Environmental Defense Fund

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U.S. Army Corps of Engineers
NYNJHAT Study Team, Planning Division
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New York, NY 10279-0090

[submitted via e-mail to: NYNJHarbor.TribStudy@usace.army.mil]

Re: NY & NJ Harbor & Tributaries Focus Area Feasibility Study (HATS), Tentatively Selected Plan

To Mr. Bryce W. Wisemiller and Ms. Cheryl R. Alkemeyer:

On behalf of the Environmental Defense Fund, I thank the US Army Corps of Engineers (USACE) for its commitment to seeking protection for communities from the impacts of flooding threats. Since the inception of the New York New Jersey Harbor and Tributaries Study (NYNJHATS), we have advocated along with many partners representing frontline community and environmental organizations for an approach that is multi-hazard, community-centered, and includes nature-based solutions. We have worked closely with the Rise to Resilience coalition, members of Congress, and the study sponsors to secure modifications to the study authorization and coastal storm risk management projects overall through the Water Resources Development Act. Our primary priorities for the completion of the study, described in more detail below are to:

- **Center frontline communities**
- **Address multiple flood hazards using the best available science**
- **Advance environmental justice and prioritize nature-based approaches**
- **Develop a phased and adaptive approach**
- **Wait on surge gates**

These priorities reflect the input of many community and environmental organizations, are supported by the Water Resources Development Act, and are consistent with several executive and agency policy directives and memos including Executive Order 14008, the Justice40 Initiative, and the Assistant Secretary of the Army for Civil Works' Implementation of Environmental Justice and the Justice40 Initiative memorandum.

This is the largest public infrastructure project in our region in recent history, and it is the critical responsibility of the USACE to work closely together with all non-federal sponsors to develop a plan that is based in sound science, prioritizes social equity and public values, and preserves our diverse cultural and ecological landscape for the most beneficial outcome for all.

We feel that it is possible for the USACE and partners to achieve this goal through a more iterative, extended engagement and refinement period before the plan is finalized over the next several months, keeping the study on track toward developing projects that reduce the risks of vulnerable communities. Additional refinements recommended should be developed into a supplemental Draft EIS for public review and comment. For the largest USACE study and the most complex urban environment in the nation, changes and refinements are to be expected. If these considerations are not adequately integrated, we will advocate for a locally preferred plan or restructuring that does meet these priorities. In our comments, we lay out our understanding of the USACE's ability to address these concerns under existing authorities. It is also worth acknowledging that there is precedent for "restructuring" studies to better address local needs and incorporate the best available science, as was done with the Navigation and Ecosystem Sustainability Program in the Upper Mississippi in 2001.[1]

Center frontline communities

The needs of the communities within the plan area remain inadequately addressed. We worked with members of Congress, the Rise to Resilience Coalition, Riverkeeper, and others to include a specific directive (Section 203) in the Water Resources Development Act (WRDA) of 2020 to consult with affected communities and have had several meetings with the non-federal sponsors and USACE regarding recommendations and support for improvement engagement. Yet, to date the USACE has not made sufficient efforts to proactively engage communities on their preferences and priorities, rather than sharing a finished and tremendously complex proposal for their reaction.

In addition to WRDA, consideration of greater consultation with environmental justice and disadvantaged communities is consistent with the Biden Administration's Executive Order 14008, Executive Order 13985, and the Justice40 Initiative. Interim environmental justice implementation guidance was issued on March 15, 2022, titled Implementation of Environmental Justice and the Justice40 Initiative. In Section 10 of the memorandum, the USACE is directed to take more proactive measures toward achieving environmental justice in their scoping, planning, and construction phases, stating: *"For projects which are in the study and planning phases, we will take a more proactive approach towards achieving environmental justice. This may take time to achieve, but the end result will be an approach to studies which will focus on a comprehensive evaluation of the total benefits of each plan including equal consideration of applicable benefit types in the study scope of work where the disadvantaged communities play a key role in the effort to advance their needs. This new approach goes beyond "doing no harm" to focus on putting the disadvantaged communities at the front and center of studies. This will require a commitment starting at the earliest phase in the process. USACE is directed to initiate outreach and engage disadvantaged communities early in the process to identify and address problems."*

We urge the USACE to pursue much further two-way engagement to create a more iterative and fruitful public engagement process, through the following strategies:

- **Lead an iterative extension of the public outreach and engagement strateg**y in partnership with the nonfederal sponsors that centers communities most affected by the plan and includes an extension of the current comment deadline and several additional community charettes in each neighborhood affected by the plan, presenting 1) the coastal hazards that they face; 2) the feasible approaches to addressing those risks

[1] https://www.mvr.usace.army.mil/Missions/Navigation/NESP/Program-History/

(including permanent inundation associated with sea level rise) specific to their neighborhood (berms, levees, non-structural solutions, etc.); and 3) facilitated Q&A to receive feedback on which measures and levels of risk are preferred by local communities in each planning region. This public feedback should be used to refine the plan iteratively so that the overall length of the process is not significantly challenged. We must ensure that constituencies have sufficient time and access to resources and information to weigh in adequately to inform the plan. Going forward, an **Environment and Climate Justice Work Group** should be established to provide input beyond the study period and throughout design and construction. While the District agreed to establish such a group in 2022, and later stated that the USACE could not convene such a group, we urge the USACE to reconsider or develop a work-around through the non-federal sponsors. There are multiple precedents to look to that are convened by federal agencies, especially the USEPA Superfund Community Advisory Groups.

- **Incorporate local plans and strategies, including unfunded but planned projects:** while a list of assumed coastal resilience projects is included in the main report (p137), this list both contains projects that are assumed but as yet unfunded (e.g. Lower Manhattan Coastal Resiliency) and omits other projects for which plans exist but that have no or only partial funding (e.g. Hunts Point Coastal Resiliency, Vision Plan for a Resilient East Harlem). The final plan and authorization should include a pathway to include, fund, and expedite the construction of these unfunded projects and assess the ability to transfer funds to local sponsors to lead the implementation and engagement around detailed design for some projects.

Address multiple flood hazards using the best available science

The current plan has an overly myopic focus on storm surge and should be revised to better address other types of flooding, especially tidal flooding, and incorporate the best available, regional climate projections. A residual risk study of the TSP should be completed to quantify the costs associated with multiple flood hazards relevant to the area including tidal flooding and permanent inundation due to sea level rise over time using local projections. This should be used as a filter to determine which proposed measures within the study address multiple hazards, and to inform prioritization of which measures may need further analysis and refinement before being recommended for construction. Background and reasoning for these inclusions are as follows:

- ***Use locally relevant and up to date climate projections:*** the sea level projections used are based on outdated sea level rise (SLR) projections. While the draft analysis is based on ER 1100-2-8162 (June 2019), which states that "... *the most recent trends on relative sea level change from NOAA...,*" the graph on that page 196 of the main report indicates that the intermediate SLR projection used by USACE for 2100 will be 1.8 feet. A 2022 NOAA publication projects a year 2100 intermediate SLR for the Northeast US of 1.3 meters (4.3 feet), more than double the design criteria.[2] This is important, as by the USACE's own estimation, this could likely shift the relative net benefits toward a different alternative (Table 18 on page 177 of the Integrated Feasibility Report demonstrates that the difference between intermediate and high USACE scenarios is also the difference between 3A and 3B being favored by the NED scenario). Additionally, state and local projections for the region exceed USACE's projections and are based on regional models developed through extensive peer-review. For example, the

[2] NOAA. 2022. Sea Level Rise Technical Report. https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html

moderate (25th-75th percentile) New York City Panel on Climate Change (NPCC) scenario presents a range of between 2.0-4.2 feet. The USACE should adopt regional climate projections developed by the NPCC, as has been directed and requested through the below letters and authorizations:

- **Water Resources Development Act of 2020, Section 113**, directs the USACE to: (A) "*coordinate the review with the Engineer Research and Development Center, other Federal and State agencies, and other relevant entities; and (B) to the maximum extent practicable and where appropriate, utilize data provided to the Secretary by such agencies.*"
- In the appended **March 8, 2022 letter, the City of New York via the Mayor's Office of Climate and Environmental Justice requested** the USACE "*use the New York City Panel on Climate Change (NPCC) SLR projections for the New York City Region…NPCC SLR projections use a probabilistic approach drawing on an ensemble of 35 global climate models, integrated with observations of vertical land movement, glacio-isostatic adjustment and other important regional factors (e.g., ocean circulation) identified in USACE SLR guidance. The USACE's relative sea level change projections* ***do not account for regional variation and are considerably lower than the NPCC's projections****. Consequently, the NPCC projections provide a more accurate estimate based on New York City's unique conditions, and are considered the best available, peer-reviewed data on SLR for the New York region. The use of the NPCC SLR projections would:*
  - *Result in a better analysis of coastal flooding overall;*
  - *Facilitate a better benefits comparison analysis in the National Economic Development (NED), Regional Economic Development, Environmental and Other Social Effects categories; and*
  - *Better inform the closure frequency analysis that feeds into the environmental impacts assessment and would have impacts on navigation channels and port operations."*

- **A May 26, 2021 letter from 18 members of Congress** to "*ensure that the implementation guidance directing USACE work related to NYNJHATS reflects the intent of the language included in WRDA 2020*," that stated "*WRDA 2020 calls for a revision of existing planning guidance documents and regulations to ensure they are reflective of best available peer-reviewed data and the effects of sea level rise regardless of storm surge inducing events and inland flooding on communities in Section 113. The ability for cost-share partners to request use of local, peer-reviewed data should be clearly articulated in the guidance for this section. Authorization specifically for NYNJHATS (Section 203) was expanded to evaluate and address sea level rise and low-frequency precipitation events. For the NYNJHATS study, the USACE should use regionally down-scaled peer reviewed climate data like those developed by the New York City Panel on Climate Change and Rutgers University and the Mayor's Office of Resiliency to model and map future flood risk in New York City.*"

- ***Incorporate tidal flooding and permanent inundation into the hazard-damage assessment:*** It is critical that the costs and benefits associated with avoided losses due to tidal flooding over time are used to evaluate the relative value of specific measures within the alternative, as some measures will provide no benefits, or even exacerbate damages related to the impacts of long-term inundation due to sea level rise, whereas others may address storm surge as well as long-term inundation. These costs must be considered to ensure that the best available science is incorporated and thus identify solutions that address multiple flood hazards, thereby promoting fiscal responsibility. These inclusions are supported both by the Water Resources Development Act of 2020 and 2022 (excerpts below)

- WRDA 2020 Section 113 directs the USACE to revise regulations on the assessment of the effects of sea level rise or inland flooding on future water resources development projects to ensure that such guidance documents and regulations are based on the best available, peer-reviewed science and data on the current and future effects of sea level rise or inland flooding on relevant communities and Section 203 directs the USACE to evaluate and address the impacts of low-frequency precipitation and sea-level rise on the study area.
- WRDA 2022 Section 8106 directs the USACE to formulate alternatives to maximize the net benefits from the reduction of comprehensive flood risk within the geographic scope of the study from the isolated and compound effects of:
    - a riverine discharge of any magnitude or frequency;
    - inundation, wave attack, and erosion coinciding with a hurricane or coastal storm;
    - flooding associated with tidally influenced portions of rivers, bays, and estuaries that are hydrologically connected to the coastal water body;
    - a rainfall event of any magnitude or frequency;
    - a tide of any magnitude or frequency;
    - seasonal variation in water levels;
    - groundwater emergence;
    - sea level rise;
    - subsidence; or any other driver of flood risk affecting the area within the geographic scope of the study.

- ***Evaluate designs beyond the 100-year storm:*** given the one in four chance likelihood that the 100-year storm will be exceeded once every 30 years and that different features have different design life lengths and abilities to be modified as sea level changes, it does not seem that designing for the 100-year storm for all measures is sufficient for protection. As stated in the Committee on U.S. Army Corps of Engineers Water Resources Science, Engineering, and Coastal Planning: Coastal Risk Reduction's 2014 report, Reducing Coastal Risk on the East and Gulf Coasts, "**There is no solid basis of evidence to justify a default 1 percent annual chance (100-year) design level of coastal risk reduction**. **The 100-year flood criterion used in the National Flood Insurance Program was established for management purposes, not to achieve an optimal balance between risk and benefits.** There is also no evidence that reducing risk to a 1 percent annual-chance event is in the best interests of society or that this level is necessarily acceptable to the general public. This level of risk reduction may be appropriate in some settings, unwarranted or excessive in others, and inadequate in highly developed urban areas. **Such decisions should, instead, be informed by risk-constrained benefit-cost analyses reflecting site specific conditions**."[3] The USACE should evaluate a longer time frame and higher protection design level for those structures that either have a longer design life, take longer to build, or are not easily adapted overtime, such as surge gates. At minimum, the sponsors should set the target risk reduction level consistent with other regional approaches, and ways to adapt the infrastructure over time.
- ***Conduct additional uncertainty analysis on storm surge model and correct/revise text (ADCIRC Modeling, Appendix B) prior to finalizing the***

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[3] Committee on U.S. Army Corps of Engineers Water Resources Science, Engineering, and Planning: Coastal Risk Reduction, 2014 Water Science and Technology Board, National Academy of Engineering and National Research Council, 167p https://nap.nationalacademies.org/catalog/18811/reducing-coastal-risk-on-the-east-and-gulf-coasts

report. As the study is refined, we recommend the following considerations for the ADCIRC analysis:[4]

- Review the uncertainty surrounding the new surrogate modeling methodology used to extrapolate water levels (see also "***surge barriers***").
- **Address apparent errors in the document text/analysis:**[5]
  - There appears to be an error in Eqs. (1-b). Should the final term be: $SWL_{RSS,NACCS,base}$?
  - Sections 6.3 & 6.4 seem to have several inconsistencies or errors:
    - Page 22 of the appendix states, "All simulations for this study were performed using CSTORM coupled ADCIRC+STWAVE since inclusion of waves in the coupled model can have a significant impact on the final water elevation results and accuracy of the solution." Pg 29, item 8 indicates, "The ratios and differences computed up to the previous step are used to estimate NYNJHATS SWL (i.e., surge+waves+tide) ....". However, section 6.3 (pg. 30) states, "Therefore, the NYNJHATS SWL must be corrected for the lack of wave effects, such as wave setup." Section 6.3.1 (pg. 30) states, "After the NYNJHATS simulations are corrected by adding wave setup, ..." Similarly, section 6.4.1 (pg. 32) states, "After the NYNJHATS TC SWL is corrected for wave setup, ..." It is presumed that the point of running ADCIRC+STWAVE was to capture wave setup in the solution. It is not clear why or how simulations were corrected by adding wave setup.
    - The first sentences of section 6.3.1 discuss base ratios $K_{R,base}$ and $K_{A,base}$, however, the accompanying text discusses alternatives.

