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# Perimeter Protection Analysis Discovery Report

WAGGONNER & BALL

THE WATER INSTITUTE OF THE GULF

moffatt & nichol

ARCADIS

Robinson Design Engineers

**This analysis was conducted under the direction of the City of Charleston Mayor's Office of Resilience and Emergency Management and the Department of Planning, Preservation & Sustainability. The analysis was funded through a public-private partnership between the City of Charleston and a group of private funders.**

## Funders

City of Charleston

Historic Charleston Foundation

South Carolina Ports Authority

Lowe Enterprises

Middle Street Partners

Origin Development

The Beach Company

Preservation Society of Charleston

Coastal Conservation League

## Perimeter stakeholders engaged

Medical University of South Carolina

Roper Hospital

VA Hospital

Palmetto Railroad

Citadel

SC Aquarium

Charleston Yacht Club

Wagener Terrace Neighborhood Association

## Project Team

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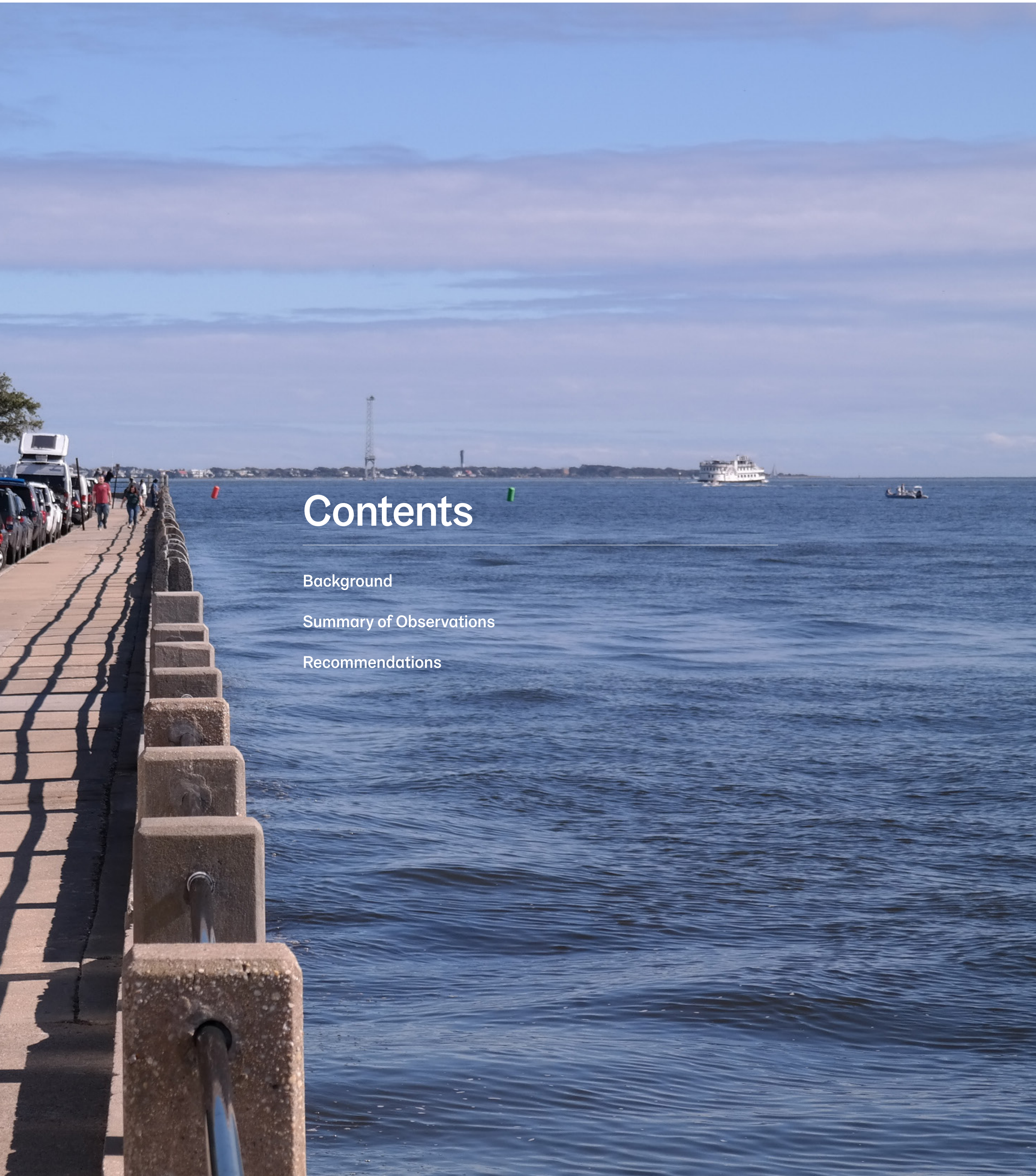
# Introduction & Summary



# Contents

# Background

## Purpose

This team was invited to advise the City of Charleston on its approach to the US Army Corps of Engineers' (USACE) perimeter protection study in alignment with Dutch Dialogues™ principles and recommendations. This document does not propose a design vision for a wall, nor does it propose alternatives to the USACE process. It aims to preface how that process can be navigated to address the peninsula's multiple flood reduction needs without sacrificing its essential character. The USACE project is highly constrained but presents an opportunity for the City, if taken, to leverage federal funding support for storm surge protection as one part of a holistic, integrated strategy for urban water solutions on the Charleston Peninsula.

## Team

Led by Waggonner & Ball with David Waggonner at the helm and Dale Morris of the Water Institute of the Gulf—leaders of Dutch Dialogues Charleston—the team includes engineers from the Dutch Dialogues effort with specific expertise in surge protection design, in working with the US Army Corps, and in Charleston's water and ecology. Moffatt & Nichol reviewed the USACE analysis, including water level projections, design storm events and the risk of overtopping. Arcadis contributed operations and maintenance perspective based on projects in the Netherlands and with the USACE around the country, as well as ideas of nature-based offshore elements. Robinson Design Engineers contributed guidance on Lowcountry ecology, the environmental regulatory framework and long-term marsh resilience.

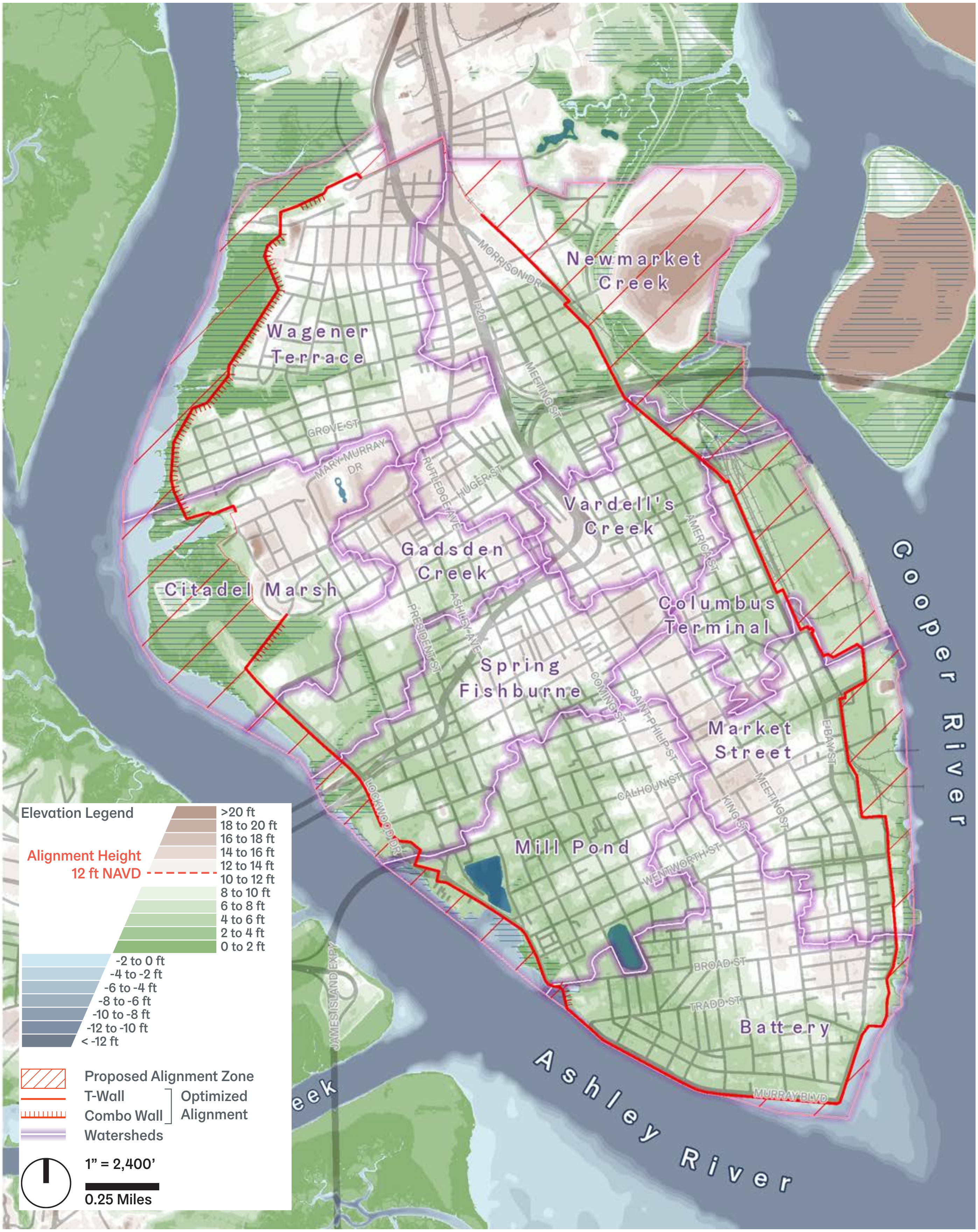
## Process

The analysis began in late October 2020. The team conducted a technical analysis of the USACE study to date, virtual stakeholder listening sessions and meetings, and a 3-day working session in Charleston in November 2020 with City officials and staff, key perimeter stakeholders and USACE project leadership and technical staff. (A robust engagement process is recommended to involve stakeholders missed in this conceptual analysis.)

The analysis progressed both within the USACE process and alongside it, an effort to determine if its potential benefits justified the City's further participation. The team identified gaps, functional concerns, alternative pathways and design criteria not factored into the USACE 3x3x3 process that are nevertheless of primary importance to the City, and documented other public and private initiatives, goals and investments that should guide the City's engagement with USACE process going forward. After a preliminary review of USACE documents, the team advised the City that a Locally Preferred Plan (LPP) was impractical and untimely given limited funding and schedule. Instead, we recommended the initiation of a broader planning and coordination effort to incorporate design inputs beyond the limited, storm surge risk-only scope of the USACE study to better align future phases of the USACE process with the City's wider interests.

The team proposed multiple perimeter options and zones of immediate and future investigation between the early 2021 release of the USACE optimized plan and the future USACE Preliminary Engineering & Design (PED) Phase. These options present a zonal approach with an expanded menu, rather than a single delineation, including more desirable options that lessen impacts, protect additional properties, and recognize the critical need for the City, beyond the USACE coastal storm surge charge and purview, to manage water, other chronic flooding and future sea rise challenges.

Finally, the team worked with City staff to understand better the potential consequences for the City, its commitments and decision impacts within upcoming USACE study milestones.




**USACE Optimized Alignment Overview.**
*Credit: Waggonner & Ball*

# Summary of Observations

## Perimeter Context & the Nature of Protection

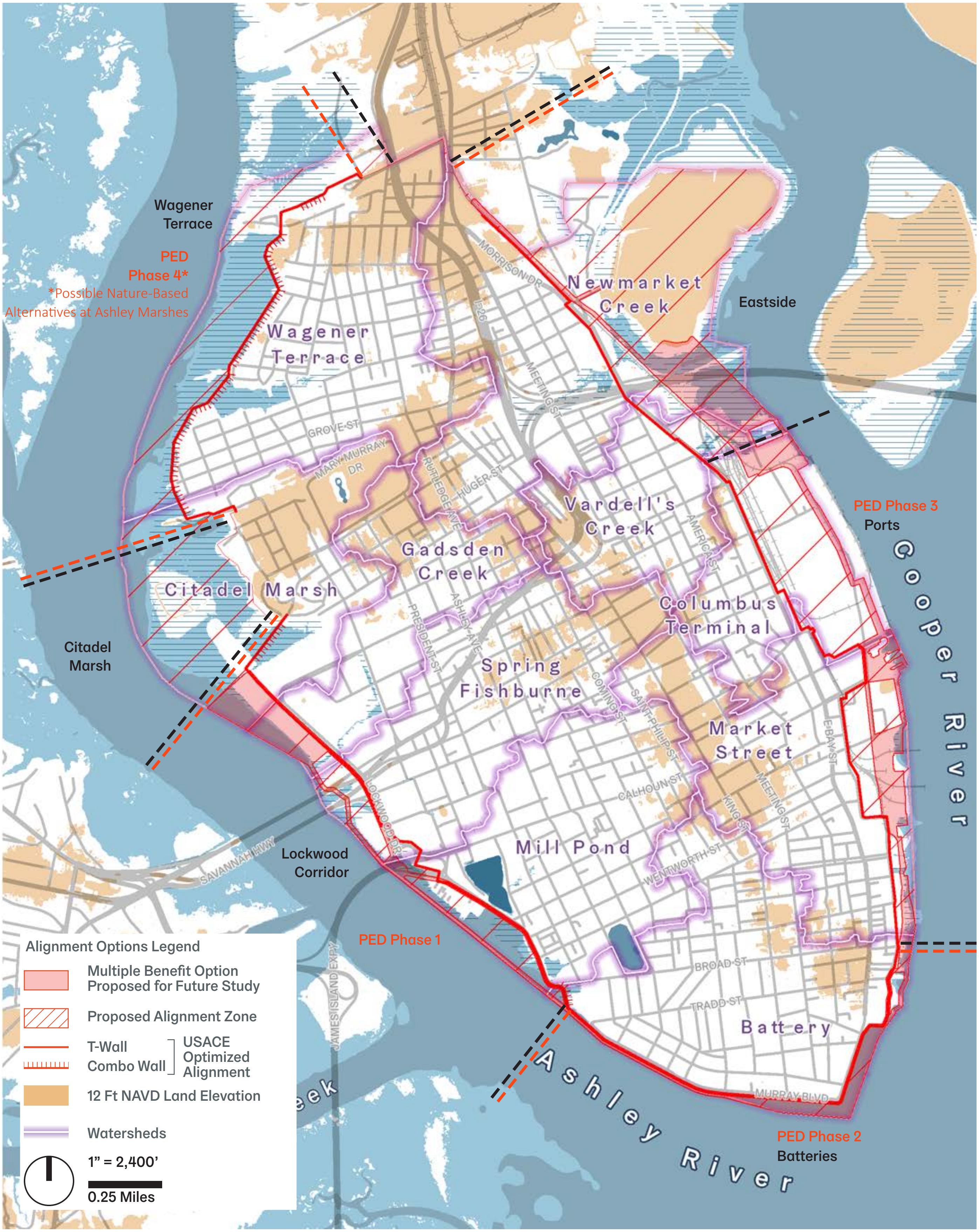
1. Some type of raised, protective perimeter will be required to preserve the Peninsula as sea level continues to rise this century. Charleston has a long history of building protective structures at waters edge, and environmental change demands adaptation anew. As described in the Dutch Dialogues, it is likely the Peninsula will eventually function like a Dutch polder, or self-contained water management entity, similar to the City of New Orleans today. Barriers will be needed to keep high tides as well as storm surge out and pumps will be needed to manage rainfall and groundwater within. Once a polder perimeter is established it must be operated and maintained in perpetuity, as investments will increasingly depend upon it.

2. The team believes storm surge protection on the Peninsula is necessary given the potential for significant—if infrequent—storm surge impacts. A damaging, deadly surge event would substantially impact life, mobility and economic activity on the peninsula for many years. Recovery would be costly. Surge protection alone, however, does not address the immediate and increasing challenge of tidal flooding and it is not sufficient for overall Peninsula flood risk mitigation. The USACE proposed structure will have a measurable impact on storm surge risk reduction, but will have to be raised over time as sea level rises to maintain the same level of protection. The City's 2019 Flooding & Sea Level Rise Strategy anticipates an increase of 2 to 3 feet within the 50 year design life of the USACE structure.

3. The 12' NAVD88 structure elevation proposed by the USACE is designed to protect against a 2% annual recurrence event (or 50 year storm) and is low as planning standard for coastal risk reduction. FEMA Community Rating System (CRS) standards for insurance rate reductions in other cities are based on higher levels of protection (1% annual recurrence event (or 100 year storm) in New Orleans; 0.3% annual recurrence event (300 year storm) on Staten Island).

4. Resilient, raised perimeter systems are built on the principle of multiple lines of defense with both man-made and natural features. Reliance on one structure or line concentrates risk and lacks redundancy. In New Orleans, multiple lines of defense include natural ridges and wetland buffers outside the levees. In the Netherlands, these include primary and secondary levees, dikes and dams, redundant pump and drainage infrastructure, and internal sub-basins and space for runoff storage. The USACE-proposed structure would provide significant risk reduction but should not be imagined or depended upon as the only aspect of the future risk reduction system.

5. The many water-related projects already completed or underway give Charleston momentum and a planning advantage, but plans may need revision and coordination to anticipate a future raised perimeter system. The transition to a polder model within an enclosed perimeter will require fundamental adaptations to internal hydrology and retrofits for existing drainage infrastructure. A raised perimeter fundamentally changes the operating environment for some City infrastructure—and presents new opportunities—and plans must be adapted in response. Related projects include the Comprehensive Plan Update (2021), Parks & Recreation Master Plan (2021), Stormwater Project Prioritization Effort (2021), All Hazards Vulnerability & Risk Assessment (2020), Stormwater Design Standards Manual (2020), Sea Level Rise Strategy (2019), Dutch Dialogues Report (2019), and drainage improvements such as check valves, Spring Fishburne and Calhoun West tunnels and Huger and King Street work (ongoing).




**Proposed Alignment Zone overview. PED segments & phasing (red dashes) as decribed to the analysis team by USACE project leadership in November 2020. Analysis team segments (black dashes) largely correspond, with additional subdivisions.**

*Credit: Waggonner & Ball*

## USACE Process & Expected Outcomes

6. The City should not expect the USACE process to deliver a solution for holistic water management. The USACE perimeter study is limited to a single risk driver, storm surge; is constrained by rules and regulations to factor a narrow set of possible strategies and benefits; and must seek the lowest initial cost option (not necessarily lowest operating cost or highest value option). If not properly planned, designed, engineered, operated and maintained, the surge structure will constrict the City's ability to manage many future needs. The team recommends a role for the USACE in Charleston's future perimeter system, but to make the investment worthwhile the City needs a broader strategy to a) set its own terms of engagement with USACE and b) enable the development of a comprehensive water strategy for all types of flood risk.

7. The typical 3x3x3 study requires a 50/50 cost share between the USACE and local partner (the City). Uniquely, the Charleston perimeter study is fully funded by the federal government, saving the City money in the short term but limiting its ability to influence the process as an equal partner. An upcoming Environmental Impact Statement (EIS) provides an opportunity for the City to state impacts and priorities yet to be identified and documented.

8. A portion of the City's cost share may be eligible for State support where regional and state-level interests overlap, such as for state-owned roads, the South Carolina Port Authority and Medical University of South Carolina.

9. The USACE Benefit Cost Ratio (BCR), by regulation, excludes some costs and assets of real value to the City and State. The values of USACE-excluded costs and assets should nevertheless factor into City decision-making surrounding this project. These exclusions include the value of transient cargo (such as automobiles awaiting shipment), non-permanent structures, structures raised above the floodplain (even if access is subject to flooding), the projected value of future development and a full accounting of operations and maintenance costs to the City (such as frequent operation of gates for high tide events). The team was not able to verify the figures used for repair costs of historic structures, but questions whether the BCR accounts for the high cost and specificity of historic buildings on the Peninsula.

10. Mitigations for documented impacts, similar to overall project cost, are cost-shared 65% USACE / 35% local partner. Betterments are City-requested changes that may be made for any reason, and are paid 100% by the City.

11. "Movable" and "temporary" structures are red flags for risk and reliability. Movable elements such as road, rail and tide gates, removable floodwall panels and temporary pumps create operational complexities: all elements must be maintained, and staff must be trained and available, to perform properly when called upon in emergencies. Movable parts are risk and cost multipliers and concentrate potential for technical and human operator failure. The need for each gate and temporary feature should be highly questioned and avoided everywhere possible.

12. Significant changes can be expected in PED phase, including the structure type, alignment, number and type of gates, and size and location of pumps. The USACE Optimized Alignment is the basis of cost estimating and risk modeling to prove overall feasibility, not a final design proposal.

13. If the City chooses to proceed through the USACE project development process it will be required to fund a percentage of design and construction costs in phases. These costs grow over time and with inflation; the full cost of the project is also paid over time and will span at least one, if not two, decades. The City will have opportunities to stop the project, and its cost share, at future interim

phases, even after its initial financial commitment for the full construction amount (expected to be required in late 2021). With negotiation, a Locally Preferred Plan may be developed at each PED phase.

14. The City's decision to proceed with the USACE process may provide additional short-term benefits:

    A) Potential economic benefit to the local economy. The City's cost share portion can take the form of professional services, such as hiring its own designer or engineer, as long as the work conforms to USACE standards (USACE remains "lead designer" in PED).
    B) Preliminary Engineering & Design phases will generate significant survey and geotechnical data which may prove valuable for other infrastructure and development projects on the Peninsula.

15. The City's decision not to support the next steps of the USACE process, now or at future phases, may come with tradeoffs:

    A) A loss of momentum for resilience and flood mitigation. No other prospects for a federal cost share of needed perimeter flood protection infrastructure are on the horizon.
    B) Sea level and tidal flood risk will continue to increase; these increase the damage potential of any significant future surge event. 2020 saw the most +8' tides in the recorded history of Charleston harbor in a year with no hurricane-driven surges.
    C) An incomplete system. The City may elect to end its cost share before all phases are designed and constructed, but would be left with a partial system that does not mitigate surge risk.
    D) If a major storm event strikes near term, a signed Chief's Report "on the shelf" may be implemented as-is with full federal funding. It is therefore necessary to engage the USACE to produce a study with acceptable outcomes for the City at every stage of planning.
    E) An acceleration of private sector flood retrofits in the absence of holistic City plan. Private sector adaptation is a necessary part of a layered flood defense strategy. Individual, ad-hoc responses, however, erode the likelihood of future large-scale projects by effectively removing at-risk properties from the cost/benefit calculation. This conflict between the goal of safety and USACE cost/benefit methodology should be understood, and may be addressed through integrated systems planning.

# Recommendations

## 1. Proceed incrementally with the USACE process.

A) Continue to work with the USACE as a partner for federal cost sharing but understand the limits, set of rules and narrow focus of its surge-only process. The team believes that flood risks justify continued engagement with the USACE process and that there are pathways for the City to achieve its desired outcomes. However, these pathways require strategic, deliberate navigation of the USACE 3x3x3 process to assert the City's priorities at every opportunity, and a parallel process led by the City to clarify and develop its broader flood risk reduction goals before PED phase begins.

B) Identify and understand key decision points in time and their consequences for the City, including:

EIS: Scope the USACE's recently announced Environmental Impact Statement (EIS) for as much flexibility as possible to capture the breadth of impacts of the barrier on the existing hydrological, ecological, historical, cultural and economic context. Through this process, the City can clarify impacts, possible mitigation measures, and refine costs before committing to a cost share. Required mitigation measures identified through the EIS are cost-shared with the USACE.

NED: anticipated at the end of 2021, the National Economic Development (NED) milestone will require the City to commit to the project's overall cost share. The report is then submitted for approval at USACE headquarters in Washington, DC.

PED: If the study's recommendation is approved and funded by the USACE, the City's first cost share for the first PED phase is expected to occur in 2023. PED begins the comprehensive planning, engineering, design and siting work for the surge structure. PED phase one is currently planned in the Lockwood Corridor.

Construction, and construction costs, are not anticipated before 2025 for phase one.

## 2. Integrate water issues and opportunities with land use, development and ongoing efforts through a spatial, nature-based, design-driven approach as recommended in the Dutch Dialogues™ Charleston report.

A) A Charleston water plan would build on the foundation of plans and projects completed and underway. The water plan can be imagined as an update to the Downtown Plan (1999) in that it focuses on water but encompasses interrelated urban systems, stakeholders and spaces. The City does not need another study, but rather a specific approach to design, coordination and implementation of significant projects and up-to-date plans.

B) Building on the Vulnerability Assessment and other existing data, perform an analysis specific to the Peninsula for how a perimeter structure will affect related risks, planned projects, and overall sustainability goals.

C) Surge and flood mitigation infrastructure must, wherever possible, be multi-functional and adaptable. It must not constrain other land-use, development, transportation, occupation, aesthetic, ecological and cultural considerations on the Peninsula. It must be integrated with current and future tidal, stormwater and groundwater solutions. Flood mitigation infrastructure must enable and not impair the temporal, physical, social, environmental and economic adaptations that today are unknown but will surely surface in coming decades. The Charleston Peninsula is an iconic, irreplaceable historic asset in a dynamic natural environment, and surge protection and water management must be designed to respond over time to these changing conditions.

D) Design multiple lines of defense that include internal water management and external nature-based features, like breakwaters and oyster banks, that will grow and adapt over time. Internal lines of defense may include multi-functional detention areas, networked pump and conveyance systems, and, crucially, passive natural features that reinforce Charleston's landscape and character.

E) Integrate and coordinate Peninsula investments. Every capital improvement project—drainage, public space and recreation, ecosystem protection and restoration, transportation infrastructure—can leverage flood mitigation opportunities. This is smart, efficient investment.

F) Begin planning for the organizational structure that will be needed to operate and manage the future Peninsula water system (tide, surge, stormwater, groundwater). This includes a framework for the future tax base and revenue stream required to operate and maintain the perimeter system. These costs may be minimal at first but will grow over time.

G) Develop a decision-making framework that includes operations and maintenance costs as well as long-term replacement cycles with necessary capital reinvestments to sustain the system over its lifecycle.

H) Define City goals and values in advance of major projects. A water plan could be used to develop and build public consensus for infrastructure investments and to ensure the USACE and other design processes are accountable to the City's stated priorities (not the other way around).

I) Get ahead of PED. The USACE process must conform to City's stated priorities and planning framework once it is a cost share partner. An early and integrated planning process underway—or completed—before further commitments will create significant efficiencies, leverage points and cost savings for the City if and as the surge protection project proceeds.

## 3. Develop a clear stakeholder engagement & communication process for flood mitigation work.

A) Continue the City department leadership working group. Include and coordinate with State agencies, like SCDOT, to align objectives and investments.

B) Engage the public. Create a Citizens Advisory Council to facilitate public input and review. Engage the local and regional business community to uncover additional challenges and ideas. Engagement should focus not just on the perimeter alignment itself, but on the internal watersheds and communities behind the alignment who have yet to be reached. All Peninsula residents and organizations, and indeed all of Charleston, should be heard in this effort.

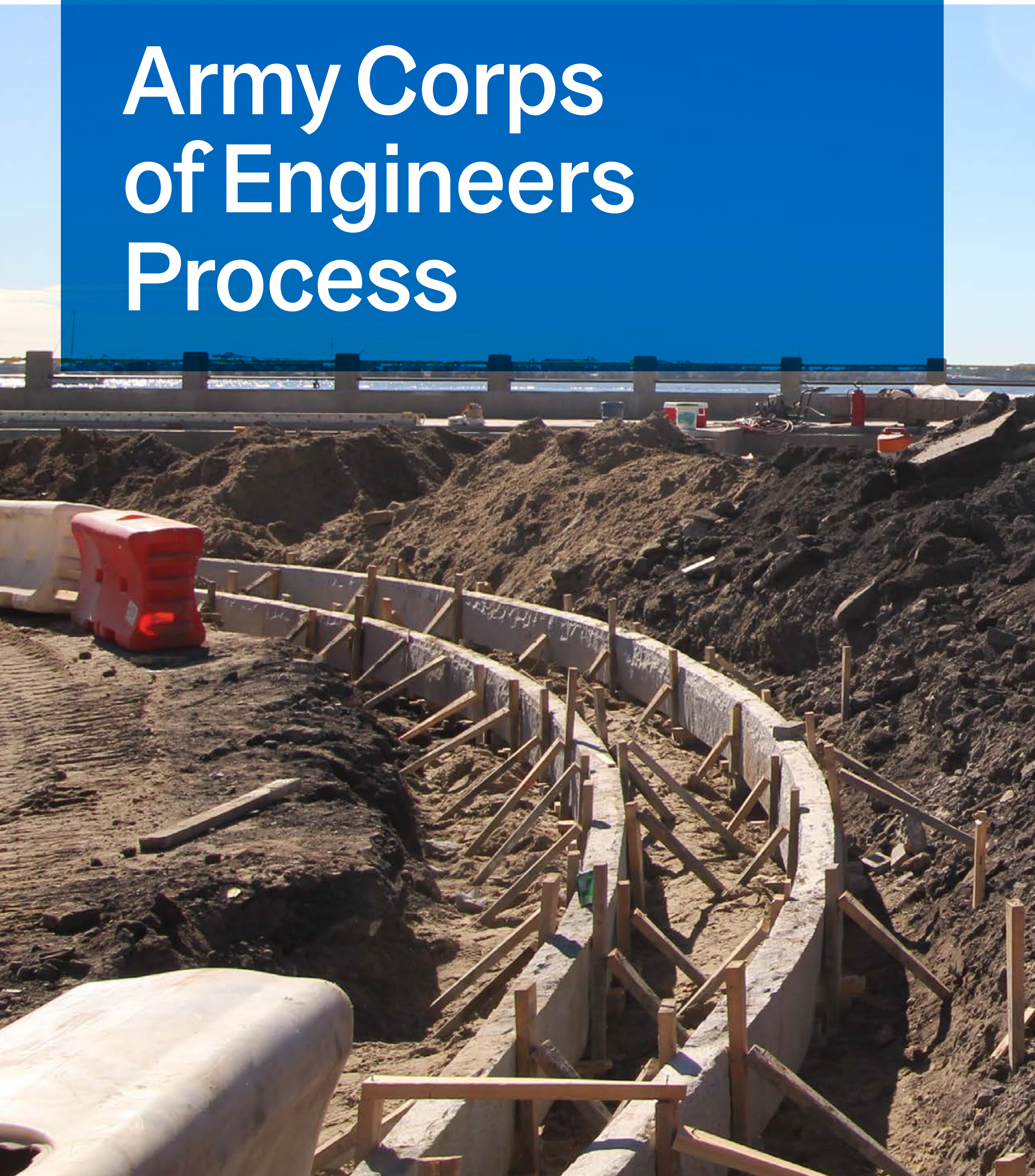
C) Remove from consideration alignments and related options that are unacceptable and do so as early as possible to eliminate negative public feedback and wasted community effort.

D) Devise an information strategy or portal so the larger Charleston community can access planning and project information. Develop information sharing and educational processes to build community awareness and gather input to build support.

# Alignment Zone & Urban Watersheds


EASTSIDE
COLUMBUS
TERMINAL
MUSEUM
DISTRICT
UNION PIER
TERMINAL
WATERFRONT
PARK
HIGH
BATTERY
W
ERY
COOPER RIVER

# Army Corps of Engineers Process

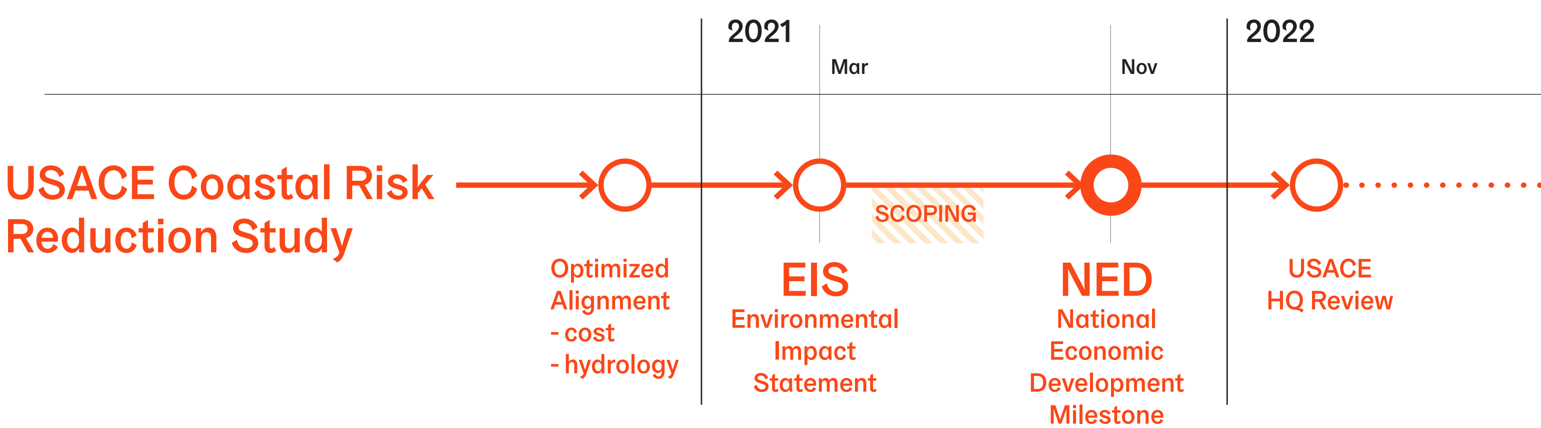


# USACE Process

## USACE Authority and Other City Goals

As residents of Charleston, the USACE project team understands the City's need to balance and achieve multiple goals, next year and in twenty years. These goals must be integrated into any surge mitigation infrastructure the City eventually decides to fund and construct, alone or in collaboration with the federal government. The USACE, however, is constrained, bound by clear federal administrative and regulatory policies that preclude it from incorporating many of these other goals into surge structure considerations. The USACE mission is not organized to design and engineer a truly multi-purpose structure that enables, and even embraces, alignment with these other essential City goals.

The specific focus of the USACE structure, and lack of authority to explore interrelated opportunities, is a double-edged sword. The City stands to benefit from the significant federal cost share for storm surge reduction, but for the City's share to be worthwhile the project must return multiple benefits without sacrificing essential historic and ecological assets. This is pressing, difficult and necessary work; it will require creativity, understanding and openness on the part of the City and the USACE. Closing off future adaptation pathways in advance of PED and then construction must be avoided. The City's need to achieve meaningful storm surge risk reduction alongside other City goals must be (a) acknowledged and negotiated as the TSP Final Report and Environmental Impact Statement are developed, (b) considered in the City's financial commitment decision in 2021, and (c) integrated during the PED phase.

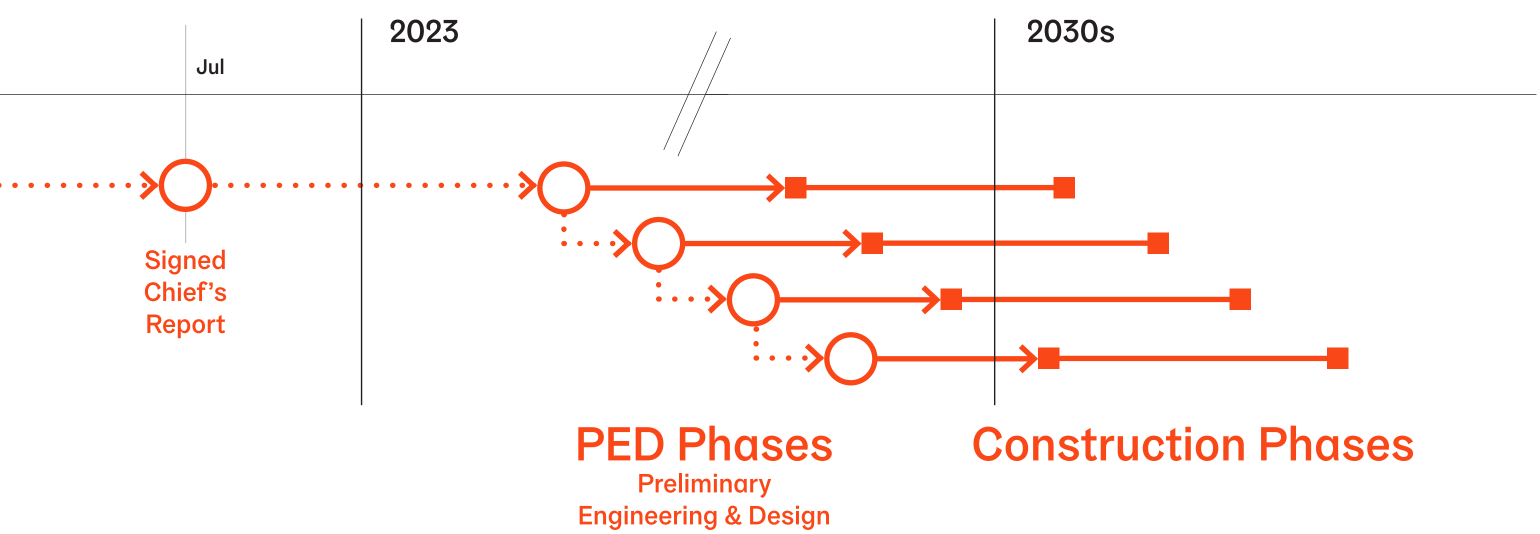


## Preliminary Engineering & Design (PED) Phase

PED phase is part of typical USACE process following a 3x3x3 feasibility study that requires separate federal authorization and funding. Design decisions related to alignment and barrier type are made in PED. USACE acknowledges that key questions remain about the structure, its design, construction, location, operations, maintenance and impacts, and that those need to and will be addressed in PED phase. PED itself is planned to occur in four phases: 1) Lockwood Corridor, 2) Low and High Batteries, 3) Eastside and 4) Wagener Terrace. These will begin in 2023 at the earliest and may last for five or more years. Construction is also planned in phases and may begin before all PED phases are complete. The City is responsible for acquiring land for the structure during PED phase, a process that will play a guiding role in its ultimate alignment.

A design and political challenge of the USACE process is that the local sponsor (the City) must agree to support the project before any real design has been completed. The order of decisions makes it difficult to understand what the City will get. However, PED begins where feasibility left off, and there is strong momentum within USACE to pursue solutions outlined in 3x3x3. It is important to get the 3x3x3 report as close to City's desired outcome as possible. The structure will physically touch and influence current and future planning and uses: transportation, water access, viewsheds, stormwater management, land use, housing, historic structures, ecology, development, among others.  Changes in any of these areas before and during PED will require USACE to adapt.

A well-considered urban plan presents an opportunity for the City to set its spatial terms: PED must occur within the urban context and planned public investments at the time it begins. Meanwhile, tides continue to rise, flooding impacts change, marsh conditions may change. There is now a window of time before PED starts to anticipate the requirements of a perimeter system, coordinate them with City plans through a public design process, and set the context into which the USACE process must conform.



## City Internal Coordination related to the USACE

Most USACE 3x3x3 studies are jointly funded, with 50% from the federal government and 50% from the non-federal sponsor (the City). The Charleston Peninsula Study, however, is fully funded through the 2018 Bipartisan Budget Act and the Emergency Supplemental Appropriations Act, which means that no local cost-share was required. While the terms of the study were developed jointly by USACE and the City, the Discovery Report team was struck by many citizens' concern when the Tentatively Selected Plan (TSP) was released in April 2020 and the many questions posed thereafter. City-wide interest in, awareness of and widespread engagement to shape the study were possibly diminished because the City had "no financial skin in the game." No criticism of any party is intended by this observation.

We think it imperative for all 3x3x3 impacted City agencies and City Council to establish a coordinating committee to monitor, vet and discuss 3x3x3 developments. Leadership of key City agencies have undertaken a regular biweekly call to share information about 3x3x3 developments. We applaud this effort. We think this coordinating structure must be formalized and strengthened so the Environmental Impact Statement (EIS) process, the financial commitment process and PED phase developments are transparent and coordinated with City departmental priorities. We believe City Council should have access to the coordinating structure or to meeting summaries. These meetings should become the venue in which the "other goals" noted above, in particular those related to land-use, transportation, stormwater and tidal water management issues, are vetted and coordinated in line with 3x3x3 processes and requirements.

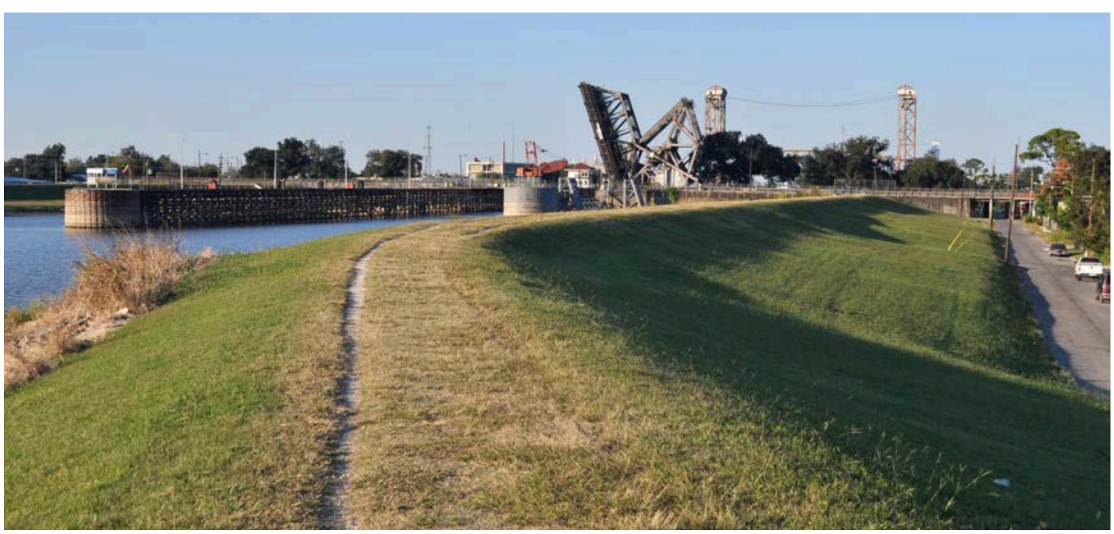
## Types of Structures

The USACE proposes two types of structures for the Peninsula: T wall, a vertical concrete wall so named because its cross section looks like an upside-down T, and combo wall, consisting of a vertical steel or concrete wall reinforced with diagonal "batter piles" on the dry side. The T wall is designed for use on land. The combo wall is designed for use through marsh or water, is more difficult to construct, and is estimated at 2-3 times more expensive than T wall. These are standard structural types familiar to the USACE for the purpose of evaluating cost, impacts and overall feasibility. Per USACE standards these structures typically require a permanent maintenance easement on both sides after construction, posing a challenge for other uses in dense urban environments. Standard gates within the structure can be expected to take the form of rolling or swing gates similar to those found in New Orleans' Hurricane and Storm Damage Risk Reduction System (HSDRRS).

While other structure types are possible to explore in future design phases, these two types, with the addition of earthen levees, are proven elsewhere and are typically pursued by USACE through implementation. They are fundamentally defensive structures with little precedent in historic settings. The Discovery Report team is unaware of other types of storm surge protection structures constructed by USACE that are integrated with public roads and spaces in sensitive urban areas. It is incumbent upon the City to define acceptable alternatives that are integrated into Charleston's unique urban and natural environment. Should the City proceed into PED phase without doing so, it is likely that one of these two structural types will become the final USACE design, or that the cost of any alternative will be fully shouldered by the City.

**T wall structure in New Orleans along Lake Pontchartrain.**
*Credit: Waggonner & Ball*

**Combo wall structure part of the Lake Borgne Surge Barrier.**
*Credit: Philip Gould Corbis*



**Earthen Levee in New Orleans.**
*Credit: Waggonner & Ball*

## Environmental Impact Analysis

The surge structure will have substantial impacts on the Peninsula's physical, human and natural environments during the construction phase and beyond. While an Economic Analysis (EA) was conducted early in the 3x3x3 process, a more thorough NEPA Environmental Impact Analysis leading to an Environmental Impact Statement (EIS) was requested and announced by the USACE in early 2021. Issues to guide EIS include ecological, cultural and historical impacts. Once defined, the USACE must recommend strategies to mitigate them ("mitigations"), which are cost shared with the federal government as part of base project costs. Any changes requested by the City in future phases are considered "betterments" and are funded 100% by the City.

The April 2020 draft Tentatively Selected Plan (TSP) issued by USACE impacted approximately 110 acres of Peninsula marshes. Since its release and following meetings with State resource agencies, USACE "optimized" the proposed alignment to dry land wherever possible and reduced marsh impacts to approximately 45 acres. This reduction in impacts, and therefore reduction in required marsh mitigation costs, resulted in nearly half a billion dollar cost savings for the project based on current USACE projected mitigation costs of $850,000 to $1 million per acre.

Regardless of where a surge structure is located, and whether it is even constructed at all, many acres of marsh (some high quality, and some of marginal and declining quality) around the Peninsula will be lost over the projected 50 year design life of the barrier due to (a) sea level rise and (b) the lack of marsh migration capacity (space) on the Peninsula's existing edge. The Peninsula's "hard edge" in places makes marsh migration unlikely; marsh loss in these places is already "baked-in." Changes to marsh quality and extent driven by sea level rise are likely but difficult to predict in time. The current regulatory regime and project cost estimate do not account for these potential future changes or likelihood of certain marshes to succumb or rebound faster than others. Current state environmental regulations also lack the flexibility to study if and how a barrier structure may safeguard, or even improve, the health or marsh within it in a future with ever-higher tides.

While marsh impact is avoided, in many places the land-based alignment is more difficult to locate and operate around existing buildings and infrastructure. The complexity of the landward orientation requires more pedestrian and vehicle gates and substantial operational guidance and practice. Closing of the structure during increasingly frequent high-water events will impact transportation, institutional and pedestrian uses. We are concerned that the girdle-like nature of the optimized plan on the Peninsula's edge will deprive the City of space needed for rainfall and tide management, potential management of storm surge overtopping, and reduce future adaptive capacity by constricting space inside the structure for public uses, private development and construction area for surge structure retrofits. Trade-offs between these goals and ecological impacts will be required.

## Segments & Phasing

The segments used for analysis in this report mostly align with the preliminary engineering and design (PED) phases, with some subdelieations (i.e. PED phase 3 is broken into the Eastside and Ports). The segments and phasing outlined in this report should be discussed, vetted and refined with care in collaboration with stakeholders and impacted communities.


PED segments & phasing (red dashes) as decribed to the analysis team by USACE project leadership in November 2020. Analysis team segments (black dashes) largely correspond, with additional subdivisions. Perimeter segments should correspond to internal urban watershed boundaries to integrate internal drainage with perimeter planning.

## PED phase 1

Lockwood Corridor

## PED phase 2

Low & High Battery

## PED phase 3

Ports

Eastside

Consider switching PED phase 2 and 3 to make use of existing protection at the High and Low Battery and provide new protection for Eastside communities.

## PED phase 4

Citadel Marsh

Wagener Terrace

## Charleston as a New USACE Precedent

The Charleston Peninsula, for its density and quality of historic structures, its intimate scale, and its intertwined relationship with water and nature, is unlike any other urban context in which the USACE has performed a 3x3x3 analysis. Another 3x3x3 study for the Port of Charleston deepening project illustrates a more typical application of the process: infrastructure planning with fewer variables and with far less direct public impact. As the USACE engages in more studies like the Charleston Perimeter Analysis for climate change adaptation in urban environments, this study presents an opportunity for the organization to set a new internal precedent for collaboration, innovative design and responsiveness to the local sponsor that could improve outcomes and working relationships in districts across the country. Procedural change within the USACE is slow and difficult, requiring approval at multiple levels of bureaucracy, but the potential rewards for the organization's engineering outcomes and reputation are significant.

Nature-based planning provides another precedent setting opportunity for the USACE Charleston District. Congress recently required the USACE to prioritize Natural and Nature-Based Features (NNBFs) in the planning of flood resilience projects. The requirement for NNBFs, although enacted after authorization for this study, should continue to be evaluated as the study advances into PED and construction. While the USACE has not identified NNBFs on their own as effective for storm surge mitigation for this project, it is likely that technology and innovation will develop new ways to utilize NNBFs to complement the built infrastructure as this study proceeds through approval, PED and construction.

## Considerations for a Locally Preferred Plan (LPP)

In November 2020, the City faced a deadline within the 3x3x3 process to indicate to the USACE whether or not it intended to pursue a Locally Preferred Plan (LPP). An LPP is an alternative feasibility study for all or part of the proposed perimeter structure that occurs in parallel to the USACE process and is funded entirely by the City, thus requiring City Council approval. The Discovery Report ultimately recommended that a LPP was not necessary to achieve the City's desired outcomes, as long as it took advantage of other opportunities within the 3x3x3 process to assert key priorities.

Our team posed questions to the USACE to identify "red flags" and determine if the USACE would require any option to be developed through a LPP if the City chose to pursue it. These questions were not intended to suggest a preference for any alignment option. The responses recorded below were provided verbally by the USACE via a virtual meeting in December 2020. Questions for LPP triggers included:

1. The inclusion of additional openings or gate types within the structure (i.e. tide gates).

USACE response: Tide levels for structure operation have not yet been determined with resource agencies. USACE is open to consideration in PED phase. LPP is not required.

2. A line of protection on non-City owned property (e.g. Port terminals; proposed alignment already crosses private property at Yacht Club, Citadel, Wagener Terrace).

USACE response: it is the City's responsibility to acquire property for the structure during PED phase. LPP is not required.

