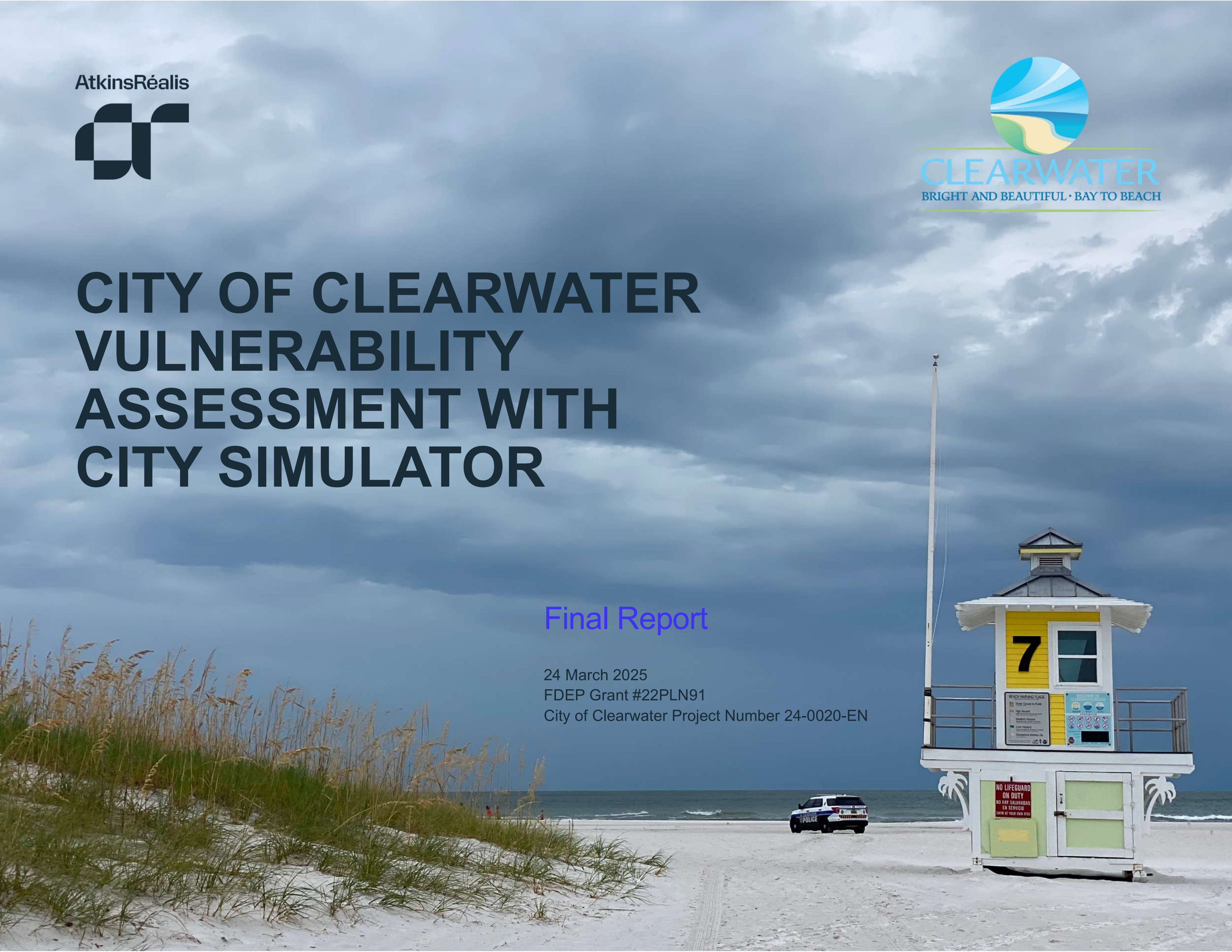

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CLEARWATER
BRIGHT AND BEAUTIFUL · BAY TO BEACH

CITY OF CLEARWATER VULNERABILITY ASSESSMENT WITH CITY SIMULATOR

Final Report

24 March 2025
FDEP Grant #22PLN91
City of Clearwater Project Number 24-0020-EN

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This work was funded in part through a grant agreement from the Florida Department of Environmental Protection, Resilient Florida Program, by a grant provided by the Office of Resilience and Coastal Protection. The views, statements, findings, conclusions, and recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the State of Florida or any of its subagencies.

Introduction

The City of Clearwater was awarded a grant by the Florida Department of Environmental Protection (FDEP) to perform a vulnerability assessment that examines the potential impacts from future flooding based on a range of climate projections. This document provides insights as to where the community may want to invest in higher levels of protection, while also making the City eligible to apply for future funding under the Resilient Florida program.

1. About the Study

This Vulnerability Assessment (VA) is meant to allow the City of Clearwater to focus on long term growth while identifying future vulnerabilities from climate stressors such as increased rainfall, sea level rise, stronger tropical systems, and heat. Not only does the project identify these impacts to a projected growth of the city's infrastructure, buildings, and population via the creation of a geospatial digital twin, but it allows the city to test a portfolio of mitigation actions and refine those that are most cost effective and beneficial to the community. The project was funded under a grant (22PLN91) from the Resilient Florida program administered by the Florida Department of Environmental Protection (FDEP).

1.1 Project Purpose

The project is intended to provide the City with an understanding of its exposure to future climate conditions and what options they may consider implementing to reduce the vulnerabilities associated with those hazards. This assessment also provides the City with eligibility to apply for additional grant funding under the Resilient Florida program.

1.1.1 Resilient Florida Grant Requirements and Legislation.

Communities across the state are utilizing new funding opportunities available through the Resilient Florida program, which was authorized via Section 380.093, F.S. The legislation identified that FDEP may "provide grants to a county or municipality to fund the costs of community resilience planning and necessary data collection for such planning, including comprehensive plan amendments and necessary corresponding analyses that address the requirements of s.163.3178(2)(f); vulnerability assessments that identify or address risks of flooding and sea level rise; the development of projects, plans, and policies that allow communities to prepare for threats from flooding and sea level rise; and projects to adapt critical assets to the effects of flooding and sea level rise."

Furthermore, the legislation specified that "A vulnerability assessment conducted pursuant to paragraph (b) must encompass the entire county or municipality; include all critical assets owned or maintained by the grant applicant; and use the most recent publicly available Digital Elevation Model and generally accepted analysis and modeling techniques."

1.1.2 The City's Grant Agreement

The City of Clearwater was awarded grant agreement 22PLN91 on August 2, 2022, had a change order on October 24, 2022, to update language, and an amendment on March 11, 2024, to update language and extend the end date to September 30, 2024. The City's project, Vulnerability Assessment with City Simulator, includes specifications for compliance with standardized FDEP vulnerability assessments, as well as additional elements to evaluate heat and initial adaptation activities. Furthermore, in addition to the analytical and report components, the grant also requires community engagement to convey findings of the project.

1.2 Community Profile

The City's location in west central Florida, as well as within the center of Pinellas County, provides residents and businesses with favorably mild climate conditions year-round. Its famed Clearwater Beach and attractions, such as the Clearwater Marine Aquarium, help to drive tourism and make the city a destination for visitors. The City's eastern border along Tampa Bay, and the western border, along the Gulf of Mexico and Clearwater Harbor, expose the community to tidal and surge flooding that are the main topic of this report.

1.2.1 Population and Demographics

US Census estimates from 2022 have the city's population at 117,292, which is an increase of approximately 8,000 residents from 2010 (109,005). The median age of residents is 46, and the ethnic distribution is as follows:

Ethnicity	Percentage
American Indian or Alaska Native Alone	0.4%
Asian	2.8%
Some Other Race Alone	3.7%
Two or More Races	6.8%
Black or African American	9.7%
Hispanic or Latino	14.4%
White	62.2%

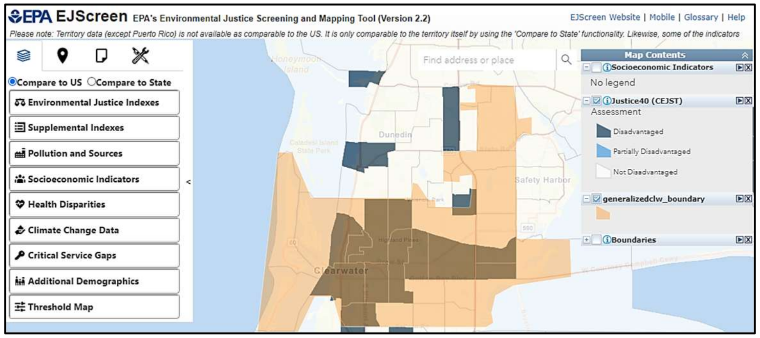
1.2.2 Workforce

US Census 2022 information identifies that the employment rate within the community is 55%. The key industries and the percentages are shown below:

Industry	Percentage
Educational services, and health care and social assistance	21.00%
Professional, scientific, and management, and administrative and waste management services	13.30%
Arts, entertainment, and recreation, and accommodation and food services	12.10%
Other services, except public administration	10.30%
Construction	10.00%
Finance and insurance, and real estate and rental and leasing	7.70%
Retail trade	7.50%
Manufacturing	6.10%
Transportation and warehousing, and utilities	4.40%
Public administration	3.50%
Information	1.70%
Agriculture, forestry, fishing and hunting, and mining	1.20%
Wholesale trade	1.20%

1.2.3 Environmental Justice

The US Environmental Protection Agency provides an environmental justice screening tool to allow users to understand indicators related to the protection of public health and the environment. There are 13 census tracts within the municipal boundary that are designated with “disadvantaged” status.

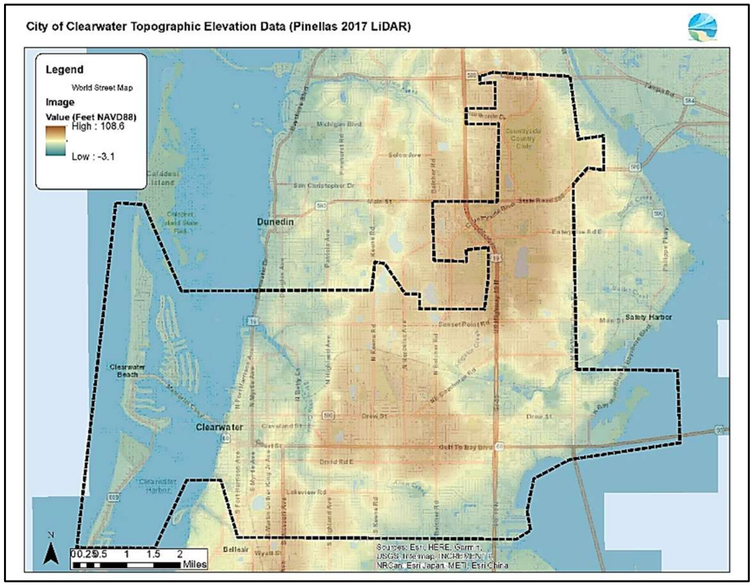


The tracts located near downtown contain the most categories of disadvantage, including:

- Energy
- Health
- Housing
- Legacy Pollution
- Water and Wastewater
- Workforce Development

1.2.4 Topography

The City’s elevation ranges from approximately 0 feet along the coasts to 110 feet in the northeastern parts of the community near US 19 and the Countryside area. The average elevation is 26 feet. Pinellas County’s 2017 LiDAR data set was utilized as the basis for assessment with this study.



1.2.5 Built Environment

The city has been relatively built out since 2010 with most recent activities being associated with redevelopment initiatives. The graphic below utilizes “effective year built” and “use code” attributes from the 2022 parcel base to illustrate the built environment of the community over time. It also identifies that the approximately fifty-two thousand parcels have a justified value of nearly twenty-five billion dollars.

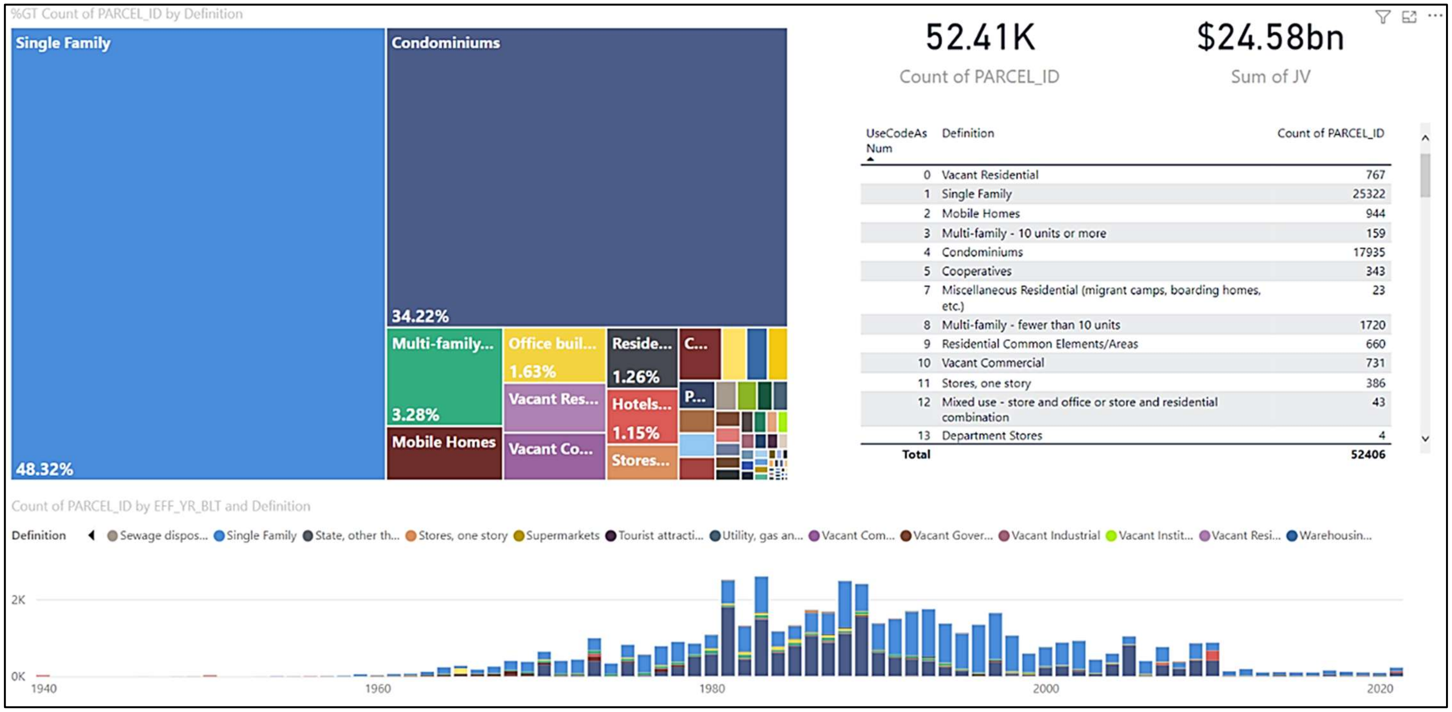


Figure 1-1 - Types of structures within the city and their development over time.

The transportation network is also of importance to the study as it helps identify how residents and visitors get to places of work, recreation, and home. The network is a vital component of the assessment process as it is used to calculate how many trips are potentially disrupted due to climate projections and how the city can assess return on investment when evaluating roads and infrastructure improvements. The graphic on the following page shows the network and assumptions used for data gaps.

Annual Average Daily Traffic (AADT)

The AADT was calculated for this project by performing the steps below:

- Road network based on original GIS layer provided by city staff.
- Local AADT estimated from residential structures on each road segment * 10 trips/structure.
- FDOT AADT sampled to road network for FDOT-maintained roads-sampling challenging because of mismatch in road lines between layers.
- RW sampled from the City's roads layer; if not FDOT provided, then if RW >= 80, set to 2,000 trips/day.
- Minimum AADT set at 200 trips/day.
- Some manual adjustments were required.

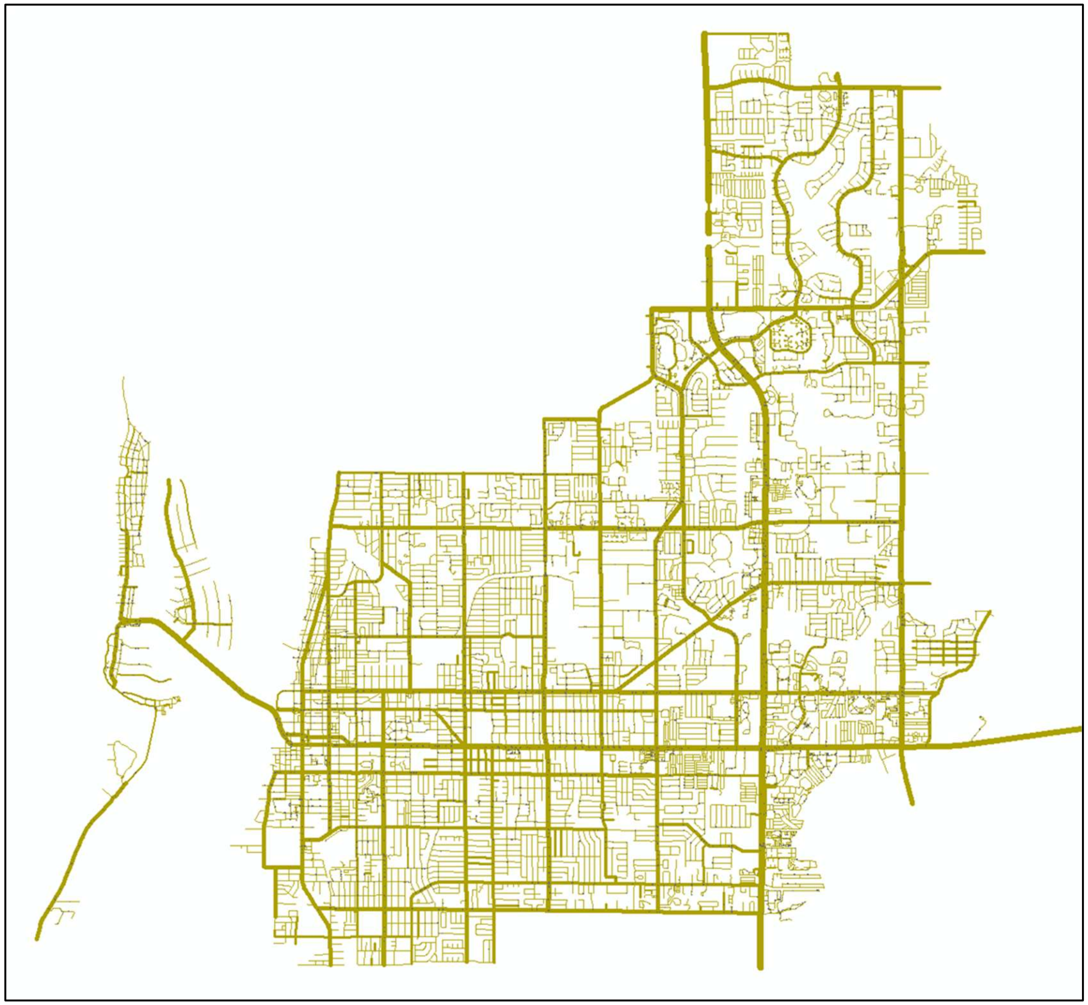


Figure 1-2 - Roadway Network per Annual Average Daily Trips (AADT)

1.3 Climate Trends and Background

The Vulnerability Assessment with City Simulator is intended to stress test the community to expected futures by implementing a model that takes climate projections and synthetic storms based on those projections into the 2100 planning horizon. The following items provide information on recently observed temperature, precipitation, and tidal deviations to help understand the changing climate.

1.3.1 Recent Sea Level Rise Observations

The Tampa Bay area has two tidal gauges that collect information on surface water elevations over time. These are the St. Petersburg and the Clearwater Beach gauges. The National Oceanic and Atmospheric Administration (NOAA) provides a tool to help users understand the trends of sea level change in terms of local relative sea level (Tool). In the following graphic, the trends are provided across the whole state to help illustrate the different rates of change in different geographies. This helps to show how communities across Florida may have to plan differently as they may be experiencing inundation faster or slower than neighboring areas.

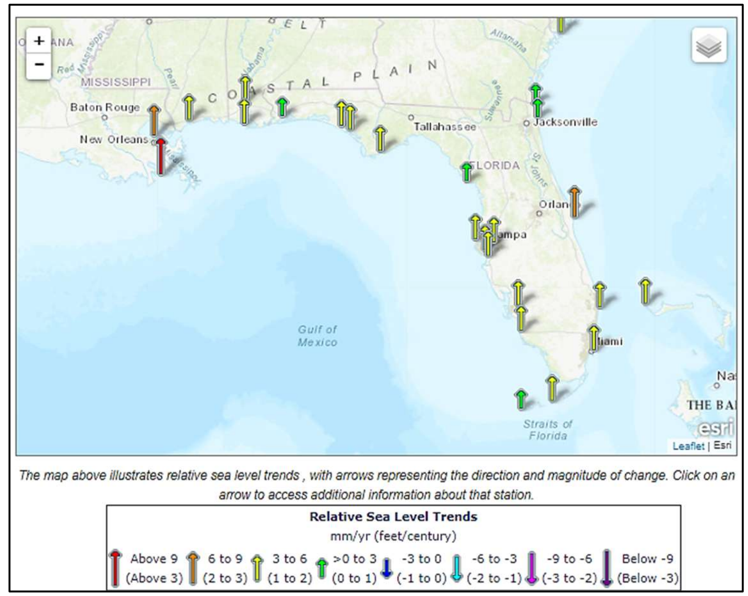


Figure 1-3 - NOAA's Sea Level Rise Trends

The **Clearwater Beach gauge (8726724)** shows the relative sea level trend is **4.33 mm/year** with a 95% confidence interval of +/- 0.52 mm/year based on monthly mean sea level data from 1973 to 2023 which is equivalent to **a change of 1.42 feet in 100 years**.

The **St. Petersburg gauge (8726520)** shows the relative sea level trend is **3.09 mm/year** with a 95% confidence interval of +/- 0.23 mm/year based on monthly mean sea level data from 1947 to 2023 which is equivalent to **a change of 1.01 feet in 100 years**.

1.3.2 Historical Flood Events and Average Rainfall

Residents and businesses may experience flooding from a variety of sources including, tropical systems, non-tropical systems, heavy precipitation/flash flood events, or even from local drainage. There have been 19 disaster declarations for Pinellas County from tropical systems or severe storm events. NOAA's Coastal Inundation Mapping website provides available data for each gauge. The following graphic identifies the highest water levels observed at the Clearwater gauge relative to the Mean Sea Level vertical datum as provided by the NOAA tool.

NOS/NOAA/CO-OPS
Top-10 Highest Water Levels
8726724, Clearwater Beach FL

Units: Standard | Datum: MSL | JSON Link | XML Link

Date	Height (Feet above MSL)	Event Category	Event	Source
March 13, 1993	5.28	Extra Tropical	1993 Storm of the Century	Observed Peak Water Level
January 3, 1999	5.25	TBD	To Be Determined	Observed Peak Water Level
August 30, 2023	5.13	Tropical	Hurricane Idalia	Observed Peak Water Level
October 10, 2018	4.89	Tropical	Hurricane Michael	Observed Peak Water Level
December 17, 2023	4.70	Other	December East Coast Storm	Observed Peak Water Level
October 8, 1996	4.55	Tropical	Tropical Storm Josephine	Observed Peak Water Level
August 31, 1985	4.44	Tropical	Hurricane Elena	Observed Peak Water Level
September 2, 2016	4.28	Tropical	Hurricane Hermine	Observed Peak Water Level
December 21, 2018	4.13	Extra Tropical	Coastal Low Pressure	Observed Peak Water Level
June 6, 2016	4.09	Tropical	Tropical Storm Colin	Observed Peak Water Level

Listing of the top historical water levels, along with the associated weather event (if known). Most values are based on the 6-minute peak water level observed at the tide gauge. Top historical water levels prior to 1996 are typically based on hourly observations. At times where observed water levels are unavailable, values may be taken from high water marks. For additional information or data, please visit the Extreme Water Levels website.

Figure 1-4 - Top 10 Highest Water Levels Observed at Clearwater Beach Gauge

Precipitation data is available at the county level and provides insight into how much rainfall to expect on an annual basis. The graphic below is pulled from the Pinellas County Water Atlas tool and identifies the following statistics for Pinellas County.

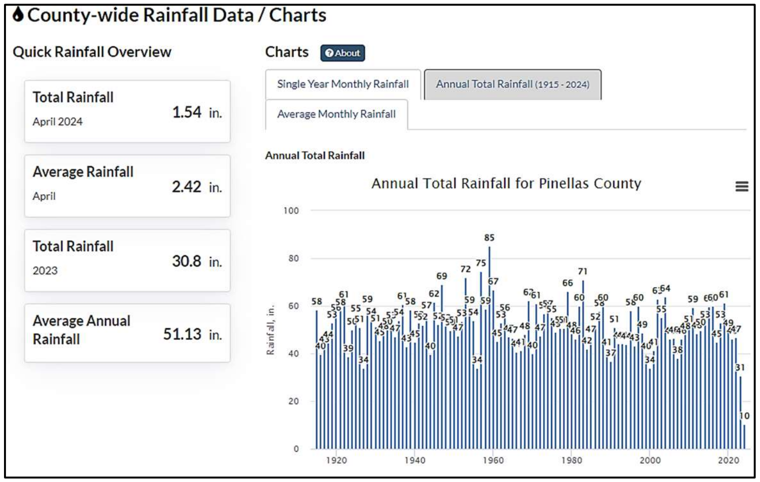


Figure 1-5 - Historical rainfall data from the Pinellas County Water Atlas

1.3.3 Temperature

The City's location along the west coast of Florida allows for a sea breeze to moderate some of the hotter temperatures that it would otherwise be exposed to in central portions of the state. Additionally, thunderstorms can cool down the air temperature and the associated heat index. The National Weather Service Forecast Office for Tampa Bay Area, FL (Tampa Bay Area, FL (weather.gov)) provides climate and past weather data, including temperature, to help understand climate norms. The following graphic helps to illustrate historical averages for temperatures within the region. The figure indicates that the maximum temperature varies from a low of 70.6 degrees in January to a high of 90.6 degrees in August. For the year, the average maximum temperature is 81.9 degrees

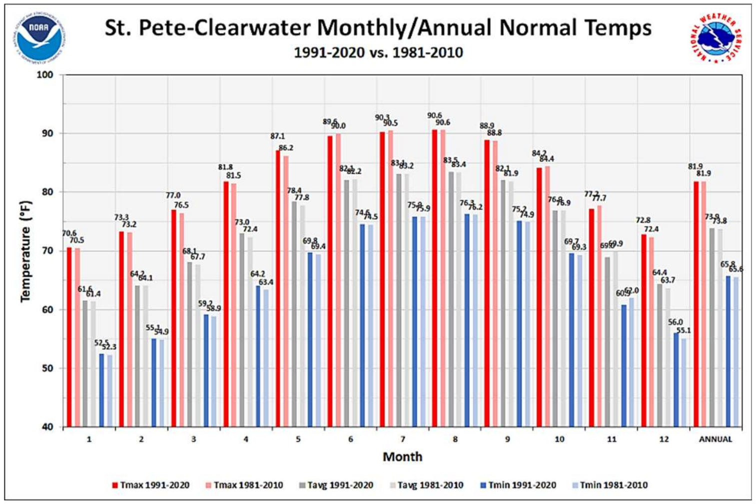


Figure 1-6 - Normal maximum temperature per month for the St. Pete-Clearwater area.

CLIMATE CHANGE DRIVERS AND FORECASTS

2. Climate Change Drivers and Forecasts

2.1 Introduction

To understand Clearwater's vulnerability to future conditions, a simulation was conducted that evolved a digital twin of Clearwater from 2020 to 2100. The simulation included all existing buildings and critical facilities, the transportation system, and simulated activities of the Clearwater population on a daily time step. The simulation was driven by a set of time series projections of weather (temperature and precipitation) and sea level. As acute events such as storms and chronic events such as rising sea level and temperature occurred, the simulation captured the disruption they caused, providing a way to quantify exposure and risk. This section describes how the driver projections were developed.

2.2 Future Rainfall

Using the StormCaster module within City Simulator (see figure 2-1), general circulation model (GCM) projections of monthly rainfall were downscaled to daily time step using local historical data measured at weather gauges (Bourne et.al, 2012). The GCM projections are from scenarios that follow the UNIPCC suite of greenhouse gas (GHG) control scenarios, the so-called Representative Concentration Pathway (RCP) scenarios. The Fifth Assessment Report of IPCC identified four RCPs, including one mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6), and one scenario with very high greenhouse gas emissions (RCP8.5) (https://ar5-syr.ipcc.ch/topic_futurechanges.php)

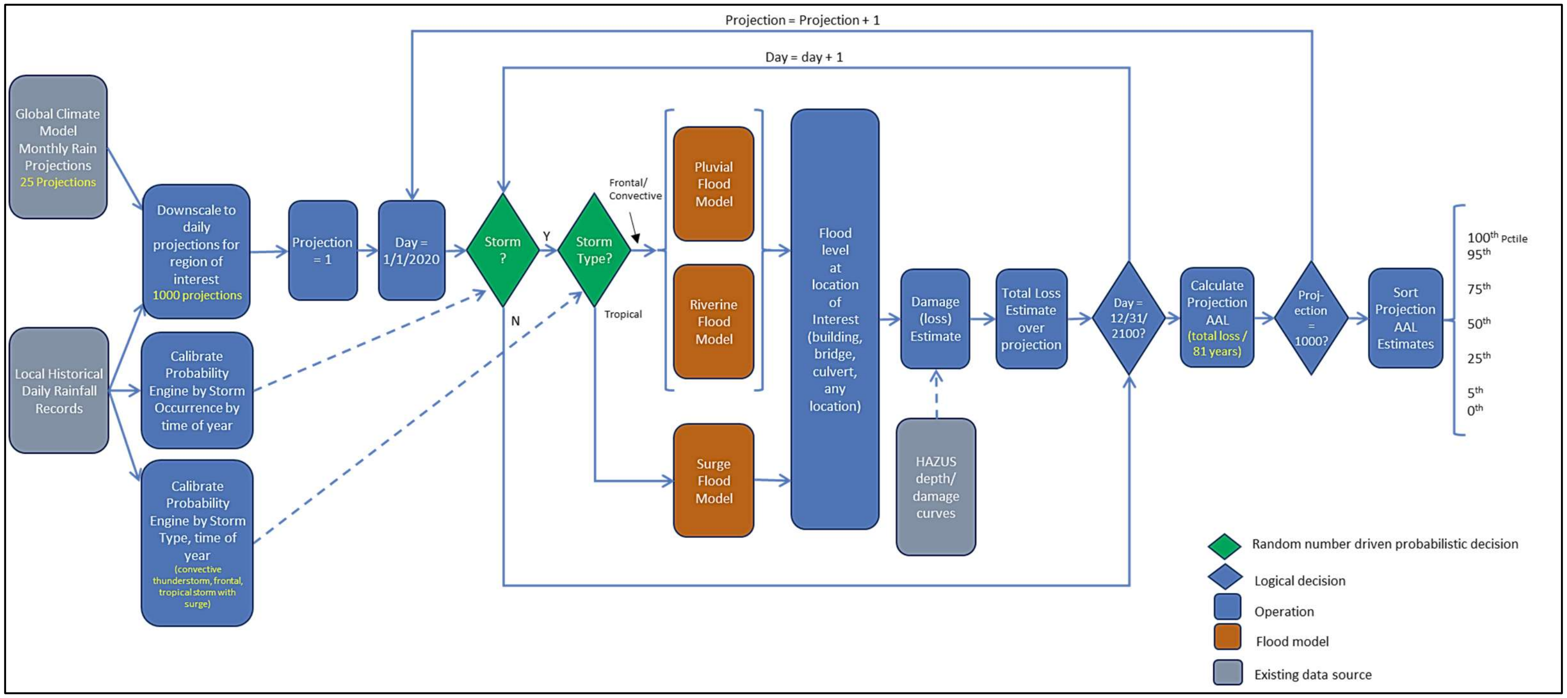


Figure 2-1 - Flood modeling algorithm used in this study. The algorithm downscales monthly GMC precipitation projections for the Clearwater region into an ensemble of 1,000 daily precipitation realizations. The realizations are then used to simulate flooding through use of existing pluvial, riverine, and surge flood models focused on the City.

In this study, the RCP8.5 scenario was used. This scenario is the so-called “do-nothing” scenario, as it assumes that governments around the globe will continue to control GHG as they have been doing in the early twenty first century, without any intervention. The rationale for using this scenario was that it represents a worst-case condition and will provide a conservative baseline on which to improve city resilience.

2.2.1 Local Precipitation Estimates

Rainfall data was modeled based on results from NOAA's Atlas 14 information for the Clearwater station (Site ID 08-1632). Data is focused on the 24-hour rainfall event for 10-, 50-, 100-, 500-, and 1000-year return periods.

Table 2-1 - Return Periods and Depths

Return Period (yr)	Rain Depth (in)
10	7.14
50	11.1
100	13.3
500	19.4
1000	22.5

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.556** (0.450-0.698)	**0.626** (0.506-0.787)	**0.736** (0.593-0.927)	**0.823** (0.659-1.04)	**0.936** (0.722-1.22)	**1.02** (0.769-1.35)	**1.10** (0.801-1.49)	**1.17** (0.822-1.65)	**1.26** (0.853-1.84)	**1.33** (0.877-1.98)
10-min	**0.815** (0.659-1.02)	**0.917** (0.741-1.15)	**1.08** (0.868-1.36)	**1.21** (0.965-1.53)	**1.37** (1.06-1.78)	**1.49** (1.13-1.97)	**1.61** (1.17-2.19)	**1.72** (1.20-2.41)	**1.85** (1.25-2.69)	**1.94** (1.28-2.90)
15-min	**0.994** (0.804-1.25)	**1.12** (0.904-1.41)	**1.31** (1.06-1.66)	**1.47** (1.18-1.86)	**1.67** (1.29-2.17)	**1.82** (1.37-2.41)	**1.96** (1.43-2.67)	**2.09** (1.47-2.94)	**2.26** (1.52-3.28)	**2.37** (1.57-3.53)
30-min	**1.53** (1.24-1.92)	**1.68** (1.36-2.11)	**1.94** (1.56-2.44)	**2.16** (1.73-2.73)	**2.47** (1.92-3.24)	**2.72** (2.07-3.63)	**2.97** (2.18-4.08)	**3.24** (2.28-4.59)	**3.60** (2.44-5.27)	**3.88** (2.57-5.78)
60-min	**2.00** (1.62-2.51)	**2.21** (1.79-2.78)	**2.57** (2.07-3.24)	**2.88** (2.31-3.65)	**3.33** (2.59-4.39)	**3.69** (2.81-4.94)	**4.07** (2.99-5.60)	**4.46** (3.15-6.34)	**5.01** (3.40-7.34)	**5.43** (3.59-8.09)
2-hr	**2.46** (2.01-3.07)	**2.74** (2.22-3.41)	**3.20** (2.59-4.01)	**3.61** (2.91-4.54)	**4.20** (3.29-5.49)	**4.67** (3.57-6.21)	**5.17** (3.82-7.07)	**5.69** (4.04-8.03)	**6.41** (4.38-9.34)	**6.98** (4.64-10.3)
3-hr	**2.69** (2.19-3.34)	**3.02** (2.46-3.75)	**3.58** (2.91-4.46)	**4.08** (3.30-5.11)	**4.80** (3.78-6.27)	**5.39** (4.14-7.15)	**6.01** (4.46-8.20)	**6.67** (4.75-9.39)	**7.58** (5.20-11.0)	**8.30** (5.54-12.2)
6-hr	**3.09** (2.54-3.81)	**3.50** (2.87-4.31)	**4.23** (3.46-5.24)	**4.92** (4.00-6.12)	**5.97** (4.76-7.83)	**6.87** (5.33-9.12)	**7.84** (5.88-10.7)	**8.90** (6.41-12.5)	**10.4** (7.23-15.1)	**11.7** (7.84-17.1)
12-hr	**3.57** (2.95-4.37)	**4.02** (3.32-4.92)	**4.94** (4.06-6.07)	**5.86** (4.80-7.24)	**7.38** (5.98-9.76)	**8.75** (6.87-11.7)	**10.3** (7.80-14.1)	**12.0** (8.75-16.9)	**14.6** (10.2-21.1)	**16.7** (11.3-24.3)
24-hr	**4.12** (3.42-5.01)	**4.69** (3.89-5.70)	**5.89** (4.87-7.18)	**7.14** (5.87-8.75)	**9.23** (7.55-12.2)	**11.1** (8.82-14.8)	**13.3** (10.2-18.2)	**15.8** (11.6-22.2)	**19.4** (13.7-28.1)	**22.5** (15.3-32.5)
2-day	**4.81** (4.02-5.80)	**5.59** (4.67-6.74)	**7.16** (5.96-8.67)	**8.76** (7.25-10.7)	**11.4** (9.37-14.9)	**13.8** (11.0-18.2)	**16.4** (12.6-22.3)	**19.5** (14.4-27.1)	**23.9** (17.0-34.3)	**27.7** (19.0-39.7)
3-day	**5.40** (4.53-6.48)	**6.21** (5.20-7.46)	**7.87** (6.58-9.49)	**9.57** (7.95-11.6)	**12.4** (10.2-16.1)	**14.9** (11.9-19.6)	**17.7** (13.7-23.9)	**20.9** (15.5-29.1)	**25.7** (18.3-36.7)	**29.7** (20.4-42.5)
4-day	**5.90** (4.96-7.06)	**6.71** (5.64-8.04)	**8.39** (7.02-10.1)	**10.1** (8.41-12.2)	**12.9** (10.7-16.8)	**15.5** (12.4-20.3)	**18.4** (14.3-24.8)	**21.7** (16.2-30.1)	**26.6** (19.0-37.9)	**30.7** (21.2-43.8)
7-day	**7.11** (6.01-8.45)	**7.92** (6.68-9.43)	**9.59** (8.07-11.5)	**11.3** (9.47-13.6)	**14.2** (11.8-18.3)	**16.8** (13.5-21.8)	**19.7** (15.3-26.3)	**23.0** (17.2-31.7)	**28.0** (20.1-39.6)	**32.1** (22.3-45.6)
10-day	**8.11** (6.87-9.60)	**8.95** (7.58-10.6)	**10.7** (8.99-12.7)	**12.4** (10.4-14.8)	**15.2** (12.6-19.4)	**17.8** (14.3-22.9)	**20.6** (16.1-27.3)	**23.8** (17.8-32.6)	**28.6** (20.6-40.2)	**32.6** (22.7-46.0)
20-day	**10.9** (9.29-12.8)	**12.0** (10.2-14.1)	**14.0** (11.9-16.5)	**15.8** (13.4-18.8)	**18.6** (15.4-23.2)	**21.0** (16.9-26.5)	**23.5** (18.3-30.6)	**26.2** (19.7-35.3)	**30.2** (21.8-41.9)	**33.3** (23.4-46.8)
30-day	**13.4** (11.4-15.7)	**14.8** (12.7-17.3)	**17.2** (14.7-20.2)	**19.3** (16.3-22.8)	**22.2** (18.3-27.3)	**24.5** (19.8-30.7)	**27.0** (21.0-34.7)	**29.5** (22.1-39.2)	**32.9** (23.8-45.2)	**35.6** (25.0-49.8)
45-day	**16.7** (14.4-19.5)	**18.7** (16.0-21.8)	**21.8** (18.6-25.5)	**24.3** (20.6-28.6)	**27.7** (22.7-33.6)	**30.2** (24.3-37.3)	**32.7** (25.5-41.6)	**35.1** (26.4-46.3)	**38.3** (27.7-52.2)	**40.7** (28.7-56.7)
60-day	**19.7** (17.0-22.9)	**22.2** (19.1-25.8)	**26.0** (22.3-30.3)	**29.0** (24.7-34.0)	**32.9** (27.1-39.7)	**35.8** (28.8-44.0)	**38.5** (30.1-48.8)	**41.1** (30.9-53.8)	**44.4** (32.1-60.1)	**46.7** (33.1-64.8)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Figure 2-2 - Atlas 14 Precipitation Estimates for Clearwater

NOAA Atlas 14 estimates are used to design, plan, and manage much of the nation's infrastructure for a wide variety of purposes under federal, state, and local regulations. NOAA Atlas 14 estimates cover a range of storm durations from 5-minutes through 60-days, for average recurrence intervals of 1-year through 1,000-year. Compared to previous volumes, Atlas 14 estimates benefit from use of better-quality data (e.g., precipitation stations with longer period of record, increased station density, etc.), enhanced quality control methods, consideration of uncertainties, and improved frequency analysis and spatial interpolation methods that account for variation in terrain, proximity to the coastline, etc.