- **Establish a peer-review panel:** with such a complex study encompassing a broad geography and changes to USACE policy through recent federal directives, we strongly urge the USACE to establish a peer-review panel to inform the plan and future phases.

Develop a phased and adaptive approach

The study should be pursued through a phased approach to authorization and development, prioritizing environmental justice, critical infrastructure, and long-term, nature-based approaches. This approach should be included in the final TSP and Chief's Report, by planning region or measure and including cost-share information, to move forward widely supported and priority elements of the plan while allowing for refinement of those that require further study. Specific areas of consideration for phasing include the following:

- ***Pursue a phased approach, fast-tracking measures that protect critical infrastructure and environmental justice communities:*** the USACE should develop a phased approach that prioritizes measures that protect critical infrastructure and communities most vulnerable to the impacts of climate change, using the public comment period and social vulnerability and environmental justice analysis to inform prioritization. In similarly large-scale studies, the USACE was able to move specific elements to construction while recommending others for further study, as was done with the Navigation and Ecosystem Sustainability Program (NESP) in the Upper Mississippi, for which the Chief's Report recommended "*a framework plan consisting of a blending of Alternatives 4 and 6 to include* ***immediate implementation of some small-scale structural and nonstructural measures, a phased approach*** *for*

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[4] This entire section (*conduct additional modeling…")* was informed by personal communication with Dr. RA Luettich via a January 25, 2023, review memo and subsequent conversation on February 20, 2023.

[5] Ibid.

implementation of Alternative 6, and continued study and monitoring of the system."[6] Both the NESP and the New Jersey Back Bays study were also either planned or authorized in a way that required prioritization of components within the alternative in consultation with local government and other stakeholders.[7][8] See also *Appendix A*.

- **Include plans and a budget for adaptive management:** given the enormous scale of the study, the long timeline to construction, and the changing physical risk, the final report should include strategies for adapting risk reduction measures (and associated costs) over time, with particular attention to changing sea levels. While designing for adaptability can involve more upfront costs, it can also lead to longer project lifespan. USACE should consider increasing the capacity of any structural systems to accommodate additional fill, height, or features to prepare for uncertainty and adapt if sea levels rise more than expected. With the Upper Mississippi Navigation and Ecosystem Sustainability Program, the USACE explicitly recommended that construction authorization be sought in stages and provided a flexible rubric for adaptive management using a plan that "*was developed with the stakeholders to address critical ecosystem needs and to provide insight into the response of the environment to the various Navigation project modifications and measures*" and emphasized "*measures that provide: 1) the best return on investment; 2) best gains in diversity; and 3) additional knowledge required to guide future investments,*" and that "*specific actions may be modified and refined based on information gained through performance evaluation and the adaptive implementation of the plan.*" The plan recommended using an adaptive management framework that includes a science panel, system level learning and monitoring, and monitoring, including these components in the budget.[9] A similar acknowledgement of the need for flexibility and further analyses over time was reflected in the New Jersey Back Bays Study - "*additional more detailed analyses will be performed going forward during the conduct of the study which will likely result in revisions to the TSP and associated economic and other account calculations…to reduce the uncertainty and risk associated with risk management solutions.*"[10] The USACE should review and pursue similar flexibility in language in the final selected plan and Chief's report, given the complexity and long timeframe for NYNJHATS.

Wait on surge gates

For all surge barriers proposed, there is greater uncertainty surrounding the benefits and costs associated with these measures that needs further analysis before advancing. The main report (pg. 158) indicates, that the current surge gate "*design concept levels are for screening purposes, and the TSP will be evaluated at different sizes to maximize net benefits after the draft report*" and further, "*The footprint of the alternative is not expected to change*

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[6] CRS, Upper Mississippi River System: Proposals to Restore an Inland Waterway's Ecosystem at page 10 (updated May 2005) (summarizing the final feasibility report).

[7] Specifically, the USACE was required to consult with an advisory panel chaired by the Secretary of the Army and made up of a representative from each of the five UMR states (Illinois, Iowa, Minnesota, Missouri, and Wisconsin); representatives from USDA, DOT, USGS, USFWS, EPA; one representative of "affected landowners"; two representatives from conservation and environmental advocacy groups; and two representatives from agriculture and industry groups.

[8] The NJBB CSRM Draft Integrated Feasibility Report and Tier 1 Environmental Impact Statement report explains that another benefit of this phased, scalable approach is that it "identifies eligibility threshold stages over time to accommodate as sea level change causes more structures in the study area to become vulnerable and fall below the eligibility threshold stage." p. 490.

[9] Ibid.

[10] USACE Philadelphia District, NJBB CSRM Draft Integrated Feasibility Report and Tier 1 Environmental Impact Statement (Aug. 2021) at page 300. The draft report notes that such revisions may occur before the ADM Meeting which was at the time scheduled for January 2022.

substantially, but the height could be lower or higher and the study could consider more cost-effective ways to achieve the target level of risk reduction," suggesting that the final design standard is not fully determined and that the relative benefit-cost ratio rank of alternatives 3b and 4 could change at the next design level.[11] In addition, the NEPA documents do not fully capture the environmental and social impacts of surge barriers and the uncertainties around those impacts. Overall comments on barrier analysis are below, and comments on specific barriers are included in planning region comments.

- **Use precipitation estimates that reflect the design life:** the USACE should include a climate-adjusted re-run of its water level rise on the interior analysis (Storm Surge Barrier Sub-Appendix, Annex C) to be based not only on observed precipitation data, but on the expected design life of the structure to reflect real risks. Using local climate projections to adjust NOAA Atlas-14 for future conditions is a standard best practice in design rating systems (Envision, WEDG) and is expected to soon be required for all projects within a flood hazard area via New Jersey's Inland Flood Rule. Such analyses of precipitation events of any magnitude are authorized by WRDA 2022 Section 8106.
- **Improve Advanced Hydraulics (AdH) modeling to better understand potential sediment and tidal range shifts:** The model is not validated for many areas of the HATS region, in particular the Hudson, the Meadowlands and Jamaica Bay, and improved and well-validated modeling should be performed and compared to conflicting models to understand potential sedimentary and hydrodynamic changes in these areas and others. Sediment is critical to supporting marsh ability to keep pace with sea level rise. USACE's assessment differs from others conducted, such as Ralston, 2022, which found significantly larger changes in tidal ranges (about triple those of AdH) using ROMS.[12] Specifically, Table 4 of *Sub-Appendix B7: AdH model report,* indicates that tide range differences for Alt 3a using the AdH model are small (less than 3%) relative to the Ralston ROMS results - he found roughly a 6-8% reduction in tide range. It is possible that these differences arose because the Verrazzano barrier was represented differently in the two models. But it is also possible that parameterizations of horizontal turbulent eddies in the models differ in important ways that may require more careful examination. If it is found that models give unexplained differences in the effects of surge barriers, this would be an important uncertainty to acknowledge. And, if there are large discrepancies in tidal range changes, changes to other environmental variables such as sediment transport would also differ.[13]
- **Better quantify ecological impacts:** the long term ecological impacts of surge barriers are not well understood and require long term data sets.[14,15] Studies that have been conducted have shown that surge barriers can cause major

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[11]Informed by personal communication with Dr. RA Luettich via a January 25, 2023, review memo and subsequent conversation on February 20, 2023.

[12] Ralston, D. K. (2022). Impacts of storm surge barriers on drag, mixing, and exchange flow in a partially mixed estuary. Journal of Geophysical Research: Oceans, 127, e2021JC018246. https://doi.org/10.1029/2021JC018246

[13] Philip Orton, personal communication.

[14] De Vet, P., Van Prooijen, B., & Wang, Z. (2017). The differences in morphological development between the intertidal flats of the Eastern and Western Scheldt. Geomorphology, 281, 31-42.

[15] Troost, K., & Ysebaert, T. (2011). ANT Oosterschelde: Long-term trends of waders and their dependence on intertidal foraging grounds: IMARES Wageningen UR.

changes to sediment and marsh systems.[16] In the Netherlands, the Eastern Scheldt surge barrier reduced tidal energy and sediment, shifting the system out of equilibrium and leading to erosion of tidal flats and a 63% loss of tidal marshes.[17,18]

- **Conduct additional analysis on salinity and drinking water impacts:** researchers have found that surge barriers could potentially impact drinking water quality due to potential saline intrusion during closures.[19,20] This should be thoroughly evaluated, including using the 95th or 99th percentile in addition to the 50th and 75th percentiles in the spatial maps of salinity change, using simulations of closures of different durations to reflect extreme salt intrusion scenarios and better understand how they can be avoided. While there is evidence of saline intrusion potential, Appendix A11, conversely, states that across alternatives, storm surge barriers would "*induce habitat switching from estuarine intertidal areas to freshwater tidal ecosystems*" (page 22 and figure 11.18). These discrepancies should be further investigated.
- **Evaluate the potential for impacts due to increased closures over time:** the potential for closure over-utilization in response to sea level rise-driven chronic flooding could lead to much more significant estuary changes. The report lays out a realistic assessment of closures and how SLR will affect frequency (and the need to raise the trigger water level). However, it neglects uncertainty, and the fact that different basins have very different water level return periods. This should be considered in the final EIS.[21,22] An increased frequency of closures has already occurred with the New Bedford Hurricane Barrier, now used increasingly to reduce frequent flooding arising due to sea level rise (Figure 1).[23] Methods for estimating the effect of uncertainty on closure frequency are available (e.g. Chen et al., 2020), and these prior results suggest that the frequencies in the report are underestimated by a factor of three and that trigger water level is likely to come sooner than projected. Also, the assessment of closure duration may be biased toward shorter durations for two reasons: (1) The tropical cyclones (TCs) used in the study are synthetic and have simplified radial wind fields, unlike TCs that often affect the area which are undergoing extratropical transition (e.g., Irene, Sandy). Real-world TCs sometimes have longer-duration storm surges that last multiple tidal cycles. (2) The neglect of uncertainty in forecast water levels likely leads to cases where closure duration is underestimated. During storm surge

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16 Tognin, D., D'Alpaos, A., Marani, M., & Carniello, L. (2021). Marsh resilience to sea-level rise reduced by storm-surge barriers in the Venice Lagoon. Nature Geoscience, 14(12), 906-911. https://doi.org/10.1038/s41561-021-00853-7

17 De Vet, P., Van Prooijen, B., & Wang, Z. (2017). The differences in morphological development between the intertidal flats of the Eastern and Western Scheldt. Geomorphology, 281, 31-42.

18 Brand, N., Kothuis, B., & Van Prooijen, B. (2016). The Eastern Scheldt Survey: A concise overview of the estuary pre- and post-barrier - Part 1: MEMO, Urban Integrity-Naarden/ B Business Energy Amsterdam. Retrieved from http://pure.tudelft.nl/ws/files/4682712/2016_The_Eastern_Scheldt_Survey_Brand_Kothuis_Pro412 oijen_final.pdf

19 Ralston, D. K. (2022). Impacts of storm surge barriers on drag, mixing, and exchange flow in a partially mixed estuary. Journal of Geophysical Research: Oceans, 127, e2021JC018246. https://doi.org/10.1029/2021JC018246 Received 15 NOV 2021 Accepted 5 APR 2022 10.1029/2021JC018246

20 Chen, Z., P. M. Orton, and T. Wahl (2020), Storm Surge Barrier Protection in an Era of Accelerating Sea Level Rise: Quantifying Closure Frequency, Duration and Trapped River Flooding, Journal of Marine Science and Engineering, 8(9), 725, doi:10.3390/jmse8090725.

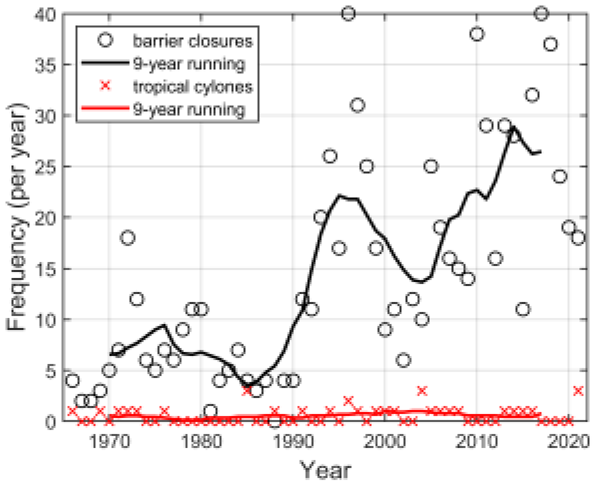
21 Ibid.

22 Orton, P., Ralston, D., van Prooijen, B., Secor, D., Ganju, N., Chen, Z., et al. (2023). Increased utilization of storm surge barriers: A research agenda on estuary impacts. Earth's Future, 11, e2022EF002991. https://doi.org/10.1029/2022EF002991

23 Ibid.

events in NY Harbor, water level fluctuations have complex and amplified responses to winds that are not well-predicted (hour-to-hour) in advance.[24]

Figure 1: Annual frequency of New Bedford Barrier closures (USACE, 2022b) and tropical cyclones passing within 200 km from 1966-2021[25]



- **Conduct further analysis on sediment dynamic impacts:** targeted modeling improvements should be made, especially in the Hackensack and Jamaica Bay regions, due to extensive tidal marshes and a wide range of sediment types (e.g., Hu *et al*. 2018) that should be explicitly characterized in more advanced sediment modeling such as that recently conducted by David Ralston.[26,27] Understanding the impacts of the surge barriers on sediment import in Jamaica Bay would be especially useful, given that surge barriers can prevent sediment import and the Bay is already in a deficient sediment budget.[28,29]

Advance environmental justice and nature-based approaches first

The USACE should pursue a more equitable and holistic approach to TSP refinement and cost-benefit analysis, consistent with the January 5, 2021 Policy Directive, "*Comprehensive Documentation of Benefits in Decision-Making*" and the following recommendations, including

[24] Ayyad, M., P. M. Orton, H. E. Safty, Z. Chen, and M. R. Hajj (2022), Ensemble Forecast for Storm Tide and Resurgence from Tropical Cyclone Isaias, *Weather and Climate Extremes*, doi:10.1016/j.wace.2022.100504.

