Wilmington Harbor Navigation Improvement Project Draft Environmental Impact Statement Technical Review

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Executive Summary

The Draft Environmental Impact Statement (DEIS) for the Wilmington Harbor Navigation Improvement Project contains major methodological deficiencies across notable project impact areas. In our estimation, it is very likely that some of these issues could lead to significant and systematic underestimation of the project impacts across certain critical areas. These deficiencies and their impact on the DEIS's main conclusions, including the economic benefit calculations, need further scientific study and careful re-evaluation of the updated assessments.

Most concerning of these oversights is that the DEIS heavily relies on flawed hydrodynamic modeling to assess the impacts of increased large vessel traffic along the Cape Fear River. In our technical assessment, we determined that the analysis presented in the DEIS is limited by inadequate model calibration and insufficient model parameterization, including of key parameters such as sediment composition and bed roughness values. Critically, the vessel wake impact modeling is based on a smaller 12,400 twenty-foot equivalent units (TEU) design vessel, rather than the larger 14,220 TEU ships already calling at the port. Empirical equations show that there is a direct correlation between vessel size and wake height, and therefore of bank erosion and long-term maintenance dredging requirements.

Regarding climate risk, the DEIS uses a USACE sea level rise (SLR) scenario that is not only mischaracterized relative to NOAA's SLR projections, but is in fact 1.7 feet, or 26%, lower than NOAA's highest-end projections by end-of-century. Because of this, the DEIS SLR scenarios underestimate the potential for worst-case storm surge flooding and coastal change. Furthermore, the analysis of compound flooding risk is found to be superficial, treating natural hazards in isolation. This is contrary to peer-reviewed best practices for coastal risk assessment which recognize and plan for non-linear interactions of coastal natural hazards.

The DEIS also fails to test for PFAS contamination in the project area riverbed sediments. This is despite well-documented PFAS contamination in the Cape Fear River and recent USACE guidance identifying PFAS as a challenge for dredging projects. The lack of PFAS testing is particularly problematic given that the economic cost-benefit analysis assumes extensive beneficial use of dredged material without considering the potential for PFAS to be mobilized. Proposed beneficial use of dredged sediment includes habitat restoration and beach nourishment, including of public beaches where human exposure risk would be high.

Finally, our review suggests that the DEIS minimizes potential impacts to groundwater and wildlife by using oversimplified models and by masking project-related habitat and wildlife losses against those expected from background environmental change. This approach makes it difficult to parse out project impacts from changes due to sea level rise. With regards to saltwater intrusion risks, our review of the regional groundwater model shows that the DEIS fails to adequately parameterize known dynamics in the groundwater systems and dismisses risks to shallow aquifers, e.g., from breached geologic confining units related to proposed channel dredging and/or blasting. However, regional well data are limited, which is a significant challenge for model verification.

In summary, our analysis suggests that the Wilmington Harbor Navigation Improvement Project DEIS does not provide a sufficiently comprehensive scientific analysis of risks or alternatives, particularly as it relates to contamination risks from PFAS, beneficial use of dredged sediments, wave energy hydrodynamics, future sea-level rise and compound flooding hazards, and impacts to wildlife and the groundwater resources. In Lynker's technical opinion, substantial revision of the DEIS is required to meet scientific best practices. Without these corrections, the project's environmental and public health impacts will remain uncharacterized and unquantified.

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Technical DEIS Review

1. Hydrodynamics and Coastal Erosion

Key Findings:

The DEIS likely understates the risks of channel deepening and increased large vessel traffic on coastal erosion and shoreline stability due to critical flaws in its hydrodynamic modeling. For example, the advanced wake analysis used a 12,400 TEU design vessel (Main DEIS p. 3-7; Appendix B p. B-239), which is smaller than the largest ships already calling at Wilmington (such as the 14,220 TEU *Yang Ming Warranty*) and did not evaluate the deeper drafts these vessels will operate at after deepening. Published empirical formulas (e.g., Kriebel and Seelig, 2005) show that wake energy, and resulting erosional force, rises sharply with vessel size and especially with increased draft. By not modeling the larger, deeper-loaded vessels expected with the project, the DEIS likely underestimates future wake heights and shoreline erosion risk.

The hydrodynamic analysis also underrepresents long-term and cumulative erosion effects by focusing on single-vessel or annual conditions rather than maximum wave energy conditions or the 50-year compounding impact of large-vessel transits combined with projected sea-level rise (Main DEIS p. 3-3; Appendix B p. B-234). Sea-level rise modeling assumes only 1-2 inch tidal increases, even though the DEIS cites a high scenario of 3.77 ft by 2086 (Appendix B p. B-184), likely understating future shoreline attack height and salinity intrusion.

In addition, the sediment transport modeling omits key pathways near the Ocean Dredged Material Disposal Site (ODMDS) and excludes the two seaward reaches most affected by offshore placement (Baldhead Shoal Reaches 3 & 4; Main DEIS p. 3-14), perhaps underestimating shoaling and long-term maintenance needs.

Recommendations:

1. Request that the revised EIS update its vessel wake and erosion modeling to use a design vessel that matches the largest ships currently calling or anticipated to call to Wilmington Harbor, i.e., the 14,220 TEU Post-Panamax Gen III containerships cited in the DEIS. The design vessel's draft should realistically reflect the projected cargo loaded onto inbound vessel traffic.
2. Note that the EIS should quantify the uncertainty and sensitivity of sediment transport and erosion forecasts, with explicit analysis of how results change with vessel size and peak-force events, not just annual averages
3. Ask that the revised EIS provide transparent modeling assumptions and results, and include validation of model outputs against observed wake, erosion, and shoreline change along the Cape Fear River

Supporting Analysis:

Our review finds that, despite the extensive modeling presented in the DEIS, there are several critical methodological deficiencies that likely lead to an underestimation of key environmental risks. For example, the DEIS relies heavily on hydrodynamic and wave models that use uncalibrated parameters and lack validation against observed conditions. Some modeling assumptions also appear to be unsupported. These limitations may challenge the reliability of the DEIS's projections for maintenance dredging volumes, bank and shoreline erosion along the Cape Fear River, and the potential risks of dredged material placement in ecologically sensitive areas. Key technical issues include:

Coastal Erosion Predictions: The DEIS uses an uncalibrated model and misleading annualized metrics to conclude erosion will decrease, contradicting its own data showing that peak erosive forces (bed shear stress) from individual large vessels will significantly increase at some locations. Erosion is an event-driven process governed by maximum bed shear stress, not annual averages. At least one location was projected to experience a doubling of peak bed shear stress under scenario AA1 (Ft. Caswell, +102%; Appendix B, Table 11-7, p. B-258). By relying on annualized metrics (Appendix B-II, Figure 87, p. II-61), the DEIS obscures these increases in peak erosive risk that are most relevant to physical channel change.

Misapplication of Erosion Models (XBeach, GenCade) to Riverbank Environments: The DEIS uses sand transport models (e.g., XBeach) that are not designed for the Cape Fear's cohesive/composite banks of silt, clay, rock, and marsh (Main DEIS, p. 3-66). This is a fundamental flaw, as the physics of bank failure are very different from sandy beaches, and the predictions are likely to be unreliable or physically meaningless (Appendix B, pp. B-157, B-236; see also Stark & Eid 1994; Winterwerp & van Kesteren 2004).

Cumulative and Long-Term Effects: The DEIS primarily assesses wake and erosion impacts for single vessels or annual conditions, rather than the cumulative effect of thousands of large-vessel transits over 50 years, compounded by rising sea levels and storm frequency (Main DEIS, p. 3-3; Appendix B, p. B-234). This approach likely underestimates long-term shoreline retreat, chronic habitat loss, and mitigation needs.

Dredging Estimates: The DEIS does not directly model sedimentation or dredging needs for Baldhead Shoal Reaches 3 and 4, which are the most dynamic and newly constructed segments of the proposed channel. Instead, the DEIS extrapolates from other areas with different conditions. For Reach 4, which has no historical data, this means that about 32% of the projected maintenance dredging volume for the preferred alternative (AA1) is not supported by site-specific modeling. As a result, the reliability of the shoaling and maintenance analysis is highly uncertain (Main DEIS, Table 3-5, p. 3-11).

Omission of Key Sediment Pathways: The sediment transport modeling domain excludes the offshore ODMDS, and the most seaward channel reaches, neglecting the possibility of reworked dredged material increasing shoaling rates (Appendix B, Section B-9; Main DEIS, p. 3-14). This likely leads to underestimation of both maintenance dredging requirements and environmental impacts.

Undersized Design Vessel: The wake analysis (XBeach model) is based on a 12,400 TEU design vessel (Main DEIS, p. 3-20; Appendix B, Table 11-3, Page B-239), which underestimates potential impacts as the DEIS later notes that larger 14,220 TEU vessels are already in service at the port (Main DEIS, Section 2.2, p. 2-6). It is unclear if even larger vessels will be supported under the proposal.

