code.

Importance of the meeting invitation: Workshop-based mediated modeling is an investment by the agency leading development as well as attendees and their respective organizations. Ultimately, the structure and content of a model depend, in part, on those developing it. Thought and care should be given to how potential participants are identified and engaged, for instance: How was the participant list identified? Are the "right" disciplines and partners included? Is a trusted party (i.e., a champion) used for initial communication? Does the invitation include relevant context and background? Crawford et al. (2017) provide a more thorough treatment of workshop initiation for structured decision-making, which also applies to modeling workshops.

Setting the stage for an effective workshop: Mediated modeling workshops can be intellectually demanding activities with ambitious goals and objectives. Organizers should carefully consider the best way to prepare participants and set expectations. A detailed agenda, clearly stated goals, read-ahead documents, and introductory presentations all serve valuable roles in preparing attendees and making a workshop more effective. For instance, Workshop-3 provided a detailed read-ahead as well as an introductory presentation to set the tone for the day. In particular, attendees were reminded that model development is a participatory exercise, and they were encouraged to provide input. However, some attendees felt unprepared to provide specific references, models, data sets, or points-of-contact spontaneously and preferred to follow-up after the meeting. If participants are expected to provide detailed content, it may be useful to recommend they bring notes to the meeting or treat the workshop as an "open book" exercise.

Creating a level playing field: Workshop participants rarely arrive with equivalent understanding of ecological modeling (e.g., population modeling theory), the study system (e.g., experts on benthic and riparian habitats), constraints on model development (i.e., project scope, schedule, and resources), or mediated modeling (i.e., development processes). Organizers should strive to provide sufficient background when opening the workshop and facilitating. For instance, exercises or break-out sessions should be clearly explained along with the expected products of activities. In some cases, organizers can structure exercises (e.g., with worksheets or posters) to facilitate good outcomes. Modeling workshops are often most productive when focusing on technical issues (e.g., NYBEM) rather than specifics of a project (e.g., NJBB or HATS).

Significance of facilitation: A facilitator or workshop leader manages the workshop environment in small and large ways that collectively impact an attendee's meeting experience. For mediated modeling specifically, the leader should be seen as an "honest broker" who is not vested in a particular outcome or strategy. From the outset, a workshop should try to set a collaborative, positive, respectful, and technical tone, rather than confrontational and project-specific. A range of facilitation choices are crucial to the outcome of any meeting (Marcy 2013), including: agenda setting (i.e., time management, breaks), selection of exercises (e.g., group size, structured vs. unstructured, break-outs vs. posters vs. large group, presentation vs. activity), and ensuring attendees' comfort (e.g., break timing, snacks, healthcare needs). A facilitator must balance the need to keep moving toward the stated goals, while allowing for flexibility when needed (e.g., workshop-2 started with one goal and finished with another based on participant input). Simply put, an effective modeling workshop is first an effective meeting and then a technical dialog.

Importance of interim model review: Workshops provide a useful mechanism for informal review and input, which helps avoid modeling problems and controversies early in a project. By engaging external partners in the process, they have an opportunity to provide direction and indicate what approach, references, variables, or data are the "right" ones. Model development also aligns well with the USACE planning process (McKay et al. 2019) and provides an opportunity to develop relationships with stakeholders aside from project-specific controversies.

Potential for over-reliance on the meetings: Mediated modeling workshops are not a substitute for good modeling practice; they are information gathering and consensus building components of it. Models are rarely developed purely in a meeting, and critical work is done between meetings to execute the workshop ideas. For instance, concepts proposed at workshops must be vetted against and augmented with other resources (e.g., peer-reviewed literature, data analysis).

Iteration helps with model building: A series of workshops with USACE and non-USACE audiences is being used to construct NYBEM, which allows for sequentially refining models. While all projects may not have the resources or scope to convene multiple workshops, some degree of iteration is likely possible and should be pursued (McKay and Pruitt 2012). For instance, Workshop-1 was effectively an expanded NJBB project team meeting.

SUMMARY: The NJBB and HATS projects are large-scale efforts focused on regional CSRM actions affecting many stakeholders, agencies, and outcomes. Mediated ecological model development has been shown to be a useful mechanism for transparently developing tools to inform these types of complex environmental decisions (Voinov and Bousquet 2010, Herman et al. 2019). McKay and Pruitt (2012) identified consistency, efficiency, collaboration, and identification of key uncertainties as benefits of constructing regional ecological models, all of which were hallmarks of the ecological modeling activities described here. The NYBEM is being developed with a five-step model process focused on conceptualization, quantification, evaluation, application, and communication (Grant and Swannack 2008), and multi-agency processes were a crucial component to the development strategy. This technical note documents mediated model development at a series of four workshops over the course of a year with four major outcomes: (1) an overarching conceptual model of the ecosystem for communication with broad audiences (Figure 3), (2) a suite of process-oriented, ecosystem-specific conceptual models (e.g., Figure 5), (3) a basic quantitative structure upon which to build numerical models, and (4) a group of partners and resources to inform and review models.

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