ABSTRACT

Title of Thesis	GUIDING DESIGN FOR SEA-LEVEL RISE AND STORM SURGE IN NATIONAL PARKS: AN EXAMPLE AT THE CONFLUENCE OF THE POTOMAC AND ANACOSTIA RIVERS NEAR THE TIDAL BASIN IN WASHINGTON, D.C.
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Climate change threatens to disrupt human communities and lifestyles globally. Coastal areas in particular face sea-level rise and storm surge issues. Identifying design procedures for climate change design could promote successful implementation and long-term sustainability. Based on existing literature, a set of design criteria is formed to guide the implementation of nature-based design in response to projected sea-level rise in East Potomac Park in Washington, D.C. The design criteria address socio-ecological factors of landscape, planning and design for adaptation and resilience, communicating climate change, and design performance evaluation. The design criteria inform a site design focused on adapting with projected sea-level rise. The design is cross-evaluated with the criteria for robustness. The project connects research with practice by creating a design-science feedback loop and provides a platform for innovative solutions in climate change design in national parks and other landscapes threatened by issues of sea-level rise.

GUIDING DESIGN FOR SEA-LEVEL RISE AND STORM SURGE IN NATIONAL PARKS: AN EXAMPLE AT THE CONFLUENCE OF THE POTOMAC AND ANACOSTIA RIVERS NEAR THE TIDAL BASIN IN WASHINGTON, DC

by

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Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Landscape
Architecture
2021

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Acknowledgments

Many thanks are indebted to more people than can be given due credit in short space. Especially, I extend gratitude to Jaleesa, a very supportive wife, and my parents, Bob and Kathy, for always encouraging higher education.

Notably, Chris Ellis was a helpful thesis advisor who made regular time for discussion and collaborated in submitting research to the Council of Educators in Landscape Architecture. Thesis committee members Peter May and Elizabeth Van Dolah brought insightful and needed outside perspective to the project, thank you. And committee member David Myers provided a keen eye in the editing process.

Finally, thank you to the friends, classmates, colleagues, and professors who all, in their own way, have propelled my academic journey.

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List of Terms

Flooding: An instance of water temporarily being on land.

Inundation: Water that permanently remains on what was previously dry land.

Relative sea level: A comparison of water level to a reference point on land.

Sea level: Average seawater surface level.

Sea level change: In reference to relative sea level change, mainly due to increases in ocean water volume or land level changes. Sometimes mistaken with sea level rise.

Sea-level rise: An increase in sea level.

Storm surge: Storm-driven rise of water above the normal, predicted tide.

*Adapted from Caffrey, Beavers, & Hoffmann, 2018.

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Chapter 1: Introduction

Topic

Climate change poses immediate challenges for human populations worldwide. Coastal urban areas in particular face significant issues, with vulnerability to sea-level rise and storm surge being especially poignant for the nearly 600 million people living at elevations near sea level (Araos et al., 2016; Neumann et al., 2015). Sea-level rise threatens transportation and housing infrastructure, while increasingly destructive storm surge and frequent flooding put human lives in danger. Exceptionally dire circumstances might even necessitate that communities relocate, threatening to undermine community frameworks and distance people from a sense of place and identity.

Designing for climate change, and specifically for sea-level rise, then, is a monumental challenge facing designers today. Fair weather flooding, for instance, is already common problem in coastal cities and poses threats to local economies (Hino et al., 2019). Yet, the issues of sea-level rise are not confined to the typical city landscape.

National Parks—important in preserving cultural and natural resources—are vulnerable to sea-level rise, too, especially considering that more than one quarter of lands managed by the National Park Service fall on ocean coastlines (Caffrey, Beavers, & Hoffman, 2018). In fact, in 2010 former Park Director Jonathan Jarvis stated "I believe climate change is fundamentally the greatest threat to the integrity of our national parks that we have ever experienced" (National Park Service, 2010). The National Capital Region, which hosts famed landscapes managed by the National Park Service such as those of the National Mall and Tidal Basin in Washington, D.C., is expected to experience the highest rate of sea level change in the National Park System by 2100 (Caffrey, Beavers, & Hoffman, 2018). In Washington, D.C., sea-level rise in addition to storm surge could precipitate serious flooding issues threatening to undermine the monumental core of the city. Indeed, the National Trust for Historic Preservation named the National Mall Tidal Basin as one of the United States' most endangered historic places in 2019, largely due to flooding issues. In response to this threat, the Trust helped form the National Mall Ideas Lab, which identified five landscape architecture firms—DLANDstudio, GGN, Hood Design Studio, James Corner Field Operations, and Reed Hilderbrand—to imagine a redesign of the Tidal Basin addressing flooding issues (National Trust for Historic Preservation, 2019).

Purpose

The purpose of this thesis is to guide design for the effects of sea-level rise and storm surge in East Potomac Park, an artificial island landscape managed by the National Park Service near the Tidal Basin on the National Mall in Washington, D.C. The thesis uses a literature review of journal articles, agency reports, and other written documents addressing design and planning concerns related to climate change, particularly sea-level rise, to inform and formulate a set of pre- and post-evaluation guidelines. These guidelines—the iterative methods framework—identify a common set of procedures across professions and provide recommendations for directing decisions throughout the design process, and later, to evaluate the success of the design.

The design process embraces a nature-based design approach for sea-level rise and storm surge. Nature-based design explores using natural features to increase coastal protection (Pontee et al., 2017). Precedents for nature-based design in landscape architecture include SCAPE's Living Breakwaters project in New York City and Turenscape's Sanya Mangrove Park in China (Scape Landscape Architecture; Turenscape). In studying nature-based design solutions, the project proposes that parts of the study site be planned as future wetland and hillside to provide protective and adaptation capacity, while preserving natural and cultural resources, maintaining place identity, and incorporating climate change education initiatives in context of sea-level rise on the National Mall.

Significance

Most broadly, the thesis explores how the effects of climate change might influence the built environment and infrastructure of a National Park landscape adjacent the National Mall in Washington, D.C. The project integrates science and design, and aspires to connect research and design throughout the design process in a manner that is informative to future design projects addressing issues of climate change. Philosophically, the project also explores strategies of adaptation vs. defense in respect to sea-level rise, prompting questions such as whether to accommodate or fight against coastal change, be proactive or reactive in coastal planning efforts, or whether to invest in built, hybrid, or natural solutions for sea-level rise. Therefore, in tackling the complexities of sea-level rise, the project transcends any single discipline. Research and design components pull on a richness of detail and depth informed by multiple sources of published information from many parts of the design, planning, and research process. Rather than focusing on a narrow scope of issues only relevant to local issues, the project seeks an increasingly comprehensive and interdisciplinary approach.

Ultimately, the project aspires to improve the decision-making processes for communities affected by climate change issues such as sea-level rise. The project accommodates both human and environmental concerns through the creation of an iterative methods framework and accompanying site design that work to engage and support community members in the decision-making process. The iterative methods framework and accompanying design could be useful as a foundational tool and case study for park managers, policy-makers, and communities concerned with sea-level rise and storm surge. The project furthers dialogue on the applicability of nature-based design and associated management approaches for preserving natural and cultural resources at risk from climate change issues. Although the thesis addresses issues of sea-level rise in an urban land area managed by the National Park Service, the study aims to be widely applicable to other study sites. By addressing issues of sea-level rise and storm surge in national park landscapes in the nation's capital, this thesis aims to inspire, understand, and further dialogue on the topic, and in turn, propel design possibilities for climate change adaptation strategies.

Chapter 2: Literature Review

Climate Change/Sea-level rise

Climate change poses significant challenges in human-made environments and natural systems worldwide (IPCC, 2014). More than half of the world's population lives in urban areas and urbanization is expected to continue in the future (Revi et al., 2014). Many cities lack measures for climate change adaptation planning, while those that are better prepared are mostly located in high-income countries (Araos et al. 2016). Moreover, growing populations of people are living less than 10 m above sea level, creating significant risks from climate change issues related to sea-level rise, including elevated tides, increased flooding, erosion and groundwater salinsation (Oppenheimer et al., 2019)

Global average sea-level rise since the late 19th century is around 210 mm, with a linear trend of 1.7-1.9 mm per year (Church & White, 2011), and global average sea level is likely to increase in the future, with some studies reporting a possible global sea-level rise increase of 2 m by 2100 in high emission scenarios considering ice sheet losses (Bamber et al., 2019; Kopp et al., 2017; Le Bars et al., 2017). According to an Intergovernmental Panel on Climate Change Special Report (Oppenheimer et al., 2019), likely sea-level rise projections for global mean sea-level rise range from 0.24-0.32 m by 2050 and 0.43-0.84 m by 2100, with a 17 percent chance of 0.59-1.1 m by 2100. Moreover, sea-level rise is not uniform, and some regions could see up to 30 percent higher sea-level rise than the global average due to factors such as ocean dynamics and subsidence (Oppenheimer et al., 2019).

In the United States, the North Atlantic Coast is extremely vulnerable to sea-level rise, especially considering the region's population density and coastal hazards such as hurricanes and severe storms. Based on climate models from the Intergovernmental Panel on Climate Change

(IPCC) Fourth Assessment Report (AR4), Yin, Schlesinger, & Stouffer (2009) project sea-level rise ranging .36-.51 m in New York City; .37-.52 m in Boston; and .33-.44 m in Washington, D.C. by the end of the 21st century. Sea-level rise in the Mid-Atlantic region is also exacerbated by land subsidence following the last Ice Age 12,000 years ago (Satterfield, 2018 & National Capital Planning Commission, 2018). Moreover, the region has regularly experienced severe storms in the past. Hurricane Isabel in 2003, for instance, caused significant flooding in in the Chesapeake Bay (Boesch, 2013 & Strauss et al. 2014). In 2012, Hurricane Sandy, brought widespread economic damage, where storm surges reached 9.4-12.65 ft above normal high tides in the New York Metropolitan area. The event revealed an immediate need to address sea-level rise and storm surge issues in coastal areas (US Army Corps of Engineers New York District, 2019).

Tide gauges along the East and Gulf Coasts have also been used to extrapolate on storm surge and flooding. Dahl, Fitzpatrick, & Spanger-Siegfried (2017) studied 52 locations along the U.S. East and Gulf Coasts, with projections indicating that Washington, D.C. will experience up to 337 tidal flooding events per year by 2045, the most of all the study cities. Moreover, the study ranked Washington, D.C. in the top 10 for number of flooding events that received a Coastal Flood Advisory in 2012-2013, with almost 70, and in the top three for average tidal flood events between 2001-2015. The greater Washington D.C. metropolitan area is susceptible to multiple flooding risks, including riverine, coastal, and interior flooding (National Capital Planning Commission, 2018). Tidal flooding and storm surge, which can be caused by hurricanes, have the potential to produce extremely high water when occurring at high tide in the Washington, D.C. area (National Capital Planning Commission, 2008). In fact, Strauss et al. (2014) found that Washington, D.C. has around a 50 percent chance of experiencing a record-breaking flood by 2040. For a 100-yr flood, this would be 11 ft above the high tide line. For comparison, previous high floods were 7.9 ft in 1942 during torrential rains; 7.4 ft in 1936 due to storm water; and 7.1 ft in 2003 during Hurricane Isabel. Under the highest sea-level rise scenarios, floods exceeding these records would become annual events by 2080-2100, according to the study.

Furthermore, Caffrey, Beavers, & Hoffman (2018) estimate that the National Capital Region is estimated to have the highest rate of sea level change in the National Park System by 2100, with an average of 0.8 m sea-level rise. U.S. national parks are important in preserving cultural and natural resources. Yet, with more than one quarter of lands managed by the National Park Service existing on ocean coastlines, many National Parks are vulnerable to the effects of climate change, especially issues resulting from sea-level rise. Peek and Beavers (2015) estimate that with 1 m of sea-level rise, over $40 billion of National Park assets will be at risk. For the National Mall in Washington, D.C. the effects of sea-level rise alone may not cause significant damage, but in combination with storm surge, the area could face serious issues (Caffrey, Beavers, & Hoffman, 2018). Economic costs of 0.1 m and 5 m of sea-level rise for Washington, D.C. are between approximately $2 billion and $24.6 billion, respectively (Ayyub, Braileanu, and Qureshi, 2012), while sea-level rise threatens $4.6 billion in property value less than 6 ft above the high tide line, with the amount increasing to $9 billion at 10 ft above high tide level (Strauss et al., 2014).

The Washington, D.C. tide gauge 8594900 (NOAA, Tide & Currents), which is located near the Tidal Basin in the Washington Channel, has experienced an annual mean change of around 3.43 mm from 1924-2020, equivalent to 1.13 ft in 100 years (NOAA, 2020), with the area projected to experience 0.33 m sea level rise by 2050 (Tebaldi, Strauss, & Zervas, 2012). Largely due to flooding issues, the National Trust for Historic Preservation named the National Mall Tidal Basin as one of the United States' most endangered historic places in 2019. Annually, an estimated 36 million people from around the world visit the National Mall, with the Tidal Basin cherry trees attracting 1.5 million visitors during the National Cherry Bloom Festival. However, the Tidal Basin experiences regular flooding during high tide, creating accessibility and safety issues as well as threatening the longevity of the Tidal Basin cherry trees (National Trust for Historic Preservation, 2019). In Washington, D.C., sea-level rise of 0.1-2.5 m affects 10.5-55.1 or road; 3.4-7.1 km of metro tracks; 1-6 parks; and 2-13 monuments and museums, adverse effects that could hamper tourism and incur economic losses (Tebaldi, Strauss, & Zervas, 2012). Similarly, in nearby Annapolis, Maryland, Hino et al. (2019) found that visitation numbers to historic downtown Annapolis are likely to drop by 37,506 visits, or approximately 24%, during high tide flooding with 1 ft of sea-level rise.

Nature-based Solutions

A number of protective design solutions based on natural systems have been proposed to combat the effects of sea-level rise, including seawalls, floodwalls, tide gates, levees and surge barriers. However, many of these options require ongoing upkeep, may not be cost-effective, create ecological problems, and fail to offer long-term solutions (Hirschfeld & Hill, 2017). Alternatively, nature-based design and ecosystem-based adaptation is receiving increasing attention as a strategy for adapting to sea-level rise, storm surge, and flood risks (Oppenheimer et al., 2019; Bridges et al., 2018).

Nature-based design incorporates natural features that improve coastal protection (Pontee et al., 2016). For instance, coral reefs and salt marshes can reduce wave height up to 70 and 72 percent, respectively (Narayan et al., 2016). In New York City, wetland and dune restoration have been suggested as methods of shoreline protection (Rosenzweig et al., 2011). Tidal wetlands can even offer a level of coastline protective capacity against storm surge during hurricanes, with larger wetlands providing increased protection from flooding damage and storm surge (Highfield, Brody, & Shepard, 2018). During Hurricane Sandy, wetlands were found to protect against $625 million in direct flood damages from North Carolina to Maine. In Ocean County, NJ, salt marshes contributed to a 16% average reduction in annual flood losses (Narayan et al., 2017). Coastal wetlands have been shown to provide additional benefits such as providing erosion control, sequestrating carbon, and maintaining fisheries (Barbier et al., 2011).

Moreover, nature-based solutions can often be more cost-effective than built infrastructure solutions. Salt marshes and mangroves were shown to be 2-5 times cheaper than a submerged breakwater for waves up to 0.5 m, and the habitats become more effective than breakwaters at increasing depth (Narayan et al., 2016). In addition, Hirschfeld and Hill (2017) observed that a shift from using walls to protect vulnerable coastlines to earthen systems reduces the cost of adaptation to coastal flooding.

Living shorelines offer another avenue for maximizing coastal habitat benefits. However, living shorelines have been thought of as inferior to armoring strategies in protecting coastlines from erosion and storm damage (Bilkovic et al., 2016). Living shorelines can be also be applied along armored shoreline, though living shorelines fall short of complete, natural restoration. Still the method has potential benefits. Notably, studies have revealed that all of the Virginia coast is suitable for living shoreline, but only 20% of permit requests are for living shoreline, indicating a shortfall related to policy, public education, and incentives on living shorelines (Bilkovic et al., 2016).

Utility in Landscape Architecture

SCAPE Landscape Architecture's Living Breakwaters project in New York City provides an example of integrating nature-based design. The design incorporates breakwaters off of Staten

Island to help absorb wave energy and reduce coastal flooding, while also making habitat for fish, oysters, and other species. In China, Turenscape's Sanya Mangrove Park works to restore damaged habitat and the protect coastline against storm surge. And in response to flooding and projected sea-level rise, the National Mall Ideas Lab in Washington, D.C. has identified five landscape architecture firms—DLANDstudio, GGN, Hood Design Studio, James Corner Field Operations, and Reed Hilderbrand—to imagine a redesign of the threatened Tidal Basin (National Trust for Historic Preservation, 2019).

A nature-based design approach opens a route for weaving scientific experiment into the design process, complimenting the "designed experiment" method proposed by Felson and Pickett (2005). With an ecological base, design can offer a route for collecting quality ecological data in urban settings. Furthermore, designed experiments encourage partnerships among urban designers, landscape architects, and architects that enables ecologists and researchers to weave experiments into the urban setting. Similarly, Ahern et al. (2014) propose an adaptive urban planning approach that includes "safe-to-fail" designs, which enable pilot testing of innovative, experimental design solutions in small spatial extents and low risk contexts. The approach offers an opportunity to further integrate design and science, and a method for incorporating ecosystem services into the planning and design process. Mutually beneficial for designers, planners, and researchers, such collaborative efforts work to integrate design into science. Nassauer and Opdam (2008) argue that design can be a vehicle used by scientists and practitioners to include scientific knowledge in the decision-making process related to landscape change, contending that through transdisciplinary collaboration, scientists and practitioners of many fields enhance landscape science and knowledge. Therefore, design can act as common ground between researchers and professionals, connecting science and society by informing the design process and bolstering the outcomes of landscape projects.

While mutual collaboration between researchers and practitioners is a critical component for in climate change planning, engaging and empowering the local community is also an essential and informative part of the process, or a project might risk unsuccessful adaptation or create inequities. Based on interviews in Lake Entrance, Victoria in Australia, where adaptation processes for sea-level rise have been controversial, Hurlimann et al. (2014) concluded that successful planning for sea-level rise should include adaptation strategies that promote local ownership of the response; local collaboration within and between communities, as well as among various branches of government; and adaptation responses that are fair across space and time. Lacking many of these aspects and other inconsistencies have hampered adaptation processes in the study area. Similarly, Woodruff, BenDor, & Strong (2018) found disparities between social, political, and economic measures related to sea-level rise adaptation in Dorchester County, Maryland and Dare County, North Carolina. In particular, the study highlights differences between communities that can and cannot invest in adaptation strategies, bringing into question how resources are allocated, with some communities be chosen over others in adapting to sea-level rise. Similarly, Van Dolah, Miller Hesed & Paolisso (2020) underscore the need for more community engagement in coastal wetland resilience work, as well as additional study into the legal and political dimensions influencing human adaptiveness in rural coastal areas.

Wetlands

Tidal wetlands provide an interesting opportunity to help absorb wave energy. Highfield, Brody, & Shepard (2018) examined the protective capacity of estuarine and tidal wetlands against surge flooding following landfall of Hurricane in Galveston, Texas in 2008. The findings indicate that tidal wetlands reduce flood damage from storm surge under specific distances and locations. In this case, structures within 500 ft of wetlands had less flood damage than structures beyond this distance or those with no wetland protection. Interestingly, at distances more than 500 ft from a wetland flood damage begins to increase. Additionally, larger wetlands provided more protection from storm surge flooding damage. The findings might be attributed to the complexity of the storm surge and island orientation. Local context and site-specific factors play an important role in the effects of flood damage from storm surge, as does human effects on wetlands.

Kirwin & Megonigal (2013) find that conversion of wetlands into other land uses, such as agriculture and aquaculture, has resulted in the loss of 25-50% of the world's coastal wetlands in the twentieth century, and posit that the survival of wetlands, in part, might be related to economic and sociological decisions to protect coastal infrastructure from climate change. However, Runting et al. (2018) find that the cost of preserving wetlands under sea-level rise will likely be higher than under current conditions, due to factors such as coastal wetlands migrating further inland to higher elevations, which are often private land and have a higher price value, under sea-level rise. More specifically, much attention has been given to creating policies and management strategies to enable marsh migration for the sake of protecting their ecological value, but less focus has been on the effects of wetland migration on people living in these landscapes. For instance, some coastal populations feel governments and environmentalists tend to prioritize wetland protection over coastal communities, highlighting the complexities of coastal resilience work in the context of equity and social justice (Van Dolah, Miller Hesed & Paolisso, 2020).

In the Chesapeake Bay, Beckett, Baldwin, & Kearney (2016) found that wetlands decreased in elevation nearly 1.8 mm per year, a level at least 5 mm less than the requirement to keep pace with sea-level rise. Although the measurements did not vary much along the salinity gradient, the greatest rate of elevation loss occurred in moderately saline oligohaline marshes, while an increase in elevation occurred in the freshwater marshes. However, the deposition of sediment and accumulation of organic matter play a crucial role in whether wetland ecosystems can survive sea-level rise, too. In a brackish marsh, Langley et al. (2019) found that elevated carbon dioxide levels can increase soil elevation on average by 3.9 mm/yr, with the effect mainly attributed to the below ground growth of plant material, rather than above ground growth. Therefore, elevated carbon dioxide levels, by spurring underground growth that works to increase surface elevation, might increase the resiliency of coastal wetlands to sea-level rise. Tidal freshwater marshes have also been shown to have a strong correlation with season, sediment accretion and marsh elevation, with gains largely occurring in the growing season and losses in the non-growing season (Delgado et al., 2013).

The National Park Service has taken interest in restoration of tidal freshwater wetlands. Just south of the National Mall in Washington, D.C., the National Park Service is working to restore Dyke Marsh along the Potomac River. Historically, the land was first altered in the early 1800s, when colonial landowners sought to establish ship docking and pasturelands. Later, establishing the nearby George Washington Memorial Parkway also caused alterations to the area. In working to restore the area, the National Park Service aims to provide habitat for wildlife and work to minimize the establishment of nonnative species. Additionally, a main goal is to enable natural buffers for storm and flood control in populated areas as well as provide educational, interpretation, and research opportunities at Dyke Marsh for diverse audience, demonstrating the importance of including human connection in wetland restoration projects (National Park Service, 2014).

Community Collaboration on Climate Change

Engaging and communicating with the public on climate change issues is an essential step in resilience projects. Le Cozannet et al. (2017) find that locally both public and private sectors take part in developing climate services, but a global framework of climate services remains fragmented and coastal climate services are slow to develop in order to meet the challenges of coastal climate change. However, the authors suggest there will likely be a viable market in providing services to adapt and mitigate climate change effects in the next decade.

Public lands, which are widely visited and instill inspiration throughout the country, are an especially important place to engage with the public on climate change. Local, place-based communication can prove successful, with many visitors to public lands taking interest in websites, trailside exhibits, interpretive programs, indoor exhibits, and informative videos as methods to discuss climate change (Campbell et al., 2020 & Thompson, Davis, & Mullen, 2013).

A case study in Alaska by Thompson, Davis, & Mullen (2013) revealed that visitors preferred to learn about climate science by choice rather than having information forced on them and found past/present photographs and other technology to be powerful communication tools. Interestingly, the study also identified a disconnect between park employees and visitors in communicating climate change, with less than 9% of employees believing that visitors were "very or extremely" concerned with climate change, while in reality, surveys indicated that 56% of visitors fell into this category. In Missouri, Groshong, Stanis, & Morgan (2018) found that park visitors were challenged to document examples of climate change in their local parks. Although visitors often felt climate change was difficult to visualize in Missouri, the visitors largely agreed that climate change exists and saw opportunity for education and ecological management related to climate change in the state's park system, regardless of the some of the conservative political challenges for tackling the issue in the state, again, highlighting the local context in climate change communication.

In the National Park System, climate change threatens parks, memorials, and monuments, providing opportunity for National Park Service personnel to help visitors learn about climate change issues. In the National Capital Region, culturally iconic parks provide a connection and sense of place to make climate change messaging accessible, and might include examples such as park-specific graphics, which offer a simple way to interpret complex topics; waysides and picture posts, which provide direct, meaningful connection for visitors and can even engage citizen science; a series of regional trading cards, which used ecology to highlight various geologic aspects of the parks; informative videos, including those highlighting the effects of sea-level rise (Campell et al., 2020).

In a proof-of-concept study for coastal adaptation to sea-level rise in the Toms River-Barneget Bay ecosystem in New Jersey, Burger et al. (2017) demonstrate how including local communities in the design process can lead to well-rounded adaptation solutions. The authors' adaptation plan was developed in collaboration with federal, state, and local officials, and included meetings and consultations with local experts, interest groups, and residents. Notably, the plan does not immediately call for population movement from vulnerable coastlines. Rather than fighting sea-level rise, the authors suggest redistributing the area considered "shoreline" such that the plan allows for continued social, ecological, and economic health of the region under sea-level rise.

Moreover, Samuelsson et al. (2018) and Ordonez Barona (2015) emphasize the importance of how stakeholders can provide valuable information for climate-adaptive approaches. Using qualitative measures, Samuelsson et al. show how large urban populations benefit and have positive experiences from natural environments that help regulate temperature, while Ordonez Barona suggests that satisfying public values in urban forest management and reducing urban-forest vulnerabilities to climate change can center the conversation on adaptive management processes and work to include people in management process. In wetlands, Van Dolah, Miller Hesed, & Paolisso (2020) posit that long-term sustainability requires meeting local needs, and that rural coastal communities not only can contribute significant wetland planning advice and knowledge, but that rural coastal communities are driven to find adaptation solutions for climate change. Therefore, collaborating with communities in the design process can inform and strengthen adaptation responses to climate change that support socioecological needs.