High and Unquantified Uncertainty: Sediment transport forecasts in the DEIS are shown to be highly sensitive to grain size assumptions, with modeled shoaling rates varying by as much as +85% to -62% depending on the selected sediment size (Appendix B, Section B-9.4.4, p. B-205).

Despite this sensitivity, the DEIS presents only deterministic results using a single grain size, without quantifying or incorporating this uncertainty into its impact assessments. As a result, the actual range of potential outcomes, along with the risks to navigation and habitat, remain insufficiently quantified.

Inadequate Model Validation: The model is considered "validated" for Anchorage Basin by falling within a historical dredging range that has a nearly 400% variance. This is not a rigorous validation of model for a new, deeper channel configuration (Appendix B, Section B-9.4.2)

2. Sea-Level Rise

Key Findings

In Section 3.6, the DEIS acknowledges that channel deepening alternatives will increase the tidal range and raise the mean high-water level (MHW). However, the DEIS fails to fully investigate the *compounding* effects of channel deepening, SLR, and tidal amplification, and it minimizes the potential future impacts of these processes on the project area and surrounding estuarine systems. The DEIS briefly describes sea level rise (SLR) in Section 3.10.1, indicating a projected increase of 3.77 feet over the 50-year period of 2036-2086 under the USACE high SLC scenario at the Wilmington tidal gage. Furthermore, in comparison to the NOAA SLR scenarios, the USACE SLR scenario used in the DIES is a 26% lower than the worst-case NOAA projections by 2100. As a result, the DEIS may systematically underestimate the magnitude and rate of future SLR and its influence on tidal dynamics, salinity intrusion, and long-term project sustainability, leading to a significant underestimation of future project vulnerability (Nicholls et al., 2013).

The Corps' 2020 Review Assessment of the earlier Wilmington Harbor analysis specifically found that the project did not meet the standards of ER 1100-2-8162, which requires a transparent, quantitative assessment of sea-level change and its influence on project performance and environmental conditions. Despite referencing this guidance, the current DEIS again treats SLR largely as a static boundary condition rather than a dynamic forcing (a model input that drives system behavior, such as water levels, tides, or river discharge) that interacts with dredging depth, tidal hydraulics, and storm surge propagation.

Recommendations

1. The USACE should perform a fully coupled hydrodynamic modeling analysis that integrates all compounding factors (including fluvial discharge and wind effects) to accurately quantify the total peak water level risk associated with the deepened channel.
2. The EIS should adequately describe the full scope of impacts from increased tidal range and SLR, including an assessment of the change in the return period of flooding events.
3. The EIS must evaluate how sea-level rise will reduce the hydraulic efficiency of channel deepening and thereby increase long-term shoaling and dredging demands.
4. Despite high end uncertainty of end-of-century SLR scenarios, the DEIS modeling should evaluate the low probability, high consequence end of SLR scenarios, which includes +6.66 feet of SLR at Wilmington tidal gage by 2100.

Supporting Analysis

Compounding Effects are Non-Linear: Flood risk from multiple factors combined are non-linear, so the total risk is greater than the sum of its parts (Leuven et al. 2023; Talke and Jay 2020). The DEIS explicitly neglects riverine discharge and wind effects in Section 3.6. Leuven et al. (2023) find that ignoring any one factor of SLR, wind-induced water levels, fluvial discharge, and bed-level geometry can lead to significant misinterpretation of flooding risks.

Impacts from Tides, SLR, and Channel Deepening: The DEIS provides estimates of tidal amplification for Scenarios AA1 and AA2 (e.g., AA1 increases the mean range of tide by 5.9%) but dismisses the 5.3% increase in MHW in AA1 as "minimal" compared to the increase from SLC3. This is a misrepresentation of compounding flood risk, where a small increase in water levels above a critical threshold can cause a disproportionately large increase in inundation area and damage. Even a "*modest*" increase of 0.11 feet from channel deepening accelerates the timeline for high-tide flooding. Recent peer-reviewed scientific research shows that minor flooding in Atlantic estuaries is becoming increasingly worse as tidal amplification and SLR interact (McKeon & Piecuch, 2025). In a separate 2020 study, Talke & Jay showed that channel deepening and dredging reduce bottom friction and alter estuarine geometry, which can lead to nonlinear amplification of tidal range. In shallow systems like the Cape Fear River, even modest deepening can cause nonlinear amplification of tidal range and storm surge heights. These studies suggest that small tidal increases due to project impacts are likely to compound with SLR to significantly heighten flood frequency and severity, risks which the DEIS fails to evaluate.

SLR Impacts on Deepening and Dredging: In Section 3.10, the DEIS states that "*increased sea level change could lead to a reduction in required maintenance due to increased depth in the channel*." However, a paper from Cox et al. (2022) found that SLR reduces the hydraulic efficiency of deepened channels. In other words, dredging becomes increasingly ineffective as SLR alters tidal asymmetry and sediment transport. This expands the area requiring maintenance dredging by shifting deposition zones farther upstream. Furthermore, as Talke & Jay (2020) showed, channel deepening reduces bottom friction and enhances tidal energy propagation, which can exacerbate upstream flooding and erosion under higher baseline sea levels. These physical dynamics suggest that SLR will not only undermine the long-term efficacy of the proposed deepening but also amplify flood and sedimentation risks in adjacent low-lying areas along the Cape Fear River.

SLR Projections: The DEIS uses the USACE scenarios for projections of future SLR under climate change. The high scenario (SLC3) projects an increase of 3.77ft, however this may be underestimating the potential for future flood risk, when comparing the USACE SLR scenarios to those from NOAA (Figure 1). Figure 1 shows that the USACE high scenario is slightly below NOAA's intermediate-high scenario, and significantly below the NOAA high scenario (NOAA Sea Level Rise Viewer). Beyond just the Wilmington gage, the difference between the scenarios results in widespread discrepancies in inundation areas (Figure 2 and Figure 3).

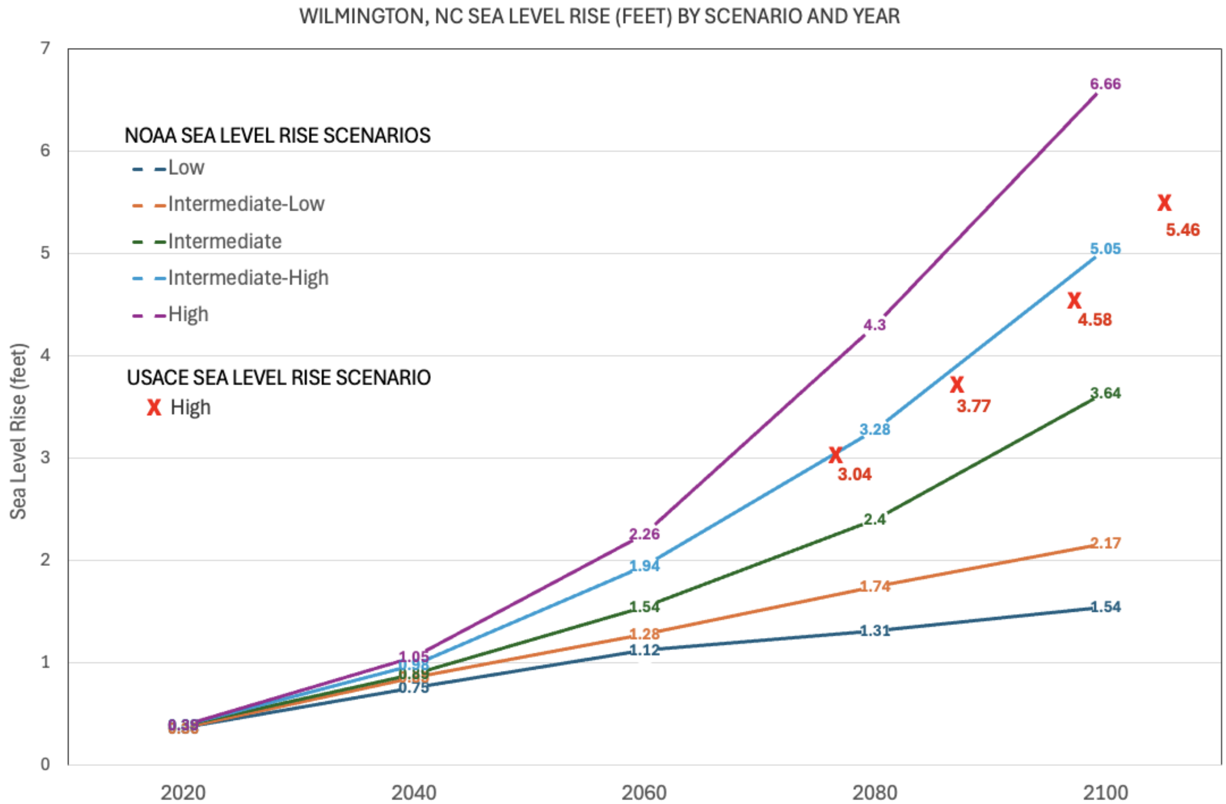

Figure 1: *Projected USACE and NOAA sea level rise (SLR) scenarios at Wilmington through 2100. The red 'X' markers indicate the USACE High scenario used in the DEIS for evaluating long-term SLR effects, while the color lines show five NOAA SLR scenarios. The figure illustrates that the DEIS SLR scenario underestimates end-of-century SLR by approximately 1.7 feet, or 26%, relative to NOAA's 'High' SLR scenario.*