It should be noted that recently, NOAA Atlas 14 has been questioned, as climate change has begun to shift the statistics the site reports. As such, concentrated research is underway to update the reported statistics and incorporate understanding of future potential changes due to changing rainfall behavior. As these changes occur, it is recommended this study be updated regularly.

2.2.1.1 Downscaling and Integrating Rainfall Projections

To support the downscaling process, a close gauge with a long continuous record of historical rainfall observations is ideal. This ensures that a comprehensive range of rain conditions and local microclimatic behaviors are embedded in the projection of future rainfall. In reviewing the historical record for the Clearwater gauge (USC000081632, with historical record shown below), the determination was made that the gaps in data, short period of record, and lack of recent data were insufficient, and thus, an alternate gauge should be used in development of future rain projections.

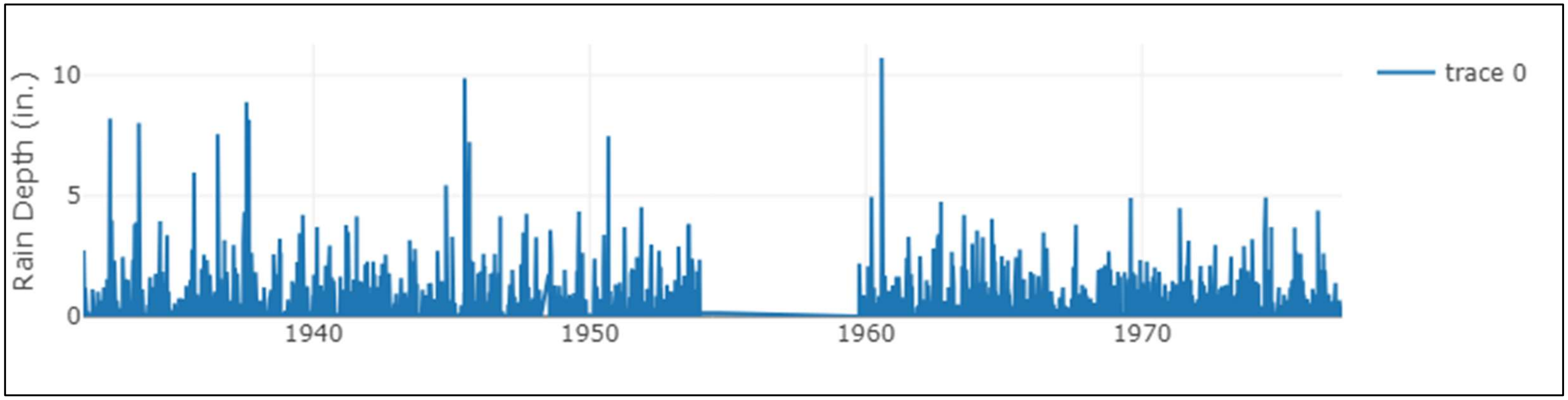


Figure 2-3 - Clearwater gauge (USC000081632) not used due to historical record gaps

An ensemble of 20 general circulation model (GCM) monthly RCP 8.5 precipitation projections (see figure 2-4) was used in conjunction with the historical rain data from USC 00087851 (St. Leo, FL) in the StormCaster Monte Carlo process to synthesize 1,000 realizations of future daily rainfall in Clearwater. Each realization covered the 2020-to-2100-time horizon (see figure 2-5). The RCP 8.5 scenario was used because it represents the least attempt to control GHG emissions in the future and contains the most intense future weather conditions of the available scenarios. As the desire is to stress-test the Clearwater systems, this scenario is the appropriate choice.

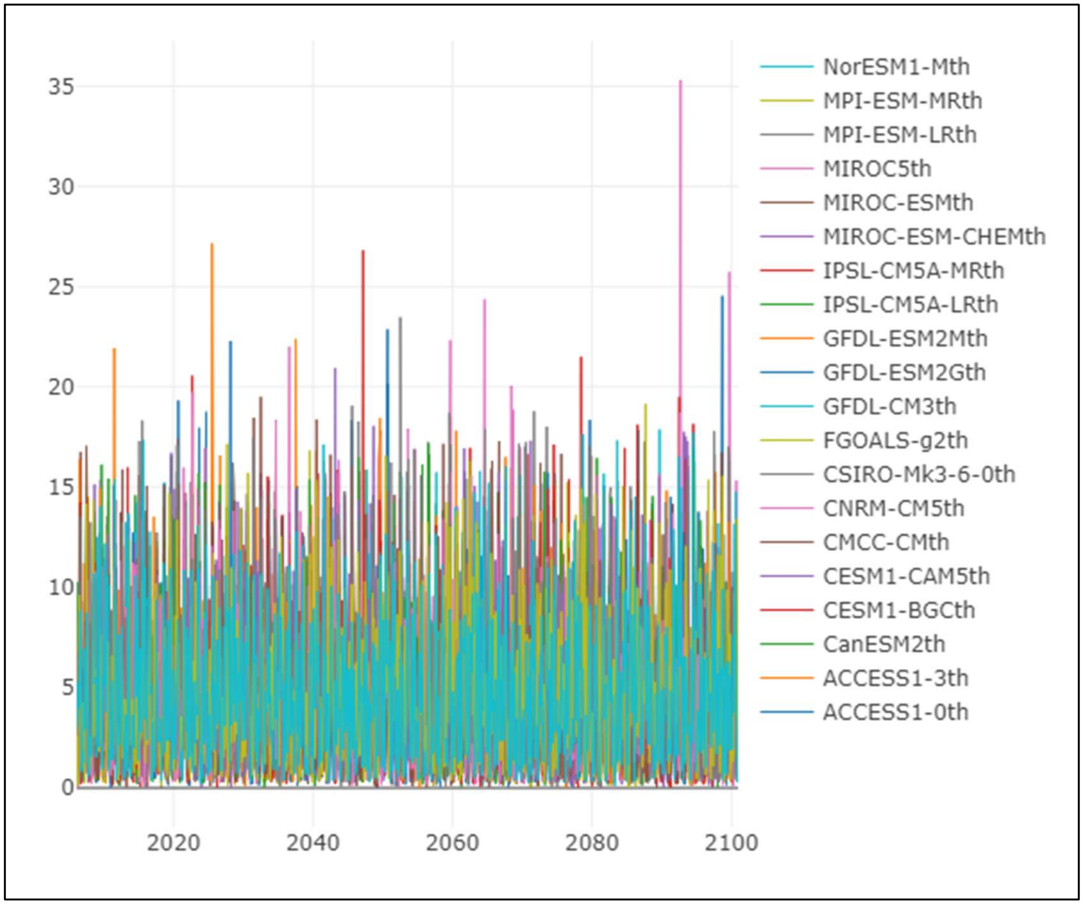


Figure 2-4 - Global Climate Model Projections for Precipitation Events

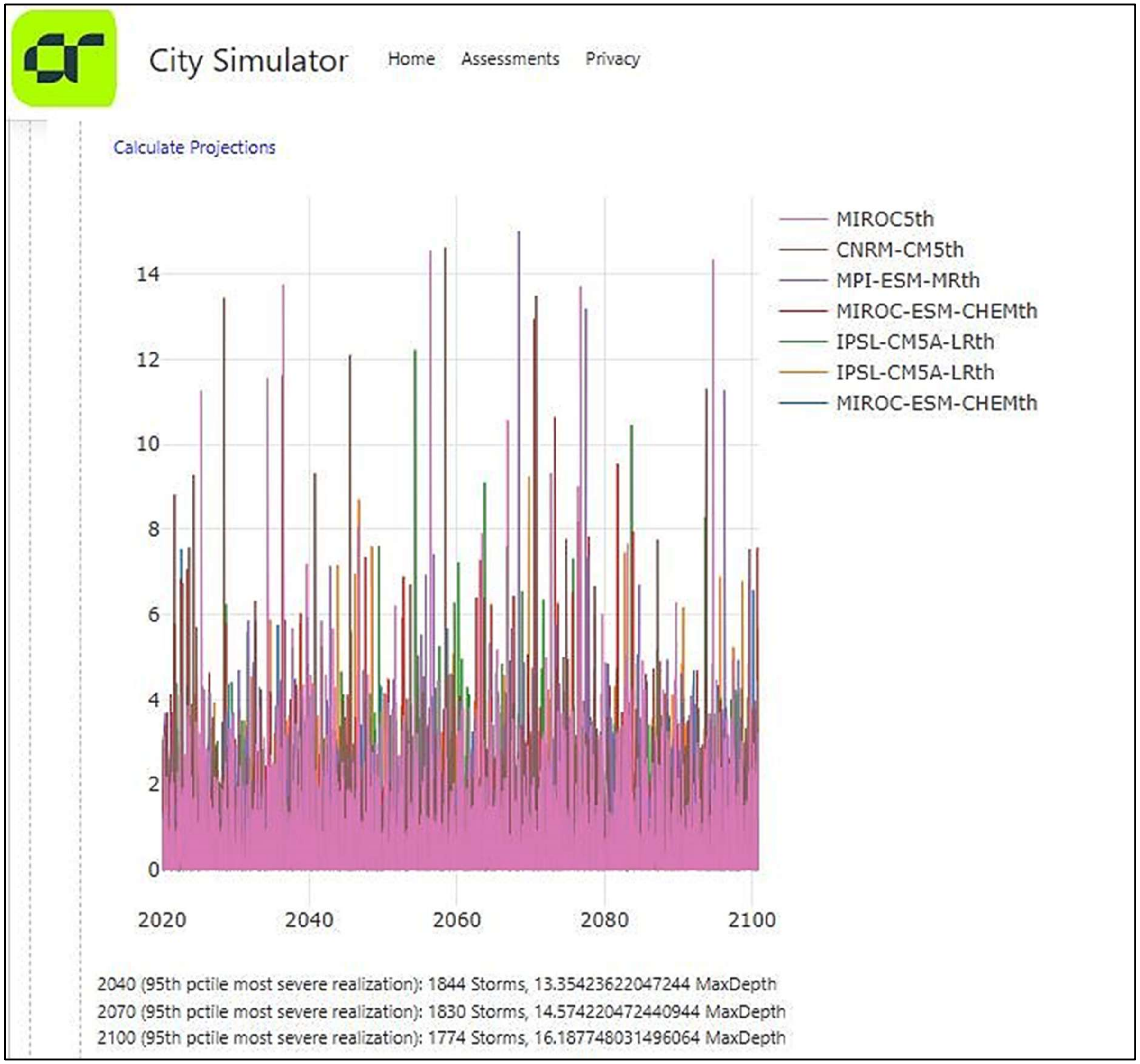


Figure 2-5 - Downscaled global climate model data to be applied to the Clearwater simulations.

A second search of the region identified a closer gauge in Tarpon Springs, FL (gauge 08-8824), with a longer period of record (124 years and no gaps). Its Atlas 14 precipitation data was also nearly identical to the Clearwater gauge, making it the better station for rainfall simulation. The max pluvial/riverine flood depth values in the image below, Figure 2.6, represent conservative (maximum) values when global models are downscaled to the local area. The graph on the right side of the image visualizes how the 100-year storm event is expected to change over time per the downscaled models.

		2020	2040	2070	2100
100yr Atlas 14		13.3"	-	-	-
Median	**100yr Rain** (based on historical record with Gumbel Extreme Value Analysis)	11.03"	11.42"	12.09"	13.97"
	Change in 100yr	-	0.39"	1.06"	2.94"
	Pct Change	-	4%	10%	27%
	Atlas14 with Projected Change	13.3"	13.69"	14.36"	16.24"
Max	**100yr Rain** (based on historical record with Gumbel Extreme Value Analysis)	11.36"	12.69"	15.01"	16.27"
	Change in 100yr	-	1.33"	3.65"	4.91"
	Pct Change	-	12%	32%	43%
	Atlas14 with Projected Change	13.3"	14.63"	16.95"	18.21"
Max Pluvial/Riverine Flood Depth		**13.5'**	**13.73'**	**14.13'**	**14.34'**

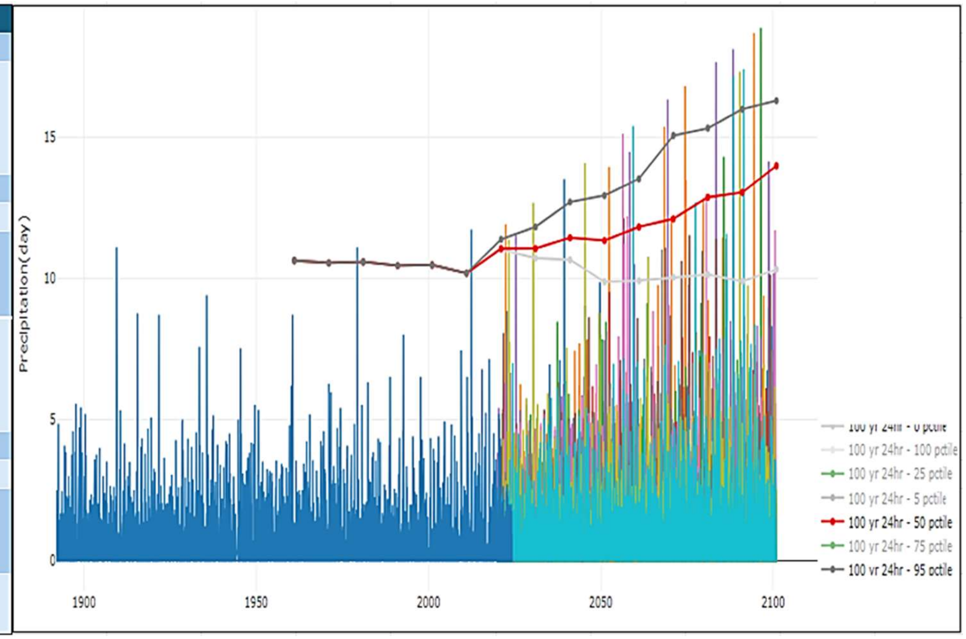


Figure 2-6 – 100-Year precipitation values for the Tarpon Springs gauge (historical observations and future predictions).

Figure 2.6 shows:

- The historical daily rain data for the Tarpon Springs gauge,
- The 0^{th}, 5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}, and 100^{th} percentile severity realizations from the 1000-member ensemble of realizations derived using this gauge, where severity is defined as the sum of cubed rainfall depths across the 2020-2100 realization,
- An assessment of 100-year 24-hour storm based on these realizations.

The estimates of the 100-year 24-hour rain depths are based on a rolling 70-year window evaluated every 10 years. For each 70-year window, a series of annual maximum daily rainfall is defined. The annual maximums are then used to fit a Gumbel distribution and the 1% rain depth is estimated from the resulting distribution. The results show a near-stationary pattern historically, which shifts abruptly at the start of the 21st century and continues to rise to the end of the 21^{st} century. The red line represents the median estimate, while the upper and lower gray lines show the maximum and minimum value of the estimates based on the ensemble of rainfall projections available.

The table in figure 2.6 was derived from the assessment of 100-year 24-hour rain depths. It shows the median (red line) and maximum (top gray line) estimates of the rainstorm depth at the 2020, 2040, 2070, and 2100 planning years, which are specified by the Resilient Florida Grant.

The following findings can be made from this assessment:

- Projections show a 47% increase in the 100-year 24-hour rainstorm depth from 2020 to 2100 in the median case and an 80% increase for the maximum case.
- When looking at potential large storms in the 95th percentile most severe realization (acute events within the study), the city may be impacted by storms equivalent to Hurricane Ian’s rainfall (~12 inches in 24 hours) twice in the period from 2020 to 2100.
- The simulations also show six (6) 8-inch rainstorms (50-year events) potentially occurring over the same period.

The corresponding statistics for the 500-year (0.2%-annual chance) flood event were also captured and included within the exposure analysis later in the report.

		2020	2040	2070	2100
500yr Atlas 14		19.3"	-	-	-
Median	**500yr Rain** (based on historical record with Gumbel Extreme Value Analysis)	13.72"	14.15"	14.96"	17.33"
	Change in 500yr	-	0.43"	1.24"	3.61"
	Pct Change	-	3%	9%	26%
	Atlas14 with Projected Change	19.3"	19.73"	20.54"	22.91"
Max	**500yr Rain** (based on historical record with Gumbel Extreme Value Analysis)	14.15"	15.85"	18.92"	20.36"
	Change in 500yr	-	1.70"	4.77"	6.21"
	Pct Change	-	12%	34%	44%
	Atlas14 with Projected Change	19.3"	21.00"	24.07"	25.51"
Max Pluvial/Riverine Flood Depth		**14.53'**	**15.32'**	**18.78'**	**20.38'**

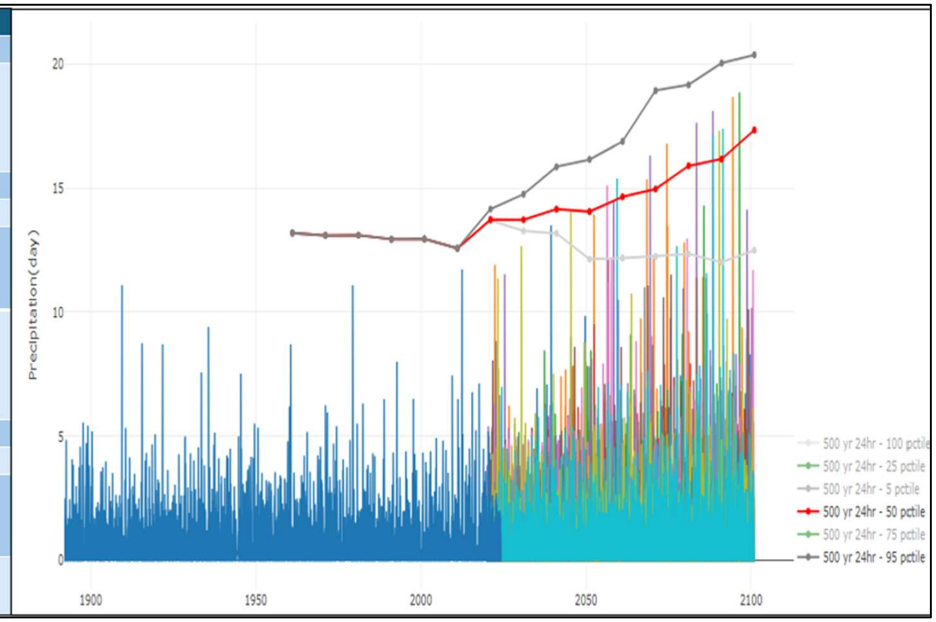


Figure 2-7 - 500-Year precipitation values for the Tarpon Springs gauge (historical observations and future predictions).

Similar to the representation of the 100-yr flood statistics, Figure 2.7 shows the following items relative to the 500-year:

- The historical daily rain data for the Tarpon Springs gauge,
- The 0th, 5th, 25th, 50th, 75th, 95th, and 100th percentile severity realizations from the 1000-member ensemble of realizations derived using this gauge, where severity is defined as the sum of cubed rainfall depths across the 2020-2100 realization,
- An assessment of 500-year 24-hour storm based on these realizations.

2.3 Future Temperature

2.3.1 Developing Temperature Projections

The City's grant covered future flood potential per state statutory requirements. However, the City also felt that it was important to understand projections of future heat and thus studied this at the same time outside of the grant. Future temperatures in Clearwater are projected to increase significantly over the century. As figure 2-8 from Climate Explorer shows, average daily maximum temperature is likely to increase from about 83F to 89.5F by the end of the century according to the RCP8.5 scenario. Even with more control on greenhouse gases (GHG), temperatures are still likely to increase until midcentury.

Within this study, an ensemble of future maximum daily temperatures was extracted from the Localized Constructed Analogs (LOCA) dataset, which uses a statistical procedure to downscale temperature data to a daily time step, and at high spatial resolution. The dataset was produced by researchers at the Scripps Institute at UCSD and is commonly used in vulnerability assessments like the Clearwater Vulnerability Assessment (https://loca.ucsd.edu/). The data is downscaled from the CMIP5 collection of climate projections produced from GCM by multiple research centers around the world.

Figure 2-9 shows the ensemble of projected number of days per year above 90F from each of the GCMs-projections in the LOCA dataset in Clearwater.

When evaluating temperature models, the key findings were as follows:

- All models agree that there will be a pronounced and sustained increase in daily maximum temperatures in Clearwater between 2020 and 2100.
- Lower emissions scenario (RCP2.6 and RCP4.5) show maximum temperatures levelling off by 2050-60.
- In this study, the higher emissions scenario (RCP8.5) was used to fully stress test the city for vulnerability.

The following image, Figure 2.8, was retrieved using the Climate Explorer tool available from ClimateExplorer.com, https://crt-climate-explorer.nemac.org/climate_graphs/?city=Clearwater%2C+FL&county=Pinellas%2BCounty&area-id=12103&fips=12103&zoom=7&lat=27.9655722&lon=-82.7958948).

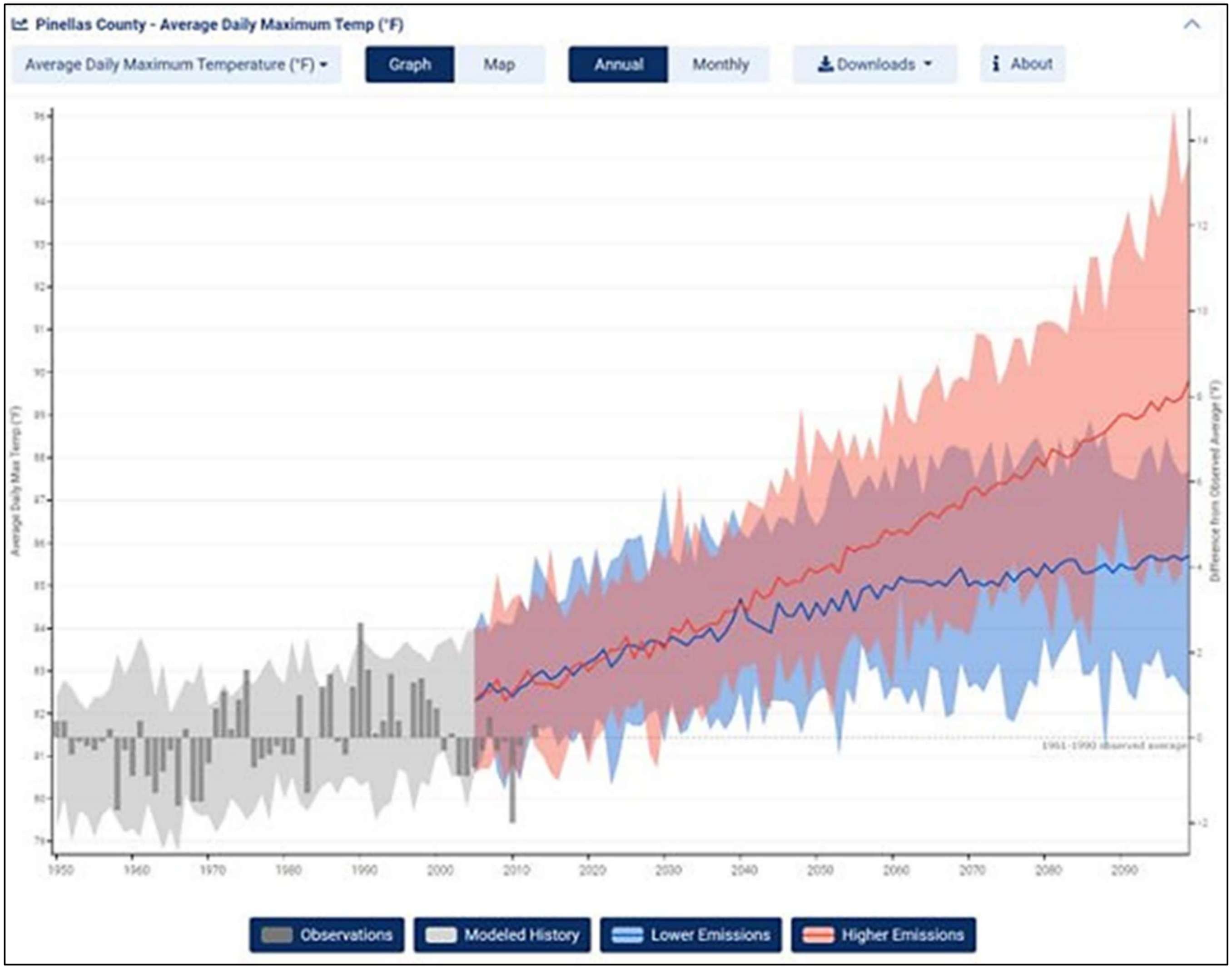


Figure 2-8 - Projected Maximum Temperature in Clearwater

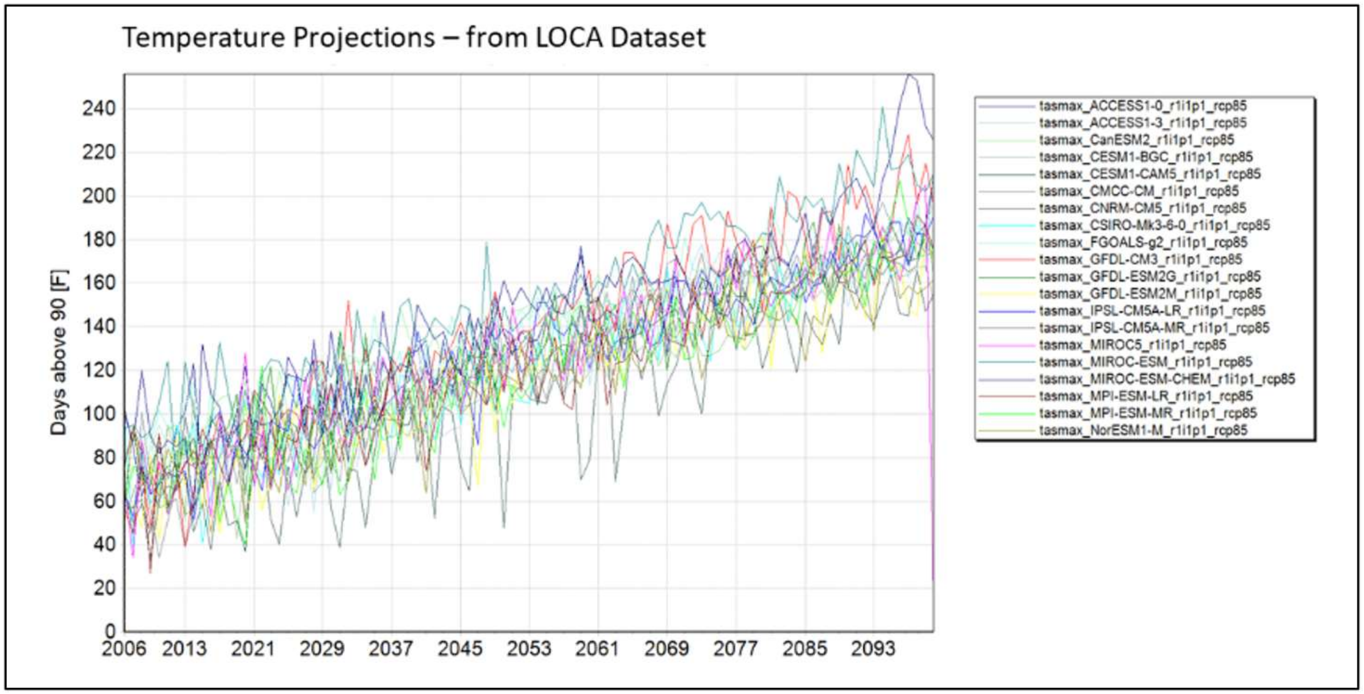


Figure 2-9 - Projected days above 90F from the LOCA Dataset for Clearwater

2.4 Future Sea Level (Tide and Surge)

The simulation also required a projection of future sea level. Sea level projections were derived from NOAA's 2017 and 2022 multi-agency studies that projected sea level from present day to 2150 and/or 2020 for multiple tide gauges on the US coast. For the study, the 2017 intermediate-low and intermediate-high projections were used.

The initial approach during the assessment was to use the intermediate-high projections, as this represented the closest match to conditions observed from 2000-2024. At the beginning of the project, the intent was to use the NOAA 2017 projections as seen below in an excerpt from the *Recommended Projections of Sea Level Rise in the Tampa Bay Region* produced by the Tampa Bay Climate Science Advisory Panel (View or Download).

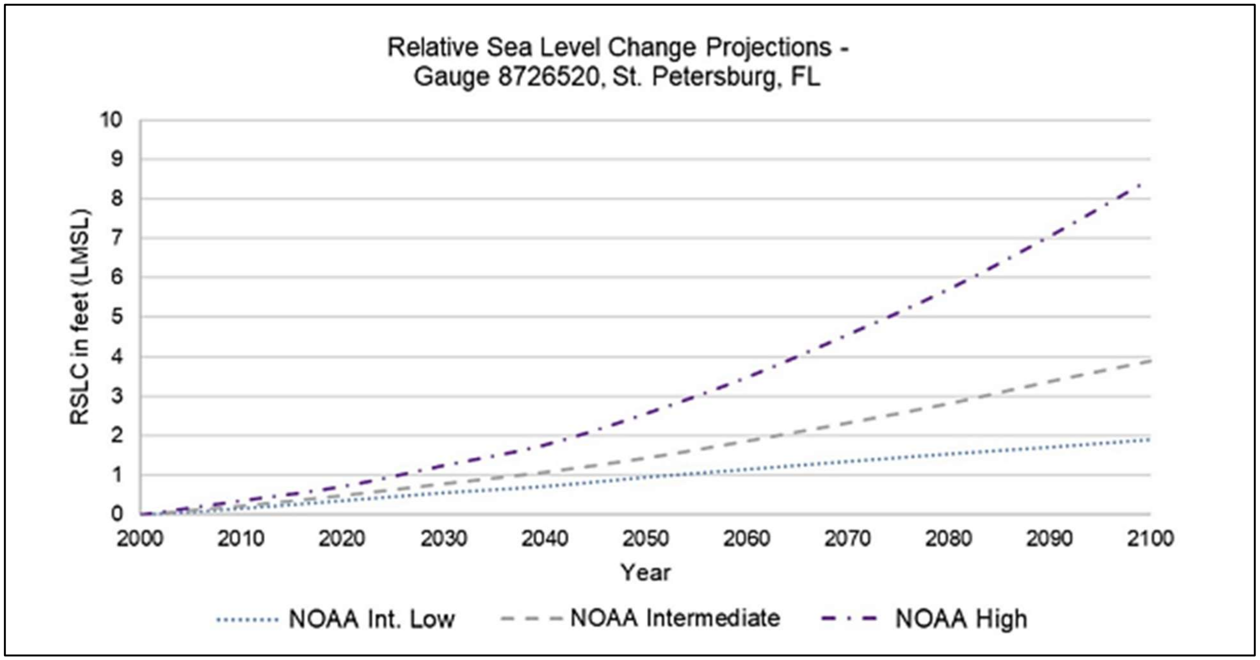


Figure 2-10 - 2017 Sea Level Rise Projections from Climate Science Advisory Panel

As the project progressed, a new set of projections (NOAA 2022) were released to reflect the recent climate science captured within the *2022 Sea Level Rise Technical Report* (View or Download).

The City Simulator tool downloads data directly from tidal gauges through application programming interface (API) data calls to NOAA's servers. These NOAA datasets have been updated to utilize the information available from the 2022 Sea Level Rise Technical Report.

To address concerns with the Resilient Florida program referencing 2017 projections in statutory requirements but also moving towards optional 2022 projections in future deliverables, the tool was configured to allow for both sets of projections with the ability for the user to select any combination of individual projections. The screen shot from the tool (Figure 2-11 shown on the next page) provides information from the Clearwater Beach station and its array of available projections from both 2017 and 2022 studies.

While the 2022 projections were available, to follow the Resilient Florida guidelines, the 2017 intermediate-low and 2017 intermediate-high projections were used in the exposure and sensitivity analysis.

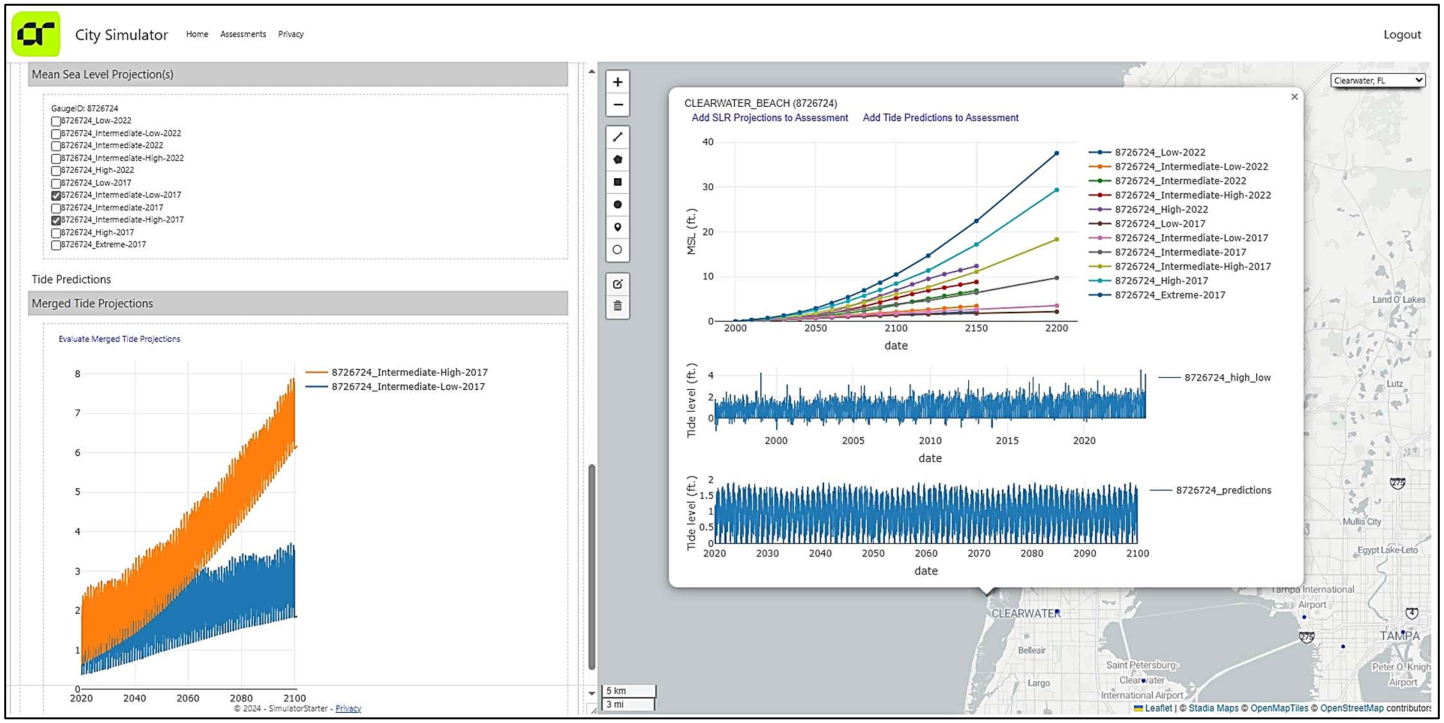


Figure 2-11 - Redesigned City Simulator to allow the user to select any of the 2017 or 2022 projections to be used in the climate simulations.

