Coastal Vulnerability Assessment: City of Clearwater, Florida

Contract # C1469
Florida Department of Economic Opportunity

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The City of Clearwater is one of the three communities involved in the Community Resiliency Initiative Pilot Projects administered through the Florida Department of Economic Opportunity (DEO) and funded by the National Oceanic and Atmospheric Administration (NOAA). The overall effort seeks to assess community vulnerability to projected increases in coastal flooding and develop strategies to improve resilience to the associated impacts.

This report summarizes activities conducted under Task 1 of the pilot project in the City of Clearwater – the community Coastal Vulnerability Assessment. Knowledge, material and the outputs of Task 1, summarized here, will be leveraged by Task 2 of the pilot study. Task 2 focuses on reviewing existing federal, state and local programs and policy to provide strategy recommendations that focus on the City's priorities and identified risks. Such strategies are intended to be integrated into existing local planning, policy, and budgeting mechanisms.

Three types of coastal flooding were identified for analysis in the study effort. These included:

- Nuisance flooding – a minor flood event that occurs monthly and typically results in the flooding of roads, disrupting travel.
- The 100-yr recurrence interval flood, which defines the Special Flood Hazard area depicted on Federal Emergency Management Agency Flood Insurance Rate Maps. Such an event has a 1% chance of occurring any given year, and a 26% chance of occurring over a 30-year timeframe.
- The 500-yr recurrence interval flood, which represents a catastrophic flood event and is often used to assist in the safe siting of critical infrastructure. Such an event has a 0.2% chance of occurring any given year, and a 6% chance of occurring over a 30-year timeframe.

The study assessed the vulnerability of the City to these existing flood conditions, along with three scenarios of future sea level. The scenario values were developed to represent the range of uncertainty of sea level rise (SLR) projections for three timeframes, including:

- 1 ft of SLR, representing change projected in the short-term (30-years from present). This timeframe is similar to the municipal planning horizon.
- 2 ft of SLR, representing conditions projected in the moderate-term (60-year) time frame.
- 3 ft of SLR, representing long-term (80+ years) projections.

These conditions were used to assess the City's existing and future coastal flooding vulnerability. The study established cartographic layers of each coastal flood type and SLR scenario combination. The amount, changes in land area subject to each flood condition, and projected flooding "hotspots" were identified. The flood cartographic layers were then overlaid on the City's GIS data to assess vulnerability of buildings, roads, bridges, schools, fire stations and water treatment facilities. Additional analyses provided projections of future changes in heavy precipitation that may affect stormwater management, future shoreline change along the Gulf of Mexico shoreline, and the City's vulnerability to saltwater intrusion, changes to potential future. The essential results of these assessments are summarized below:

Where are the flooding "hotspots" in Clearwater?

- The barrier islands, especially Clearwater Beach Island, have the greatest vulnerability to changes in flooding due to increasing sea levels. Sand Key and Island Estates are also relatively vulnerable to future flooding. These areas are projected to experience an increasing frequency and duration of instances of nuisance flooding as sea level rises.
- Other areas of concern include Stevenson Creek, Cooper Bayou and Allen Creek.

How much more flooding is expected?

- The area subject to nuisance flooding is projected to increase at more than twice the rate of the 100- or 500-yr floodplains for the examined scenarios.
- Nuisance flooding is expected to double from present day conditions with a 1 ft rise in sea level – an increase of 1.6 square miles. Further increases are associated with 2 and 3 ft of SLR, an additional 3.8 and 5.9 additional square miles of flooding, respectively. Large areas of Clearwater Beach Island would be impacted by this change.
- Increases in the 100- and 500-yr floodplains are similar – these include a 1.3 and 2.7 square mile increase in the floodplain for 1 and 2 ft increase in sea level. A SLR scenario of 3 ft will increase the 100-yr floodplain by 4.1 square miles and the 500-yr floodplain by 4.4 square miles. Most growth of the 100- and 500-yr floodplains is around the existing floodplain "fringe".
- Floodplain impacts are described in terms of expansion of the horizontal footprint. It is worth noting that SLR means floodwaters in these areas are also getting deeper which will magnify damages to infrastructure and property.

How will street-level vulnerability to flooding change?

- Street-level flood vulnerability increases the most for nuisance flooding, a notable finding given the frequency of this flood type.
- Existing street-level nuisance flood vulnerability is relatively low at 3.5 miles; this increases 2-fold with 1 ft of SLR, and then expands rapidly by 7- and 11- fold (25 and 40 miles) for 2 and 3 ft of SLR, respectively.
- As vulnerability increases with each scenario, existing vulnerable areas will experience step-wise increases in flood frequency and flood depth.

How will building vulnerability to flooding change?

- Similar to changes in vulnerability noted for roads, nuisance flooding shows the greatest increase of vulnerable buildings relative to existing susceptibility.
- For nuisance flooding, a 41- and 77-fold increase in building exposure was determined for 2- and 3-ft of SLR, respectively. With these increases, in sea level, almost 3,000 buildings will be vulnerable to a nuisance flood type event, just 1,000 less than exposure to today's 100-yr flood event.
- Building vulnerability classification indicates that a building is within the flooding extent for each condition, but does not assess potential damages. In other words, many of these vulnerable buildings could be subject to flooding *around* the structure with minimal damage.

How will the bridge vulnerability to flooding change?

- Causeway Boulevard and the Island Way Causeway would start experiencing passability issues to nuisance flood events with 2 ft of SLR; and
- Additional sea level rise would increase the frequency and duration of instances when the passability of these bridges would be impacted due to water over the roadway.

What essential facilities will be affected by changes in flooding?

- No schools in the City school facility layer were found to be vulnerable to any flood hazard or SLR combination examined by this study effort.
- Two of nine fire stations are vulnerable to projected future changes in nuisance flooding.
- Two of six water pollution control facilities are vulnerable to flooding by 100- and 500-yr events under existing and projected future conditions.

How might the Gulf of Mexico shoreline change trends respond to increases in sea level?

- Although quantitative analysis was performed, the uncertainty and limitations of the methodology allows only qualitative projections.
- Rates of shoreline retreat on Sand Key would be expected to increase.
- Clearwater Beach Island, which has experienced shoreline advance in the recent past, may experience lower rates of growth or maintain current position with sea level increases. Future changes are dependent on coastal sediment sources more than the response to sea level rise.

What changes in heavy precipitation are projected?

- The frequency of heavy rainfall events, characterized here by the 24-hour duration, 25-year and 100-yr recurrence intervals, are expected to increase by about 12-13% in the next 30-years, and 17-20% in the next 60 years – 30% higher than existing values in the Clearwater Stormwater Drainage Manual.
- Projected changes, while subject to some uncertainty due to the range of model forecasts, are outside of the 95% confidence error of the historical observations. This reduces uncertainty in the trend and magnitude of these projections.
- Current design values in the Clearwater Stormwater Drainage Manual may be based on outdated rainfall recurrence statistics. The NOAA Atlas 14 values may provide an improved data source over existing values.

What are the Anticipated Changes in the Clearwater Water Table?

- The City is vulnerable to saltwater intrusion because of its exposure as a peninsula and series of barrier islands, with saline and/or brackish water on all sides.
- Clearwater's Groundwater Replenishment Project (GWR) network may be useful for long-term monitoring.
- A groundwater replenishment project using reclaimed water from the Clearwater's Northeast Water Reclamation Facility is currently in a feasibility stage. This project would help mitigate saltwater intrusion using purified reclaimed water to replenish local aquifers.

1 OVERVIEW

Florida's low-lying topography, developed coast and growing population result in the state having one of the greatest needs in the nation to promote and execute sea level rise adaptation planning. In response, the Florida Coastal Management Program Section 309 strategy included a five-year initiative titled "Community Resiliency: Planning for Sea Level Rise" to examine the statewide planning framework and establish best practices for integrating adaptation and coordinating efforts across Florida. Through this initiative, the Florida Department of Economic Opportunity (DEO), in partnership with the National Oceanic Atmospheric Administration (NOAA), Florida Department of Environmental Protection (DEP), the Florida Coastal Management Office (FCMO), and the Florida Division of Emergency Management (DEM), are working together to integrate coastal adaptation measures into existing local planning, policy and budgeting mechanisms.

As part of the Community Resiliency Initiative, DEO has initiated pilot studies in three communities across the state. The pilot studies will undertake coastal hazard risk and vulnerability analysis to inform adaptation planning measures that may be integrated into existing local planning, policy and budgeting mechanisms. The effort is not seeking to create a "one-size-fits-all" approach, but rather provide unique case studies that reflect the unique exposure, characteristics and goals of the individual communities. The three participating communities including the City of Clearwater, Escambia County, and the City of St. Augustine represent a cross-section of Florida's geography and provide distinctive examples to explore risk informed adaptation planning.

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2 PROJECT SCOPING

2.1 *Initial Questionnaire*

To initiate the project, the project team used a questionnaire to learn the City's motivation and goals, existing flood related issues, understanding of SLR, and data assets available for the study. At the project Kickoff Meeting, participants discussed the City's responses and used that information to shape the scope of the discussion during the design meeting.

The questionnaire asked the following eight questions:

1. What do you want the community to get out of the coastal resilience vulnerability and adaptation study?

   Response: The City anticipates that this study will provide recommendations that can be incorporated into our comprehensive plan, development code, and/or other plans (e.g., Local Mitigation Strategy, Post Disaster Redevelopment Plan as appropriate) so that the City is prepared for disasters and better able to adapt to the effects of sea level rise and storm surge. This could include the need for controls on building requirements or the limiting of encroachment into areas that are designed to provide a barrier. The potential may exist that this study can build or reflect upon items in Clearwater Greenprint sustainability plan.

   In addition to the changes in our comprehensive plan and/or development code, we expect that the study will provide a summary and impact of flood impacts to buildings, infrastructure, and on tourism and the economy based on low-end and high-end sea level rise projections, as well as tidal flooding events. It is also anticipated that the study will include the costs associated with implementing proposed upgrades into the City's scheduled capital improvements for each of the projections mentioned above, and potentially a comparison of costs to the "do nothing" approach (e.g., repair and rebuilding after a disaster compared).

2. Should the study focus on a particular geography of the community, such as a downtown or area targeted for redevelopment? If so, please describe.

   Response: The City's beach community will be one of the major focus areas, as it is a large piece of the City's economy. There are currently four hotels/resorts currently under construction, and numerous other projects have been approved. Other areas of focus will be Island Estates, Sand Key, properties that are near creeks, and parts of the mainland that lie just west of the City's bluffs fronting the harbor which would be impacted by sea level rise and flooding. Portions of the City along Tampa Bay should also be considered as they are currently improved with both commercial and residential uses, as well as a City water treatment plant. There are also proposed residential developments that could potentially be affected by sea level rise.

3. Should the study focus on particular infrastructure (e.g. due to aging, proximity to hazard, etc.)? If so, please describe.
   Response: An identification and evaluation of the infrastructure that would be prone to damage or increased wear and tear as a result of sea level rise should be included (e.g., roadways, bridges, stormwater infrastructure, and other utilities). The City has an expansive stormwater

system, but it should be studied to determine how to mitigate the chances and effects of tidal flooding or flooding from substantial rainfall events. Roads within the affected areas should also be studied so that the City can implement changes during scheduled resurfacings and also so that the City can minimize the chances that a roadway will be lost. Other Utility plants (e.g., water treatment or reverse osmosis) that may be impacted should be identified and included within any evaluations.

4. Has the community discussed planning scenarios in relation to adaptation planning?

   Response: The City approved a Post Disaster Redevelopment Plan in 2013, and our Economic Development Department has disaster recovery plans for businesses. As part of the Post Disaster Redevelopment Plan, the City completed the Coastal Resilience Index Community Self-Assessment in partnership with the Pinellas County IFAS extension Sea Grant Agent.

5. Are there particular timelines (e.g. the master planning time frame) that are of interest?

   Response: At this time the City doesn't have a particular timeline/time frame for this Plan in mind. It could include recommendations for the short-term as well as long-term. For example, there may be recommendations that address how future infrastructure projects address/consider future sea level rise projections that would be implemented in the short-term, while there may also be recommendations for larger improvements or policy changes that are more long-term.

6. What data do you have about the community to help characterize the built environment and natural assets?
   ・ Parcel data | ・ Building footprints | ・ Roads | ・ Above/underground utilities | ・ Others
   Response: The City has a pretty extensive amount of GIS data available, and can request assistance from other sources (e.g., Pinellas County, MPO) as needed. The City can also provide data on the Community Rating System.

7. Studies of this type typically involve leadership from the departments responsible for emergency management, public works, and planning. Who from the community do you anticipate being key points of contact from your community (provide name, phone, and email)?

   Ed Chesney, Manager, Environmental Engineering
   Elliot Shoberg, Manager, Stormwater Engineering
   Dave Porter, Director, Public Utilities
   Scott Ehlers, Emergency Manager

8. Stakeholder engagement will be a key to long-term success for any of the initiatives developed during this process. Please list who you perceive as stakeholders to this project.

   a. Internal Stakeholders –
   Engineering, Fire & Rescue, Police, Public Utilities, Planning & Development, IT, Public Communications, Marine & Aviation, Risk Management

   b. External Stakeholders –

Homeowners associations (e.g., Island Estate, Carlouel, Mandalay Point, Clearwater Beach, Old Clearwater Bay, Edgewater Drive, Pierce 100 Condominium, Sand Key Civic, Old Clearwater Bay, Edgewater Drive, Harbor Oaks)
Utility Companies (e.g., Duke Energy, Verizon, Brighthouse)
Hotel Managers/Owners, business owners, insurance agencies, realtors
Various Agencies (e.g., NOAA, SWFWMD, MPO, PSTA)
The City's Environmental Advisory Board
Clearwater Innkeepers Association
Pinellas County Emergency Management
Chambers of Commerce (Regional Chamber and Beach Chamber)
Visit St. Pete/Clearwater (tourism)

2.2 *Design Meeting*

The purpose of the design meeting was to frame the problems faced by the City with respect to coastal resilience and to identify analysis products that would support the adaptation planning process. During the meeting, the research team gathered contact information and the names of datasets that could be leveraged to address some of these issues. The breakout sessions during the January 2016 design meeting revealed a number of key issues, identified by attendees representing the City and the gas utility. A synopsis of the design meeting follows, with a full summary provided in Appendix B.

Priority issues included:

- Impacts on infrastructure and utilities, especially in areas with recurring tidal and nuisance flooding.
- Establishing citywide support in preparing for at least one foot of sea level rise over the next 30 years.
- Economic impacts.

Representatives of the following institutions participated in the design meeting:

- City of Clearwater
    - Gas
    - Engineering Department, Environmental Division
    - Planning and Development
    - Public Utilities
    - Emergency Management
- Florida Department of Economic Opportunity
- Dewberry Consultants, LLC

Subsequent to the meeting, the research team contacted the designated personnel and collected the data described during the meeting. This data augmented basic geospatial data already supplied by the City. Based on the issues identified, data holding and initial data exploration, the team refined the problem statement and developed a proposed approach, which is described in Section 2.3.

2.3 *Work Plan*

Task 1 of the overall study effort focused on performing a vulnerability and risk assessment to assess the City of Clearwater's potential impacts from SLR. The design meeting, as described in the preceding section, included facilitated breakout sessions to gain an understanding of City goals and concerns, which informed the problem statement. Discussion also focused on establishing the SLR scenarios and flood conditions for the study effort. The flood conditions and SLR scenarios decided on from that discussion is presented in the following section and thus not repeated here. From design meeting, the study team developed a work plan to address the key items identified during the design meeting breakout sessions. A draft work plan was circulated to the City for feedback. The study team finalized the work plan to accommodate feedback and then initiated the vulnerability assessment. The assessments presented in this report reflect this process.

3 MAPPING SEA LEVEL RISE

Geospatial coverages of how SLR would expand the selected scenarios and flood types to visualize the extent of future flooding. A summary of the methodologies for mapping sea level rise conditions are presented first, followed by the results of the analysis. For further detail on the analytical approach, refer to the Appendix A.

3.1 *What was the Process for Mapping Sea Level Rise?*

The first step for mapping sea level rise was to establish sea level rise scenarios in consultation with the City during the design meeting. Sea level rise scenarios were based on 2012 NOAA Technical Report OAR CPO-1, Global Sea Level Rise Scenarios for the United States National Climate Assessment. The design meeting established a preference for representative short-, moderate-, and long-term values with short-term value providing a "no regrets" planning elevation.

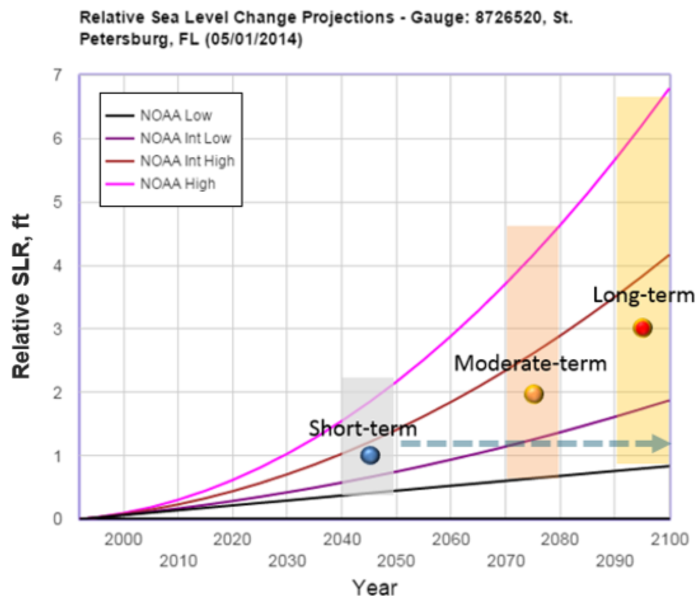

Figure 1. Representative planning values shown with NOAA SLR Projections for St. Petersburg, FL. Vertical datum is local mean sea level.

Relative SLR projections were retrieved from the U.S. Army Corps of Engineers Sea Level Rise Calculator http://www.corpsclimate.us/ccaceslcurves.cfm). The St. Petersburg, FL NOAA station was selected as the source for the projections due to the longer period of record. It is also the station recommended by the Tampa Bay Climate Science Advisory Panel for this purpose. Representative values for each of the three identified time frames were established by taking the average value of the projections across the set of curves for each time frame. NOAA sea level rise scenarios and the established representative values from the design meeting are presented in the following table (Table 1). These values are shown against the NOAA SLR curves in Figure 1.

At the design meeting, the City identified the coastal flood types of interest as the nuisance flood as well as the 100-yr and 500-yr recurrence interval floods (Table 2).

Table 1. NOAA SLR scenarios and representative values established during design meeting discussion[1]. All units are in feet.

Time Horizon	Low	Inter-mediate Low	Inter-mediate High	High	Average Value	Representative Value
Short-term (2040s)	0.41	0.66	1.2	1.9	1.0	**1**
Moderate-term (2070s)	0.64	1.25	2.6	4.2	2.2	**2**
Long-term (2090s)	0.80	1.74	3.8	6.2	3.1	**3**

Table 2: Selected flood type descriptions.

Coastal Flood Event Type	Description	Frequency/Likelihood	Water Elevation, ft NAVD88	Data Source
Nuisance Flooding	Areas frequently flooded by tides and/or small coastal storms. Results in shallow flooding, which may disrupt or limit use.	~1-2 times monthly	3 ft	Tidal gauge analysis and coordination with the City
100-year Floodplain	Areas subject to flooding by significant coastal storms. Defines the Special Flood Hazard Area as delineated on Federal Emergency Management Agency Flood Insurance Rate Maps. Also known as the "Base Flood"	1% chance per year, ~26% chance in 30 years	~6-10 ft	Preliminary FEMA FIS for Pinellas County
500-year Floodplain	Areas subject to flooding by extreme hurricanes. These areas are at higher elevations and otherwise have minimal flood hazards from coastal events.	0.2% chance per year, ~6% chance in 30 years	~10-14 ft	Preliminary FEMA FIS for Pinellas County

Changes to each coastal flood hazard event were estimated by increasing the present day base surface elevations by simply adding each sea level rise scenario to the base flood conditions. After applying sea level rise conditions to each coastal flood event type, inundation and coastal flooding extents were established for each scenario and flood frequency by intersecting the water surface elevation models with the topographic elevation models in a Geographic Information System (GIS). The resulting cartographic coverages were post-processed to remove artifacts. An additional check was performed to remove areas shown as flooded that were not hydraulically connected to a water body.

[1] NOAA Low scenario: continuation of historical observations; NOAA Intermediate-Low scenario: upper end of the IPCC Fourth Assessment Report; NOAA Intermediate-High scenario: upper end of semi-empirical methods; NOAA High scenario: potential change with maximum possible glacier and ice sheet loss by the end of the century.

3.2 *How Will Vulnerability to Flooding Change with Sea Level Rise?*

Sea level rise increases water elevations relative to land, resulting in larger and deeper floods. Vulnerability to these future conditions varies by each flood type and local land elevations. The mapping layers produced for each flood type and SLR scenario were reviewed to gain a better understanding of how each flood type would change with SLR. This included a review of the sequence of increasing flooding, from today's condition (the baseline) through the 1, 2, and 3 ft SLR scenarios for each event type. Changes in land area vulnerable to flooding to each event type are summarized in Figure 2.

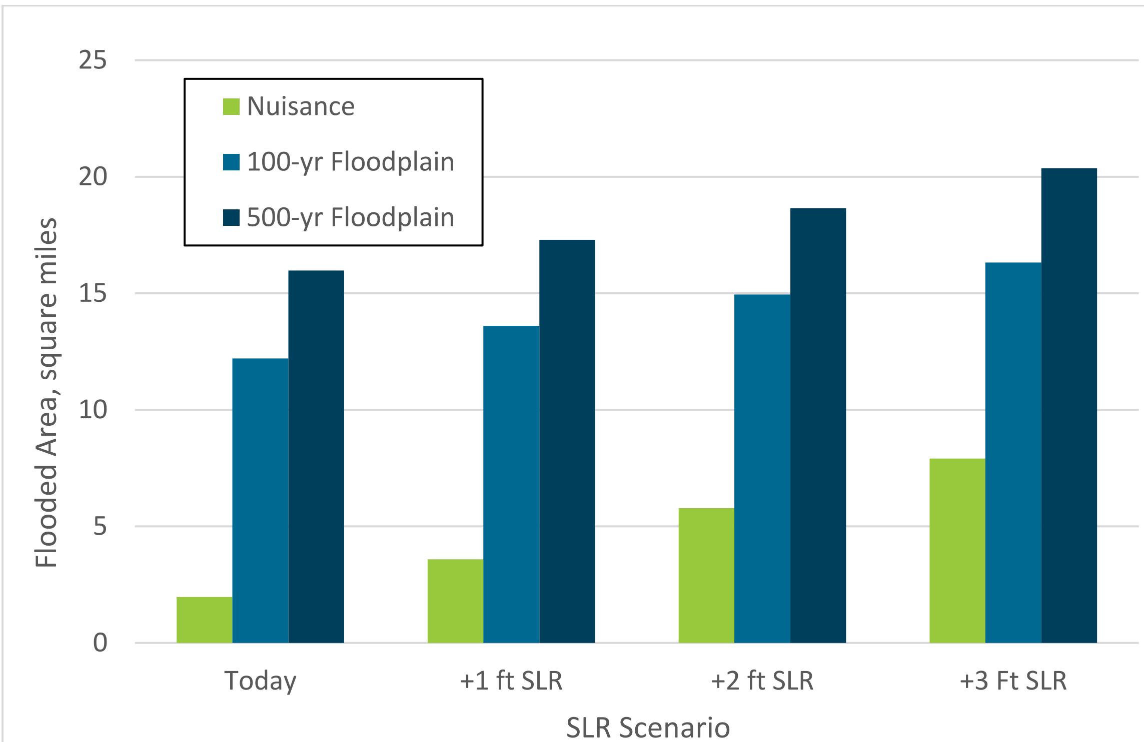

Figure 2. Changes in land area flooded by each flood type with 1, 2, and 3 feet of SLR as compared to existing conditions.