<u>Flooding and Tidal Impacts:</u> Appendix B-10 describes modeling of channel deepening effects on tides and flooding using the Delft3D model. Hurricane Florence (2018) is used as a test case in these simulations, along with synthetic 100-year and 500-year storms. The analysis focuses on changes in river discharge, wave height, and wind fields. It does not appear to show how these events would affect flood risk or overall vulnerability in the project area. The main DEIS also does not connect the Hurricane Florence outcomes to broader system resilience, nor does it compare the modeling to actual flood impacts experienced during Florence (Figure 1). It's also worth noting that the tidal flood scenarios do not include wind or freshwater inflow, both of which are key drivers of compound flooding during hurricanes. Because of these limitations, the DEIS likely underestimates the true coastal flooding risk for the lower Cape Fear River, particularly under future warming scenarios.

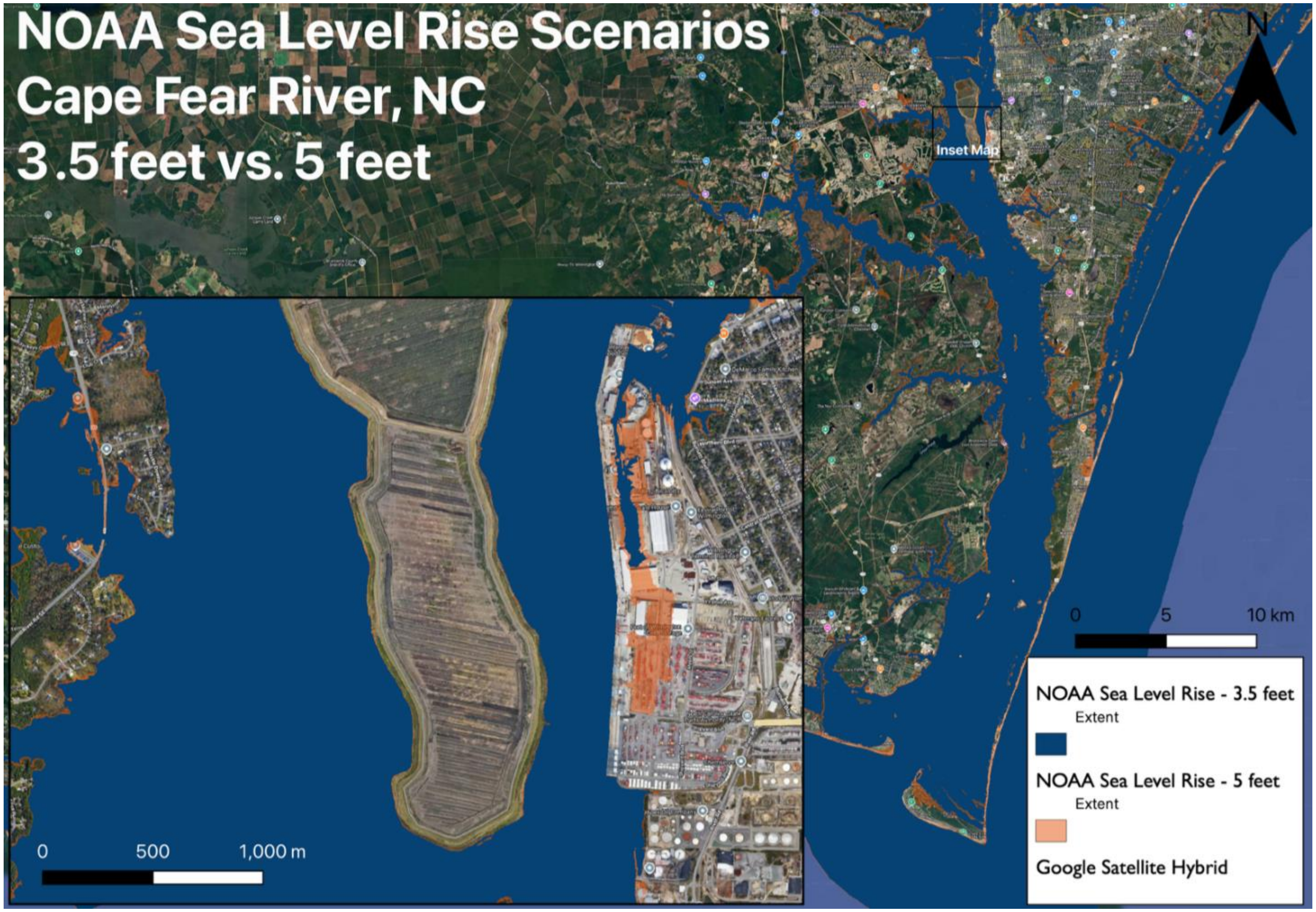

Figure 2: *Sea level rise (SLR) inundation extent map showing two NOAA SLR scenarios: the 3.5-foot (dark blue; intermediate scenario) and 5-foot (orange; intermediate-high scenario). Inset map on the bottom left shows the Port of Wilmington site, where the projected inundation from the 5-foot NOAA SLR scenario extends to the existing port site. The NOAA 5-foot SLR scenario roughly corresponds with the USACE 'High' SLR scenario used in the DEIS by 2100. NOAA's worse case SLR scenario projects a total of 6.66 feet by 2100, a scenario not evaluated in the DEIS. See Figure 3 below for more scenarios.*

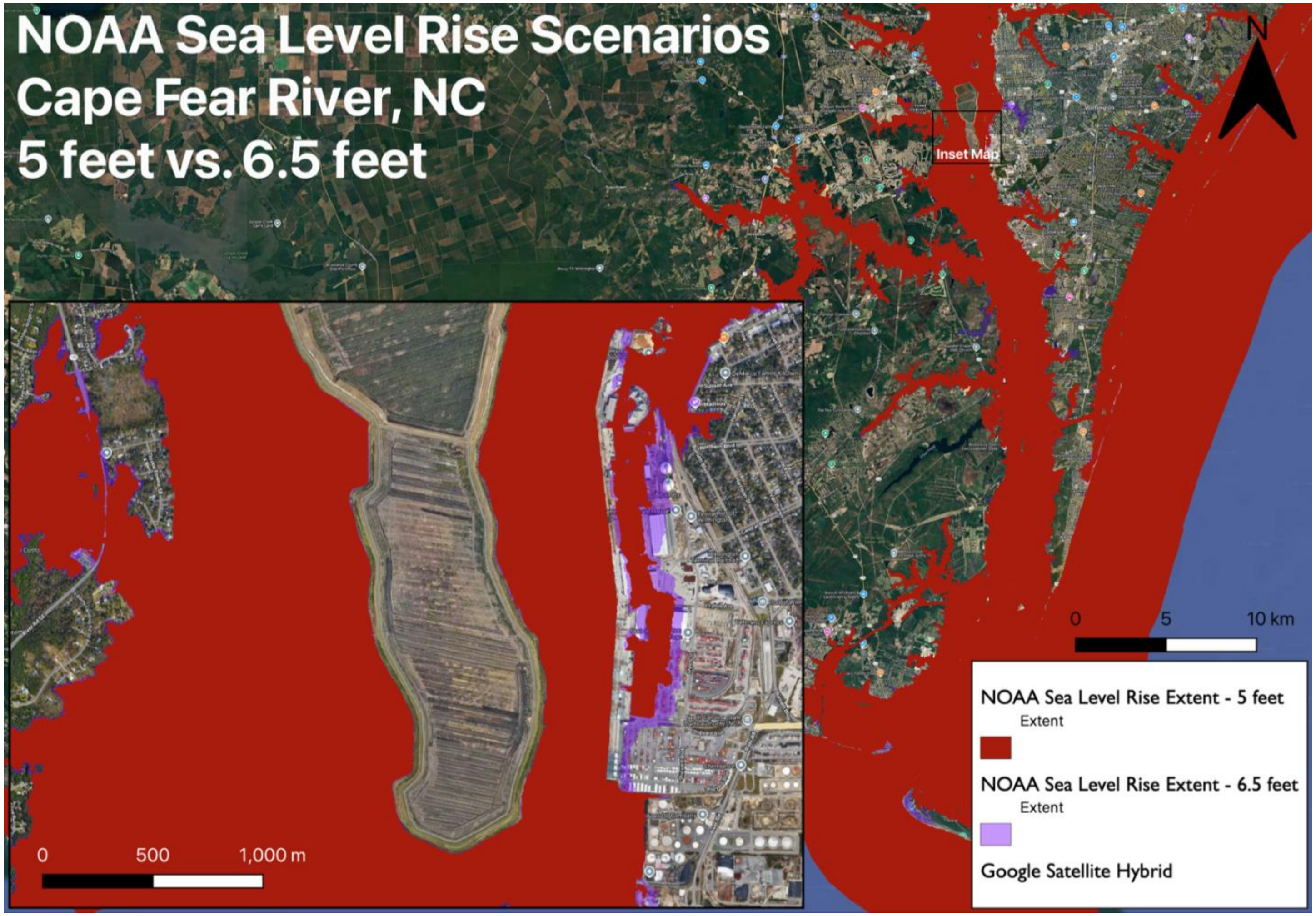

Figure 3: *Sea level rise (SLR) inundation extent map showing two NOAA SLR scenarios: the 5-foot (dark red; intermediate-high scenario) and 6.5-foot (purple; high scenario). Inset map on the bottom left shows the Port of Wilmington site. The NOAA 5-foot SLR scenario roughly corresponds with the USACE 'High' SLR scenario used in the DEIS by 2100. NOAA's worse case SLR scenario projects a total of 6.66 feet by 2100.*