2.4.1 Tidal Predictions

To capture tidal changes in sea level-and exposure to tidal range - the mean sea level projections were summed with predictions of tide level, also downloaded from the NOAA servers. Figures 2-12 and 2-13 show the historical tide level and the 21st century predicted tide levels, respectively, at the Clearwater Beach station (Station ID: 8726724). During the simulation, this time series was used to assess when, where, and how frequently tidal inundation occurred to the City's roads and buildings.

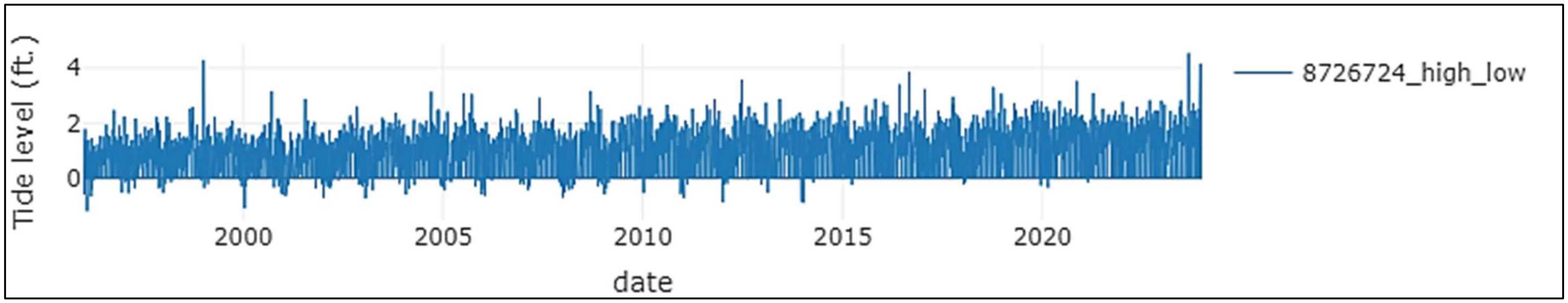


Figure 2-12 - The last 25 years of tide levels at the Clearwater tide gauge.

Future tide predictions (based on gravitational effects) are also available for the gauge and are visualized below.

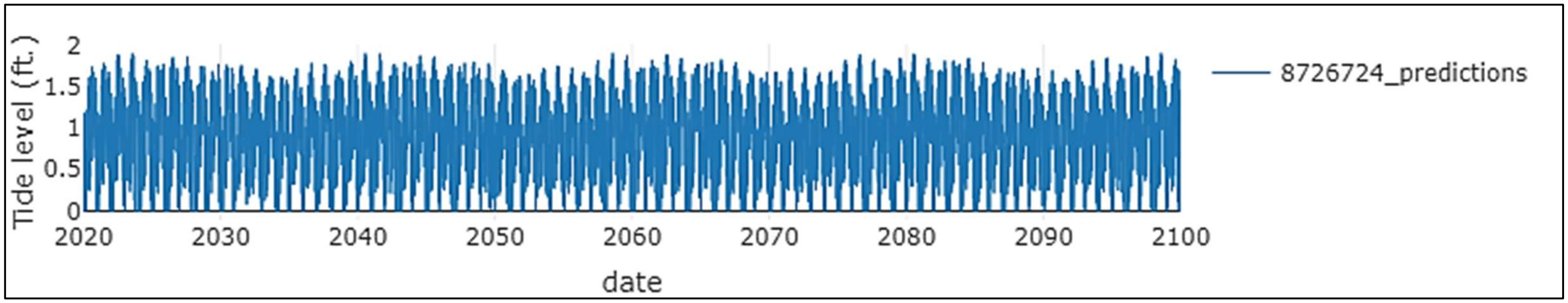


Figure 2-13 - Tide predictions through 2100 for the Clearwater gauge.

When evaluating tidal impacts for the study, the 2017 intermediate-low and the 2017 intermediate-high projections impact the tide as shown below.

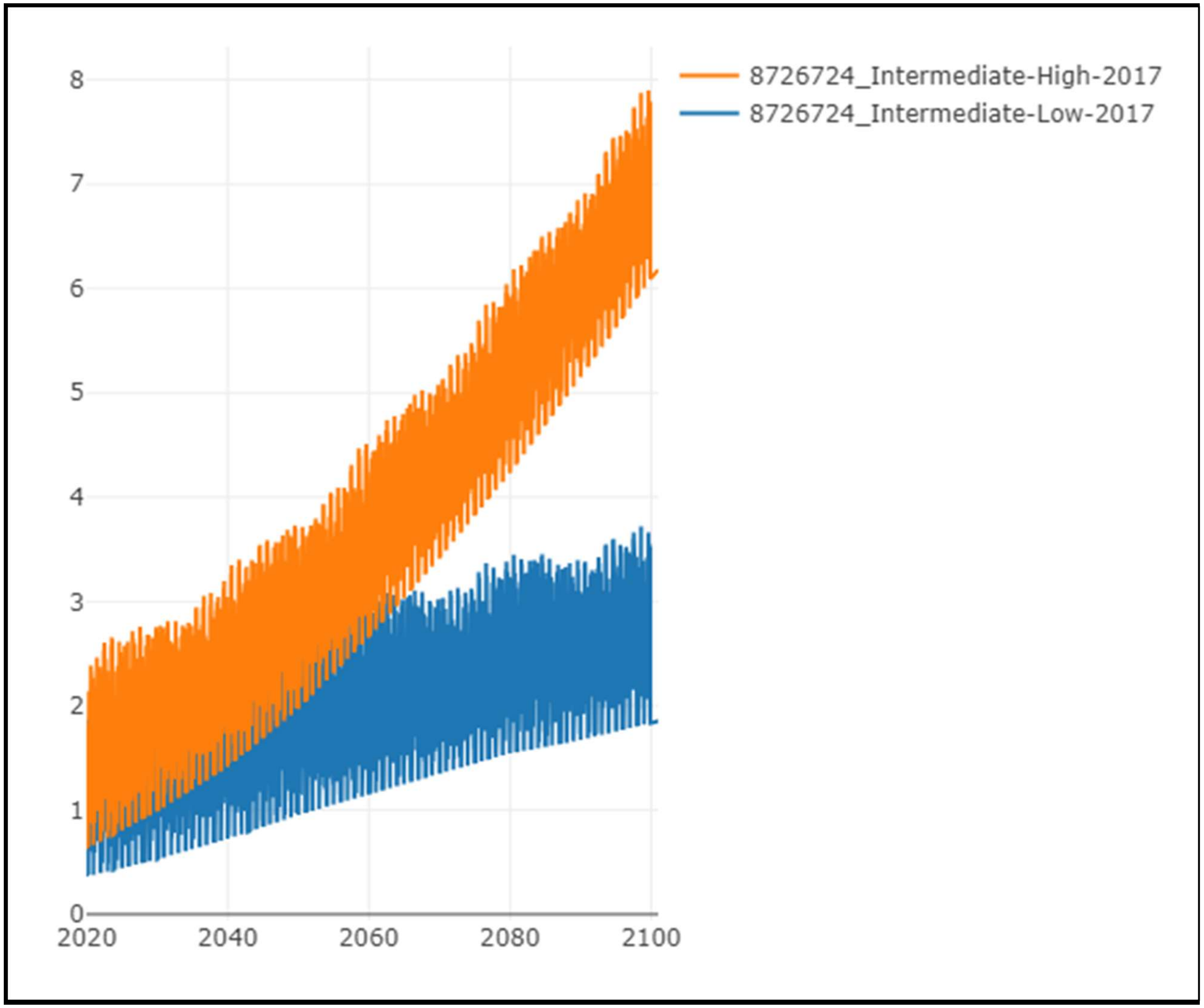


Figure 2-14 - Tide predictions (in feet) using the intermediate-low and intermediate-high rojections.

2.4.2 Surge Predictions

The following algorithm was used to estimate surge flood risk at all buildings and all stormwater nodes in the digital twin:

1. 1,000 realizations of future rainfall were projected using the Tarpon Springs gauges and 20 GCM monthly rainfall projections as described in section 2.2.1.1.

2. The historical rain events from the Tarpon Springs record were tagged as either storm surge events or pluvial/riverine events based on time of year and depth. These were then used to establish a monthly Markov probability model that was used in tandem with a random number generator to tag the future storms generated in step 1.

3. For each of the planning years 2040, 2070, and 2100, each of the realizations was scored by calculating a severity index in the periods 2020-2040, 2050-2070, and 2080-2100. The index was defined as the cubed sum of rainfall depths in these periods. The scores were then ranked and the 95th percentile most severe realizations for 2040, 2070, and 2100 periods were selected.

4. The three 95th percentile severity future rainfall forecasts were then combined with the two NOAA SLR scenarios (Intermediate-Low and Intermediate-High from the 2017 report) to create six future simulation scenarios. These scenarios were then used to drive simulations of future flooding.

5. When the future event was caused by tropical or windstorm, the resulting surge depth was estimated by:

    a. Determining the projected change in mean sea level based on the associated NOAA SLR scenario.

    b. Using the return period of the future rainstorm as an estimator of the return period of the future storm surge.

    c. Interpolating/extrapolating the surge depth with the projected change in sea level from the USACE SACS study family of rain-to-flood curves at each building and stormwater node, as described below.

6. Record the flood events at each building and stormwater node; within the 2020-2040, 2050-2070, and 2080-2100 periods, evaluate the median and max surge flood depth.

To estimate surge level of designated probability that incorporate projected sea level rise, the study blended the NOAA 2017 projections of rise in mean sea level with the US Army Corps of Engineers Southeast Atlantic Coastal Study (SACS).

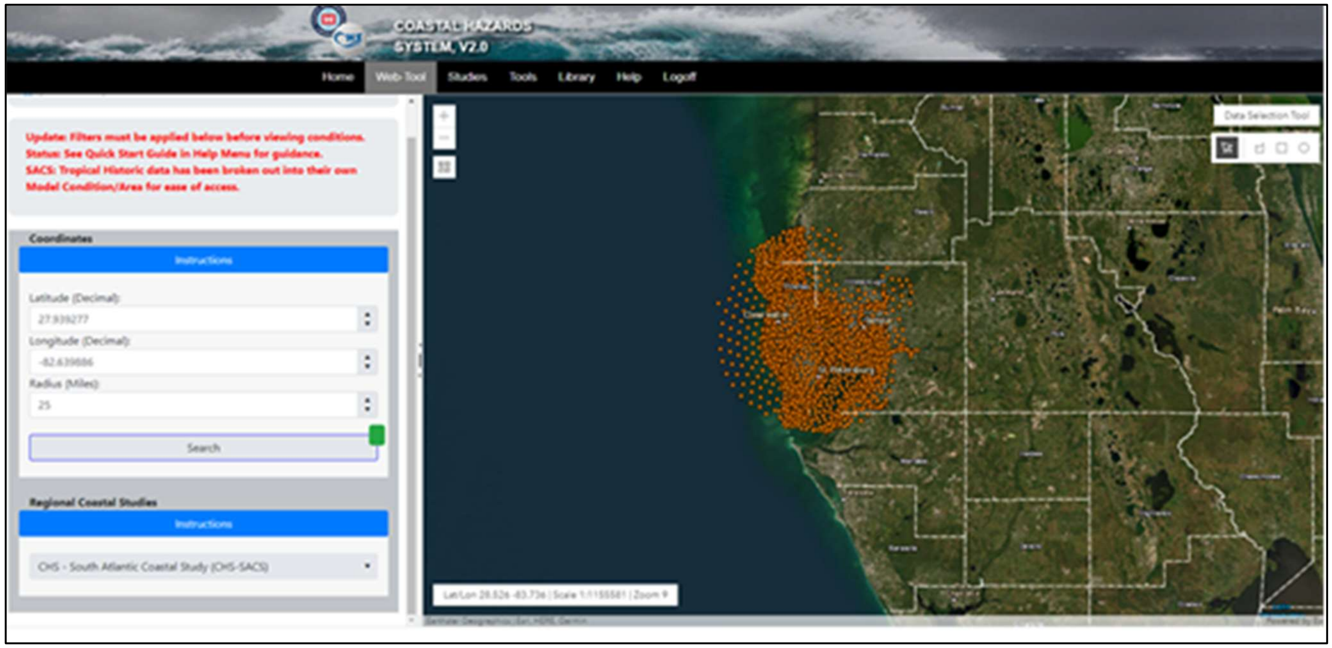


Figure 2-15 - USACE Coastal Hazards System (Red dots are node locations used for this study)

The SACS study coupled hydrodynamic models with wave actions models to estimate still water level plus wave setup level in a mesh of points along the Clearwater coast. The study used an ensemble of 1,060 storms that varied in oncoming direction and speed, and intensity to estimate the annual exceedance probability of surge water levels at 10-, 100-, and 1000-year return periods (probabilities). This estimate was completed for three scenarios of sea level: SLC0 = current sea level, SLC1 = current sea level plus 2.73ft, and SLC2 = current sea level plus 7.35ft. The results were used to create a family of three sets of 10-, 100-, and 1000-year probability annual exceedance level rasters that were used to interpolate/extrapolate future surge depths as described in the algorithm on the previous page.

EXPOSURE ANALYSIS

3. Understanding How the City is Impacted by its Exposure to Climate Hazards

The exposure analysis is focused on quantifying the depth and location of flooding that will potentially impact the community in future floods. Additionally, as the City of Clearwater's study includes heat as a climate consideration, metrics are provided to help quantify its exposure to additional temperature impacts.

3.1 Flood Hazards

Flood hazards include tidal, surge, and pluvial (rainfall) events that result in days of flooding and depths of flooding relative to buildings, critical assets, and the stormwater and transportation infrastructure emulated within the digital twin of the city. Figure 3-1 diagrams the flood risk metrics calculated for each building, where "buildings" implies all non-linear structures, including residential and commercial buildings, transmission stations, water treatment plants, etc. Each of these structures was assessed for tidal and acute flooding against multiple SLR scenarios and risk was estimated at each of three planning years (2040, 2070, and 2100) and are reported within the Sensitivity Assessment.

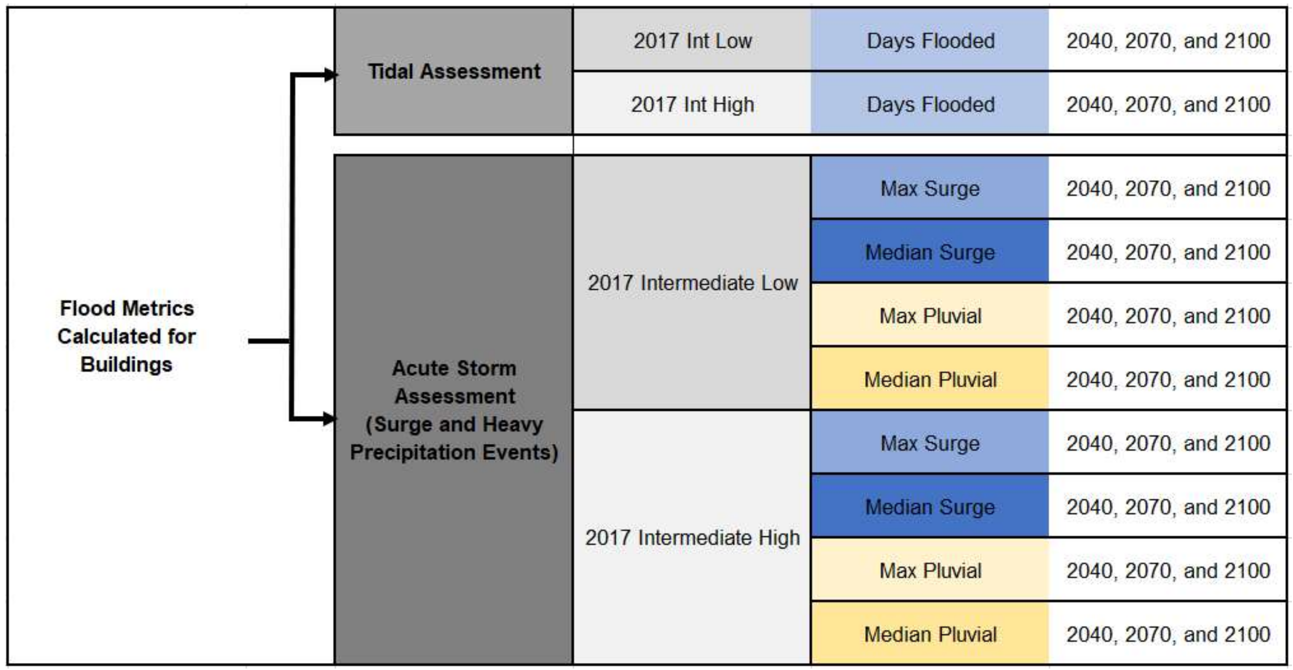


Figure 3-1 - Metrics captured for all structures exposed to flooding within the study.

For tidal flooding, a days flooded metric was calculated for each building at each planning year. For acute flooding, including storm surge and pluvial/riverine flooding, the median and max surge flood depth was calculated. Acute flooding is calculated by running each driver rainfall realization created in the driver forecasts tab. These results are then downscaled as daily time step rainfall projections that have been evaluated for severity in the 2040, 2070, and 2100 timeframes. The 95th percentile represents the most severe result and is included in the final driver realizations evaluated in this process. The SLR scenarios are those selected in the driver forecasts tab (in this case the 2017 intermediate-low and the 2017 intermediate-high). The tool runs each SLR realization within each driver realization. As storms occur within the simulation, the tool decides if they are frontal/convective or if they are tropical, based on historical patterns. If tropical, the tool uses the projected SLR and USACE SACS study to evaluate the flood level across the landscape. Otherwise, it uses pluvial and fluvial flood models. For each structure, the tool publishes the maximum and median surge, as well as the maximum and median pluvial/fluvial flood level to an array of fields names that are then exportable for further analysis within a GIS or database platform. The following sections present the results for these metrics.

3.1.1 Tidal Flood Results

Figure 3-2 presents the “days flooded” results for the intermediate-low and intermediate-high scenarios from the NOAA 2017 study. These scenarios were used in all the exposure assessment analyses.

Note that the days inundated per year is the average of the days inundated per year for the eleven years leading up to the planning year of interest. For example, for 2040, the days per year inundated is the average of years per year inundated for the years 2030-2040. This averaging was used to avoid reporting unusually high and unusually low tidal years caused by gravitational effects. The tidal depths under various projections and planning horizons are identified below.

For reference, the 2020 depth is 4.3 feet (NAVD88). These estimates are the maximum tide depth from ground across all buildings in the city. The tides are estimated by adding the relevant SLR mean sea level projection to tide predictions at the gauge of interest.

Planning Horizon	Max Depth from Intermediate-Low (2017) Projections at each Planning Horizon	Max Depth from Intermediate-High (2017) Projections at each Planning Horizon
2020	4.3 Feet	4.3 Feet
2040	4.5 Feet	5.3 Feet
2070	5.0 Feet	7.0 Feet
2100	5.6 Feet	9.8 Feet

The results show that:

- There is little impact from the intermediate-low scenario, given that there is approximate 1 foot of mean sea level rise over the century, this is not surprising. There are minimal impacts at the 2100 planning year, with essentially zero in the 2040 and 2070 years.
- There is substantial impact with the intermediate-high scenario. Given the approximately 5.2 feet of projected rise, this is not surprising. The scenario shows that by 2100, more than 3,000 parcels are projected to be inundated at least part of the year, with a majority inundated more than 300 days per year. This represents close to 10% of parcels in the city. Similarly, about 1,400 buildings are flooded above FFE by 2100 as well, again with just under 50% of those inundated more than 300 days per year.
- With the intermediate-high scenario, it’s worth noting that the largest impacts don’t occur until end of century. Up to mid-century little projected impacts are expected.

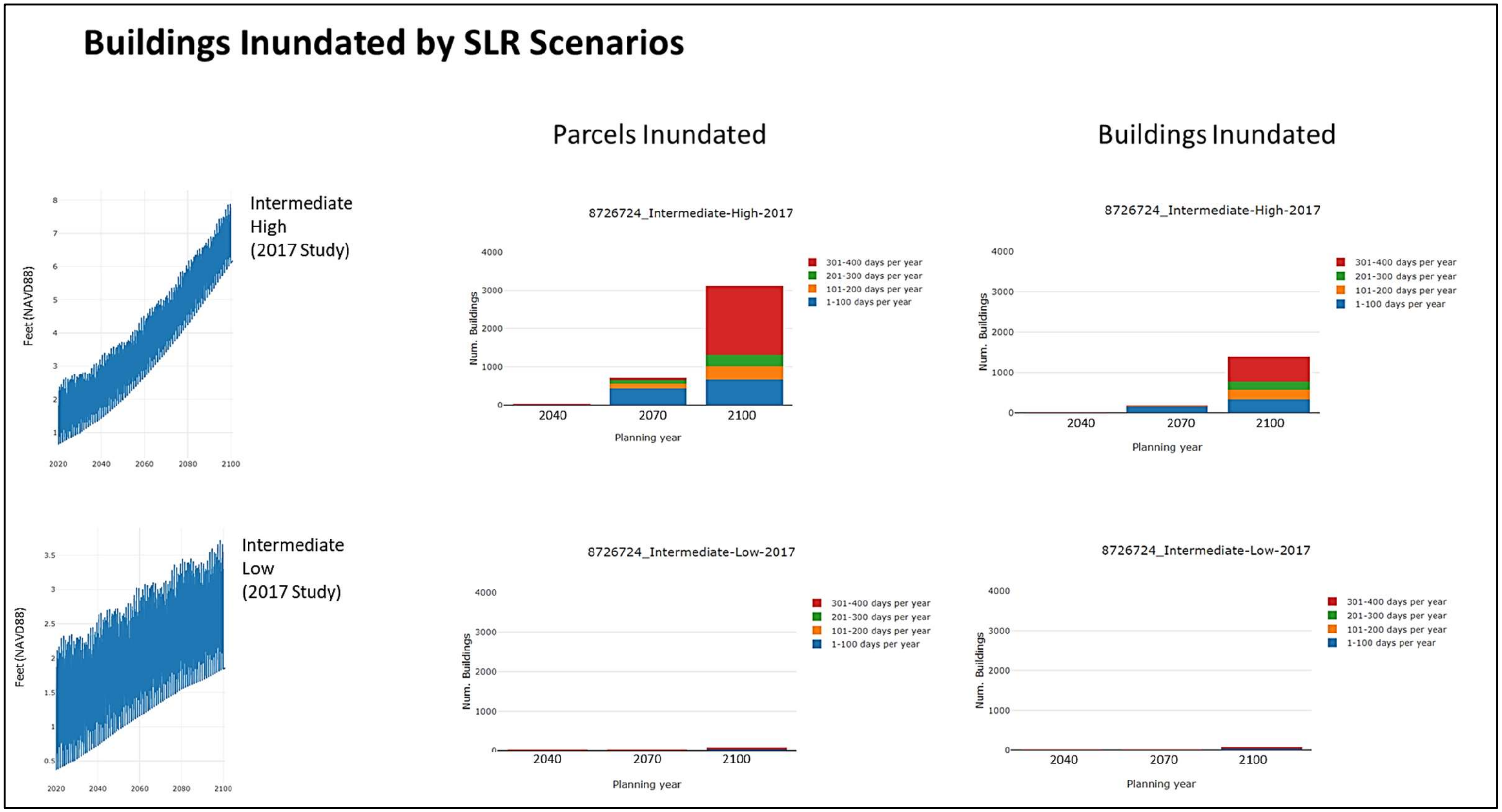


Figure 3-2 - Projected tidal flooding impacts under the 2017 intermediate-low and intermediate-high scenarios.

3.1.1.1 2040 Intermediate-Low Projection

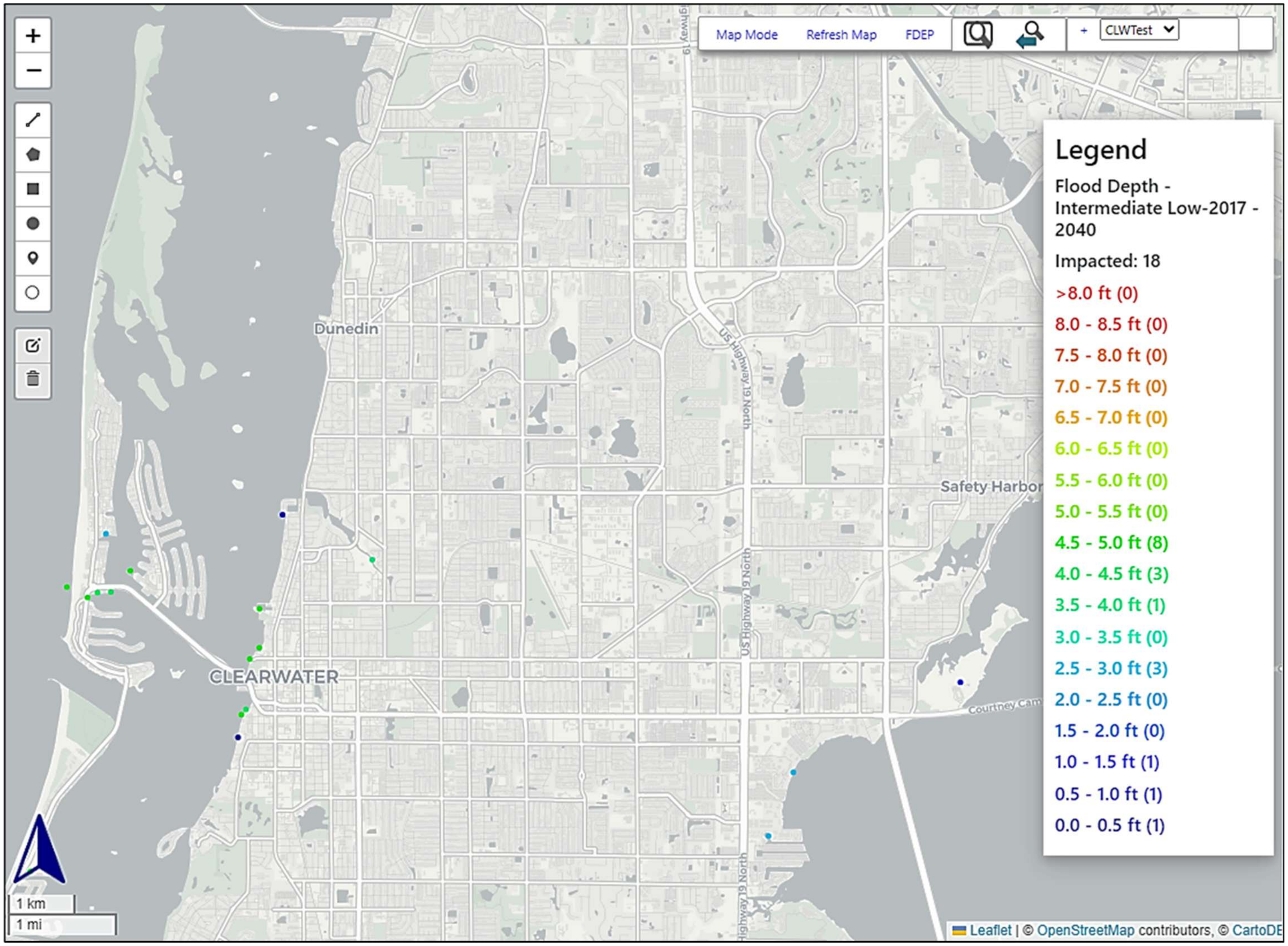


Figure 3-3 - 2040 Intermediate-Low Projection (2017) – Representative Depths and Extents of Tidal Only

3.1.1.2 2070 Intermediate-Low Projection

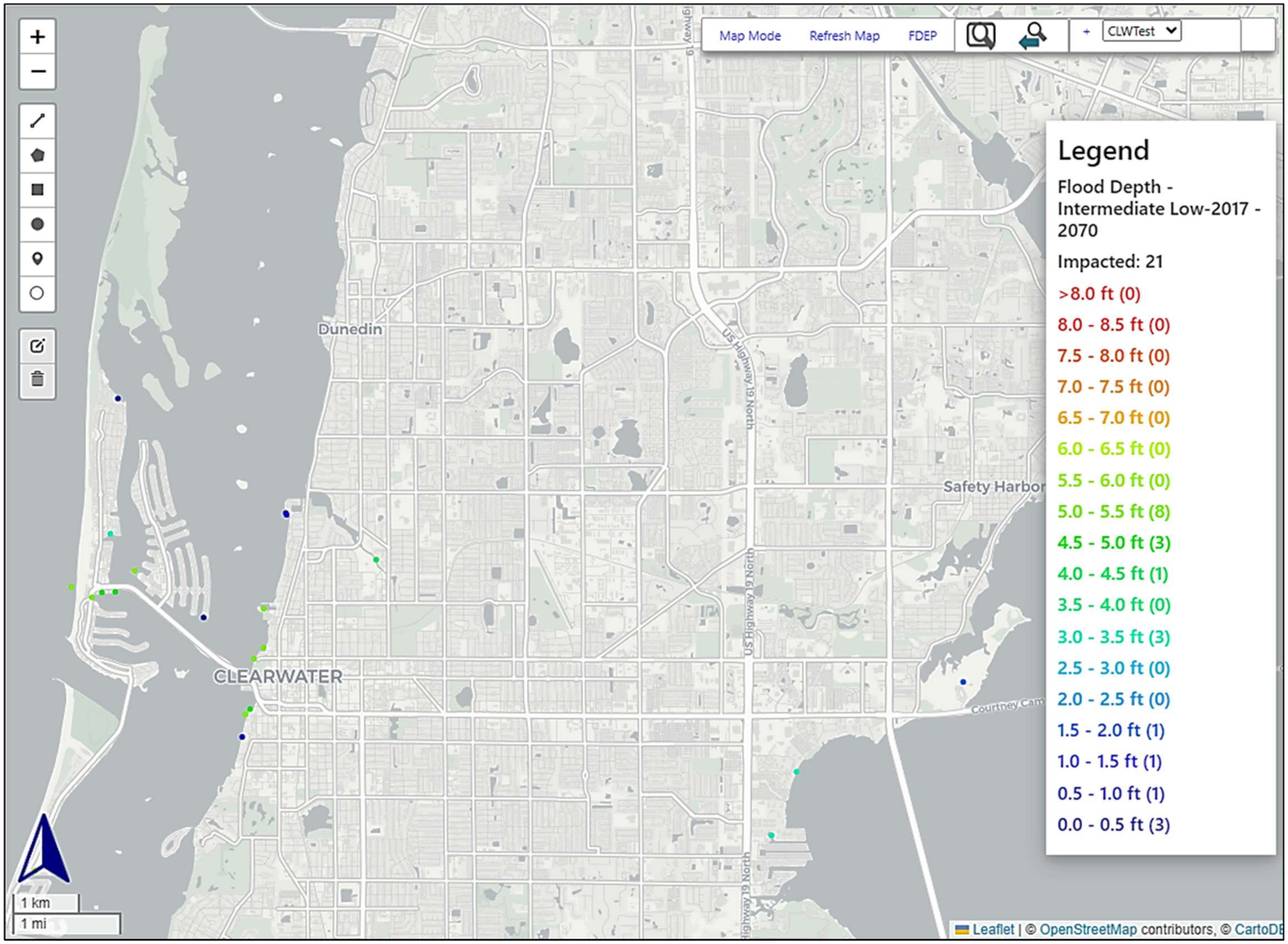


Figure 3-4 - 2070 Intermediate-Low Projection (2017) - Representative Depths and Extents of Tidal Only

3.1.1.3 2100 Intermediate-Low Projection

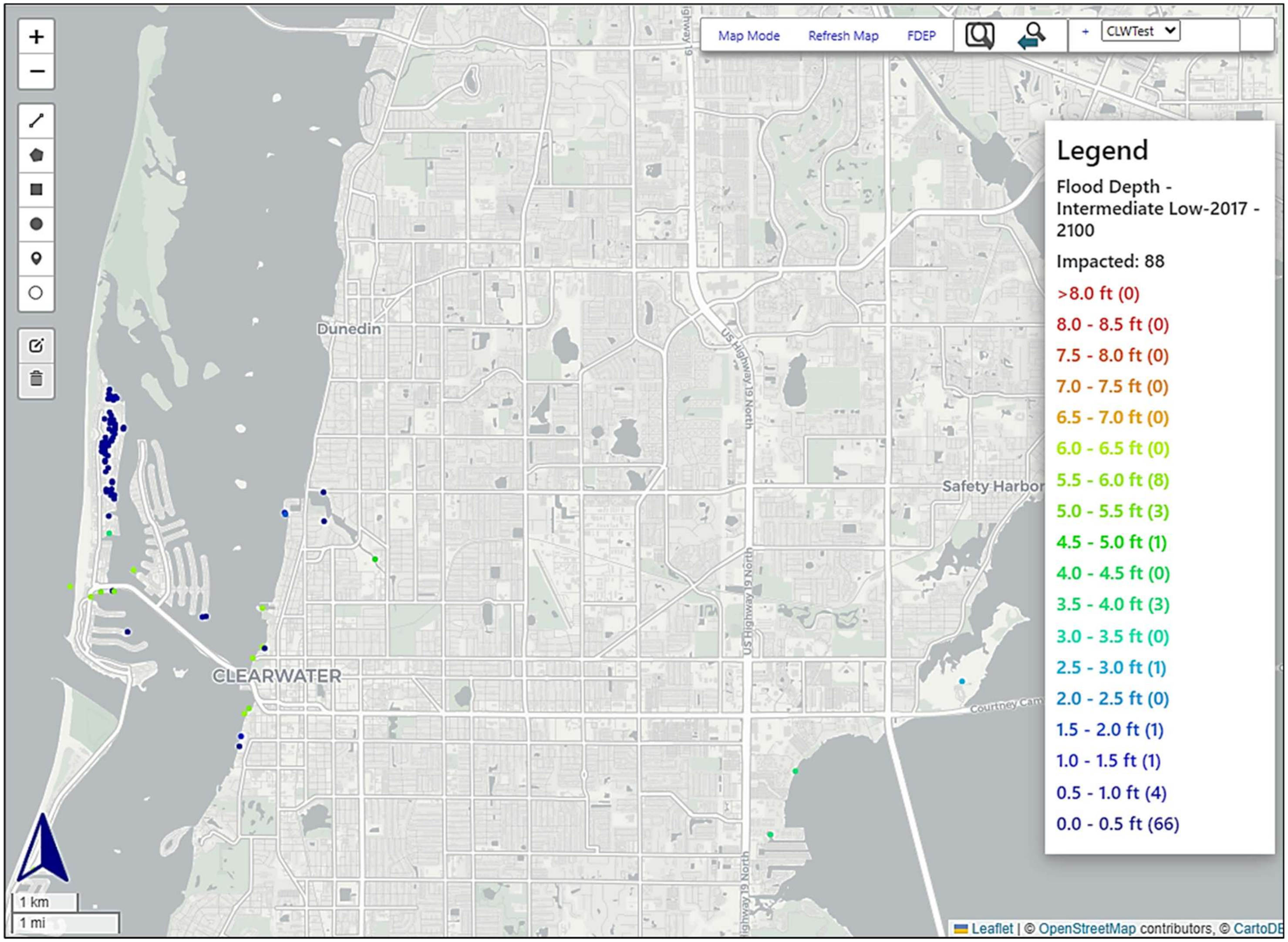


Figure 3-5 - 2100 Intermediate-Low Projection (2017) - Representative Depths and Extents of Tidal Only

