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Sea Level Rise Adaptation Plan

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AECOM

MIAMIBEACH
RISING ABOVE

Prepared for:

City of Miami Beach

Prepared by:

AECOM
2 Alhambra Plaza
Coral Gables, FL 33134
aecom.com

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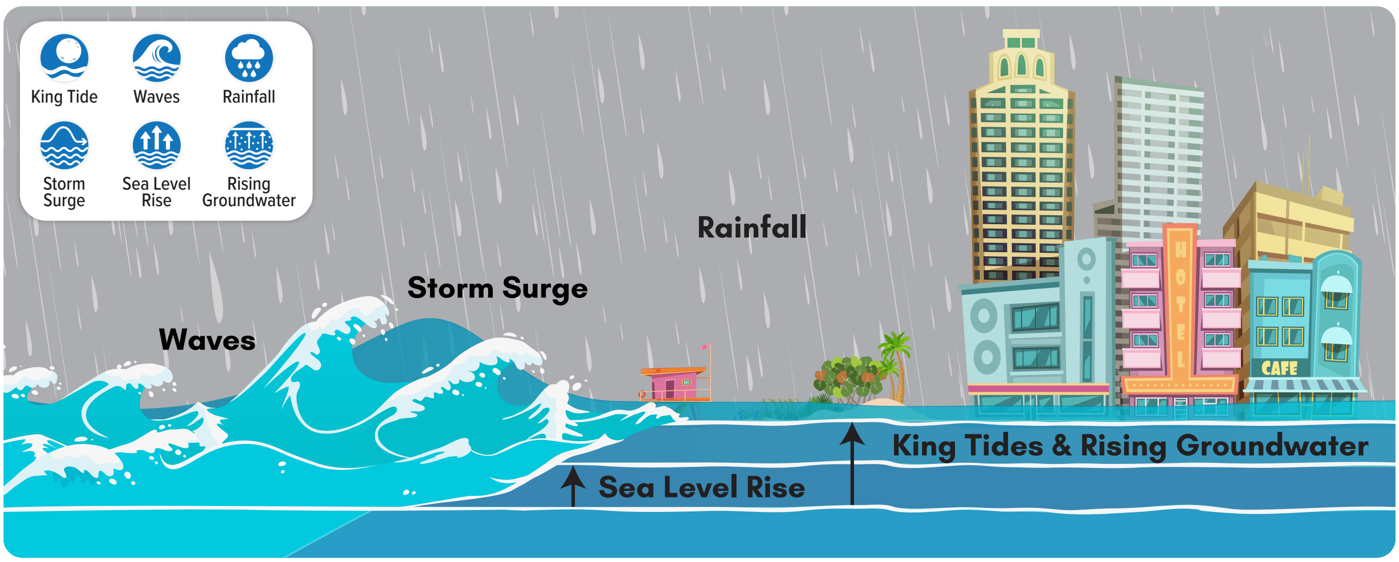
Executive Summary

Rising Waters, Rising Challenges and Possibilities

The City of Miami Beach (City) is working to reduce flood risk through incrementally adapting to sea level rise. The City's setting on a low barrier island with porous limestone bedrock makes the area vulnerable to flooding during heavy rainfall events, annual king tides, wave overtopping during windy days and storm surge, and periods of high groundwater conditions. As sea level rises, flooding due to these factors will extend further inland, increasingly affecting City infrastructure and facilities. Miami Beach worked with consultant AECOM to perform a Sea Level Rise Vulnerability Assessment (Assessment) through the Resilient Florida grant program to **identify and prioritize over 67,000 assets** vulnerable to flooding through 2070 based on 2017 NOAA sea level rise projections.



Prioritizing What's At-Risk

The Assessment evaluated a range of asset types that support the community and provide essential services, including adding highly valued assets identified by input from over 150 City residents. Utilizing best available data and modern stormwater modeling techniques, vulnerability was assessed based on asset's exposure to flooding scenarios through 2070, sensitivity to floodwaters, and the potential community consequences of their failure. **Findings from the assessment will be used to target improvements and pursue grant funding to address the identified flood vulnerabilities and reduce the City's risk.**

What is a Sea Level Rise Vulnerability Assessment?

A process of evaluating the structural and social assets likely at risk to future flooding due to sea level rise.

Citywide Sea Level Rise Vulnerabilities

- The timing and extent of future flooding impacts will vary across the City's regions based on relative ground elevations and current flood protection infrastructure in place.
- Assets with higher vulnerability are generally located adjacent to canal shorelines, with the west ("Bay") side of the City at the greatest risk of flooding due to the low elevation of mostly privately-owned seawalls.
- The City's beach and coastal dune system provides a natural buffer from most ocean wave impacts, but extreme coastal storms, such as the effects felt by Hurricane Ian and Helene on the Florida West Coast, could flood certain areas of the City by up to 5 feet, even without additional sea level rise.
- The water and wastewater pipeline network contains several areas with pipelines that are over 70 years old, that are more susceptible to corrosion or may contain small cracks that can be infiltrated by elevated groundwater.
- With 1-foot of sea level rise (since the year 2020), over half of the City's roadways are projected to experience flooding during heavy rainfall events that coincide with king tides, potentially restricting traffic and limiting mobility within the City.
- By 2040, a 25-year, 24-hour rainfall event combined with a king tide could cause flooding at four emergency response facilities, including Mt Sinai, Police Station HQ, Sailport Substation, and Fire Station #1. By 2070 this number increases to include the majority of emergency response facilities across the City.

Multiple Paths to Achieve Adaptation

The Assessment findings highlight the increasing flood risks facing the City and the need for adaptation strategies that provide long-term resilience for residents and infrastructure. The City has several existing policies, studies, and plans that detail flood protection strategies. However, the full implementation of these strategies may take decades, leaving many areas of the City at risk. To address gaps, **the City's Sea Level Rise Adaptation Plan (Adaptation Plan) identifies additional and supplemental strategies to provide flood protection through the end of the century**.

The proposed strategies are organized by geographic area or asset type and include key implementation details, such as a strategy timeline and critical considerations for successful implementation. The Adaptation Plan also identifies additional metrics beyond sea level rise amounts that can be used to help guide the initiation or phasing out of strategies based observed levels of flood protection effectiveness. Lastly, to support future decision-making, the **strategies were summarized using six adaptation pathway diagrams**, which provides a decision tree planning framework to guide transitions between strategies as conditions evolve. **This flexible approach provides a structured, yet adaptable roadmap to inform major flood protection investments**.

What is a Sea Level Rise Adaptation Plan?

A strategic planning document that establishes a process to implement actions that minimize future flood impacts.

Next Steps

The Vulnerability Assessment and Adaptation Plan work in tandem to identify the City's growing sea level rise-driven flood risks and document targeted strategies to address both near- and long-term flood protection gaps in existing efforts. The organization of the strategies into **adaptation pathways provides decision-makers with a phased implementation plan that can be adjusted to changing environmental conditions to better support the City's sea level rise adaptation process**.

The City can foster successful implementation of the Adaptation Plan by:

- Continuing inter-departmental coordination to discuss strategies, potential metrics, and a monitoring plan that will serve as a tool to provide consistent long-term flood protection of City assets.
- Integrating adaptation strategies into new iterations of the City's existing planning and visioning documents as they are updated to avoid projected flood impacts of future projects.
- Establishing ongoing monitoring programs to track observed impacts and inform flood-protection decision-making and investments.
- Identifying funding sources to implement prioritized flood strategies for near- and long-term planning horizons.
- Continuing to engage with the community as part of the decision making process to understand how flooding impacts the quality of life for residents and how infrastructure improvements have decreased observed flooding.

Sunny Day flooding on Miami Beach street. Source: Miami Beach

Bayfront Flood Protection Strategies

The following presents a list of strategy options for the City to consider over time as sea level rise changes flood conditions. The implementation timing of listed strategies will be dependent on the rate of future sea level rise and observed impacts. Please refer to the full Sea Level Rise Adaptation Plan for more information.

Strategy Name and Description	Flood Hazards Addressed
Elevate Seawalls to Current Ordinance Modify existing public and privately owned seawalls to comply with the existing seawall ordinance (5.7 feet NAVD88).	King Tide, Waves
Temporary Seawall Flood Barriers Install deployable flood barriers (e.g., Tiger Dams) along low-lying seawalls to provide short-term flood protection while longer-term solutions are being designed or constructed.	King Tide, Waves
Install Canal Tide Gates Closable tide gates could be installed at the openings of the Collins Canal to provide flood protection for properties along the canal and reduce the number of seawalls requiring higher elevation.	King Tide, Waves, Storm Surge
Update Seawall Ordinance Revise the existing seawall ordinance to reflect the latest sea level rise amounts and future projections to provide continuous flood protection through the end of the century.	King Tide, Waves
Elevate Seawalls to Updated Ordinance Modify existing public and privately owned seawalls to comply with the updated seawall ordinance.	King Tide, Waves
Add Living Shoreline to Seawalls To protect seawalls from local scouring while also enhancing the ecological conditions of the Bay, a living shoreline could be added to the seaward side of seawall structures.	Waves
Restore Natural Shorelines Frequently flooded properties that are cost-prohibitive to maintain could be restored to coastal wetlands, allowing the shoreline to return to a natural state of transitional wetland habitat between the built and natural environment.	King Tide, Waves, Storm Surge
Expand Waterfront Setback for Increased Resilience Expanding waterfront setbacks involves revising land use regulations for shoreline-adjacent development to reduce the risk of property damage due to flooding.	King Tide, Waves, Storm Surge

Strategy Theme:
Keeping Water Out, **Nature-Based Flood Protection**, **Strategic Relocation**, **Plans and Policies**

Flood Hazards:

King Tide | Waves | Rainfall | Storm Surge | Rising Groundwater

Oceanside Protection Strategies

The following presents a list of strategy options for the City to consider over time as sea level rise changes flood conditions. The implementation timing of listed strategies will be dependent on the rate of future sea level rise and observed impacts. Please refer to the full Sea Level Rise Adaptation Plan for more information.

Strategy Name and Description	Flood Hazards Addressed
Continue Routine Beach Renourishment Maintain beach width based on the updated CRSM renourishment schedule to replenish eroded sand.	Waves, Storm Surge
Dune Enhancement Increase the height and width of dune features and fortify with natural elements to provide an increased natural buffer for inland infrastructure and assets.	Waves, Storm Surge
Redesign Public Access Alter the traditional access path angle or install walkover structures that span over the City's dune system, allowing for public beach access while minimizing potential flood pathways and negative dune impacts.	King Tide, Waves, Storm Surge
Hybrid Dune Systems Reinforce dunes with armoring materials behind or under the dune features as a final line of defense to prevent shoreline retreat impacts to inland infrastructure and assets.	Waves, Storm Surge
Reimagine Coastal Areas Reimagine how the coastal beachfront is utilized, including scaling back or eliminating development in favor of expanded recreational opportunities and enhanced natural spaces.	Waves, Storm Surge
Expand Offshore Wave Attenuation Create a network of offshore structures, such as artificial reefs or breakwaters, to absorb wave energy and reduce erosion impacts on the shoreline.	Waves

Strategy Theme:
Keeping Water Out, **Nature-Based Flood Protection**, **Strategic Relocation**

Flood Hazards:

King Tide | Waves | Rainfall | Storm Surge | Rising Groundwater

Critical Infrastructure Flood Protection Strategies

The following presents a list of strategy options for the City to consider over time as sea level rise changes flood conditions. The implementation timing of listed strategies will be dependent on the rate of future sea level rise and observed impacts. Please refer to the full Sea Level Rise Adaptation Plan for more information.

Strategy Name and Description	Flood Hazards Addressed
Implement current Neighborhood Improvement Projects Carry out infrastructure improvement projects, such as replacing aging infrastructure and pipelines, which were prioritized at the neighborhood scale.	
Update Neighborhood Prioritization Plan for future sea level rise The Neighborhood Prioritization Plan will likely need to be revised over time to reflect evolving environmental conditions due to sea level rise and the shifting implementation landscape.	
Implement future Neighborhood Improvement Projects An updated Neighborhood Prioritization Plan would facilitate the implementation of Neighborhood Improvement Projects that consider the potential project impacts from future sea level rise through the end of the century.	
Floodproof Critical Infrastructure Apply dry (e.g., waterproof coverings, sealants) and wet floodproofing (e.g., flood resistant materials, adding sump pumps) techniques to critical infrastructure in flood prone areas of the City to reduce or prevent flood damage.	
Elevate Critical Infrastructure Elevate critical infrastructure components to be above projected flood levels to reduce the risk of flood damage.	
Relocate Frequently Flooded Critical Infrastructure Assess the feasibility of relocating key infrastructure from flood-prone areas to enhance resilience, particularly when existing floodproofing and elevation strategies are not feasible or effective.	

Strategy Theme:

Keeping Water Out, **Strategic Relocation**, **Plans and Policies**

Flood Hazards:

King Tide

Waves

Rainfall

Storm Surge

Rising Groundwater

Roadway Flood Protection Strategies

The following presents a list of strategy options for the City to consider over time as sea level rise changes flood conditions. The implementation timing of listed strategies will be dependent on the rate of future sea level rise and observed impacts. Please refer to the full Sea Level Rise Adaptation Plan for more information.

Strategy Name and Description	Flood Hazards Addressed
Incremental Roadway Elevation Coordinate the elevation of prioritized roadways with other infrastructure projects based on the recommendations of the Road Elevation Strategy to reduce potential flood risks of critical access routes.	
Temporary Roadway Flood Barriers Deploy temporary flood barriers along critical roadways that frequently flood to safeguard evacuation routes and essential access points during flood events.	
Update Road Elevation Strategy Revise the Road Elevation Strategy to prioritize the most vulnerable roadways in need of elevation based on latest sea level rise observations and end of century projections.	
Implement Updated Road Elevation Strategy Continue the coordinated elevation of select roadways with other infrastructure projects as specified in the revised Road Elevation Strategy to reduce potential flood risks of critical access routes through the end of the century.	
Transition to Stormwater Streets Designate specific low-lying roadways to intentionally accumulate floodwater during heavy rainfall, allowing them to serve as stormwater retention areas and reduce widespread flooding risks elsewhere.	
Repurpose Rights-of-Way Transition the use of certain rights-of-way, including the removal of roadway infrastructure, to maintain mobility and reduce maintenance commitments.	

Strategy Theme:
Keeping Water Out, **Living with Water**, **Strategic Relocation**, **Plans and Policies**

Flood Hazards:

King Tide | Waves | Rainfall | Storm Surge | Rising Groundwater

Critical Facilities Flood Protection Strategies

The following presents a list of strategy options for the City to consider over time as sea level rise changes flood conditions. The implementation timing of listed strategies will be dependent on the rate of future sea level rise and observed impacts. Please refer to the full Sea Level Rise Adaptation Plan for more information.

Strategy Name	Flood Hazards Addressed
Continue to Floodproof Critical Facilities Continue to implement wet or dry floodproofing measures for facilities to reduce potential flood damages.	
Temporary Facility Perimeter Flood Walls Erect temporary flood walls around critical facilities during high water events to provide short-term protection against flooding and safeguard essential services.	
Include SLR in FFE for Critical Facilities Establish building design criteria for City facilities that exceed federal and state minimum standards and consider projected sea level rise.	
Elevate Existing Critical Facilities Elevate structures above projected flood elevations using structural fill or pilings.	
Repurpose Frequently Flooded Critical Facilities Remove or relocate facilities that are frequently flooded and cannot be feasibly elevated or floodproofed to repurpose the space for stormwater management or recreation.	

Strategy Theme:
Keeping Water Out, **Living with Water**, **Strategic Relocation**, **Plans and Policies**

Flood Hazards:

King Tide | Waves | Rainfall | Storm Surge | Rising Groundwater

Stormwater Flood Protection Strategies

The following presents a list of strategy options for the City to consider over time as sea level rise changes flood conditions. The implementation timing of listed strategies will be dependent on the rate of future sea level rise and observed impacts. Please refer to the full Sea Level Rise Adaptation Plan for more information.

Strategy Name	Flood Hazards Addressed
Implement Stormwater Modeling and Master Plan Recommendations Execute Critical Needs Projects identified in the Stormwater Modeling and Master Plan to improve the City's stormwater management system flood control and water quality performance for the next 20 years.	
Create Network of Blue Green Stormwater Infrastructure Projects Integrate Blue Green Stormwater Infrastructure elements throughout City infrastructure improvements to develop a cohesive network of projects that utilize nature-based features to improve stormwater management.	
Update Stormwater Modeling and Master Plan Revise the stormwater modeling setup to include system updates and the latest rainfall and coastal tailwater conditions. Use the modeling output to identify new Critical Needs Projects to provide the continued level of service through the year 2100.	
Promote Easement Acquisition Land use policies may require updates to acquire additional easements necessary for additional stormwater infrastructure upgrades (e.g., pump stations).	
Implement Updated Stormwater Modeling and Master Plan Actions Execute the newly identified Critical Needs Projects from the updated Stormwater Modeling and Master Plan to retrofit stormwater infrastructure to provide enhanced flood protection through 2100.	
Increase Floodable Areas Identify city locations, such as parks and designated retention areas, that can be designed to temporarily absorb and manage excess floodwater during heavy rainfall or coastal high water level events.	

Strategy Theme:
Keeping Water Out, **Nature-Based Flood Protection**, **Plans and Policies**, **Living with Water**

Flood Hazards:

King Tide | Waves | Rainfall | Storm Surge | Rising Groundwater

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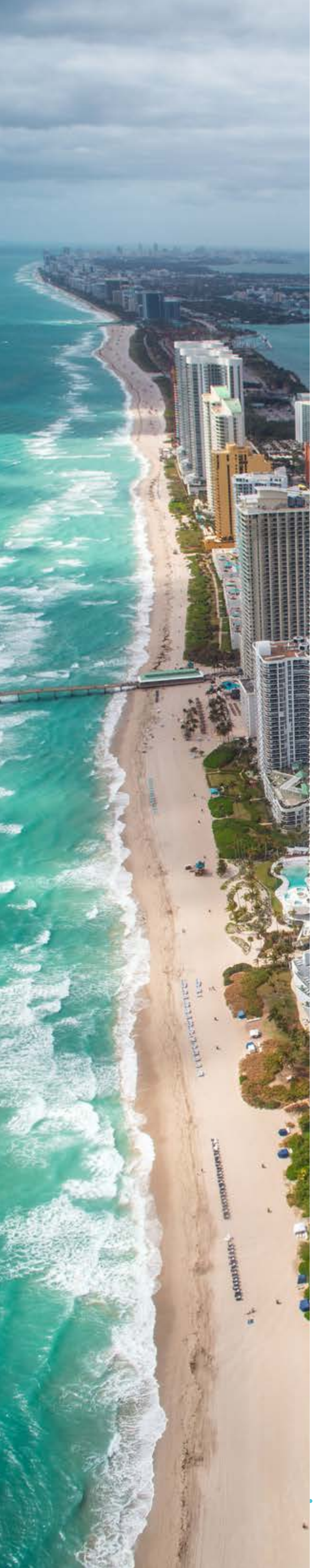
1 Introduction



1. Introduction

The City of Miami Beach (City) is a vibrant coastal city renowned for its iconic beaches, historic cultural landmarks, and thriving tourism industry. It is also at the forefront of addressing the challenges of sea level rise, one of the most pressing issues facing many waterfront communities. The rate of sea level increase has significantly accelerated over the past century with observed global rates increasing from 1.4 millimeters per year (0.06 inches per year) during 1900 to 2000, which equates to a 6-inch increase, to 3.4 millimeters per year (0.13 inches per year) from 2000 to 2024, which equates to a 3.1-inch increase. Along the shore of Southeast Florida, sea level rise is exceeding global rates. Observed sea level rise at the Key West tide station from 2000 to 2023 was about 6 inches—nearly double the global rate[1]. As a low-lying city surrounded by water, Miami Beach is increasingly vulnerable to the impacts of climate change, including intensifying coastal storm surges, more frequent and intense rainfall events, and higher annual king tides, which are all worsened by the addition of rising sea levels. The urgency of the issue is compounded by the City's unique porous limestone geologic setting that allows groundwater to push through the surface and flood interior parts of the City during high tides.

On April 13, 2023, a 1-in-1000-year rainfall event occurred in South Florida, bringing historic rainfall to the area. Although Miami Beach did not receive the 20+ inches of rainfall that was recorded 30 miles north in the City of Fort Lauderdale, the City still experienced approximately 13 inches of rainfall. The flooding from this event caused many roadways to be inundated, forcing drivers to abandon stalled vehicles and wade to safety[2]. A few months later in November 14-16, 2023, extensive flooding occurred across the City again due to 8-12 inches of rainfall. Even though the event did not reach tropical storm levels, the amount of rainfall made many streets impassable and low-lying areas, including Flamingo Park, were completed flooded[3]. From June 11 through 14, 2024 another tropical disturbance across South Florida caused flash flooding as rainfall amounts reached 13.6 inches in the City, causing the City to declare a state of emergency[4].

In response to these challenges, the City's Sea Level Rise Adaptation Plan (Adaptation Plan) outlines a comprehensive, forward-thinking, and flexible framework to safeguard the City's infrastructure and Protect its residents. This plan builds on the results of the City's Sea Level Rise Vulnerability Assessment, which identified the most vulnerable infrastructure and facilities to be prioritized for flood protection based on their projected timing of flood exposure, potential for asset damage, and impacts to the community[5].

1 https://southeastfloridaclimatecompact.org/wp-content/uploads/2024/12/2024-SLR-Statement_120924_FINAL.pdf
2 https://www.miamiherald.com/news/local/community/miami-dade/miami-beach/article289246370.html
3 https://www.local10.com/weather/2023/11/16/steady-downpours-flood-miami-dade-streets-cause-extensive-damage/
4 https://www.nytimes.com/2024/06/14/weather/florida-rain-flooding.html
5 https://www.mbrisingabove.com/your-city-at-work/resilience-strategy/sea-level-rise-vulnerability-assessment/#:~:text=Q%3A%20What%20is%20the%20Vulnerability,related%20to%20sea%20level%20rise.

The Adaptation Plan is also part of the City's broader climate resilience framework. It integrates ongoing City plans and initiatives to align adaptation efforts with existing flood management, land use, and neighborhood improvement projects. Integration with existing City plans also promotes the adoption of long-term resilience considerations into individual plan updates based on evolving climate conditions. The goal of the Adaptation Plan is to develop a holistic, coordinated path to flood resilience that addresses the complex, interconnected nature of sea level rise hazards, which often require a flexible and phased approach to adapt in the face of inherent uncertainty.

The Adaptation Plan is organized as follows:

1. **Introduction –** provides background and context of the Adaptation Plan.
2. **Vulnerability Assessment Review –** revisits the approach and key findings of the City's Vulnerability Assessment.
3. **Adaptation Strategy Identification and Evaluation –** describes the City's existing relevant plans and initiatives, the process to identify supplemental flood protection strategies, and evaluate strategies for potential trade-offs and co-benefits.
4. **Adaptation Pathways –** provides a structured approach to address uncertainties of future flood conditions using flexible adaptation pathways that adjust over time as new information becomes available or conditions change.
5. **Next Steps –** summarizes key findings and next steps to advance implementation of the Adaptation Plan and its strategies.

Appendix A – Lists the initial strategies considered for the Adaptation Plan.

Appendix B – Lists the final strategies considered for the Adaptation Plan.

Appendix C – Describes the evaluation criteria and scoring methodology to compare and rank strategies.

Appendix D – Presents the performance of strategies based on evaluation criteria.

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2 Vulnerability Assessment Review

2. Vulnerability Assessment Review

To more comprehensively understand the City's evolving flood risk due to sea level rise, the City completed a Sea Level Rise Vulnerability Assessment (Assessment) to identify and prioritize nearly 60,000 assets vulnerable to flooding across a range of potential future sea level conditions. Assets included both City-owned (e.g., City buildings and utilities) and non-City-owned (e.g., hospitals, cultural centers) facilities and infrastructure. Future sea levels were evaluated under three water level conditions:

- **High Tide** – High tide flooding was represented by the City's median annual king tide water elevation (1.8 feet NAVD88) determined by tidal elevation data from the Virginia Key National Oceanic and Atmospheric Administration (NOAA) Tide Station.
- **Compound Flood** – Compound flooding was represented by the simultaneous occurrence of a 10-year, 24-hour rainfall event (8.75 inches) and a king tide (1.8 feet NAVD88). A 10-year rainfall event has a 10 percent chance of occurring in any given year.
- **Coastal Storm Flooding** – Coastal storm flooding was represented by the 1-percent annual chance (i.e., 100-year) coastal water elevation. The event has a 1 percent chance of occurring in any given year and is modeled by FEMA to be approximately 6.2 feet NAVD88 in Miami Beach.

This section briefly summarizes the methodology used for the Assessment, highlighting key vulnerability findings and their role in shaping the strategy development approach in the Adaptation Plan.

Assessment Methodology

The Assessment provided information about the potential timing, extent, and consequence of future flooding events influenced by sea level rise. A range of assets that support the community were compiled from City, regional, and governmental partners and community engagement workshops (Figure 2.1).

Figure 2.1. Asset Types Considered in the Vulnerability Assessment

Individual assets were evaluated and scored based on the following factors to understand their relative vulnerability (Figure 2.2):

- **Exposure** – "How many flooding scenarios impact the asset?" Exposure is associated with the number of scenarios under which an asset would be flooded.
- **Sensitivity** – "What are the impacts and potential damage to the asset if it is flooded?" Sensitivity is associated with the likelihood an asset will incur significant damage, fail, or become unusable for any duration of time due to flood exposure.

- **Consequence** – "What are the community impacts if the asset fails?" Consequence is associated with the severity of community, environmental, and economic impacts that would occur should the asset fail, incur significant damage, or become unusable.

Assets that scored highly across the three categories were considered highly vulnerable to future sea level rise flooding. The Federal social vulnerability index, based on U.S. Census variables, was used to identify neighborhoods that may need support before, during and or after disasters[6]. These assets received an additional score weighting to promote prioritization of assets serving socially vulnerable neighborhoods.

Exposure + **Sensitivity** + **Consequence** = **Total Vulnerability Score**

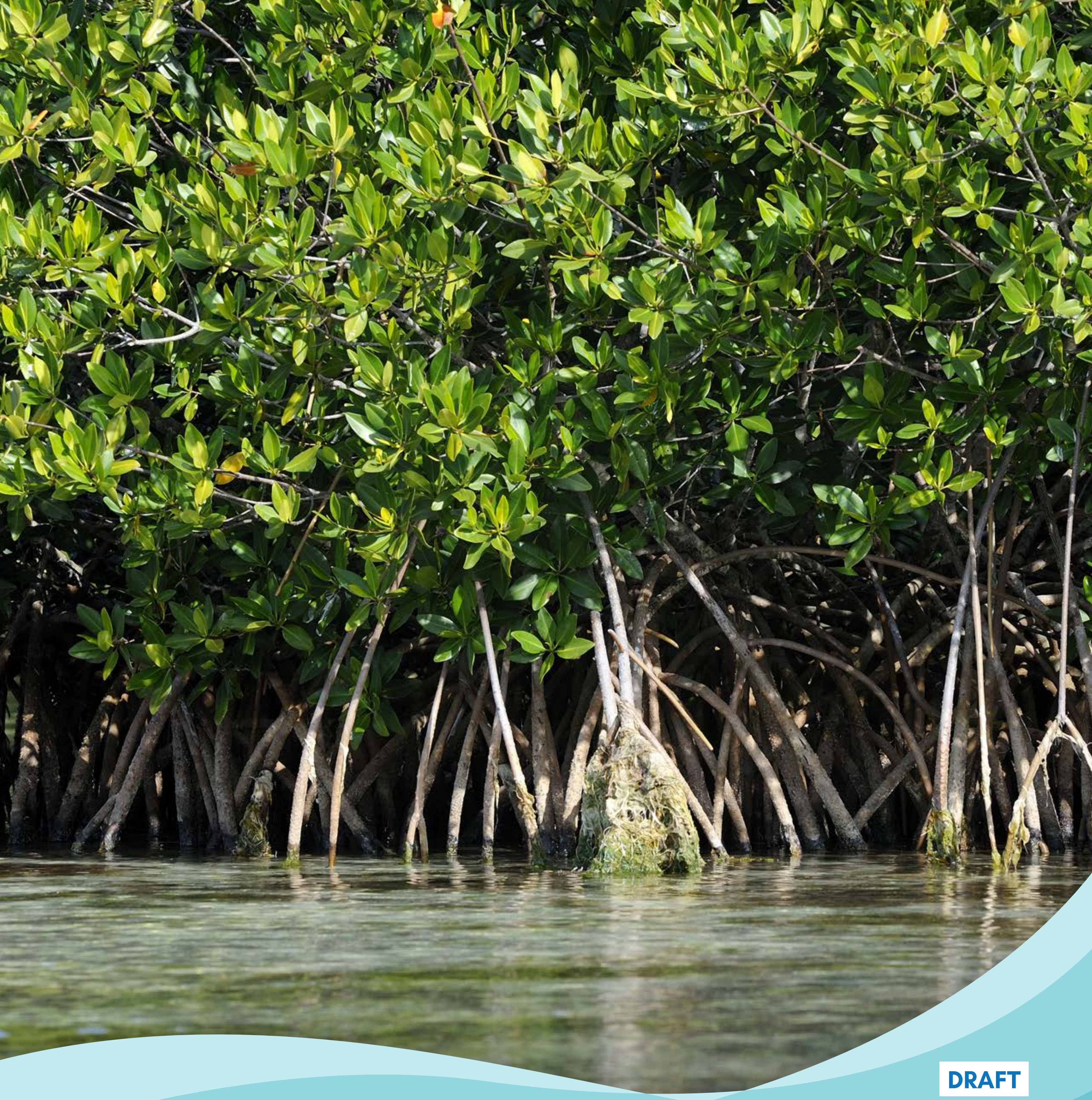
Figure 2.2. Vulnerability Assessment Methodology

Key Assessment Findings

The Assessment findings highlight several key themes based on the prioritized list of most at-risk assets. These findings assisted the City to prioritize types of assets and locations most in need of targeted adaptation measures. Example key findings include:

- Higher vulnerability assets are located adjacent to canal shorelines which are currently overtopped or projected to be overtopped by future high-water events. The west (Biscayne Bay or "Bay") side of the City is at the greatest risk of flooding due to the low elevation of mostly privately-owned seawalls.
- The City's water and wastewater pipeline network contains several areas with a high concentration of high-vulnerability infrastructure due to pipelines that are over 70 years old. Older pipelines are more susceptible to corrosion or may contain small cracks that allow the infiltration of flooding and high groundwater.
- With one foot of sea level rise, over half of the City's roadways are projected to experience flooding during 10-year, 24-hour rainfall events coinciding with king tides. Depending on the depth of flooding, vehicle traffic could be restricted, creating congestion, detours and limiting mobility within the City.
- By 2040, a 25-year, 24-hour rainfall event combined with a king tide could cause flooding at four emergency response facilities, including Mt Sinai, Police Station HQ, Sailport Substation, and Fire Station #1. By 2070 this number increases to include the majority of emergency response facilities across the City.
- Fifty percent of the City's existing stormwater pump locations are projected to experience flooding impacts during 10-year, 24-hour rainfall events coinciding with king tides when combined with 1 foot of sea level rise. If stormwater inflow exceeds pump capacity, flooding throughout the City could intensify and spread to typically unaffected areas. Newer pump stations are built to a higher elevation of Base Flood Elevation +2, and many older pump stations are being retrofitted.
- The City's beach and coastal dune system provides a natural buffer from most ocean wave impacts, but coastal storm flooding remains a significant threat, with a 1-percent annual chance storm surge (approximately 6.2 feet NAVD88) projected to bring flood depths up to 5 feet in certain areas of the City, even without additional sea level rise.

6 https://www.atsdr.cdc.gov/place-health/php/svi/index.html



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3 Adaptation Strategy Identification and Evaluation

3. Adaptation Strategy Identification and Evaluation

Although the City already has a series of plans to address ongoing flood risks through incremental adaptation initiatives such as stormwater management, road elevation, and green infrastructure projects, many of these plans only extend to mid-century sea level rise projections and do not yet include the type of innovative or complex approaches to flood protection that may be necessary for end-of-century conditions. This section describes a review of the City's existing relevant plans and initiatives and the process to develop supplemental strategies that could be used to adapt them to enhance their ability to provide long-term flood protection. The Adaptation Plan is the next step for long-term planning.

Review of Existing City Plans and Initiatives

The Adaptation Plan was developed to address both present-day and future flood hazards within the context of the City's existing policies, studies, and plans. The existing plans are carried out in tandem, providing an ongoing and comprehensive approach for flood protection. These plans also serve as the foundation for the City's Adaptation Plan. The following key plans and ordinances were reviewed and included in the Adaptation Plan. This is not an exhaustive list to date but represents a subset of the most relevant documents that were used to inform development of the plan.

- **Stormwater Modeling and Master Plan (SWMMP)** – evaluates the City's stormwater network to provide an improved level of stormwater flood protection from a 10-year, 24-hour rain event through the year 2060. The plan does not consider shoreline overtopping due to coastal storms and high tides. The SWMMP also identifies and prioritizes 20 smaller-scale Critical Needs Projects that alleviate some storm conditions and improve water quality; they are proposed for a shorter time horizon to be constructed by 2036. The projects are also designed to be integrated with the Neighborhood Improvement Projects (NIP) that include road elevation and additional infrastructure needs to minimize community disruptions during construction.
- **Neighborhood Prioritization Plan (NPP)** – details over 56 City capital improvement projects, organized into NIPs, that have been prioritized based on their potential to provide flood protection, maintain essential services, and equity considerations of residents served by the project. The prioritized projects focus on upgrading aging or undersized critical stormwater, water, and sewer infrastructure and elevating roadways based on the recommendations of the Road Elevation Strategy. The projects may also include quality of life enhancements such as new utilities, sidewalks, bike lanes, landscaping, and trees.
- **Road Elevation Strategy (RES)** – provides recommended roadway elevations to reduce flooding by accounting for projected sea level rise through mid-century. The RES also recommends varying design elevations for different road classifications based on their criticality.
- **Dune Management Plan** – outlines maintenance considerations and planting and pruning specifications for the City's coastal dune system to maintain healthy and stable dunes. The plan prioritizes the utilization of natural elements to enhance the dunes and reduce erosion impacts from extreme wave events.
- **Blue-Green Stormwater Infrastructure (BGSI) Concept Plan** – provides an evaluation of BGSI strategies, concepts, and potential locations for pilot projects in the City. The plan also provides best practices for integrating BGSI concepts into traditional infrastructure projects.
- **Nature-Based Shoreline Assessment** – assesses the feasibility of converting degraded publicly owned seawall sections into living shorelines based on site-specific conditions. The assessment prioritized 10 shoreline sections for potential projects and offers a model for the City to implement similar shoreline improvement projects in other locations.

- **Resilience Code** – revises the City's Land Development Regulations to enhance flexibility in addressing impacts like sea level rise. Chapter 7 specifically includes zoning and setback requirements for new development that are intended to provide space for future land use and infrastructure upgrades.
- **Seawall Minimum Height Ordinance** – current seawall ordinance (No. 2021-4393) that establishes a minimum construction elevation of 5.7 feet (NAVD88) for new or substantially improved or repaired seawall sections. Seawalls may be elevated to a lower elevation of 4.0 feet (NAVD88) if the seawall is designed to support future raising to 5.7 feet.
- **Building Freeboard Ordinance** – current freeboard ordinance (2016-4009) that permits the first floor of structures to be built up to five feet above the established FEMA base flood elevation. The ordinance represents one of the City's design standards adopted to provide additional flood protection above state and federal requirements.

Supplemental Strategy Development

To address the potential gaps in the City's existing flood protection efforts, additional strategies were developed by reviewing regional and national adaptation plans to identify relevant approaches that have been considered for other communities with similar needs as the City. Through collaboration with City staff, an initial long list of strategies was compiled and organized by primary flood hazard addressed, strategy category, and strategy type (Figure 3.1). The initial list, provided in **Appendix A**, included an array of physical (e.g., modifications to infrastructure and facilities) and non-physical (e.g., policy and plan updates) options to address flood risks posed by a variety of flood hazards facing the City, including tidal, stormwater, coastal storm surge, and high groundwater.

Through a series of conversations with City staff, the initial strategy list was further refined and consolidated into broader adaptation concepts, provided in **Appendix B**.

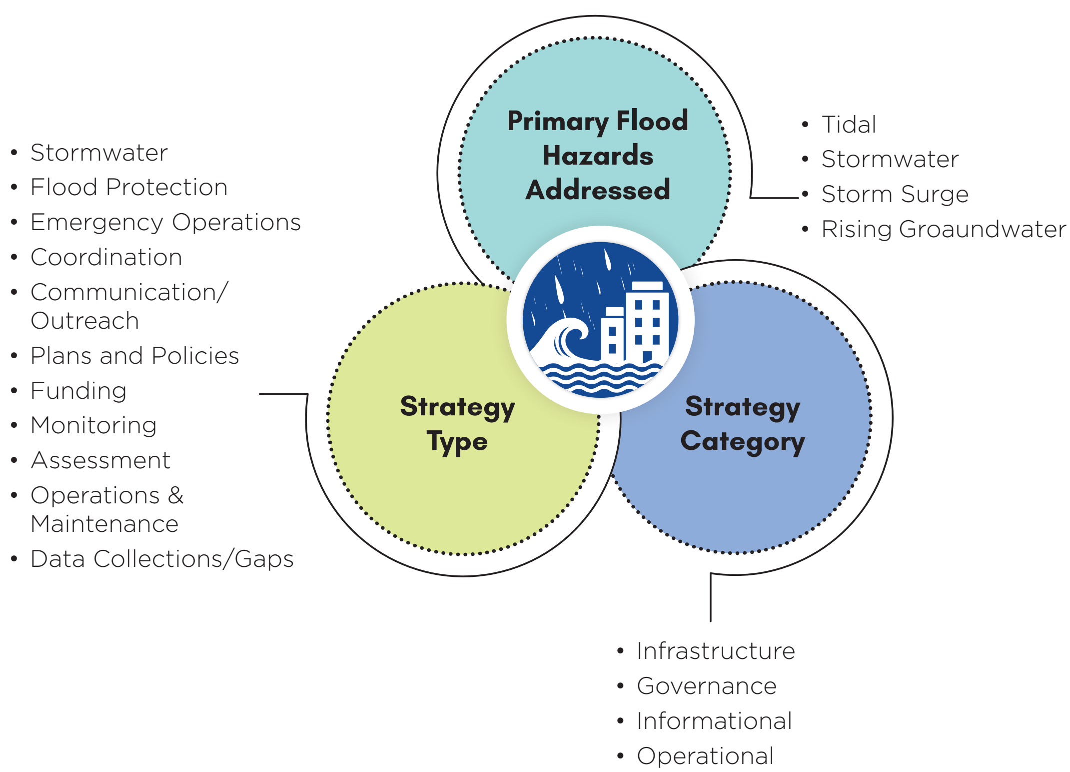


Figure 3.1. Initial Strategy List Organization

Evaluation Criteria

The most successful strategies are those that can address identified flood hazards while also providing additional co-benefits, which are additional benefits beyond flood protection. Strategies that provide multiple benefits and limit negative impacts for the community offer a more holistic approach to resilience by strengthening communities and the surrounding environment. These additional benefits also make them more likely to secure funding, political will, and community buy-in. The final list of broader strategy options was evaluated using a set of evaluation criteria to understand potential tradeoffs and prioritize strategies that perform well across each of the considered factors.