3. Compound Flooding Hazard Risk

Key Findings

The DEIS does not provide a robust assessment of compound flood hazards. It analyzes storm surge, riverine, and rainfall flooding largely in isolation instead of as interconnected and compounding risks. Although Hurricane Florence is modeled from a storm surge perspective in Appendix B, the DEIS fails to treat it or other major storms as compound events, despite clear evidence that such events frequently drive record flooding in the Cape Fear River basin. By not integrating channel deepening into a system-wide, probabilistic (i.e., multi-scenario analysis) compound flood analysis, and omitting joint hazard probability or ensemble event approaches, the DEIS very likely underestimates both the frequency and severity of future flooding in the project area.

Deeper channels allow storm surge to travel farther and faster upriver by reducing bottom friction and resistance that normally dampen incoming waves. As a result, the same coastal storm can produce higher water levels, faster currents, and longer-lasting inundation farther inland. These amplified surges also interact with river flow and rainfall-driven runoff, trapping freshwater behind elevated tides and prolonging flooding across adjacent low-lying areas (Familkhalili & Talke, 2016; Gori et al., 2022).

Recommendations

1. The USACE should perform a joint hazard probability distribution analysis to accurately demonstrate the total expected annual damage from compounding events.
2. The EIS should consider an ensemble of events, as opposed to one "storm of record," to fully capture the response to a range of events.
3. The EIS's Environmental Consequences of Action Alternatives should include a description of compound events and how channel deepening potentially changes each flood type.

Supporting Analysis

<u>Compound Flood Events are a Greater Risk for Wilmington</u>: Gori et al. (2020) investigated the compound nature of six tropical storms to impact the Cape Fear Basin. Most events resulted in impacts from compound flooding types. They stated the impacts of pluvial and fluvial contributions can increase peak storm tide by over 1 foot (Gori et al. 2020). Future trends in compound flooding can be affected by both changes in tropical cyclone climatology and SLR (Gori et al. 2022), therefore flooding from extreme rainfall and SLR around Wilmington will become increasingly interdependent with climate change.

<u>Hurricane Florence Modeling Requirements</u>: Hurricane Florence presents an opportunity to assess the impacts of a compound event (Ye et al. 2021). Figure 3, from (Ye et al. 2021), highlights where flooding was dominated by storm surge, rainfall, and river runoff. Large areas of compound types are evident throughout the basin. The compounding characteristics and contributions from different flood types for each storm event will be unique (Gori et al. 2020), therefore analyzing an ensemble of events will more accurately capture the range of variability (Familkhalili et al. 2020).

<u>Channel Deepening Magnifies Storm Surge Risk Upstream</u>: A compound event will become even more severe because the deepened channel leads to further upstream penetration of storm surge and amplifies storm surge values (Familkhalili et al. 2020). Familkhalili and Talke (2016) found that

worst-case-scenario storm surge increased by 3 to 6 feet due to channel deepening that has already occurred. Storm surge modeling should not only include an ensemble of events but should model the entire system and integrate channel deepening (Familkhalili et al. 2020; Talke et al. 2021).

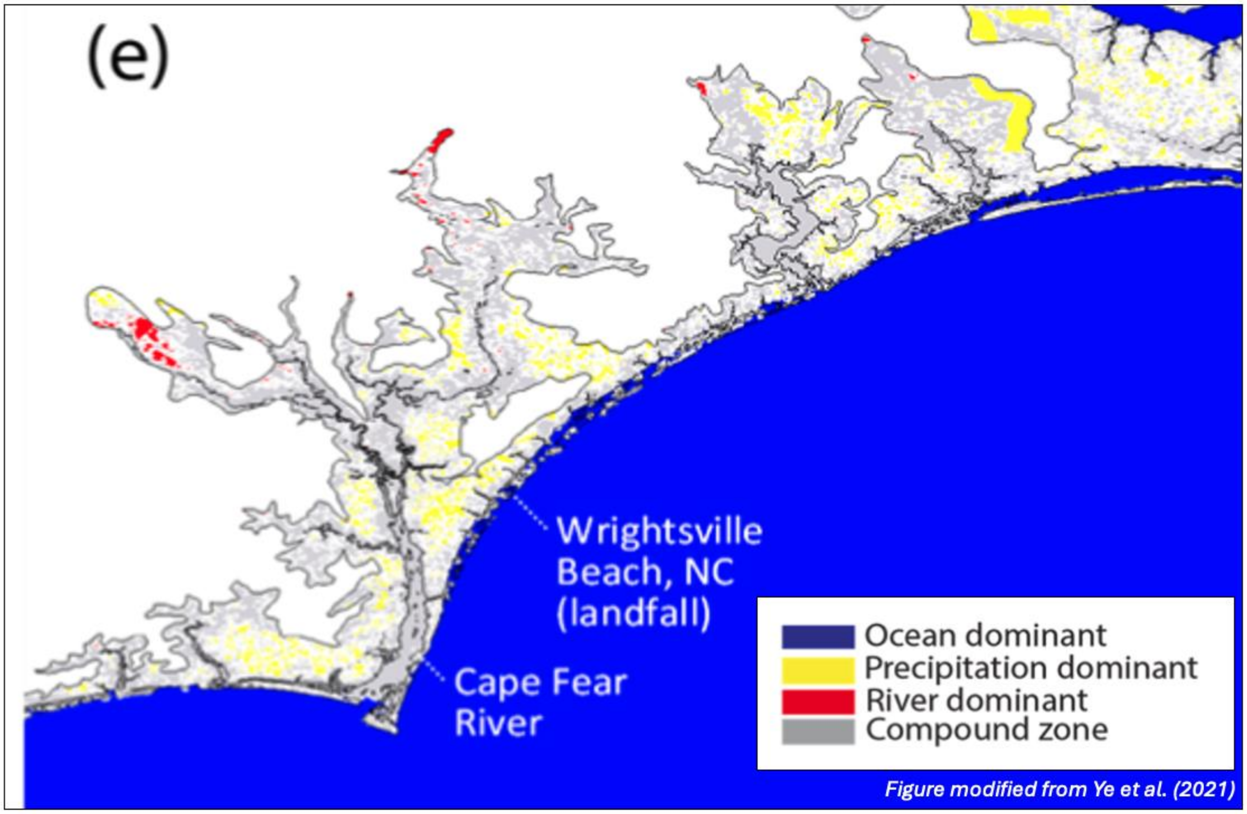

Figure 4: *Dominant flood drivers across the lower Cape Fear River and adjacent coastal region during Hurricane Florence (2018). Colors indicate zones where flooding was primarily ocean (storm surge) dominant (blue), precipitation dominant (yellow), river dominant (red), or controlled by compound interactions (gray). The widespread extent of compound flooding highlights the need to assess flood risk using a multi-driver framework, as the relative influence of surge, rainfall, and river flow varies spatially across the basin. Figure sourced from Ye et al. (2021).*

4. Pollution and Legacy Contamination

Key Findings:

The DEIS fails to characterize potential risks from legacy contamination within the project area, most notably because of the lack of PFAS testing of the riverbed sediments. Despite this shortcoming, the USACE acknowledges that PFAS contamination in sediments is an emerging and widespread challenge for dredging projects nationwide.

Multiple peer-reviewed scientific studies, including Saleeby et al. (2021) and Pétré et al. (2022), have documented widespread occurrence of both legacy PFAS (e.g., PFCAs and PFSAs) and newer compounds (e.g., GenX) in the Cape Fear River system. Pétré et al. (2022) detected PFAS compounds in all river water samples near the Chemours/DuPont Fayetteville Works facility (located approximately 87 miles upstream of the project area), with approximately 50% of PFAS detected at Kings Bluff near Wilmington attributed to Chemours discharges. Additional recent assessments (e.g., Geosyntec 2025) confirm that substantial PFAS loads continue to reach downstream reaches near Wilmington, even after remedial measures were implemented at the source.