3.1.1.4 2040 Intermediate-High Projection

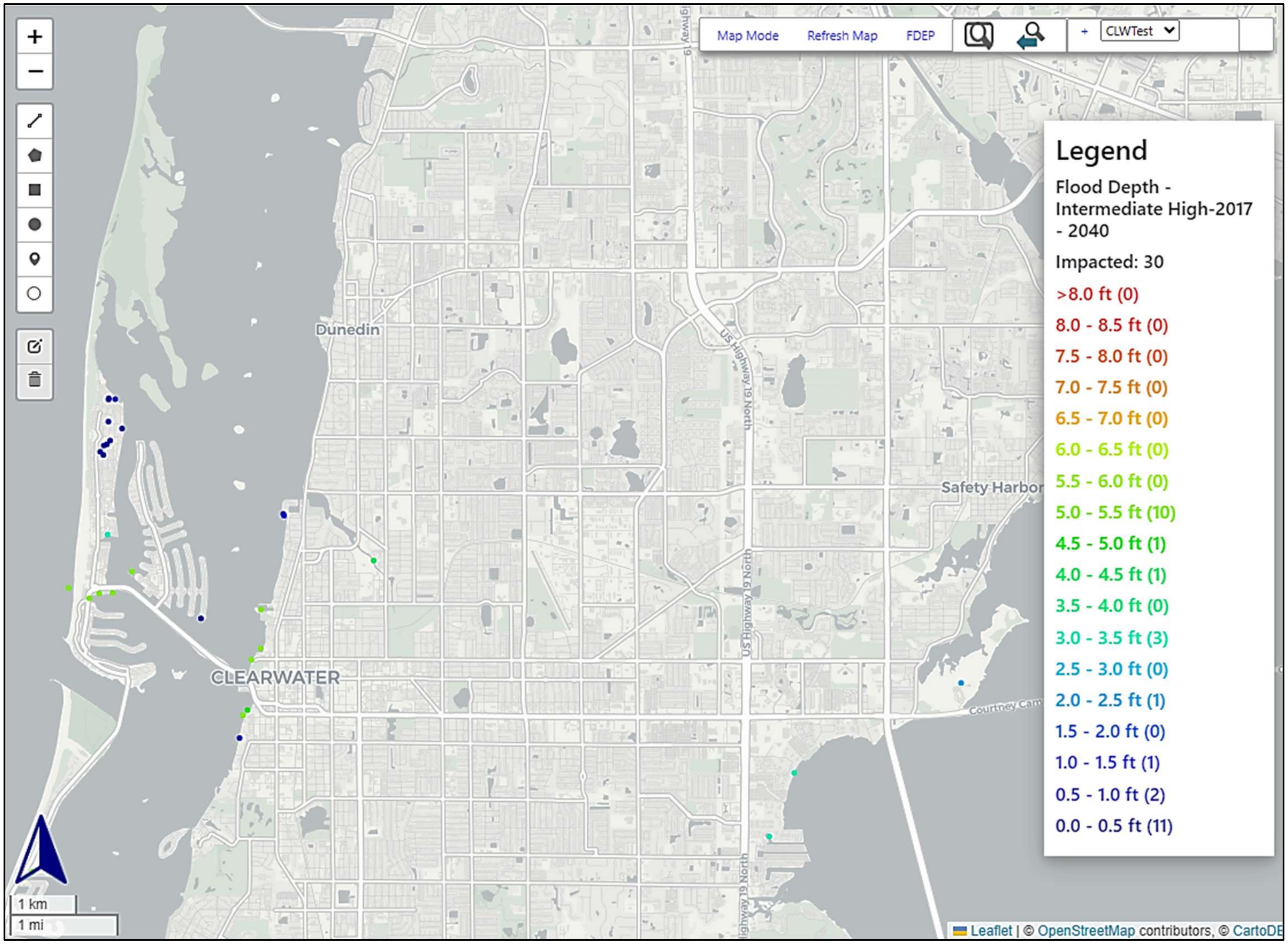


Figure 3-6 - 2040 Intermediate-High Projection (2017) - Representative Depths and Extents of Tidal Only

3.1.1.5 2070 Intermediate-High Projection

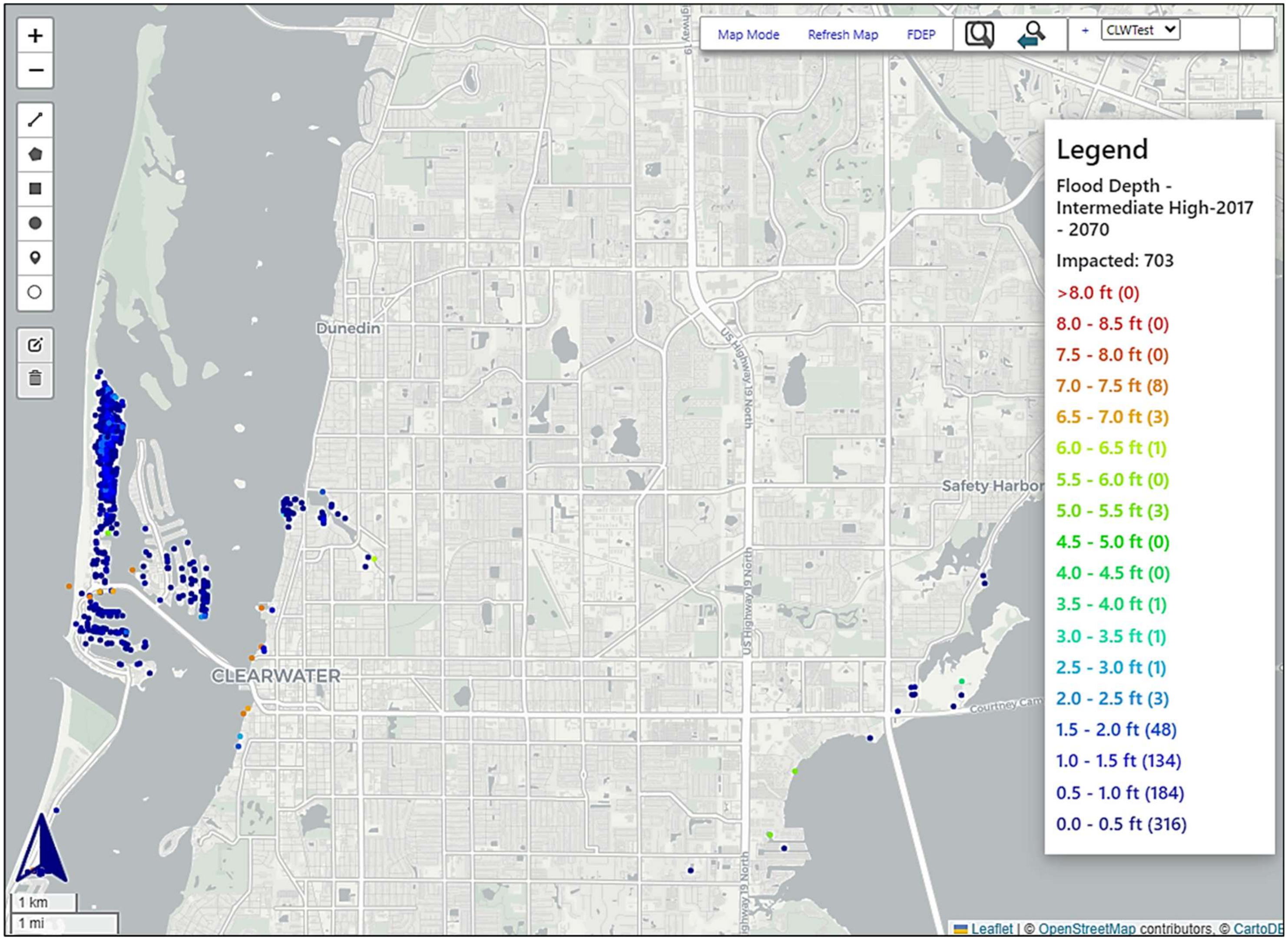


Figure 3-7 - 2070 Intermediate-High Projection (2017) - Representative Depths and Extents of Tidal Only

3.1.1.6 2100 Intermediate-High Projection

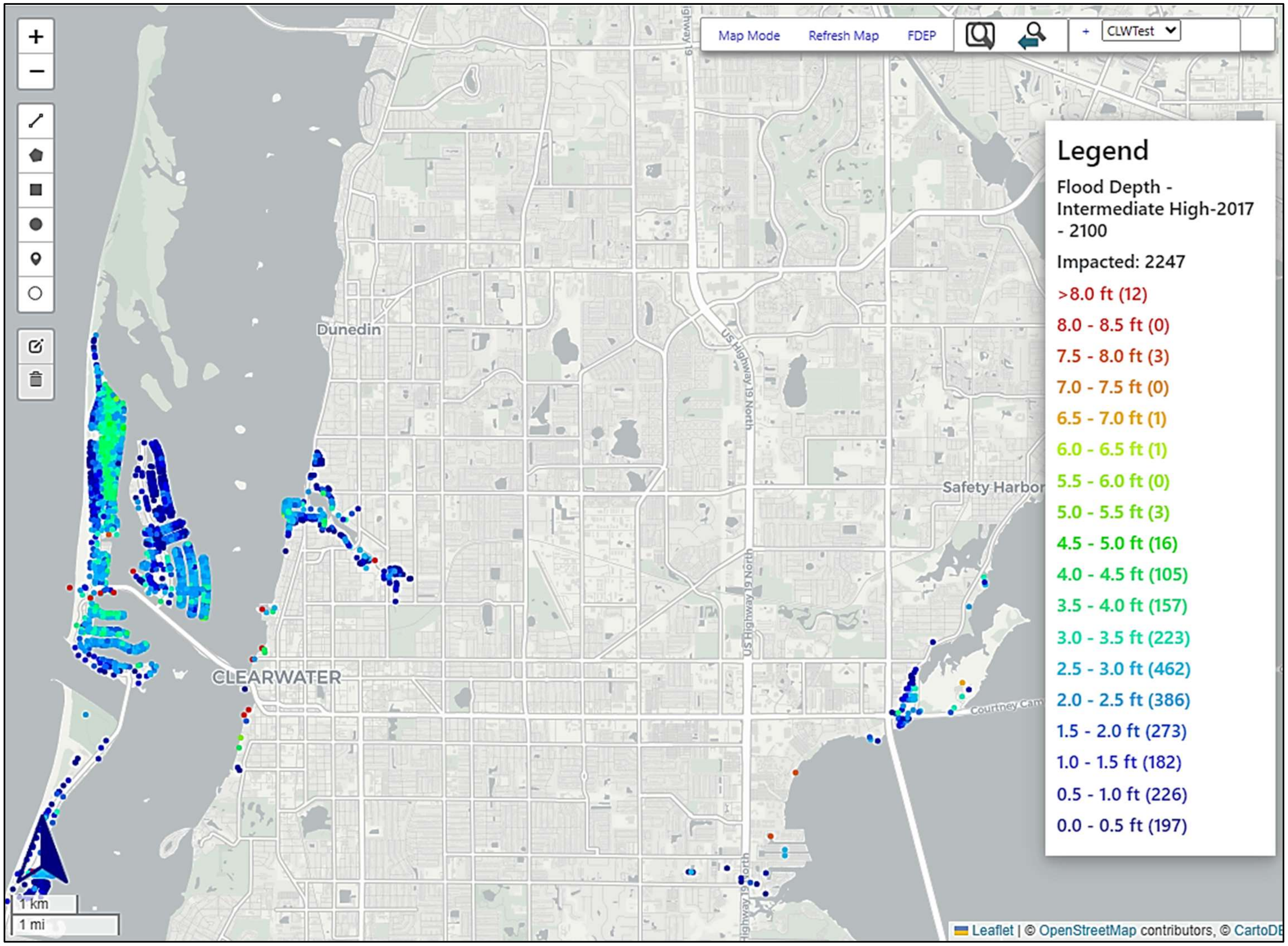


Figure 3-8 - 2100 Intermediate-High Projection (2017) - Representative Depths and Extents of Tidal Only

3.1.2 Acute Flooding - Large Rainfall Events

The algorithm described in section 2.4 was used to estimate flood risk for acute events like large rainstorms (pluvial/riverine) and wind-driven storm surge. The following figures show exposure to pluvial flood risk. Exposure to storm surge flood risk is shown in the next section. The same algorithm was used with the 500-year flood risk analysis.

Note that the three figures only show flood risk at buildings in the interior (non-coastal) portions of the city, where pluvial flood risk is dominant. The respective 2040, 2070, and 2100 planning year maps show that flood depth across the city indeed increases in time.

100-Year Results

2040	2070	2100
Precipitation Estimate: 14.63”	Precipitation Estimate: 16.95”	Precipitation Estimate: 18.21”
Max Depth: 13.73’	Max Depth: 14.3’	Max Depth: 14.34’

500-Year Results

2040	2070	2100
Precipitation Estimate: 21.00”	Precipitation Estimate: 24.07”	Precipitation Estimate: 25.51”
Max Depth: 15.32’	Max Depth: 18.78’	Max Depth: 20.38’

3.1.2.1 2040 Planning Horizon – Pluvial Flooding; 100-Yr Event

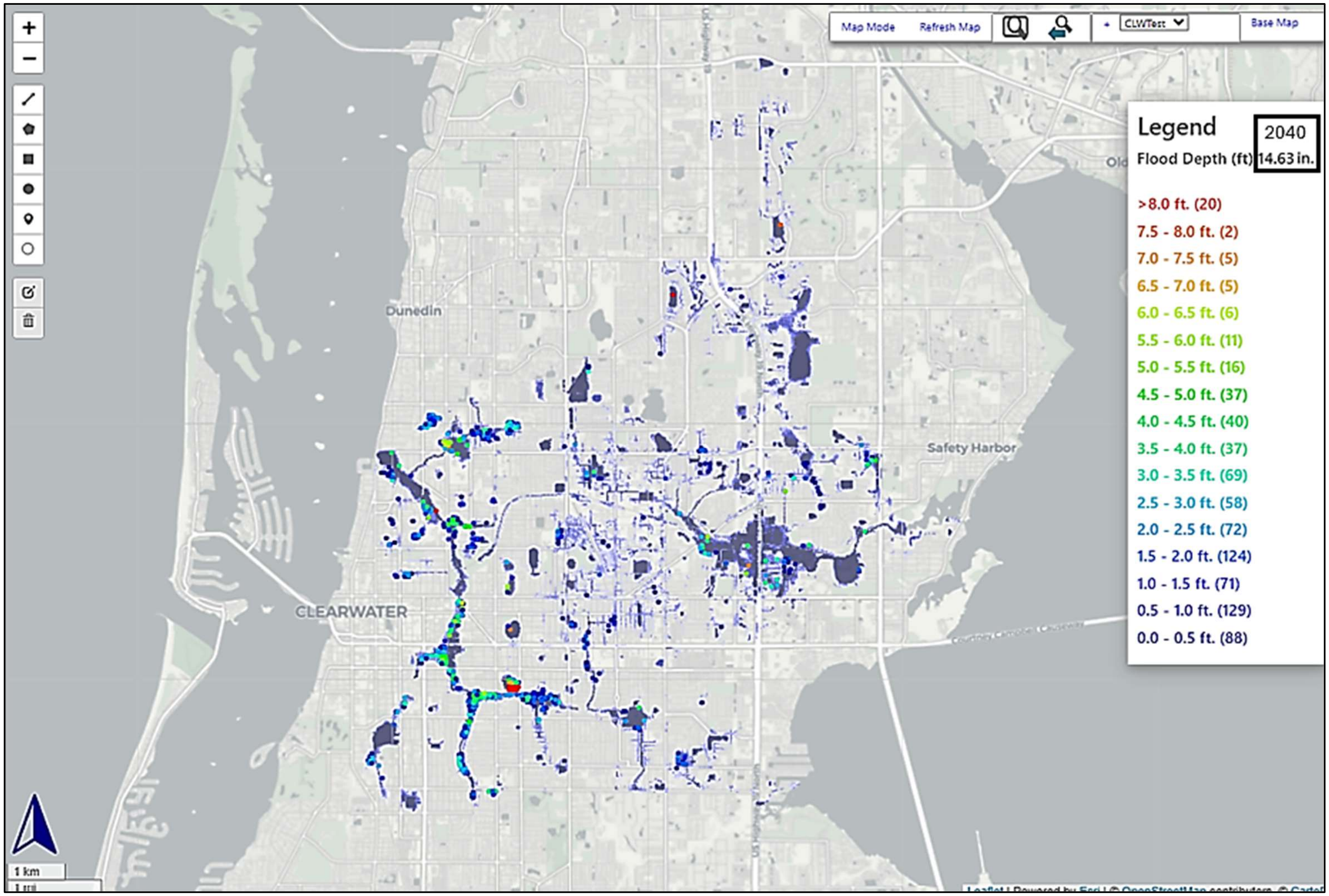


Figure 3-9 – Existing 100-year flood depth grid with locations (circles) representing flood depths and extents of the modeled 2040 rainfall event (14.63 inches in 24-hour period)

3.1.2.2 2070 Planning Horizon – Pluvial Flooding; 100-Yr Event

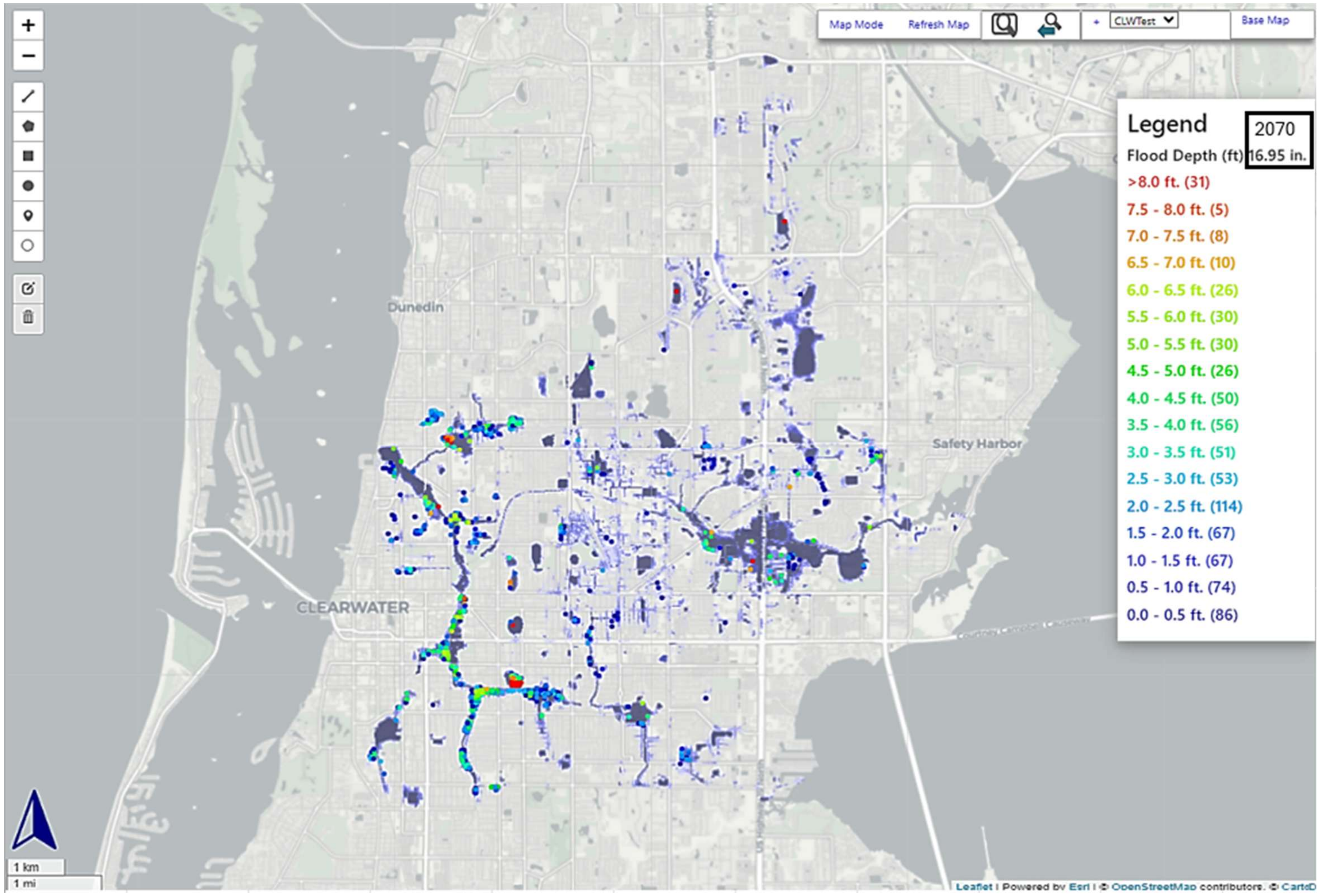


Figure 3-10 - Existing 100-year flood depth grid with locations (circles) representing flood depths and extents of the modeled 2070 rainfall event (16.95 inches in 24-hour period)

3.1.2.3 2100 Planning Horizon – Pluvial Flooding; 100-Yr-Event

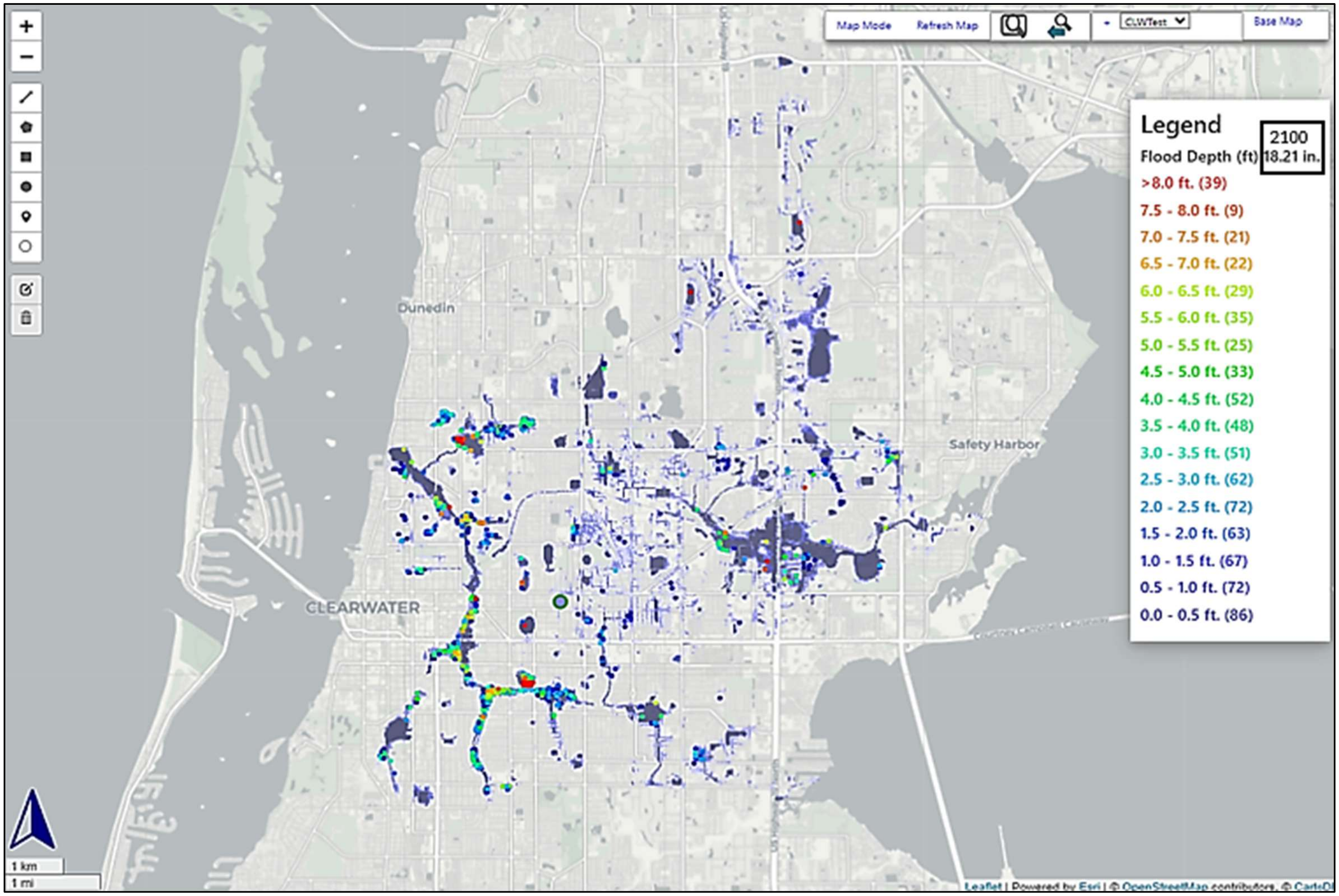


Figure 3-11 - Existing 100-year flood depth grid with locations (circles) representing flood depths and extents of the modeled 2100 rainfall event (18.21 inches in 24-hour period)

3.1.2.4 2040 Planning Horizon – Pluvial Flooding; 500-Yr-Event

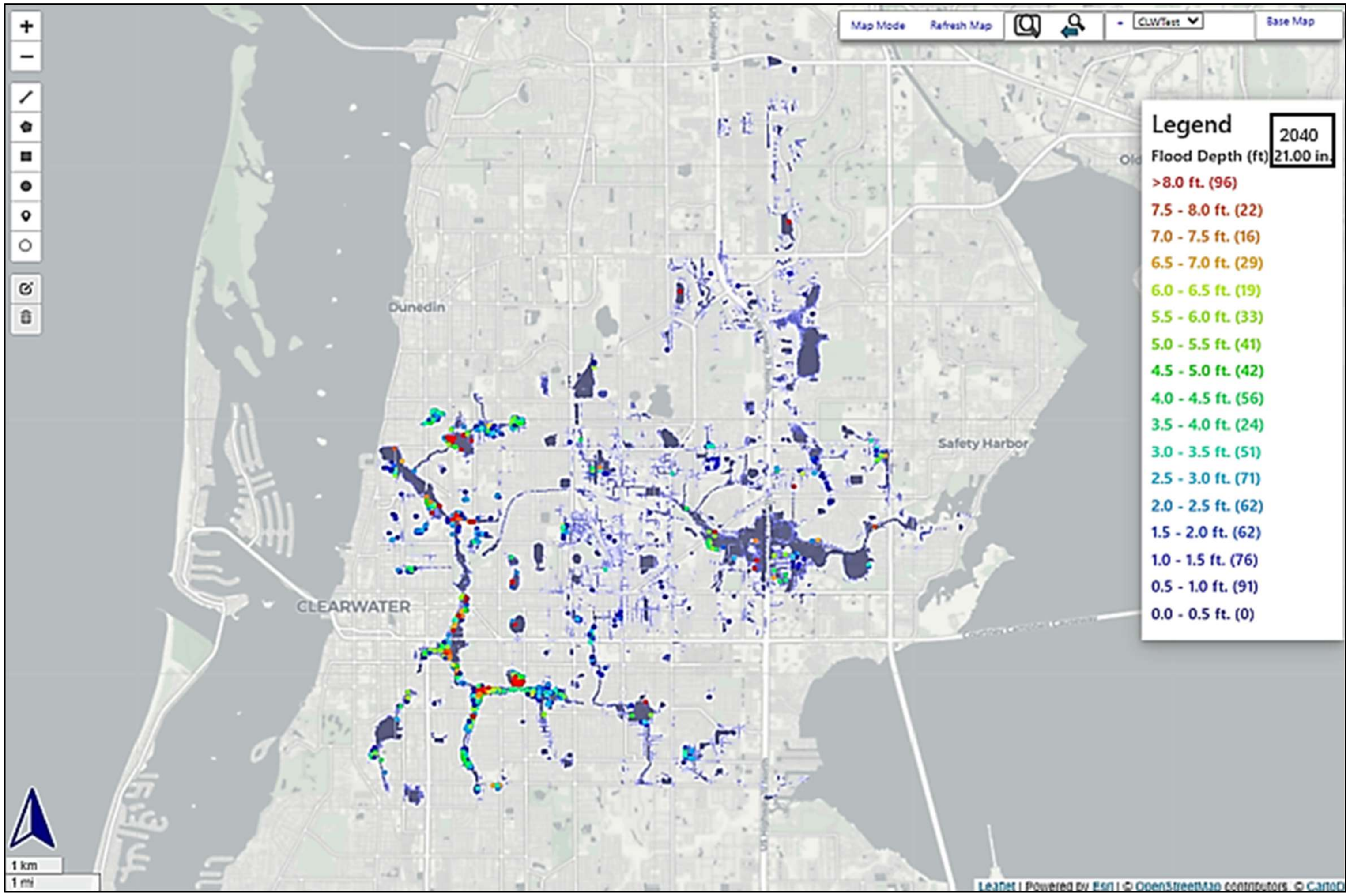


Figure 3-12 - Existing 100-year flood depth grid with locations (circles) representing flood depths and extents of the modeled 2040 500-yr rainfall event (21.00 inches in 24-hour period)

3.1.2.5 2070 Planning Horizon – Pluvial Flooding; 500-Yr-Event

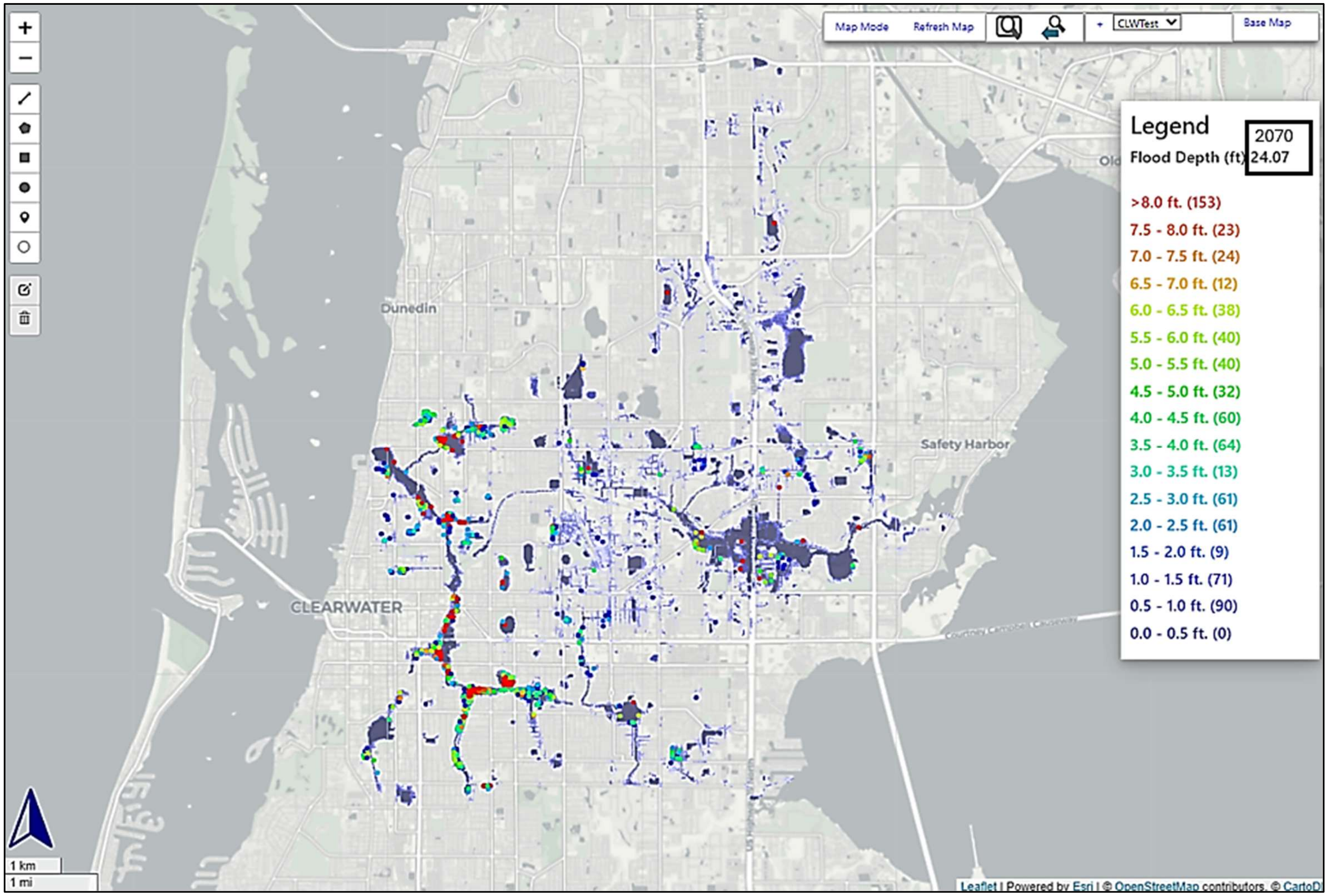


Figure 3-13 - Existing 100-year flood depth grid with locations (circles) representing flood depths and extents of the modeled 2040 500-yr rainfall event (24.07 inches in 24-hour period)

3.1.2.6 2100 Planning Horizon – Pluvial Flooding; 500-Yr Event

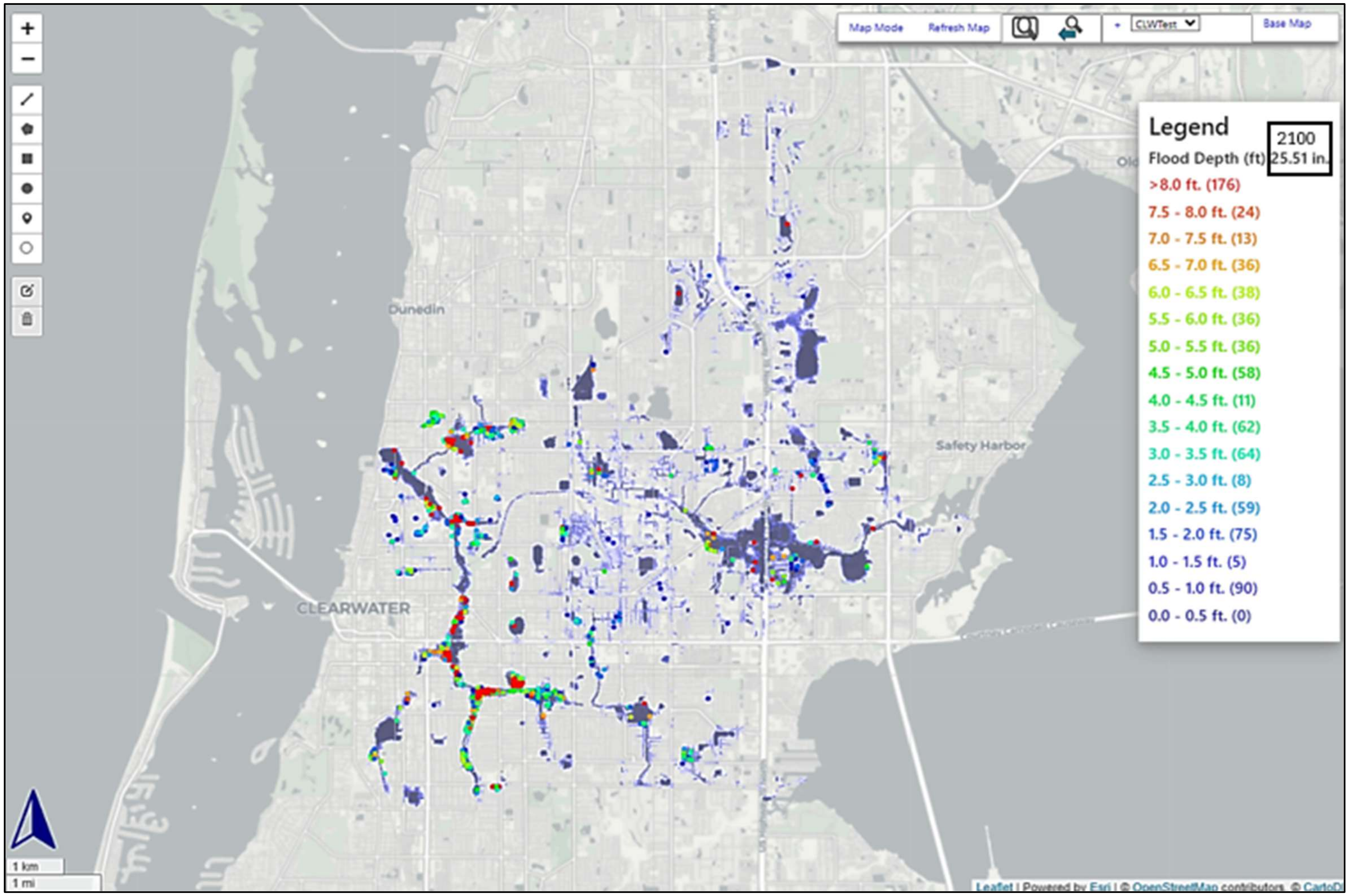


Figure 3-14 - Existing 100-year flood depth grid with locations (circles) representing flood depths and extents of the modeled 2040 500-yr rainfall event (25.51 inches in 24-hour period)

3.1.3 Acute Flooding – Storm Surge Events

The algorithm described in section 2.4 was used to estimate flood risk for acute events like large rain storms (pluvial/riverine) and wind-driven storm surge. The following figures show exposure to surge flood risk. Exposure to pluvial flood risk is shown in the previous section.

Note that the three figures only show flood risk at buildings in the coastal portions of the city, where storm surge flood risk is dominant. The respective 2040, 2070, and 2100 planning year maps show that flood depth across the city indeed increases in time

The table below provides a quick summary of the flood risk, showing the deepest flood level estimated across the landscape for the three planning horizons and two SLR scenarios.