3. of structural foundations to allow future lifts and adaptive management over time:

USACE response: for feasibility purposes, USACE has specified deeper pilings into the marl to allow for approximately 3' of additional structural height to be added in the future. Specific design of the structure and its ability to be raised is not known at this time. Specific design criteria for foundations will depend on detailed geotechnical reports in PED phase. LPP is not required.

4. The creation of "new land" through fill along water's edge in order to build T wall (e.g. alongside Palmetto Railroad line or in front of Rice Mill building). Fill would be limited to the minimum extent required for T wall constructability.

USACE response: USACE does not believe it would be a cost savings to switch from T wall to Combo wall in this condition given overall constructability challenges. Temporary access or bridging would be required in both scenarios.

5. A Battery breakwater (could be a separate project as a supplemental layer).

USACE response: the breakwater was removed from the project to save approximately $300 million in construction cost after modeling demonstrated that its impact on overall storm surge reduction was negligible. The City could propose a similar structure as a betterment.

## Additional notes recorded in December 2020

- USACE determined that the breakwater structure off the Battery cannot be justified on a cost/ benefit basis for the level of storm surge reduction provided and the federal ship channel boundary is a limitation.
- A living shoreline approach is difficult to compute for costs and benefits in the USACE model in terms of potential wave height reduction. There may be opportunity to use one or more reaches as pilot projects for future USACE internal study to evaluate the value of nature-based approaches. Natural features may not reduce still water elevations but could function as one line in a "multiple lines of defense" system.
- USACE phasing segments 1 & 2 (Lockwood and Batteries) prioritize the locations of highest modeled incurred damages from storm surge. These areas are subject to the "most extensive threat."
- USACE believes alignment options may be zero-sum: reductions in real estate cost may be offset by increases in marsh mitigation and construction complexity costs.
- The City requests a method to capture and integrate the benefits of additional urban features excluded by USACE (transit integration, flood protection, recreation, etc.).
- The City's letter in the NED report (approximately Nov. '21) can (should) indicate caveats, priorities and requests from the City leading into PED phase.

# Analysis Framework

# Contents


# Design Criteria

These criteria outline the functional and spatial factors that will influence the design of the perimeter structure. They are intended as a framework for the City to gauge impacts, organize the effort to integrate co-benefits it requires from the perimeter system, and analyze proposed USACE and other alternatives. Some criteria are intended to help clarify planning aspects already included in the USACE process; some are reframed or broadened to capture other impacts and benefits; and some criteria are new to the analysis. The criteria are ordered by the Discovery Report team to prioritize safety first through level of protection and internal water management, followed by ecology and operations. These system criteria become parameters for urban design. All perimeter protection and water system elements should complement Charleston's historic character.

## Storm Surge Risk Management (Level of Protection) & Internal Water Management

Moffatt & Nichol analyzed a range of variables and work completed to date related to water volumes and levels at this working stage of the USACE study. A further conceptual design study will be needed to outline the physical water infrastructure of a polder system. Some infrastructure can be upgraded and repurposed; new water storage and conveyance infrastructure will also be required for internal drainage. Analyses included:

- the challenges and opportunities of different levels of protection, including alternative elevations greater or less than USACE target of 12' NAVD.
- a review of the USACE study's hydrology criteria: the probability, and potential volume, of wave or storm surge overtopping for given water elevations and how to manage it.
- the need to elevate the structure in the future to keep up with sea level rise.
- the possibility to elevate different segments to different elevations over time.
- various alternative types of barriers in a system of layered defenses.

## Ecology

Salt marsh at the Peninsula's edge is a vital, character-defining feature of Charleston and a critical habitat. Changes in marsh quality and extent are likely to occur due to sea level rise, a possibility with important consequences for alignment and funding of the raised perimeter:

- Which areas of marsh are already susceptible to loss due to sea level rise, at what rate, and when? If marsh is expected to be degraded or lost due to natural phenomenon, the cost scenarios for future marsh mitigation may influence design decisions today.
- Strategies for marsh creation and preservation "behind the line," such as thin layer dredge disposal and passive tidal flow management through the barrier, may sustain internal ecologies.
- Federal and state environmental regulatory frameworks do not currently account for the potentially dramatic impacts of sea level rise on marsh health and location.
- Difference between direct and indirect marsh mitigation costs for BCR analysis.
- Availability and alternatives to local marsh mitigation credits.

## Operations & Maintenance

Ongoing O&M costs—normal upkeep, repairs, emergency operations, pump station management, staffing—will be the City's responsibility after the USACE completes construction. Design choices made today will have long-term financial and therefore safety consequences for the City. Key factors include:

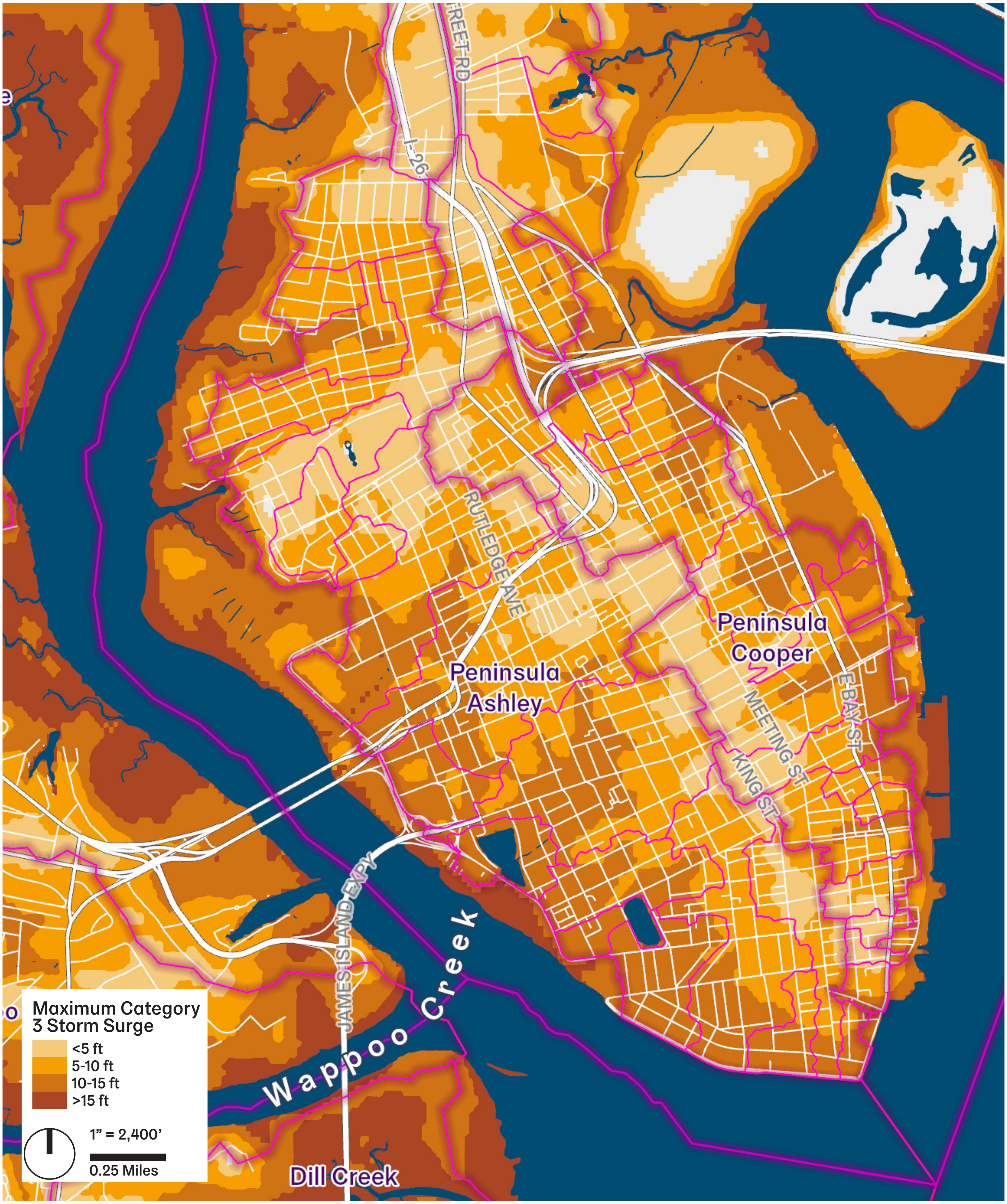
- Definition of tidal level that will trigger gate closures. At what sea level will gates be permanently closed? While not part of this study, these critical thresholds must be developed through future phases.
- "Movable" and "temporary" components. These are red flags for reliability, especially resulting from human error. Movable components are risk multipliers and represent potential points of failure in emergency situations.
- Annual operations and maintenance cost assumptions by the USACE.
- Organizational structure. As indicated by other cities with perimeter protection, an authority with dedicated staff and budget will likely be needed to manage and maintain the perimeter system.

## Urban Design & Historic Character

Charleston is a design city. The design of the perimeter structure must fit this sensitive context; include layered benefits for health, transportation and recreation; and provide equitable access to these urban amenities. Key design factors include:

- The identification of urban design "non-starters," building on analysis conducted by the Charleston Design Division.
- Aesthetic and viewshed impacts of structure height and type, proximity to historic structures, and access to water.
- The definition of public space and recreation requirements and the integration of other infrastructure investments planned and underway.
- A better understanding of the true cost of reconstruction of historic structures damaged by a potential storm surge event. Historic buildings in Charleston are highly specific and reconstruction costs may be factored too low in the USACE Benefit Cost Ratio (BCR).

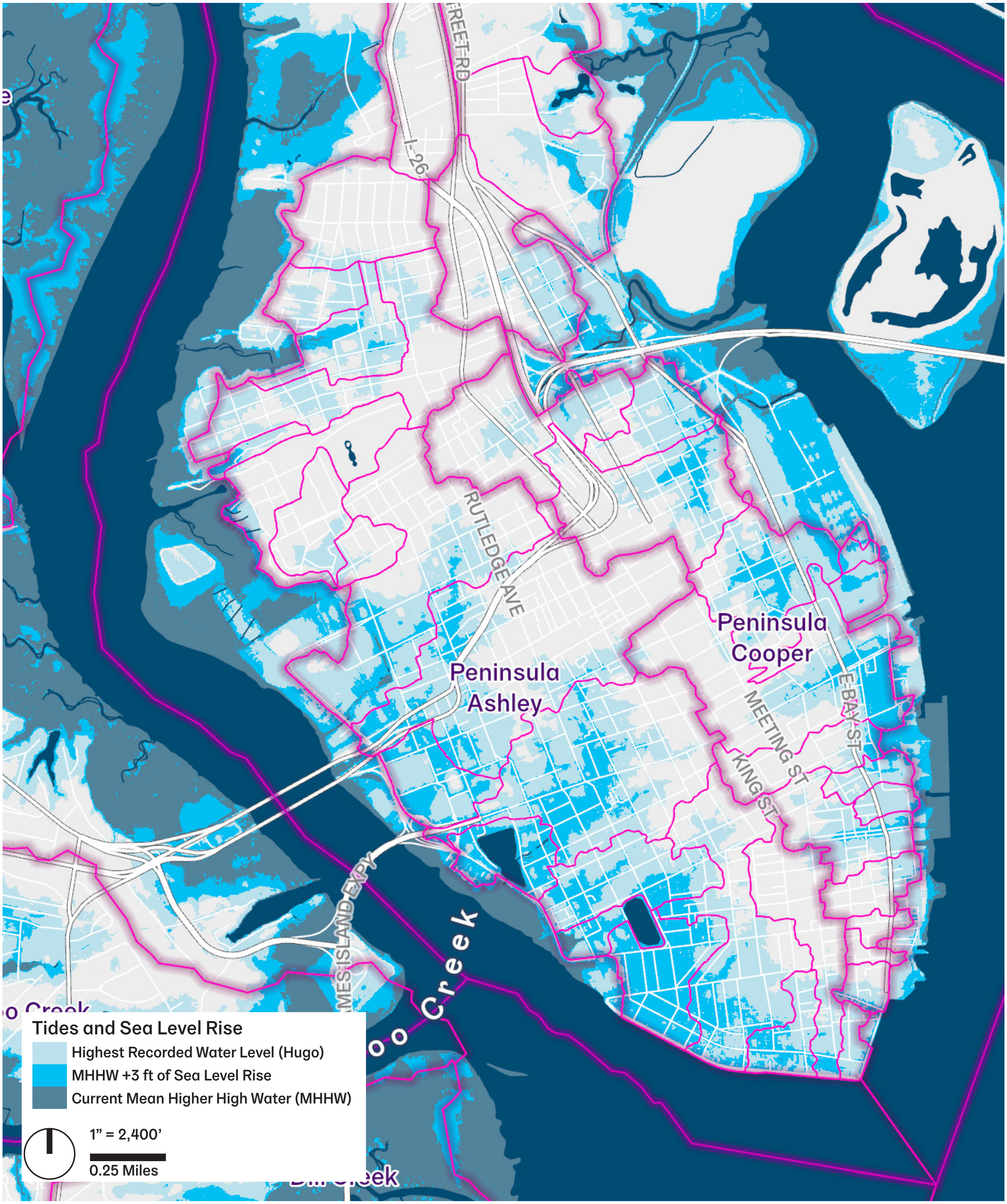
# Maximum Category 3 Storm Surge




**Virtually all of the Peninsula is within the max category 3 storm surge, with the exception of Laurel Island.**

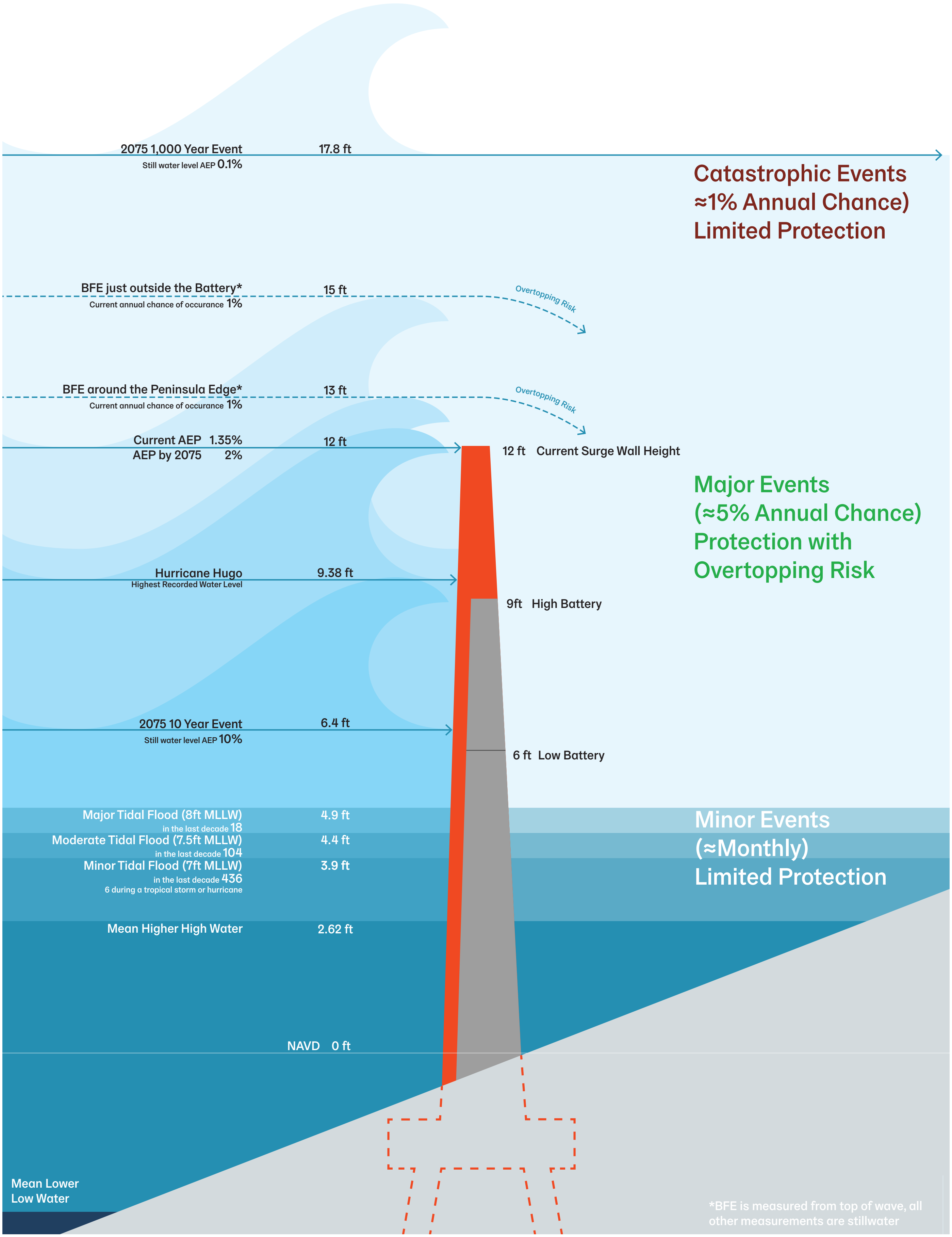
*map sources: NOAA*

# 3 Feet of Sea Level Rise




Large portions of Peninsula are at risk of regular inundation with 3 feet of sea level rise. Most of those areas are former tidal creeks.

*map sources: USGS*




**Critical external water thresholds and risk levels in Charleston.**
*Credit: Waggonner & Ball*

# Risk Management (Level of Protection)

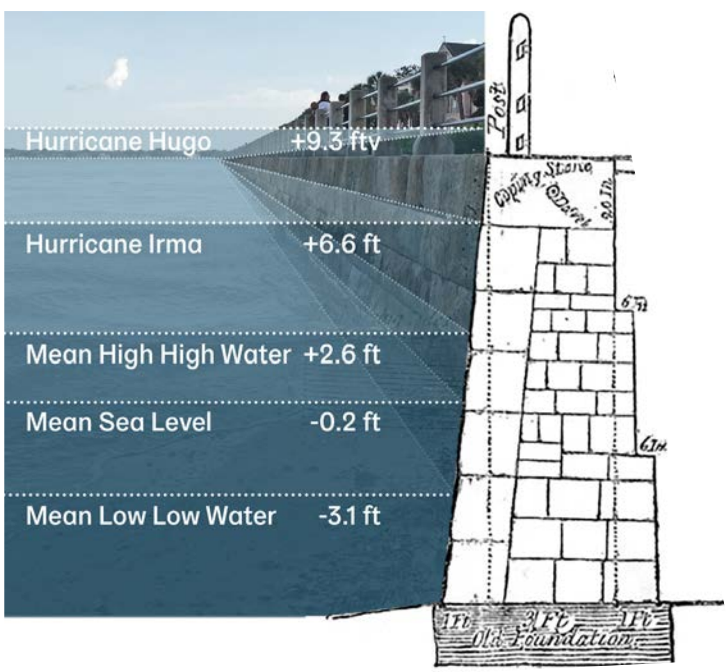
Analysis by:
moffatt & nichol

## Substantial Surge Risk Reduction, Residual Risk and Adaptation

The USACE proposed storm surge structure and its current alignment will mitigate most but not all surge risk on the peninsula. This is an essential benefit to the City and the residual surge risk that remains is manageable. The currently proposed structure has an annual exceedance probability of 2% which, in layman's terms, means that it is designed to mitigate the 50-year surge event, or an event with a 2% historical probability of occurring any given year. Maintaining reasonable levels of surge risk as sea levels rise requires that the structure be constructed to enable future height increases in proportion to future still water, surge height and wave load increases. If the structure is not adaptively elevated as sea levels rise the peninsula's surge risk increases and its surge protection will decrease. A 50-year surge structure upon completion will likely be a 25-year or 10-year surge structure in year 30 or year 50 respectively if its height is not increased.

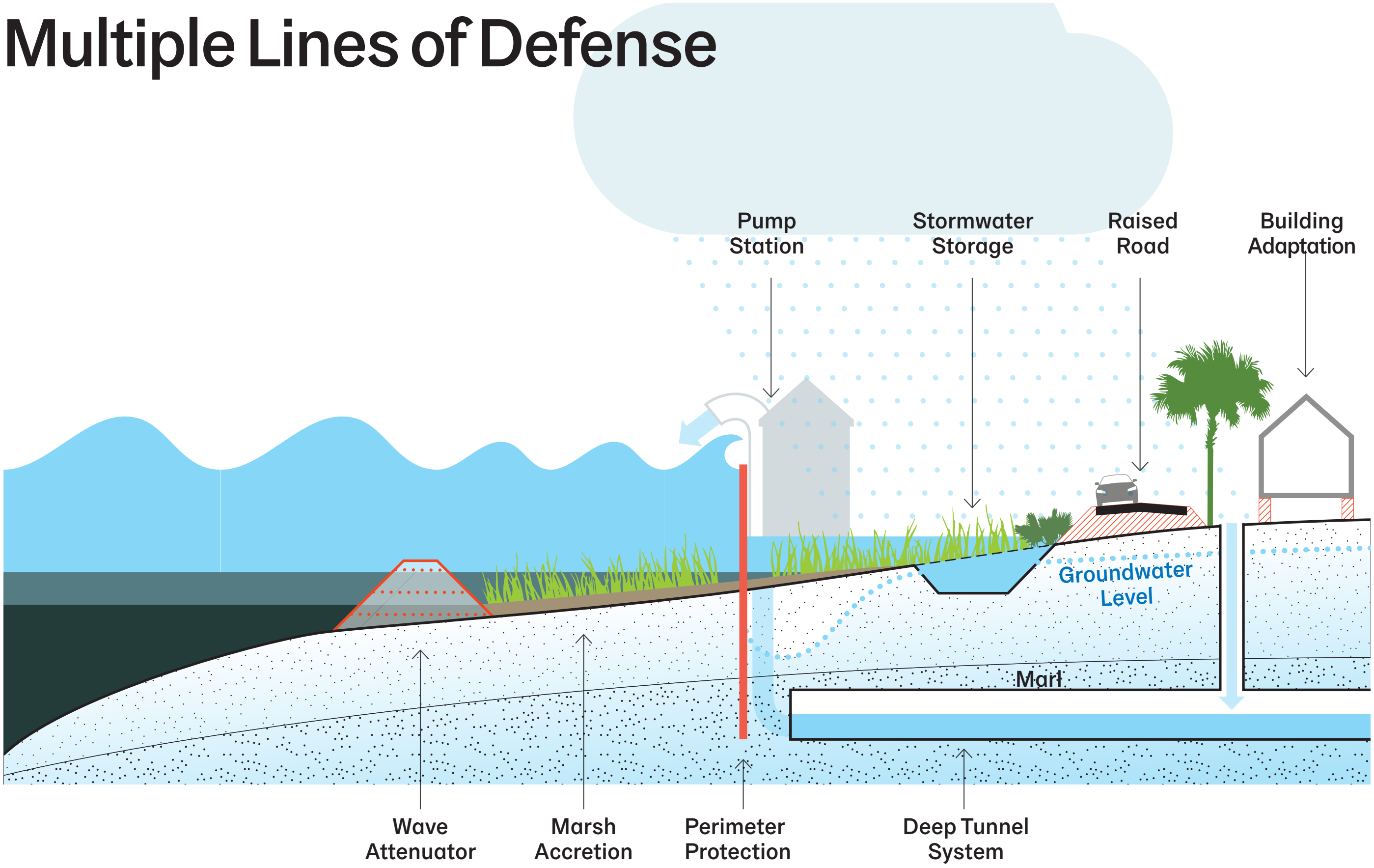
Residual risk beyond the 50-year design storm includes water that overtops the barrier in a larger storm. This is not considered failure of the structure. Overtopping volumes can be managed by the internal drainage system if enough storage space exists inside the perimeter. In Charleston, deep tunnels already create some additional storage volume. Park space, lakes and detention basins designed into the new perimeter can efficiently store the large volumes required to effectively mitigate overtopping risk. In addition, future raising of the perimeter can occur incrementally and to different heights in different parts of the system depending on how effectively internal water is managed. Designing space for internal water into the system at the outset may be cheaper compared to future adaptation costs without it; can function as part of the everyday drainage system; and provides flexibility for future decisions.

See Moffatt Nichol report in the appendix for more detailed information.




**Tide and storm surge at the High Battery.**
*Credit: Parker Survey / Waggonner & Ball*

# Multiple Lines of Defense




## Dutch Lines of Defense: 1 in 10,000 year protection

A combination of external and internal flood measures—not only one structure or line—help the Dutch achieve "1 in 10,000 year" protection. In addition to levees, there are regional networks of barriers (Delta Works and Zuiderzee Works) and neighborhood-scale features such as scenic canals and water-storing parks. Though Dutch storms are smaller and occur less frequently than those experienced along the U.S. East and Gulf Coast and 10,000 year protection may not be achievable, multiple lines of defense increase redundancy and reduce risk for events of all types and sizes.

x100 year protection: The Maeslant Barrier, a Delta Works project outside Rotterdam, is the city's first line of defense, closing to stop storm surges from the North Sea.

x70 year protection: Inside Rotterdam, levees are incorporated into the urban fabric as roads and inhabitable public spaces to subdivide the city for added flood resilience.

x1.5 year protection: Canals and lakes in Rotterdam are beautiful and provide storage capacity for managing stormwater.

*Credit: Greater New Orleans Urban Water Plan, Waggonner & Ball, 2013*

## The Power of Storm Surge

Major surge events are relatively rare any given year, however their impacts are severe and are felt for years.

**Hurricane Hugo damage on Sullivan's Island**
*Credit: Wade Spees Post and Courier*

**Hurricane Sandy damage on the Jersey Shore.**
*Credit: USFWS*

**Hurricane Ike damage along the Bolivar Peninsula, southeast Texas.**
*Credit: NWS*

**Hurricane Katrina flooding in Mid City New Orleans.**
*Credit: NOAA*

# Internal Water Management

*Analysis by:*

moffatt & nichol

## Overtopping and Flood Risk

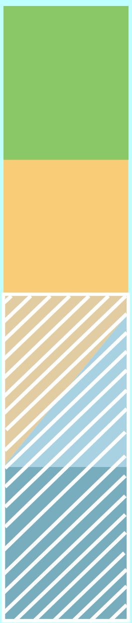
Surge-related water levels that exceed the structure's height will overtop and spill into nearby neighborhoods. The structure will impound overtopped water via the "bathtub effect" and, if the overtopped water is not sufficiently drained or safely stored, create additional flood risk inside the structure. Management of this overtopped water is a City responsibility through the operation of pumps, gates and the existing drainage system. Management of overtopped water must be incorporated into either the City's land use plan (storage) or its drainage plan (pumps), or the peninsula's flood risk and flood impacts will increase. The USACE responsibility to limit flood impacts is qualified by its policy comparing a "no project scenario" with the "project scenario:" water levels in the City caused by overtopping (project scenario) will be lower than the water levels in the City if the structure was not built (no project scenario). In other words, during a storm surge event, water that overtops the structure will create less internal flooding than if the structure weren't there at all, and thus the management of such overtopping does not require USACE mitigation. The consequences of this policy must be carefully understood by City planners and decision makers.

See Moffatt & Nichol report in the appendix for more detailed information.


**Wave overtopping during Hurricane Gustav in New Orleans.**
*Credit: Jim Watson / AFP / Getty*

## Charleston City Plan Land & Water Analysis

Waggonner & Ball was contracted separately to provide Land & Water Analysis for the Charleston City Plan, the update to its Comprehensive Plan. Part of the analysis involved classifying elevation risk zones throughout Charleston. While most of the Peninsula falls into the “tidal flood risk zone,” the perimeter protection alignment (all areas below 12 ft NAVD and within the alignment) would encapsulate all of that zone as well as the “compound flood risk zone” and part of the “adapt zone“. See the Charleston City Plan for further detail.



### High Ground

High ground is defined as land outside of the 100 year floodplain and above the max category 3 storm surge.

### Adapt Zone

The adapt zone consists of land outside of the 100 year floodplain that is still within the maximum storm surge of a category 3 hurricane.

### Alignment Zone

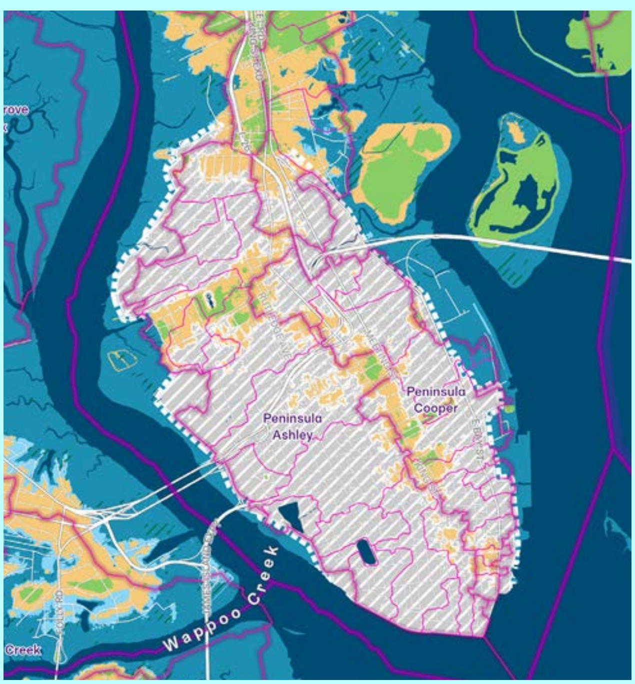
The USACE proposed perimeter protection would provide storm surge mitigation for areas below 12 ft NAVD and inside the alignment.

### Compound Flood Risk

This zone encompasses areas within the floodplain above the tidal flood risk zone.

### Tidal Flood Risk Zone

This zone corresponds to the elevation where 95% of the land is in the 100 year floodplain.




**Elevation Risk Zones with USACE proposed protection.**
*Credit: Waggonner & Ball*


**Elevation Risk Zones without USACE structure (existing).**
*Credit: Waggonner & Ball*

## Development of the Peninsula Polder

Most of the Peninsula's existing drainage system relies on gravity: stormwater drains into catch basins and outfalls through pipes to the Ashley or Cooper. As tidal flooding has increased, check valves have been installed at many of these outfalls to prevent sea water from backflooding the City. Check valves are a first adaptation, ultimately not a long-term solution as sea level continues to rise. Further modifications to the existing drainage system will be required with or without a perimeter structure.

With a perimeter protection system Charleston will become a polder: a self-contained water management unit where water inside a raised perimeter is actively managed. Polders are common in Netherlands where low lying areas are surrounded by a raised perimeter, such as a levee. Rainfall within the polder flows by gravity to a perimeter canal or basin where pumps actively control the water level. Multiple pumps drawing from the same basin create redundancy: if one pump goes offline during a storm, water can flow to another. If enough passive storage space exists inside the polder, for some storms the pumps may not need to be turned on at all. Reducing the need for pumping allows water to stabilize weak soil, thereby limiting the potential for subsidence.

In the short term, Charleston's raised perimeter may remain open to tides and gravity drainage most of the time, closing only during exceptional high tides or storm surge. When the gates are closed, the system will rely on pumps to drain water that cannot be stored, and the system will operate more like a true polder. A continuous ring canal may not be possible within the Peninsula polder, however a series of interconnected basins in each phase or segment could provide similar pump efficiency. Each existing outfall pipe will either need its own pump over the structure or need a connection to a common collection point. Where possible, existing components may serve this function. For example, Long Lake could connect via pipes or open connections along Lockwood to remnant marshes and creeks along the west side and to new storage space in Brittlebank Park, creating an interconnected storage system for the Medical District. Integration of the Spring/Fishburne deep tunnel system in this area, and pump station already underway, should be studied to leverage this existing investment.

Internal water storage space can and should be beautiful and multifunctional, providing recreation and habitat characteristic of the Lowcountry. Storage space for water should be created in parks, under streets and parking lots, and on private property, everywhere possible to supplement the perimeter system. Risks and benefits are shared within the polder.

See Dutch Dialogues Charleston, Peninsula chapter, report for more information.

### Key Terms for Internal Water Management

#### Subsidence:

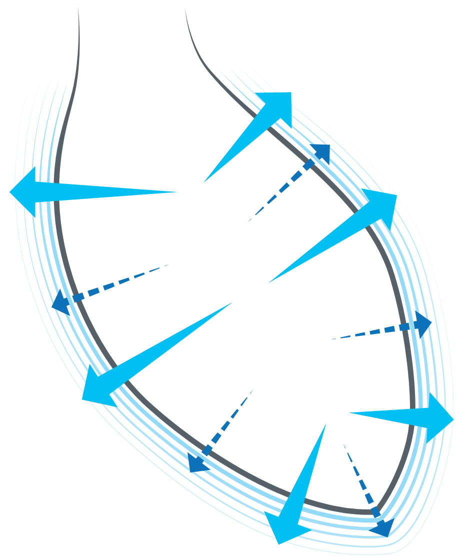
The sinking of land that can occur through natural compaction, or when organic soils dry out due to artificially lowered groundwater (such as pumps within a floodwall). The rate of subsidence can be managed, but soils do not typically rebound to former levels.

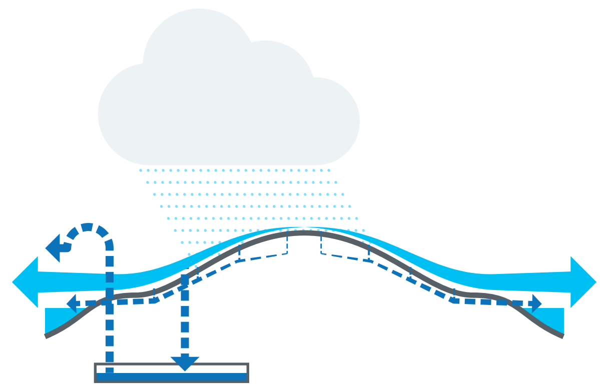
#### Soil Oxidation:

The chemical breakdown of organic matter in soil that occurs in the presence of oxygen. Oxidation is a primary cause of subsidence in areas where highly organic soils that typically remain saturated are exposed to oxygen (air). Pumped drainage systems often cause land subsidence through oxidation by unintentionally lowering groundwater levels.

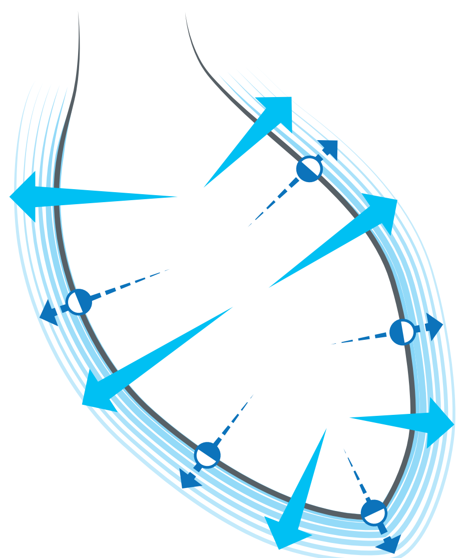
#### Water Assignment

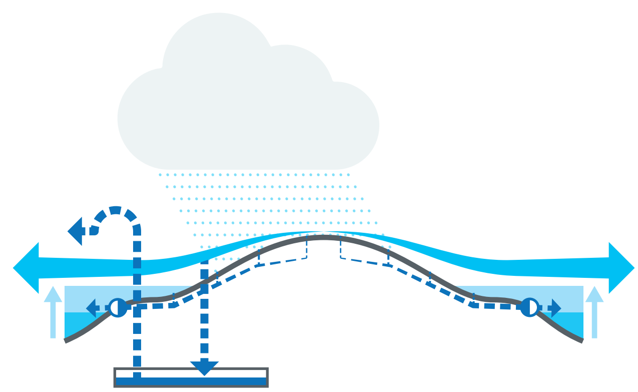
The volume of stormwater runoff that a drainage system cannot handle, which appears as flooding.



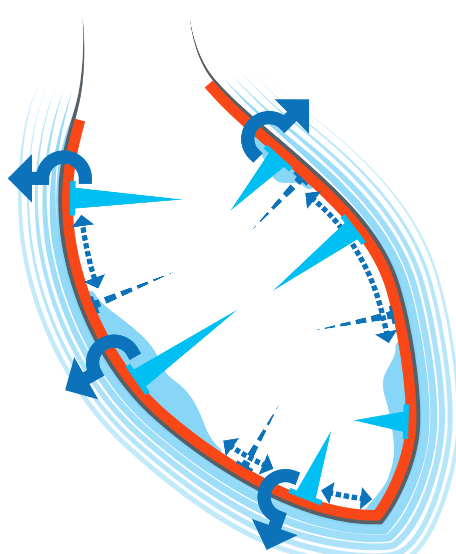


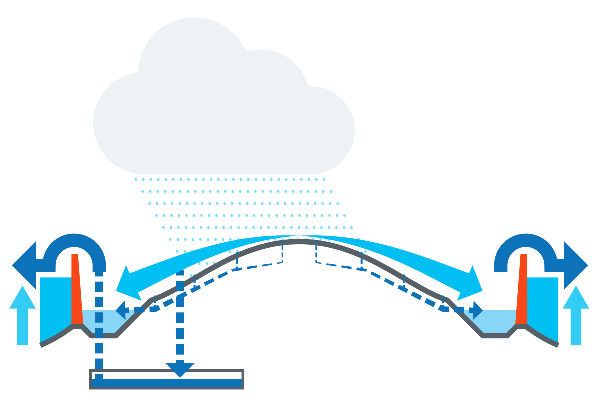
Currently runoff drains via gravity into the Cooper or Ashley River overland or in pipes with some water going into the deep tunnel system, where it is pumped out after a storm event.





With sea level rise and more severe tidal flood events, drain lines need check valves to prevent back flow.





After the perimeter protection system goes is built runoff becomes trapped behind the wall during rain events. Water will need to be managed by a combination of pumping, the deep tunnel system and an interconnected ring of detention basins and water storage infrastructure.

# Ecology

*Analysis and text by:*
Robinson Design Engineers

## Long Term Marsh Resilience

A holistic storm surge barrier strategy must offer protection to both the built infrastructure of the Charleston Peninsula and the natural aquatic resources along its margin. Storm surge barrier alignments should consider locations along the outside of the marsh edge and must include carefully designed openings and gates that allow natural tidal inflows but that dampen, throttle, and/or completely block extreme tides and storm surge. This approach will also enable salt marsh resilience against sea level rise impacts through thin layer placement of sediments. The USACOE Feasibility Report states, in contrast, that the TSP will impose permanent impacts to aquatic resources following construction and into perpetuity. Erosion of the salt marsh outside the structure, resulting from altered near shore processes caused by the storm surge barrier itself, will inevitably lead to permanent loss of intertidal habitat.

## Key Points

1. The City of Charleston, USACE, and natural resource agencies all agree on the many benefits of the aquatic resources—salt marsh in particular—along the perimeter of the Charleston Peninsula.
2. The Peninsula's vulnerability to coastal storms is expected to increase over time due to relative sea level rise. The purpose of the storm surge barrier is to reduce damages to the built infrastructure of the Peninsula from coastal storm surge inundation, thereby enabling Charleston to remain habitable for the foreseeable future.
3. The design life of the Tentatively Selected Plan is 50 years following construction; however, the timescale of the environmental regulatory review extends only through construction.
4. Over the next 50 years, the aquatic resources along the perimeter of the Charleston Peninsula—salt marsh in particular—are expected to be permanently and detrimentally impacted by sea level rise and changes in temperature and salinity, with or without a storm surge barrier. Salt marsh is transient and dynamic by nature and will respond to these changing processes over time.
5. A storm surge barrier strategy is ostensibly a holistic project for the Charleston Peninsula, and therefore must consider the long-term health of aquatic resources (salt marsh) as a part of the overall project.
6. The TSP will impose temporary impacts to aquatic resources during construction, such as turbidity in shallow open water, and temporary direct impacts for construction staging. More importantly, however, the TSP will also impose permanent impacts following construction and into perpetuity:

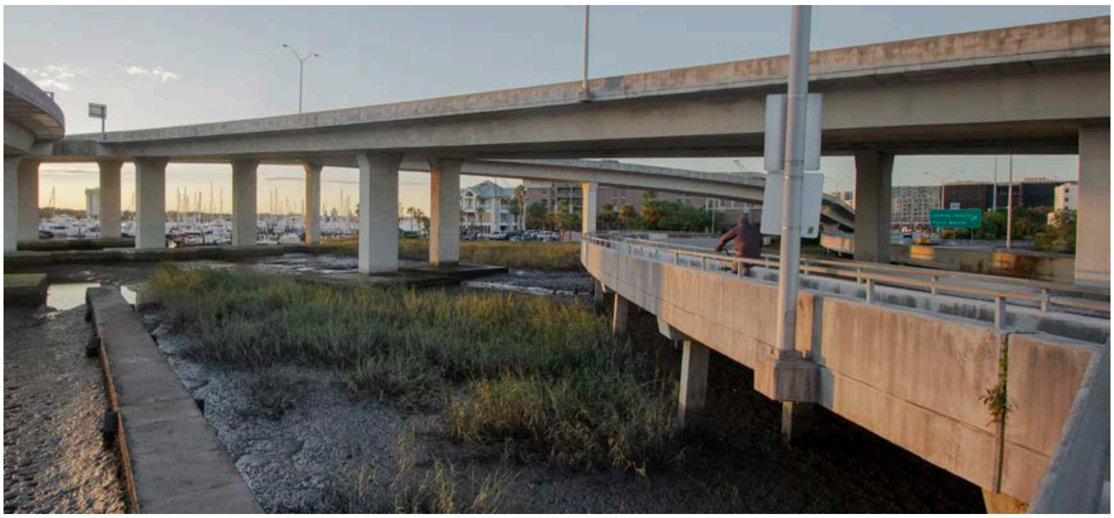
- "...where the combo-wall and storm gates are proposed, water quality could be permanently modified by altering flow rates." (pg. 165)
- "Sheet flow of stormwater and daily tidal flow across the high marsh would be reduced and channeled directly into tidal creeks and tributaries through the storm gates. This has the potential to alter sediment supply to marsh surfaces and increase channel incising." (pg. 165)
- Erosion of the salt marsh, resulting from altered near shore processes caused by the storm surge barrier itself, leading to loss of intertidal habitat.
- The 3x3x3 Feasibility Report states, "The tidal creeks that would be impacted by the combo-wall and gates are currently not well-studied, and water quality modeling has not been conducted." (pg. 166).

**Marsh living behind a small barrier in Sullivans Island.**
*Credit: Robinson Design Engineers*

**Openings in the wall throttle major tidal events.**
*Credit: Robinson Design Engineers*

7. The regulatory timescale must be congruent with the TSP timescale. The TSP must not be constrained or changed because of an artificial misalignment in functional and regulatory timescales. A responsive regulatory perspective must include:

- Evaluation of the long-term and inevitable impacts to aquatic resources imposed by the storm surge barrier itself.
- Appraisal of the expected impacts to aquatic resources during the project timescale even considering the “do nothing alternative”—i.e. what impacts to aquatic resources are expected in the next 50 to 75 years as the result of relative sea level rise and climate change.
- Provisions for how, when, and where the TSP could enhance the resilience of aquatic resources during the lifespan of the project.



**Degraded wetlands along the Lockwood Corridor likely could disappear with even small increments of sea level rise.**
*Credit: Waggonner & Ball*

**Healthier wetlands along Halsey Creek face less immediate threats from sea level rise.**
*Credit: Waggonner & Ball*

## Thin Layer Dredge Disposal

There is enough potential in shallow area south of peninsula – in terms of width and depth – to further investigate the hydrodynamic effectiveness of a nature-based wave-reducing type of solution.

**USACE pilot projects locally and nationally are studying the technique.**
*Credit: Ray, G.L. 2007. Thin layer disposal of dredged material on marshes: A review of the technical and scientific literature. ERDC/EL Technical Notes Collection (ERDC/EL TN-07-1), Vicksburg, MS: U.S. Army Engineer Research and Development Center.*

## Nature Based Alternatives for Flood Mitigation

ARCADIS

- There is enough potential in shallow area south of peninsula – in terms of width and depth – to further investigate the hydrodynamic effectiveness of a nature-based wave-reducing type of solution.

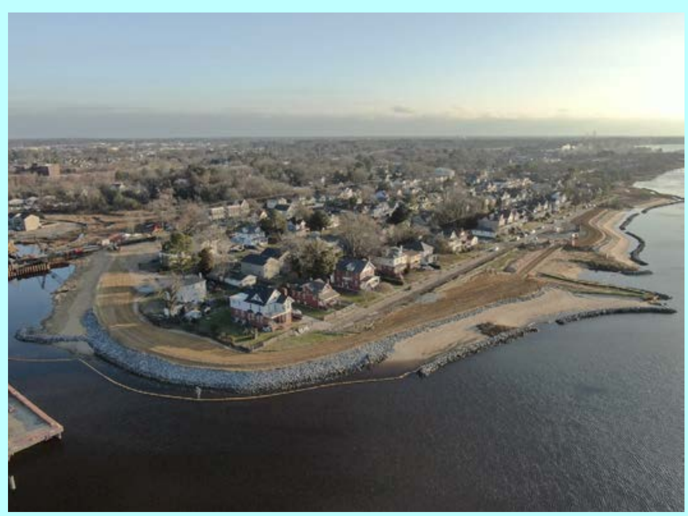
- A well-designed Living Shoreline may reduce wave heights up to 2-3 ft at the battery. This could reduce the risk and volume of overtopping water.

- The V-shape border between shallow and deep water is a good indicator for the location, and a v-shaped structure along this line also helps to divide flows into the Ashley River and South Channel (these may encounter some rise in water levels, to be studied and confirmed).

- In addition to the Battery, there is potential for wetland restoration or development along the waterline near the projected dike or floodwall alignment near Wagener Terrace.

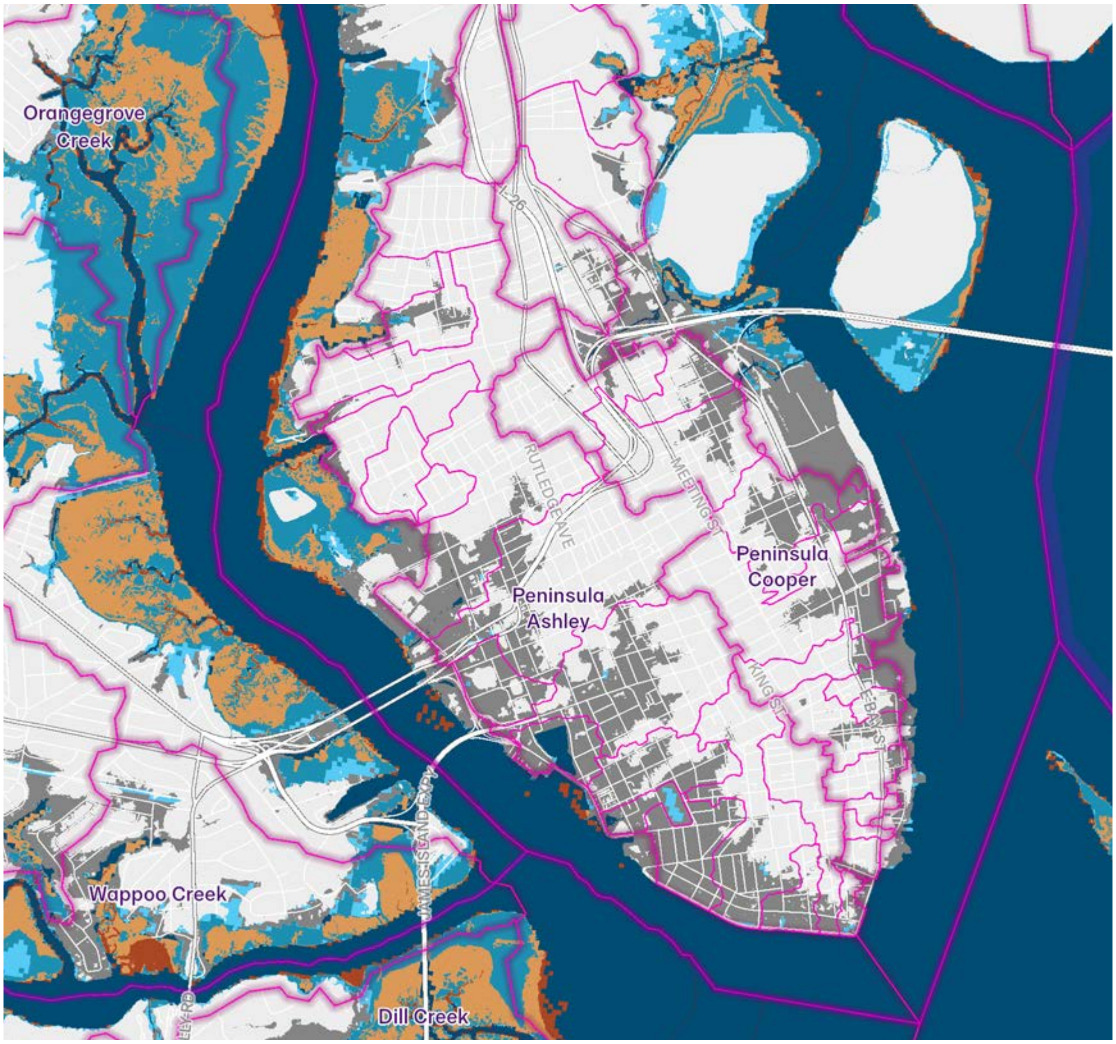
- Hydrodynamic and ecomorphological (sedimentation and erosion) modelling are needed, in addition to more investigation into types of material, environmental and ecosystems impacts.

