SURGE BARRIER ENVIRONMENTAL EFFECTS AND EMPIRICAL EXPERIENCE

WORKSHOP REPORT

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Surge Barrier Environmental Effects and Empirical Experience Workshop Report

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Executive Summary

Storm surge barriers or tide gates can effectively protect harbors and minimize flooding, property damage, and loss of life during large storms. However, studies of possible location, design and operation of barriers need to consider the impacts to an estuary's tidal range, salinity, stratification, sediment transport, and other physical factors, which in turn may affect water quality, wetlands, ecological processes, and living resources.

A study of this topic is currently underway in the New York City metropolitan area, an area with highly valuable and vulnerable coastal infrastructure. The U.S. Army Corps of Engineers (USACE), in cooperation with the New York State Department of Environmental Conservation (NYSDEC) and New Jersey Department of Environmental Protection (NJDEP) and in partnership with the City of New York, is undertaking the New York and New Jersey Harbor and Tributaries (HAT) Focus Area Feasibility Study to examine measures to reduce future flood risk and the economic costs and risks associated with flood and storm events, while contributing to the resilience of communities and important infrastructure. The potential cross-estuary surge barriers being considered within the New York/New Jersey (NY/NJ) Harbor Estuary and relevant to this report include: an Outer Harbor barrier (Sandy Hook to Rockaway Peninsula), Throgs Neck barrier, Verrazzano Narrows barrier, Jamaica Bay barrier, Arthur Kill barrier, Kill van Kull barrier and Hackensack River barrier.

A workshop was held in September 2019, titled Surge Barrier Environmental Effects and Empirical Experience, as part of a project funded by the National Estuarine Research Reserve Science Collaborative. The workshop goals were to: (1) identify the present scientific understanding regarding surge barrier environmental effects, highlighting both areas of consensus and divergence; (2) identify key additional data, research and models; (3) build collaboration among people involved in the topic around the world, including empirical data and experience from past surge barrier projects, as well as approaches for evaluating environmental effects in present studies; and (4) improve the scientific foundation for Decision-maker End Users within the HAT Study.

Three main focus topics for the workshop were (a) empirical experience from constructed gated storm surge barriers, (b) potential surge barrier effects on migrating organisms, and (c) potential surge barrier effects on tidal wetlands. The workshop's presentations and break-out sessions identified key areas of agreement, but also areas where research is needed. Several key takeaways and research needs are listed in Section 9, but highlights include:

- Examples of constructed storm surge barriers show that the degree of environmental impacts (post-construction) scales with the degree of obstruction of tidal flows, and suggest that by minimizing flow obstruction, it is possible to avoid severe environmental degradation.

- Globally, little physical and very little biological data are available to describe the pre-construction condition of riverine and estuarine systems where surge barriers have been constructed. This makes it difficult to comprehensively assess the effects of barriers on these systems or to know how the ecological systems have changed.
- A more complete set of baseline environmental measurements is needed for the NY/NJ Harbor-Estuary, including data on what organisms are present, when, and how.
- More research is needed into the region's estuarine and tidal river sedimentary systems and to identify the types of events that are important to sediment deposition in tidal marshes.
- If a gated barrier system is built to protect against storm surge, then significant expenditures will still be required in future decades for adaptive management of sea level rise (e.g. through raised shoreline seawalls) and likely also for unexpected environmental effects.

The USACE has a variety of studies underway that will address several of the issues raised in this forum, including the development of an ecological model of the NY Bight system. The Corps noted that no construction will occur without thorough environmental evaluation and coordination with environmental resource agencies.

1. Introduction

Coastal cities around the nation are exploring structural engineering options for defending against extreme storms and the resulting surges of ocean water that cause massive flooding. Storm surge barriers or tide gates can effectively protect harbors and minimize flooding, property damage, and loss of life during large storms. These barriers typically span the opening to a harbor or river mouth and include gates that are only closed when storm surges are expected. However, even when gates are open, the barriers may reduce water flow and tidal exchange, which in turn could affect water quality and ecological processes.

A study of this topic is currently underway in the New York City metropolitan area, an area with highly valuable and vulnerable coastal infrastructure. The U.S. Army Corps of Engineers (USACE), in cooperation with the New York State Department of Environmental Conservation (NYSDEC) and New Jersey Department of Environmental Protection (NJDEP), and in partnership with the City of New York, is undertaking the New York and New Jersey Harbor and Tributaries (HAT) Focus Area Feasibility Study to examine measures to reduce future flood risk and the economic costs and risks associated with flood and storm events that are affecting the HAT study area, while contributing to the resilience of communities and important infrastructure. A major goal of the HAT study is to find the optimal choice of risk reduction, be it elevated waterfronts, cross-harbor surge barriers or side-estuary surge barriers. The study is driven by a very serious problem, in that coastal flood vulnerability and risk is very high in the region. The study's interim report (USACE, 2019) estimated that expected average annual average damages in 2030 will be $5.1 billion and by 2100 will rise to $13.7 billion under an intermediate sea level rise trajectory.

The National Estuarine Research Reserve Science Collaborative funded a "Catalyst" project for one year with the working title *Estuary Effects of Storm Surge Barriers* and the following goals: (1) to facilitate development of a collaborative research agenda that can help interested parties better understand potential barrier effects on nearby estuaries, and (2) to undertake targeted research in close collaboration and with information-sharing among scientists and key end-users such as the U.S. Army Corps of Engineers (USACE) and its partners. The project team is conducting modeling and analyses of the physical influences of surge barriers and hosting a series of workshops to synthesize and share information. More details are given in the Background section below.

The Estuary Effects project convened a workshop titled *Surge Barrier Environmental Effects and Empirical Experience* on Friday September 13, 2019, at the Hudson River Foundation. Goals of the workshop were to:

- Identify the present scientific understanding regarding surge barrier environmental effects, highlighting both areas of consensus and divergent views, and identify key additional data, research and models

- Build collaboration among people involved in the topic around the world, including empirical data and experience from past surge barrier projects, as well as approaches for evaluating environmental effects in present studies
- Improve the scientific foundation for Decisionmaker End Users within the HAT Study

Three main focus topics for the workshop were developed during a prior Scoping Session workshop attended by 35 people and the Estuary Effects study's 14-member Project Advisory Committee. These topics were (1) empirical experience from constructed gated storm surge barriers, (2) potential surge barrier effects on migrating organisms, and (3) potential surge barrier effects on tidal wetlands.

This report summarizes the September workshop's content, as well as key discussion points and emerging recommendations, generally following the same order as the workshop. In Section 2 we give more detail on the HAT Study and Estuary Effects study, including a demonstration of how sea level rise can affect surge barrier closure frequency and duration. In Section 3, preliminary research results are presented on how sea level rise can influence barrier closure frequency and duration. Section 4 reviews two presentations given on past "empirical experiences" – case studies of surge barriers in the Netherlands and United Kingdom. Section 5 gives more specifics relating to the HAT Study and its evaluation of environmental effects of surge barriers. Section 6 and 7 are science background presentations on the topics #2 and #3 above, and Section 8 summarizes the two subsequent breakout sessions on these topics. The report conclusions and project next steps are given in Section 9. The agenda with presentation URL links, and a list of attendees are included in Appendices A and B.

2. Background

2.1 Harbor and Tributaries Study

Bryce Wisemiller, USACE Project Manager for the HAT Study, gave a review of the study. The study region is the largest and most densely populated of the nine high-risk focus areas identified in the North Atlantic Coast Comprehensive Study (NACCS). Its area covers 2,150+ square miles and 900+ miles of affected shoreline, including 25 counties in New York & New Jersey and an affected population of roughly 16 million people, including New York City and some of the most populated cities in New Jersey. Under existing conditions, this region could be subjected to water levels varying spatially from 14 to 21 feet for a 0.2% annual chance storm (at the "upper 95% confidence limit", i.e. reflecting a high-end 97.5th percentile estimate).