A qualitative set of evaluation criteria was created spanning four categories to evaluate strategy benefits from a variety of perspectives:

- **Engineering** – The ability of a strategy to continue providing flood protection as sea level rises
- **Environmental** – The benefits a strategy provides for ecosystems protection or greenhouse gas (GHG) emission reductions
- **Social** – The benefits a strategy offers to improve the quality of life for residents
- **Implementation Feasibility** – The ability of the strategy to be enacted given current City capacities

Each category included a set of 14 criteria based on considerations applied in similar climate adaptation planning projects across the country and feedback from City staff (Figure 3.2). A simple rating approach was used to compare tradeoffs among each of the categories for each strategy. Criteria were assigned a score of 0 through 3 based on the strategy's alignment with the goal of the criteria: 0 (no alignment), 1 (limited alignment), 2 (some alignment), or 3 (full alignment) (**Appendix C**). The scores were tallied across all categories for each strategy for a total score ranging from 0 (low benefits) to 42 (high benefits).

The full breakdown of strategy scores for each evaluation criteria is provided in **Appendix D**.

Engineering	Environmental
• Protects critical City assets • Ability to adapt to changing climate conditions • Addresses multiple flood types	• Improves water quality • Protects, enhances, or expands sensitive habitats and ecosystem services • Reduces or offsets greenhouse has emissions
Social	**Implementation Feasibility**
• Improves public health metrics (e.g., public access, recreation, or access to emergency services) • Enhances resilience of the transportation network • Benefits socially vulnerable communities • Reduces risk of injury or loss of life	• Funding/Financing is partially or fully available or can be obtained • Capital Costs • Maintenance Costs and Staff Burden • Ability to implement given current professional market capabilities, policies, and regulations

Figure 3.2. Evaluation Criteria to Determine Strategy Benefits

DRAFT

4 Adaptation Pathways

4. Adaptation Pathways

Strategy options developed in Section 3 (Adaptation Strategy Identification and Evaluation) were incorporated into a series of adaptation pathways that identify long-term actions based on defined adaptation thresholds that indicate a potential transfer to another strategy to support the City's decision-making process for flood resilience. Adaptation pathways are a strategic approach to managing the uncertainties of long-term impacts of climate change by identifying flexible, phased strategies that can be implemented over time. This framework helps communities by developing adaptive actions that can evolve as conditions change and the existing strategies are no longer effective.

This is an innovative approach to adaptation that differs from the traditional planning approach taken by most municipalities. Traditional planning is typically more rigid and long-term solutions are based on a fixed understanding of future conditions with limited mechanisms for revisiting and adjusting plans as new data and conditions arise.

Interpreting Adaptation Pathway Diagrams

Adaptation pathway diagrams provide a roadmap or decision tree that helps planners understand the timing of initial adaptation strategy implementation and options for phasing subsequent strategies over time. Pathways begin with the existing primary approach the City is using for flood protection and then diverge into different adaptation strategies that provide an enhanced level of flood protection as sea levels continue to rise.

Adaptation pathways, which merge the functionality of a phasing diagram and a decision tree, provide a flexible means to transition between individual strategies depending on how the future unfolds (e.g., accelerated sea level rise or percent of assets experiencing flooding). This flexibility facilitates better-informed decision making about major investments over time.

Adaptation pathways, as shown in an illustrative example in Figure 4.1, include the following elements:

- **Timing of potential sea level rise:** To assist with planning, three planning time horizons were included to illustrate the range of potential sea level rise amounts that could occur from the year 2020 through the end of the century based onNOAA 2017 projections. The timing of adaptation strategies is aligned to reduce potential impacts based on flood mapping performed for the City's Sea Level Rise Vulnerability Assessment (2024). However, the timing of strategies can also be informed by a set of metrics and adaptation thresholds defined in each pathway.

- **Strategy planning and lead time:** Many strategies will require lead time prior to implementation to account for project funding, planning, permitting, and design activities. The initiation of planning time is indicated by a gray circle, followed by a dashed line representing the duration of potential planning activities. Longer dashed lines indicate that the strategy opportunity has a longer lead time required due to its complexity and/or scale.

- **Strategy start:** The start of a strategy, indicated by black circle, marks the point where the strategy could be implemented and fully functional.

- **Strategy duration:** Each strategy duration is depicted by a solid horizontal line. The color of the line indicates the strategy theme (discussed in more detail in the next section): keeping water out (orange), living with water (blue), nature-based protection (green), strategic relocation (red), and plans and policies (gray).

- **Functional end of strategy:** A vertical line indicates the functional end of the strategy due to its inability to continue offering flood protection or when the sea level rise amount is beyond the intended level of planned flood protection.

- **Potential strategy transfer:** Potential transfer points are depicted by hollow triangles on the strategy lines. Transfer points represent an opportunity to switch to a different adaptation strategy if the existing strategy approach no longer provides the desired level of flood protection. Transfer to the alternative strategy is represented by vertical gray lines, indicating the transition.
- **Adaptation threshold:** Adaptation thresholds are defined in the pink call out boxes. These thresholds indicate when potential flood impacts (e.g., percent of assets exposed to flooding) exceed a predetermined level that could indicate the need to transfer to a different adaptation strategy.

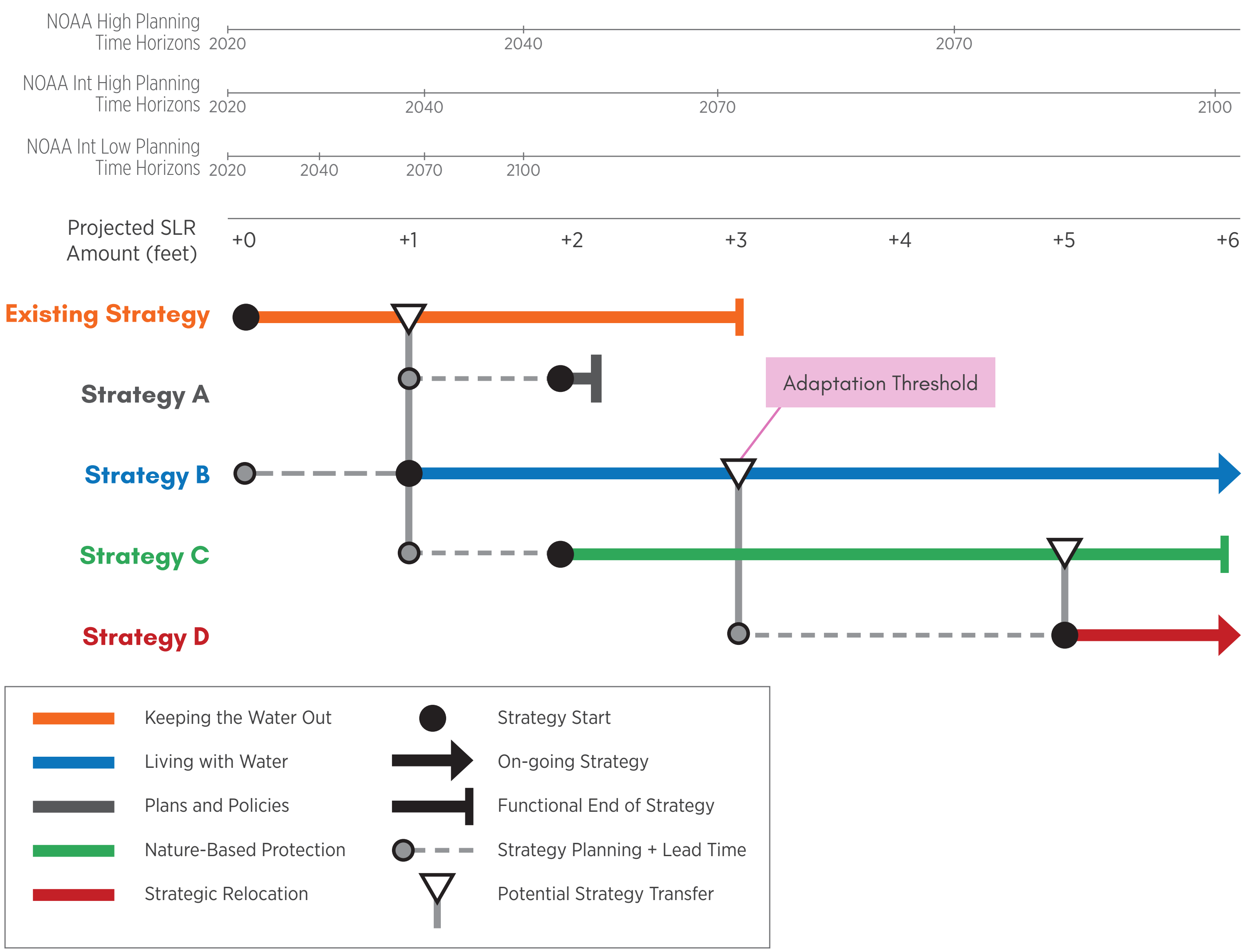


Figure 4.1. Conceptual Adaptation Pathway Diagram and Components

All the strategies included in the pathway diagrams respond to potential flood exposure observed in sea level rise maps prepared as part of the City's 2024 Sea Level Rise Vulnerability Assessment; however, the precise timing of strategy implementation may differ based on the timing of observed flood impacts. Including adaptation thresholds as part of an adaptive management plan will prompt proactive decision-making and adaptation response by promoting the monitoring of implemented strategies and their effectiveness. Strategy implementation timelines may also be driven by non-flood hazard factors such as the required duration for project design, permitting, allocating project funding, or timing of maintenance/retrofit schedules that can provide an opportunity for strategy implementation. Adaptation metrics, thresholds, and monitoring plans are described within each pathway section (Section, Adaptation Pathway Summaries).

Adaptation Themes

Individual strategies are grouped into adaptation themes based on identified similarities in their general approach to flood protection. The adaptation themes, described below, were modified based on categories defined by the Intergovernmental Panel on Climate Change (IPCC)[7].

- **Keeping Water Out** – This approach refers to techniques to prevent or limit water from entering specific areas. Typical methods involve physical barriers, such as seawalls, tide gates, or other raised structures designed to protect against flooding.
- **Living with Water** – This concept focuses on coexisting with water by using floodable designs rather than trying to completely prevent water from entering an area. Typical methods include elevating facilities and infrastructure or designing it to accommodate occasional flooding.
- **Nature-Based Flood Protection** – Nature-based protection uses natural ecosystems and processes to reduce the impacts of flooding. Techniques include natural shoreline restoration, enhancing dune features, and blue/green infrastructure.
- **Strategic Relocation** – This refers to the planned relocation of specific facilities or assets that are at risk to flooding or the modification of existing land uses to avoid infrastructure damage. This approach deviates from the City's preferred approach of protecting existing facilities and infrastructure through other adaptation approaches. However, relocation may become necessary as sea levels reach end of century conditions or following disaster scenarios, such as large coastal storm events that cause widespread damages, or when the risk to human life or the cost to protect assets in place becomes too high.
- **Plans and Policies** – This refers to modifications in City plans, design criteria, or ordinances to provide an enhanced level of flood protection.

In most cases, a combination of these approaches will be necessary to provide flood protection for the City and the suite of strategy approaches may change over time to accommodate evolving climate conditions. For example, the primary approach for flood protection for the City has been focused on Keeping Water Out using strategies such as seawalls, stormwater upgrades, and elevating roads. Additional bioretention approaches, such as bioswales and stormwater retention lake, have been integrated into recently designed parks. However, as sea levels continue to rise, the City may benefit from supplementing traditional engineering approaches with more Living with Water, Nature-based Protection, or in some instances, Strategic Relocation strategies (Figure 4.2) to provide a more comprehensive form of flood protection.

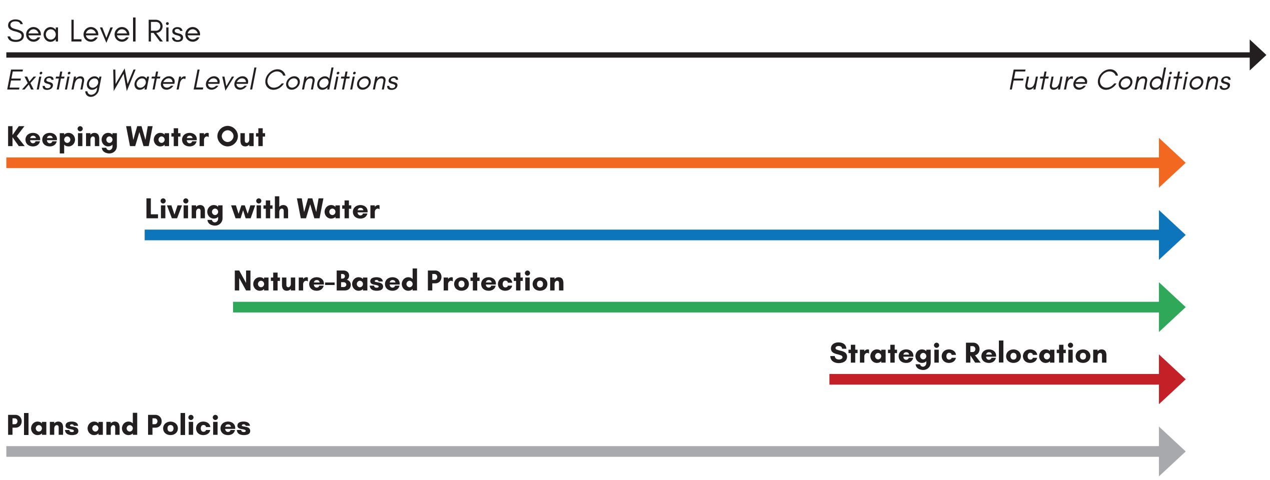


Figure 4.2. Conceptual Transition of Adaptation Themes

7 https://www.nrdc.org/bio/rob-moore/ipcc-sea-level-rise-adaptation-essential-not-optional

Adaptation Pathway Summaries

A set of six adaptation pathways were developed to inform the potential phasing of adaptation strategies for the City. The pathways include: Bayfront Flood Protection, Stormwater Flood Protection, Roadways, Critical Facilities, Critical Infrastructure, and Oceanside Flood Protection. Each adaptation pathway was developed to address the geographic variability of flood hazard sources experienced across the City (Figure 4.3) and reflects the types of assets protected. For example, the Bayfront Flood Protection pathway focuses on strategies that provide area-scale flood protection for multiple assets from Biscayne Bay flood sources (king tides and coastal storms). The Oceanside Flood Protection Pathway also focuses on area-scale flood protection but includes strategies to reduce wave impacts to the City. Stormwater Flood Protection, Roadways, Critical Facilities, and Critical Infrastructure pathways focus on asset-specific flood protection from more inland flood sources (rainfall flooding and high groundwater) that are more likely to cause localized flooding of individual assets.

Figure 4.3. Geographic Variability of Adaptation Pathways and Strategies

The sections below provide a detailed description of each of the six adaptation pathways. Each section describes the associated strategies and includes information about the flood protection lifespan, strategy considerations, flood hazards addressed, estimated cost, and a set of metrics, adaptation thresholds, and potential monitoring plans to inform their phased implementation.

Role of Neighborhood Improvement Projects in Citywide Adaptation

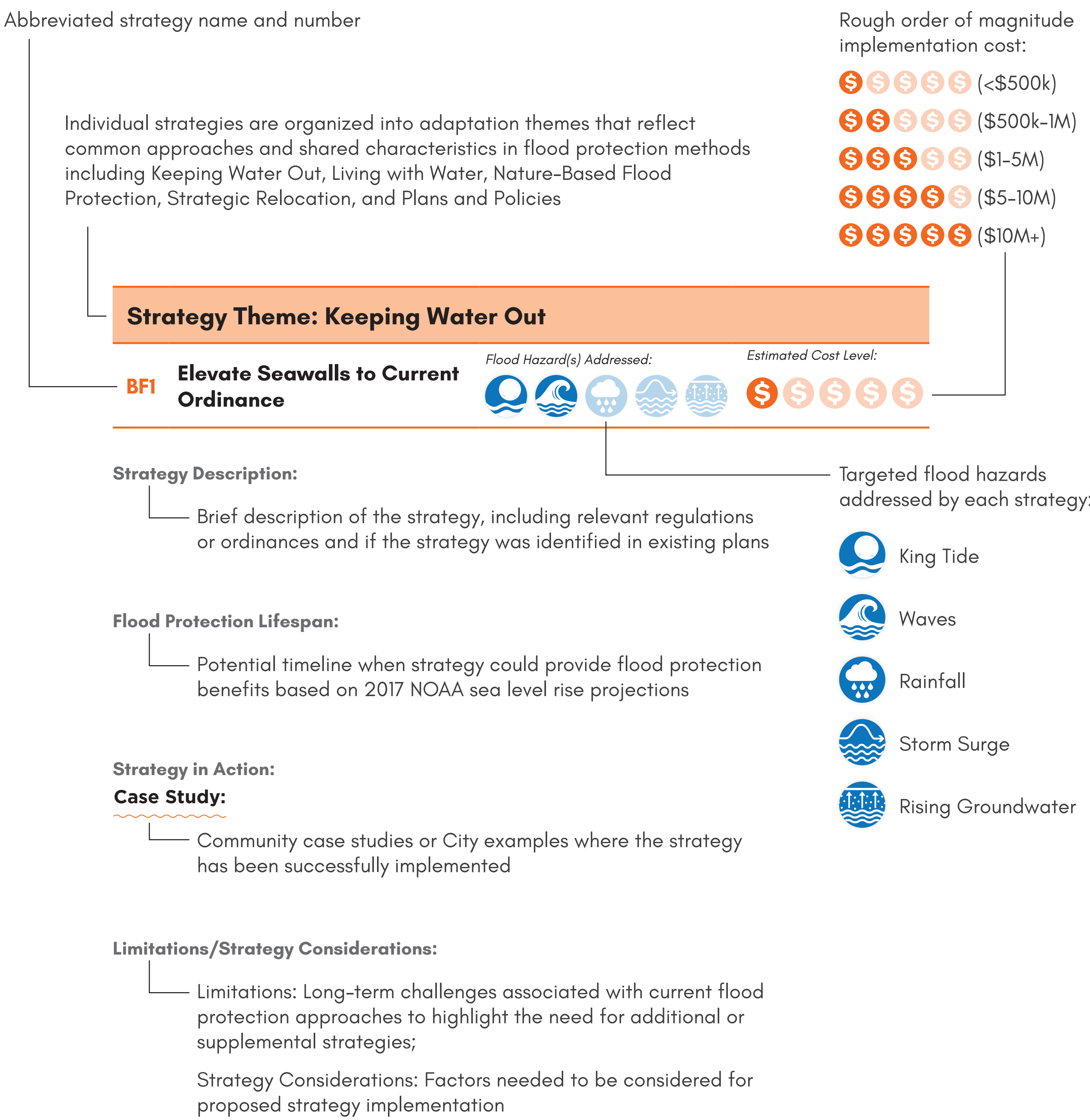
To better coordinate resources, priorities, and broader resiliency efforts, the City created the Neighborhood Project Prioritization (NPP) plan. The NPP reviewed over 400 capital improvement projects proposed in previous City plans and organized them into 50 neighborhood-based project groups, called Neighborhood Improvement Projects (NIPs). The NIPs were prioritized based on the expected flood mitigation benefits, accounting for sea level rise impacts, and the population size benefiting from the improvements.

NIPs aim to consolidate multiple proposed infrastructure projects within the same neighborhood into a single initiative to streamline upgrades, reduce construction disruptions, and minimize the administrative burden of managing separate planning and design efforts. These projects encompass a range of infrastructure improvements, including increasing stormwater capacity, elevating roadways, integrating green infrastructure, and upgrading water and sewer infrastructure. Many strategies outlined in the adaptation pathways rely on coordination with future NIPs to ensure successful implementation. For relevant strategies, additional detail is provided regarding how the approach will be integrated with future NIPs.

Aerial photo of Miami Beach. Source: Adobe Stock

How to Read the Pathway Summaries

The graphic below outlines the content of the pathway strategy summaries in the following section. Individual strategies have been organized into a summary based on the geographic area or asset type they are designed to protect from flooding. Within each pathway is an adaptation pathway diagram to illustrate the phased and coordinated implementation of the strategies, as well as additional metrics the City can monitor to determine when to initiate or phase out strategies based on the flood protection effectiveness.



Bayfront Flood Protection Adaptation Pathway Summary

This set of strategies aims to elevate or modify the City's western shoreline to provide enhanced flood protection from existing and future high tide events.

The Need to Adapt

Nearly 90% of the Biscayne Bay shoreline is protected by public and privately-owned seawalls, which are the City's primary line of defense from high tide flooding events. The Bayfront shoreline and areas landward represent the lowest elevations of the island, particularly in South Beach and North Beach. Currently, abnormally high-water events (e.g., king tides) enable tides to overtop low-lying seawall sections several times each year. By 2040, a 1-foot increase in sea levels from the baseline year of 2020 (based on the NOAA 2017 Intermediate High scenario) could cause more than 50% of the shoreline to be overtopped during king tide conditions if current infrastructure is not elevated or modified, leading to frequent flooding of public and private property located behind the seawall structures.

As sea levels rise, the City will need to continue to address low-lying publicly owned shorelines and work with private property owners, who own more than 90% of the shoreline, to increase flood protection levels of the Bayfront.

Seawall upgrades at Parkview Island Park, Source: AECOM

Living shoreline installation at Brittany Bay Park, Source: Miami Beach

Seawall at South Pointe Park, Source: AECOM

The strategies below provide a set of options for the City to consider for ongoing flood protection along the Bayfront shoreline. The strategies provide a suite of approaches that include continuing flood protection infrastructure upgrades to keep the water out, increasing the use of nature-based flood protection, adopting policy updates, and the strategic relocation of assets to reduce increasing flood risks to infrastructure.

Each strategy includes a summary documenting implementation considerations, a rough order of magnitude cost, metrics and adaptation thresholds that could indicate an appropriate time for the strategy to begin, and a case study example, where applicable, of where the strategy has been applied within the City or in other municipalities with similar needs. The strategies are also presented in an adaptation pathways diagram at the end of this section to understand key decision points and the potential timing of strategy implementation.

Strategy Number	Strategy Name	Flood Hazards Addressed
BF1	**Elevate Seawalls to Current Ordinance** Modify existing public and privately owned seawalls to comply with the existing seawall ordinance (5.7 feet NAVD88).	
BF2	**Temporary Seawall Flood Barriers** Install deployable flood barriers (e.g., Tiger Dams) along low-lying seawalls to provide short-term flood protection while longer-term solutions are being designed or constructed.	
BF3	**Install Canal Tide Gates** Closable tide gates could be installed at the openings of the Collins Canal to provide flood protection for properties along the canal and reduce the number of seawalls requiring higher elevation.	
BF4	**Update Seawall Ordinance** Revise the existing seawall ordinance to reflect the latest sea level rise amounts and future projections to provide continuous flood protection through the end of the century.	
BF5	**Elevate Seawalls to Updated Ordinance** Modify existing public and privately owned seawalls to comply with the updated seawall ordinance.	
BF6	**Add Living Shoreline to Seawalls** To protect seawalls from local scouring while also enhancing the ecological conditions of the Bay, a living shoreline could be added to the seaward side of seawall structures.	
BF7	**Restore Natural Shorelines** Frequently flooded properties that are cost-prohibitive to maintain could be restored to coastal wetlands, allowing the shoreline to return to a natural state of transitional wetland habitat between the built and natural environment.	
BF8	**Expand Waterfront Setback for Increased Resilience** Expanding waterfront setbacks involves revising land use regulations for shoreline-adjacent development to reduce the risk of property damage due to flooding.	

Strategy Theme:
Keeping Water Out, **Nature-Based Flood Protection**, **Strategic Relocation**, **Plans and Policies**

Current Strategy

Strategy Theme: Keeping Water Out

BF1 **Elevate Seawalls to Current Ordinance**

Flood Hazard(s) Addressed:

Estimated Cost Level: $ $ $ $ $

Strategy Description:

The City's current seawall ordinance (No. 2021-4393), adopted in 2021, establishes a minimum construction elevation of 5.7 feet (NAVD88), or 4.0 feet (NAVD88) if the seawall is designed to support a future elevation to 5.7 feet. The elevation requirement becomes effective for new, substantially improved, substantially repaired seawalls, and for any sections that are tidally overtopped or deemed to be in a state of disrepair.

Flood Protection Lifespan:

Projected SLR Amount (feet) +0 +1 +2 +3 +4 +5 +6

Strategy Start: 0 feet of SLR

The City is actively prioritizing seawall improvements across the City to meet the latest ordinance requirement.

Strategy End: 4 feet of SLR

By 4 feet of sea level rise, a typical king tide event (1.8 feet, NAVD88) is projected to overtop seawalls that meet the latest seawall ordinance rendering the elevated seawalls ineffective for providing flood protection.

Future King Tide Event
5.8 feet (NAVD88)
(1.8 feet + 4 feet sea level rise)
>
Current Seawall Ordinance
5.7 feet (NAVD88)

Strategy in Action:

Case Study: Indian Creek Drive Seawall Project (Miami Beach)

In 2023, the City elevated and reinforced City-owned seawall sections along Indian Creek Drive to prevent shoreline overtopping during extreme high tide and king tide events. Elevating the seawall sections to the latest ordinance (5.7 feet NAVD88) was completed in tandem with stormwater drainage improvements to also reduce flood risks to areas landward of the seawall. This work was undertaken to complement the broader neighborhood improvements for resilience in the Indian Creek neighborhood.

Elevated canal water levels along Indian Creek Drive seawall. Source: Miami Beach

Limitations:

Cost

Elevating seawalls is very costly and often requires significant planning, design and permitting prior to construction.

Slow Implementation Rate

Enforcement of the City's seawall ordinance is largely reliant on an application process to permit the construction of a new or renovated seawall structure. Other means of enforcement rely on neighboring property owners documenting property damage due to an overtopped seawall or code enforcement violations documented by City staff traveling in the canal waterways. While effective, these approaches are unlikely to result in the scale and pace of seawall improvements that are needed to preserve the City's level of flood protection as sea levels rise.

Private Property Compliance

Over 90% of the City's existing seawalls are privately owned. Elevating seawalls will require significant coordination with residents and there are currently limited incentives or enforcement mechanisms to motivate private property owners to elevate seawalls.

Strategy End Date

Even if the City is able to elevate all the City's seawalls to comply with the latest seawall ordinance, this strategy is expected to lose its efficacy with 4 feet of sea level rise. Sea levels are projected to be nearly 6 feet above existing conditions by the end of the century based on the NOAA 2017 Intermediate High scenario, requiring the City to consider alternative strategies to provide ongoing flood protection.

Elevation Tracking Gap

The City does not currently track the percentage of public or private seawalls that have been elevated to meet current ordinance requirements (5.7 feet NAVD88). This lack of data leaves a gap in the City's ability to identify which shoreline areas remain vulnerable to overtopping.

Adaptation Strategy Options

As sea levels continue to rise, the existing level of flood protection offered by elevating seawalls to the current seawall ordinance will be less effective during high water conditions, such as king tides and coastal storms. This section describes additional strategy options the City may need to consider as a replacement or supplemental strategy to provide ongoing flood protection of the Bayfront shoreline.

The strategies in this section are not always intended to be applied in isolation, and some may be most effective and offer the greatest benefits if applied in tandem with another strategy (e.g., living shoreline in front of an elevated seawall). Site specific application of a strategy or combination of strategies should be based on the expected level of flood protection, suitability of local site conditions, implementation costs, and landward assets located behind the shoreline. In combining these strategies with existing efforts, the City can reduce and mitigate flooding impacts along Bayfront shoreline as sea level rise increases.

Strategy Theme: Keeping Water Out

BF2 **Temporary seawall flood barriers**

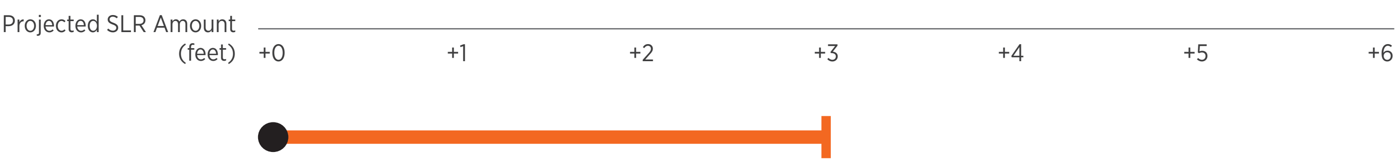
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

Temporary flood barriers are removable, and often portable, devices that can be deployed on or behind seawalls prior to high water events to reduce flood damage. They are typically characterized by modular rigid walls or water/sand-filled structures. To increase resiliency, temporary barriers are often adaptable in design and their barrier height can be raised to provide increased flood protection for the site. They can be used to provide short-term flood protection for both public and private property and may be used while longer-term solutions are being designed or constructed.

Flood Protection Lifespan:

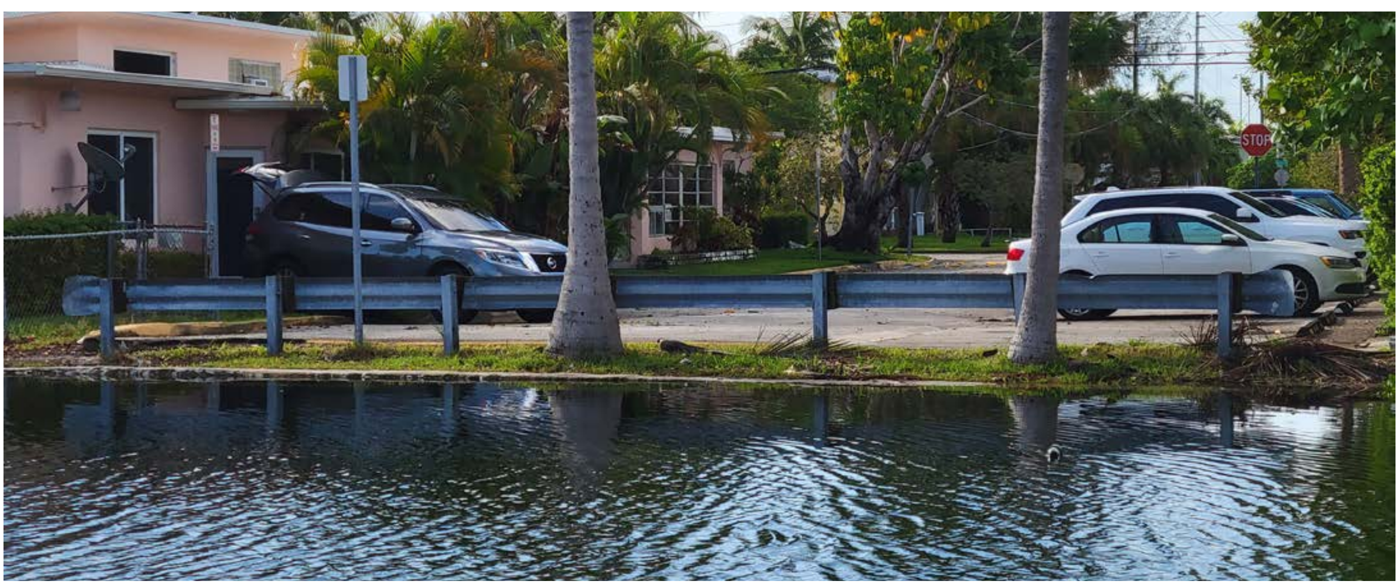


Strategy Start: 0 feet of SLR

The City could begin investing in temporary flood barriers for sections of public seawalls that are currently overtopped repeatedly during king tide events to provide short-term flood protection while permitting and financing of raising the seawall structure is underway.

Strategy End: 3 feet of SLR

By 3 feet of sea level rise, seawalls are likely to be overtopped so frequently that the deployment of the event-based barriers may be required too often to be considered temporary.



Miami Beach canal seawall overtopped during king tide event. Source: Miami Beach

Strategy in Action:

Case Study:
Tiger Dams for Jefferson-Chalmers Neighborhood (Detroit, Michigan)

To address rising lake water levels after heavy rainfall events, the City of Detroit deployed Tiger Dam barriers and sandbags along the shoreline of a densely populated canal neighborhood. The temporary water-filled barriers have been placed in private backyards along the canal for flood protection during multiple high-water events over the past several years and are intended to mitigate flood damages in the short term until a more permanent solution is developed for the neighborhood. The cost to protect 350 properties with this approach was $3.5 million.

Tiger Dams Deployed on Resident Properties of the Jefferson-Chalmers Neighborhood. Source: Planet Detroit

Application to Miami Beach:

Temporary barriers are not practical or feasible for the entire Biscayne Bay shoreline for each high-water event. However, the City can prioritize areas with deficient seawalls or those protecting critical assets where barriers can provide supplemental flood protection targeted areas. Additionally, the City can incentivize or require private property owners to adopt these temporary solutions until seawalls are reinforced and elevated to meet ordinance requirements.

Strategy Considerations:

- To be effective, this strategy assumes the ground surface behind the seawall or existing seawall structure can support the weight of the barrier, is stable enough to prevent it from shifting or collapsing under pressure, and is void of cracks or holes that may allow water to infiltrate under the barrier. A site-specific suitability assessment may need to be performed to select the appropriate barrier type.
- Temporary flood barriers will need to tie into elevated land or seawall elevations to prevent water from overtopping a neighboring low-lying shoreline and flooding the property from behind. The size and orientation of the barriers can be adapted to meet site-specific needs.
- Although some semi-permanent barriers (e.g., Tiger dams) can be installed for a multiyear period, they may have a shorter functional lifespan than other more permanent options, such as increasing the seawall elevation with a concrete cap.
- The effectiveness of temporary flood barriers requires an understanding of deployment needs (e.g., site preparation time, number of people required, correct tools, retraction needs), long-term maintenance, and storage requirements. The placement of the barriers may also require permitting.
- To assist private property owners, the City could provide educational materials and informational sessions about the proper use and efficacy of barriers as a short-term solution for flood protection along private seawalls.
- These barriers would need to be deployed along low-lying, vulnerable stretches of contiguous shoreline. This deployment might require coordination with private property owners, allowing the City to implement barriers directly or support private owners in deploying their own protective measures. The City may require easements or access to private properties to place the barriers.
- Seawall integrity, assets and property to be protected, and other site conditions will all influence the areas suitable for flood barriers.

Strategy Theme: Keeping Water Out

BF3 Install canal tide gates

Flood Hazard(s) Addressed:

Estimated Cost Level: $ $ $ $ $

Strategy Description:

Tide gates are water control structures used to prevent the flow of tidal water from moving inland, providing flood protection for infrastructure and facilities behind the gate structure. For example, tide gates could be installed at the openings of the Collins Canal and Indian Creek to provide flood protection during high water events. Placement of the tidal gates at these locations can prevent tidally-influenced flooding for the large number of properties along the canal if seawalls are not elevated to mitigate rising sea levels.

Flood Protection Lifespan:

Projected SLR Amount (feet) +0 +1 +2 +3 +4 +5 +6

Strategy Start: 1 foot of SLR

The City could consider implementing tidal flood gates at 1 foot of sea level. With this amount of sea level rise, king tide flooding begins to overtop 60% of the canal shorelines.

Strategy End: 4 feet of SLR

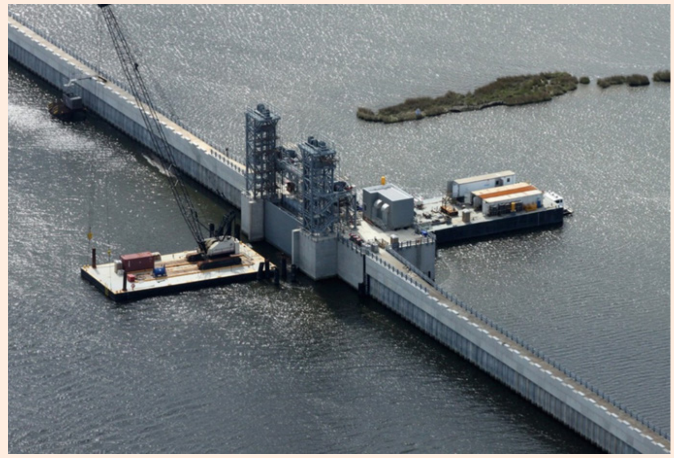
By 4 feet of sea level rise, king tides overtop occurs at nearly all Biscayne Bay shorelines. This level of overtopping provides flood pathways to inland locations regardless of the tide gate installation.

King tide floodwaters overtopping canal seawall in Miami Beach. Source: Miami Beach

Strategy in Action:

Case Study: Lake Borgne Surge Barrier (New Orleans, Louisiana)

The two-mile Lake Borgne Surge Barrier is designed to protect the City of New Orleans from significant storm surges, such as the one experienced during Hurricane Katrina. The barrier features three large gates that remain open during calm water conditions to allow ship traffic but can close during severe storm events to prevent extreme tidal events from entering the city's canal system.



Lake Borgne Surge Barrier gate. Source: U.S. Army Corps of Engineers

Application to Miami Beach:

While the City's canal system would require smaller tidal gates than the Lake Borgne example, the core flood protection principles remain. Tidal gates could be installed at the northern and southern ends of Collins Canal, or at the northern end of Indian Creek for larger scale protection, and close during king tides or storm events to prevent overtopping of waterfront seawalls. This approach could protect waterfront areas behind the gates, reducing the number of private properties requiring immediate seawall elevation.

Strategy Considerations:

- Collins Canal is considered part of the Biscayne Bay Aquatic Preserve, which receives protection from the State's Department of Environmental Protection. Implementation of structural features within the canal waterway will require a change in State statutes (F.S. 258.397) that currently restrict alteration of the aquatic preserve's physical condition.
- Implementation of flood gates will also require coordination with federal partners, likely led by the USACE, as these canals are considered navigable waters under Section 10 of the Rivers and Harbors Act (33 U.S.C. §403)
- Selection of the optimal flood gate design and installation location will require a hydraulic study to understand the existing flow patterns and stormwater volumes that may discharge into the canal.
- Tide gate structures will need to tie into elevated land or adjacent seawall elevations to prevent water from overtopping a neighboring low-lying shoreline and entering the canal from behind.
- The USACE is also considering storm surge barrier gates for the proposed Atlantic Coastline Alternative for the Back Bay Coastal Storm Risk Study. If these larger storm barriers are implemented, additional feasibility studies should be done on the effectiveness of tidal gates.

Strategy Theme: Plans and Policies

Flood Hazard(s) Addressed:

Estimated Cost Level:

BF4 Update seawall ordinance

Strategy Description:

The existing seawall ordinance of 5.7 feet (NAVD88) was designed to provide flood protection during an average king tide event through the year 2060 (based on the USACE Intermediate curve) with an additional 3 feet of freeboard to account for wind and wave action that could further elevate local water levels. As sea levels continue to rise, the protection provided by seawalls at this elevation will be reduced over time. To maintain the level of flood protection through the end of the century, the City will need to update the current ordinance to consider the observed rate of sea level rise and latest projections at the time of the update. Assuming the NOAA 2017 Intermediate High projections, which also align with the City's existing flood protection goals and the Southeast Florida Regional Climate Change Compact guidance, a revised seawall ordinance for flood protection through the year 2100 could be as high as 10.6 feet NAVD88. This is calculated as the average king tide (1.8 feet NAVD88) + 5.8 feet of sea level rise + 3 feet of freeboard.