**Markerwadden constructed archipeligo in the Netherlands.**
*Credit: cermivelli CC by NC*

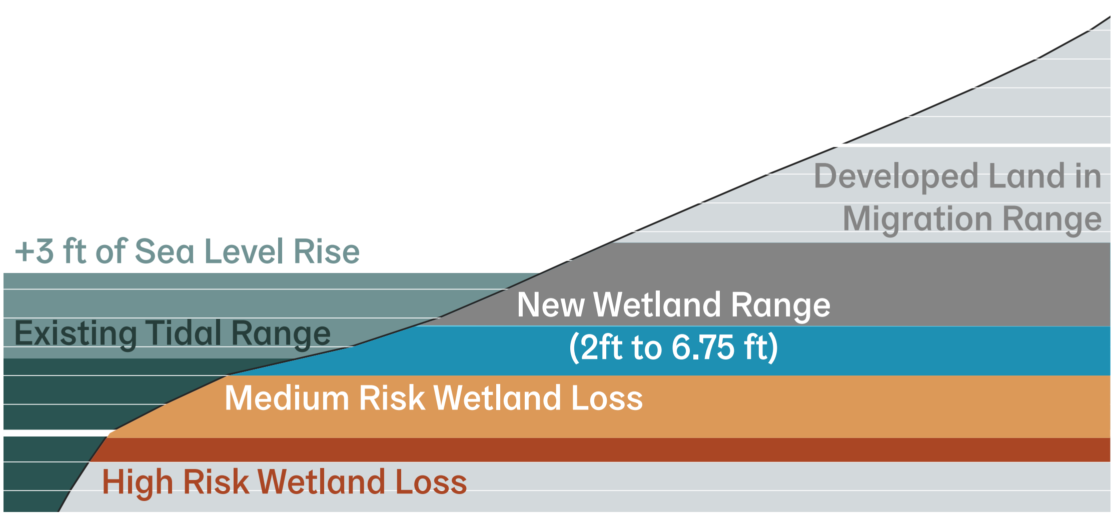


**Living shoreline under construction in Norfolk, VA, 2020.**
*Credit: Arcadis/Waggonner & Ball design team*

# Marsh Migration with 3ft of Sea Level Rise




**Peninsula wetlands are at risk of drowning under rising sea level (red and yellow), and existing development limits the area where marshes would naturally migrate upslope (gray).**
*map sources: USGS, MRLC*



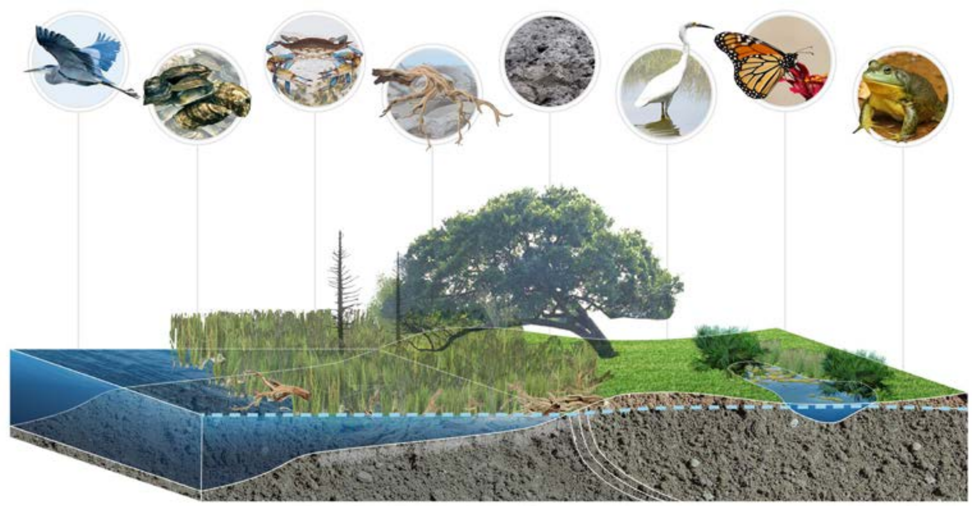

**Most of the wetlands along the edge of the Peninsula become at risk with 3 ft of sea level rise. Existing development restricts potential areas for marsh migration.**

# Marsh Migration Scenarios

SURCULUS

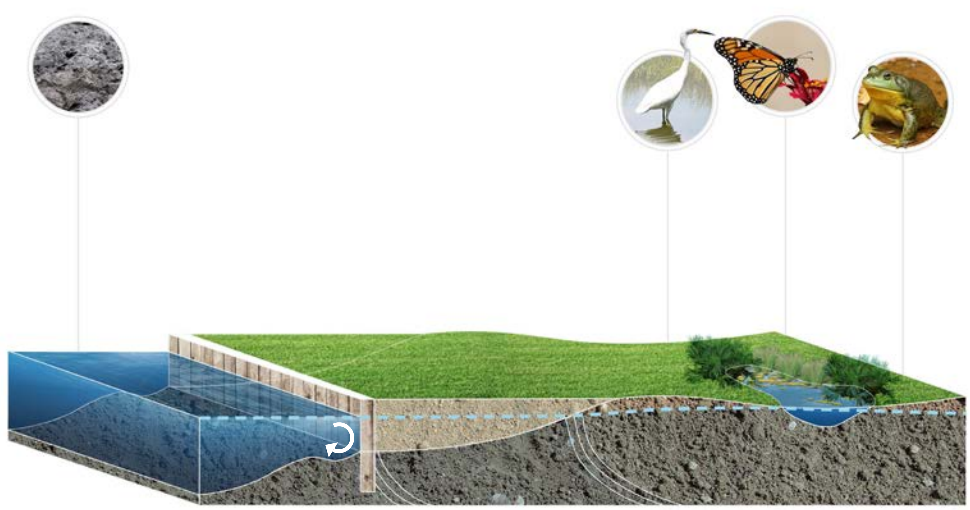
### Existing marsh

### Natural marsh mgiration



Marshes can rise with sea levels, in place or up slopes, up to certain rates. Salinity changes will cause landscape succession at the edge and groundwater may begin to surface inland

### Shore hardening



Strategies to defend coastal property, such as sea walls, cut off marsh migration and can result in scouring from wave action.

*Images source: Surculus Design*

# Operations & Maintenance

*Analysis and text by:*

ARCADIS

## Benefit-Cost Ratio (BCR)

In Charleston, a favorable BCR for a storm surge perimeter protection system of the type proposed by the USACE is most likely only achievable on the Peninsula. The current estimated BCR is 2.4, a relatively low ratio given a project of this cost and scale. For other flood prone parts of Charleston, a perimeter flood protection system would be too expensive in construction and operations & maintenance (O&M) costs relative to the low potential of avoided damages in low density suburban environments.

The current estimated BCR may be affected by low damage and consecutive repair costs from previous floods though these relatively low costs may not be indicative of current or potential future damage values given 1) the rapid urban development of the Peninsula since the last major storm surge event, and 2) the potential increase of future damages due to impacts of climate change. The current base line and direct BCR calculations, while capturing costs, do not include many other socio-economic and ecosystem resilience benefits that consider the inclusivity of people and communities, businesses, livability, other properties, future reinvestment costs, impacts on O&M, and structure enhancement or replacement.

## Adaptation

Because a relatively low level of protection is proposed (50-year event), the perimeter protection system should be easily adaptable for potential future conditions or resiliency needs. If concrete floodwalls are chosen for protection, could these flood walls or lines of defense be raised if required by climate change impacts or urban development requiring a higher protection level? In the Netherlands, new types of levees are designed to allow for some overtopping and for lifting the height of the levee without the need to completely rebuild the system. In some cases, hybrid structures with a hard (armored) and a soft (sandy) side allow for interaction with existing and natural landforms and permits increases in height to be made by use of enhanced dunes and beaches. An adaptive design approach for flood gates aim to create a "future-proof" design by selecting an appropriate reference period and values for each element (foundation, gate, mechanical system) in the structure. Uncertainty is thus explicitly included in design.

A typical adaptation issue with movable (operable) gates is that their closure frequency will increase with rising sea levels, creating additional challenges for reliability, operations and maintenance. In general, a high closure frequency entails more maintenance and creates a higher risk of failure. One approach is to raise the sill to reduce the exposed height of the opening, however at a certain height the gate is no longer a gate. If the gate closes off a road, vehicles must be still able to pass. If the gate closes off a backwater, it will need to be closed for high tides to protect property and ecosystems like wetlands and other nature elements on the inside. In some cases, navigation may require vessel access. It is also possible that a second gate set could be necessary in the future as a result of climate change and/or development on the interior. Eventually the closure frequency will increase to such a level (daily) that the gates that were supposed to close only during storm surges or exceptional King Tides have to close at every high tide, essentially becoming a tidal gate. With continued sea level rise the movable gates may no longer be operable at all. The only way to discharge the excess drainage water on the protected side that can no longer be stored without impacts to the protected features is via pumps and/or conveyance to storage areas within the interior. This future operational possibility should be included in the present-day design where possible.

## Reliability

Gates in a flood protection system always introduce an additional risk of failure in comparison to solid structures such as levees. Closing a gate requires time and may fail due to organizational difficulties such as lack of staff, missing spare parts and poor maintenance or technical issues like component failure or software system errors. The higher the number of movable gates the higher the risk of failure. This risk can be lowered by compartmentalization of the protected area (limiting flooding to a localized area in the event of one gate failure to close) and lowering the closure frequency by raising the threshold or berm above which the movable parts are attached.

Movable gates always require more maintenance, earlier replacement of vital parts, more staff attention, and more emphasis on risk-based operations through staff training and employment of risk managers. As flood gates are seldomly used on a frequent basis the risk of failure due to unnoticed defects is high. Frequent training and tests are required to ensure everything works when required, and yearly test closures should be the minimum standard. In general, climate-adaptive, robust, non-movable defenses are preferred.

**Rail and road gate on the St Bernard Parish border.**
*Credit: Waggonner & Ball*


**Swinging flood gate at the New Orleans Lakefront, Louisiana.**
*Credit: Google Street View*

## Management Authority

A flood protection system with movable parts will require a dedicated, focused, well-funded, well-equipped and adequately staffed organization. A flood protection authority or a designated agency within local or state government would be required to operate and maintain the flood protection system, including movable barriers, once completed and transferred to the local sponsor by the U.S. Army Corps of Engineers. The organization must be capable of securing the yearly required funds for operations and maintenance and also long-term replacement or renovation. The Stormwater Management Department is a candidate entity in Charleston, but the modifications and improvements required to be fully committed and prepared in time for a hand-off from USACE are still to be determined.

Average O&M costs for coastal flood protection typically average around 1-2% per year of the total up-front construction costs. Movable elements are much higher in O&M expenses than solid structures as they are technically complex, require a higher degree of maintenance and include risk for failure during closing (a risk not posed by solid structures). In addition to the maintenance costs, a set-aside for eventual replacement value must be made. A 50 or 100-year life span for conventional structures is typically used, adding another 2% or 1%, respectively, to yearly costs. However, for the more complicated and sensitive components of movable barriers, such as electro-mechanical systems, an approximate 25-year lifespan is recommended, thus adding 4% of the construction cost of that specific element per year to the required total annual budget.

The examples presented in the appendix from New Orleans, New York and the Netherlands, illustrate scenarios where the required dedicated organizational structure was or will not be not in place after design and construction of the system. Challenges vary from not having the budget required for a dedicated organization (New Orleans), to complicated and unclear responsibilities spanning across multiple agencies (New York) to underestimating the complexities of long-term O&M for movable barriers (the Netherlands). In New Orleans and New York, project design, operations, maintenance and emergency response requirements were developed in order to benefit Flood Insurance Rate Maps published by FEMA (minimum 100-year design storm protection). Requirements were developed to also comply with those published by the USACE. Experience from New York shows that the Emergency Response plan should incorporate City and State agencies, first responders, owners of the private and federal segments of the flood protection system. It is important to reach mutual agreement on responsibilities, protocols and communications for gate closure operations, sequencing and timing.

Southeast Louisiana Flood Protection Authority

## Funding

Funding the design and construction flood protection works, both in the U.S. and the Netherlands, is usually a matter of combining Federal and local public money. This also applies to Charleston. In the U.S., however, the local funder often underestimates O&M after transfer of the structures from USACE upon completion. It is therefore important to include these O&M costs as early as possible in the planning and design process and create awareness of the impacts of climate change on O&M costs.

The possibilities of attracting upfront private funding from stakeholders that benefit substantially from increased resilience has been limited. Some recent international projects (NYC Financial district, Hongkong Lantau, Singapore SESS) are exploring the opportunities for including "shoreline extension" (small layers of urban land reclamation) in coastal resilience planning, creating space for nature-based solutions, flood protection and waterfront access, but also for new waterfront-oriented high-rise buildings whose value justifies project costs. While promising for certain contexts, this model has not been substantiated yet, and there is no legal framework to guarantee such private investment outcomes. For Charleston, any proposed new development would be subject to strict local review.

Once the storm surge protection is in place, it can be expected that the attractiveness and value of the protected area will increase, thus increasing investments and economic activity, creating jobs and strengthening the local tax base for funding of the system. Over time, these investments may require continuous elevation of the flood protection level, enabled by a higher potential loss and therefore a growing BCR. Once a flood protection system is completed, the area within is committed to its maintenance in perpetuity.

**(See appendix for Arcadis reference projects in New Orleans, New York and the Netherlands.)**

**Boardwalk on top of a flood wall in Morgan City, Louisiana.**
*Credit: Waggonner & Ball*

## O&M Key Points

1. Risk Management (Level of Protection) factors:

- Relatively low level of protection is proposed (12’ elevation / 50-year or 2% annual occurence event; 100-year or 1% protection typically required for insurance rate reductions).
- How would flood walls or lines of defense be raised? Hybrid structures should be explored.
- Movable” and “temporary” parts are risk multipliers. They are red flags for O&M and reliability. Substantial risk is not accounted with movable elements.
- O&M is risk-based, accounting only today’s risk of failure (Note: USACE BCR methodology does not allow for value of protected assets enabled or developed in the future to be factored).

2. Benefit Cost Ratio (BCR) factors

- A favorable BCR for a storm surge protection system is only workable at the Peninsula. The current figure, 2.4, is not particularly high. Costly additional features, even if cost shared, may further erode the BCR and jeopardize federal funding.
- The relatively low BCR is possibly affected by low damages from previous floods
- Repair costs used may not be indicative of current construction values, especially in sensitive historic contexts.
- A true BCR should be inclusive of people, businesses, secondary effects, and new/future properties.
- Future reinvestment costs, O&M or enhancement or replacement, are not fairly factored.

3. Annual Maintenance Costs

- O&M is typically discussed as 1-2%/year of construction cost. Movable elements create much higher expense.
- Expected project life cycle replacement costs must be factored. A 50-year design life requires 2%/year set aside.
- Once storm surge or other protections are in place, investments follow with the expectation or perhaps even requirement to maintain protection.

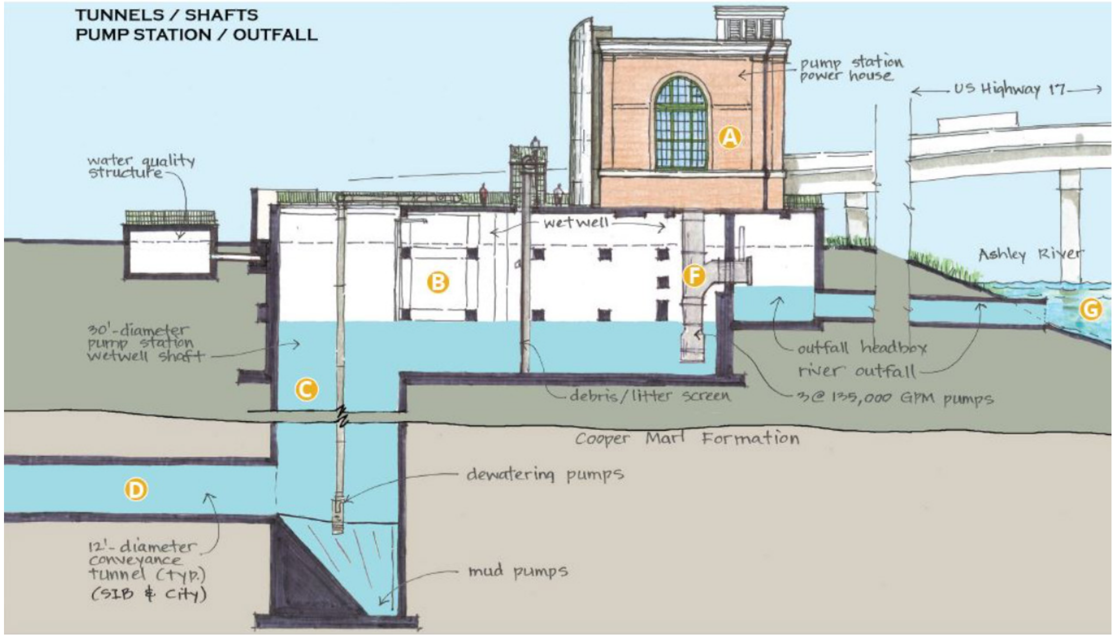
4. Management Authority

- A new agency or funded authority is needed to manage the perimeter system.
- Robust management is particularly important for movable parts, like gates and pumps. Could the Drainage Department manage and operate this system in addition to its other commitments across the City?
- Design-stage benchmarks are needed to help establish this agency or authority.

## Reference Cases:

New Orleans: Southeast Louisiana Flood Protection Authority was improvised after Hurricane Katrina through the merger of local levee boards. O&M costs began in earnest 2-3 years after the $14.5 billion Hurricane & Storm Damage Risk Reduction System (HSDRRS) completion.

Rotterdam: 22 full-time staff are required to operate and maintain the City’s showcase Maeslant Barrier.




**Market Street Deep Tunnel System.**
*Credit: City of Charleston*

**Plan drawing of an integrated water management system for the Peninsula polder produced in the Dutch Dialogues workshop.**
*Credit: Waggonner & Ball*


**Map of historic districts and public amenities in Charleston.**
*Credit: Waggoner & Ball*

# Urban Design & Historic Character

The Peninsula is made up of some of America's best-preserved historic homes and structures. Neighborhoods throughout the Peninsula are diverse and unique, some with cultural and family connections dating back generations. Protecting their character and connections should be paramount to the project. Any disrupts to the urban and historic character of the Peninsula are likely to create substantial public and institutional backlash, undermining project support and therefore the overall goal of risk reduction. The implementation of a raised perimeter for long-term resilience to climate change cannot compromise the character of the very place it is intended to protect.

## Mitigations vs. Betterments

The TSP alignment as currently represented, while only at feasibility stage, creates significant urban design challenges, and the types of structures proposed are at odds with the historic character of the Peninsula. The upcoming EIS process provides an opportunity to document these impacts and cost share strategies to mitigate them. Access to Water—both direct and through viewshed—is a primary impact. The preservation of public access to the water is paramount, whether that takes place in the location of the alignment, the structure's design, or both. Views toward the water from buildings and public spaces are characteristic of Charleston and should be preserved where possible. It should also be noted that existing opportunities for elevated views from the perimeter—such as from atop the High Battery or Waterfront Park—provide equally characteristic experiences.

City design requirements that might be considered betterments in less historic contexts may qualify for cost-share mitigations given the sensitive and iconic nature of the Peninsula. One mitigation may be the design of additional structural typologies calibrated to, or disguised within, the local context. An example already exists in Charleston at the Battery, where two versions of a successful, beautiful seawall have been in place for generations. In strategic areas, the use of fill on the land side of the structure may be usable as an open space and seamlessly connect the city to the top of the barrier. Another possible mitigation is landscape. In addition to quality of place, the City's urban trees provide numerous benefits related to water management, building energy usage, reduction of urban heat island, sense of place, tourism, walkability and human comfort. Creative solutions that prevent the removal and allow for the replacement and addition of street trees on and around the barrier should be pursued.

## Relationship to Related City Plans, Projects & Design Standards

The storm surge project must enable the City to implement any elements of the Downtown Plan that remain relevant and further realize its downtown urban design and development objectives. While excluded from BCR calculations, the perimeter design and alignment must consider emerging and planned infill development and redevelopment sites in a manner that does not diminish their real market or place value.

The City envisions an uninterrupted system of passive and active open spaces around the Peninsula composed of a mix of hardscape, green space and vegetation with an integrated pathway network. Such a complete perimeter plan would consider and include the revitalization of all waterfront spaces along its route, continuing the legacy of waterfront reclamation and transformation established by the city's great local examples, such as the High Battery, Low Battery, and Joe Riley Waterfront Park. The surge protection structure should further this vision. The project must seek to avoid the reduction of existing and planned pedestrian and bicycle infrastructure and minimize any removal or reduction of amenities that contribute to the comfort, safety and beauty of this network (street trees, landscaping, etc.). Whenever the raised perimeter is located alongside or within a roadway, every effort must be taken to enhance the streetscape and upgrade the roadway into a multimodal complete street.

The City needs a clear understanding of USACE standards within the required rights of way, especially related to landscape, materials, public accessibility. These standards were not devised for historic urban contexts, and design negotiation between the City and USACE—without compromising safety—will likely be required to maintain public support. City-advocated design standards may include the use of high-quality materials; well-designed stairs, ramps and vertical transitions to the street and sidewalk; landscaping; public art; low-profile railing systems; viewing areas; opportunities to connect from the city to outlying barriers; and contextual standards for the design and configurations of gates and pump stations. It is in both the City's and USACE's interest to find a mutually acceptable design outcome. Examples for possible collaboration include creative construction methodologies, alterations of adjacent easement widths, and other context-sensitive design and implementation approaches fit to the City's historic urban environment.

## Development & Redevelopment Considerations

While structures under construction on sites outside the proposed alignment are already raised above flood risk—and therefore would not contribute to the value of protected property in USACE BCR methodology—the development of elevated structures within a future alignment only improves their flood resilience. The current TSP alignment option along Morrison places several such buildings outside the line of protection. The Discovery Report team believes the alignment along the Eastside and Port segments should be located as close to the Cooper as possible to protect as much land as possible. Access must be maintained to these properties especially when the structure is closed under high water conditions.

The inclusion of open space within the alignment, while not quantified in the BCR, may contribute to the value of nearby protected properties. Structures and properties adjacent to the barrier stand to lose value if it encroaches on their functionality, detracts from urban character or limits accessibility.

## Design Division Goals & Guidelines

The Design Division, within the Department of Planning, Preservation and Sustainability, analyzed each segment of the proposed TSP for urban design concerns, opportunities and future considerations. Keeping in mind that the alignment and structure type are likely to change in PED, this work can become a basis for analysis of future designs. Key points include:

• maximize urban development/redevelopment, multimodal transportation, landscape and open space improvement opportunities.

• integrate well-designed infrastructural connections and crossings into the barrier (gates, outfalls, etc).

• identify strategic locations where the raised perimeter structure can significantly enhance the experience of the public realm.

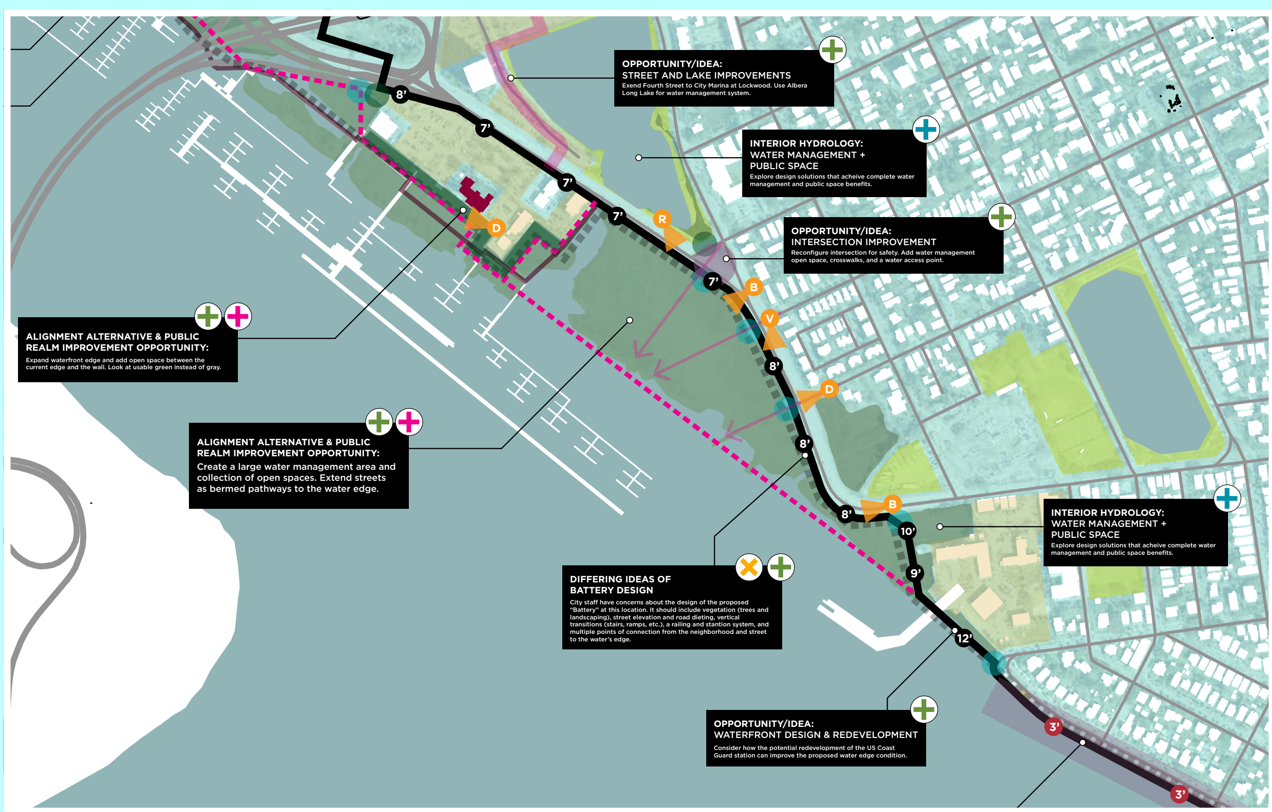
• reduce the visibility of "grey" infrastructure where the perimeter meets highly visible and historic areas of the city.

• allow for high quality adjacent landscaping, vegetation and streetscape improvements in strategic locations.

• make use of existing infrastructural or industrial areas including, but not limited to: railroad rights-of-way, industrial sites, streets, bridge landings, alleys and the rear areas of buildings.

**Public park next to a levee in the Netherlands.**
*Credit: Waggonner & Ball*

## City of Charleston Design Division




**City of Charleston Design Division map highlighting urban design issues and opportunities.**
*Credit: City of Charleston Design Division*

# What is a Charleston Water Plan?

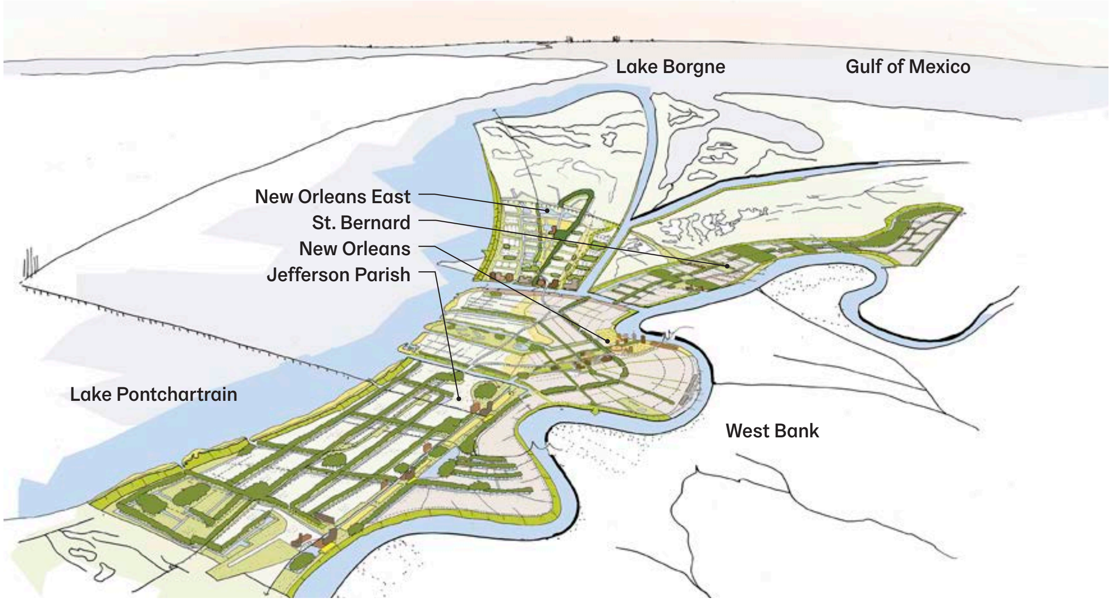
Water knows no boundaries, and in a city defined by water it influences all departments, projects and plans. A water plan for Charleston would serve to coordinate many plans and efforts underway, and it would begin from spatial analysis to find and make space for water. A spatial analysis would look for ways to incorporate water in existing and new public spaces and build on the City's stormwater manual to establish criteria for water management in private sector. Multiple scales of coordination through the lens of water are needed to maximize public investments. Scales range from the movement of water in rivers and creeks, to urban water systems per borough, to neighborhood-level planning for buildings and blocks. This approach results in the integration of known projects and often in the identification of new ones. A water plan would take a holistic approach to water in the city, from rain to tide to storm surge to groundwater, following the paths of water across the city. It could provide opportunities to develop practical steps to realize urban goals, such as a continuous perimeter park, at the same time water risks and challenges are addressed.

Development, housing availability and affordability, transportation and environmental/social justice considerations will be impacted, individually and collectively, by water and how the City deals with it. Water impacts will not shrink or stay static; they are the overwhelming threat to how people live, work, visit, commute and consume on the peninsula and across the City. A Water Plan will help Charleston understand all water risks, consider alternatives, their impacts and their interactions (costs/benefits), and chart a way forward to guide project selection, prioritization, and investment efficiency.

## Selected list of related projects, plans and analyses

- All Hazards Vulnerability & Risk Assessment
- Comprehensive Plan update (Charleston City Plan)
- Sea Level Rise Strategy
- The Downtown Plan
- Parks & Recreation Master Plan
- Transportation planning (including Lowcountry Rapid Transit and CARTA electric bus master planning)
- The deep tunnel network (including drop shafts and pump stations)
- Drainage improvements planned and underway

**Resilient Vision for the Eastside waterfront**
*Credit: Waggonner & Ball / Dutch Dialogues Charleston*




**Vision image from the Greater New Orleans Urban Water Plan**
*Credit: Palmbout Urban Landscapes / Greater New Orleans Urban Water Plan*

**Bayou St. John in New Orleans**
*Credit: Waggonner & Ball*

**Westerpark in Amsterdam**
*Credit: Waggonner & Ball*

# Defining the Alignment Zone

## Inner & Outer Boundaries

The selected perimeter alignment will guide all future flood mitigation decisions in Charleston. While the perimeter protection system is not directly tasked with mitigating tidal flood risk, sea level rise, or rainfall flooding, the design of the alignment will set the boundaries for how those problems are addressed in the future. All the alignment options reduce flood risk from storm surge. When it comes to mitigating other sources of flood risk, various options present both challenges and opportunities, some of which are considered through the USACE design process, some of which must be weighed independently by the City. The alignment zone defined in this report captures a range of practical locations for a raised perimeter structure to allow the City, and its citizens, to better understand the spectrum of alternatives, and ultimately to advocate for a multi-benefit outcome.

### Inner Alignment

The current USACE Optimized Alignment is located as close to the urban edge as possible, essentially an "inner" boundary. This configuration was driven by the USACE's mandate to achieve the identified level of protection at the lowest cost. Avoidance of wetland mitigation costs pushed the alignment inward across the Peninsula. This inner alignment creates significant collateral impacts, such as a need for closure gates across roads, and constricts available space and flexibility inside the structure to solve future flood challenges, such as expected overtopping during exceptionally strong storms, a risk compounded by sea level rise. All alignment options create a bathtub effect, trapping runoff and overtopping water behind the perimeter protection line. The inner alignment, however, potentially burdens the City's drainage system by containing runoff and overtopping water where it is more likely to flood roads and structures. While the USACE-proposed structure cannot increase flood depths inside the city beyond what is currently experienced, it is not designed to reduce existing flooding, and it introduces a new demand on City drainage systems in the form of impounded, overtopped storm surge.

## Outer Alignment

Throughout this section several “outer” alignment options are explored to illustrate the relative values and consequences of a looser perimeter fit. For purposes of analysis, the outer alignment boundary was considered as approximately the -5’ NAVD88 water depth contour, a line beyond which structural or nature-based alternatives become impractical. Shifting the alignment toward the Ashley and Cooper—where feasible—may incur higher up-front costs in the form of wetland mitigation and constructability factors but can make more space for passive water storage inside the city. Space and time are related: more space allows more time for the drainage system to function, whether by gravity or pump, and reduces the potential for flash flooding. By expanding the configuration, the space between the alignment and the city can be used as storage space for runoff and overtopping volume and can be designed to achieve additional City goals for public space and development. In a dense and layered historic city like Charleston, space itself is an invaluable resource.

## Space for water, at what cost?

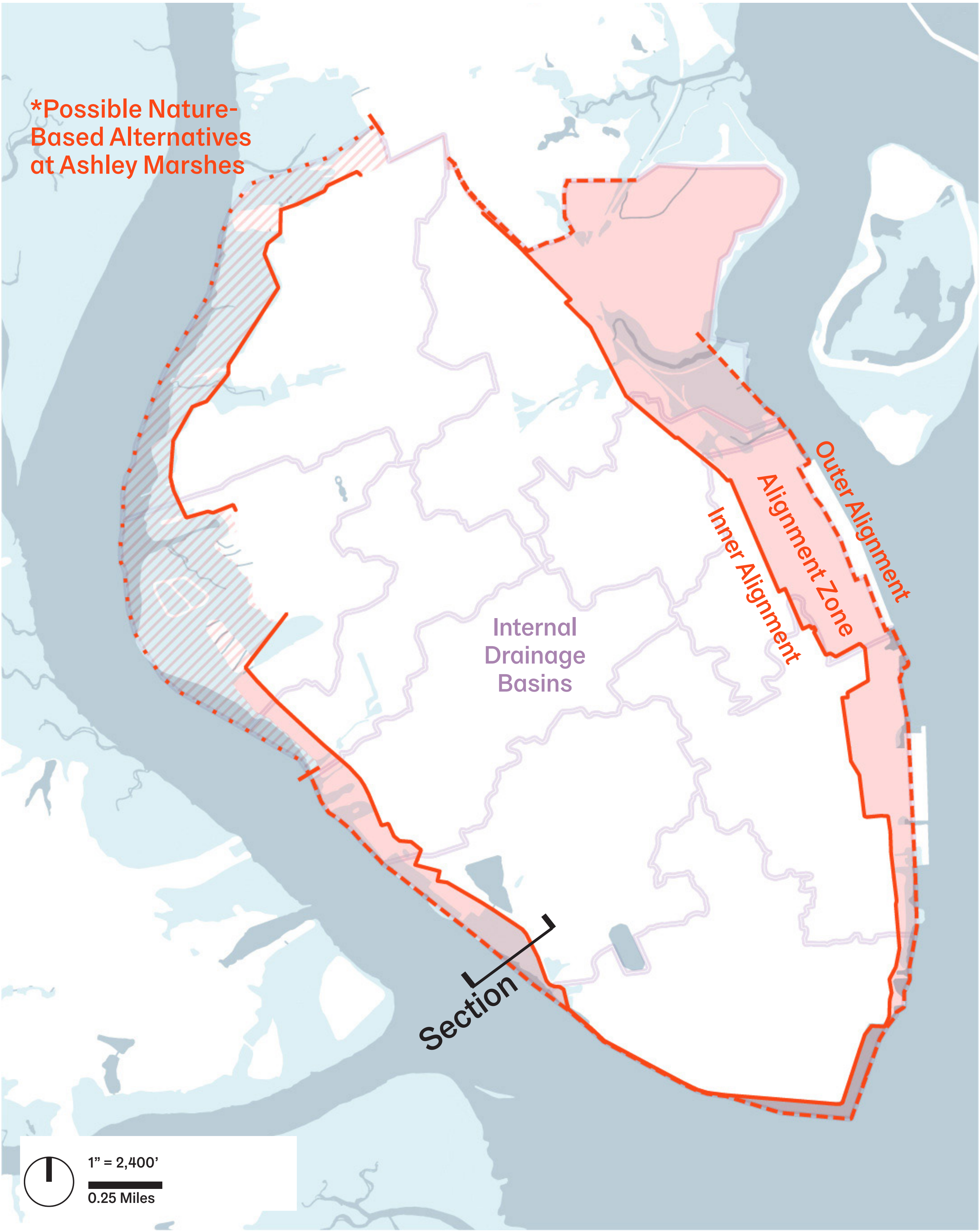
More storage space is needed to solve the Peninsula’s flooding and drainage problems. Currently the deep tunnel system is the largest source of stormwater storage in the city, however the system creates a relatively small storage volume at a high overall price. For reference, a 10 year/24 hour rainfall event produces a drainage demand, or water assignment, of over 1,200 acre feet in volume (see Dutch Dialogues report pg 163); the Spring/Fishburne deep tunnel project provides approximately 17 acre feet in storage volume (see source, next page). The outer alignment provides potential storage space above ground with significantly more storage volume than deep tunnels and likely a lower price tag, but the City must balance wetland impacts and the near-term cost of wetland mitigation against the future cost of deep tunnel construction. While future deep tunnels may be required in any scenario given the lack of available water storage space in some parts of the city, the inner alignment will likely make this option—with its high cost, limited urban design co-benefits, and lengthy construction timeline—the only available choice.

# Adaptability

Sea level rise makes flood risk mitigation a moving target. At some point in the future the wall will need to be raised to keep up with increasing storm surge risk. As tidal events become higher and more frequent, gates will need to close more often. More overtopping volumes will have to be dealt with in the future, requiring upsized pumps and more storage space.

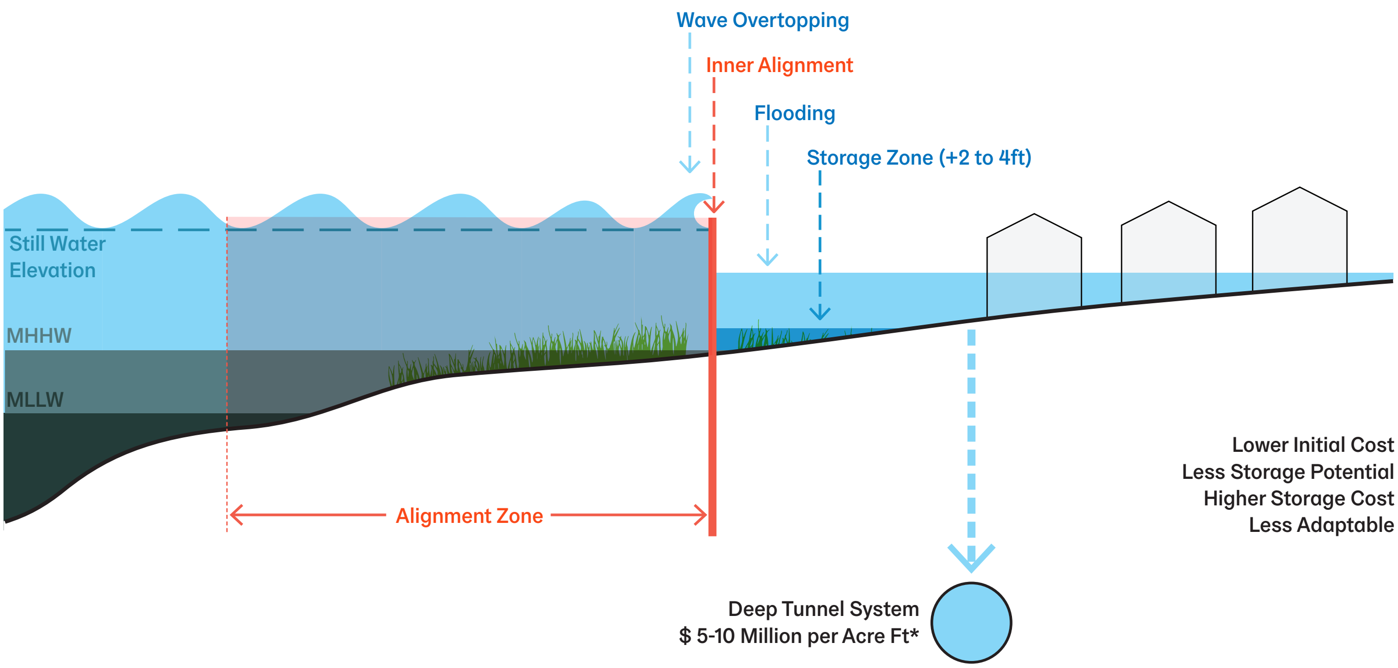
The perimeter system’s foundation and construction type must anticipate the need to be raised in the future. However, visual impact thresholds in historic areas should be considered: how high is too high? The perimeter may not need to be raised to the same level everywhere, or at the same time, if the space and systems behind the barrier can adapt to more water inside.

Less gates in the initial design, has a multitude of benefits: reducing traffic disruption, lowering the operations and maintenance (O & M) cost, and helping the alignment double as a tidal flood protection system. Currently gates are designed to only be closed in surge events and substantial tidal events, both risks increase with sea level rise. In transportation corridors like Lockwood and Morrison, frequently closed gates in the future would substantially disrupt traffic flow and access to critical facilities. Shifting the alignment outward away from major corridors preserves access without gates. This keeps corridors open in the long term and helps mitigate nuisance flooding immediate term.

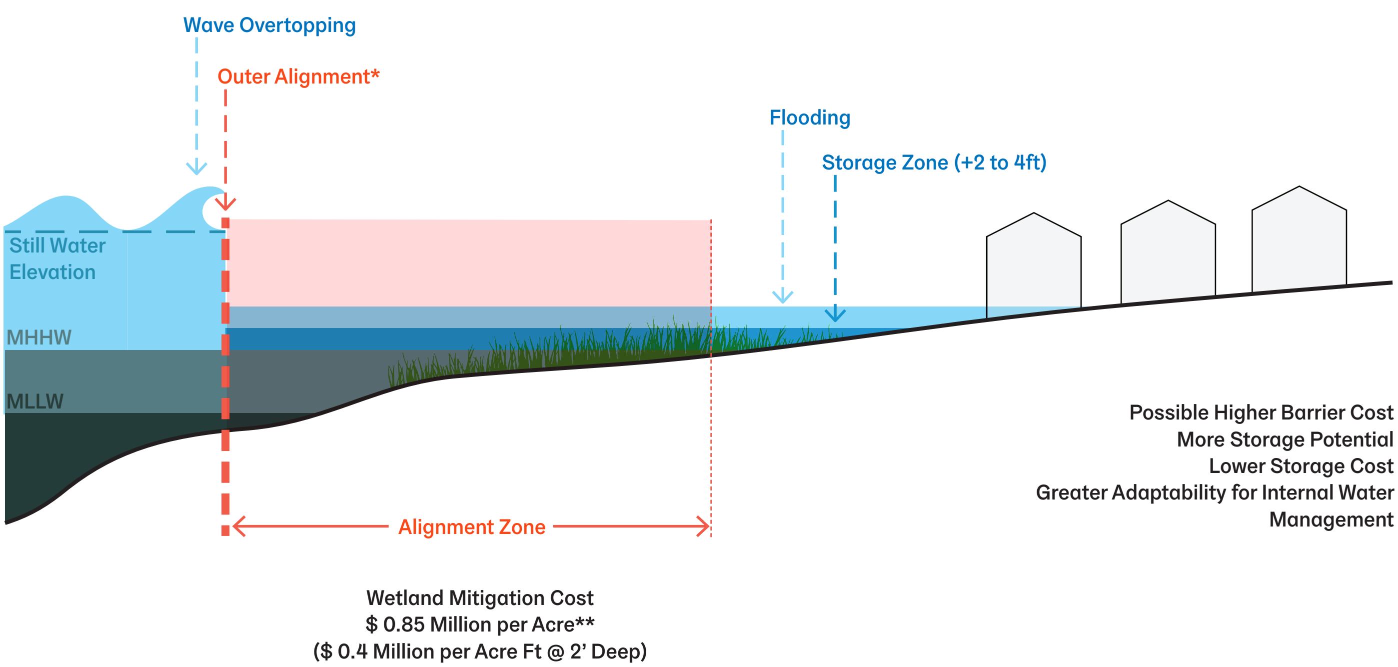



Conceptual map of the alignment zone. Actual alignment and structure type will be determined through future engagement and design phases.
*Credit: Waggonner & Ball*

## USACE Optimized (Inner Alignment Concept)

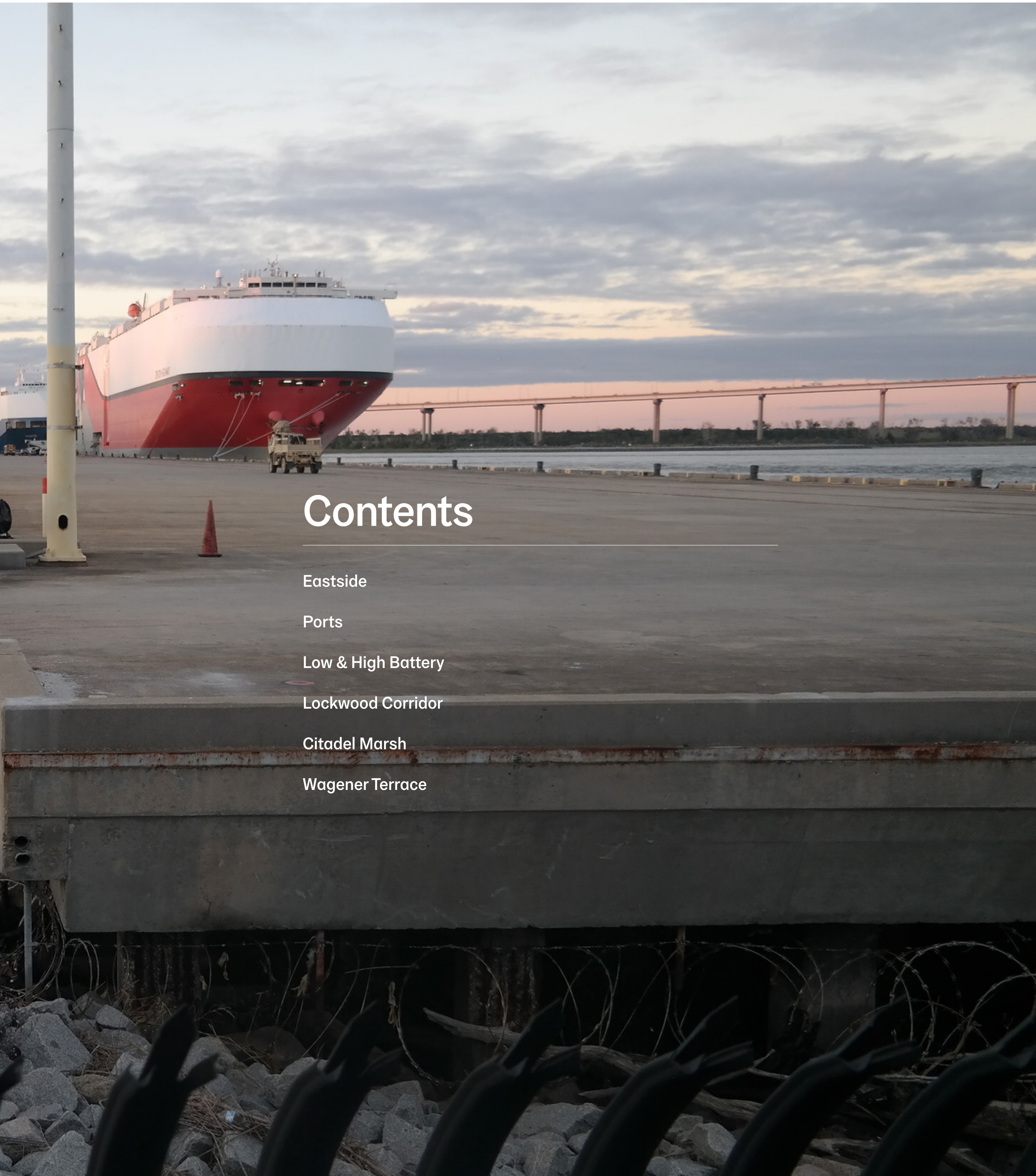



## Outer Alignment Concept




*Spring/Fishburne project cost $198 million (Post & Courier, "Checking in on Charleston's nearly half-billion dollars worth of drainage projects," October 22, 2020). Spring/Fishburne deep tunnel storage volume is approximately 17.4 acre feet (springfishburnedrainage.com, accessed 2/28/2021): 5,400' of 12' diameter tunnel + 2,950' of 8' diamteter tunnel + 4 drop shafts 30' wide x 180' deep.
**Working estimate provided by USACE project staff in November 2020.

# Alignment Options



# Contents

# Lockwood Corridor

## Overview

This key medical center and transportation corridor requires surge, tidal and stormwater protection. Also required is robust coordination for future transportation projects (such as the Ashley River bike crossing and the final locations of LCRT stations), their interface along Bee and nearby streets, with possible future capacity additions to the Spring-Fishburne deep tunnel system, and with Charleston Medical District (CMD) capital projects in planning stages. Design, engineering and construction of these projects will start before or during PED Phase 1; a federal-state-City-CMD coordination body may be needed. Given the regional importance of the CMD we agree with USACE's prioritization of this area for PED Phase 1.