Chapter 3: Study Site

Washington, D.C. is a city with expansive parkland, much of which is managed by the National Park Service. The city sits at the confluence of two major rivers in the region—the Potomac and Anacostia rivers—and is situated in the Chesapeake Bay watershed. The watershed is freshwater, but the Potomac River is tidal approximately nine miles beyond the confluence of the two rivers. The Anacostia River has tidal influence to its headwaters in Bladensburg, Maryland, well beyond the confluence of the rivers (National Capital Planning Commission, 2008). The confluence of the rivers is around 108 miles from the Chesapeake Bay and experiences tidal amplitudes of around three feet. Geology of the area includes both the Appalachian Piedmont and Atlantic Coastal Plain (U.S. Army Corps of Engineers Baltimore District, 1994). The National Mall is within the Coastal Plain area (Means, 2010).

The thesis focuses on the Hains Point area of East Potomac Park, just south of the Tidal Basin on the National Mall. The Tidal Basin has a legacy in flooding and tides. A devastating flood in 1881 left much of the southern part of the city and parts of the National Mall flooded and available only to those traveling by boat. Following the flood, funds were allotted for a major overhaul in the area, with tide gates being installed in the area of what is now the Tidal Basin. At high tide, one of the gates off of the Potomac River opened and

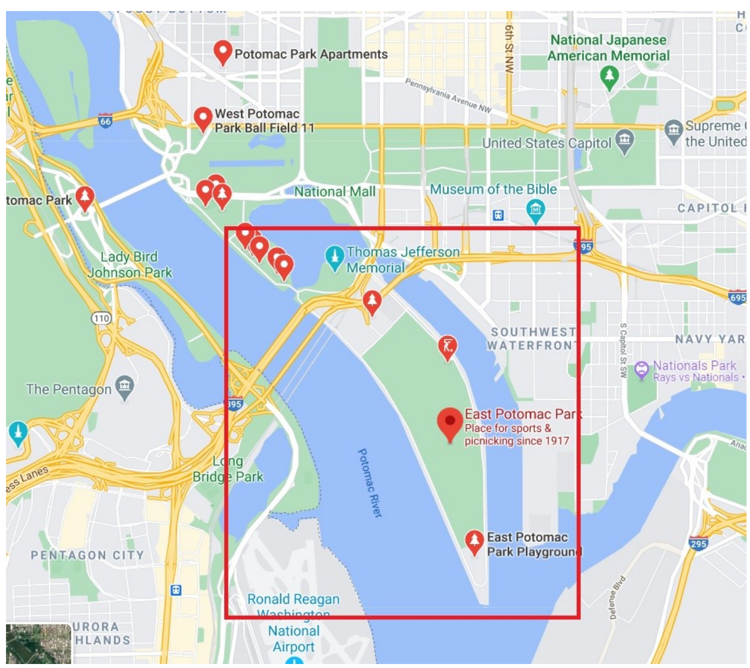


Figure 1: East Potomac Park

filled the area with water, while at low tide the water exited through a gate emptying into the Washington Channel with the aim of taking away leftover sediment deposits to keep the channel navigable. The project, which led to the creation of the 118-acre Tidal Basin, produced another 621 acres of reclaimed land from dredge and fill materials. The reclaimed land area also received a seawall in 1890 to prevent erosion. The 621 acres of reclaimed land and 118 acres of the Tidal Basin were designated by Congress as Potomac Park in 1897. In 1933, the National Park Service became responsible for Potomac Park (National Trust for Historic Preservation, 2019).

Today, the Tidal Basin and surrounding areas face challenges from increased flooding. Sidewalks of the Tidal Basin are flooded daily at high tide, creating accessibility issues. Further, the daily flooding has adverse effects on the Tidal Basin Cherry Trees, which attract 1.5 million visitors during the National Cherry Bloom Festival (National Trust for Historic Preservation, 2019).

Hains Point on East Potomac Park is the southernmost point of the artificial island, which is protected by a seawall and is just south of the Tidal Basin. The Hains Point part of East Potomac Park, where the Potomac and Anacostia rivers meet, is especially at risk of sea-level rise, having been severely undermined by tidal action as far back as 1958 (Chappell, 1973). GIS data reveals that much of the Hain's Point landscape ranges from 0-2 ft in elevation, while the entire area of Hains Point does not exceed 6 ft of elevation. The island is vulnerable to flooding and storm surge from hurricanes, with much of the landscape being in hurricane evacuation study zones 1 and 2 (Fig. 7). The island supports a variety of natural and cultural resources, providing outdoor recreation and leisure space for park users, including a golf course designed by renowned golf course architect Walter J. Travis. The golf course, unavailable for play to African Americans, prompted a 1941 policy change preventing discrimination at all federally owned golf courses, thereby altering policies for National Park Service-owned resources around the country (Garrison & Lester, 2016).

Chapter 4: Methods

Timeline

Broadly, the thesis project consisted of a few main development phases. Brief points on each phase below provide context and understanding on the thesis process and timeline for readers, landscape architects, and coastal resilience planners. The phases, followed by additional details on the iterative methods framework and site design, are discussed below:

Site Concept & Proposal

Spring 2020 included concept and idea building, an early literature review (ideally reading two papers per week); presenting and writing a thesis proposal highlighting the proposed area of research and goal of the project; determining possible methods, site location, and learning outcomes.

Site Context & Literature Review

Summer 2020 was designated for researching the site background and history and a literature review in which approximately five papers per week were read and summarized in one or a few brief paragraphs in a single document. Papers were summarized in plain, original language and summaries aimed to capture the main ideas of a paper and any other critical information. Topics included climate science, natural science, social science, and parks and recreation. Reading included research articles, government reports, and media or papers from other organization. Summaries of the literature were recorded in a single document and then organized by topic toward the end of the summer. Summarizing the papers in this way was critical to later being able to effectively—and rather quickly—write a literature review for a paper submitted to the Council of Educators in Landscape Architecture annual conference and the final thesis document (Samoray & Ellis, Under Review).

Site Analysis & Framework Development

Fall 2020 was largely dedicated to using the papers from the literature review to develop the design guidelines framework. Two interviews with employees of the National Park Service and National Capital Planning Commission were also completed during this time. The interviews provided insight on site context, the political ecology of the site, park users, and future aspirations for the area. Social media analysis using Instagram provided additional insight into how the park is used by visitors. GIS analysis of the site was also done during this time. The analysis detailed the site's elevation profile, areas vulnerable to sea-level rise and storm surge, and bathymetry of the adjacent rivers. Data was used to inform the development of the iterative methods framework, and an abstract focused on the design guidelines framework was submitted for a virtual presentation at the 2021 Council of Educators in Landscape Architecture annual conference during March 2021. Later, winter 2021 was spent writing a paper invited for submission in Council of Educators in Landscape Architecture annual conference proceedings publication, *Landscape Research Record.* The guidelines of the iterative methods framework were also used to guide the design concept developed in the winter and spring 2021 phases.

Design Development, Completion, & Thesis Defense

Spring 2021 focused on design development and completion. Concepts were refined and based in the context of projected sea-level rise in the area. Wetland and flood tolerant plantings were explored. The Council of Educators in Landscape Architecture annual conference was also during this time in March. A presentation was prepared and given on March 17. Following the conference, design production progressed rapidly. A final site plan, along with sections, modeling work, perspective renderings and planting tables were completed. Writing began in mid-May, but should be started sooner, in early April, for spring graduation. Summer 2021 included thesis defense on June 4, followed by any editing or revisions to the thesis writing.

Development of Iterative Methods Framework

The iterative methods framework was developed as a set of pre- and post-design guidelines to provide a roadmap throughout the design process. The framework is set in the context of climate change with a focus on sea-level rise on land managed by the National Park Service in Washington, D.C. Attempting to bridge the gap between science and design, the framework develops a set of actions and objectives across diverse disciplines and takes initiative to involve stakeholders before, during, and after design.

The framework is based on supporting literature. Triangulation identified relevant research from journal articles (JA), National Park Service reports (NPS), and documents from other institutions (O) such as government or non-profit entities. Research broadly fell into topic categories of climate change, nature and ecosystem-based design, parks and places, and communication. The framework text is based on a review of more than 60 research papers in these categories. The framework includes Action and Objective columns with text developed to reflect and summarize information from the review of the research literature. For brevity, the framework includes 15 examples from the identified literature (JA, NPS, O). Each Action and Objective section correspond to examples from the supporting literature, with one example from each identifier in every section, to support the directives of the proposed framework method.

Iterative Methods Framework

An iterative methods framework (Table 1) was developed to inform and guide a design process for coastal resiliency. The framework is populated with an Action and Objective column supported by relevant literature from three different source types. The Action column is organized by the following sections: Explore, Acclimate, Plan & Design, Communicate, and Monitor. The process is iterative, beginning at Explore and following through to Monitor. However, a section can, and should, be revisited as needed at any point while using the framework (Fig. 3).

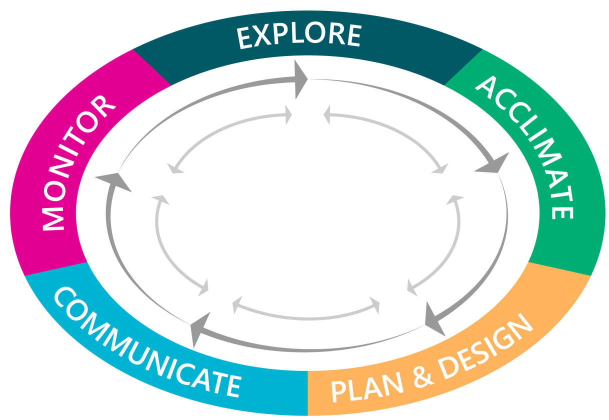


Figure 2. Conceptual layout of the iterative methods framework

Each section contains a directive to address in achieving the related Objective. For instance, the Action "Explore" aims to achieve the Objective "Identify the issue and key players" (See Table 2). Recommendations of useful steps in going through the process are included in each section. Continuing the Action "Explore" example, the directive to "study site history and context" is to "locate natural and cultural resources," while the directive to "determine users and community relationships" is to "connect decision-makers and information users," and finally, the directive to "consider opportunity for innovative and creative solutions" is to enable "collaboration in defining the issue." This process is repeated for each Action section. Additionally, each Action and Objective describes relevant parties to involve at a given stage of the process and a concrete example enabling progress toward the Objective. The Action "Explore" suggests engaging social scientists and stakeholders at this stage, while using social media is listed under the Objective column as one potential route in working to achieve the Objective "Identify the issue and key players."

A third and fourth column attaches supporting literature to the corresponding Action and Objective columns. The supporting literature informs and is directly related to the directives in the Action and Objective columns. Each section contains supporting literature from three source types: journal articles (JA), National Park Service reports (NPS), and Other (O), lending multi-source support to the directives in the Action and Objective columns. Using the Action "Explore" as an example, Hino et al., 2019 (JA), Beavers et al., 2016 (NPS), and Aiken et al., 2014 (O) each contain content that supports the directives in the Action "Explore" column and the Objective "Identify the issue and key players" column. Although over 60 literature sources informed the development of the iterative methods framework, the supporting literatures that appear in the table were selected for relevance, instructiveness, and accessibility to a wide audience.

The process described using the above examples for the Action "Explore" are followed likewise for each Action. For instance, the Action "Communicate" aims to achieve the Objective "Promote dialogue and idea-sharing." The directive "provide educational and engagement opportunities" aims to "use the site as a demonstration of climate change." At this stage, the Action "Communicate" suggests engaging communication professionals and end-users, and recommends using past and present photograph comparisons as one potential example in achieving the Objective "Promote dialogue and idea-sharing." Importantly, the Action "Communicate" is meant to promote two-way engagement, with stakeholders helping to advance a site's identity and contribute to the climate narrative and environmental education aspect of a project through activities such as citizen science. Similarly, the Action "Monitor" aims to achieve the Objective "Study design outcome." The directive "connect research and practice" is to "create a practice-science feedback loop." At this stage the Action "Monitor" suggests engaging all relevant parties and recommends comparing baseline and outcome data as one potential example in achieving the Objective “Study design outcome.”

Together, the Action, Objective and Supporting Literature columns form the iterative methods framework. The directives capture perspectives from three types of literature that also serve to provide further reading and context for those using the iterative methods framework for climate change design.

Table 1: The iterative methods framework includes four columns: Action, Objective, Supporting Literature and Type. The supporting literature informs the content of the Action and Objective columns.

Action	Objective	Supporting Literature	Type
Explore • Study site history and context • Determine users and community relationship • Consider opportunity for innovative and creative solutions *Engage social scientists and stakeholders*	**Identify the issue and key players** Locate natural and cultural resources Connect decision-makers and information users Collaborate to define the issue *Ex: Social media postings for site use*	1) "High-tide flooding disrupts local economic activity" Hino, M. et al. (2019) 2) "Coastal Adaptation Strategies Handbook" Beavers, R. et al. (2016) 3) "Designing With Water: Creative Solutions From Around The Globe." Aiken, C. et al. (2014)	1) JA 2) NPS 3) O
Acclimate • Assess vulnerability to climate change • Specify relevant adaptation and resilience strategies • Evaluate appropriate nature-based designs and ecosystem services *Engage ecosystem scientists and allied researchers*	**Define socioecological factors** Identify vulnerable experiences and ecosystems Determine habitat type of nature-based design Balance user needs, coastal services, and design solution *Ex: Mapping and projections to study site*	1) "Nature-based solutions: Lessons from around the world" Pontee, N. et al. (2016) 2) "Climate Change Response Strategy" National Park Service. (2010) 3) "When Rising Seas Hit Home." Spanger-Siegfried, E. et al. (2017)	1) JA 2) NPS 3) O
Plan & Design • Integrate culture and nature • Consider time horizons and scenarios • Strengthen preparedness, adaptation, and resilience *Engage planners and designers*	**Implement adaption, mitigation, and resilience measures** Design solutions that provide multiple socio-eco benefits Use scenario planning and phasing for uncertain futures Encourage local and regional preparedness and adaptation *Ex: Plan two alternative futures*	1) "The shore is wider than the beach: Ecological planning solutions to sea level rise for the Jersey Shore, USA" Burger, J. et al. (2017) 2) "Climate change scenario planning: A tool for managing parks into uncertain futures" Weeks, D. et al. (2011) 3) "Engineering with Nature" Bridges, T.S. et al. (2018)	1) JA 2) NPS 3) O
Communicate • Bring attention to place identity and meaning • Provide educational and engagement opportunities • Encourage curiosity and discussion *Engage communicators and end users*	**Promote dialogue and idea-sharing** Engage users in local context and a sense of place Use site as a demonstration of climate change Develop public dialogue between science and design *Ex: Past and present photographs for context*	1) Climate change impacts in Missouri State Parks: Perceptions from engaged park users" Groshong, L. et al. (2018) 2) "Using social science in National Park Service climate communications: A case study in the National Capital Region" Campbell, E. (2020) 3) "Climate Change Communication Campaign Planning: Using Audience Research to Inform Design" Thompson, J. et al. (2013)	1) JA 2) NPS 3) O
Monitor • Research and evaluate pre-post site performance for long-term sustainability • Make findings accessible and instructive • Connect research and practice *Engage all relevant parties*	**Study design outcome** Identify relevant metrics and indicators Examine design contribution to cultural and ecological goals Create a practice-science feedback loop *Ex: Baseline and outcome data for comparison*	1) "Designed experiments: new approaches to studying urban ecosystems" Felson, A.J. & Pickett, S. (2005) 2) "Coastal Adaptation Strategies: Case Studies." Schupp, C.A. et al. (2015) 3) "Site Commissioning White Paper" U.S. General Services Administration (2017)	1) JA 2) NPS 3) O

Design Process

The iterative methods framework informed design. Each Action and Objective encouraged a process that uncovered both cultural and environmental information about the site. Concepts of the iterative methods framework were used to inform site plan design, which aims to buffer the area from the effects of sea-level rise, while growing park users' connection with the landscape. The "Informing Design" subsection in the next chapter, "Chapter 5: Results" gives a detailed overview of the information gained from using the iterative methods framework to orchestrate the climate adaptive benefits and user-landscape connection of the site design.

Informed by the iterative methods framework, National Park Service reports gave insight into the historical context of the site and social media analysis using Instagram provided a glimpse into how people are using the park today. The design process also incorporated GIS data and analysis to understand elevation and land use of the site. Bathymetric contours were used to approximate depths of the adjacent Potomac River and Washington Channel. Additional data included mapping hurricane evacuation zones. A site inventory mapped structures and other points of interest on or nearby East Potomac Park.

Sea-level rise projections were informed initially on a general level by resources such as The National Park Service Sea-level rise Viewer, NOAA Sea-level rise Viewer, and Climate Change Surging Seas Analysis Tools. However, projections were refined and specified by the scientific literature and a number of relevant research papers were identified, with Boesch et al. (2018) being especially relied on as the projections are specific to Maryland. The researchers provide projections under three climate scenarios: growing, stabilized, and limited. At 2100, even in a stabilized climate sea-level rise ranges 1.6-3.4 ft (Table 2). These projections are important for considering planning horizons on projects, which range from short at 25 years to very long at more than 100 years, and were used to inform design. Tide analysis was evaluated using NOAA Tides and Currents, specifically station 8594900, which is set in the Washington Channel.

Table 2: Estimates of sea-level rise under three climate scenarios from Boesch, D.F. et al (2018).

Year	Emissions Pathway	Central Estimate 50% probability SLR meets or exceeds:	Likely Range 67% probability SLR is between:	1 in 20 Chance 5% probability SLR meets or exceeds:	1 in 100 Chance 1% probability SLR meets or exceeds:
2030		0.6 ft	0.4 – 0.9 ft	1.1 ft	1.3 ft
2050		1.2 ft	0.8 – 1.6 ft	2.0 ft	2.3 ft
2080	Growing	2.3 ft	1.6 – 3.1 ft	3.7 ft	4.7 ft
	Stabilized	1.9 ft	1.3 – 2.6 ft	3.2 ft	4.1 ft
	Paris Agreement	1.7 ft	1.1 – 2.4 ft	3.0 ft	3.2 ft
2100	Growing	3.0 ft	2.0 – 4.2 ft	5.2 ft	6.9 ft
	Stabilized	2.4 ft	1.6 – 3.4 ft	4.2 ft	5.6 ft
	Paris Agreement	2.0 ft	1.2 – 3.0 ft	3.7 ft	5.4 ft
2150	Growing	4.8 ft	3.4 – 6.6 ft	8.5 ft	12.4 ft
	Stabilized	3.5 ft	2.1 – 5.3 ft	7.1 ft	10.6 ft
	Paris Agreement	2.9 ft	1.8 – 4.2 ft	5.9 ft	9.4 ft

Design concentrated on the Hains Point area of East Potomac Park, the southern point of East Potomac Park. The area is low-lying, not exceeding 6 ft, but much being 2 ft or below in elevation (Fig. 7). Although the design is focused on Hains Point, many of the ideas can be applied to other parts of East Potomac Park, markedly, to the low-lying outer edges below 4 ft of elevation surrounding the exterior of the island.

Hand-drawing and measuring on paper jumpstarted the design process. Later, design was finished in Adobe Illustrator and Photoshop. SketchUp modeling and Lumion were used to explore the elevation-dependent elements of the site. A number of local resources were relied on to inform planting design, including resources from the not-for-profit Environmental Concern, Chesapeake Bay Native Plant Center, Chesapeake Bay Program, Kenilworth Park & Aquatic Gardens, as well as Dyke Marsh report by the National Park Service and a regional

Environmental Impact Statement by the US Army Corps of Engineers Baltimore District.

Finally, the completed site design was evaluated against the iterative methods framework.

Chapter 5: Results

Informing Design

The site design was informed by the iterative methods framework. The Explore, Acclimate, Plan & Design, Communicate, and Monitor Actions guided the design of the site for sea-level rise and storm surge. Each Action pertains to an Objective that was meant to contribute to strengthening the design's resiliency and sustainability. Provided below are examples of information learned through the iterative methods framework that was incorporated into the subsequent site design.

Explore

The Explore Action enhanced understanding of the site context and users. Originally, the island landscape did not exist. Instead, the area was the Potomac River with a bridge known as the Long Bridge stretching from 14th Street to Virginia. The bridge caused silting and aquatic grasses to grow in an area called the Potomac flats. Much of the siltation by the bridge came from upstream development and erosion, and the siltation affected navigation of the river and led to sometimes stagnant smells. In 1857, it was proposed to replace the Long Bridge and dredge the Washington Channel. The dredge material was then used to create parts of the Tidal Basin and East Potomac Park. Indeed, Hains Point, at the southern tip of East Potomac Park, is named after Major Peter Conover Hains, who led the dredging and reclamation project. The land area receive interest from various spheres, but became a park in 1897 and managed by NPS in 1933.

Much of the island consists of three golf courses. The initial course was designed by Walter J. Travis, former U.S. amateur golf champion and renowned golf course landscape architect, in 1917and attempted to mimic areas of Scotland adjacent the coastline. The courses also played a role in civil rights. Although the land was federal and meant to be publicly accessible, African Americans were barred from the East Potomac Park courses and played on adjacent courses in West Potomac Park, which were not well kept. The courses were so bad that three African American players challenged the segregated courses, leading to a federal policy change in 1941 preventing discrimination at all federally owned golf courses and altering policies for other National Park Service resources around the country.

At this stage, social media played a large role in determining current site uses. Although anecdotal and archival evidence included a slew of activities (cycling, walking/running, picnicking, playground use, field sports, golf, mini golf, tennis, swimming in the pool, cherry blossom bloom viewing, sightseeing, parking, bird watching, fishing, airplane viewing), none of this could be confirmed by talking with park users due to constraints of the COVID-19 pandemic. Therefore, Instagram and iNaturalist were searched to discover how park users enjoyed the space. Search terms included "East Potomac Park" and "Hains Point," as well as making use of geolocation points (Figs. 3-4) The findings confirmed many of the activities, and some new ones, such as dancing. The site design attempts to maintain space for these current park uses.

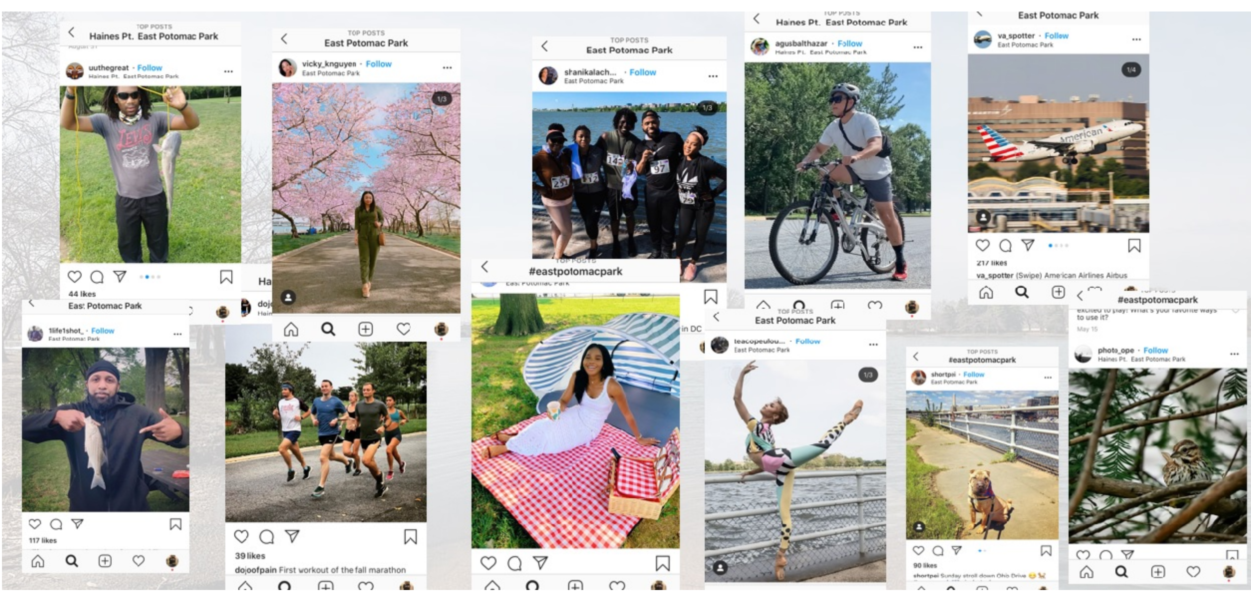


Figure 3: Site use examples from Instagram.