Local sea level rise scenarios were shown, to give context of USACE scenarios as well as New Jersey's and New York City's own projections. For the year 2100, these range from 0.7 to 5.0 feet in the USACE scenarios, up to 6.25 feet for the New York City Panel on Climate Change (NPCC) 90th-percentile and up to 10 feet for New Jersey's 99.9th-percentile. For the purposes of benefit-cost analysis in the present phase of the HAT Study, an intermediate sea level rise curve is being used that projects about 2.0 feet of sea level rise by 2100. However, a sensitivity analysis will be performed using the NPCC 90th-percentile projection for 2100.

Coastal storm risk management (CSRM) Alternatives in the HAT Study range from those with significant in-water structures (e.g. surge barriers) to those with only shoreline based measures (e.g. seawalls). Of particular interest to the Estuary Effects study are Alternatives 2, 3a, 3b, and 4, all of which have gated surge barriers crossing major estuarine regions (**Figure 1**). Alternative 2 includes the Outer Harbor barrier (Sandy Hook to Rockaway Peninsula) and Throgs Neck barrier. Alternative 3A includes the Throgs Neck, Verrazzano Narrows (**Figure 2**), Jamaica Bay and Arthur Kill barriers. Alternative 3B includes the Arthur Kill, Kill van Kull and Jamaica Bay barriers and Alternative 4 includes a Jamaica Bay and Hackensack River barrier.

Figure 1: Map of conceptual storm surge barrier locations

The net benefit for each Alternative is the benefit of reduced damages minus cost, computed over a 50-year lifespan from when the barrier begins operation. Estimates as of July 2019 were shown, based on either of two assumed management options: (1) large gates initially operating only for 10% annual exceedance probability (AEP) events (i.e. a 10-year return period event), and (2) large gates initially operating only for 50% AEP events (i.e. a 2-year return period event). Net benefits ranged from $30 to 130 billion, on a present worth basis. Alternative 3A had the greatest benefits for closure at 50% AEP. Net benefits for Alternatives 3A, 3B and 4 were similar for closures at 10% AEP (less frequent closure).

Figure 2: Rendering of example surge barrier and gates at Verrazzano Narrows, for illustration purposes only. Design and siting subject to change).

Many factors were listed that affect the screening of Alternatives and need further evaluation and the net benefit estimates and preferred options are still to be determined. Upcoming dates in the HAT Study include a Draft Integrated Feasibility Report and Tier 1 Environmental Impact Statement (EIS) (including the TSP decision) in summer 2020, public meetings on the draft report in fall 2020, Final Integrated Feasibility Report and Tier 1 EIS (summer 2021), and final Chief Engineer's Report (summer 2022).

Sea level rise will increase the need for closures, if a constant vertical water level trigger is used to determine closures. However, once sea levels rise enough to cause this trigger to be exceeded more frequently, the likely plan is to adjust the threshold periodically (e.g. every decade), to track an annual exceedance probability (AEP) of either 50% or 10% (TBD). As such, barriers would not be used to protect against flood risk solely from long-term sea level rise and sunny-day flooding – they would be used to protect against storm surge events (as exacerbated by sea level rise). Future increases to chronic "sunny-day" flooding are not, by definition, driven by coastal storms, and occur in future decades so are not the primary focus of the USACE study. However, they are seeking to address them in the longer-term HATS plans.

2.2 Estuary Effects Study: Spatial Domain

The Estuary Effects Study evaluates potential physical and ecological effects of gated surge barriers, and was originally intended to focus on the Hudson River estuary from NY/NJ Harbor up to Troy. While this was the project's main focus, it was made clear up front that the workshop participants could also consider other parts of the network of estuaries, as needed. For discussion of tidal wetlands, the workshop participants could consider similar sub-estuaries with wetlands such as the Hackensack and Raritan. For migrating organisms, the entire multi-estuary system was deemed relevant for discussion.

3. Estuary Effects Study: Research Overview and Preliminary Results

Philip Orton presented an overview of the Estuary Effects Study's research, including useful demonstrations of how sea level rise could affect barrier closures and their effects. Research is being conducted on the following:

- gate closure frequency and duration and future evolution with sea level rise,
- inter-comparisons of existing model results from scientists and the USACE,
- the influence of gate closures on estuary physical conditions, and
- the potential for trapped river water flooding.

The gate closure frequency and duration are important because both strongly influence the effects of a surge barrier system on the enclosed estuaries. These results have been drafted, and are shown below.

The study's analyses use simplifying assumptions regarding sea level rise and surge barrier management that are different from the HAT Study analyses, so should be viewed as qualitative. Analysis of barrier gate closures contrasted two potential approaches for managing barrier gate closure: (1) the case of a constant water level "trigger" and (2) the case of a constant annual exceedance probability (AEP) such that the trigger water level rises as sea levels rise. The HAT Study is presently calling for the latter, yet it is still valuable to consider estuary effects under both scenarios.

Preliminary research results for a constant water level trigger demonstrate how sea level rise could cause increases to the frequency and duration of barrier gate closures (**Figure 3**). The

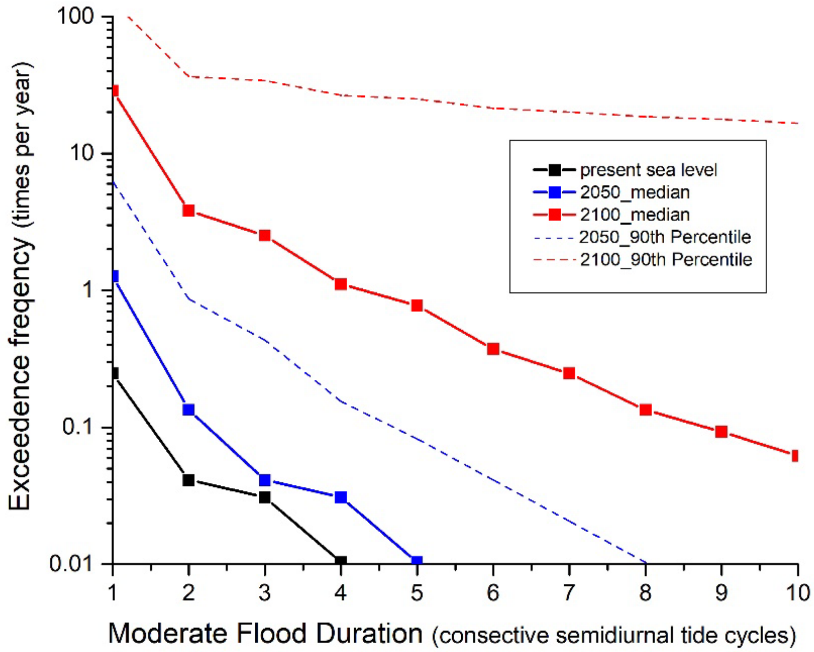

Figure 3: Preliminary research result showing future evolution of gate closure frequency and duration due to sea level rise, based on an assumption of a constant water level trigger of 1.74 m NAVD88 (the National Weather Service's "moderate flood" level for The Battery tide gauge). The sea level rise scenario for greenhouse gas emissions pathway RCP4.5 is used here. For future decades of 2050 and 2100, cases of median and 90th percentile sea level rise are shown.