The original (west of Lockwood Drive) surge structure alignment from the Crosstown bridges south to the area around the marina should be reconsidered. Any need for surge gates across Lockwood Drive as imagined in the optimized alignment must be avoided. Such gates, under sea level rise projections, would eventually be operated as tidal control structures and sever the key transportation function of Lockwood Drive. Access into and out of the CMD would be technically possible but significantly complicated by the currently proposed alignment. The mixing bowl of Lockwood Drive, the James Island Connector and the Crosstown must not be made even more torturous by the placement of surge structures in the middle of this critical area.

The Corridor and areas just east of it are regularly impacted by tidal, stormwater and compound flooding. Because tidal and compound flooding will increase as sea levels rise, the original outward alignment will create essential opportunities for stormwater and tidal flood management within the structure. This outward alignment could also unlock the potential for additional CMD stormwater and tidal water management in Alberta Long Lake. It will provide the foundation for a coherent pedestrian and bike path along the Ashley River from the Low Battery to Brittlebank Park, a key City goal.

Most of the close-in marshes to the west of Lockwood Drive will likely be lost as sea levels rise as land surface levels are low and there is no space for the marsh to migrate. Geotechnical and environmental analysis will be needed to determine where an outward alignment is constructible: river sediments in this area may be contaminated and require remediation if disturbed.

# Key Questions

## Risk Management (Level of Protection)

- Where can the alignment move closer to the Ashley, especially under the James Island Connector? Can it take the place of the elevated bike path?
- Can the perimeter structure take the form of raised roads?
- Is a Low Battery-like extension viable along Lockwood?
- Do alternative alignments sidestep the 12’ NAVD clearance limit at Ashley River bridges?

## Internal Water Management

- Can the structure type and/or adjacent road provide water storage space?
- Can a “ring canal” or surface water feature in this segment connect and create redundancy at perimeter pumps?
- Can salt marsh, Long Lake and Colonial Lake become a storage network?
- How will existing drainage outfalls, such as the box culvert under the James Island Connector, meet a raised perimeter?
- How is the perimeter structure and its pump station requirements integrated with the deep tunnel system and the pumps under construction? (Spring-Fishburne and Calhoun West)

## Ecology

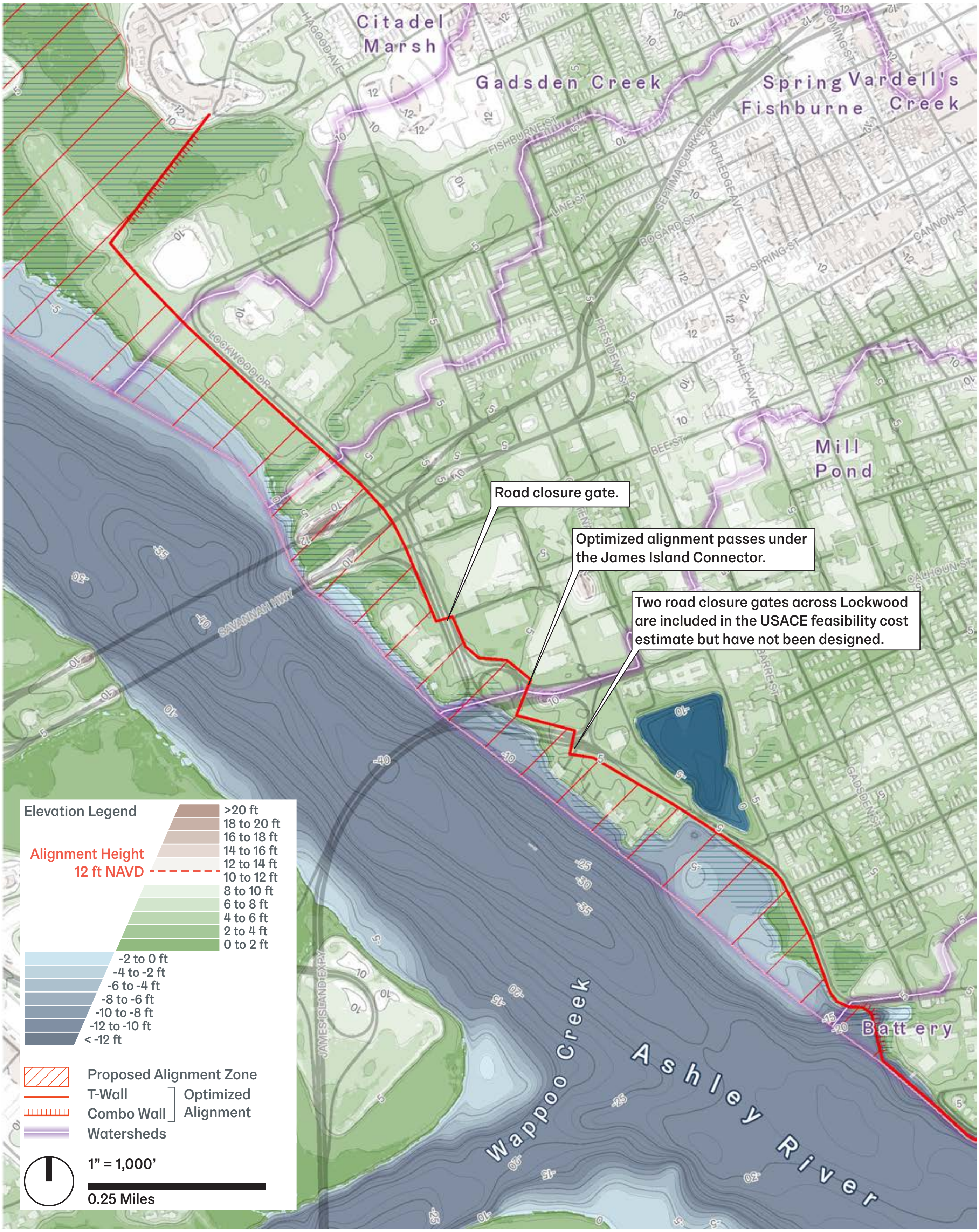
- Does potential soil contamination preclude barrier construction?
- Is there a need to classify degraded, at-risk marsh as such?

## Operations & Maintenance

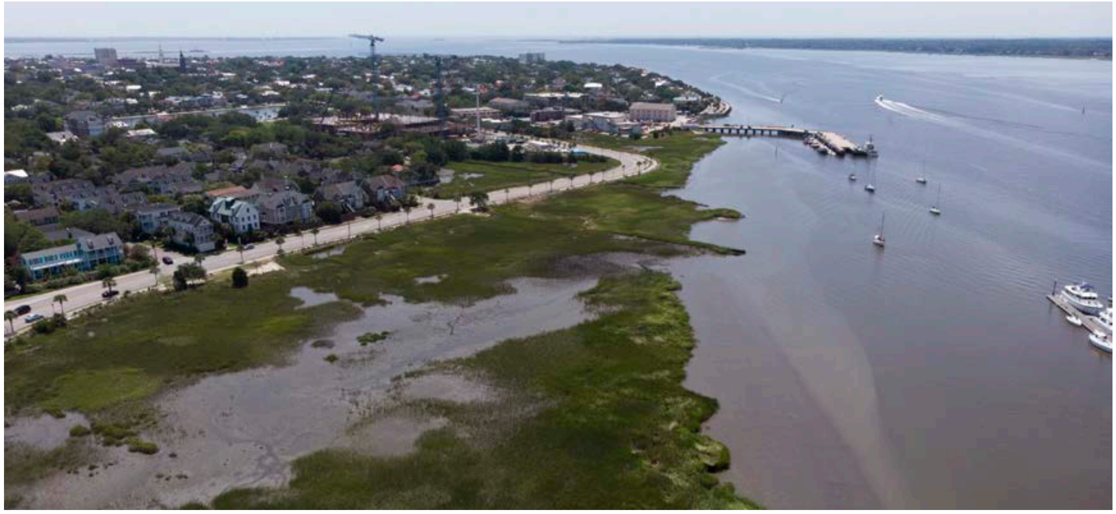
- Can tide gates be designed to preserve or enhance marsh ecology within the structure?
- Can vehicular and pedestrian gates be avoided entirely?

## Urban Design & Historic Character

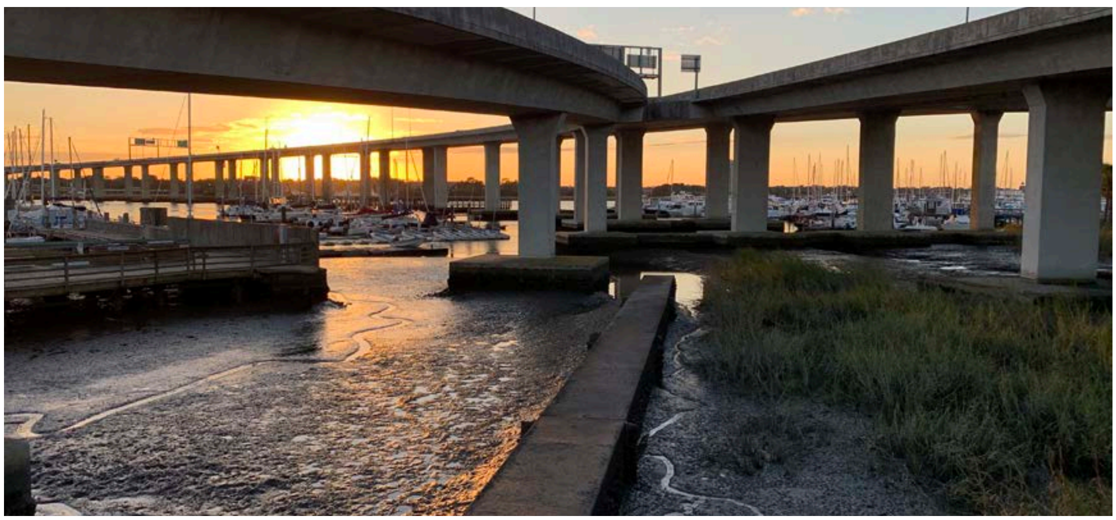
- Can the Historic Rice Mill Building be adapted outside the flood defense line?
- How can access to the Marina and waterfront be preserved, if not expanded, through structure design?
- How can the structure integrate into Brittlebank Park to increase recreation opportunities and waterfront access?




**Lockwood Corridor USACE optimized alignment.**
*Credit: Waggonner & Ball*

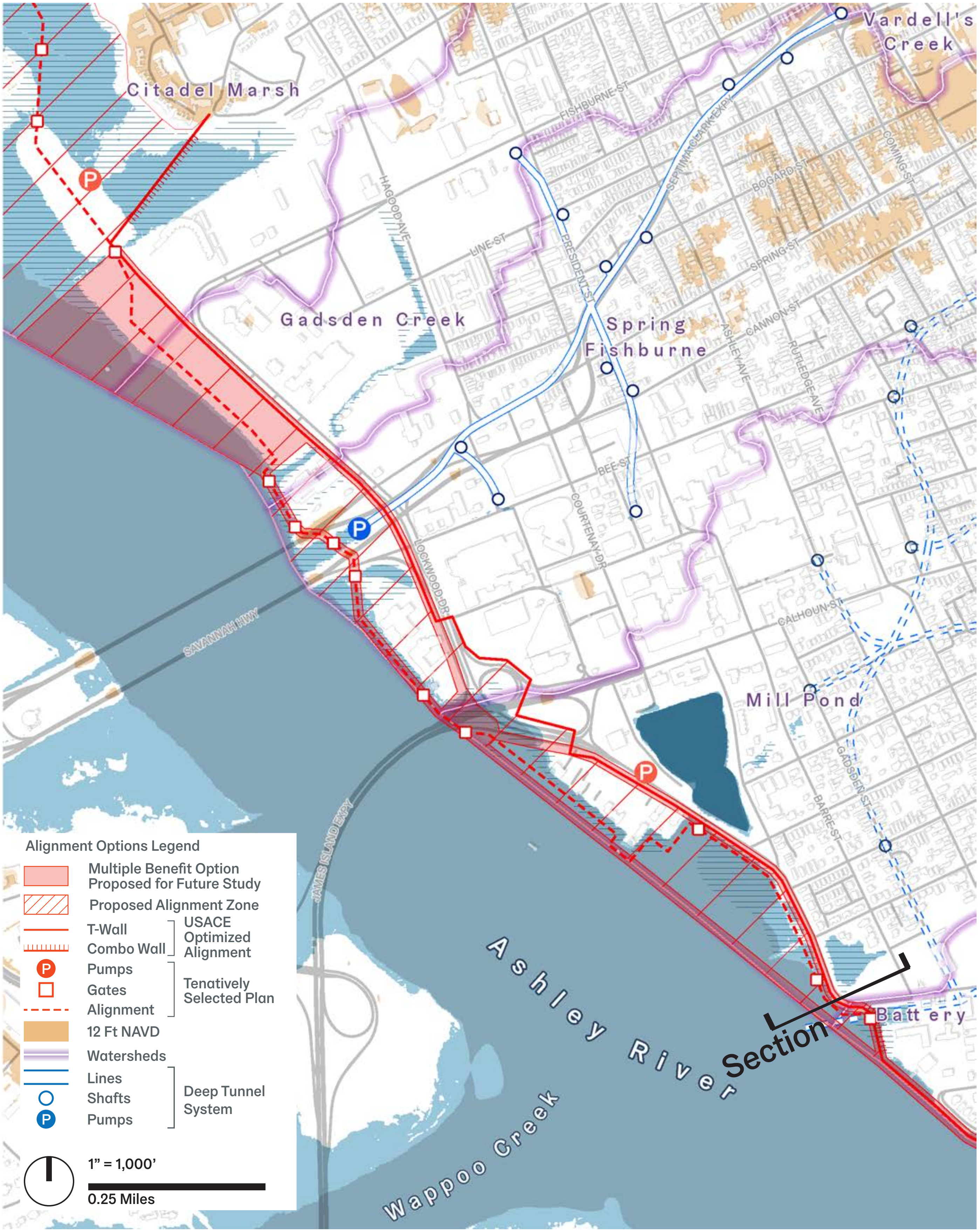


**Aerial view of Lockwood looking towards the Low Battery.**
*Credit: Waggonner & Ball*



**Box culvert drainage outlet underneath the James Island Expressway.**
*Credit: Waggonner & Ball*

**Waters edge at low tide at Brittlebank Park.**
*Credit: Waggonner & Ball*




**Lockwood Corridor alignment zone.**

*Credit: Waggonner & Ball*

# Lockwood Corridor Alignment Options

Current USACE Alignment (subject to revision in PED)
2 vehicle gates across Lockwood
Multiple vehicle and tidal gates along Lockwood
Limited space for overtopping & runoff water


Optional Typology: Raise Lockwood
Can be raised from Broad St to Long Lake and along Brittlebank Park
Possible storage and conveyance underneath road


Optional Alignment: Mudflat Combo Wall
Eliminate all vehicle gates
Increased space for overtopping & runoff storage

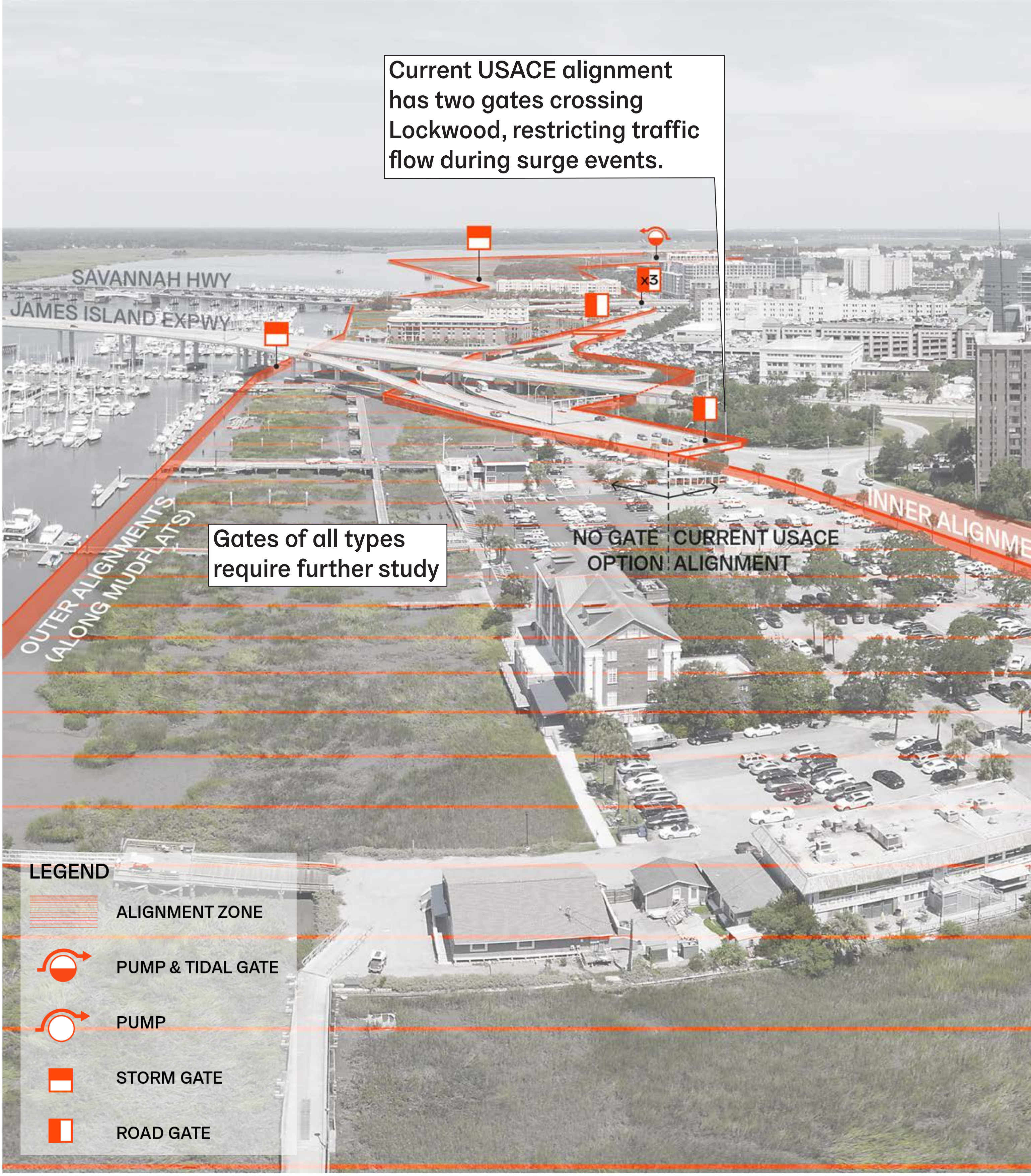
# Lockwood Corridor

## Looking Toward the Low Battery


INNER/OUTER SPLIT
Storm and tide gate location and design require further study to preserve marsh function.
OUTER ALIGNMENT (ALONG MUDFLATS)

# Lockwood Corridor

## Looking Toward the Medical District




LONG LAKE
NT (USACE)
RAISING LOCKWOOD OPTION

# Ports

## Overview

We strongly recommend that the storm surge alignment through Port property be located as close as possible to the Cooper River while still on land. This alignment protects most of the Port, except for the pier structures, inside of the perimeter protection system. USACE's optimized alignment locates the surge structure along Concord, Pritchard and East Bay and Washington streets, putting the Union Pier Terminal (UPT) property outside of the surge protection structure. This alignment would disrupt traffic to and from the port and require the installation of numerous gates and control structures, complicating the structure's design, engineering, construction, operation and maintenance. While future use and value of this property are currently under discussion, such an alignment would substantially constrain its future use and development potential. The City's potential benefits from an outer alignment are at least three fold: 1) a greater degree of overall safety through a simpler alignment with fewer moving parts; 2) greater tax revenue through a more valuable development parcel; and 3) the opportunity to use the outer alignment to extend Waterfront Park, increase public access to the water, and connect all the way to the Museum District. An outer alignment in this zone may also be cheaper to construct: the farther from city fabric, the less likely to run into buried infrastructure, utilities, and historic archaeology.

The same recommendation applies to the Columbus Street Terminal (CST). This facility is a roll-on/roll-of (ro-ro) export platform for high value vehicles, other cargo and breakbulk goods, and import platform for materials supporting local manufacturing, and a key economic driver for the Charleston region and the State. Stranding CST outside the line of protection is unwise and unnecessary. USACE's optimized alignment along Washington and East Bay streets would substantially and negatively impact East Side neighborhoods, the key Downtown to North Charleston transportation corridor, and negatively impact City plans for a pedestrian pathway/bikeway between the Columbus Terminal rail lines and East Bay Streets.  An alignment closer to the Cooper—through CST property—will eliminate negative impacts and simplify surge structure planning, engineering, construction and maintenance.

South Carolina Ports Authority (SCPA) is a vital perimeter and regional stakeholder. The Port has shown this team an openness to considering a realignment through its property and must be consulted further. The outer alignment in this area is a win-win-win for the Port, City and citizens.

The Museum District, between UPT and CST, requires special attention. The suggested outer alignment of the surge structure through UPT and CST creates an opportunity to explore moving the surge structure outward in this zone, too. The International African American Museum, the Aquarium, and the Fort Sumter Ferry are cultural assets and important tourist locations. They may also play a future educational and outreach role in public communication around perimeter protection. Surge and high-tide events will have considerable and growing impact on the buildings outside the surge structure's current alignment. While most buildings here have elevated first floors, access to the area, and to the City's protected area during surge events, will be severely compromised. The cost of clean-up of the area after tidal or surge events will burden the City.

The District's waterfront is dense and already highly constructed. Locating a structure at the land-water interface will be difficult but is worth exploring. A combo wall just offshore reduces alignment complexity but creates new problems. The intense use of this zone by private and commercial boat owners challenges the design and operation of the storm surge structure and piers in the area would likely need to be relocated or rebuilt. Additionally, SCPA's navigation channel for CST is very close to the combo-wall alignment in the Cooper River near-shore zone. The essential operation of the navigation channel, and the wave energy forces of deep-draft ship wake on the combo wall, further stresses the outer alignment. This entire area requires further study, using the outer alignment proposed for UPT and CST as a starting point.

# Key Questions

## Risk Mitigation (Level of Protection)

- How can stakeholders, including the State, be engaged early to benefit all parties? (The City is responsible for negotiating the purchase of all easements for the structure.)
- Can the USACE BCR be modified to account for the value of transient cargo and future real estate value of protected land? (approx. $500 million in vehicle exports at any given time)

## Internal Water Management

- How do stormwater drainage outfalls through Port property flow through, or over, the structure?
- How does the Market Street deep tunnel and pump station interact with the structure?

## Ecology

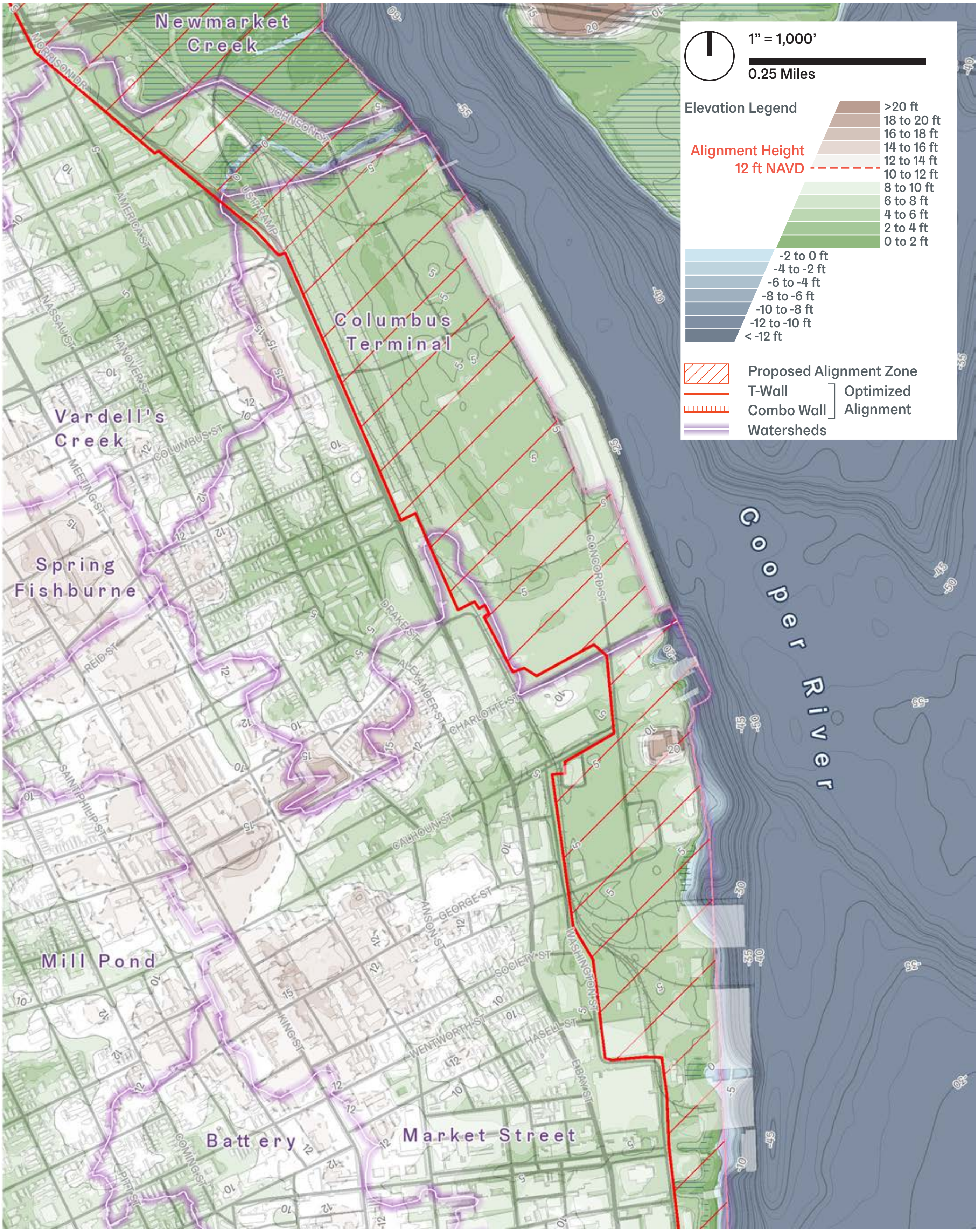
- Is there an opportunity to protect and/or grow marsh behind the line of protection?

## Operations & Maintenance

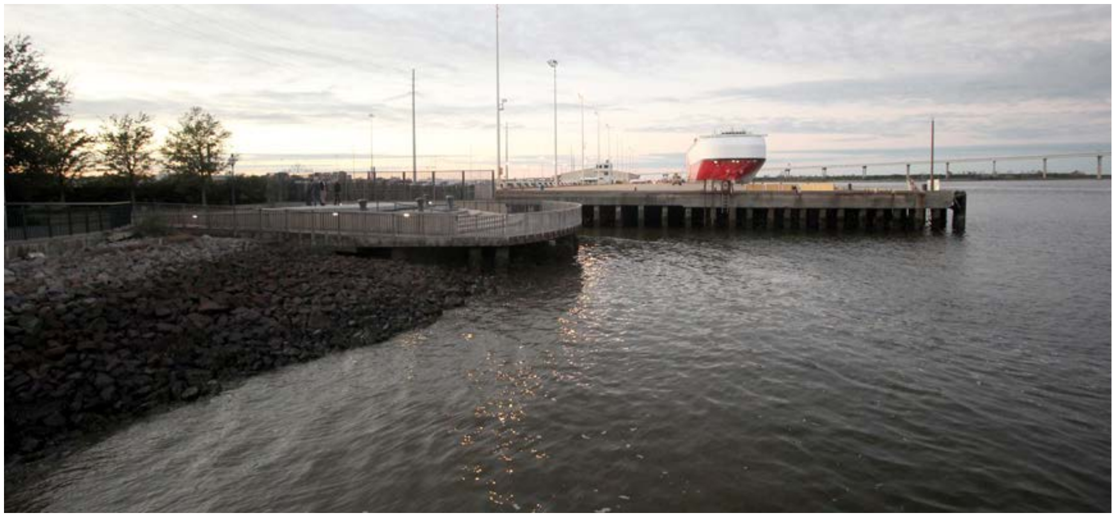
- Who will operate gates on private (including SCPA) property?

## Urban Design & Historic Character

- How can the perimeter structure be integrated into public park space, both within the existing Waterfront Park and as new public waterfront access through the UPT and Museum District?



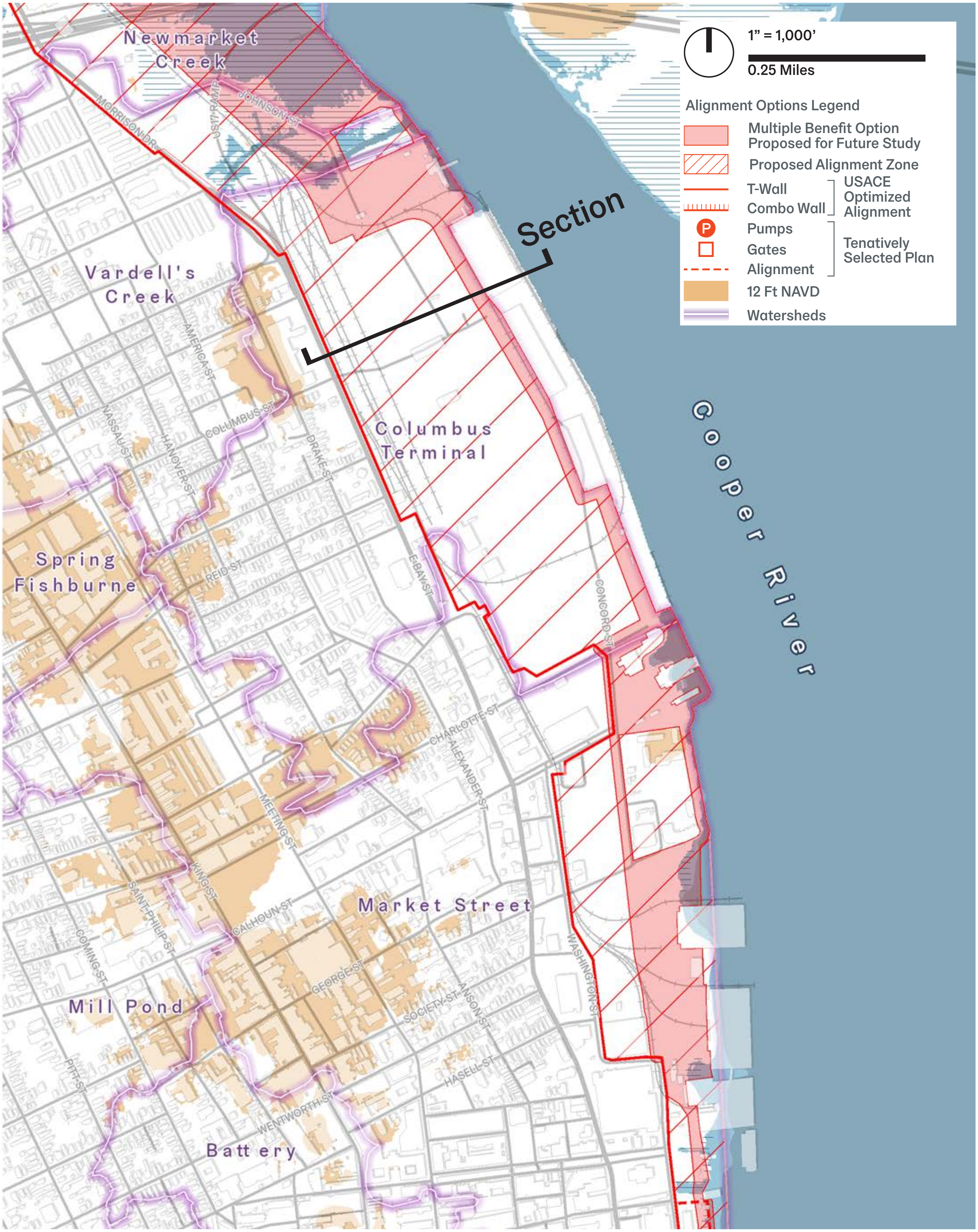

**Ports area USACE optimized alignment.**
*Credit: Waggonner & Ball*



**RORO ship docked at the Columbus Terminal.**
*Credit: Waggonner & Ball*


**Old rail connection at the Union Pier Terminal.**
*Credit: Waggonner & Ball*

**Subsidence at Columbus Terminal.**
*Credit: Waggonner & Ball*

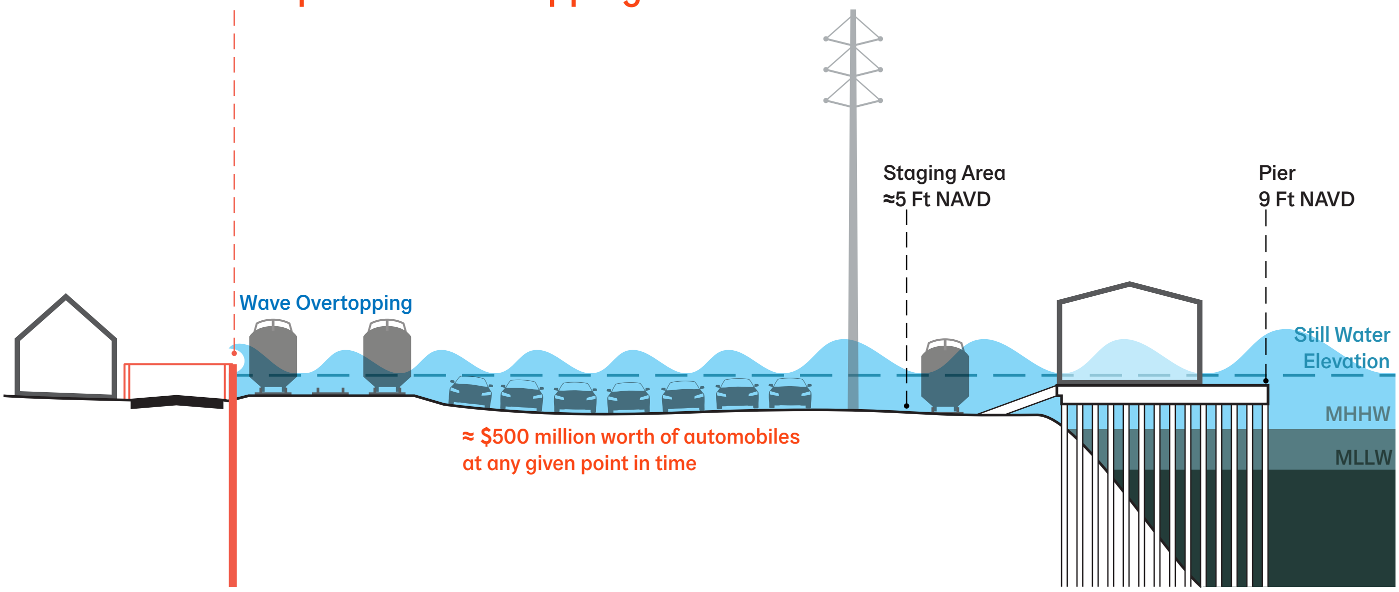



**Ports area alignment zone.**

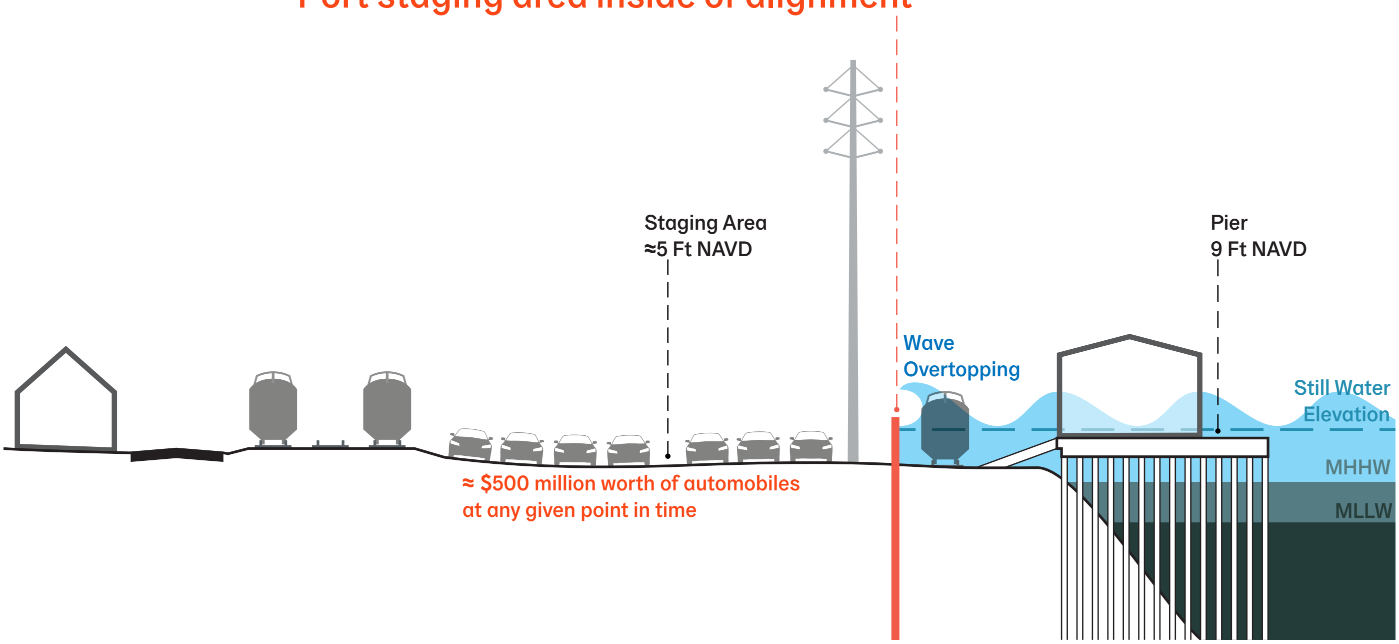
*Credit: Waggonner & Ball*

# Ports Alignment Options

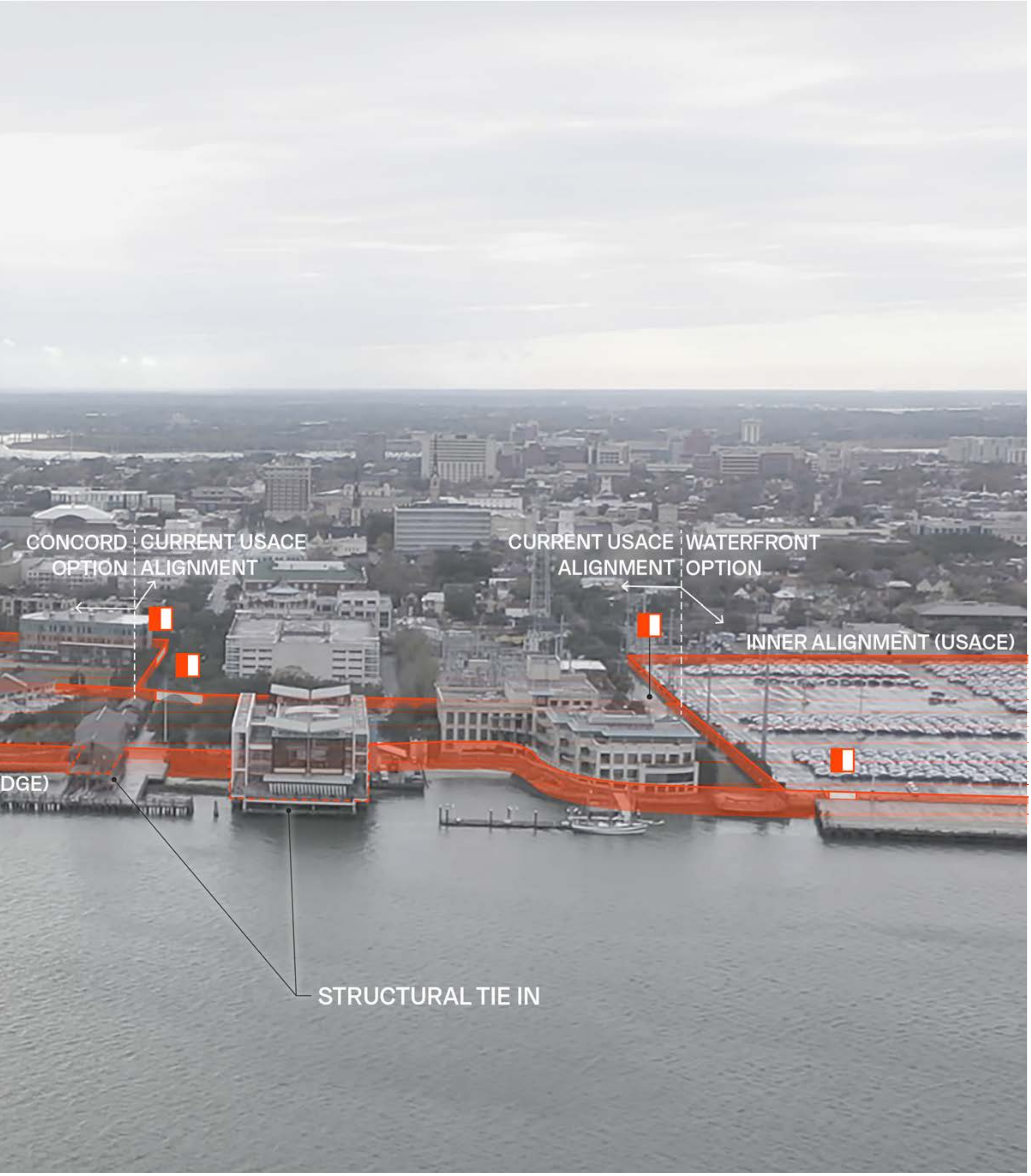
Current USACE Alignment (subject to revision in PED)
Multiple gates along Morrison
No space for overtopping & runoff water



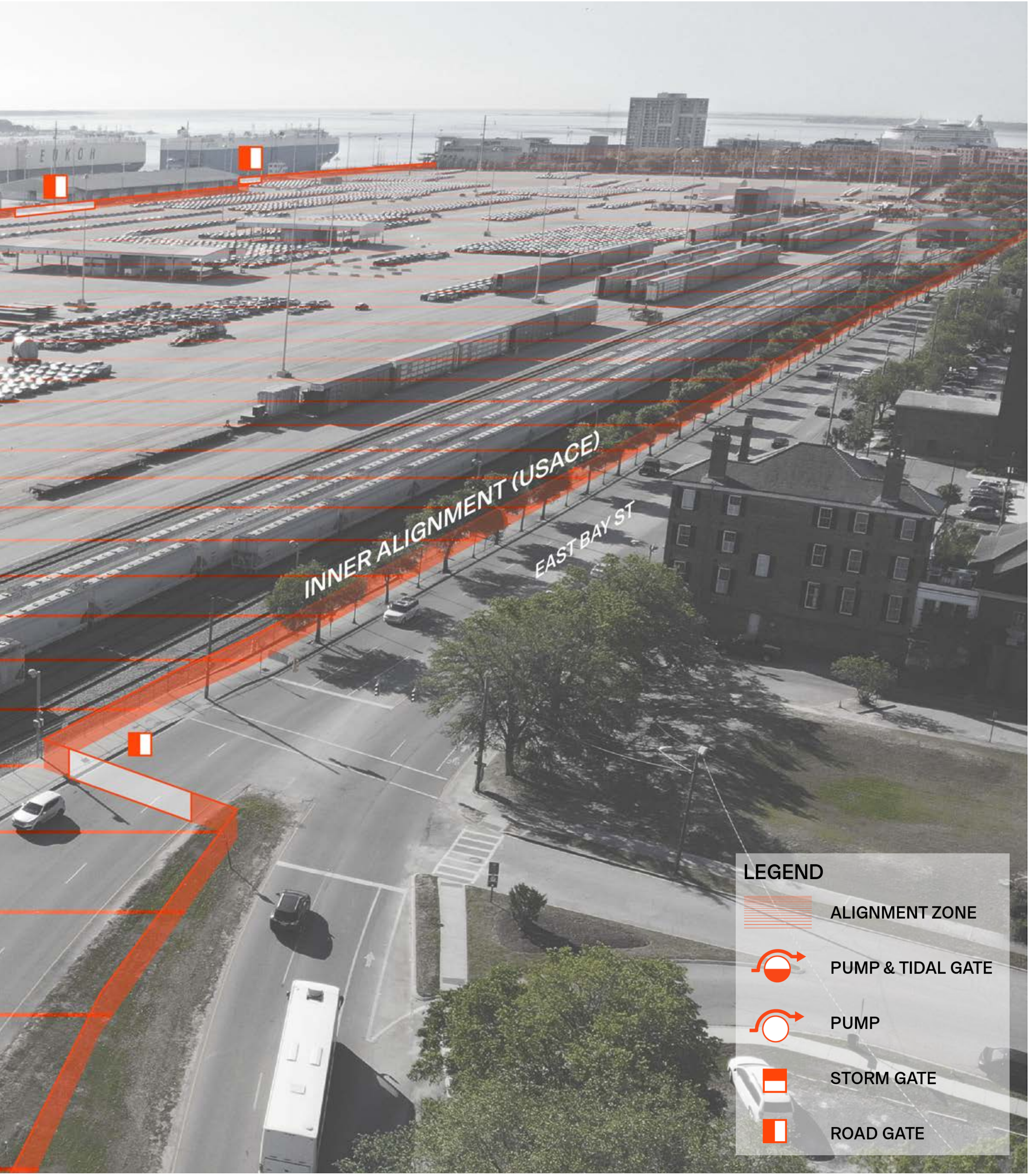

Optional Alignment
Multiple gates inside of port
Port staging area inside of alignment



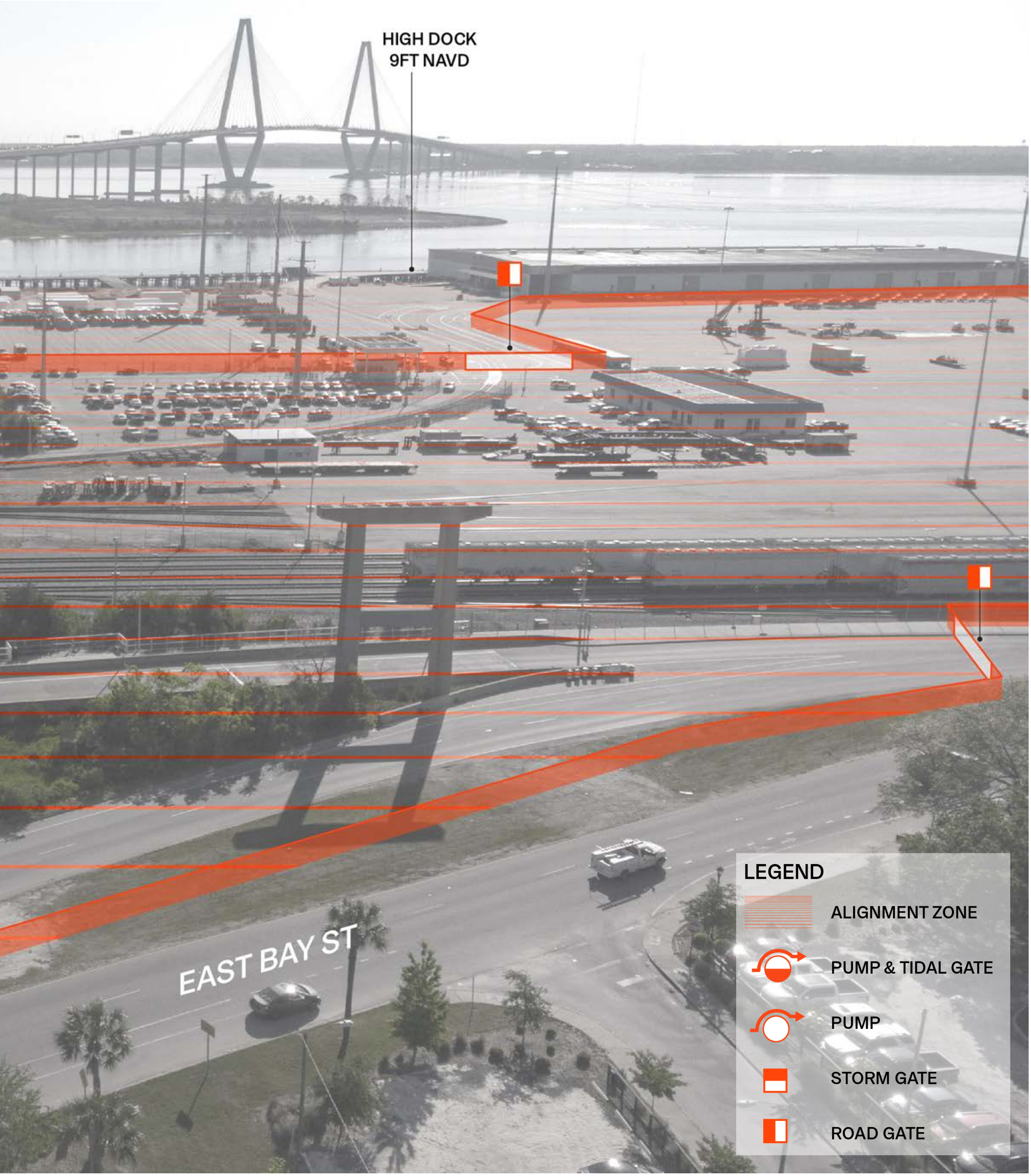
# Museum District


CONCORD OPTION
CURRENT USACE ALIGNMENT
CURRENT USACE ALIGNMENT
WATERFRONT OPTION
INNER ALIGNMENT (USACE)
DGE)
STRUCTURAL TIE IN

# Columbus Terminal


INNER ALIGNMENT (USACE)
EAST BAY ST
LEGEND
ALIGNMENT ZONE
PUMP & TIDAL GATE
PUMP
STORM GATE
ROAD GATE

# Columbus Terminal & East Bay Street


HIGH DOCK
9FT NAVD
EAST BAY ST
LEGEND
ALIGNMENT ZONE
PUMP & TIDAL GATE
PUMP
STORM GATE
ROAD GATE

# Eastside

## Overview

An outer alignment through the Columbus Street Terminal (CST) creates an opportunity to move the perimeter structure away from, and reducing the impact upon, Morrison Drive. One possible alignment would follow Johnson Street at the northern end of CST and then the Palmetto Rail Line under the Ravenel Bridge northward to Foundry Point. This would protect ongoing and future developments near Morrison Yards, in the area between the railway and Morrison Drive, and lower impacts on the east side of Morrison Drive. This alignment will substantially reduce transportation impacts during construction and operation and substantially reduce the number of gate structures needed in this area. While the precise routing of the USACE-proposed alignment along Morrison is not known at this stage, any alignment adjacent to Morrison creates unnecessary complications for traffic and property access.