[25] Orton, P., Ralston, D., van Prooijen, B., Secor, D., Ganju, N., Chen, Z., et al. (2023). Increased utilization of storm surge barriers: A research agenda on estuary impacts. Earth's Future, 11, e2022EF002991. https://doi.org/10.1029/2022EF002991

[26] Hu, K., Q. Chen, H. Wang, E. K. Hartig, and P. M. Orton (2018), Numerical modeling of salt marsh morphological change induced by Hurricane Sandy, *Coast. Eng.*, *132*, 63-81.

[27] Ralston, D. K. (2023), Changes in Estuarine Sediment Dynamics with a Storm Surge Barrier, *Estuar. Coasts*, 1-19.

[28] Chant, R. J., D. K. Ralston, N. K. Ganju, C. Pianca, A. E. Simonson, and R. A. Cartwright (2021), Sediment budget estimates for a highly impacted embayment with extensive wetland loss, Estuar. Coasts, 44, 608-626.

[29] Peteet, D. M., J. Nichols, T. Kenna, C. Chang, J. Browne, M. Reza, S. Kovari, L. Liberman, and S. Stern-Protz (2018), Sediment starvation destroys New York City marshes' resistance to sea level rise, Proceedings of the National Academy of Sciences, 115(41), 10281-10286.

a closer analysis of distributional equity, as described in more detail in ***Appendix A*** of these comments.

- ***Address environmental justice and adhere to the Justice 40 Initiative:*** as stated in the March 15, 2022 directive, *Implementation of Environmental Justice and the Justice40 Initiative,* the "*USACE will use investments as the metric to measure benefits, essentially providing that 40% of USACE investments in climate and critical clean water and waste infrastructure must benefit disadvantaged communities*". USACE should ensure that environmental justice and disadvantaged communities (as defined in each state) receive at least 40% of the benefits of the project. It is important also that the USACE not only characterize benefits but also the relative impacts of each measure and alternative on these communities including air quality, construction and other near-, mid, and long-term impacts.
- ***Revise the Cost-Benefit Analysis to better center frontline communities and reflect public values:*** It is critical that the USACE better center communities with less accumulated wealth, and that have been marginalized and victims of systemic racism. The current approach fails to adequately capture the value of protecting and advancing justice for these communities. While the USACE has looked at all benefit accounts in this study, the Other Social Effects (OSE) analysis (the only analysis that attempts to address public value, environmental justice, and social vulnerability) is grossly generalized based on a proxy rather than actual engagement with communities. In fact, there is no reference in the report as to any community organizations or stakeholders from environmental justice communities who were engaged in the process, or any targeted outreach within these communities until after the study was completed. Further, the Environmental Quality analysis is conducted only through a lens of environmental impact and does not include measures of potential benefit. These entire analyses should be revisited. With the OSE analysis, several weighting adjustments have been made since the NACCS study that are not reflective of stakeholder values. Criteria weights were elicited from only five city and state representatives using Google forms (*Sub-appendix A12: Other Social Effects and Environmental Justice*, p 62). **These representatives are far beyond a valid reflection of the millions of stakeholders affected by the proposed project.** Further, several errors arose during the weighting process. These challenges were transparently reflected in the Sub-appendix but should be clear grounds for redoing this analysis. In comparison, engagement with participants from more than 52 community organizations, eight academic institutions, and eight government agencies or community boards, was conducted by Rebuild by Design and highlighted core principles that included protection and promotion of nature as a much higher priority than is articulated in the Sub-appendix.[30] The USACE should use the results of this survey and feedback from the comment period to re-analyze the relative importance of different components, including environment and habitat. Currently, **environment and habitat weights have been eliminated** (assigned a 0% weight), counter to the priorities heard from organizations throughout the region. As stated in Sub-Appendix 12, "*concern about environmental impacts was the most common type of comment received from members of the public by the NYNJHATS study team and that 91% of all submitted remarks included concern about environmental impacts, with a specific focus on concerns about surge barriers*." There are not only risks to but also multiple benefits that natural infrastructure shore-based measures provide (public health, urban heat reduction) that should be captured as factors in this analysis and that are completely omitted. Lastly, the cost-benefit analysis should be revised to place a greater weight on equity and environmental justice and identify any residual social and economic risks. In keeping with anticipated changes

[30] Rebuild by Design. 2023. Guiding Principles for Coastal Infrastructure. https://rebuildbydesign.org/usace-hats/

spurred from federal policy directives and the Principles, Requirements, and Guidelines for federal investment in water resources, we encourage the district to use guidance from the following to support this analysis:

- **Evolution of Benefits Evaluation and Prioritization of Water Resources Projects;**
- **A Community Engagement Framework Using Mental Modeling**
- **Consideration of Nature-Based Solutions in USACE Planning Studies**; and
- **Planning and Valuation Methods for Case Study Analysis**

- ***Prioritize and conduct analysis of natural and nature-based infrastructure approaches as primary solutions, not just residual risk reduction features***, before the Chief's Report is signed. We believe that an overemphasis on storm surge and a lack of reflection of natural benefits in cost-benefit analyses have resulted in an over-reliance on surge barriers and other gray infrastructure. Natural and nature-based approaches were not sufficiently considered in the study despite being a consistent priority of many community organizations that have engaged with the study to date (as highlighted via a survey conducted by Rebuild by Design of 52 community groups) and a requirement of WRDA 2020 Section 116. Natural and nature-based approaches provide multiple benefits to people and ecosystems in addition to physical risk reduction, as is recognized in USACE's own Engineering With Nature (EWN) program, through which a study is under way to better incorporate the benefits associated with natural infrastructure into USACE cost-benefit analyses. We specifically recommend that the EWN program be brought in to assist with further development of this project, as has been done in other regions, such as with the New Jersey Back Bays project, which aimed to align with the EWN program and specifically identified natural and nature-based features in detail that could be used to address flood risk in the region.[31] The interim results of this study should be used to refine the cost-benefit analysis, particularly with any updated methods or guidance developed to better quantify these benefits. These efforts should seek to maximize natural shoreline habitats such as maritime forests, dunes, wetlands, and others, but also the maximization of natural features within hybrid structures (e.g., living breakwaters, ecologically-enhanced seawalls and promenades, parks, multilayered approaches) and use of ecologically-sensitive materials (e.g. natural stone, ecologically-sensitive and complex concrete and rock surfaces).
- ***Thoroughly and accurately evaluate voluntary buyouts as a primary risk reduction feature, as they are the only solution that permanently eliminates risk to those homes and structures.*** Despite both states having buyout program funding and, in the case of New Jersey an ongoing and well-established program (Blue Acres), buyouts were not considered in the study to date. This is the only **long-term** strategy that fully eliminates risk in the areas in which they occur and should be considered in terms of long-term costs and benefits, especially in areas expected to experience regular tidal flooding. Sub-Appendix B5 4.4. Acquisitions states that acquisitions were not a part of plan formulation because "*data is not currently sufficient to evaluate specific locations in detail*," but it is not clarified what data would be needed and is counter to how these programs work - areas of risk and impact are identified, and

[31] The Engineering With Nature + Landscape Architecture: New Jersey Back Bays' Report is part of the Natural and Nature-Based Features Appendix G at page 9. Additionally, the draft main report notes on page 215 that in addition to larger-scale NNBFs, "stand-alone NNBFs are also being considered as well as in combination with structural management measures. For instance, plan formulation analyses suggest that NNBFs would meet the project objectives when placed in combination with … structural management measures" like unarmored shorelines, floodwalls, and levees.

aggregated buyouts are negotiated over time. The further refinement of the nonstructural measures should explicitly include and evaluate buyouts as a primary strategy prior to the final EIS, detailing that this approach would be conducted in partnership with the relevant local sponsor. It is also referenced in the Sub-Appendix (B5) that complying with the Uniform Relocation Assistance and Real Property Acquisition Act (URA) is difficult. However, three federally funded buyout and acquisition programs within the study area have already successfully complied with URA despite the challenging real estate market (Governor's Office of Storm Recovery, New York City's Build it Back, and the US Department Agriculture's Natural Resource Conservation Service Emergency Watershed Protection Program). Further, there is also precedent for allowing non-governmental organizations to be non-federal sponsors of projects (with consent of the affected local government) and to acquire land for ecosystem restoration either in fee title (full ownership) *or* using floodplain conservation easements (see Navigation and Ecosystem Sustainability Program in the Upper Mississippi), providing additional ways to support buyouts through the many existing established conservation programs in the states.

Planning region-specific recommendations

Overall, there should be much further refinement of specific measures in each planning region in concert with the localities and communities impacted. It is likely that further refinement may shift the relative cost-effectiveness between proposals such that the difference between alternatives and perhaps other options may become more favorable at the next design level.

- ***Hackensack/Passaic***
  - **Inclusion of a surge barrier without analysis:** while there is a surge barrier proposed for this area, it is not included in the AdH modeling. Without such modeling, an understanding of the benefits and impacts is not clear. Additionally, given the extensive wetlands and ecological value of the region, we recommend evaluating expanding wetlands restoration and shallowing deeper channels as an alternative to a surge barrier in this region.
  - **Integrate local plans at Kearny Point**: the USACE has proposed a series of floodwalls for an area that has a complete resilience master plan including green infrastructure, elevation, and natural habitat surrounding the site. The Hugo Neue corporation is working to elevate buildings 16 feet above sea level and a flood-protective berm is being built around the edge, suggesting there is no need for the level of protection proposed by the USACE in this area. We encourage the USACE to directly connect with Hugo Neue and prioritize other areas for protection.
  - **Address Superfund contamination risks:** as the entire Passaic River is a Superfund site, the USACE should develop a clear plan in partnership with the US Environmental Protection Agency to fast-track contamination remediation in areas where projects are proposed and address these risks prior to construction, as well as clarify how extreme caution will be taken to avoid disturbing contaminants.
- ***Lower Hudson/East River***
  - **Newtown Creek barrier:** given the high volumes of untreated sewage that regularly overflow into this narrow tributary, a barrier along this narrow waterway could worsen water quality and rain-based flooding when closed. These impacts should be adequately evaluated by USACE, as should the potential for disturbance of Superfund pollution controls.

- **Incorporate adjacent plans into modeling and planning:** the Astoria Houses NYCHA development has been upgraded to better withstand flooding due to a large FEMA grant. USACE should ensure coordination with/incorporation of the modifications to topography associated with this project into modeling and incorporate any unaddressed elements that could boost the resilience of this area. Additionally, the USACE should incorporate the priorities articulated by Newtown Creek Alliance and Riverkeeper in the Newtown Creek Vision Plan, and better clarify how the USACE proposal intersects with Manhattan plans including the Financial District and Seaport Climate Resilience Master Plan, Brooklyn Bridge-Montgomery Coastal Resilience Project, the Battery Coastal Resilience Project, the Vision Plan for a Resilient East Harlem, and South Bronx Unite's Mott Haven-Port Morris Waterfront Plan. The TSP currently appears to propose a very different vision in some areas of Harlem and the South Bronx than were developed by communities in the latter two plans. For example, a focus on seawalls and floodwalls along the Harlem River, whereas the community and city-led plan prioritizes road/edge elevation on the Manhattan side and water access on the Bronx side of the Harlem River.
- **Revise placement of shore-based measures and seawalls to be consistent with existing landscape and features around Hunters Point South Park:** rather than replace a recently developed, well-loved and award-winning restored wetland park edge that was built to flood, flood control measures should be built inland from the park edge or integrated into the existing design.

- ***Long Island Sound***
  - **Incorporate currently omitted south Bronx communities:** despite being highly vulnerable, containing critical infrastructure (e.g., Hunts Point Food Market, which serves more than 22 million people across the region) and populous, these areas were omitted from the study. Many of the areas of the South Bronx are considered environmental justice communities by federal and local definitions, and have historically borne the burden of industrial pollution, inaccessible waterfronts, and lower access to services that support quality of life. The USACE should incorporate local community plans such as Hunts Point Forward and others to ensure this area is not left exposed to the impacts of climate change.
  - **Develop nonstructural and shore-based measures instead of the Flushing Bay barrier:** this surge barrier protects a relatively less populated area consisting of many parking lots and undeveloped land. Investing in barriers in this area rather than shore-based restoration and critical/asset-specific hardening (e.g., the MTA Corona Train Yard) and street elevation/other non-structural solutions (and requirements of future development to meet higher flood standards) over time seems of less relative value. Further, the primary risk to the park - a critical public resource, is permanent inundation due to sea level rise and rain-based flooding is a tremendous impact in the area. The approach for this area needs further thinking that integrates these risks and better connects to both a federally funded resilience study that is underway for the area and a community-based plan that was already developed for the creek .[32,33] These plans are or will be representative of many public engagement sessions and should be prioritized. See also the ***surge barriers*** section.