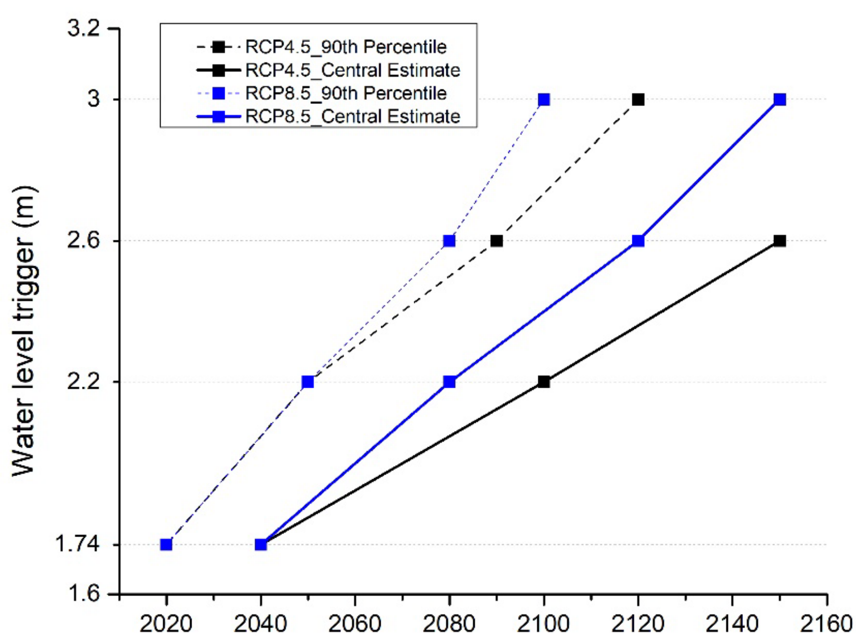

Figure 4: Preliminary result showing future evolution of the water level trigger due to sea level rise, based on the assumption that gate closures occur only for water levels with a 50% AEP. Sea level rise scenarios are shown of RCP 4.5 and 8.5, cases of median and 90th percentiles.

water level trigger used here is National Weather Service's "moderate flood" level of 1.74 m, and a sea level rise scenario is used that is based on a RCP 4.5 future greenhouse gas emissions trajectory. Preliminary research results for a constant gate closure AEP show how the trigger water level could rise in future decades (**Figure 4**). Because this scenario assumes that the gates would not be closed for lower water levels, this is equivalent to the required elevation for protective shoreline-based measures. Here, the closure AEP was assumed to be 50%. This research can help inform the HAT Study benefit-cost analyses and discussions about barrier gate closure management.

4. Empirical Experiences of Estuary Effects on Surge Barriers

Given the limited studies of barriers in the United States that include pre- and post- construction monitoring, the workshop's morning session focused on empirical experiences in other nations. Several speakers and cases were identified and discussed with the Estuary Effects Project Advisory Committee, prior to inviting two speakers from overseas.

4.1 Dutch Experiences

Bram van Prooijen, Associate Professor of Hydrodynamics and Sediment Dynamics at Delft University of Technology, reviewed Dutch experiences on the impact of storm surge barriers. Storm surge barriers are an essential part of the protection of the Netherlands against flooding (e.g. **Figure 5**). Large parts of the Netherlands are prone to flooding, and high safety standards (based on the risk: chance of occurrence and subsequent loss) are required because of the large vulnerable population as well as the challenge of getting water out of areas below sea level once they are flooded. The environmental impact of the Rotterdam storm surge barrier (Maeslant Barrier) has been small, as the flow cross section was not significantly influenced by its construction and it has been closed only twice since 1997. In contrast, in the Eastern Scheldt the cross section was significantly changed by the 1985 construction of a storm surge barrier (both are shown in **Figure 5**). The morphological and ecological impact of this barrier was, therefore, further discussed.

The Eastern Scheldt barrier experience provides insight into the physical and ecological responses that can occur following barrier construction (e.g., Brand et al., 2016). When the surge barrier system was constructed, the mean tide range decreased by about 9%, the estuarine surface area decreased by 22%, and the tide prism decreased by 28%, with increased water speeds in the area of the gates. The barrier has reduced tidal energy and sediment suspension, and eliminated the sediment flux from the ocean through the barrier into the estuary. The system is out of equilibrium, as the channels are too deep for the limited tidal energy. This leads erosion of the intertidal flats and filling of the channels (De Vet et al., 2017). Erosion mitigation measures are now being explored, such as tidal flat sediment nourishment and oyster shell gabions that can grow into reefs.

Figure 5: (left) Maeslant Storm Surge Barrier near Rotterdam. (right) Eastern Scheldt Storm Surge Barrier.

While the ecology of the resulting Eastern Scheldt water body is generally considered to have been quite resilient to the changes, little pre-construction monitoring data exists. There are no data to indicate pre-construction biodiversity. Effects of the changes on birds and benthos have been modest (e.g. 20-30% reduction in some bird taxa (Troost & Ysebaert, 2011) until now, but loss of intertidal flats could eventually have major effects, especially with the more pessimistic future sea level rise scenarios. Bram was not aware of any data observing changes in fish population or diversity. The estuary has substantial aquaculture (mussels, oysters, lobsters) and many seals and porpoises, though there is some debate about the health of the latter population. The concern was raised that the seal population inside the estuary is no longer mixing with the population outside the estuary, and that this isolation could have negative consequences. For further reading, volume 282/283 in the peer-reviewed journal *Hydrobiologia* covers the ecological impacts to the Eastern Scheldt from top to bottom (Nienhuis & Smaal, 1994).

Accelerated sea level rise will lead to exponential increase in closure frequency. In 2050 the Eastern Scheldt is expected to be closed four times a year, while it will increase to about two hundred times per year after 2100.

Van Prooijen's remarks focused on the following conclusions and lessons learned:

Conclusions

- Examples of constructed storm surge barriers show that the degree of environmental impacts (post-construction) scales with the degree of obstruction of tidal flows, and suggest that by minimizing flow obstruction it is possible to avoid severe environmental degradation.

- The Dutch consider the Eastern Scheldt a healthy ecosystem, especially compared to other, fully dammed estuaries, but pre-construction biological monitoring data are very limited.
- It has clear water contains many species (also invasive species), and supports aquaculture
- A well-understood negative ecological impact of the barrier is that it reduced sediment supply to intertidal zones in the estuary, inducing erosion and loss of intertidal areas, as explained above.

Lessons learned:

- A substantial amount of money (~$2.5 billion USD) was available, for design, construction and monitoring in the early 1990s. This boosted research on hydraulic engineering and ecology.
- There was a set of baseline physical measurements (salinity, sediment, tides), but a more detailed set over a longer time would have been helpful.
- Monitoring does not stop after five years as many processes have a time lag. Therefore: continue monitoring over decades.
- Mitigation after construction of some negative effects is possible – e.g. through nourishments and artificial reefs.
- The Eastern Scheldt Storm Surge Barrier is considered a success in the Netherlands as it provides the safety of the hinterland and the ecosystem is relatively healthy compared to other, fully dammed estuaries.

4.2 UK Experiences

Charles Schelpe, Global Technology Leader for Flood Infrastructure at Jacobs Engineering Group, reviewed his experiences with United Kingdom surge barriers. He covered the key stages of the surge barrier life cycle and key environmental factors that should be considered, as well as the barrier management schemes that influence environmental effects. He mainly cited examples of smaller surge barriers, but still felt that many of the effects are the same, regardless of scale.

Major environmental factors are geotechnical and geo-environmental conditions, estuarine processes and geomorphology, flora, fauna and biodiversity, and surface water conditions, including water quality. Key planning needs include understanding the effect of <u>climate change</u> on storm tides, sea level rise, fluvial flows and compound rain/surge probabilities; <u>closure/operation</u> – the barrier closure trigger water level, forecasting error, and frequency and duration of closure; <u>barrier configuration</u> – structure footprint (abutment, sills, scour/erosion protection), reduction in effective cross-sectional area for flow, and changes to flow velocities; and <u>construction methodology and temporary works</u>.