An alternative outer alignment could link CST to Laurel Island along the Palmetto Railways line. This path requires an extensive geotechnical analysis of Laurel Island's artificial fill and coordination with proposed development on the island. Such an alignment would create the potential for more robust internal stormwater management in New Market Creek by using the creek bed and existing wetlands as stormwater storage space. This option requires additional marsh mitigation cost but could help alleviate rain flooding for an area with few other options for flood mitigation.

# Key Questions

## Risk Mitigation (Level of Protection)

- Can the barrier tie into Laurel Island and/or the rail corridor?
- How can future real estate value factor into BCR? ($250 million in development in Morrison Yards alone)
- If enough internal storage space is provided in the design stage, can future structural elevations in this area for sea level rise and overtopping be avoided? Space for water may save future costs.

## Internal Water Management

- How can Newmarket & Vardell's Creeks function as stormwater detention areas to benefit residents now and anticipate future water storage needs inside the raised perimeter?
- How can a stormwater master plan for the Eastside be developed to protect from rainfall flooding?
- Where is a future pump station located to take best advantage of internal detention basins?
- How does a perimeter structure impact existing drainage outfalls? Can these outfalls be joined by a ring canal segment or detention basin to make storage and pumping (when necessary) more efficient?
- How can future pumps be located and operated to avoid land subsidence in this sensitive area with weak organic soils? (There is evidence of severe and active subsidence at CST.)

## Ecology

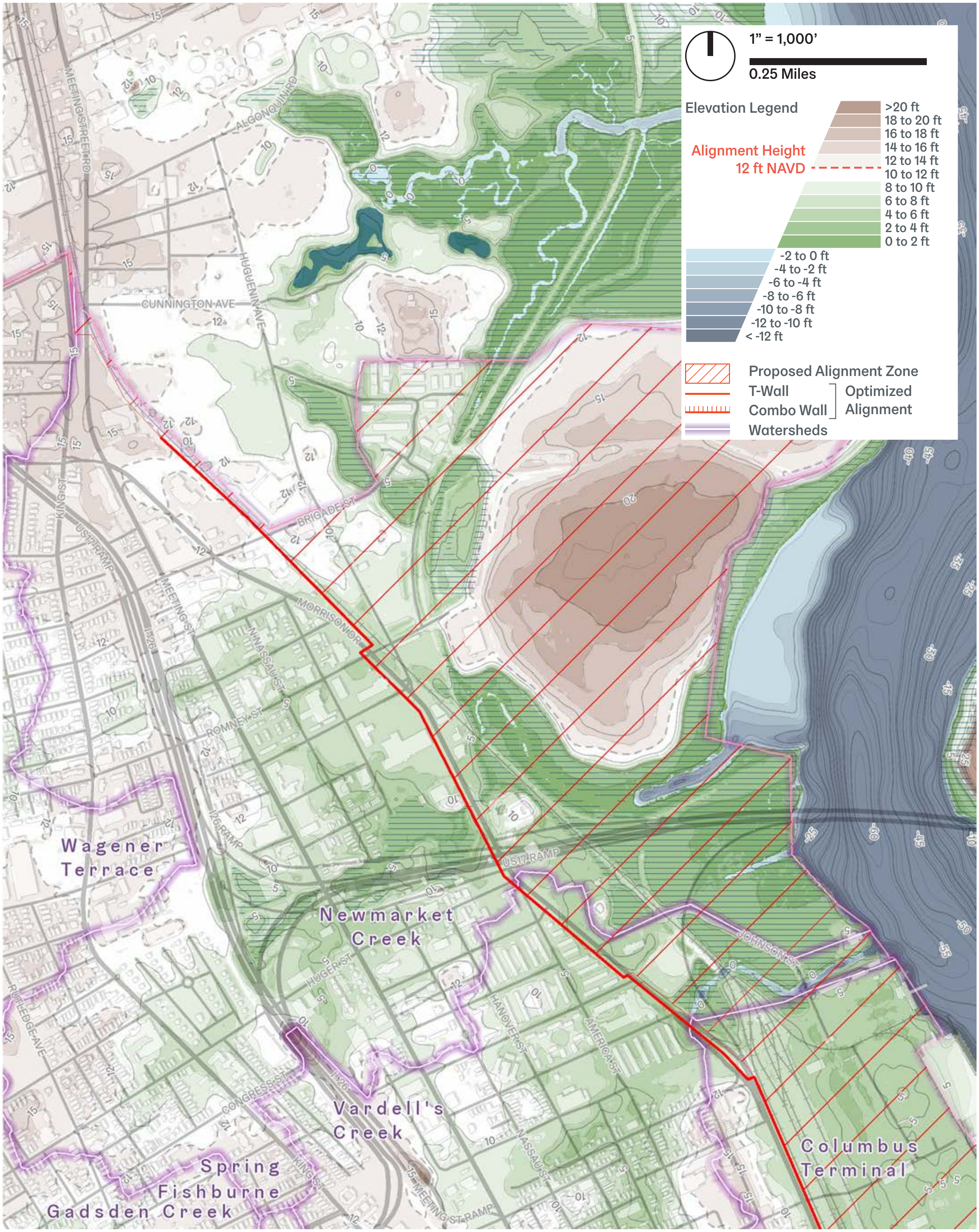
- How can marsh behind the barrier be preserved, sustained and enhanced?
- How can existing marsh become stormwater storage space over time as sea levels rise and conditions change?
- How can tide gates be designed to preserve flow for marsh health while protecting against high tide flooding?
- Are there soil contamination issues in this area?
- How were Ravenel Bridge ramps constructed to avoid marsh impacts? Can these strategies be used for perimeter protection?
- Are there opportunities to create new marsh mitigation credits in this area?

## Operations & Maintenance

- What type of gates are needed to preserve marsh function? How and how often are they operated?
- Can vehicular and rail gates be eliminated from the project?

## Urban Design & Historic Character

- How can access to the Cooper River and new internal water space be expanded for Eastside residents?
- How can all impacts to Morrison Drive properties be avoided?



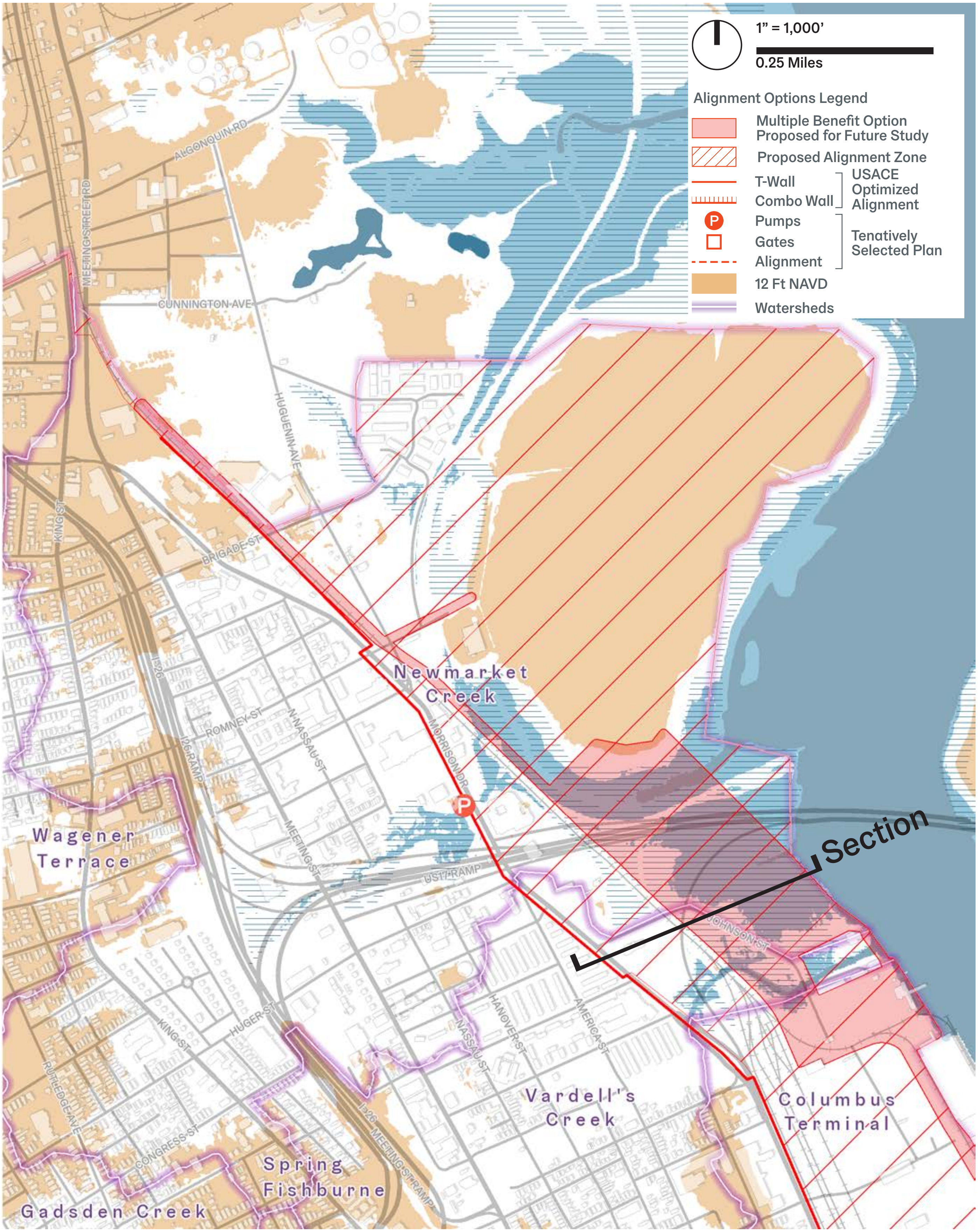

**Eastside USACE Optimized Alignment**

*Credit: Waggonner & Ball*

**Charleston Tech center on Morrison Drive. The current alignment would run along the far side of Morrison drive in front of the building.**
*Credit: Waggonner & Ball*

**Railway underneath the Ravenel Bridge.**
*Credit: Waggonner & Ball*

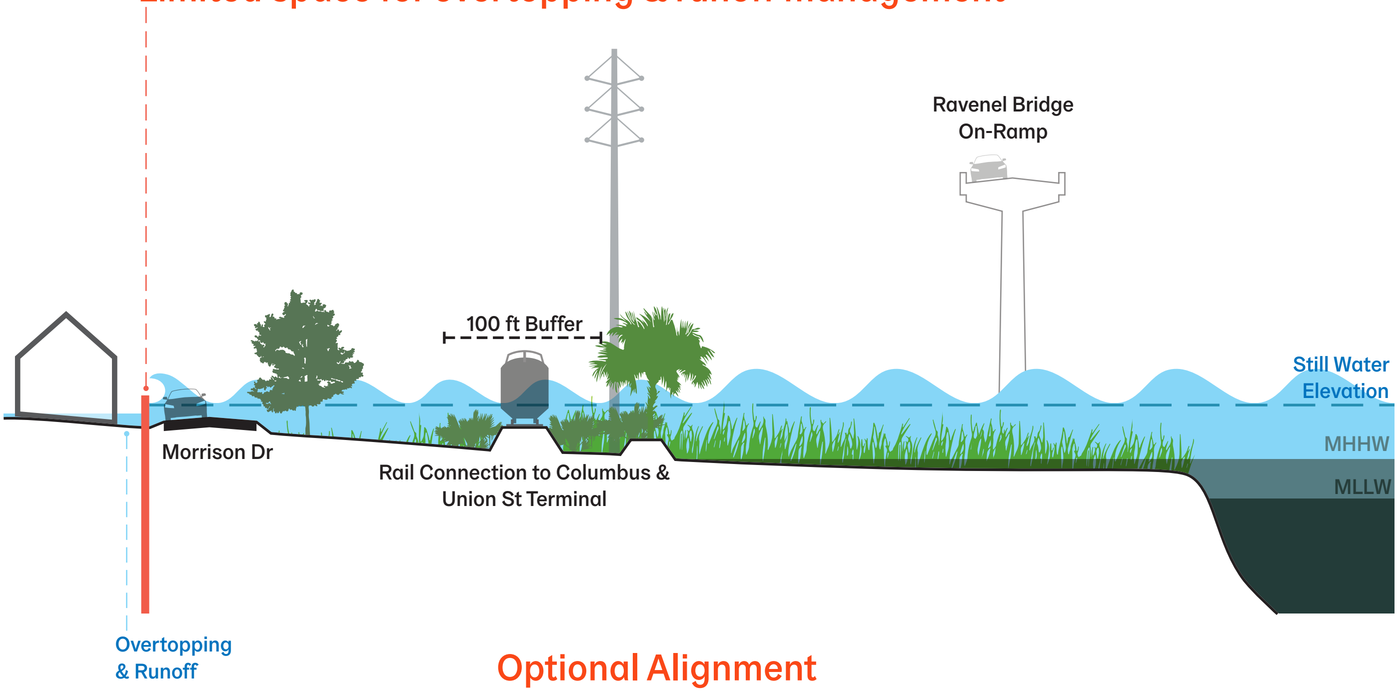
**Raised development site near Laurel Island and Bridgeview Village.**
*Credit: Waggonner & Ball*



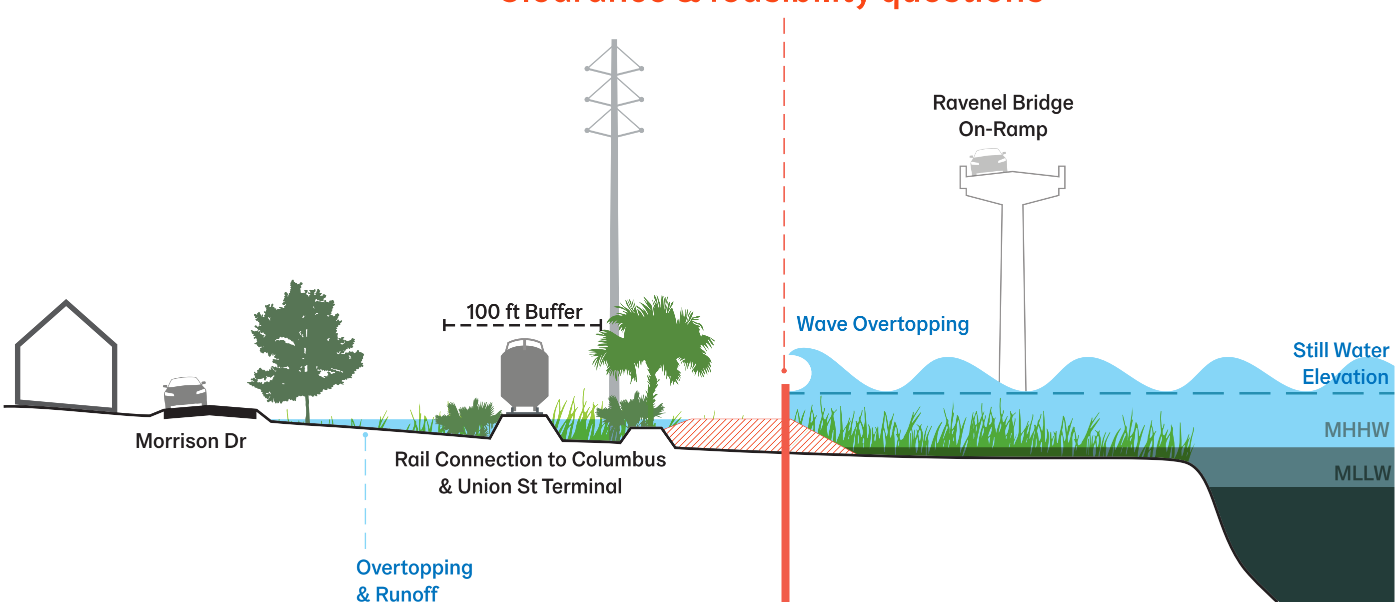

**Eastside alignment zone.**
*Credit: Waggonner & Ball*

# Eastside Alignment Options

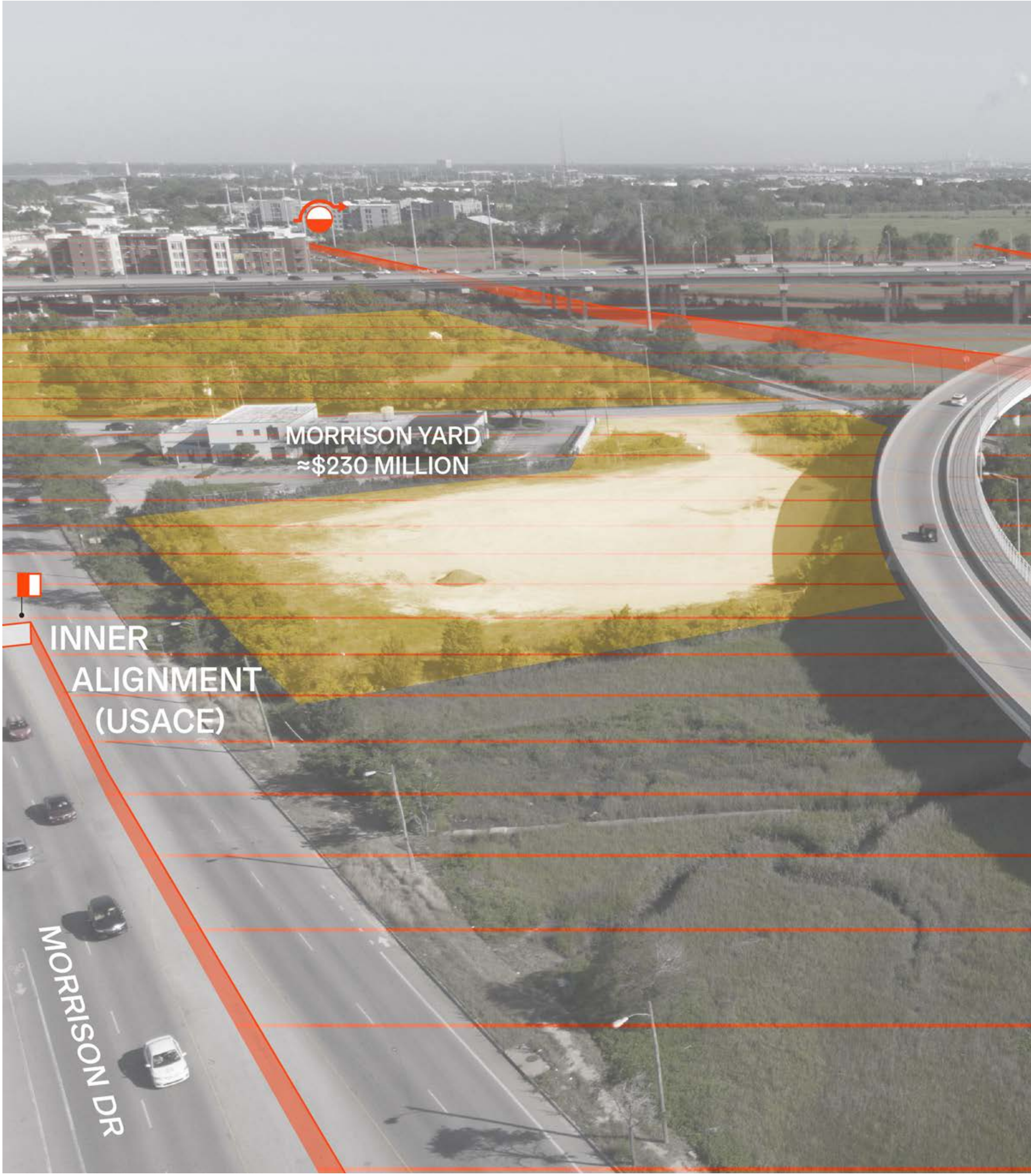
**Current USACE Alignment (subject to revision in PED)**
**Multiple vehicle gates along Morrison**
**Limited space for overtopping & runoff management**

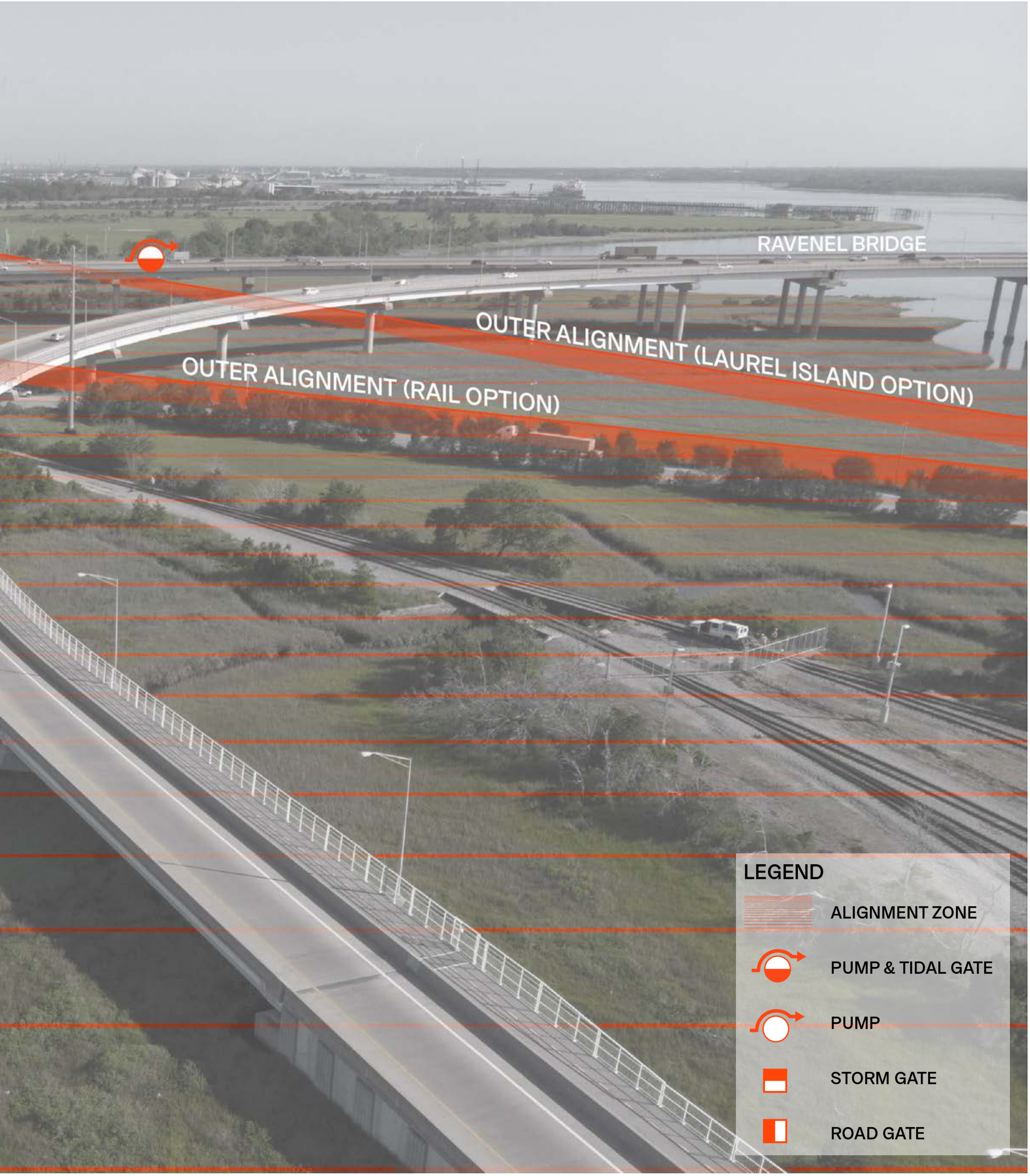



**Optional Alignment**
**Reduce or eliminate all vehicle and rail gates**
**Space for internal overtopping & runoff management**
**Rail connection inside of line of protection**
**Clearance & feasibility questions**



# Ravenel Bridge Overpass & Laurel Island




RAVENEL BRIDGE
OUTER ALIGNMENT (LAUREL ISLAND OPTION)
OUTER ALIGNMENT (RAIL OPTION)
LEGEND
ALIGNMENT ZONE
PUMP & TIDAL GATE
PUMP
STORM GATE
ROAD GATE

# Low & High Battery

## Overview

### Low Battery

The reconstruction and elevation of the Low Battery currently underway will improve storm surge protection. The USACE and the City should analyze, before and during PED, how best to increase the Low Battery's height to 12 ft NAVD88. For cost and construction feasibility, the most likely alignment in this area follows the path of the current Low Battery. Can the foundations designed and built as part of the reconstruction anticipate the future barrier? The reconstructed Low Battery should not have to be torn apart again unless absolutely necessary. The Low Battery reconstruction proves that new construction of a raised perimeter—if designed with care—can successfully integrate into historic city fabric and provide value as an accessible public space.

Multiple lines of defense should be explored. Even if the Low and High Battery are rebuilt in place at higher elevations, the shallow waters off White Point Garden may provide opportunities to implement nature-based strategies such as breakwaters, oyster banks, and living shoreline to knock down wave heights before they hit the structure.

### High Battery

The High Battery serves as the best regional example of multifunctional coastal infrastructure. Completed in the mid-nineteenth century, its strong material palette, harbor vistas, and unique pedestrian experience have become iconic parts of Charleston's identity. The next generation of storm surge protection should aspire to its success.

To meet 12 ft NAVD88, the High Battery structural elevation will need to be raised to approximately the level of the existing railing. USACE standards do not rise to the level of design and aesthetic quality of the existing High Battery, and a new type—or significant re-working of standard designs—will be required.

The surge structure should be placed closer to or along the water's edge at the Carolina Yacht Club. Access to Club piers and boat ramp will have to be addressed. North of the Yacht Club to Union Pier an alignment that follows the east side of Concord street past Adger's Wharf to the southern tip of Riley Waterfront Park should be explored. The structure should then follow the water's edge to avoid impacts to the live oak allee. This outer alignment substantially minimizes Concord Street disturbances and eliminates pedestrian or transportation gates and their impacts along Riley Waterfront Park and the Cooper Hotel. The seawall fronting the Park may have to be reconstructed to support this alignment, but this alignment is preferable to the optimized plan which would bisect the Park. This water's edge alignment enables a simpler structure, parts of which could be purposed for an extension of a pedestrian path from Fleet Landing through the Park to the Yacht Club.

# Key Questions

## Risk Mitigation (Level of Protection)

- Should a new perimeter structure replace the Batteries or be located offshore?
- Can nature-based layers of defense lower the elevation of the storm surge structure by knocking down wave heights?

## Internal Water Management

- What happens to existing drainage outfalls? Can a buried "ring canal" create redundancy & storage by connecting to perimeter pumps where more space exists to build them?

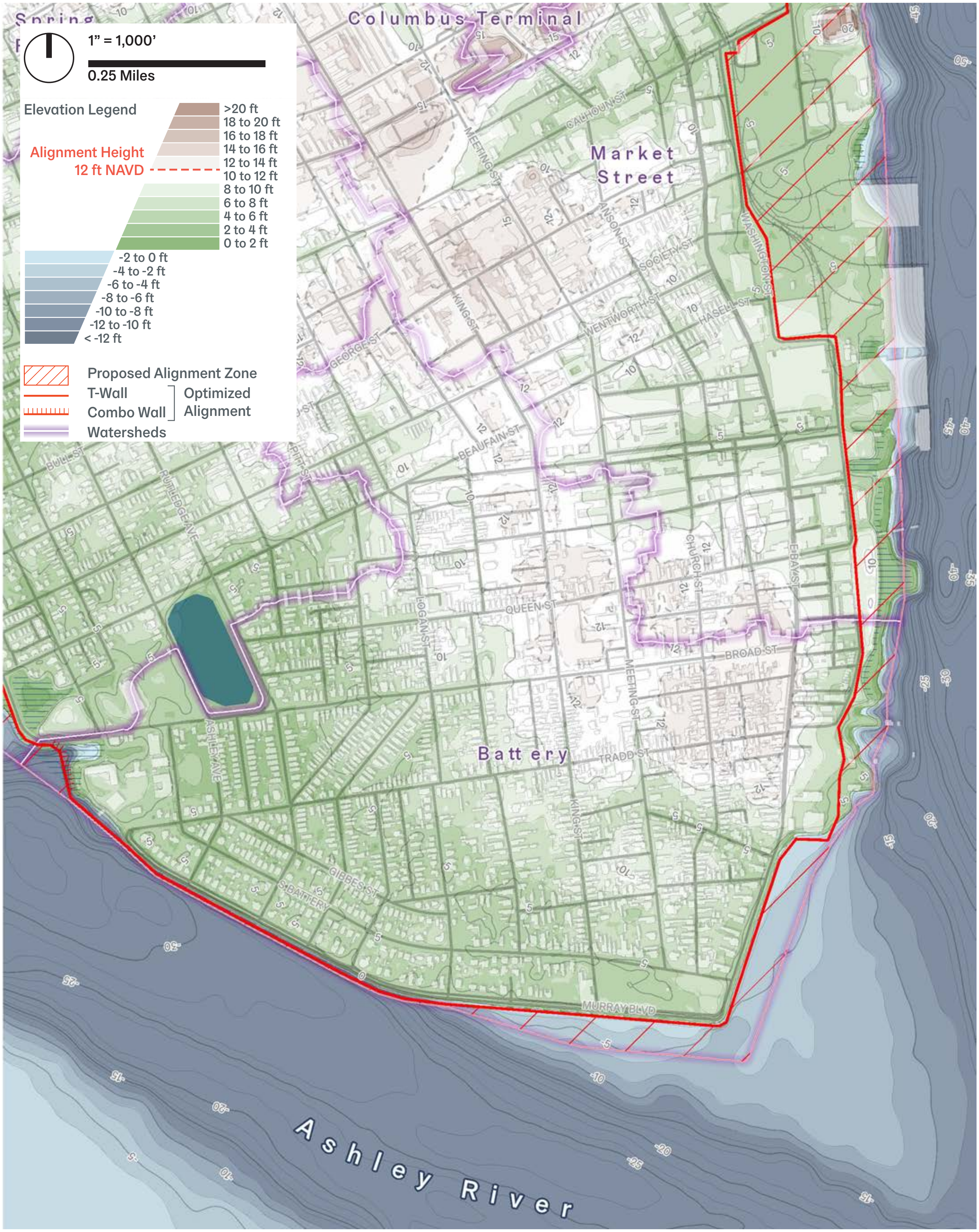
## Ecology

- Can a new ecological zone be created between two lines of protection or behind a breakwater?
- Can new marsh be counted for mitigation credits?

## Urban Design & Historic Character

- Should the historic High Battery be preserved as-is, with new protection offshore?
- What is the visual impact and recreational potential of alternative offshore alignments?

**Reconstructed Low Battery.**
*Credit: Robert Behre/Post & Courier Staff*



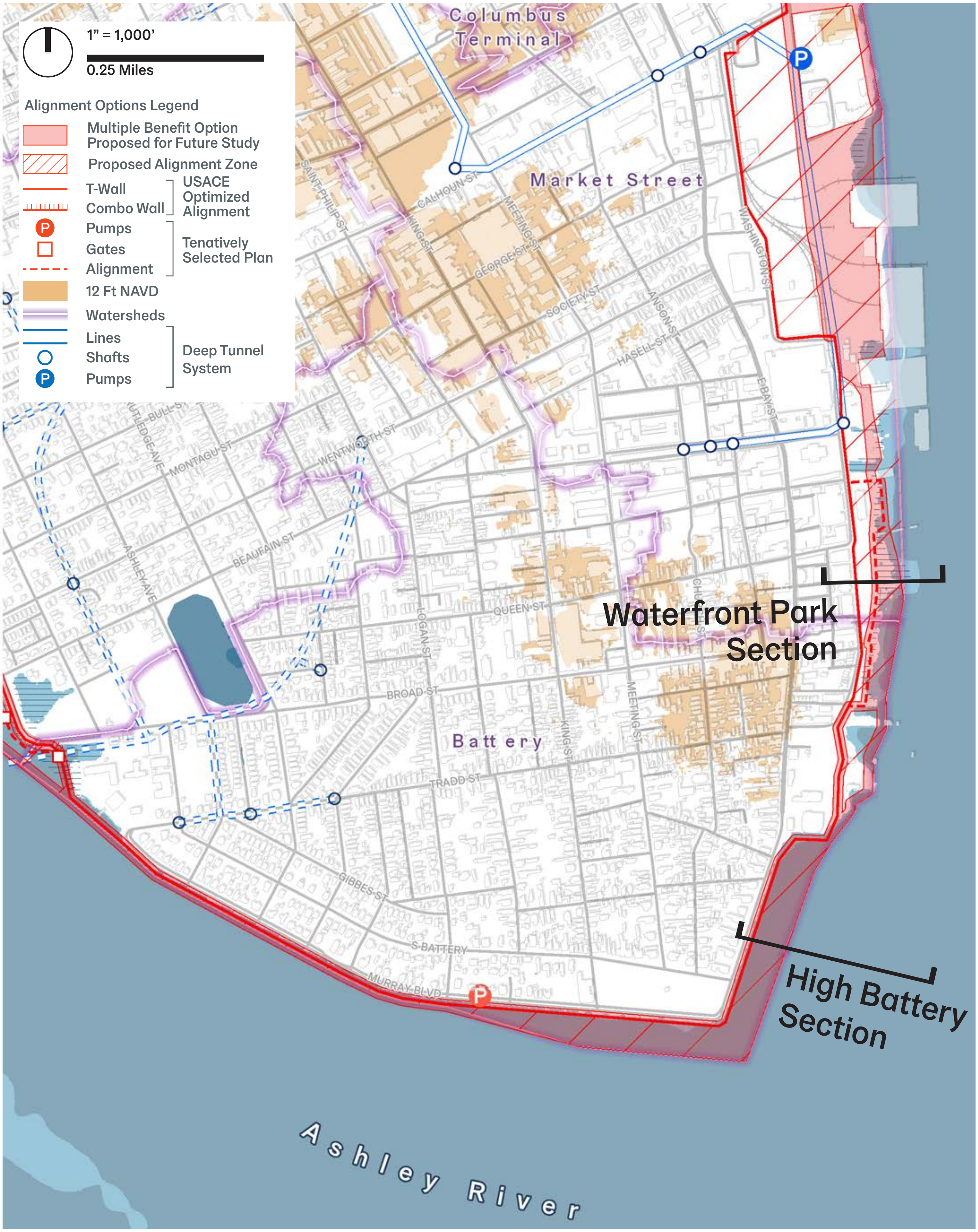

**Low & High Battery USACE optimized alignment.**

*Credit: Waggonner & Ball*

**Old water access point along the Low Battery.**
*Credit: Waggonner & Ball*

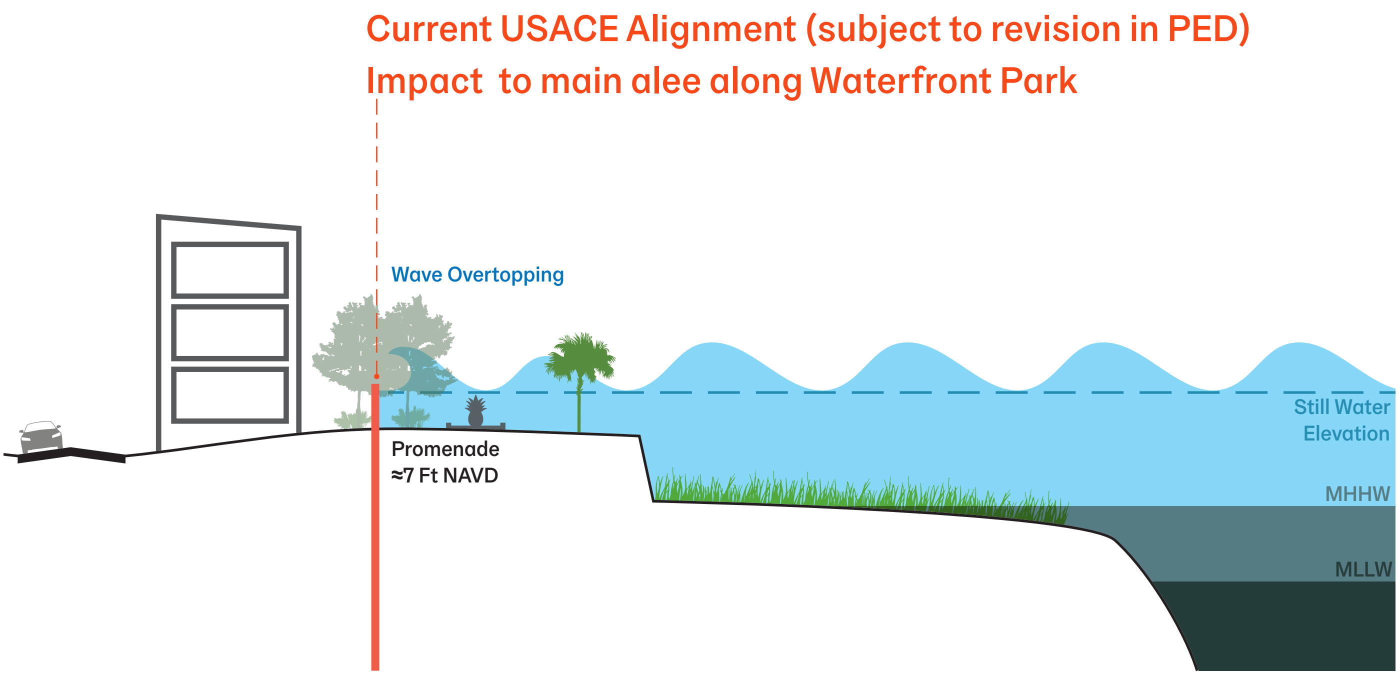
**High Battery.**
*Credit: Waggonner & Ball*

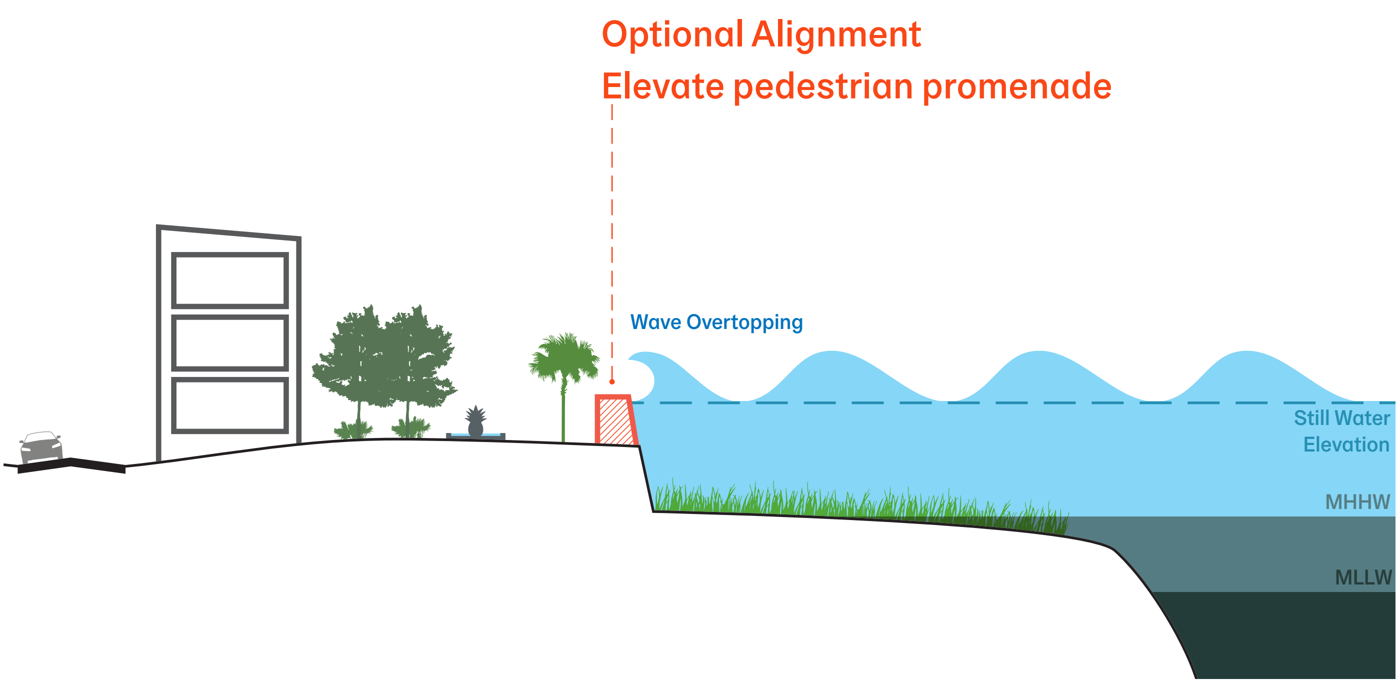
**Public promenade at Waterfront Park**
*Credit: Waggonner & Ball*




**Low & High Battery alignment zone.**
*Credit: Waggonner & Ball*

# Waterfront Park Alignment Options



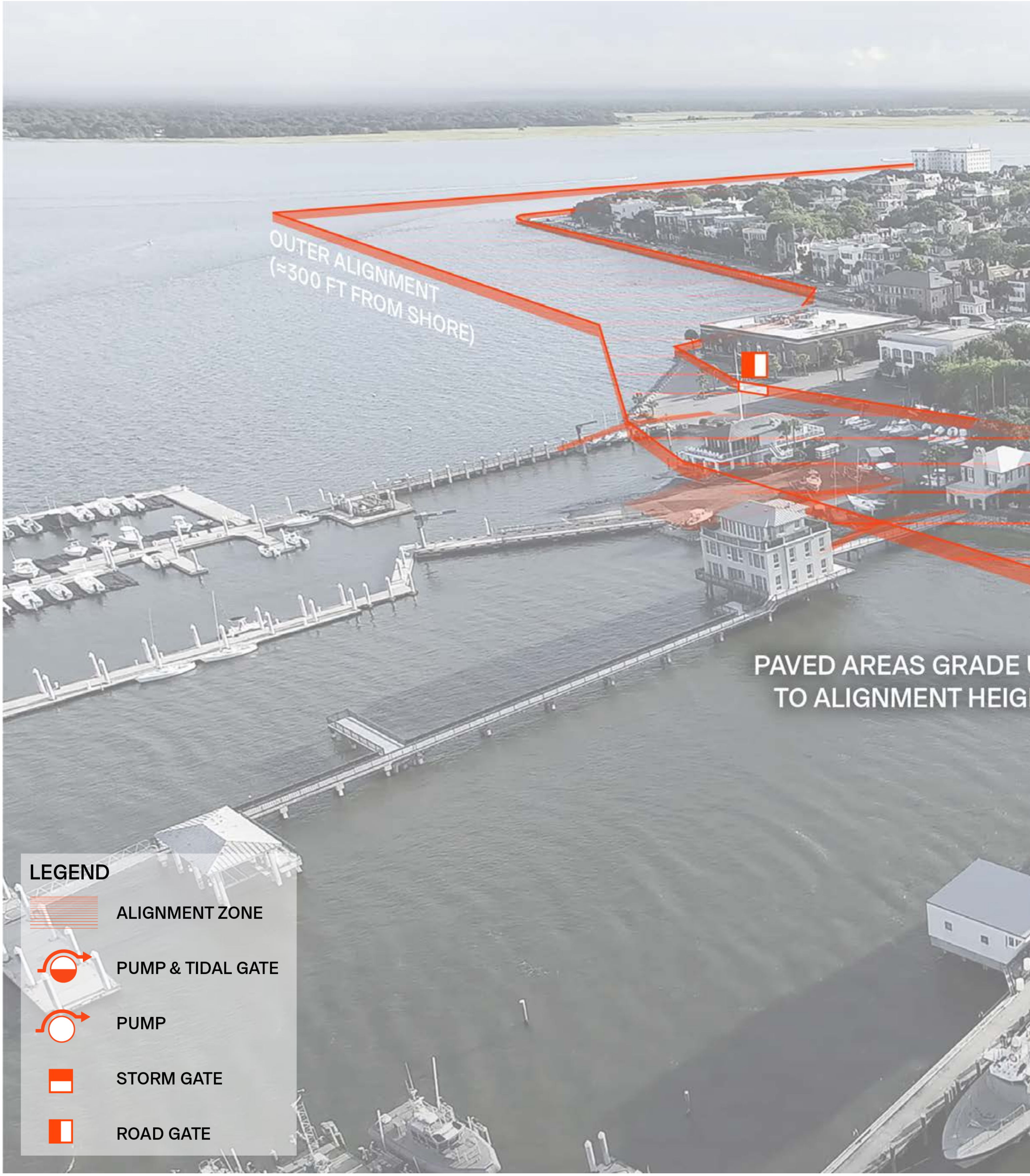



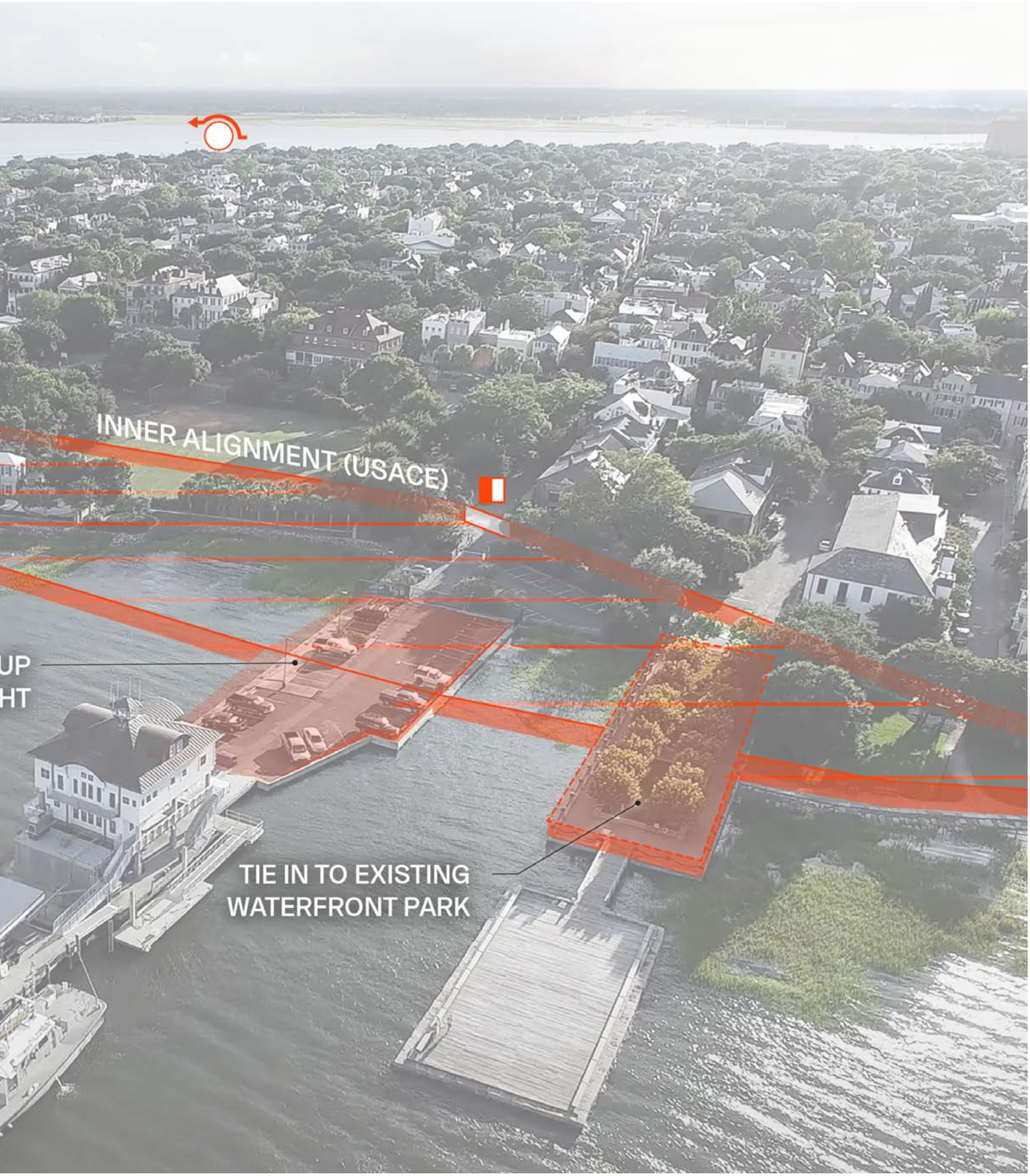
# Riley Waterfront Park

## Looking North Toward Union Pier Terminal


UNION PIER
TERMINAL
WATERFRONT
PARK
Reconstruct public promenade at higher elevation.