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[32] See *Flushing Meadows Corona Park: A Hub for Climate Resilience:* https://waterfrontalliance.org/wp-content/uploads/2022/03/CPFAnnounce.March2022.PressRelease.final_.pdf

[33] Riverkeeper and Guardians of Flushing Bay. 2018. Flushing Waterways Vision Plan. https://www.riverkeeper.org/campaigns/restore-nyc-waterways/flushing-waterways-vision-plan/

- ***Upper Bay/Arthur Kill***
    - **Conduct further analysis of the Arthur Kill/Kill Van Kull Barrier and prioritize other measures until critical questions of its value can be answered.** The expense of the major Arthur Kill and Kill Van Kull surge barriers do not yet seem to be convincingly justified compared to the potential costs and risks and the small reduction in 1% flood level. The surrogate modeling methodology used to extrapolate water levels from a database of 1150 NACCS ADCIRC runs conducted without structural modifications plus 20 additional ADCIRC runs for each proposed modification, provided an efficient way to evaluate the various design alternatives. However, it is not clear how well a surrogate model can be trained to represent the effects of the surge barriers based on this data set. For example, Appendix VI of Appendix B6 presents maximum water surface elevations from the 20 new ADCIRC runs for Alternative 3B (the TSP). In most of these runs there is minimal response in the Arthur Kill-Newark Bay-Kill Van Kull area with the barriers. However, for four of the storms significant surge occurs in this area presumably due to the overtopping of one or both barriers. **In two of these storms the water levels are greater in this area than for the case of no barriers**. It is unclear how well four storms can train the surrogate model to replicate the overtopping and associated surge response behind the barrier. It is also unclear how much uncertainty exists in these results and how this may have affected the relative Benefit Cost Ratios of alternatives 3b and 4. Lastly, it is important that any changes in hydrology due to current and expected future harbor deepening are incorporated into the model for these barriers. These uncertainties need to be better understood and warrant further study prior to moving forward.
    - **Gowanus barrier:** given the high volumes of untreated sewage that regularly overflow into this narrow tributary, barriers along this narrow waterway could worsen water quality and rain-based flooding when closed. These impacts should be adequately evaluated by USACE, as should the potential for disturbance of Superfund pollution controls.
- ***Jamaica Bay***
    - **Review Philip Orton's concept of narrowing the inlet and shallowing the deep channels of Jamaica Bay as a primary alternative for consideration** in comparison to the proposed barrier before the Agency Decision Milestone. Nature-based alternatives of shallowing the bay's inlet and channels and narrowing the bay's inlet have been shown in research for a decade now to be effective for risk-reduction.[34,35,36,37] These concepts have been in the scientific literature since 2015 and were first studied (and modeled by Arcadis) in work for the 2013 post-Sandy Special Initiative on Rebuilding and Resiliency

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[34] Orton, P. M., S. A. Talke, D. A. Jay, L. Yin, A. F. Blumberg, N. Georgas, H. Zhao, H. J. Roberts, and K. MacManus, 2015. Channel Shallowing as Mitigation of Coastal Flooding, Journal of Marine Science and Engineering, 3(3), 654-673, DOI: 10.3390/jmse3030654.

[35] Orton, P., MacManus, K., Sanderson, E., Mills, J., Giampieri, M., Fisher, K., Yetman, G., Doxsey-Whitfield, E., Hugens, D., Wu, Z., Yin, L., Georgas, N. and Blumberg, A. 2016. Quantifying the Value and Communicating the Protective Services of Nature-Based Flood Mitigation using Flood Risk Assessment Technical Report. Research funded under the National Oceanic and Atmospheric Administration Coastal Ocean Climate Applications program. http://adaptmap.info/jamaicabay/technical_report.pdf

[36] Orton, P. M., E. W. Sanderson, S. A. Talke, M. Giampieri, and K. MacManus, 2020. Storm tide amplification and habitat changes due to urbanization of a lagoonal estuary, Natural Hazards and Earth System Science, 20(9), 2415-2432, doi:10.5194/nhess-20-2415-2020.

[37] Pareja-Roman, L. F., Orton, P. M., & Talke, S. A. (2023). Effect of estuary urbanization on tidal dynamics and high tide flooding in a coastal lagoon. Journal of Geophysical Research: Oceans, 128, e2022JC018777.

(SIRR). The USACE should study these solutions, as well as their combinations with wetland restoration, buyouts, shorefront measures and non-structural approaches, to determine whether there is a realistic alternative that can provide a similar level of protection while ensuring the long-term maintenance of natural systems in Jamaica Bay. The potential for surge barriers to further reduce sediment supply to Jamaica Bay and its wetlands, for long-term increases in surge barrier closure frequency, and for other environmental problems, calls for a more comprehensive assessment of the potential for nature-based solutions playing a larger role in the flood risk reduction.

  - **Address direct and induced flooding of adjacent communities and better integrate natural features:** the proposed risk reduction features stop around Beach 33rd street, leaving no strategies (not even non-structural or buyouts) as an option for adjacent communities in Far Rockaway and adjacent areas. Further, this is one of the few areas with significant undeveloped land for which a wider natural dune and maritime forest restoration (a priority of the Hudson-Raritan Estuary Comprehensive Restoration Plan) may be feasible and possibly even more effective given the land extent available as a preferred alternative to the reinforced dune proposed.
  - **Maintain or enhance public access along the Shore Parkway:** the communities of Bath Beach and Gravesend have historically been cut off from their waterfronts with few access points to a bike/walkway along the water. Any modification should seek to not only maintain but increase this access.
  - **Protect and enhance public access and natural restoration around Coney Island Creek:** the community surrounding the Creek regularly uses the dune and parkland for recreation, fishing, and boating, and treasures this waterfront access. Further, the recently restored dunes and areas around Calvert Vaux Park serve as important habitat for horseshoe crabs and other migratory species. The proposal of levees along the otherwise natural edges are out of step with these uses. The USACE should seek to explore flood management structures inland of the park edge in Calvert Vaux Park and ways to maximize access while still providing flood management on the south side of the Creek. Further, as the Creek is heavily contaminated, the potential impacts of installing a surge gate and modifying the edge should be considered.
  - **Expand nonstructural options, including buyouts, in low density areas around Jamaica Bay:** multiple communities (Broad Channel, Howard Beach) are in areas that will be permanently inundated due to sea level rise by as early as the 2050s. Elevation, buyouts, and other non-structural solutions should be primary solutions for these areas given their vulnerability to regular tidal flooding over time.

Comments on the Environmental impacts analysis (2.2 Natural Environment section)

The following are specific recommendations for improving the Environmental Impact Statement. Overall, as referenced above, we recommend a more robust analysis not only of the impacts of each approach but also the potential benefits associated with each from an ecological perspective. This analysis is largely missing from the study and has great importance to communities.

- ***Better incorporate public access and viewshed impacts:*** The analysis of visual impacts has been primarily limited to national park lands and monuments, despite the proposed measures posing a tremendous visual impact on the region. Seawalls and other measures that impact the visual sightlines will impact economic and aesthetic values. Such considerations should be analyzed and further fleshed out in the final report.

- ***Analyze traffic impacts during construction:*** while vessel traffic impacts are described in the study, vehicle traffic and circulation during construction are barely mentioned. Where they are mentioned (p 455), they are characterized as temporary and minor, though major construction especially of shore-based structures in congested areas is very likely to result in significant on-shore traffic and circulation impacts. No quantitative studies of traffic and circulation studies are presented, nor is there any justification suggesting that such impacts are negligible.
- ***Align with local green infrastructure and stormwater management plans and better address combined sewer overflows (CSOs)*:** the draft integrated report states that combined sewer overflows are "*known to cause variation in water quality after large events and measures have since been implemented to mitigate this*." While measures have been implemented in some areas, there are still regular and large environmental impacts from CSOs across the region. A more robust analysis of how the proposed measures impact CSOs either positively or negatively in each reach is needed, as well as how mitigation for exacerbated impacts will be developed, consistent with Long Term Control Plans and green infrastructure plans. The proposed approach is not reflective of these plans, and the $1.7 billion proposed for pumping infrastructure should be reexamined to determine how the plan can capture stormwater at the source, employing green infrastructure, capture, and infiltration to the maximum extent feasible, potentially saving on otherwise expensive costs associated with pumping over time.

We thank you for your efforts to reduce the risk of the residents of New Yorkers and New Jersey to climate hazards and welcome the opportunity to discuss these comments.

Sincerely,

Kate Boicourt
Director, Climate Resilient Coasts and Watersheds, New York – New Jersey
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Appendix A: Analysis of benefits by race and income of benefits by USACE sub-reach

EDF analyzed the per capita and total distribution of benefits (calculated by USACE as avoided flood damages) accrued in different sub-reaches by race and income, using sub-reaches defined by the USACE and data received via a Freedom of Information Act request. We estimated the demographic and socioeconomic characteristics of each sub-reach using areal population-weighted average of Census tract-level data from the 2020 American Community Survey. Specific patterns of distributional equity are difficult to identify using these methods. The large size of the sub-reaches designated by the USACE makes comparison of a highly heterogenous urban population difficult, potentially masking patterns. If benefits data were available at a census tract or property level, this would enable easier comparison at more accurate, finer scale and potentially better enable the USACE to understand how the project complies with the Justice40 initiative. It is assumed that not all households within a reach would benefit from these alternatives, yet it is unclear what proportion of household would experience avoided damages. Lastly, it is unclear how the benefits are distributed among residential and commercial/industrial properties (see note regarding the Hackensack Meadowlands, below). Regardless, this analysis demonstrated and reiterated several points that warrant further investigation.

First, many areas in the Bronx receive no benefits in alternative 3b, despite overlapping vulnerability to coastal flooding and the lowest median income and percent white population in the entire area. Canarsie is also an area that warrants closer analysis from an equity lens, given the high concentration of low-income people and people of color compared to other areas that receive more benefits per capita (Figures 1-2).

Figure 1: Per capita benefits by sub-reach, for alternative 3b

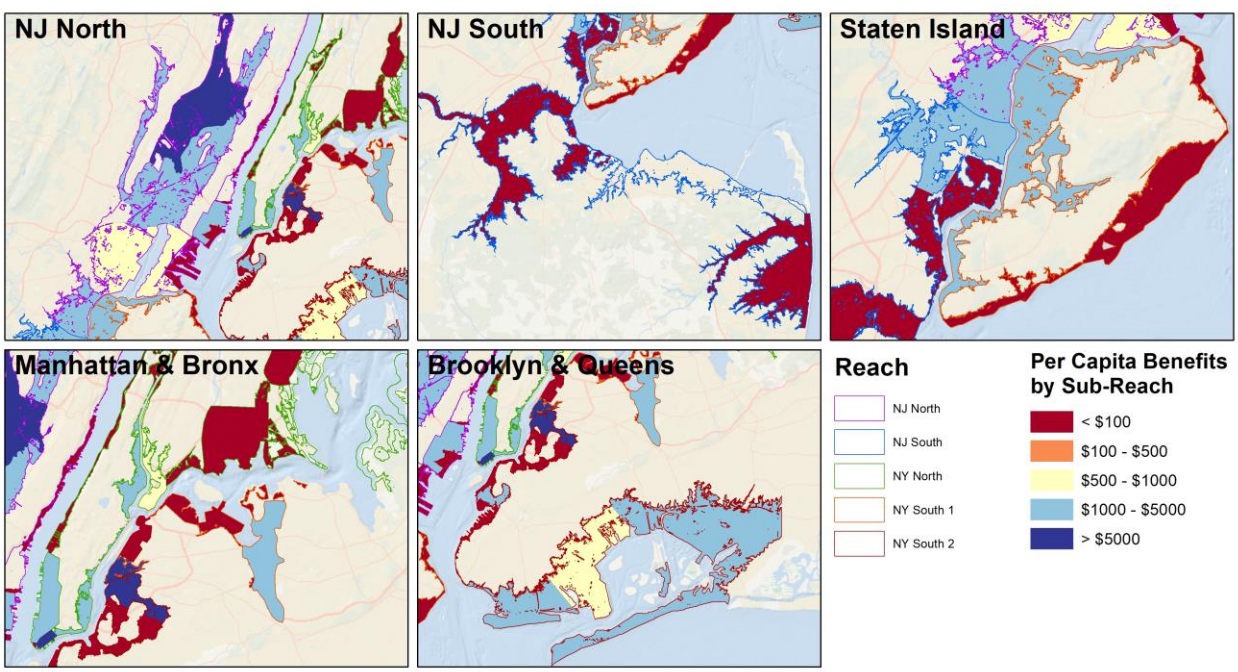
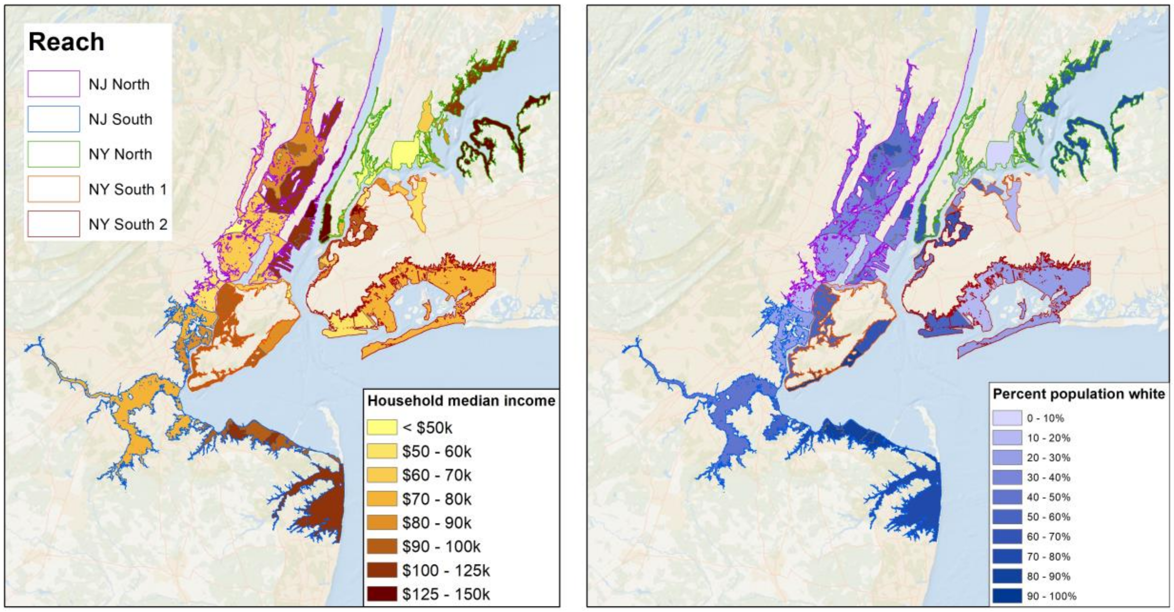
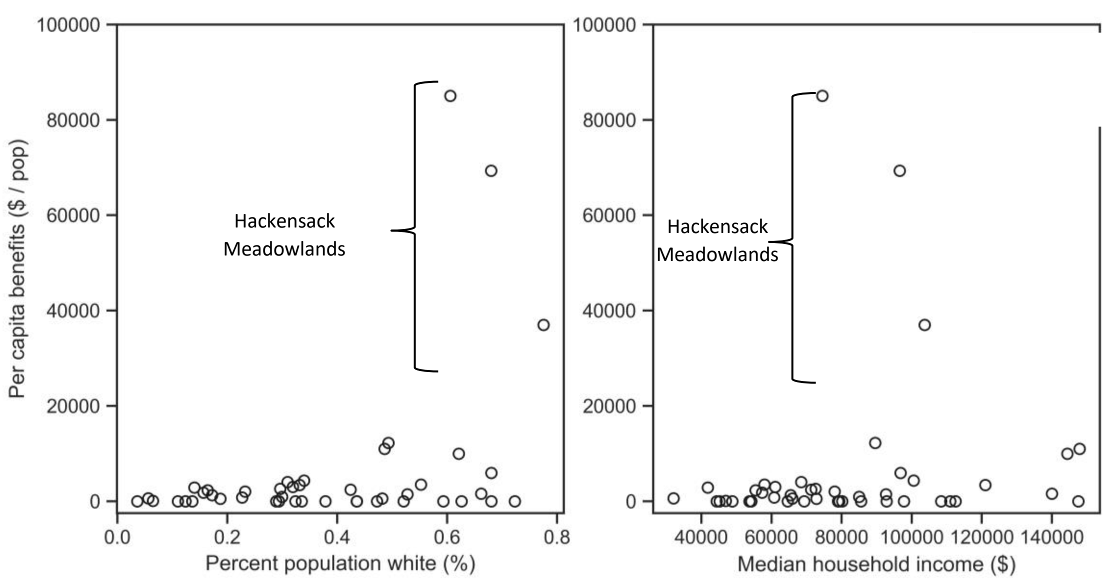


Figure 2: Median household income and percent white and non-white populations within NYNJHATS sub-reaches.