Planning Horizon	Max Depth from Intermediate-Low (2017) Projections at each Planning Horizon	Max Depth from Intermediate-High (2017) Projections at each Planning Horizon
2040	16.5 Feet	17.1 Feet
2070	18.1 Feet	20.0 Feet
2100	19.6 Feet	22.7 Feet

3.1.3.1 2040 Intermediate-Low Projection (2017) - Storm Surge

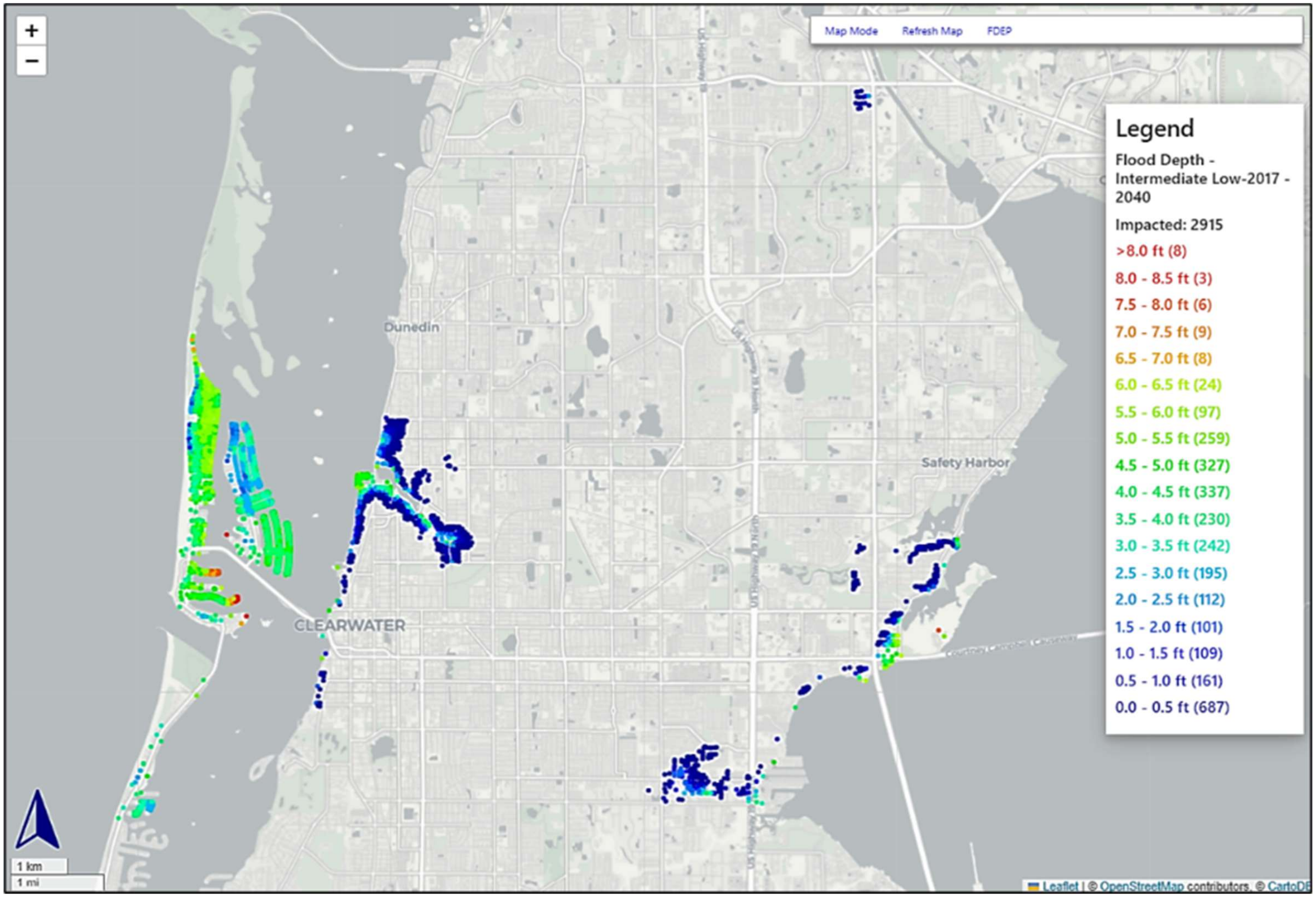


Figure 3-15 - 2040 Intermediate-Low (2017) - Storm Surge Extent and Depths

3.1.3.2 2070 Intermediate-Low Projection (2017) - Storm Surge

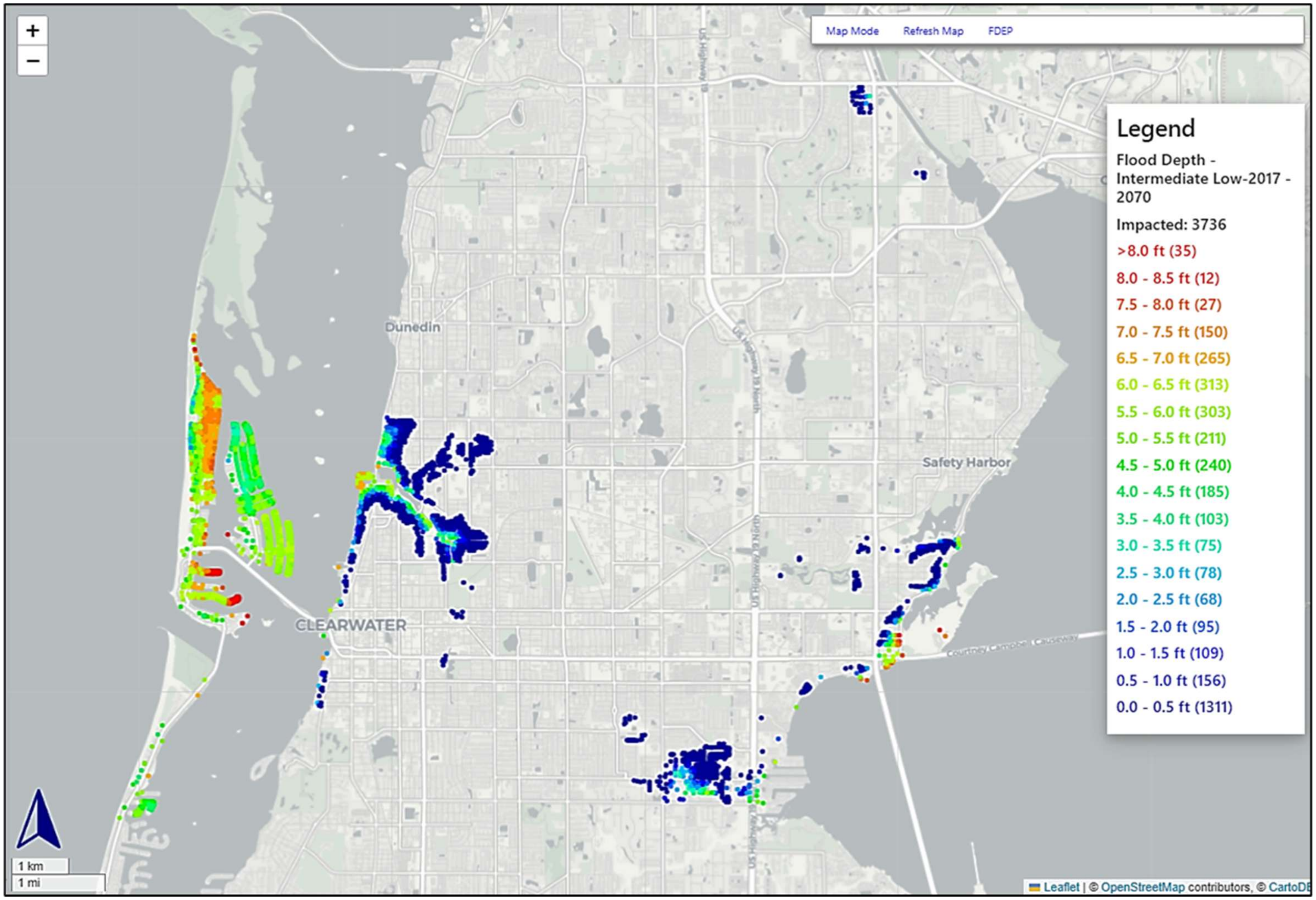


Figure 3-16 - 2070 Intermediate-Low (2017) - Storm Surge Extent and Depths

3.1.3.3 2100 Intermediate-Low Projection (2017) - Storm Surge

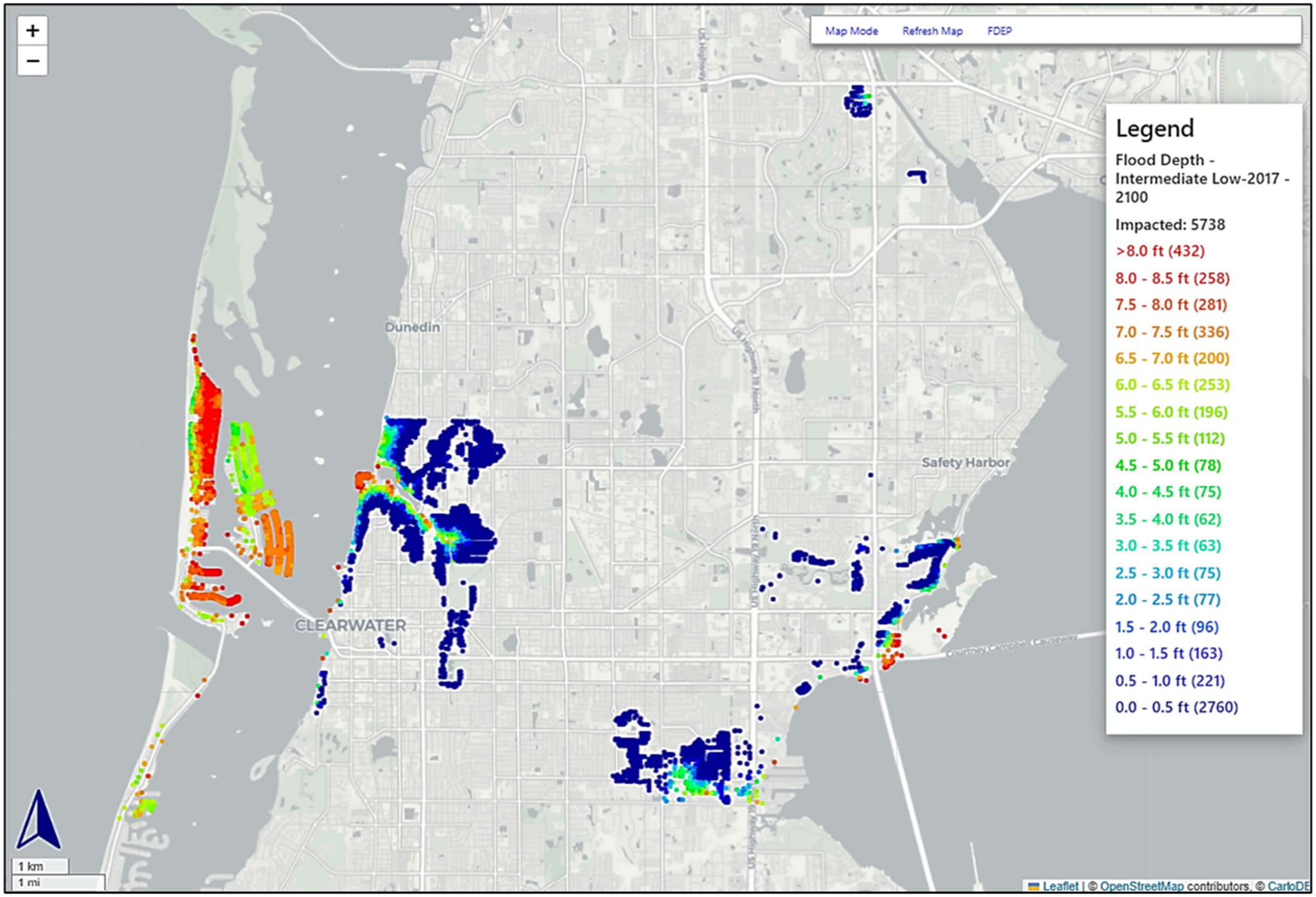


Figure 3-17 - 2100 Intermediate-Low (2017) - Storm Surge Extent and Depths

3.1.3.4 2040 Intermediate-High Projection (2017) - Storm Surge

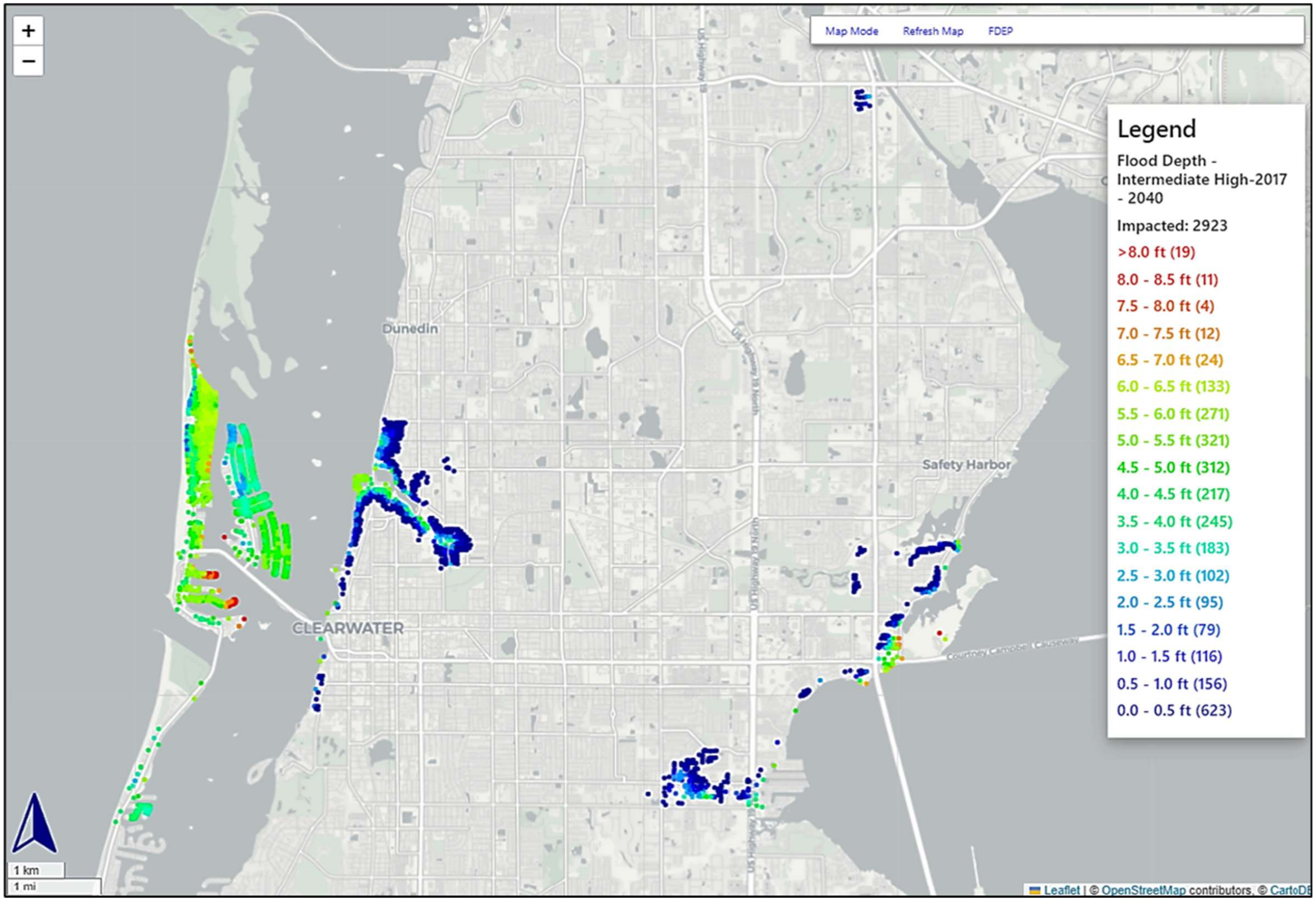


Figure 3-18 - 2040 Intermediate-Low (2017) - Storm Surge Extent and Depths

3.1.3.5 2070 Intermediate-High Projection (2017) - Storm Surge

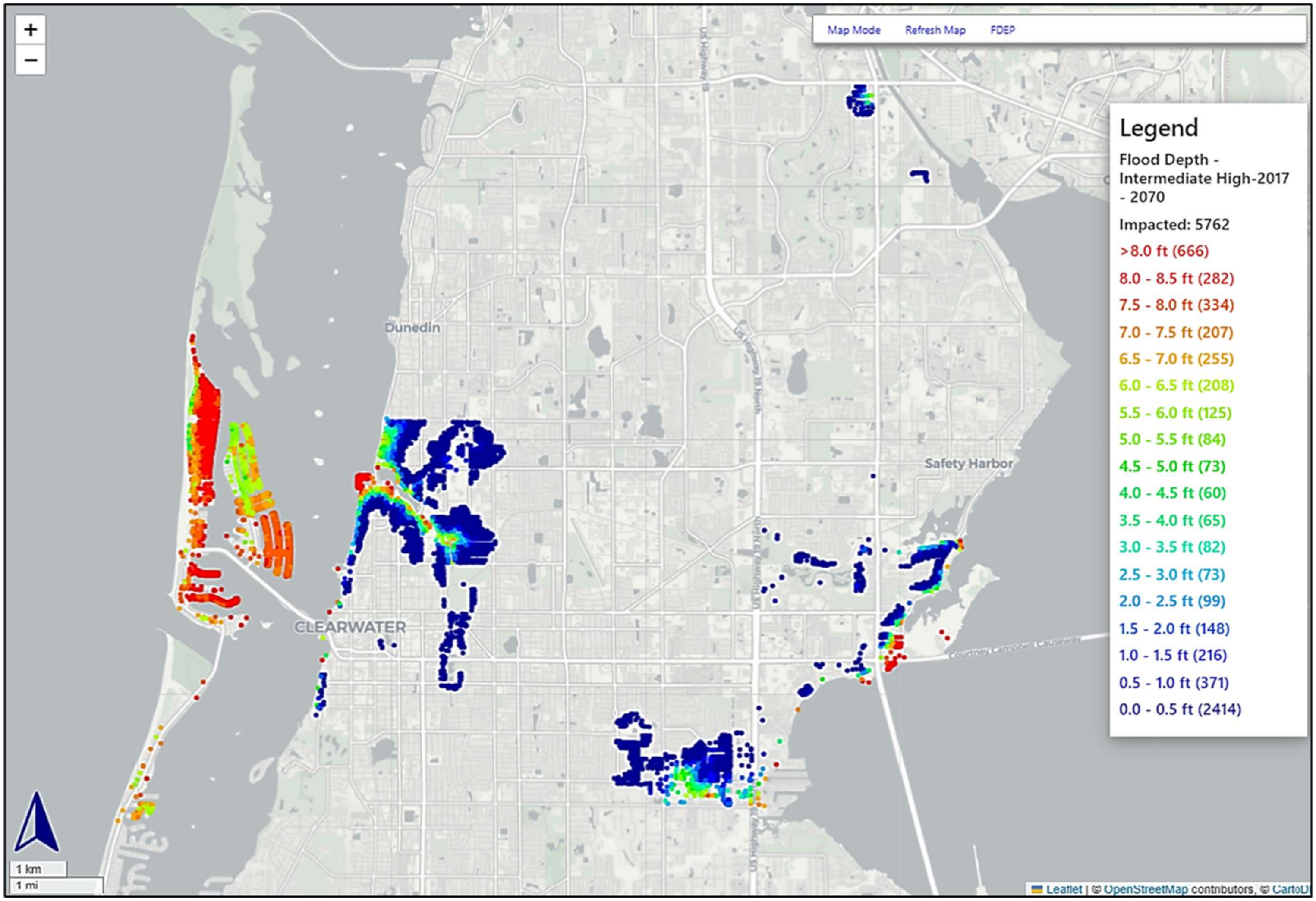


Figure 3-19 - 2070 Intermediate-Low (2017) - Storm Surge Extent and Depths

3.1.3.6 2100 Intermediate-High Projection (2017) - Storm Surge

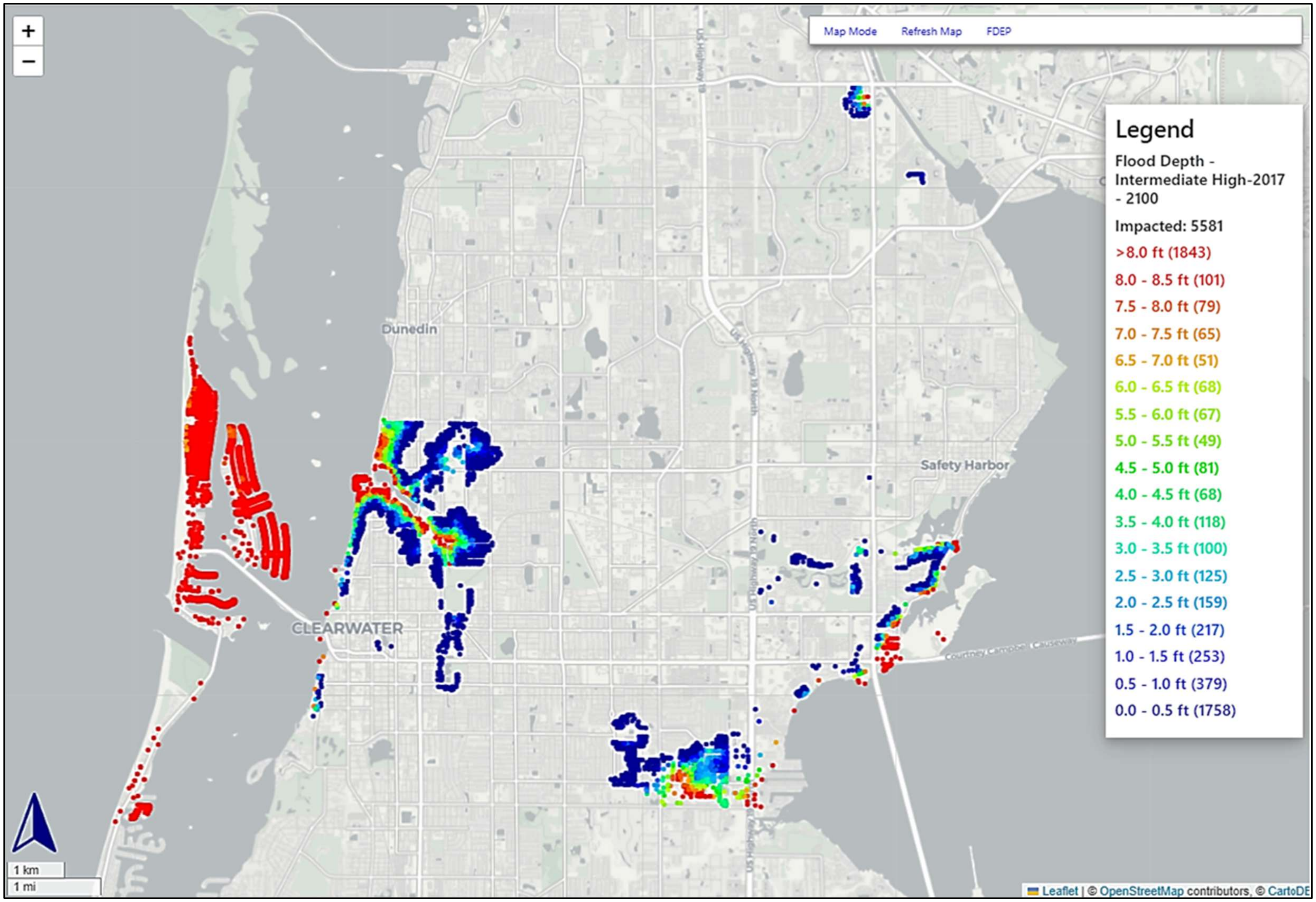


Figure 3-20 - 2100 Intermediate-High (2017) - Storm Surge Extent and Depths

3.1.4 Stormwater and Transportation Exposed to Future Flood Conditions

One of the key sets of assets provided at the start of the study was a collection of stormwater assets. These assets were used in conjunction with transportation assets to create a set of tracking points that could be used to geospatially understand where flooding was occurring, how deep it may get at those locations, and what disruptions this may cause for residents and businesses as they try to navigate the city’s transportation network.

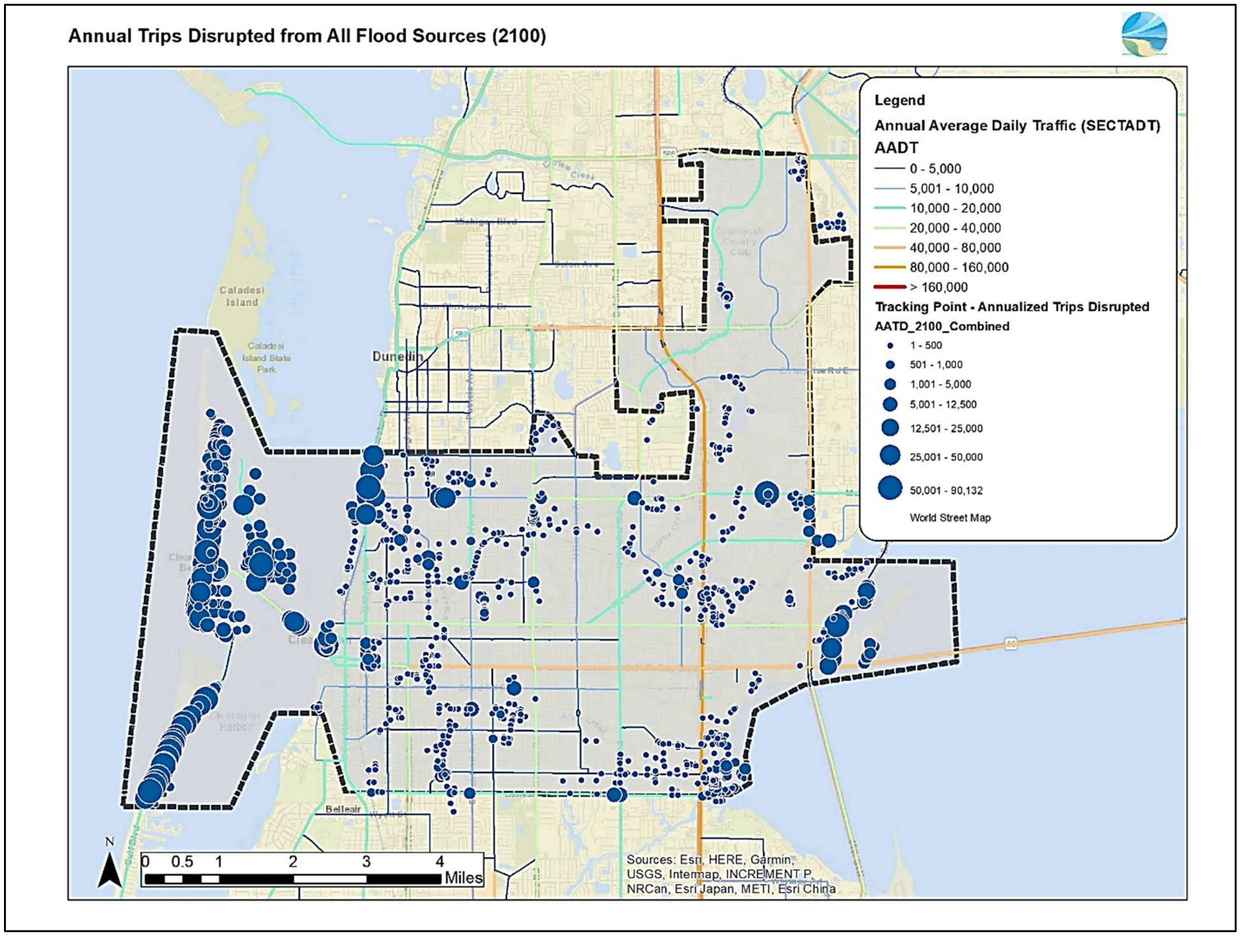


Figure 3-21 - Trips disrupted from all flood events (2100)

3.2 Heat Exposure

Note: Heat exposure is outside of the grant requirements and funding. The heat and temperature assessment were conducted at the same time to provide the City with a comprehensive view of climate projections and their potential impacts to the community.

As seen within the Exposure and Climate Drivers section of the report, increases in temperature are expected to be experienced across the city. To provide an assessment of what parts of the city are expected to incur more impacts from the increase in temperatures, a model was developed to utilize the downscaled local temperature projections along with existing spatial data of shaded locations and buildings. The model uses the locations of buildings to identify how many days throughout the year that the spot can expect to receive a maximum temperature (Max T) above 90 degrees Fahrenheit. The buildings have been analyzed for trees in the area around the building, and the Max T is adjusted down based on tree percentage. The amount of reduction maxes out at 5 degrees and is linearly related to a linear, distance-weighted estimate of tree percentage based on the tree percentage raster, which has results at 30-meter grid cells. The tree percentage of the cell right over the structure's centroid gets the highest weight, the grid cells in the square of cells one cell distance out from the centroid gets the next highest weight, and the grid cells in the next concentric square gets a low weight. If the weighted tree percent is 1.0, the Max T is reduced 5 degrees. If the tree percentage is zero, then the Max T is not reduced at all. The maps below show the results per each planning horizon (2040, 2070, and 2100) and each climate projection (2017 intermediate-low and 2017 intermediate-high).

3.2.1 Citywide Heat Exposure

Results from the model are summarized as follows:

2040 Planning Horizon

- There are 10,081 study locations where temperatures are increasing in the number of days that experience maximum temperatures greater than 90 degrees when existing shade conditions are accounted for.
- All locations are within the category of 1-25 days per year.

2070 Planning Horizon

- There are 14,603 study locations where temperatures are increasing in the number of days that experience maximum temperatures greater than 90 degrees when existing shade conditions are accounted for.
- Of those locations, the majority of locations (9,244) are within the category of 76-100 days per year.

2100 Planning Horizon

- There are 17,446 study locations where temperatures are increasing in the number of days that experience maximum temperatures greater than 90 degrees when existing shade conditions are accounted for.
- Of those locations, most locations (9,262) are within the category of 176-200 days per year.

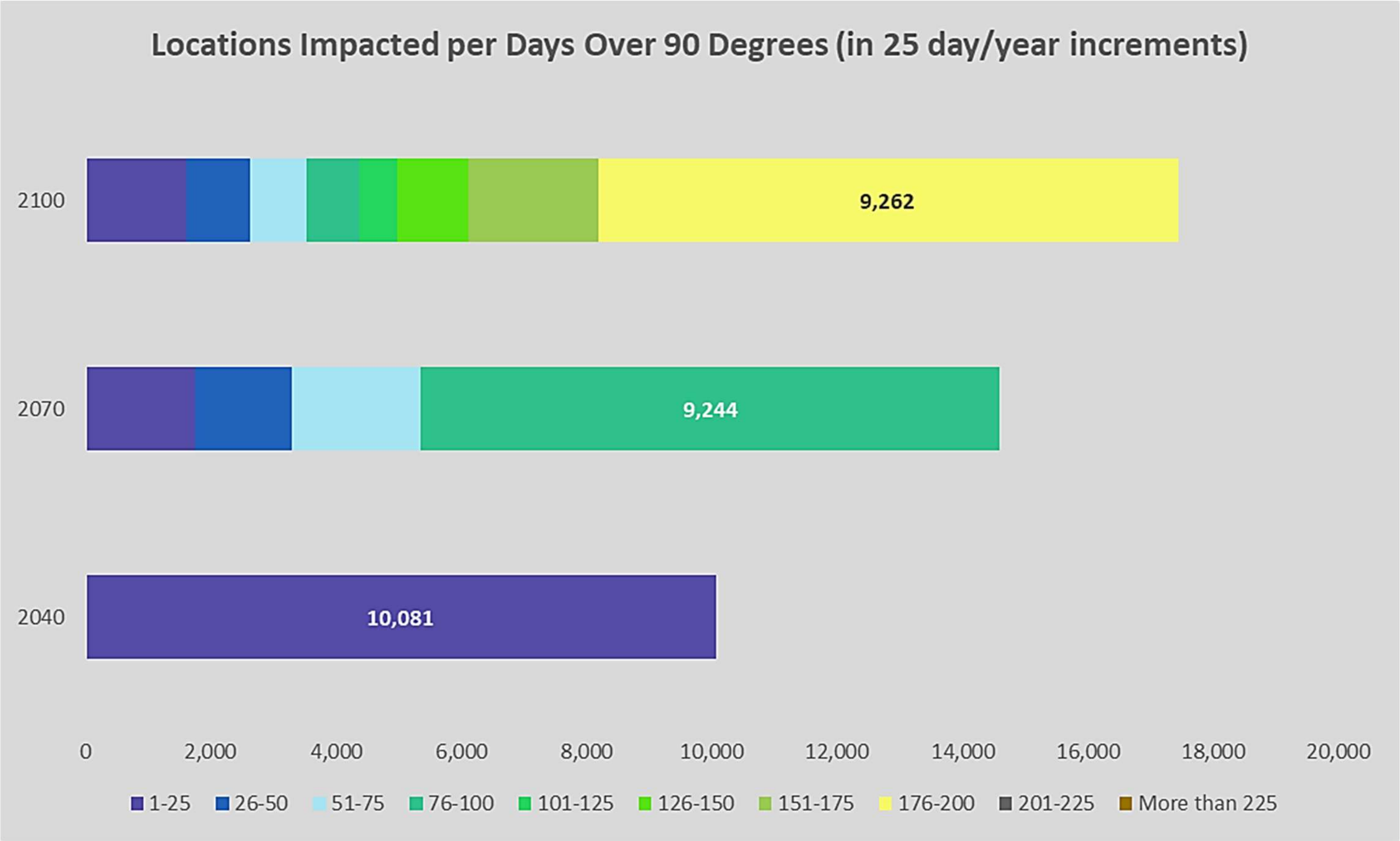


Figure 3-22 - The number of locations expected to experience increasing days of temperature greater than 90 degrees for each planning horizon (2040, 2070, 2100).

The graphic above illustrates that not only are the amount of days/year with high temperatures increasing, but also the number of locations is increasing; and most of the locations are experiencing the worst of the temperature increases. This is shown spatially by the maps on the following pages.

3.2.1.1 Year 2040 Locations with Days Greater than 90 Degrees (2017 Projections)

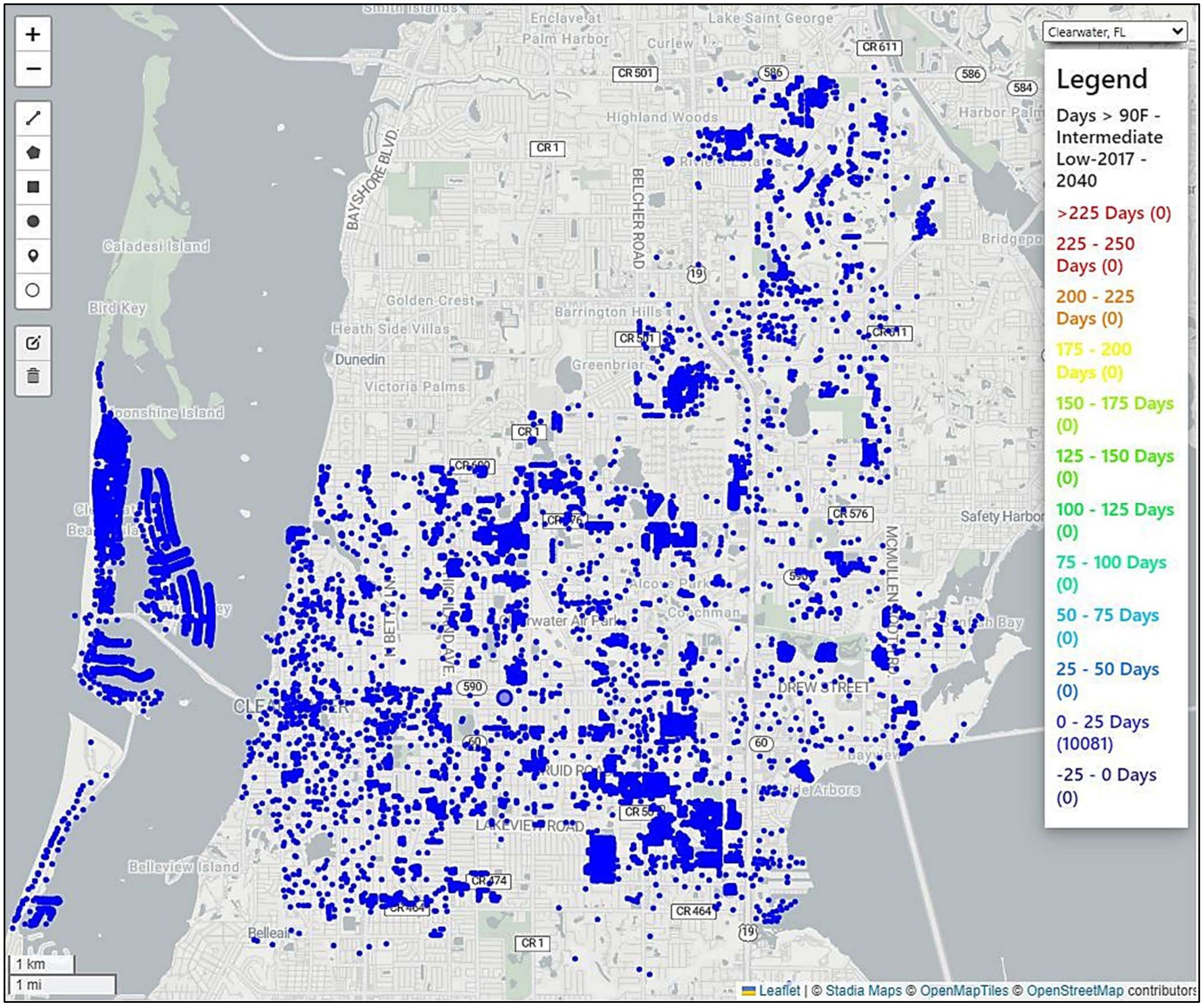


Figure 3-23 - Heat impacts at building locations using the 2017 projections (Year 2040).