Some examples were given for negative environmental effects, as well as adaptive management solutions that have helped ameliorate them. Localized effects on benthic habitat around the construction area and due to increased water speeds and scour post-construction can potentially be mitigated in advance with habitat creation elsewhere (if space is available). Also, the complete range of conditions must be considered. In one example, maximum water speeds in one system occurred during spring low tides with rain and snowmelt. Areas of scour and shoreline protection were often found to be greater than initially expected, requiring additional hardening. Scour and remobilization of contaminated sediments were a concern with the Ipswich Barrier. Sites have, in some cases, been chosen just below an upriver choke point, like a bridge crossing, so that there is only a small change in cross-sectional area when the barrier is open. The Bridgwater Barrier in the Parrott Estuary (currently in planning stages) was sited further up-river to reduce detrimental effects on the sediment equilibrium (e.g. similar to what was observed in the Eastern Scheldt). Often, adaptive management is used to address habitat or fish passage issues. In the case of the Boston Barrier construction (currently under construction), constraints have been imposed for pile-drive timing and duration, and fish refuges were needed for the temporary bypass. To minimize impacts, fish and eel passage can be optimized with careful study of critical life stages (e.g. **Figure 6**) and gate closure timing/management.

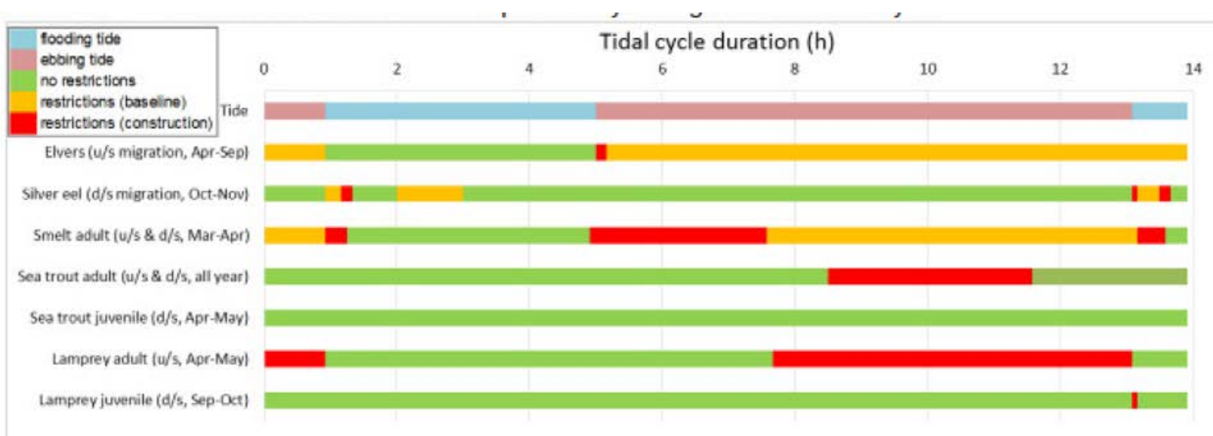

Figure 6: Diagram showing periods of restrictions to fish during the modeled tidal cycle (source: Mott MacDonald)

In his remarks, Schelpe offered some final recommendations and observations, including the following:

- Ensure a baseline understanding of the physical and biological system and consider limits of deviation for the environmental assessment,
- Recognize that management of effects is invariably an iterative process, and invariably involves compromise
- Consider the adequacy/veracity of baseline environmental data
- Think of the opportunities, not just the negatives, associated with barrier development – e.g. there can be some opportunities in habitat creation

- With barriers large or small, the potential effects are often the same, except for their scale

Regarding the first point, he recommended expanding the limits of deviation of the environmental assessment, conceding any large uncertainties. It is easier to plan for the impacts and associated mitigation/costs in advance and shrink them later if more optimistic information becomes available.

5. HATS Study Specifics and Evaluation of Environmental Effects of Surge Barriers

Next, Maarten Kluijver, a Coastal Engineer at Moffatt and Nichol working on the HAT Study, presented on "Geometrical characteristics and considerations for constructed storm surge barriers." Gates in surge barriers accommodate two main functions - navigation and water exchange - and are referred to as Auxiliary Flow Gates and Navigable Gates. The cumulative gate span is the sum of all navigable gate widths and flow gate widths. The total flow area is the sum of cross-sectional areas of all gate spans. If presented as a percentage relative to the unaltered estuary, this is the same as the "gated flow area" (GFA) used by Orton and Ralston (2018). For a given tidal prism or flow rate (e.g. per second), a smaller total flow area leads to higher water speeds through the gates. A brief review was given of prior research on surge barriers worldwide (e.g., Mooyaart & Jonkman, 2017), including the total barrier span widths of HAT Study barriers compared with other systems.

Conceptual designs have been drawn up for possible surge barrier locations for the HAT Study (e.g. **Figure 7**) and all have GFA ranging from 50 to 60%. A conceptual figure showing how water speeds through the gates change as a function of GFA for a simplified 1-basin, 1-storm surge barrier situation was shown, indicating 160-210% (or roughly a doubling of water speeds) may be expected for the listed GFAs. However, the actual changes for the HAT Study storm surge barriers will depend on the local hydrodynamics. Preliminary modeling for all the surge barriers in the HAT Study suggest peak flow speeds of 6 ft/s for the Verrazzano Narrows barrier and 4-5 ft/s for the other barriers.

Responding to an audience question on the status of modeling of barrier estuary effects, Wisemiller said that the Hudson River estuary salinity and sediment modeling for the HAT Study is not yet calibrated, and thus there are not final results detailing how open gates would influence estuary salinity and stratification. However, this is expected to be completed within this phase of study, in the coming months.

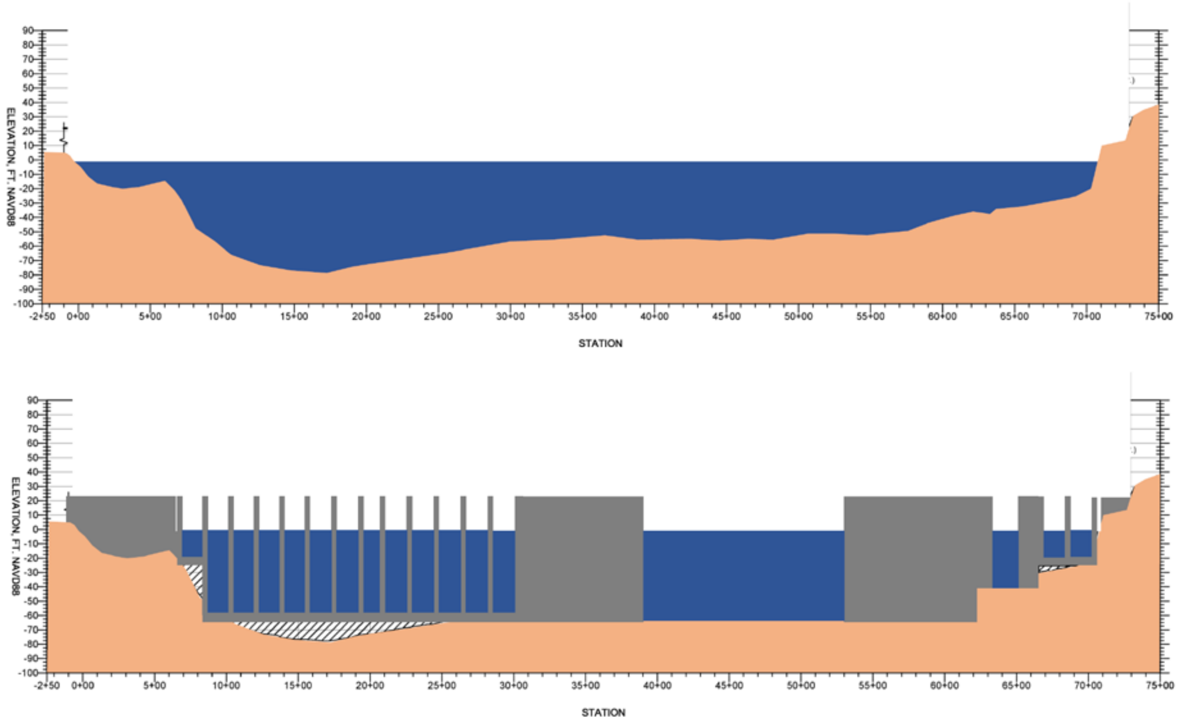

Figure 7: Cross-section view of conceptual geometric design of a possible Verrazzano Narrows surge barrier (looking north, as **Figure 2**), showing the (top) present-day bathymetry and (bottom) the locations of fixed infrastructure/blockages. The small auxiliary flow gate areas are shown at the sides and the larger navigable gate area is right-of-center.