Key areas of future vulnerability, or "hotspots" are identified in Figure 3. Overall, the Gulf-side islands have the most vulnerability to future flooding. Future increases in flood vulnerability are relatively limited on the mainland coast, existing creeks and bayous.

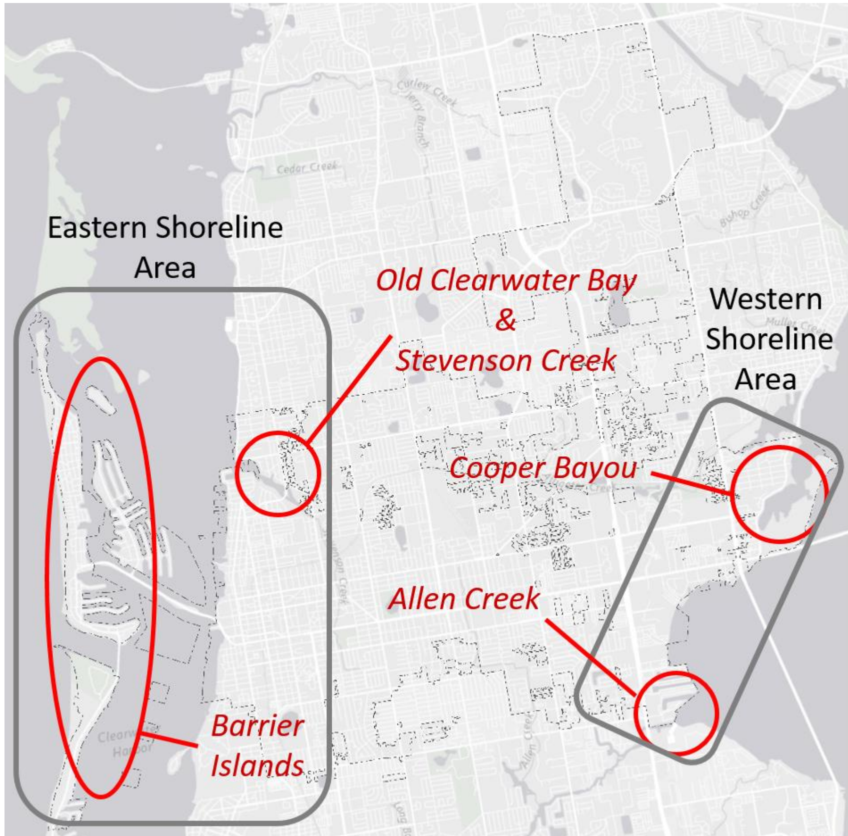

Figure 3. Hotspots of SLR impacts across City of Clearwater.

The map coverages for the City's vulnerability to future flooding was broken out into two areas, including the western shoreline (Figure 4, Gulf of Mexico, Clearwater Harbor and St. Joseph Sound shorelines) and the eastern shoreline (Figure 5, Old Tampa Bay shoreline). Key vulnerabilities to each flood type and SLR scenario are discussed in greater detail in the following text.

- Overall, for the flood types examined, a "step-change" or "tipping point" where a much large area is becomes vulnerable to flooding was not apparent. Changes in the area vulnerable to flooding for each event type relative to today are shown in Table 3.

Table 3. Estimated changes in flooded area as compared to today's condition.

SLR Scenario, ft	Change in vulnerable area, sq. mi		
	Nuisance flood	100-yr Flood Event	500-yr Flood Event
1	1.62	1.39	1.31
2	3.81	2.74	2.67
3	5.93	4.11	4.38

- Nuisance Flooding:
  - Nuisance flooding is projected to increase at more than double the rate of the 100-yr and 500-yr floodplains for the examined SLR scenarios.

  - An almost 2-fold increase in vulnerable area is expected with 1 ft of SLR, 3-fold for 2 ft and 4-fold for 3 ft.
  - The majority of vulnerable areas to future nuisance flooding are located on Clearwater Beach Island:
    - The soundside of the island has the greatest vulnerability – an area from Aster Street to northern end of Bay Esplanade is vulnerable to a 1 ft increase in SLR.
    - Existing street level flooding in this area would be expected to expand and impact buildings while becoming more frequent and deeper.
    - Exposure of the island increases with 2 and 3 ft of SLR, expanding towards the southern end and affecting the finger islands in Clearwater Bay.
    - The vulnerable area is already hardened with bulkheads or similar.
  - Island Estates has extensive vulnerability to nuisance flooding, however, impacts are not anticipated until towards the latter end of the century.
    - Windward, Midway and Leeward Islands would be almost completely flooded by a nuisance-type event at the 2 and 3 ft SLR scenarios.
  - Sand Key has relatively low vulnerability to future nuisance flooding:
    - In the near term, areas vulnerable to a 1 ft SLR are mostly limited to the ocean beaches.
    - Street-level flooding is apparent with a 2 ft SLR; and
    - Nuisance flooding expands to areas outside the streets with a 3 ft rise.
  - Vulnerability of the mainland coast of the City of Clearwater is limited:
    - On the eastern side of the City, areas directly adjacent to Stevenson Creek Areas are vulnerable to nuisance flooding at the 2 and 3 ft SLR scenarios.
      - Homes on the northern end of Venetian Point Dr. are vulnerable to nuisance flooding at 2 ft of SLR; and
      - The water treatment plant will be exposed at 3 ft of SLR.
    - On the western side of the city, future nuisance flood vulnerability is concentrated in two locations:
      - Buildings at Safety Harbor Pier become exposed to nuisance flooding at the 2 and 3 ft SLR scenarios.
      - The area surrounding Clearwater Christian College, building exposure is limited at the 1 ft SLR scenario, but increases with the 2 and 3 ft scenarios.
      - Residences on the finger piers at Bay Aristocrat Village are vulnerable at the 3 ft scenario.

- 100-yr Flood Event
  - Projected changes to the 100-yr Flood Event with each SLR scenario are provided in Table 3.
  - Compared to today, the 100-yr Flood Event is anticipated to increase by 1.1, 1.2 and 1.3 times to 1, 2, and 3 ft of SLR, respectively.
  - On the eastern side of the City:
    - The Gulf-side islands are presently almost completely flooded in by the 100-yr Flood Event – thus changes are limited.
    - On the mainland, expansion in the 100-yr floodplain is limited to the area north of Stevenson Creek.

  - On the western side of the City:
    - The 100-yr Flood Event expands into the upper end of Alligator Creek with 2 ft of SLR;
    - Expansion of the 100-yr Flood Event is also notable along Allen Creek.

- 500-yr Flood Event
  - Projected changes to the 500-yr floodplain with each SLR scenario are provided in Table 3.
  - Compared to today, the 500-yr Flood Event is anticipated to increase in vulnerable area by 1.1, 1.2 and 1.3 times to 1, 2, and 3 ft of SLR, respectively – very similar to the 100-yr Flood Event growth.
  - On the eastern side of the City:
    - Under existing conditions, the Gulf-side islands are completely flooded by the 500-yr Flood Event – such events would have deeper flooding and larger wave heights with SLR.
    - On the mainland coast, notable expansion occurs of the north side of Stevenson Creek, mostly in an undeveloped area between Sunset Point Road and State Street. Flooding expands to include a few more homes in this area with SLR.
  - On the western side of the City:
    - Expansion of the 500-yr Flood Event is limited to mostly small increases at the fringe;
    - Flooding does appear to extend up from Allen Creek to Allen's Creek Park and Imperial Park; however, the floodplain is constrained to the creek and does not appear to impact any structures.
    - A number of buildings enter the 500-yr Flood Event in the vicinity of Coach Mobile Home Park, especially with the 2 and 3 ft SLR scenarios.
    - A small number of structures enter the floodplain along Mullet Creek, mostly in response to 2 and 3 ft of SLR.

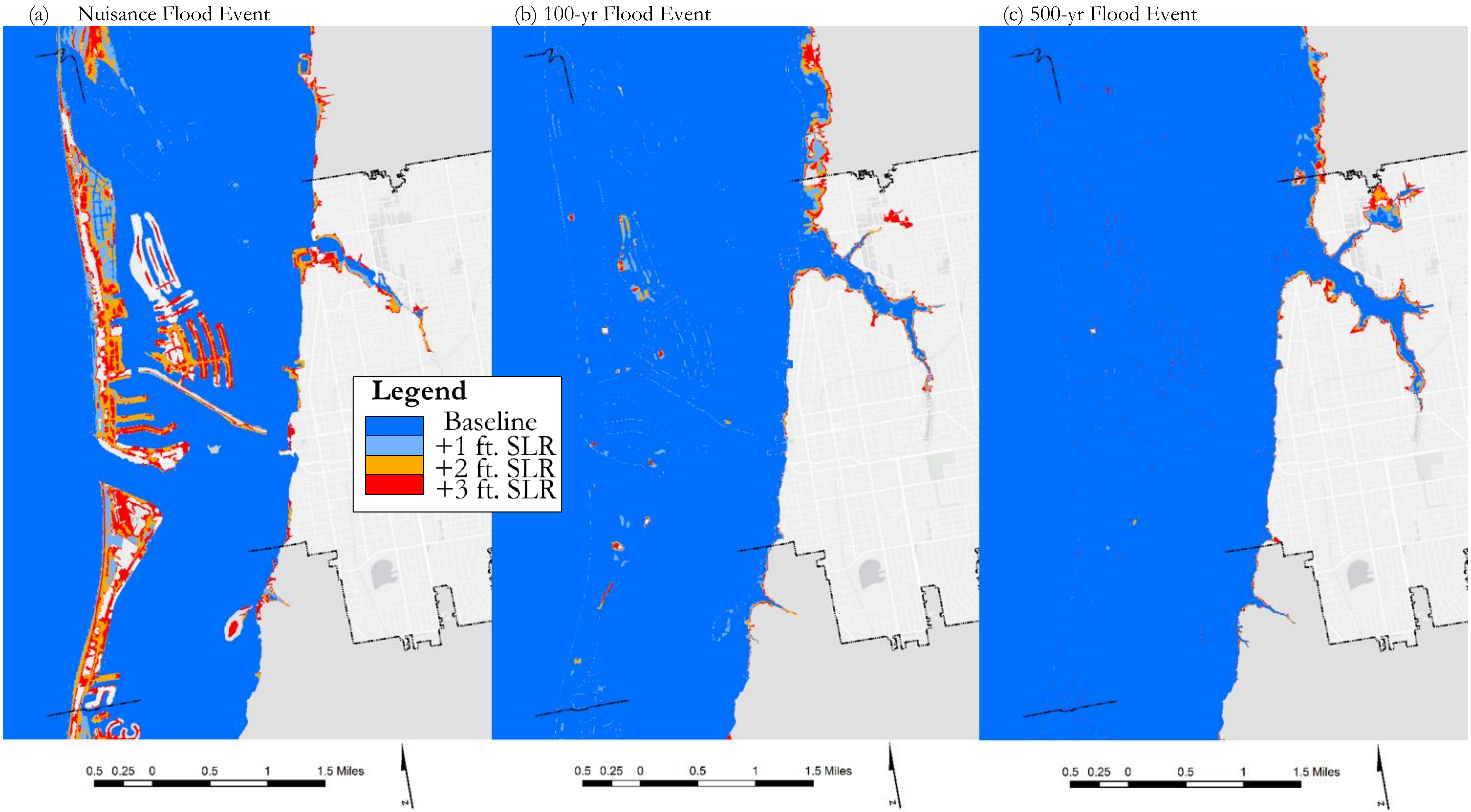

Figure 4. Changes in flood extents for nuisance flooding (a), the 100-yr floodplain (b) and the 500-yr floodplain (c) along the western shoreline Area of Clearwater. For reference, baseline flood elevations for these conditions are: nuisance (3 ft NAVD88), 100-yr Flood Event (6-10 ft NAVD88), 500-yr Flood Event (10-14 ft NAVD88).

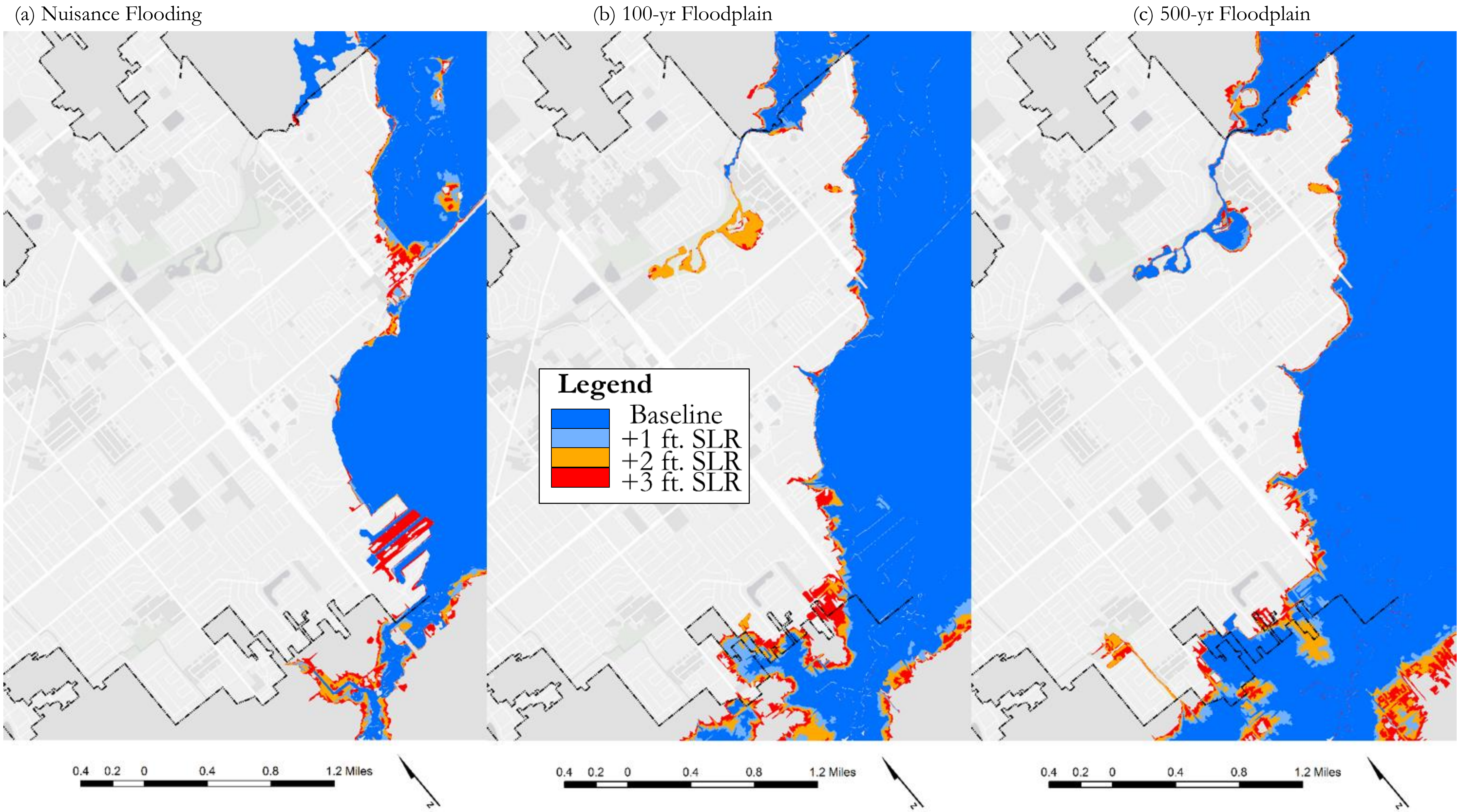

Figure 5. Changes in flood extents for nuisance flooding (a), the 100-yr floodplain (b) and the 500-yr floodplain (c) along the eastern shoreline area of Clearwater. For reference, baseline flood elevations for these conditions are: nuisance (3 ft NAVD88), 100-yr Flood Event (6-10 ft NAVD88), 500-yr Flood Event (10-14 ft NAVD88).

4 VULNERABILITY ASSESSMENT

The objective of the vulnerability assessment was to identify infrastructure impacted by sea level rise and to summarize key impacts and vulnerability "hot spots". In order to assess vulnerability to critical assets in Clearwater, the analysis focused on five main components:

Vulnerability Assessment Process	
Assessment Item	**Information Analyzed**
Road Vulnerability	• Percent of network affected by each flood type and SLR scenario combination
Buildings	• Change in number of buildings exposed to flooding from each event type and SLR scenario
Bridges	• Bridges impacted by flooding from each event type and SLR scenario
Facilities	• Structures exposed (fire stations, schools, and wastewater treatment facilities) to flooding from each event type and SLR scenario
Groundwater Impacts	• Local and regional response to SLR

For each component of the vulnerability assessment, a summary of the methodologies is presented first, followed by the results of the analysis. For further detail on the technical approach, refer to the Appendix A.

4.1 *Road Vulnerability Assessment*

To address the roads component of the vulnerability assessment a simple analysis of road segment vulnerability to each flood condition was performed. To accomplish this, the city road GIS network centerline coverage was segmented into small, discreet lengths. The length of each individual segment varied on local complexity of the roads but no segment was longer than 100 ft. The road segments were then intersected with the flood extents mapped for each SLR scenario and the total length of road affected in each scenario was summarized. A limitation of this approach is that elevated road segments, typically bridges, are classified as vulnerable due to position within the flood coverage. A separate bridge vulnerability analysis was undertaken and is presented later in the report to address this issue.

4.1.1 How Vulnerable are Roads to Future Sea Level Rise Impacts?

SLR will increase the vulnerability of the City's roads to flooding. A summary of the relative changes in road vulnerability to each flood type is shown in Figure 6, length of roads vulnerable to each flood type is provided in Table 4. Changes are summarized relative to each flood type below:

- Nuisance Flooding
    - Road vulnerability increases the most for nuisance flooding, a notable finding given the frequency of this flood type.
    - Existing vulnerability is relatively flood frequency and flood depth.
    - The geographic distribution of this vulnerability is shown in Figure 7.

- 100-yr and 500-yr Flood Events

- Approximately 10% of the City's road network is vulnerable to flooding to the higher flood elevations associated with the 100-yr and 500-yr recurrence interval events.
- Increases in the road vulnerability are relatively low and just over a 1-fold increase through 3 ft of SLR as compared to today's condition for both the 100- and 500-yr recurrence interval events.
- The geographic distribution of the increasing vulnerability to the 100-yr event is shown in Figure 8 and for the 500-yr event in Figure 9.

Table 4. Changes in length of road segments vulnerable to each flood type and SLR combination.

Street Flooding - Clearwater FL		
Flood Event	***SLR Scenario, ft***	***Length of affected road, miles***
Nuisance	0	3.5
	1	8.3
	2	25.2
	3	39.8
100-yr Flood Event	0	65.7
As vulnerability increases with each scenario, existing vulnerable areas will experience step-wise increases in	**1**	**71.2**
	2	76.0
	3	80.8
500-yr Flood Event	0	81.5
	1	85.9
	2	90.5
	3	95.5

- low at 3.5 miles; this increases 2-fold with 1 ft of SLR, and then expands rapidly by 7-and 11-fold (25 and 40 miles) for 2 and 3 ft of SLR, respectively.

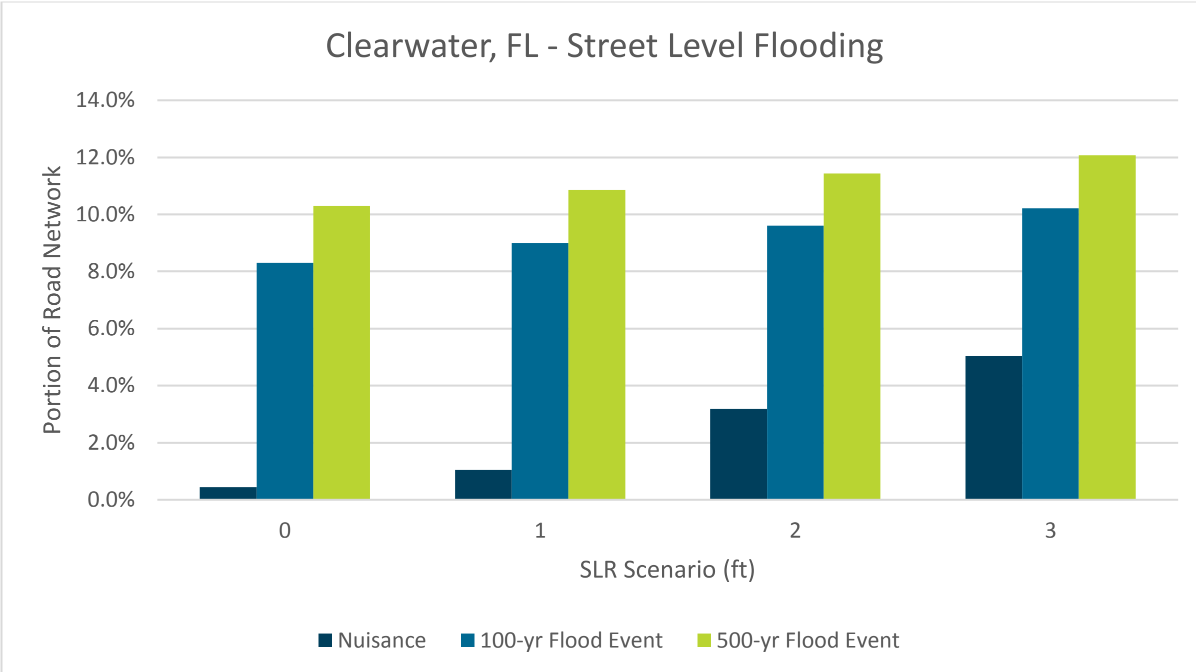

Figure 6. Percent of road network affected by nuisance, 100-yr and 500-yr flood events for each SLR scenario.