Based on these published findings and current federal guidance, it is feasible (if not likely) that both legacy and Chemours-related PFAS are present in the sediments within the project area. The presence of PFAS would represent a significant and unevaluated environmental risk in the DEIS. Furthermore, if PFAS-contaminated sediments are slated to be used in beneficial use projects (such as beach nourishment), this could result in long-term environmental and public health risks that are not currently addressed in DEIS, including the economic cost–benefit analysis.

Recommendations:

1. Recommend that the EIS incorporate PFAS testing of sediment, shoreline deposits, and the Cape Fear River water, in line with the latest USACE and EPA guidance (EPA, 2025) for managing dredged material. Testing should include a full suite of legacy and emerging PFAS compounds, including precursors.
2. Ask that the EIS reassess dredging and disposal plans to address the potential for mobilizing PFAS and other emerging contaminants during both construction and maintenance dredging, and to incorporate USACE risk-based management protocols.
3. Suggest that the revised EIS include a full ASTM-compliant Phase I ESA, with radius search and field reconnaissance, to more thoroughly identify any Recognized Environmental Conditions (RECs) in and near the project area.
4. Request that the EIS assess PFAS and other contaminant risks in all dredged material proposed for Beneficial Use (BU) projects. The analysis should explicitly address how PFAS presence could impact water quality, habitat safety, and the suitability of BU placements, and require that the cost–benefit analysis incorporate potential long-term risks, monitoring, and mitigation costs if PFAS contaminated sediments are used.

Supporting Analysis:

The DEIS evaluated risks from contaminated soil, groundwater, and sediments within the project footprint. As noted in Attachment 5 of Appendix C, the EIS relied on database reviews rather than a full ASTM Phase I ESA with field reconnaissance. Consequently, onsite and adjacent RECs may have been overlooked.

The most significant site identified was the former Southern Wood Piedmont (SWP) facility at the Anchorage Basin, an EPA-recognized contaminated site (EPA, 2025). Investigations documented arsenic and PAHs in sediments above ecological criteria and localized dioxins/furans within 200 feet of the river. Soils near the waterfront also exceeded human-health criteria for arsenic and PAHs. The EIS concluded that channel deepening and widening would not disturb these materials since no dredging is proposed at the SWP facility.

Harbor-wide sediment testing in 1996, 2013, 2016, and confirmed in 2023 found contaminant levels acceptable for ocean disposal. The USACE and EPA evaluated dredged material under the Ocean Testing Manual (“Green Book”) and Region 4 SERIM, requiring bulk sediment sampling, elutriates, and, at Tier III, toxicity and bioaccumulation tests. Analytes include metals (e.g., As, Cd, Cr, Cu, Pb, Hg, Ni, Zn), PAHs, PCBs, pesticides, and dioxins/furans. *PFAS — including PFOS, PFOA, and GenX — were not included.*

According to the Corps, groundwater in the Surficial, Castle Hayne, and Peedee aquifers flows toward the Cape Fear River. Modeling predicted only minor gradient changes under the project, insufficient to mobilize or exacerbate contaminant plumes. Overall, the EIS concluded that the project is not expected to worsen contamination.

The Chemours/DuPont Fayetteville Works complex is a major PFAS source to the Cape Fear River, historically releasing GenX (a trademarked name of a PFAS chemical) and other compounds through outfalls, seeps, and air emissions. Since 2017, enforcement actions required Chemours to halt discharges and install remedies including a barrier wall and treatment systems. Although PFAS the facility is approximately 87 river miles upstream of Wilmington Harbor, PFAS are detected downstream and a recent study (Pétré et al., 2022) showed that impacts from plant discharges and legacy PFAS have likely contaminated sediments at the project site.

This 2022 study also showed that PFAS levels downstream of the plant and in the vicinity of Wilmington were above drinking water standards (EPA, 2024), posing long-term public health challenges, and that desorption of PFAS from sediments could contribute to ongoing contamination. They also highlight the role of precursor PFAS (e.g., fluorotelomer sulfonates, sulfonamides), which can transform into terminal PFAS during transport. Sediment dynamics are mentioned only as a possible contributor to persistence of PFAS in the water column, sediments themselves were not sampled and analyzed as part of the 2022 study.

Based on the peer-reviewed study from Pétré et al. (2022), Lynker believes that PFAS contamination from legacy sources, possible nearby sources, and the Fayetteville Plant is present in sediments planned for dredging as a part of this project and that the planned activities as described in the DEIS will release and spread sediment-bound PFAS contamination into the river and dredging disposal site(s). PFAS were not considered in dredge management assessments. Further sampling and analysis are warranted, as PFAS may be released during dredging or disposal. USACE's 2022 *Preliminary Risk-Based Guidance for the Assessment of PFAS in Dredged Material* highlights the urgent need for PFAS-specific management protocols. Additionally, the reliance on an abridged ESA method means RECs could have been missed. Thus, an ASTM-compliant Phase I ESA with radius search and site reconnaissance is also recommended.

5. Water Resources and Groundwater Vulnerability

Key Findings:

The DEIS likely underestimates, or at least fails to adequately evaluate, the risk of saltwater intrusion into regional aquifers because it relies on a simplified, region-scale groundwater model. Key model assumptions (e.g., that the river system is almost always a gaining reach and that geologic confining units effectively separate aquifers) are not well supported by field data and other published studies showing that tidal fluctuations, storm surges, and localized groundwater pumping can periodically reverse gradients and allow saltwater migration into the Surficial, Castle Hayne, and Peedee aquifers.

The groundwater modeling in the DEIS also unrealistically assumes a static salinity boundary and averages seasonal stress conditions over a 50-year simulation period. These broad-level assumptions remove the very conditions under which intrusion risk is greatest, such as summer pumping, drought, and coastal storm surge. Overall, the methodological flaws of the groundwater modeling suggest that the DEIS likely underestimates both the likelihood and the magnitude of saltwater intrusion and masks the potential for cumulative, irreversible degradation of shallow groundwater resources. A more comprehensive assessment of the model was not feasible because the modeling figures referenced in Appendix C, Attachment 6 could not be located within any of the DEIS documents.

Recommendations:

1. Critically, we note that the groundwater modeling figures referenced in Appendix C, Attachment 6 were not found in any of the DEIS documents. The lack of technical modeling figures prevents independent technical review of the groundwater modeling in the DEIS.
2. Suggest that the revised EIS include a more robust groundwater modeling analysis that is calibrated and validated to observed salinity and incorporates transient processes such as tides, storm surges, and variable pumping.
3. Recommend that the EIS address the vulnerability created by weak or discontinuous confining units, including direct hydraulic connection between aquifers where channel deepening intersects these units.
4. Ask that the EIS groundwater modeling use dynamic boundary conditions to better capture the risk of salinity intrusion during extreme hydrologic events, with a focus on assessing whether additional mitigation or monitoring measures are warranted.

Supporting Analysis:

The DEIS acknowledges that the groundwater model is only a "yardstick" for regional comparisons. However, the DEIS still relies on its results to conclude that navigational channel deepening will not create a moderate or high risk of saltwater intrusion into regional aquifers. This conclusion is based on a regional groundwater model that does not employ best modeling practices (e.g., Langevin et al., 2017). For example, the model was not calibrated to salinity, used broad and static boundary conditions, and did not account for important transient drivers such as tides, storms, or seasonal pumping.

The DEIS also characterizes the project area as one where existing salinity conditions are already influenced by sea level rise and groundwater pumping and therefore asserts that the proposed channel deepening would not exacerbate saltwater intrusion. However, the fact that conditions are already degraded should not determine the risk of adding additional stress to the system.

The following summarizes the model's implications and highlights the primary concerns identified during review of the DEIS and the supporting Groundwater Modeling report (Appendix C, Attachment 6, all referenced page numbers hereafter refer to Appendix C, Attachment 6 page numbers). Note that this review is based solely on the materials provided in the DEIS package; figures referenced in Appendix C, Attachment 6 were not included and therefore could not be evaluated.

<u>The river-aquifer interaction is oversimplified.</u> The DEIS assumes the Cape Fear River is almost always a gaining reach, meaning aquifer heads are above river stage and flow from the regional aquifers is outward. Yet, the report acknowledges that groundwater dynamics vary in the region, generally as a result of groundwater pumping: *"Heads in the area are almost always well above the river stage except in a few areas where there is significant pumping that has drawn the water level down below sea level."* (p. 1). The presumption that the Cape Fear River can be universally treated as a gaining river ignores the well-documented reality that coastal rivers can shift to losing

conditions under certain circumstances, such as storm surges, high tides, or localized pumping depressions. As one example, evidence from New Hanover County shows that there has been chloride intrusion into Castle Hayne and Peedee wells under such conditions (USGS, 2016; Coastal Review, 2014). Even if the river is generally and mostly "gaining", saltwater intrusion can occur whenever gradients reverse. The DEIS acknowledges but does not adequately address this fact, especially in the groundwater modeling study.