Both Peter Weppler and Kyle McKay presented on the HAT Study evaluation of environmental effects. Weppler is Chief in the Environmental Analysis Branch, Planning Division, at the Corps of Engineers' New York Office, and McKay is a Research Civil Engineer with the U.S. Army Engineer Research and Development Center (ERDC) Environmental Laboratory. Weppler explained how environmental evaluation is a large part of the HAT Study process, and that no construction will occur without thorough environmental evaluation and coordination with environmental resource agencies. Specifically, the National Environmental Policy Act (NEPA) integrates multiple laws, executive orders and regulations at the federal and state levels. Tiered NEPA analyses are planned for the HAT Study, which will involve the preparation of a "Tier 1" EIS to aid in the selection of a plan. After the Tentatively Selected Plan is identified at the end of the present study phase, the Pre-Construction Engineering and Design (PED) phase begins and will include further NEPA analysis via the preparation of a site-specific "Tier 2" EIS that has necessary design details to better evaluate potential impacts.

The USACE has solicited extensive public comments – both written and in-person – as part of its recent scoping process. Of the written comments, 91% were about environmental concerns, including barriers to tidal flow, water quality, wildlife and ecology, contaminants and combined sewage overflows. Weppler noted that all potential impacts will be analyzed as part of NEPA, with the tiered approach providing more opportunities for stakeholder feedback than the non-tiered (typical) process. Scoping has helped identify key environmental impacts of concern related to study. The Interim Report incorporated existing studies and existing condition information for the study area, as well as environmental considerations and next steps for impact analysis. Future Steps include: 1) model potential physical changes to hydrodynamics, sediment transport, and tidal exchange from concept Alternatives carried forward, 2) develop a quantitative ecological model for assessing environmental benefits and impacts that could occur related to Alternatives proposed, and 3) identify any additional needed analysis for environmental impacts.

McKay addressed how ecological models can inform the process going forward. He explained that the HAT Study is working toward building conceptual models of all components of the New York Bight ecosystem. The goal is to at least qualitatively, and in some cases quantitatively, capture all potential impacts and potential mitigation requirements and costs. He gave an example of a patch-scale model, for an estuarine subtidal ecosystem. It started with the conceptual model, of how the "system works". A quantitative model could then be developed using a "suitability index" indicative of ecosystem quality, and applied to compute the effects of different HAT Study Alternatives.

A systems-scale model is also being constructed for organismal connectivity, adopting a network-based approach from a long history of ecological applications. Passage rate may be assessed using a gradient of approaches such as professional judgement, "rules" (e.g. flow speed exceeds swimming speeds of a focal fish), or agent-based models of movement. Focal taxa will be grouped by movement strategies and life history – possibly including marine mammals (e.g. whales), anadromous pelagic fish (e.g. herring), anadromous benthic fish (e.g. sturgeon), drifting organisms (e.g. larvae), and others.

A series of workshops is being held to obtain expert input and iteratively develop both the patch- and system-scale models, with research and synthesis between meetings. Models will be developed iteratively and applied to the project with data available at each phase of project planning for the entire project area (greater than 2,000 square miles). McKay expressed interest in collaborating with workshop participants as his modeling moves forward.

6. Potential Surge Barrier Effects on Migrating Organisms

David Secor, Professor at the University of Maryland Center for Environmental Science, presented on "New York Harbor: High Stakes Ecological Corridor." The New York/New Jersey Harbor Estuary (HE) is a high-stakes ecological corridor, as one of several regional estuaries that serve migrating marine fishes and crabs. Together with the Chesapeake and Delaware Bays, the

HE is one of three principal estuarine nurseries in the Mid Atlantic Bight. Owing to its strong connectivity to productive shelf and canyon ecosystems, faunal assemblages are both productive and diverse. Further, past recovery and conservation efforts have been quite effective in restoring fauna to the HE (Waldman, 2000). The HE is an obligate corridor for blue crabs, Atlantic sturgeon, eels, shad, and herring, and an evacuation route for resident striped bass when there are extreme rainfall events in the Hudson. It also is a facultative corridor for striped bass, marine fishes and whales, who come and go, forage fishing (e.g. for menhaden). However, how the HE corridor functions, and the relative importance of the HE versus other regional habitats is largely unknown as most past ecological studies focus only on the Hudson River, so haven't informed s about the broader system.

Secor also cited foreign examples that could shed light on how flow obstructions of varying sorts may effect changes in faunal assemblages, phenology, and changed migration behaviors. The Geum Estuary Barrage in South Korea was built to intentionally reduce the tide prism and protect freshwater supply, and - after construction - downstream fish assemblage became more marine and the upstream assemblage more freshwater (Yoon et al., 2017). Secor cited another case already mentioned in van Prooijen's earlier presentation, noting that after the Eastern Scheldt Barrier was built, there was increased residency by harbor porpoises, suggesting an ecological trap (Jansen et al., 2013). After construction of the Tawes Barrier Barrage in the UK, it was observed to delay upstream and downstream migrations by adult and juvenile salmon (Russell et al., 1998).

In evaluating connectivity and the influence of storm surge barriers, Secor suggested that key questions were (1) Are the NY Bight, NY/NJ Harbor Estuary, and Hudson River discrete ecological provinces? (2) Can impoundments make these provinces increasingly discrete? And (3) could barriers work against faunal adaptations to climate change by curtailing connectivity across these provinces?

Evidence from tagged striped bass was presented showing that some rely on migration pathways to evade extreme events such as Irene's extreme rainfall-driven flood down the Hudson (Bailey & Secor, 2016). Secor concluded that the NY/NJ Harbor Estuary is a key ecosystem province supporting resilience and stability through a portfolio effect, allowing fish to better adapt to both extreme events such as Irene, climate change and other anthropogenic stresses.

In designing impact studies of barriers on estuarine fauna, Secor recommended a "Before-After-Gradient" approach, justified because fish's habitats are best modeled according to gradients and gradients also define key impacts expected with the construction and operation of storm surge barriers. Before-After-Gradient designs can be built into the more traditional Before-After-Control-Impact framework through careful planning with the key constraint that sufficient years' baseline information is collected given the dynamic nature of the HE.

7. Potential Surge Barrier Effects on Tidal Wetlands

David Ralston, Associate Scientist with Tenure at the Woods Hole Oceanographic Institution, and Neil Ganju, Research Oceanographer with the United States Geological Survey, spoke next, explaining estuarine and wetland processes to set up the discussion of potential surge barrier effects on salinity, sediment, and tidal wetlands. The Hudson River is a partially-mixed estuary, where salinity stratification and the distance that salty ocean water moves landward both vary with spring-neap changes in tidal mixing (Orton & Visbeck, 2009; Ralston et al., 2008). During neap tides mixing decreases, stratification increases, and the salinity intrusion moves farther up the river due to stronger estuarine circulation[1]. During spring tides mixing increases, so stratification and the estuarine circulation decrease and the salt is pushed back toward the mouth. Simply put, small changes to tidal range can result in large changes in salinity and stratification. The salinity intrusion and stratification in the Hudson also vary seasonally with river discharge: higher flows push the salt seaward and increase stratification, while during summer low discharge conditions the salt moves landward and stratification decreases.