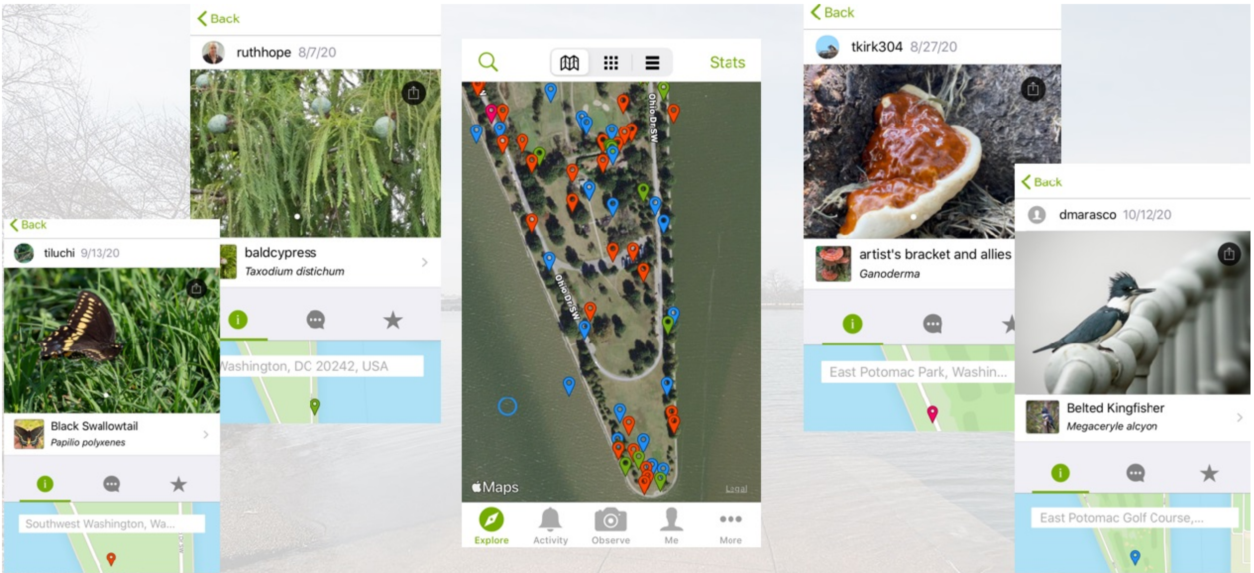


Figure 4: Site observations from iNatuarlist.

<u>Acclimate</u>

The Acclimate Action largely provided information on the site's vulnerability to climate change. The literature indicated that the landscape had already sunk by 3.5 ft by 1950 and that tidal action had severely undermined the seawall at Hains Point by 1958. Additionally, Library of Congress images showed extensive flooding at East Potomac Park in 1936 and 1985 (Fig. 5).

Figure 5: Flooding in 1985 (left) and flooding in 1936 (right) at East Potomac Park. Credit: Library of Congress.

The area also experiences semidiurnal tides, or two high tides and two low tides of around the same height each day. The NOAA Tides & Currents station 8594900 is located in the Washington Channel, adjacent East Potomac Park. Precisely, the station is at 38° 52.4 N, 77° 1.3

W. The station is around 7 ft above mean sea level. With a semidiurnal tidal range of around 3 ft and prevailing winds in the area largely from the S/SW (Fig. 6), the landscape is vulnerable to sea level rise and storm surge. Additionally, strong winds can increase the height of storm surge. In 2013, Hurricane Isabel produced a 7 ft storm surge in the Potomac River near Washington, D.C. Given that the Potomac River can push water northward from the Chesapeake Bay in the south, a scenario involving high tide, strong prevailing winds, and a high energy hurricane could produce significant storm surge and flooding.

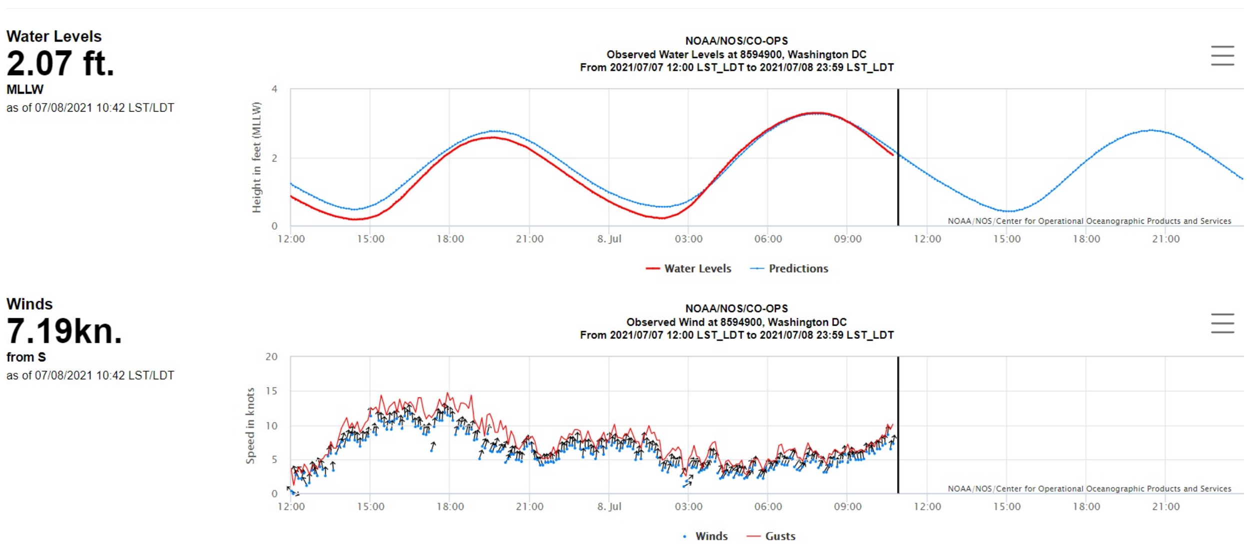


Figure 6: NOAA Tides & Currents Station ID 8594900 shows semidiurnal tides (top) and prevailing winds (bottom) in the Washington Channel, which is next to the site at East Potomac Park.

Last, GIS analysis assessed the topography and determined areas of the island vulnerable to flooding and storm surge. Much of the island is under 6 ft of elevation, with high-risk areas around edges and especially at the southern tip, Hain's Point, where elevation largely ranges 0-4 ft. Similarly, the areas of the landscape vulnerable to hurricane extend from major risk on the edge of the island to well into the interior parts of the island (Fig. 7)

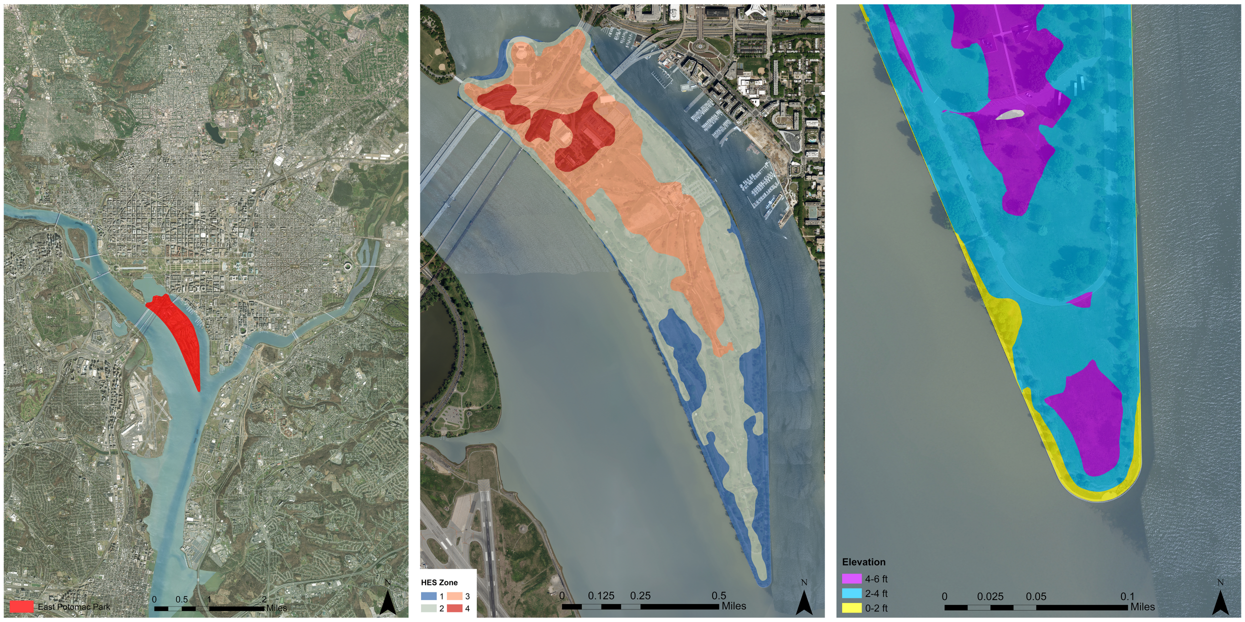


Figure 7: Examples of studies related to sea-level rise for East Potomac Park, Washington, D.C. East Potomac Park (left) encompasses four hurricane evacuation study zones (center), while the southern portion of Hains Point is below 6 ft of elevation (right), making it vulnerable to sea-level rise.

<u>Plan & Design</u>

The Plan & Design Action considered different sea-level horizons at certain time periods. Within the scope of the project, sea-level rise was studied at 2050 and 2100. A recent Intergovernmental Panel on Climate Change puts sea-level rise at .24-.32 m by 2050 and .43-.84 m by 2100, while a number of other estimates range from .25-2 m of sea-level rise by 2100.

For local context, the project relied on estimated from Boesch et al. 2018. The study estimates a likely range of .8-1.6 ft of sea-level rise, with a 50 percent chance of 1.2 ft, 5 percent chance of 2 ft, and 1 percent chance of 2.3 ft. Under a stable emissions scenario in 2100, the study estimates a likely range of 1.6-3.4 ft of sea-level rise, with a 50 percent chance of 3 ft, 5 percent chance of 4.2 ft, and 1 percent chance of 5.6 ft. Under a growing emissions scenario in 2100, the study estimates a likely range of 2.0-4.2 ft of sea-level rise, with a 50 percent chance of 3 ft, 5 percent chance of 5.2 ft, and 1 percent chance of 6.9 ft (Table 2).

The 2050 scenario and 2100 scenarios under both stable and growing emissions presented alternative futures to be considered in the site design. Figures 28-32 explore sea-level rise scenarios ranging from 2.5-4 ft of sea-level rise at 2100, which cover the central estimate for a stable emissions scenario and the upper end of the likely range in a growing emissions scenario. The scenarios were also explored under nature-based design solutions, such as a hillside buffer, where sea-level rise would be allowed to rise up the hillside (Fig. 8), working to strengthen preparedness, adaptation, and resilience of the landscape.

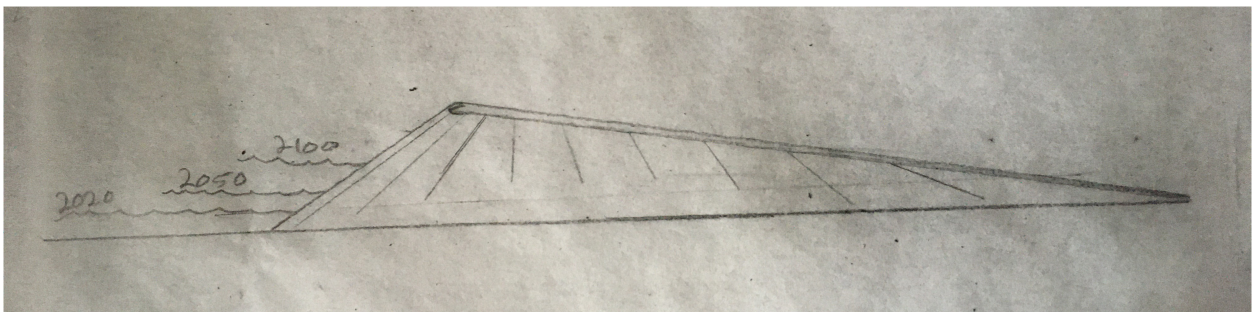


Figure 8: A nature-based solution concept involving a hillside buffer and rising sea level under different scenarios.

This nature-based design also provided the opportunity to integrate culture and nature, with the apex of the hillside providing a new connection to the nearby National Mall memorial landscape. Likely, the Washington Monument, around 2 miles from the site, could be seen from atop this nature-based solution. The Jefferson Memorial also may be within a sight line (Fig. 9). The hillside nature-based solution also promoted dialogue of a possible connection to the indigenous heritage of the area—as a connection to earthwork indigenous cultures that traded in the area. In this instance, tribal members or collaborative work with Native American Museum could be engaged to explore interest. In creating new

Figure 9: The Washington Monument and Jefferson Memorial in the distance from Hains Point.

user experiences, bringing culture to the forefront, and providing climate adaptation benefit, the natural and cultural landscapes work together to support socio-ecological resilience.

<u>Communicate</u>

The Communicate Action proposes engagement and outreach opportunities. Climate change can be difficult to visualize (Groshon, Stanis, & Morgan, 2018) and many people prefer to learn about the issue on their own by choice, with a sense of place proving a powerful medium (Thompson, Davis, & Mullen, 2013). The time aspect of climate change presented an interesting way to engage park users on the issue. Sea-level rise, in particular, can be observed over time as it creeps up and changes the landscape. And that the area experiences semidiurnal tides, offered another opportunity to invite change over time in the site design.

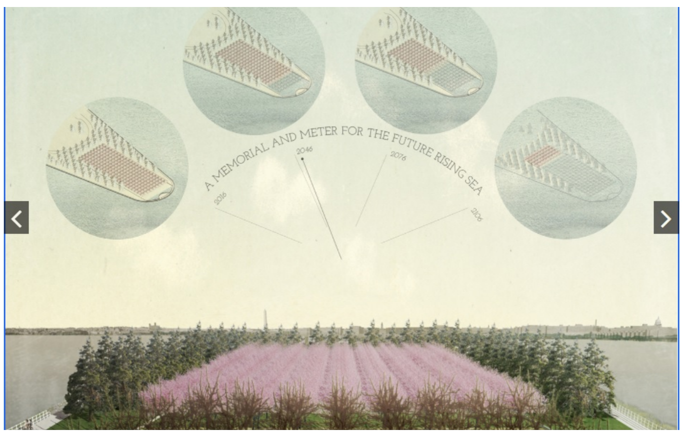


Figure 10: The "Climate Chronograph" from the "Memorials for the Future" competition. Credit: Azimuth Land Craft.

Figure 11: National Peace Garden concept. Credit: Histories of the National Mall/National Peace Garden

In fact, a design visualizing sea-level rise over time at Hains Point was selected as the winner of the "Memorials for the Future" competition held by the National Park Service, National Capital Planning Commission, and Van Alen Institute (National Capital Planning Commission). The landscape also has been previously proposed as the location for the National Peace Memorial, which a contract was approved for in 1983, but expired in 2003 without being built (Roy Rosenzweig Center for History and New Media, George Mason University). The designs suggest that the landscape could be ripe for a memorial or monument (Fig. 10-11). If so, two-way engagement with the public could steer the dialogue on the design. These ideas entered into subsequent design as a way to engage discussion among park users and use the site as a demonstration of climate change.

Monitor

The Monitor Action aims to provide data on the outcome of the site design. Therefore, it is necessary to collect data both before and after the site design is completed. A number of relevant measures for natural and cultural resources could be assessed. Just a few include total maximum daily load (TMDL), marsh and planting migration, rising groundwater, and park uses and other social metrics.

Given that East Potomac Park is surrounded by the Potomac and Anacostia Rivers, studying TMDL in the area could provide a baseline of the nitrogen, phosphorus and suspended sediment loads in the area. Moreover, knowing TMDL levels would provide a baseline establishing how a nature-based solution might provide water quality credits.

In terms of sea-level rise, researchers have found that wetlands in the Chesapeake Bay decreased in elevation nearly 1.8 mm/yr over the four-year study period, a level at least 5 mm below the requirement to keep pace with sea-level rise. In freshwater marshes, the marsh migrated to higher ground (Beckett, Baldwin, & Kearney, 2016). In a nature-based solution including marshland as an aspect of the design, studying landward marsh migration could prove a useful metric. Similarly, rising groundwater caused by sea-level rise could threaten plantings. As seawater encroaches inland, salt taints the freshwater and can cause ghost forests (NOAA). Therefore, monitoring salinity levels in groundwater present another avenue of important study in context of sea-level rise.

Finally, social metrics could illuminate how the site design supports current and proposed future uses; engages public discussion on issues of climate change; promotes landscape identity and a sense of place; encourages tourism, such as in relation to the National Mall landscape or cherry blossom viewing, as East Potomac Park has a significant number of cherry trees; and facilitates human connection with the landscape. In urban parks in New York City, for instance, parks were found to support psycho-social-spiritual wellbeing, and provide space for users to connect with nature and engage with a larger reality (Svendsen, Campbell, & McMillen, 2016).

Together, measures for natural and cultural features are an integral component to ensure long-term sustainability of the landscape.

Site Design

As described in the previous section, the site design is informed by the iterative methods framework. Each Action of the framework provided guidance on how to undertake climate change design in context of sea-level rise and storm surge. The site design explored ideas of adapting with climate change vs. defending against climate change, and ultimately, took a stance to adapt with climate change. In this case, the main climate change issue addressed was sea-level rise. Site analysis identified structures and areas of interest on and nearby the island. Much of the island is dedicated to three golf courses, but there are also National Park buildings, a decommissioned swimming pool, and Reagan National Airport across the Potomac River (Fig. 12). The exterior edges of East Potomac Park range from around 45-65 feet of space between the Potomac River/Washington Channel and the road wrapping around the island, Ohio Drive. A number of concepts are described and pictured as sections for how these areas might be adapted for projected sea-level rise (Figs. 28-32). The focus of the main site design, however, is at Hains Point at the southern point of East Potomac Park. This area consists of open, low-lying space that is exceedingly vulnerable to sea-level rise.

Figure 12: Site Analysis of East Potomac Park. The artificial island is south of the Tidal Basin, between the Potomac River and Washington Channel, and hosts many structures areas of interest.

Currently, Hains Point provides space for activity in open areas and views of the river. The ultimate goal of the site design is to reimagine the area in the context of projected sea-level rise for 2100. Introducing a large hillside and freshwater tidal wetland connected with the Potomac River and Washington Channel create significant grading and landscape changes at the site. In doing so, the design strives to ameliorate storm surge and sea-level rise issues, reclaim freshwater tidal wetland habitat, and enhance and preserve landscape for current and future park-users and communities.

Site Plan

The site plan is focused at Hains Point (Fig. 13). At present, the area ranges from 2-6 feet in elevation, with an existing seawall surrounding the island holding historical significance and contributing to the stability of the landscape. A proposed freshwater tidal wetland and planted hillside transforms the site from a flat landscape vulnerable to sea-level rise to a landscape of adaption and restoration. The freshwater tidal wetland splits the site into what can be considered upper and lower sections.

The lower section of the site plan, which ranges from around 2-10 feet of elevation, hosts a parking area for cars and tourist buses. The parking area takes advantage of an existing service road to create space for parking. Adjacent to the parking area, is a central gathering area from which extends multiple pathways and open greenspace supporting human activities, such as picnicking. The lower section also enables interaction with the freshwater tidal wetland. Banks and edges give shoreline access to the wetland and a 6 ft high boardwalk allows users to traverse over the wetland while also being elevated enough to withstand considerable sea-level rise of 6 ft by 2100.

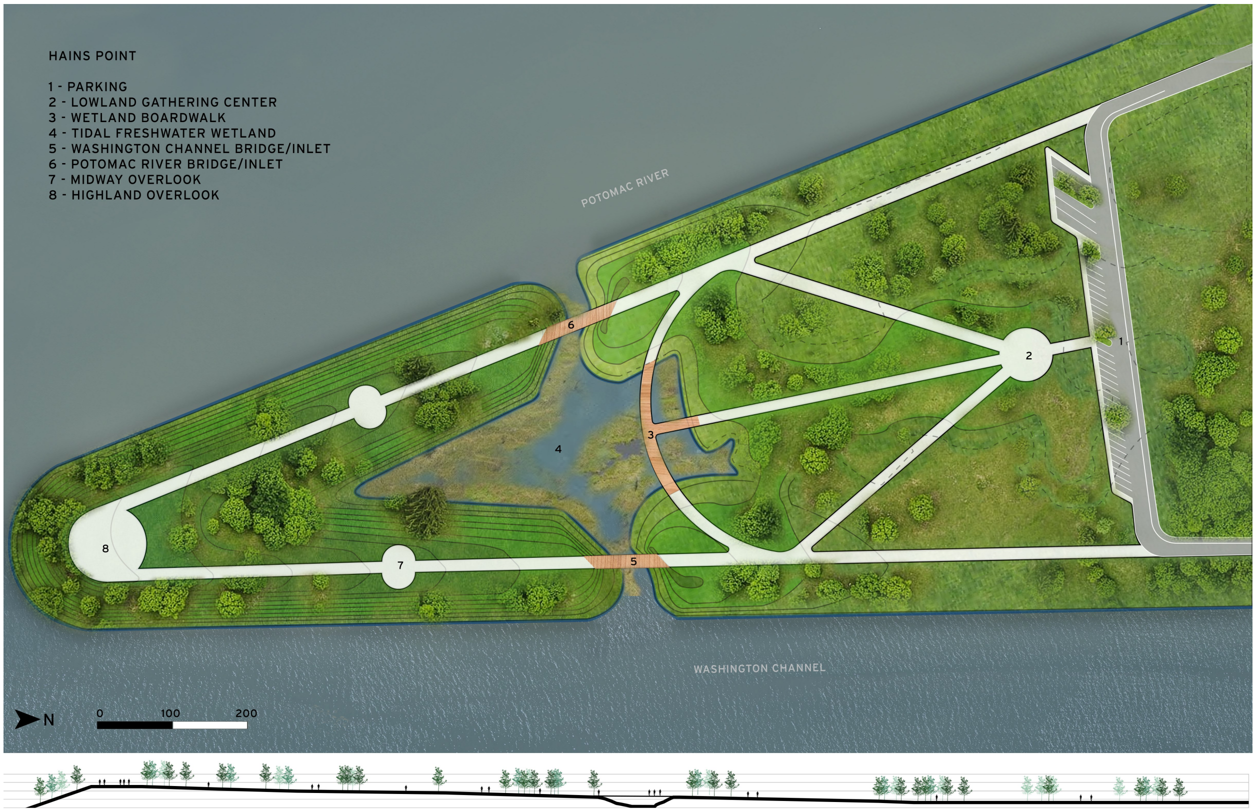


Figure 13: Proposed site plan of Hains Point. A wetland splits a lowland and highland area. Below the site plan is a section stretching the length of hillside, from the hillside top to the parking lot.

The site plan significantly changes the grading and landscape of the area and considers sea-level projections for 2100 ranging from 2 ft sea-level rise in a stable emissions scenario to 6 ft sea-level rise in an extreme growing emissions scenario (Figs. 14-16). Moving from the lower park to the upper park requires ascending a hillside 24 feet in height with a gradual incline of <2 percent. Bridges connecting the lower and upper park traverse inlets connecting to the Potomac River and Washington Channel that feed and provide current for the inland freshwater tidal wetland. These bridges create another opportunity for users to interact with the wetland from another vantage point. The location of the bridges is based on sea-level rise and storm surge projections, with the bridges beginning at 10 ft elevation and extending approximately 100 ft to 12 ft elevation. This placement makes it such that the bridges could accommodate significant sea-level rise and storm surge. For instance, the height could accommodate up to 3 ft of sea-level rise and 7 ft of storm surge, such as that observed in Hurricane Isabel in 2013. Additionally, the hillside creates a buffer against storm energy that could help to protect the interior freshwater tidal wetland.

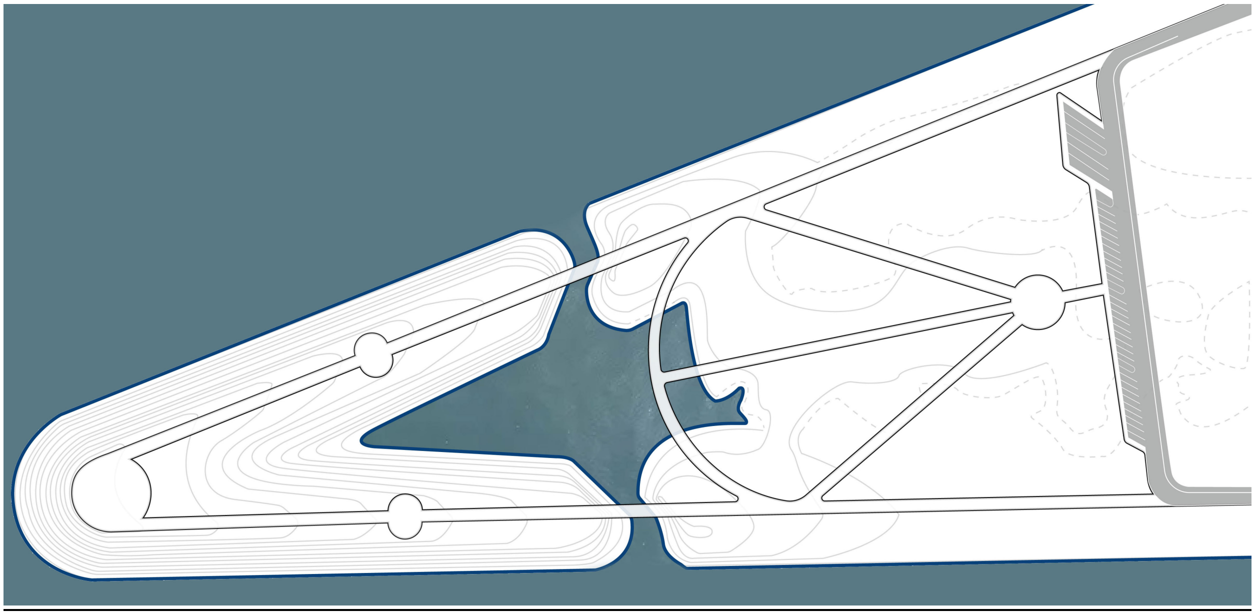


Figure 14: Sea-level rise of 2 ft in a 2100 stable emissions scenario.