Conversely, the Hackensack region receives the highest per capita benefits and comprises a majority white and moderate-high income population (Figures 2-3). It is possible that this is an artifact of a low residential, primarily industrial and commercially zoned region. This should be further analyzed to inform whether other areas with more critical infrastructure and residential populations should be prioritized. Of note, this area includes Teterboro airport which serves a small portion of the population and primarily private plans. Its relative regional importance compared to its vulnerability to sea level rise and extreme rain even led the Regional Plan Association suggesting that it should be closed and replaced with improvements to JFK, Newark, and La Guardia in the organization's Fourth Regional Plan.[38]

Figure 3: Per capita benefits by percent population white and median household income of each sub-reach.



[38] https://rpa.org/latest/lab/time-transition-away-teterboro-airport

Additional analyses are included below.

Figure 4: Median household income and percent white and non-white populations within NYNJHATS sub-reaches.

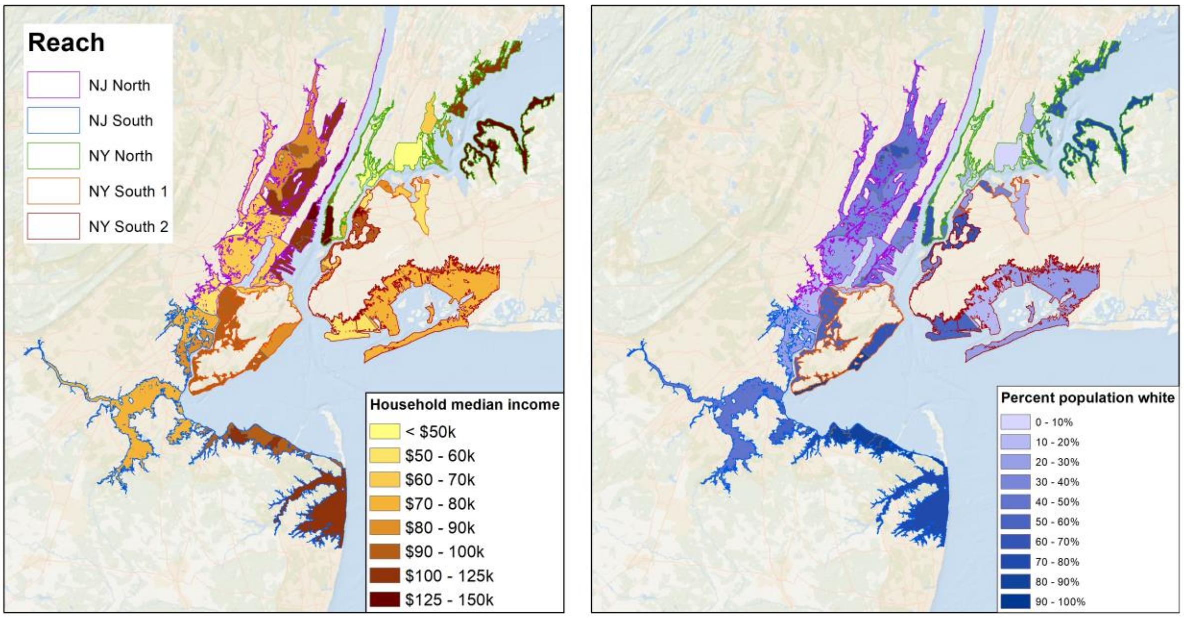


Figure 5: Per capita benefits by percent white population and median household income, by sub-reach, by alternative.

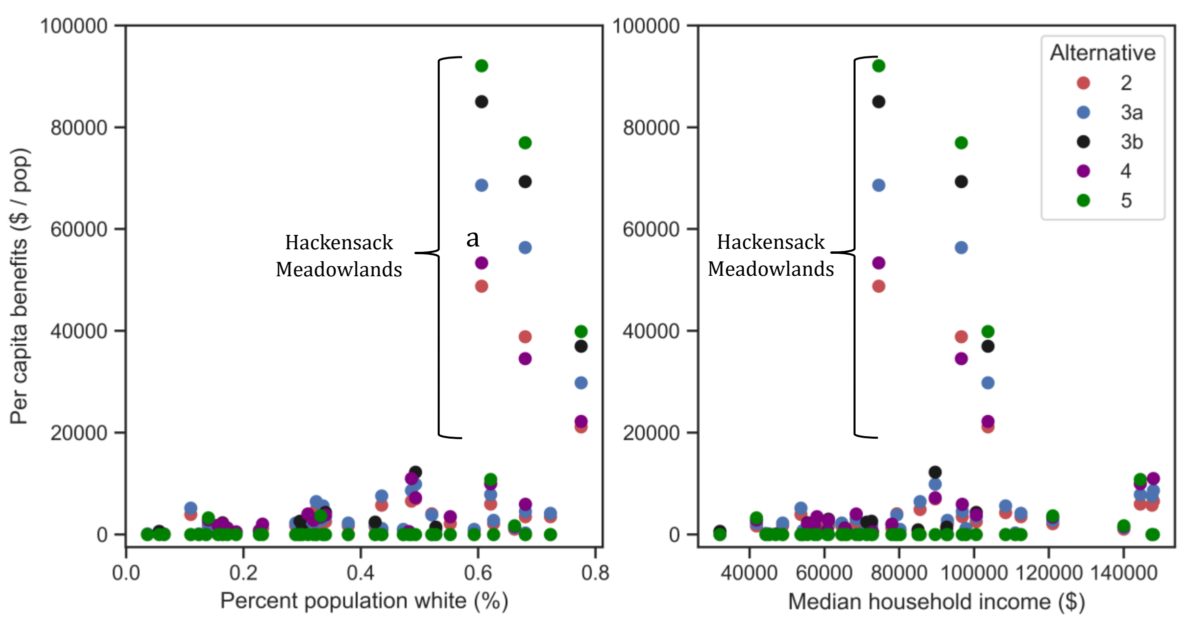


Figure 6: Per capita benefits by percent population white and median household income of each sub-reach, alternative 3b.

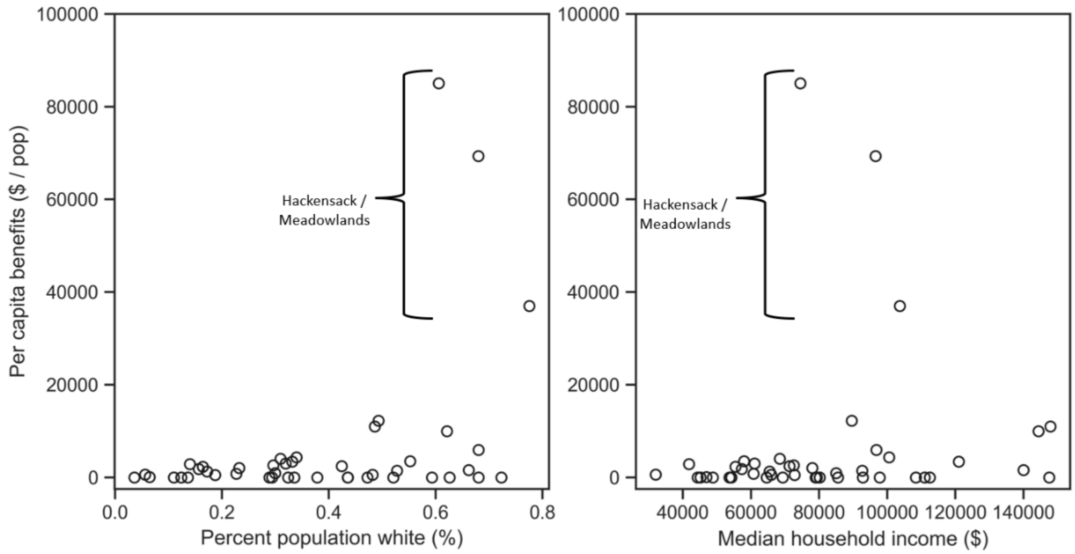


Figure 7: Benefits as a percentage of alternative total by sub-reach, alternative 3b

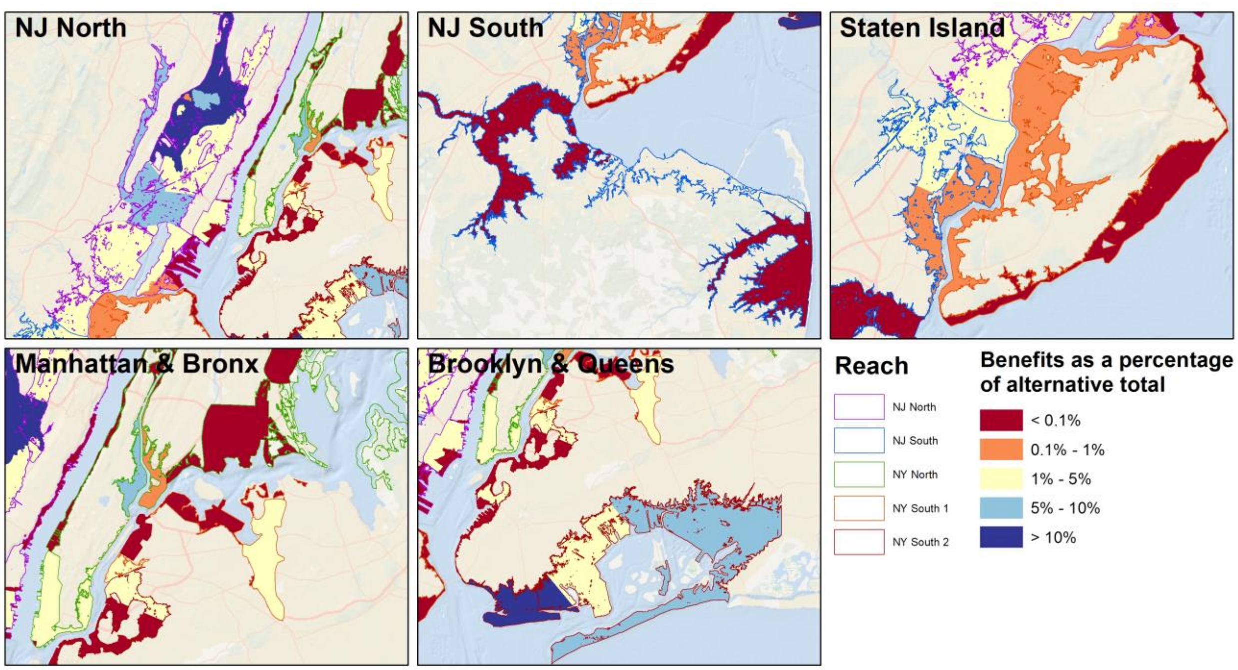


Figure 8: Benefits as a percentage of alternative total by sub-reach, by percent white population and median household income, alternative 3b