The salinity distribution has a large impact on sedimentation from turbid river waters, which was shown with satellite imagery from after Tropical Storm Irene's passage. Estuaries are excellent sediment traps, focusing sediment deposition and resuspension in the region around the salt intrusion limit, as it varies seasonally and from neap to spring tide (**Figure 8**). The main source of sediment in the Hudson is from the watershed through river floods, but for the NY/NJ Harbor Estuary region, coastal storm events can also provide an important source of sediment (e.g. for Jamaica Bay or Arthur Kill). Trapping occurs due to flow convergence and stratification, and in the Hudson there are two primary Estuarine Turbidity Maxima (ETM) regions, one in Haverstraw Bay and another near George Washington Bridge (e.g., Woodruff et al., 2001). These areas have high sediment accumulation rates (Nitsche et al., 2010), and the location of a tidal marsh relative to these sources is a critical factor in how estuary physical changes may translate into effects on tidal wetlands.

Ralston cited two examples of the central importance of sediment supply to tidal marshes. Sediment cores collected by Brian Yellen (Univ. Massachusetts) from Tivoli Bay (in the Hudson's tidal river portion) have high sediment deposition and rates of vertical accretion, much greater than the rate of sea level rise, and as a result the marshes are growing rapidly. In contrast, a location like Jamaica Bay, which lacks a good sediment supply, has low inorganic sediment delivery and as a result is more susceptible to SLR (Peteet et al., 2018). He also noted in his presentation that flooding and sediment deposition on marshes aren't purely driven by the tides and freshwater floods, but also by coastal storms such as winter nor'easters.

[1] "Estuarine circulation" refers to the typical two-layer flow pattern in an estuary, where average bottom flow is directed upriver and average surface flow seaward, driven by the density (salinity) gradient between ocean and river water (Geyer & MacCready, 2014).

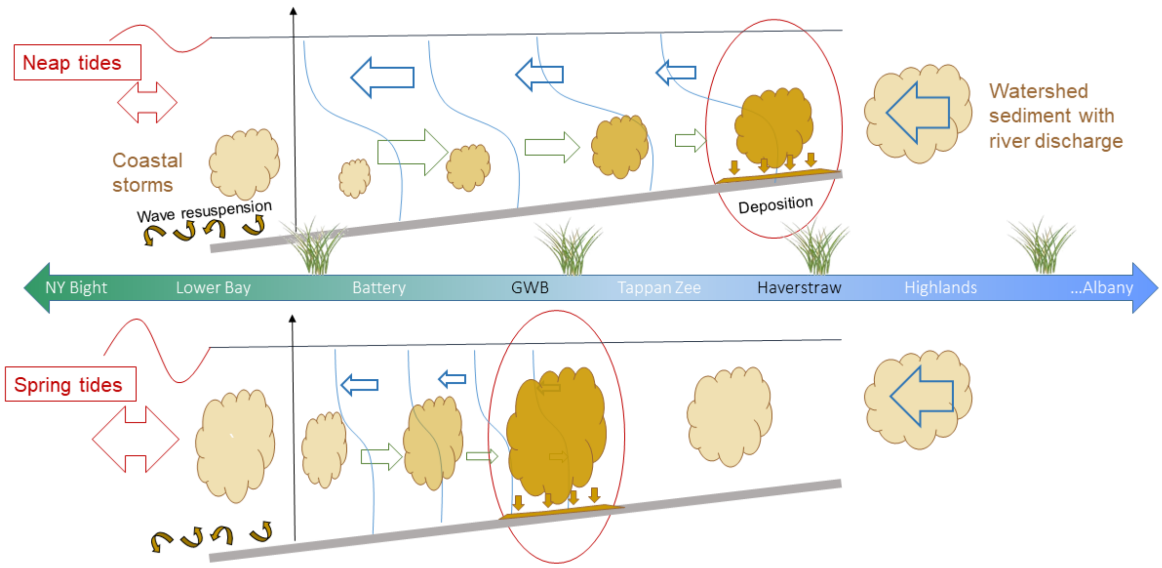

Figure 8: Conceptual diagram showing how the salinity distribution (blue lines) and Estuarine Turbidity Maximum (ETM) respond to neap-spring tidal variations in the Hudson.

Neil Ganju summarized the fundamental science of salt marshes and their geomorphic and sedimentary processes, but also provided some points to consider in evaluating effects of surge barriers. Salt marshes are geomorphic, three-dimensional features, not simply biological. Vegetation response and habitat quality are largely controlled by vertical dynamics, but the system is intrinsically three-dimensional. Tides, low-frequency water level, salinity, and sediment transport are all strong controls on 3D marsh stability and evolution.

Salt marshes are rarely in equilibrium, particularly given commonly evolving sediment supply and sea levels. However, they are inherently stable in the vertical dimension, as demonstrated with a recent meta-analysis of a wide range of systems (Kirwan et al., 2016). Vertical growth is partially controlled by biomass production in root zone, burial of aboveground material. Mineral, inorganic sediment supply is important in micro-tidal settings and for maintenance of channels, flats, and levees. A higher tide range or large sediment supply can lead to marsh growth in spite of sea level rise. With a lower tide range and/or low sediment input, ponds on the marsh can rapidly grow. With accelerating sea level rise, the threshold can be crossed where sediment supply is too low and marsh collapse occurs.

Most marsh edge erosion occurs during common moderate storm events and/or regular wind regimes, not in rare extreme storms. This is because lateral, wave-driven erosion occurs when waves impact the marsh edge, but is a linear function of wave power. Also, extreme storms can cause high water levels and move wave breaking inland instead of at the marsh edge. On the other hand, for deposition and vertical accretion, salt marshes are often dependent on extreme events, and individual storms can account for most of the annual sediment flux. It was again stressed that a marsh's location relative to sediment supply can be an important factor in marsh health, contrasting two nearby salt marsh sites off Chesapeake Bay.

Ganju concluded by presenting several points to consider for evaluating possible effects of surge barriers:

- Reduction in tidal amplitude will decrease accretion through reduced biomass production and sediment deposition
- Reduction in high water levels will decrease inundation time and sediment deposition
- Reduction in water level in severe storms will modify edge erosion processes, depending on relative elevation of marsh, and flats
- Changes to harbor/estuary salinity or its extremes could cause an evolution of marsh species (e.g. *Phragmites* likes freshwater, whereas *Spartina* does not)
- Barrier? influence on sediment supply will depend on location relative to riverine and marine sediment? loading
- Conceptual models (e.g. **Figure 9**) for individual marsh complexes helpful to diagnose future trajectory

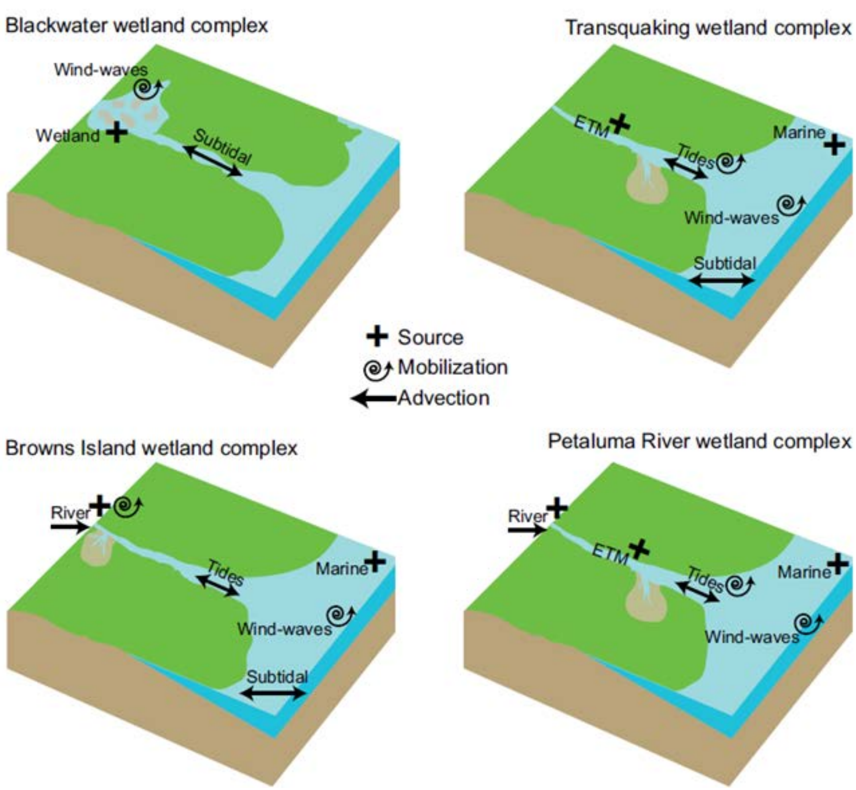

Figure 9: Conceptual diagrams for marshes in several estuaries mentioned in Ganju's presentation. Sediment sources, remobilization/resuspension, and advection are all indicated.