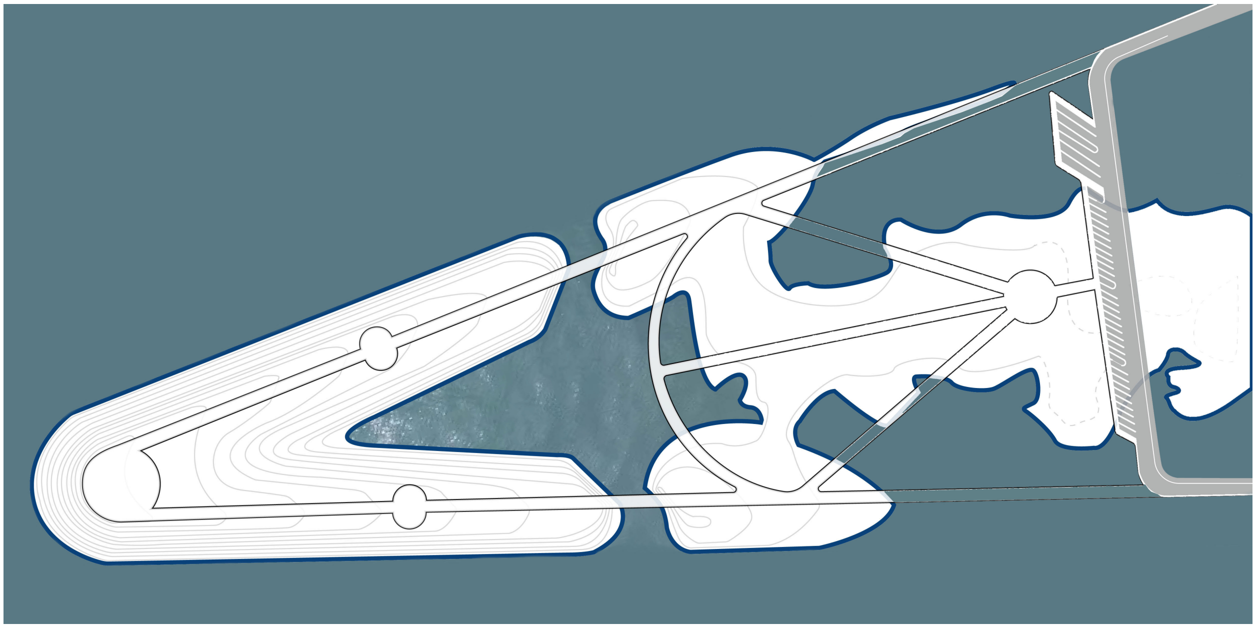


Figure 15: Sea-level rise of 4 ft in a 2100 growing emissions scenario.

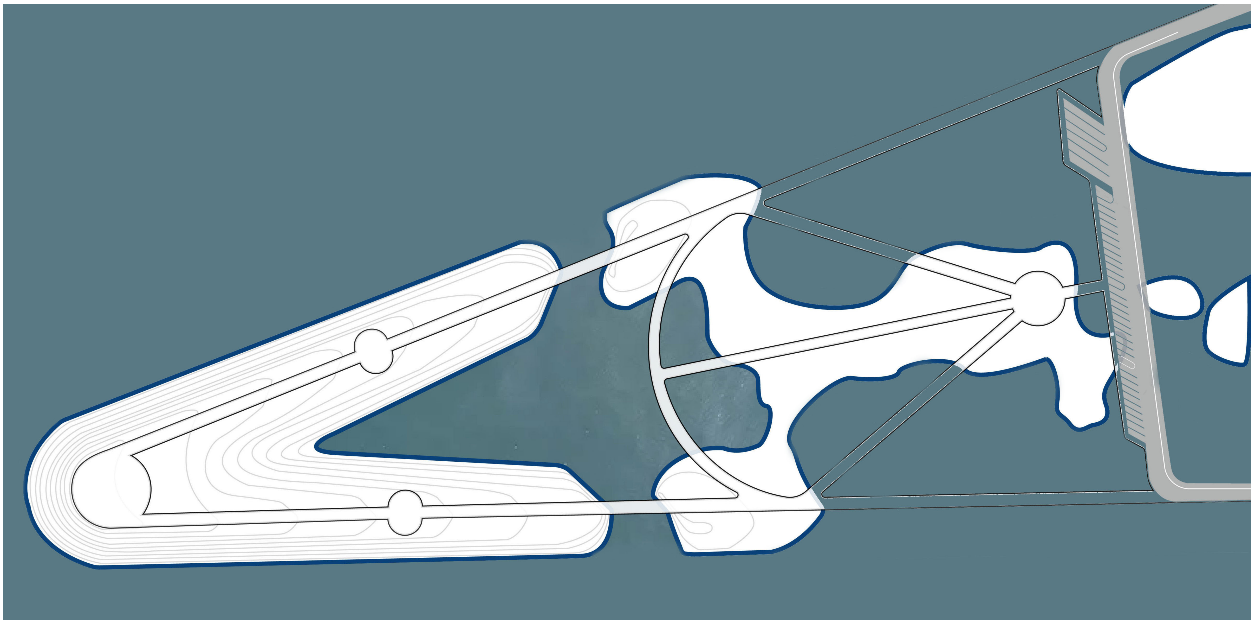


Figure 16: Sea-level rise of 6 ft in a 2100 extreme growing emissions scenario.

Crossing the elevated bridges begins the transition to the upper park, which extends from 12 ft elevation to 24 ft elevation at the top of the hillside. Midway between the bridges and top of the hillside are viewing platforms for park users to rest and look over the Potomac River, Washington Channel, or interior freshwater tidal wetland. The top of the hillside supports a large gathering and viewing platform, which at the confluence of the Potomac and Anacostia Rivers, provides elevated views of the area for park users. This vantage point also attempts to connect the area to the memorial landscape of the National Mall (Fig. 17). The Washington Monument is on axis with Hains Point, and from atop the proposed hillside at Hains Point it is likely that an observer could see the Washington Monument in the distance to the north.

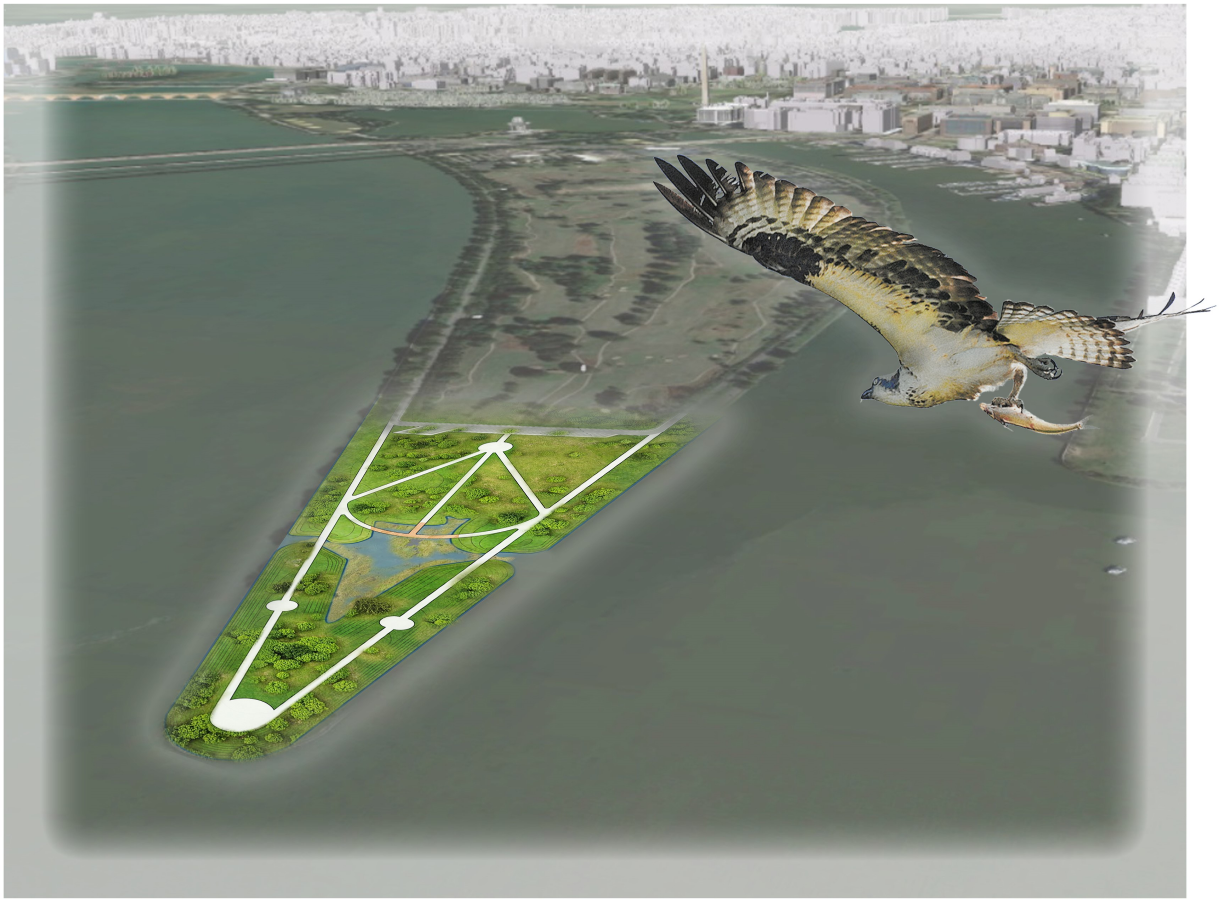


Figure 17: The site design at Hains Point is at the confluence of the Potomac and Anacostia Rivers, and the Tidal Basin and Washington Monument are to the north.

The grading of the site aims to direct runoff stormwater into the freshwater tidal wetland, supporting the feeding of water and sediment into the wetland. Furthermore, the inlets to the wetland from the Potomac River and Washington Channel connect the wetland to a larger system to ensure constant feeding of sediment to support long-term sustainability and biodiversity of the wetland. Connecting the interior wetland to the larger river systems also allows the area to adapt with sea-level rise over time, rather than attempt to maintain a static environment.

The park is designed as a shared use space. Therefore, the pathways are 12 ft wide to ensure adequate space for uses such as walking, running, and biking. The idea of shared use space aims to create an inclusive use environment, rather than creating a situation in which one user group might feel entitled to a certain space over another. Lastly, the loop road at East

Potomac Park is heavily used for biking. The new site design maintains biking around the island by providing a throughway for biking through the parking lot or the option to bike the hillside in a shared-use space.

Overall, the proposed design provides an alternative landscape for adapting to climate change and sea-level rise. The design buffers the area from the effects of sea-level rise and storm surge, while maintaining the flexibility to change with and plan for a variety of future sea-level rise scenarios. Moreover, the design preserves space for the community under projected sea-level rise and provides a way to integrate Hains Point into the memorial typology of the National Mall.

Perspectives

The following perspectives provide a site tour. The perspectives depict the interior wetland; connections to the Washington Channel and Potomac River; and the hillside buffer with a vantage point toward the Washington Monument (Figs. 18-27).

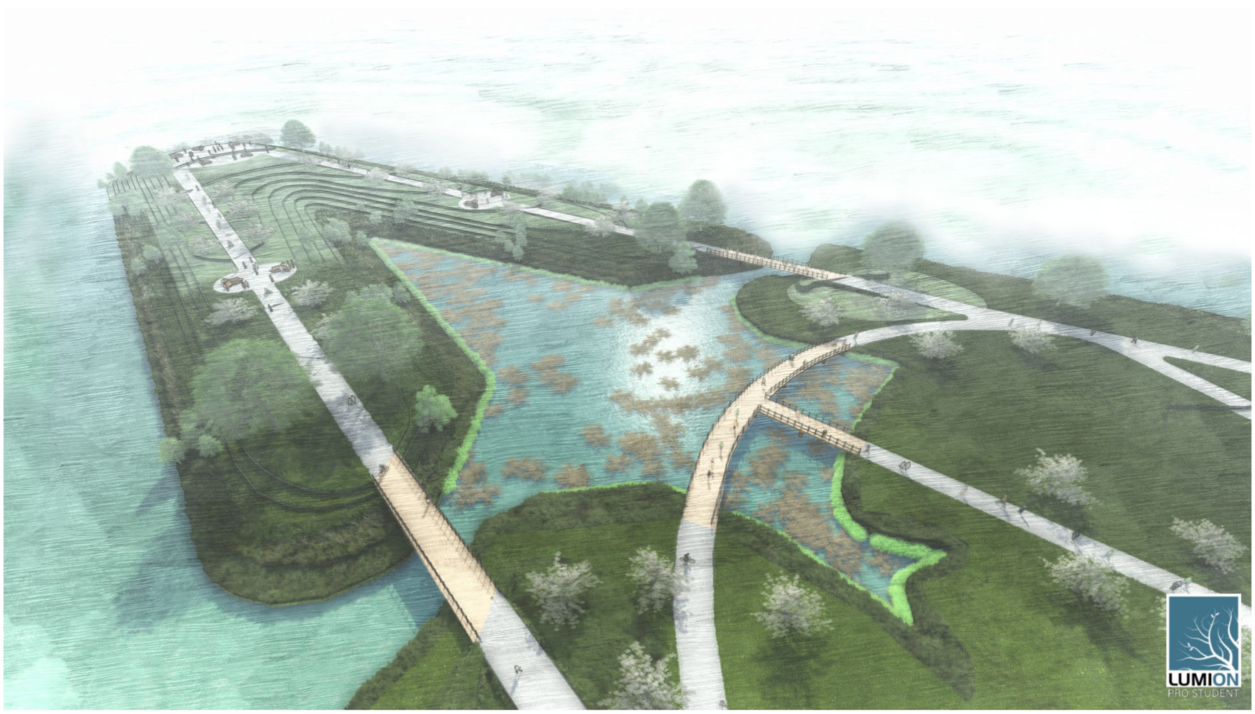


Figure 18: Aerial view looking southwest showing the interior wetland connecting to the Washington Channel and Potomac River.

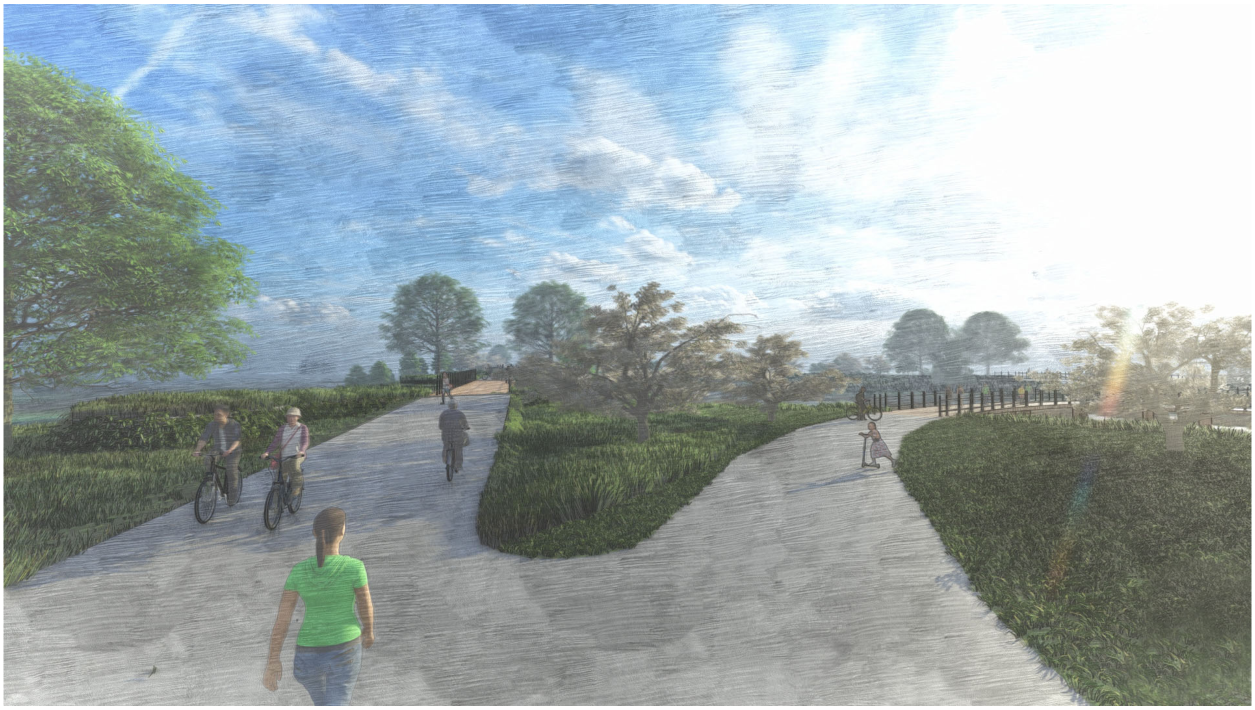


Figure 19: A pathway split. To the right leads to the wetland boardwalk, while the left crosses a bridge and traverses the hillside.

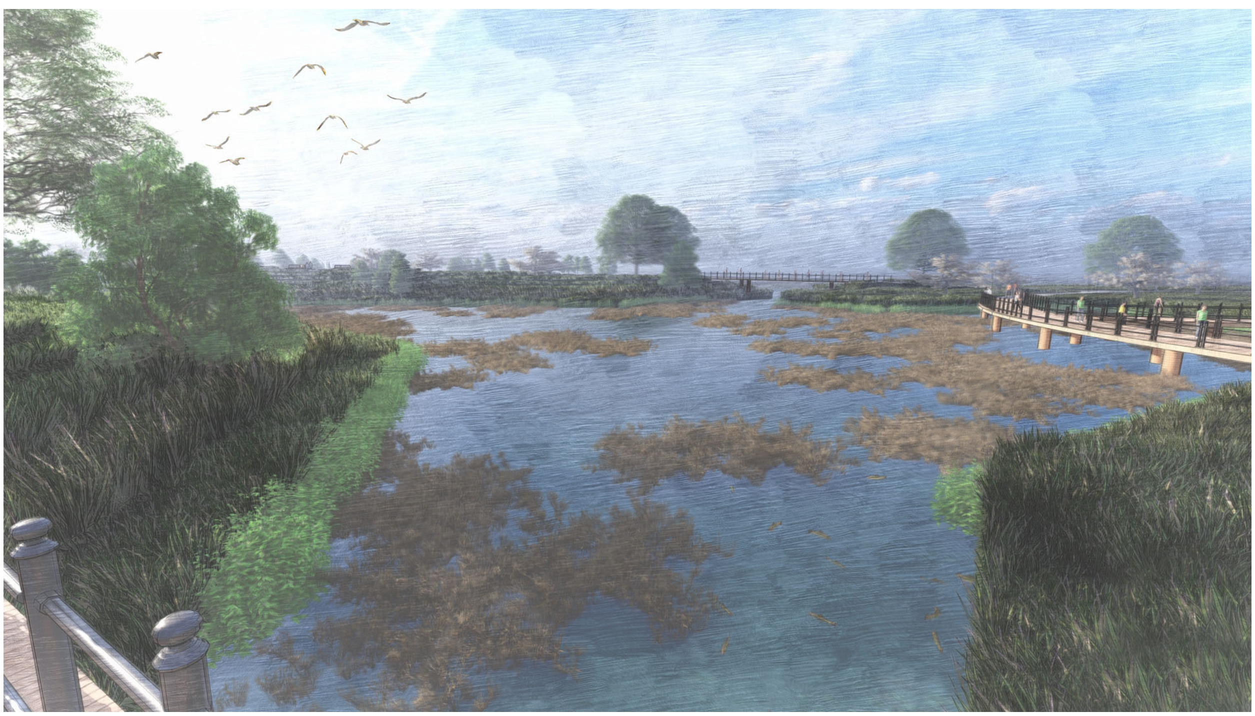


Figure 20: Looking over the wetland from the east bridge. The wetland boardwalk is on the right of the image.

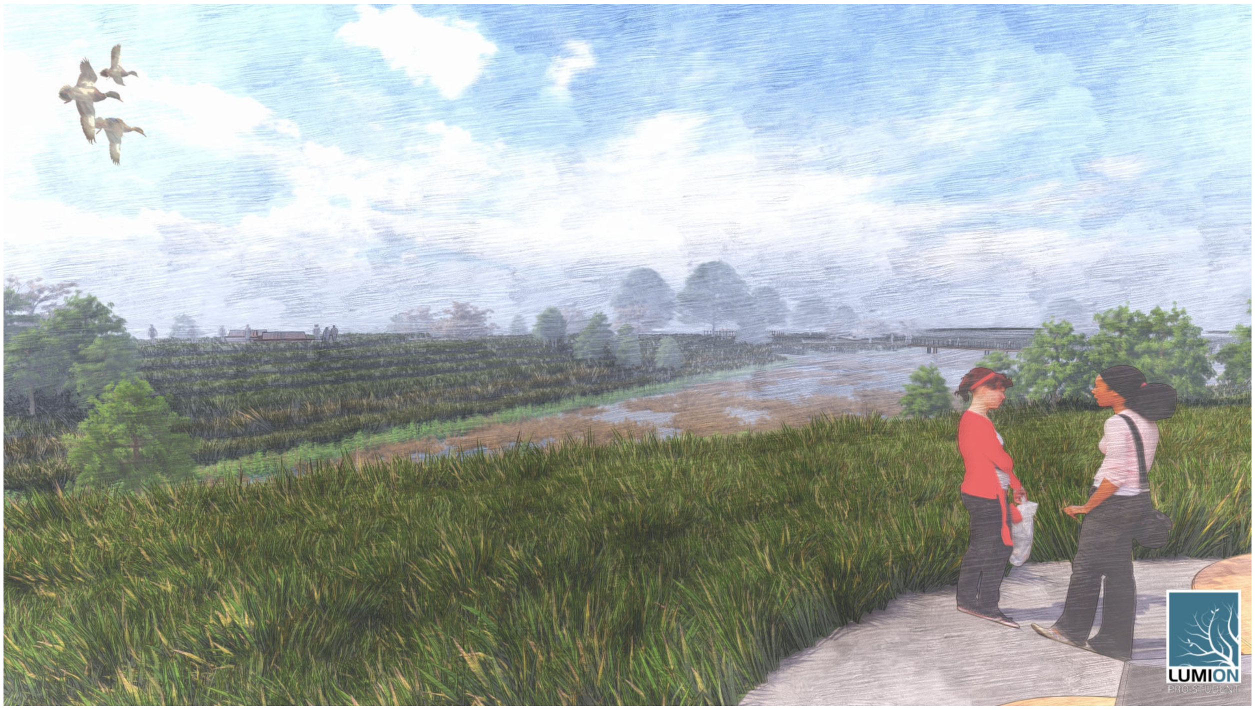


Figure 21: A gathering point midway up the east hillside overlooking the wetland.

Figure 22: The hillside top at the confluence of the Potomac and Anacostia Rivers with the Washington Monument in the background.

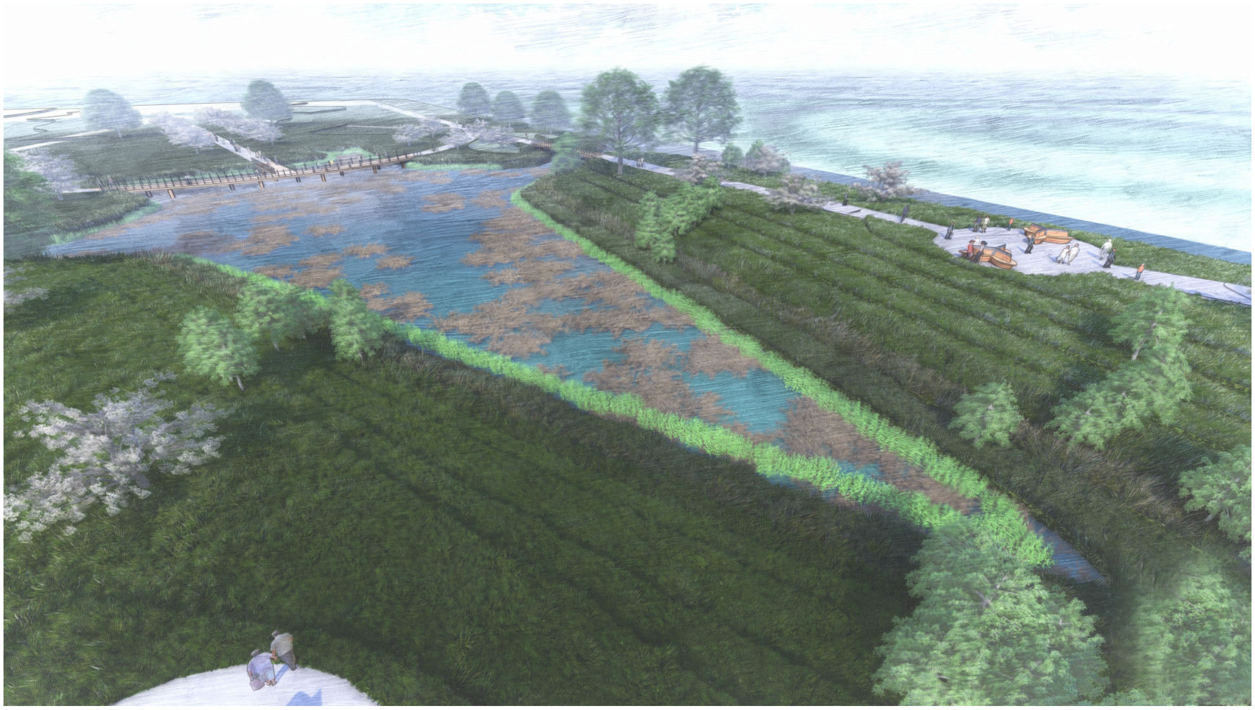


Figure 23: Aerial view above the midway gathering point on the west hillside overlooking the interior wetland.