Flood Protection Lifespan:

Projected SLR Amount (feet) +0 +1 +2 +3 +4 +5 +6

Strategy Planning: 0 feet of SLR

Initiating a sea level rise monitoring program will assist the City with tracking the ongoing rate of sea level rise. This information will be useful in understanding how the existing level of flood protection offered by the seawall ordinance will be less effective over time and serve as a threshold for when the seawall ordinance will need to be updated.

Strategy Timing: ~3 feet of SLR

By approximately 3 feet of sea level rise, the City can initiate the implementation of this strategy to increase the likelihood that the updated ordinance will be in effect before the current requirement becomes obsolete (estimated at 4 feet of SLR).

Strategy Considerations:

- Updating the seawall ordinance will require significant engagement with the public and the City's decision makers.
- The selected elevation of the revised seawall ordinance will need to consider the latest science and observations available at the time of drafting the policy to reflect current rates of sea level rise.
- The timing of implementation will depend on the rate of sea level rise. The City can track this rate so that an updated ordinance is adopted early enough to provide time to elevate seawalls before previous standards become ineffective.
- Elevating seawalls alone will not prevent flooding that may occur in areas of low ground elevation adjacent to seawalls. Elevated groundwater could continue to flood areas landward of elevated seawalls.

Strategy Theme: Keeping Water Out

BF5 Elevate seawalls to new ordinance

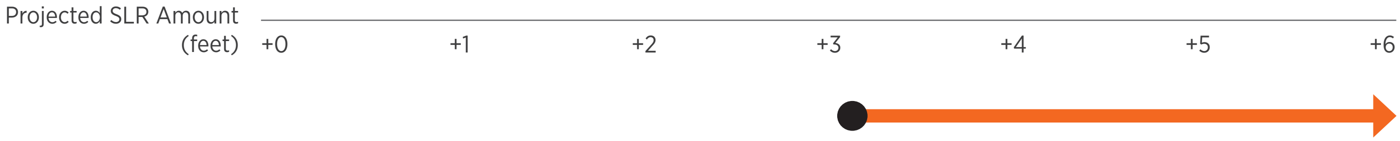
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

This strategy focuses on further elevating the City's existing seawalls to comply with the updated seawall ordinance discussed in Strategy BF4. New seawall elevations can be achieved by adding height to existing seawalls using a concrete cap, where seawall foundations can support the additional load, or a complete seawall structure replacement to the new elevation.

Flood Protection Lifespan:



Strategy Start: ~3 feet of SLR

The elevation of seawalls to comply with the new ordinance update should begin after the updated ordinance is adopted by the City.

Strategy End: 6 feet of SLR

Assuming the updated ordinance is designed to provide protection for up to 6 feet of sea level rise, compliant seawall structures should prevent king tide overtopping through the end of the century.

Strategy Considerations:

- Beyond 6 feet of sea level rise, the City may need to re-assess the feasibility of further elevating the City's seawalls to provide continued shoreline flood protection.

Strategy Theme: Nature Based Protection

BF6 **Add living shoreline to seawalls**

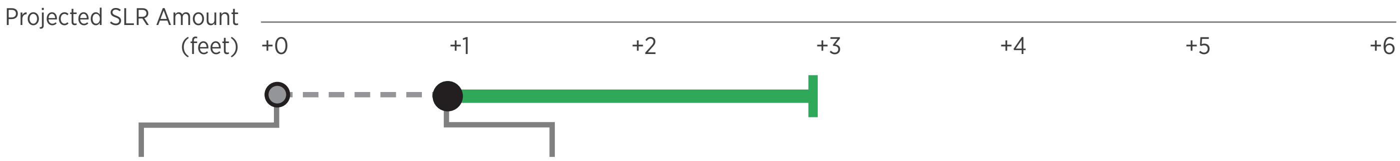
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

A living shoreline in front of seawalls is a hybrid shoreline stabilization approach designed to mimic nature's ability to limit wave energy, reduce currents, and prevent scour using vegetation, such as mangroves and other organic materials. The strategy is typically applied on the seaward side of the seawall to provide nature-based protection of the structure with the added benefit of enhancing the ecological conditions of the Bay, wildlife habitat, and natural aesthetics of the shoreline. Prioritization of a living edge could be applied in areas where seawalls are experiencing scour or regular wave action during high tide or windy days. The City has already identified several areas suitable for living shoreline in the Nature Based Shoreline Assessment based on several site conditions including seawall length, structure condition, constructability, and wave exposure.

Flood Protection Lifespan:



**Strategy Planning:
0 feet of SLR**

Planning for this strategy could begin immediately by identifying seawall sections that could benefit from the addition of a living shoreline due to ongoing wave action impacts such as scour of the seawall toe or wave overtopping and erosion landward the seawall.

**Strategy Start:
1 foot of SLR**

The City could consider implementing additional living shorelines at 1 foot of sea level to reduce erosion and toe scour impacts occurring at existing seawall structures.

**Strategy End:
~3 feet of SLR**

With 3 feet of sea level rise, 90% of the Biscayne Bay shoreline is likely to experience overtopping during king tide events.

Strategy in Action:

Case Study: Brittany Bay Park Living Shoreline (Miami Beach)

In 2023, the City renovated Brittany Bay Park with several natural infrastructure elements, including adding a living shoreline in front of an elevated seawall that also serves as a bench. The living shoreline features mangroves, native wetland vegetation and riprap bioswales to provide enhanced flood and erosion protection at the park. The project also removed invasive plants species and added an elevated deck to increase public access and connection to the water's edge.

Aerial photo of Brittany Bay Park, showing natural shoreline elements. Source: Miami Beach

Strategy Considerations:

- Pre-construction activities such as planning, public engagement, and permitting for a living shoreline could be a multi-year effort.
- The Nature Based Shoreline Assessment identifies the top 10 publicly owned sites suitable for living shorelines, providing initial sites for implementation of this strategy. The City is currently proceeding with designs for three of the top locations.
- Unless the living shoreline is continuously elevated or designed to adapt to rising sea levels, living elements of the design may not be able to withstand regular flooding, lessening their effectiveness of protecting the shoreline from wave energy or localized erosion.

Strategy Theme: Nature Based Protection

BF7 Restore natural shorelines

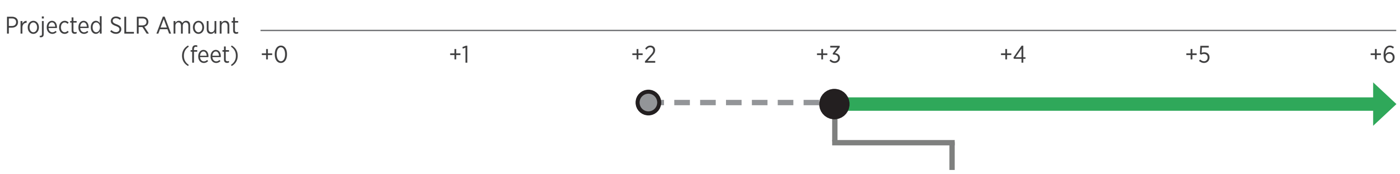
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

Restoring shorelines requires the removal of traditional shoreline protection infrastructure (e.g., seawall or revetment) and allowing natural processes to return the shoreline to its natural state. This provides wave attenuating, transitional wetland habitat between the built and natural environment, and allows room for wetlands, mangroves, and other coastal vegetation to expand along the shoreline and migrate landward with sea level rise. Eligible sections of the shoreline may include frequently flooded properties that are unable to elevate fronting seawall structures, or publicly owned property that has become cost-prohibitive to maintain due to the frequency of flood events.

Flood Protection Lifespan:



Strategy Planning: 2 feet of SLR

Planning for this strategy could begin well in advance of its planned implementation due to the complex logistics associated with transitioning a built shoreline to a more natural setting.

Strategy Start: 3 feet of SLR

By 3 feet of sea level rise, 90% of the existing Bayfront shoreline is projected to be overtopped by king tide flooding and could increase the desire and eligibility of portions of the shoreline to be restored to provide enhanced flood protection for landward infrastructure.

Strategy End: 6 feet of SLR

As sea level rise continues, restoration of the shorelines could become an increasingly favorable strategy for eligible sections of the waterfront. It is expected that this strategy could be implemented through the end of the century.

Strategy in Action:

Case Study: Project GreenShores (Pensacola, Florida)

Project GreenShores is a multi-phase initiative along the Pensacola shoreline, utilizing living shoreline elements, such as restored coastal wetlands and oyster reefs to function as natural breakwaters to reduce wave action and erosion along urban sections of the coast. The reefs shield over 20 acres of intertidal salt marsh wetlands planted with native vegetation. Completed in 2022, the two phases of the project have established more than 50 acres of resilient coastal habitat, which have successfully withstood multiple hurricanes while safeguarding nearby roadways and properties.

Oyster reefs and restored marsh habitat. Source: GreenShores

Application to Miami Beach:

Restoring the natural shoreline of Biscayne Bay would be a significant undertaking requiring extensive planning, coordination, and long-term effort. A phased approach, like Project GreenShores, can help manage the scale of work involved. For example, the City could first prioritize marsh and vegetation restoration efforts or installation of living shorelines immediately adjacent to the shoreline. This could later be expanded to include more extensive marsh areas the provide a greater level of flood protection and removal of traditional seawall structures to allow the marsh habitat to transition landward with sea level rise over time.

Strategy Considerations:

- Pre-implementation activities such as planning, public engagement, and permitting for coastal restoration could be a multi-year effort.
- Soil remediation and removal may be need in certain wetland areas to facilitate restoration, as well as the removal of any buried infrastructure.
- This strategy may also require the expansion of waterfront setback regulations (BF8), requiring the strategic relocation of infrastructure and buildings located immediately adjacent to the shoreline.
- Shoreline stabilization, public safety, and flood protection for coastal property will need to be addressed to allow for natural shorelines within an urban setting.
- Collins Canal is considered part of the Biscayne Bay Aquatic Preserve, which receives protection from the State's Department of Environmental Protection. Implementation of structural features within the canal waterway will require a change in State statutes (F.S. 258.397) that currently restrict alteration of the aquatic preserve's physical condition.

Strategy Theme: Strategic Relocation

BF8 Expanding waterfront setback for increased resilience

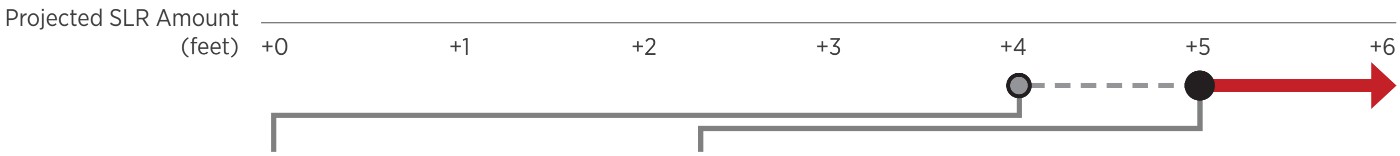
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

This strategy includes transforming waterfront properties from living areas to more natural and water retention areas. The City's Resilience Code (Chapter 7) establishes current setback and zoning requirements for coastal development, aiming for these requirements to accommodate future sea level rise in infrastructure upgrades. Expanding or updating these setback requirements for certain development could support the transformation of coastal and shoreline areas into less developed, natural spaces that offer increased flood protection for other City assets. This strategy may also require the relocation of critical assets, infrastructure, and property from the shoreline.

Flood Protection Lifespan:



Strategy Planning: 4 feet of SLR

"At 4 feet of SLR, more than 50% of the shoreline may face repeated flooding, highlighting the need to plan and prioritize for areas of potential setback demonstration projects.

Strategy Start: 5 feet of SLR

By 5 feet of sea level rise, 99 % of the shoreline is projected to be overtopped during a king tide event. Without implementation of other strategies, this level of flooding is likely to necessitate the relocation of assets and facilities to prevent damage.

Strategy End: 6 feet of SLR

As sea level rise continues, the expansion of coastal setbacks and strategic relocation of assets could become an increasingly favorable strategy for eligible sections of the shoreline. It is expected that this strategy could be implemented through the end of the century.

Aerial view of construction at Maurice Gibb Park. Source: Miami Beach

Strategy in Action:

Case Study: Flood Buyout Program (Charlotte-Mecklenburg, North Carolina)

Since 1999, the Charlotte-Mecklenburg Flood Buyout Program has purchased and removed over 400 flood-prone properties, transitioning these areas to open space. The Program aims to increase the setback distance between development and flooding sources to minimize future damages. The program also aims to disincentivize development in high-risk areas to reduce the need for additional flood control infrastructure. Through this program, Charlotte-Mecklenburg has successfully decreased the vulnerability of flood-prone neighborhoods while improving water quality and ecological resilience in the region.

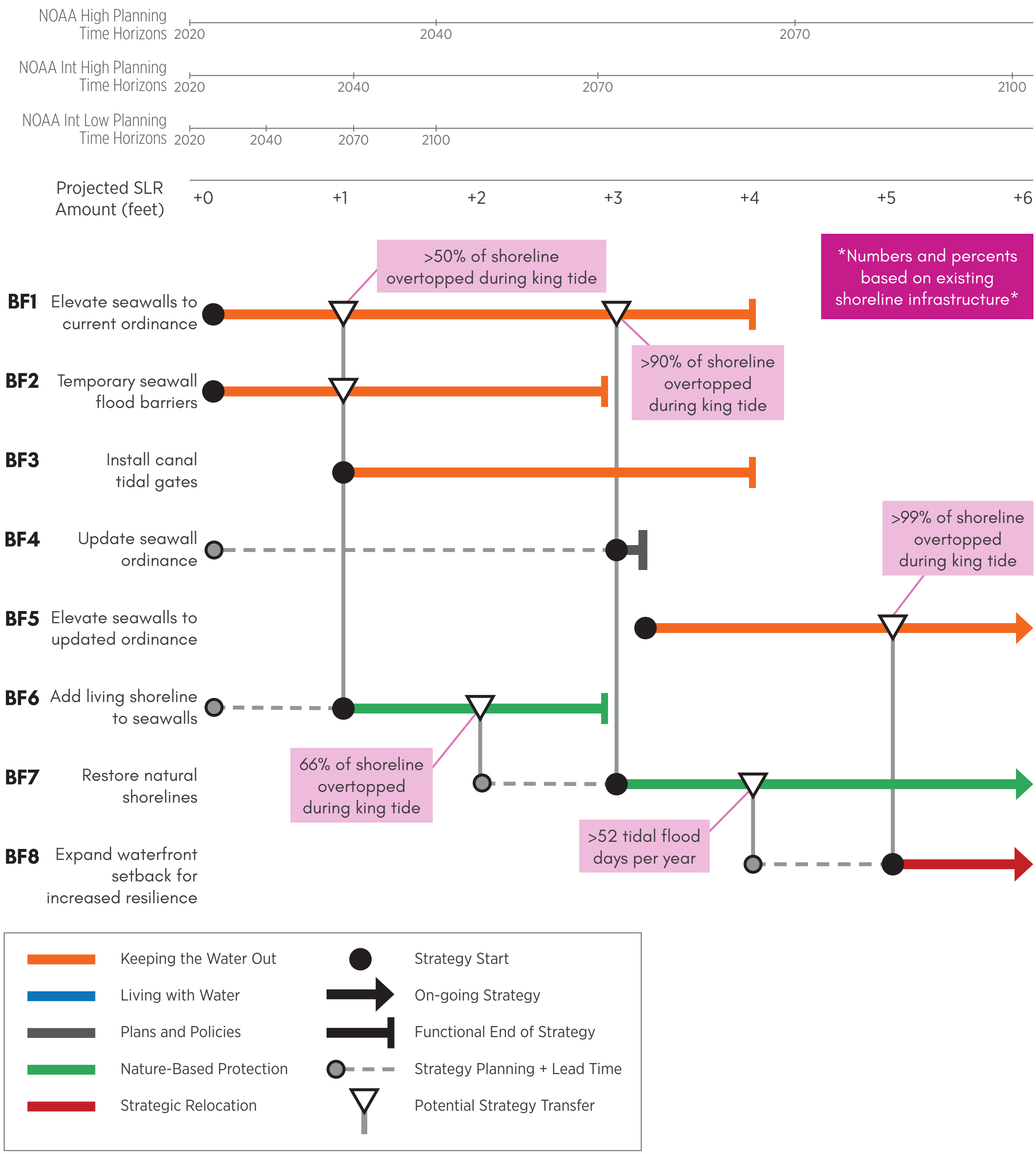
An aerial view of the Hidden Valley Community where Charlotte-Mecklenburg Storm Water Services purchased eight homes through the local floodplain buyout program. Source: Charlotte-Mecklenburg Storm Water Services

Application to Miami Beach:

Relocating all shoreline properties away from flood-prone areas is impractical, as the entire City is at risk of flooding and valuation of properties within the City is $56 billion (as of 2024). Instead, the City could adopt a targeted approach similar to Charlotte-Mecklenburg and focus on properties with the highest frequency of flooding. This strategy could be applied where other solutions, such as seawall elevation or living shorelines, prove neither logistically viable nor cost-effective in delivering the necessary level of protection. Using buyouts to transition even small shoreline sections from development to open space can reduce damages to adjacent properties.

Strategy Considerations:

- Strategic relocation of infrastructure is a long-term flood protection strategy and may require multiple years of planning and engagement efforts before implementation is possible.
- This strategy will require the support of multiple other legal, economic and logistical plans.
- Waterfront setback locations should be considered in the City's broader land-use planning efforts to promote cohesive use of waterfront spaces (e.g., parks, restoration of wetlands).
- Given the current high value of the City's bayfront property, the timing for this strategy is not likely to be a consideration for the City until sea level rise impacts cause flood damage conditions to devalue waterfront property values.



Existing king tide flooding extent was determined from the City's median annual king tide water elevation from 1994 to 2020 (1.8-feet NAVD88) determined by tidal elevation data at the National Oceanographic and Atmospheric Administration's (NOAA) Virginia Key Tide Gage. Projected sea level rise amounts were added to this baseline to determine future shoreline overtopping percents.

Annual tidal flooding days were estimated by analyzing historical tidal observations from the Virginia Key tide station and combining these data with current projected king tide events under future sea level rise scenarios to calculate the number of days per year when high water events could overtop shoreline areas, causing flooding impacts.

Bayfront Flood Protection Metrics, Adaptation Thresholds, and Monitoring Plan

Sea level rise has traditionally been a primary consideration in the City's planning efforts to reduce or avoid potential flood risks. However, there are other relevant metrics that the City could also monitor to provide an understanding of how rising sea levels may worsen flood impacts or place additional stress on the City's infrastructure and natural systems. Monitoring these metrics, along with sea level rise, can help to identify key thresholds that may serve as early warning signals that existing strategies may no longer be sufficient.

This section includes a list of proposed metrics and thresholds that the City could consider to inform the most effective strategies for long-term Bayfront flood protection. Additionally, a suitability matrix is provided to identify metrics that could be used to inform each strategy included in the Bayfront Flood Protection Pathway Summary.

Metrics

Metrics are measurable indicators that are used to track the effectiveness of adaptation actions over time. They are useful in helping make decisions on when to transition between different adaptation strategies based on changing sea level conditions and the observed effects.

Adaptation Thresholds

Thresholds are a pre-defined change in the existing physical conditions or social tolerances for flooding impacts and serve as early warning to signal that existing strategies are losing their effectiveness and could benefit from supplemental or alternative adaptation strategies.

Monitoring Plan

Monitoring allows the City to track the defined metrics over time for evidence of specified adaptation thresholds being met to avoid large potential impacts to the City's assets and facilities. While the City has existing plans and methodologies to track some of the proposed metrics, others will require the development and implementation of new monitoring programs.

Metric: Amount of City Shoreline Overtopped

Adaptation Threshold: Percentage of shoreline overtopped

Rising sea levels will elevate baseline coastal water levels, increasing the areas of Bayfront shoreline that are vulnerable to overtopping during king tides or other high-water events. When increasing percentages of the Bayfront shoreline are overtopped, it can indicate that current shoreline elevations are insufficient to provide flood protection and can highlight a need for further elevation of existing seawall structures or a transition to a replacement or supplemental strategy for flood protection. Additionally, if overtopped, seawalls and living shorelines can experience wave impacts or erosion on the landward side, compromising the structural integrity and effectiveness in flood protection.

Monitoring Plan:

The City could establish a coastal water level monitoring system to continuously monitor tide water levels in real time, providing data on tide fluctuations and storm tide levels. The City already tracks regional water levels via the Virginia Key NOAA tide station, but this effort could be supplemented using smaller-scale, City-managed water monitors placed in key offshore areas in Biscayne Bay. The water level information can be compared with seawall elevations to tally the number of seawalls segments that are exceeded by coastal water levels at a property scale. The findings from this effort can serve as a guide for the City to understand the timing of when large areas of the shoreline need to transition to a replacement or supplemental strategy for flood protection.

Metric: Shoreline Overtopping Frequency

Adaptation Threshold: Number of overtopping events per year

While the Bayfront shoreline is generally low in elevation, there are variations in seawall heights for individual properties that make areas of the shoreline more vulnerable to flood overtopping during high water events. When high coastal water levels overtop certain areas of the shoreline section frequently, seawalls and living shorelines can experience wave impacts or erosion on the landward side, compromising the structural integrity and effectiveness in flood protection. Frequent impacts can indicate that the existing seawall structure is no longer able to provide consistent flood protection, potentially leading to a need for a replacement or supplemental strategy for flood protection.

Monitoring Plan:

The City could establish a coastal water level monitoring system to continuously monitor tide water levels in real time, providing data on tide fluctuations and storm tide levels. The City already tracks regional water levels via the Virginia Key NOAA tide station, but this effort could be supplemented using smaller-scale, City-managed water monitors placed in key offshore areas in Biscayne Bay. The water level information can be compared with seawall elevation to tally the number of hours per year the seawall elevations are exceeded by coastal water levels at a property scale. This information can serve as a guide for the City to understand which shoreline segments may be overtopped the most frequently and could be prioritized for higher elevations or a transition to a replacement or supplemental strategy for flood protection.

Metric: Seawall Condition

Adaptation Threshold: Seawall Age and Structural Condition

As seawalls age, their structural integrity decreases due to erosion of the supporting sediments around the structure, the weathering of structure materials, an increase in marine growth, and any changes in hydrostatic pressure landward of the seawall due to sea level rise. Cracked or crumbling seawalls are at risk of potential failure, leading to increased overtopping and flood impacts. The condition of seawalls, with seawall age being a useful proxy, can be an indicator to consider whether the seawall should be replaced, elevated, or supplemented by another strategy.

Monitoring Plan:

Periodic (e.g., every 5 years) seawall inventory updates and water-based visual inspections can be used to track the condition of City's seawalls to document and signify structures in need of a higher elevation or a transition to a different strategy. The City will need to determine an approach for evaluating seawalls on private properties, which could potentially be conducted by staff via boat surveys.

Metric: Seawall Maintenance Cost

Adaptation Threshold: Repairs costs

Higher sea levels can increase the maintenance cost and schedule frequency by accelerating scour or erosion around the seawall foundation, causing overtopping that leads to erosion and an increase in hydrostatic pressure behind the structure, and corroding the seawall concrete and metal materials. Significant or frequent repair costs approaching or exceeding the projected cost of elevating or replacing the seawall may indicate the need to implement an additional flood protection strategy.

Monitoring Plan:

The City's seawall inventory and permit record can be used to also monitor repair costs and frequency and track the costs incurred to individual seawall segments when a permit is issued. This information can also be used to track the frequency repairs are being made to individual seawalls across the City to monitor cumulative costs to repair seawall segments over time.

Metric: Vegetation Health for Living Shorelines

Adaptation Threshold: Percentage decline in vegetation coverage

Assuming favorable conditions, living shorelines typically maintain high vegetation coverage that increases with time. A decline in vegetation coverage can indicate an ecological stress (e.g., plant species at the site are unable to keep pace with rising sea levels) and lead to a loss in flood protection offered by the shoreline. A significant and consistent decline over time can indicate that intervention may be necessary to maintain or supplement the strategy.

Monitoring Plan:

The City could establish an annual living shoreline survey program to measure the percentage and diversity of intertidal vegetation present to identify any consistent coverage declines.

Flood Protection Strategy	Potential Metrics: Amount of City Shoreline Overtopped	Shoreline Overtopping Frequency	Seawall Maintenance Cost	Seawall Condition	Vegetation Health for Living Shorelines
Elevate Seawalls to Current Ordinance	✓	✓	✓	✓	
Temporary Seawall Flood Barriers		✓	✓	✓	✓
Install Canal Tide Gates	✓				
Update Seawall Ordinance	✓	✓	✓		
Elevate Seawalls to Updated Ordinance	✓	✓	✓	✓	
Add Living Shoreline to Seawalls		✓	✓	✓	
Restore Natural Shorelines	✓		✓	✓	✓
Expand Waterfront Setback for Increased Resilience	✓	✓	✓	✓	✓

Stormwater Flood Protection Strategy Summary

The strategies in this section seek to enhance the City's ability to convey and treat stormwater runoff to prevent flooding impacts to City assets and private property.

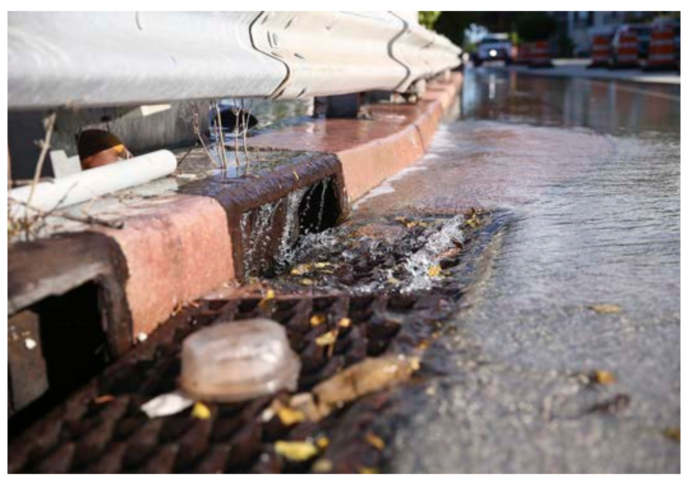
The Need to Adapt

Intense rainfall events can overwhelm the City's existing stormwater system, which was originally designed for 1930-1950 conditions. Flooding of the City's lowest elevations is especially common when heavy rainfall occurs during high tide events when stormwater runoff is unable to efficiently discharge to the Bay or coastal areas.

The City is actively performing stormwater system upgrades based on the recommendations of the Stormwater Modeling and Master Plan (SWWMP) adopted in 2024. The SWWMP identified key deficiencies in aging or undersized infrastructure and provided upgrade recommendations in response to increasing flood risks through 2060. The plan is designed to accommodate stormwater runoff from a 10-year, 24-hour rainfall event, considering the effect of sea level rise through 2060 on the system's discharge efficiency. Many of SWMMP recommendations are designed to be integrated into the City's targeted infrastructure improvement initiatives, such as the Neighborhood Improvement Projects (NIPs) to streamline improvements and minimize construction disruptions. However, recognizing the planning and costs of the NIPs, the SWMMP additionally developed 20 smaller Critical Needs Projects to address nuisance flooding in targeted areas prone to recurring flooding to be constructed by 2036. These projects are intended to be complimentary and adaptable to future NIPs.

Although the Critical Needs Projects are smaller and therefore easier to implement, the estimated 10-year timeline to complete all Critical Needs Projects may require the City to identify interim strategies to maintain adequate flood protection as planned projects are implemented. Additionally, prior to 2060, the City will need to consider whether to conduct a similar SWMMP effort to identify updated Critical Needs Projects or if other adaptation strategies are more suited to extend stormwater flood protection through the end of the century.

Temporary stormwater pump used to clear floodwaters during June 12, 2024, rain event. Source: Miami Beach



Runoff entering stormwater system in Miami Beach. Source: Miami Beach

The strategies below provide a set of options for the City to consider for ongoing stormwater flood protection through the end of the century. The strategies provide a suite of approaches that include continuing flood protection infrastructure upgrades to keep the water out, increasing the use of nature-based flood protection, adopting policy updates, and transitioning areas for on-site containment and treatment of stormwater runoff.

Each strategy includes a summary documenting implementation considerations, a rough order of magnitude cost, metrics and adaptation thresholds that could indicate an appropriate time for the strategy to begin, and a case study example, where applicable, of where the strategy has been applied within the City or in other municipalities with similar needs. The strategies are also presented in an adaptation pathways diagram at the end of this section to understand adaptation thresholds and the potential timing of strategy implementation.

Strategy Number	Strategy Name	Flood Hazards Addressed
SW1	**Implement SWMMP Recommendations** Execute Critical Needs Projects identified in the SWMMP to improve the City's stormwater management system flood control and water quality performance for the next 10 years.	
SW2	**Create Network of BGSI Projects** Integrate BGSI elements throughout City infrastructure improvements to develop a cohesive network of projects that utilize nature-based features to improve stormwater management.	
SW3	**Update SWMMP** Revise the stormwater modeling setup to include system updates and the latest rainfall and coastal tailwater conditions. Use the modeling output to identify new Critical Needs Projects to provide the continued level of service through the year 2100.	
SW4	**Promote Easement Acquisition** Land use policies may require updates to acquire additional easements necessary for additional stormwater infrastructure upgrades (e.g., pump stations).	
SW5	**Implement Updated SWMMP Actions** Execute the newly identified Critical Needs Projects from the updated SWMMP to retrofit stormwater infrastructure to provide enhanced flood protection through 2100.	
SW6	**Increase Floodable Areas** Identify city locations, such as parks and designated retention areas, that can be designed to temporarily absorb and manage excess floodwater during heavy rainfall or coastal high water level events.	

Strategy Theme:
Keeping Water Out, **Nature-Based Flood Protection**, **Plans and Policies**, **Living with Water**

Current Strategy

Strategy Theme: Keeping Water Out

SW1 **Implement SWMMP recommendations**

Flood Hazard(s) Addressed:

Estimated Cost Level:

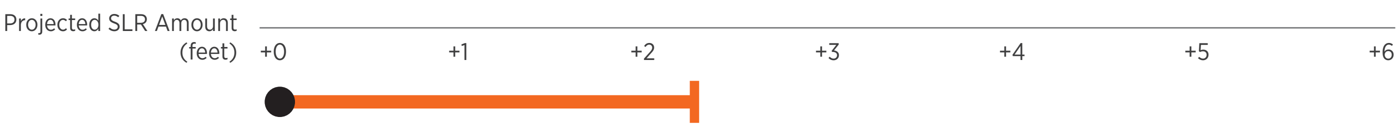
Strategy Description:

To modernize the stormwater system ahead of changing flood conditions, the City can continue the design and implementation of the recommendations and Critical Needs Projects identified in the SWMMP. The Critical Needs Projects are designed to accommodate stormwater runoff from a 10-year, 24-hour rainfall event. Although sea level rise is considered in the projects, it is limited to the stormwater system's ability to discharge against elevated coastal water levels, and does not account for coastal flooding.

Key recommendations include modernizing drainage infrastructure, installing additional pump stations, incorporating tidal backflow prevention measures, and promoting ecosystem restoration to enhance onsite stormwater capture and treatment. These large-scale infrastructure improvements are designed to be integrated with future Neighborhood Improvement Projects (NIPs) so that related infrastructure is modernized simultaneously, helping to minimize disruptions.

As of 2024, the City has begun the implementation of four Critical Needs Projects.

Flood Protection Lifespan:



Strategy Start: 0 feet of SLR

The City is currently implementing projects recommended through the SWMMP. The City can continue to pursue funding for these projects to modernize and upgrade stormwater infrastructure for future conditions.

Strategy End: ~2.2 feet of SLR

The SWMMP recommendations aim to provide stormwater flood protection through 2060, which equates to approximately 2.2 feet of sea level rise.

Strategy in Action:

Case Study: First Street Neighborhood Improvements & South Pointe Stormwater Project (Miami Beach)

The First Street Neighborhood Improvements & South Pointe Stormwater Project includes the installation of new storm drainage pipelines and a 200,000 gallon per minute underground stormwater pump, and adding green infrastructure elements, including bioswales and tree plantings, and regrade and repave several roadways to improve the area's stormwater drainage. The planned upgrades, which are currently in the design phase, will not only reduce roadway flooding from intense rainstorms and tidal events but also modernize the neighborhood's water and wastewater infrastructure, enhance vegetation, and improve sidewalks to increase walkability and safety.

Flooding at First Street and Alton prior to neighborhood improvements. Source: Miami Beach

Limitations:

Tidal and Coastal Storm Flooding

Although the SWMMP provides a series of Critical Needs Projects to address flooding, they are primarily directed at stormwater flooding due to rainfall events. The City is also at risk of coastal flooding due to overtopping of the shoreline during high tides and coastal storm surge events, which are not captured in the stormwater modeling. Implementation of many of the Critical Needs Projects may not address coastal flood risks.

Sea Level Rise

As sea level rises, coastal outfalls may become submerged, decreasing the efficiency of drainage for gravity-drained portions of the stormwater network and cause flood waters to back up into inland areas of the City. Similarly, stormwater pump stations will have to increase pumping capacity to pump stormwater runoff against higher coastal water levels.

Rising Groundwater

While the SWMMP accounts for rising groundwater levels, it is a challenging factor to address for stormwater improvements. Rising sea levels will elevate the City's shallow groundwater table and could cause groundwater to rise above the surface in many low-lying areas of the City. Although the City is providing more discharge capacity and efficiency within the stormwater network, rising groundwater levels can contribute additional volumes of water that could overwhelm the system and cause inland flooding.

Limited Space for Infrastructure Upgrades

The City's dense urban environment has decreased the amount of undeveloped areas or publicly-owned easements available for the installation of additional infrastructure or large greenspaces necessary for traditional stormwater practices, such as stormwater retention or more pump stations.

Adaptation Strategy Options

As sea level rises, stormwater management challenges and compound flooding impacts may begin to impact the City before the SWMMP recommendations can be implemented. This section describes additional strategies the City could consider to be used in tandem with the implementation of the SWMMP recommendations to provide ongoing stormwater flood protection through the end of the century.

The strategies in this section are not always intended to be applied in isolation, and some may be most effective and offer the greatest benefits if applied in coordination with another strategy. Site specific application of an additional strategy or combination of strategies should be based on the expected level of flood protection, suitability of local site conditions, implementation costs, and assets at-risk to stormwater flooding. By combining these strategies with existing efforts, the City can increase the effectiveness of its stormwater management system and improve resilience to flooding while also improving local water quality and supporting ecological health.

Strategy Theme: Nature Based Protection

SW2 Create network of BGSI projects

Flood Hazard(s) Addressed:

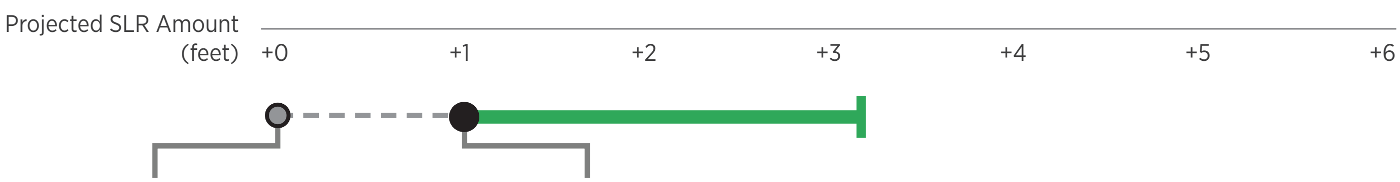
Estimated Cost Level:

Strategy Description:

Blue-Green Stormwater infrastructure (BGSI) refers to a stormwater management approach that integrates blue infrastructure (e.g., canals, stormwater retention areas) and green infrastructure (e.g., vegetation, permeable surfaces) to mimic natural processes for reducing flooding and improving water quality. In October 2024, the City adopted a resolution requiring that blue-green strategies be evaluated for NIPs, park projects, and stormwater projects with a cost in excess of $10,000. Incorporating these elements into specific projects can provide localized stormwater management and water quality benefits. Scaling these elements Citywide and integrating them into all infrastructure improvement projects could create a cohesive network of BGSI systems that work together to mitigate stormwater flooding impacts. This comprehensive approach could reduce the need for traditional stormwater infrastructure and lower City maintenance and replacement costs.

The City's Blue-Green Stormwater Infrastructure (BGSI) Concept Plan identifies several pilot projects, including bioswales, rain gardens, permeable pavements, and green roofs, that the City could utilize as the foundation for a Citywide BGSI network. Ahead of future projects the City could update the BGSI Concept Plan to incorporate best management practices learned from current efforts and to provide guidance on how to effectively integrate BGSI elements, focusing on developing a network of interconnected projects to enhance the overall effectiveness of the stormwater management system.

Flood Protection Lifespan:



Strategy Planning: 0 feet of SLR

Planning for this strategy could begin immediately by designing projects identified in the Blue-Green Stormwater Infrastructure Concept Plan.

Strategy Start: 1 foot of SLR

With 1 foot of sea level rise, over 50% of the City's roadways are projected to flood during a compound event. Integrating the proposed BGSI measures with other stormwater improvements, such as road raising, can reduce local flooding impacts and improve the quality of runoff discharged into Biscayne Bay.

Strategy End: ~3 feet of SLR

At 3 feet of sea level rise, over 60% of the City's limited green spaces, such as parks, are projected to experience flooding during a compound event. Given the scale of these impacts, the City may identify more comprehensive stormwater management strategies.

Strategy in Action:

Case Study: Indian Creek Drive Landscaping Project (Miami Beach)

This project aimed to revitalize the Indian Creek Drive corridor between 25th to 41st Street by constructing an improved pedestrian walkway with enhanced, natural landscaping to retain stormwater runoff and reduce roadway flooding. These improvements were designed to be harmonized with current infrastructure and planned roadway and utility improvements along the roadway. BGSI elements including layered shrubs beds, bushes and large canopy trees, were incorporated to increase natural features along the walkway to improve aesthetics and enhance stormwater retention. This project was completed to complement the broader improvements for resilience in the Indian Creek neighborhood.

Use of blue-green stormwater infrastructure elements at Canopy Park. Source: Miami Beach

Strategy Considerations:

- BGSI elements can be integrated into other planned infrastructure initiatives, such the NIPs or Critical Need Projects. This integration would help the City maximize use for these projects within the densely developed urban environment.
- Certain BGSI elements, including permeable pavements, may have limited Citywide effectiveness due to rising groundwater with sea level rise.
- The planning and design of these projects should carefully assess any potential adverse impacts on nearby infrastructure or property from anticipated water storage and infiltration.
- The successful implementation of BGSI elements requires the proper selection and design of the nature-based features. Coordination among City departments will be required to choose the appropriate vegetation and integrate these features into infrastructure projects, supporting their long-term viability.
- The proposed projects will require consistent monitoring to determine if the project is providing the desired level of flood protection and water quality improvements.
- Nature-based stormwater projects may introduce new or increased maintenance demands compared to traditional infrastructure. Staff training and resources may be required to effectively support these projects. The Blue-Green Stormwater Infrastructure Concept Plan provides maintenance requirements and best practices that could be used to support formal trainings.

Strategy Theme: Plans and Policies

SW3 Update SWMMP

Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

The City plans to review the SWMMP every five years and update the document within 15 years to account for ongoing infrastructure improvements, advances in stormwater modeling methods, and the latest sea level rise and rainfall projections. Through this process, the City could also identify a new set of Critical Needs Projects based on updated stormwater conditions and evolving population vulnerabilities. To provide a consistent flood protection level, the next SWMMP could be revised to consider conditions through the end of the century (2060-2100), which is comparable to the 40-year planning horizon of the current SWMMP planning horizon (2020-2060).