Ganju recommended using conceptual models to predict how sediment might get into and out of a marsh to anticipate surge barrier effects. Conceptual models can be built much more easily than detailed hydrodynamic-sediment-morphology models, and they do not need a great deal of data. He recommended including what you need from a sustainability perspective. Additionally, he shared examples from other marsh studies (in systems without surge barriers) in the U.S. The least sustainable case is the Blackwater Marsh, which has few sources of sediment. The most sustainable is marsh in Petaluma River, because it has multiple sediment sources from river, ocean, ETM and tidal resuspension.

8. Breakout Sessions

While the morning and early afternoon sessions centered on the technical presentations detailed above, a significant portion of the later afternoon session focused on breakout group discussions intended to gauge participants' perspectives on key drivers to study as part of the ongoing effort to understand the potential environmental effects of gated surge barriers. One breakout session focused on potential effects on migrating organisms; the second, on tidal wetlands.

<u>Goal of breakout sessions</u> - The goal of both breakout sessions was to take in broad inputs and perspectives on the most important drivers and their potential effects on the system, and what information about drivers and their effects is available or could be sought. We aimed to finish with a list of potentially important drivers, a catalog of what is known, a list of knowledge gaps and how they can be addressed.

<u>Breakout session discussion parameters</u> - Participants were provided several overview points to keep in mind during the session:

- Regard climate change as a given, and consider storm surge barriers as the unknown to be added.
- Assume a central estimate of 1.5-3 feet of sea level rise in 2080, a warming of 3-7 °F, as well as continued increases in extreme event precipitation/runoff, but small changes in average streamflow (e.g., González et al., 2019; Gornitz et al., 2019; Horton et al., 2015).
- The geographic scope is the entire tidal stretch of the Hudson River to the Troy dam and across the NY/NJ Harbor Estuary. If a process is important in the context of surge barriers for a marsh anywhere in the system (e.g. brackish or freshwater), then it was considered to be of interest.

<u>Background on range of physical changes from barriers</u> – Preliminary modeling of barriers with 50-60% Gated Flow Area resulted in the following estimates:

- Elimination of extreme coastal floods in the harbor, its sub-estuaries and tidal wetlands (by design)

- A doubling of estuary water speeds around open gates (**Section 5**), which leads to enhanced turbulence and vertical mixing (Orton and Ralston, 2018)
- Widespread but small reductions in tidal range, currents and mixing through the rest of the estuary (Orton and Ralston, 2018)
- More pronounced changes during spring tides than neap tides (Orton and Ralston, 2018)

The USACE attendees explained that detailed modeling of estuary circulation, salinity, stratification and sediment transport are all still forthcoming in the HAT Study.

8.1 Breakout Session A – Migrating Organisms

<u>Part 1: Possible guilds of species</u> – To focus the conversation, breakout group participants were asked to think about the potential effects on organisms based on five broad guilds:

- marine mammals
- obligate migrators (diadromous fishes such as eels, sturgeon and shad)
- marine fishes and other facultative migrators (e.g., bluefish, flounders and weakfish) and forage fishes (e.g., menhaden, bay anchovy, Atlantic silversides)
- invertebrate resource species (e.g., crabs and oysters)
- drifting organisms (fish and invertebrate larvae, plankton)

Breakout group participants confirmed these five guilds as a useful way to consider potential effects.

<u>Part 2: Key migrating organism drivers</u> – Participants were asked to list and prioritize key drivers affecting migrating organisms. To foster discussion, the planning team put forward a strawman list of potential relevant drivers, considering all the different guilds. This strawman list included season, flow, landforms, bathymetry, storms, water height, salinity, temperature, dissolved oxygen, sediment, predators, species forage.

After a brief discussion, breakout group participants identified a short-list of top drivers likely to affect migratory organisms (and, therefore, important to understand): season, flow (velocity), salinity and forage.

<u>Part 3: Identifying key research and modeling needs</u> **–** The breakout group was split into two subgroups to consider compelling research and modeling needs. As modeling or research needs were identified for each driver, they were noted on a flip chart. Participants were then asked to clarify the research questions and prioritize them via dot voting. The following were the key findings:

- It was recognized by participants that there is only rudimentary knowledge on the life cycle use of the non-Hudson regions of the NY/NJ Harbor Estuary for most of the species discussed. Very little information exists on what organisms are here, when they are here, and how they use the water column or shoreline.

- It is critical to understand what and how organisms are using the region in order to first locate and subsequently properly mitigate the environmental effects of gates. There is a need to understand what characteristics of the estuary are driving population and distribution of forage fish.
- To address this critical knowledge gap, a census should be developed with bi-weekly surveys using radio telemetry, trawls and plankton nets in the possible areas for gate siting (Verrazzano, Throgs Neck, Arthur Kill or other sites). This may require multiple teams and gear types over the course of a year. There is a need for a team experienced with surveying in highly trafficked waters. These data should be collected to complement long-term USACE monitoring in the Lower and Upper Bay as part of the Harbor Deepening Project.
- A regular longitudinal cross-section survey will help with siting, pre- and post-construction monitoring and could inform real-time management of the barrier.
- We do not have information on when and how larval species move through this area. A hydrodynamic model coupled with a larval transport model (oyster, crab, bay anchovy) could also be moved forward to understand the implications of gates for larval species and be used to model different potential barrier locations. A particle tracking model with vertical control would be needed and the USACE's Adaptive Hydraulics (ADH) Model can work with PTM (the Particle Tracking Model).
- More research is needed to understand how the structure of the barrier and operation and management might impact animal behavior (esp. fish and larger mammals). The longitudinal survey may inform this as well.
- Separate research is needed to understand the critical thresholds for effective mitigation of construction and noise impacts. Can effects be mitigated? What is the range of construction impacts and noise levels produced by the operation and maintenance of a barrier?

The ideas of the census and transport modeling came forward with strong agreement and could be bounded and scoped in the near-term, taking one or a few years to complete, not decades.

8.2 Breakout Session B – Tidal Wetlands

<u>Part 1: Key tidal wetland drivers</u> – As in the migrating organism breakout, participants in the tidal wetlands breakout group were asked to list and prioritize key drivers affecting tidal wetland success. A few important drivers were suggested to start the discussion, and participants were asked to add to the list, which was recorded on a flip chart. Participants were then asked to vote, using sticky dots, on what they considered to be the top three most important drivers affecting tidal wetlands. The top drivers were: (1) tidal range; (2) deposition events from storm surge; (3)

sea level rise; (4) upland migration; and (5) Estuarine Turbidity Maximum (ETM) position/location of sediment pool relative to a marsh. Salinity and deposition events from freshet/rain also received votes for being important drivers for tidal wetlands, but it was determined that gated storm surge barriers would not impact these drivers, so they were not included in the discussion. Other less important, but noted drivers included wave collision with marsh edge, dredging, sediment contaminants, water quality (e.g. nitrogen), ocean sediment supply, and invasive species/disease.

Part 2: Gated surge barriers impact on drivers – Participants were asked to discuss how each tidal wetland driver might be affected by the proposed gated surge barriers, considering the preliminary surge barrier characteristics outlined by the USACE. They were asked to note significant uncertainties and possible research questions throughout the discussion. The discussion was led by asking the questions below for each driver, recording the responses on a flip chart.