Figure 24: The wetland boardwalk with the top of the hillside in the distance.

Figure 25: The wetland is accessible on the shoreline of the lowland.

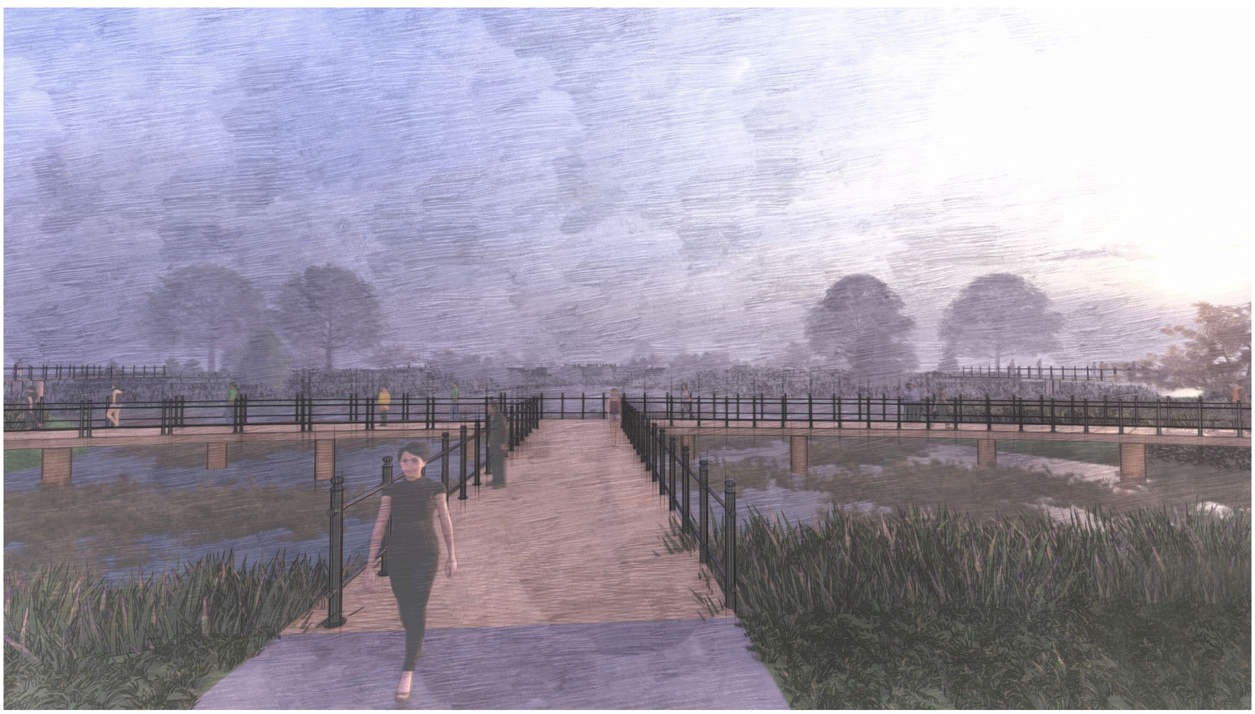


Figure 26: The wetland boardwalk.

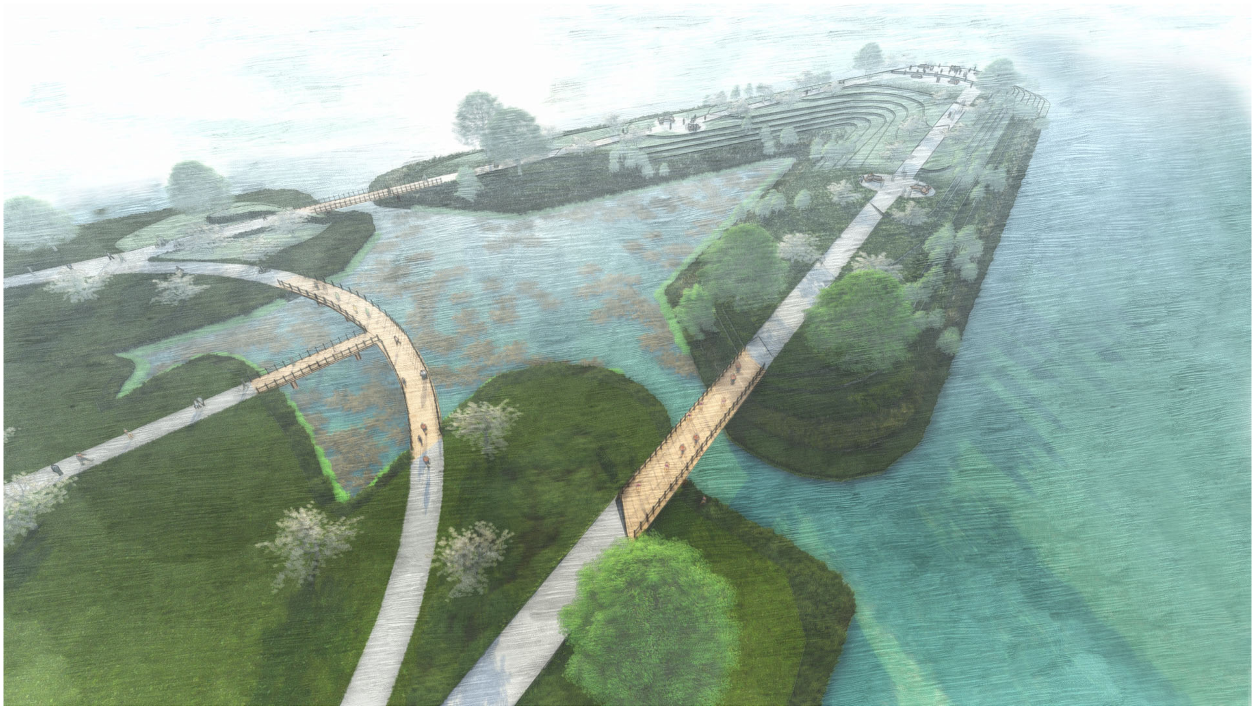


Figure 27: Aerial view looking southeast showing the interior wetland connecting to the Potomac River and Washington Channel.

Sections

A number of sections describing different possible landscape and wetland configurations for the exterior edges of East Potomac Park are equally relevant for the lower park parts of Hains Point as they are for the edges of the rest of the island. The edges of the island do not typically exceed 2-4 ft elevation. Considering projected sea-level rise scenarios, much of the exterior edge landscape would be under water. Therefore, the edges provide another opportunity to adapt and work with sea-level rise. With edge landscape approximately 45-65 ft wide between water bodies and the road, this provides space to integrate additional freshwater tidal wetland and berm landscapes to buffer against wave energy.

An existing landscape and water level section is provided for context (Fig. 28). Then, scenarios of 2.5 ft sea-level rise and 4 ft sea-level rise by 2100 were considered. Four different landscape and wetland alternative were considered under each scenario (Figs 29-32). In each section alternative, the seawall surrounding East Potomac Park is preserved. The seawall is considered a historic resource and removal of the seawall would require an extensive, complex political process. Repairing the seawall, which is in disrepair, in East Potomac Park would cost an estimated $245 million (National Historic Trust, 2019). Besides retaining the seawall for its historic value, incorporating the seawall in the site design has benefits for wetland sediment supply and preventing erosion. Ideally, the seawall will help to maintain sedimentation levels in these wetlands to ensure survival of the wetland as well as stabilize the landscape in preventing erosion.

In the sections, the landscape is cut to different points of the seawall, creating various levels of water depth under the sea-level rise scenarios. The sections depict evolving landscapes of submerged, emergent, and upland plantings. Some provide more wetland than upland space, while others provide more upland than wetland space. Additionally, each section creates a different vantage point for park users from a walkway to the wetland and larger water bodies of the Potomac River or Washington Channel.

To elaborate, section 4 will be used as an example case. Section 4 depicts a 2020 water level approximately halfway up the seawall. In a stable emissions scenario, sea-level rise could reach 2.5 ft by 2100. In this scenario, water would flow over the seawall. With the landscape cut halfway down the seawall, this creates space for a shallow wetland with emergent and upland plantings. In a growing emissions scenario, sea-level rise could reach 4 ft by 2100. Significant water would flow over the seawall, creating space for submergent, emergent, and upland planting areas. Notably, the growing emissions scenario of 4 ft sea-level rise by 2100 provides more wetland space than the stable emissions scenario of 2 ft sea-level rise by 2100. In each scenario, the upland area provides space between the wetland and the walkway, which sits atop a berm separating the landscape from the road. This berm acts as an elevated walkway giving the user an interesting vantage point of the landscape, and in combination with the wetland, working to protect the road from flooding and storm surge issues.

The other section alternatives follow a similar analysis process. There is not necessarily a preferred section. Rather, each section should be analyzed and used in context of the anticipated sea-level rise projection. Instead of planning for a single future, providing multiple options of how a landscape might be constructed aims to embrace a scenario planning approach to designing a landscape for multiple futures.

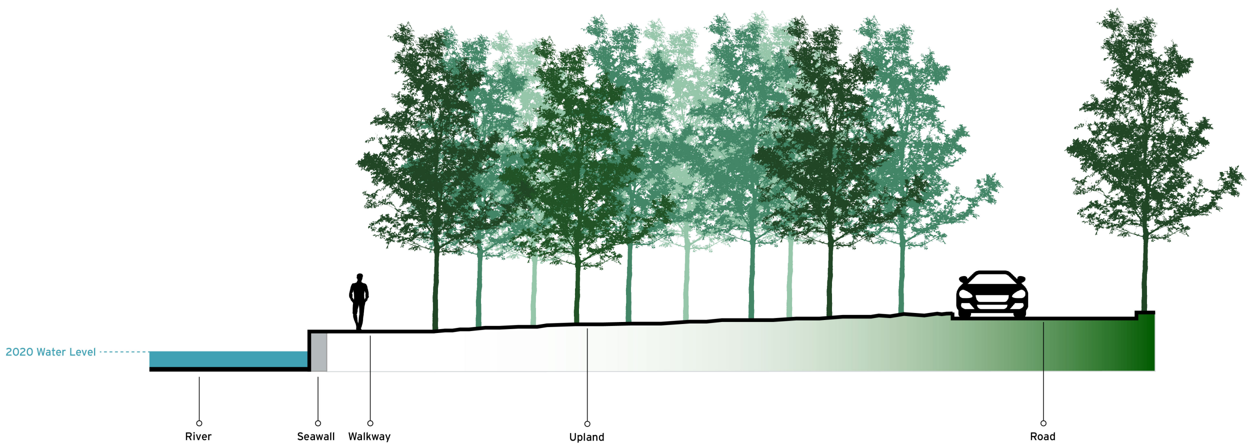
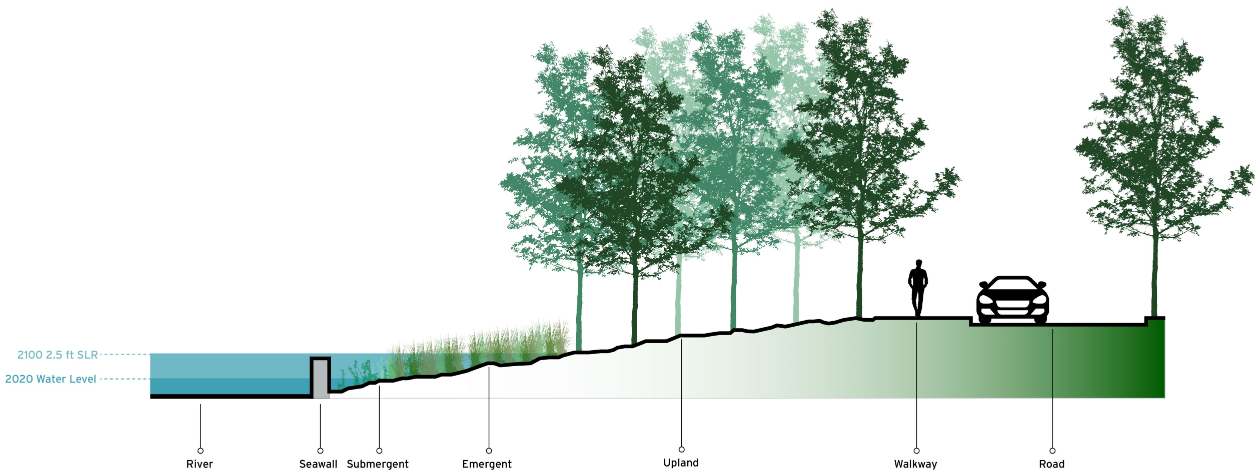


Figure 28: The existing edge landscape, with open space between the road and river.



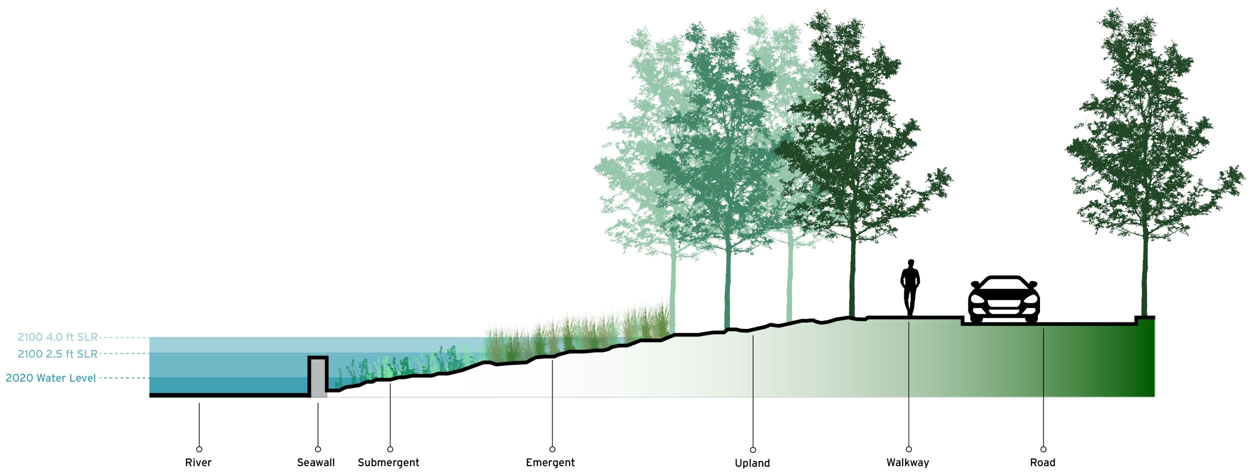


Figure 29: Section 1 alternative for 2.5 ft and 4 ft of sea-level rise by 2100. Section 1 cuts fill down to the bottom of the seawall to encourage wetland growth. Wetland growth is substantial and expansive. The road is protected from wave energy by the hillside elevation.

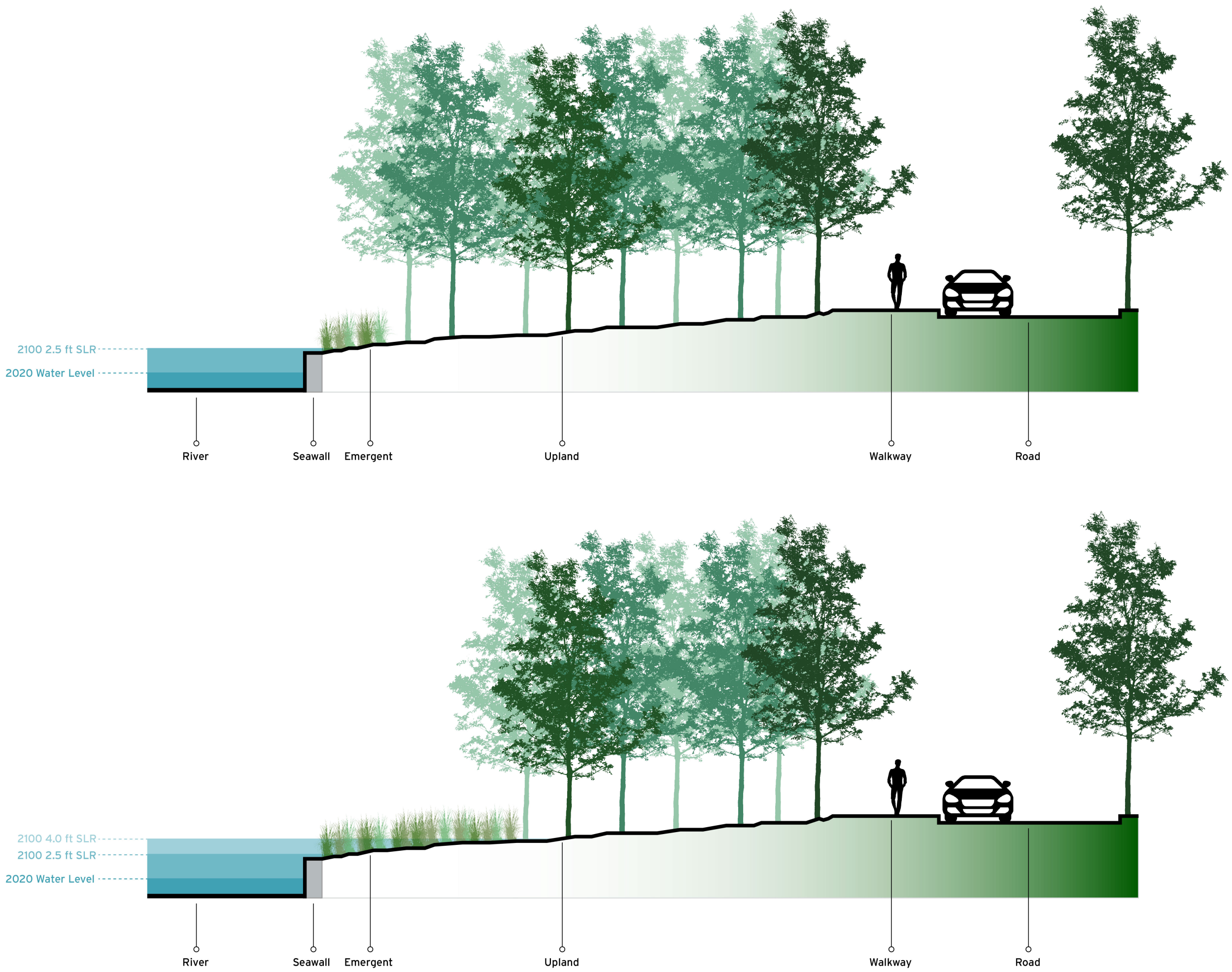


Figure 30: Section 2 alternative for 2.5 ft and 4 ft of sea-level rise by 2100. Section 2 does not cut the fill on the seawall. Wetland growth is minimal. The road is protected from wave energy by the hillside elevation.

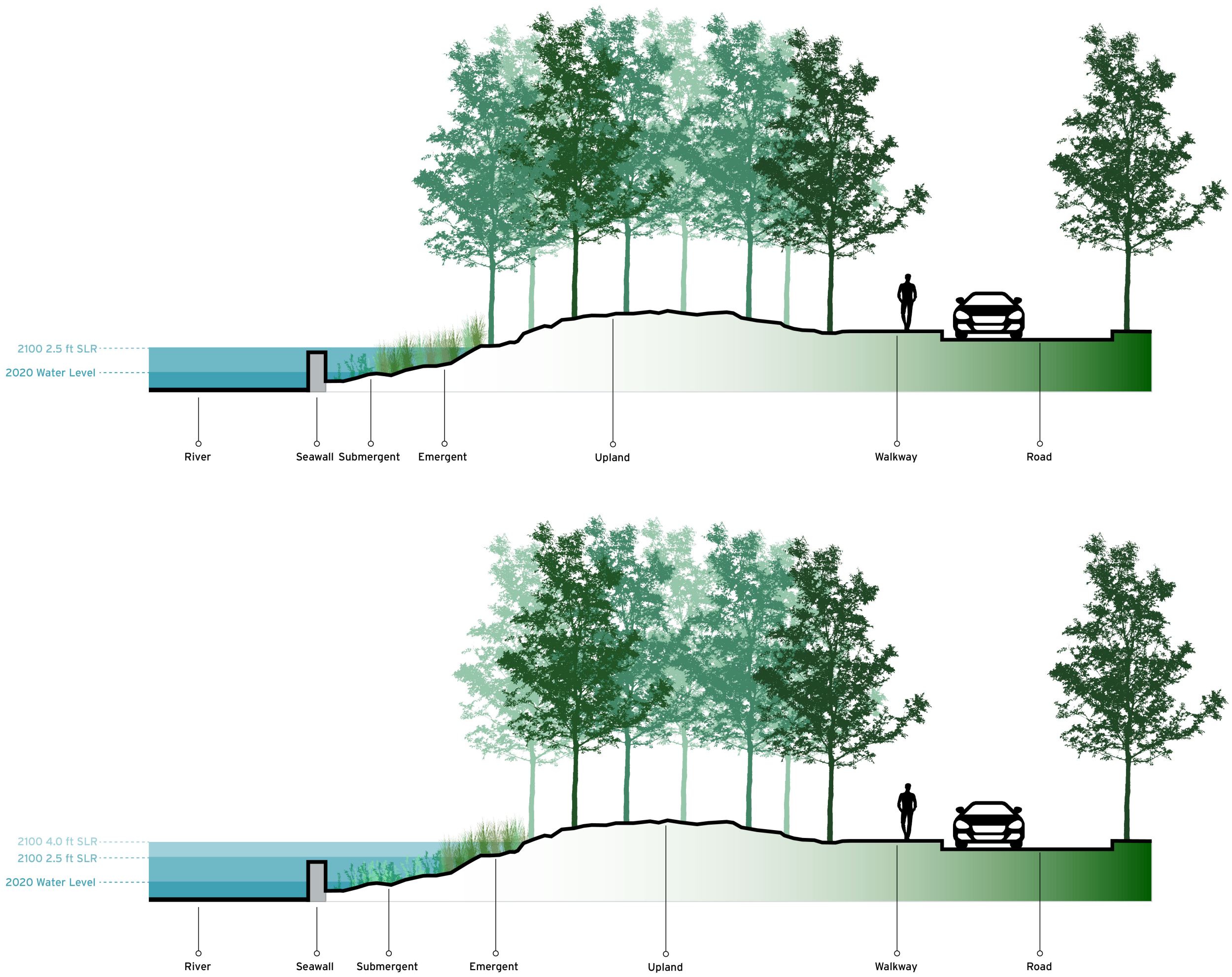


Figure 31: Section 3 alternative for 2.5 ft and 4 ft of sea-level rise by 2100. Section 3 cuts fill down to the bottom of the seawall and introduces a hillside berm. Wetland growth is substantial, but confined. The road is lower in elevation than the previous sections, but protected from wave energy with the hillside berm.

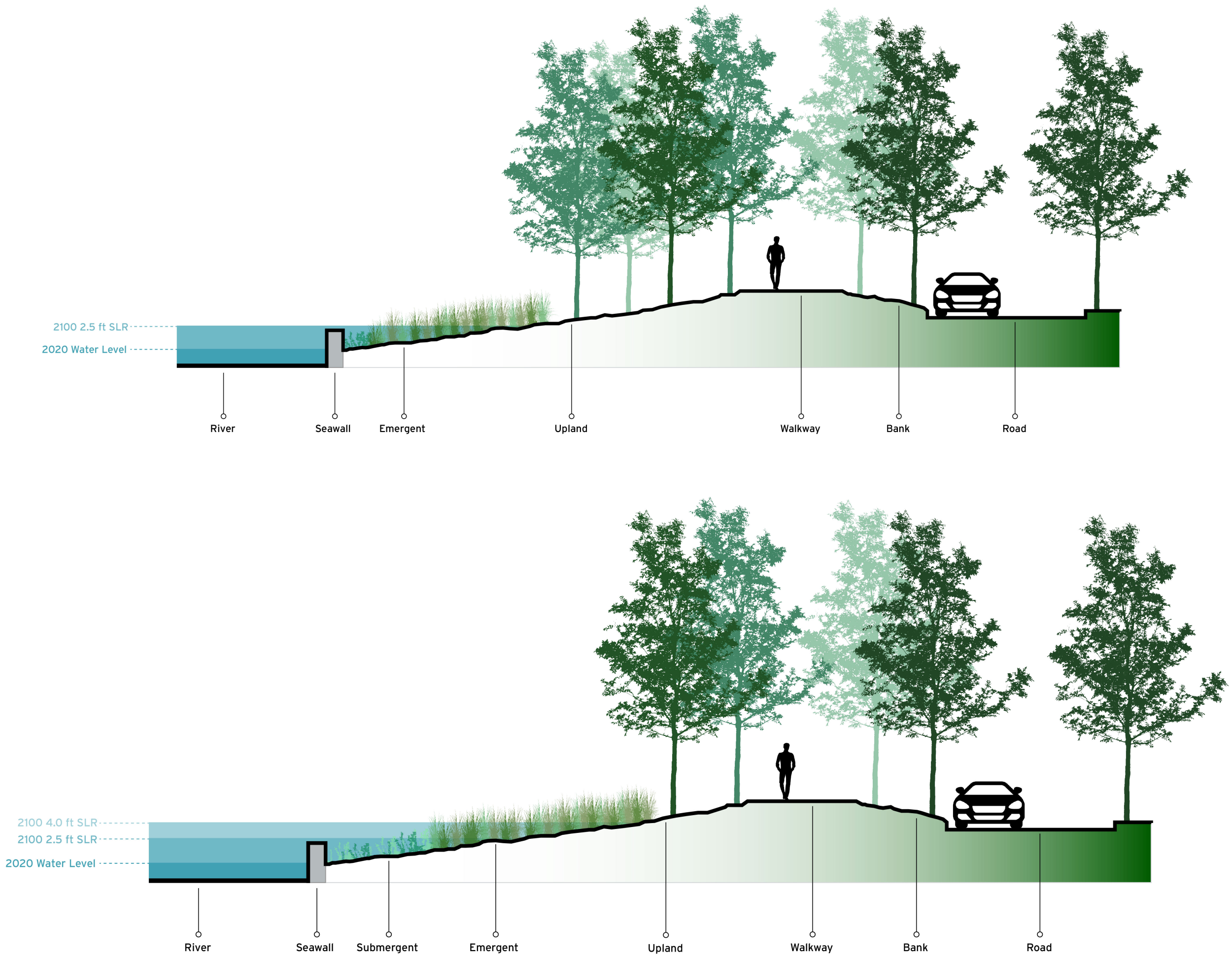


Figure 32: Section 4 alternative for 2.5 ft and 4 ft of sea-level rise by 2100. Section 4 cuts fill down to the middle of the seawall and introduces a hillside berm supporting a walkway. Wetland growth is notable and expansive. The road is lower in elevation than the previous sections, but protected from wave energy with the hillside berm and walkway.