Flood Protection Lifespan:

Projected SLR Amount (feet) +0 +1 +2 +3 +4 +5 +6

Strategy Timing: ~2 feet of SLR

The City can consider updating and remodeling projected stormwater impacts in a revised SWMMP prior to 2 feet of sea level rise, when more than one-third (33%) of the City's area is projected to be impacted by a compound flood event, likely bringing additional stormwater management challenges. This timing also allows for an updated SWMMP to be established before the current SWMMP project recommendations reach the end of their effective lifespan.

Strategy Considerations:

- Updating the SWMMP and selection of Critical Needs Projects will require significant engagement with the City's decision makers and the public.
- The updated recommendations and Critical Needs Projects can be designed to integrate with other infrastructure improvement projects, such as the NIPs.
- Modeling for the existing SWMMP is based on a coastal water elevation of 2.7 feet (NAVD88) to represent a 2060 king tide event. To account for evolving coastal water level conditions, this elevation may need to be updated and adopted by City Commission prior to any updates of the SWMMP.
- The selected climate conditions and level of service of the updated SWMMP will need to consider the latest science and observations available at the time of to reflect current rates of sea level rise.

Strategy Theme: Plans and Policies

SW4 **Promote easement acquisition**

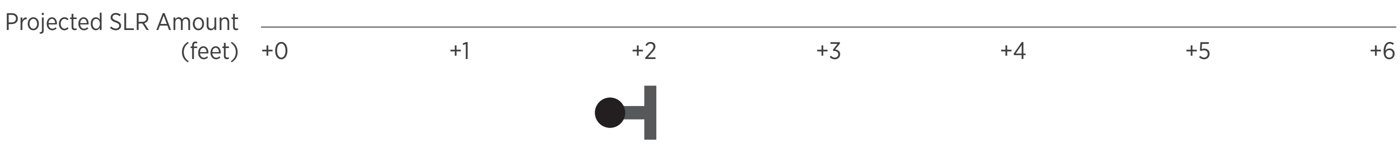
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

Large-scale infrastructure improvements (e.g., additional pump stations, upsized pipes) described in the SWMMP often require a larger footprint for their effective implementation. The City's heavily urbanized environment limits the availability of existing publicly owned or undeveloped property. Therefore, the City may need to develop incentive programs (and potentially revise land use policies and ordinances) to streamline the acquisition of property easements necessary for expanding stormwater infrastructure. This process could align with the SWMMP update (SW3), as the updated Critical Needs Projects are likely to require additional easements for implementation. Additionally, with more room available for projects, BGSI elements (SW2) could be more easily integrated into future SWMMP projects.

Flood Protection Lifespan:



Strategy Timing: ~2 feet of SLR

This strategy can be timed to align with the SWMMP update process, enabling the City to pre-identify areas for future stormwater improvement projects.

Strategy in Action:

Case Study: South Hillsborough Pipeline Easement & Property Acquisition (Tampa Bay, Florida)

To support the South Hillsborough Pipeline project, Tampa Bay Water has maintained ongoing communication with affected property owners, notifying them of the need for easements on their properties. Throughout the design process, multiple notifications have been provided to streamline the acquisition. Property owners are encouraged to coordinate the acquisitions prior to project commencement to receive fair market value for the property.

Application to Miami Beach:

The City currently maintains a strong and proactive outreach strategy for communicating projects benefits and construction impacts to residents and business owners, using community meetings, electronic communication methods, mailers and dedicated project webpages to keep affected property owners informed about proposed and ongoing infrastructure work. Messaging about potential easement acquisition needs could be incorporated into these resources to increase transparency and potentially streamline the acquisition process.

Strategy Considerations:

- Acquiring easements, particularly at the scale needed for this strategy, will bring significant legal, financial and logistical challenges. Identifying properties will require coordination with several stakeholder groups including urban planners, legal advisors, and landowners. Advance identification of City areas where future easements may be required could facilitate and ease public engagement.
- Property values are likely to remain a significant barrier to offering fair market value for potential easements. To address this challenge, the City could establish a dedicated funding program, such as a special use tax or property fee, to raise funds for future acquisitions.
- Demonstration and pilot projects on public property could highlight the anticipated benefits of future easements, helping to gain public support for future acquisitions by highlighting the value in addressing stormwater flooding.

Protecting Water Quality

Biscayne Bay is a protected aquatic preserve known for its rich biodiversity, supporting seagrass beds, coral reefs, and various marine species. It plays a vital role in South Florida's ecosystem and economy. However, increased flooding—exacerbated by climate change and urban development—could significantly impact its water quality if proactive initiatives are not implemented. In addition to increased stormwater runoff treatment, community initiatives, such as street sweeping and increased green space, will be needed to prevent pollutants from entering the bay.

Biscayne Bay, Source: Miami Beach

Strategy Theme: Keeping Water Out

SW5 Implement updated SWMMP actions

Flood Hazard(s) Addressed:

Estimated Cost Level: $ $ $ $ $

Strategy Description:

Once the SWMMP update process is complete, the City could begin to implement the newly identified Critical Needs Projects to retrofit and enhance the stormwater system to expected flooding hazards through the end of the century. Implementation of these projects can begin around 2.2 feet of sea level rise so that these systems are updated prior to previous infrastructure reaching the end of their functional life and could be designed to provide flood protection through the end of the century.

Flood Protection Lifespan:

Projected SLR Amount (feet) +0 +1 +2 +3 +4 +5 +6

Strategy Start: ~2 feet of SLR

The implementation of the updated SWMMP recommendations should occur prior to the functional end of the existing SWMMP projects.

Strategy End: 6+ feet of SLR

The recommendations proposed in the updated SWMMP would ideally provide stormwater flood protection through 2100.

Strategy Considerations:

- The updated Critical Needs Projects should be coordinated with other major capital improvement projects where possible to minimize disruptions. The City could also identify project aspects that could use a phased implementation approach to minimize long-term disruptions.
- The implementation of the Critical Needs Projects will require significant engagement with the City's decision makers and the public.
- The updated recommendations and Critical Needs Projects can be designed to integrate with other infrastructure improvement projects, such as the NIPs.
- Projects in the updated SWMMP will likely require high capital costs to implement. The City will need to consistently identify funding opportunities or develop local funding mechanisms to support these projects.

Strategy Theme: Living with Water

SW6 Increase floodable areas

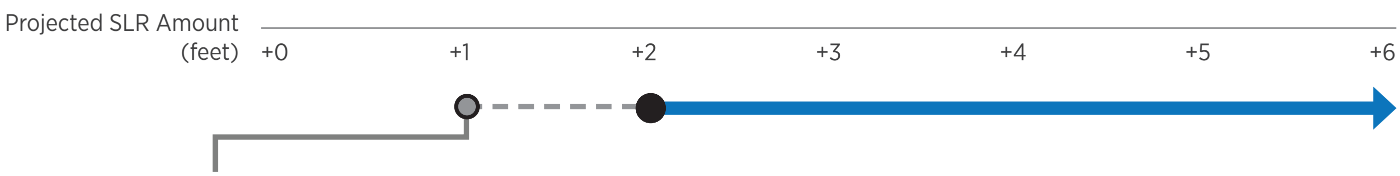
Flood Hazard(s) Addressed:

Estimated Cost Level: $$$

Strategy Description:

Floodable spaces are designed urban areas that are intentionally planned to accommodate periodic flooding. These short-term flood retention areas help the City to cope with increased flood events by diverting and containing flood water away from properties and infrastructure. They often serve as multifunctional spaces, such as public parks, open space, or recreational areas that are designed to be flooded during storm events without causing damage and allowing them to continue providing valuable community services during dry weather conditions.

Flood Protection Lifespan:



Strategy Planning: 1 foot of SLR

Identifying areas for conversion to floodable spaces will require significant stakeholder engagement and coordination. The City can begin planning these efforts at 1 foot of sea level rise, when >50% of roads are projected to flood during compound flood events, demonstrating the need for additional water storage areas across the City.

Strategy Start: 2 feet of SLR

At 2 feet of sea level, one third (33%) of the City is projected to be impacted by compound flood events. The City may need identify additional areas to manage the expected stormwater.

Strategy End: 6+ feet of SLR

As sea level continues to rise, the City may need to continually identify areas that can store floodwaters through the end of the century.

Strategy in Action:

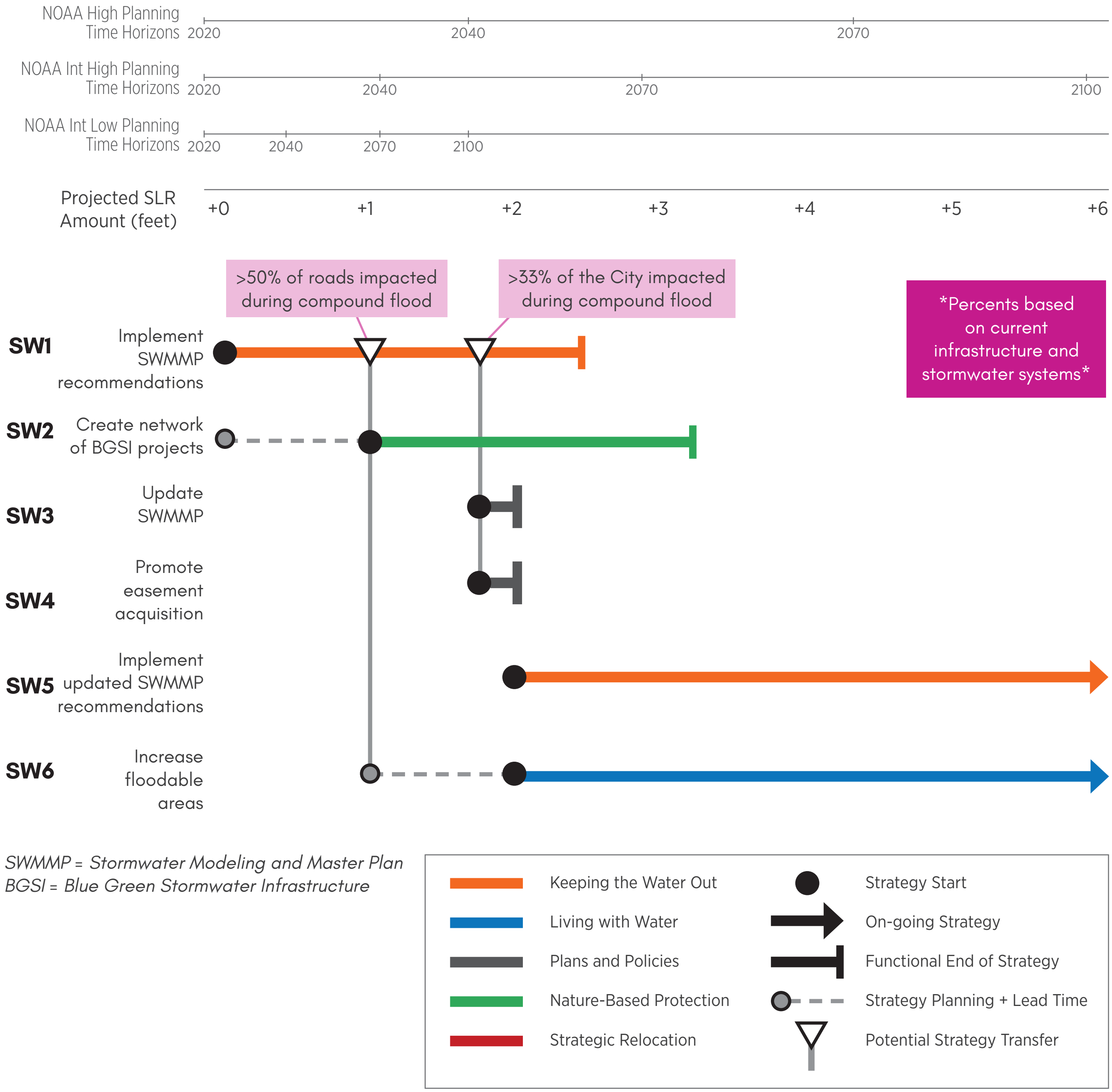
Case Study: Bayshore Park (Miami Beach)

The City is transforming the former Bayshore par-3 golf course into a 19-acre public park to feature walking paths, an outdoor amphitheater, a playground, multiple tennis courts, a dog park, and a water retention lake. The transition from a golf course to a passive park space is designed to serve dual purposes by providing recreational amenities and improving stormwater management with the retention lake intended to mitigate flooding impacts to adjacent roadways during heavy rainfall events. Additionally, the park's design incorporates green infrastructure principles, such as permeable surfaces and vegetation, to enhance its ability to manage runoff and improve water quality.

Aerial photo showing the construction of Bayshore Park and retention lake
Source: Miami Beach

Strategy Considerations:

- Identifying developed areas to transition to floodable spaces will require significant engagement with the City's decisions makers and the public. The City can develop demonstration projects using frequently flooded publicly owned areas to build support for future transformations.
- Proposed floodable spaces can be designed to retain and filter stormwater, improving water quality before it enters important ecological areas, such as Biscayne Bay.
- Proposed floodable spaces should be designed to retain projected stormwater volumes and avoid overflow impacts on surrounding infrastructure and areas. These spaces could connect to the traditional stormwater system to allow a delayed drainage of the floodable space following the storm event. The spaces should also maintain recreational value when not being used for stormwater retention.
- To protect public safety, the City will need to develop public educational materials and signage for the floodable spaces to explain that the public feature doubles as a flood storage area during large storm events and the types of conditions that will cause the public space to transition to a flood storage basin. The City will also need to enact measures to reduce public contact with stormwater to protect public health.
- Determining an appropriate site location for a floodable space will need to account for groundwater levels, as rising sea levels may elevate groundwater and reduce the space's ability to collect and retain rainfall runoff. Certain elements, including permeable pavements, may have limited effectiveness due to rising groundwater with sea level rise.
- The City could consider requiring that private properties add or increase on-site storage capacity to supplement larger City efforts. The City would need to implement a system to monitor areas of standing water that could pose health risks and provide ideal habitat for mosquitoes.



SWMMP = Stormwater Modeling and Master Plan
BGSI = Blue Green Stormwater Infrastructure

Existing compound flooding extent was determined by the simultaneous occurrence of a 10-year, 24-hour rainfall event (8.75 inches) and a king tide (1.8 feet NAVD88). Projected sea level rise amounts were added to this baseline to determine future compound flooding extents.

Impacts to roads were assessed by overlaying the relevant compound flooding scenario extent onto the City's stormwater assets in GIS to determine the percent of assets projected to experience flooding impacts.

Impacts to the City were assessed by determining, in GIS, the amount of City area that overlapped with the NOAA 2040 Intermediate High compound flooding scenario extent to determine the percent of the City projected to experience flooding impacts.

Stormwater Flood Protection Metrics, Adaptation Thresholds, and Monitoring Plan

Sea level rise has traditionally been a primary consideration in the City's planning efforts to reduce or avoid potential flood risks. However, there are other relevant metrics that the City could also monitor to provide an understanding of how rising sea levels may worsen flood impacts or place additional stress on the City's infrastructure and natural systems. Monitoring these metrics, along with sea level rise, can help to identify key thresholds that may serve as early warning signals that existing strategies may no longer be sufficient.

This section includes a list of proposed metrics and thresholds that the City could consider to inform the most effective strategies for long-term Stormwater flood protection. Additionally, a suitability matrix is provided to identify metrics that could be used to inform each strategy included in the Stormwater Flood Protection Pathway Summary.

Metrics

Metrics are measurable indicators that are used to track the effectiveness of adaptation actions over time. They are useful in helping make decisions on when to transition between different adaptation strategies based on changing sea level conditions and the observed effects.

Adaptation Thresholds

Thresholds are a pre-defined change in the existing physical conditions or social tolerances for flooding impacts and serve as early warning to signal that existing strategies are losing their effectiveness and could benefit from supplemental or alternative adaptation strategies.

Monitoring Plan

Monitoring allows the City to track the defined metrics over time for evidence of specified adaptation thresholds being met to avoid large potential impacts to the City's assets and facilities. While the City has existing plans and methodologies to track some of the proposed metrics, others will require the development and implementation of new monitoring programs.

Metric: Roadways Flooded

Adaptation Threshold: Percent of Roadways Flooded

Flooded roadways can restrict both vehicle and pedestrian traffic, significantly limiting mobility and access within the City. Low-lying streets are more prone to stormwater flooding during high-intensity rainfall events as stormwater systems may be unable to adequately drain stormwater runoff. If a significant percentage of City roadways flood during these compound events, this may signal the need to evaluate and implement additional stormwater management measures or infrastructure upgrades to reduce flood impacts on transportation routes.

Monitoring Plan:

The City could deploy a flood monitoring system using real-time sensors (e.g., rain and tide gages) and GIS-based mapping to track potential flooding on critical roadways. Deploying a Citywide network of rain gages would be challenging; however, the City could place gauges in key locations nearby critical roadways to monitor flood water levels. The City's Sea Level Rise Vulnerability Assessment already includes flood exposure of roadways for various flood sources (storm surge, king tide, and compound flooding) under a suite of sea level rise scenarios projected through the next century. Results from the assessment could serve as the basis for the select roadways to monitor. This data, along with continuously gathered sensor information can be analyzed against road elevation data, to provide insights into areas most frequently affected by stormwater accumulation. Regular monitoring will enable the City to respond efficiently when threshold levels are reached, allowing for timely adaptation of additional or replacement flood mitigation strategies. Sensor information could be supplemented by traffic reports that indicate impassable roadways during heavy rainfall events.

Metric: Changing Storm Conditions

Adaptation Threshold: Change in Average Design-Storm Rainfall Rate

Stormwater infrastructure is typically designed to manage runoff from a specific modeled storm event, such as a 10-year, 24-hour rainfall event, to ensure adequate flood protection capacity. However, with Florida's climate projected to bring more intense rainfall events, the current 10-year, 24-hour storm will not be the same in the future. Increased rainfall volumes can overwhelm infrastructure not designed for these higher runoff levels. If storm intensities exceed the design criteria of SWMMP upgrades, operational adjustments or additional flood management infrastructure may be necessary to maintain effective stormwater control.

Monitoring Plan:

The City should continue to monitor return period rainfall events released by the South Florida Water Management District to assess when existing stormwater network infrastructure may require adaptation to maintain its level of service. The City can also coordinate closely with Public Works staff to identify stormwater infrastructure that is consistently unable to manage stormwater runoff volumes. This information could be tracked in the Cityworks software.

Metric: Pump Station Failure

Adaptation Threshold: Failure of Pump Station to Handle Design Storm Event

The failure of pump stations during relatively common rainfall events, such as 10- to 25-year recurrence, may indicate that the asset is not designed for current storm events. As rainfall events are projected to become more intense in the future, this may indicate the need for increased capacity or operational adjustments to prevent localized flooding and infrastructure damage.

Monitoring Plan:

Stormwater pump performance can be measured using several key performance metrics, such as the pump efficiency ratio, observed flow rate, or run time. These key performance measures are typically measured using real-time monitoring tools, such as SCADA systems that can be used to identify early issues with pump operating systems.

Metric: Stormwater Infrastructure Condition

Adaptation Threshold: Infrastructure Condition and Age

As infrastructure ages, its integrity declines due to wear, stress, and environmental exposure. Additionally, older infrastructure was built with materials and designs suited for past environmental conditions, making it less resilient to evolving climate challenges. Older stormwater pumps are likely to require additional maintenance to operate properly and are more likely to be under-designed for current flood conditions. Stormwater infrastructure aging past its design life suggests a higher risk of failure.

Monitoring Plan:

Stormwater pump age can be tracked based on the construction or install date. Routine inspections and condition assessments of stormwater infrastructure should be conducted to track the remaining design life and will help guide planning for phased upgrades and replacements. This information could be integrated into the CItyworks tracking software managed by Public Works.

Metric: Access to Green Space

Adaptation Threshold: Walking time to Green Space

In addition to the stormwater benefits, access to green space areas have many proven benefits for the public health of residents, particularly for local residents able to walk to these spaces. Many cities use walking standards as a benchmark to promote equitable access to green areas for residents. Lack of access to these spaces or long travel times may indicate a need to increase the use of blue/green infrastructure in stormwater management to generate these important co-benefits.

Monitoring Plan:

The City could use GIS to map locations of parks, green space, and BGSI projects and define a buffer zone around them to measure how much of the population is within an appropriate walking distance.

Metric: Public Property Easements

Adaptation Threshold: Percentage of Public Property Available for Infrastructure Upgrades

Public property is preferable for the placement of new infrastructure as it avoids the need to purchase private property. However, the City has significantly few public property areas still available that have not already been developed. Without sufficient public utility easements, the City will be unable to implement many of the required large-scale infrastructure projects outlined in the SWMMP. When a low percentage of the land within the City is allocated for public utility easement, the City may need to obtain more property or evaluate other adaptation strategies to reduce flood impacts.

Monitoring Plan:

Planned and existing utility easement locations should be kept up to date using property records and city zoning documents. The City could use its GIS system and land ownership records system to monitor the number of used and available easement locations to track when more should be acquired for future infrastructure upgrades.

Metric: Amount of Impervious Surfaces

Adaptation Threshold: Impervious Surface Ratio

Increases in impervious surfaces directly affect the amount of stormwater runoff and pollutants that are discharged into adjacent water bodies. Neighborhoods that could receive large benefits from the additional of floodable spaces and BGSI projects could be informed by their impervious surface ratio. Neighborhoods with a large impervious surface ratio could be prioritized for replacement or supplemental stormwater management strategies.

Monitoring Plan:

The City can use GIS mapping to remotely estimate the total area of impervious surfaces within the City boundary. A GIS-based impervious surface model can be used to quickly classify roads, buildings, and other hard surfaces as impervious. This exercise can be repeated periodically (e.g., every five years) to understand temporal changes in the impervious surface ratio.

Metric: Standing Water Work Orders

Adaptation Threshold: Requests for standing water removal per year

Standing water on roadways can restrict access across the City, to residences and businesses, and neighborhoods. This can lead to increased travel times due to detours, limited access to services and private property, and create challenges for emergency services during hazard events. The Public Works Department considers water ponding greater than 3 inches to be "significant standing water". If Public Works receives several requests per year for standing water removal at the same property or area, it may suggest insufficient stormwater drainage to manage water after rainfall events.

Monitoring Plan:

The City currently tracks public work order requests and the locations of standing water removal. By adding criteria to track request frequency per location, Public Works could identify areas exceeding the threshold and prioritize them for additional stormwater management strategies.

Flood Protection Strategy	Potential Metrics							
	Roadways Flooded	Changing Storm Conditions	Pump Station Failure	Stormwater Infrastructure Condition	Access to Green Space	Public Property Easements	Amount of Impervious Surfaces	Standing Water Work Orders
Implement SWMMP Recommendations	✓		✓	✓				✓
Create Network of BGSI Projects	✓			✓	✓		✓	
Update SWMMP	✓	✓	✓			✓		
Promote Easement Acquisition						✓		
Implement Updated SWMMP Actions	✓	✓	✓	✓				✓
Increase Floodable Areas	✓	✓			✓		✓	

Roadway Flood Protection Pathway Summary

The strategies in this pathway are designed to minimize roadway flooding impacts, reduce travel disruptions, and reimagine roadway use for frequently flooded streets to preserve and enhance mobility throughout the City.

The Need to Adapt

The City's 169 miles of roadways are critical for providing the efficient daily transport of people and goods. However, 53% (89 miles) of these roads are at an average elevation of less than 3 feet above current sea levels, making them increasingly vulnerable to sea level rise flood impacts. The City's low-lying roadways already experience flooding during king tide and heavy rainfall events, leading to travel disruptions and potential safety risks due to blocked emergency routes and restricted access to neighborhoods.

To address these impacts, the City developed a Road Elevation Strategy (RES) to evaluate existing and future roadway flood risk and to prioritize key sections for elevation. The RES established a minimum road edge elevation for all City and State-owned roads, as well as critical emergency routes, to avoid impacts during common high water conditions. To keep pace with projected sea level rise, the RES also includes incremental increases in the minimum elevation guidance for future projects through 2040. The phased guidance supports a level of flood protection throughout the expected 30-year design life of an elevated roadway and allows for harmonization with improvements to adjacent infrastructure.

Road raising projects based on RES recommendations are generally coordinated with other infrastructure improvements, such as the Neighborhood Improvement Projects (NIPs)[8], to streamline improvements and minimize construction disruptions. However, the time needed to properly plan and implement these projects and the scale of roadways that require elevation suggest that not all roadways will be elevated in time to mitigate worsening flooding impacts. To maintain roadway flood protection through the end of the century, the City may need to explore additional adaptation strategies to reduce travel disruptions and maintain mobility throughout the City.

Road raising in Sunset Harbour, Miami Beach. Source: Miami Beach

Roadway flooding at Byron Ave. and 85th St, Miami Beach. Source: Miami Beach

8 For more information the NIPs, see the Critical Infrastructure Strategy Summaries.

The strategies below provide a set of options for the City to consider for ongoing roadway flood protection through the end of the century. The strategies provide a suite of approaches that include continuing to elevate roadway infrastructure based on recommendations in the RES, adapting roadways to accommodate additional stormwater volume, updating roadway plans and policies, and repurposing rights-of-way to accommodate more pedestrian-focused transportation.

Each strategy includes a summary documenting implementation considerations, a rough order of magnitude cost, metrics and thresholds that could indicate an appropriate time for the strategy to begin, and a case study example, where applicable, of where the strategy has been applied within the City or in other municipalities with similar needs. The strategies are also presented in an adaptation pathway diagram at the end of this section to understand adaptation thresholds and the potential timing of strategy implementation.

Strategy Number	Strategy Name	Flood Hazards Addressed
RW1	**Incremental Roadway Elevation** Coordinate the elevation of prioritized roadways with other infrastructure projects based on the recommendations of the Road Elevation Strategy to reduce potential flood risks of critical access routes.	
RW2	**Temporary Roadway Flood Barriers** Deploy temporary flood barriers along critical roadways that frequently flood to safeguard evacuation routes and essential access points during flood events.	
RW3	**Update Road Elevation Strategy** Revise the Road Elevation Strategy to prioritize the most vulnerable roadways in need of elevation based on latest sea level rise observations and end of century projections.	
RW4	**Implement Updated Road Elevation Strategy** Continue the coordinated elevation of select roadways with other infrastructure projects as specified in the revised Road Elevation Strategy to reduce potential flood risks of critical access routes through the end of the century.	
RW5	**Transition to Stormwater Streets** Designate specific low-lying roadways to intentionally accumulate floodwater during heavy rainfall, allowing them to serve as stormwater retention areas and reduce widespread flooding risks elsewhere.	
RW6	**Repurpose Rights-of-Way** Transition the use of certain rights-of-way, including the removal of roadway infrastructure, to maintain mobility and reduce maintenance commitments.	

Strategy Theme:
Keeping Water Out, **Living with Water**, **Strategic Relocation**, **Plans and Policies**

Current Strategy

Strategy Theme: Keeping Water Out

RW1 **Incremental roadway elevation**

Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

The Road Elevation Strategy (RES) assessed the flooding risk to the City's road network and prioritized several low-lying roadways for elevation that have the highest annual chance of tidal flooding through the year 2040. The RES recommends different minimum design elevations based on road criticality (e.g., residential, commercial, and emergency access). The document provides design elevations for starting construction years from 2020 through 2040 at 5-year increments to support roadway performance over the design life of typical roadway projects.

The City has previously coordinated the raising of roadways with NIPs to simultaneously upgrade aging infrastructure such as water and sewer systems and maintain roadway harmonization with adjacent properties and infrastructure. To date, the City has completed five roadway elevation projects with another three underway.

Flood Protection Lifespan:

Projected SLR Amount (feet) +0 +1 +2 +3 +4 +5 +6

Strategy Start: 0 feet of SLR

The City is currently integrating road raising into the implementation of NIP projects.

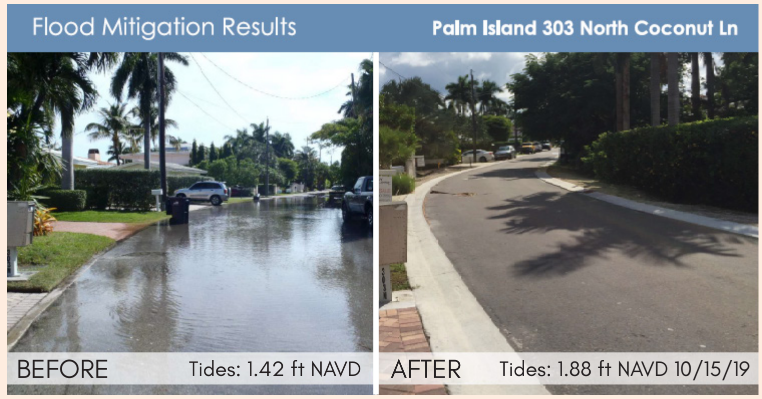
Strategy End: ~4.4 feet of SLR

Under the current RES elevation guidance, roadways constructed in 2040 are to be designed to accommodate up to 4.4 feet of sea level rise over the 30-year design life. Sea level rise greater than this amount is likely to leave roadways built to the existing RES guidance at risk of increased flooding impacts.

Strategy in Action:

Case Study: Palm and Hibiscus Neighborhood Improvements Project (Miami Beach)

Completed in 2021, the Palm and Hibiscus Neighborhood Improvements Project coordinated the elevation of critical roadways on the islands with several other critical infrastructure replacements or upgrades, including three new stormwater pump stations, street lighting, and natural landscaping improvements. The prioritized roadways were generally elevated to the recommended 3.7 feet NAVD88.



Impact of road raising and drainage project on Palm Island during high tide conditions, Miami Beach. Source: City of Miami Beach

Limitations:

Cost

Roadway elevations require significant capital investment. Projects are likely to require the raising of underground utilities and adjacent infrastructure including sidewalks, building access points, and critical facilities. This harmonization is necessary to maintain essential services and mobility throughout the City but can substantially increase overall project costs.

Service and Access Disruptions

Road raising projects require temporary closures or detours that disrupt traffic and limit access to businesses and residences. Additionally, raising associated utilities may result in temporary service interruptions. As sea levels rise, the increased frequency and scale of these project could lead to more widespread and prolonged disruptions across the City.

Implementation Timeline

Under traditional funding, planning, and construction timelines, completing all recommended roadway elevations could take decades, potentially leaving lower-priority access roadways at increased risk of periodic flooding.

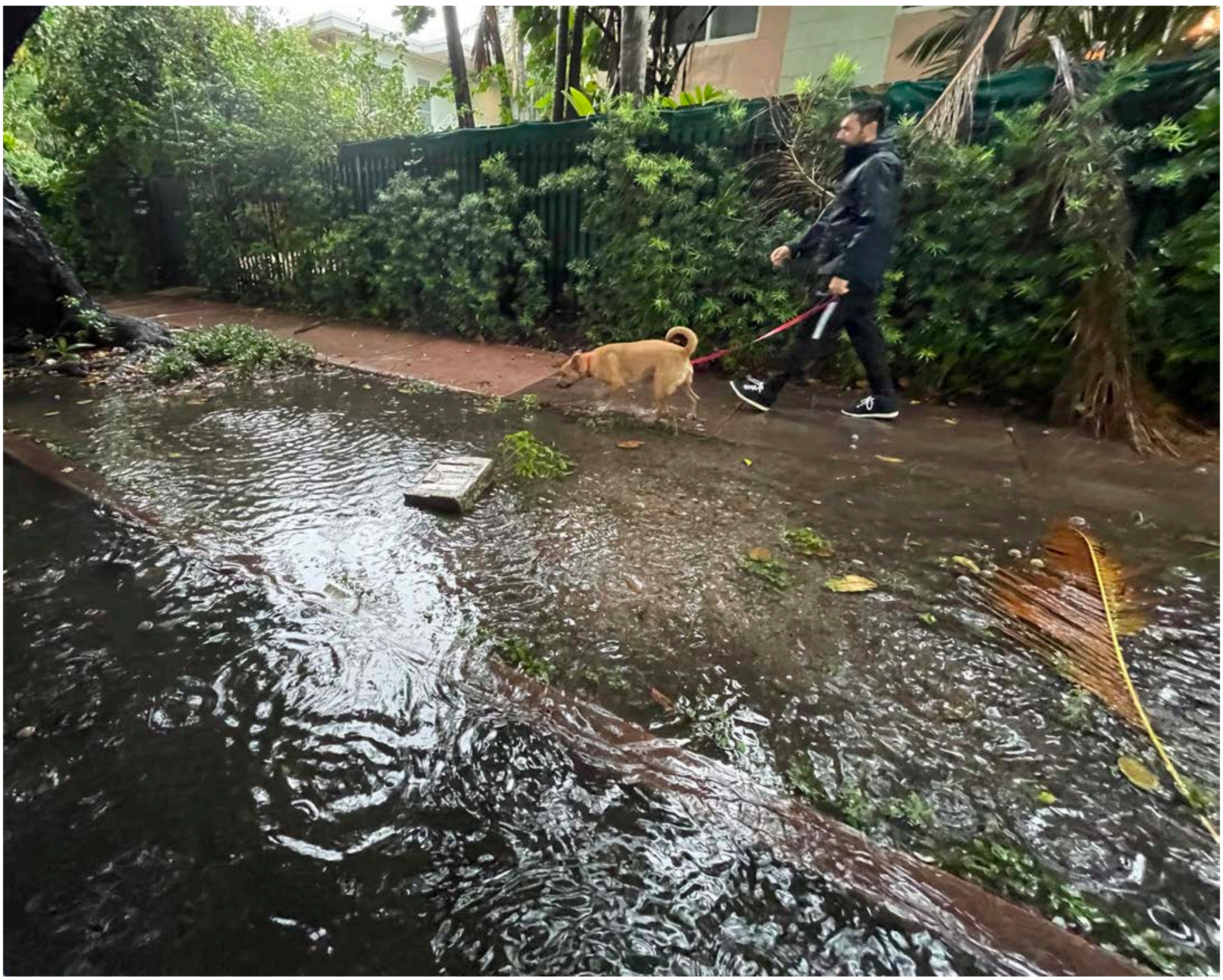
Environmental Considerations and Permitting

Elevating roadways near sensitive ecosystems and private properties may require environmental reviews and mitigation strategies, potentially requiring additional resources and extending project timelines. Roadway elevation projects near sensitive ecosystems like Biscayne Bay, will need to consider how construction and the proposed elevation could affect stormwater runoff volumes. Projects near private properties must be carefully planned to minimize impacts to properties and to avoid potential legal and planning challenges.

Adaptation Strategy Options

As sea level rise increases, the number of roadways requiring elevation and the associated costs are expected to grow, forcing the City to consider whether to elevate certain roadways or explore additional strategies to provide a higher level of flood protection. This section outlines strategies the City could consider to use in coordination with prioritized road elevation projects to maintain the resilience of the City's road network.

The strategies in this section are not always intended to be applied in isolation, and some may be most effective and offer the greatest benefits if applied in tandem with another strategy (e.g., continuing to elevate critical roadways while repurposing lower-priority side streets). Site specific application of an additional strategy or combination of strategies should be based on the expected level of flood protection, suitability of local site conditions, implementation costs, and the neighborhoods or businesses served by the roadways.



Roadway flooding following heavy rains. Source: Miami Beach

Strategy Theme: Keeping Water Out

RW2 Temporary roadway flood barriers

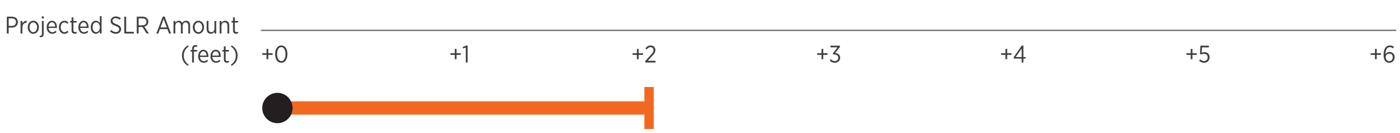
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

Temporary roadway flood barriers are portable, often modular, systems designed to safeguard critical roadways during high-water events to minimize travel disruptions and maintain access for emergency vehicles. These barriers may include a combination of rigid structures, water-filled tubes, or sandbags that can be connected or stacked. The City can prioritize frequently flooded roadways and deploy barriers as part of the City's emergency storm preparations to protect critical infrastructure and increase public safety. Temporary barriers are typically considered an interim solution, offering protection while a more permanent strategy for the roadway is developed.

Flood Protection Lifespan:



**Strategy Start:
0 feet of SLR**

The City can begin to identify low-lying roadways requiring temporary barriers to mitigate flooding impacts at current sea levels.

**Strategy End:
2 feet of SLR**

At 2 feet of sea level rise, over half (65%) of the City roadways are projected to experience flooding during a compound flood event. The frequency and extent of flooding will likely render temporary barriers an impractical solution.

Strategy in Action:

Case Study: Temporary Flood Barriers (Hollywood, Florida)

Hollywood, Florida, deploys temporary water-filled barriers like Tiger Dams along low-lying streets and waterfront areas during king tide and storm surge events. These barriers protect critical infrastructure and residential areas until long-term solutions, such as raised seawalls and roadway elevations, are completed. The City places barriers as needed along flood-prone stretches, such as Route A1A along openings in the beach entrances, helping to prevent disruption and flood damage in the short term.

A Tiger Dam employed at the Buchanan street entrance to Hollywood Beach. Source: Jose A. Iglesias, Miami Herald

Application to Miami Beach:

In Miami Beach, temporary roadway flood barriers could be deployed along vulnerable, low-lying roadway sections such as Alton Road, Indian Creek Drive, West Avenue, Collins Avenue, and the Venetian Causeway. Portions of these key routes often flood during high tide and severe weather events, impacting travel and public safety. By using portable barriers in these areas, the City can reduce flood impacts, maintain critical access, and protect both residential and commercial properties until permanent infrastructure improvements are in place.

Strategy Considerations:

- Low-lying, critical roadways that have historically flooded often could be good locations for this strategy.
- The City may need to build staff capacity and trainings to educate staff on the proper set-up and removal of barriers.
- Periodic inspections and as-needed maintenance will be necessary for the barriers to remain functional over multiple deployments.
- The City should consider how placement of barriers could impact runoff volumes to prevent flooding of adjacent areas, including private properties.
- Temporary barriers can be effective for maintaining road access during or following temporary coastal storms and rainfall events; however, high tide conditions can elevate groundwater levels, which may cause flooding within the barrier area from below.
- Proactively engaging with property owners before the deployment is advisable to address concerns and provide information about the temporary barrier's purpose and operation. The communication can include details about maintaining access to private properties and minimizing other disruptions or impacts.

Strategy Theme: Plans and Policies

RW3 **Update Road Elevation Strategy**

Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

As sea level rises, the City can revise roadway elevation guidance and prioritization criteria through an updated Road Elevation Strategy to better align with future projections. The City can extend the standards established in the initial RES by considering minimum road edge elevations that can reduce flooding impacts over a road's design life through the end of the century. During the RES update process, roadway flooding tolerances will need to be updated based on the latest observed sea level rise amounts and rainfall projections to establish the new minimum elevation recommendations. Achieving these elevation recommendations should continue to be implemented incrementally and with relevant infrastructure projects to maintain harmonization with adjacent infrastructure and minimize disruptions.

Flood Protection Lifespan:

Projected SLR Amount (feet) +0 +1 +2 +3 +4 +5 +6

Strategy Timing: 3 feet of SLR

The RES update process should occur prior to the recommendations of the existing RES becoming outdated. Additionally, at 3 feet of sea level rise, over 80% of the City's existing roadways are projected to experience compound flood impacts and may necessitate that the City consider re-prioritizing which roadways are to be elevated.