Our independent analysis of local monitoring wells confirms that water levels in both shallow (Surficial Aquifer) and deep (Castle Hayne/Peedee) aquifers fluctuate significantly, and that water levels can be below the corresponding elevation of the harbor. This indicates that losing conditions do occur due to localized pumping during drier times of the year. The groundwater model does not simulate these dynamics but instead assumes static boundary conditions. The assertion that the river will always behave as a gaining reach, despite channel deepening, sea level rise, and increased pumping, is likely an oversimplification of a dynamic groundwater system.

<u>Confining units are patchy and easily breached, yet impacts are underestimated.</u> The DEIS acknowledges that the "*Surficial and Castle Hayne Aquifers deepen and thicken towards the east… Neither of the confining units are laterally extensive and both are missing in places, providing direct hydraulic communication between aquifers*." (p. 1). Despite this, the DEIS interprets channel deepening impacts as minimal. This reasoning ignores established research showing that small discontinuities or permeability variations in confining units can fundamentally alter groundwater flow patterns and saltwater movement, reducing barrier effectiveness and increasing uncertainty in predicting salinity intrusion into coastal aquifers (Yu & Michael, 2022; Barlow, 2003). The System Illustrations (p. III–IV) demonstrate escalating levels of aquifer compromise: Scenario 1 shows deepening further penetrating the Surficial Aquifer; Scenario 2 shows complete breaching of the Surficial Aquifer with penetration into the Castle Hayne confining unit; and Scenario 3 shows dredging directly into the Castle Hayne Aquifer itself. Critically, all three scenarios threaten the Surficial Aquifer, which, while not a major regional water source, provides essential drinking water to numerous private wells across the area (NC DWR, n.d.). Given its shallow depth and natural susceptibility to contamination, even modest increases in saltwater intrusion could render these private wells unusable, yet the DEIS treats breaching of confining units as having "negligible" impact without defining this threshold or accounting for cumulative effects on already-compromised barriers.

<u>The static salinity boundary contradicts known saltwater wedge dynamics.</u> The model applies a fixed ocean salinity of 35 parts-per-thousand (ppt) throughout the 50-year simulation (p. 30). Yet, the DEIS notes, *"tidal variations in the ocean combined with the density difference between freshwater and seawater cause a saltwater wedge to move up and down the base of the channel."* (p. 2). This moving salinity wedge, influenced by tides, drought, and rainfall, is the primary driver of saltwater intrusion. By substituting a static salinity boundary for a dynamic wedge, the DEIS likely oversimplifies a key process potentially endangering aquifers near the Cape Fear River.

<u>Future seasonal variability not captured in groundwater model.</u> The groundwater modeling study claims the proposed channel deepening will not significantly worsen saltwater intrusion over its 50-year lifetime (2036-2086), yet the predictive model eliminates all seasonal variability that the calibration period (2011-2018) demonstrated as critical. During model calibration, the model captured dramatic seasonal patterns using quarterly stress periods, like 12-14 foot head swings at monitoring wells and tourist-season pumping spikes (p. 40-43). However, for the 50-year

predictions, all the observed dynamics were oversimplified: pumping rates were held constant at annual averages, precipitation was averaged across seasons, and the entire 50-year simulation period was modeled as a single unchanging stress period (p. 34, p. 83-84). This approach obscures the most dangerous scenario: summer conditions when maximum tourist pumping coincides with hurricane season, storm surge, and lowest natural recharge – exactly when breached confining units from deepening would create maximum vulnerability.

Even during calibration, the model could not reproduce observed seasonal head patterns, showing reversed seasonal signatures because only annual average pumping data was available (p. 36, p. 42). By averaging out these extremes, the model cannot assess whether summer saltwater intrusion pulses penetrate deeper through compromised barriers while winter recovery fails to reverse the damage, creating cumulative salinity accumulation over 50 years of cycles that constant-condition modeling cannot simulate.

6. Habitat and Species Impacts

Key Findings:

It is highly likely that the DEIS understates impacts of channel deepening on sensitive habitats and federally protected species. Habitat Suitability Index (HSI) models, for example, exclude substrate variables essential for assessing spawning habitat quality for Atlantic sturgeon and southern flounder. No HSIs or quantitative analyses were developed for other ESA-listed species such as sea turtles, right whales, or manatees, leaving major risks from dredging, blasting, and vessel strikes unassessed.

The wetlands analysis relies on outdated 2016–2017 data and median salinity values that mask short-term extremes driving marsh conversion. More recent mapping by the North Carolina Department of Environmental Quality (NCDEQ, 2024) documents widespread 2016–2022 change across the coastal plain, highlight how the DEIS baseline fails to represent current conditions. While the DEIS attributes most habitat loss to sea-level rise, it also shows project-related freshwater wetland reductions of 2–3%, a small but ecologically meaningful acceleration of habitat decline.

Decades of research demonstrate that dredging and canalization have long-lasting, system-wide impacts on estuarine hydrology and vegetation. Hackney and Yelverton (1990) documented that dredged navigation channels in the lower Cape Fear River increased salinity penetration and converted cypress–gum swamps to oligohaline and brackish marsh. Turner and Ohimain (2024) showed that dredging produces not only direct wetland removal but also indirect, legacy effects as spoil banks block surface and subsurface flow, creating prolonged waterlogging, sulfide toxicity, and erosion that accelerate wetland loss for decades after construction. Without modeling such feedbacks (e.g., hydrologic isolation, sediment starvation, and vegetation stress) the DEIS cannot capture cumulative or chronic degradation of freshwater and tidal wetland habitats.

Recommendations:

1. Request that the revised EIS include substrate variables when modeling HSIs for Atlantic sturgeon, southern flounder, and other sensitive species, in addition to performing HSIs on all ESA-listed species within the project area
2. Recommend that the wetland transition analysis be updated to incorporate the most current wetland conditions (i.e., from the National Wetland Inventory) and employ non-median, varying salinity to more accurately represent wetland impacts due to project alternatives
3. Ask that the EIS set quantitative thresholds for and incorporate modeling of construction-phase effects on aquatic species, including sediment plume dispersion and relevant water quality variables

Supporting Analysis:

Inadequate Species Coverage and Methodology: Appendix H introduces the Habitat Suitability Index (HSI) models, which quantify habitat quality on a 0–1 scale using variables such as temperature, salinity, and dissolved oxygen (derived from the Delft3D water quality modeling output) that are scaled through piecewise equations to represent species preferences. While described as "*modified based on literature review and subject matter expert consensus*" (p. 2), several adjustments weaken the model's impact assessment. Substrate variables were removed for Atlantic sturgeon and southern flounder because sediment data were deemed "*not high enough quality*" (p. 12). Assuming that "*spawning habitat substrate is not expected to be impacted by the project*" (p. 12) without supporting information of dredging impacts on spawning substrates, the DEIS reports minimal 2–4% reductions in sturgeon spawning habitat units (Table 3-54). These assumptions conflict with established evidence that sturgeon eggs require clean gravel or sand for adhesion and oxygenation, and that fine sediment deposition can bury eggs (ASMFC 2012; Hatin et al. 2007). By eliminating substrate — the defining parameter for spawning suitability — the model is unable to represent likely physical disturbances from dredging.

Although Appendix H cross-references NOAA's Detailed Method for Mapping Sea Level Rise Inundation to align its SLC3 scenario with NOAA's 3.77-ft "high" sea level rise projection, HSIs were clipped to mean higher high water (MHHW) and limited to "verified" spawning zones. This excludes shallow transitional habitats used by juvenile species and obscures potential early losses under sea-level rise. Moreover, total habitat units vary more with flow and sea-level scenarios than with dredging alternatives (see Sec. H.3.5), suggesting the model design may mask project-specific stressors. Finally, no HSIs were developed for ESA-listed species such as sea turtles, right whales, or manatees.

Unrepresentative Wetlands Assessment: Appendix I evaluates wetland change by overlaying Delft3D-modeled salinity fields onto wetland classification zones, assigning each polygon to a salinity category (tidal-fresh, oligohaline, mesohaline, polyhaline, or euhaline). The analysis compares median growing-season (May–October) salinity conditions across projected timeframes of 2036 (no sea-level rise) and 2086 (low, intermediate, and high SLR scenarios) for three project alternatives and three hydrologic years (dry, typical, wet). However, the baseline wetland maps are outdated, based on 2016–2017 wetland conditions (used in a prior 2020 North Carolina State Ports Authority (NCSPA) feasibility study (WRDA 203)) that predate years of documented shoreline erosion, marsh retreat, and forest die-off in the Cape Fear system. More recent state monitoring shows widespread 2016–2022 transitions from forested to marsh vegetation across the coastal plain (NCDEQ, 2024), highlighting that the DEIS baseline fails to reflect current wetland conditions. Furthermore, the use of median growing-season salinity values could mask short-term extremes (such as king tides, droughts, and storm surges) that can rapidly stress vegetation and trigger conversion (Enwright et al., 2016; Doyle et al., 2010).