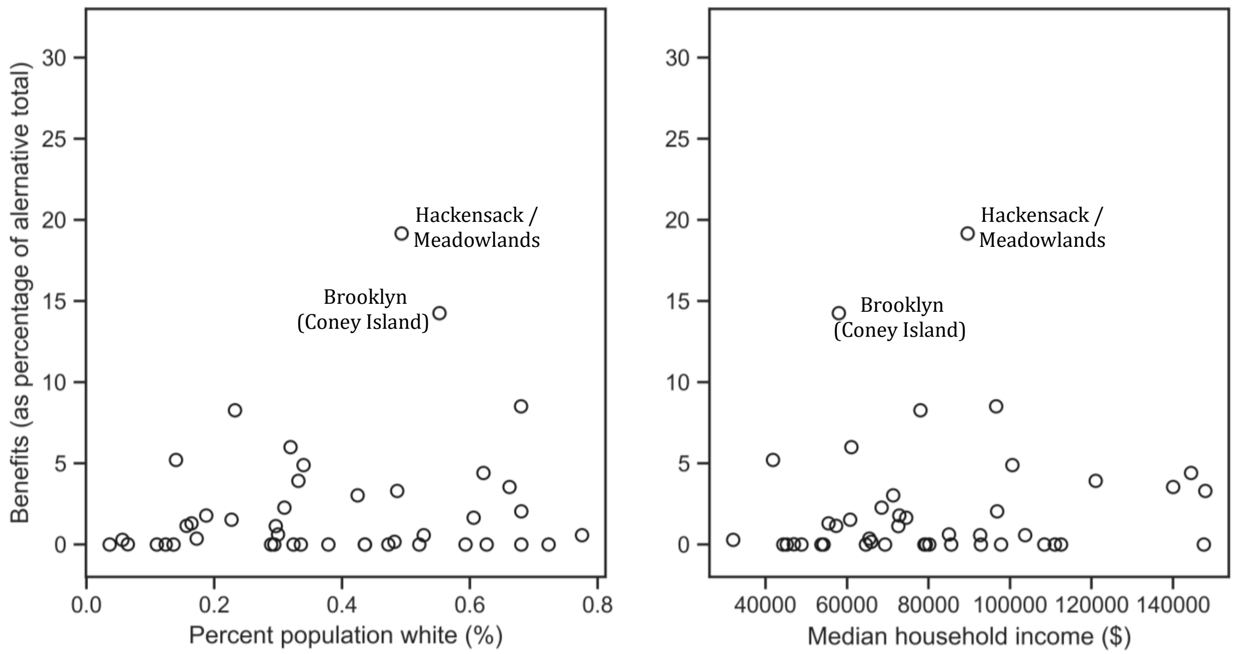


Figure 9: Total benefits by sub-reach, alternative 3b

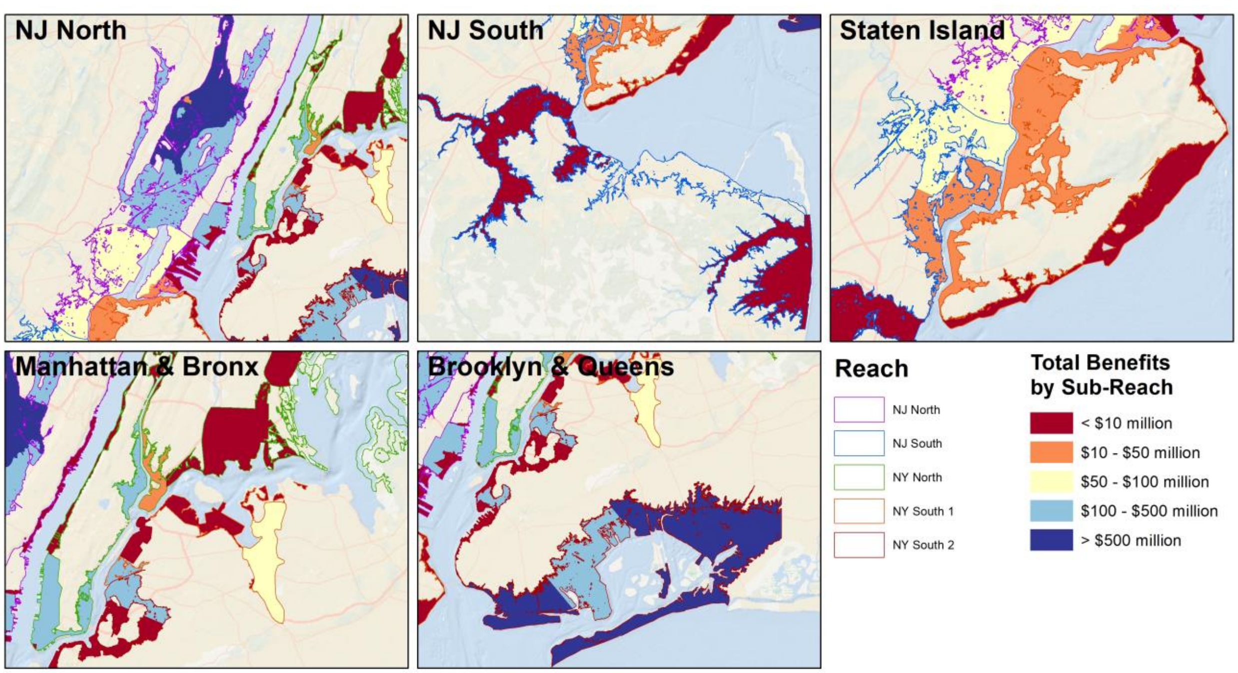
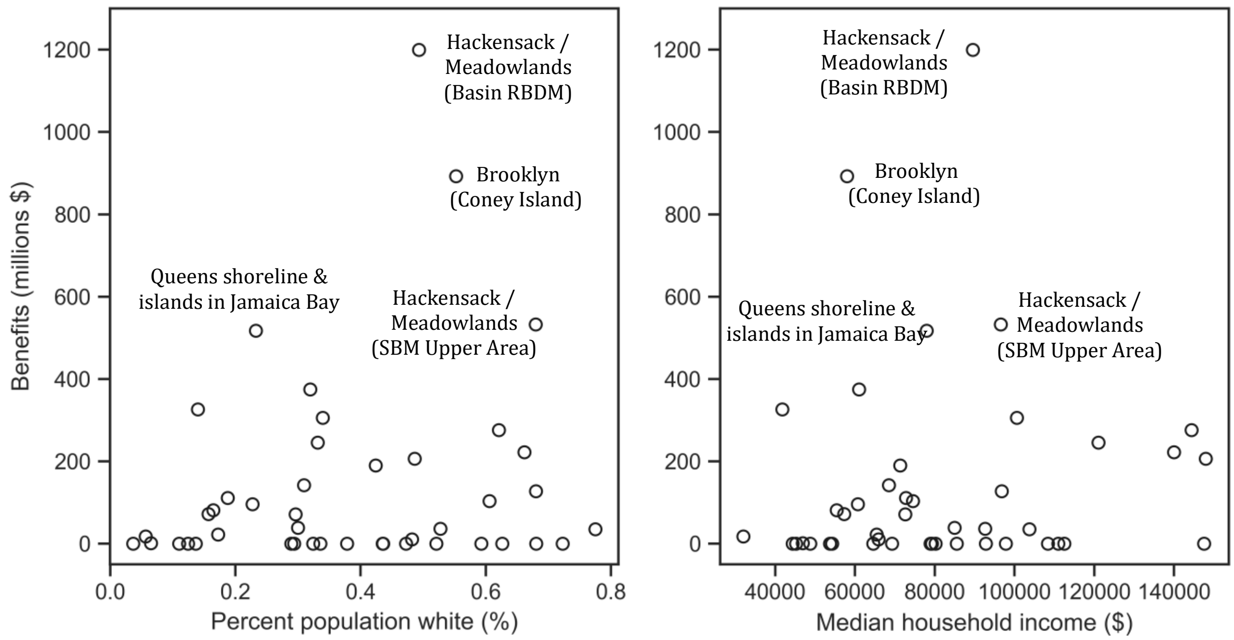


Figure 10: Total benefits by sub-reach by percent white population and median household income, alternative 3b



Mayor's Office of Climate & Environmental Justice

March 8, 2022

Colonel Matthew W. Luzzatto
New York District Commander and District Engineer
U.S. Army Corps of Engineers, New York District
26 Federal Plaza
New York, NY 10278-0090

RE: WRDA 2020, Section 113(b) Implementation Guidance for New York/New Jersey Harbor and Tributaries Coastal Storm Risk Management Study (NYNJHATS)

Dear Colonel Luzzatto:

The City of New York is in receipt of your coordination letter to non-Federal interests dated January 12, 2022 regarding Implementation Guidance (IG) for Section 113b of the Water Resources Development Act (WRDA) of 2020, specifically as it pertains to NYNJHATS and the associated Tentatively Selected Plan (TSP). The language of Section 113b directs the Secretary to consider, upon written non-Federal interest request, whether the need for a project is predicated upon or exacerbated by conditions related to sea level rise (SLR) or inland flooding.

Pursuant to the IG, USACE is required to coordinate with non-Federal interests for NYNJHATS to determine whether the non-Federal interests want to include, as part of the study, documentation of the expected benefits of the project relating to SLR or inland flooding. The January 12th letter indicates that NYNJHATS is already evaluating varying degrees of SLR as it relates to drainage and coastal storms, but notes that non-federal interests may want to further expand this scope.

The City of New York, as a non-Federal interest, requests USACE document the expected benefits of the project relating to SLR only and initiate a preliminary determination pursuant to paragraph 8 of the IG.

Regarding the inclusion of the impacts of inland flooding, New York City is predominantly a coastal city that does not experience significant riverine/fluvial flooding. While the city does not experience such flooding, it may apply to other parts of the study area beyond the City's jurisdiction. We defer to the New York State Department of Environmental Conservation and the New Jersey Department of Environmental Protection to make that determination and request of USACE.

In addition, while the City is aware that NYNJHATS includes SLR as part of the study's storm surge analysis, USACE does not currently analyze the future risk of chronic tidal flooding from SLR and the impacts to low lying coastal communities that would occur at least 50 years after the completion of a project. Additionally, the City understands that NYNJHATS's existing evaluation of the five alternatives will include some land-based measures that will protect against coastal storm surge and some measures that would offer additional protection against residual risk flooding. These approaches should be further analyzed to assess their ability to protect against future chronic tidal flooding caused by SLR. We recommend that USACE: 1) evaluate which alternatives would best address the risk of future chronic tidal flooding; and 2) perform a sensitivity analysis on neighborhood tidal flooding impacts in order to inform a prioritization framework for implementation – a phased approach that would reduce risk for the lowest lying areas in the short term while continuing to plan for projects that may take longer to implement.

Furthermore, we request that USACE use the New York City Panel on Climate Change (NPCC) SLR projections for the New York City Region. NPCC is a highly credentialed advisory body that provides an authoritative and actionable source of scientific information on future climate change and its potential impacts. NPCC SLR projections use a probabilistic approach drawing on an ensemble of 35 global climate models, integrated with observations of vertical land movement, glacio-isostatic adjustment and other important regional factors (e.g., ocean circulation) identified in USACE SLR guidance. The USACE's relative sea level change projections do not account for regional variation and are lower than the NPCC's projections. Consequently, the NPCC projections provide a more accurate estimate based on New York City's unique conditions, and are considered the best available, peer-reviewed data on SLR for the New York region. The use of the NPCC SLR projections would:

- Result in a better analysis of the on-shore high frequency flooding needs and approaches;
- Facilitate a better benefits comparison analysis in the National Economic Development (NED), Regional Economic Development, Environmental and Other Social Effects categories; and
- Better inform the closure frequency analysis that feeds into the environmental impacts assessment and would have impacts on navigation channels and port operations.

Lastly, with the recent restart of the study, we are looking forward to our continued partnership with USACE in reaching the next important milestone: the release of the TSP. Leading up to the release of the TSP, we strongly encourage USACE to actively engage with New Yorkers and inform them of the components of the study and the potential opportunities and implications the recommended plan may have on our coastal neighborhoods. Broad community awareness and engagement is essential to the success of the study and requires a robust outreach plan.

Thank you for providing the City of New York with the opportunity to request additional analysis on this very important study.

Sincerely,

Kizzy Charles-Guzman
Executive Director

Cc: Joseph Seebode, USACE New York District
Clifford Jones, USACE New York District
Steve Couch, USACE New York District
Bryce Wisemiller, USACE New York District
Olivia Cackler, USACE New York District
Matthew Chlebus, New York State Department of Environmental Conservation
Joanna Field, New York State Department of Environmental Conservation
Dennis Reinknecht, New Jersey Department of Environmental Protection
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AGU ADVANCING EARTH AND SPACE SCIENCE

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COMMENTARY

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Increased Utilization of Storm Surge Barriers: A Research Agenda on Estuary Impacts

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Key Points:

- Gated storm surge barriers represent a fundamental change to our coastlines and potentially to ocean-estuary exchanges
- They are increasingly being built for coastal protection and closure frequency of existing barriers is increasing with sea level rise
- Funding of interdisciplinary basic and applied science research is critical to inform billion-dollar decisions on coastal engineering

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Abstract Rising coastal flood risk and recent disasters are driving interest in the construction of gated storm surge barriers worldwide, with current studies recommending barriers for at least 11 estuaries in the United States alone. Surge barriers partially block estuary-ocean exchange with infrastructure across an estuary or its inlet and include gated areas that are closed only during flood events. They can alter the stratification and salt intrusion, change sedimentary systems, and curtail animal migration and ecosystem connectivity, with impacts growing larger with increasing gate closures. Existing barriers are being used with increasing frequency due to sea level rise. New barrier proposals typically come with maximum closure frequency recommendations, yet the future adherence to them is uncertain. Given that the broader environmental effects and coupled-human dynamics of surge barriers are not well-understood, we present an interdisciplinary research agenda for this increasingly prevalent modification to our coastal zone.

1. Introduction

Increasing coastal flood risk worldwide is driving greater interest in the construction of storm surge barriers for coastal flood risk reduction. Storm surge barriers or tide gates cross an estuary's entrance and include gated areas that are closed only during coastal floods (e.g., Figure 1). Surge barriers can effectively minimize flooding, property damage, and loss of life during large storms, and can be a relatively cost-effective approach to mitigate coastal flood hazards (e.g., Deltacommissie, 2009; NRC, 2014). More surge barrier projects were completed worldwide in the 2010s than any prior decade, including flood risk reduction projects for St. Petersburg (Russia) and New Orleans (Mooyaart & Jonkman, 2017). The MOSE Barrier project is nearly completed and mostly operational on the Venice Lagoon, Italy (Mel et al., 2021). Surge barriers have recently been tentatively selected for flood risk reduction in Coastal Storm Risk Management studies by the United States Army Corps of Engineers (USACE) for 11 estuaries, including Jamaica Bay (New York), Hackensack River (New Jersey), Barnegat Bay (New Jersey), and Galveston Bay (Texas), among others (USACE, 2018, 2020, 2021a, 2021b, 2022a).

The rapid increase in coastal flood disasters in recent decades has primarily been driven by increases in population and property exposure, and increasingly chronic flooding at many locations is being driven by sea level rise (NRC, 2014). Yet, storm surge barriers are not a long-term solution to rising sea levels unless their gates are closed at an exponentially increasing frequency (Chen et al., 2020). Typically, management of barrier closures requires closures when a pre-defined water level threshold (the "trigger") is forecast to be exceeded. Recently, surge barrier plans have proposed 2-year or 5-year return period water levels (USACE, 2021b) as the trigger for closure. Additional shorefront risk reduction features (e.g., nature-based features or seawalls) must be built to address any flooding that occurs when higher-frequency events are coupled with rising sea levels (Chen et al., 2020). Thus, there is also potential that surge barriers, once in place, will have their gates closed more frequently than planned in the initial environmental impact assessment.