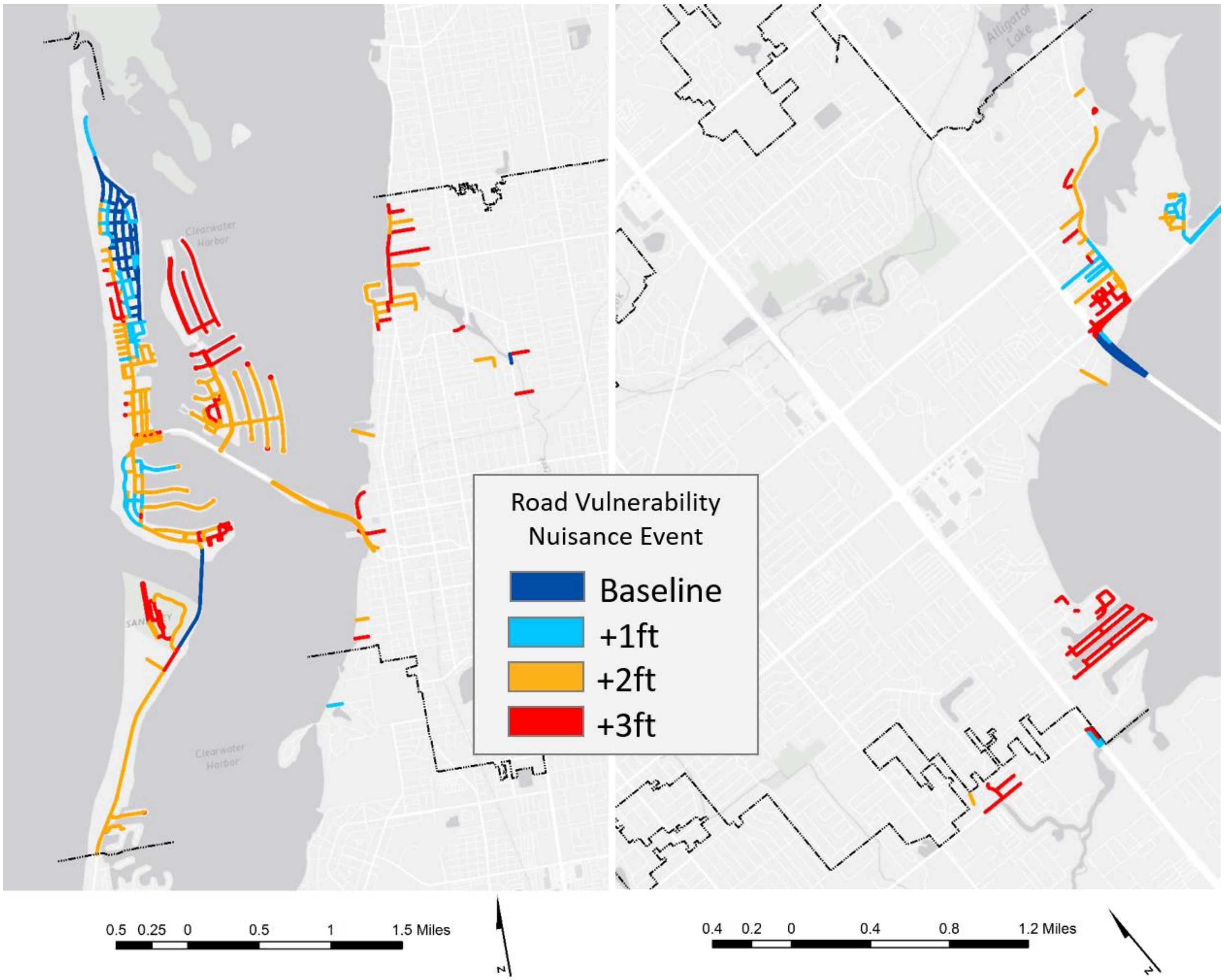

Figure 7. Changes in road vulnerability to nuisance flooding with increasing SLR. Patterns of vulnerability reflect the changing vulnerability to the flood event as shown in the mapping section. Vulnerability is concentrated on Clearwater Beach Island and back lying areas, expanding from a relatively limited area along the sound side of Clearwater Beach Island to the southern half of the island as well as the other islands in St. Joseph sound with increasing SLR.

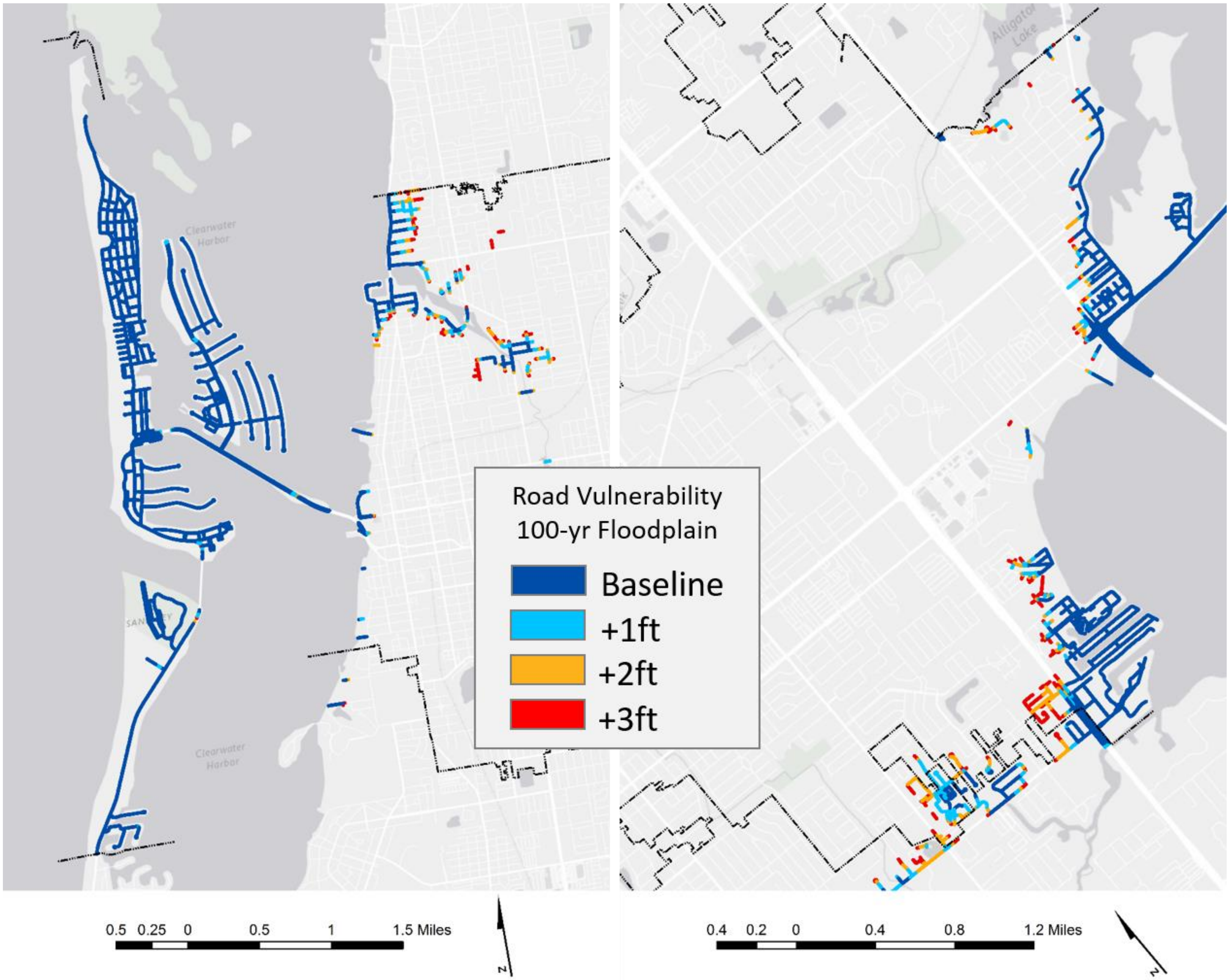

Figure 8. Changes in road vulnerability to a 100-yr flood event with increasing SLR. Increases are relatively minimal, especially when compared to the nuisance flood event type. The largest areas of increase are on the eastern side of the City, along Old Tampa Bay in the vicinity of Allen Creek.

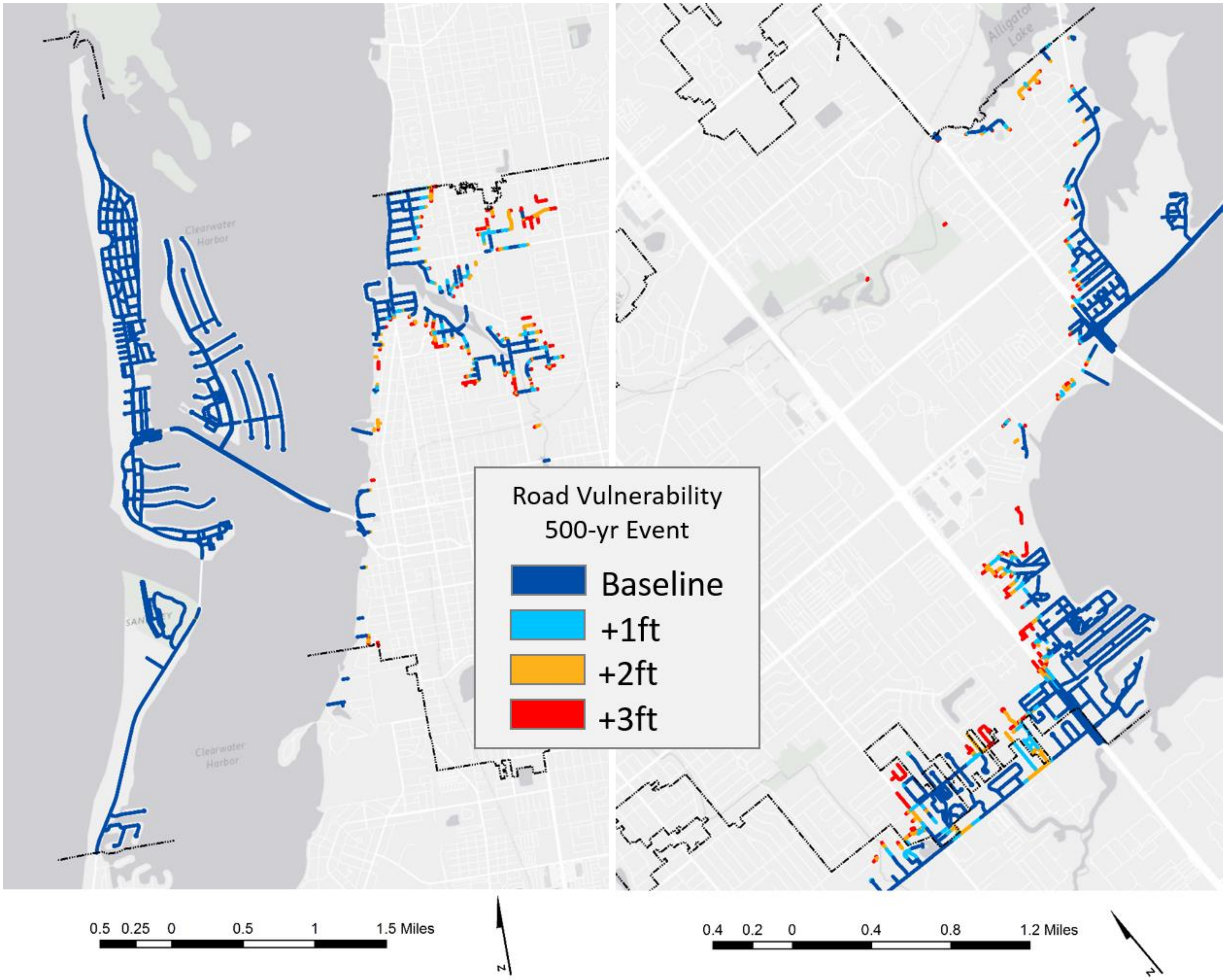

Figure 9. Changes in road vulnerability to a 500-yr flood event with SLR. As with the 100-yr event, increases are limited – on the western shoreline, small increases occur adjacent to Stevenson Creek. On the eastern shoreline, most increases are in the Allen Creek Area.

4.2 *Building, Bridge, and Facility Vulnerability Assessment*

The critical infrastructure, bridge, and building components of the vulnerability assessment were evaluated against each flood type and scenario by using an overlay approach in GIS. Exposed assets were identified for each flood type and SLR combination.

4.2.1 How will Sea Level Rise Impact Building Vulnerability?

Building flood exposure to the different flood hazard types was evaluated in order to identify how the number of buildings would change under the sea level rise scenarios. Building finished floor elevation data was not provided and vulnerability is simply attributed to cases where the building lies within each particular flood extent layer. Depth-damage analysis would provide further information on potential impacts to these flood conditions. Due to this data gap, depth of flooding, or depth-damage analysis were not assessed. Given this, results below should be evaluated in the context that although these buildings may be exposure to flooding around the structure, but waters may not be entering the structure at lower SLR scenarios.

Total counts of vulnerable structures to each flood type and SLR scenario combination are reported in Table 5, changes in the counts are shown in Figure 10.

- Nuisance Flooding
    - Overall, and similar to changes in vulnerability noted for roads, the greatest increase of vulnerable buildings is to nuisance flooding (Figure 10).
    - Building vulnerability increases by 17-fold for 1 ft of SLR, increasing exposure by approximately 600-additional buildings with a relatively small increase in water level.
    - A 41- and 77-fold increase in building exposure was determined for 2- and 3-ft of SLR, respectively. With these increases, in sea level, almost 3,000 buildings will be vulnerable to a nuisance flood type event, just 1,000 less than exposure to today's 100-yr flood event.
    - The geographic distribution of exposed buildings in shown in Figure 11, patterns follow those discussed in the mapping section.
- 100-yr and 500-yr Flood Events
    - Although building exposure is higher to these events, building exposure exhibits relatively small increases to SLR.
    - Building vulnerability increases by just over 1-fold for all three future SLR conditions for both the 100- and 500-yr flood events.
    - The geographic distribution of buildings to each SLR scenario for the 100-yr event in shown in Figure 12, the 500-yr event is shown in Figure 13. Patterns follow those discussed in the previous sections.

Table 5. Total counts of structures vulnerable to each flood type.

SLR Scenario, ft	Flood Event Type		
	Nuisance	100-yr Event	500-yr Event
0	36	4,104	4,875
1	626	4,372	5,136
2	1,479	4,566	5,416
3	2,788	4,873	5,697

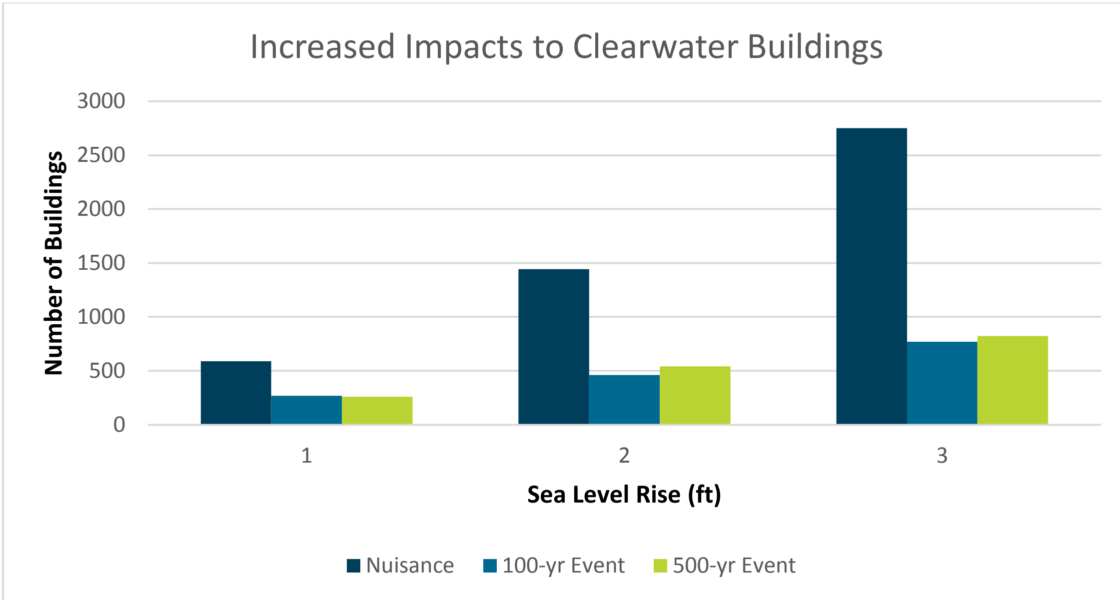

Figure 10. Increases in building vulnerability to the 100- and 500-yr events is relatively negligible as compared as the large increases in structures vulnerable to nuisance flooding under increasing SLR.

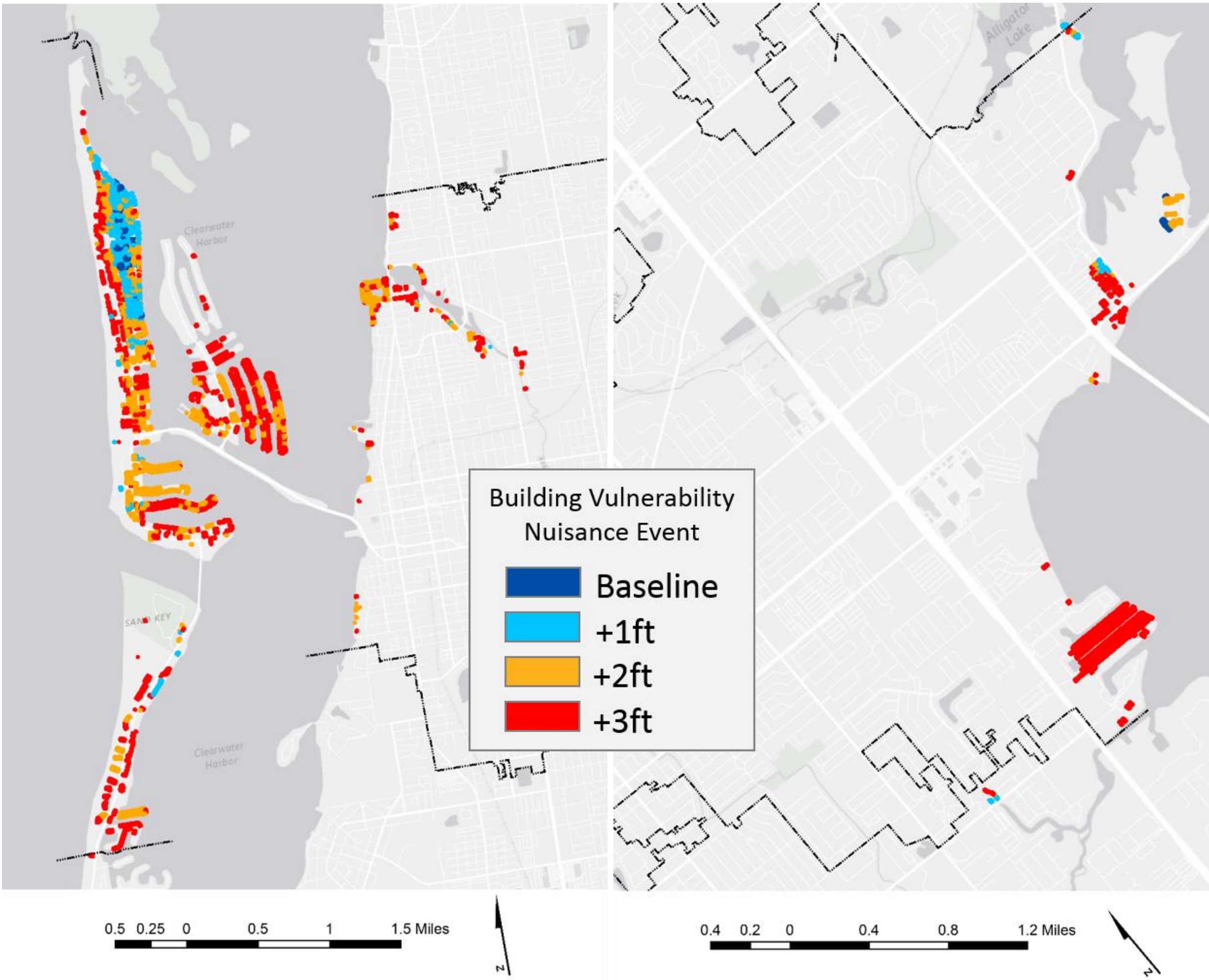

Figure 11. Changes in building vulnerability to nuisance flooding with SLR. Similar to previously observed trends, the majority of the increased vulnerability is associated with Clearwater Beach Island. Higher SLR scenarios increase building exposure on Clearwater Beach Island, in addition to Island Estates and Sand Key. On the eastern shoreline, the bulk of building vulnerability is to higher SLR scenarios.

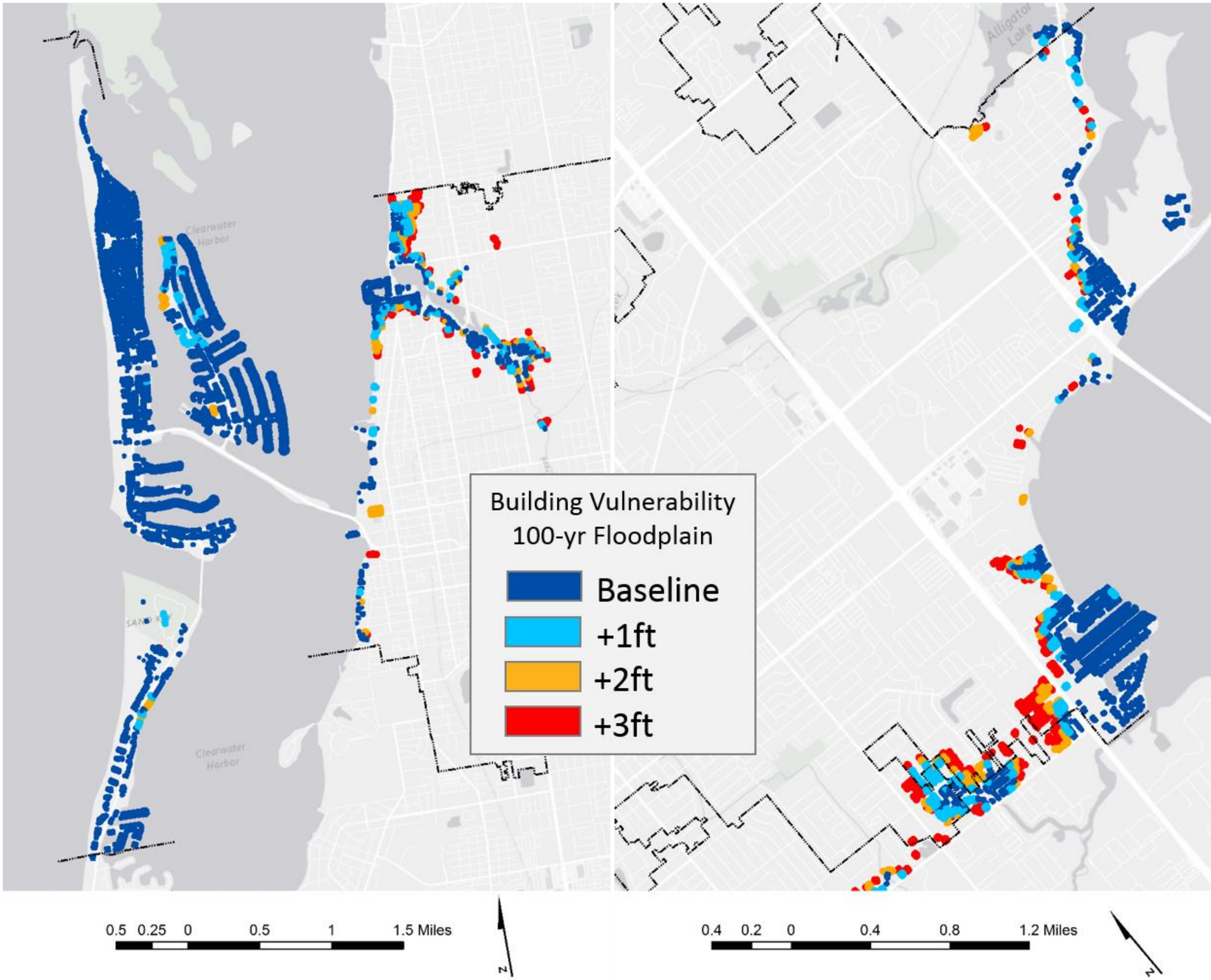

Figure 12. Changes in building vulnerability to a 100-yr flood event with SLR. Changes are relatively small as compared to the nuisance flood type event. Increases are apparent in areas adjacent to the Stevenson and Allen Creeks.