Scenario comparisons, which are represented by raw acreage change and change maps (Main DEIS: Table 3-34, Table 3-35, Table 3-36, Figure 3-11, 3-12), identify salinity transition zones to track how rising salinity drives wetland type conversion under different SLR and project conditions (Main DEIS Sec. 3, pp. 53-56). Despite these change tables and maps, the relative incremental project effects are under-shadowed by impacts due to sea level rise. To clarify this, **Table 1** summarizes the conversion of freshwater wetlands (0-0.5 ppt salinity) to oligohaline (0.5-5 ppt) as relative percent changes over the modeled 2036–2086 period, revealing that while the most severe freshwater losses are attributed to sea-level rise, even small project-induced salinity increases can substantially accelerate the decline of freshwater wetlands and associated habitats. Under the No-Action Alternative, tidal-fresh wetlands decline by roughly 660 acres (–2 %) under low SLR1 (2036) and nearly 9,600 acres (–29 %) under high SLR3 (2086) (Main DEIS Table 3-34, Figure 3-11; Appendix I, Table 10). When project alternatives are layered on top of high-SLR conditions, they cause an additional ~2–3 % reduction in freshwater area. This is seemingly minor in raw terms, but ecologically meaningful when viewed as a compounding stress on already contracting freshwater zones.

Table 1: *Summary of Appendix I results on tidal freshwater wetland change across DEIS project scenarios.*

Scenario Description		Tidal Freshwater (acres)	Δ Freshwater (acres)	Relative Percent Change in Tidal Freshwater Area
1	Project Alternatives under No SLR (SLC0, Typical Hydrology) vs NAA (in year 2036)	NAA = 32,730 AA1 = 31,659 AA2 = 31,758	AA1-NAA = –1,071 AA2-NAA = –972	AA1-NAA = –3.3 % AA2-NAA = –3.0 %
2	Project Alternatives under High SLR (SLC3, Typical Hydrology) vs NAA (in year 2086)	NAA = 23,103 AA1 = 22,467 AA2 = 22,619	AA1-NAA = –636 AA2-NAA = –434	AA1-NAA = –2.8 % AA2-NAA = –2.1 %
3	Sea-Level Rise Only (NAA, SLC 1–3 in year 2086 vs SLC0 in year 2036)	SLC0 = 32,730 SLC1 = 32,071 SLC2 = 30,574 SLC3 = 23,103	SLC1-SLC0 = –659 SLC2-SLC0 = –2,156 SLC3-SLC0 = –9,627	SLC1-SLC0 = –2.0 % SLC2-SLC0 = –6.6 % SLC3-SLC0 = –29.4 %

By expressing results only as absolute acre changes, the DEIS fails to accurately convey how project effects may amplify climate-driven habitat migration, which could push sensitive systems past ecological tipping points. In an estuary already experiencing rising base salinity, altered tidal exchange, and reduced freshwater inputs, marginal changes from channel deepening can accelerate vegetation loss, soil oxidation, and marsh collapse. Conversion of tidal-fresh and oligohaline wetlands to more saline types disrupts vegetation structure and nursery functions vital to species such as Atlantic and shortnose sturgeon. These feedbacks mirror patterns already visible in the Cape Fear region's expanding ghost forests, where chronic saltwater intrusion and altered tidal dynamics have caused widespread cypress mortality and conversion to open water (Kirwan et al., 2019; Magolan et al., 2020).

Channel deepening can further exacerbate these transitions by intensifying tidal exchange and salinity intrusion, altering estuarine circulation and wetland health. Studies across the Southeast show that dredging and channel modification increase tidal amplitude and upstream salt penetration, accelerating wetland conversion (Rummel et al., 2025; Krauss et al., 2014). In the lower Cape Fear, these mechanisms likely interact with ongoing sea-level rise, magnifying stress on freshwater and oligohaline wetlands that are already at the edge of their salinity tolerance.

Finally, the wetlands assessment relies on the Uniform Mitigation Assessment Method (UMAM) to translate salinity-induced type conversions into functional loss estimates, yet the appendix provides no parameter tables or calibration documentation to show how scores were derived.

Qualitative Biological Species Assessment: The DEIS relies heavily on qualitative descriptions (i.e., Main DEIS: Table 3-51; Appendix F: Tables 8, 9) while deferring critical analyses to future plans. For example, confined blasting, which can displace, injure, or kill fish eggs, larvae, and juveniles in spawning and nursery habitats, is acknowledged as "likely to adversely affect" sturgeon and may be required over ~158 acres (Appendix J, p. 18; Appendix F, Sec. 3.3), yet project-specific modeling is deferred. Similarly, dredging impacts are discussed without establishing quantitative thresholds for turbidity, dissolved oxygen, or exceedance-day caps, leaving no easy way to evaluate water quality stress. Appendix F further expands potential risks: hopper dredges may be used "on any portion" of the channel (Sec. F.2.2), which may introduce entrainment threats to turtles and sturgeon in upriver habitats. For right whales, vessel track maps (2021–2024) are shown (Sec. F.2.2), but strike risk is not quantified, and protective measures are limited to SMA speed restrictions for ≥65-ft vessels, leaving smaller project vessels unaddressed. Despite an extensive qualitative effects determination for each sensitive species, the DEIS fails to back up its claims with modeling or evidence beyond referencing the USACE's 2020 South Atlantic Regional Biological Assessment (SARBO) report.

Dredging Impacts: In Appendix D, the DEIS presents the beneficial use of dredged material as an ecological opportunity but also reveals how dredging and channel modification fundamentally reshape the Lower Cape Fear River's biological systems. Deepening and widening the navigation channel, which proposes to relocate nearly 35 million cubic yards of sediment, would alter benthic and intertidal habitats, increase turbidity, and modify salinity and current regimes that sustain sensitive aquatic life (Maren et al., 2015; van Rijen et al., 2018). Proposed material placements at intertidal flats, bird islands, and shoreline margins aim to offset these effects by supplementing lost marsh and nesting habitats. Yet this approach underscores a growing ecological dependence on engineered intervention: maintaining fisheries, wetlands, and avian habitats could increasingly rely on artificial sediment redistribution and ongoing management.

Despite acknowledging these broad effects, the DEIS includes no quantitative modeling of construction-phase impacts. The Delft3D simulations were limited to long-term salinity and wetland transition analyses and were not applied to model short-term turbidity, sediment dispersion, or water-quality changes during dredging or placement. Similarly, there are no spatial or temporal predictions for suspended sediment, dissolved oxygen, or plume extent, and no morphodynamic modeling to evaluate shoreline or habitat response to material placement. This absence of modeling underestimates the spatial footprint and cumulative intensity of dredging-related impacts on aquatic life, wetlands, and intertidal ecosystems.

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References

Atlantic States Marine Fisheries Commission (ASMFC). (2012). Atlantic Sturgeon Benchmark Stock Assessment: Addendum IV to Amendment I of the Interstate Fishery Management Plan for Atlantic Sturgeon. Arlington, VA: ASMFC Habitat Management Series.

Barlow, P. M. (2003). Gr*ound water in freshwater-saltwater environments of the Atlantic Coast* (Circular 1262). U.S. Geological Survey. https://pubs.usgs.gov/circ/2003/circ1262/pdf/circ1262.pdf

Cox, J. R., J. Lingbeek, S. a. H. Weisscher, and M. G. Kleinhans, 2022: Effects of Sea-Level Rise on Dredging and Dredged Estuary Morphology. *Journal of Geophysical Research: Earth Surface*, **127**, e2022JF006790, https://doi.org/10.1029/2022JF006790.

Doyle, T. W., Krauss, K. W., Conner, W. H., & From, A. S. (2010). *Predicting the retreat and migration of tidal forests along the northern Gulf of Mexico under sea-level rise.* Forest Ecology and Management, 259(4), 770–777. https://doi.org/10.1016/j.foreco.2009.10.023

Enwright, N. M., Griffith, K. T., & Osland, M. J. (2016). *Barriers to and opportunities for landward migration of coastal wetlands with sea-level rise.* Frontiers in Ecology and the Environment, 14(6), 307–316. https://doi.org/10.1002/fee.1282

Familkhalili, R., and S. A. Talke, 2016: The effect of channel deepening on tides and storm surge: A case study of Wilmington, NC. *Geophysical Research Letters*, **43**, 9138–9147, https://doi.org/10.1002/2016GL069494.

Familkhalili, R., Talke, S. A., & Jay, D. A. (2020). Tide-storm surge interactions in highly altered estuaries: How channel deepening increases surge vulnerability. *Journal of Geophysical Research: Oceans*, *125*(4), e2019JC015286.