Strategy Considerations:

- The updated RES should consider the most recent sea level rise projections at the time of the plan update. Strategy timing is based on the rate of sea level rise from the 2017 NOAA Intermediate High scenario. The City will need to monitor for changes in the rate of sea level rise to determine if an update to the RES is required prior to this proposed timing.
- The updated RES should include an updated prioritization methodology that balances the cost to achieve an enhanced level of flood protection with the need to protect critical roadway access regardless of water elevations.
- The updated RES could consider supplemental or alternative approaches to flood adaptation strategies for less critical roadways to maintain a desired level of flood protection, including transitioning to stormwater streets (RW5) and repurposing rights-of-way (RW6).

Strategy Theme: Keeping Water Out

RW4 Implement updated Road Elevation Strategy

Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

For this strategy, the City would begin elevating prioritized roadways to meet the revised minimum edge elevations established in the updated RES (RW3).

Flood Protection Lifespan:

Projected SLR Amount (feet) +0 +1 +2 +3 +4 +5 +6

Strategy Start: ~3 feet of SLR

The City could begin incorporating roadway elevation guidance into infrastructure projects following completion of the updated RES.

Strategy End: 6+ feet of SLR

The City will likely need to consider a roadway raising schedule that accounts for future sea level rise through the end of the century, as documented in the updated RES.

Strategy Considerations:

- Road elevation projects should continue to align with other City infrastructure projects, such as the NIPs and other capital improvement projects, to maximize flood mitigation benefits and minimize disruptions.
- Based on the prioritization methodology of the updated RES, the City can focus resources toward high-priority roadways, including evacuation routes and major commercial roadways.
- The roadway elevation projects should be designed with the flexibility to allow for further elevation.
- Road elevation projects should continue to maximize harmonization with other City infrastructure to maintain access and mobility.
- Significant public engagement, including with private property and business owners located adjacent to high priority roadways, will be required to address community needs and increase transparency to proposed projects.

Strategy Theme: Living with Water

RW5 Transition to Stormwater Streets

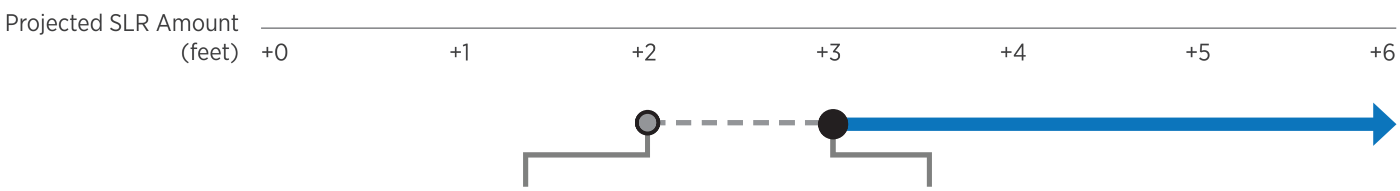
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

Stormwater streets are designed to temporarily collect and retain stormwater during heavy rainfall events, alleviating pressure on the broader stormwater system and roadway network. Stormwater streets are low-traffic volume roadways that are closed to vehicle and pedestrian traffic in the event of heavy rainfall to ensure safety of drivers and pedestrians. Stormwater streets are typically located in low-lying areas where stormwater can be passively diverted to collect following a heavy rainfall event and allow for the slow release of stormwater into the network.

Flood Protection Lifespan:



Strategy Planning: 2 feet of SLR

Planning for this strategy could begin at 2 feet of sea level rise when over 65% of current City roadway infrastructure is projected to flood during compound flood events. At this scale, the City may need to prioritize resources for elevating critical roadways.

Strategy Start: 3 feet of SLR

At 3 feet of sea level, >80% of current roadways are projected to have flooding impacts during compound flooding events. Impacts at this scale may lead the City to reassess which roadways to prioritize for elevation and those to redesign as Stormwater Streets.

Strategy End: 6+ feet of SLR

As sea levels continue to rise through the end of the century, the City may need to continually prioritize which roadways should be elevated and those that can be transitioned as Stormwater Streets.

Strategy in Action:

Case Study: Sankt Kjeld's Square & Bryggervangen (Copenhagen, Denmark)

Completed in 2019, the Sankt Kjeld's Square & Bryggervangen pilot project is an example of multifunctional design to balance urban livability with flood risk management. It integrates the conversion of a 2,300-ft roadway into a "stormwater detention road" and floodable adjacent park space to alleviate local flood issues. Traditional roadway and stormwater infrastructure (e.g., pumps and pipelines) was largely replaced by a series of rain gardens, detention basins, increased pedestrian areas, and underground water storage. Stormwater runoff is directed from adjacent roadways and buildings using subtle grading and temporarily stored in the pilot project area to reduce the burden on the stormwater system.

Sankt Kjled's Square & Bryggervangen pilot road detention project, Copenhagen, Denmark. Source: SLA

Application to Miami Beach:

The City could adopt a similar approach to provide enhanced flood protection for major roadways and alleviate capacity issues within the City's stormwater network. Approaches could include condensing the number of lanes or identifying minor roads to be designated as stormwater streets. Where possible, areas adjacent to the stormwater streets could be adapted into nature-based areas, including rain gardens or bioswales, while still including paths to maintain pedestrian mobility and increasing stormwater retention capacity and on-site stormwater treatment.

Strategy Considerations:

- Proposed stormwater streets are only suitable for minor roadways that have low average traffic volumes and are not critical access routes for certain neighborhoods. Emergency or state roadways are not eligible, and emergency vehicles will still need access to neighborhoods during hazard events.
- Integration of green infrastructure into the Stormwater Street design is advised to assist with on-site stormwater treatment; however, water quality standards and treatment systems will need to be coordinated with regulatory authorities.
- Designating a stormwater street typically may not require redesigning the roadway or placing additional infrastructure to support stormwater detention. However, the detention capacity of the roads will need to be evaluated to ensure these areas can retain projected stormwater runoff volumes without understanding the flooding conditions of adjacent properties. Minor changes, including adding localized retention areas or removal of stormwater pumps, could be done to facilitate the transition.
- Public safety messaging will be needed to prevent public access of stormwater streets during periods of flooding.
- Following heavy rainfall events, collected stormwater should be drained into the City's existing stormwater network to prevent public health issues associated with stagnant water.

Strategy Theme: Strategic Relocation

RW6 Repurpose rights-of-way

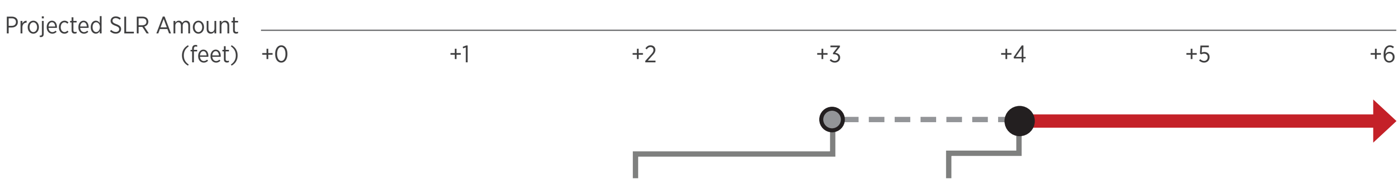
Flood Hazard(s) Addressed:

Estimated Cost Level: $$$$ (4 of 5)

Strategy Description:

As sea levels reach end of century projections, the extent and frequency of flooding may require the City to re-evaluate the use of certain roadways. This may include repurposing existing rights-of-way by closing the roadway to vehicle traffic and removing existing roadway in favor of pedestrian uses, such as walking trails and bicycle paths. Streets applicable for repurposing could include roadways around or connecting the City's network of parks, or minor connector roadways within neighborhoods (e.g., every other east-west connector is repurposed). Converting frequently flooded, minor roadways also allows the City to reallocate maintenance funds toward protecting higher priority roadways.

Flood Protection Lifespan:



Strategy Planning: 3 feet of SLR

Planning for this strategy could begin at 3 feet of sea level rise when over 80% of current City roadway infrastructure is projected to flood during compound flood events. At this scale, the City may need to prioritize resources for critical roadways.

Strategy Start: 4 feet of SLR

At 4 feet of sea level, nearly all (>90%) of current roadways are projected to have impacts during a compound flooding event. Impacts at this scale may lead the City to reassess which roadways to prioritize for elevation and those to repurpose.

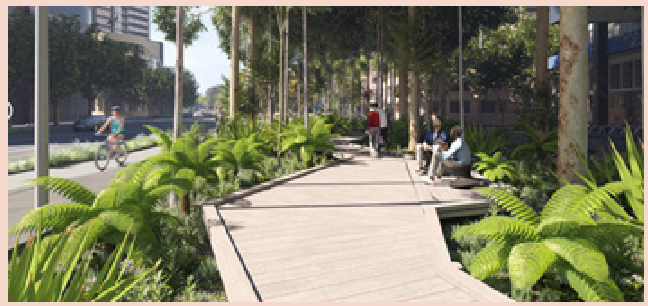
Strategy End: 6+ feet of SLR

As sea levels continue to rise through the end of the century, the City may need to continually prioritize which roadways should be elevated and those that can be repurposed.

Strategy in Action:

Case Study: Repurposing Flood-Prone Roads in Southbank Boulevard and Dodds Street (Melbourne, Australia)

Major redevelopments are planned to address stormwater network capacity and pedestrian safety issues in one of the most densely populated suburbs of the Melbourne, Australia, including the repurposing of select roads into public parks and pedestrian pathways. These purposed changes also include integration of green infrastructure, such as bioswales, to reduce flood risk, provide on-site water treatment, and enhancing the livability of the urban area.



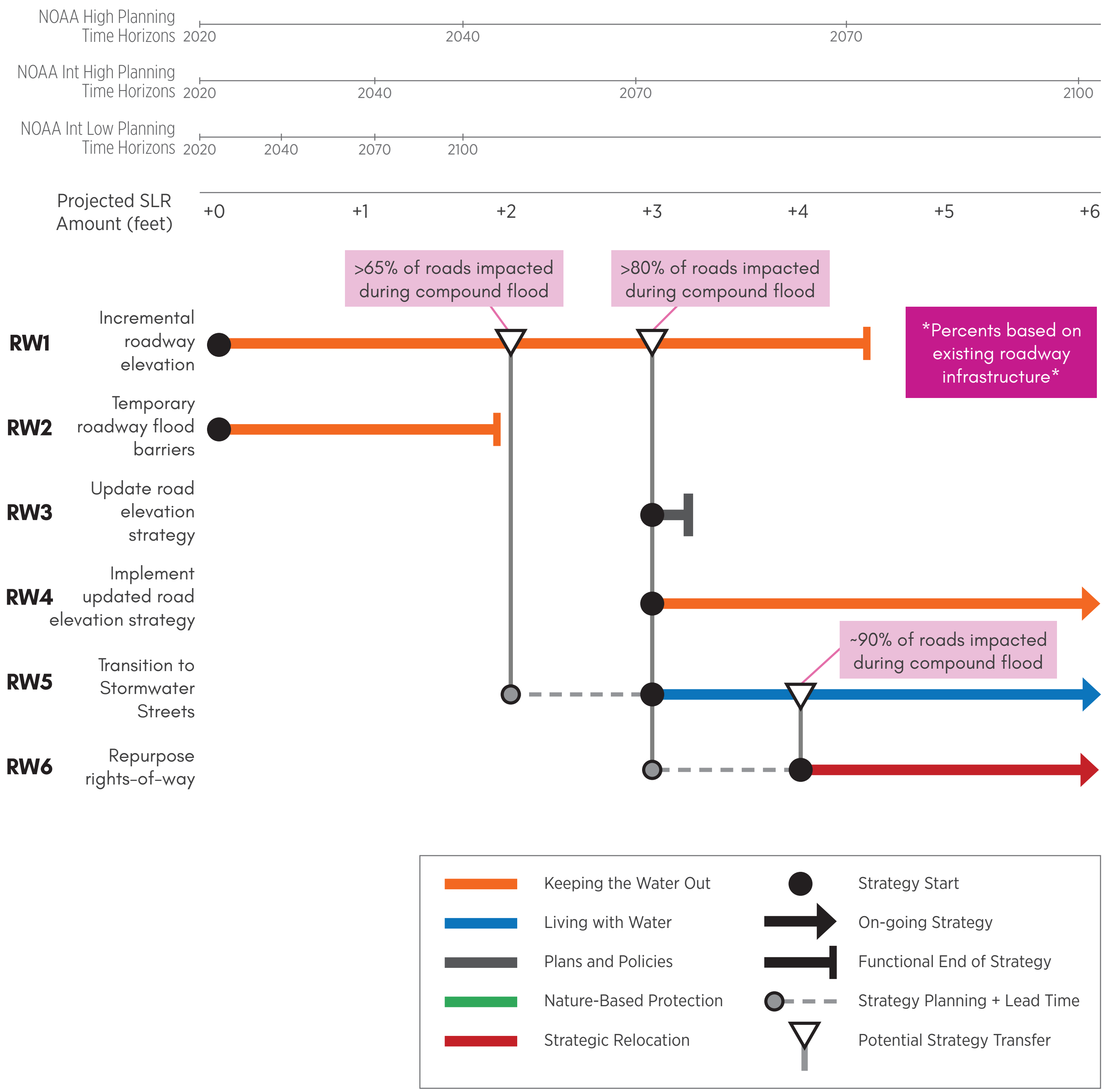
Example of repurposing a former roadway for elevated pedestrian path and green space. Source: City of Melbourne

Application to Miami Beach:

Like Melbourne, Miami Beach is a highly urbanized environment with ongoing flood issues and a need for more multimodal forms of transportation for pedestrians. The City could undergo a similar assessment of opportunities for repurposing of select roadways to provide residents with more greenspace and pedestrian access while also providing additional stormwater capacity and a reallocation of road maintenance funds to address flooding of critical roadways through other strategies such road elevation.

Strategy Considerations:

- To identify roadways appropriate for repurposing, the City can conduct a comprehensive assessment that includes the identification of roadways prone to frequent flooding, an evaluation of roadway criticality and adjacent critical infrastructure, and an analysis of the annual maintenance cost per roadway to determine the prioritization of roadways to be repurposed that are no longer cost-effective to maintain or protect.
- Prior to the removal of roadways and ancillary infrastructure, the City should aim to maintain essential services for affected property owners, such as identifying new service connections or rerouting subgrade utilities that have been removed.
- Overall stormwater management could be improved by adding natural stormwater elements, such as green spaces or other natural buffers and stormwater capacity areas on these repurposed roadways. These roadways could be repurposed in coordination with the stormwater streets strategy (RW5).
- Access to adjacent properties and/or businesses could be redesigned, such as expanding elevated sidewalks or bike lanes, which are less costly to implement than raising streets, to provide more reliable multimodal pedestrian access throughout the City.



Existing compound flooding extent was determined by the simultaneous occurrence of a 10-year, 24-hour rainfall event (8.75 inches) and a king tide. Projected sea level rise amounts were added to this baseline to determine future compound flooding extents.

Impacts to roads were assessed by overlaying the existing compound flooding scenario extent onto the City's roadways in GIS to determine the percent of roadways projected to experience flooding impacts.

Roadway Flood Protection Metrics, Adaptation Thresholds, and Monitoring Plan

Sea level rise has traditionally been a primary consideration in the City's planning efforts to reduce or avoid potential flood risks. However, there are other relevant metrics that the City could also monitor to provide an understanding of how rising sea levels may worsen flood impacts or place additional stress on the City's infrastructure and natural systems. Monitoring these metrics, along with sea level rise, can help to identify key thresholds that may serve as early warning signals that existing strategies may no longer be sufficient.

This section includes a list of proposed metrics and thresholds that the City could consider to inform the most effective strategies for long-term Roadway flood protection. Additionally, a suitability matrix is provided to identify metrics that could be used to inform each strategy included in the Roadway Flood Protection Pathway Summary.

Metrics

Metrics are measurable indicators that are used to track the effectiveness of adaptation actions over time. They are useful in helping make decisions on when to transition between different adaptation strategies based on changing sea level conditions and the observed effects.

Adaptation Thresholds

Thresholds are a pre-defined change in the existing physical conditions or social tolerances for flooding impacts and serve as early warning to signal that existing strategies are losing their effectiveness and could benefit from supplemental or alternative adaptation strategies.

Monitoring Plan

Monitoring allows the City to track the defined metrics over time for evidence of specified adaptation thresholds being met to avoid large potential impacts to the City's assets and facilities. While the City has existing plans and methodologies to track some of the proposed metrics, others will require the development and implementation of new monitoring programs.

Metric: Roadways Flooded

Adaptation Threshold: Percent of Roadways Flooded

Flooded roadways can restrict both vehicle and pedestrian traffic, significantly limiting mobility and access within the City. As sea levels rise, the percentage of flooded roadways is expected to increase, resulting in water ponding on roadway surfaces. At a certain level of roadway flooding, mobility throughout the City could be severely restricted and may necessitate application of additional strategies to preserve connectivity throughout the City.

Monitoring Plan:

The City could deploy a citywide flood monitoring system using real-time sensors (e.g., rain and tide gages) and GIS-based mapping to track potential flooding on critical roadways. Deploying a citywide network of rain gages would be challenging; however, the City could place gauges in key locations nearby critical roadways to monitor flood water levels. The City's Sea Level Rise Vulnerability Assessment already includes flood exposure of roadways for various flood sources (storm surge, king tide, and compound flooding) under a suite of sea level rise scenarios projected through the next century. Results from the assessment could serve as the basis for the select roadways to monitor. Real-time rainfall or high tide water level information, when continuously gathered and analyzed against road elevation data, can provide insights into areas most frequently affected by stormwater and king tide ponding. Regular monitoring will enable long-term planning to identify priority roads for potential application of adaptation strategies.

Metric: Evacuation Routes Flooded

Adaptation Threshold: Percent of Evacuation Routes Flooded

If not properly elevated or otherwise protected from floodwaters, the City's evacuation routes can be similarly impacted by flooding events as other roadways. If the City's evacuation routes were to flood and become inaccessible during a storm event, there would be significant impacts to the life and safety of residents and emergency services. If a significant number of these roadways are impacted by a flood hazard event, the City can consider implementing additional strategies that can preserve the critical movement of evacuees and first responders during a hazard event.

Monitoring Plan:

The City could deploy a citywide flood monitoring system using real-time sensors (e.g., rain and tide gages) and GIS-based mapping to track potential flooding on critical roadways. Deploying a citywide network of rain gages would be challenging; however, the City could place gauges in key locations nearby critical roadways to monitor flood water levels. The City's Sea Level Rise Vulnerability Assessment already includes flood exposure of evacuation routes for various flood sources (storm surge, king tide, and compound flooding) under a suite of sea level rise scenarios projected through the next century. Results from the assessment could serve as the basis for the GIS-based flood maps. Real-time rainfall or high tide water level information, when continuously gathered and analyzed against road elevation data, can provide insights into areas most frequently affected by stormwater and king tide ponding. Regular monitoring will enable long-term planning to identify priority portions of the evacuation route for potential application of adaptation strategies.

Metric: Roadway Flood Frequency

Adaptation Threshold: Number of Times Roadway Travel is Restricted per Year

Standing water on roadways can restrict access across the City, to residences and businesses, and neighborhoods. This can lead to increased travel times due to detours, limited access to services and private property, and create challenges for emergency services during hazard events. The Public Works Department considers water ponding greater than 3 inches to be "significant standing water", that could restrict use of the roadway. If these flooding events occur frequently on specific roadway sections, it may indicate the City should consider additional strategies to maintain access.

Monitoring Plan:

The City could deploy real-time sensors (e.g., rain and tide gauges) on critical roadways and utilize GIS to track and map potential ponding on roads. Deploying a citywide network of rain gages would be challenging; however, the City could place gauges in key locations nearby critical roadways to monitor flood water levels. The City could also develop a system to track when a roadway reaches a level of flooding that prevents the use of the roadway (e.g., >3-inch flood depth). This remotely sensed data could also be supplemented with visual inspections during and following flood events to document roads that experience ponding water.

		Potential Metrics		
		Roadways Flooded	Evacuation Roadways Flooded	Roadway Flooding Frequency
Flood Protection Strategy	Incremental Roadway Elevation	✓	✓	✓
	Temporary Roadway Flood Barriers		✓	✓
	Update Road Elevation Strategy	✓	✓	✓
	Implement Updated Road Elevation Strategy	✓	✓	✓
	Transition to Stormwater Streets			✓
	Repurpose Rights-of-Way	✓		✓

Critical Facilities Flood Protection Pathway Summary

The strategies in this section provide approaches to reduce or prevent flood impacts to the City's critical facilities while maintaining their accessibility and provision of essential services.

The Need to Adapt

The City's critical facilities, such as police and fire stations, hospitals, government buildings, community centers, schools and libraries, provide essential services necessary for City operations, emergency functions, and public programs. Critical facilities need to maintain access regardless of flood conditions because they play essential roles in ensuring public safety and wellbeing, especially during emergencies. Flood-related damages can lead to service interruptions or delays and result in significant life-safety and quality-of-life impacts for residents.

Currently, over one-third (37%) of the City's critical facilities are projected to be exposed to compound flood events (10-year, 24-hour rainfall event (8.75 inches) combined with a king tide), and nearly all (97%) are projected to be exposed to a 100-year (1-percent annual chance) coastal storm surge event. To mitigate flood risks, the City complies with federal and state building code requirements, such as requiring the first floor elevation (FFE) of buildings, including critical facilities, to comply with FEMA requirements and encouraging the use of floodproofing measures outlined in the Florida Building Code (FBC). While the City's critical facilities meet federal and state standards, they may face restricted access challenges due to flooding of the building property or roadway, which can cause access and service disruptions. Additionally, FEMA's FFE requirements do not account for sea level rise, increasing future flood risks for facilities built to minimum standards.

Locally, the City has adopted several policies and actions that go beyond these minimum standards, including updating the building code (Chapter 54) to allow for up to five feet of freeboard above FEMA's Base Flood Elevation (BFE). The City has also implemented increased protective measures, such as elevating mechanical and electrical equipment above FEMA requirements, to safeguard high-priority facilities, like the Miami Beach Convention Center. To ensure the long-term resilience of its critical facilities, the City may need to continue to implement adaptation strategies that go beyond current minimum standards. Given that many facilities are not owned or managed by the City (e.g., schools, Mt. Sinai Hospital), coordination with facility managers will be crucial to encourage adoption of these strategies. The City can design supplemental measures to address increasing flood risks to City-owned facilities, while incentivizing other facility managers to take proactive steps to safeguard their operations.

Miami Beach Police Headquarters Source: Miami Herald

Fire Station No. 1, Miami Beach. Source: WLRN

The strategies below provide a set of options for the City to consider for ongoing critical facility flood protection through the end of the century. The strategies provide a suite of approaches that include continuing to utilize floodproofing techniques and temporary flood barriers to keep water out, adopting additional higher standard building design criteria, elevating prioritized structures to avoid damaging impacts of being flooded, and strategic relocation of facilities to repurpose frequently flood spaces.

Each strategy includes a summary documenting implementation considerations, a rough order of magnitude cost, metrics and adaptation thresholds that could indicate an appropriate time for the strategy to begin, and a case study example, where applicable, of where the strategy has been applied within the City or in other municipalities with similar needs. The strategies are also presented in an adaptation pathways diagram at the end of this section to understand adaptation thresholds and the potential timing of strategy implementation.

Strategy Number	Strategy Name	Flood Hazards Addressed
CF1	**Continue to Floodproof Critical Facilities** Continue to implement wet or dry floodproofing measures for facilities to reduce potential flood damages.	
CF2	**Temporary Facility Perimeter Flood Walls** Erect temporary flood walls around critical facilities during high water events to provide short-term protection against flooding and safeguard essential services.	
CF3	**Include SLR in FFE for Critical Facilities** Establish building design criteria for City facilities that exceed federal and state minimum standards and consider projected sea level rise.	
CF4	**Elevate Existing Critical Facilities** Elevate structures above projected flood elevations using structural fill or pilings.	
CF5	**Repurpose Frequently Flooded Critical Facilities** Remove or relocate facilities that are frequently flooded and cannot be feasibly elevated or floodproofed to repurpose the space for stormwater management or recreation.	

Strategy Theme:
Keeping Water Out, **Plans and Policies**, **Living with Water**, **Strategic Relocation**

Current Strategy

Strategy Theme: Keeping Water Out

CF1 **Continue to floodproof critical facilities**

Flood Hazard(s) Addressed:

Estimated Cost Level: $$$

Strategy Description:

Floodproofing facilities refers to a set of measures aimed at preventing or reducing the risk of flood damage to an individual building using wet or dry floodproofing techniques. Wet floodproofing allows water to enter and exit the facility, focusing on protecting the interior sensitive components (e.g., electrical) and building contents. It can include use of flood vents, flood damage resistant materials (e.g., concrete, tile, brick, and stainless steel), elevating electrical components, or installing sump pumps to remove water that enters a building. Dry floodproofing focuses on preventing water from entering a facility, often through the application of waterproof sealants or watertight enclosures, such as the use of flood panels at building access points.

FEMA and the FBC provide guidance for implementing floodproofing measures for critical facilities, however there are opportunities for the City to exceed those recommendations, particularly for the placement of utilities and encouraging dry over wet floodproofing, where feasible. The City has already started to floodproof some City-owned buildings, including the Convention Center (see case study below) to reduce or prevent damages during potential flood events. This strategy focuses on expanding these higher standard floodproofing efforts to the City's existing critical facilities and newly constructed critical facilities.

Flood Protection Lifespan:

Projected SLR Amount (feet) +0 +1 +2 +3 +4 +5 +6

Strategy End: 0 feet of SLR

The City can continue to implement floodproofing techniques for critical facilities.

Strategy End: ~3 feet of SLR

At about 3 feet of sea level rise, over half of the City's critical facilities are projected to experience king tide flood exposure for more than 52 days a year. Frequent flooding events may restrict facility access, potentially rendering floodproofing ineffective as a standalone strategy, though the City is likely to need to integrate floodproofing measures into all facilities through the end of the century.

Strategy in Action:

Case Study: Miami Beach Convention Center (Miami Beach)

Recent renovations to the Miami Beach Convention Center enhance the building's sustainability by using more efficient utilities to reduce annual emissions, while also increasing the facility's resilience to flood risks. The project integrated a combination of wet and dry floodproofing measures into the renovation, including raising the base floor elevation by one foot and relocating all critical building systems, such as emergency generators, communications and electrical equipment, and emergency response assets, to the second floor. Building-specific upgrades were complimented by area-scale improvements (e.g., raising the adjacent road elevation, addition of nature-based stormwater elements), increasing the resilience of the facility and enhancing its function as a supply staging area during emergency events.

Miami Beach Convention Center, Miami Beach. Source: Greater Miami Convention & Visitors Bureau

Limitations:

Restricted Facility Access

Even with floodproofing techniques applied to individual facilities, more intense and frequent flooding may impede dependable access to the building, affecting provided services and the timing of potential flood damage repairs.

Design Limitations

While floodproofing techniques significantly reduce the risk of floodwater entering a building and causing damage, they cannot fully eliminate the potential for flooding, especially in extreme events. Floodproofing is often designed to protect against a specified level of flooding, such as a flood event with a certain recurrent interval (e.g., 10-year, 100-year flood). However, if a flood exceeds the set level of flood protection, even a well-designed floodproofing strategy could experience damage. For example, the maximum flood panel height allowable by FEMA is 3 feet, which may not provide protection from large coastal storm surge events.

Limited Protection Against Floodwater Infiltration

While floodproofing can be effective for event-based flood protection, it may not be able to keep out all forms of water infiltration, such as rising groundwater or small cracks in the walls that allow moisture to penetrate over time. Moisture buildup in walls can lead to mold growth that weakens the structure over time and presents health hazards. Additionally, standing water that was prevented from entering the building may remain on site and pose similar health concerns.

Ownership

The City does not own or manage all of its critical facilities, including the schools, hospital, or state and federal government buildings. The City can leverage policy, regulations, incentives, and serve as a coordination partner to encourage the adaptation of other critical facilities.

Adaptation Strategy Options

As sea levels continue to rise, utilizing floodproofing techniques as the primary flood mitigation strategy may prove insufficient to protect the City's critical facilities. This section outlines additional adaptation strategies the City could consider in coordination with floodproofing efforts to maintain the services provided by these facilities.

The strategies in this section are not always intended to be applied in isolation, and some may be most effective and offer the greatest benefits if applied in tandem with another strategy (e.g., elevating electrical components and floodproofing facility access points). Site specific application of an adaptation strategy or combination of strategies should be based on the desired level of flood protection, suitability of local site conditions, implementation costs, and services provided by the facility.

Strategy Theme: Keeping Water Out

CF2 Temporary facility perimeter flood walls

Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

Temporary flood perimeter walls are movable, and often modular, barriers to be used around a facility to prevent floodwaters from reaching a building during a high-water event. In contrast to the use of flood panels at key access points (CF1), this approach focuses on temporarily deploying barriers that are not physically attached to the facility to prevent water from accessing the building foundation. Flood walls can vary in height depending on the asset requiring protection, making them a practical option for facilities where permanent structural improvements (i.e., elevation) are either prohibitively expensive or logistically challenging, especially in the near term. Perimeter flood walls can also be used as a short-term strategy while other adaptation options are made to the facility itself, preventing damages and improving the City's ability to maintain essential services.

Use of flood barriers to protect building from flood damage on Pennsylvania Ave. Miami Beach. Source: Miami Beach

Flood Protection Lifespan:

Projected SLR Amount (feet) +0 +1 +2 +3 +4 +5 +6

Strategy Start:
0 feet of SLR

The City could immediately begin coordinating the placement of temporary flood barriers at prioritized facilities that have limited existing flood protections.

Strategy End:
~2 feet of SLR

At about 2 feet of sea level rise, over half (51%) of critical facilities are projected to be exposed to compound flooding events. The frequency and extent of flooding will likely render temporary barriers an impractical solution to provide flood protection to these facilities.

Strategy in Action:

Case Study: Tampa General Hospital Flood Barrier Project (Tampa, FL)

Tampa General Hospital is situated along the waterfront of a low-lying island, leaving it highly susceptible to flood events. In 2019, the hospital began to deploy AquaFence, a temporary flood barrier system, ahead of expected large coastal storms. The flood barrier system is rapidly deployable and once in place and anchored, it forms a water-tight barrier that stabilizes and strengthens with increasing water pressure. The barrier is intended to withstand water levels up to 15 feet and has successfully protected the hospital from flooding damage during multiple hurricane events that impacted the area, including Hurricanes Helene and Milton in 2024.

Aquafence flood barrier at Tampa General Hospital ahead of Hurricane Ian (Sept 2024). Source: Tampa Bay Times

Application to Miami Beach:

The City could use temporary flood barriers at critical facilities, focusing on those that provide emergency services, such as the City's fire stations, or police stations. This approach offers targeted, short-term protection that can be integrated into a broader resilience strategy and helps provide critical operations continue during major flooding events.

Strategy Considerations:

- Flood walls could be used to protect non-City owned critical facilities while floodproofing or other improvements are coordinated for the facility.
- Proper deployment and removal of temporary flood barriers requires significant manual labor, time, and staff training. This can be challenging in a time-sensitive emergency situation, such as an approaching storm or other high-water event. While there are temporary and low-cost approaches, such as sandbags, these have limited effectiveness for significant events.
- Temporary flood barriers must be stored and properly maintained when not in use. If not stored properly, it can cause the materials to degrade and reduce their effectiveness for future flood protection.
- Perimeter floodwalls are not effective against flooding due to high groundwater levels, which can flood building foundations from below, or rainfall, which can fall within the barrier interface.

Strategy Theme: Plans and Policies

CF3 Include sea level rise in FFE for critical facilities

Flood Hazard(s) Addressed:

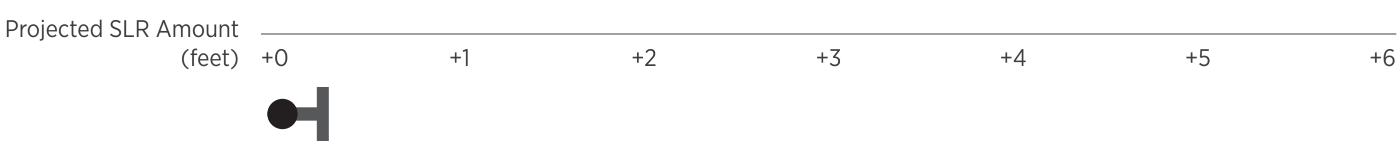
Estimated Cost Level:

Strategy Description:

The Florida Building Code requires critical facilities to be built two feet higher than Base Flood Elevation. The City's Resilience Code allows for first floor elevations of all structures to include up to five feet of freeboard above the FEMA BFE, though this allowance is voluntary. To increase flood resilience, the City could require that the FFE of new critical facilities be built above the FEMA BFE, plus the required level of freeboard, plus the projected sea level rise amount anticipated to occur over the building structure's functional lifespan (e.g., 50 years). An example for this is the plans for Fire Station No. 1, which will be built to the BFE + 5 feet.

This requirement could follow the model of the Road Elevation Strategy, where recommended minimum roadway elevations are based on the construction date to account for the sea level rise expected to over the roadway's design life. In the RES, these recommendations increase every five years to ensure new roads are built to account for projected sea level rise. Similarly, for critical facilities, a building constructed in 2020 would require a FFE of 11.9 feet (NAVD88). This accounts for the FEMA BFE of 8 feet (NAVD88), 1 foot of freeboard required by the FBC, and 2.9 feet of projected sea level rise by 2070[9] (the building's 50-year lifespan). For this strategy, FFE requirements would be adjusted every five years for new building design criteria to ensure that they are designed to maintain their intended level of flood protection throughout the duration of their design life.

Flood Protection Lifespan:



Strategy Timing: Current Sea Levels

The City can consider creating a policy to require critical facility FFEs to reflect the SLR projected over the facility's design life at current sea levels.

9 Based on the 2017 NOAA Intermediate High scenario.

Strategy in Action:

Case Study: Updated Building Standards Post-Hurricane Sandy (New York City, New York)

After Hurricane Sandy in 2012, New York City updated its building code to enhance resilience against future extreme flooding events by requiring that structures located in flood-prone areas be elevated at least 2 feet above the FEMA BFE. This additional freeboard allowance provides an additional margin of safety for structures built in these high-risk areas, including critical facilities such as the Ruth Bader Ginsberg Hospital constructed in 2022. The hospital included additional resilient building measures, such as floodproofing the emergency wing and first floor critical infrastructure.

The Ruth Bader Ginsburg Hospital constructed with FEMA funding following Hurricane Sandy, New York City. Source: The City of New York

Application to Miami Beach:

The City could require the minimum FFE for critical facilities to account for sea level rise, similar to the New York City example. However, the City could refine this effort by specifying the amount of sea level rise to incorporate into the FFE of newly constructed buildings that is adjusted to the amount of sea level rise projected over the structure's design life.

Strategy Considerations:

- The sea level rise values used to determine the FFE should be regularly reviewed and updated based on the most recent projections available at the time.
- This strategy may only be applicable for City-owned facilities, though the City could encourage other facility owners and managers to consider sea level rise in the construction of these facilities.
- Depending on the facility's function, more than one foot of freeboard above the FEMA BFE may be required. For example, hospitals currently mandate three feet of freeboard. Proposed FFEs under this strategy will need to comply with these existing federal standards, at a minimum.
- Much of the City's FEMA BFE is 8 feet (NAVD88). In areas where this is higher or lower, the required FFE should also be adjusted.
- A facility's design life may be influenced by the services it provides. FFE estimates should be adjusted higher or lower based on the expected design life.
- Updating building design criteria for critical facilities also represents an opportunity to revise standards for non-critical and residential structures for more comprehensive flood protection across the City.
- It may only be cost effective to require compliance for newly constructed buildings or buildings receiving significant upgrades.
- Revised building codes should also require the elevation of ancillary utilities (e.g., electrical systems, HVAC systems).

Strategy Theme: Living with Water

CF4 Elevate existing critical facilities

Flood Hazard(s) Addressed:

Estimated Cost Level:

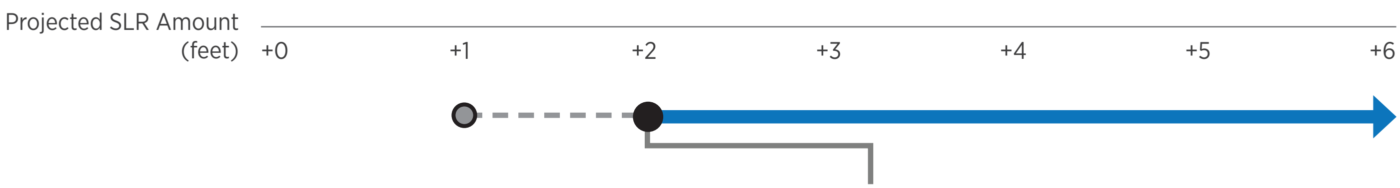
Strategy Description:

For existing critical facilities, the City may need to assess whether additional elevation is necessary before the end of a structure's design life to mitigate potential flood exposure and damage. Structures could be either elevated on earthen fill by adjusting the adjacent grade under the structure foundation or with vertical pilings that are driven into the earth to elevate the structure on vertical pilings or understory.

This approach may be most practical for structures requiring minimal elevation (e.g., less than five feet). In such cases, elevating the building slightly could be more cost effective than rebuilding or relocating the facility. A hybrid strategy could also be employed, where the second floor is elevated to the desired height, while the ground floor is redesigned as a floodable space, allowing water to flow in and out during extreme flood events.

Miami Beach Facilities building, with office space area elevated. Source: Miami Beach

Flood Protection Lifespan:



Strategy Planning: 1 foot of SLR

Planning for this strategy could begin at 1 foot of sea level rise as the implementation of this strategy will require significant planning and stakeholder engagement.

Strategy Start: 2 feet of SLR

At 2 feet of sea level rise, nearly all (97%) of existing critical facilities are projected to be impacted during a storm surge event. At this scale, the City may consider elevating critical facilities that cannot be relocated to maintain the provision of essential services.

Strategy End: 6+ feet of SLR

The City may need to continually evaluate whether to elevate certain critical facilities through the end of the century.

Strategy in Action:

Case Study: Facilities Management Building (Miami Beach)

The construction of the new Facilities Management building incorporates several enhanced flood protection design considerations. For example, the building's first floor is designed to accommodate floodwaters during extreme storm events, while the utilities and office spaces have all been elevated to the second floor, above the FEMA BFE. Additionally, the building's structural components and exterior finishes have been floodproofed with flood resistant materials. These standards could serve as guidance for any critical facility that may require elevation before reaching the end of its design life.

Strategy Considerations:

- Elevating some critical facilities (e.g. hospitals and fire stations) may not be feasible as it may complicate emergency vehicle access. If done for these facilities, roads, ramps, and parking areas would also be designed to account for higher facility elevations.
- Elevated facilities may make access more difficult for visitors, especially if stairs or long ramps are required to reach the higher entrance doors. Maintaining service access for disabled visitors will also need to be considered.
- Ancillary utilities (water, sewage, electrical) servicing the facility will also need to be elevated or protected from flooding as recommended in the FBC.
- The City's high urban density may limit the ability to use earthen fill, which requires enough surrounding land to tie the new elevation in with neighboring properties.
- Selected elevation for critical facilities will require compliance with local building codes (CF3) and FEMA floodplain management regulations.
- Elevated facilities will require additional investment for foundational and structural reinforcement that could result in higher initial construction costs.
- Historic buildings may not be able to easily adapt to meet higher building elevations. Additional strategies, such as floodproofing techniques (CF1) and temporary flood perimeter walls (CF2) may be considered for site-specific flood protection.