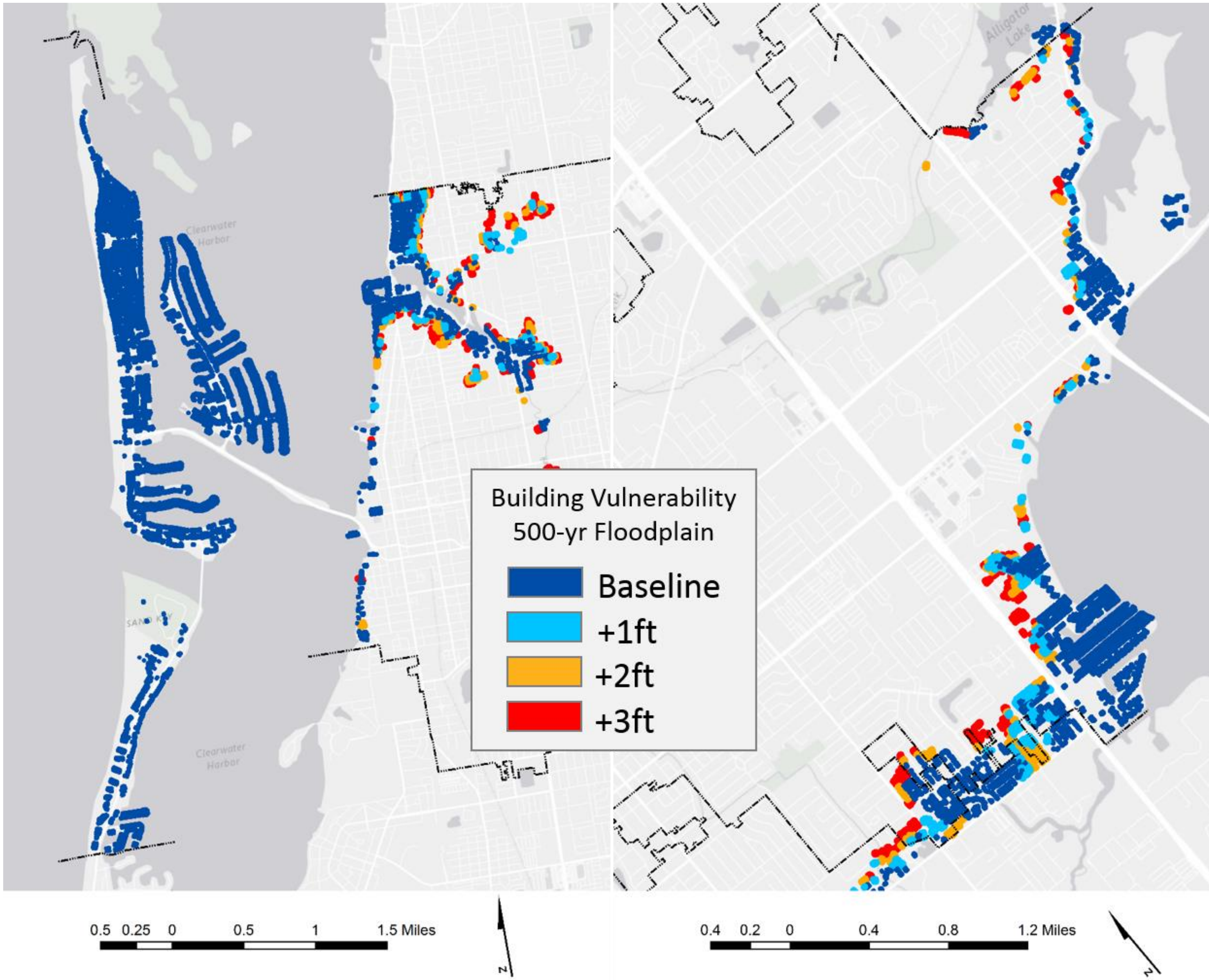

Figure 13. Changes in building vulnerability to a 500-yr flood event with SLR. Areas of increasing vulnerability are similar to the 100-yr flood event.

4.2.2 How will Sea Level Rise Change Bridge Passability?

Bridge vulnerability to the different flood hazard types with sea level rise was evaluated in order to identify future changes in the functionality of bridges and associated access routes. The assessment included bridges within, or providing ingress/egress to the City of Clearwater. It should be noted that bridge deck elevation data was not provided as part of this study; thus, impacts of SLR on bridges were determined by inspecting the floodplain extents against on City bridges and visually evaluating the vulnerability considering elevated deck heights. Figure 14 depicts routes projected to be impacted versus routes that will remain passable under all scenarios. This effort focused on bridges on major connecting roads.

The results indicated that:

- The passability of US 19 and Bayside Bridge are not vulnerable to any of the examined conditions;
- Bridges on McCullen Booth Rd, Curlew Rd and FL 580 are not vulnerable to existing or future nuisance flooding. Passability for these bridges is impacted by the 100- and 500-yr recurrence interval Flood Events under existing conditions and future SLR scenarios.
- Causeway Boulevard and the Island Way Causeway would start experiencing passability issues to nuisance flood events with 2 ft of SLR; and
- Additional sea level rise would increase the frequency and duration of instances when the passability of these bridges would be impacted due to water over the roadway.

Bridge vulnerability to each event type and SLR combination is further summarized in Table 6.

4.2.3 What Facilities are Vulnerable to Sea Level Rise?

The study effort also assessed the vulnerability of City facilities to the selected flood condition and SLR scenarios. Data were provided for schools, fire stations, and water treatment/pollution control facilities. Vulnerability was assessed by overlaying each layer on the facility geospatial data and identifying which structures were in or outside of the flood hazard layer. Overall, City facilities had limited flood exposure:

- Schools:
    - No schools in the city school facility layer were found to be vulnerable to any flood hazard or SLR combination examined by this study effort.

- Fire Stations:
    - Of the nine facilities present in the provided dataset, two were found to have vulnerability to the study flood conditions:
        - Fire Station 44, 1060 Gulf Blvd, Clearwater Beach
            - Nuisance flooding with 2 and 3 ft of SLR
            - 100-yr/500-yr flooding for all existing and future conditions
        - Fire Station 46, 534 Mandalay Ave, Clearwater Beach
            - Nuisance flooding with 3 ft of SLR
            - 100-yr/500-yr flooding for all existing and future conditions

Table 6. Summary of bridge vulnerability to each flood type and SLR combination. "O" indicates "Open"; "P" indicates "Passable", meaning bridge or approach to bridge partially obstructed in one lane; "NP" indicates bridge is not passable due to inundation or approach inundation under the flood event and SLR scenario combination.

Bridge	Nuisance Flood Event			100-yr Flood Event			500-yr Flood Event			
	1 ft SLR	2 ft SLR	3 ft SLR	1 ft SLR	2 ft SLR	3 ft SLR	1 ft SLR	2 ft SLR	3 ft SLR	Notes
US 19	O	O	O	O	O	O	O	O	O	Recently constructed overpass appears to be above all flood conditions.
Bayside Bridge	O	O	O	O	O	O	O	O	O	Southbound overpass will allow traffic to bridge.
Courtney Campbell Pkwy	O	O	P	NP	NP	NP	NP	NP	NP	Causeway is impacted in all 100-yr and 500-yr conditions. Intersection at Gulf to Bay Blvd begins to be impacted by nuisance flooding at the 3 ft SLR scenario.
FL 580	O	O	O	NP	NP	NP	NP	NP	NP	Bridge access clear in all scenarios on the Clearwater side. On the east side it will not be passable to the 100-yr and 500-yr conditions.
McCullen Booth Rd	O	O	O	P	NP	NP	NP	NP	NP	For a 100-yr condition, 1 ft of SLR may cause issues south of intersection. Vulnerable, but passable to the 100-yr condition with 1 ft SLR. Not passable to 100-yr events with 2, and 3 ft SLR or any 500-yr conditions.
Curlew Rd	O	O	O	NP	NP	NP	NP	NP	NP	East side of Curlew Rd bridge not passable for all 100-yr and 500-yr scenarios.
Causeway Blvd	O	P	NP	NP	NP	NP	NP	NP	NP	Causeway begins to be vulnerable to nuisance flooding at the 2 ft SLR scenario. Inundated by nuisance flooding with the 3 ft scenario.
Clearwater Memorial Causeway	O	O	P	NP	NP	NP	NP	NP	NP	Causeway begins to be vulnerable to nuisance flooding at the 3 ft SLR scenario. Not passable under any existing or future 100-yr or 500-yr event conditions.
Island Way Causeway	O	NP	NP	NP	NP	NP	NP	NP	NP	Not passable under nuisance flood events after 2 ft of SLR.
Gulf Blvd Bridge	O	NP	NP	NP	NP	NP	NP	NP	NP	Bridge passable, but routes on both ends are inundated under nuisance flooding with 2 ft of SLR.

- Water Treatment and Pollution Control Facilities:
  - Of the six facilities present in the provided dataset, two were found to be vulnerable:
    - East Plant Water Pollution Control Facility
      - No vulnerability to nuisance flooding
      - 100-yr/500-yr flooding for all existing and future conditions
    - Marshall Street Plant Water Control Pollution Facility
      - No vulnerability to nuisance flooding
      - 100-yr/500-yr flooding for all existing and future conditions

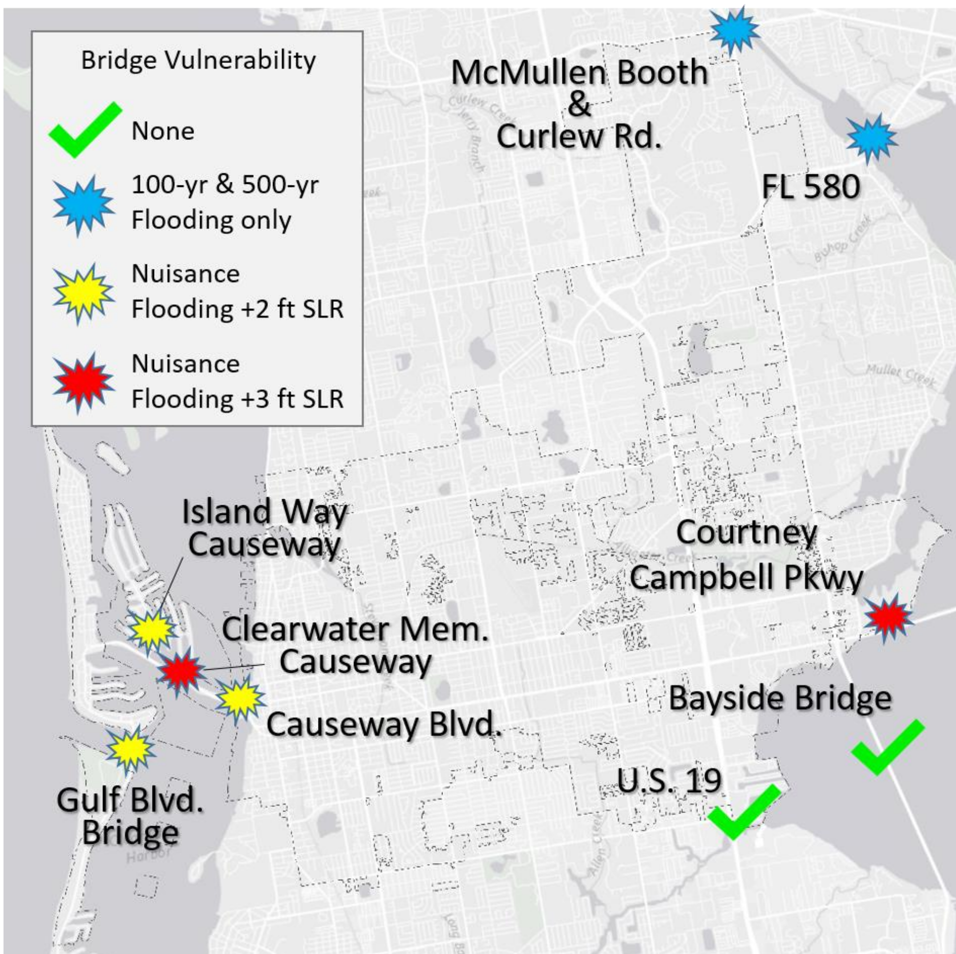

Figure 14. Vulnerability of bridges to the existing and future nuisance, 100-yr and 500-yr flood events. Bridges subject to nuisance flooding are vulnerable to 100- and 500-yr flooding for existing and all SLR conditions.

5 GULF SHORELINE REPONSE

The Gulf of Mexico shoreline was evaluated to estimate how existing shoreline change rates may respond to increasing sea levels. Shoreline response was evaluated only for the Gulf of Mexico shoreline of the barrier islands; the backside of the barrier island, mainland bay shorelines and shorelines along Tampa Bay were not studied. The analysis approach required historical shoreline change rates as an input; these data were only available for the Gulf shorelines. A summary of the methodologies for evaluating shoreline response is presented first, followed by the results of the analysis. For further detail on the analytical approach, refer to the Appendix A.

5.1 *How was Shoreline Response Evaluated?*

Shoreline response to SLR on the Gulf of Mexico shorelines was evaluated through the tasks outlined in Table 7:

Table 7. Summary of methodology used to evaluate shoreline response.

Task	Data Source
1. Calculate short-term and long-term historical shoreline change rates.	• United States Geological Survey (USGS) National Assessment of Shoreline Change Project (http://coastal.er.usgs.gov/shoreline-change/)
2. Review coastal management activities as well as a general history of the barrier islands in Clearwater.	• Pinellas County Coastal Management Program Summary Planning Document • Aerial imagery
3. Separate past shoreline change due to shoreline retreat from shoreline change due to ongoing coastal processes.	
4. Estimate future shoreline change due to sea level rise.	• Shoreline change models • Grain-size estimates • Depth of closure (DOC) estimates • Cross-shore transects
5. Estimate future shoreline change due to coastal processes.	
6. Combine future shoreline change due to coastal process and shoreline change due to sea level rise to obtain an estimate of total future shoreline change.	

5.2 *Coastal Management Activities*

Coastal management activities as well as a general history of the barrier islands in the City of Clearwater were taken from the Pinellas County Coastal Management Program Summary Planning Document (Coastal Planning and Engineering, 2013). These are summarized below:

Caladesi Island

- Undeveloped.
- No structures or nourishment projects have been constructed.
- 2.3 miles long.
- Consistently accreted in recent history.

- Formed the southern half of Hog Island, Honey Moon Key forming the northern half, until the 1921 Hurricane opened Hurricane Pass.
- Since Dunedin Pass closed in 1978, it has been connected to Clearwater Beach Island.
- Acquired by the state in 1966 and designated as a state park.

Clearwater Beach Island

- Shoreline fluctuated significantly in the 1960s.
- Since 1960s many properties fronted by seawalls.
- Many groins including terminal groin at southern end.
- Nourished post 1960s, not nourished since 1982.

North Sand Key

- Terminal groin at north end of island.
- Shoreline continues to erode rapidly.
- Nourished.

5.3 *How does the Shoreline Respond to Coastal Processes and Sea Level Rise?*

Historical shoreline change rates and trends were reviewed based on available analysis by the U.S. Geological Survey. A review of the available data indicated that:

- The shores of Clearwater beach have experienced shoreline advance in the recent past. This is likely due to ongoing coastal processes and a potential source of sediment from an ebb shoal left over from when the Dunedin Pass was closed in the 1970's. Review of aerial imagery suggests that a large offshore shoal was left behind when Dunedin Pass closed in 1978. Sand deposited in this feature is likely to be serving as a source of sediment to the island as it slowly disperses through on- and along-shore transport. It would be anticipated that this feature would continue to provide sediment to the island until the excess material is fully dispersed.
- Clearwater Pass has been relatively stable (i.e. not significant net loss or gain in beach sediment), likely due to the terminal groin extending from Clearwater Pass that is intended to stabilize and control erosion.
- There has been a trend towards shoreline retreat in the northern portion of Sand Key.

The historical rates, in combination with other geologic parameters, were used to project and estimate future trends and magnitudes of shoreline change in response to SLR. A full technical explanation of the approach is provided in Appendix A.

All shoreline change assessments considered 2015 as the starting point. Shoreline change with sea level rise was based on three SLR scenarios with two time horizons for each scenario (Table 8). In general, the first horizon for the analysis corresponded with the year that the SLR scenario was reached by the NOAA Intermediate-High curve. The second time horizon generally corresponded with the year the SLR scenario was reach by the NOAA Intermediate-Low curve. The slope of the nearshore beach profile cross-section was a required input. A review of available bathymetry data indicated that slope varied across the study area. Rather than select a single slope, shoreline change calculations were made for three separate slopes (50:1, 75:1, and 100:1) in order to represent the range of results for potential profile slopes across the study area.

Table 8. SLR scenario and time intervals considered for the shoreline change analysis.

SLR Scenario	Time Horizon 1	Time Horizon 2
1 ft	2040	2060
2 ft	2070	2100
3 ft	2095	2100

Overall, the analysis indicated a continuation of existing trends - shorelines along Sand Key are projected to continue to retreat as sea levels rise, while those along Clearwater Beach and Caladesi Islands are likely to continue advancing or essentially stabilize. Ongoing coastal processes, such as the likely supply of sediment to Clearwater Beach Island from the relict shoal of Dunedin Pass may counter SLR trends by supplying sediment to those areas. In each of the three examined scenarios, the timing of the change is important. Greater increase of sea level over shorter times will increase the trend towards shoreline retreat across the Gulf shoreline. Likewise, the magnitude of change is anticipated to be relatively lower if SLR occurs over longer time frames. Shoreline change trends for Clearwater Beach Island are highly dependent on the continued supply of sediment to this area. A decrease in the supply of sediment to the shoreline would likely result in a change of shoreline trend from stable to accretion to stable and/or receding. Further analysis, using a sediment budget type approach that comprehensively quantifies sediment sources, sinks along with sediment transport pathways and magnitudes would be required to better inform the presented projections.

Projected shoreline changes for the 1, 2 and 3 ft SLR scenarios are shown in Figure 15, Figure 16 and Figure 17, respectively. The Appendix A includes additional results from the shoreline change calculations made using three separate representative slopes for the offshore profile (50:1, 75:1, and 100:1) under each SLR scenario and time horizon combination. The figures depict results for the 75:1 slope that represents the average amount of change between the three cases. In general, slopes steepen from the north to the south.

We caveat the results given the uncertainties and approach – the values are a glimpse to potential changes and not a "prediction." In general, results should be considered more uncertain further out in time and with higher SLR scenarios. The methodology is highly dependent on historical shoreline change rates, which in turn are dependent on past and existing coastal processes, storm events and coastal management practices. The method applied does not attempt to anticipate changes in these inputs, but rather projects how the shoreline change rate may change as additional shoreline recession pressure is added due to sea level rise. Given these limitations, these projections are intended to inform the City on the overall trend of shoreline change.

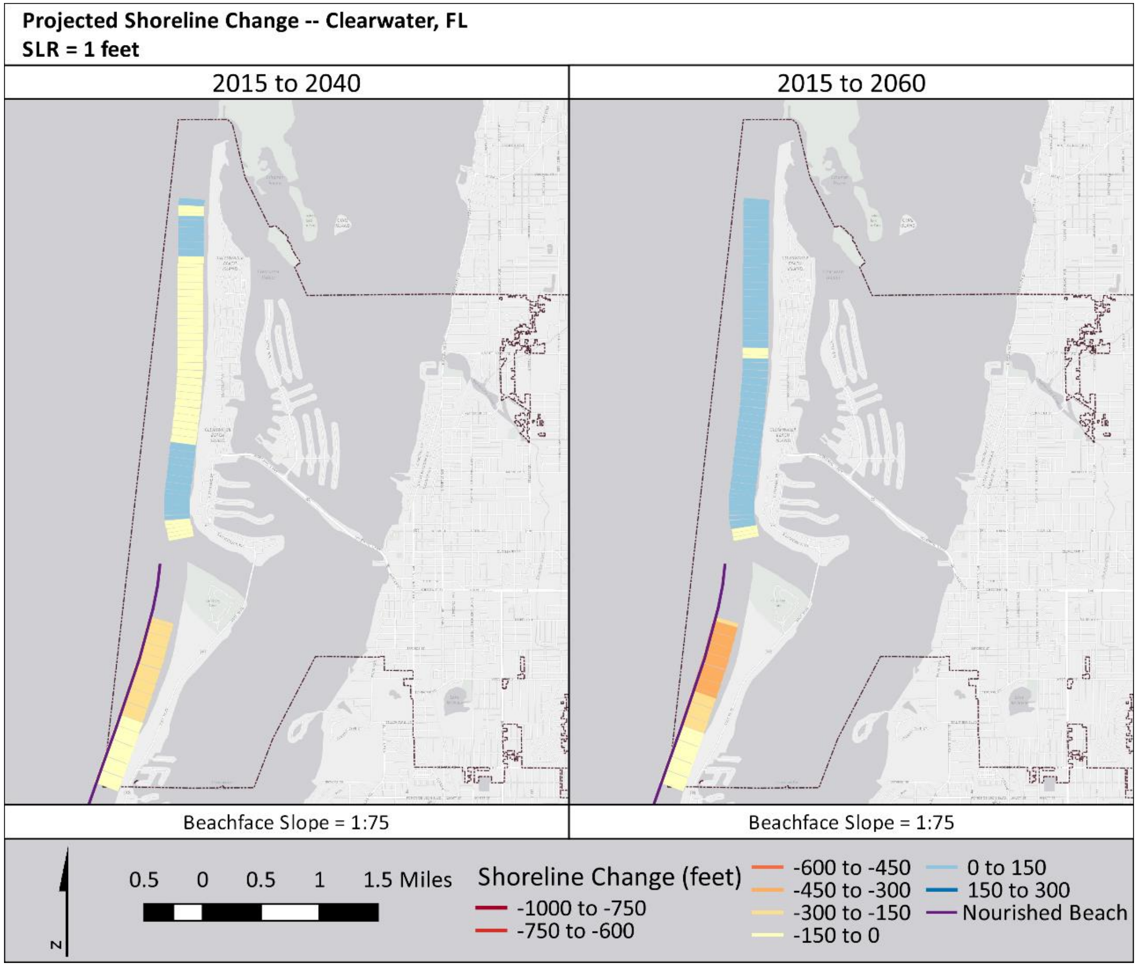

Figure 15. Projected Shoreline Change with +1 ft of SLR. Overall, existing trends are projected to continue. The potential for shoreline retreat is greater if the projected rise occurs over a shorter timeframe. Future trends for areas north of Clearwater Pass are highly dependent on sediment supply. Reduction or exhaustion of sediment sources to this area would result in a greater likelihood of future shoreline retreat for this area.