Geosyntec Consultants. (2025). Cape Fear River PFAS Mass Loading Assessment – First Quarter 2025 Report, prepared for Chemours.

Gori, A., N. Lin, and J. Smith, 2020: Assessing Compound Flooding From Landfalling Tropical Cyclones on the North Carolina Coast. *Water Resources Research*, **56**, e2019WR026788, https://doi.org/10.1029/2019WR026788.

Gori, A., Lin, N., Xi, D., & Emanuel, K. (2022). Tropical cyclone climatology change greatly exacerbates US extreme rainfall–surge hazard. Nat. Climate Change, 12, 171–178.

Gust, K. (2025). Food Web-Based Computational Tool to Estimate PFAS Risk to Human Health from Dredge Material. USACE Environmental Laboratory.

Hatin, D., Fortin, R., & Caron, F. (2007). Movements and aggregation areas of adult Atlantic sturgeon (Acipenser oxyrinchus) in the St. Lawrence River estuary, Québec, Canada. Journal of Applied Ichthyology, 23(6), 548–557. https://doi.org/10.1046/j.1439-0426.2002.00395.x

Kirwan, M. L., & Gedan, K. B. (2019). *Sea-level driven land conversion and the formation of ghost forests.* Nature Climate Change*, 9,* 450–457. https://doi.org/10.1038/s41558-019-0488-7

Krauss, K.W., Duberstein, J.A., Doyle, T.W. et al. *Site condition, structure, and growth of baldcypress along tidal/non-tidal salinity gradients.* Wetlands 29, 505–519 (2009). https://doi.org/10.1672/08-77.1

Langevin, C. D., Hughes, J. D., Banta, E. R., Niswonger, R. G., Panday, S., & Provost, A. M. (2017). *Documentation for the MODFLOW 6 Groundwater Flow Model (Techniques and Methods 6-A55).* U.S. Geological Survey. https://doi.org/10.3133/tm6A55

Leuven, J. R. F. W., I. Niesten, Y. Huismans, J. R. Cox, L. Hulsen, T. van der Kaaij, and A. J. F. (Ton) Hoitink, 2023: Peak Water Levels Rise Less Than Mean Sea Level in Tidal Channels Subject to Depth Convergence by Deepening. *Journal of Geophysical Research: Oceans*, **128**, e2022JC019578, https://doi.org/10.1029/2022JC019578.

Lotufo, G. (2022). *Preliminary risk-based guidance for the assessment of PFAS in dredged material (Fact Sheet No. 21-06).* U.S. Army Corps of Engineers, Engineer Research and Development Center. https://doer.el.erdc.dren.mil/factSheets/RISK/21-06_FactSheet_Lotufo_Preliminary-Risk-Based-Guidance-for-the-assessment-of-PFAS-in-Dredged-Material.pdf

Magolan, J. L., & Halls, J. N. (2020). *A multi-decadal investigation of tidal creek wetland changes, water level rise, and ghost forests.* Remote Sensing, 12, 1141. https://doi.org/10.3390/rs12071141

Maren, D.S., Kessel, T., Cronin, K., Sittoni, Luca. (2015). *The impact of channel deepening and dredging on estuarine sediment concentration.* Continental Shelf Research. 110. 10.1016/j.csr.2014.12.010. https://www.sciencedirect.com/science/article/pii/S0278434314003720?via%3Dihub

McKeon, K., and C. G. Piecuch, 2025: Compound Minor Floods and the Role of Discharge in the Delaware River Estuary. *Journal of Geophysical Research: Oceans*, **130**, e2024JC021716, https://doi.org/10.1029/2024JC021716.

Nicholls, R. J., Hanson, S. E., Lowe, J. A., Warrick, R. A., Lu, X., & Long, A. J. (2014). Sea-level scenarios for evaluating coastal impacts. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(1), 129-150.

North Carolina Department of Water Resources (NC DWR). (n.d.). North Carolina Aquifers. Retrieved from https://www.ncwater.org/?page=525

North Carolina Department of Environmental Quality, Division of Water Resources. (2024). *Assessment of change in North Carolina's outer coastal plain wetlands, 2016–2022*. Raleigh, NC: NCDEQ Division of Water Resources.

Pétré, M.-A., Salk, K. R., Stapleton, H. M., Ferguson, P. L., Tait, G., Obenour, D. R., Knappe, D. R. U., & Genereux, D. P. (2022). *Per- and polyfluoroalkyl substances (PFAS) in river discharge: Modeling loads upstream and downstream of a PFAS manufacturing plant in the Cape Fear watershed, North Carolina.* Science of the Total Environment, 831, 154763. https://doi.org/10.1016/j.scitotenv.2022.154763

Redmon, J. H., Walker-Franklin, I., Lillys, T., Womack, D., Harrington, J., & Pero Parker, J. (2023). *Cape Fear River PFAS: Why is PFAS in my water?* RTI International. https://www.rti.org/insights/piedmont-eastern-nc-why-pfas-my-water

Rummel, K., Gräwe, U., Klingbeil, K., Kolb, P., Li, X., Reese, L., & Burchard, H. (2025). *Spatially resolved salt intrusion mechanisms in a tidal estuary and the impact of channel deepening*. Journal of Geophysical Research: Oceans, *130*(6). https://doi.org/10.1029/2024JC022073

Saleeby, B., Shimizu, M.S., Sanchez Garcia, R.I., et al. (2021). Isomers of emerging PFAS in water and sediment from the Cape Fear River, NC. Chemosphere 262: 128359.

Schaffer-Smith, D. (2020). Hurricanes Matthew and Florence: impacts and opportunities to improve floodplain management. Knowledge Network for Biocomplexity. doi:10.5063/F1JM280P.

Talke, S. A., and D. A. Jay, 2020: Changing Tides: The Role of Natural and Anthropogenic Factors. *Annual Review of Marine Science*, **12**, 121–151, https://doi.org/10.1146/annurev-marine-010419-010727.

Talke, S. A., R. Familkhalili, and D. A. Jay, 2021: The Influence of Channel Deepening on Tides, River Discharge Effects, and Storm Surge. *Journal of Geophysical Research: Oceans*, **126**, e2020JC016328, https://doi.org/10.1029/2020JC016328.

Turner, R. E., & Ohimain, E. I. (2024). Dredged Canals, Wetland Loss, and Legacy. *Estuaries and Coasts*, *47*(8), 2147-2159.

U.S. Army Corps of Engineers, Wilmington District. (2020). Wilmington Harbor and Morehead City Harbors – Draft Environmental Assessment (includes Section 103 sediment testing and disposal description). https://eft.usace.army.mil/saw-nav/FILES/Public_Notice/Wilmington_Morehead_City_Harbors_Maintenance_Dredging_Draft_EA_19Aug2020.pdf

U.S. Environmental Protection Agency. (2015). *Region 4 ecological risk assessment supplemental guidance.* https://www.epa.gov/sites/default/files/2015-09/documents/r4_era_guidance_document_draft_final_8-25-2015.pdf

U.S. Environmental Protection Agency. (2023). *Wilmington Ocean Dredged Material Disposal Site (ODMDS) Site Management and Monitoring Plan (SMMP).*

https://www.epa.gov/system/files/documents/2024-05/final_2023_wilmington_odmds_smmp_signed.pdf

U.S. Environmental Protection Agency. (2024). *PFAS National Primary Drinking Water Regulation: General Fact Sheet* (EPA 815-F-24-003). https://www.epa.gov/system/files/documents/2024-04/pfas-npdwr_fact-sheet_general_4.9.24v1.pdf

U.S. Environmental Protection Agency. (2025). *Dredged material testing and evaluation for permitting under the Marine Protection, Research, and Sanctuaries Act (MPRSA).* https://www.epa.gov/marine-protection-permitting/dredged-material-testing-and-evaluation-permitting-under-marine

U.S. Environmental Protection Agency. (2025). *Southern Wood Piedmont Co# (EPA ID: NCD058517467) site profile.* https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0402821

van Rijn, L., Grasmeijer, B. & Perk, L. *Effect of channel deepening on tidal flow and sediment transport: part I—sandy channels.* Ocean Dynamics 68, 1457–1479 (2018). https://doi.org/10.1007/s10236-018-1204-2

Ye, F., W. Huang, Y. J. Zhang, S. Moghimi, E. Myers, S. Pe'eri, and H.-C. Yu, 2021: A cross-scale study for compound flooding processes during Hurricane Florence. *Natural Hazards and Earth System Sciences*, **21**, 1703–1719, https://doi.org/10.5194/nhess-21-1703-2021.

Yu, X., & Michael, H. A. (2022). *Impacts of the scale of representation of heterogeneity on simulated salinity and saltwater circulation in coastal aquifers.* Water Resources Research, 58, e2020WR029523. https://doi.org/10.1029/2020WR029523