Strategy Theme: Strategic Relocation

CF5 **Repurpose frequently flooded critical facilities**

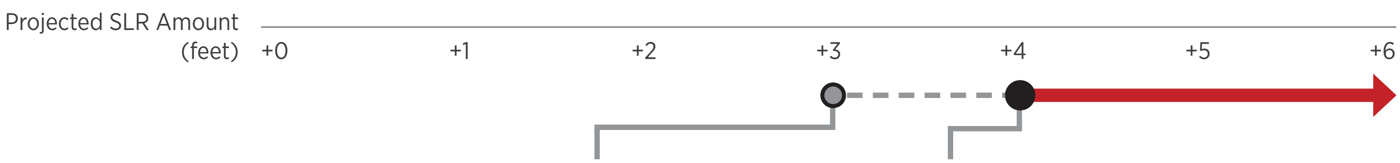
Flood Hazard(s) Addressed:

Estimated Cost Level: $$$$$

Strategy Description:

Many of the City's critical facilities are projected to face increasingly frequent flooding impacts as sea level rises if they are unable to be adequately floodproofed or elevated above these impacts. To maintain the services provided by these facilities, the City could consider relocating at-risk facilities to alternative, less flood-prone sites. The site could then be repurposed to accommodate stormwater retention or to provide other community functions, such as developing recreational spaces, to reduce flood risks while maintaining the community benefits of the space. This approach will lower capital and maintenance costs associated with protecting these facilities, avoid costly repairs following flooding impacts, and increase the amount of City-owned area dedicated to flood management and recreation.

Flood Protection Lifespan:



Strategy Planning: 3 feet of SLR

Planning and public engagement for this strategy could begin at 3 feet of sea level rise to provide enough time to implement the strategy at 4 feet of sea level rise

Strategy Start: 4 feet of SLR

At 4 feet of sea level, over 80% of existing critical facility locations are projected to experience flooding impacts during compound flooding events. At this scale, the City may consider ways to repurpose these spaces, rather than investing in protecting the facility at this location.

Strategy Start: 6+ feet of SLR

The City will likely need to continually evaluate and prioritize facility locations for repurposing through the end of the century.

Strategy in Action:

Case Study: Slidell Police Headquarters Relocation (Slidell, Louisiana)

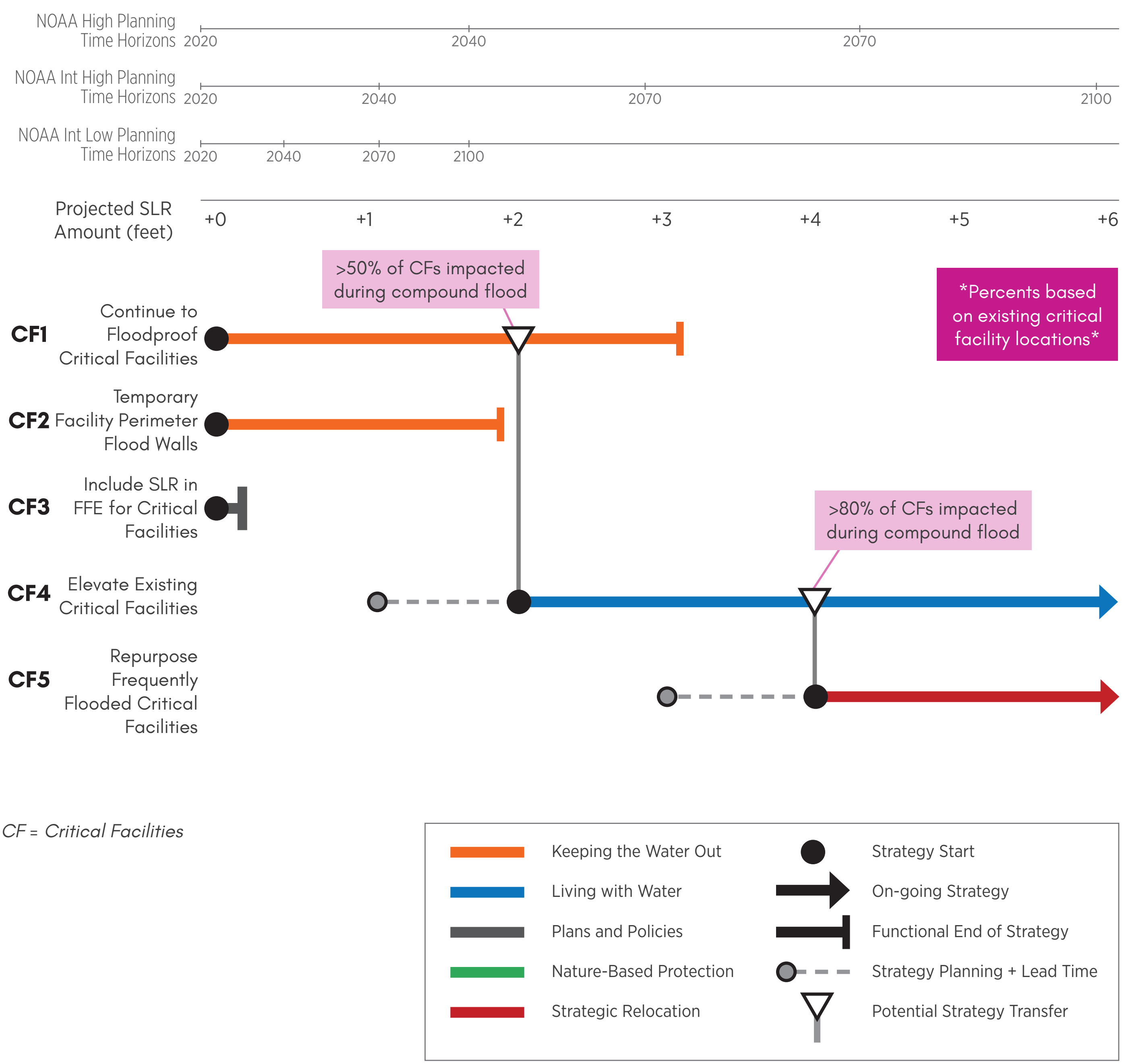
In 2024, the Slidell City Council approved the relocation of the City's police headquarters to a less flood-prone area located 2 miles away from the existing site. The existing site, vulnerable to flooding during storm events, posed challenges for police operations, including forcing the evacuation of the building during severe floods. The City evaluated the option of rebuilding and elevating the facility at its existing location but found that the $6M additional cost to raise the building was not a cost-effective solution. The City plans to fund the new facility through a temporary local sales tax to offer greater flood protection and operational efficiency.

Application to Miami Beach:

Similar to the City of Slidell, the City of Miami Beach could prioritize relocating frequently flooded critical facilities, focusing on buildings in low-lying areas where existing or future flooding may disrupt operations or pose a threat to on-site structural or asset damage. After relocating these facilities, the City can repurpose the vacated site (e.g., open or recreational space) to reduce flood risks in surrounding areas while maintaining the community benefits of the space.

Strategy Considerations:

- The decision to relocate critical facilities should be informed by a cost-benefit analysis to comparing the long-term costs of adequately floodproofing the facility at its current location with the costs of relocating it to a less-flood prone areas.
- Relocating critical facilities, such as hospitals, police stations, and fire stations, can be expensive. Costs required to acquire new land, design and construct the new facility, and move the operations could be prohibitively high and funding may be difficult to obtain.
- Identifying a suitable location with a lower flood risk within the City boundary may be challenging because most of the City is vulnerable to existing or future flood exposure through the coming decades. City areas of higher elevation that could be optimal for these relocations could include the City's golf course and areas of North Beach.
- Relocating facilities may cause a temporary disruption of vital services during the move. Logistical planning would be required to avoid potential disruptions.
- Some site-dependent services cannot be relocated due to their functional or geographical requirements (e.g. fire stations). In these cases, the City can evaluate whether the existing facility can be adapted for resilience to future flood conditions, perhaps through elevation (CF4) or floodproofing (CF1).



Existing compound flooding extent was determined by the simultaneous occurrence of a 10-year, 24-hour rainfall event (8.75 inches) and a king tide. Projected sea level rise amounts were added to this baseline to determine future compound flooding extents.

Impacts to assets were assessed by overlaying the relevant compound flooding scenario extent onto the City's critical infrastructure facilities in GIS to determine the percent of facilities projected to experience flooding impacts.

Critical Facilities Flood Protection Metrics, Adaptation Thresholds, and Monitoring Plan

Sea level rise has traditionally been a primary consideration in the City's planning efforts to reduce or avoid potential flood risks. However, there are other relevant metrics that the City could also monitor to provide an understanding of how rising sea levels may worsen flood impacts or place additional stress on the City's infrastructure and natural systems. Monitoring these metrics, along with sea level rise, can help to identify key thresholds that may serve as early warning signals that existing strategies may no longer be sufficient.

This section includes a list of proposed metrics and thresholds that the City could consider to inform the most effective strategies for long-term Critical Facilities flood protection. Additionally, a suitability matrix is provided to identify metrics that could be used to inform each strategy included in the Critical Facilities Flood Protection Pathway Summary.

Metrics

Metrics are measurable indicators that are used to track the effectiveness of adaptation actions over time. They are useful in helping make decisions on when to transition between different adaptation strategies based on changing sea level conditions and the observed effects.

Adaptation Thresholds

Thresholds are a pre-defined change in the existing physical conditions or social tolerances for flooding impacts and serve as early warning to signal that existing strategies are losing their effectiveness and could benefit from supplemental or alternative adaptation strategies.

Monitoring Plan

Monitoring allows the City to track the defined metrics over time for evidence of specified adaptation thresholds being met to avoid large potential impacts to the City's assets and facilities. While the City has existing plans and methodologies to track some of the proposed metrics, others will require the development and implementation of new monitoring programs.

Metric: Critical Facilities Exposed to Compound Flooding (Rainfall during a King Tide)

Adaptation Threshold: Percentage of Facilities Exposed to Compound Flooding

Critical facilities affected by flooding impacts could sustain interior or exterior damage that could cause the facility to close for repairs, leading to temporary service disruptions. If many of the City's critical facilities are affected simultaneously, the City's capacity to maintain necessary daily operations could be compromised.

Monitoring Plan:

The City could establish a compound flood monitoring system, consisting of a network of rain gages and the NOAA Virginia Key tide station, to continuously monitor flood water levels in real time. Deploying a Citywide network of rain gages would be challenging; however, the City could place gages in key locations nearby critical facilities to monitor flood water levels at these important assets. Water level information can be compared with the elevations of facility first floors and critical components to document those are exceeded by compound flood levels. This information could also be used to inform post-flood inspections of buildings to document potential damages and can serve as a guide for the City to understand the timing of when a large number of critical facilities could need to transition to a supplemental or replacement adaptation strategy for flood protection.

Metric: Past Flooding Experienced

Adaptation Threshold: Record of Impacts from Past Flood Events

Critical facilities affected by flooding impacts could sustain interior or exterior damage that could cause the facility to fail to deliver essential services, leading to temporary service disruptions. Documented occurrences of previous flood impacts at critical facility locations can serve as an indicator for future potential damage. Critical facility buildings with a known history of flood exposure or damage could be a candidate for adaptation strategies to enhance flood protection.

Monitoring Plan:

The City could leverage current facility tracking systems to create a database that documents/tracks flood occurrences at the building-specific scale, particularly for critical facilities. Initial historical flood documentation could be gathered from City Department knowledge of previous flood impacts to their buildings, collection of flood impact reports for insurance claims, or a comparison of building elevations with historical tide and rain station datasets that can serve as a proxy for potential flood exposure.

		Potential Metrics	
		Critical Facilities Exposed to Compound Flooding	Past Flood Experience
Flood Protection Strategy	Continue to Floodproof Critical Facilities	✓	✓
	Temporary Facility Perimeter Flood Walls		✓
	Include SLR in FFE for Critical Facilities	✓	✓
	Elevate Existing Critical Facilities	✓	✓
	Repurpose Frequently Flooded Critical Facilities	✓	✓

Critical Infrastructure Flood Protection Pathway Summary

The strategies in this section are intended to provide options to safeguard wastewater, water, and electrical distribution infrastructure from potential flood damage to maintain essential services for City residents.

The Need to Adapt

The City's ability to perform and deliver essential services to residents and businesses, including as drinking water, wastewater management, and reliable power, depends on a complex network of Citywide distribution infrastructure, such as pipelines and transmission lines. Maintaining these services requires well-functioning and modernized infrastructure that is designed for environmental conditions and hazards that could occur throughout the infrastructure's functional lifespan. Nearly half (48%) of the city's water mains were installed before 1980, and 98% of the wastewater pipelines have an unknown age. As a result, the City's key infrastructure may be especially at risk of failure due to age, wear, or being under designed for future flooding caused by rising sea levels.

The City currently upgrades and replaces aging critical infrastructure through Neighborhood Improvement Projects (NIPs) to streamline upgrades and minimize construction disruptions. These projects often include various critical infrastructure improvements, including repairing, modernizing and upsizing water and sewer infrastructure. The City has also developed two Master Plans, one for the water system and one for the sewer system, that evaluate the condition of these distributions systems and recommended phased improvements to ensure resilience of the infrastructure through 2045.

However, the substantial planning and design leads times necessary for the implementation of these projects suggest that rising sea levels may complicate implementation efforts or reduce the expected flood protection benefits of the project. For example, with one foot of sea level rise, over 65% of the City's existing critical infrastructure (i.e., pipelines, pump stations, and substations) locations are projected to face more frequent flooding from king tides, rising groundwater and compound flood events[10]. Anticipating these logistical challenges, the City may need to evaluate whether to implement additional strategies to adapt or relocate the City's critical infrastructure to withstand projected flooding impacts and maintain the provision of essential services.

City drinking water storage tank, Source: AECOM

Electrical substation, Source: Google Maps Street View

10 Analysis was completed by overlaying 2040 NOAA Intermediate High compound flooding layer created in the Vulnerability Assessment with existing critical infrastructure locations in GIS.

The strategies below provide a set of options for the City to consider for ongoing flood protection for the City's critical infrastructure (e.g., water, wastewater, and electrical assets) through the end of the century. The strategies provide a suite of approaches that include continuing flood protection infrastructure upgrades to keep the water out, but also include adopting policy updates, and the strategic relocation of key assets to reduce increasing flood risks to these assets.

Each strategy includes a summary documenting implementation considerations, a rough order of magnitude cost, metrics and adaptation thresholds that could indicate an appropriate time for the strategy to begin, and a case study example, where applicable, of where the strategy has been applied within the City or in other municipalities with similar needs. The strategies are also presented in an adaptation pathways diagram at the end of this section to understand adaptation thresholds and the potential timing of strategy implementation.

Strategy Number	Strategy Name	Flood Hazards Addressed
CI1	**Implement current NIPs** Carry out neighborhood improvement projects, such as replacing aging infrastructure and pipelines, which were prioritized at the neighborhood scale.	
CI2	**Update NPP for future sea level rise** The NPP will likely need to be revised over time to reflect evolving environmental conditions due to sea level rise and the shifting implementation landscape.	
CI3	**Implement future NIPs** An updated NPP would facilitate the implementation of NIPs that consider the potential project impacts from future sea level rise through the end of the century.	
CI4	**Floodproof Critical Infrastructure** Apply dry (e.g., waterproof coverings, sealants) and wet floodproofing (e.g., flood resistant materials, adding sump pumps) techniques to critical infrastructure in flood prone areas of the City to reduce or prevent flood damage.	
CI5	**Elevate Critical Infrastructure** Elevate critical infrastructure components to be above projected flood levels to reduce the risk of flood damage.	
CI6	**Relocate Frequently Flooded Critical Infrastructure** Assess the feasibility of relocating key infrastructure from flood-prone areas to enhance resilience, particularly when existing floodproofing and elevation strategies are not feasible or effective.	

Strategy Theme:
Keeping Water Out, **Plans and Policies**, **Strategic Relocation**

Current Strategy

Strategy Theme: Keeping Water Out

CI1 Implement current NIPs

Flood Hazard(s) Addressed:

Estimated Cost Level: $$$

Strategy Description:

Neighborhood Improvement Projects are the primary tool for upgrading the City's critical infrastructure, such as water, wastewater, and electrical systems. Ongoing planning efforts, like the Water and Sewer Master Plans, recommend significant upgrades and replacements to these networks, which are included in several NIPs. For example, the top five prioritized NIPs include projects like wastewater pipeline and water main replacements, pump station rehabilitations, and expanding water and wastewater system capacity. These upgrades are supported by additional improvements, such as road elevations and stormwater system enhancements.

The City has already implemented four NIPs that include these critical upgrades. Moving forward, the City should continue to focus on retrofitting or replacing older infrastructure, particularly water and wastewater pipelines, through these NIPs.

Flood Protection Lifespan:

Projected SLR Amount (feet) +0 +1 +2 +3 +4 +5 +6

Strategy Start: 0 feet of SLR

The City is currently making critical infrastructure upgrades through the NIPs. The City can continue to pursue funding to for these projects to prioritize replacing aged infrastructure.

Strategy End: ~2 feet of SLR

At 2 feet of sea level rise, over 70% of current critical infrastructure locations are projected to be impacted by compound flood events. Prior to this scale of impacts, the City may need to consider other adaptation strategy options to protect critical infrastructure assets from flood impacts.

Strategy in Action:

Case Study: Miami Beach's West Avenue Neighborhood Improvement Project (Miami Beach)

West Avenue Pump Station under construction. Source: Miami Beach

The West Avenue Neighborhood Improvement Project focuses on reducing flood risk while also improving walkability of the neighborhood community. In addition to increasing the area's stormwater capacity and elevating sections of roadway, the NIP includes the replacement of aging underground water and sewer lines to minimize the chances of future breaks and disruptions in service. Water infrastructure upgrades also include the replacement of the existing water main distribution and transmission system, the installation of new service connections, water meters, fire hydrants, and irrigation lines. Wastewater upgrades include rehabilitation of the exiting sewer collection system to improve system performance.

Limitations:

Cost

The comprehensive improvements outlined in the NIPs mean significant capital is required to implement these projects. Projects are likely to require the raising of sidewalks and building access points in addition to the elevation of utilities. This harmonization is necessary to maintain essential services but can substantially increase overall project costs.

Long Lead Times

Under traditional funding, planning, and construction timelines, completing all recommended NIPs would take decades, potentially leaving lower-priority critical infrastructure at increased risk of periodic flooding. Community feedback substantially impacts the long project planning and implementation timeline.

Changing Site Suitability

The NIPs require extensive planning and design, leading to long lead times prior to implementation. During this time, environmental changes, including sea level rise and changing rainfall intensities, may increase the likelihood of flood damages at the project site or alter the requirements of proposed improvements, reducing the effectiveness of the proposed infrastructure upgrades.

Service Disruptions

NIPs often require temporary loss of service while repairs and improvements are made. As sea levels rise, the increased frequency and scale of these project could lead to more widespread and prolonged disruptions across the City.

Rising Groundwater

Rising sea levels will also elevate groundwater levels to the surface, which could infiltrate and degrade buried water and wastewater pipelines, decreasing the functional lifespan of installed infrastructure.

Adaptation Strategy Options

As sea levels rise and rainfall events become more intense, an increasing number of critical infrastructure assets will be exposed to flood events, making them more prone to potential damage or failure and risking of the loss of essential service to residents. This section outlines strategies the City could consider to be conducted in coordination with the implementation of the NIPs to avoid disruptions.

The strategies in this section are not always intended to be applied in isolation, and some may be most effective and offer the greatest benefits if applied in tandem with another strategy (e.g., elevating one component of an asset while floodproofing another). Site specific application of an adaptation strategy or combination of strategies should be based on the expected level of flood protection, suitability of local site conditions, implementation costs, and the services provided by the infrastructure.

Before (left) and after (right) road Indian Creek roadway improvements. Source: City of Miami Beach.

Strategy Theme: Plans and Policies

CI2 Update NPP for future sea level rise

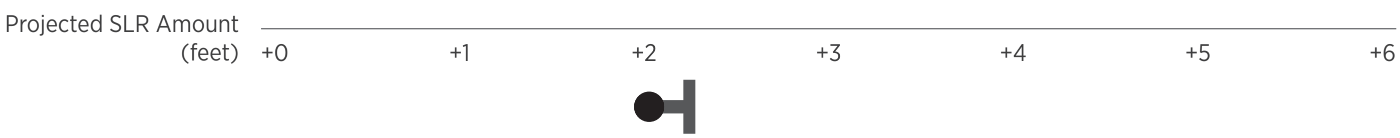
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

To ensure ongoing flood protection for critical infrastructure across the City, the NPP should be updated to reflect evolving climate conditions. This update should incorporate recent planning efforts, such as the SWMMP and the Sea Level Rise Vulnerability Assessment and Adaptation Plan, to create a new set of NIPs. Integrating these plans will help ensure the updated NIPs address increased flood risks from sea level rise and more intense rainfall events. Additionally, the updated NPP can assess completed NIPs to document key project benefits and best management practices.

Flood Protection Lifespan:



Strategy Timing: 2 feet of SLR

With 2 feet of sea level rise, more than half (70%) of existing critical infrastructure assets are projected to be impacted during compound flood events. At this scale, the City can review the proposed flood mitigation benefits of current NIPs to determine if an update to the NPP is required.

Strategy Considerations:

- The City can review the NPP on a regular basis to determine if the current NIPs adequately address projected flood risks or if an update is required.
- The City's Vulnerability Assessment provides a resource for identifying locations and the timing of potential flood impacts to City assets that can inform the NPP update.
- The updated NPP should include a process to evaluate the flood risk of assets located within the project areas as well as opportunities for reducing flood impacts through supplemental adaptation strategies.
- Updating the NPP will require significant engagement with elected officials and public stakeholders

Strategy Theme: Keeping Water Out

CI3 Implement future NIPs

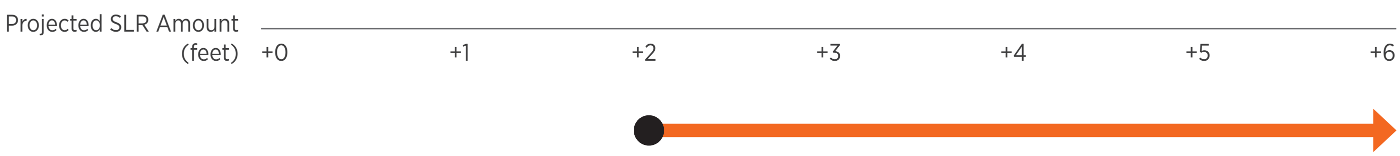
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

An updated NPP can facilitate the implementation of reprioritized NIPs that consider the potential project impacts from future sea level rise through the end of the century. Based on the updated prioritization, the City can pursue funding to design and implement identified projects.

Flood Protection Lifespan:



Strategy Start:
2 feet of SLR

The City can begin pursuing funding for reprioritized NIPs following the NPP update.

Strategy End:
6+ feet of SLR

The updated NPP should identify and prioritize NIPs that will provide long-term flood protection through the end of the century.

Strategy Considerations:

- The design and implementation of projects will require significant public engagement and coordination with City Departments.
- It may not be feasible from an engineering or economic perspective to adapt all project components to the level of flood protection required at the end of the project's design life. Where possible, project components should be designed with the capacity to adapt incrementally to keep pace with changing flood conditions over time.

Strategy Theme: Keeping Water Out

CI4 Floodproof critical infrastructure

Flood Hazard(s) Addressed:

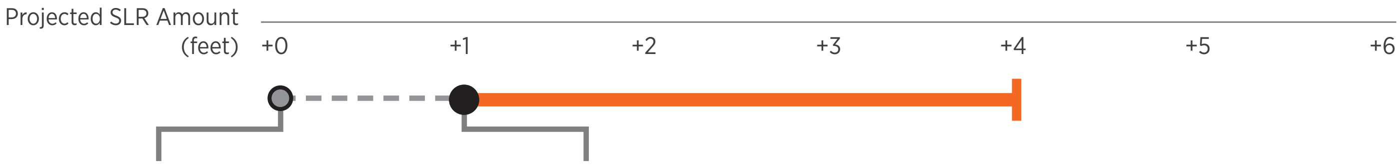
Estimated Cost Level:

Strategy Description:

Critical infrastructure in flood-prone areas can be protected using wet or dry floodproofing techniques. Wet floodproofing allows floodwaters to enter non-critical areas while protecting key components. Examples include anchoring water storage tanks, lining aging wastewater pipelines, using flood-resistant materials for electrical components, and installing sump pumps in low-lying areas.

Dry floodproofing, used for highly sensitive assets, seals infrastructure to prevent water intrusion. Examples include applying waterproof coverings, installing backflow prevention valves, and encasing critical components. Both approaches help limit damage and maintain operations. The choice of method depends on the infrastructure's sensitivity and operational needs.

Flood Protection Lifespan:



**Strategy Planning:
0 feet of SLR**

Planning for this strategy could begin immediately by identifying critical infrastructure that should be floodproofed prior to 1 foot of sea level.

**Strategy Start:
1 foot of SLR**

At 1 foot of sea level, 65% of current critical infrastructure locations are projected to have flooding impacts during compound flooding events and certain assets may require floodproofing for protection.

**Strategy End:
4 feet of SLR**

With 4 feet of sea level rise, floodproofing techniques may be ineffective without additional strategies incorporated.

Strategy in Action:

Case Study: Miami Beach Venetian Causeway Water and Sewer Main Upgrades (Miami Beach)

The Venetian Causeway Water and Sewer Main Upgrades project is a County initiative that aims to enhance the City's flood resilience by upgrading and dry floodproofing essential water and sewer infrastructure. This project involves replacing old water main lines along the Venetian Causeway with new, flood-resistant materials and using Horizontal Directional Drilling to protect pipes from flood exposure. By installing these utilities deeper underground and improving durability, Miami Beach strengthens its water and wastewater systems against rising sea levels and storm surge. This initiative is part of the City's broader strategy to safeguard critical infrastructure in flood-prone areas.

A view of the west entrance to the Venetian Causeway. Source: Pedro Portal, Miami Herold

Strategy Considerations:

- For redundant flood protection, some projects could incorporate both wet and dry floodproofing techniques for the same asset. For example, protection of wastewater pump stations may include using flood resistant materials for electrical control panels and waterproof sealant applied to pump station exterior walls.
- This strategy can be combined with elevation efforts (Strategy CI5) to enhance flood protection.
- Floodproofing may provide an adequate level of protection for certain assets beyond 4 feet of sea level rise. However, the financial and logistical challenges of achieving comprehensive flood protection Citywide only through floodproofing techniques may necessitate consideration of other strategies.

Strategy Theme: Keeping Water Out

CI5 Elevate critical infrastructure

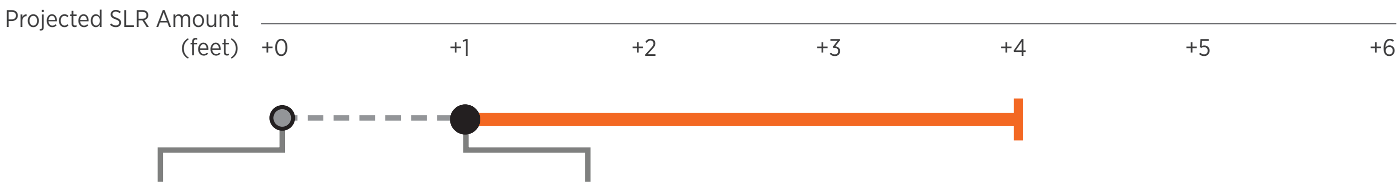
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

For this strategy, critical infrastructure remains in the current location but is elevated above projected floodwater levels. Elevation can include constructing platforms for assets or relocating assets to higher floors within a building. In some cases, only certain components may need to be elevated (e.g., electrical features, potable water line air valves). The City's building codes specifies that critical infrastructure should be elevated to at least FEMA's BFE plus 1 foot of freeboard. The City could consider elevating key infrastructure components above this minimum to provide a higher level of flood protection.

Flood Protection Lifespan:



Strategy Planning:
0 feet of SLR

Planning for this strategy could begin immediately by identifying critical infrastructure that should be elevated prior to 1 foot of sea level.

Strategy Start:
1 foot of SLR

At 1 foot of sea level, 65% of current critical infrastructure locations are projected to have flooding impacts during compound flooding events and may require elevation above expected floodwaters.

Strategy End:
4 feet of SLR

At 4 feet of sea level rise, certain critical infrastructure may need to be elevated to a height that makes access and maintenance difficult.

Strategy in Action:

Case Study: 18th Street and Sunset Harbour Drive (Miami Beach)

The stormwater pump station at 18th Street and Sunset Harbour Drive features underground components, with elevated electrical panels to prevent power loss during storms and permanent generators installed at select stations for backup during grid outages. Most components of a stormwater pump station are located underground, but the elevation of the electrical panels, is essential to protect against potential water damage from flooding. This proactive approach helps pumps to remain operational during flood events and safeguards essential services in the Sunset Harbour Neighborhood.

Elevated generator for Facilities building, Miami Beach.
Source: Miami Beach

Elevated stormwater pump station and electrical panels.
Source: Miami Beach

Strategy Considerations:

- This strategy is not applicable for buried critical infrastructure, such as pipelines.
- The level of designed flood protection (e.g., annual king tides vs. 1-percent annual chance coastal storm event) for infrastructure types may vary based on the criticality and sensitivity of each project.
- The design elevation of infrastructure may be limited by maintenance access capabilities.
- This strategy can be combined with floodproofing efforts (Strategy CI4) to enhance flood protection.
- The City could choose to elevate assets as they reach the end of their functional lifespan. Certain asset types, such as stormwater pumps, undergo routine inspections and have defined lifespans documented in the City's Asset Management Plan. Using this information, along with projected flooding depths, the City can prioritize which assets to elevate during replacement.
- Elevation will likely need to continue for certain assets beyond 4 feet of sea level rise. However, the financial and logistical challenges of achieving comprehensive flood protection Citywide only through elevation, may necessitate consideration of other strategies.

Strategy Theme: Strategic Relocation

CI6 Relocate frequently flooded critical infrastructure

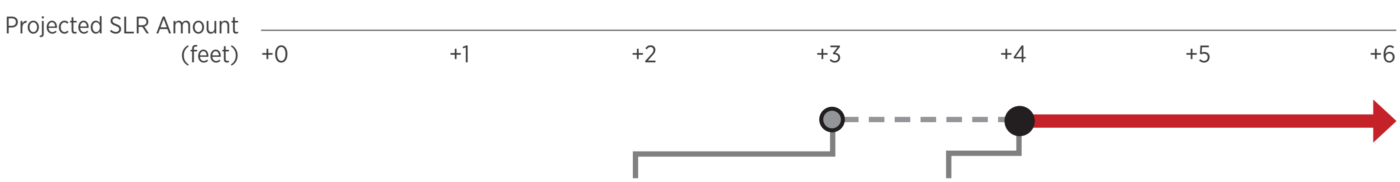
Flood Hazard(s) Addressed:

Estimated Cost Level: $$$$$

Strategy Description:

Rising sea levels and more frequent intense rainfall events may may impact the suitability of certain City areas for critical infrastructure. For example, rising sea levels could increase the frequency backflow events, disrupting pump station operations, while elevated groundwater levels may challenge the frequency of maintenance of underground pipelines. Such events may force the City to consider relocating critical infrastructure to other areas of the City to maintain the service of the network. Rather than replacing or adapting infrastructure located in sites that are projected to be frequently flooded, the City could assess whether relocation offers better cost-efficiency and resilience over time.

Flood Protection Lifespan:



Strategy Planning: 3 feet of SLR

Planning for the relocation of critical asset will require planning and coordination to ensure essential services are maintained.

Strategy Start: 4 feet of SLR

At 4 feet of sea level, >90% of current critical infrastructure assets are projected to be exposed to flooding. If floodproofing or elevation are no longer feasible, the City could consider relocating these assets.

Strategy End: 6+ feet of SLR

As sea level rises, the City will likely need to consistently evaluate whether to relocate critical infrastructure components through the end of the century.

Strategy in Action:

Case Study: Iowa City Closes Vulnerable Wastewater Facility (Iowa City, Iowa)

Relocating critical infrastructure represents a viable strategy for reducing long-term flood risk when alternative options are no longer feasible from an economic or engineering perspective. Iowa City took this approach in 2023 by closing its flood-prone North Wastewater Treatment Plant and consolidated services at a modernized second plant located outside of the floodplain. The aging North Wastewater Treatment Plant had history of sanitary sewage overflow events following heavy rainfall and was unable to continue meeting environmental regulatory requirements. The decommissioned site is being repurposed into a public recreational greenspace.

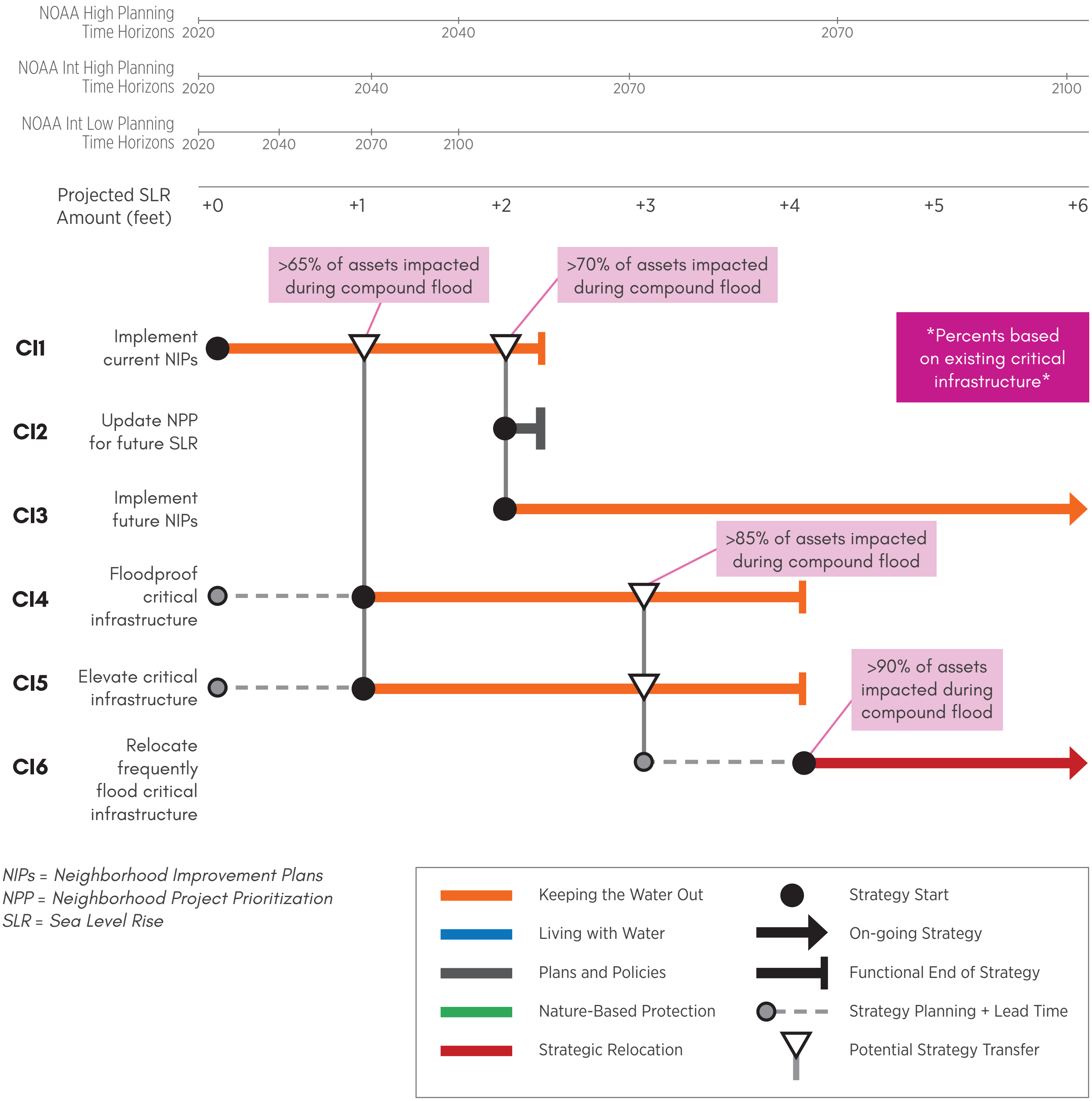
Flooded North Wastewater Treatment Plant.
Source: Iowa Homeland Security and Emergency Management

Application to Miami Beach:

Miami Beach could adopt a similar approach by relocating critical infrastructure, such as highly vulnerable pump stations or utility assets identified in the Vulnerability Assessment, to areas of the City with higher elevations. The City could also consolidate utility services to rely on a smaller number of assets capable of servicing a larger population. This strategy could also help the City with achieving operational efficiencies, lowering energy consumption, and reduce maintenance costs by reducing the number of individual assets located across the City.

Strategy Considerations:

- The decision to relocate critical infrastructure should be informed by a cost-benefit analysis to comparing the long-term costs of adequately floodproofing the infrastructure at its current location with the costs of relocating it to a less-flood prone areas.
- Relocating critical infrastructure assets should not be considered when removal of the asset would result in a significant loss of service to existing residents or businesses.
- Consolidation of services from decommissioned critical infrastructure will likely require increased investment and upgrades of redundant infrastructure to maintain a continued level of utility services for residents.
- This strategy will likely require the purchase of easements or property acquisition by the City to maintain suitable sites for infrastructure relocation.
- The relocation of assets will require significant public engagement and coordination with other City departments, particularly for projects that would result in service disruptions.



NIPs = Neighborhood Improvement Plans
NPP = Neighborhood Project Prioritization
SLR = Sea Level Rise

Existing compound flooding extent was determined by the simultaneous occurrence of a 10-year, 24-hour rainfall event (8.75 inches) and a king tide. Projected sea level rise amounts were added to this baseline to determine future compound flooding extents.

Impacts to assets were assessed by overlaying the relevant compound flooding scenario extent onto the City's critical infrastructure assets in GIS to determine the percent of infrastructure projected to experience flooding impacts.

Critical Infrastructure Flood Protection Metrics, Adaptation Thresholds, and Monitoring Plan

Sea level rise has traditionally been a primary consideration in the City's planning efforts to reduce or avoid potential flood risks. However, there are other relevant metrics that the City could also monitor to provide an understanding of how rising sea levels may worsen flood impacts or place additional stress on the City's infrastructure and natural systems. Monitoring these metrics, along with sea level rise, can help to identify key thresholds that may serve as early warning signals that existing strategies may no longer be sufficient.

This section includes a list of proposed metrics and thresholds that the City could consider to inform the most effective strategies for long-term Critical Infrastructure flood protection. Additionally, a suitability matrix is provided to identify metrics that could be used to inform each strategy included in the Critical Infrastructure Flood Protection Pathway Summary.

Metrics

Metrics are measurable indicators that are used to track the effectiveness of adaptation actions over time. They are useful in helping make decisions on when to transition between different adaptation strategies based on changing sea level conditions and the observed effects.

Adaptation Thresholds

Thresholds are a pre-defined change in the existing physical conditions or social tolerances for flooding impacts and serve as early warning to signal that existing strategies are losing their effectiveness and could benefit from supplemental or alternative adaptation strategies.