3.2.1.2 Year 2070 Locations with Days Greater than 90 Degrees (2017 Projections)

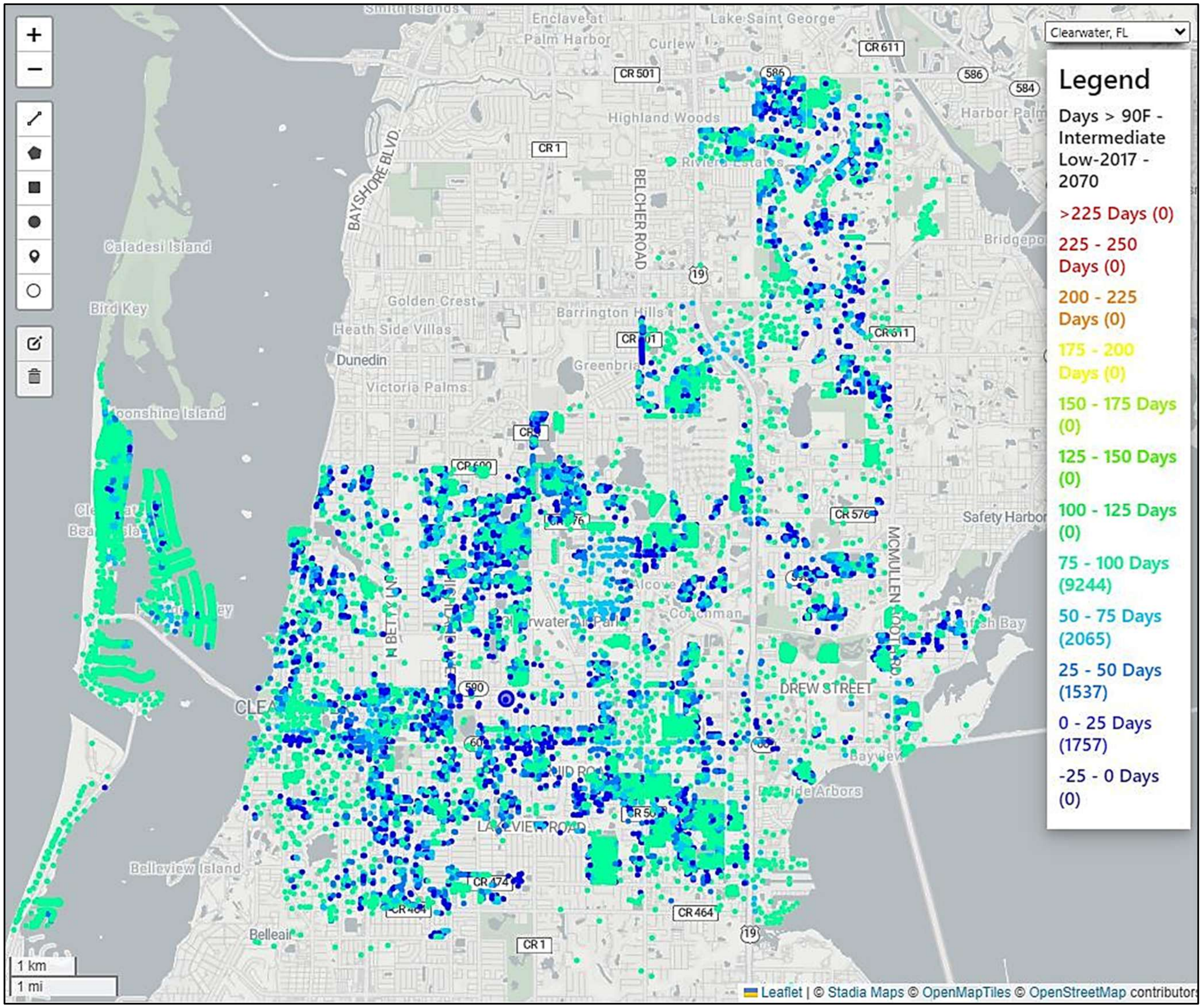


Figure 3-24 - Heat impacts at building locations using the 2017 projections (Year 2070).

3.2.1.3 Year 2100 Locations with Days Greater than 90 Degrees (2017 Projections))

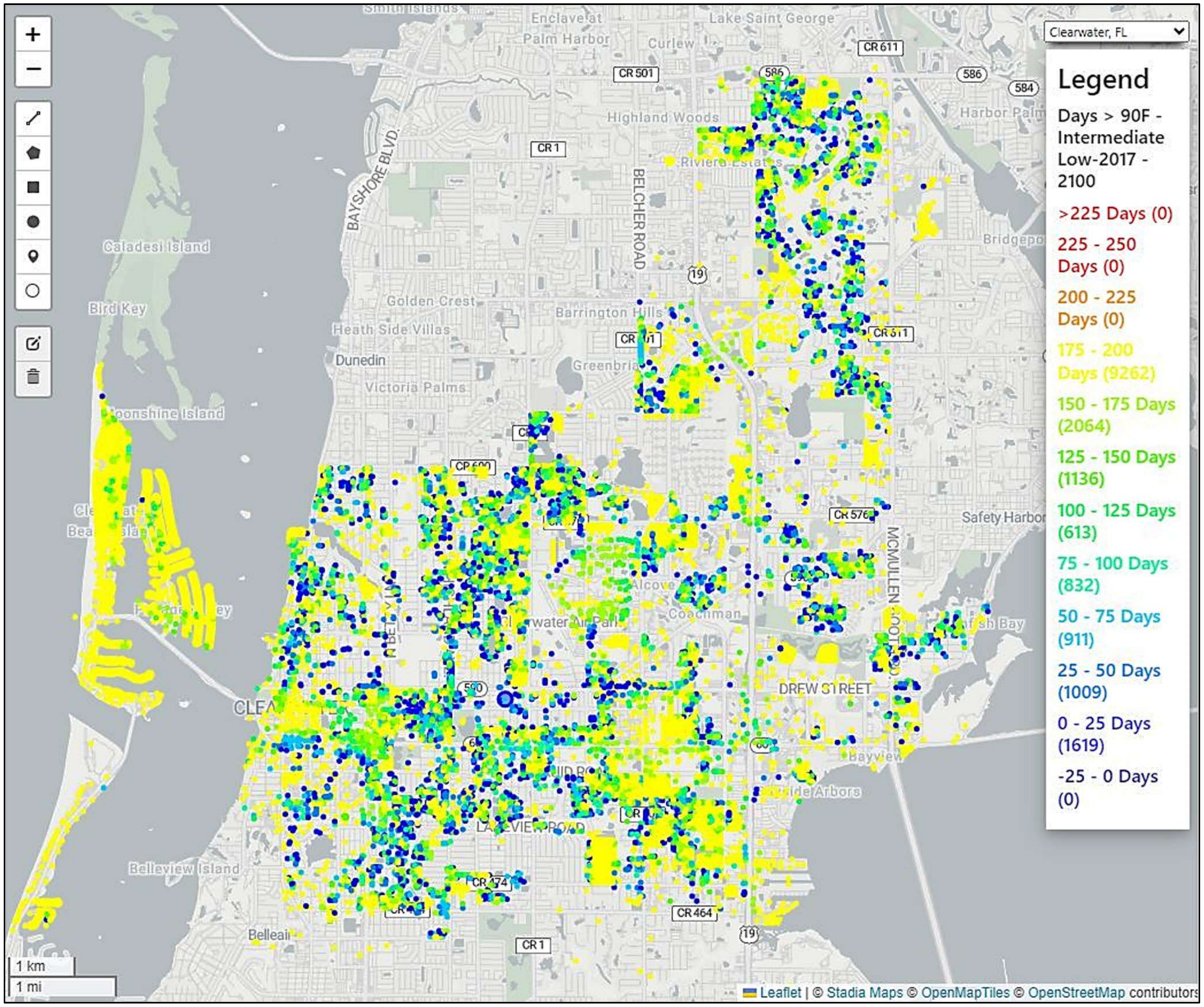


Figure 3-25 - Heat impacts at building locations using the 2017 projections (Year 2100).

4. Understanding How Vulnerable the City's Assets are to Projected Climate Scenarios

This section of the report is intended to identify what assets are vulnerable to the future flood conditions and how vulnerable they may be under each condition. Additionally, as the City of Clearwater's study includes heat as a climate consideration, metrics are provided to help quantify impacts from its exposure to additional temperature impacts.

4.1 Flood Hazards

Critical Assets
Assets at risk are identified for each projection and planning horizon throughout this chapter.

As a reminder the flood hazards studied included tidal, surge, and pluvial (rainfall) events that result in days of flooding and depths of flooding relative to buildings, critical assets, and the stormwater and transportation infrastructure emulated within the digital twin of the city. Figure 3-1 earlier in the report diagramed the flood risk metrics calculated for each building, where "buildings" implies all non-linear structures, including residential and commercial buildings, transmission stations, water treatment plants, etc. Each of these structures was assessed for tidal and acute flooding against multiple SLR scenarios and risk was estimated at each of three planning years (2040, 2070, and 2100).

4.1.1 Tidal Flood Results

As identified in Section 3.1.1 of the report, tidal exposure from SLR alone is minimal until the 2070-2100 planning horizons. As the digital twin process created a representation for all buildings within the city, there are multiple visualizations provided for each future projection. There is a map for buildings impacted at each planning scenario, as well as a map for the critical assets impacted at each planning scenario. The maps have dots to represent each building or asset, and these dots are color-coded by depth of fooding. The critical assets are color-coded per a specific priority system where flood depths greater than two feet are categorized as "high risk", half a foot to two feet of flood depth as "medium risk", and less than half a foot of flood depth is "low risk".