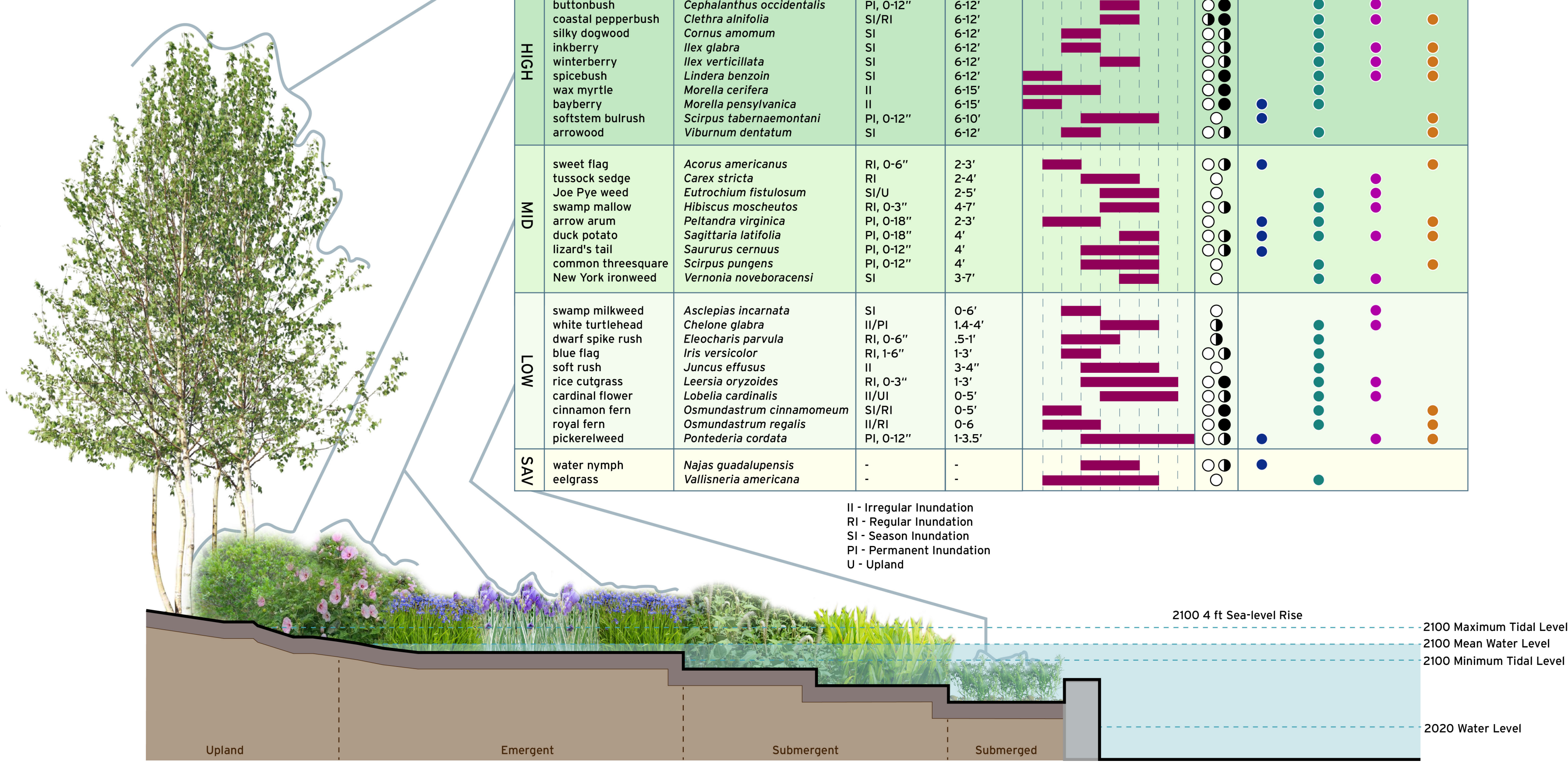
Planting Table/Aquatic Bench

Suggested plantings were identified for the wetland and exterior edges of the site. Plantings were selected for their tolerance to different levels of inundation and ability to survive in a tidal freshwater wetland. Resources such as National Park Service reports from Dyke Marsh, just south of East Potomac Park, were heavily relied on in selecting plantings for the site (National Park Service, 2014; Lindholm, 1992).

Table 3: A planting table shows suggested plants for the site and related inundation tolerances, plant height, bloom time, and wildlife benefits. The aquatic bench below shows where some of the plantings might be on the site's edges under different sea-level rise scenarios.

	PLANT NAME		WATER TOLERANCE	
	Common Name	Scientific Name	Inundation Level	Plant Height (ft)
TREE	shadbush	*Amelanchier canadensis*	SI	35-50'
	river birch	*Betula nigra*	SI	50-75'
	willow oak	*Quercus phellos*	SI	40-60'
	bald cypress	*Taxodium distichum*	RI/PI	75-100'
HIGH	buttonbush	*Cephalanthus occidentalis*	PI, 0-12"	6-12'
	coastal pepperbush	*Clethra alnifolia*	SI/RI	6-12'
	silky dogwood	*Cornus amomum*	SI	6-12'
	inkberry	*Ilex glabra*	SI	6-12'
	winterberry	*Ilex verticillata*	SI	6-12'
	spicebush	*Lindera benzoin*	SI	6-12'
	wax myrtle	*Morella cerifera*	II	6-15'
	bayberry	*Morella pensylvanica*	II	6-15'
	softstem bulrush	*Scirpus tabernaemontani*	PI, 0-12"	6-10'
	arrowood	*Viburnum dentatum*	SI	6-12'
MID	sweet flag	*Acorus americanus*	RI, 0-6"	2-3'
	tussock sedge	*Carex stricta*	RI	2-4'
	Joe Pye weed	*Eutrochium fistulosum*	SI/U	2-5'
	swamp mallow	*Hibiscus moscheutos*	RI, 0-3"	4-7'
	arrow arum	*Peltandra virginica*	PI, 0-18"	2-3'
	duck potato	*Sagittaria latifolia*	PI, 0-18"	4'
	lizard's tail	*Saururus cernuus*	PI, 0-12"	4'
	common threesquare	*Scirpus pungens*	PI, 0-12"	4'
	New York ironweed	*Vernonia noveboracensi*	SI	3-7'
LOW	swamp milkweed	*Asclepias incarnata*	SI	0-6'
	white turtlehead	*Chelone glabra*	II/PI	1.4-4'
	dwarf spike rush	*Eleocharis parvula*	RI, 0-6"	.5-1'
	blue flag	*Iris versicolor*	RI, 1-6"	1-3'
	soft rush	*Juncus effusus*	II	3-4"
	rice cutgrass	*Leersia oryzoides*	RI, 0-3"	1-3'
	cardinal flower	*Lobelia cardinalis*	II/UI	0-5'
	cinnamon fern	*Osmundastrum cinnamomeum*	SI/RI	0-5'
	royal fern	*Osmundastrum regalis*	II/RI	0-6
	pickerelweed	*Pontederia cordata*	PI, 0-12"	1-3.5'
SAV	water nymph	*Najas guadalupensis*	-	-
	eelgrass	*Vallisneria americana*	-	-

II - Irregular Inundation
RI - Regular Inundation
SI - Season Inundation
PI - Permanent Inundation
U - Upland



The main characteristics described of the plantings are inundation level, plant height, bloom season, light requirements, and benefit to wildlife (Table 3). More than 40 plants were studied for their ability to live in freshwater wetland environments and relevance to the project. However, 32 plants were ultimately selected as candidate plantings for the site. Table 3 identifies both the common and scientific names of the plants. The table is organized by height of the plant—TREE, HIGH, MID, LOW, SAV (submerged aquatic vegetation). Trees range 35-100 ft; high plants range 6-16 ft; mid plants range 2-7 ft; low plants range 0-6 ft; and submerged aquatic vegetation are plants living underwater.

In a few cases, height of the plant height is loosely related to the plant's placement on a suggested aquatic bench design. The aquatic bench example accompanying Table 3 represents a scenario of 4 ft sea-level rise by 2100. Maximum and minimum tidal levels are denoted and considered in planting design. A reference 2020 water level is also marked on the seawall. The aquatic bench consists of 4 steps: a top step 10 ft wide and three descending steps that are 5 ft wide. The step arrangement helps to reduce erosion and wave energy, while the plantings maintain the form.

The aquatic bench has upland, emergent, and submergent areas with suggested plantings that take into consideration plant height and inundation tolerance. The upland area in the aquatic bench shows river birch (*Betula nigra*; 50-75 ft, SI), and inkberry (*Ilex glabra*; 6-12 ft; SI). The emergent area shows swamp mallow (*Hibiscus moschuetos*; 4-7 ft; RI), sweet flag (*Acorus americanus*; 2-3 ft; RI), and blue flag (*Iris versicolor*; 1-3 ft; RI). The submergent area shows arrow arum (*Peltandra virginica*, 2-3 ft; PI), white turtlehead (*Chelone glabra*; 1.4-4 ft; II/PI), and water nymph (*Najas guadalupensis*; SAV). The aquatic bench described represents just one possible design and planting arrangement.

All of the plants in Table 3 bloom between March-November, with the majority of blooms concentrated in June-September (Fig. 33). Light requirements of the plantings range from full sun to full shade, and the plantings provide a variety of benefits for waterfowl, birds, pollinators, and mammals. Duck potato (*Sagittaria latifolia*), located in the mid planting section of the table, is used as an example. The plant tolerates permanent inundation of 0-18 in. and reaches 4 ft in height. The plant has a bloom season of August-September and enjoys full sun-part shade. It benefits diverse wildlife, including waterfowl, birds, pollinators, and mammals.

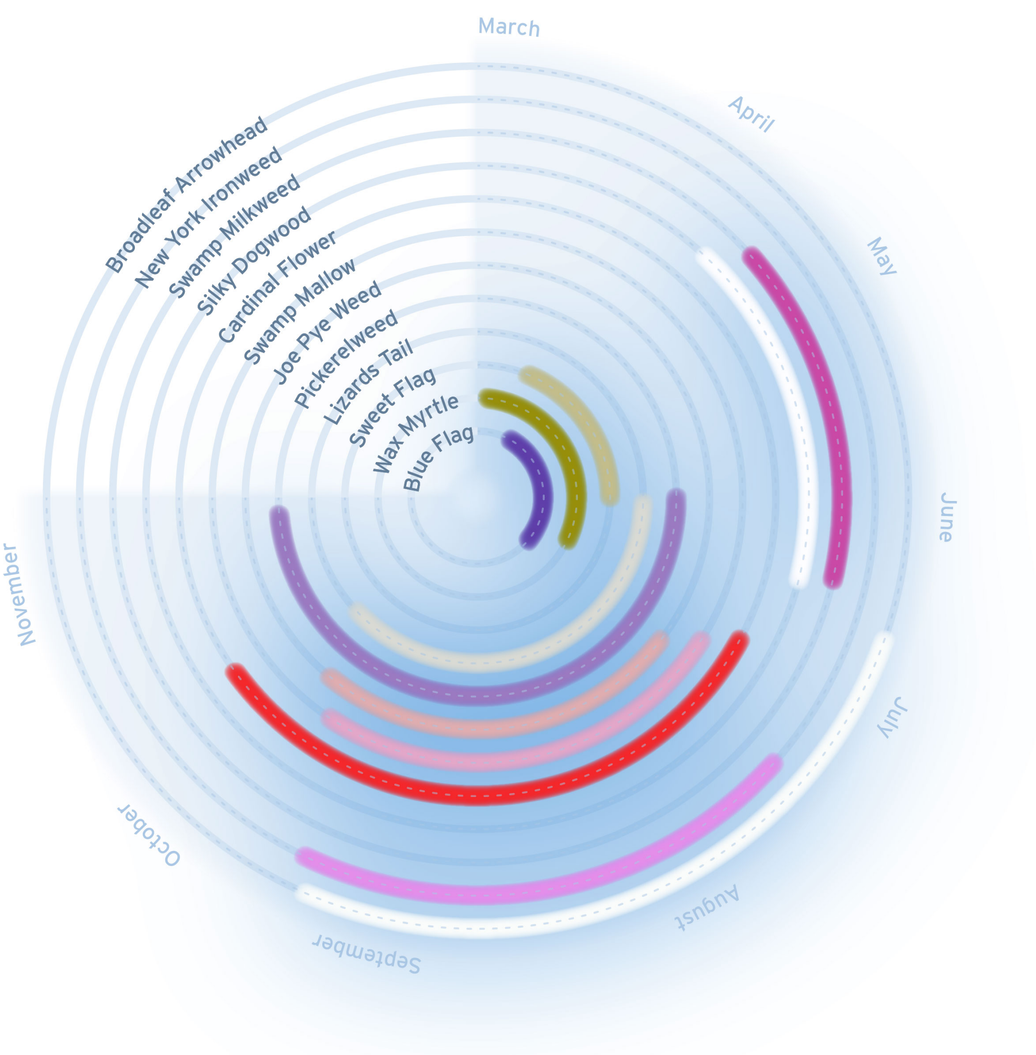


Figure 33: A planting palette showing bloom times and colors for some of the suggested site plantings.

A word of caution: some of the plantings, such as duck potato and pickerelweed (*Pontederia cordata*), are extremely attractive to geese, which can significantly hinder wetland restoration efforts, such as has been observed at Kingman Island further up the Anacostia River (National Capital Planning Commission, 2008). Therefore, the planting recommendations are only suggestions and should be adopted as necessary given the site context and ability to manage herbivory. Nonetheless, the plantings are well-adapted wetland plants offering significant benefits to wildlife and human enjoyment.

Calculations

The site design proposes several significant natural features, notably, the hillside and tidal freshwater wetland areas. Each have associated environmental costs and benefits.

Hillside Fill and Dredge Material

The hillside requires fill material, which is expensive to obtain and move, and creates a large carbon footprint in transportation. Being at the confluence of the Potomac and Anacostia Rivers, however, the site could accommodate river dredge material in constructing the hillside. Parts of the Potomac and Anacostia Rivers are dredged regularly. Finding where to put dredge material and the costs with transporting the material can be challenging for city managers. The site at Hains Point could play an interesting role in reusing dredge material locally, turning waste from one part of the river into a monument on another part of the river, and thereby, limiting the environmental problems related to moving and storing dredge material.

The proposed hillside of the site design requires approximately 104,951.08 yd^3 (80,240.87 m^3) of fill material. This is no small number. Yet, it is not unachievable either. Dredging parts of the Potomac, Anacostia, and Washington Channel produced 25,000 yd^3 (19,113.87 m^3) in 1985 (U.S. Army Corps of Engineers, 2017). At Kingman Island, wetland restoration covering 47 acres required 45,000 yd^3 (34,404.97 m^3) of cut material and 148,000 yd^3 (113154.12m^3) of fill material, which was acquired from dredging of the adjacent Anacostia River, while the nearby River Fringe project raised wetland bottom elevations to be 18-24 in at high tide, requiring 128,978 yd^3 (98610.76 m^3) of fill material (U.S. Army Corps of Engineers, 1994). Today, the upper part of the Anacostia River near Bladensburg Waterfront Park—just outside of the Washington D.C. boundary—are dredged annually. A 2020 dredging proposal for the area estimates excavating 45,000 yd^3 (34,404.97 m^3) from the river (U.S. Army Corps of Engineers, 2020). The material is left across the river from Bladensburg Waterfront Park at Coleman Manor to dewater, and later moved to storage off-site.

Alternatively, following dewatering at Coleman Manor, the dredge could be transported from Bladensburg to Hains Point using a barge on the Anacostia River. The sites are 7.8 mi apart on the river (Fig. 34). On the road, the sites are separated 11.7 mi. At Hains Point, the dredge material could comprise the bulk of the fill material and be capped with fresh material to prevent any potential pollutant escape. The benefits of reusing dredge material from Bladensburg at Hains Point are numerous. First, the Hains Point site would acquire fill material for the site at a fraction of the normal cost, if not for free. Second, there would be no need to find far away storage sites for the dredge material. Third, moving the dredge material

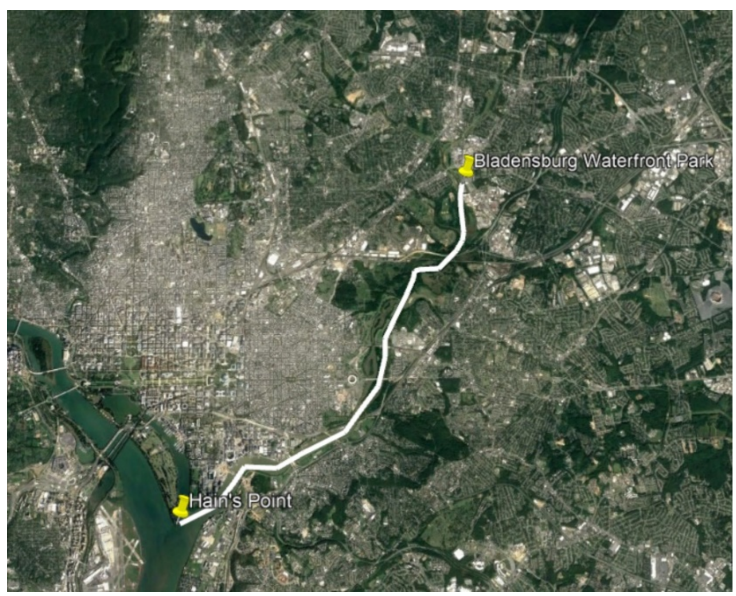


Figure 34: Hains Point is down the Anacostia River from Bladensburg Waterfront Park.

would not only be a local endeavor, but a nautical rather than road affair, which would likely carry more sediment at a lower cost, saving in disposal transport expenses.

At the recent proposal of dredging 45,000 yd^3 (34,404.97 m^3) of material from Bladensburg, could accommodate around 2.25 years' worth of the dredge material the Hains Point site requiring 104,951.08 yd^3 (80,240.87 m^3) of fill material. Likely, the Coleman Manner dewatering site can actually handle additional annual dredge volume, which could shorten the time required to obtain the 104,951.08 yd^3 (80,240.87 m^3) of fill material needed at Hains Point. Moreover, other berms proposed around the exterior of East Potomac Park could take on additional dredge material, extending the time that dredge material from Bladensburg could be repurposed at Hains Point, providing both an economic and environmental service.

Water Quality Credits

The site also incorporates a tidal freshwater wetland area. Therefore, the design has benefits for reduction of total nitrogen (TN), total phosphorous (TP), and total suspended solids (TSS). Calculations for the site are based on numbers for water quality protocols in the Environmental Protection Agency "Recommendations of the Expert Panel to Define Removal Rates for Shoreline Management Projects" for Maryland. Calculations cover denitrification—an annual mass nitrogen reduction credit; sedimentation—an annual mass sediment and phosphorous reduction credit; and the Marsh Redfield ratio—a one-time nutrient reduction credit based on nutrient uptake for vegetative growth in marshes (Mason et al., 2014).

The design introduces 1.65 acres of wetland in the main area. The area results in a denitrification pollutant load reduction of 140.24 TN lb/yr; sedimentation pollutant load reduction of 8.73 TP lb/yr and 11,482.35 TSS lb/yr; and Marsh Redfield Ratio pollutant load reduction of 11.27 TN lb/yr and .50 TP lb/yr.

Not considering permanent inundation of the landscape due to sea-level rise, the 1.65-acre tidal freshwater wetland would require between 2,600-4,000 yd^3 of cut at 1-2 ft of depth, respectively. This cut material could be repurposed on-site in the hillside or exterior berms. Given that the site is within the Chesapeake Bay Watershed, Washington, D.C. could receive water quality credits from a redesign of Hains Point including a tidal freshwater wetland, helping the District to meet its environmental goals.

Analysis of Iterative Methods Framework

The site design is cross-evaluated with the iterative methods framework to evaluate the robustness of the iterative methods framework in informing design for sea-level rise. The iterative methods framework categories Explore, Acclimate, Plan & Design, Communication, & Monitor are described for strength and weakness in context of the completed site design. Specific examples of how the Action was addressed and whether the Objective was met are provided, followed by a short description of the overall feasibility of the Objective of the Action.

Explore

Strength: The Action "study site history" and Objective "locate natural and cultural resources were achieved following a site analysis of the area, which included using National Park Service reports and mapping. Notably, the Objective example "social media postings for site use" proved especially useful in determining site use and players. Instagram revealed specific activities, such as fishing and picnicking, that people engage in at East Potomac Park.

Weakness: The Action "determine users and community relationship" and the Objective "connect decision-makers and information users" was difficult to achieve in the allotted time period and considering the Covid-19 pandemic.

Feasibility: The Objective "identify the issue and key players" is feasible. However, time constraints may pressure design to move faster than the time it takes to access a full scope of informed stakeholders. One suggestion for addressing time constraints is to identify and meet with leaders of the relevant stakeholder groups. Meeting first with community leaders to gain a foundational sense of the landscape could help direct and specify conversation and topics in subsequent community meetings open to all community members.

Acclimate

Strength: The Action “assess vulnerability to climate change” and Objective “determine habitat of nature-based design” were achieved through a combination of mapping and relevant literature on sea-level rise projections, which revealed the area to be vulnerable and identified a tidal freshwater wetland and hillside as potential nature-based design solutions. Additionally, the final site design meets the Objective “balance user needs, coastal services, and design solution” by providing a mixture of open space, wetland boardwalk, wetland access, and hillside. The combination of spaces supports user needs, such as walking, running, biking, picnicking, wildlife viewing, and sightseeing, while enabling adaptation with sea-level rise. In particular, the proposed hillside not only provides protection to wave energy, but a vantage point that creates a new way to experience and connect to the existing memorial landscape on the National Mall.

Weakness: Two interviews with National Park Service and National Capital Planning Commission personnel were conducted. But the category would have been more fully informed with additional interviews and collaboration with researchers. Interviews with park users, in particular, would be very beneficial in assessing the community’s future expectations for the landscape as well as desired features missing from the current landscape. Research collaborations would likely provide increasingly holistic and informed data sources for the site that could strengthen the design.

Feasibility: The Action and Objective of this category were largely met. The Objective "define socioecological factors" is at the heart of the site design. In following the framework, socioecological factors are identified that inform the site design. As both the existing landscape and current user experiences are threatened by projected sea-level rise, vulnerable areas of the site, such as Hains Point and the island's outer edges, and meeting the needs of users in accessing the space for recreational and gathering purposes were priorities. By considering the interplay of both environmental and social factors, site planning and thinking was directed in finding ways to integrate the landscape and user experience, such as the hillside, which serves as a sea-level rise buffer and preserves user experiences such as wildlife watching and exercising, among others. In defining, and incorporation, socioecological factors, the site plan elevates both the site's climate preparedness and accessibility for future generations.

Plan & Design

Strength: The Action "integrate culture and nature"' and Objective "design solutions that provide multiple socio-eco benefits" might be best represented in the hillside and tidal freshwater wetland components of the design. These multifaceted design aspects provide a means to adapt to sea-level rise, revitalize local ecology, build on existing park values and uses, create new landscape experience, and connect to the wider memorial landscape in the city. Together, the plan and design work to engage the environment to bolster human experience on and with the landscape.

Weakness: The Action "consider time horizons and scenarios" and Objective "use scenario planning and phasing for uncertain futures" is integrated within the design. However, the design mainly considers endpoints in stable and growing emissions scenarios at 2100. The design would benefit from further considering how the landscape evolves between site design and anticipated maturity.

Feasibility: The Objective “implement adaption, mitigation, and resilience measures” is feasible. Attention to phasing and multiple future scenarios is especially important and should be given due diligence.

Communicate

Strength: The Action “bring attention to place identity and meaning” and Objective “use site as a demonstration of climate change” is attempted through the imagery of the landscape. Historically, much of the area was tidal freshwater wetland. Therefore, introducing a tidal freshwater wetland in the area seeks to bring attention to the landscape’s identity and meaning. In particular, the transformation aims to maintain the site’s existing meaning as a valuable landscape for city residents’ leisure and recreation as it transitions to also create new user experiences. In preserving space for activities noted in the site analysis, including fishing, bike riding, cherry blossom viewing, airplane watching, and picnicking to name a few, the design preserves its place identity and meaning, while growing new experiences such as a stronger connection to the memorial core. Moreover, the hillside design element provides a canvas for engaging with climate change, as it should enabling viewing over time of how the landscape might change due to sea-level rise, with plantings migrating up the hillside. Additionally, the Objective example “past and present photographs for context” provides a striking opportunity to communicate and engage the public about climate change and the environment, and a number of past photographs were located through National Park Service report and Library of Congress images.