Monitoring Plan

Monitoring allows the City to track the defined metrics over time for evidence of specified adaptation thresholds being met to avoid large potential impacts to the City's assets and facilities. While the City has existing plans and methodologies to track some of the proposed metrics, others will require the development and implementation of new monitoring programs.

Metric: Critical Infrastructure Maintenance and Costs

Adaptation Threshold: Annual Maintenance and Repair Costs.

As sea levels rise, compound flood events become more likely as high coastal waters prevent the efficient discharge of stormwater runoff. This can place additional strain on water and wastewater infrastructure, potentially leading to asset failure or increased maintenance costs and more frequent maintenance schedules to maintain proper operation. If these costs exceed a certain annual threshold, the City may need to consider adapting or relocating critical water and wastewater infrastructure.

Monitoring Plan:

The City currently tracks public works projects, including maintenance work orders, through Cityworks. The City can continue to track infrastructure maintenance project costs to capture cost and frequency. The City's Water and Sewer Renewal & Replacement Plan outlines expected future costs to replace key water and sewer infrastructure components at the end of asset's useful life. If maintenance costs exceed the adaptation threshold, this may require a different or supplemental strategy to provide the desired flood protection for the site.

Metric: Critical Infrastructure Condition

Adaptation Threshold: Critical Infrastructure Age

As infrastructure ages, its integrity declines due to wear, stress, and environmental exposure. Additionally, older infrastructure was built with materials and designs suited for past environmental conditions, making it less resilient to evolving climate challenges. Infrastructure over a certain age is more likely to have deteriorated and may not meet the demands of future climate conditions, requiring the infrastructure to be adapted or relocated.

Monitoring Plan:

The City currently tracks public works projects, including the installation of critical infrastructure through Cityworks. The City can continue to monitor this information and include infrastructure age in the criteria for future project prioritization. The City's Water and Sewer Renewal & Replacement Plan outlines expected future dates to replace key water and sewer infrastructure components at the end of asset's useful life. If critical infrastructure components this threshold, it may require a different or supplemental strategy to provide the desired flood protection for the site.

Metric: Utility Service Outages

Adaptation Threshold: Outage Frequency

Impacts from compound flood events can damage critical infrastructure components and create outages or delays of service. The increased frequency or longer duration of utility service outages may indicate infrastructure issues, particularly if outages coincide with flood conditions. A rising rate of component or system failures (e.g., burst pipes, transformer malfunctions) may indicate a need for increased investment in system upgrades, replacements, or adaptation of the asset.

Monitoring Plan:

The City could track the number of outages, the average duration, and the concurrent metocean conditions by adding these metrics to the maintenance reports gathered through Cityworks. This information can be used to assess potential connections with evolving climate conditions and reductions in the level of service.

		Potential Metrics		
		Critical Infrastructure Maintenance and Costs	Critical Infrastructure Condition	Utility Service Outages
Flood Protection Strategy	Implement current Neighborhood Improvement Projects (NIP)		✓	
	Update Neighborhood Project Prioritization (NPP) for future sea level rise	✓	✓	✓
	Implement future NIPs		✓	✓
	Floodproof Critical Infrastructure	✓		✓
	Elevate Critical Infrastructure	✓		✓
	Relocate Frequently Flooded Critical Infrastructure	✓		✓

Oceanside Flood Protection Pathway Summary

This set of strategies provide opportunities for the City to support efforts that reduce beachfront erosion, mitigate wave impacts, and strengthen the dune system to protect coastal infrastructure and preserve recreational uses.

The Need to Adapt

The City's seven miles of Atlantic shoreline are an important segment of the broader Southeast Florida coastal system, supporting multiple recreational opportunities and serving as an important local and regional economic driver. The beachfront and coastal dunes also serve as a natural protection system for billions of dollars in adjacent real estate. However, over time, this natural buffer is vulnerable to erosion caused by wave action, storm surge events, and sediment transport. To maintain beach widths that can support recreational activities and provide adequate wave and flood protection, sand has been routinely trucked in or pumped from offshore sources.

The beach and dune system are owned by the State of Florida and conducting beach renourishment projects requires significant multi-jurisdictional cooperation among several federal, state, county and City entities. The U.S. Army Corps of Engineers (USACE) leads the beach renourishment projects for the City and coordinates closely with Miami-Dade County (County) as the local sponsor. Utilizing annual County beach width measurements submitted to the State, the USACE estimates beach erosion rates to determine if a renourishment project is necessary. Although the USACE and County are the State facilitators for beach renourishment projects, the City assists with traffic management during the renourishment events and works with local stakeholders (e.g., vendors) to advise them of timeline expectations for when it will be safe to move concessions back to the beach area.

As sea levels rise, coastal erosion is projected to accelerate as elevated ocean water levels allow waves to reach higher beach elevations. In 2022, Congress authorized a 50-year extension of the Miami Dade County Coastal Storm Risk Management (CSRM) authority that will support USACE routine renourishment projects for the City's beach areas[11]. However, the current costs and planning time required for beach nourishment projects could make it difficult for these projects keep pace with accelerated erosion rates due to sea level rise and intensifying coastal storms. The City is also part of USACE's Miami-Dade Back Bay Study, aimed at reducing coastal storm risk through the implementation of management measures, such as storm surge barriers, floodwalls, elevated buildings, floodproofing, and nature-based infrastructure to protect vulnerable coastal areas. The study is currently projected for completion by August 2027.

Beach renourishment activities. Source: Matais J. Ocner | Miami Herald

Miami Beach Dune System. Source: Adobe Stock

11 https://www.saj.usace.army.mil/About/Congressional-Fact-Sheets-2024/Dade-County-CSRM-FL/

The strategies below provide a set of options for the City to consider for ongoing oceanside protection through the end of the century. Since the beach and dune system are owned by the State, most of the proposed strategies will involve strong advocacy and robust collaboration with Federal (e.g., USACE) and County partners. The strategies provide a suite of approaches that include enhancing the dune system with hybrid gray/green infrastructure, redesigning public access to the beach and the strategic reimagining of the City's coastal areas to preserve its economic and recreational benefits despite rising sea levels.

Each strategy includes a summary documenting implementation considerations, a rough order of magnitude cost, metrics and thresholds that could indicate an appropriate time for the strategy to begin, and a case study example, where applicable, of where the strategy has been applied within the City or in other municipalities with similar needs. The strategies are also presented in an adaptation pathways diagram at the end of this section to understand adaptation thresholds and the potential timing of strategy implementation.

Strategy Number	Strategy Name	Flood Hazards Addressed
OS1	**Continue Routine Beach Renourishment** Maintain beach width based on the updated CRSM renourishment schedule to replenish eroded sand.	
OS2	**Dune Enhancement** Increase the height and width of dune features and fortify with natural elements to provide an increased natural buffer for inland infrastructure and assets.	
OS3	**Redesign Public Access** Alter the traditional access path angle or install walkover structures that span over the City's dune system, allowing for public beach access while minimizing potential flood pathways and negative dune impacts.	
OS4	**Hybrid Dune Systems** Reinforce dunes with armoring materials behind or under the dune features as a final line of defense to prevent shoreline retreat impacts to inland infrastructure and assets.	
OS5	**Reimagine Coastal Areas** Reimagine how the coastal beachfront is utilized, including scaling back or eliminating development in favor of expanded recreational opportunities and enhanced natural spaces.	
OS6	**Expand Offshore Wave Attenuation** Create a network of offshore structures, such as artificial reefs or breakwaters, to absorb wave energy and reduce erosion impacts on the shoreline.	

Strategy Theme:
Keeping Water Out, **Nature-Based Flood Protection**, **Strategic Relocation**

Current Strategy

Strategy Theme: Keeping Water Out

OS1 Continue routine beach renourishment

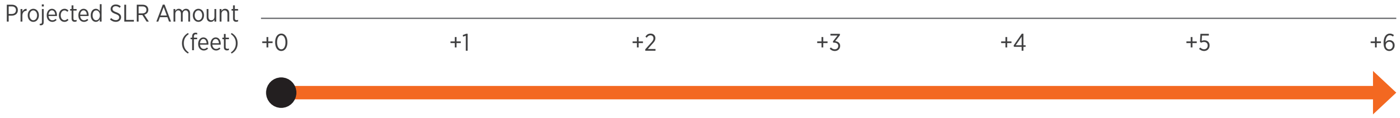
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

The City's beachfront is subject to annual erosion from natural wave processes and periodic severe storm events that reduce beach width. Since 1980, the USACE and the County have completed 38 renourishment projects on City beaches, the second highest number of renourishment activities in the state . The 50-year extension of the Miami-Dade County CSRM authority will provide USACE-led support for regular beach renourishment along 6.1 miles of Southeast Florida coastline, along 7 miles of the City's beaches[12]. Renourishment projects are anticipated to occur every 3 to 4 years based on modeled conditions. For this strategy, the City will continue to coordinate with the USACE and County to routinely renourish the City's beachfront to preserve a beach width that can support traditional beachfront uses and flood protection for landward properties and infrastructure.

Flood Protection Lifespan:



Strategy Start:
0 feet of SLR

The City is regularly renourishing its beaches in coordination with the County and USACE.

Strategy End:
6+ feet of SLR

The City will likely need to coordinate with USACE to perform routine beach renourishment projects through the end of the century to maintain the desired beach width and provided adequate protection from strong coastal wave events.

12 Statistics used from the National Beach Renourishment Database (https://gim2.aptim.com/ASBPANationwideRenourishment)

Strategy in Action:

Case Study: 2022-2023 Miami Beach Renourishment Project (Miami Beach)

The City's most recent beach renourishment project was completed in the summer of 2023. Through the Dade County Beach Erosion and Hurricane Protection Project, the USACE placed roughly 835,000 cubic yards of sand along 2 miles of shoreline near Allison Park, Indian Beach Park, Mid-Beach Park, and along 27th Street. The estimated cost of the project was over $40,000,000[13].

Miami Beach Renourishment Project.
Source: U.S. Army Corps of Engineers.

13 Statistics used from the National Beach Renourishment Database (https://gim2.aptim.com/ASBPANationwideRenourishment)

Limitations:

Required Coordination

Each renourishment project requires extensive planning and coordination with Federal, State, and County partners. The City is subject to the approval processes of these agencies, which can result in extended permit timelines or unexpected changes to the schedule, costs, and scope. The City's limited control over the renourishment efforts may lead to delays in sand replacement, leaving it vulnerable to strong wave events during the interim.

Project Schedule

Under the new Miami-Dade County CSRM authority, renourishment projects are expected to occur every 3 to 4 years based on recent erosion models. However, as sea level rise accelerates, erosion rates are also likely to increase. Without regular updates to localized erosion models and associated adjustments to the renourishment schedule, project frequency could lag behind erosion rates, resulting in a diminished beach profile. Additionally, while the 50-year extension to the CSRM aims to provide routine projects through 2075, such efforts will likely be required through the end of the century. The CSRM or a similar framework will need to be updated prior to 2075 to address evolving erosion conditions.

Cost

Beach renourishment projects require significant capital investment. Over the 50 years of the Miami-Dade County CSRM authority, the total cost required for anticipated projects is over $368 million, with the County required to cover more than half (55.7%) of the cost. Although the City does not directly fund beach renourishments, each project incurs costs to the City through staff time needed to support actions such as beach closures, traffic management, and providing access for project vehicles and machinery. Sea level rise could increase the need for more frequent beach renourishment projects, thereby elevating the associated annual costs.

Increased Competition

As sea level rise accelerates beach erosion across the Southeast Florida region, there may be increased competition among adjacent coastal communities to obtain Federal funding and coordination for renourishment activities.

Sand Resource Availability

Renourishing the City's beaches requires significant amounts of sand. Historically, sand was trucked in from inland quarries, however due to depleting land-based sources, the updated CRSM identified offshore borrow sites necessary for future projects. If the frequency of beach renourishment projects is increased, these offshore areas could also be depleted, forcing the identification of alternative sources located farther away and increasing the associated costs for acquisition and transport. Increasing project costs and potentially required environmental reviews could alter or delay anticipated projects. Additionally, the newer sand may not be the same grain size or quality that is allowable environmentally and has been historically characteristic of the City's beaches.

Adaptation Strategy Options

As the City continues beach renourishment efforts to replace sand lost to erosion, additional strategies could be implemented to maintain beach width and protect coastal infrastructure between projects. This section describes potential strategies the City may need to consider as supplemental or replacement options to mitigate erosion and provide coastal protection.

The additional strategies are not always intended to be applied in isolation, and some may be most effective and offer the greatest benefits if applied in tandem with another strategy (e.g., continuing to nourish the beach following a storm event while also enhancing the dune system). Site specific application of an additional strategy or combination of strategies should be based on the expected level of flood protection, suitability of local site conditions, implementation costs, and criticality of infrastructure landward of the beach. In combining these strategies with existing efforts, the City can more effectively preserve existing recreational opportunities, enhance the natural beach environment, and maintain a natural buffer against coastal flood hazards.

Beach access point. Source: Adobe Stock

Strategy Theme: Nature Based Protection

OS2 Dune enhancement

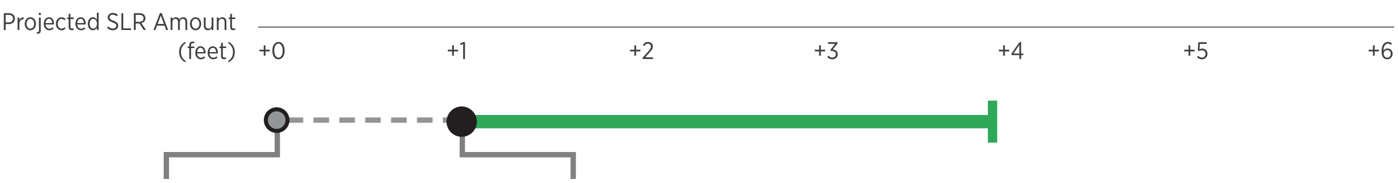
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

Dune enhancement refers to the process of naturally improving and restoring coastal sand dunes to increase their ability to provide flood and erosion protection while also preserving local biodiversity. Key elements of dune enhancement could include the addition of sand to expand the dune system's landward position and height, adding native vegetation to stabilize the dune feature, and dune reconstruction for areas where dunes have been lost or severely eroded. The City's Dune Management Plan provides guidance and specifications for enhancement practices, including invasive species removal and planting of natural vegetation to strengthen and support the integrity of the coastal dune system. The City can continue and increase the scale of these enhancement efforts to promote a resilient coastal dune system.

Flood Protection Lifespan:



Strategy Planning:
0 feet of SLR

The City can begin prioritizing increased dune enhancement efforts at current sea levels utilizing guidance from the Dune Management Plan to improve erosion protection for the dune system.

Strategy Start:
1 foot of SLR

The City can plan to start this strategy at 1 foot of sea level, when 17% of the City's dune areas could be exposed to the 1-percent annual chance storm surge event.

Strategy End:
4 feet of SLR

At 4 feet of sea level rise, over 80% of the City's dunes are projected to be exposed during a 1-percent annual chance storm surge event. With this scale of impacts, the City may consider other strategies to preserve the dune structures.

Coastal dunes with native vegetation, Miami Beach. Source: Miami Beach

Strategy in Action:

Case Study: Dune Restoration and Enhancement (Santa Rosa County, Florida)

Beginning in 2018, cities along the Florida Panhandle, including several in Escambia and Santa Rosa Counties, have implemented dune restoration projects to combat coastal erosion and storm damage. These efforts have focused on restoring and stabilizing the coastal dunes along Pensacola Beach, Perdido Key, and Navarre Beach. These projects aim to limit erosion impacts by renourishing dunes with sand, planting of native vegetation (e.g., sea oats), and installing sand fencing. The restoration efforts are credited with mitigating storm surge and erosion impacts during Hurricane Sally in 2020.

Scrub community on the dunes of Gulf Islands National Seashore, Santa Rosa Island. Source: Ashlynn Smith, UF/IFAS

Application to Miami Beach:

Since the early 1990's, the City has partnered with the Surfrider Foundation to organize volunteer dune restoration projects to remove invasive species. Recently, the City has applied for and been awarded several grants to expand its dune restoration efforts, .including a $1M Resilient Florida grant with $300,000 in matching funds from an RDA. The City is also a finalist for a $20K grant from NOAA, depending on federal funding availability. The City can utilize these funds to scale up its dune enhancement efforts and incorporate best management practices through coordination with Escambia and Santa Rosa counties and other communities engaged in similar initiatives.

Strategy Considerations:

- Additional resources may be required to effectively support these projects. Nature-based elements may introduce new or increased maintenance demands, and the effectiveness of these enhancements will require dedicated monitoring. The Dune Management Plan provides best maintenance practices and specifications for invasive species removal and native plantings that could be used to support formal trainings ahead of increased enhancement projects.
- This strategy does not require that a uniform enhancement method be deployed for the entire dune system. The City can prioritize enhancement methods based on site characteristics and monitor the effectiveness of each approach.
- Both the height and width of the dune will need to be monitored to ensure dune health. Placement of additional sand on the dunes will require coordination with the County, FDEP, and USACE.
- The Dune Management Plan was released in 2016. The City should consider regularly updating the Plan to provide guidance and recommendations that are appropriate for observed sea level rise and erosion rates.
- Should parts of the dune system be severely eroded during a storm event, current federal requirements allow for the use of federal support to rebuild dunes to a height, width, and profile that existed before the storm. If the City elects to elevate the dunes further, the City would be responsible for the cost.

Strategy Theme: Nature Based Protection

OS3 Redesign public access

Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

The City's dune system currently has an extensive network of beach public access locations that cut through the dune system. The creation and maintenance of these gaps in the system has lowered the dune elevations and removed dune vegetation within the pathway areas, providing potential flood pathways for high coastal water levels to expose landward properties during storm events. This strategy focuses on coordinating with FDEP and local stakeholders to update the existing beach access locations by redesigning the pathway configuration to be oriented at an angle to the shoreline, reducing their overall number of access points, or creating beach access via elevated dune-walkover structures. The redesign options will maintain pedestrian beach access while protecting and preserving the elevation and health of the natural dune system.

Flood Protection Lifespan:

Strategy Planning:
0 feet of SLR

The City can begin prioritizing increased dune enhancement efforts at current sea levels utilizing guidance from the Dune Management Plan to improve erosion protection for the dune system.

Strategy Start:
1 foot of SLR

The City can plan to start this strategy at 1 foot of sea level, when 17% of the City's dune areas could be exposed to the 1-percent annual chance storm surge event.

Strategy End:
4 feet of SLR

At 4 feet of sea level rise, over 80% of the City's dunes are projected to be exposed during a 1-percent annual chance storm surge event. With this scale of impacts, the City may consider other strategies to preserve the beachfront.

Strategy in Action:

Case Study: Dune Walkover Structures (Playalinda Beach, Florida)

To protect the Canaveral National Seashore's extensive and fragile dune system, a series of wooden dune crossover structures were erected to provide public access from the parking lot and restroom areas to the beach. Many of the structures are also wheelchair accessible, promoting equitable access to coastal recreational spaces. Similar structures exist across the State, including Pass-a-Grille Beach, Melbourne Beach, and Jupiter Beach. Dune crossovers remain difficult to permit and to replace due to storm impact potential.

Dune crossover structure at Canaveral National Seashore. Source: Florida Today

Application to Miami Beach:

The City could construct a similar series of crossover structures to replace many of the existing beach access pathways that currently cut through the dunes. The City should also consider making the features wheelchair accessible to increase access to beach recreation areas. The City could also exchange best practices with other communities that have already implemented this strategy to understand the best materials to use and construction options that may limit damage during large coastal storm events.

Strategy Considerations:

- Structural design must account for long-term durability, especially against the impacts of erosion and severe weather events such as hurricanes, ensuring the walkovers remain functional and safe for public use.
- The City has 173 beach access points, which may necessitate a phased approach to dune redesign to keep the strategy cost effective. The City could also consider reducing the number of access points to reduce areas for potential erosion and management requirements.
- Detailed planning is necessary to minimize disruption to existing dune systems during construction, including managing and restoring affected areas of native vegetation and addressing potential erosion risks.
- Effective public outreach and education are essential to ensure proper use of walkovers and to reduce the risk of unauthorized access that could compromise the integrity of the dune systems.
- Construction of the structures must comply with Beach and Dune Walkover Guidelines Coastal Construction Control Line Program set by FDEP to avoid the potential for projectile wood planks.
- Successful implementation of this strategy will require routine inspection and maintenance of the redesigned access points to ensure accessibility and coastal protection.
- The redesign or transition of access points should be designed to support integration with the Beachwalk at-grade, where possible.

Strategy Theme: Keeping Water Out

OS4 Hybrid dune systems

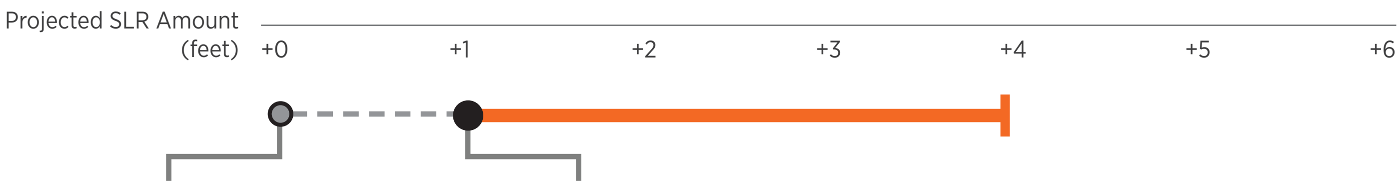
Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

Hybrid dunes combine the natural protection offered by dune sand and vegetation with physical reinforcements, such as rock revetments or seawalls, placed behind or beneath the dune system. This reinforcement aims to provide a last resort of flood protection in the event that the oceanside beach and dune buffer are compromised.

Flood Protection Lifespan:



Strategy Planning:
0 feet of SLR

The City can begin identifying potential locations for hybrid dunes at current sea levels to improve erosion protection for the dune system.

Strategy Start:
1 foot of SLR

The City can plan to start this strategy at 1 foot sea level, as 17% of the City's dune areas could be exposed to a 1-percent annual chance storm surge event.

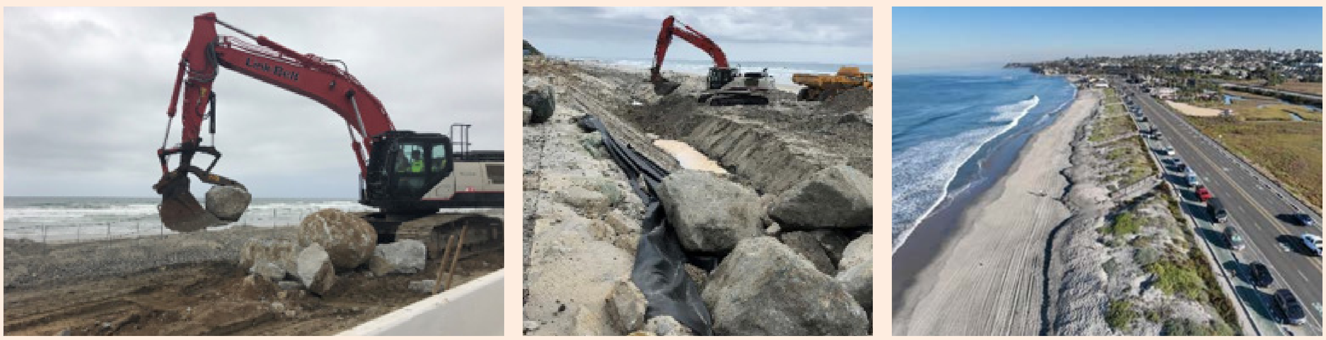
Strategy End:
4 feet of SLR

At 4 feet of sea level rise, over 80% of the City's dunes are projected to be impacted during a 1-percent annual chance storm surge event. With this scale of impacts, the City may consider other strategies to preserve the beachfront.

Strategy in Action:

Case Study: Cardiff Beach Living Shoreline Project (Cardiff Beach State Park, California)

In 2019, the City of Encinitas and California State Parks partnered to implement a living shoreline project to address frequent flooding and erosion of Highway 101 and create coastal dune habitat. The project involved installing engineered rock revetment topped by a sand dune system. The project also included a five-year monitoring program to assess the project's effectiveness during high tides and significant storm events. In January 2024, a large wave event impacted the park but demonstrated the effectiveness of the strategy. Although a large amount of sand was eroded from the dune, the engineered revetment remained intact and avoided flooding and undermining of Highway 101.



Buried revetment acting as the last line of defense at Cardiff State Beach. Source: City of Encinitas.

Application to Miami Beach:

Similar to the City of Miami Beach, Cardiff Beach State Park has a narrow beach area with urban development located adjacent to the coastal dune system. The City could construct a similar engineered structure on the landward extent of the existing dune system to "hold the line" and prevent damage to the roadways and other development located immediately landward of the dunes.

Strategy Considerations:

- Hardening of dune systems will require coordination with federal and state environmental agencies, such as USACE and FDEP, to limit environmental and biodiversity impacts.
- The cost of transitioning the entire dune system may be significant and unnecessary. The City could research and prioritize the coastal areas most suitable for this transition based on the localized erosion rates and the criticality of infrastructure located landward of the dunes.
- The dunes are currently managed as a natural system and implementing hybrid dune structures would represent a significant shift in regional beach management. The City could implement a hybrid dune pilot project following a large storm event that results in a large loss of the dune structure, so that the natural system is not unnecessarily altered.
- Placement of hybrid dune structures can be completed in tandem with offshore wave attenuation devices (OS6) to provide protection for erosion hotspots.
- A Beachwalk is located directly behind the City's dune system. Any hybrid structure (e.g., revetment or sheetpile) will need to consider potential impacts to this public access pathway.

Strategy Theme: Strategic Relocation

OS5 Reimagine coastal areas

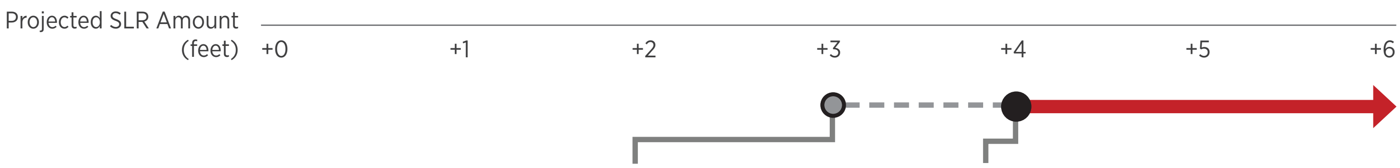
Flood Hazard(s) Addressed:

Estimated Cost Level: $$$$$

Strategy Description:

This strategy focuses on redesigning and repurposing the City's coastal waterfront areas to expand natural shoreline spaces while reducing the extent of development at risk to sea level rise. The strategy could include an incremental removal of at-risk development to allow coastal areas to transition into natural space more capable of providing a buffer for flood hazards.

Flood Protection Lifespan:



Strategy Planning: 3 feet of SLR

Potential redesign or reconfiguration of the City's coastal areas will require significant coordination and public engagement. The planning for this strategy effort could begin at 3 feet of sea level rise.

Strategy Start: 4 feet of SLR

The City could begin implementing changes to coastal areas at 4 feet of sea level as most other identified strategies may fall short of providing the desired level of coastal wave and erosion protection.

Strategy End: 6+ feet of SLR

The City will likely have to consistently assess how to repurpose its coastal areas through the end of the century as sea levels rise.

Strategy in Action:

Case Study: Waterfront Setback Requirements (Tampa, Florida)

50-acre redevelopment on Water Street in downtown Tampa featuring waterfront setbacks that began in 2017. Source: Water Street Tampa

The City of Tampa has implemented increased waterfront setback requirements to protect properties from increasing flood and erosion risks. Under Section 27-290.8 of Tampa's zoning code, all new accessory structures must maintain a minimum setback of 30 feet from the jurisdictional high-water line along the Hillsborough River and other designated waterfront areas, which is an additional 5-feet more than FDEP requirements. This ordinance, part of the City's broader resilience strategy, aims to create a buffer zone that reduces the impact of storm surges and high-water events on residential and commercial properties. The setback provides space for potential green infrastructure, such as riparian buffers, that can be repurposed into recreational areas.

Application to Miami Beach:

Miami Beach could leverage the Resilience Code to implement a similar redesign of the City's waterfront by increasing waterfront setbacks. Like Tampa's approach, the City could establish designated land use zones with expanded setbacks to support the widening of natural or public access spaces, including the coastal dunes or the Beachwalk, to provide ecological, recreational and flood resilience benefits.

Strategy Considerations:

- This approach represents a shift in the City's current coastal development practices and relationship with the coastal area. This strategy's success would require robust public engagement and buy-in, including from developers and property owners.
- The Resilience Code (Chapter 7) establishes current setback and zoning requirements for coastal development to accommodate future sea level rise in infrastructure upgrades. Expanding or updating these setback requirements for certain development could support the transformation of coastal and shoreline areas into less developed, natural spaces that offer increased flood protection for other City assets.
- This strategy is likely to require changes to multiple zoning laws and land use policies, including potential amendments to existing land use plans, which could face resistance from developers or property owners concerned about limiting usable land area. The City may need to consider incentive programs to increase support.
- The City could promote this strategy by implementing demonstration projects on publicly owned parcels to showcase the benefits of these transitions. By developing natural spaces that enhance public access and recreation, these sites could present the value of repurposing at-risk coastal areas for broader community and environmental benefits.
- Long-term monitoring of flood risks and property vulnerability would be needed to determine that the revised setbacks continue to provide adequate protection as sea levels rise.
- This strategy could contribute to enhanced biodiversity and ecosystem services by preserving natural buffers and enhancing the coastal dune system. This strategy could be accomplished in coordination with OS2 (Dune Enhancement) and OS4 (Hybrid Dune System).

Strategy Theme: Keeping Water Out

OS6 **Expand offshore wave attenuation**

Flood Hazard(s) Addressed:

Estimated Cost Level:

Strategy Description:

Offshore wave attenuation devices refer to structures that are designed to mitigate the energy of ocean waves, typically for the purpose of protecting coastal infrastructure from flood or erosion hazards. They may include the offshore placement of revetment stones (breakwater) parallel to the shoreline or artificial reefs that mimic coral habitat while also disrupting the formation of waves. The County has several existing and planned breakwater projects to address areas of severe beach erosion, while the Reefline and University of Miami's U-LINK laboratory have deployed pilot studies on the effectiveness of natural wave attenuation devices, including seahives and coral reefs. This strategy proposes that the City support the design and integration additional projects with existing efforts to establish a more comprehensive level of beach and erosion protection.

Flood Protection Lifespan:

Strategy Planning: 3 feet of SLR

The potential installation of offshore wave attenuation features will require significant coordination and public engagement. The planning for this strategy effort could begin at 3 feet of sea level rise.

Strategy Start: 4 feet of SLR

The City may need to consider offshore options to reduce beach erosion at 4 feet of sea level rise as over 80% of the City's dunes are projected to be exposed to a 1-percent annual chance storm surge event.

Strategy End: 6+ feet of SLR

The City may need to continue implementing or enhancing offshore wave attenuation features through the end of the century to prevent erosion of the City's beachfront.

Strategy in Action:

Case Study: Miami-Dade County Artificial Reef Program

Since 1981, the Miami -Dade County Artificial Reef Program has established 17 artificial reef projects constructed from materials like cast concrete, limestone, retired vessels, and surplus military equipment. These offshore structures help to absorb and dissipate wave energy, reducing shoreline erosion rates and protecting coastal infrastructure. The sites selected are prioritized to provide enhanced habitats, fisheries, and recreational diving opportunities. The Program has included several studies on the effectiveness of the substrates used and associated habitat creation and erosion reductions.

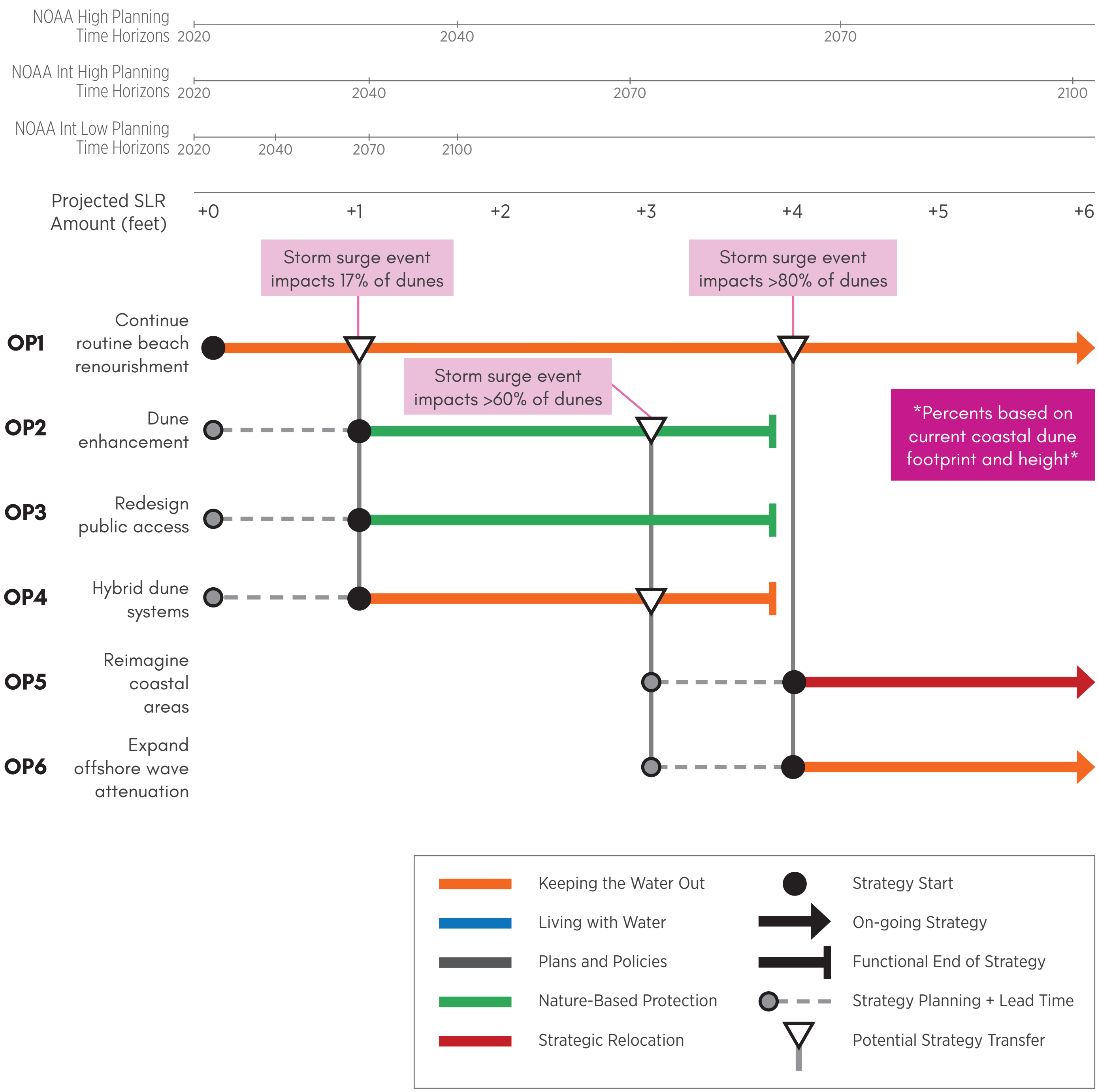
'Concrete Coral' reef design by Leandro Erlich. Source: The ReefLine

Application to Miami Beach:

The City could expand collaboration efforts with the County to establish additional or more large-scale artificial reef sites offshore along the City's Atlantic coastline, particularly in areas with significant erosion. Increasing the number of these sites could enhance coastal resilience by mitigating wave energy, reducing erosion rates, and providing recreational opportunities to support local tourism.

Strategy Considerations:

- The installation of offshore structures will be led by federal, state, and university partners. The City should begin coordinating with relevant federal and state review agencies early in the planning period and support data collection, where possible. The installation will also require an assessment of potential environmental impacts and compliance with regulatory permit processes across multiple agencies, such as USACE, Florida Fish and Wildlife Conservation Commission, and FDEP.
- Wave attenuation materials should be selected to reduce negative impacts, such as attracting invasive species, invasive species or affecting littoral sand transport or hardbottom habitat.
- Improperly sited attenuation devices can accelerate erosion to adjacent beach areas. Proper site selection and design for offshore wave attenuation structures will require coastal hydraulic modeling and sediment transport studies.
- Traditional engineered structures such as seawalls, breakwaters, and other barriers will likely need long-term maintenance and improvements to meet the desired level of flood protection. Nature-based approaches, such as artificial reefs, have the potential to become more self-sustaining with less maintenance requirements over time.



Existing storm surge flooding extent was determined by the Federal Emergency Management Agency (FEMA) 1-percent annual chance (i.e., 100-year) coastal water elevation (6.2 feet NAVD88). Projected sea level rise amounts were added to this baseline to determine future dune impact percents.

Impacts to dunes were assessed by overlaying each storm surge flooding scenario extent onto the City's coastal dune system in GIS to determine the percent of dune area projected to experience flooding impacts.

Oceanside Flood Protection Metrics, Adaptation Thresholds, and Monitoring Plan

Sea level rise has traditionally been a primary consideration in the City's planning efforts to reduce or avoid potential flood risks. However, there are other relevant metrics that the City could also monitor to provide an understanding of how rising sea levels may worsen flood impacts or place additional stress on the City's infrastructure and natural systems. Monitoring these metrics, along with sea level rise, can help to identify key thresholds that may serve as early warning signals that existing strategies may no longer be sufficient.

This section includes a list of proposed metrics and thresholds that the City could consider to inform the most effective strategies for long-term Oceanside flood protection. Additionally, a suitability matrix is provided to identify metrics that could be used to inform each strategy included in the Oceanside Flood Protection Pathway Summary.

Metrics

Metrics are measurable indicators that are used to track the effectiveness of adaptation actions over time. They are useful in helping make decisions on when to transition between different adaptation strategies based on changing sea level conditions and the observed effects.

Adaptation Thresholds

Thresholds are a pre-defined change in the existing physical conditions or social tolerances for flooding impacts and serve as early warning to signal that existing strategies are losing their effectiveness and could benefit from supplemental or alternative adaptation strategies.

Monitoring Plan

Monitoring allows the City to track the defined metrics over time for evidence of specified adaptation thresholds being met to avoid large potential impacts to the City's assets and facilities. While the City has existing plans and methodologies to track some of the proposed metrics, others will require the development and implementation of new monitoring programs.

Metric: Dunes Exposed to Flood Events

Adaptation Threshold: Percentage of dunes eroded

Sea level rise will worsen erosion of the shoreline and dune system during large coastal storms by allowing waves to impact further inland, increasing the overall extent of dune erosion. As the percentage of affected dune area grows, it may signal a decline in the system's capacity to provide effective coastal flood protection. These thresholds can serve as markers for evaluating the need for additional measures, such as dune restoration, structural reinforcement, or reimagining of the coastal waterfront as a natural buffer from hazards, to enhance the City's overall coastal flood resilience.

Monitoring Plan:

High-resolution satellite imagery can be used to identify erosion hotspots along the City's shoreline and track changes in dune structure over time. Aerial surveys and on-the-ground inspections can also track the extent of dune damage after significant storm events. This data can be compared with observed coastal water levels to understand conditions contributing to dune erosion. The City could also establish partnerships with local organizations or universities to monitor and document the position and elevation of dune features, such as the dune toe, following major storm events. This information can be used to determine the health of the coastal dune system under increasing erosion and guide if proactive reinforcement or restoration efforts are necessary.