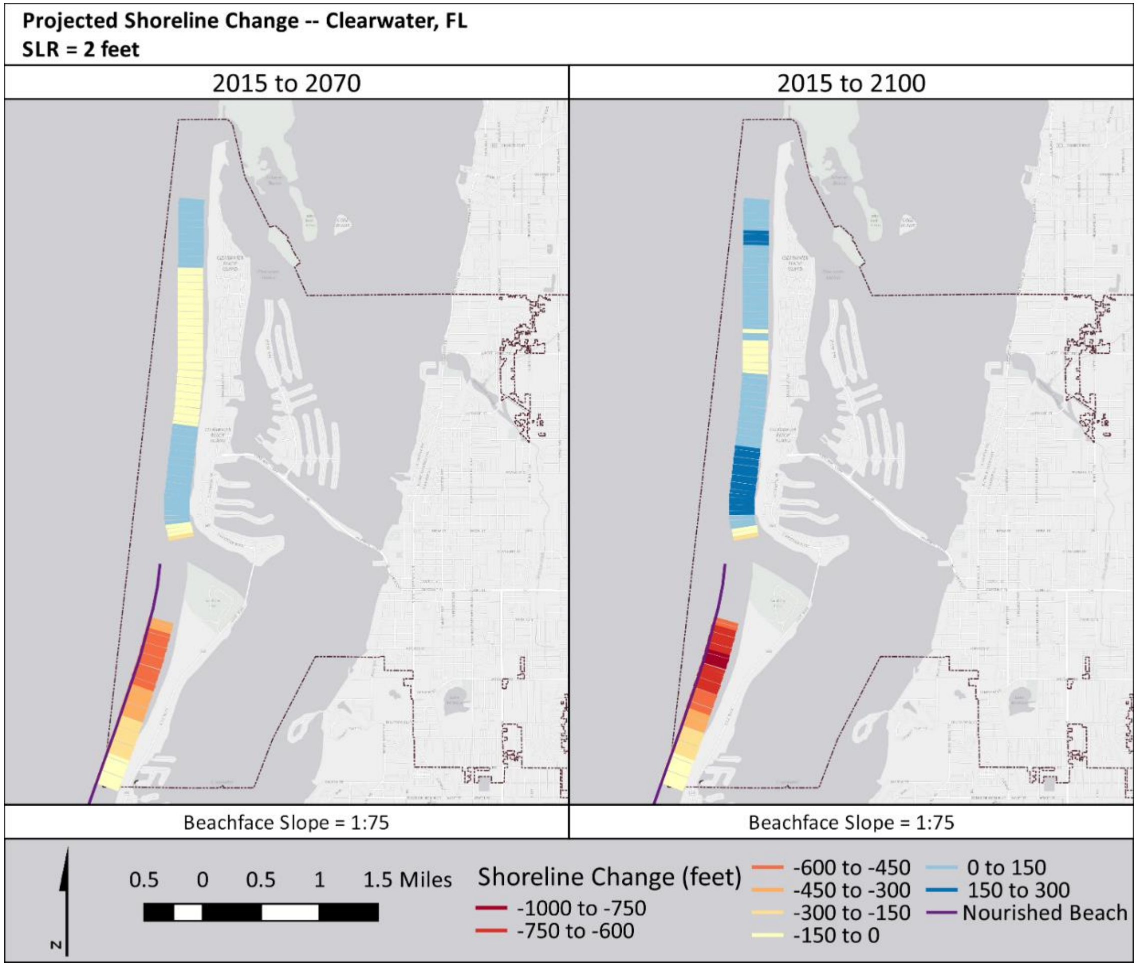

Figure 16. Projected Shoreline Change with +2 ft of SLR. In comparison to 1 ft of SLR, much greater rates of shoreline retreat are expected south of Clearwater Pass. Projected increases in shoreline position to the north of Clearwater Pass should be viewed with skepticism given the simplicity of the applied approach. It is likely that shoreline advance would be more limited and the shoreline would be stable or begin retreating under this scenario.

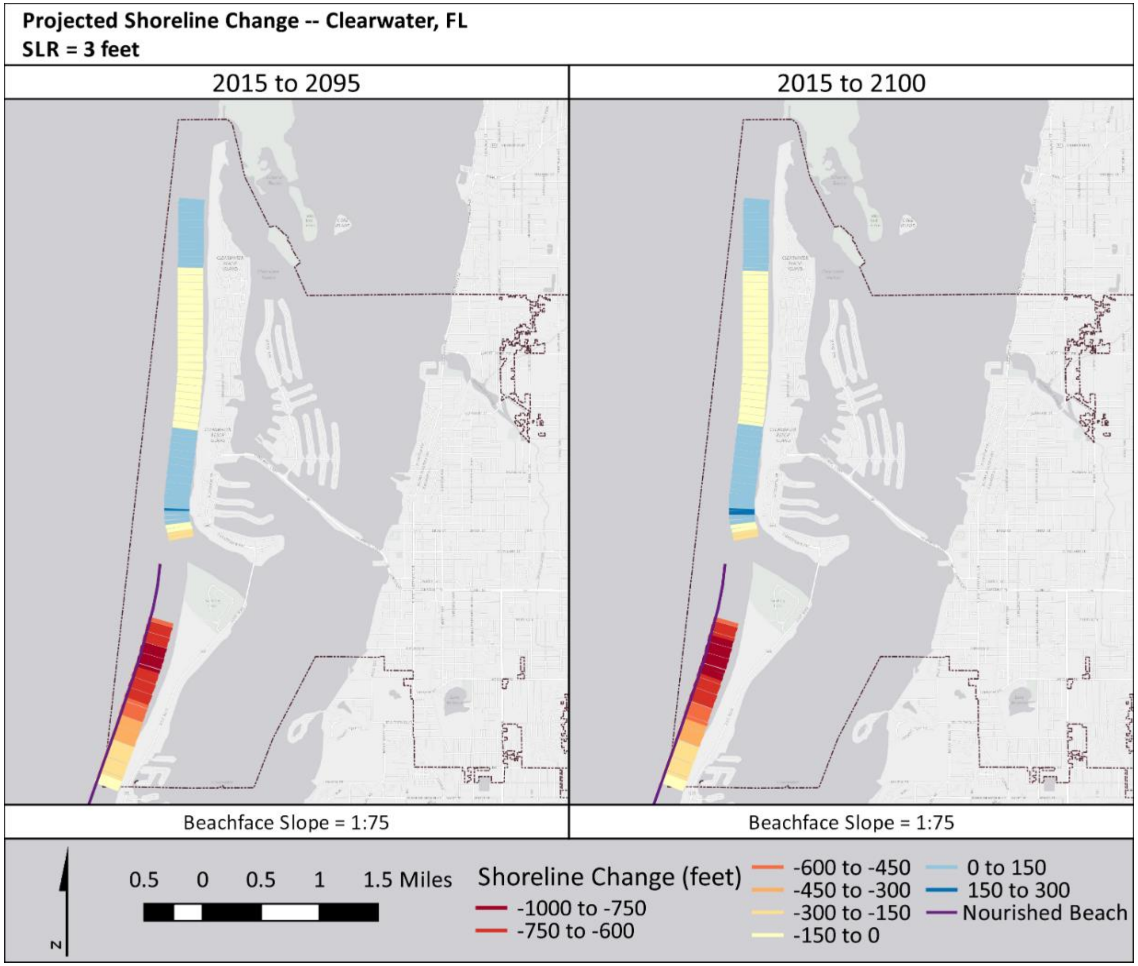

Figure 17. Projected Shoreline Change with +3 ft of SLR. Despite the simplicity of the assumptions behind the approach, this projection suggests that most areas north of Clearwater Pass will experience shoreline retreat in response to this scenario. Shoreline change rates to the south of Clearwater Pass could be on the order of 10 ft/year under this condition.

6 FUTURE CHANGES TO PRECIPITATION

Historical and projected changes in future precipitation were reviewed at the local and national levels in order to evaluate potential changes in frequency of heavy rainfall events.

A summary of the methodologies for evaluating changes to precipitation is presented first, followed by the results of the analysis. For further detail on the analytical approach, refer to the Appendix A.

6.1 *How were Precipitation Projections Developed?*

This study evaluated changes to the 24-, 48- and 72-hour duration rainfall events in addition to percentage and absolute change in precipitation intensity. The 24-hour duration event, in particular the 25-year and 100-year return periods, was the particular focus for the study in part because the 24-hour duration is a good proxy for tropical storm and hurricane induced rainfall, which dominate the heavy rainfall statistics for the City. Historical and projected precipitation changes were examined through the following tasks:

Table 9. Summary of methodology used to evaluate future changes to precipitation.

<table>
<tr><th>Precipitation Analysis Task</th><th>Method Summary</th></tr>
<tr><td>1. Obtain downscaled climate projections for Clearwater</td><td>• Combined data from eight different General Circulation Models and the HydroMetrics – Frequency/Intensity Tool (Hydro-FIT)
• Made estimates for three time periods (Figure 8), each having a duration of 30 years.</td></tr>
<tr><td>2. Identify relevant changes in the historical record</td><td rowspan="3">• National level historical and projected precipitation data was obtained from the U.S. Global Change Research Program (USGCRP), the U.S. government’s open data catalog (www.data.gov/climate), and the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report.
• Data from the Southeast Regional Climate Center and NOAA Atlas 14 Volume 9 (Perica et al. 2013) was used to analyze heavy rainfall recurrence statistics at the local level.</td></tr>
<tr><td>3. Evaluate changes in 24-hour duration rainfall for 25-year and 100-year recurrence intervals.</td></tr>
<tr><td>4. Evaluate potential changes in frequency of heavy precipitation.</td></tr>
</table>

6.2 *What are the Historical and Future Changes in Precipitation?*

National/international and local level sources for climate data were reviewed to identify trends in precipitation. Sources for the information and results are provided in the following text.

6.2.1 National/International Level

The following data sources are notable for having historical, projected, and other supporting data sets in a single location. Although this list is not exhaustive, the three sources indicated below are an excellent starting point for organizations seeking to obtain up-to-date data from a reputable source. At the time of this report, national and international data sources for climate data include the following:

- **<u>The Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report</u>.** The IPCC is an international entity that produces climate assessment reports at regular intervals. Their Data Distribution Center includes historical estimates from 1960-1990, global climate models (GCMs), socio-economic scenarios, scenarios for other environmental changes, and a number of other resources. The latest set of model simulations is the Coupled Model Intercomparison Project Phase 5 (CMIP5).

- **<u>The U.S. Global Change Research Program</u> (USGCRP).** The USGCRP is an organization that produces climate assessment reports for the U.S. – the National Climate Assessment. The USGCRP website contains links to both historical and projected climate data sets.

- **<u>www.data.gov/climate</u>.** The U.S. government's open data catalog, which includes useful products such as storm data, hurricane tracks, 15 minute and hourly precipitation, and river forecasting center outputs. Downscaled (relatively fine resolution) future projections made available through the United States Geological Survey are also linked at this site.

Figure 18 and Figure 19 show the historically observed and future projections for precipitation, specifically, heavy precipitation events. Model results estimating future annual precipitation totals are somewhat mixed for much of the continental United States. However, both the historical record and future projections are in agreement that heavy precipitation events (i.e. downpours as well as prolonged heavy rain events) are on the rise.

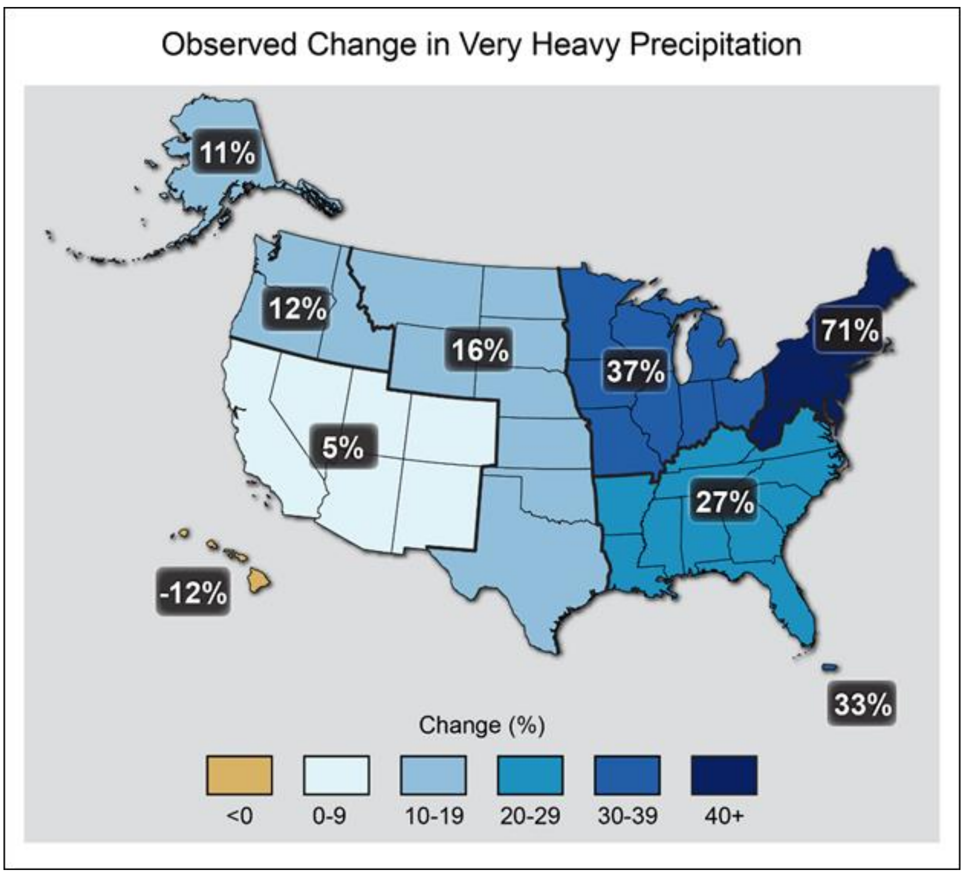

Figure 18. Observed change in heavy precipitation events (i.e. downpours, the heaviest 1% of annual rainfall events). The estimate over Florida shows a 27% increase in occurrence. However, a local analysis could reveal slightly

different results depending on which exact rainfall gage is considered. Source is 2014 National Climate Assessment, http://nca2014.globalchange.gov/report/our-changing-climate/heavy-downpours-increasing.

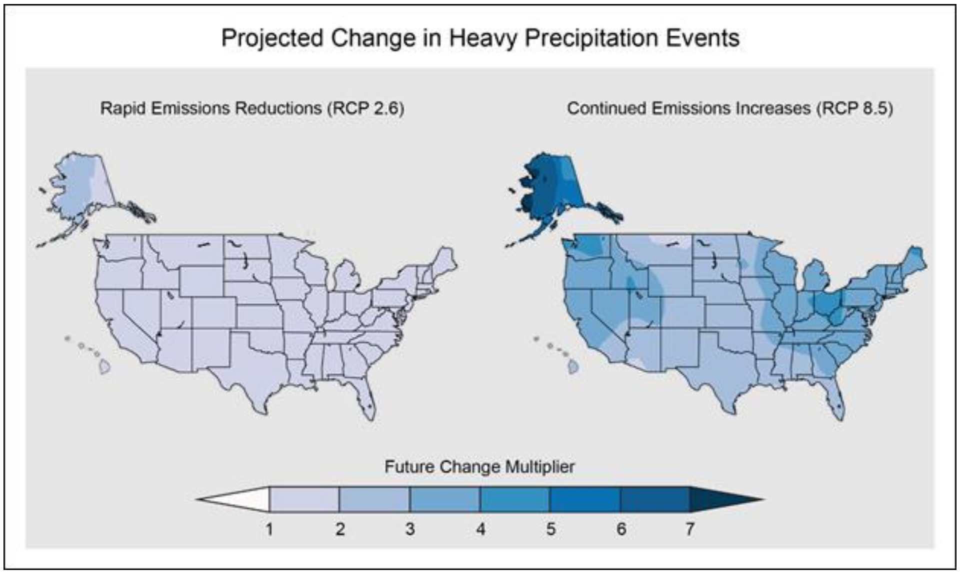

Figure 19. The most recent climate data uses four future emissions scenarios (representative concentration pathways, or RCPs). The figure above shows projected changes under the highest (RCP 8.5, "business as usual") and lowest (RCP 2.6, rapid and sustained decrease of emissions) scenarios. Projections are for the 20-year event, which has a 5% chance of being equaled or exceeded in a given year. Future change multiplier indicates frequency, meaning under the low scenario, heavy precipitation events in Clearwater may occur up to twice as often by the late 21st century, whereas in the high emissions scenario, these events would occur between two and three times as often.

6.2.2 Local level

Clearwater (Pinellas County) is located on Florida's Gulf of Mexico coast and classified as a "humid subtropical" climate. Data from the Southeast Regional Climate Center was accessed to investigate rainfall statistics. Analysis showed that the area experiences frequent rainfall, quite often in the form of thunderstorms. However, there is very distinct wet seasons from June through September, with that 4- month period accounting for over 60% of its *annual* rainfall.

NOAA Atlas 14 Volume 9 (Perica et al. 2013) was used to analyze heavy rainfall recurrence statistics for the area. Figure 20 shows the Depth-Duration-Frequency curve which shows rainfall intensity as a function of duration, ranging from 5-minutes to 60-days. Colored lines show how rainfall increases with rarer recurrence intervals, ranging from 1 year to 1000 years. The particular focus herein is the 24-hour event, in particular the 25-year and 100-year return periods, as suggested by reviewing the City of Clearwater's Stormwater Drainage Manual (2015) as well as the latest draft of the Pinellas County Stormwater Manual (2016). The 24-hour timeframe is also a good proxy of tropical storm and hurricane induced rainfall, which dominate the heavy rainfall statistics for the City of Clearwater.

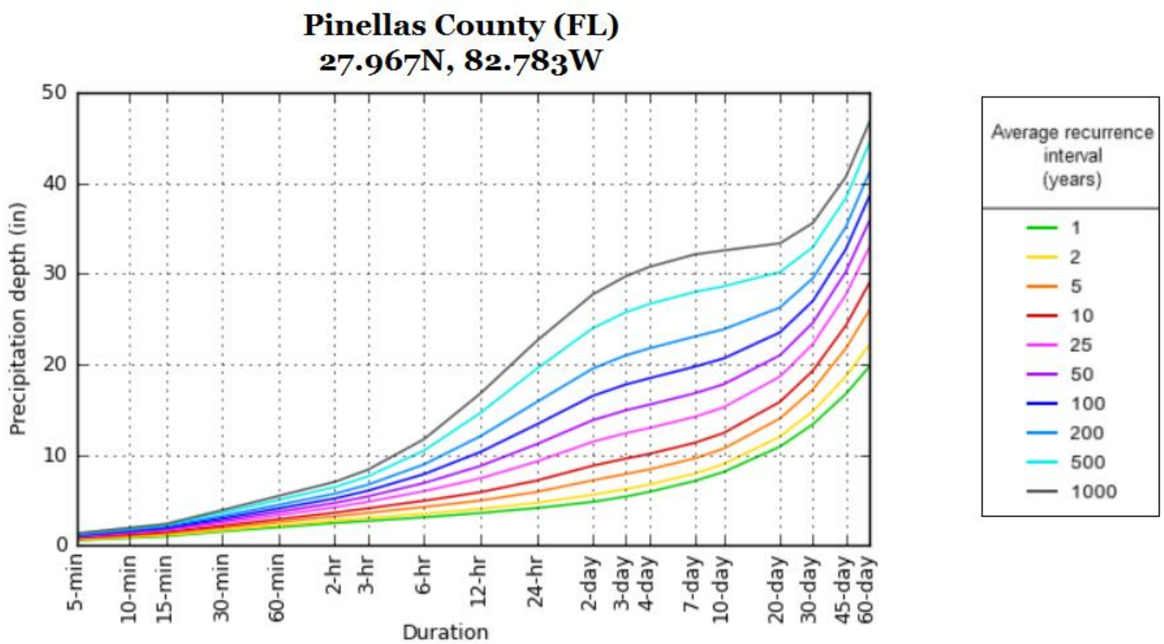

Figure 20. Depth-Duration-Frequency curve for Pinellas County. Source: NOAA Atlas 14, Volume 9, Version 2.

From Figure 20, it is seen that the Atlas 14 value for the 24-hour duration, 25-year recurrence interval event is 9.2 inches, while incorporating the uncertainty at the 90% confidence level yields a range of 7.6 to 12.2 (not shown). The 24-hour duration, 100-year recurrence interval event is 13.3 inches, with a range from 10.2 to 18.2. As discussed previously, average rainfall has a strong seasonality that favors the summer and fall months. However, when considering very heavy rainfall such as the 25-year or 100-year recurrence interval events, tropical storms and hurricanes are disproportionately responsible for most of these cases. More specifically, Figure 21 shows that along Florida's Gulf Coast, more than 50% of all heavy rain events (defined in that study as 1 in 5 year return periods, but applicable to the 25-year and 100-year recurrence interval vents also) are associated with tropical storm or hurricane passage.

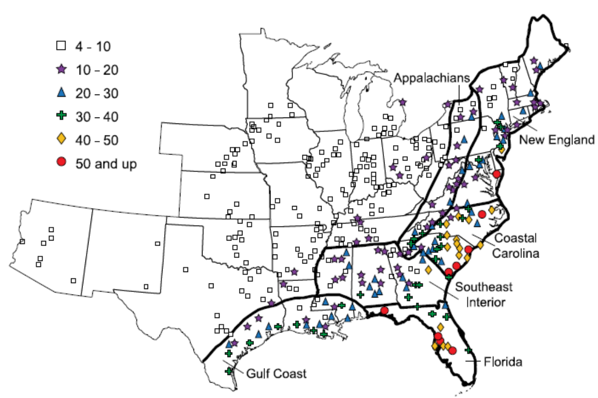

Figure 21. Percent of heavy events associated with tropical cyclones (TC) at individual stations (delineated by color and symbol type) and regional groupings (delineated by thick black lines). Only stations with at least 1 TC - associated event are plotted. Source: Figure 3 from Kunkel et al. 2010.