Weakness: The Action “provide educational and engagement opportunities” and the Objective “develop public dialogue between science and design” are embedded within the site design. However, no specific initiatives or attempts to engage the public in climate change dialogue were completed in the span of this project due to the COVID-19 pandemic. Last, a suggestion for the Objective example “past and present photographs for context” would be to include imagery of future scenarios on site due to climate change.

Feasibility: The Objective “promote dialogue and idea-sharing” is feasible. It is critical in directing the dialogue of the site as well as working to connect science and design. Especially important in successful communication messaging is collaborative dialogue with public stakeholders. In this case, the landscape attempts to speak for itself, but the effectiveness of the Objective is likely to benefit from time spent on directed communication initiatives and public engagement.

Monitor

Strength: The Action “connect research and practice” and the Objective “examine design contribution to cultural and ecological goals” were achieved through the integration of scientific research into the site design and cross evaluation of the site design with the iterative methods framework. The height of the hillside and exterior edge berms, for instance, were designed in anticipation of future sea-level rise projections. In terms of cultural goals, the design supports user values through providing space for leisure and recreational activity. The design integrates with the memorial dialogue of the city, and presents an opportunity for community input in developing a memorial alternative to those of the nearby National Mall. The process is informed by moving between research and design, and the iterative methods framework activates a method for evaluating the design’s ability to provide cultural and ecological services.

Weakness: The Action “research and evaluate pre-post site performance” and the Objective “identify relevant metrics and indicators” remain largely unmet. The topics were often talked about, but nothing specific entered the project. However, this data would be beneficial in quantifying the site’s performance and might include metrics on tidal change, flooding occurrence, visitation numbers, and cultural and community aspects. Additionally, the Objective “create a practice-science feedback loop” has potential but has yet to be fully developed.

Feasibility: The Objective “study design outcome” is feasible. However, it is prudent to involve researchers early on to measure and collect data before the start of a project and throughout a project’s lifetime. Additionally, soliciting feedback from stakeholder groups would likely yield further insight into quantifying and qualifying, and thereby improving, the site design.

Chapter 6: Discussion

Unlike previously in history, human centers and coastal areas of interest have not been managed or planned for in an era of rapid sea-level rise and climate change. Large urban centers, such as cities immediately come to mind as hotspots in need of adaptation and coastal resiliency plans. But other areas of human interest, such as coastal national parks, are also primed to benefit from considering adaptive strategies addressing climate change issues like sea-level rise. Nature-based design offers an innovative and exciting approach in adapting to climate change and may serve as a vehicle for exploring and reinvigorating a research-design feedback loop. Tackling the complexities of sea-level rise, for instance, transcends any single discipline, presenting an opportunity for interdisciplinary collaboration and breaking down communication barriers across disciplines.

The thesis aims to guide design for sea-level rise and storm surge in national park areas. The thesis develops a framework for informing coastal resilience design and planning projects, and uses the framework in nature-based site design at Hains Point in East Potomac Park, Washington, D.C. The framework is constructed in the context of Hains Point—national park land in Washington, D.C.—but endeavors to be widely applicable to other coastal areas facing similar issues.

The text within the framework reflects interdisciplinary thinking to capture a cohesive method to work from in the design process for sea-level rise issues. A number of studies considered in the framework address the design process, with many even seeking to understand design and planning adaptation strategies specifically in response to or preparation for sea-level rise and coastal change (Kirshen, Knee, & Ruth, 2008; Hurlimann et al. 2014; Burger et al. 2017; Woodruff, BenDor, & Strong, 2018; Molinaroli, Guerzoni, & Suman, 2019). Given the many disciplines involved in addressing sea-level rise issues, a comprehensive methods framework attempting to bring together and structure relevant interdisciplinary information might promote an informed, effective, collaborative, and sustainable design and planning process to address climate changes issues such as sea-level rise.

Informed by the iterative methods framework, the site design addresses sea-level rise issues at Hains Point. The design incorporates a lowland and highland area separated by a proposed tidal freshwater wetland. In doing so, the design attempts to buffer against and adapt with projected sea-level rise in the area and engage human connection with the landscape. Notably, the design's tidal freshwater wetland speaks to the historical ecology of the area. Tidal freshwater wetlands are a rare habitat type. In the past, tidal freshwater wetlands were present in abundance in the area. By 1987, however, 98% of tidal wetlands and 75% of freshwater wetlands in Washington, D.C. area had been destroyed (National Capital Planning Commission, 2008). Moreover, the conversion of wetlands into other land uses, such as agriculture and aquaculture, has resulted in the loss of 25-50% of the world's coastal wetlands in the twentieth century (Kirwin & Megonigal, 2013). By intentionally incorporating a tidal freshwater wetland, the design seeks to achieve a level of ecological restoration and celebrate the unique ecosystems of the area.

In addition to the tidal freshwater wetland, the highland hillside is perhaps the most monumental part of the design. Discussion with the thesis committee often deliberated whether the hillside could indeed be a monument. Ultimately, the design does not specify, but there is reason to develop the idea further. For instance, the area has been slated as a landscape suitable for a memorial on multiple occasions. In 1983, Hains Point was approved as a site for the National Peace Garden, but the initiative never transpired and expired in 2003 (Roy Rosenzweig Center for History and New Media, George Mason University). Additionally, the National Park

Service and National Capital Planning Commission held the "Memorials for the Future" competition and selected a design focused on climate change as the winner (National Capital Planning Commission). The thesis committee suggested that the hillside might be fit for some kind of climate change, nature-based, or indigenous peoples monument. This seems especially worthy of consideration given that the landscape, situated on/near ancestral Piscataway and Nanticoke tribe lands, will persist and evolve with projected sea-level rise and provides a vantage point atop the hillside toward the National Mall. Interestingly, "Piscataway" can be translated as "meeting of the waters," a fitting link for the design location at the confluence of the Potomac and Anacostia Rivers. Perhaps any potential monument could integrate both angles from the nature-based/climate monument and indigenous people's perspectives. The Native American Museum on the National Mall and related stakeholders, for instance, may have ideas on how the Indigenous story reflects the climate change story, with a climate justice perspective embedded within the narrative. As Reagan National Airport is also directly across the Potomac River from Hains Point, such a monument at Hains Point would transcend beyond being valuable only to on-site users: it would provide a significant statement to people viewing the landscape from above when arriving by air to Washington, D.C.

Another interesting idea the thesis committee discussed related to indigenous peoples is trading routes between indigenous cultures of this area and Midwest mound building cultures. How might these linkages add another layer of meaning to the site design, which includes hillsides and berms. At least, discussing with local indigenous members could lend insight on native plants that were used and valued by local indigenous peoples, and a planting scheme reflecting indigenous values would provide further substance to a narrative on place meaning and identity. Thesis committee members put the author in touch with local representatives of the Piscataway and Nanticoke tribes. Attempts were made to set up a meeting for discussion, but unfortunately, nothing was solidified within the time scope of the thesis. A suggestion would be to include local indigenous members early on in the project, and indeed, engaging stakeholders is recommended in the Explore Action of the iterative methods framework.

Where fill material for the hillside would come from also entered discussion. The neighboring Potomac and Anacostia Rivers might provide a perfect source for hillside fill material. The Army Corps of Engineers dredges these rivers to maintain openness of shipping navigation channels. A regular question is where to put the dredged material. Given that Hains Point is at the confluence of these rivers, the location would be an easy dropping point for dredged river material that could then be used to create the hillside. Testing would be required to analyze the dredge material for pollutants and contaminants. But assuming the integrity of the dredged material, the hillside could accommodate and make use of a significant amount of dredge river material, reducing costs and emissions associated with transporting dredge and fill material.

Future study should also assess the ability of the design to buffer against storm surge. The hillside and wetland were planned in such a way as to absorb storm energy and prevent erosion. But the actual effectiveness of the design's performance remains unknown. Likely, this would require hydrological modeling and refined projections for sea-level rise at Hains Point. One potential route for acquiring a base level of study on design performance and effectiveness could be to test it using Augmented Reality Sandbox technology, which provides visualization and analysis of hydrology and topography features. However, advanced computer models would likely prove most insightful. Such modeling could also illuminate questions on sedimentation. Continuous sediment capture is necessary for maintaining wetlands. Partly, the seawalls should help to trap and retain sediment from the river. But additional study of flow dynamics could help to identify proper placement of any structures or landscape forms aimed at routing sediment to the wetland.

Finally, it would be interesting to know what sea-level rise benefits the design has beyond the immediate site. The Tidal Basin and National Mall areas lie just over 2 miles away from Hains Point. Reasonably, it could be assumed that the Hains Point design might have additional storm surge and flood amelioration benefits for these nearby landscapes, which act as America's front doorstep. Moreover, possibilities might exist to incorporate the proposed Hains Point design at East Potomac Park as part of system in the region, working with other sites of wetland reclamation in the area, such as Kingman Island on the Anacostia River to the north and Dyke Marsh on the Potomac River to the south. Together, as parts of a larger system, these three sites might act as one in providing nature-based adaptation for sea-level rise and storm surge in Washington, D.C.

Regarding the iterative methods framework, future study should evaluate the effectiveness, fluidity, and transferability of the framework in multiple contexts and timescales. Whether the framework has applicability in both urban and rural contexts, for instance, provides an interesting route of future study, as does how well the framework stands up to issues of climate change beyond sea-level rise. Likely, the framework may need to be appropriately adjusted for use on a case specific basis. The framework's ability to connect multiple nature-based design projects in a shared area into a larger functioning system that provides numerous ecosystem services presents another interesting route of study complimenting questions related to the interactions of Hains Point, Dyke Marsh, and Kingman Island. The framework is meant to act as guide for design related to climate change, specifically sea-level rise, and it is encouraged to use the framework as a foundation rather than canon. Therefore, the adoptability of the framework in various contexts is a critical question warranting further study.

Chapter 7: Conclusion

The main results of this project were the iterative methods framework and the site design. The iterative methods framework serves as a set of criteria to guide design in the context of climate change. The framework was developed using three main sources of literature to define Action and Objective methods. The framework was applied to site design at Hains Point in East Potomac Park, Washington, D.C.

Throughout the design process, the iterative methods framework provided a foundation from which to base design decisions. The framework directed design by acting as a reference for meeting target design goals, such as blending climate change and human experience initiatives. The framework steered design direction, and flexibility of the framework was key to providing room for growth and evolution of the design. The framework's flexibility promoted design creativity, while also directing design through times of uncertainty. The framework is an iterative process, but also welcomes revisiting any part of the design criteria at any time during design to further inform the design process and proposed site design.

For instance, the project covers a large land area and wrestles with complex climate change science. At the beginning of the project, when starting design seemed overwhelming, the framework offered simple steps to take to make progress, such as "study site history and context" in the Explore Action. Later in the process, when design was free-flowing, the method did not restrict ideas, but instead offered as a backdrop for inspiration. Toward the end of design, the framework acted as a reference for reflection as to whether design goals were met. And if not, the framework served as a vehicle to editing the design to achieve the project's design standards.

Essentially, the iterative methods framework is an organized design process that maintains the flexibility for creative, original design solutions. However, the iterative methods framework and associated design process is not without shortcomings and limitations. Several improvements could be considered.

The framework suggests including a number of diverse collaborators at different steps of the process. This proved challenging for a thesis project, but input from interdisciplinary collaborators is critical. In a real-world setting, it might take significant time to identify potential partners. The framework could make additional suggestions on how to partner with collaborators. The framework would also benefit from additional literature sources. The supporting literature in the framework is just a sampling of the literature used to create the framework. Literature was selected for its relevance and topic area, but the process was somewhat subjective. Triangulation of multiple sources for each section of the framework alleviates some of the subjectivity involved in the development of the framework. However, this literature may become outdated overtime. Although the content of the framework will likely remain relevant, it may be prudent to update and review the literature sources of the framework after a certain time period, and users of the framework are encouraged to adopt additional relevant literature as necessary. Finally, the framework addresses climate change issues. Considering the timescales involved with preparing for, defending against, or adapting to climate change, design in the context of climate change would be hard-pressed not to consider time horizons and phasing as in a project. Concepts of time are embedded within the framework, such as the "use scenario planning and phasing for uncertain futures" in the Plan & Design Action, but this directive is rather broad. Additional specificity in the context of time could likely be applied to help guide design for climate change issues.

In addressing sea-level rise scenarios under different emission scenarios (Figs. 35-38). the design does consider the time aspect of climate change design. The hillside, for instance, is constructed to a height (24 ft) that should buffer much of the landscape from even an extreme see-level rise and storm surge scenario. In a similar manner, the bridges connecting the lowland to the highland were constructed at 10-12 ft, which should be high enough to be buffered from most storm surge under moderate sea-level rise of 3 ft in a growing emissions scenario. For reference, storm surge from Hurricane Isabel in 2013 reached 7 ft (Boesch et al., 2013).

Figure 35: The Hains Point site design in 2020.

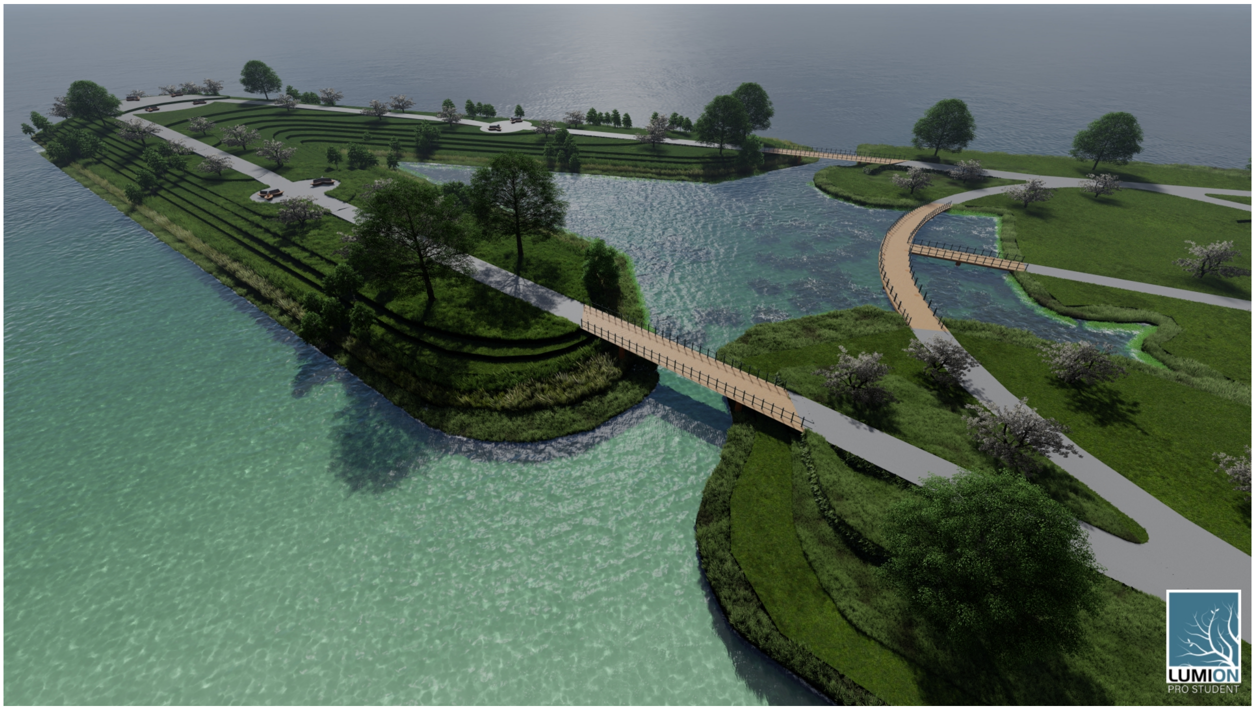


Figure 36: The Hains Point site design with 4 ft of sea-level rise by 2100.

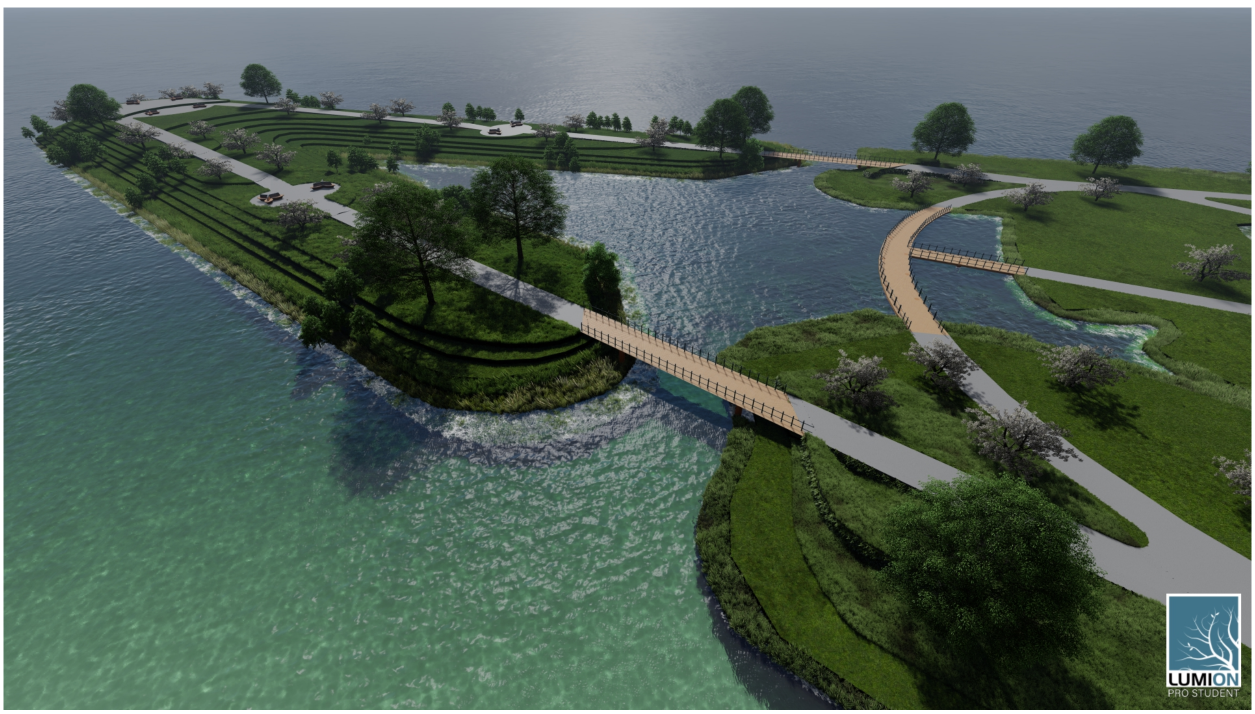


Figure 37: The Hains Point site design with 6 ft of sea-level rise by 2100.

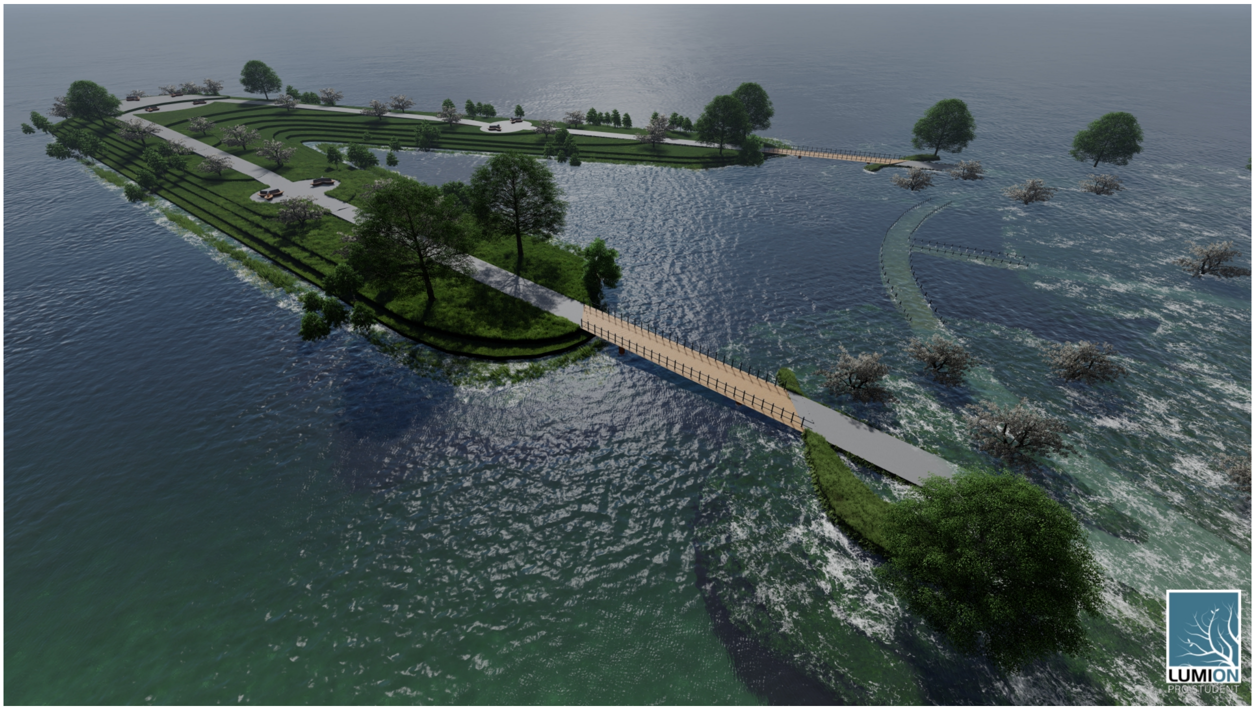


Figure 38: The Hains Point site design with 10 ft of storm surge.

Although the design manages sea-level rise and storm surge, the design could be elevated if it calculated other climate change, maintenance, and human experience benefits. For instance, how much carbon do the plantings and wetland area capture? What effects, if any, does the wetland design have on water quality? And how does the area support biodiversity? Outside of climate change issues, maintenance is another factor warranting further consideration. Currently, flooding and storm surge leaves significant trash on the landscape. Does the proposed design, with its wave attenuation and buffering qualities, reduce or prevent unwanted jetsam from reaching shore? Additionally, what maintenance procedures will be needed for the proposed wetland? Compared with the current largely grass landscape, do the maintenance requirements of the wetland lessen the burdens of maintenance crews? How does this affect the budget of the National Park Service? Last, specified metrics for evaluating human experience on the landscape would help uncover whether the design achieves it socio-ecological goals.

Overall, the site design appears to be a reasonable proposal for adapting to sea-level rise and connecting human experience with the landscape. The design supports a landscape that buffers against and adapts with projected sea-level rise, while simultaneously, providing elevation and ecology changes that engage human connection with the site. Further, the design creates a unique vantage point toward the Washington Monument on the National Mall, attempting to weave the site with the nearby monumental landscapes managed by the National Park Service.

The interdisciplinary nature of this project has implications for coastal resiliency and adaptation efforts, and the study may be useful in designing to buffer against and adapt with the effects of climate change on the coastal front. In an era of climate change, it is critical to reevaluate how the National Park System can continue to meet its mission to "conserve the scenery and the natural and historic objects and wildlife therein, and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." By addressing issues of sea-level rise and storm surge on national park land in the nation's capital, this thesis aims to contribute to innovative management approaches for preserving natural and cultural resources of national parks. This research is not purporting to try to solve all the flooding issues of the watershed, or be a solve-all solution for sea-level rise on the National Mall. But is hoped that the study furthers dialogue on design for climate change and offers a way forward in using nature-based design in the context of climate change, specifically sea-level rise and storm surge issues. Although the future of coastal areas seems tenuous, never has there been such urgency in developing sustainable, resilient, and innovative paths forward to preserving—and reimagining—human connections with coastal zones.

Appendix – Council of Educators in Landscape Architecture Paper Submission

The iterative methods framework portion of this thesis was submitted and accepted for oral presentation at the 2021 Council of Educators in Landscape Architecture Annual Conference. The research was presented as part of the CELA Landscape Planning & Ecology track. In addition, the research was invited for submission as a paper in the conference proceedings publication *Landscape Research Record*. The publication is a peer-reviewed journal and is published each year featuring research presented at the annual conference. The paper was developed and written in collaboration with Dr. Christopher Ellis and can be found on the following appendix pages. The text style and layout are intentionally left as what was required by *Landscape Research Record.*

GUIDING DESIGN FOR SEA-LEVEL RISE: AN ITERATIVE METHODS FRAMEWORK

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1. ABSTRACT

Climate change poses immediate challenges for human populations worldwide. Coastal areas in particular face sea-level rise and storm surge issues. Several artificial designs, including seawalls and surge barriers, have been used to manage the effects of sea-level rise, but these options often require ongoing upkeep and fail to offer long-term solutions. Nature-based solutions offer an alternative for coastal resilience and adaptation strategies relevant to both urban areas and other coastal areas such as national parks. Identifying design procedures for nature-based design could promote successful implementation and long-term sustainability. Based on existing literature, a set of design criteria is formed to guide the implementation of nature-based design in response to projected sea-level rise in East Potomac Park in Washington, DC. The design criteria address socio-ecological factors of landscape, planning and design for adaptation and resilience, communicating climate change, and design performance evaluation. The goal is to provide an iterative methods framework, composed of the design criteria, for climate change design projects and to connect research with practice by creating a design-science feedback loop. The framework provides a platform for innovative solutions in climate change design and furthers dialogue on nature-based design.