4.1.1.1 Tidal - 2040 Intermediate-Low

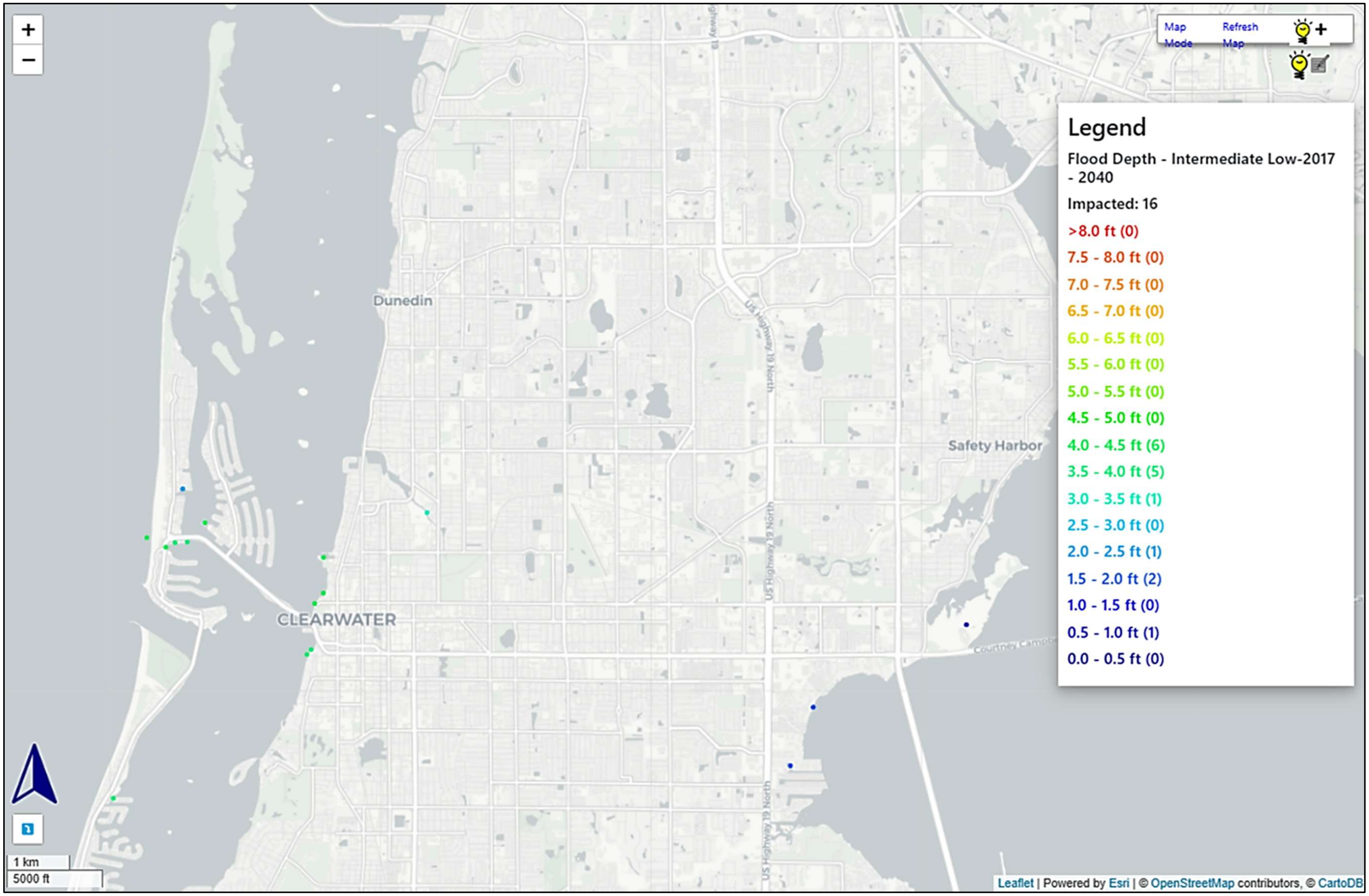


Figure 4-1 - Tidal Impacts - 2040 - Intermediate-Low

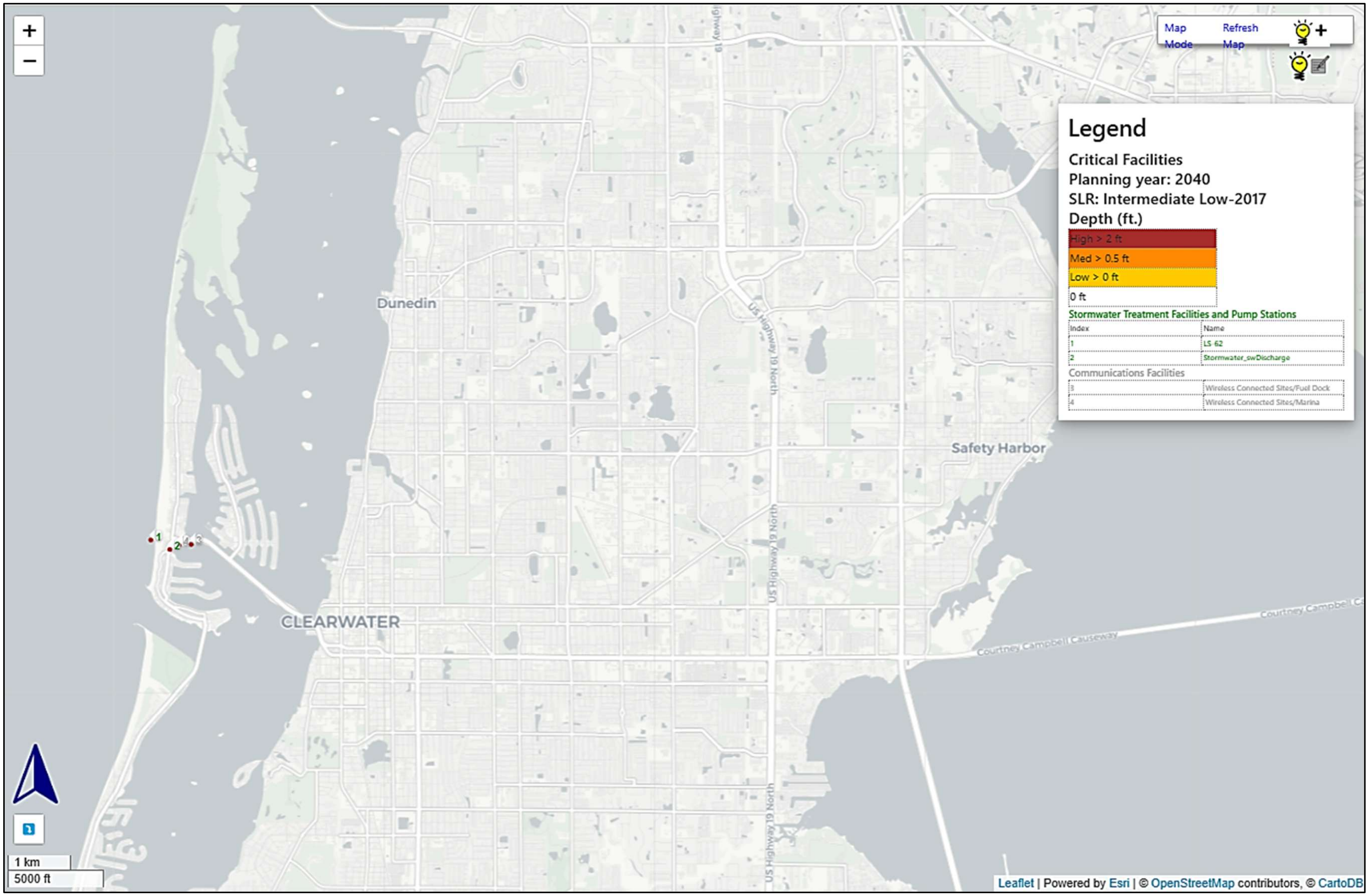


Figure 4-2 - Tidal - 2040 Intermediate-Low; Impacted Critical Assets

4.1.1.2 Tidal - 2040 Intermediate-High

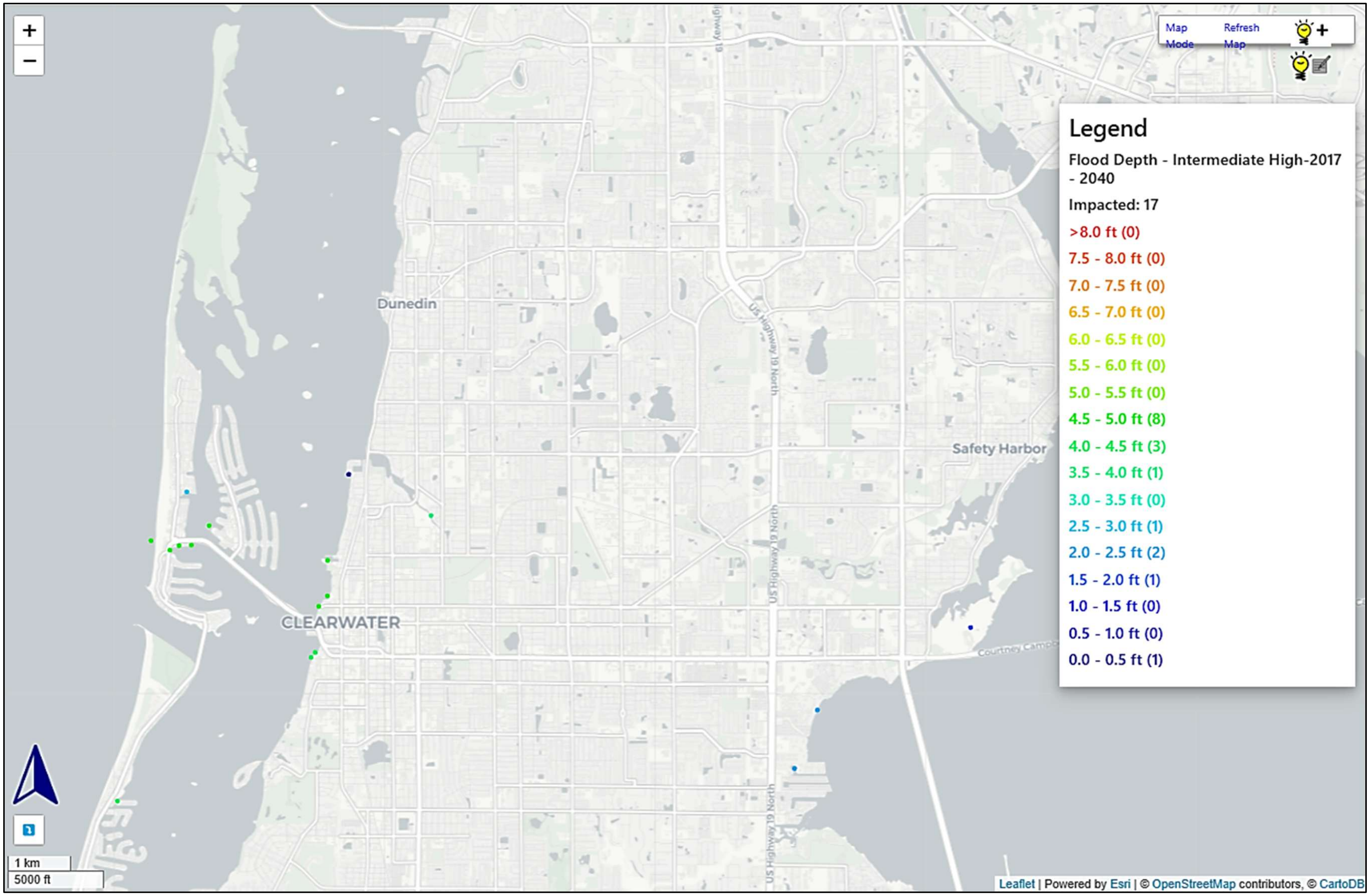


Figure 4-3 - Tidal Impacts - 2040 - Intermediate-High

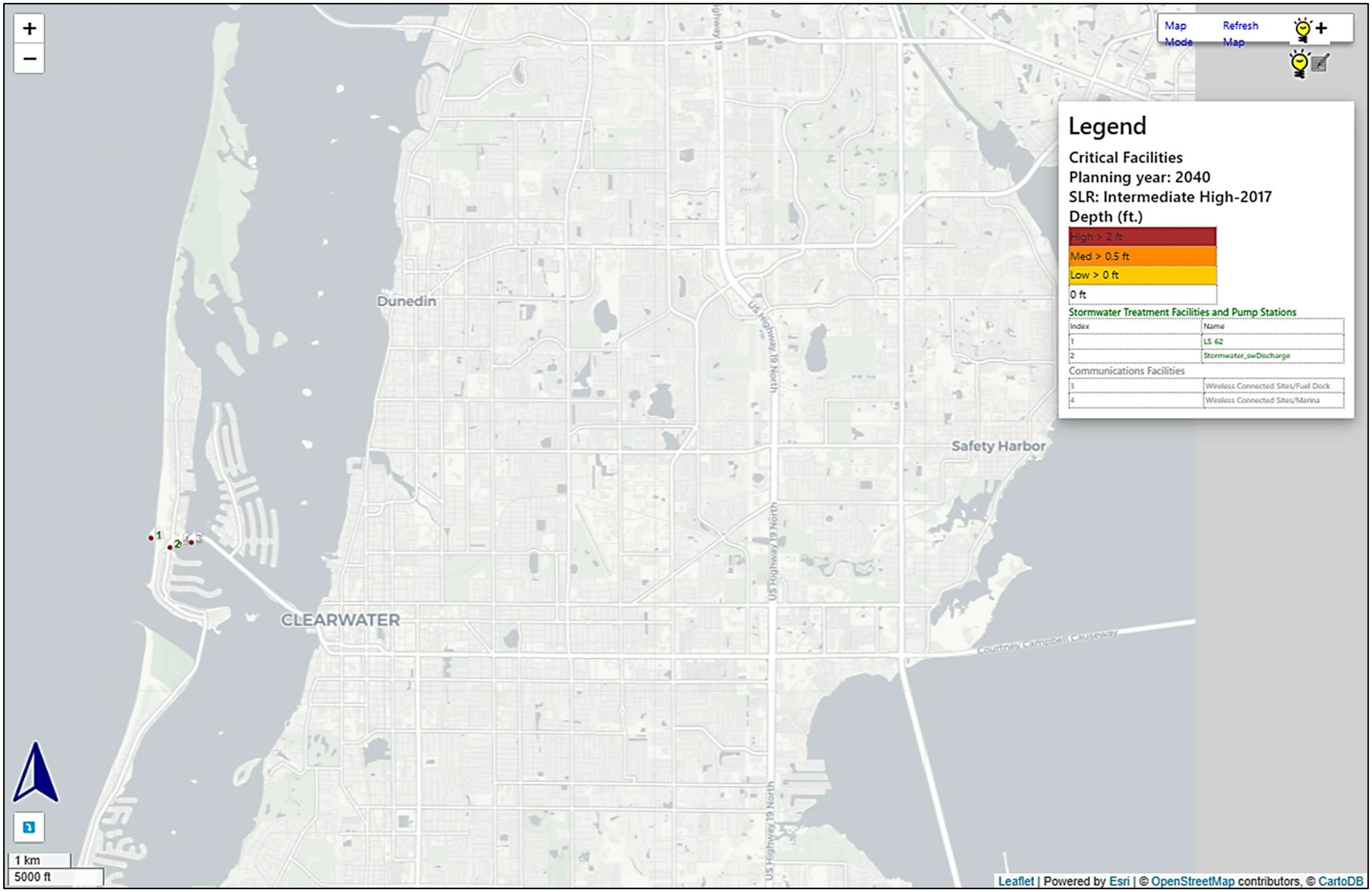


Figure 4-4 - Tidal - 2040 Intermediate-High; Impacted Critical Assets

4.1.1.3 Tidal - 2070 Intermediate-Low

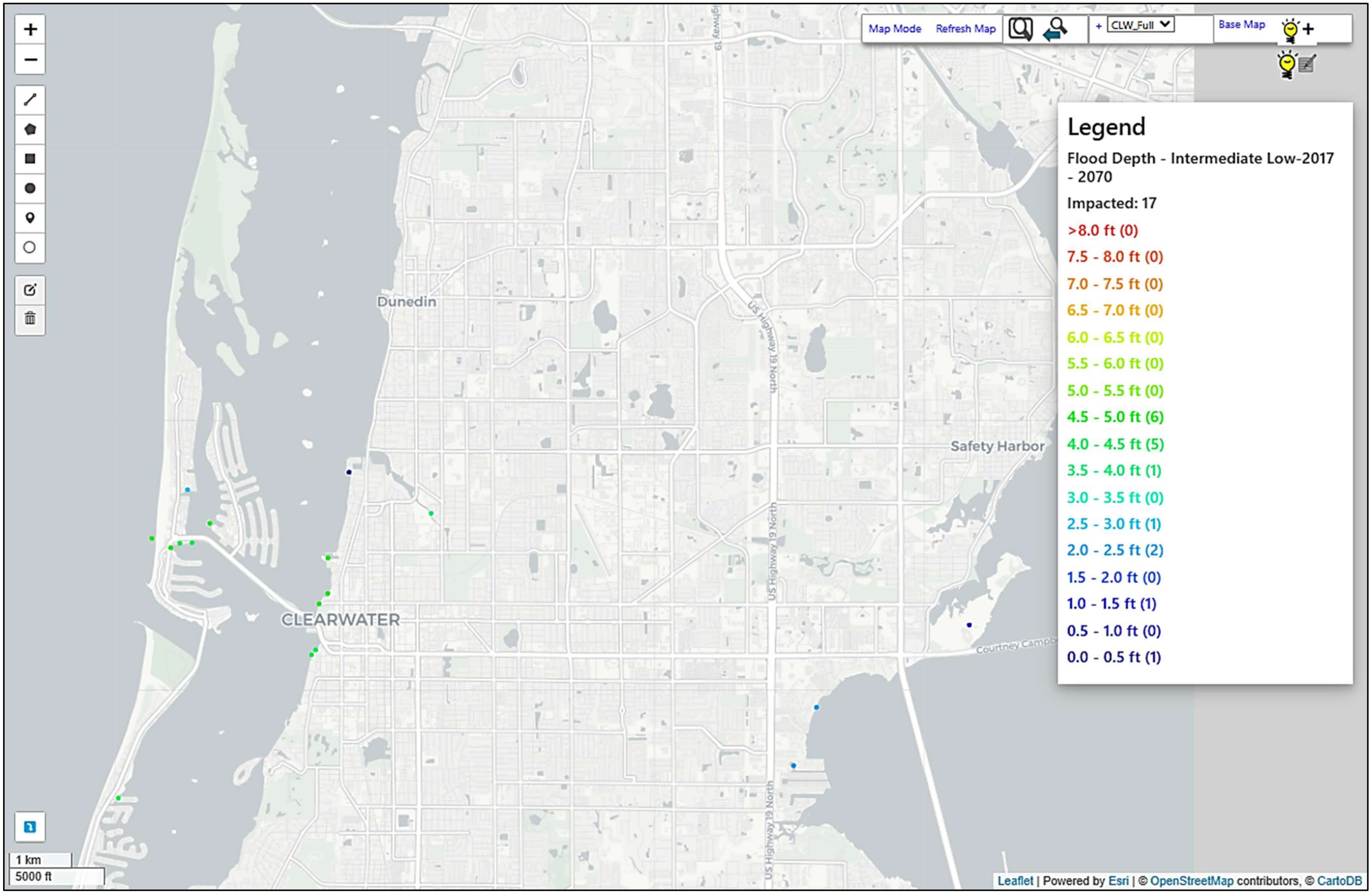


Figure 4-5 - Tidal Impacts - 2070 - Intermediate-Low

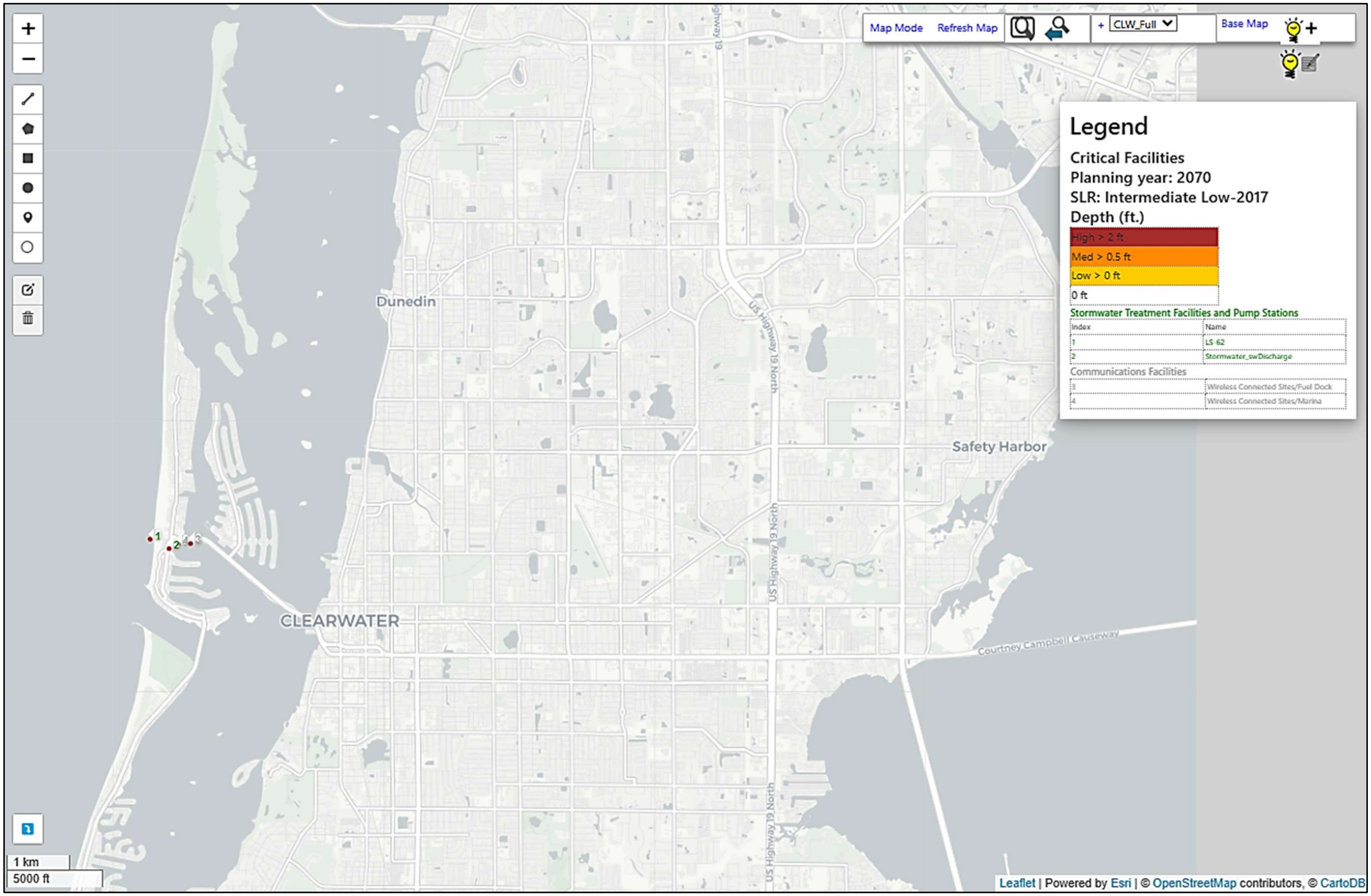


Figure 4-6 - Tidal - 2070 Intermediate-Low; Impacted Critical Assets

4.1.1.4 Tidal - 2070 Intermediate-High

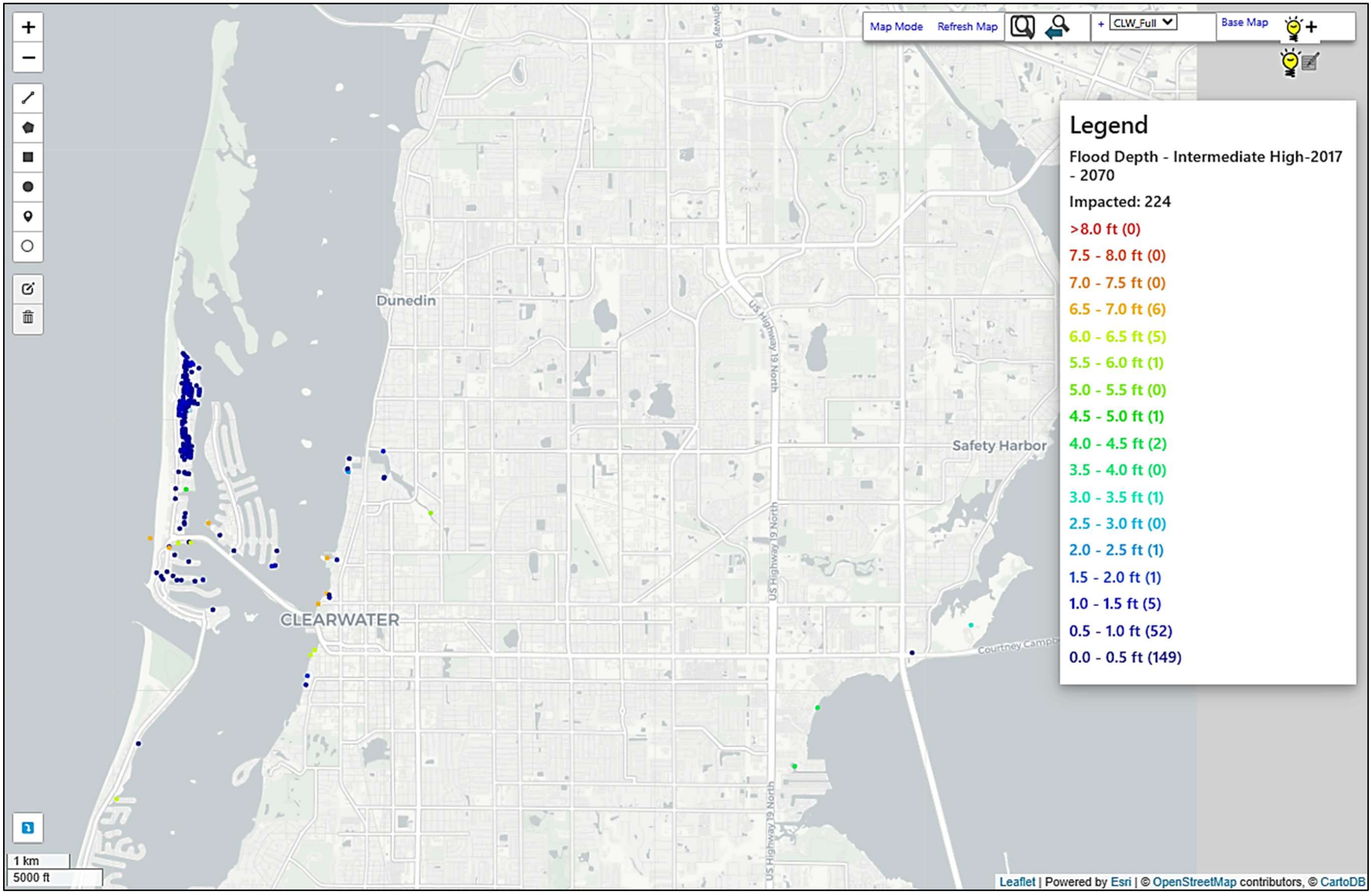


Figure 4-7 - Tidal Impacts - 2070 - Intermediate-High

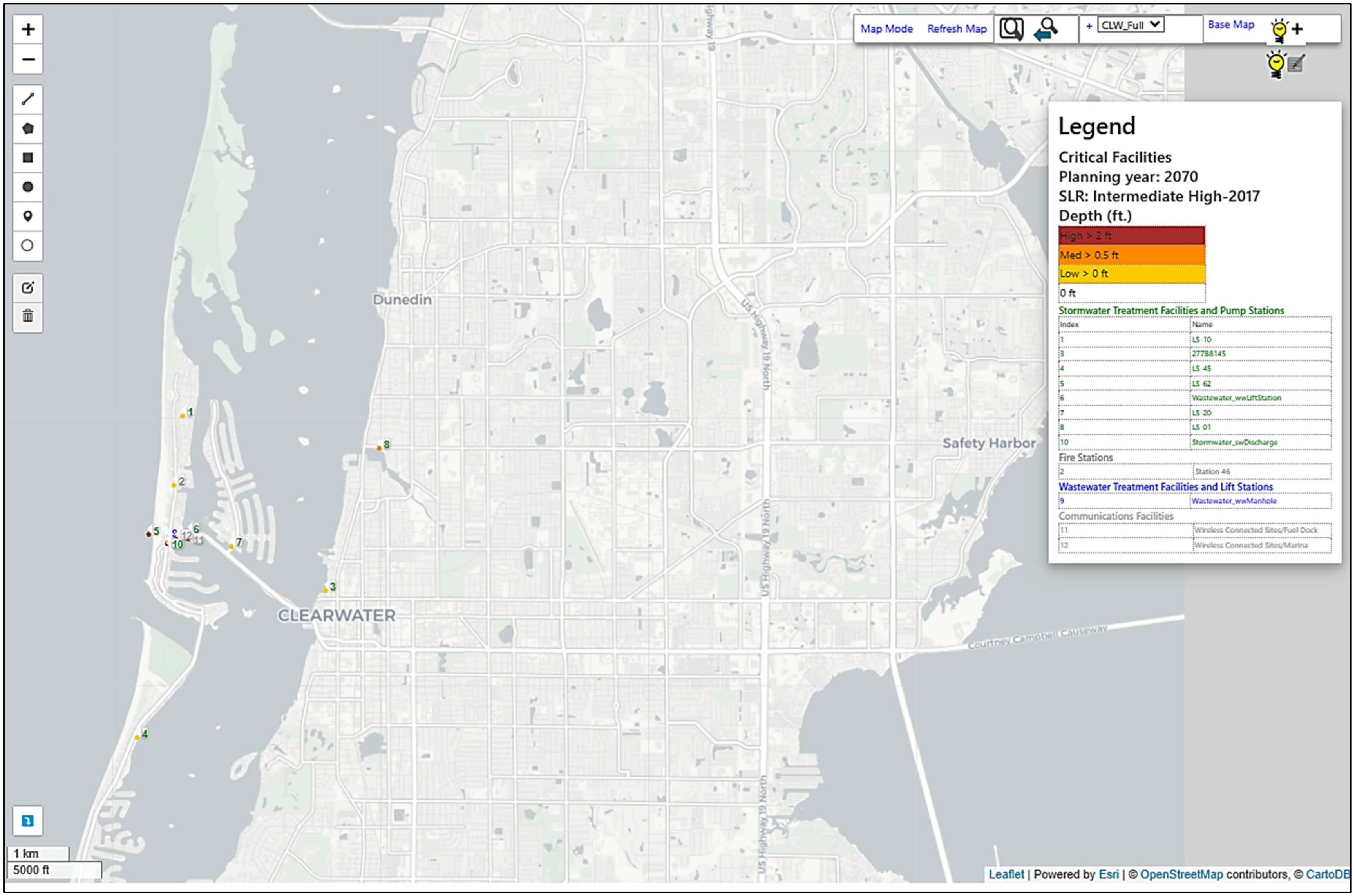


Figure 4-8 - Tidal - 2070 Intermediate-High; Impacted Critical Assets

4.1.1.5 Tidal - 2100 Intermediate-Low

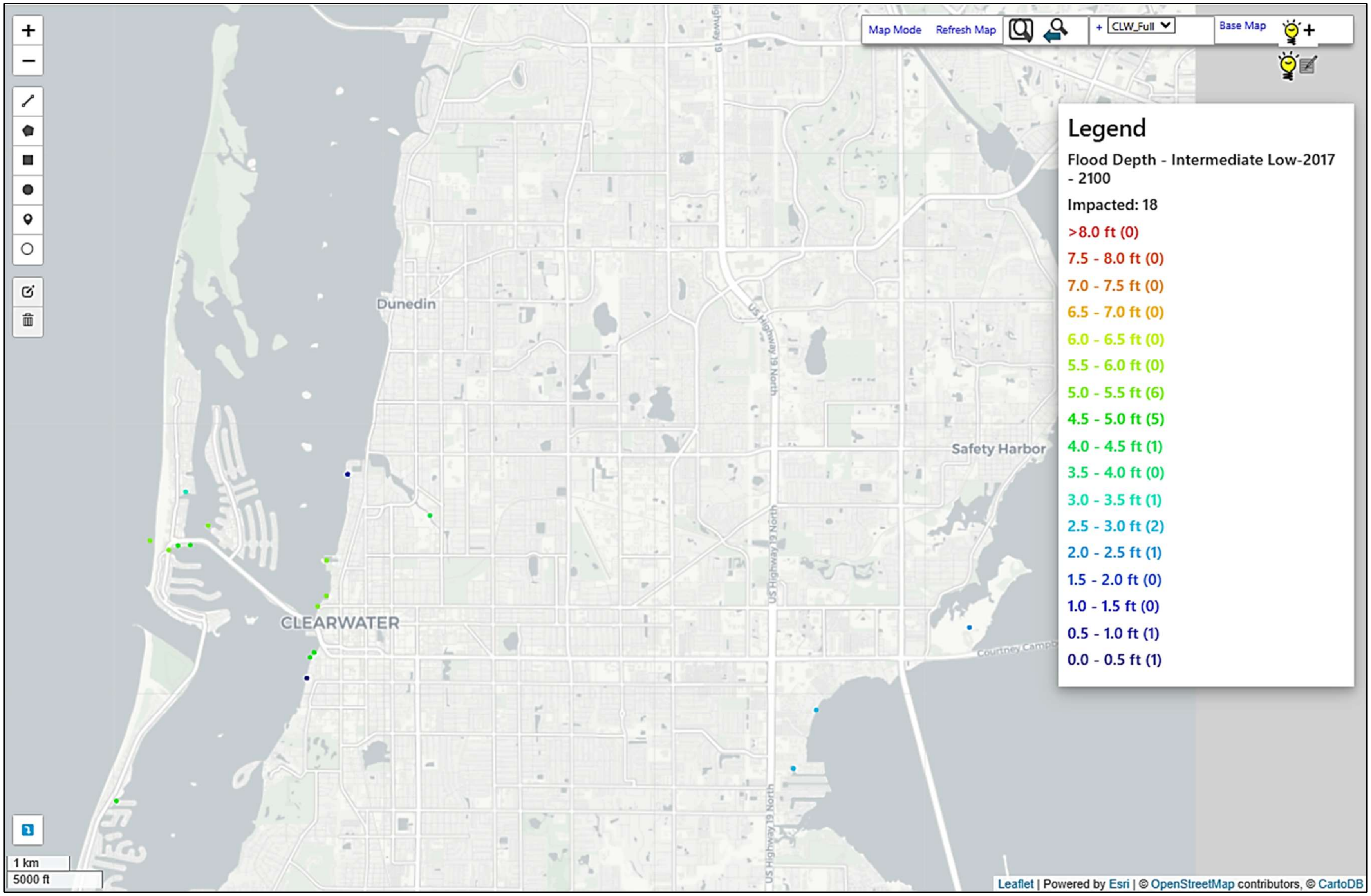


Figure 4-9 - Tidal Impacts - 2100 - Intermediate-Low

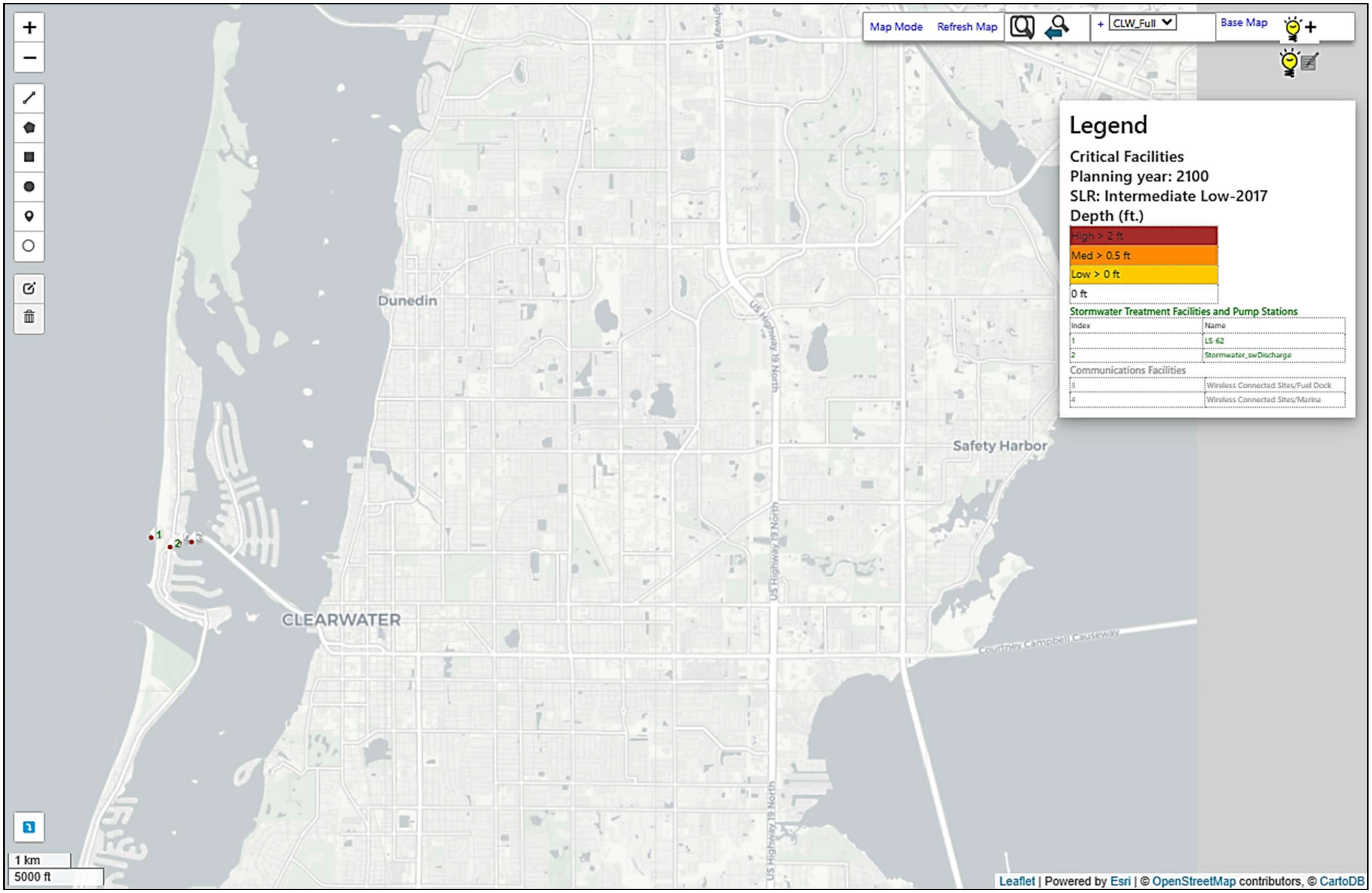


Figure 4-10 - Tidal - 2100 Intermediate-Low; Impacted Critical Assets

4.1.1.6 Tidal - 2100 Intermediate-High

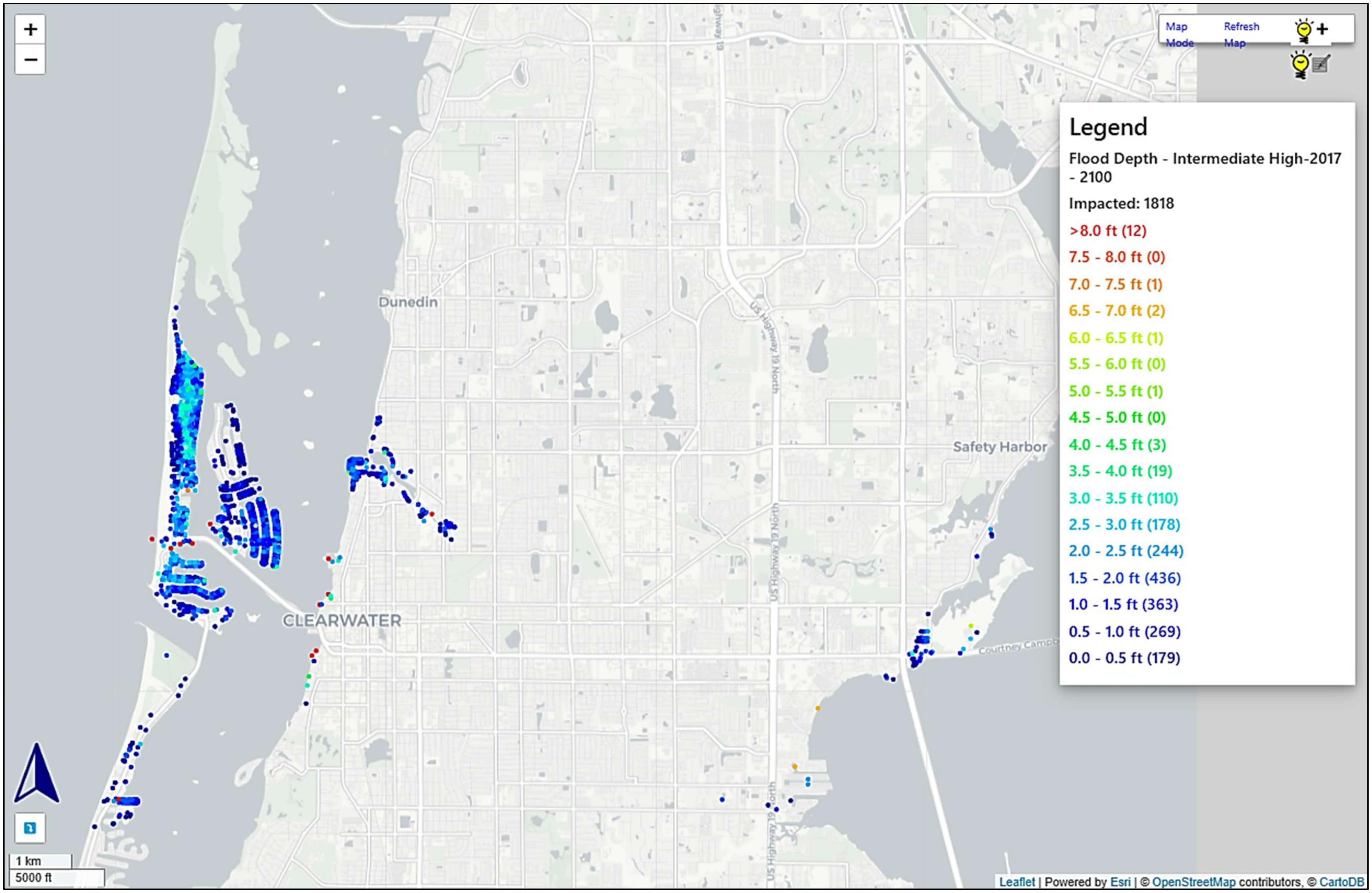


Figure 4-11 - Tidal Impacts - 2100 - Intermediate-High

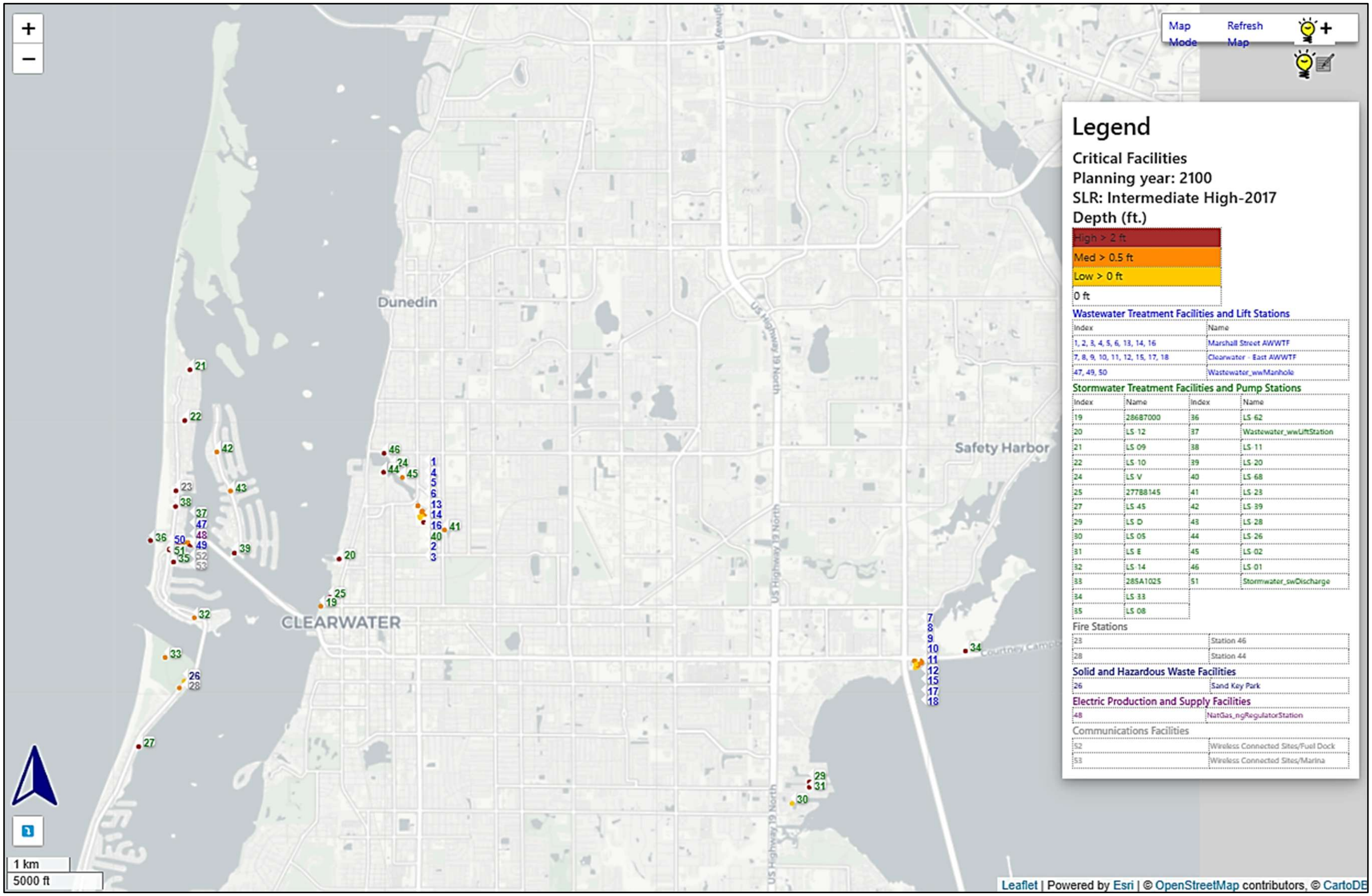


Figure 4-12 - Tidal - 2100 Intermediate-High; Impacted Critical Assets

4.1.1.7 Tidal – Critical Asset Summary Table

The flood risk table below is intended to show the sensitivity of the critical assets studied in this project (406 total). The assets that are exposed to future tide conditions (sea level increases plus tides) alone are shown below. Regionally significant assets become impacted at the 2100 intermediate-high scenario. The flood risk identified (high, medium, or low) is based on the following flood depths:

- Low Risk: 0.1 – 0.5 feet
- Medium Risk: 0.51 – 2.0 feet
- High Risk: Greater than 2 feet

Note that the table that follows uses the naming conventions below for the "Asset Type" column to help with legibility within the table:

Full Asset Type Name	Condensed Name for Table
Airports	Airports
Communications Facilities	Communications
Electric Production and Supply Facilities	Electric P & S
Emergency Operation Centers	EOCs
Fire Stations	Fire Stations
Health Care Facilities	Health Care
Historical and Cultural Assets	Historic and Culture
Law Enforcement Facilities	Law Enforcement
Local Government Facilities	Local Government
Risk Shelter Inventory	Risk Shelter
Schools	Schools
Solid and Hazardous Waste Facilities	Waste Facilities
Stormwater Treatment Facilities and Pump Stations	Stormwater
Wastewater Treatment Facilities and Lift Stations	WWTF & LS

Not all assets listed are owned or maintained by the City, but they are within or adjacent to the study area, and part of the Pinellas countywide asset data available at the time of this analysis.

Table 4-1 - Flood Risk Level for Critical Assets (Tidal Flooding)

Asset Group	Asset Type	Index	Asset Name	Regionally Significant	Tide 2040 Int-Low	Tide 2040 Int-High	Tide 2070 Int-Low	Tide 2070 Int-High	Tide 2100 Int-Low	Tide 2100 Int-High
Critical Community & Emergency Facilities	Fire Stations	63153	Station 46					Low		High
Critical Community & Emergency Facilities	Fire Stations	63257	Station 44							Medium
Critical Infrastructure	Communications	63373	Wireless Connected Sites/Fuel Dock		High	High	High	High	High	High
Critical Infrastructure	Communications	63374	Wireless Connected Sites/Marina		High	High	High	High	High	High
Critical Infrastructure	Electric P & S	63369	NatGas_ngRegulatorStation							Medium
Critical Infrastructure	Waste Facilities	63205	Sand Key Park							Low
Critical Infrastructure	Stormwater	63372	Stormwater_swDischarge		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62974	Marshall Street AWWTF	Yes						Low
Critical Infrastructure	WWTF & LS	62976	Marshall Street AWWTF	Yes						Medium
Critical Infrastructure	WWTF & LS	62977	Marshall Street AWWTF	Yes						Medium
Critical Infrastructure	WWTF & LS	62979	Marshall Street AWWTF	Yes						Medium
Critical Infrastructure	WWTF & LS	62982	Marshall Street AWWTF	Yes						Low
Critical Infrastructure	WWTF & LS	62985	Marshall Street AWWTF	Yes						Medium
Critical Infrastructure	WWTF & LS	62987	Clearwater - East AWWTF	Yes						Low
Critical Infrastructure	WWTF & LS	62988	Clearwater - East AWWTF	Yes						Low
Critical Infrastructure	WWTF & LS	62989	Clearwater - East AWWTF	Yes						Medium
Critical Infrastructure	WWTF & LS	62990	Clearwater - East AWWTF	Yes						Medium
Critical Infrastructure	WWTF & LS	62991	Clearwater - East AWWTF	Yes						Medium
Critical Infrastructure	WWTF & LS	62994	Clearwater - East AWWTF	Yes						Medium
Critical Infrastructure	WWTF & LS	63027	Marshall Street AWWTF	Yes						Low
Critical Infrastructure	WWTF & LS	63029	Marshall Street AWWTF	Yes						Medium
Critical Infrastructure	WWTF & LS	63050	Clearwater - East AWWTF	Yes						Low
Critical Infrastructure	WWTF & LS	63060	Marshall Street AWWTF	Yes						Medium
Critical Infrastructure	WWTF & LS	63061	Clearwater - East AWWTF	Yes						Medium
Critical Infrastructure	WWTF & LS	63062	Clearwater - East AWWTF	Yes						Low

Asset Group	Asset Type	Index	Asset Name	Regionally Significant	Tide 2040 Int-Low	Tide 2040 Int-High	Tide 2070 Int-Low	Tide 2070 Int-High	Tide 2100 Int-Low	Tide 2100 Int-High
Critical Infrastructure	WWTF & LS	63074	286B7000							Medium
Critical Infrastructure	WWTF & LS	63090	LS-12							High
Critical Infrastructure	WWTF & LS	63127	LS-09							High
Critical Infrastructure	WWTF & LS	63144	LS-10					Low		High
Critical Infrastructure	WWTF & LS	63159	LS-V							High
Critical Infrastructure	WWTF & LS	63169	277B8145					Low		High
Critical Infrastructure	WWTF & LS	63208	LS-45					Low		High
Critical Infrastructure	WWTF & LS	63265	LS-D							High
Critical Infrastructure	WWTF & LS	63266	LS-05							Low
Critical Infrastructure	WWTF & LS	63274	LS-E							High
Critical Infrastructure	WWTF & LS	63276	LS-14							Medium
Critical Infrastructure	WWTF & LS	63277	285A1025							Medium
Critical Infrastructure	WWTF & LS	63290	LS-33							High
Critical Infrastructure	WWTF & LS	63291	LS-08							High
Critical Infrastructure	WWTF & LS	63292	LS-62		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63293	Wastewater_wwLiftStation					Medium		High
Critical Infrastructure	WWTF & LS	63294	LS-11							High
Critical Infrastructure	WWTF & LS	63295	LS-20					Low		High
Critical Infrastructure	WWTF & LS	63298	LS-68							High
Critical Infrastructure	WWTF & LS	63299	LS-23							Medium
Critical Infrastructure	WWTF & LS	63307	LS-39							Medium
Critical Infrastructure	WWTF & LS	63308	LS-28							Medium
Critical Infrastructure	WWTF & LS	63309	LS-26							High
Critical Infrastructure	WWTF & LS	63310	LS-02							Medium
Critical Infrastructure	WWTF & LS	63311	LS-01					Medium		High
Critical Infrastructure	WWTF & LS	63368	Wastewater_wwManhole							Medium
Critical Infrastructure	WWTF & LS	63370	Wastewater_wwManhole							Medium
Critical Infrastructure	WWTF & LS	63371	Wastewater_wwManhole					Medium		High

4.1.2 Acute Flooding (Storm Surge and Large Rainfall Events)

The following tables and maps present the counts and locations of structures exposed to acute flooding conditions. Acute refers to rare events such as frontal and convective thunderstorms as well as storm surge caused by large windstorms such as tropical cyclones.

The procedure used for simulating these events included creating a joint scenario that included the 95th percentile most severe rainstorm scenario for the planning year of interest (2040, 2070, and 2100) as well as the NOAA sea level rise scenario of interest (2017 intermediate-high and 2017 intermediate-low). The rainstorm scenario was generated using the Monte Carlo-based StormCaster algorithm described above. Each realization in the 1,000-realization ensemble was evaluated in terms of its severity in the 20-year period leading up to the planning period. Severity was quantified as the sum of all rain depths occurring in the period to the power of five. The power was used to emphasize the larger storms in the series. The realizations were then ranked by severity for the planning period of interest, and the 95th percentile realization selected.

For surge, the study used the projected rise in sea level from the NOAA 2017 projections to get an increase in sea level for the year in question. Then, it interpolated the projected surge levels from the US Army Corps of Engineers' South Atlantic Coastal Study (USACE SACS) scenarios to get an estimate of surge level in the year in question for the desired return period at the geographic location of interest. For each planning year (2040, 2070, and 2100), storms occurring in the twenty years prior to the planning year were collected, and the median and maximum surge level were estimated from these levels. The result of this process was the following set of six distinct, joint scenarios: 2040 Planning Horizon – 2017 Intermediate-Low Projection; 2040 Planning Horizon – 2017 Intermediate-High Projection, 2070 Planning Horizon – 2017 Intermediate-Low Projection, 2070 Planning Horizon – 2017 Intermediate-High Projection, 2100 Planning Horizon – 2017 Intermediate-Low Projection, and 2100 Planning Horizon – 2017 Intermediate-High Projection.

Sections 4.1.2.1 through 4.1.2.14 present the results for each of the six joint scenarios for storm surge as well as the 100-yr and 500-yr pluvial (rainfall) flooding showing the locations of acute flood risk and summarizing the critical assets impacted.