In consistency with Figure 21, Figure 22 shows the Atlas 14 seasonal decomposition for the 24-hour event. There is a distinct peak across all recurrence intervals from August to November, coincident with climatological peak of the Atlantic tropical cyclone season. Figure 22 indicates that it is extremely rare for Clearwater to experience a 1 in a 100-year recurrence interval event outside of the August-November period.

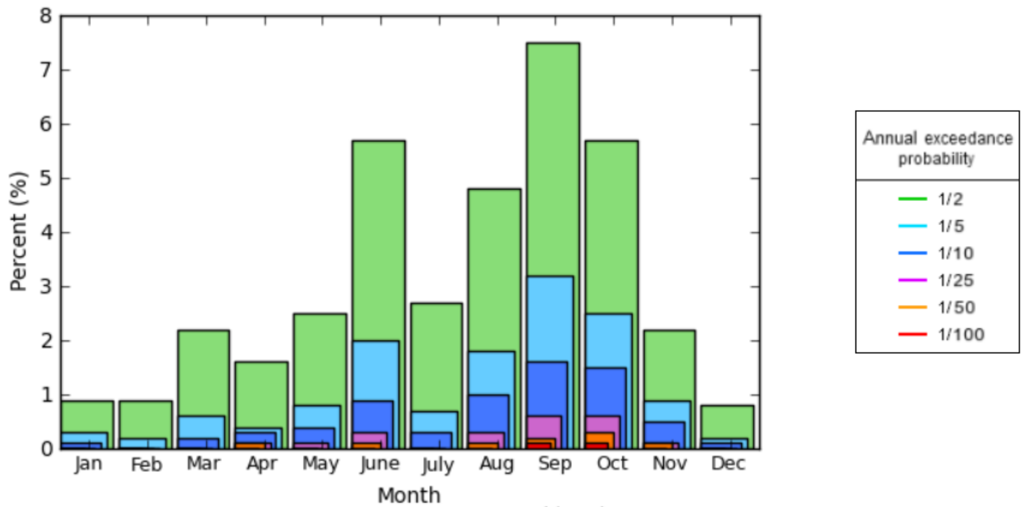

Figure 22. Seasonal decomposition of heavy rainfall recurrence probability using the 24-hour duration. Source: NOAA Atlas 14, Volume 9, Version 2.

6.2.3 Projections of future heavy rainfall

Estimates of the future peak 24-hour rainfall event for recurrence intervals up to 200 years were made for three time periods (Figure 23), each having a duration of 30 years: **historical period (1980 – 2009)**, **mid-term outlook (2030 – 2059)**, and **long-term outlook (2060 – 2089)**.

Each estimate was created from an ensemble of statistically downscaled precipitation data to encompass the range of model uncertainty; further detail into the approach is available in the Appendix A. Figure 23 shows a projected increase of rainfall intensities across all recurrence intervals, while Table 10 lists the specific values for changes in the 24-hour duration, 25-year and 100-year recurrence interval events (compared to the historical period). Note that most projections are outside of the existing error range, the 95% confidence interval of the current values. This indicates a solid trend in the projections of increasing rainfall for these instances.

Table 10. Projected increases (%) in 24-hour duration, 25-year and 100-year recurrence interval rainfall for the mid-term and long-term periods. *denotes that estimate is outside the error range of this historical period.

24-hour duration event	Mid-term (2045)	Long-term (2075)
25-year recurrence interval	+12%*	+20%*
100-year recurrence interval	+13%	+17%*

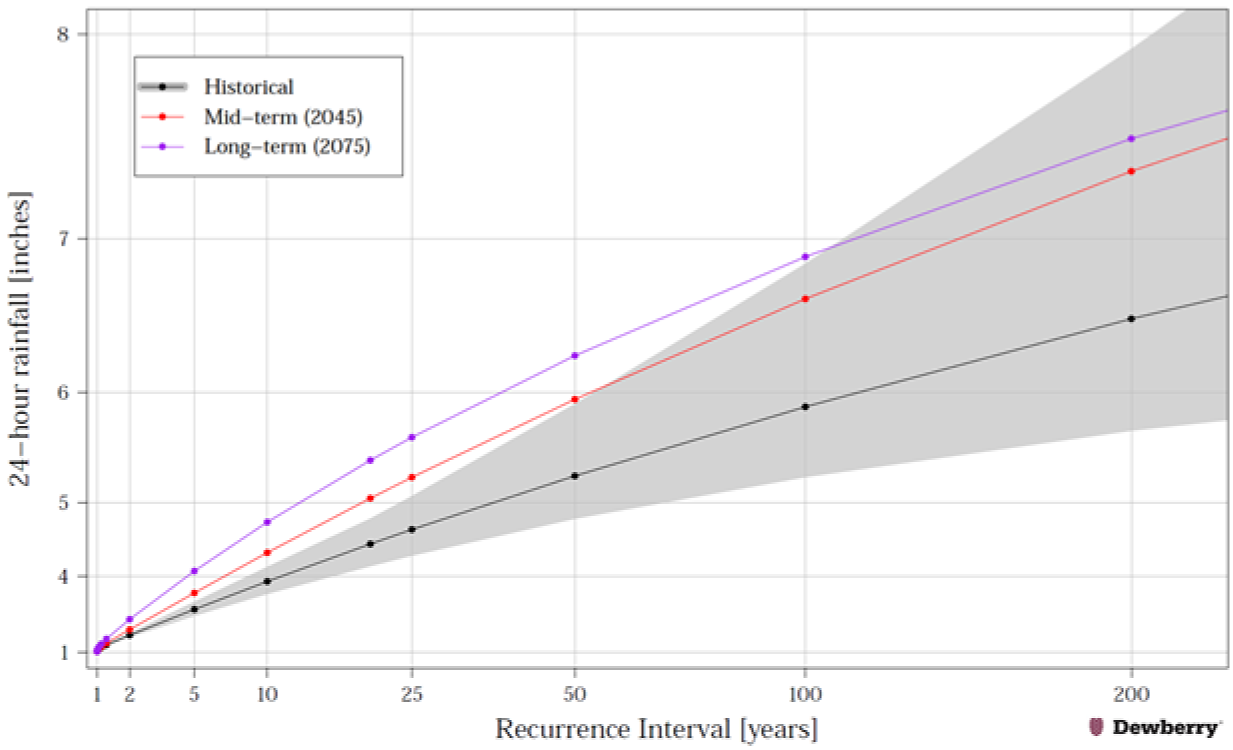

Figure 23. Estimated annual 24-hour peak precipitation amounts using data from the years 1980 – 2009 (historical; black line with gray shading showing the error range), 2030 – 2059 (mid-term outlook; red line), and 2060 – 2089 (long-term outlook; purple line), from eight different GCMs.

Table 10 shows that the 24-hour duration, 25-year recurrence interval event is projected to increase outside of the historical error range by the mid-term, while the 24-hour duration, 100-year recurrence interval is projected to do so by the long-term. It is important to note that these estimates may be conservative given that the statistically downscaled precipitation data used here does not fully capture the impact of changes in tropical cyclone activity. For example, if we compare the above results to the NOAA Atlas 14 estimated 100-yr exceedance event mentioned above (13.3 inches with 90 percent confidence limits of 10.2 inches to 18.2 inches), it is seen that the NOAA value is about twice as high as the values that were estimated based on the GCM data for each time period. Note that this does not undermine the analysis since the interest is to projecting changes using a consistent framework, which this dataset allows us to do. In other words, we are interested in the *relative changes* between the historical period and the future projection. In relation to the tropical storm and hurricane impact, peer-reviewed scientific literature confirms that rainfall increases of about 10% can be expected across the entire area of a tropical storm/hurricane, however localized changes of up to 30% can be expected especially near the inner core of a stronger hurricane.

Although the projected increases in rainfall may not appear all that large, they may still impact design criteria. For example, Figure D-7 in the Clearwater Stormwater Drainage Manual shows a 24-hour duration, 100-year recurrence interval value of about 12 inches, which may be based on outdated rainfall recurrence statistics. If we apply the projected 17% change to the Atlas 14 24-hour duration, 100-year recurrence interval estimate of 13.3, we arrive at a value of 15.6 inches or 30% higher than indicated by the Drainage Manual. This suggests there may be a benefit to update standards to incorporate NOAA Atlas 14, which also includes the added benefit of uncertainty estimates unlike many past rainfall recurrence atlases such as the commonly used US Weather Bureau's TP40.

6.3 *Aquifer and Water Table Changes*

A literature review was performed to address the groundwater impact component of the vulnerability assessment. This review included examination of local hydrogeological studies to understand the local and regional hydrogeological setting, identified mechanisms for saltwater intrusion, and consider how the water-table might respond to sea level rise.

The City of Clearwater is uniquely vulnerable to saltwater intrusion because of its exposure as a peninsula and series of barrier islands to saline and/or brackish water on all sides, bounded by Tampa Bay to the east and the Gulf of Mexico to the west. The City of Clearwater, in cooperation with the Southwest Florida Water Management District (SWFWMD), is implementing a multi-phased groundwater replenishment (GWR) project using reclaimed water from the Clearwater's Northeast Water Reclamation Facility (NEWRF). The purpose of the GWR project is to use purified reclaimed water to replenish the Upper Floridan aquifer in order to offset current and future withdrawals from the City's well fields and protect the fresh ground-water from saline contamination (LBG 2014). The City is currently conducting a study to look at the feasibility of groundwater replenishment technology through ongoing hydrologic monitoring and operation of a Pilot Treatment System to investigate the effects of recharging the Upper Floridan aquifer with up to 3 million gallons per day (MGD) of purified reclaimed water at the NEWRF (LBG 2014).

6.3.1 What are the Anticipated Changes in the Clearwater Water Table?

Sea-level rise coupled with tidal effects accelerate the migration of the salt-freshwater interface, lifting the water table closer to the ground surface.

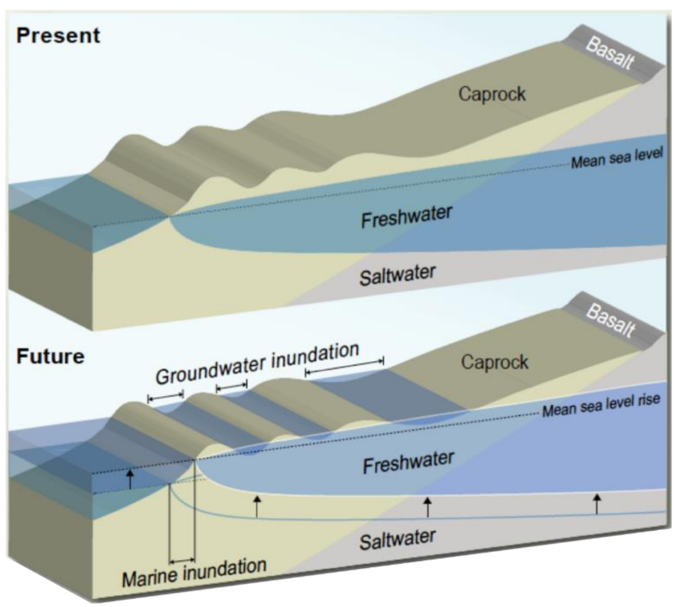

Figure 21: Conceptual diagram of groundwater inundation, obtained from Rotzoll and Fletcher (2012).

Groundwater inundation, a form of coastal flooding, originates from below the land surface as sea-level rise and/or heavy rainfall lift the water table to an elevation that penetrates the land surface with groundwater of varying water quality (freshwater, saltwater, or brackish water) depending on local hydrogeology (Figure 21; Rotzoll and Fletcher 2012). An in-depth qualitative analysis of anticipated changes in the water table in Clearwater would require a long-term groundwater-level monitoring network in the surficial aquifer system in order to construct a spatially distributed estimated water table surface that could serve as a baseline from which to forecast future scenarios. Presently, the United States Geological Survey (USGS) has two active groundwater observation wells in Clearwater, an inadequate dataset for a qualitative analysis of water-table response to sea-level rise. However, Clearwater's GWR Program includes construction of exploratory wells, with core collection, a test recharge well and associated monitoring wells (LGB 2014); these exploratory wells could potentially be used to enhance the existing USGS groundwater monitoring network for use as an input to geospatial model to map the coastal water table in Clearwater and forecast water-table response to sea-level rise scenarios.

Further information on the hydrogeological setting of the City of Clearwater and surrounding region, as well as primary mechanisms for saltwater intrusion are provided in Appendix A.

7 CLOSING DISCUSSION

The results of the City of Clearwater's Vulnerability Assessment provide quantitative and qualitative building blocks for the next phase of the project, Adaptation Planning. The City's staff was instrumental in providing feedback throughout the project from the questionnaire, to the design meeting, to the review of draft results.

The depth of each aspect of the analyses provided by the study effort were constrained by a combination of study scope, budget, schedule and available data. Additional and more in depth analyses are possible by building on data developed through this effort. For example, more accurate assessments of building impacts would require finished floor elevations for each structure, which were not available to the study team.

The uncertainties associated with sea level rise require the city to take a pragmatic approach as to how it proceeds with addressing the vulnerabilities identified in this report. This report is not meant to identify all possible future impacts from sea level rise but helps to prioritize those issues most concerning to the city staff at the present time and may serve as a starting point for additional vulnerabilities as the science changes and more planning resources become available. This report concludes first task of the overall FLDEO pilot study, the Vulnerability and Risk Assessment for the City of Clearwater. Information gathered by the study team and presented in this report will inform the second task of the study, which focuses on approaches to decrease short- and long-term vulnerability through Adaptation Planning.

The results of this report and the documentation of the planning process throughout will be captured as part of the State's Community Resiliency Initiative and thus help other communities facing stressors from sea level rise.

8 REFERENCES

Ashton, A. D., Walkden, M. J., & Dickson, M. E. (2011). Equilibrium responses of cliffed coasts to changes in the rate of sea level rise. Marine Geology, 284(1), 217-229.

Barlow, P. M. (2003). Ground Water in Freshwater-Saltwater Environments of the Atlantic Coast. United States Geological Survey, Circular 1262.

Birkemeier, W. (1985). Field data on seaward limit of profile change. Journal of Waterway, Port, Coastal, and Ocean Engineering, 111(3), 598-602.

Broska, J. C., & Barnette, H. L. (1999). Hydrogeology and Analysis of Aquifer Characteristics in West-Central Pinellas County, Florida. United States Geological Survey Open-File Report 99-185.

Brutsche, K. E., Rosati III, J., Pollock, C. E., & McFall, B. C. (2016). Calculating Depth of Closure Using WIS Hindcast Data. Washington DC: US Army Corps of Engineers.

Bruun, P. (1962). Sea-level rise as a cause of shore erosion. Journal of the Waterways and Harbors Division, 88, 117-130.

City of Clearwater Stormwater Drainage Criteria Manual (effective July 1, 2015). Retrieved online on May 16, 2016.

Davis, R. J. (1994). Barriers of the Florida Culf Peninsula. In R. Davis Jr., Geology of Holocene Barrier Island Systems (pp. 167-206). Berlin: Springer-Verlag.

Elko, N. A. (2006). Storm-influenced sediment transport gradients on a nourished beach. PhD Dissertation. Retrieved from http://digital.lib.usf.edu/SFS0025894/00001

Hallermeier, R. J. (1981). A profile zonation for seasonal sand beaches from wave climate. Coastal Engineering, 4, 253-277.

Hosking, J. R. M., and J. R. Wallis, 1997: Regional Frequency Analysis: An Approach Based on L-Moments", Cambridge University Press, Cambridge, UK, 224 p.

Knutson and co-authors, 2013: Dynamical Downscaling Projections of Late 21st Century Atlantic Hurricane Activity CMIP3 and CMIP5 Model-based Scenarios. J. Climate, doi:10.1175/JCLI-D-12-00539.1.

Kunkel, K.E. and co-authors, 2010: Recent increases in U.S. heavy precipitation associated with tropical cyclones. Geophysical Research Letters, 37, l24706, doi:10.1029/2010gl045164.

Knochenmus, L. A., & Thompson, T. H. (1991). Hydrogeology and simulated development of the brackish ground-water resources in Pinellas County, Florida. US Department of the Interior, US Geological Survey.

Langevin, C. D., & Zygnerski, M. (2013). Effect of Sea-Level Rise on Salt Water Intrusion near a Coastal Well Field in Southeastern Florida. Groundwater, 51(5), 781-803.

Leggette, Brashears & Graham, Inc. (LBG) (2014). City of Clearwater Groundwater Replenishment Recharge Test, Geochemistry, and Groundwater Modeling Report. Prepared for the City of Clearwater Engineering Department. Available online at: http://www.swfwmd.state.fl.us/download/final_report_102014.pdf

Metz, P.A., and Brendle, D.L., 1996, Potential for water quality degradation of interconnected aquifers in west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 96–4030, 54 p.

Morton, R. A., Miller, T. L., & Moore, L. J. (2004). National Assessment of Shoreline Change: Part 1. Historical Shoreline Changes and Associated Coastal Land Loss along the U.S. Gulf of Mexico. Open File Report: 2004-1043, United States Geological Survey, Washington DC. Retrieved from http://pubs.usgs.gov/of/2004/1043/ofr-2004-1043.pdf

Pinellas County Stormwater Manual (2nd Draft), 2016. Retrieved online on May 16, 2016.

Perica, S. and co-authors, 2013: NOAA Atlas 14 Volume 9 Version 2, Precipitation-Frequency Atlas of the United States, Southeastern States. NOAA, National Weather Service, Silver Spring, MD.

Rotzoll, K., & Fletcher, C. H. (2013). Assessment of groundwater inundation as a consequence of sea-level rise. Nature Climate Change, 3(5), 477-481.

Southwest Florida Water Management District (SWFWMD) (2016). West-Central Florida's Aquifers: Florida's Great Unseen Water Resources. Available online at: https://www.swfwmd.state.fl.us/publications/files/flas_aquifers.pdf.

Southwest Florida Water Management District (2006). Aquifer Characteristics within the Southwest Florida Water Management District. Fourth Edition, Report 99-1.

Southwest Florida Water Management District, Hydrologic Evaluation Section (2002). Draft Issue Paper: Saltwater Intrusion and the Minimum Aquifer Level in the Southern Water Use Caution Area.

U.S. Weather Bureau, 1963: Technical Paper No. 40, Rainfall Frequency Atlas of the United States. U.S. Dept. of Commerce, Washington, D.C

Wang, P., & Davis, J. R. (1999, April & July). Depth of Closure and the Equilibrium Beach Profile: A Case Study from Sand Key, West-Central Florida. Shore & Beach, 67(2&3), 33-42.

Williams, J. M., & Kuniansky, E. L. (2015). Revised Hydrogeological Framework of the Floridan Aquifer System in Florida and Parts of Georgia, Alabama, and South Carolina. United State Geological Survey Professional Paper 1807, Version 1.1

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APPENDIX A: TECHNICAL APPROACH

A-1 Flood Hazard Elevation Sources

Nuisance flooding was identified at the design meeting as a flood type of interest. A first step to assess potential elevations for this parameter was to review records at the closest NOAA water level station (Station ID 8726724, Clearwater Beach FL). This provided for an average monthly maximum tide of 2.3 ft, and annual maximum tide of 3.2 ft relative to NAVD88, based on a review of records from 3/2015 to 3/2016. Feedback from the City on these elevations indicated that a typical ocean nuisance flood elevation was approximately 3 ft tidal elevation variances from the ocean to bay side of the City were assessed using the NOAA VDatum tool and found to be negligible. As such, a single elevation of 3 ft above NAVD88 was set as the baseline nuisance flood condition.

The 1% annual chance floodplain is defined as the area that will be inundated by the flood event having a 1% chance of flooding of being equaled or exceeded in any given year. The 1-percent annual chance flood is also referred to as the base flood or 100-year flood. This area defines the Special Flood Hazard Area (SFHA) that is delineated on Federal Emergency Management Agency Flood Insurance Rate Maps. The 0.2% annual chance floodplain is also known as the 500-year recurrence interval. The base coastal flood elevations for these recurrence intervals data were sourced from the ongoing Flood Insurance Study update for Pinellas County, FL. These data are considered provisional at the time of this effort. Permission to use the data in this study was granted by FEMA Region IV. Data were provided by FEMA as a raster surface that provided sufficient extent to geospatially model floodplains for all scenarios against the base topography.

A-2 Implementation of Sea Level Rise Conditions for each Water Level Type

Changes to each coastal flood type were estimated by increasing the present day base surface elevations by the projected changes to sea level for each scenario. Implementation was accomplished by the method of linear superposition, which entails simple addition of the scenario to the base surface. For example, to achieve a scenario of 0.5 ft above present day condition, 0.5 ft was added to the baseline water surface elevation models.

A-3 Flood Layer Production

Inundation and coastal flooding extents were established for each scenario and flood frequency by intersecting the WSEL raster surfaces with the topographic elevation models. The process resulted in raw polygon coverage representing the flood extent for each frequency. Flood extent coverages were post-processed to remove small artifacts, hydraulically disconnected areas, and to smooth boundary edges.

Automated post-processing for artifacts involved the removal of voids (relatively small areas surrounded by flooding) and islands (relatively small disconnected areas of flooding). Tolerances for voids and islands were evaluated and set at 22,500 and 40,000 square ft. The void tolerance was based on the desire to exclude un-inundated areas (such as an individual building footprint) less than 150 x 150 ft. Likewise, the island tolerance was based on the desire to remove insignificant disconnected areas less than 200 x 200 ft. After removal of the voids and islands, flood extent boundaries were smoothed with a tolerance of 20 ft.

The next processing step involved removing disconnected areas of flooding. The steps are described below:

- Disconnected polygons were evaluated for proximity to the main floodplain through an automated process. Polygons within 150 ft of the main polygon were identified for inclusion in the draft floodplain (ancillary flood extent). This was followed by a second pass to identify polygons within 150 ft of the ancillary floodplain for inclusion. The 150-ft distance was based on a representative four-lane highway, under which flooding could propagate through a culvert.
- A visual review of the automated process results was performed to confirm or change the exclusion/inclusion of disconnected polygons. This effort focused on larger areas of flooding that were disconnected by culverts.
- Floodplain extents were passed through a topologic enforcement process to ensure a lower-level floodplain did not exceed a higher level floodplain due to geo-processing or editing variances. This was accomplished by clipping lower-elevation floodplains to the next highest scenario floodplain for each flood type.