# Yacht Club & Waterfront Park



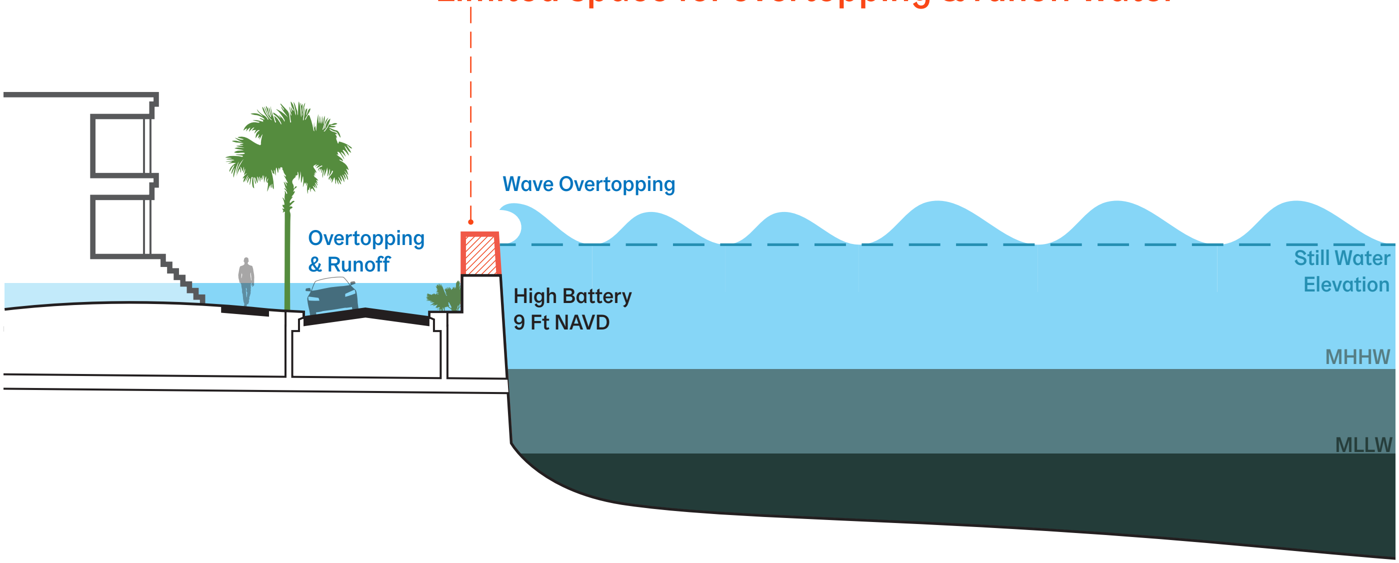

INNER ALIGNMENT (USACE)
UP
HT
TIE IN TO EXISTING
WATERFRONT PARK

# Low & High Battery Alignment Options

Current USACE Alignment (subject to revision in PED)

Reconstructed High Battery

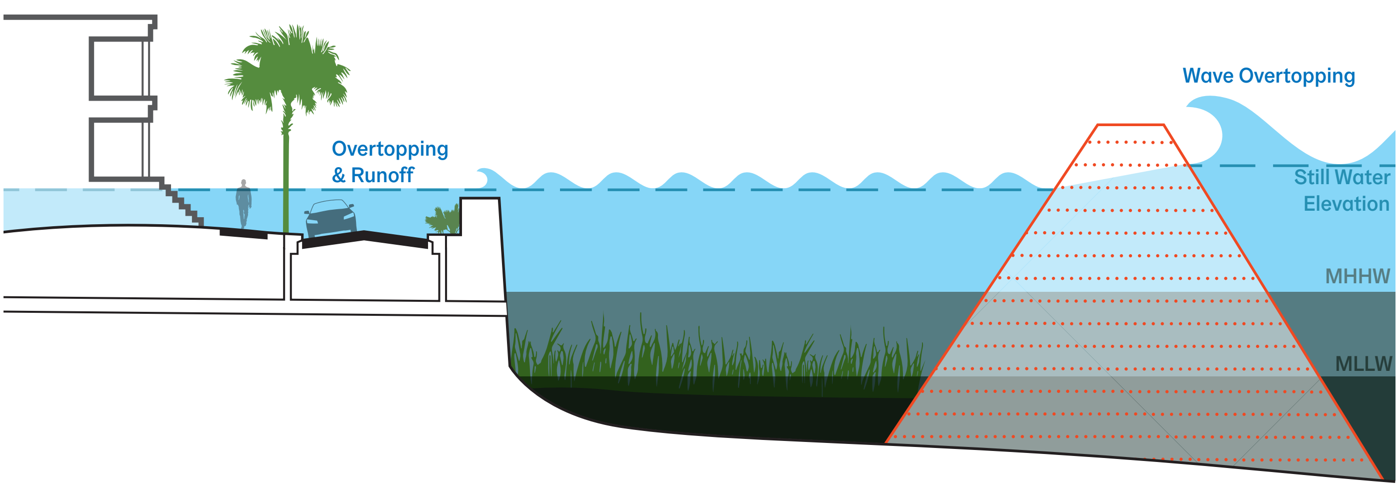
Limited space for overtopping & runoff water




Optional Wave Attenuation Alignment

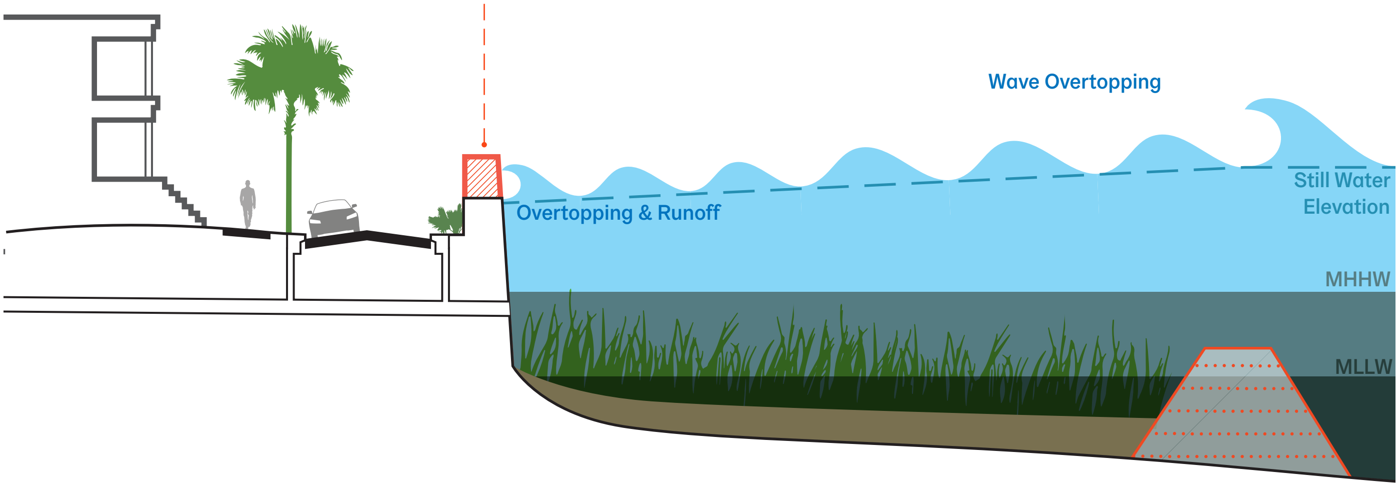
Wave attenuation (elevation TBD; USACE proposed 16 ft NAVD) and marsh construction

Limited storm surge reduction



Reconstructed High Battery

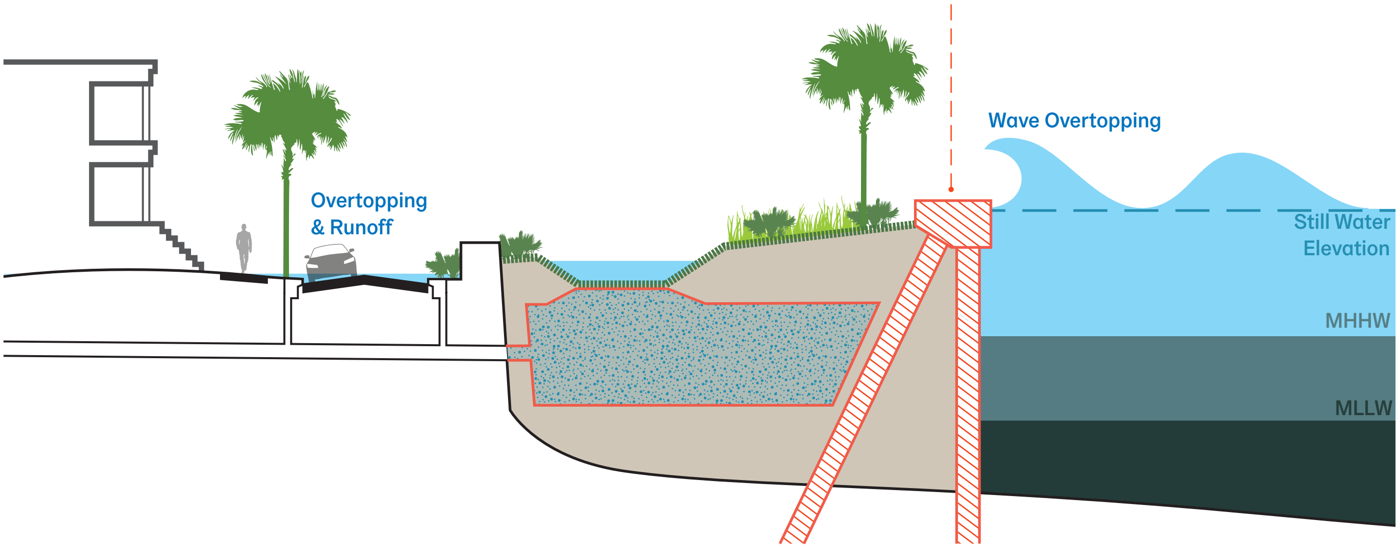
Breakwaters and marsh construction reduce wave height and overtopping



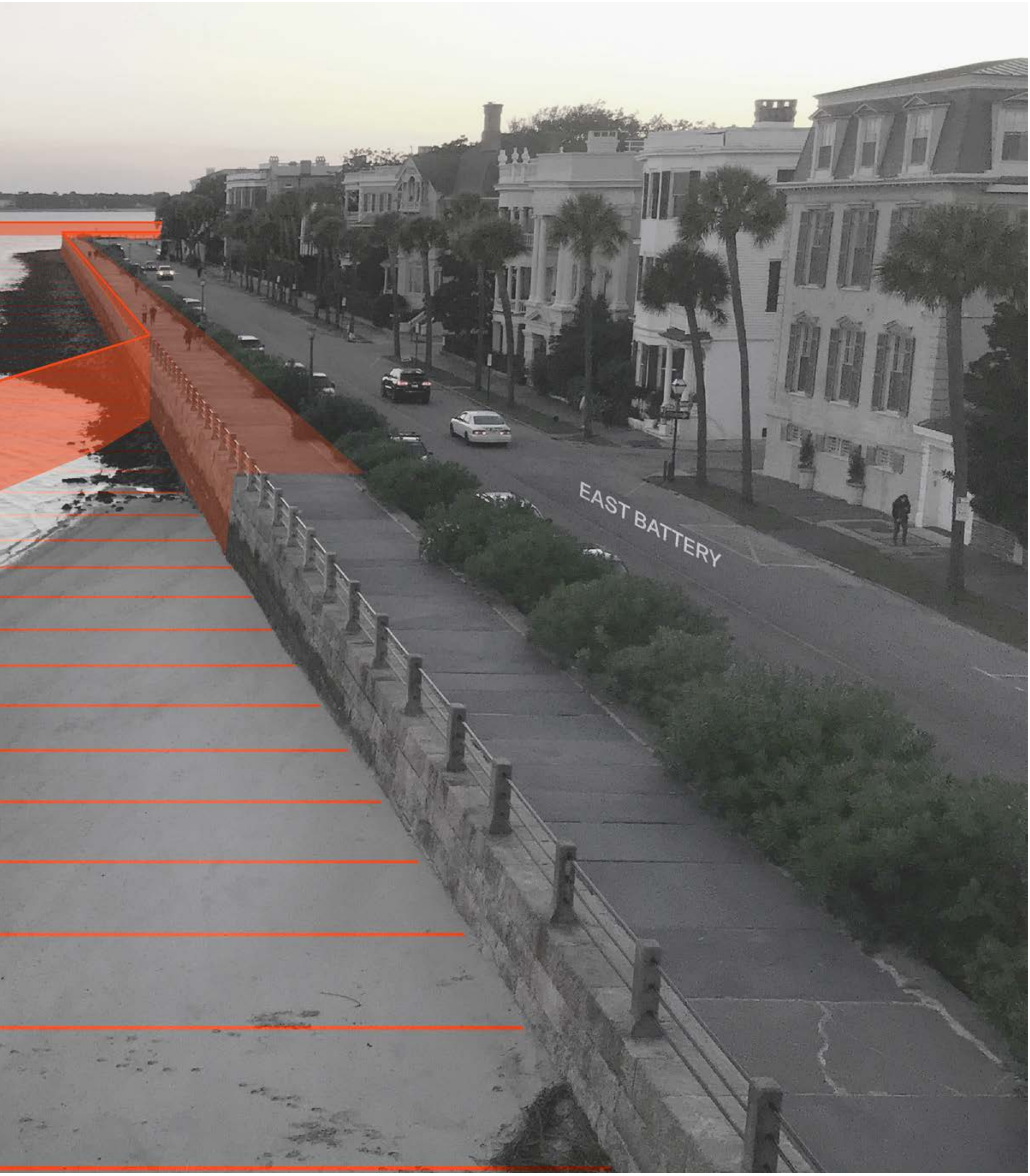

Optional Green Space Typology

Alignment runs parallel to battery

Space in between converted into park space with stormwater detention



# High Battery

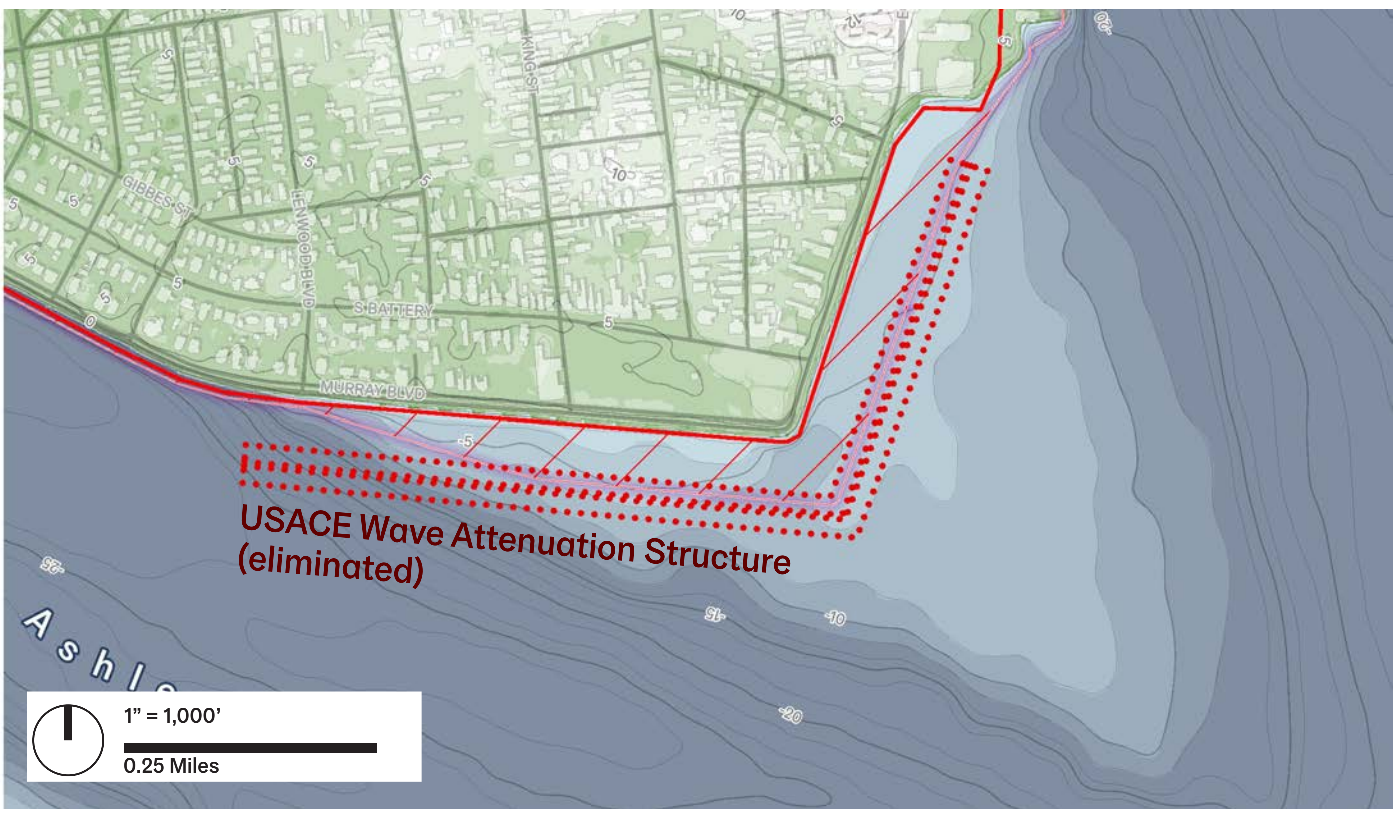

EAST BATTERY

# Wave Attenuation

The April 2020 Tentatively Selected Plan suggested a “wave attenuation structure” just offshore of the Low and High Battery. The optimized alignment eliminated this structure from consideration. We suggest an analysis—as a separate project or as a specific, targeted Locally Preferred Plan (LPP)—to determine whether a robust living shoreline in the same general area would either reduce substantial amounts of wave energy and/or reduce wave heights, either of which would provide additional protection to this vulnerable and historic part of Charleston. Substantial overtopping can and will occur under future conditions. If a living shoreline structure could substantially reduce wave heights and wave energy, the overtopping and related stormwater management tasks inside the surge structure (storage and drainage when necessary) may be more manageable. Further study is recommended.

- There is enough potential in shallow area south of Peninsula – in terms of width and depth – to further investigate the hydrodynamic effectiveness of a nature-based wave-reducing type of solution.
- Per Arcadis precedent research, a well-designed living shoreline may reduce wave heights 2-3 ft at the battery. This could reduce the risk and volume of overtopping water.
- The V-shape underwater shelf between shallow and deep water is a good indicator for the location, and a v-shaped structure along this line also helps to divide flows into the Ashley River and South Channel (these may encounter some rise in water levels).
- In addition to the Battery, there is potential for wetland restoration or development of nature-based features along the shoreline near the projected Wagener Terrace alignment.
- Hydrodynamic and ecomorphological (sedimentation and erosion) modelling are needed, in addition to more investigation into types of material, environmental and ecosystems impacts, etc.


**Living breakwater archipelago from the *Imagine the Wall* report**
*Credit: one architecture*




**Original USACE wave attenuation structure**
*Credit: Waggonner & Ball*

# Citadel Marsh

## Overview

The USACE's optimized alignment eliminates a storm surge protection structure between most of the Citadel campus and the Ashley River, thereby avoiding significant marsh impacts in this area. Coming from the Joe, the perimeter structure would terminate into the bluff at Register Road. It would begin again north of the Citadel Boathouse. Much of the Citadel campus lies on high ground at or above 12' NAVD88, but existing buildings and future building sites along Hammond Avenue would require alternative storm surge mitigation strategies.

Space is already at a premium on campus. If a structure is constructed following USACE's optimized alignment there is concern about stormwater impoundment in the low area (old creek bed) that begins near the Hammond and Wilson Avenue intersection and extends to Dunneman and 10th avenues. If an alignment follows a more outward orientation, localized flood mitigation for this area will be needed as sea level rise will increase tidal impacts here. If no surge structure is built for Wagener Terrace, the northern tie-in for the inward alignment will require careful thought as there is little high ground (12ft NAVD 88 or above) in the southwestern portion of Wagener Terrace (see severability discussion, page 125). Citadel stakeholders have expressed concern about the optimized alignment's path and elevation along Grier and between Hammond and Jones avenues. Special attention in PED phase must be given to low-lying buildings and properties west of Hammond Avenue and along Register Road.

The alignment from the Citadel to the spit of land north of Joe Riley Stadium provides an opportunity to explore stormwater storage potential within the march for the areas draining along Hagood, Fishburne and Line streets.

Regardless of the alignment, the Citadel has expressed interest in thin-fill marsh restoration for this stretch of Ashley River marsh using sediment regularly dredged from the boat channel. (This material is currently stored in dredge ponds out in the marsh.) This restorative strategy can jump-start marsh migration and marsh impact mitigation opportunities specially if an outward surge alignment is pursued.

# Key Questions

## Risk Mitigation (Level of Protection)

- Is a barrier needed in front of the Citadel, on land or at the marsh edge? What are the cost and campus development trade offs?

## Internal Water Management

- Can marsh be used for storage? (especially at the former landfill, now marsh, between the Citadel and Riley Park)
- How can perimeter planning address existing tidal and stormwater flooding on the Citadel campus?

## Ecology

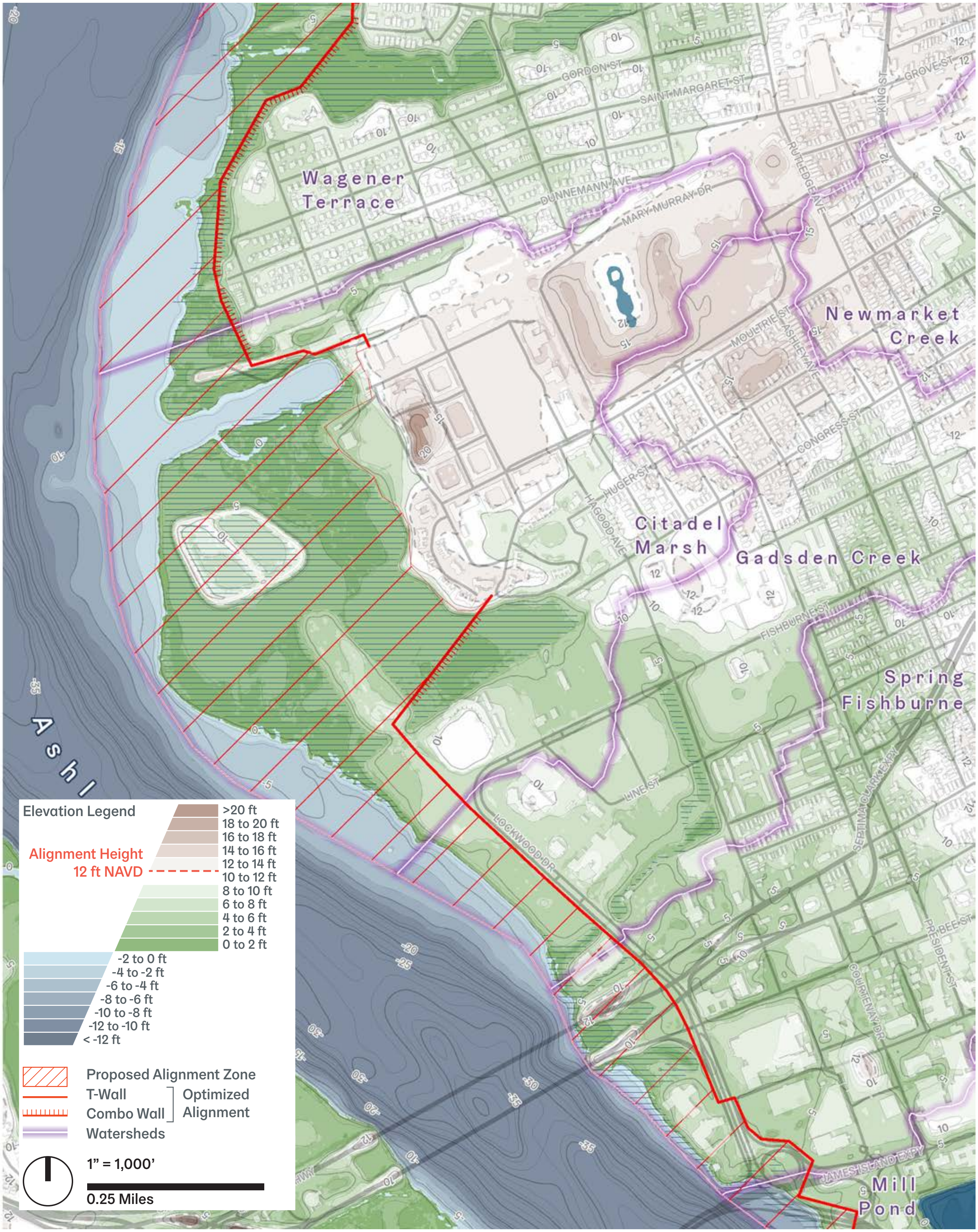
- How at-risk are Citadel marshes from sea level rise?
- Can strategies like thin layer dredge disposal be piloted here as part of a larger program, building on studies already underway within Ashley River marshes? (See Robinson Design Engineers, Ecology Design Criteria)

## Operations & Maintenance

- Where are pump stations located behind the Joe, how do they tie into the drainage system, and what is their impact on marsh?

## Urban Design & Historic Character

- What does the barrier look like from shore?
- How can the perimeter supplement recreational opportunities around the Joe and Brittlebank Park?
- Is there an opportunity to develop pedestrian connections from Hampton Park to the Ashley Waterfront?




**Citadel Marsh USACE optimized alignment.**
*Credit: Waggonner & Ball*

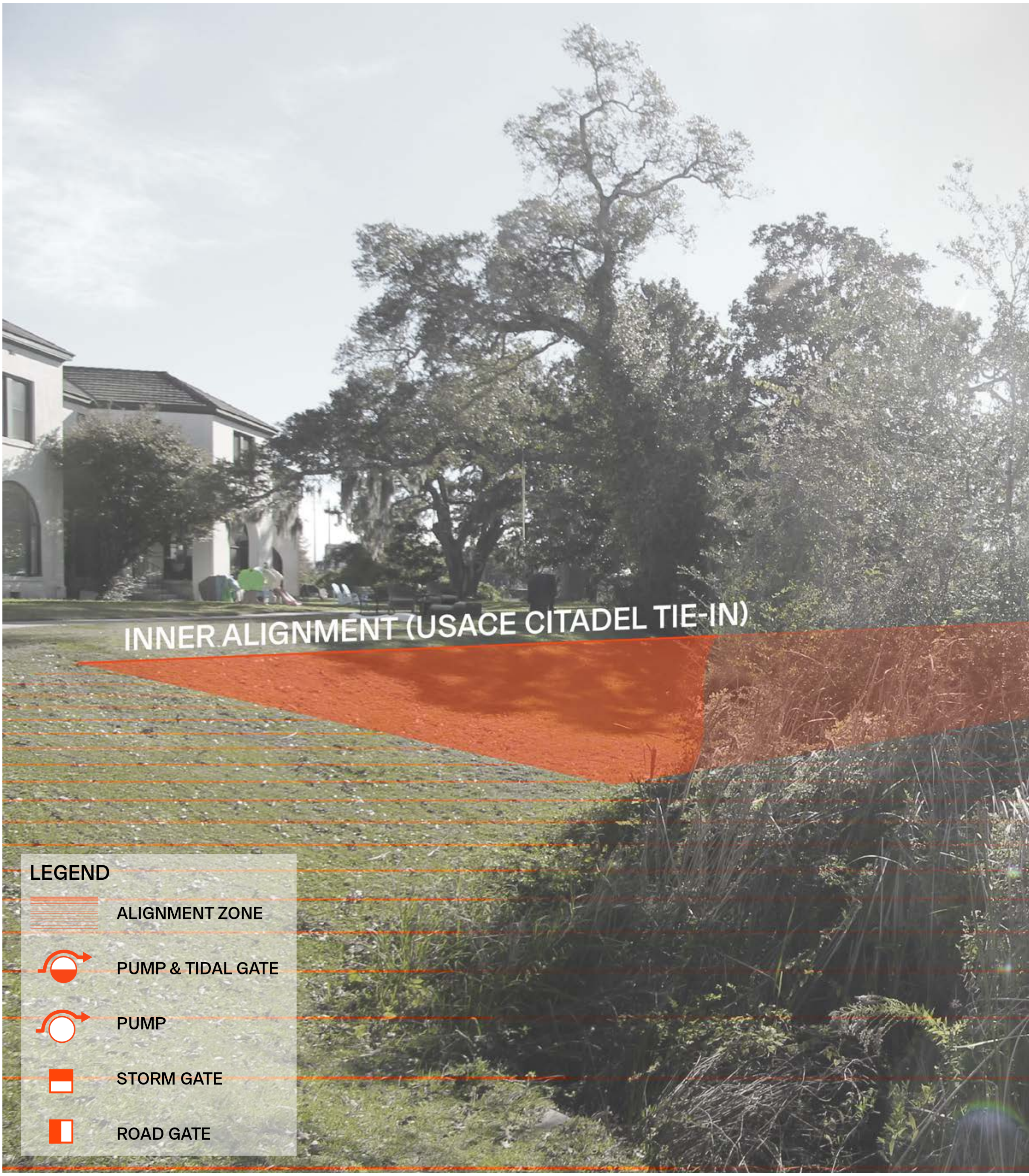
**High ground along the Citadel's edge where the current alignment would tie into.**
*Credit: Waggonner & Ball*

**Parking lot near the marshy edge of the Citadel.**
*Credit: Waggonner & Ball*


**Water access channel to the Citadel. The current alignment would tie into high ground near this location.**
*Credit: Waggonner & Ball*

# Citadel Tie-In

## Looking South




OUTER ALIGNMENT
(ALONG MUDFLAT)

# Wagener Terrace

## Overview

Wagener Terrace has the benefit of time and topography. A surge structure for Wagener Terrace is likely to be the final Peninsula component to be built. Wagener Terrace is also severable from the Peninsula study and from the Peninsula surge protection system (see page 125). Storm surge risks here are acute to homeowners and small neighborhood businesses, but not to city-wide economic activity or critical infrastructure. The active, knowledgeable neighborhood association can serve as an important sounding board for the City for what eventual surge protection is desirable.

Stormwater and tidal flooding are likely to increase in Wagener Terrace. A preliminary analysis by our team and anecdotally supported by USACE analysis indicates that surge overtopping here will be substantial due to the large "fetch," or wide expanse of open marsh and river where wind and waves can grow. At the same time, the need for water management and adaptation space (water storage) today and within any future raised perimeter is evident based on flooding that already occurs in the neighborhood.

The USACE optimized alignment moved the surge structure inward from the Ashley River marshes to near shore and close-in to Halsey Creek. This alignment will impact Wagener Terrace viewsheds and water access as well as create limited opportunity for stormwater and tidal management between the structure and the shoreline.

Given the above, we believe an outward shift of the surge structure alignment warrants study. The alignment zone indicated in the following section extends out as far as the -5 ft NAVD88 contour: in other words, the outermost location where it is feasible to construct storm surge protection. This alignment zone captures a wide area for consideration of nature-based alternatives. We acknowledge the marsh impacts of this outward alignment and the associated mitigation costs. Geotechnical analysis is needed to delimit the proper alignment of this outward push for risk reduction, constructability and marsh impact mitigation purposes. Structure openings to ensure robust tidal exchange and connection to the Ashley, plus march restoration and marsh migration optimization through thin-soil additions, will be needed.

# Key Questions

## Risk Management (Level of Protection)

- Is a structural barrier needed for Wagener Terrace?
- What are the trade-offs for an alignment—nature-based or structural—close to shore and farther out in the marsh?
- What are the alternatives to a combo wall?
- If there is enough internal space to store overtopped water, can the overall height of the structure be lowered to lessen visual impacts?

## Internal Water Management

- Can marsh within a line of protection be used for storage? (especially at Halsey Creek)
- How is existing tidal inundation solved in this area?
- Are pump stations needed for future conditions, and if so, where do they go? How do they connect to a redundant network of detention basins? Can they be avoided altogether?

## Ecology

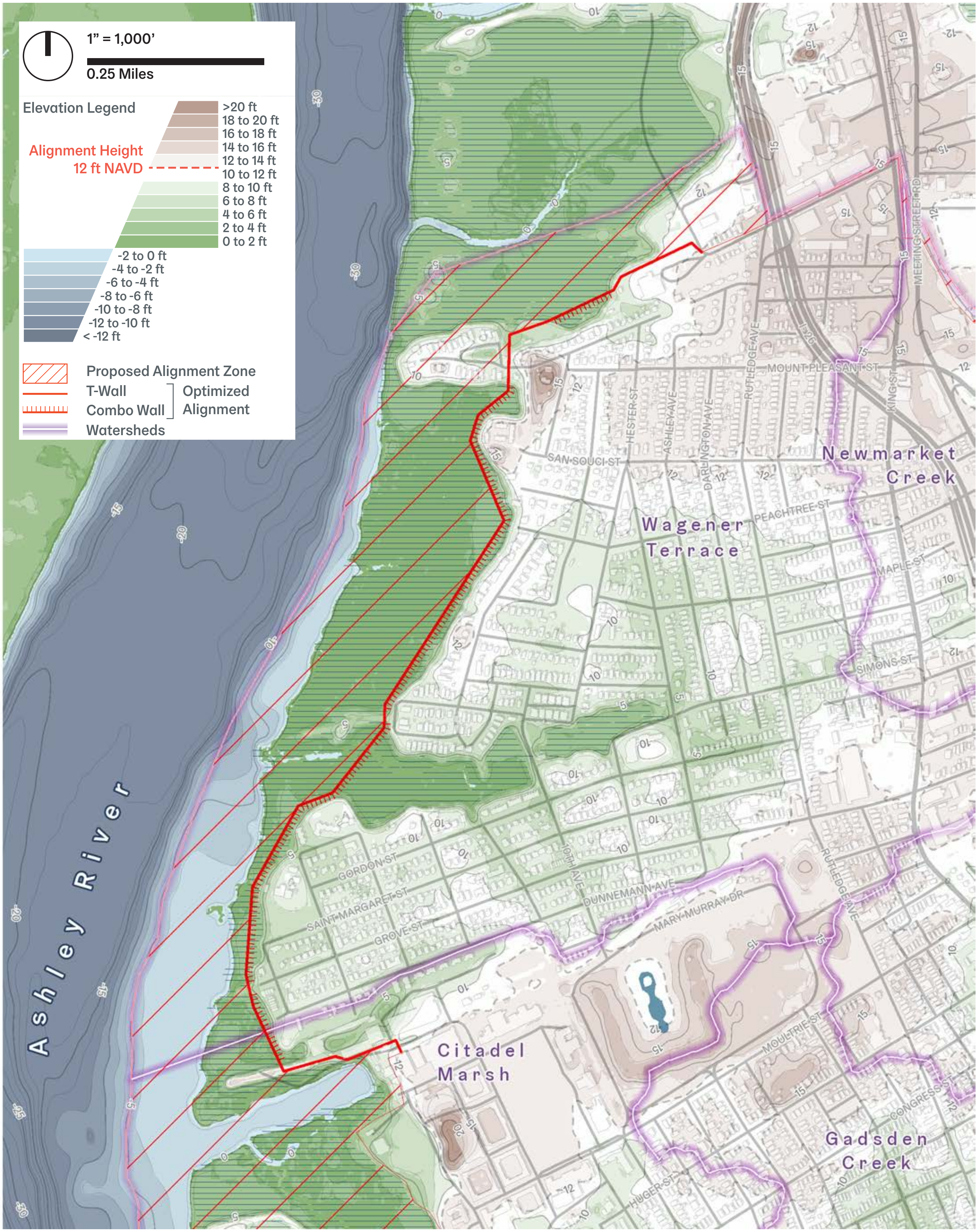
- How at-risk are marshes in this area from sea level rise?

## Operations & Maintenance

- Can marsh function be preserved through design of gate type, number and location?

## Urban Design & Historic Character

- What does the barrier look like from homes?
- Which strategies are considered acceptable for residents, and how much risk are they willing to tolerate?



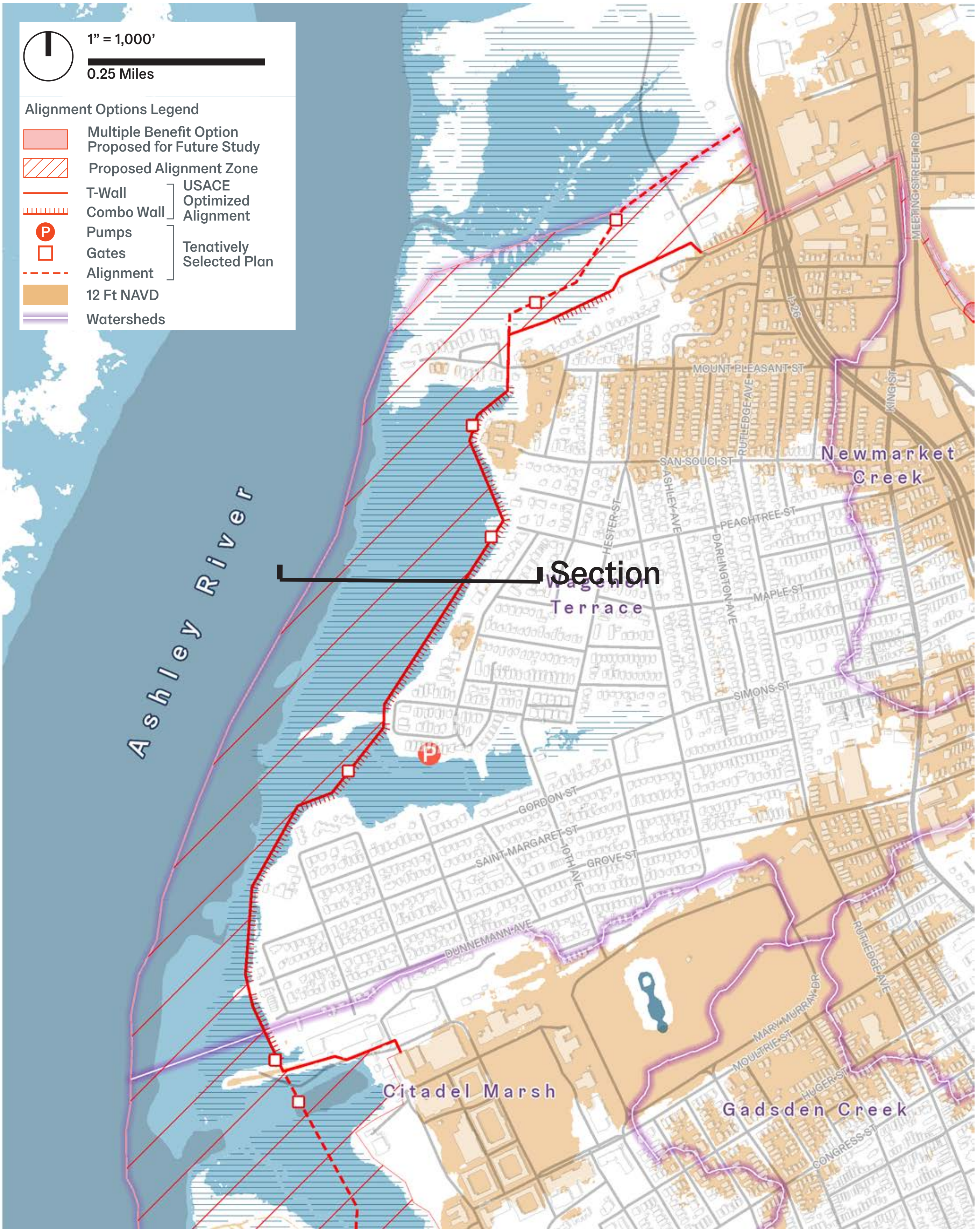

**Wagener Terrace USACE optimized alignment.**

*Credit: Waggonner & Ball*

**Public walking path along Mary Ellen Dr.**
*Credit: Waggonner & Ball*

**Access Road to Lowndes Point. The current alignment would run through the center of this photo putting all of Lowndes Point on the outside of the perimeter protection system.**
*Credit: Waggonner & Ball*

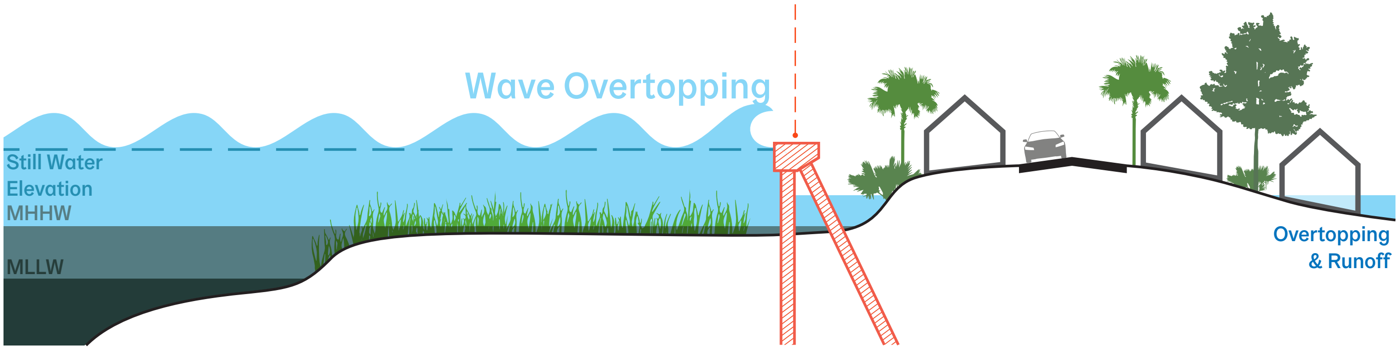
**Raised homes in Wagener Terrace.**
*Credit: Waggonner & Ball*



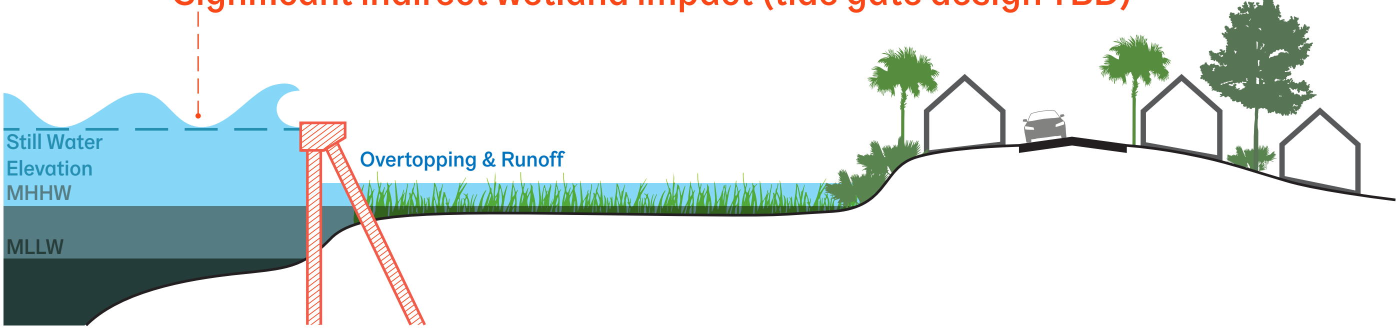

**Wagener Terrace alignment zone.**
*Credit: Waggonner & Ball*

# Wagener Terrace Alignment Options

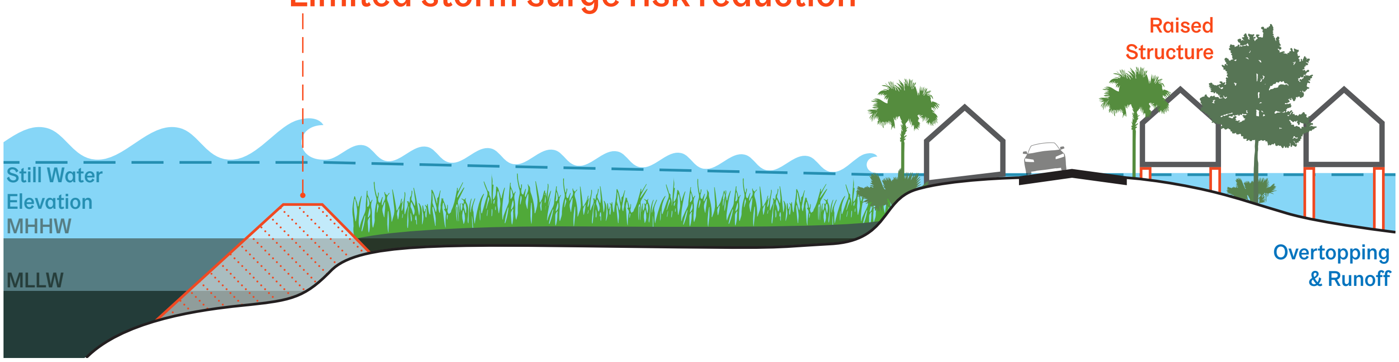
Current USACE Alignment (subject to revision in PED)
Combo wall from Citadel to tie in near Sunnyside Ave
Limited space for internal overtopping & runoff management
Significant visual impact to homes




Optional Mudflat Alignment
Combo wall on the Ashley side of marshes
Increased space for overtopping & runoff management
Significant indirect wetland impact (tide gate design TBD)

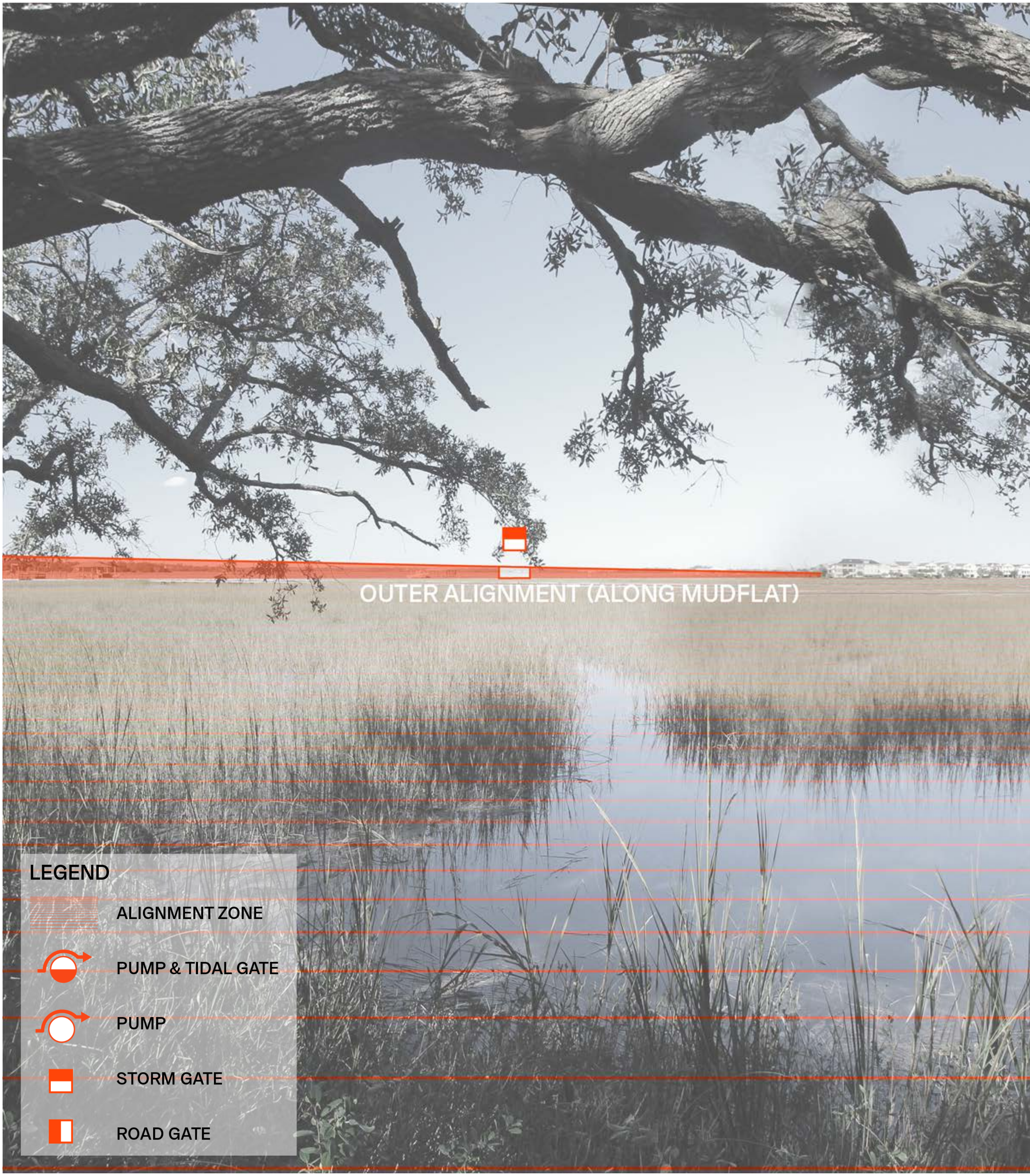


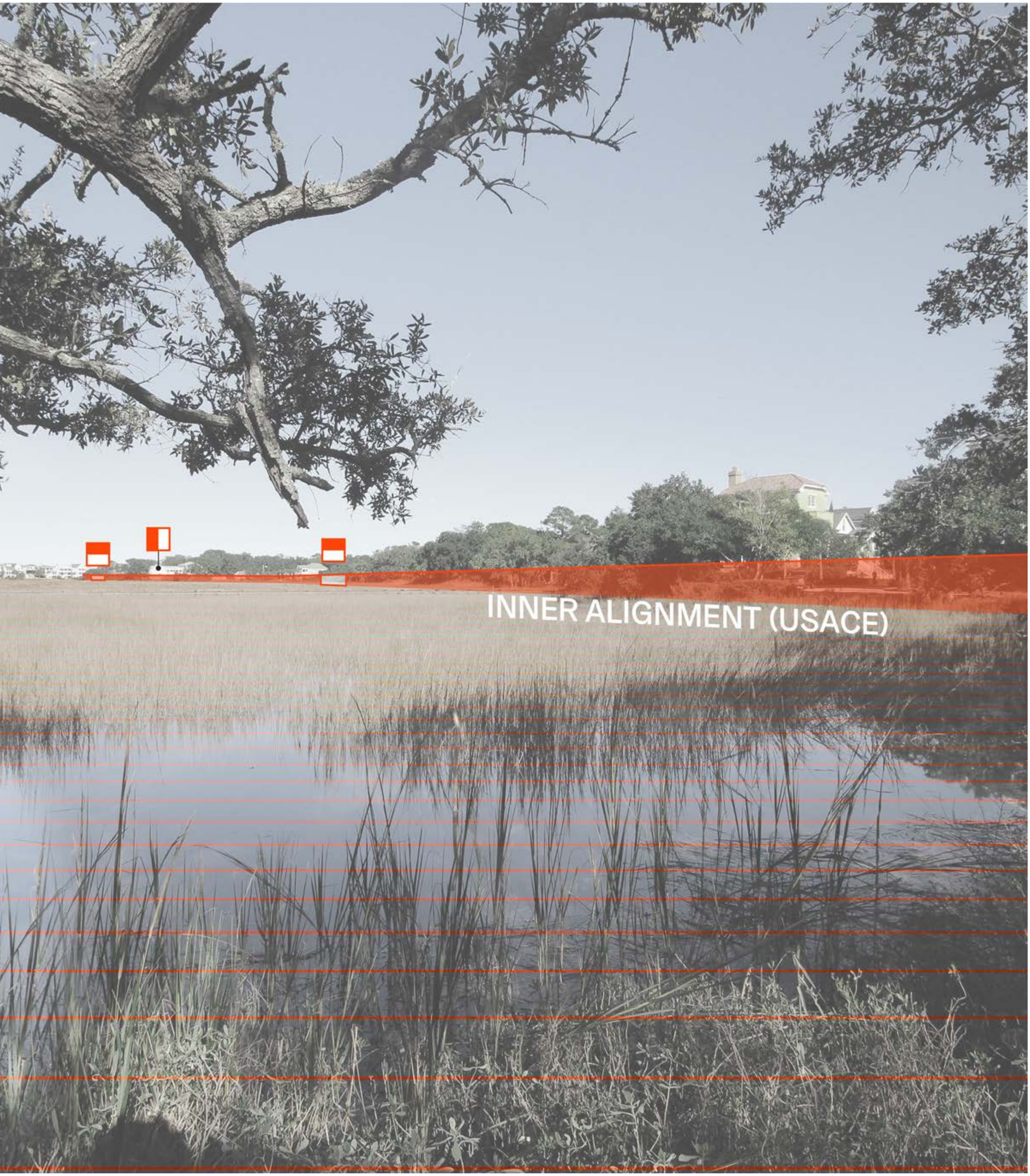

Optional Wave Attenuation & Living Shoreline Typologies
Managed marsh accretion over time
Wave attenuation and marsh construction
Limited storm surge risk reduction