1.1 Keywords

climate change, sea-level rise, coastal resilience, nature-based design, national parks

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1. ABSTRACT

Climate change poses immediate challenges for human populations worldwide. Coastal areas in particular face sea-level rise and storm surge issues. Several artificial designs, including seawalls and surge barriers, have been used to manage the effects of sea-level rise, but these options often require ongoing upkeep and fail to offer long-term solutions. Nature-based solutions offer an alternative for coastal resilience and adaptation strategies relevant to both urban areas and other coastal areas such as national parks. Identifying design procedures for nature-based design could promote successful implementation and long-term sustainability. Based on existing literature, a set of design criteria is formed to guide the implementation of nature-based design in response to projected sea-level rise in East Potomac Park in Washington, D.C. The design criteria address socio-ecological factors of landscape, planning and design for adaptation and resilience, communicating climate change, and design performance evaluation. The goal is to provide an iterative methods framework, composed of the design criteria, for climate change design projects and to connect research with practice by creating a design-science feedback loop. The framework provides a platform for innovative solutions in climate change design and furthers dialogue on nature-based design.

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2 INTRODUCTION

Designing for climate change, and specifically for sea-level rise, is one of the biggest challenges facing designers today. Fair weather flooding is now common among coastal cities and considerable resources are going into planning and design for a variety of mitigation measures. Research articles, agency reports and other documents identify important strategies for studying and addressing these problems, but typically focus on a narrow set of issues relevant to local problems in need of solutions. The benefit is the richness of detail and depth of consideration in each situation. The drawback is the lack of broader coordinated procedures that can bring in additional stakeholders, experts, and ideas from an increasingly comprehensive viewpoint. The research presented here draws from multiples sources of published information that each encapsulate one or more parts of the design and planning process. Together, the research brings into focus a more fully developed set of actions and objectives that could improve the decision-making processes for communities affected by climate change issues such as sea-level rise. The results of the study offer a framework, supported by a diverse collection of literature that is organized by triangulation, into a set of actions and objectives for identifying and addressing issues relevant to climate change design.

2.1 Literature Review

2.1.2 Climate Change

Climate change poses significant challenges in human-made environments and natural systems worldwide (IPCC, 2014). More than half of the world's population lives in urban areas and urbanization is expected to continue in the future (Revi et al., 2014). Many cities lack measures for climate change adaptation planning, while those that do not are mostly located in high-income countries (Araos et al. 2016). Moreover, growing populations of people are living less than 10 m above sea level, creating significant risks from climate change issues related to sea-level rise, including elevated tides, increased flooding, erosion and groundwater salinsation (Oppenheimer et al., 2019)

Global average sea-level rise since the late 19th is around 210 mm, with a linear trend of 1.7-1.9 mm per year (Church & White, 2011), and global average sea level is likely to increase in the future, with some studies reporting a possible global sea-level rise increase of 2 m by 2100 in a high emission scenario. However, likely sea-level rise projections for global mean sea-level rise range from 0.24-0.32 m by 2050 and 0.43-0.84 m by 2100, with a 17 percent chance of 0.59-1.1 m by 2100. Moreover, sea-level rise is not uniform, and some regions could see up to 30 percent higher sea-level rise than the global average due to factors such as ocean dynamics and subsidence (Oppenheimer et al. 2019).

In the United States, the North Atlantic Coast is extremely vulnerable to sea-level rise, especially considering the region's population density and coastal hazards such as hurricanes and severe storms. Based on climate models from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), Yin, Schlesinger, & Stouffer (2009) project sea-level rise ranging .36-.51 m in New York City; .37-.52 m in Boston; and .33-.44 m in Washington, D.C. by the end of the 21st century. Moreover, the region has regularly experienced severe storms in the past. Hurricane Sandy in 2012, for instance, brought widespread economic damage, where storm surges reached 9.4-12.65 ft above normal high tides in the New York Metropolitan area. The event revealed an immediate need to address sea-level rise and storm surge issues in coastal areas (US Army Corps of Engineers New York District, 2019).

Tide gauges along the East and Gulf coasts have also been used to extrapolate on storm surge and flooding. Dahl, Fitzpatrick, & Spanger-Siegfried (2017) studied 52 locations along the U.S. East and Gulf Coasts, with projections indicating that Washington, D.C. will experience up to 337 tidal flooding events per year by 2045, the most of all the study cities. Moreover, Washington, D.C. ranked in the top 10 for number of flooding events that received a Coastal Flood Advisory in 2012-2013, with almost 70, and in the top three for average tidal flood events between 2001-2015. The National Capital Region is susceptible to multiple flooding risks, including riverine, coastal, and interior flooding (National Capital Planning Commission, 2018). Tidal flooding and storm surge, which can be caused by hurricanes, have the potential to produce extremely high water when occurring at high tide in the Washington, D.C. (National Capital Planning Commission, 2008). In fact, Washington, D.C. has around a 50 percent chance of experiencing a record-breaking flood by 2040. For a 100-yr flood, this would be 11 ft above the high tide line. For comparison, previous high floods were 7.9 ft in 1942 during torrential rains; 7.4 ft in 1936 due to storm water; and 7.1 ft in 2003 during Hurricane Isabel. Under the highest sea-level rise scenarios, floods exceeding these records would become annual events by 2080-2100 (Strauss et al., 2014).

Furthermore, the National Capital Region is estimated to have the highest rate of sea level change in the National Park System by 2100, with an average of 0.8 m sea-level rise. U.S. national parks are important in preserving cultural and natural resources. Yet, with more than one quarter of lands managed by the National Park Service falling on ocean coastlines, many National Parks are vulnerable to the effects of climate change, especially issues resulting from sea-level rise (Caffrey, Beavers, & Hoffman, 2018). Peek and Beavers (2015) estimate that with 1 m of sea-level rise, over $40 billion of National Park assets will be at risk. For the National Mall in Washington, D.C. the effects of sea-level rise alone may not cause significant damage, but in combination with storm surge, the area could face serious issues (Caffrey, Beavers, & Hoffman, 2018). Economic costs of 0.1 m and 5 m of sea-level rise for Washington, D.C. stand at approximately $2 billion and $24.6 billion, respectively (Ayyub, Braileanu, and Qureshi, 2012), while sea-level rise threatens $4.6 billion in property value less than 6 ft above the high tide line, with the amount increasing to $9 billion at 10 ft above high tide level (Strauss et al., 2014). The Washington, D.C. tide gauge 8594900, which is located near the Tidal Basin in the Washington Channel, has experienced an annual mean change of 3.09 mm from 1959-2008, with the area projected to experience 0.33m by 2050. (Tebaldi, Strauss, & Zervas, 2012). In 2019, the National Trust for Historic Preservation named the National Mall Tidal Basin as one of America's most endangered historic places, largely due to flooding issues. The Tidal Basin experiences regular flooding during high tide, creating accessibility issues and possibly adverse effects on the Tidal Basin Cherry Trees, which attract 1.5 million visitors during the National Cherry Bloom Festival. Similarly, in nearby Annapolis, Maryland, Hino et al. (2019) found that visitation numbers to historic downtown Annapolis are likely to drop by 37,506 visits, or approximately 24%, during high tide flooding with 1 ft of sea-level rise.

2.1.3 Nature-based Solutions

A number of protective design solutions based on natural systems have been proposed to combat the effects of sea-level rise, including seawalls, floodwalls, tide gates, levees and surge barriers. However, many of these options require ongoing upkeep, may not be cost-effective, create ecological problems, and fail to offer long-term solutions (Hirschfeld & Hill, 2017). Alternatively, nature-based design and ecosystem-based adaptation is receiving increasing attention as a strategy for adapting to sea-level rise, storm surge, and flood risks (Oppenheimer, 2019; Bridges et al. 2018). In New York City, for instance, wetland and dune restoration have been suggested as methods of shoreline protection (Rosenzweig, et al. 2011). Nature-based design incorporates natural features that improve coastal protection (Pontee et al. 2016). For instance, coral reefs and salt marshes can reduce wave height up to 70 and 72 percent, respectively (Narayan et al., 2016). Tidal wetlands can even offer a level of coastline protective capacity against storm surge during hurricanes, with larger wetlands providing increased protection from flooding damage and storm surge (Highfield, Brody, & Shepard, 2018). Related to Hurricane Sandy, wetlands were found to protect against $625 million in direct flood damages from North Carolina to Maine (Narayan et al., 2017). Coastal wetlands have been shown to provide additional benefits such as providing erosion control, sequestrating carbon, and maintaining fisheries (Barbier et al., 2011). Moreover, nature-based solutions can often be more cost-effective than traditional infrastructure solutions. Salt marshes and mangroves were shown to be 2-5 times cheaper than a submerged breakwater for waves up to 0.5 m, and the habitats become more effective than breakwaters at increasing depth (Narayan et al., 2016). In addition, Hirschfeld and Hill (2017) observed that a shift from using walls to protect vulnerable coastlines to earthen systems reduces the cost of adaptation to coastal flooding.

2.1.4 Implementation Examples

SCAPE Landscape Architecture's *Living Breakwaters* project in New York City provides an example of integrating nature-based design. The design incorporates breakwaters off of Staten Island to help absorb wave energy and reduce coastal flooding, while also making habitat for fish, oysters, and other species. In China, Turenscape's Sanya Mangrove Park works to restore damaged habitat and the protect coastline against storm surge. And in response to flooding and projected sea-level rise, the National Mall Ideas Lab in Washington, D.C. has identified five landscape architecture firms—DLANDstudio, GGN, Hood Design Studio, James Corner Field Operations, and Reed Hilderbrand—to imagine a redesign of the threatened Tidal Basin (National Trust for Historic Preservation, 2019).

A nature-based design approach opens a route for weaving scientific experiment into the design process, complimenting the "designed experiment" method proposed by Felson and Pickett (2005). With an ecological base, design can offer a route for collecting quality ecological data in urban settings. Furthermore, designed experiments encourage partnerships among urban designers, landscape architects, and architects that enables ecologists and researchers to weave experiments into the urban setting. Similarly, Ahern et al. (2014) propose an adaptive urban planning approach that includes "safe-to-fail" designs, which enable pilot testing of innovative, experimental design solutions in small spatial extents and low risk contexts. The approach offers an opportunity to further integrate design and science, and a method for incorporating ecosystem services into the planning and design process. Mutually beneficial for designers, planners, and researchers, such collaborative efforts work to integrate design into science. Nassauer and Opdam (2008) argue that design can be a vehicle used by scientists and practitioners to include scientific knowledge in the decision-making process related to landscape change, contending that through transdisciplinary collaboration, scientists and practitioners of many fields enhance landscape science and knowledge. Therefore, design can act as common ground between researchers and professionals, connecting science and society by informing the design process and bolstering the outcomes of landscape projects.

3 RESEARCH OBJECTIVES

The primary purpose of this research is to review journal articles, agency reports, and other written documents addressing design and planning concerns related to climate change, particularly sea-level rise, and identify a common set of procedures across professions. The study aims to develop an iterative methods framework based on triangulation of relevant literature sources. The goal of the framework is to pull together diverse thinking on the topic of design for sea-level rise into a comprehensive, organized reference source for designers, planners, researchers, community organizers, and stakeholders.

Furthermore, the project seeks to present a process integrating science and design, and aspires to further connect research and design throughout the design process in a manner that is informative to future design projects addressing issues of climate change. Although the iterative methods framework was developed to address issues of sea-level rise in an urban land area managed by the National Park Service, the study aims to be widely applicable to other study sites by furthering dialogue on the applicability of nature-based design for climate change and by contributing to management approaches in preserving natural and cultural resources at risk from climate change issues.

4 METHODS

A search for journal articles, agency reports and other documentation on design for sea-level rise was conducted. These materials were organized based on the actions involved and the people engaged in the actions. Triangulation was used to determine how strongly the literature supported the categories of action and engagement identified in the documents reviewed. The iterative methods framework was formed in the context of addressing design for sea-level rise using nature-based design solutions in Washington, D.C., an urban area where much of the parkland is managed by the National Park Service. Thus, although the review includes global and regional (Atlantic/Gulf coast) perspectives, the primary strength is related to the Chesapeake Bay and Washington D.C. area (Figure 1).

4.1 Framework Development

The framework is based on supporting literature. Triangulation identified relevant research from journal articles (JA), National Park Service reports (NPS), and documents from other institutions (O) such as government or non-profit entities. Research broadly fell into topic categories of climate change, nature and ecosystem-based design, parks and places, and communication. The framework text is based on a review of more than 60 research papers in these categories. The framework includes Action and Objective columns with text developed to reflect and summarize information from the review of the research literature. For brevity, the framework includes 15 examples from the identified literature (JA, NPS, O). Each Action and Objective section correspond to examples from the supporting literature, with one example from each identifier in every section, to support the directives of the proposed framework method.

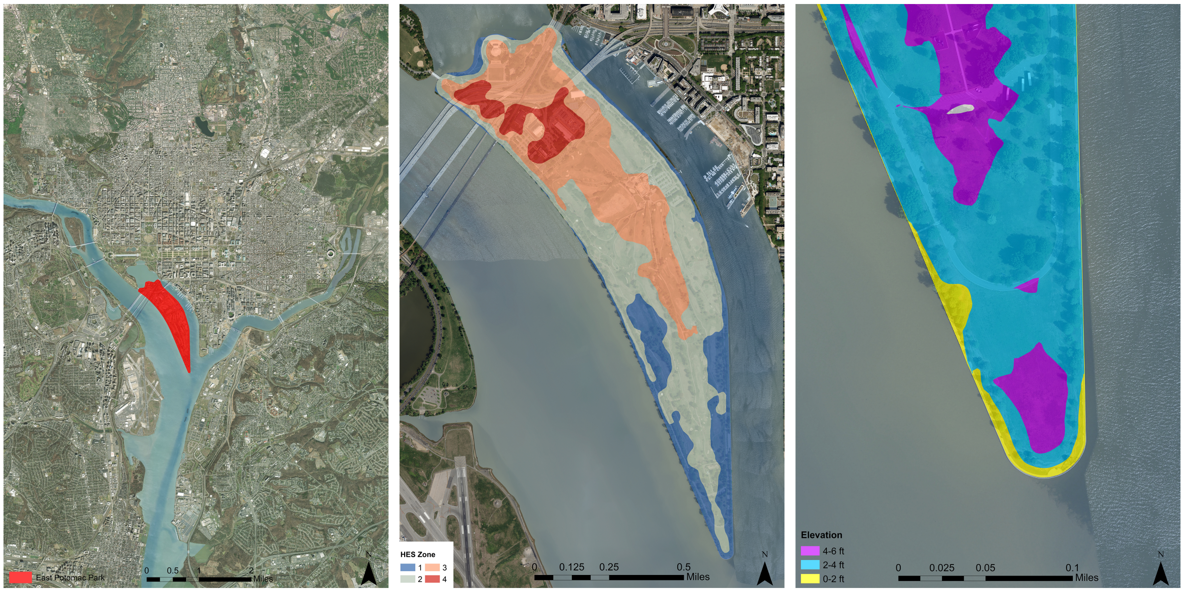

Figure 1. Examples of studies related to sea-level rise for East Potomac Park, Washington, D.C. East Potomac Park (left) encompasses four hurricane evacuation study zones (center), while the southern point is below 6 ft of elevation (right), making it vulnerable to sea-level rise.

5 RESULTS

An iterative methods framework (Table 1) is developed to inform and guide a design process for coastal resiliency. The framework is populated with an Action and Objective column supported by relevant literature from three different source types. The Action column is organized by the following sections: Explore, Acclimate, Plan & Design, Communicate, and Monitor (Figure 2). The process begins at Explore and follows through to Monitor. However, the process is iterative and a section can, and should, be revisited as needed at any point while using the framework.

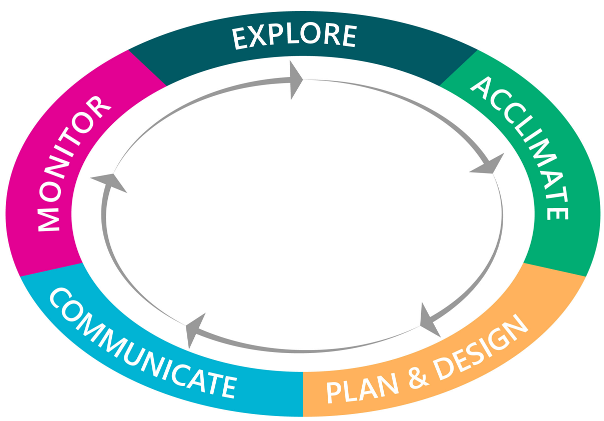

Figure 2. Conceptual layout of the iterative methods framework

Each section contains a directive to address in achieving the related Objective. For instance, the Action "Explore" aims to achieve the Objective "Identify the issue and key players." Recommendations of useful steps in going through the process are included in each section. Continuing the Action "Explore" example, the directive to "study site history and context" is to "locate natural and cultural resources," while the directive to "determine users and community relationships" is to "connect decision-makers and information users," and finally, the directive to "consider opportunity for innovative and creative solutions" is to enable "collaboration in defining the issue." This process is repeated for each Action section. Additionally, each Action and Objective describes relevant parties to involve at a given stage of the process and a concrete example enabling progress toward the Objective. The Action “Explore” suggests engaging social scientists and stakeholders at this stage, while using social media is listed under the Objective column as one potential route in working to achieve the Objective “Identify the issue and key players.”

A third and fourth column attaches supporting literature to the corresponding Action and Objective columns. The supporting literature informs and is directly related to the directives in the Action and Objective columns. Each section contains supporting literature from three source types: journal articles (JA), National Park Service reports (NPS), and Other (O), lending multi-source support to the directives in the Action and Objective columns. Using the Action “Explore” as an example, Hino et al., 2019 (JA), Beavers et al. 2016 (NPS), and Aiken et al. 2014 (O) each contain content that supports the directives in the Action “Explore” column and the Objective “Identify the issue and key players” column. Although many literature sources informed the development of the iterative methods framework, the supporting literatures that appear in the table were selected for relevance, instructiveness, and accessibility to a wide audience.

The process described using the above examples for the Action “Explore” are followed likewise for each Action. For instance, the Action “Communicate” aims to achieve the Objective “Promote dialogue and idea-sharing.” The directive “provide educational and engagement opportunities” is in to “present the site as a demonstration of climate change.” At this stage, the Action “Communicate” suggests engaging communication professionals and end-users, and recommends using past and present photograph comparisons as one potential example in achieving the Objective “Promote dialogue and idea-sharing.” Similarly, the Action “Monitor” aims to achieve the Objective “Study design outcome.” The directive “connect research and practice” is to “create a practice-science feedback loop.” At this stage the Action “Monitor” suggests engaging all relevant parties and recommends comparing baseline and outcome data as one potential example in achieving the Objective “Study design outcome.”

Together, the Action, Objective and Supporting Literature columns form the iterative methods framework. The directives capture perspectives from three types of literature that also serve to provide further reading and context for those using the iterative methods framework for climate change design.

Table 1. The iterative methods framework identifying actions, objectives, and triangulated supporting literature (JA: journal article; NPS: National Park Service; O: Other)

Action	Objective	Supporting Literature	Type
Explore	*Identify the Issue and Key Players*		
Study site history and context	Locate natural and cultural resources	High-tide flooding disrupts local economic activity Hino, M. et al. (2019)	JA
Determine users and community relationship	Connect decision-makers and information users	Coastal Adaptation Strategies Handbook Beavers, R. et al. (2016)	NPS
Consider opportunity for innovative and creative solutions	Collaborate to define the issue	Designing With Water: Creative Solutions From Around The Globe Aiken, C. et al. (2014)	O
Engage social scientists and stakeholders	*Ex: Social media postings for site use*		
Acclimate	*Define Socioecological Factors*		
Assess vulnerability to climate change	Identify vulnerable experiences and ecosystems	Nature-based solutions: Lessons from around the world Pontee, N. et al. (2016)	JA
Specify adaptation and resilience strategies	Determine habitat type of nature-based design		

Evaluate appropriate nature-based designs and ecosystem services	Balance user needs, coastal services, and design solution	Climate Change Response Strategy National Park Service (2010)	NPS
Engage ecosystem scientists and allied researchers	*Ex: Mapping and projections to study site*	When Rising Seas Hit Home Spanger-Siegfried, E. et al. (2017)	O
Plan & Design	*Implement Adaption, Mitigation, and Resilience*		
Integrate culture and nature Consider time horizons and scenarios	Design solutions that provide multiple socio-eco benefits Use scenario planning and phasing for uncertain futures	The shore is wider than the beach: Ecological planning solutions to sea-level rise for the Jersey Shore, USA Burger, J. et al. (2017)	JA
Strengthen preparedness, adaptation, and resilience *Engage planners and designers*	Encourage local and regional preparedness and adaptation *Ex: Plan two alternative futures*	Climate change scenario planning: A tool for managing parks into uncertain futures Weeks, D. et al. (2011)	NPS
		Engineering with Nature Bridges, T.S. et al. (2018)	O
Communicate	*Promote Dialogue and Idea-sharing*		
Bring attention to place identity and meaning Provide educational and engagement opportunities	Engage users in local context and a sense of place Use site as a demonstration of climate change	Climate change impacts in Missouri State Parks: Perceptions from engaged park users Groshong, L. et al. (2018)	JA
Encourage curiosity and discussion	Develop public dialogue between science and design	Using social science in National Park Service climate communications: A case study in the National Capital Region Campbell, E. (2020)	NPS
Engage communicators and end users	*Ex: Past and present photographs for context*	Climate Change Communication Campaign Planning: Using Audience Research to Inform Design Thompson, J. et al. (2013)	O
Monitor	*Study Design Outcome*		
Research and evaluate	Identify relevant metrics and	Designed experiments: new	JA

pre-post site performance for long-term sustainability	indicators	approaches to studying urban ecosystems Felson, A.J. & Pickett, S. (2005)	
Make findings accessible and instructive	Examine design contribution to cultural and ecological goals	Coastal Adaptation Strategies: Case Studies Schupp, C.A. et al. (2015)	NPS
Connect research and practice	Create a practice-science feedback loop	Site Commissioning White Paper” U.S. General Services Administration (2017)	O
Engage all relevant parties	*Ex: Baseline and outcome data for comparison*		

6 CONCLUSIONS

The study presents an iterative methods framework for informing coastal resilience design and planning projects. The framework is constructed in the context of national park land in Washington, D.C., but endeavors to be widely applicable to other coastal areas facing similar issues. The text within the framework reflects interdisciplinary thinking to provide a cohesive method to work from in the design process for sea-level rise issues.

A number of studies address the design process. Many even seek to understand design and planning adaptation strategies specifically in response to or preparation for sea-level rise and coastal change (Kirshen, Knee, & Ruth, 2008; Hurlimann et al. 2014; Burger et al. 2017; Woodruff, BenDor, & Strong, 2018; Molinaroli, Guerzoni, & Suman, 2019). Given the many disciplines involved in addressing sea-level rise issues, however, a comprehensive methods framework attempting to bring together and structure relevant interdisciplinary information might promote an informed, effective, collaborative, and sustainable design and planning process to address climate changes issues such as sea-level rise.

The proposed iterative methods framework is unlikely to be applicable in every instance of climate change design. Moreover, the framework may need to be appropriately adjusted for use on a case specific basis. It is important to note that the framework is meant to act as guide for design related to climate change, specifically sea-level rise, and therefore, it is encouraged to use the framework as a foundation rather than canon.

Additional limitations of the study include the extent of the literature review the framework is built on. A number of other studies and works could further inform and specify the framework. Literature was selected for its relevance and topic area, but the process was somewhat subjective. The authors hope that the triangulation of multiple sources for each section of the framework alleviates some of the subjectivity involved in the development of the framework, and advocate that users of the framework adopt additional relevant literature as necessary.

Finally, future study should evaluate the effectiveness, fluidity, and transferability of the iterative methods framework in multiple contexts and timescales. Whether the framework has applicability in both urban and rural contexts, for instance, provides an interesting route of future study, as does how well the framework stands up to issues of climate change beyond sea-level rise. The framework’s ability to connect multiple nature-based design projects in a shared area into a larger functioning system that provides numerous ecosystem services presents another interesting route of study.

7 DISCUSSION

Unlike previously in history, human centers and coastal areas of interest have not been managed or planned for in an era of rapid sea-level rise and climate change. Large urban centers, such as cities immediately come to mind as hotspots in need of adaptation and coastal resiliency plans. But other areas of human interest, such as coastal national parks, are also primed to benefit from considering adaptive strategies addressing climate change issues like sea-level rise. Nature-based design offers an innovative and exciting approach in adapting to climate change and may serve as a vehicle for exploring and reinvigorating a research-design feedback loop. Tackling the complexities of sea-level rise, for instance, transcends any single discipline, presenting an opportunity for interdisciplinary collaboration and breaking down communication barriers across disciplines.

The interdisciplinary nature of the content informing the iterative methods framework in this study has implications for coastal resiliency and adaptation efforts, and the study may be useful in designing to buffer against the effects of climate change on the coastal front. The framework provides a step in promoting dialogue on design for climate change and connecting science and design. Although the future of coastal areas seems tenuous, never has there been such urgency in developing sustainable, resilient, and innovative paths forward to preserving—and reimagining—human connections with coastal zones.

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