Storm surge barriers represent a fundamental change to the geometry of our coastlines and potentially to ocean-estuary exchanges (Figure 2). There is a strong consensus that further study of their estuary impacts is needed, with participation from a broad range of scientific disciplines (e.g., Brand et al., 2016; Swanson et al., 2013). Direct impacts of the barriers (e.g., on water levels) can be predicted and observed relatively easily. More complex consequences with longer time scales (e.g., for sediment dynamics, tidal marshes, migrating

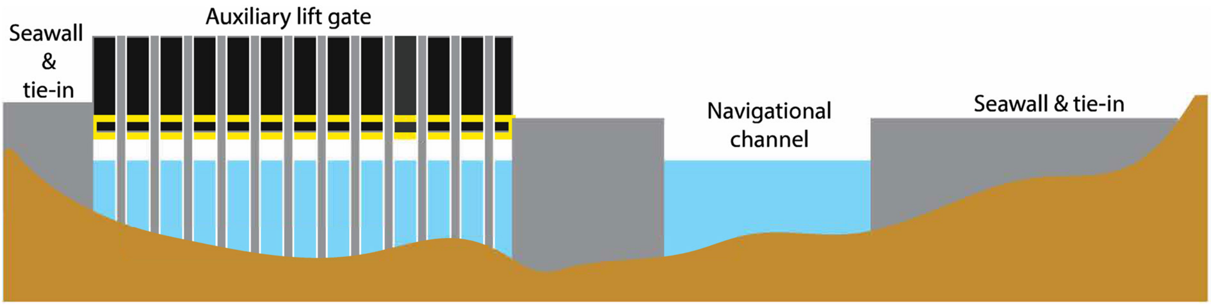

Figure 1. Schematic cross-section of a storm surge barrier system for an estuary with a wide ocean entrance. It includes auxiliary gates intended to reduce flow obstruction during non-storm periods and a wide navigation channel (which also has large gates, not pictured). A similar barrier is proposed for Jamaica Bay, New York City (USACE, 2022a).

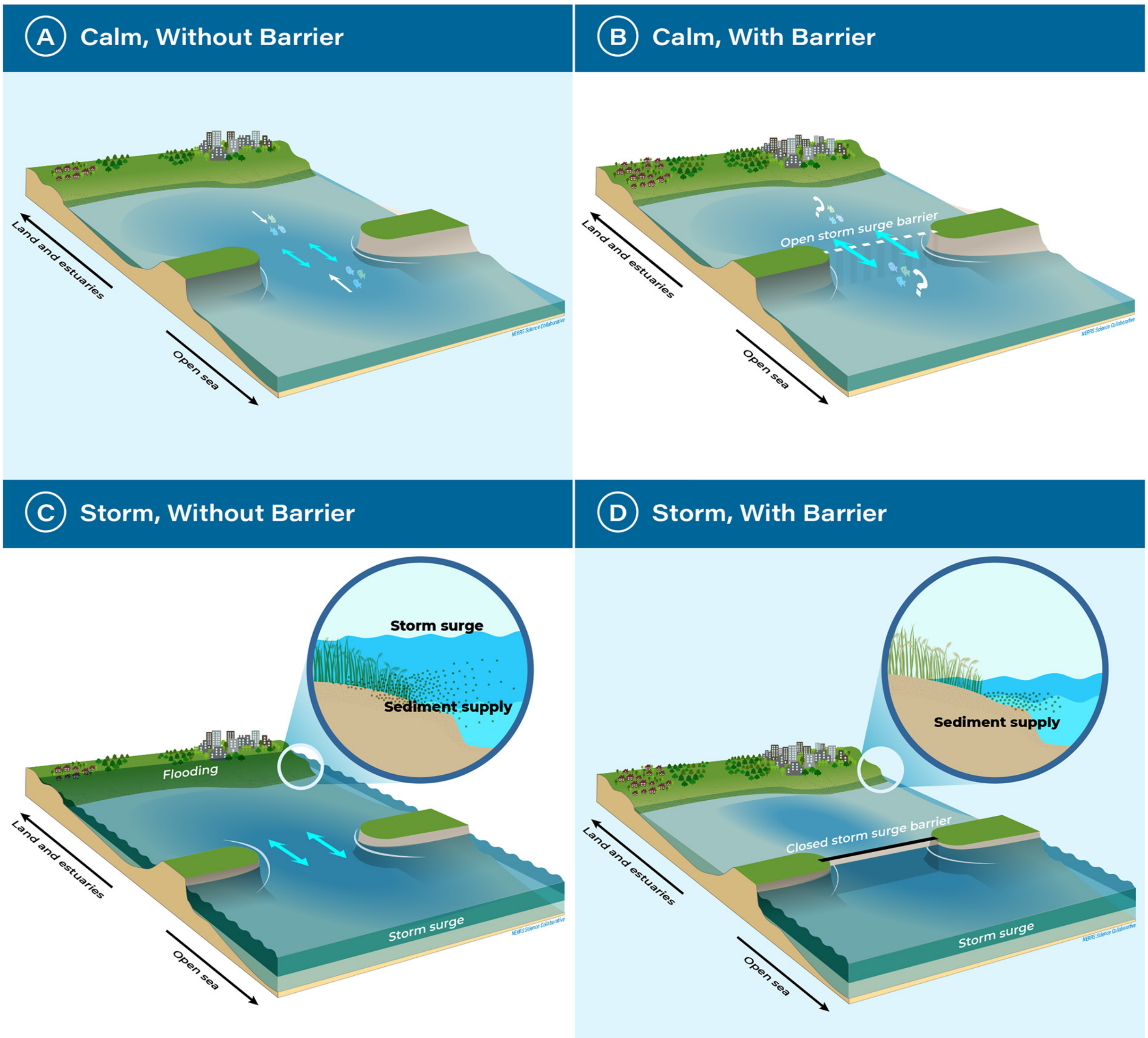

Figure 2. Conceptual diagram showing cases (a, c) without a surge barrier, (b, d) with one, and during (a, b) calm weather, and (c, d) a severe storm surge event. Selected known effects of surge barriers are to increase water speed (blue arrows) through open gates during calm weather (comparing a to b) and reduce flooding of wetlands and populated areas during storms (comparing c to d). Some of the topics for which further research is needed are sedimentation on marshes during flooding (c, d inset circles), induced development in floodplains (increasing buildings from a to b), and effects on migrating organisms (comparing a to b).

fishes; Figure 2) are more difficult to predict and require long term data sets (e.g., De Vet et al., 2017; Troost & Ysebaert, 2011). The proposed widespread deployment of surge barriers should be matched with an equivalent research agenda to improve our understanding of both the natural systems effects and the coupled human systems that will manage the barriers, once built.

The goal of this commentary is to catalyze a broad, interdisciplinary global research effort to study surge barrier estuary physical, chemical, sedimentary and ecological effects. We proceed with (Section 2) background on the known estuary impacts of surge barriers, (Section 3) a proposed research agenda to better understand their effects, and (Section 4) an outline of a pathway forward to address the research agenda.

2. Background

2.1. Open Surge Barrier Physical Effects due to Fixed Infrastructure

The fixed infrastructure of a storm surge barrier system when gates are open typically causes several long-term physical effects. These include locally enhanced water velocities around the open gates (Figure 2; Ralston, 2022), and reductions in velocities and tide amplitudes inside an estuary. For example, after construction of the surge barrier for the Eastern Scheldt estuary in the Netherlands, tidal range in the estuary decreased by 12% on average and tidal velocities decreased by 20–30% (Louters et al., 1998). These reductions in tidal amplitude were associated with reduced vertical mixing, increased salinity stratification (Bakker et al., 1990), and increased residence times (Nienhuis & Smaal, 1994). Modeling studies of hypothetical surge barriers for two "drowned river valley" type estuaries, Chesapeake Bay and the Hudson River estuary, found that open barriers would constrict and accelerate the flow, thereby increasing the total drag and turbulent mixing. This in turn would reduce the tidal amplitude inside these long river-estuaries, widely reducing vertical mixing, increasing stratification, and increasing saltwater intrusion (Du et al., 2017; Ralston, 2022). The amplitude of these changes scales with the degree of obstruction of tidal flows (Orton & Ralston, 2018). Past experience from constructed barriers and modeling of hypothetical barriers both suggest that adding auxiliary flow gates (Figure 1) can reduce flow obstruction and associated impacts but increase overall barrier cost (Mooyaart & Jonkman, 2017).

2.2. Closed Barrier Effects and Assessment Challenges

Barrier closure during a storm can have potentially positive estuary environmental impacts, such as by preventing flood-induced contaminant release/pollution, including wastewater, fuels, and contaminated sediments. Also, the prevention of storm erosion impacts at marsh edges or developed shorelines can be viewed as a positive ecosystem service, though it has ambiguous estuary-wide environmental effects given that erosion at one location often leads to sedimentation and accretion at another (Hu et al., 2018; Tognin et al., 2021).

Short-term effects from gate closures have similar effects on estuary salinity and stratification as the long-term effect of open barriers, but more immediate and amplified, and these are relieved gradually after the gates reopen. In some cases (e.g., smaller surge barriers) closure can be limited to a few hours during high water. However, in other cases multi-day gate closures may be necessary and have the potential to increase saltwater intrusion and stratification past historical maxima. Recovery time to normal conditions after re-opening depends on closure duration, streamflow and estuary length, with dry conditions slowing recovery (Chen & Orton, 2023). Barrier closures trap river water and rain and could cause flooding inside the protected area, particularly during long-duration events. Thus, an important precondition to building or closing barriers is to understand the probability of trapped water flooding (Chen et al., 2020).

Given the large but short-lived estuary effects of barrier closures, and the potential complexity of societal management of closures, assessing the impact of future barrier closures is more challenging. As mentioned in Section 1 (Introduction), there is potential that storm surge barriers, once built, will be closed more frequently in response to sea level rise, essentially using them as "sea level rise barriers". This has already occurred with some constructed surge barriers (e.g., Thames Barrier in Britain, Hall et al., 2019). Existing surge barriers in the northeastern United States are typically referred to as "hurricane barriers" (Morang, 2016; USACE, 2022b), but have a relatively low trigger water level that occurs frequently (Morang, 2007). Public data on the New Bedford Hurricane Barrier show that the closure frequency has generally increased through time and far exceeds the frequency of tropical cyclones of any intensity (Figure 3). The barrier is now used to prevent the increasingly frequent

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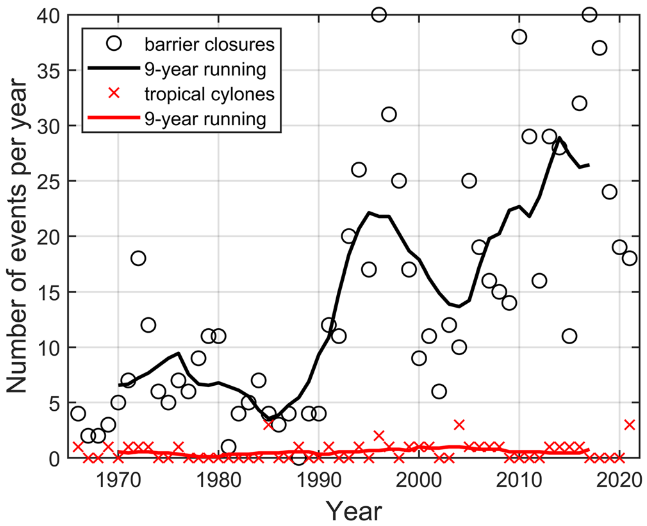

Figure 3. Annual frequency of New Bedford Hurricane Barrier closures (USACE, 2022b) and tropical cyclones (TCs) passing within 200 km from 1966 to 2021 (Landsea & Franklin, 2013), along with 9-year running averages.

flooding that is arising due to sea level rise. Variation in closure frequency over time, such as a local maximum in the 1990s and minimum in the 2000s, may be due to reductions in forecast uncertainty (Chen et al., 2020) or other governance factors such as a management decision to increase the trigger water level.

2.3. Surge Barrier Effects on Migrating Organisms

Flow obstructions of varying sorts can cause changes in faunal assemblages, phenology, and migration behaviors. Keystone fish species migrate from coastal waters to estuaries and freshwater for the purpose of spawning (Limburg & Waldman, 2009). For other species of fishes, cetaceans and turtles, nursery, overwintering, and spawning habitats straddle estuaries and immediately adjacent coastal shelf regions (Woodland et al., 2012). Increasingly, evidence is calling into question the concept of "estuarine-dependent" nektonic fauna (Able, 2005; Brown et al., 2019). Storm surge barriers could curtail reproductive migrations and bisect key habitats that straddle the estuarine-coastal interface where barriers are likely to occur (Figure 2). Specific studies on surge barrier impacts remain rare in the literature. The Geum Estuary Barrage in South Korea was built to intentionally reduce the tide prism and protect freshwater supply. After construction, downstream fish assemblage became more marine and the upstream assemblage more freshwater (Yoon et al., 2017). After the Eastern Scheldt Barrier was built in the Netherlands, there was increased residency by harbor porpoises, suggesting an ecological trap (Jansen et al., 2013). The barrier was also linked to a shift in the phytoplankton assemblage in the Eastern Scheldt due to increased water clarity with the reduction in tidal amplitude and sediment resuspension (Bakker et al., 1990). After construction of the Tawe Barrier Barrage in the United Kingdom, upstream and downstream migrations by adult and juvenile salmon were delayed (Russell et al., 1998).