A-4 GIS Overlay on Buildings and Infrastructure

Asset exposure was evaluated to each flood type and scenario. Data layers were selected for attribution based on City preferences as defined during the design meeting in conjunction with the availability and quality of geospatial data. For the selected data, three attribute fields, one corresponding to each flood type, were added to each data layer. A select by location query was performed for the set of floodplain layers for each flood type and SLR combination. At the completion of each query, feature selection was attributed to the scenario. Attribute values recorded for each asset represent the minimum SLR scenario that the feature was exposed to. For summary purposes, it is assumed that the feature is then exposed to all higher SLR conditions for that flood type. Null values (no exposure) were set to "-1".

A-5 Shoreline Retreat Projections

Shoreline retreat projections involved a review of coastal management activities and historical rates. These activities are summarized below, and then used to inform the future retreat projections.

Tables A-1 – A-3 show the results of the shoreline change calculations made using three separate representative slopes for the offshore profile (50:1, 75:1, and 100:1) under each SLR scenario and time horizon combination.

Table A-1. Results for a one foot SLR scenario with two time horizons and three active profile slopes considered.

SLR Scenario		1 foot SLR					
Time Horizon		2040			2060		
Slope of Active Profile		50	75	100	50	75	100
Shorline Change (feet)	*mean*	-40.2	-58.3	-76.3	-32.4	-44.9	-57.4
	std	87.7	87.7	87.7	157.9	157.9	157.9
	min	-246.1	-264.2	-282.2	-403.0	-415.5	-428.0
	25%	-77.1	-95.2	-113.3	-98.8	-111.4	-123.9
	50%	-3.3	-21.4	-39.4	34.0	21.5	9.0
	75%	17.2	-0.9	-18.9	70.9	58.4	45.9
	max	67.2	49.2	31.1	161.0	148.5	136.0

Table A-2. Results for a two foot SLR scenario with two time horizons and three active profile slopes considered.

SLR Scenario		2 feet SLR					
Time Horizon		2070			2100		
Slope of Active Profile		50	75	100	50	75	100
Shorline Change (feet)	*mean*	-78.4	-113.2	-147.9	-66.7	-93.1	-119.5
	std	193.0	193.0	193.0	298.2	298.2	298.2
	min	-531.4	-566.2	-600.9	-766.7	-793.1	-819.6
	25%	-159.7	-194.4	-229.2	-192.3	-218.7	-245.1
	50%	2.7	-32.0	-66.8	58.7	32.3	5.9
	75%	47.8	13.1	-21.7	128.4	102.0	75.6
	max	157.9	123.1	88.4	298.6	272.1	245.7

Table A-3. Results for a three foot SLR scenario with two time horizons and three active profile slopes considered.

SLR Scenario		3 feet SLR					
Time Horizon		2095			2100		
Slope of Active Profile		50	75	100	50	75	100
Shorline Change (feet)	*mean*	-118.6	-171.4	-224.2	-116.7	-168.1	-219.5
	std	280.7	280.7	280.7	298.2	298.2	298.2
	min	-777.5	-830.3	-883.1	-816.7	-868.1	-919.6
	25%	-236.8	-289.6	-342.4	-242.3	-293.7	-345.1
	50%	-0.6	-53.4	-106.2	8.7	-42.7	-94.1
	75%	65.0	12.2	-40.6	78.4	27.0	-24.4
	max	225.1	172.3	119.5	248.6	197.1	145.7

A-5.1 Historical Data

Historical shoreline change rates were obtained from the United States Geological Survey (USGS) National Assessment of Shoreline Change Project (http://coastal.er.usgs.gov/shoreline-change/). This study found both long-term shoreline change rates (LRR) as well as more resent short term rates (EPR). Short-term rates were calculated using the endpoint method, comparing a shoreline from the 1970s and a more recent (post-1995) LIDAR-derived shoreline. Long-term rates were calculated using a linear regression applied to four historic shorelines, one each from the time periods: 1800s, 1920s-1930s, 1970s, and post-1995 (Morton, Miller, & Moore, 2004).

Due to extensive nourishment activities occurring over much of the study area since the 1960s, the EPR values for the study area skew sharply positive (accretionary). Because these management activities do not necessarily accurately represent the ongoing background coastal processes, the long-term rates were used for the rest of the analysis.

A-5.2 Range of Future Conditions – Scenarios

Shoreline change with sea level rise is based on three sea level rise scenarios with two time horizons for each scenario. All shoreline change assessments consider 2015 as the starting point.

Table A-4. SLR Scenarios considered for the shoreline change analysis.

SLR Scenario	Time Horizon 1	Time Horizon 2
1 ft	2040	2060
2 ft	2070	2100
3 ft	2095	2100

A-5.3 Shoreline Change Models

Applied modified Bruun approach of Ashton et al. (2011). In this approach historic SLC due to coastal processes was separated from SLC due to SLR using historic SLC data, historic SLR trends, and predicted erosion via the Bruun rule. The Bruun rule simply states that shoreline recession as infinite time, R_∞, is equal to the vertical sea level rise, S, multiplied by the length of the active profile, L_a, divided by the sum of the magnitudes of the depth of closure, h_c, and the height of the dune crest, B (Equation 1).

$$R_\infty = S \frac{L_a}{h_c + B} \quad (1)$$

In Eq. 2 a SLR Factor is calculated based on the rates of future and historic SLR, S_f and S_h respectively, and an exponent m which is based on the shore type. For sandy coasts, such as the Gulf Coast of Florida, the exponent m in Eq. 2 is equal to one, implying an instantaneous shoreline response to SLR.

$$SLR\ Factor = \left(\frac{S_f}{S_h}\right)^m \quad (2)$$

It is assumed that historic erosion, E_h, was composed of two distinct parts: erosion due to coastal processes, $E_{Coastal}$, and erosion due to historic sea level rise, $E_{h,SLR}$ (Equation 3).

$$E_h = E_{Coastal} + E_{h,SLR} \quad (3)$$

$E_{h,SLR}$ was first calculated using historic SLR and the Bruun rule and then used with Eq. 3 and the historic shoreline change data from the USGS to calculate $E_{Coastal}$. Future shoreline erosion, E_f, was then calculated using Equation 4, where future erosion due to SLR, $E_{f,SLR}$, was calculated using Equation 5 and the previously calculated SLR Factor.

$$E_f = E_{Coastal} + E_{f,SLR} \quad (4)$$
$$E_{f,SLR} = E_{h,SLR}(SLR\ Factor) \quad (5)$$

A-5.4 Grain-size

Sediment samples previously taken from Long Key, south of Clearwater in Pinellas County, showed a bimodal median (D_{50}) grain-size distribution with a D_{50} of ~0.45mm (Elko 2006). However, previous measurements by Wang and Davis in the same area showed an average D_{50} of 0.33mm over a five-year survey period (Wang & Davis, 1999). The carbonate sand fraction contains larger grains composed mostly of broken shell fragments (>2mm) while the quartz-sand component is much finer (~0.2mm) (Elko, 2006). This analysis agrees with the typical bimodal grain-size distribution of sediments all along the Gulf Coast of Florida as presented by Davis (1994, Figure A-1Figure).

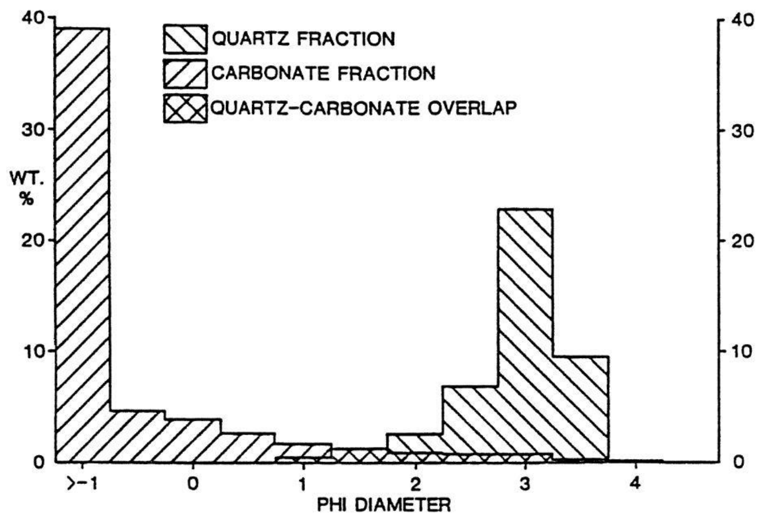


Figure A-1. "Histogram of typical beach sediment from this coast [sic] [recte the Gulf Coast of Florida] showing distinct bimodality of coarse shell and fine quartz sand with little overlap between the two modes" - (Davis 1994).

A-5.6 Cross-Shore Transects

Extracted cross-shore profiles from DEM at three locations (near location of depth of closure [DOC] estimates made by USGS) (Figure A-2).

A-5.7 Depth of Closure

The USGS has calculated annual DOC values for the thirty three year period from 1980-2012 for the entire Gulf Coast (Brutsche, Rosati III, Pollock, & McFall, 2016). The calculations employed wave data from the USACE Wave Information Studies (aka WIS data) and the DOC formulations presented by Hallermeier (1981) and Birkemeier (1985).

Given the average grain-size depth of closure estimates were obtained from the USGS document. These depth of closure values were used with the extracted cross-shore profiles to estimate the slope of the active profile (see Table). The final weighted average was calculated giving double the weight to the T2 measurements due to the location of this transect in the center of the study area. Shoreline change calculations were made for three separate slopes (50:1, 75:1, and 100:1) in order to accommodate the range of potential active profile slopes seen Table A-5.

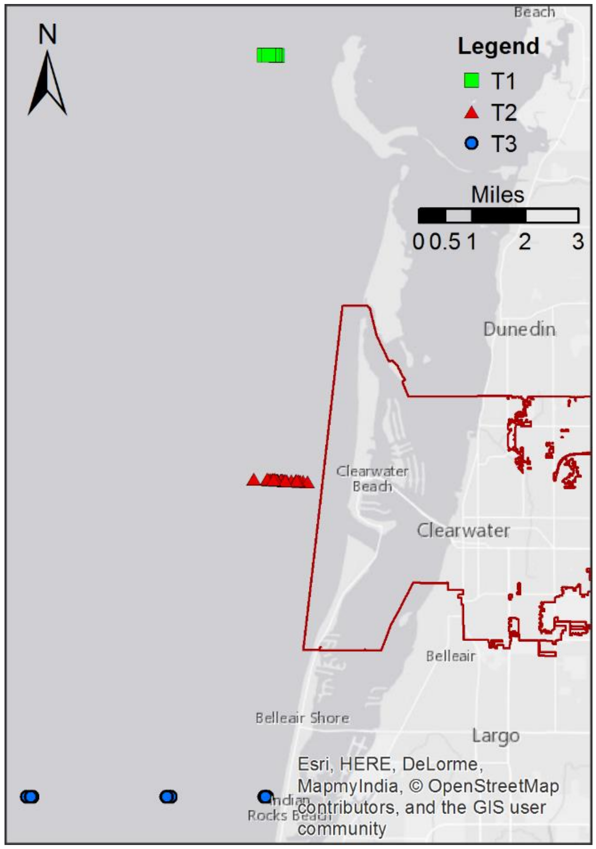


Figure A-2. Location of USACE Depth of Closure transects.

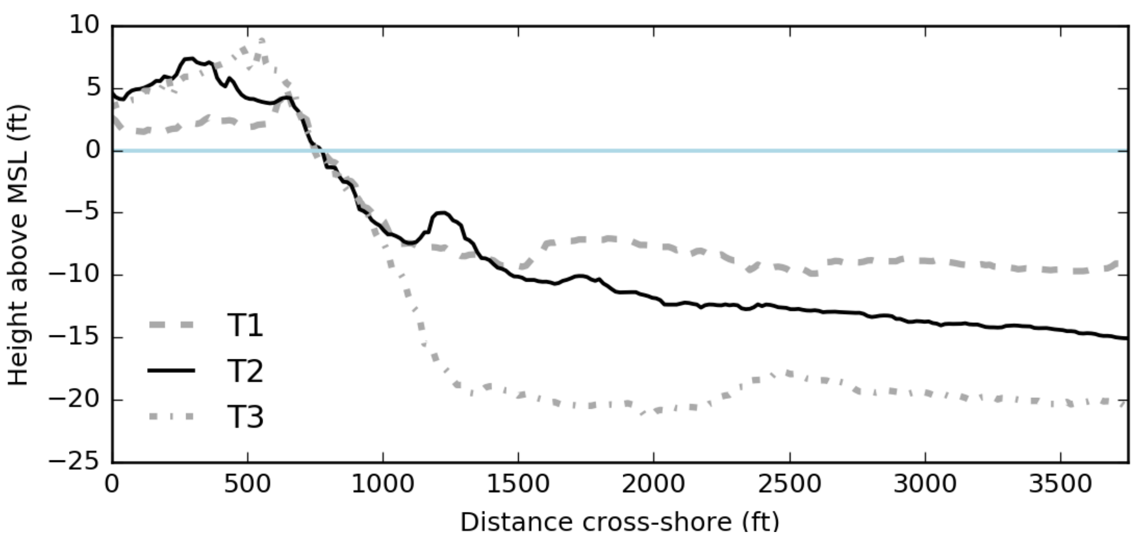


Figure A-3. Cross-shore transects extracted from available digital elevation model.

Table A-5. Dimensions of active profiles as extracted from cross-shore transects along with a weighted average calculated by doubleing the importance of measurements from the T2 transect.

Scenario	Parameters (ft)			Result
	B	*h*	*L*	*Slope*
T1 - Low	4.5	7.0	400	**34.8**
T1 - High	4.5	9.0	760	**56.3**
T2 - Low	4.0	12.0	1350	**84.4**
T2 - High	4.0	14.5	2600	**140.5**
T3 - Low	8.0	12.0	500	**25.0**
T3 - High	8.0	20.0	800	**28.6**
Weighted Avg.	5.1	12.6	1295	**73.0**

A-5.8 Datum Conversion

The analysis of DOC presented in Equation 7 of Hallermeier (1981) gives a depth of closure value relative to mean sea level while the topographic and bathymetric terrain data used are referenced to NAVD88. In order to convert between the two datum's NOAA gauge #8726706 (Clearwater, Clearwater Harbor FL) was used. At this gauge location mean sea level is equivalent to -0.29 ft NAVD88. This correction was applied to the terrain data along the analyzed transects.

A-6 Future Changes to Precipitation

Estimates of the peak 24-hour rainfall event for recurrence intervals up to 200 years were made using combined data from eight different General Circulation Models (Table A-8) and the HydroMetriks – Frequency/Intensity Tool (Hydro-FIT).

Table A-8. Downscaled daily precipitation data was accessed for the following GCM simulations.

CESM1-BGC	CESM1-CAM5	MPI-ESM-MR	GFDL-ESM2M
GFDL-ESM2G	HadGEM2-ES	HadGEM2-AO	ACCESS1-0

Estimates were made for three time periods (Figure A-4), each having a duration of 30 years: **historical period (1980 – 2009)**, **mid-term outlook (2030 – 2059)**, and **long-term outlook (2060 – 2089)**. The black line in Figure A-4 represent fits to the historical GCM data by fitting the Generalized Extreme Value (GEV; orange) and Pearson Type III (PE3; blue) distributions and then averaging; the gray region displays the error bounds as described by Hosking and Wallis (1997). The red line represents the most likely fit to the mid-term outlook, while the purple line represents the most likely fit to the long-term outlook. The GEV and PE3 distributions were found to be the two distributions out of 13 tested that produced the best fits to the GCM data.

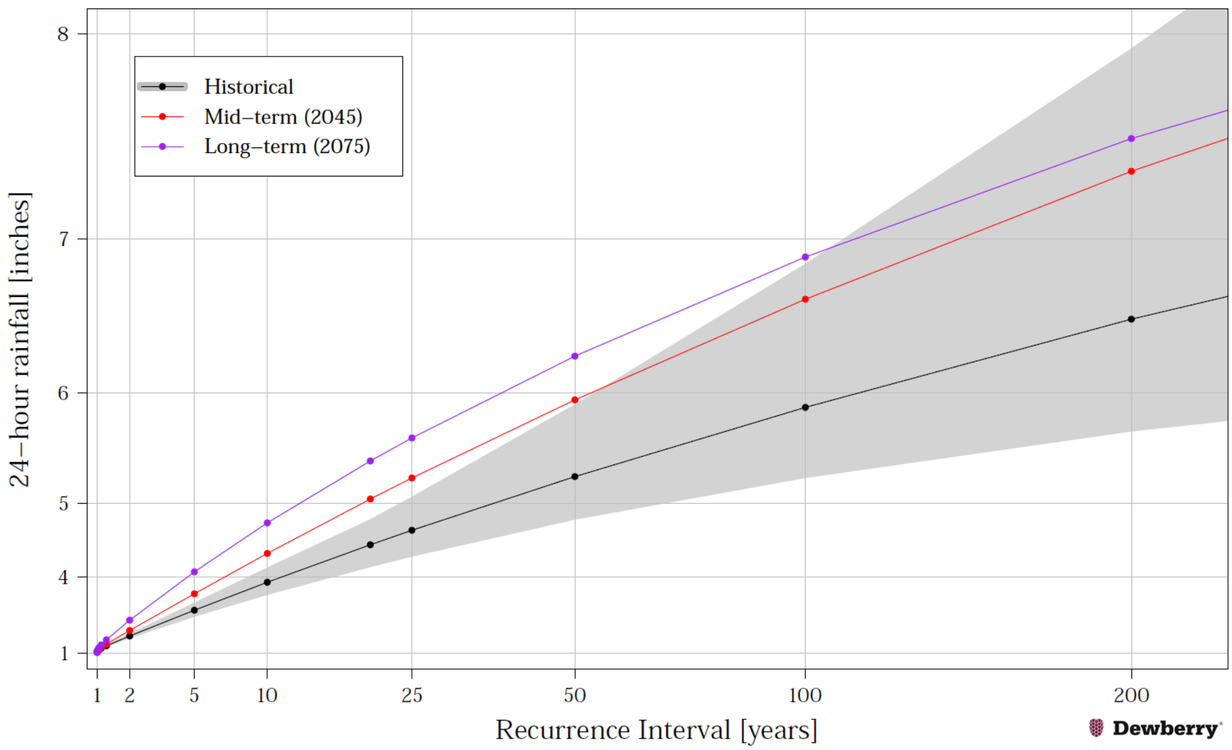


Figure A-4. Estimated annual 24-hour peak precipitation amounts using data from the years 1980 – 2009 (historical; black line with gray shading showing the error range), 2030 – 2059 (mid-term outlook; red line), and 2060 – 2089 (long-term outlook; purple line), from eight different GCMs.

Figure A-4 shows a projected increase of rainfall intensities across all recurrence intervals. Table A-9 lists the specific values for changes in the 24-hour 25-year and 100-year event (compared to the historical period).

Table A-9. Projected increases (%) in 24-hour 25-year and 100-year rainfall for the mid-term and long-term periods. *denotes that estimate is outside the error range of the historical period

	Mid-term (2045)	Long-term (2075)
25-year 24-hour event	+12%*	+20%*
100-year 24-hour event	+13%	+17%*

A-7 Hydrogeological Setting of Clearwater and the Surrounding Region

The City of Clearwater is located in Pinellas County, Florida and is centrally situated within the SWFWMD, depicted in A-5. Much of the land in the SWFWMD is characterized as Karst terrain, a type of landscape with thick layers of limestone and dolomite rocks that permeable and easily dissolved by weak acid that naturally occurs in rainfall. Rainfall and/or saline water dissolves the rock to form underground conduits through which water readily flows. These unique hydrogeological features promote hydraulic connectivity between fresh groundwater and more saline zones within the aquifer system. Karst landscapes are also characterized by an abundance of sinkholes because as the rock dissolves, it can cause the surface area above it to collapse (SWFWMD 2016).

Figure A-5. Map of the Southwest Florida Water Management District obtained from: http://www.swfwmd.state.fl.us/data/map/.

The groundwater system in west-central Florida is composed of three main units: the surficial aquifer, the intermediate aquifer system, and the Floridan aquifer system. The surficial aquifer, or water table aquifer, consists of undifferentiated sands and clays that vary in composition both laterally and vertically, is generally unconfined, and ranges in thickness from 0 to 132 feet in Pinellas County (Knochenmus and Thompson 1991). Depth to the water table (DTW) is generally less than 5 feet below land surface, but ranges from close to 0 to more than 20 feet in sandy ridge areas (Knochenmus and Thompson 1991). Seasonal fluctuations result in water table fluctuations between 1 and 4 feet in response to recharge and pumping rates (Knochenmus and Thompson 1999). The principal uses for the surficial aquifer in Pinellas County are irrigation, limited domestic use, and dewatering projects for mining and infrastructure installation (SWFWMD 2006).

The intermediate aquifer system, positioned beneath the surficial aquifer system, is composed primarily of limestone, shell, sand and clay that act as a confining unit separating the surficial and Upper Floridan aquifers (SWFWMD 2016). The Floridan aquifer system, composed chiefly of limestone and dolomite, behaves as one aquifer over much of its extent; although, the system is subdivided vertically into upper and lower permeable zones: the Upper and Lower Floridan aquifers, which are separated by both confining and semi-confining units that control the movement of water between the two aquifers (Figure A-6; Barlow 2003; Knochenmus and Thompson 1991). In Pinellas County, the Upper Floridan aquifer is generally confined and consists of a thick series of continuous carbonate rocks made up of limestone and dolomite. The principle uses for the Upper Floridan aquifer in the SWFWMD are for public supply, agriculture, and industry (SWFWMD 2016).

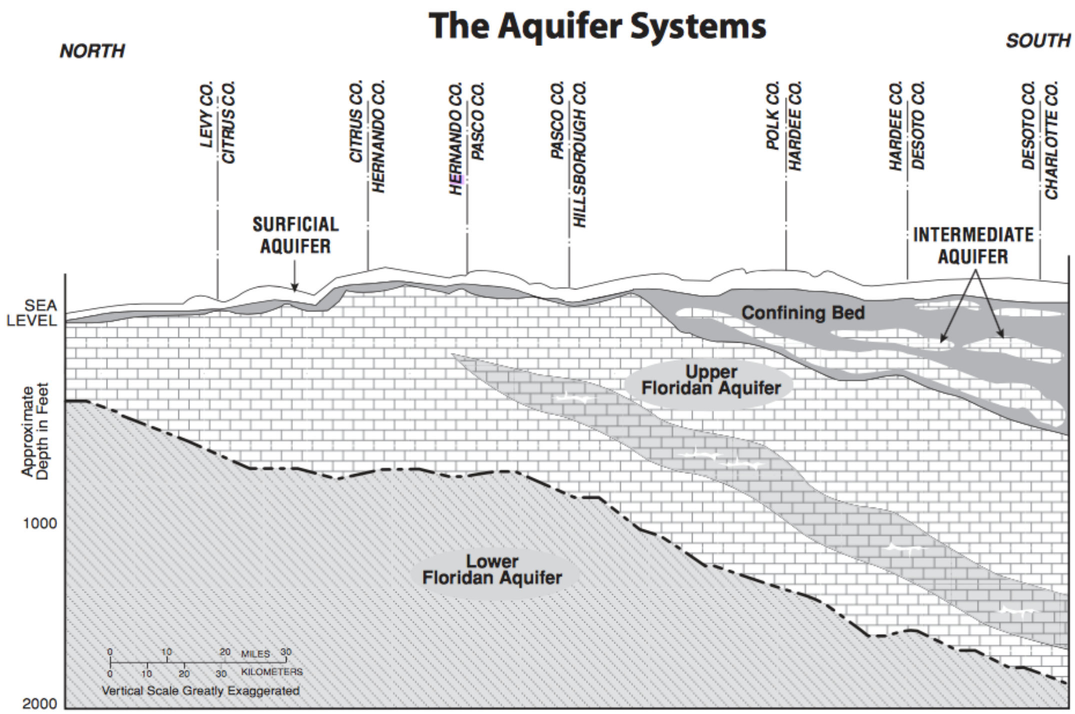


Figure A-6. Generalized hydrogeological units in West-Central Florida, obtained from SWFWMD (2016) at https://www.swfwmd.state.fl.us/publications/files/flas_aquifers.pdf.