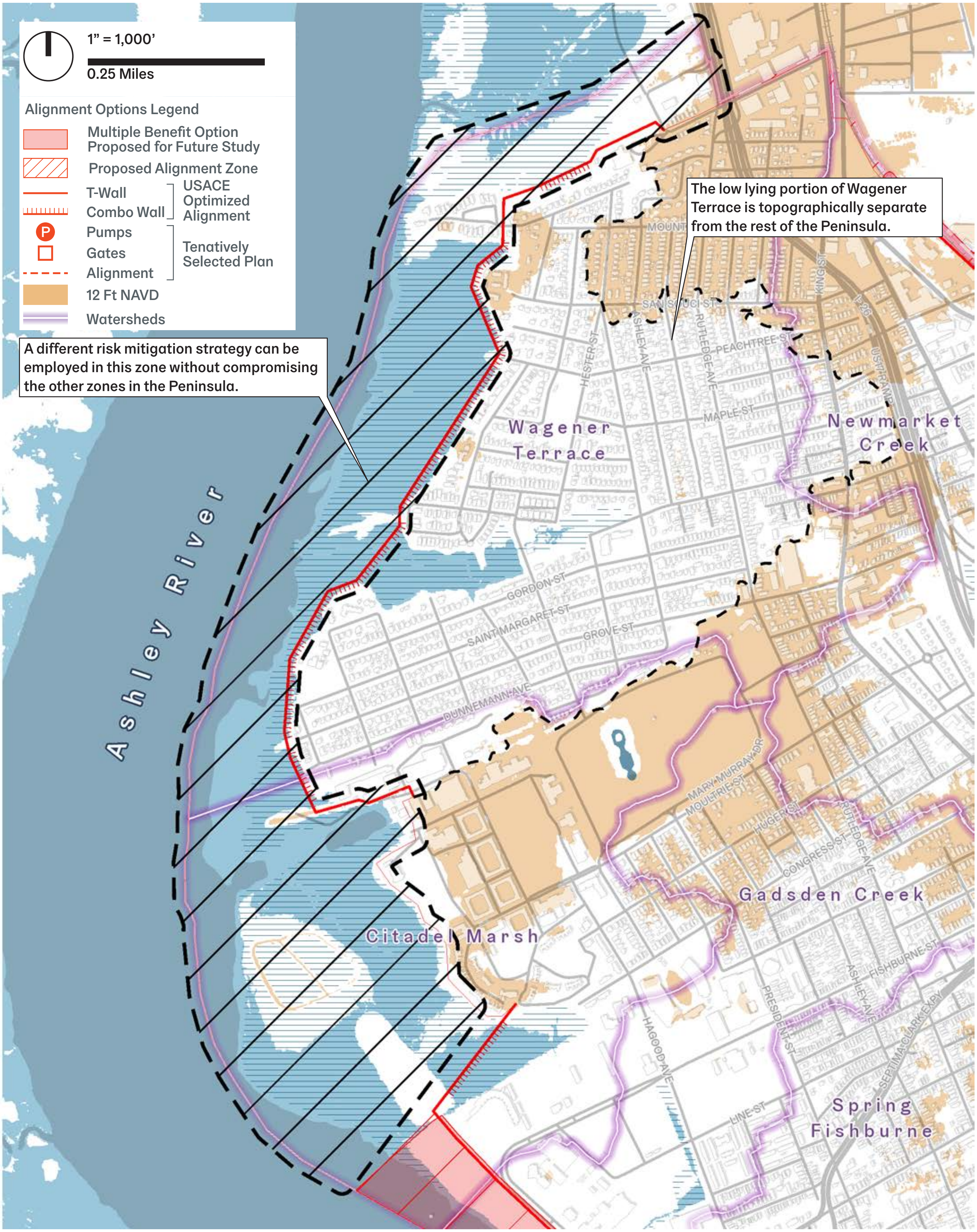


# Wagener Terrace

## Looking North from Longborough Walking Path




INNER ALIGNMENT (USACE)


1" = 1,000'
0.25 Miles
Alignment Options Legend
Multiple Benefit Option Proposed for Future Study
Proposed Alignment Zone
T-Wall
Combo Wall
USACE Optimized Alignment
Pumps
Gates
Alignment
Tenatively Selected Plan
12 Ft NAVD
Watersheds
A different risk mitigation strategy can be employed in this zone without compromising the other zones in the Peninsula.
The low lying portion of Wagener Terrace is topographically separate from the rest of the Peninsula.
Ashley River
Wagener Terrace
Newmarket Creek
Citadel Marsh
Gadsden Creek
Spring Fishburne
MOUNT
SANS SOUCI ST
ASHLEY AVE
RUTLEDGE AVE
PEACHTREE ST
HESTER ST
MAPLE ST
KING ST
I-26
GORDON ST
SAINT MARGARET ST
GROVE ST
DUNNEMANN AVE
MARY MURRAY DR
MOULTRIE ST
HUGER ST
CONGRESS ST
FISHBURNE ST
PRESIDENT ST
HAGOOD AVE
LINE ST

# “Severability”

The topography of Wagener Terrace forms a compartment that can be severed from the overall alignment without compromising the safety of other areas. In that scenario the alignment would terminate into the high ground at the Citadel and an alternative storm surge mitigation strategy would need to be developed for Wagener Terrace. The Wagener Terrace portion of the alignment accounts for the majority of wetland impacts, has high construction cost, and significant visual and accessibility impacts to homes along the marsh edge and the overall character of the neighborhood. Considering the high cost and impact of any perimeter structure in this sensitive area, the relative value of the USACE proposed approach versus a combination of natural buffers and home elevations over time should be openly discussed with neighborhood residents.

These alternatives were studied and discarded by the USACE earlier in the feasibility process because they do not provide the same level of protection as a wall-like barrier, however the stakeholders who stand to feel their impacts should determine their own tolerance for risk. While alternative nature-based strategies such as marsh accretion and wave attenuation structures could be employed in this zone to amplify the protection provided by existing natural systems, still-water levels during a surge event could significantly impact low-lying roads and homes. Standard USACE policy mandates that the perimeter structure provide the same level of risk reduction (protection) to all parts of the study area, thereby pre-empting a dialogue with residents about what they prefer. The severability of Wagener Terrace may be a prime opportunity for the USACE to explore a new approach to nature-based strategies as a pilot project for other similar areas across the country.

This portion of the alignment is currently scoped as the fourth and last phase of PED, allowing time for more alternatives to be considered.

# Appendix

# Contents

# O&M Case Studies

*Analysis and text by:*

ARCADIS

## New Orleans after Katrina

Adaptation: The USACE Hurricane Risk reduction system that was developed as an outer barrier protection shield with floodwalls, gates and pumps, after Katrina hit in 2005, did not yet include the impact off sea level rise and increased storm surges, and also not the even more severe impact of land subsidence in the Mississippi Delta. In fact, the Dutch Dialogues, as they were also performed in Charleston, came as a first reaction to create more sustainability in the New Orleans water system, and help the city to let communities benefit from the opportunities of a Living with water approach rather than reducing only the risks.

Reliability: What you can consider adaptive in the USACE approach however, and also enhanced reliability, is in the robustness, size and redundancy of the designed hydraulic structures, the fact that the floodwalls allow for overtopping and will not fail, and the multiple lines of defense strategy (though strengthening the marshes and wetlands will take many more decades to come). All in all resulting in a safety level that has been described as “a 1 in 100-year protection level, with a 400 year resilience”.

O&M: In New Orleans, the new South Louisiana Flood Protection Authority (East and West) was established for this task, merging from several local small (and understaffed and underfunded ) levee boards. This authority became responsible for long term operation, maintenance, funding and replacement of the hurricane risk reduction system that was constructed by the US Army Corps New Orleans District after Hurricane Katrina. This authority had to rapidly build a substantial and skilled organization within a very short time frame to be able to take over the immediate full O&M responsibility of this complicated and large system.

Funding: The funding base had to be developed, as these very expensive multi-billion dollar structures with a regional a national importance had to be funded from a modest local base, of a city that was partly deserted. The budget required to perform future O&M including full funding for a dedicated organization was not in place when the completed project was turned over to the local sponsor. An organizational structure was in place but not fully staffed and trained at that time.

Such an organization is in particular important for a complicated high tech system with movable parts, like gates and pumps, etc. This problem is often underestimated, as the example of the Rotterdam barrier described later in this memo shows.

## The New York ESCR Manhattan East Side Coastal Resilience case

Reliability: The ESCR project is designed to protect against the 100-year storm condition, or the storm condition that has a 1-percent chance of recurrence in each given year. The reliability of closure of flood gates within this project has been analyzed using the Dutch “Leidraad Kunstwerken”, an internationally recognized standard that covers the governing design principles for major flood defense works in The Netherlands. This method has also been used internationally in flood barrier projects including a storm surge barrier in Nieuwpoort, Belgium, the Bay Park Sewage Treatment Plant in Nassau County, New York (guideline is compared to the HSDRRS), PIANC Report Design of Movable Weirs and Storm Surge Barriers, levee design in New Orleans; and various USACE reports including Elevations for Design of Hurricane Protection Levees and Structures (October 2007).

For the New York ESCR project the reliability of two systems of flood gates was considered;

- Flood gates for roads and pedestrian areas at major roadways and areas where access by the public is required.

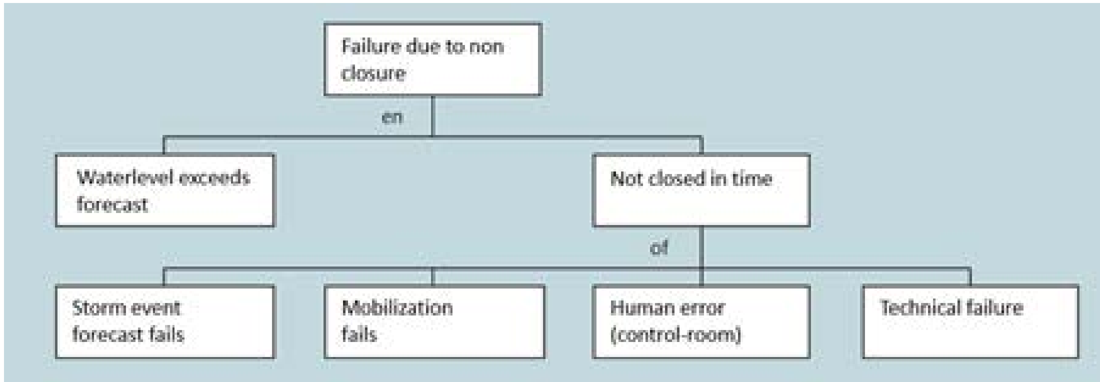



**Figure 2: Failure tree according to "Leidraad Kunstwerken"**

- Interior drainage, flood (tide) gates for drainage culverts situated at relatively low levels (below street level) and close to or at the waterfront

Drainage gates are fairly small gates that are used on a frequent, sometimes daily, basis. Although failure of one gate is undesired, it seldomly results in significant flooding due to the relatively low inflow. A drainage gate is closed when not in use. When required for drainage the gate is opened either by water pressure (passive flap gate known locally as a tide gate) or hydraulic pressure (hydraulic gate). Because these gates are used on a frequent basis the interval of maintenance and inspection is high.

Flood gates are significantly larger and are open on a day-to-day basis. Flood gates only close when high water is forecasted which means that defects will be noticed shortly before high water leaving little time for repair. If a flood gate fails to close the inflow is likely sufficiently large to result in significant flooding or breaching of adjoining barriers.

## Interior drainage system

The interior drainage management scope for the East Side Coastal Resiliency (ESCR) includes ensuring closure of nineteen (19) combined sewer (CS) outfalls that are owned and operated by the New York City Department of Environmental Protection (DEP) and located within the Project Area. Each outfall has an existing tide gate that protects the DEP's CS system from water intrusion from the East River. During wet weather events, the CS system allows overflow to discharge into the East River via a gravity-driven pipe network with passive-closure, tide gate outfalls. Failure of the tide gates to close during a storm event could potentially result in flooding beyond the flood protection system (FPS), inundating streets, basements, or homes with contaminated stormwater and raw sewage because rising tides can enter the system through outfall openings.

This study described the overall reliability of using passive closure gates (single tide gate) and active closure gates (sluice gate) during a 100-year storm event coupled with a 5-year rainfall event. To determine the probability of failure a combination of actual failure data and so called "failure tree's" were used. An example of a failure tree is shown below.

## Roadways and pedestrian area

A system of approximately 21 vehicular access gates: 7 roller, 11 swing and 3 flip up gates, along a stretch of concrete floodwalls was developed. The system allows daily passage of vehicles and pedestrians while protecting against major flood levels.

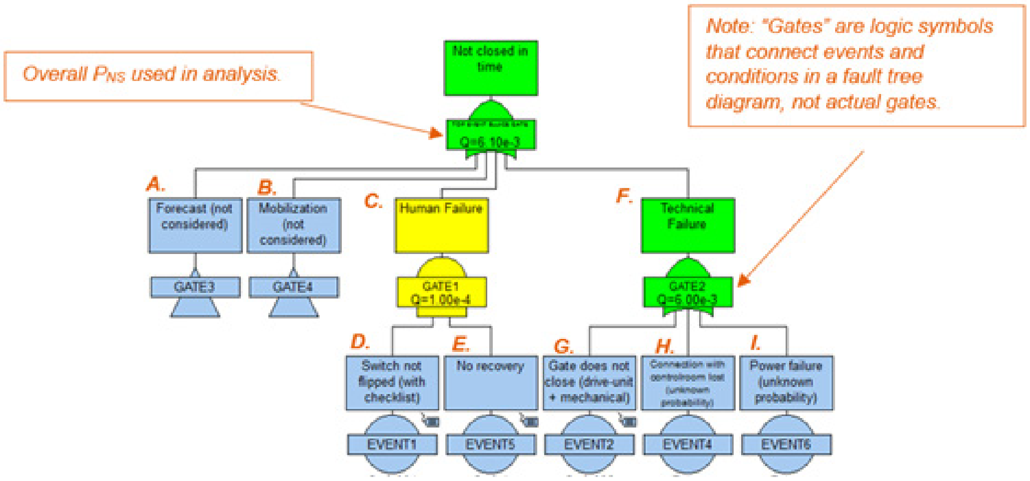



**Figure 3: Example of a simplified Failure Tree for a sluice gate in FaultTree+ (not project specific)**

The roller and swing gates are all of uniform design within each type, although the sill height differs somewhat among the gates. This means that only one single maintenance and operation manual will be required and that most (not all) spare parts will be interchangeable between gates.

The frequency of closure of the gates averages at 1/10 years currently and will increase to higher frequency of once every 1-4 years depending on projected local sea level rise using conservative assessments. At present the reliability of this system is being studied.

## O&M:

For New York, numerous challenges included identifying organization responsibilities, as responsibility spanned across multiple agencies influenced by infrastructure type, ownership, emergency operation protocols including command and control.

An additional challenge for ESCR compared to the Netherlands and New Orleans cases is that all gates have to be closed manually, the gates cannot be closed electro-mechanically or automatically. This significantly increase closure times and risk of failure and therefore yearly O&M costs.

Also the fact that ESCR is a complex project with numerous owners including the Veterans Affair Medical Facility and Con Edison Generating Station makes O&M complicated and challenging. Roles and procedures will require detailed plans and documentation via legal agreements for performing operations, maintenance and emergency response.  City government will hold ultimate responsibility for the completed project.

Funding: The City of New York is funding the ESCR project, after it secured a FEMA grant for the work in the neighborhood of $330 million.  The USACE is not providing any funding for the project. In addition, there are expectations of creating substantial resilience benefits for private stakeholders as a result of increased safety, accessibility, attractivity and livability, but these benefits are not monetized into a contribution of the private stakeholders, other than indirectly via increased regular tax incomes as a result of increased real estate values and economic activities.

## Examples in the Netherlands

## Multifunctional coastal flood protection system at Katwijk

The coastal resort of Katwijk is characterized by a relatively low coastal boulevard area. Houses and

**Maeslant Barrier in Rotterdam.**
*Credit: CC by Bertknot*

**Sector Gate construction along the Inner Harbor Navigation Canal Lake Borgne Surge Barrier in Louisiana.**
*Credit: USACE*

hotels are located just landward of this boulevard, which means that there is only a limited space for developing coastal defense works. The coastal defenses should be such that the character of the town remains, and the strong ‘connection’ between boulevard and beach-area is maintained for tourists and residents.

This so-called hybrid sea defense is a combination of both a (hidden) sea dike and a dune, which covers the dike completely. The length of this hybrid structure is approx. 1 km, located in the center of the resort. At both sides of the hybrid construction a ’regular’ dune is applied as a connection to adjacent areas. Due to the innovative, so-called ‘dike-in-dune’, design for the primary sea defenses a significant area just landward of the dike (but seaward of the boulevard) becomes available. In this area an entirely new underground parking garage was built.

Funding: In addition to the regular federal funding for national flood Protection in the Netherlands arts of the construction costs were covered by the Municipality of Katwijk, and the Province, given the local socio-economic interest. Also the local waterboard contributed. The waterboards in the Netherlands are in the fortunate position that they are completely independent and can raise local taxes if they require funding for implementation of measures within their territory. This is a right that they already own for many centuries (some waterboards go back till the year 1200 AD). The parking garage makes this flood protection a unique structure, as it actually contains a cash revenue generator that sells parking tickets. In addition, revenues are generated indirectly via an increased attractivity , capacity and accessibility of the coastal resort, that has to compete on scarce sunny days for visitors with several other nearby resorts.

CBR: Given the fact that both the sea dike and the parking garage are hidden inside the new dune, the ’natural appearance’ of the coastal zone is not affected (or even improved). So the ‘dike-in-dune’ is an example of optimal integration of multiple functions in the coastal area: combining coastal protection, preservation of Katwijk’s character, natural dune development, parking and tourism.

There is also an adaptation element to the hybrid structure:

Adaptation: When as a result of climate change, future storm surges will be more severe than now, more sand can be added at the beach and dunes in order to reduce the wave height and the crest level of the levee could be increased. So the present design of the sea defense is already prepared for future reinforcement.

## Rotterdam Maeslant Storm Surge barrier

The Maeslant Barrier, a floating sector gate protecting the City and Port of Rotterdam, is located in the Nieuwe Waterweg Shipping Canal near the Dutch Coast. The most important demand for the design was that the barrier should not hinder the shipping. The barrier is only to be closed under exceptional circumstances- no more than once or twice every ten years.

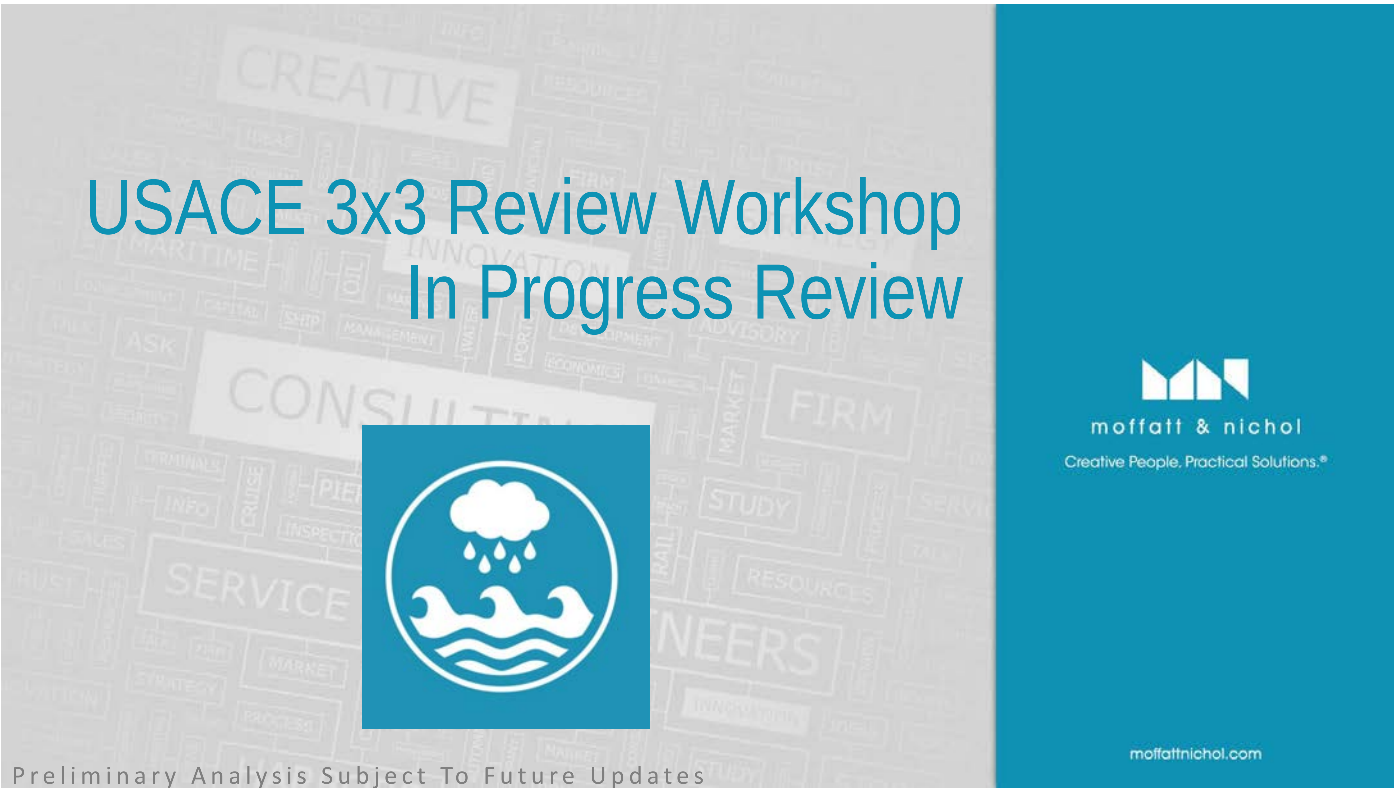
O&M: The barrier is in operation since 1997. Remarkable is the fact that this barrier was not only designed and constructed by the Dutch federal government, but is also operated and maintained by this national government, as it is considered to be a vital part of the Dutch national flood Defense system. Operations are fully automated and managed by a computer system which is linked to weather and sea level data. Under normal conditions the two doors are well protected in their dry docks so that ships have enough space to pass without any inconvenience.

Reliability: Years after completion it turned out that the probability of a closure failure of the barrier was higher than expected. It was concluded that the barrier required a focused and well trained team to operate the barrier and a risk based maintenance program than previously expected. As a result, the barrier now has a dedicated, object oriented 22 px. The probability of a failure is now back at an acceptable level of 1:100 (originally this probability was aimed at 1:1.000 closing attempts, at its worst it was only 1:10), but at much higher yearly costs than expected during evaluation of the different designs. The yearly O&M costs are approx. 20 M$/yr.

Adaptation: The barrier is expected to be closed on average once every ten years due to a storm surge. With the rise in sea levels the storm surge barrier will need to close more frequently. It is expected that in 50 years from now, it will have to close once every five years. In its first 10 years of operation, the barrier was never closed due to a storm. In November 2007, the barrier was successfully closed due to a storm surge for the first time.

Funding:  Also the Rotterdam barrier was funded by regular federal funding for National flood Protection in the Netherlands. The barrier was considered the final part and cornerstone of the Dutch delta Works (an implementation plan including national funding developed after the national flood disaster of 1953).  The additional funding required for the unexpected high yearly costs for O&M due to the reliability issues are also part for by national government.

# Risk Factor In-Progress Analysis




## In-Progress Review

- Following slides present an in-progress review of USACE's 3x3 study for Charleston (Draft Feasibility Report April 2020) centered around the proposed structure location, structure height and coastal hydraulics and interior drainage. This is a preliminary high-level analysis subject to future updates when USACE releases an updated draft of the Feasibility Study Report.

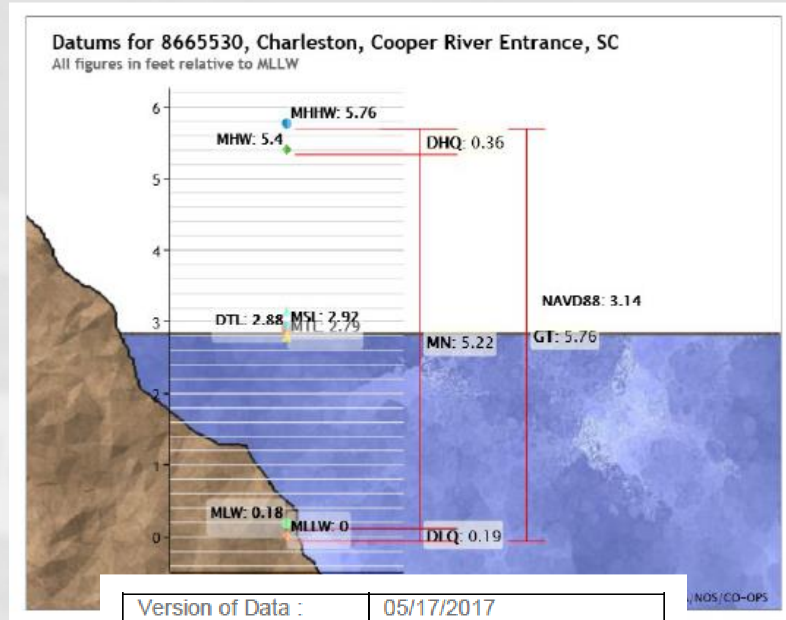
# Water Level Assessment

Brief Summary and context of USACE data from draft feasibility report

Preliminary Analysis Subject To Future Updates

# Water Level Assessment – USACE 3x3 Study

- Based on Preliminary FEMA FIS Stillwater Levels (SWLs) (10.4’ NAVD88 – Annual Exceedance Probability - AEP=1%)
- SLR Projection of 1.13’ Added (to get to 2075)
- Dynamic SWL appears to be used
  - Estimated to Add 2.27’
  - 2%AEP = El. 11.7,
  - 1% AEP = El. 13.7’
- Appears That Combination of 1% AEP SWL & Dynamic 2% AEP SWL Drove Final Top of Wall Elevation Selection of +12.0 NAVD88




| | |
|---|---|
| Version of Data : | 05/17/2017 |
| ID: | 8665530 |
| Reference Datum: | NAVD88 |
| Name: | Charleston, SC |
| HAT: | 4.12 (ft) |
| MHHW: | 2.62 (ft) |
| MHW: | 2.27 (ft) |
| MSL: | -0.22 (ft) |
| MLW: | -2.95 (ft) |
| MLLW: | -3.14 (ft) |
| NAVD88: | 0.00 (ft) |

Preliminary Analysis Subject To Future Updates

# Water Level Assessment

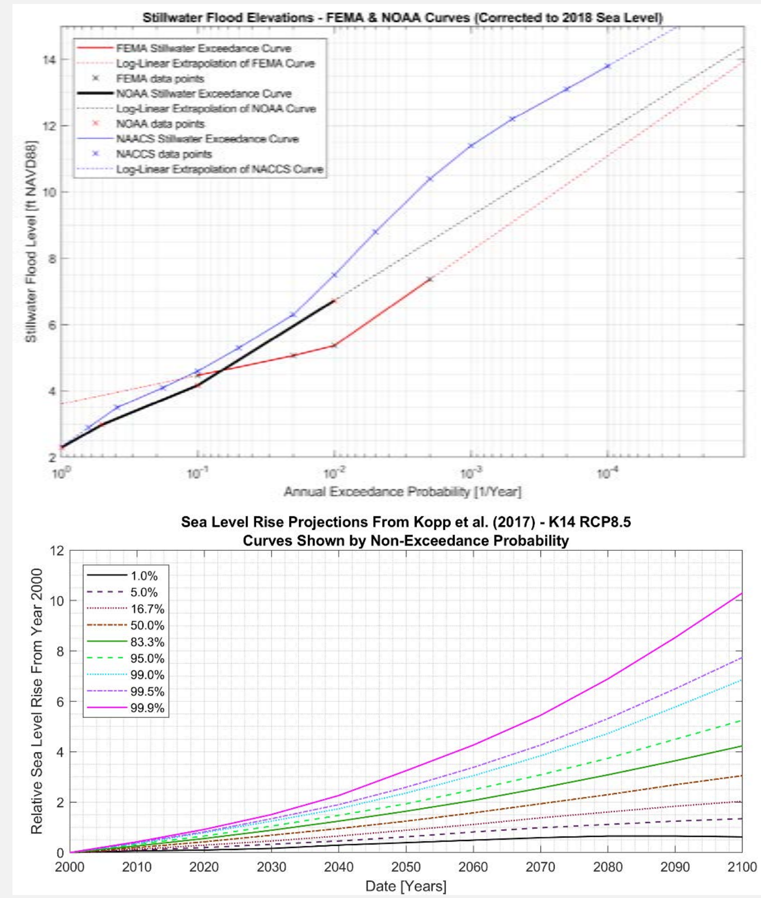
Example assessment to analyze the cumulative probability of an event exceeding a given wall height

Preliminary Analysis Subject To Future Updates

# Water Level Assessment - Monte-Carlo Simulations to Quantify Risk

- Based on Current FEMA FIS Stillwater Levels (SWLs)
- SLR Projections Based on Kopp (2017) RCP 4.5
- Projections Out Past 50 Years Are Subject to More Uncertainty and Results Require More Judgement (i.e., % May Be More Indicative of 1-2 Events Occurring During Time Period)

$$100\,YEARS \times 10{,}000\,MODEL\ RUNS = 1{,}000{,}000\,FLOOD\ EVENTS$$

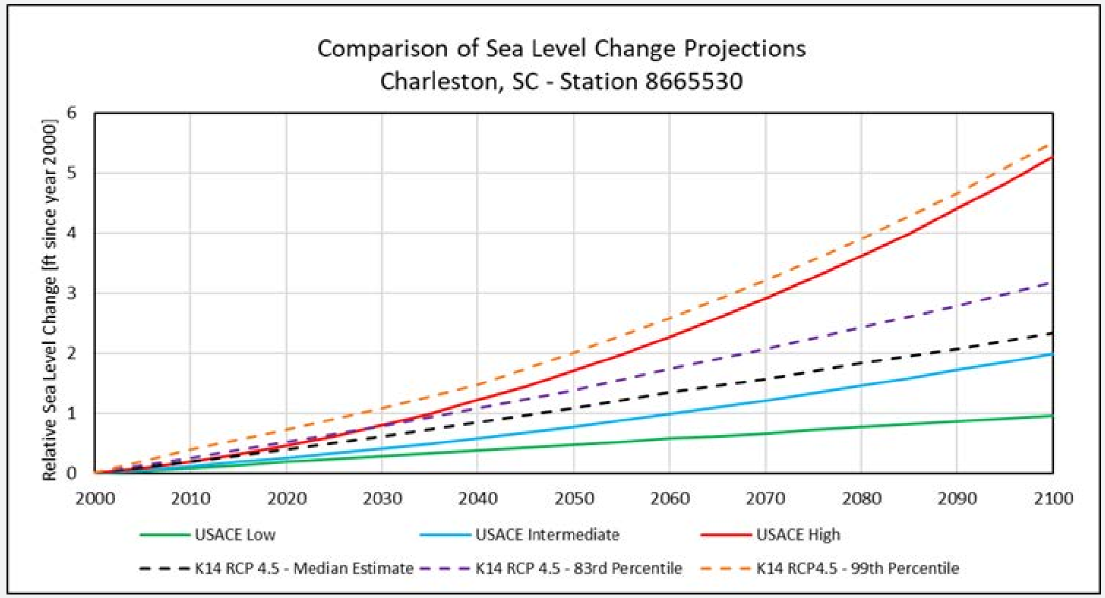



Graphical Example of Similar Analysis

Preliminary Analysis Subject To Future Updates

# Water Level Assessment - Monte-Carlo Simulations to Quantify Risk

- SLR Projections Based on Kopp (2017) RCP 4.5
- Median RCP 4.5 compares reasonably well with USACE intermediate in 2100 (0.3ft difference)




Preliminary Analysis Subject To Future Updates

# Water Level Assessment - Monte-Carlo Simulations to Quantify Risk

| Elevation [ft NAVD88] | Likelihood of Flood Elevation Occurring Once During Project Timeline (RCP4.5) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 Years 2030 | 20 Years 2040 | 30 Years 2050 | 40 Years 2060 | 50 Years 2070 | 60 Years 2080 | 70 Years 2090 | 80 Years 2100 | 90 Years 2110 | 100 Years 2120 |
| **8.0** | 24.9% | 45.9% | 63.1% | 76.2% | 85.6% | 92.0% | 95.8% | 97.9% | 99.0% | 99.5% |
| **9.0** | 16.2% | 30.6% | 43.9% | 55.9% | 66.7% | 76.2% | 83.5% | 89.2% | 93.0% | 95.6% |
| **10.0** | 11.8% | 22.9% | 33.5% | 43.3% | 52.4% | 61.1% | 68.9% | 75.9% | 81.7% | 86.5% |
| **11.0** | 8.5% | 16.8% | 25.2% | 33.3% | 41.1% | 48.8% | 56.1% | 62.9% | 69.1% | 74.8% |
| **12.0** | 5.8% | 11.8% | 18.0% | 24.3% | 30.6% | 37.1% | 43.6% | 49.9% | 56.0% | 61.7% |
| **13.0** | 4.0% | 8.2% | 12.6% | 17.2% | 22.0% | 27.1% | 32.3% | 37.8% | 43.2% | 48.7% |
| **14.0** | 2.8% | 5.6% | 8.7% | 12.0% | 15.5% | 19.3% | 23.3% | 27.6% | 32.1% | 36.8% |
| **15.0** | 1.9% | 3.9% | 6.0% | 8.4% | 10.8% | 13.6% | 16.6% | 19.8% | 23.3% | 27.0% |
| **16.0** | 1.3% | 2.6% | 4.1% | 5.7% | 7.4% | 9.5% | 11.6% | 14.0% | 16.6% | 19.5% |
| **17.0** | 0.9% | 1.8% | 2.8% | 4.0% | 5.2% | 6.6% | 8.1% | 9.8% | 11.7% | 13.8% |
| **18.0** | 0.6% | 1.2% | 1.9% | 2.7% | 3.5% | 4.5% | 5.6% | 6.8% | 8.1% | 9.6% |
| **19.0** | 0.4% | 0.8% | 1.3% | 1.8% | 2.4% | 3.1% | 3.9% | 4.7% | 5.6% | 6.7% |
| **20.0** | 0.3% | 0.6% | 0.9% | 1.3% | 1.7% | 2.2% | 2.6% | 3.2% | 3.9% | 4.6% |

- Assuming that ~10% risk of higher water level is tolerable (rounding 5.8% up and 11.8% down) in the current situation – then, one must have the ability to increase the wall height by 2’ every +20 years to maintain that level of risk

Preliminary Analysis Subject To Future Updates

# Water Level Assessment - Monte-Carlo Simulations to Quantify Risk

| Elevation [ft NAVD88] | Likelihood of Flood Elevation Occurring Once During Project Timeline (RCP4.5) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 Years 2030 | 20 Years 2040 | 30 Years 2050 | 40 Years 2060 | 50 Years 2070 | 60 Years 2080 | 70 Years 2090 | 80 Years 2100 | 90 Years 2110 | 100 Years 2120 |
| 8.0 | 24.9% | 45.9% | 63.1% | 76.2% | 85.6% | 92.0% | 95.8% | 97.9% | 99.0% | 99.5% |
| 9.0 | 16.2% | 30.6% | 43.9% | 55.9% | 66.7% | 76.2% | 83.5% | 89.2% | 93.0% | 95.6% |
| 10.0 | 11.8% | 22.9% | 33.5% | 43.3% | 52.4% | 61.1% | 68.9% | 75.9% | 81.7% | 86.5% |
| 11.0 | 8.5% | 16.8% | 25.2% | 33.3% | 41.1% | 48.8% | 56.1% | 62.9% | 69.1% | 74.8% |
| 12.0 | 5.8% | 11.8% | 18.0% | 24.3% | 30.6% | 37.1% | 43.6% | 49.9% | 56.0% | 61.7% |
| 13.0 | 4.0% | 8.2% | 12.6% | 17.2% | 22.0% | 27.1% | 32.3% | 37.8% | 43.2% | 48.7% |
| 14.0 | 2.8% | 5.6% | 8.7% | 12.0% | 15.5% | 19.3% | 23.3% | 27.6% | 32.1% | 36.8% |
| 15.0 | 1.9% | 3.9% | 6.0% | 8.4% | 10.8% | 13.6% | 16.6% | 19.8% | 23.3% | 27.0% |
| 16.0 | 1.3% | 2.6% | 4.1% | 5.7% | 7.4% | 9.5% | 11.6% | 14.0% | 16.6% | 19.5% |
| 17.0 | 0.9% | 1.8% | 2.8% | 4.0% | 5.2% | 6.6% | 8.1% | 9.8% | 11.7% | 13.8% |
| 18.0 | 0.6% | 1.2% | 1.9% | 2.7% | 3.5% | 4.5% | 5.6% | 6.8% | 8.1% | 9.6% |
| 19.0 | 0.4% | 0.8% | 1.3% | 1.8% | 2.4% | 3.1% | 3.9% | 4.7% | 5.6% | 6.7% |
| 20.0 | 0.3% | 0.6% | 0.9% | 1.3% | 1.7% | 2.2% | 2.6% | 3.2% | 3.9% | 4.6% |

- Assuming that ~10% risk of higher water level is tolerable (rounding 5.8% up and 11.8% down) in the current situation – then, one must have the ability to increase the wall height by 2' every +20 years to maintain that level of risk

Preliminary Analysis Subject To Future Updates

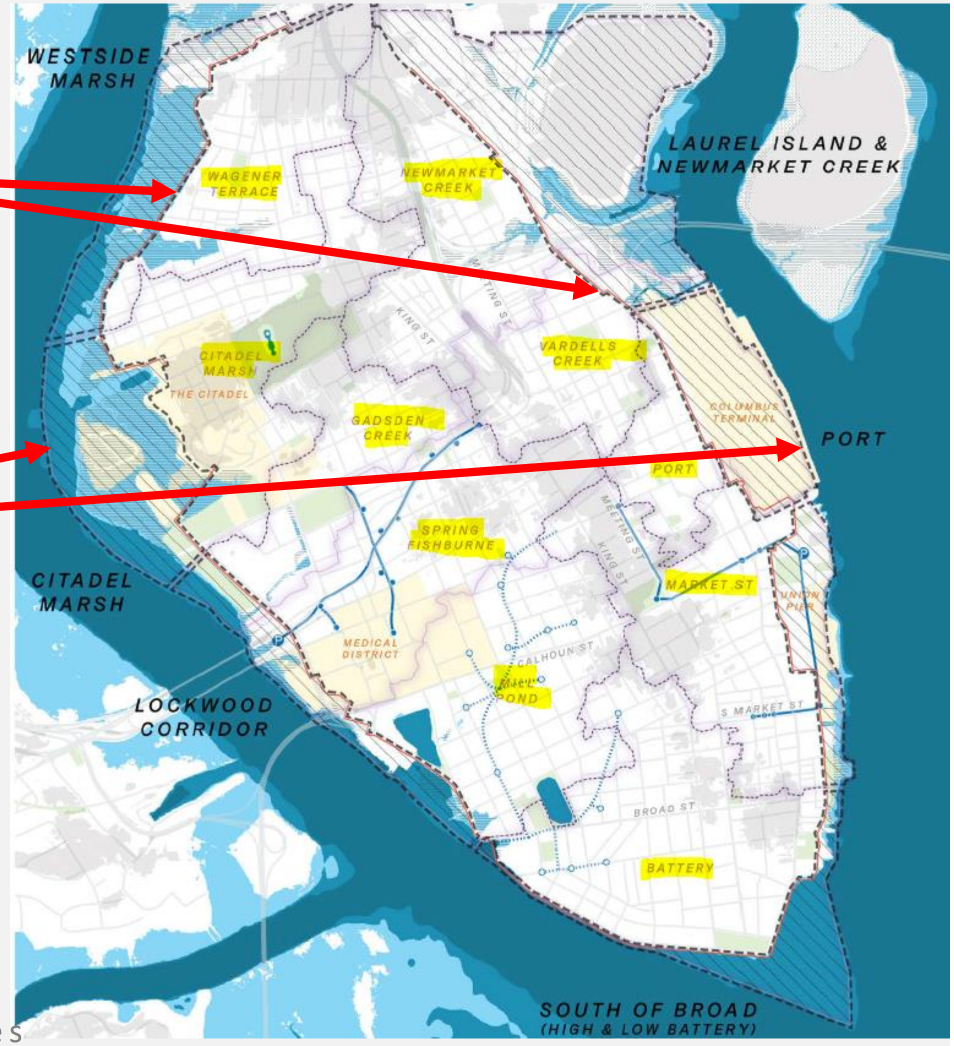
# Adaptation Pathways

Considering both increased rainfall and potential wave overtopping while considering two flood risk reduction alignments (the “outer” and “inner” alignment)

Preliminary Analysis Subject To Future Updates

# Wall Alignments – Trade Offs

- Current USACE Alignment (Inner/Interior)
- Optional Alignment (Outer/Exterior)




Preliminary Analysis Subject To Future Updates

# Wall Alignments – Trade Offs (1)

## Current USACE Alignment (Inner/Interior)

Positives – Lower Wall Elevation for Wave Overtopping, Likely Better Geotechnical Conditions for Foundation Design, Likely Lowest Cost Option

Negatives – Significant Conflicts with Traffic/Gate Operations, Utility Conflicts, Limited Storage Options for Interior Drainage, Greenspace/Recreational Opportunites Will Be Less, Port is Unprotected

## Optional Alignment (Outer/Exterior)

Positives – Considerably Less Conflicts with Traffic/Gates Operations, Less Viewshed Effects (More Distance), More Storage Allowed for Interior Drainage, Creation of Greenspace/Recreational Oppts, Port Is Protected, Provides for Resilient and Adaptable Design

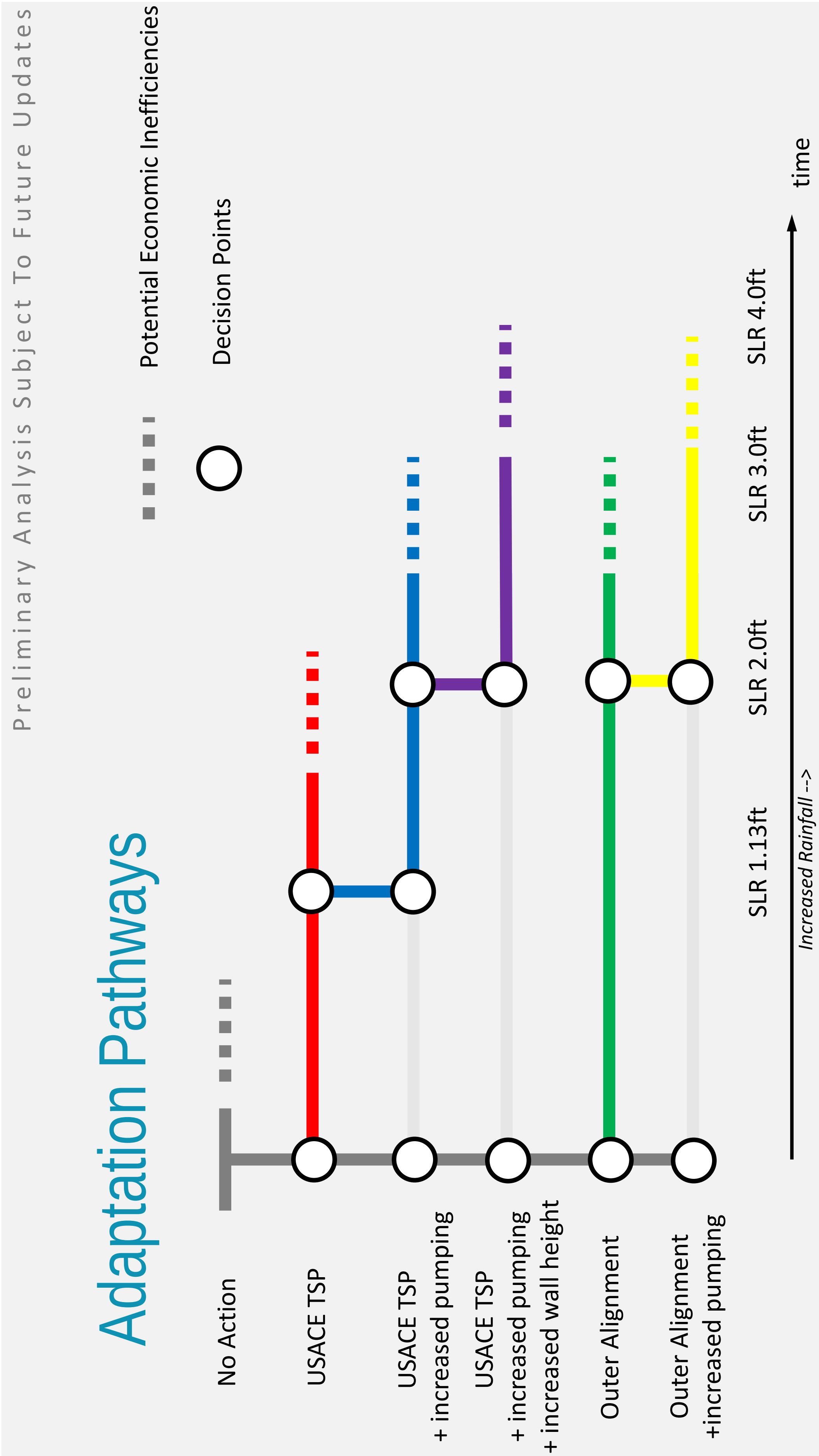
Negatives – Wall Heights Likely Higher Due to Higher Waves, Geotechnical Conditions Likely More Challenging, Potential Increase in Costs/Mitigation Requirements