2.4. Surge Barrier Effects on Sedimentary Systems and Tidal Marshes

Surge barrier projects can cause major changes to estuary sedimentary systems, leading to fundamental morphological changes including for tidal marshes. In the Eastern Scheldt (Section 2.1), the surge barrier reduced tidal energy and sediment resuspension and substantially reduced the sediment flux from the sea into the estuary. Tidal asymmetries in the flow through the barrier openings cause a divergence in sediment transport, reducing the landward transport of sediment from outside the barrier and the seaward transport of sediment sourced from inside. The sedimentary system shifted out of equilibrium, as the channels were too deep for the limited tidal energy. This led to erosion of the intertidal flats and filling of the channels (De Vet et al., 2017). Reductions in tidal resuspension and marsh inundation also led to a 63% loss of tidal marshes (Brand et al., 2016). Similarly, recent studies of Venice Lagoon have demonstrated how surge barriers can reduce coastal storm-driven sedimentation on tidal marshes and therefore their resilience to sea level rise (Tognin et al., 2021, Figure 2). This can in turn reduce the lagoon's geomorphic diversity (Tognin et al., 2022). Long-term morphological and vegetation changes can in turn feed-back on system hydrodynamics (e.g., Donatelli et al., 2018).

3. Research Agenda for Estuary Effects of Storm Surge Barriers

In this section, we identify the estuary science knowledge gaps that could be filled to improve decision-making around building or planning the operation of storm surge barriers. Interdisciplinary research addressing these gaps begins with studying a wider range of estuaries with observation and modeling as described in Section 3.1 below. The most direct effect of a surge barrier on an estuary is to change its hydrodynamics. The estuarine fluid dynamics community, both through observations and numerical models, have appropriate tools to build conceptual and deterministic models of these effects and guide research on topics that depend on the hydrodynamic impacts (e.g., Kirshen et al., 2020; Ralston, 2022). Hydrodynamic changes will cascade to sediment transport and associated geomorphic changes (Section 3.3), but modeling of hydrodynamics and sediment transport both have remaining uncertainties (Section 3.2). Impacts on biota have seen little prior research and are subject to complex feedback processes (Section 3.4). Surge barriers will exist in the context of other long-term drivers of change such as dredging and climate change (Section 3.5). As described in Section 2.2, coastal flood risk and adaptation using storm surge barriers is a challenging coupled human-geophysical subject, suggesting that social science research is also needed (Section 3.6).

3.1. Data Collection and Research on a Wider Variety of Estuaries

Globally, very little physical and 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. The case with the most published literature and data is the Eastern Scheldt, an estuary with mean depth of 9 m and limited river input because its river was diverted in the mid-1800s (Louters et al., 1998). Considering proposals for surge barriers on drowned river valley estuaries or lagoonal estuaries (e.g., USACE, 2021a, 2022a), relatively little before-and-after data exists, even though these barriers have been built in the past (e.g., Neva River, Thames River; Mooyaart & Jonkman, 2017). The transport processes affecting salinity, sediment, and other material (e.g., nutrients, pollutants) vary greatly depending on the physical characteristics of an estuary, including geometry, depth, tidal amplitude, degree of stratification and freshwater inflow (e.g., Geyer & MacCready, 2014). Potential impacts of a surge barrier on estuary conditions vary with these same factors. An expanded range of estuaries and physical and ecological measurements, both before and for decades after surge barriers are built, can greatly improve our understanding of their environmental effects.

3.2. Near-Field/Far-Field Coupling and Modeling Sensitivities

Numerical hydrodynamic and sediment transport models are typically deployed for site and regional scale assessments of response to structures (e.g., McAlpin & Emiren, 2022; Warner et al., 2010). Although these models are appealing for their capacity to compare pre- and post-barrier installation scenarios, there are large uncertainties in the models related to spatial resolution and sediment properties, among other factors. The barrier and their openings lead to sharp contraction (upstream) and expansion (downstream) of tidal flow over relatively short distances (10–100s of m). The direct physical effects of this flow obstruction on tides, stratification and salinity can extend throughout the estuary landward of the barrier (10–100s of km). Simulating flows over this range of scales remains a challenge for numerical models, and modeling sensitivity studies would be valuable (e.g., resolution, horizontal eddy parameterizations). The flow through barrier openings can result in flow separation and shedding of vortices that results in form drag felt by the tidal flow at larger scales (Ralston, 2022). The vortices have length scales similar to the pier widths and at times greater than the water depth, so have characteristics of 2D (two-dimensional) turbulence in shallow flows that are not represented in estuary-scale models (Broekema et al., 2018; Uijttewaal & Jirka, 2003). Higher resolution modeling is needed to characterize interactions between the 2D vortices and 3D bottom boundary layer turbulence in the vicinity of the barriers, and to link the localized flow properties to larger-scale impacts on tidal energy flux and transport processes.

Similar modeling challenges apply to sediment transport and morphological evolution, where additional uncertainties are compounded by the range of scales, sharp gradients, and high velocities (e.g., Fringer et al., 2019). Model development and uncertainty assessment should be applied to bed sediment scour in the vicinity of barriers and farther into the estuary where decreased tidal velocities may reduce sediment resuspension or change locations of sediment deposition. Lastly, uncertainties in modeling pollution and biogeochemical impacts will be worsened by these hydrodynamic and sedimentary uncertainties.

3.3. Effects on Sedimentary Systems and Tidal Wetlands

Surge barriers can modify both local and estuary-scale sedimentary processes, and the range of these effects and potential feedback processes for different estuary types should be assessed. The Eastern Scheldt's estuary-wide reduction of intertidal shoals (Section 2.4) may exemplify the effect of surge barriers in reducing tidal amplitudes for an estuary that imports offshore sediments. However, in estuaries where the primary sediment source is from the rivers, barriers may have the opposite effect, increasing sediment retention and leading to enhanced sediment accumulation. Correspondingly, tidal flats and marshes located seaward of a barrier on a river-dominated estuary could experience reduced sediment delivery from the river and be prone to increased erosion. The location of an estuarine turbidity maximum may shift along with any shift in the salinity intrusion (landward or seaward) (Burchard et al., 2018). Potential feedback mechanisms range from relatively straightforward impacts of morphodynamic changes on hydrodynamics, to more complex biogeomorphological feedback mechanisms discussed in Section 3.4. Potential remobilization of contaminated sediment in urbanized estuaries provides additional motivation to better understand these processes.

Storms and associated high water levels are important but relatively understudied mechanisms for sediment supply to salt marshes (Leonardi et al., 2018). Post-event sampling campaigns have shown contrasting effects depending on local sediment supply and mobilization processes (Elsey-Quirk, 2016; FitzGerald et al., 2020); reduction of episodic high-water events will likely reduce storm-associated deposition on wetland platforms (Figure 2). Wave-induced erosion of marsh edges is often maximum near inlets where oceanic swell propagates unimpeded (Tommasini et al., 2019), therefore surge barriers may reduce edge erosion (even when open, if ocean swell waves are dissipated). On the landward marsh edge, migration is controlled by sea-level rise and storm surge that increase soil salinity at the forest-marsh transition (Fagherazzi et al., 2019); whether surge barriers influence migration by limiting the storm surge contribution to soil salinity can be investigated by comparing historical rates of migration with modern rates in natural and barriered systems. The Fagherazzi et al. (2019) "ecological ratchet" model of marsh migration assumes that storms and associated saltwater intrusion initiate forest dieback and control the lower boundary where forest may persist; sea-level rise controls the upper boundary of where forest can regenerate after episodic events. Therefore, the operation of surge barriers could largely eliminate the ecological ratchet and limit the migration of marsh into coastal forest. Salinity also plays a large role in the spread of invasive species at the landward margin, including Phragmites australis (Shaw et al., 2022). Eliminating the effect of episodic salinity fluctuations during storms may influence colonization by invasive species in the forest understory. Detailed field, remote-sensing, and modeling investigations into these coupled biogeomorphic processes across the estuary-wetland continuum could facilitate understanding the effects of barriers on wetland function and trajectory.

In urban estuary systems, the monetary benefits of surge barrier construction may greatly exceed the costs, and so an important research question is whether sedimentary mitigation can be effective and its costs manageable. For example, with the Eastern Scheldt, tidal flats are now nourished to mitigate the tidal flat erosion (Van der Werf et al., 2019). In cases where riverine sediment sources have been interrupted, they could be restored to mitigate loss of storm-driven sediment supply to marshes (Tognin et al., 2021). Similarly, sediments can be pumped onto marshes as thin layer placements, to mitigate any reductions in natural sedimentation. Research should also assess the long-term capacity and costs for managing sedimentary systems in these ways.

3.4. Effects on Migrating and Resident Organisms

A likely starting point for impact research pertinent to nektonic fauna (NF: crustaceans, fishes, turtles, and cetaceans) are the dams and other barriers that segment freshwater fluvial environments. Estuarine and coastal storm surge barriers will allow much greater organismal flux than freshwater dams but are expected to alter migrations and connectivity through their operations (frequency of closure; Figure 3), changed hydrology, and presence of artificial structures. As with dams, a focus on NF passage rates can aid in predictions of how storm surge barriers and their operation might affect key ecological functions such as reproduction, growth, and overwintering of populations; and production, resilience and stability in metapopulations and communities (Secor, 2015). Here, two baseline elements are important: (a) Understanding how spatial structure upstream and downstream of the imminent barrier contributes to ecological function (McKay et al., 2017) and, (b) estimating passage rates of NF with observations and models prior to barrier construction to support Before-After-Control-Impact (also Before-After-Gradient) studies (Algera et al., 2020; Bellmore et al., 2017; Ellis & Schneider, 1997).

Science that informs riverine barrier construction, design, and removal relies on passage rates of key biota and includes a range of empirical and modeling approaches. Here, the integration of empirical estimates and modeling provides an advantage in leveraging field designs and data in prediction and simulations (McKay et al., 2017). In comparison to upstream dams, estuarine and coastal barriers and adjacent regions will receive oceanographic forcing. Here numerical models that utilize observing system data (wind, temperature, tide, salinity) and derived hydraulic models can be coupled with empirical measures of passage rates (Burke et al., 2016; Hidalgo et al., 2016). Biotelemetry arrays are a particularly powerful means to synchronize fine scale (meters and seconds) three-dimensional movements of NF to coastal forcing, supporting flexible predictive models (e.g., nonlinear General Additive Mixed models; e.g., Breece et al., 2018; Rothermel et al., 2020). An alternative approach is to model passage as emergent behaviors related to simple and more complex simulations of movement ecology through agent-based models. The most abstract model might consider NF as passive particles, arguably an unreasonable assumption, but a valuable null model to evaluate how well passage is predicted under the simplest of assumptions. Such models are conducive in evaluating, a priori, not only impacts but aspects of barrier design and operation that might mitigate impacts (Goodwin et al., 2006; Morrice et al., 2020). Finally, e-DNA could support coarser assessments to evaluate impacts to NF communities and rare species (Consuegra et al., 2021; Pfleger et al., 2016).

Intertidal flats and marshes host a range of benthic species, influencing the flow, sediment transport and morphodynamics. Complex biogeomorphological feedback mechanisms can occur between biostabilizers/bioturbators, morphodynamics and hydrodynamics (Le Hir et al., 2007; Volkenborn et al., 2007; Weerman et al., 2012; Widdows & Brinsley, 2002). The robustness of these interactions determines how the system will react to a modification like a barrier. Biostabilizers reduce the erosion, while biodestabilizers or bioturbators can lead to more resuspension of sediment. These organisms strongly depend on immersion times and hydrodynamic stresses, but also on sediment composition and predation and food availability. Relatively small changes could lead to tipping the system to another equilibrium, with changes in bed level, bed composition and benthic community as consequence. Further research is needed on how robust these biogemorphological feedback mechanisms are and whether they can be changed by the presence of barriers.

3.5. Combined Effects of Surge Barriers, Dredging and Climate Change

Surge barrier driven increases in estuary salinity, stratification and bottom-water residence time could lead to reductions in dissolved oxygen concentrations (Du et al., 2017; Kirshen et al., 2020). These are similar changes to those expected from sea level rise and climate warming (e.g., Najjar et al., 2010), as well as dredging (Ralston & Geyer, 2019) in estuaries. For example, the projected landward shift in the Hudson River's salinity intrusion from modeling of the potential New York/New Jersey Harbor barrier was similar to that from the most recent harbor deepening project (from 13.7 to 15.2 m, in 2016; Ralston, 2022). Therefore, an important additional area of future research is the combination of climate change, dredging and surge barrier effects on estuaries.

3.6. Coupled Human-Natural System Dynamics of Surge Barrier Management

Surge barrier estuary impacts are highly sensitive to human management of gate closures (Section 2.2) and understanding and predicting future closure management and evolving societal vulnerability in barrier-protected floodplains is a grand research challenge. Two choices are available as flooding becomes more frequent due to sea level rise (Chen et al., 2020): (a) Close the barrier at an increasing frequency, or (b) raise the trigger water level for closures and pre-emptively apply shorefront or non-structural measures inside an estuary to prevent flooding. However, the record of society in pre-emptive flood risk reduction is poor (NRC, 2014), and increasing closures of surge barrier systems (e.g., Figure 3) are evidence that closing barriers more frequently may be a more common response to sea level rise. Moreover, it is common for governmental institutions, households and businesses to increase development in floodplains behind coastal risk reduction projects (Figure 2), a phenomenon called induced development (NRC, 2014). Given the NRC (2014) conclusion that the primary factor in our recent increases in flood risk has been increased development in floodplains, the potential for induced development requires further study, including the case where protective structures are located far from sight (Ludy & Kondolf, 2012).

4. A Path Forward

The research agenda above is interdisciplinary and ranges from fundamental to applied research questions. A joint effort including universities, government engineers, NGOs and scientific agencies is needed to tackle this societally important and rapidly growing topic. This likely requires new funding sources and strategies, and open science is key. New baseline science, such as before-after-control-impact study designs, is also critical. The recent US Engineering with Nature initiative provides an example of this broad collaboration (Bridges et al., 2015) as does the Dutch EcoShape consortium (De Vriend & Van Koningsveld, 2012). The broader challenge will be to better understand the long-term tradeoffs of investing in barriers versus other alternatives to address multiple hazards from an economic, social, and environmental perspective.

Data Availability Statement

The only data used in this commentary are publicly available data that were used in creating Figure 3. These are: (a) HURDAT2 (Landsea & Franklin, 2013) from https://www.nhc.noaa.gov/data/#hurdat. https://www.nhc.noaa.gov/data/#hurdat and (b) New Bedford Hurricane Barrier closures (USACE, 2022b), from https://reservoircontrol.usace.army.mil/nae_ords/cwmsweb/cwms_web.other_html.BulletinPage.

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