A-8 Primary Mechanisms for Saltwater Intrusion

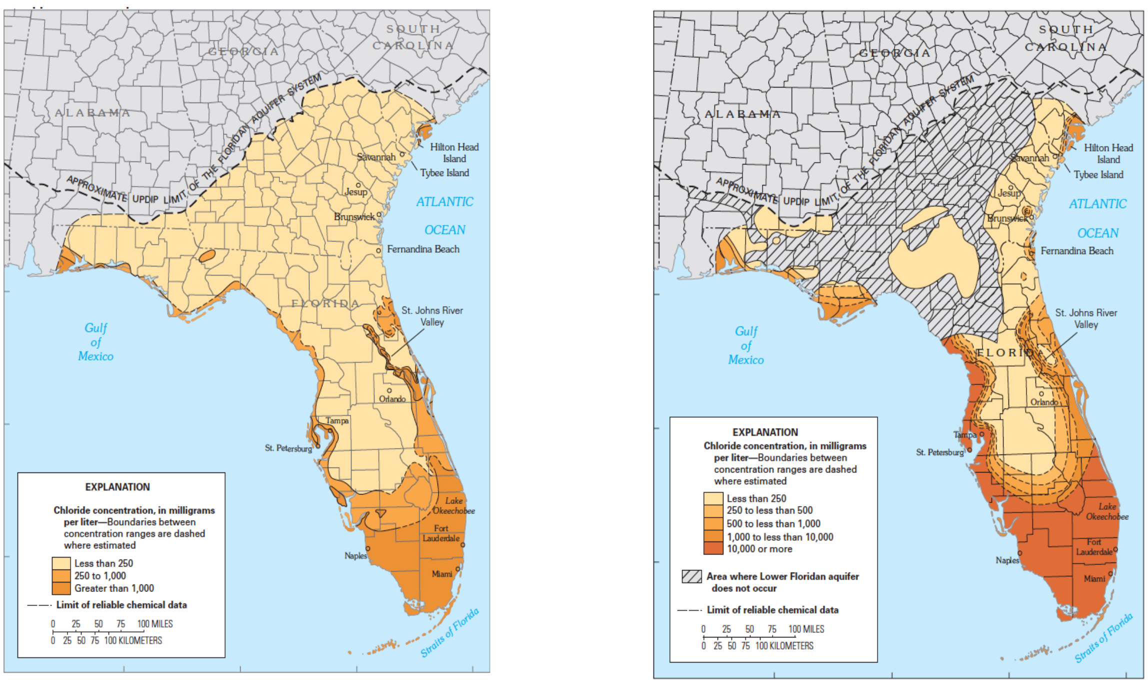
In the coastal zone, the water table typically lies above mean sea level and groundwater flows from higher elevation inland areas toward lower elevation coastal areas. This natural movement of freshwater towards the ocean prevents saltwater from intruding into coastal aquifers by maintains the position of the interface between freshwater and saltwater (Barlow 2003). However, saltwater contamination of groundwater resources is becoming an increasing concern in west-central Florida, resulting in abandonment of wells and exploration of innovative technologies to combat saltwater intrusion such as reverse-osmosis and groundwater replenishment. The City of Clearwater is uniquely vulnerable to saltwater intrusion because of its exposure as a peninsula and series of barrier islands to saline and/or brackish water on all sides, bounded by Tampa Bay to the east and the Gulf of Mexico to the west. The City of Clearwater, in cooperation with the SWFWMD, is implementing a multi-phased groundwater replenishment (GWR) project using reclaimed water from the Clearwater's Northeast Water Reclamation Facility (NEWRF). The purpose of the GWR project is to use purified reclaimed water to replenish the Upper Floridan aquifer in order to offset current and future withdrawals from the City's well fields and protect the fresh ground-water from saline contamination (LBG 2014). The City is currently conducting a study to look at the feasibility of groundwater replenishment technology through ongoing hydrologic monitoring and operation of a Pilot Treatment System to investigate the effects of recharging the Upper Floridan aquifer with up to 3 million gallons per day (MGD) of purified reclaimed water at the NEWRF (LGB 2014).

In general, saltwater intrusion in west-central Florida occurs by a variety of mechanisms depending on groundwater use and hydrogeology, including:

1. Lateral encroachment from the ocean due to excessive water withdrawals from coastal aquifers that share a hydraulic connection with the sea (i.e. pumping-induced saltwater intrusion).
2. Up-coning of saline water from deeper zones in the aquifer.
3. Karst terrain and fractures in the coastal rock formation creating conduits for saline intrusion.
4. Vertical migration of saltwater across interconnected aquifers in water-supply wells.
5. Short and long-term sea level changes (tidal fluctuations and sea level rise) inducing saltwater interface migration and water table rise.

Local hydrogeology studies focused on the aquifer system in Pinellas County reveal that the county has historically dealt with management of saline groundwater resources. The majority of Pinellas County is underlain by brackish waters (water with dissolved-solids concentrations between 1,000 and

10,000 mg/L) found in the Upper Floridan aquifer at depths ranging from about 100 to 400 ft below land surface (Broska and Barnette 1999). Clearwater is situated within a high-salinity zone of the Lower Floridan aquifer system, defined as areas having greater than 10,000 mg/L of total dissolved solids and generally associated with coastal areas of high-permeability (Williams and Kuniansky 2015). Figure 19 shows chloride concentrations in the Upper and Lower Floridan aquifers (Figure A-7A and A-7B respectively), illustrating the general transition zone between fresh and saltwater (Barlow 2003).



A: Upper Floridan Aquifer **B: Lower Floridan Aquifer**

Figure A-7. Chloride concentrations in water from the upper 200 feet of the Upper Florida aquifer (A, above) and from the Lower Floridan aquifer (B, above). Figure obtained from Barlow (2013).

Chloride concentrations in the Upper Floridan aquifer are generally related to proximity to the coast and groundwater flow. In areas where the upper confining unit is thin or absent, recharge and groundwater circulating is high. These areas of high permeability results in groundwater that readily dissolves the carbonate rocks that compose the aquifer system, creating conduits that transmit and store tremendous volumes of groundwater. Chloride concentrations tend to be low (less than 250 mg/L) in these areas where high groundwater circulation is high. Conversely, where the groundwater flow system is tightly confined, chloride concentrations in the aquifer tend to be higher (Barlow 2003).

Mechanism 4, the vertical migration of saltwater across interconnected aquifers in water-supply wells, is another possible mechanism of saltwater intrusion in Clearwater. In coastal areas where there is a source of saltwater that can be transported from one aquifer to another, improperly constructed or corroded wells and open boreholes can create pathways for inter-aquifer saltwater intrusion when hydraulic-head gradients within the wells or boreholes induce flow (Barlow 2003). Between 1900 to the early 1970s, thousands of deep water wells open to the intermediate aquifer system were drilled into the Upper Florida aquifer in west-central Florida for irrigation uses. Approximately 8,000 of these early irrigation wells were reported or estimated to be open to the Lower and Upper Floridan aquifers, providing conduits for water to flow upward or downward across the confining units (Figure A-8). A study of aquifer vulnerability in west-central Florida delineated the extent of inter-aquifer flow of saline water in ground-water wells open to both the intermediate and Upper Florida aquifers (Metz and Brendle 1996). The study found that in coastal areas, ground-water levels were as much as 20 feet higher in the Upper Floridan aquifer than in the overlying intermediate aquifer system, where an estimated 85 MGD flowed upward from the Upper Floridan aquifer to the overlying fresher water zones in the intermediate aquifer system through inter-aquifer wells, bringing along high concentrations of chloride, sulfate and dissolves solids (Metz and Brendle 1996; Barlow 2003). The SWFWMD began the Quality of Water Improvement Program (QWIP) in 1974 to re-establish confinement between aquifers by sealing wells and plugging boreholes to halt slow saltwater intrusion by inter-aquifer contamination (Barlow 2003).

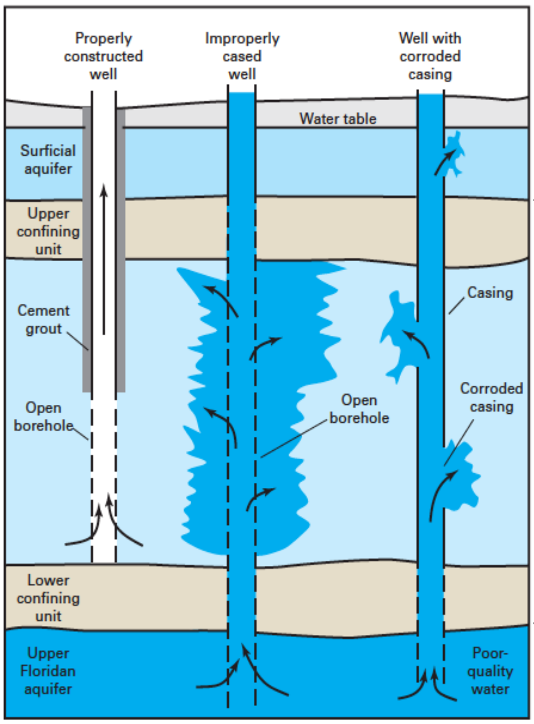


Figure A-8. Contamination by saltwater through failed, uncased or improperly constructed wells that create a conduit for flow between aquifers. Figure obtained from Barlow (2003).

Mechanism 1, pumping-induced saltwater intrusion, while likely not a direct mechanism of saltwater intrusion in Pinellas County due to limited ability to use the brackish aquifers for potable water, may impact the regional vulnerability of aquifer system in west-central Florida. Pinellas County is located directly northwest of the Southern Water Use Caution Area (SWUCA), an area that the SWFWMD established in 1992 in response to the 1993 Eastern Tampa Bay Water Resources Assessment Project (ETB WRAP) that found significant, regional saltwater intrusion that posed a limiting constraint on groundwater development in the area (SWFWMD 2002). Based on the conclusions of the ETB WRAP, the SWFWMD developed a solute transport model (the Eastern Tampa Bay Solute Transport Model) that included the southern half of Pinellas County, in order to establish minimum groundwater levels within the SWUCA to determine how much water can be safely withdrawn from the aquifer system in order to achieve the management goal of slowing the rate of saltwater intrusion (SWFWMD 2016).

While some combination of Mechanisms 1 – 4 likely explain the observed saltwater contamination of the aquifer system in west-central Florida, Mechanism 5 (short and long-term sea level change) has the potential to exacerbate the extent and magnitude of saltwater intrusion (Langevin and Zygnerski 2013).

APPENDIX B: DESIGN MEETING NOTES

Attendees:

Name	Organization	Contact
Kyle Brotherton	Clearwater	Kyle.Brotherton@myclearwater.com
Jorge Hernandez	Gas	Jorge.Hernandez@clearwatergas.com
Sarah Kessler	Clearwater Environmental & Stormwater	Sarah.Kessler@myclearwater.com
Lauren Matzke	Clearwater Planning & Development	Lauren.Matzke@myclearwater.com
David Porter	Clearwater Public Utilities	David.Porter@myclearwater.com
Scott Ehlers	Clearwater Emergency Management	Scott.Ehlers@myclearwater.com
Sean Reiss	DEO	Sean.Reiss@deo.myflorida.com
Brian Batten	Dewberry	bbatten@dewberry.com
Chris Zambito	Dewberry	czambito@dewberry.com
Krista Rand	Dewberry	krand@dewberry.com

Priorities:

1. Determine where it might make sense to implement changes to building codes, regulations and density limitations
2. Protect gas facilities (and other utilities and infrastructure)
3. Get all departments city-wide on board with planning for 1 foot of sea level rise over the next 30 years; develop the ability to work outside and across silos and interest groups
4. Understand the economic impacts
5. Incorporate resiliency into upcoming planning exercises

Breakout Session Action Items:

Evacuation Routes and Infrastructure Action Items
Improve shelter vulnerability and resilience • Planning and Economic Development (Kyle) has GIS data showing shelter locations • Needs: vulnerability maps with transportation system overlays • EM can coordinate this issue with the county • Engineering has geospatial data show bridges and culverts (including dimensions/flow capacity)
Identify vulnerability of street grids, bridges, and approaches • Planning and Economic Development (Kyle) has street grid data • The MPO has traffic data that may be useful • Needs: vulnerability maps
Evaluate regional electric grid vulnerability • The city would pursue outreach to Duke • Departments that would play a role include Planning, Utilities, Gas and Traffic

Discussion

• There are three evacuation routes:
  o Courtney Campbell Causeway
  o Howard Franklin
  o Gandy Bridge (which is slab)
• US 19 is often the limit of flooding and can be used to evacuate to the north
• Sunshine Skyway connects Manatee and Pinellas County
• There are little, lower bridges, such as that to Island Estates, which have been rebuilt in-kind rather than upgraded for increased flood threats
• Utilities on the bridges are also at risk
• Where pipelines may have been impacted, PHMSA (Pipeline and Hazardous Materials Safety Administration) coordination with city emergency management
• From a resilience perspective, if there are no utilities, people cannot come back
• Shelters could be located strategically to account for long-term vulnerability to sea level rise

Economic Impacts Action Items

Achieve county-wide collaboration on sea level rise
• Major players are Clearwater, St. Pete, and Pinellas CO
• The city could reach out to:
  o The Regional Planning Commission
  o The Regional and Beach Chambers of Commerce
• Planning and Economic Development will need to discuss further to suggest potential products needed (Lauren in discussion with Maya)

Identify vulnerabilities to hotels and tourism • Needs: parcel and footprint data included with SLR impact maps • The city can identify the locations of hotels (Planning and Economic Development – Kyle)
Identify progressive developers • The city (Planning and Economic Development) can consider who may be potential allies in adaptation
Evaluate the use of Adaptation Action Areas in high vulnerability areas • Needs: Vulnerability maps • Planning and Economic Development could consider whether and where AAAs might make sense
Discussion

• Beaches are the primary attraction – estimated 80-90% of the economy is based on beach tourism
• Changing building requirements would get push-back from developers, who will ask for exceptions
• Utility systems would have to be changed to accommodate sea level rise, especially at higher levels
  o Operations
  o Configuration
  o Master planning process
• The wastewater master plan will be completed in the next year and will be effective for the next 5-10 years; assets are already being elevated above the historical maximum flood upon replacement
• Resilience to sea level rise will pose a challenge to homeowners and business owners in terms of cost, the need for education, and losses of height for high rises
• FEMA mitigation grant dollars for elevation are difficult to qualify for and there are many drop-outs
• Outreach to developers may be helpful
• USACE has a beach nourishment program for Sand Key through Treasure Island and Madeira, but existing easements are insufficient for nourishment to 1992 historical levels in some locations
• There are 24 municipalities along the coast in this area who are potential partners and are looking to Clearwater for leadership
• Pinellas Planning Council and the MPO have useful land use and transportation data
• One Bay Working Group and the Local Mitigation Strategy group may be useful partners/collaborators

Saltwater Impacts Action Items
Identify sea level rise threats to natural systems • Needs: maps (as produced for above-mentioned action items) • City assesses
Identify septic sites impacted by sea level rise • Engineering has GIS data for septic sites
Consider corrosion hazards to gas utility infrastructure • Discussion with EM (Scott) about existing and potential issues • Receive data from Gas • Needs: hazard maps
Discussion
• Parks and soccer fields will be heavily impacted and intrusion may change natural ecosystems in the floodplains • On the barrier islands, people already want to remove dunes to improve their views • Aquifer water sources are current somewhat saline, and there are two reverse osmosis plants in operation with a third planned • The city currently has a process to convert effluent to drinking water • Saltwater currently has negative effects on infrastructure, e.g. Pier 60, which is deteriorated but cannot be easily convert to PVC due to code issues • Rising groundwater levels would pose a hazard to the city's 4,000 septic sites, 400 of which have been decommissioned • Brownfields may experience mobilization of contaminants • Corrosion can cause problems for gas and other utilities, many of which are metal or have metal components

Stormwater Action Items
Evaluate vulnerability to backups and failures • Engineering could provide records of historical issues • Gas may be able to provide after-hours call records • Needs: vulnerability maps
Include sea level rise in watershed management plans • The city would incorporate this issue into BMPs
Evaluate how to enforce site plan compliance • Building Department would lead (Lauren and Sarah would interface with this department) • Needs: materials and maps to support this conversation
Discussion

• Design elevations and storage capacity may be exceeded, such as the labyrinth weirs and storage/capacity of the parks and canals.
• Sea level rise would exacerbate rainfall-induced ponding
• Stormwater utility fees are fairly robust and paid at a homeowner rate and a business rate (by impervious area)
• Fees have funded projects such as restoring two floodplains, including a golf course, near Stevenson and Alligator Creeks
• Fees also fund:
    o Maintenance
    o Engineering
    o Capital improvement program
• The development community already faces site development challenges in complying with all requirements
• LID is supported by the city and detailed in the stormwater design manual but not fully codified yet
• There is finite storage available for water, and at some point, there's no more room
• The city employs proactive debris management before and during storms

- One example of a stormwater failure was the 2015 August combination of high-high tide and heavy rainfall There are also often problems with rainfall following saturated antecedent soil conditions.
- The CRS requires delineation of repetitive loss areas
- Stormwater sometimes backs up onto streets, and it would be useful to understand how this might change over time.
- Channels, bridges, and utilities on bridges are vulnerable to debris from high-flow events
- Engineering (Sarah) has institutional knowledge about the location of call-in hot spots for localized flooding

Nuisance Flooding Action Items

Understand changes to the frequency, depth and extent of flooding over the next 10, 20 and 30 years

- Engineering has information about stormwater system capacity (Sarah)

Perform neighborhood outreach throughout the community

- Support of the Mayor would be needed (Lauren would engage the executive level of Planning and Economic Development to begin outreach to Mayor)
- One-on-one discussion with council members would be useful
- In three months, the Environmental Advisory Board, a citizen group, is meeting and Engineering (Sarah) may want to engage with them
- Needs: Design Meeting PowerPoint would be a useful discussion tool

Incorporate sea level rise into CRS program activities

- City department involvement: Public Communications, Engineering
- Needs: maps may be useful here – discuss with Engineering (Sarah)

Evaluate adaptations

- A city working group may review adaptation priorities, options, and suggestions

Discussion

- North Beach and Bayshore are two particularly vulnerable communities
- Flooding in streets and yards is already common, and with sea level rise, flooding of homes may occur, too
- Flooding is monthly at Bayshore, due to stormwater
- North Beach is vulnerable during times of high tides, especially King tides
- FEMA will be releasing sea level rise advisory rates, new coastal FIRM products, and new multi-agency working group products soon
- Backups due to increased sea level seem likely – options seem to include
    - Seawalls
    - Raising roads
    - Storage under roads
- Erosion and undermining of roads can occur with even a few inches of inundation
- The Bayshore mobile home park could be an attractive property acquisition for floodplain management through CRS
- North Beach residents are highly engaged citizenry
- At Drew Street and Bayshore, the open drainage sometimes looks like rapids and causes pooling at intersections. People get stuck trying to cross during heavy rain and high tides.
- Wastewater treatment plants at two locations will face very costly planning issues related to the existing gravity sewers
- Developers may reach a point where they will need to put in lift stations, otherwise their sewers will exacerbate existing inflow and infiltration problems
- The city is currently reconfiguring for redevelopment and modernization, especially in the downtown areas and the US 19 corridor, which is largely residential
- Wetlands will limit redevelopment
- Combined sewer overflows are an ongoing and costly issue the city is working to resolve
- Sewers will back up, particularly during rain storms

- Because the lifespan of wastewater treatment plans are 30-50 years, it will be important to include sea level rise in the master planning process
- It is not currently feasible to put the whole city on pumps. 1 ft of sea level rise would be manageable, but at 2+ feet, the city would have to rethink a lot of infrastructure
- The city population is static at 110,000 with a seasonal tourism influx

APPENDIX C: LESSONS LEARNED

In performing the vulnerability assessment with the City of Clearwater, there were valuable insights worth noting as other communities go through similar processes:

- Scoping the Vulnerability Assessment
  - Going through an iterative process (questionnaire, kickoff discussion, facilitated design meeting) was helpful to gather feedback from multiple stakeholders and focus the community's priorities.
  - Some stakeholders varied meeting to meeting and thus effort was needed to catch new participants up to speed as well as integrate their point of view into discussions that had already been partially framed.
  - Less is more. The vulnerability assessment is technical in nature and limited funding constrains the complexity of analysis that can be performed for each assessment. Once draft results were presented, it was clear that the participants would rather have detailed discussions for a few assessments as opposed to limited-detailed discussions of many assessments.

- Data Quality/Availability
  - There are varying levels of detail and completeness between national and local datasets.
  - The community was able to provide a wide assortment of datasets, but there was still the need to supplement the data from other sources.
  - Limitations in data, such as finished floor elevations and soil borings, resulted in how some of the assessments could be performed (some assessments leaned more qualitative than quantitative in their findings).

- Communicating the Results
  - The community liked the ability to look at draft products (reports, graphics, web-enabled maps) and provide feedback on the results.
  - It is very challenging to communicate the technical and scientific aspects of the project in a way that easily understood by all audiences.

- Opportunities to Build on the Vulnerability Assessment
  - Nuisance flooding was demonstrated to be one of the primary concerns for future impacts as SLR increases. Additional analysis, such as understanding the change in frequency and duration of this flood type should be considered by the community.
  - The methodology for future shoreline change along the Gulf of Mexico Coast had limitations but provided some insights into future trends. Approaches for assessing this issue are improving, and a reliable, more robust method may become available in the next few years. Incorporating sediment budget considerations, or performing The identification of beach impacts was well received by the participants. It may calculations on potential costs to re-nourish those areas of erosion over time as the impacts become more frequent (what if the City had to pay to re-nourish beaches every 5 yrs?) could further improve understanding on a key resource for the City.
  - Due to limitations in the available data and budget, impacts from the changes in depth of flooding was not possible. The City may want to invest additional resources to

identify finished floor elevations and perform an improved vulnerability analysis, such as a depth-damage assessment. This would allow them to quantify impacts further and look to ancillary impacts such as potential changes to flood insurance and building codes.