Metric: Beach Width

Adaptation Threshold: Beach erosion greater than USACE design template

A loss of beach width compromises the protective function of the beach as a buffer for landward infrastructure. If average annual erosion outpaces natural sediment accumulation or renourishment efforts, the beach and dune system may ultimately fail to provide the desired level of flood protection. The USACE currently monitors the City's beach widths in reference to a design template that specifies a required beach with. Erosion of the beach width beyond this design template has been used an indicator that a renourishment project is necessary prior to the traditional schedule.

Monitoring Plan:

High-resolution satellite imagery can be used to identify erosion hotspots along the shoreline and track changes in erosion rates over time. Systematic field surveys, such as those already being conducted annually by the County, can support these efforts. Aerial surveys and on-the-ground inspections can also track the extent of erosion after significant storm events. This data can be compared with observed coastal water levels to understand conditions contributing to erosion. The surveys can account for seasonal erosion rate changes or increasing storm-related erosion events. These measurements can be used to adjust renourishment schedules and plan additional interventions if erosion exceeds the defined thresholds. These efforts are likely to be conducted by the County and supported by the City.

Metric: Dune Height

Adaptation Threshold: Percent of dune height decline annually

Erosion-driven declines in dune height lessens the protective function of the dune for landward infrastructure, as the dunes are more likely to be overtopped during storm events. If a loss in dune height outpaces natural sediment accumulation or dune enhancement efforts, the dune system may ultimately fail to provide the desired level of flood protection.

Monitoring Plan:

High-resolution satellite imagery can be used to establish a baseline dune crest height, which will vary along the seven miles of the dune field. Satellite imagery can also be used to identify erosion hotspots along the dune system and track changes in dune elevation over time. Systematic field surveys, such as those already being conducted annually by the County, can support these efforts. Aerial surveys and on-the-ground inspections can also track the extent of dune height loss after significant storm events. These measurements can be used to adjust enhancement schedules and plan additional interventions if erosion exceeds acceptable thresholds. These efforts are likely to be conducted by the County and supported by the City.

Metric: Flooding of Landward Properties

Adaptation Threshold: Number of times flooded per year

Flooding of landward properties and infrastructure indicates that the beach and dunes are not at a sufficient width or height to provide flood protection. Tracking the frequency of flood impacts to properties and assets adjacent to the beach can assist the City with the timing of adaptation strategies. Flooding will also need to be defined (e.g., depth) to provide a measurable metric to track consistently.

Monitoring Plan:

The City could establish a historical flood impact tracking program to document flood events across the City. The program could be informed by visual inspections of coastal properties following high water or coastal storm events or rely on a citizen science program for the public to report observed instances and severity of flooding.

Flood Protection Strategy	Potential Metrics: Dune Area Exposure to Flood Events	Potential Metrics: Beach Width	Potential Metrics: Dune Height	Potential Metrics: Flooding of Landward Properties
Continue Routine Beach Renourishment		✓		✓
Dune Enhancement	✓	✓	✓	✓
Redesign Public Access	✓		✓	✓
Hybrid Dune Systems	✓		✓	
Reimagine Coastal Areas	✓	✓	✓	✓
Expand Offshore Wave Attenuation	✓	✓	✓	✓

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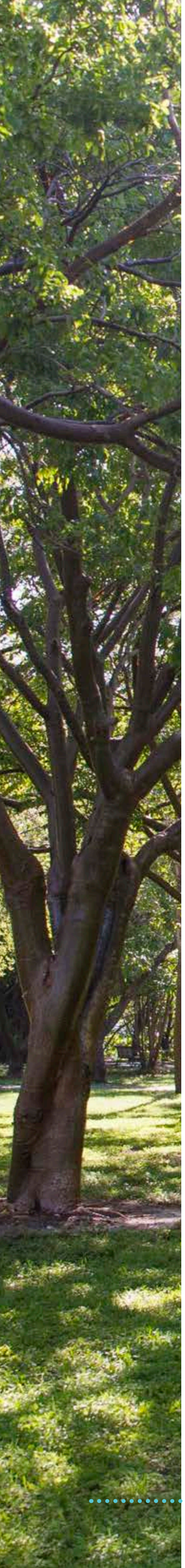
5 Next Steps



5. Next Steps

The Adaptation Plan provides a phased implementation plan, consisting of six adaptation pathways that offer long-term flood mitigation actions with the timing initiated by defined adaptation thresholds to support the City's sea level rise adaptation decision-making process. In addition to the projected timing of sea level rise, the pathways also consider other factors, such as the lifespan of assets and maintenance/repair costs, as determining factors for the initiation of a strategy. The Adaptation Plan is designed to allow for actions to be taken immediately to prepare for short-term impacts while incorporating the flexibility of options to adapt, for mid- and long-term planning horizons. The following considerations will be important for implementation of the plan:

- **Continue Inter-Department Coordination** – Internal coordination among City Department staff to share the adaptation pathway approach, strategies, metrics, and monitoring plan will be required to implement the Adaptation Plan. City staff were engaged during development of this plan to refine the strategy details, metrics, and monitoring mechanisms. However, it is important that each department continue to use the plan as a tool to provide long-term flood protection of the assets and infrastructure that they manage and for consistent Citywide enhancement of overall flood resilience.

- **Integrate with Existing City Plan Updates** – It is also important that City Department staff look for opportunities to integrate adaptation strategies into new iterations of the City's existing planning and visioning documents as they are updated. While many of the City's existing approaches to provide flood protection have reduced or eliminated existing flooding for some areas of the City, rising sea levels pose a long-term threat to City assets and infrastructure. The adaptation pathways discussed in the Adaptation Plan offer a set of updates for many of the City's key planning documents to consider long-term sea level rise trends as well as the potential timing for when the plan may need to be updated to avoid projected flood impacts during future sea level rise scenarios.

- **Establish Monitoring Programs** – An ongoing monitoring plan will be required to understand the timing of strategy implementation. Many of the monitoring mechanisms described in the six adaptation pathways rely on setting up flood monitoring tracking systems to understand the location and extent of flooding as it occurs, and the combination of flood sources that contribute to the impacts. Monitoring systems are most effective with a history of observations and may not require extensive staff or funding resources to initiate immediately.

- **Identify Strategy Funding Sources** – Identification of funding sources to carry out adaptation strategies identified in this plan will be critical. As an immediate next step, the city can scan near-term strategy options to identify those that can be included in the City's annual budget or those that will require external funding, such as State and Federal grants.

Planning for and adapting to changing sea level conditions is a critical challenge facing many coastal communities. The City has long-been considered a leader in flood adaptation and is actively implementing infrastructure improvements and policy updates to enhance flood resilience across the City. The Adaptation Plan represents an additional decision support tool that provides City staff with a set of strategy options to consider or incorporate into existing plans based on the observed need for their implementation. Use of the approach outlined in the plan will help the City remain strongly positioned to take necessary actions that anticipate, prepare for, and adapt to the potential impacts of sea level rise.

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Appendices

Appendix A – Initial Strategy List

#	Primary Flood Hazard Addressed	Strategy Category	Strategy Type	Strategy Short Name	Strategy Description
1	Multiple	Governance	Coordination	Coordinate with County on Flood Protection for Shared Assets	Continue City-County focus groups to collaborate on flood protection measures for shared assets (physical infrastructure)
2	Multiple	Governance	Plans and Policies	Review and Update Seawall Ordinance As Needed	Periodically review and update the City's minimum seawall height ordinance to account for evolving sea level rise projections
3	Multiple	Governance	Communications/ Outreach	Develop a Homeowner's SLR Guide	Develop private property sea level rise homeowner's guide to assist with understanding vulnerabilities and private adaptation options.
4	Multiple	Governance	Plans and Policies	Incorporate SLR Into CIP Planning and Design	Continue to incorporate sea level rise projections into capital projects, planning, and design.
5	Multiple	Governance	Funding	Create Local Improvement District(s) to Fund SLR Improvements	Continue to explore Local Improvement District(s) to fund seawall, pumps, road raising, and other investments
6	Multiple	Governance	Communications/ Outreach	Develop Climate Hazard Outreach Materials	Continue to refine online outreach tools to educate the public about future flood risks
7	Multiple	Governance	Communications/ Outreach	Implement Climate Hazard Real Estate Disclosure Requirements for Home Sales	Require sea level rise hazard disclosures for residential real estate transactions
8	Multiple	Governance	Monitoring	Monitor and Update Climate Projections Every 5 Years	Review sea level rise and extreme precipitation projections every 5 years to inform planning and design
9	Multiple	Governance	Plans and Policies	Assess Options for Asset Relocation and Managed Shoreline Retreat of Frequently Flooded Areas	Develop strategic relocation plan of critical assets that are in high-risk flood zones
10	Storm Surge	Governance	Plans and Policies	Review and Update Building Resilience Code for Changing Sea Level Rise Projections	Review Resilience Code for changing sea level rise projections based on federal or regional updates

Appendix A – Initial Strategy List (continued)

#	Primary Flood Hazard Addressed	Strategy Category	Strategy Type	Strategy Short Name	Strategy Description
11	Storm Surge	Governance	Plans and Policies	Update Utility Design Standards	Continue to implement utility design standards to include consideration of sea level rise and future flood elevations
12	Multiple	Governance	Plans and Policies	Establish Consistent SLR Scenarios for City Planning and Design	Coordinate across City departments to use comparable sea level rise scenarios for consistent level of flood protection
13	Multiple	Governance	Emergency Operations	Develop a Socially Vulnerable Assistance Response Plan	Continue to update the response/ evacuation plan to assist elderly and other disadvantaged community members needed assistance in flood-prone areas
14	Multiple	Governance	Plans and Policies	Develop Historic Building Flood Guidelines	Continue to evaluate and implement Buoyant City design guidelines for flood protection of historic buildings within the City
15	Multiple	Governance	Communications/ Outreach	Expand and/ or Extend Private Property Adaptation Program Grant Program	Continue the existing PPA Program where the City provides grants to match up to $20,000 of home improvements that increase resilience to flooding and continue identifying candidates for FEMA home elevation grant programs.
16	Multiple	Governance	Communications/ Outreach	Develop Property Tax Relief Program	Property owners who suffer damage to their property as the result of a flood may be eligible for certain limited forms of property tax relief .
17	Stormwater	Governance	Stormwater	Formalize blue-green stormwater infrastructure requirements into existing policy, planning, and management systems.	Develop a policy that states the objectives of the City's BGSI Concept Plan, including requirements for the City. Update codes, ordinances, zoning, and permitting requirements to reflect the BGSI policy. Include BGSI practices and strategies in master planning and land use planning.
18	Multiple	Governance	Monitoring	Develop and Implement a Storm Damage Monitoring Program	Develop a formalized storm damage monitoring program to be carried out by City staff to monitor, observe, and record storm impacts

Appendix A – Initial Strategy List (continued)

#	Primary Flood Hazard Addressed	Strategy Category	Strategy Type	Strategy Short Name	Strategy Description
19	Multiple	Governance	Communications/ Outreach	Outreach to Residents and Businesses on Waste Storage	Outreach to City waste collection customers regarding storage of waste and recycling in flood prone areas
20	Multiple	Governance	Plans and Policies	Increase Waterfront Setbacks	Establish and/or increase waterfront setback distances to mitigate damage to waterfront structures during flood events
21	Multiple	Governance	Flood Protection	Implement Voluntary Buyouts for Vulnerable Properties	Coordinate with County, State, and Federal Government to implement a voluntary buyout program for vulnerable properties or repetitive loss properties to reduce future flood damages and loses to structures.
22	Multiple	Governance	Plans and Policies	Review and Update Beach and Dune Management Plans	Continue to work with USACE and Miami Dade County to identify and implement sea level rise vulnerabilities and options into beach and dune management planning.
23	Multiple	Governance	Plans and Policies	Mainstream Consistent SLR Language into City Planning and Design Documents	Review city planning and vision documents to incorporate up-to-date sea level rise language
24	Stormwater	Informational	Assessment	Assess Green Infrastructure Opportunities	Assess and require green and green-blue infrastructure opportunities to reduce inflows to stormwater infrastructure. The MB BGSI Plan identifies the following BGSI practices with the most applicability to MB as: bioretention/bioswales/ rain gardens, blue and green roofs, constructed wetlands and floating wetland islands, detention basins/ surface storage, enhanced tree pits/ trenches, injection wells, permeable pavements, rainwater harvesting, stormwater planters, subsurface infiltration and storage, tree canopy, and wet ponds.
25	Multiple	Informational	Assessment	Develop and Maintain a Seawall Inventory	Continue to publicize and update the inventory of existing seawalls through GIS tools (location, ownership, condition, elevation)

Appendix A – Initial Strategy List (continued)

#	Primary Flood Hazard Addressed	Strategy Category	Strategy Type	Strategy Short Name	Strategy Description
26	Multiple	Informational	Data Collection/ Gaps	Survey City Buildings FFEs	Evaluate whether additional finish floor elevations and other critical equipment elevations of City-owned buildings are needed to identify structures most at risk of flood damage and inform design of elevation/flood proofing measures
27	Multiple	Informational	O&M	Inspect/Replace Aging Stormwater and Wastewater Pipelines	Continue to implement SSES and the 5-year critical needs plan for the sewer system
28	Multiple	Operational	O&M	Implement the SWMMP Critical Needs Projects	Implement the SWMMP Update prioritizing $95 Million for critical needs stormwater projects
29	Multiple	Informational	Communications/ Outreach	Develop SLR Best Practices for Businesses	Develop and disseminate guidance to businesses on the best practices for reducing the potential impacts of flooding and sea level rise on their facilities and the services and systems they rely on.
30	Storm Surge	Informational	Assessment	Investigate Feasibility of Increasing FEMA Community Rating System (CRS) Class	Continue to participate in the FEMA CRS program to maintain or improve the CRS score.
31	Tidal	Informational	Assessment	Perform Groundwater Shoaling Study	Perform analysis and/or modeling of shallow groundwater response to sea level rise and potential for saturated ground conditions or emergent groundwater flooding to impact infrastructure
32	Tidal	Informational	Assessment	Perform Salinity Intrusion Study	Perform analysis and/or modeling of salinity intrusion into groundwater and potential impacts on street streets and landscaping
33	Stormwater	Informational	Assessment	Study Climate-Driven Changes in Extreme Precipitation	Perform a study or literature review of projected changes in extreme precipitation events due to climate change and impacts on local flooding and stormwater system performance

Appendix A – Initial Strategy List (continued)

#	Primary Flood Hazard Addressed	Strategy Category	Strategy Type	Strategy Short Name	Strategy Description
34	Multiple	Informational	Communications/ Outreach	Establish Flood Impacts Monitoring Program	Investigate establishment of resident flood impacts monitoring program to document flood impacts for various flood conditions. Could be a crowd sourcing platform for collecting photo and video documentation of impacts.
35	Multiple	Infrastructure	Flood Protection	Harden Electrical Substations	Continue coordinating with FP&L to continue developing flood hardening strategies for electrical substations and equipment
36	Multiple	Infrastructure	Flood Protection	Relocate Critical Assets from Vulnerable Areas	Explore feasibility of repurposing extremely vulnerable areas.
37	Storm Surge	Infrastructure	Flood Protection	Evaluate Back Bay Storm Surge Barrier Feasibility	Evaluate feasibility of a storm surge barrier to provide inland flood protection through coordination with as part of the USACE CSRM Back Bay Study.
38	Stormwater	Infrastructure	Stormwater	Consolidate Coastal Stormwater Outfalls	Consolidate gravity-based or pumped stormwater outfalls on the open coast and bay to reduce the number of outfalls to manage
39	Storm Surge	Infrastructure	Flood Protection	Continued Beach and Dune Renourishment	Continued beach renourishment and dune monitoring in coordination with USACE CSRM studies
40	Multiple	Infrastructure	Flood Protection	Raise Critical Roadways	Continue elevating and adjusting critical roadways to maintain access during/after flood events and prevent flooding during king tides and extreme precipitation events
41	Multiple	Infrastructure	Flood Protection	Floodproof Stormwater Pump Stations	Continue to protect stormwater pump stations by flood proofing building or adding perimeter floodwall and elevating electrical components
42	Multiple	Infrastructure	Flood Protection	Floodproof Wastewater Lift Stations	Continue to protect wastewater lift stations by flood proofing building and elevating electrical components
43	Multiple	Infrastructure	Flood Protection	Install Temporary Flood Barriers for City Facilities	Continue to install temporary flood barriers (e.g., Tiger Dam, pop-up barriers at entry ways) at vulnerable City facilities prior to storm events.

Appendix A – Initial Strategy List (continued)

#	Primary Flood Hazard Addressed	Strategy Category	Strategy Type	Strategy Short Name	Strategy Description
44	Multiple	Infrastructure	Flood Protection	Replace Vulnerable Electrical Boxes	Continue to elevate electrical boxes with existing wet weather groundwater elevations within one to two feet of the ground surface for replacement with watertight alternatives
45	Storm Surge	Infrastructure	Flood Protection	Elevate Electrical Panels	Continue to elevate electrical panels to be above the FEMA BFE + sea level rise
46	Storm Surge	Infrastructure	Flood Protection	Elevate Traffic Control Boxes	Elevate vulnerable traffic control boxes to be above the FEMA BFE + sea level rise
47	Multiple	Infrastructure	Emergency Operations	Elevate Backup Power for City Facilities	Add elevated backup power/ generators with fuel for several days for critical City facilities to minimize interruptions
48	Stormwater	Infrastructure	Flood Protection	Retrofit Existing or Construct Additional Stormwater Pumps	Continue installing stormwater pumps in locations of frequent flooding or at gravity-driven stormwater outfalls likely to be impacted by sea level rise in accordance with the SWMMP Update and Neighborhood Improvement Projects; retrofit existing pump stations to pump against higher sea levels in the future
49	Multiple	Infrastructure	Flood Protection	Identify and Convert Parks Into Floodable Parks	Continue to evaluate parks, open space, and golf courses for stormwater retention during heavy rain events where possible
50	Multiple	Infrastructure	Flood Protection	Identify and Elevate Shoreline Structures	Continue to protect, elevate, or reconstruct low-lying shoreline structures
51	Storm Surge	Infrastructure	Flood Protection	Install Stormwater Pumps in Tidally Flooded Areas	Analyze feasibility of installation of pumps in tidally influenced flooded areas.
52	Stormwater	Infrastructure	Stormwater	Install Additional Stormwater Inlets	Continue increasing the number of inlets/catch basins in flood prone or disconnected areas in accordance with the SWMMP and Neighborhood Improvement Projects.

Appendix A – Initial Strategy List (continued)

#	Primary Flood Hazard Addressed	Strategy Category	Strategy Type	Strategy Short Name	Strategy Description
53	Multiple	Infrastructure	Flood Protection	Elevate Emergency Facility Parking lots	Assess elevation and adaptation of parking lots for critical emergency facilities such as police and fire stations, emergency operation centers in association with floodproofing or building retrofits of the supported facilities.
54	Stormwater	Infrastructure	Stormwater	Complete Identified BGSI pilot projects	These include those at Collins Canal and Miami Beach Golf Club. Blue-Green Stormwater Infrastructure (BGSI) solutions have a multitude of benefits, including improved water quality, stormwater detention, urban heat island mitigation, enhanced aesthetics, and groundwater recharge. Potential strategies include bioretention, green roofs, constructed wetlands, tree pits/trenches, injection wells, permeable pavement, rainwater harvesting, stormwater planters, and subsurface infiltration/storage.
55	Multiple	Infrastructure	Stormwater	Road Raising, Repaving, and Regrading	Raise, repave, and regrade existing roads to mitigate roadway flooding and direct runoff to collection points.
56	Stormwater	Infrastructure	Stormwater	Upsize Stormwater Infrastructure	Continue to upsize stormwater infrastructure (e.g., pipes, catch basins, curb inlets, outfalls, pumps) to accommodate higher runoff anticipated due to future climate change
57	Stormwater	Infrastructure	Stormwater	Connect Disconnected Drainage Areas to the Stormwater System	Continue the expansion and improvement of the network of stormwater collection systems, i.e., curb inlets, catch basins, culverts, and drains to prevent runoff from pooling in critical areas. Connect areas to pumps and/or outfalls.
58	Stormwater	Infrastructure	Stormwater	Install Stormwater Water Quality Treatment Improvements	Continue improving water quality treatment in the collection and discharge system by installing trash racks, water quality pumps, hydrodynamic separators, and membrane filtration structures.

Appendix A – Initial Strategy List (continued)

#	Primary Flood Hazard Addressed	Strategy Category	Strategy Type	Strategy Short Name	Strategy Description
59	Stormwater	Infrastructure	Stormwater	Implement Stormwater Critical Needs Projects	Implement Critical Needs Projects (CNP) as described in the Stormwater Master Plan Update. A CNP is a project that addresses stormwater and nuisance flooding to provide both beneficial and cost-effective solutions within targeted areas, which are complementary to Neighborhood Improvement Projects and may include solutions such as: minor road raising, upsizing stormwater infrastructure, connecting drainage areas, and water quality improvements. There are 20 CNPs identified for implementation over the next 10 years.
60	Stormwater	Infrastructure	Stormwater	Install Backflow Prevention at Stormwater Outfalls	Install backflow prevention (e.g., gates, valves) at stormwater outfalls to prevent high tides from back flowing into the stormwater system.
61	Multiple	Infrastructure	Stormwater	Install Onsite Generators at Stormwater Pump Stations	Install onsite generators at stormwater pump stations to provide continuity of power supply during and after storm events
62	Multiple	Infrastructure	Flood Protection	Enhance Shoreline Habitats with Living Shorelines	Continue enhancing shoreline edges using wetlands, mangroves, hybrid coral reef structures, human-made islands, and other living shoreline techniques to provide habitat and erosion protection.
63	Multiple	Infrastructure	Flood Protection	Reinforce Existing Dune System Using "Hybrid Dune" Approaches	Reinforce natural dunes by creating hybrid dune systems, which involve burying rock armoring within the dune core to make dunes more resistant to erosion during storm events
64	Multiple	Infrastructure	Flood Protection	Construct Seawall + Living Shoreline Hybrid Shorelines	Combine living shoreline techniques and traditional seawalls to enhance shoreline habitat while also providing flood and erosion protection
65	Multiple	Infrastructure	Flood Protection	Elevate or Floodproof Residential and Commercial Structures	Elevate critical, vulnerable structures above projected flood elevations. For structures that cannot be elevated, install floodproofing improvements. Raise or floodproof external electrical/mechanical equipment.

Appendix A – Initial Strategy List (continued)

#	Primary Flood Hazard Addressed	Strategy Category	Strategy Type	Strategy Short Name	Strategy Description
66	Multiple	Infrastructure	Flood Protection	Coordinate with County and USACE on Miami-Dade Back Bay and Oceanfront CSRM Studies	Continue coordinating with ongoing USACE Coastal Storm Risk Management (CSRM) programs on the Bay and Ocean
67	Storm Surge	Infrastructure	Flood Protection	Install Local Flood Gates/Storm Surge Barriers to Reduce Back Bay Surge Flooding	Evaluate feasibility of local storm surge barriers at canal and channel mouths to reduce back bay storm surge flooding along tidal channels
68	Multiple	Infrastructure	Flood Protection	Procure and Stage Portable/Temporary Stormwater Pumps to Respond to Localized Flooding	Continue identifying recurrent flooding/ponding areas and stage portable/temporary pumps for City maintenance staff to respond to localized flooding
69	Multiple	Infrastructure	Flood Protection	Install New Drainage Wells to Manage the First Flush of Stormwater	Drainage wells are structures that collect and manage stormwater, directing it underground to be stored or infiltrated.
70	Storm Surge	Infrastructure	Flood Protection	Construct Vegetated Dunes Along Oceanfront Gaps	Identify opportunities to construct natural dunes along segments of beachfront that currently have gaps in the dunes
71	Multiple	Infrastructure	Emergency Operations	Raise Fire Hydrants Above Flood Levels	Raise fire hydrants to maintain access and function during flood events
72	Stormwater	Infrastructure	Stormwater	Construct Underground Detention Basins	Construct underground stormwater detention basins to capture and store stormwater for subsequent treatment, pumping, and discharge
73	Multiple	Infrastructure	Flood Protection	Retrofit or Relocate Beachfront Restrooms	Retrofit or relocate existing beachfront restrooms to protect against future flooding and/or erosion
74	Multiple	Infrastructure	Flood Protection	Expand Blueways and Greenways	Expand parks, open space, and pathways along waterways and in flood-prone areas by increasing room for water storage and creating natural buffers against waves and debris during storms. Room can be created through setbacks and voluntary buyouts.

Appendix A – Initial Strategy List (continued)

#	Primary Flood Hazard Addressed	Strategy Category	Strategy Type	Strategy Short Name	Strategy Description
75	Multiple	Infrastructure	Flood Protection	Create Green and Blue Neighborhoods	Create a network of small spaces for water in yards, streets, and parks by removing pavement and incorporating rain gardens, swales, trees, and other permeable materials.
76	Storm Surge	Infrastructure	Flood Protection	Construct Artificial Reefs and Breakwaters	Continue piloting and investigate the feasibility of scaling projects for artificial reefs and breakwaters offshore to attenuate wave energy and provide hard substrate habitat
77	Storm Surge	Infrastructure	Flood Protection	Restore and Enhance Existing Dunes	Continue restoring and enhancing existing dunes through vegetation management and planting, promoting growth of native vegetation for erosion protection and habitat benefits
78	Multiple	Operational	Emergency Operations	Purchase Emergency Response Watercraft	Investigate procurement of additional watercraft for emergency response during flood events
79	Multiple	Operational	Emergency Operations	Develop Alternate Flood Detour Routes	Conduct road infrastructure assessment to flooding and explore alternative transportation routes for key streets in case of flooding
80	Stormwater	Operational	Stormwater	Improve Catch Basin Debris Management	Investigate catch basins debris management practices and develop procedures to clear debris for expected storms
81	Stormwater	Operational	O&M	Develop "Adopt a Storm Drain" Program	Explore community-based storm drain clearing program, such as an "Adopt a Storm Drain" program, where residents volunteer to keep storm drains clear of debris
82	Storm Surge	Operational	Emergency Operations	Create Vehicle Storm Relocation Plan	Create a City vehicle pre-storm relocation plan (including emergency response vehicles)

Appendix B – Final Strategy List

Primary Hazard Addressed	Strategy Category	Strategy Name	Supporting Actions
Multiple	Governance	Continue to incorporate consistent, up-to-date SLR projection language into the design of capital projects	• Blue-Green Stormwater Infrastructure (BGSI)
Multiple	Operational	Develop Safety Plans for Roads and Public Right of Ways	• Develop Alternate Flood Detour Routes • Purchase Emergency Response Watercraft • Activate the flood communications response plan
Multiple	Infrastructure	Assess and Pilot Blue and Green Stormwater Infrastructure Opportunities	• Formalize blue-green stormwater infrastructure requirements into existing policy, planning, and management systems. • Evaluate BGSI pilot projects for ability to gain regulatory approval and implementation feasibility • Implement BGSI pilot projects to monitor and evaluate effectiveness (based on opportunities for target neighborhoods) • Evaluate neighborhoods experiencing significant flooding for opportunities to be green and blue neighborhoods (incl. blue ways and greenways) (water retention areas) • Identify and convert parks into floodable parks • Monitor effectiveness of proposed projects (alleviate flooding in a small urban setting) (small vs large storm events) • Establish landscaping feasibility of proposed projects (in a small urban setting) • Determine tradeoffs to implement projects • Identify areas from the SWMMP to implement BGSI
Multiple	Infrastructure	Protect and Elevate Critical City Distributed Infrastructure (roadways, traffic control, pipelines, fire hydrants)	• Road raising, repaving, and regrading • Harden electrical substations • Floodproof wastewater lift stations • Elevate traffic control boxes • Elevate backup power for City facilities • Elevate emergency facility parking lots • Raise fire hydrants above flood levels • Install temporary flood barriers for City facilities • Elevate shoreline structures

Appendix B – Final Strategy List (continued)

Primary Hazard Addressed	Strategy Category	Strategy Name	Supporting Actions
Multiple	Infrastructure	Retrofit and Enhance Stormwater System for Higher Intensity Rainfall (incl. pumps, pipes, drainage areas)	• Implement the SWMMP Critical Needs Projects and Neighborhood Improvement Projects • Inspect, replace, and upgrade aging stormwater and wastewater pipelines • Upsize stormwater infrastructure • Connect disconnected drainage areas to the stormwater system • Install backflow prevention at stormwater outfalls • Install new drainage wells to manage stormwater • Construct Underground Detention Basins • Procure and stage portable/temporary stormwater pumps to respond to localized flooding • Install stormwater water quality treatment improvements • Improve catch basin debris management • Floodproof stormwater pump stations (incl. generators) • – Install additional stormwater inlets
Multiple	Governance	Coordinate with County on Flood Protection for Shared Assets	
Multiple	Governance	Develop a Socially Vulnerable Assistance Response Plan	
Multiple	Governance	Investigate Feasibility to Solidify or Increase FEMA Community Rating System (CRS) Class	
Multiple	Governance	Maintain Shoreline Protection Infrastructure	• Review Seawall Ordinance effectiveness as new SLR projections and observed conditions • Increase waterfront setbacks– Maintain seawall inventory • Identify shoreline structures to be elevated

Appendix B – Final Strategy List (continued)

Primary Hazard Addressed	Strategy Category	Strategy Name	Supporting Actions
Storm Surge	Infrastructure	Continue Beach and Dune Renourishment and Enhancements	• Implement Dune Management Plan • Fortify dunes through managing vegetation including trimming, exotic removal, and native plantings. • Construct/Reinforce existing dune system using 'hybrid dune' approaches • Evaluate how to reduce the flood risks associated with dune crossovers • Continue to pilot and expand construction of offshore wave attenuation infrastructure, such as artificial reefs and breakwaters
Multiple	Operational	Purchase Emergency Response Watercraft	
Stormwater	Informational	Develop "Adopt a Storm Drain" program	
Tidal	Informational	Develop Strategies and Monitoring Approaches for Groundwater and Saltwater Intrusion	• Perform groundwater and saltwater intrusion study • Plant salt tolerant and native species
Multiple	Operational	Establish Flood Impacts Monitoring Program	
Multiple	Governance	Coordinate with County and USACE on Miami-Dade Back Bay and Oceanfront CSRM Studies	
Multiple	Informational	Continue to develop and advocate for SLR/Flooding Resources for Private Property Owners and Businesses	• Build upon the Resilience Code and Private Property Adaptation Program to develop homeowner's guide to assist with understanding flood vulnerabilities and options. • Develop climate hazard outreach materials • Implement and explore the feasibility of expanding Private Property Adaptation Program Grant Program • Outreach to residents and businesses on waste storage • Coordinate with federal, state, local, and private entities to develop funding and financing tools for resilience improvements for private properties • Share the FEMA Voluntary Buyout program with repetitive loss properties. • Explore the purchase of vulnerable properties for stormwater management and retention.

Appendix B – Final Strategy List (continued)

Primary Hazard Addressed	Strategy Category	Strategy Name	Supporting Actions
Multiple	Governance	Update and Survey City Buildings Finish Floor Elevations (FFE) as needed	
Multiple	Operational	Identify strategies for historic properties and neighborhoods from the Buoyant City Guidelines to move forward within the regulatory environment and consider building code and zoning code updates (incl. utility standards, historic buildings)	
Multiple	Infrastructure	Protect and Elevate Critical City Facilities	• Elevate backup power for city facilities • Elevate emergency facility parking lots • Install temporary flood barriers for City facilities
Multiple	Infrastructure	Elevate or Floodproof Residential and Commercial Structures	
Multiple	Governance	Explore Transfer of Development Rights Opportunities	
Storm Surge	Infrastructure	Construct Artificial Reefs and Breakwaters	
Storm Surge	Infrastructure	Install Local Flood Gates/ Storm Surge Barriers to Reduce Back Bay Surge Flooding	

Appendix C – Evaluation Criteria and Scoring Methodology

Category	ID	Criteria	Scoring Methodology
Engineering	ENG-1	Protects critical City assets	3 = Provides protection to 2100 2 = Provides protection to 2070 1 = Provides protection to 2040 0 = Does not protect against future SLR
	ENG-2	Ability to adapt to changing climate conditions	3 = Highly flexible without wasting capital investment 2 = Moderately flexible but may result in wasting some capital investment 1 = Little flexibility and/or would result in substantial waste of capital investment 0 = No flexibility without complete rebuild
	ENG-3	Addresses multiple flood types	3 = Addresses three flood types 2 = Addresses two flood types 1 = Addresses one flood type
Environmental	ENV-1	Improves water quality	3 = Provides substantial water quality benefits 2 = Provides some water quality benefits 1 = Provides limited water quality benefits 0 = Project would not provide any water quality benefits
	ENV-2	Protects, enhances, or expands sensitive habitats and ecosystem services	3 = Provides substantial habitat benefits or ecosystem services 2 = Provides some habitat benefits or ecosystem services 1 = Provides limited habitat benefits or ecosystem services 0 = Project would not provide any habitat benefits or ecosystem services
	ENV-3	Reduces or offsets greenhouse gas emissions	3 = Provides substantial greenhouse gas benefits 2 = Provides some greenhouse gas benefits 1 = Provides limited greenhouse gas benefits 0 = Project would not provide any greenhouse gas benefits

Appendix C – Evaluation Criteria and Scoring Methodology (continued)

Category	ID	Criteria	Scoring Methodology
Social	SOC-1	Improves public health metrics (e.g., public access, recreation, or access to emergency services)	3 = Provides substantial public health benefits 2 = Provides some public health benefits 1 = Provides limited public health benefits 0 = Project would not provide any public health benefits
	SOC-2	Enhances resilience of the transportation network	3 = Provides substantial transportation resilience benefits 2 = Provides some transportation resilience benefits 1 = Provides limited transportation resilience benefits 0 = Project would not provide any transportation benefits
	SOC-3	Benefits socially vulnerable communities	3 = Provides substantial direct benefits to socially vulnerable communities 2 = Provides indirect benefits to socially vulnerable communities 1 = Provides limited benefits to socially vulnerable communities 0 = Project would not provide any direct or indirect benefits to socially vulnerable communities
	SOC-4	Reduces risk of injury or loss of life	3 = Provides substantial risk reduction benefits 2 = Provides some risk reduction benefits 1 = Provides limited risk reduction benefits 0 = Project would not provide risk reduction benefits
Implementation Feasibility	IMP-1	Funding/ Financing is partially or fully available or can be obtained	3 = Fundable within existing capital/operations budget 2 = Would require modifying existing budget or external funding, source identified or likely to secure 1 = Would require external funding, source unknown or unlikely 0 = No known funding source identified
	IMP-2	Capital Costs	3 = Limited capital investment required 2 = Moderate capital investment required 1 = Substantial capital investment required, but feasible to fund 0 = Prohibitive capital investment required
	IMP-3	Maintenance Costs and Staff Burden	3 = Will reduce existing O&M costs and/or staff burden 2 = Requires limited O&M costs and/or increase in staff burden 1 = Substantial O&M costs and/or increase in staff burden 0 = Prohibitive O&M costs and/or increase in staff burden
	IMP-4	Ability to implement given current professional market capabilities, policies, and regulations	3 = Can be implemented under current policies and regulations 2 = Can be implemented with minor changes to policies and regulations 1 = Can be implemented with substantial changes to policies and regulations 0 = No possibility to implement given existing policies and regulations that cannot be changed

Appendix D – Evaluated Strategies Scoring Breakdown

Strategy Name	Engineering			Environmental			Social				Implementation Feasibility				Evaluation Score
	ENG-1	ENG-2	ENG-3	ENV-1	ENV-2	ENV-3	SOC-1	SOC-2	SOC-3	SOC-4	IMP-1	IMP-2	IMP-3	IMP-4	
Continue to Incorporate Consistent, up-to-date SLR Projection Language into the Design of Capital Projects	2	2	3	1	1	0	2	2	2	2	3	3	2	3	28
Develop Safety Plans for Roads and Public Right of Ways That May Flood	1	3	3	0	0	0	3	3	2	3	2	2	2	2	26
Assess and Pilot Blue and Green Stormwater Infrastructure Opportunities	1	2	2	3	3	1	1	2	2	1	2	2	1	2	25
Protect and Elevate Critical City Distributed Infrastructure (roadways, traffic control, pipelines, fire hydrants)	1	2	2	1	1	0	3	3	3	3	2	1	1	2	25
Retrofit and Enhance Stormwater System for higher intensity rainfall (incl. pumps, pipes, drainage areas)	2	2	2	3	1	0	1	2	3	2	2	1	1	2	24
Coordinate with County on Flood Protection for Shared Assets	0	3	3	0	1	0	1	2	1	1	3	3	3	3	24
Develop a Socially Vulnerable Assistance Response Plan	0	3	3	0	0	0	2	1	3	2	2	3	2	3	24
Investigate Feasibility to Solidify or Increase FEMA Community Rating System (CRS) Class	0	3	3	2	2	0	1	1	2	2	2	2	1	3	24
Maintain Shoreline Protection Infrastructure	1	2	2	0	1	0	2	2	2	3	2	2	2	2	23
Continue Beach and Dune Renourishment and Enhancements	1	2	1	1	3	1	2	1	2	1	1	1	1	3	21
Purchase Emergency Response Watercraft	0	3	3	0	0	0	3	0	2	0	2	2	3	3	21
Develop "Adopt a Storm Drain" program	0	3	2	3	2	0	0	1	0	1	2	3	2	2	21

Appendix D – Evaluated Strategies Scoring Breakdown (continued)

Strategy Name	Engineering			Environmental			Social				Implementation Feasibility				Evaluation Score
	ENG-1	ENG-2	ENG-3	ENV-1	ENV-2	ENV-3	SOC-1	SOC-2	SOC-3	SOC-4	IMP-1	IMP-2	IMP-3	IMP-4	
Develop Strategies and Monitoring Approaches for Groundwater and Saltwater Intrusion	0	2	1	2	1	0	1	2	2	1	1	2	2	3	20
Establish Flood Impacts Monitoring Program	0	3	2	1	0	0	2	2	1	1	2	2	2	2	20
Coordinate with County and USACE on Miami-Dade Back Bay and Oceanfront CSRM Studies	0	3	2	0	0	0	1	0	1	1	3	3	3	3	20
Continue to Develop and Advocate for SLR/ Flooding Resources for Private Property Owners and Businesses	0	3	3	0	0	0	0	0	2	1	2	3	2	3	19
Update and Survey City Buildings FFEs as needed	0	3	2	0	0	0	0	0	0	1	2	3	2	3	16
Identify strategies for historic properties and neighborhoods from the Buoyant City Guidelines to move forward within the regulatory environment and consider building code and zoning code updates (incl. utility standards, historic buildings)	1	2	3	0	0	0	0	0	0	1	2	2	2	2	15
Protect and Elevate Critical City Facilities	1	1	2	0	0	0	2	0	2	2	2	1	1	1	15
Elevate or floodproof residential and commercial structures	1	1	2	0	0	0	2	0	1	2	1	1	2	1	14
Explore Transfer of Development Rights Opportunities	0	3	3	1	2	0	0	0	0	0	0	3	1	1	14
Construct Artificial Reefs and Breakwaters	1	1	1	2	2	0	1	0	0	1	0	1	1	1	12
Install Local Flood Gates/Storm Surge Barriers to Reduce Back Bay Surge Flooding	2	0	1	0	0	0	3	0	0	3	0	0	0	0	9

MIAMIBEACH
RISING
ABOVE