Part 3: Identifying key research and modeling needs – As modeling or research needs were identified by the group throughout the question-driven discussion of each driver, they were noted on a flip chart. Participants were then asked to clarify the research questions and prioritize them via dot voting.

The following were key findings:

- There is a need to study how wetlands would respond to the loss of storm-deposited sediment, as a result of barrier closure during storms, coupled with a diminished tidal range, which would also decrease regular sediment deposition. Other needs included understanding how the scale of this impact might vary by distance from the marsh edge, by the size of the marsh and by the frequency of sediment pulses from upstream. This could be analyzed using Pb210 in sediment cores.

- Tidal range was discussed as a key driver for tidal wetlands. Priority research and modeling needs included how current models parameterize turbulence dissipation, what magnitude of tides and surge impact tidal wetlands and an analysis of how tidal range amplifies sediment transport. Other needs included to identify how the drivers of sea level rise and upland migration of tidal wetlands will affect survivability.

- There is a need to study the position of the Estuarine Turbidity Maximum (ETM), the location of sediment pools in proximity to individual wetlands and how fast they turn over. Connectivity lines could be used to develop a matrix for sediment distribution across tidal wetlands. Other important research questions were how the frequency of closures of storm surge barriers impact may sediment pools, ETM, and the location of the salt front.

- The group discussed whether conceptual modeling is more useful than detailed hydrodynamics, waves, sediment and marsh models. The group concluded that the detailed models may be a challenge to develop and may have biases, but may still be useful for understanding trends or processes (e.g. influence of a reduction in tides). Conceptual modeling was also determined to be useful.

9. Concluding Notes

Several key themes and potential takeaways emerged from the presentations and discussions. These included:

Key Notes/Themes

- Examples of constructed storm surge barriers show that the degree of environmental impacts (post-construction) scales with the degree of obstruction of tidal flows, and suggest that by minimizing flow obstruction and gate closures it is possible to avoid severe environmental degradation.
- If the water level trigger for closure remains constant, then there is a high likelihood that the frequency and duration of gate closures will increase significantly past 2050 due to sea level rise
- If closures are allowed only for the 50% or 10% AEP flood, then the frequency of closure will not increase, but perimeter seawalls will need to be raised to avoid higher-frequency flooding.
- Globally, very little physical or biological data is available to describe the pre-construction condition of riverine and estuarine systems where surge barriers have been constructed. This makes it difficult to assess the full effect of barriers on these systems or to know how the ecological systems have changed.
- Long-term pre- and post-construction monitoring would greatly improve our understanding and long-term management of the physical and ecological effects of barrier systems.
- It may be prudent to expand the limits of possible deviation of physical and ecological characteristics in the environmental assessment, conceding any large uncertainties up front, instead of risking unexpectedly high costs later when they are discovered.
- Limited data exists on organisms in the NYNJ Harbor region, what areas they use and how they use it. More data is available for a variety of species north of the Battery.

- The primary drivers of the success of migratory organisms were identified as season, flow (velocity), salinity and forage. The primary drivers of the success of tidal wetland systems were identified as tidal range; deposition events from storm surge; sea level rise; upland migration; estuarine Turbidity Maximum (ETM) position/location of sediment pool relative to a marsh; and deposition event from freshet/rain.
- Mitigation of some of the negative physical and ecological effects of barrier systems is possible and examples exist from several barrier systems.
- USACE has a variety of studies underway that will address several of the issues raised in this forum including an ecological model of the NY Bight system. No construction will occur without thorough environmental evaluation and coordination with environmental resource agencies.

Research Needs

Several key research needs identified in the workshop and the breakout sessions on migrating organisms and tidal wetlands are listed in **Table 1**.

Table 1: Key additional data, research and modeling needs

Key Research Needs	Section
A more complete set of baseline environmental measurements	4, 8
Baseline data on what organisms are using the region, when, and how – a census should be performed with multiple surveys	8
Hydrodynamic modeling of larval transport with/without barriers	8
Research on how the structure of the barrier and its management might impact animal behavior, including noise impacts	6, 8
Studies of the spatial relationship between existing marshes and their sediment reservoirs and their variability (e.g. ETM)	7. 8
Analyses of geomorphically relevant events for tidal marshes, e.g. what magnitude of tides and surges are important for accretion?	7, 8
Research into how accurately current hydrodynamic models capture effects of gate structures on estuary spring/king tides	8

Recommended next steps

- Project speakers agreed that presentation slides will made available online to the public.

- Workshop organizers will prepare a summary report (this document) that summarizes key research questions (Table 1), emerging research priorities, and the lists of top drivers from each of the breakout groups.
- The USACE's (Kyle McKay) needs assistance filling in the necessary parameterizations for migrating organisms (e.g., guilds, behaviors) for the ' ecological model. McKay has a spreadsheet he can circulate around to that breakout group and prioritize next steps. The USACE is working on a peer-reviewed literature review.
- A final project workshop will be convened in January to review project results and collaboratively create a "Future Scope of Work" for additional investigations into estuary effects of storm surge barriers. The science workshop discussions and this report will help inform the topics for the final workshop.
- A follow-up presentation will be planned by webinar or at the final workshop for the Stevens Institute research that was presented in Section 3, which is part of Stevens Institute Ph.D. student Ziyu Chen's dissertation work.

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Appendix A: Agenda

Surge Barrier Environmental Effects and Empirical Experience

Date – Friday September 13, 2019, 9:30am-5:30pm
Location – Hudson River Foundation, 17 Battery Place #915, New York, NY
Wifi: HRF Guest Network, password HRFGuest

Draft Agenda

Workshop Goals

- Identify the present scientific understanding regarding surge barrier environmental effects, highlighting both areas of consensus and divergent views, and identify key additional data, research and models
- Build collaboration among people involved in the topic around the world, including the share of empirical data and experience from past surge barrier projects, as well as approaches for evaluating environmental effects in present studies
- Improve the scientific foundation for Decisionmaker End Users within the HAT Study
- **Output:** Summarize the workshop findings in a report, informing the HAT Study and final project workshop

9:30 AM **Introduction/Welcome – Philip Orton/Bennett Brooks (20 min)**

9:50 AM **The Harbor and Tributaries Focus Area Feasibility Study (HATS) Overview – Bryce Wisemiller + Q&A**

10:25 AM **Summary presentation on NERR-funded project, "Assessing the Effects of Storm Surge Barriers on the Hudson River Estuary", and initial research results – Orton + Q&A**

10:40 AM **Past experiences – two case studies + Q&A**

- Bram van Prooijen - Dutch barriers - Scheldt Barrier
- Charles Schelpe - English experiences (beyond the Thames)

11:40 AM **Discussions of key takeaways from presentations (Brooks)**

- Opportunity for participants to reflect on and share key takeaways from presentations
- In what ways are these experiences relevant to the Hudson? Were there surprises for you?

12:10 PM **Catered Lunch**

12:40 PM **HATS physical and management aspects of surge barriers relating to wetlands or migrating organisms – Maarten Kluyver + Q&A**

1:05 PM **HATS evaluation of environmental effects of gated surge barriers – Peter Weppler and S. Kyle McKay + Q&A**

1:30 PM **Potential surge barrier effects on migrating organisms – David Secor + Q&A**

2:00 PM **Potential surge barrier effects on tidal wetlands – David Ralston, Neil Ganju + Q&A**

2:30 PM **Coffee break, break-out setup**

2:45 PM **Breakout sessions – one on migrating organisms (led by Kristin Marcell), another on tidal wetlands (led by Sarah Fernald)**

Objectives:

- Consider broad perspectives from any attendees
- Prioritize key components (or drivers) under each topic and potential effects of gates on priority components
- Identify what information is available or and what can be sought on these effects and their thresholds

4:45 PM **Breakout Session Report Outs (includes time for Qs and observations)**

5:15 PM **Wrap up, next steps**

5:30 PM **Adjourn**

POST-WORKSHOP HAPPY HOUR – Pier A Harbor House

Appendix B: Workshop Attendees

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