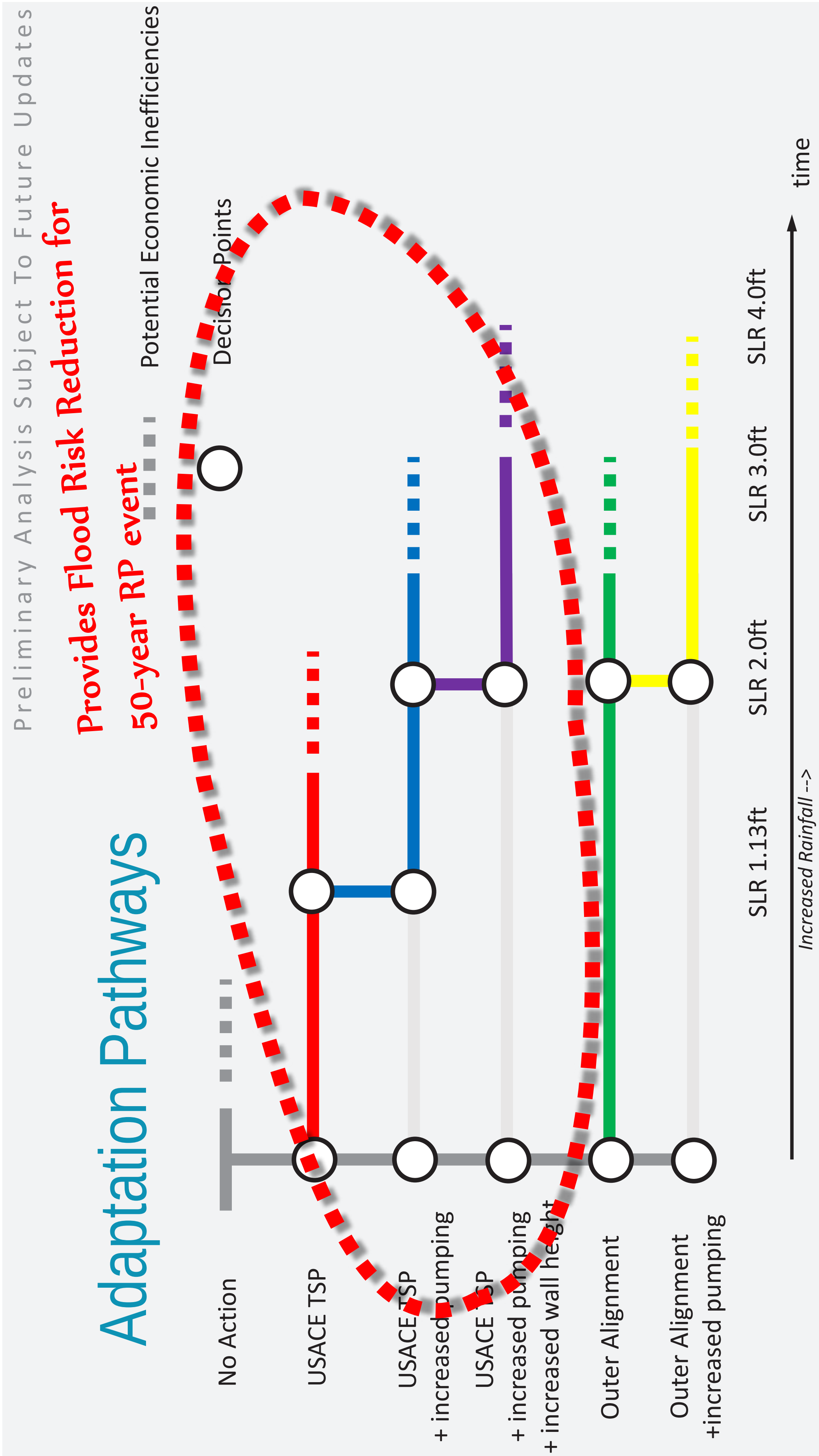
Preliminary Analysis Subject To Future Updates

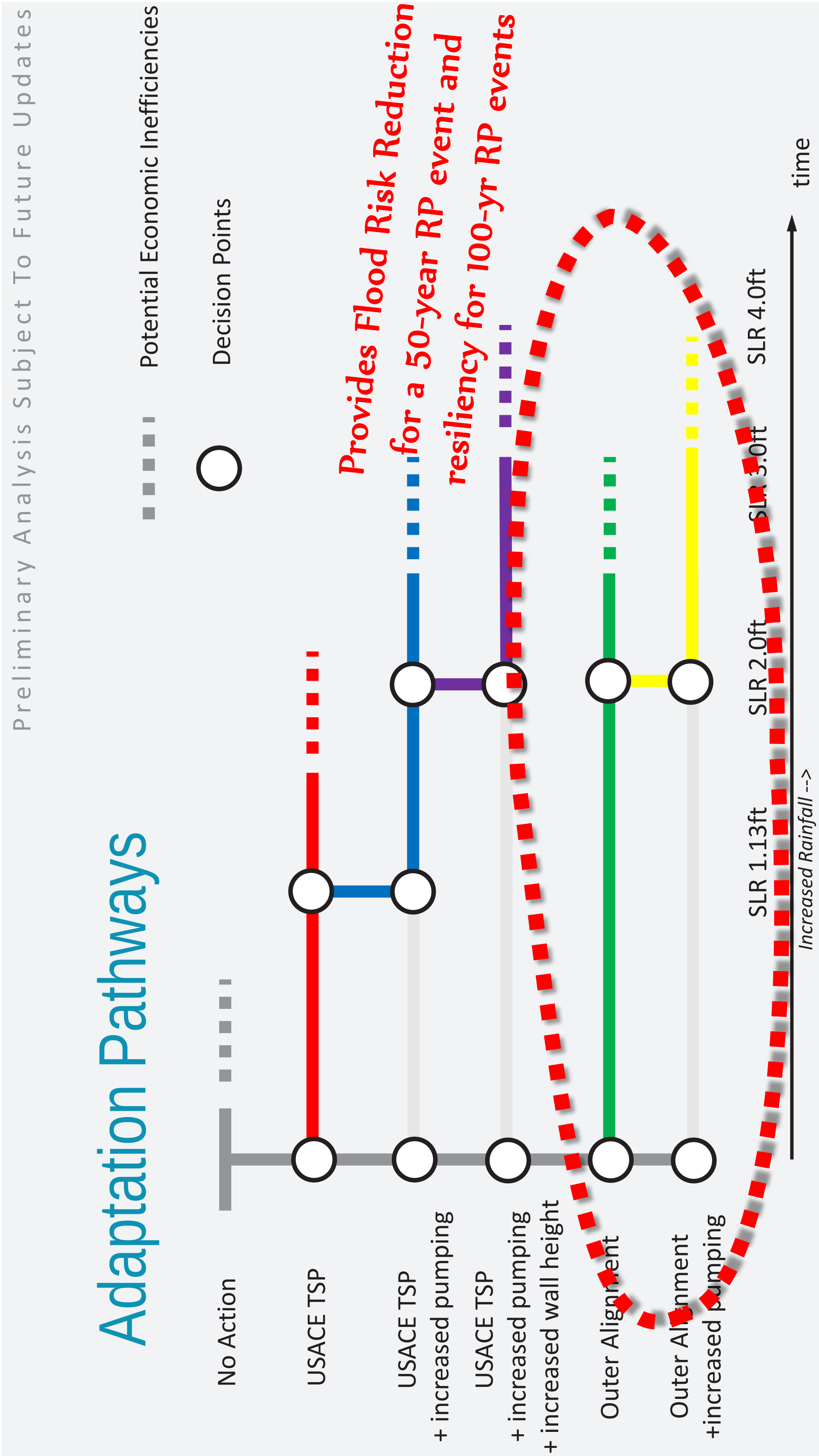
# Wall Alignments – Trade Offs (2)

- When the alignments are reviewed in the context of adaptation pathways we identified that the outer alignment provides greater flexibility and adaptive capacity in response to future uncertainties (higher storm surges, increased wave overtopping, sea level rise and increased rainfall). Visually depicted in the next slides

Preliminary Analysis Subject To Future Updates


Preliminary Analysis Subject To Future Updates
Adaptation Pathways
Potential Economic Inefficiencies
Decision Points
No Action
USACE TSP
USACE TSP
+ increased pumping
USACE TSP
+ increased pumping
+ increased wall height
Outer Alignment
Outer Alignment
+increased pumping
SLR 1.13ft
SLR 2.0ft
SLR 3.0ft
SLR 4.0ft
Increased Rainfall -->
time

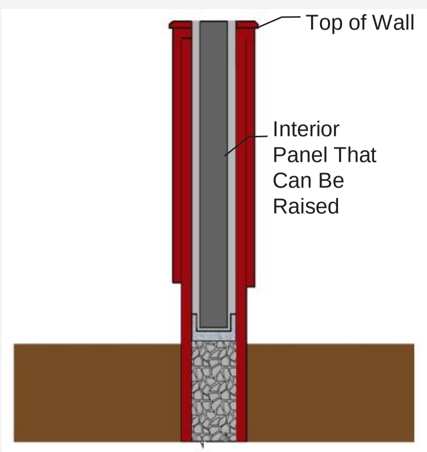

Adaptation Pathways
Preliminary Analysis Subject To Future Updates
Provides Flood Risk Reduction for
50-year RP event
Potential Economic Inefficiencies
Decision Points
No Action
USACE TSP
USACE TSP
+ increased pumping
USACE TSP
+ increased pumping
+ increased wall height
Outer Alignment
Outer Alignment
+increased pumping
SLR 1.13ft
SLR 2.0ft
SLR 3.0ft
SLR 4.0ft
Increased Rainfall -->
time

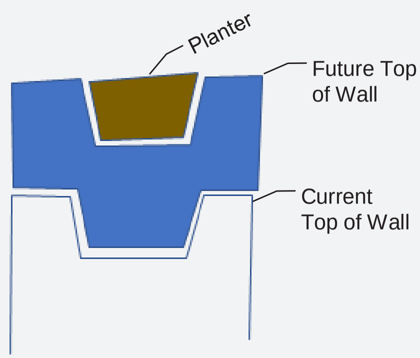


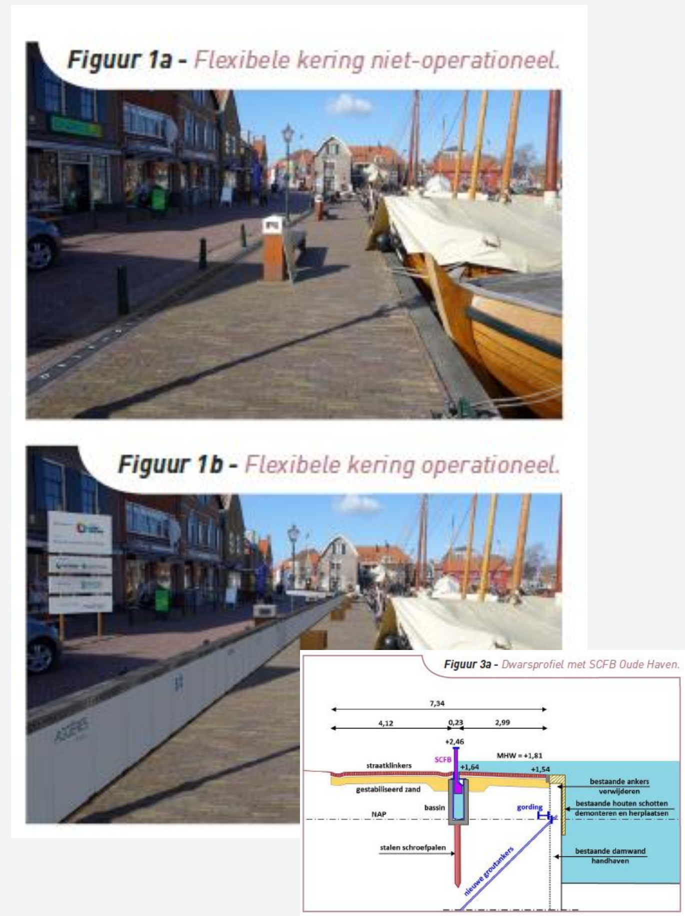
Preliminary Analysis Subject To Future Updates
Adaptation Pathways
Potential Economic Inefficiencies
Decision Points
Provides Flood Risk Reduction for a 50-year RP event and resiliency for 100-yr RP events
No Action
USACE TSP
USACE TSP + increased pumping
USACE TSP + increased pumping + increased wall height
Outer Alignment
Outer Alignment +increased pumping
SLR 1.13ft
SLR 2.0ft
SLR 3.0ft
SLR 4.0ft
Increased Rainfall -->
time

# Design Adaptability – Conceptual Thoughts

- Potential Wall Designs for PED Phase to Allow for Adaptability & Minimize Viewshed Effects
- Design Foundations Now to Allow for Wall Heights to Be Increased Over Time
- Beneficial Use of Dredge Material Can Be Used to Keep Up with SLR




Preliminary Analysis Subject To Future Updates

# Wave Overtopping

Flood risk reduction alignments in consideration of wave overtopping

Preliminary Analysis Subject To Future Updates

| Orleans Parish - Lakefront East Reaches 1% Hydraulic Boundary Conditions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Hydraulic Reach | Name | Type | Condition | Surge Level (ft) | | Significant Wave Height (ft) | | Peak Period (s) | |
| | | | | Mean | Std | Mean | Std | Mean | Std |
| NE08 | Jahncke Pump Station (OP #14) | Structure/Wall | Future | 10.0 | 0.7 | 1.6 | 0.5 | 7.1 | 1.3 |
| NE09 | St Charles Pump Station (OP #16) | Structure/Wall | Future | 9.9 | 0.7 | 4.0 | 0.3 | 7.3 | 1.3 |
| NE30-FW | Transition Reach from NE01-NE02 T-walls | Structure/Wall | Future | 10.1 | 0.7 | 4.8 | 0.4 | 7.1 | 1.3 |
| NE31 | South Point Transition Reach from NE02 to NE17 at I-10 | Levee | Existing | 9.0 | 0.7 | 3.6 | 0.4 | 5.8 | 1.2 |
| NE31 | South Point Transition Reach from NE02 to NE17 at I-10 | Levee | Future | 10.5 | 0.7 | 4.2 | 0.4 | 6.3 | 1.2 |

As an example: New Orleans Structures with similar hydraulic loading and the same wave overtopping threshold result in a structure height of 15.5ft

As such we'd expect higher overtopping rates for a wall height of +12.0ft

New Orleans Example with similar conditions
0.01cfs = 0.1l/s/m
0.1cfs/ft = 10 l/s/m

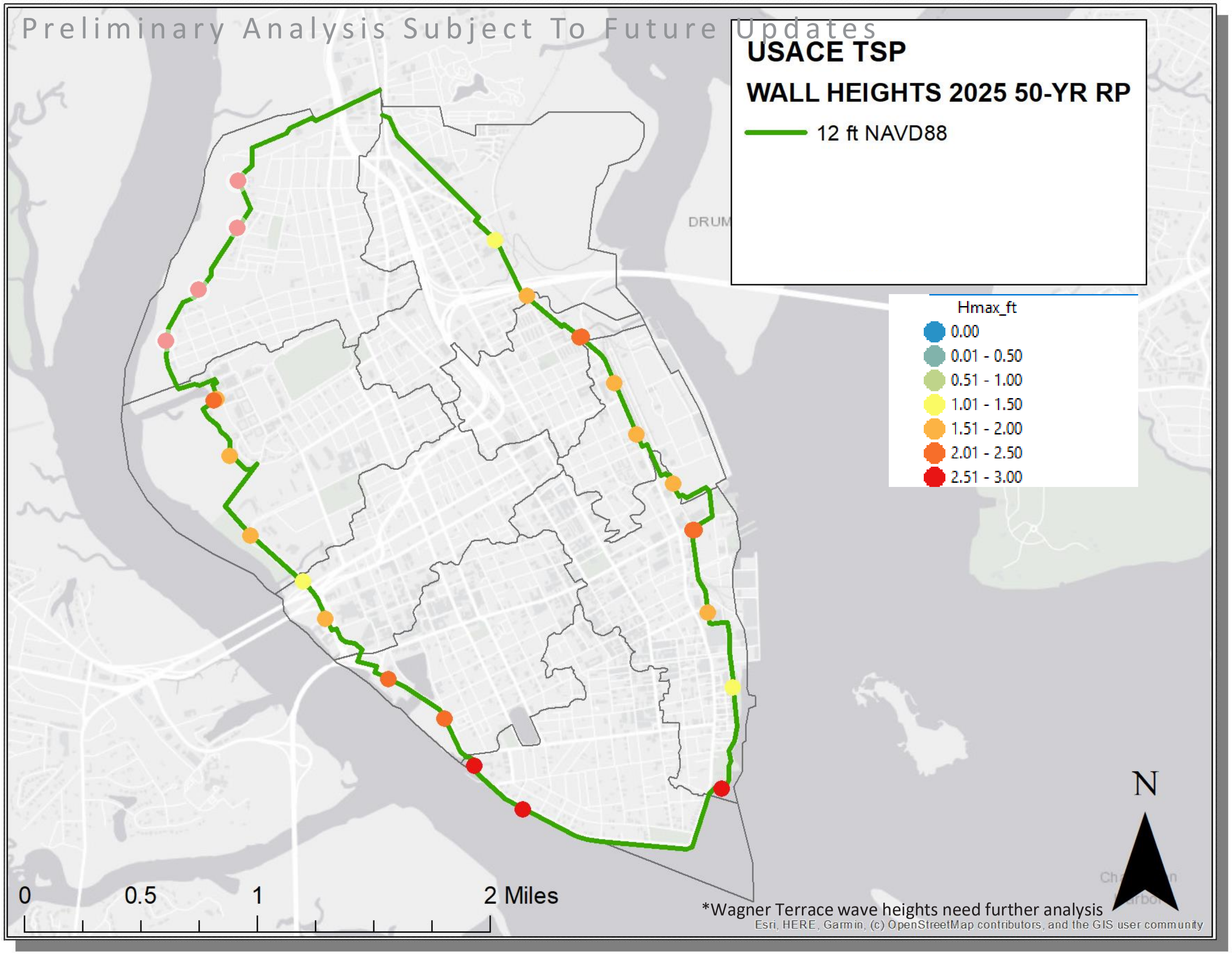
| Orleans Parish - Lakefront East Reaches 1% Hydraulic Design Elevations | | | | | | | |
|---|---|---|---|---|---|---|---|
| Hydraulic Reach | Name | Type | Condition | Depth at Toe (ft) | Elevation (ft) | Overtopping Rate q50 (cfs/ft) | Overtopping Rate q90 (cfs/ft) |
| NE07 | Citrus Pump Station (OP #10) | Structure/Wall | Future | 11.5 | 14.5 | 0.020 | 0.069 |
| NE08 | Jahncke Pump Station (OP #14) | Structure/Wall | Future | 11.5 | 14.5 | 0.020 | 0.069 |
| NE09 | St Charles Pump Station (OP #16) | Structure/Wall | Future | 10.0 | 15.5 | 0.017 | 0.060 |
| NE30-FW | Transition Reach from NE01-NE02 T-walls | Structure/Wall | Future | 12.0 | 14.5-17.5 | 0.010 | 0.087 |
| NE31 | South Point Transition Reach from NE02 to NE17 at I-10 | Levee | Existing | 9.0 | 16.5 | 0.009 | 0.058 |
| NE31 | South Point Transition Reach from NE02 to NE17 at I-10 | Levee | Future | 10.5 | 18.0 | 0.007 | 0.053 |

Preliminary Analysis Subject To Future Updates

# Overtopping Analysis

- Preliminary high-level Analysis
- Based on USACE wave heights provided in week of November 16th 2020
- Assumptions:
  - Use USACE wave heights (progressive)
  - Coincident peak water levels and wave heights perpendicular to alignment with wave transformation (50yr or 100yr RP wind speeds along transect) (conservative)
  - Use EurOtop design and assessment approach (conservative)
  - Use mean wave heights and aggregation results over districts, while in reality substantial spatial variability will be present (neutral)
  - Allow for relative high overtopping rates (progressive)
  - Overtopping duration = 1hr (neutral)
  - Storage areas determined based on assumption of 4ft of storage (progressive)
- Reanalysis warranted when USACE updates hydraulic and wave height data

Preliminary Analysis Subject To Future Updates



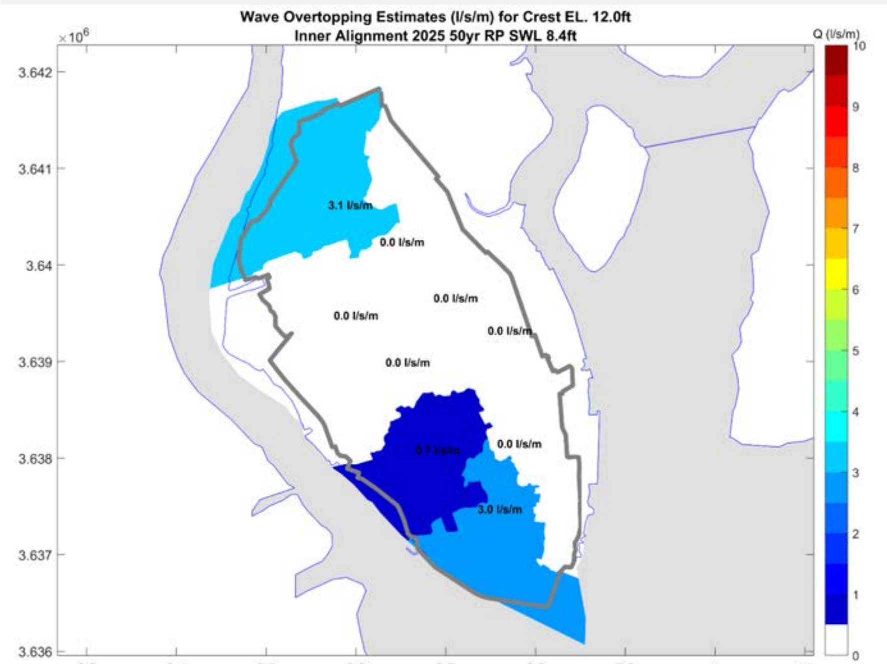

Wave Heights around the peninsula investigated for both the USACE “inner” alignment and a hypothetical “outer” alignment.

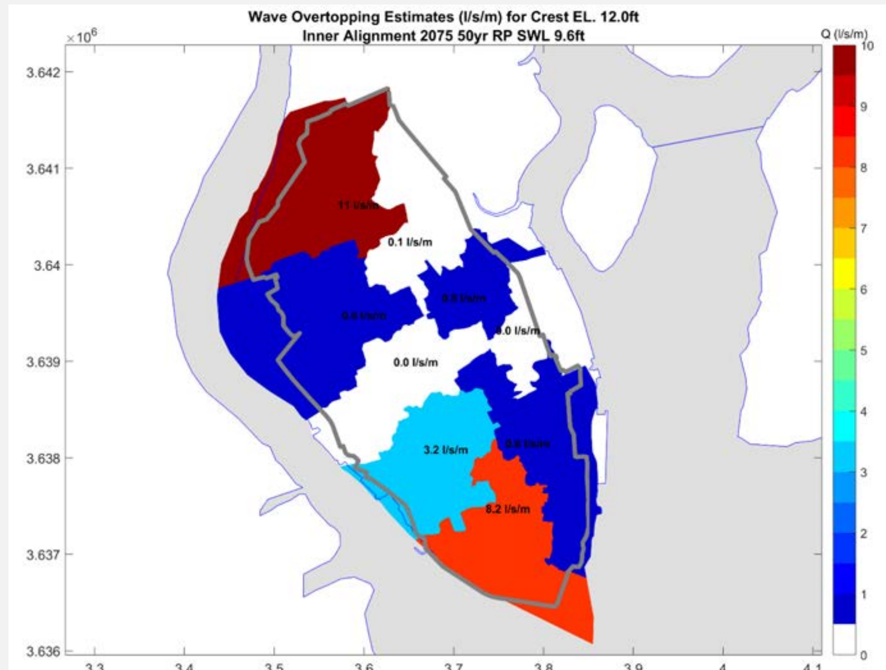
Figure shows 100yr Wave Heights at the inner alignment for 2075

# +12 ft Crest – Inner Alignment (50yr RP)

50-YEAR RP CONDITIONS: 2025
- Overtopping is relatively low for all areas

50-YEAR RP CONDITIONS: 2075
- Overtopping is relatively low for all areas




*Wagner Terrace overtopping rates will need further analysis

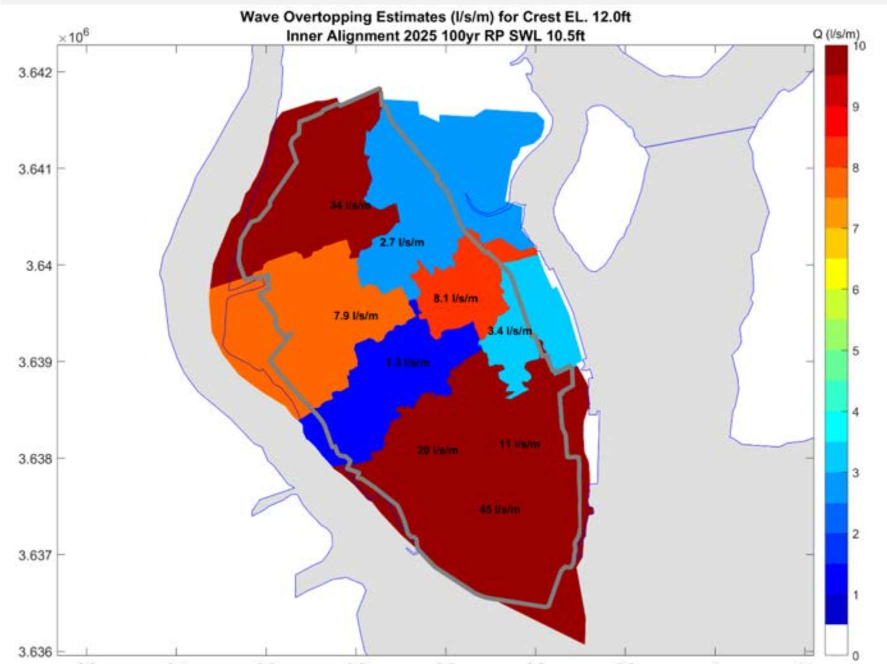
# +12 ft Crest – Inner Alignment (100yr RP)

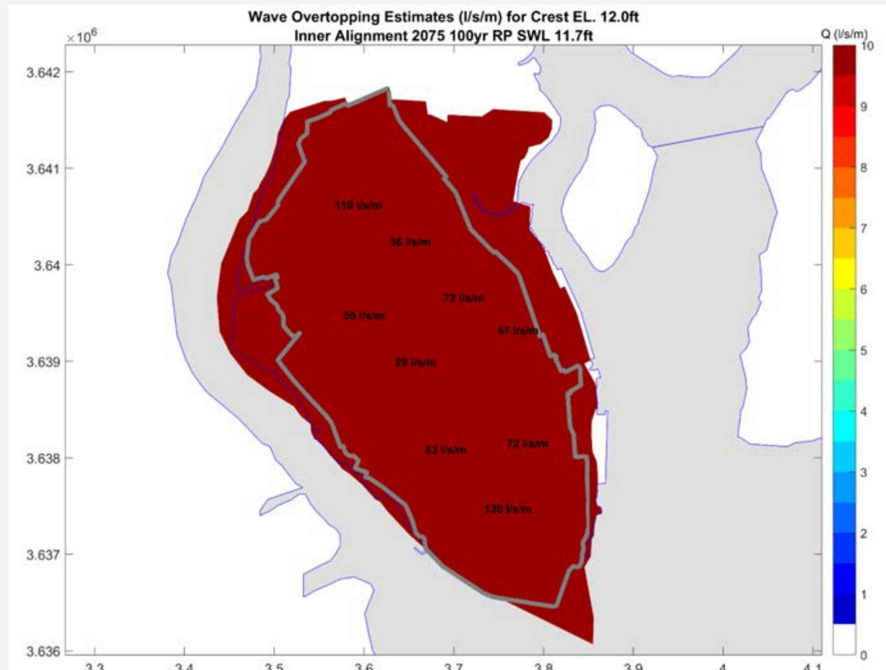
100-YEAR RP CONDITIONS: 2025

- Overtopping issues at Wagener Terrace, Mill Pond, and Battery

100-YEAR RP CONDITIONS: 2075

- Overtopping issues at all locations




*Wagner Terrace overtopping rates will need further analysis

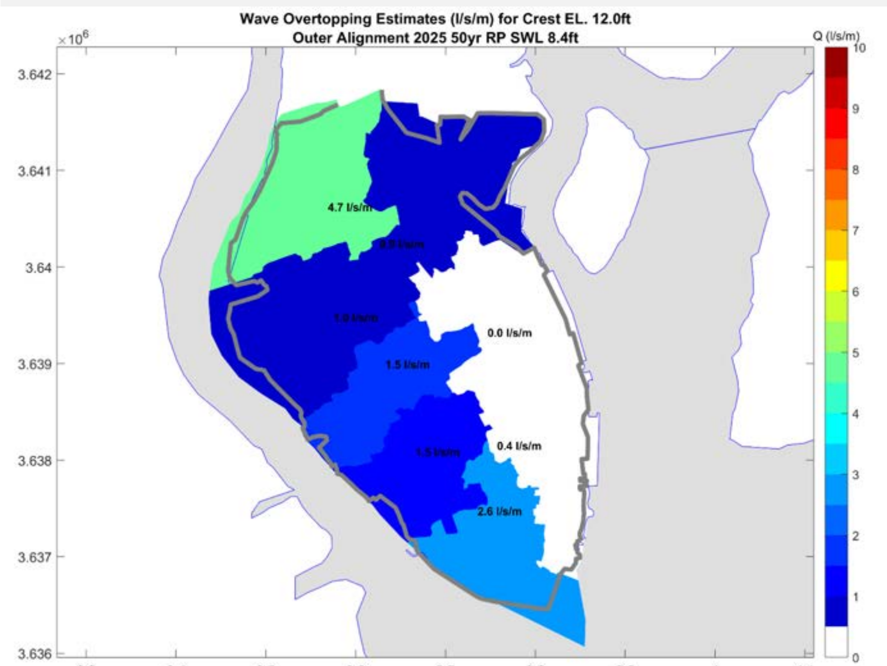
# +12 ft Crest – <u>Outer</u> Alignment (50yr RP)

50-YEAR RP CONDITIONS: 2025

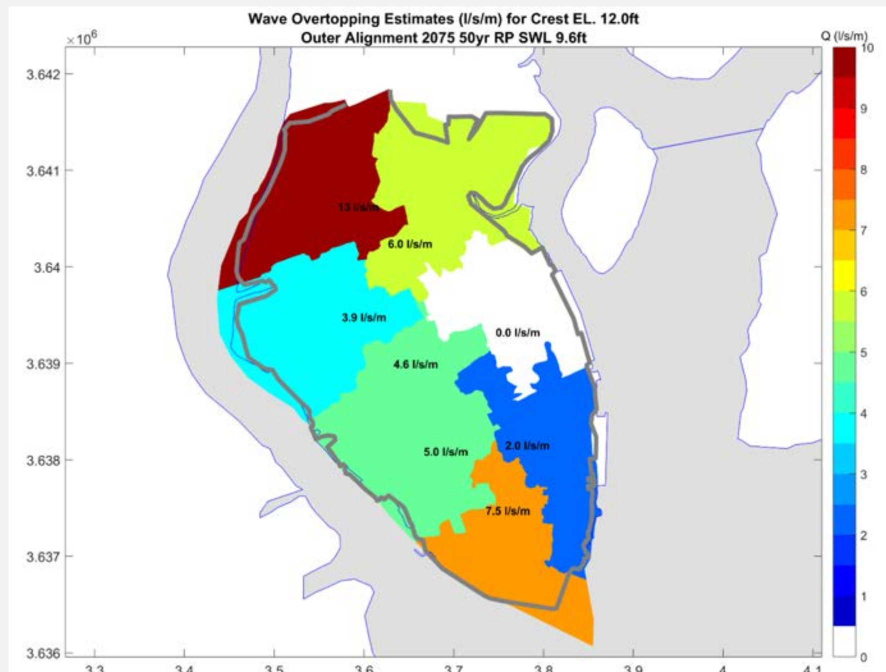
- Overtopping is relatively low for all areas

50-YEAR RP CONDITIONS: 2075

- Overtopping issues potentially at Wagener Terrace but generally relatively low






*Wagner Terrace overtopping rates will need further analysis

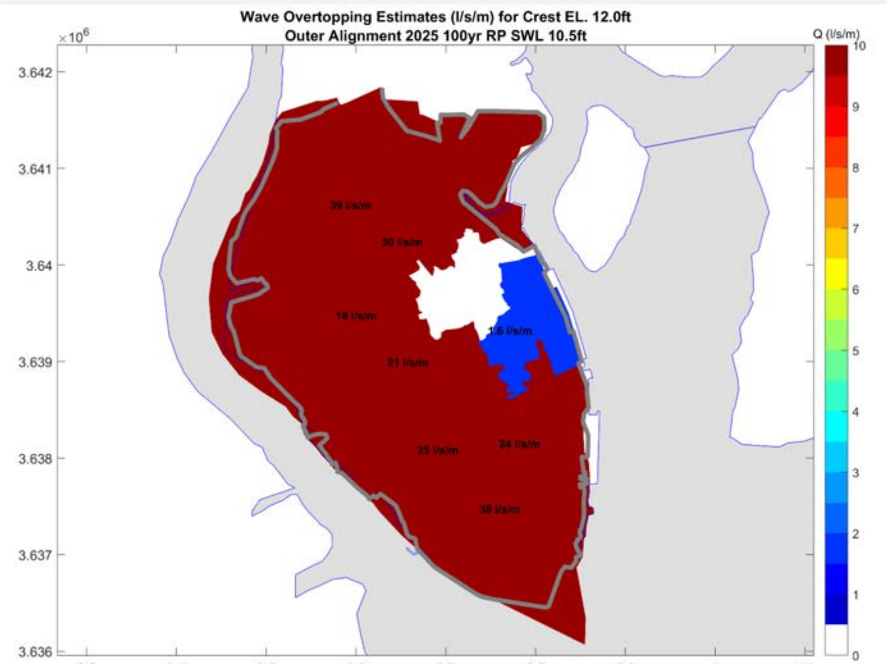
# +12 ft Crest – <u>Outer</u> Alignment (100yr RP)

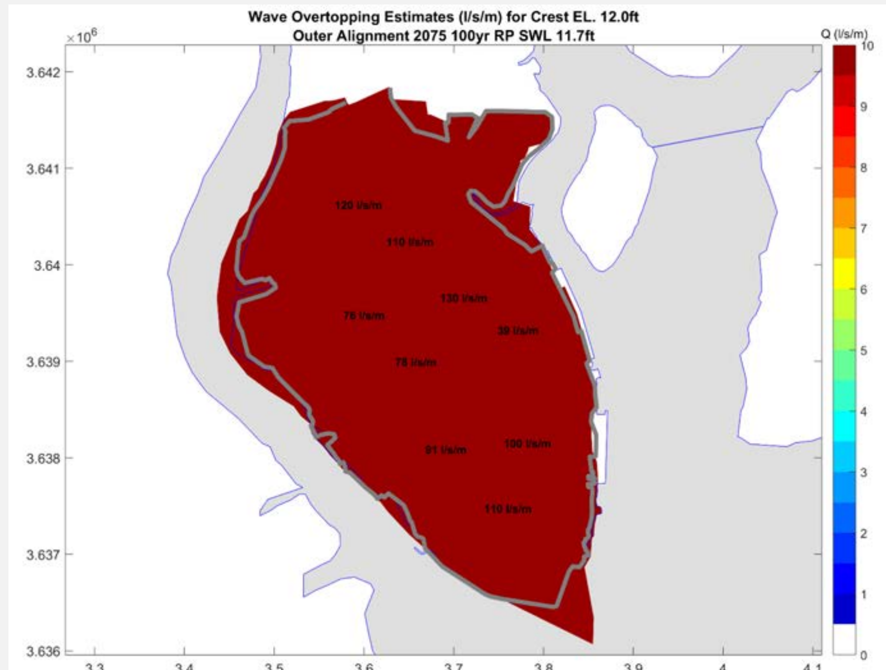
100-YEAR RP CONDITIONS: 2025

- Overtopping issues at almost all locations
- Exceptions: Vardells Creek, Columbus Terminal (Port)

100-YEAR RP CONDITIONS: 2075

- Overtopping issues at all locations




*Wagner Terrace overtopping rates will need further analysis

Preliminary Analysis Subject To Future Updates

# Overtopping Discharge Summary +12 ft Crest

| RP (years) | Year | Crest (ft, NAVD88) | Alignment | Battery | Mill Pond | Spring Fishburne | Gadsden Creek | Wagener Terrace* | Market Street | Columbus Terminal (Port) | Newmarket Creek | Vardells Creek |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | liter/second/meter | | | | | | | | |
| 50 | 2025 | 12 | USACE (Inner) | 3.0 | 0.7 | 0.0 | 0.0 | | 0.0 | 0.0 | 0.0 | 0.0 |
| 50 | 2075 | 12 | USACE (Inner) | 8.2 | 3.2 | 0.0 | 0.6 | | 0.6 | 0.0 | 0.1 | 0.6 |
| 100 | 2025 | 12 | USACE (Inner) | 44.8 | 19.8 | 1.3 | 7.9 | | 10.9 | 3.4 | 2.7 | 8.1 |
| 100 | 2075 | 12 | USACE (Inner) | 127.7 | 83.2 | 28.9 | 55.3 | | 71.8 | 47.1 | 36.0 | 71.9 |
| | | | | | | | | | | | | |
| 50 | 2025 | 12 | Outer | 3.0 | 1.5 | 1.5 | 1.0 | | 0.4 | 0.0 | 0.9 | 0.0 |
| 50 | 2075 | 12 | Outer | 8.2 | 5.0 | 4.6 | 3.9 | | 2.0 | 0.0 | 6.0 | 0.0 |
| 100 | 2025 | 12 | Outer | 44.8 | 25.1 | 20.6 | 17.5 | | 24.4 | 1.6 | 30.1 | 0.0 |
| 100 | 2075 | 12 | Outer | 127.7 | 91.1 | 78.2 | 76.0 | | 104.6 | 38.6 | 112.5 | 127.9 |

*Wagner Terrace overtopping rates will need further analysis

*Wagner Terrace overtopping rates will need further analysis

# Overtopping Volume Summary +12 ft Crest (1hr of overtopping)

Draft Subject To Revision

| RP (years) | Year | Crest (ft, NAVD88) | Alignment | Battery | Mill Pond | Spring Fishburne | Gadsden Creek | Wagener Terrace* | Market Street | Columbus Terminal (Port) | Newmarket Creek | Vardells Creek |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | acre-feet | | | | | | | | |
| 50 | 2025 | 12 | USACE (Inner) | 18.4 | 2.2 | 0.0 | 0.0 | | 0.1 | 0.0 | 0.0 | 0.0 |
| 50 | 2075 | 12 | USACE (Inner) | 51.3 | 9.8 | 0.0 | 3.8 | | 4.4 | 0.1 | 0.3 | 0.8 |
| 100 | 2025 | 12 | USACE (Inner) | 278.8 | 61.5 | 2.8 | 49.1 | | 77.8 | 15.1 | 13.2 | 10.8 |
| 100 | 2075 | 12 | USACE (Inner) | 795.4 | 259.2 | 64.3 | 344.4 | | 510.8 | 209.5 | 176.2 | 96.0 |
| | | | | | | | | | | | | |
| 50 | 2025 | 12 | Outer | 18.4 | 4.5 | 3.4 | 6.0 | | 3.0 | 0.0 | 4.5 | 0.0 |
| 50 | 2075 | 12 | Outer | 51.3 | 15.5 | 10.2 | 24.4 | | 14.4 | 0.0 | 29.2 | 0.0 |
| 100 | 2025 | 12 | Outer | 278.8 | 78.2 | 45.7 | 109.2 | | 173.9 | 7.1 | 147.4 | 0.0 |
| 100 | 2075 | 12 | Outer | 795.4 | 283.6 | 173.8 | 473.2 | | 744.2 | 171.9 | 550.3 | 170.7 |

*Wagner Terrace overtopping rates will need further analysis

# Overtopping Volume Summary +12 ft Crest (1hr of overtopping)

Draft Subject To Revision

| RP (years) | Year | Crest (ft, NAVD88) | Alignment | Battery | Mill Pond | Spring Fishburne | Gadsden Creek | Wagener Terrace* | Market Street | Columbus Terminal (Port) | Newmarket Creek | Vardells Creek |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Acres (assuming 4ft water depth) | | | | | | | | |
| 50 | 2025 | 12 | USACE (Inner) | 4.6 | 0.5 | 0.0 | 0.0 | | 0.0 | 0.0 | 0.0 | 0.0 |
| 50 | 2075 | 12 | USACE (Inner) | 12.8 | 2.5 | 0.0 | 1.0 | | 1.1 | 0.0 | 0.1 | 0.2 |
| 100 | 2025 | 12 | USACE (Inner) | 69.7 | 15.4 | 0.7 | 12.3 | | 19.4 | 3.8 | 3.3 | 2.7 |
| 100 | 2075 | 12 | USACE (Inner) | 198.8 | 64.8 | 16.1 | 86.1 | | 127.7 | 52.4 | 44.0 | 24.0 |
| | | | | | | | | | | | | |
| 50 | 2025 | 12 | Outer | 4.6 | 1.1 | 0.8 | 1.5 | | 0.8 | 0.0 | 1.1 | 0.0 |
| 50 | 2075 | 12 | Outer | 12.8 | 3.9 | 2.6 | 6.1 | | 3.6 | 0.0 | 7.3 | 0.0 |
| 100 | 2025 | 12 | Outer | 69.7 | 19.6 | 11.4 | 27.3 | | 43.5 | 1.8 | 36.8 | 0.0 |
| 100 | 2075 | 12 | Outer | 198.8 | 70.9 | 43.5 | 118.3 | | 186.1 | 43.0 | 137.6 | 42.7 |

*Wagner Terrace overtopping rates will need further analysis

# Overtopping Analysis Synopsis (1)

- Peninsula is exposed to waves, but waves appear to be low to moderate (the exception is the Battery)
- Wave overtopping will need to be considered in design of flood risk reduction measures, as recognized by USACE, but it would benefit the study if more explicitly addressed.
- Probabilistic considerations of water levels and waves and overtopping to establish wall height preferable for risk informed design
- Wall Height of 12ft
  - will result in substantial overtopping (100yr RP conditions in 2025 or 50yr RP conditions in 2075)
  - Inner Alignment constrains opportunities to deal with wave overtopping volume in a resilient manner
  - To reduce the overtopping rate, a wall height increase to +15 at the Battery may need to be considered (in the future/2075)

Preliminary Analysis Subject To Future Updates

## Overtopping Analysis Synopsis (2)

- Outer Alignment
  - At some locations more exposed to wave energy, but still moderate
  - Wall height differences (if same overtopping threshold is used) are small when compared to the inner USACE alignment
  - Provides more flexibility for water storage (without structural impacts) and adaptability in the future
  - Could be designed to accommodate higher design overtopping rates
  - Provides flexibility to store, collect or route both rainfall water and overtopping water

Preliminary Analysis Subject To Future Updates

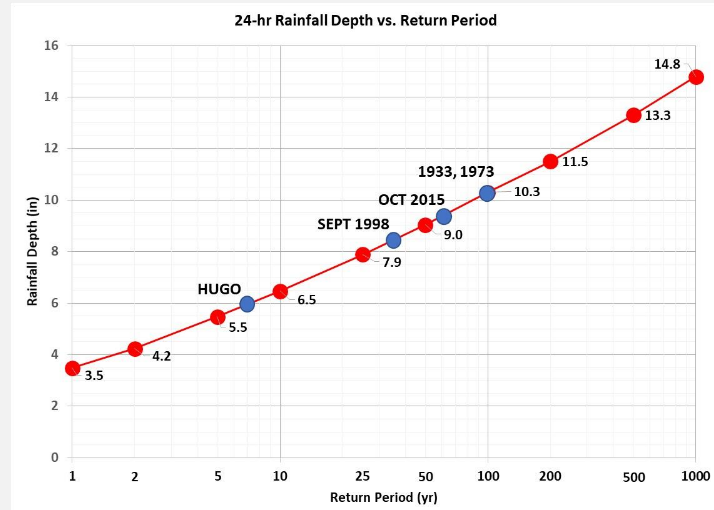
# Interior Drainage Assessment

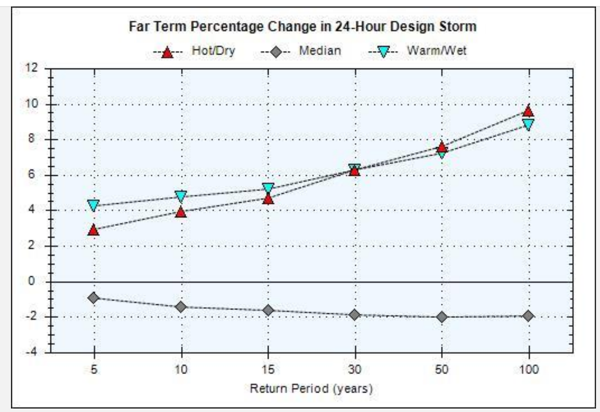
## Rainfall Runoff and Climate Change

Preliminary Analysis Subject To Future Updates

# Interior Drainage – Shared Responsibility

- Stormwater Drainage System Not a CSRM Responsibility But Effects on Interior Drainage By Project Must Be Evaluated/Mitigated As Policy Allows
- Lack of Complete Pipe Network Database Did Not Allow for SWMM Analysis
- 2D HEC-RAS Overland Analysis and Rain-on-Grid Approach Used
- Current Atlas-14 Rainfall Depths Utilized In Analysis
- Ranges in Atlas 14 and SWMM CAT Tool Show That Design Rainfall Depths May Increase 10-20% Over Project Life




Preliminary Analysis Subject To Future Updates

# Interior Drainage – Shared Responsibility

- These Potential Increases In Rainfall Depths May Increase Residual Flooding of the FWP Condition
- Addition of Wave Overtopping Rates/Volumes Planned to Be Accounted For in PED Phase
- Unclear How Ponded Volumes Were Used to Develop Preliminary Pump Sizes/Estimates (Seems to Call Out Norfolk Study For Sizes & Costs?)
- Outer Alignment Would Provide Storage Which May Reduce Pumping Requirements & Allow For Future Adaptation
- Will Post-TSP Evaluations Mentioned In the H&H Appendix Happen Before PED?

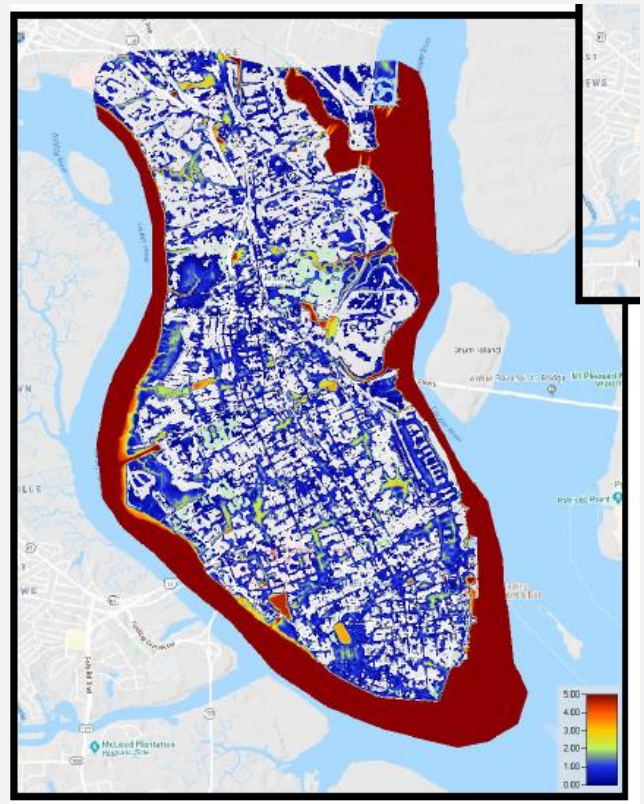



Figure 8.1.4.4. 10% AEP FWO Peak

Preliminary Analysis Subject To Future Updates

# USACE TSP Observations

- USACE TSP:
  - IF 50yr RP design with +12 ft NAVD88
    - OK, however,
    - Design the structure and area behind it for wave overtopping
    - Realize that future FEMA flood maps will then (likely) show the city within the 100 year flood plain in the near future (without adaptation – e.g. wall height adjustments)
  - IF 100yr RP design with +12 ft NAVD88
    - Large overtopping rates (potential freeflow) – very challenging to design to (without raising the wall)
    - Project adaptations needed during project service life to maintain 100yr RP
    - Would allow for adaptation towards maintaining FEMA accreditation
  - Probabilistic Analysis of wave overtopping in PED Phase would likely increase wall height further if overtopping criterion is set based on New Orleans design guidelines

Preliminary Analysis Subject To Future Updates

# USACE TSP Observations – Final Thoughts

- USACE TSP:
  - Complete Design of Wall/Foundation so Wall Can Be Incrementally Raised
    - Will Provide Adaptability
  - Can Alternative Alignments Be Shown in TSP Plan and be further assessed during PED?
    - Increased Overtopping Rates May Push More Interior Flood Storage Requirements and Make Wetland Mitigation Requirements More Attractive/Cost Effective Compared to Gray Infrastructure and Increased Pump Sizes & O&M Costs
  - Probabilistic Analysis of Increased Rainfall Depths Should Also Be Included In Analysis to More Accurately Assess Potential Project Effects and Increased Residual Flooding

Preliminary Analysis Subject To Future Updates

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