4.1.2.1 Storm Surge - 2040 Planning Horizon - 2017 Intermediate-Low Projection

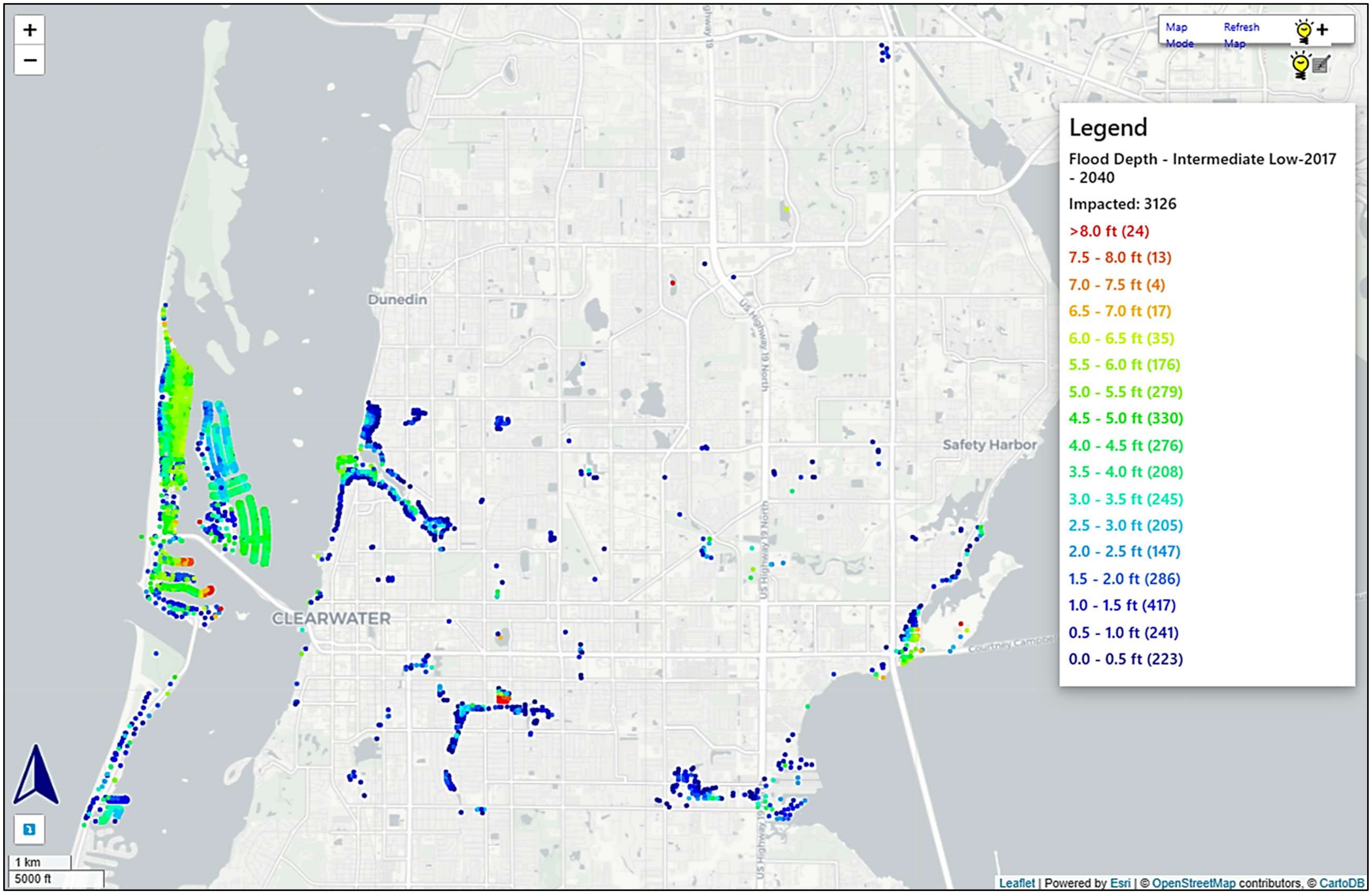


Figure 4-13 – Storm Surge Impacts - 2040 - Intermediate-Low

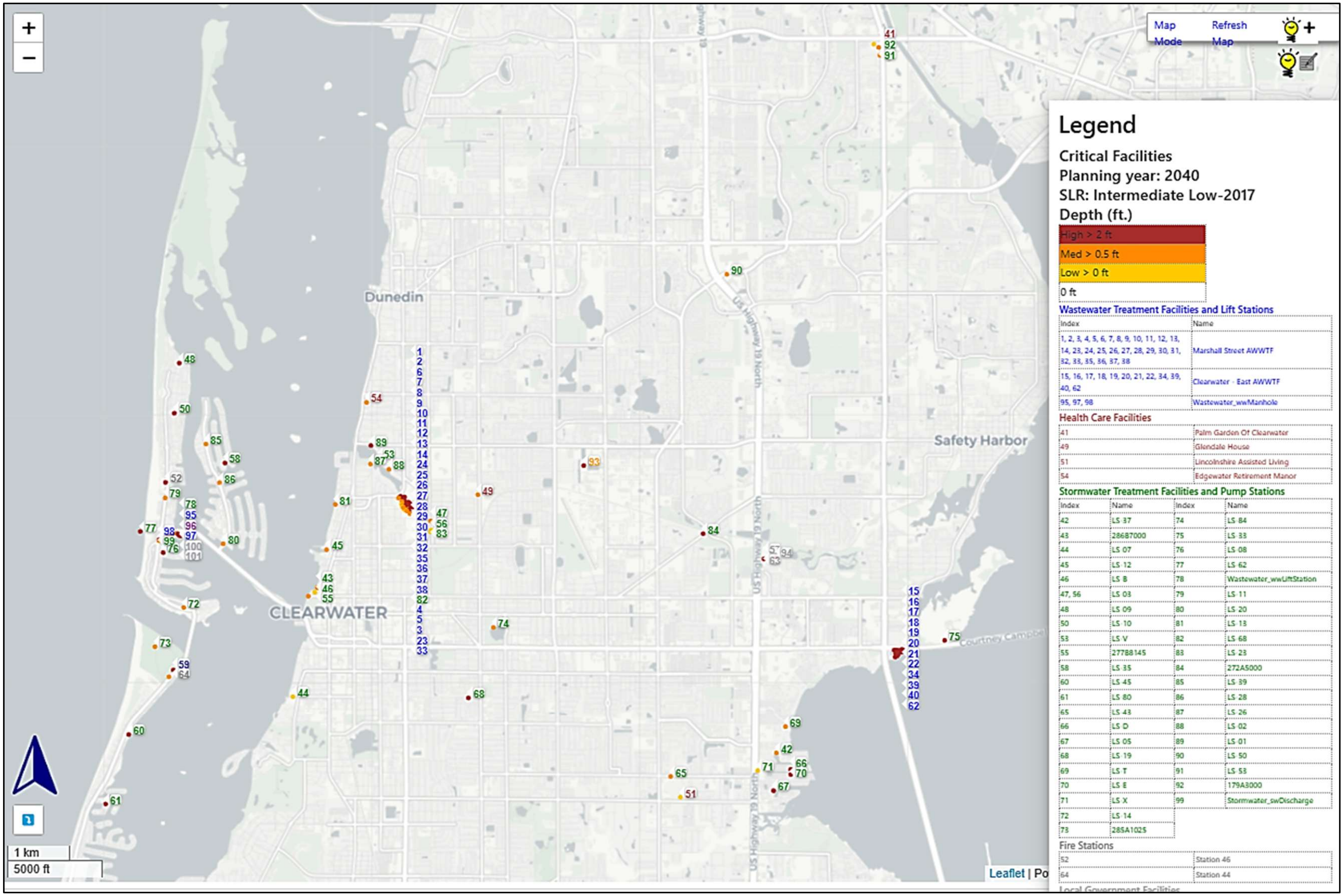


Figure 4-14 - Storm Surge - 2040 Intermediate-Low; Impacted Critical Assets

4.1.2.2 Storm Surge - 2040 Planning Horizon - 2017 Intermediate-High Projection

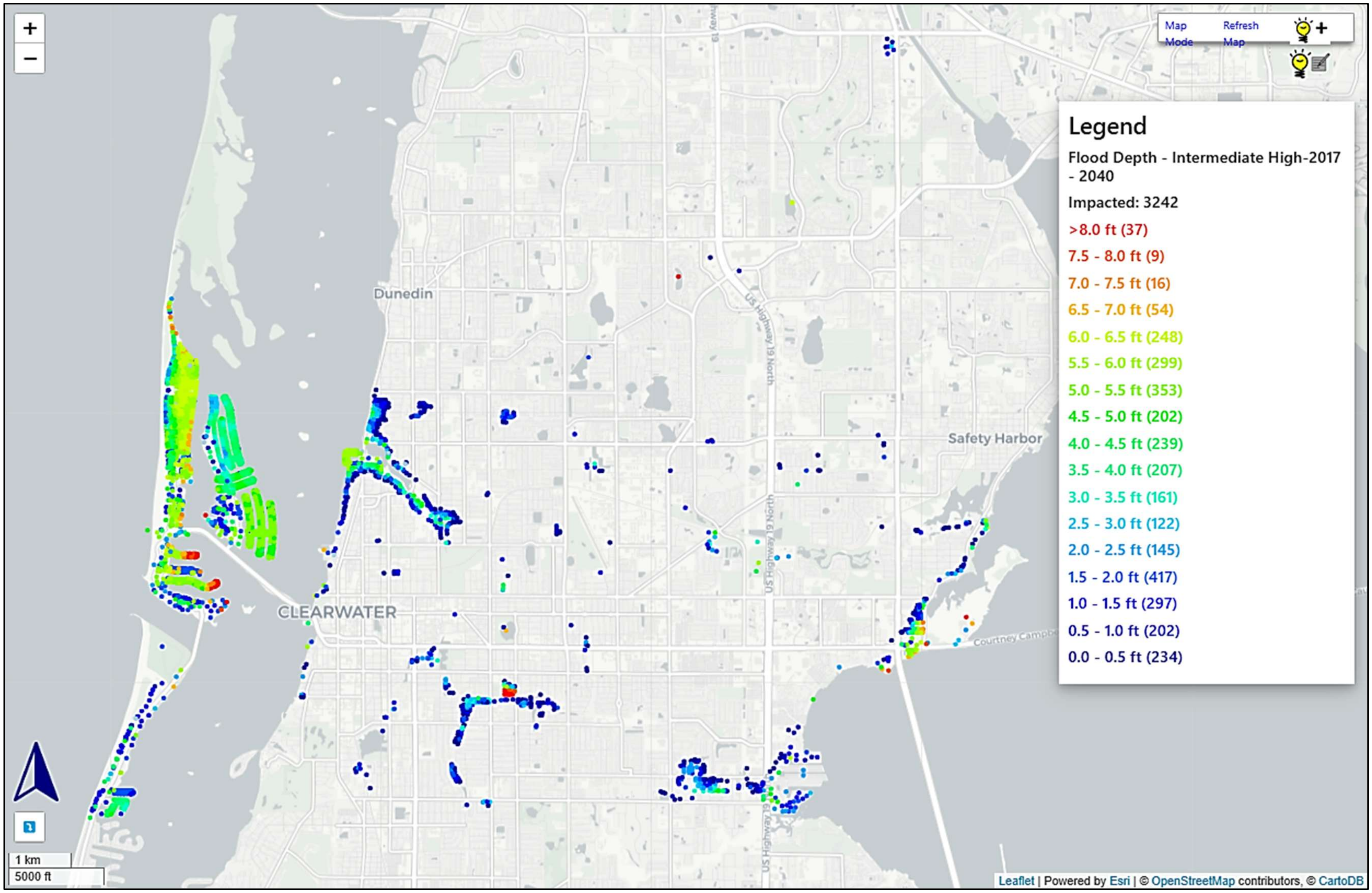


Figure 4-15 - Storm Surge Impacts - 2040 - Intermediate-High

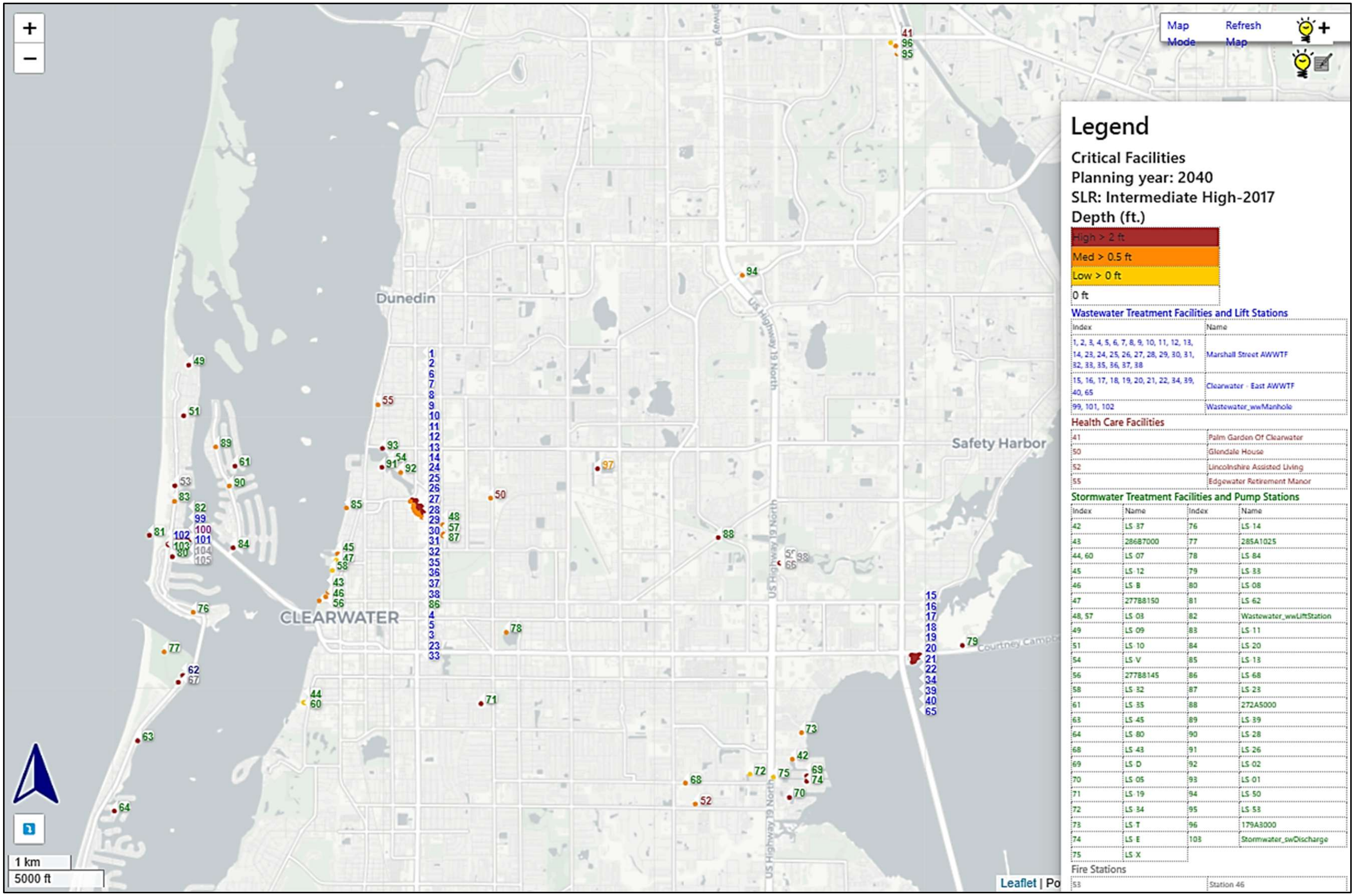


Figure 4-16 - Storm Surge - 2040 Intermediate-High; Impacted Critical Assets

4.1.2.3 Storm Surge - 2070 Planning Horizon - 2017 Intermediate-Low Projection

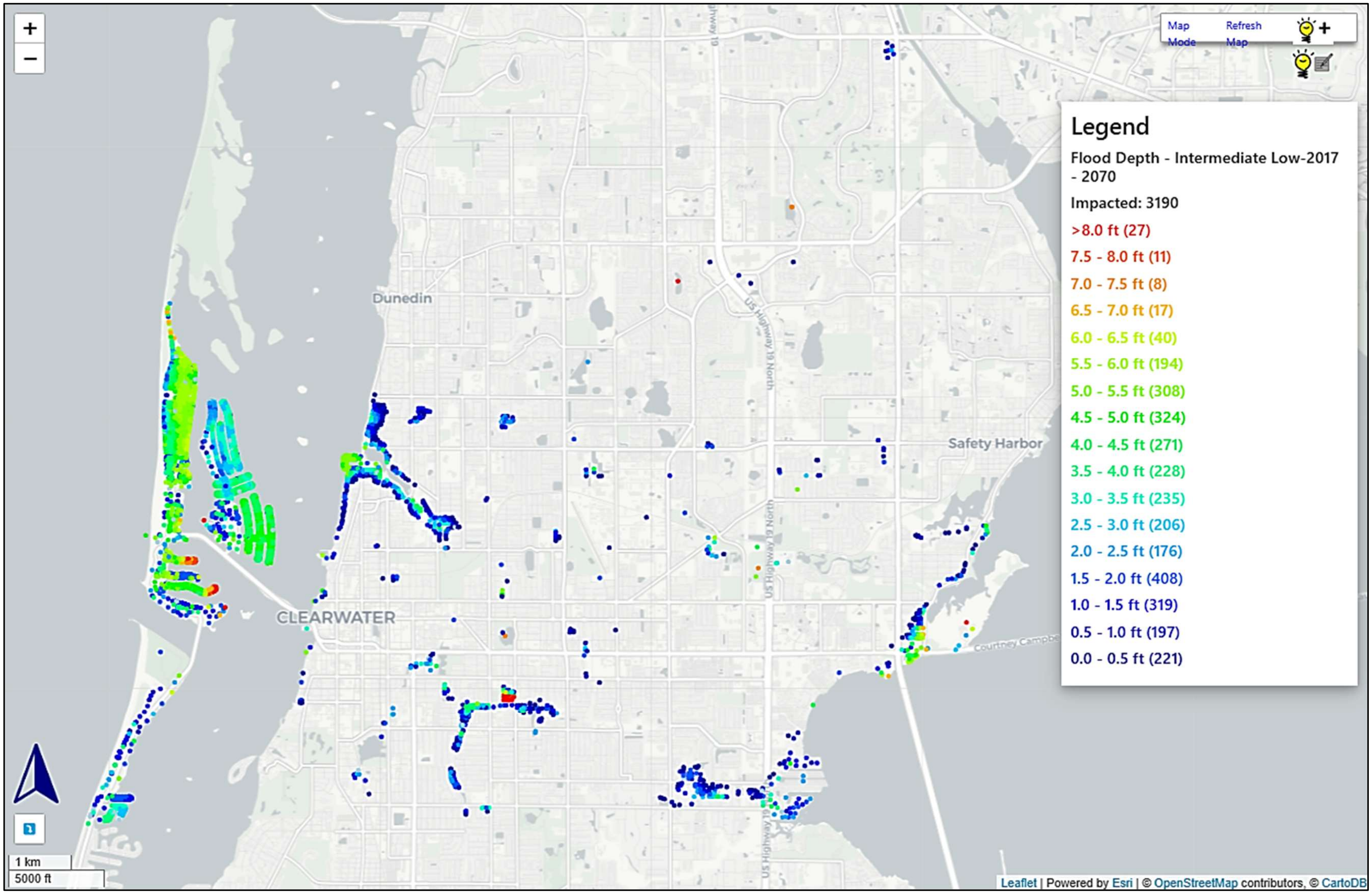


Figure 4-17 - Storm Surge Impacts - 2070 - Intermediate-Low

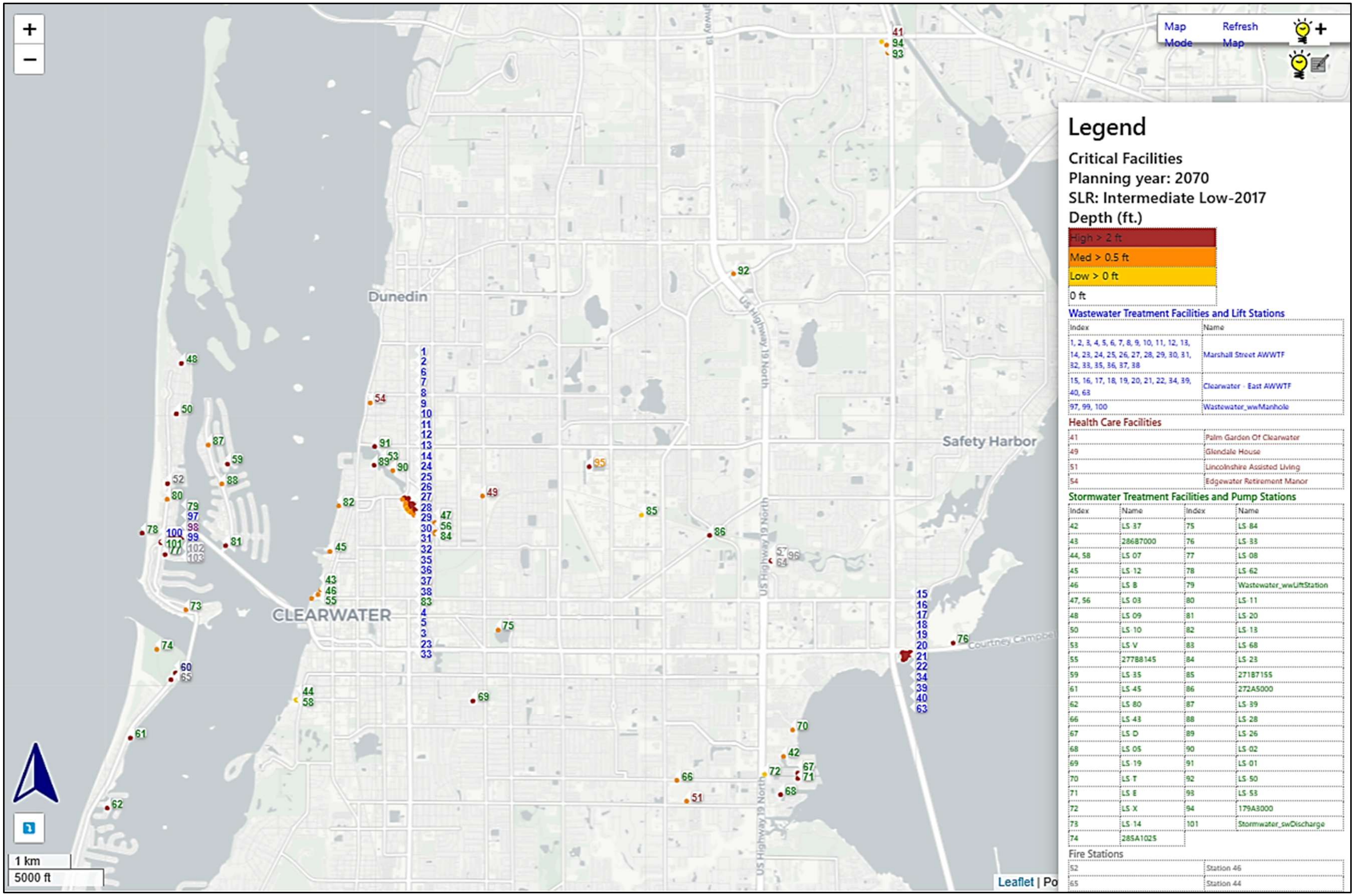


Figure 4-18 - Storm Surge - 2070 Intermediate-Low; Impacted Critical Assets

4.1.2.4 Storm Surge - 2070 Planning Horizon - 2017 Intermediate-High Projection

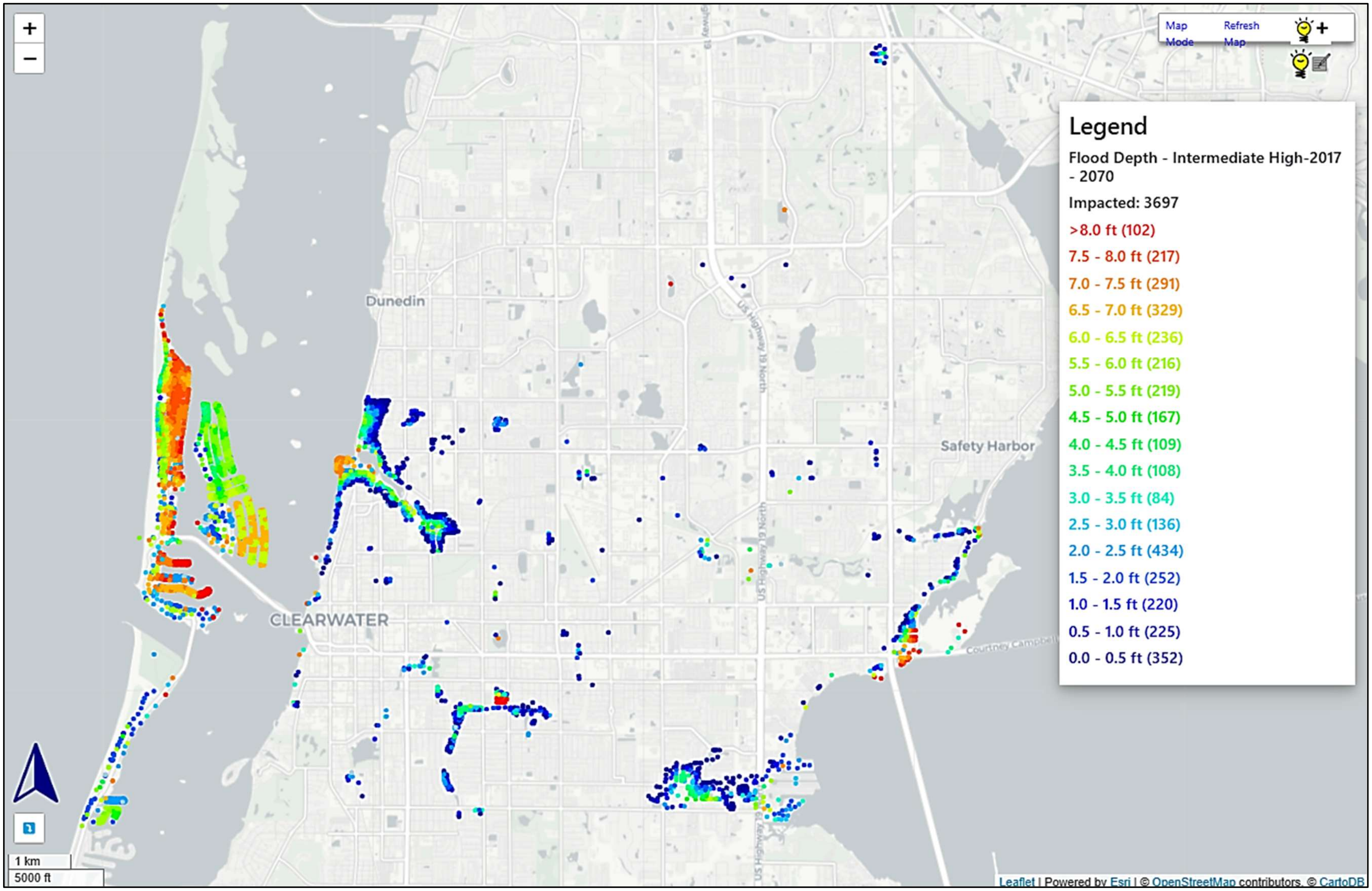


Figure 4-19 - Storm Surge Impacts - 2070 - Intermediate-High

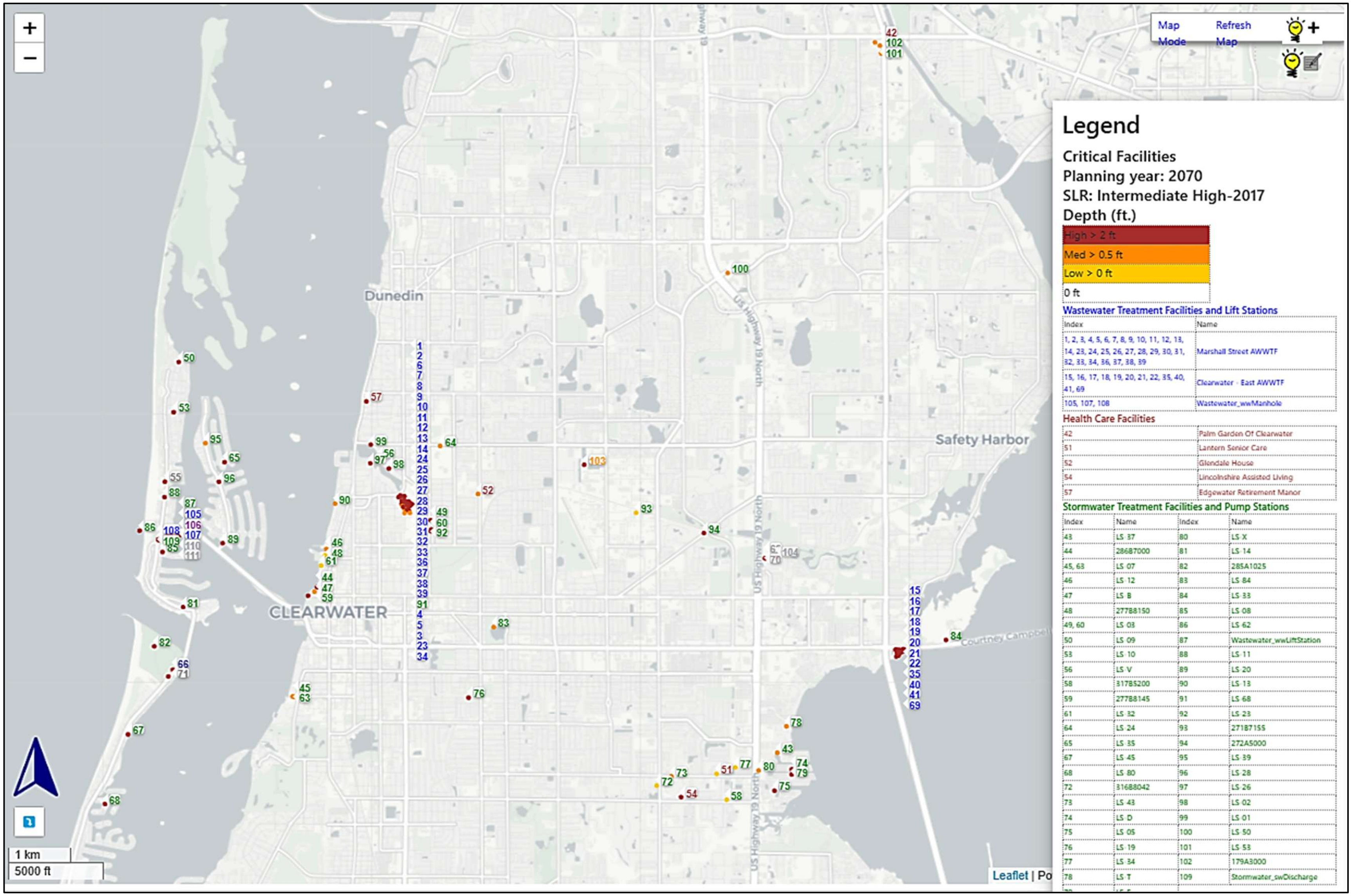


Figure 4-20 - Storm Surge - 2070 Intermediate-High; Impacted Critical Assets

4.1.2.5 Storm Surge - 2100 Planning Horizon - 2017 Intermediate-Low Projection

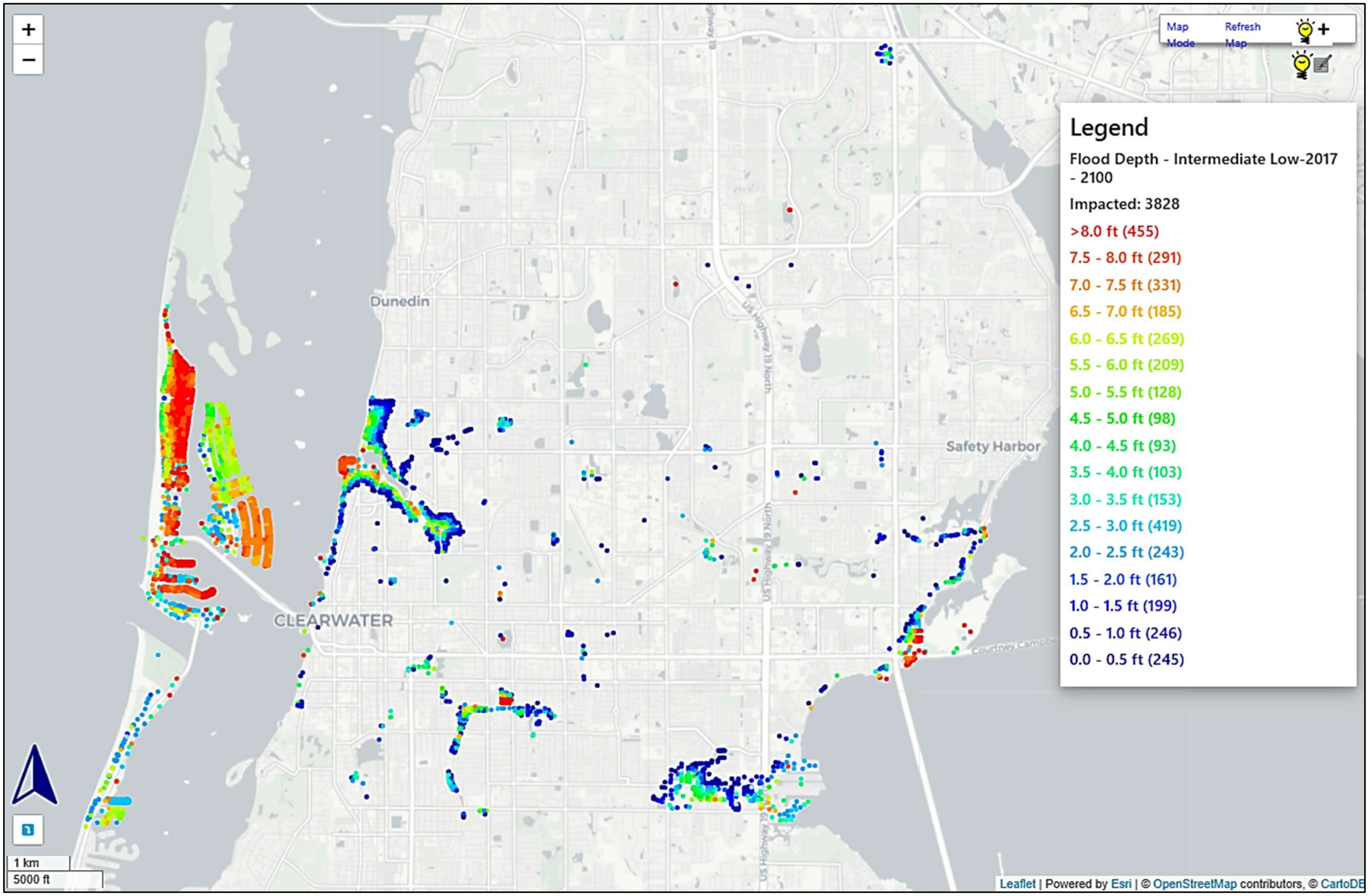


Figure 4-21 - Storm Surge Impacts - 2100 - Intermediate-Low

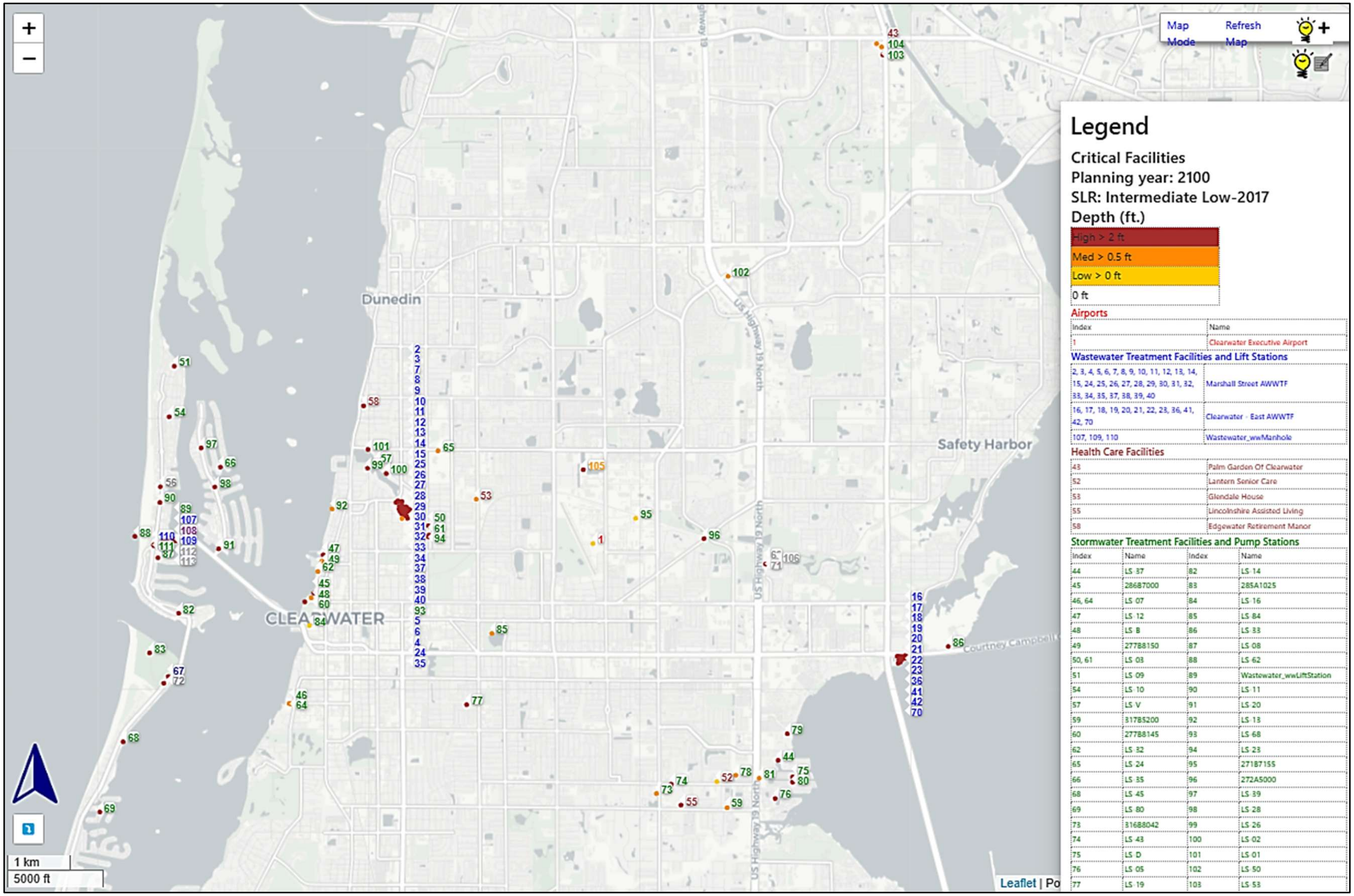


Figure 4-22 - Storm Surge - 2100 Intermediate-Low; Impacted Critical Assets

4.1.2.6 Storm Surge - 2100 Planning Horizon - 2017 Intermediate-High Projection

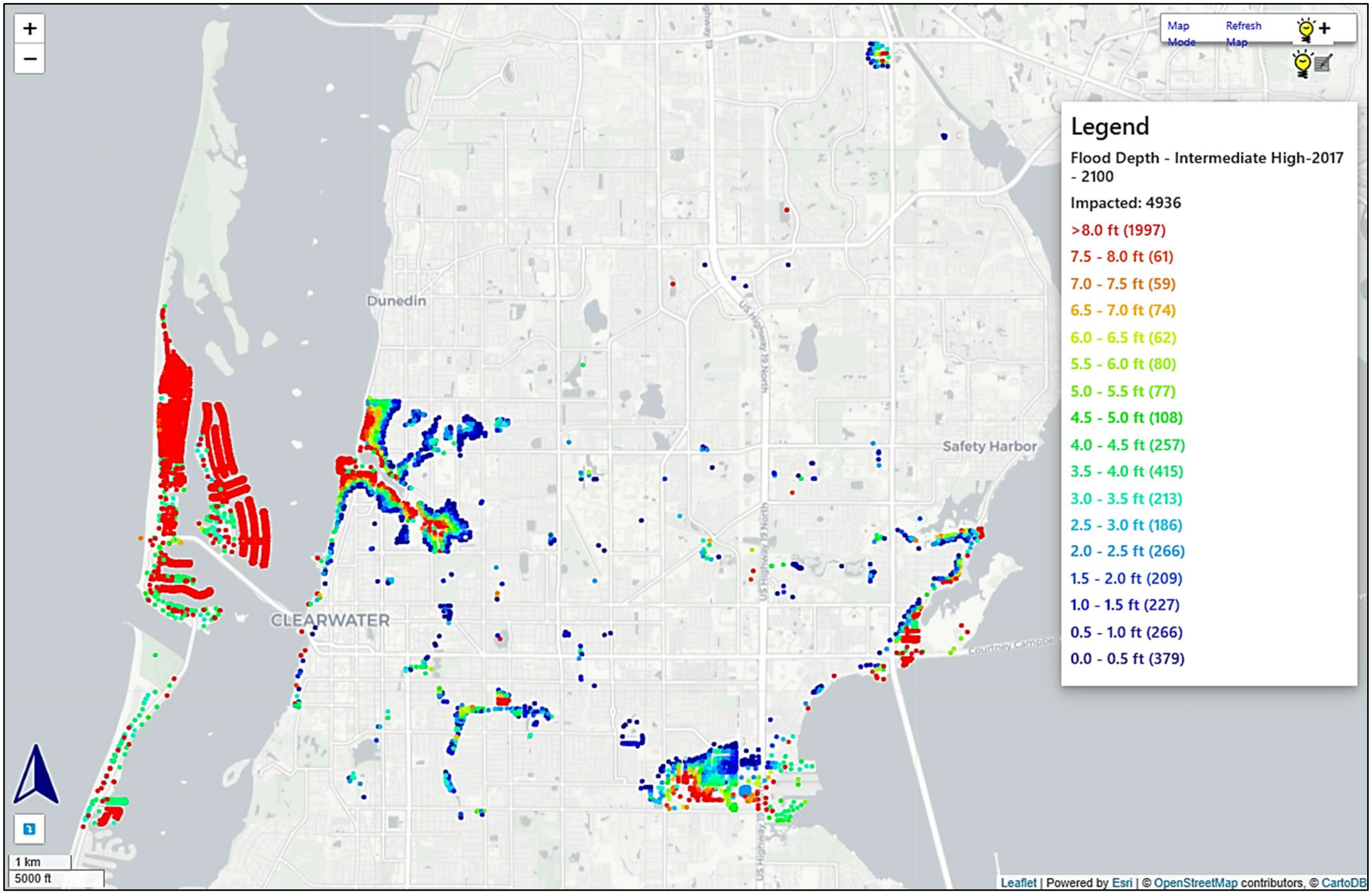


Figure 4-23 - Storm Surge Impacts - 2100 - Intermediate-High

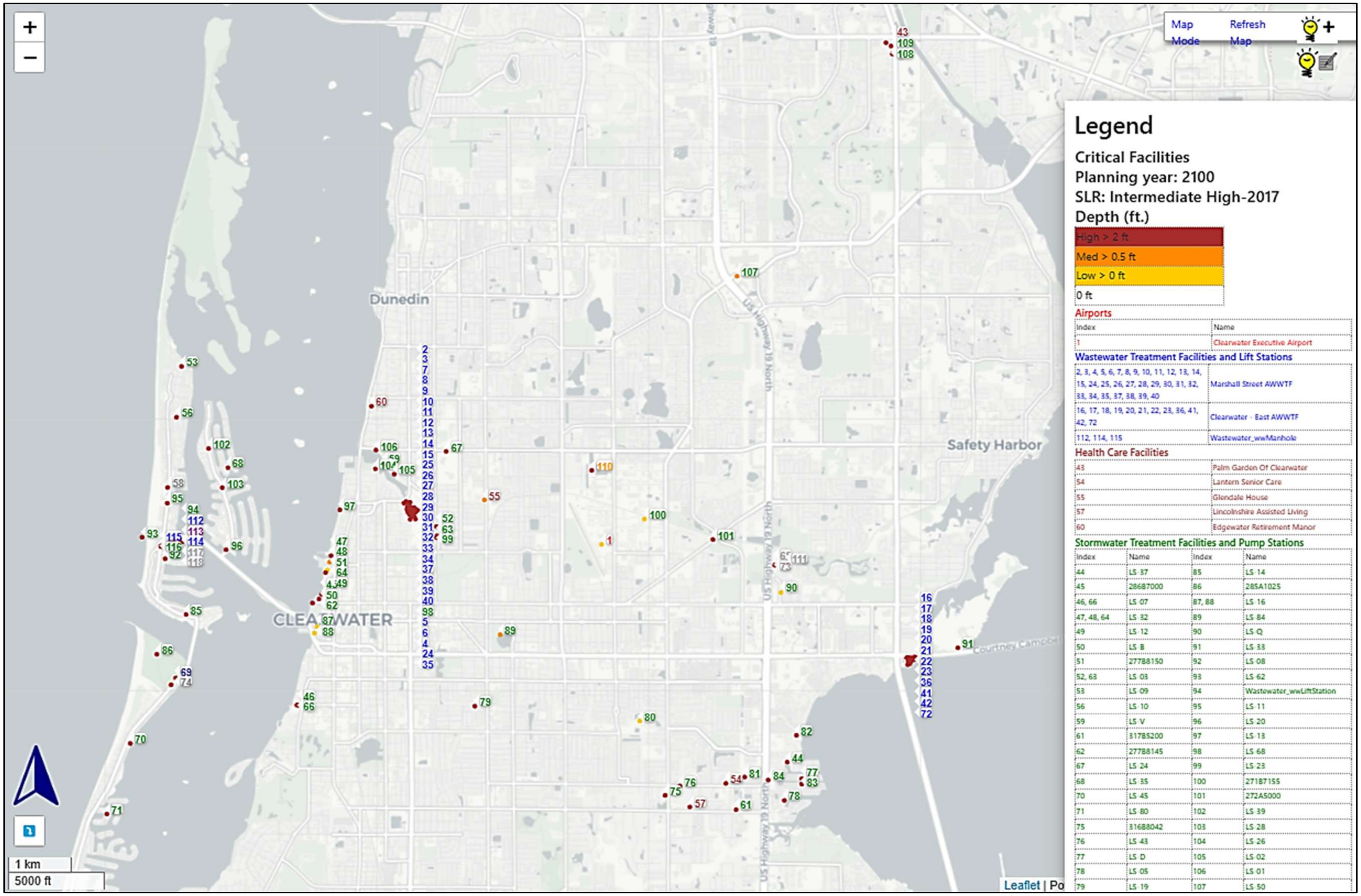


Figure 4-24 - Storm Surge - 2100 Intermediate-High; Impacted Critical Assets

4.1.2.7 Storm Surge – Critical Asset Summary Table

The flood risk table below is intended to show the sensitivity of the critical assets studied in this project (406 total). The assets with flood depths greater than 0.1 feet from future storm surge conditions alone are shown below. Regionally significant assets, particularly water treatment facilities, are impacted at the earliest planning horizon. The flood risk identified (high, medium, or low) is based on the following flood depths:

- Low Risk: 0.1 – 0.5 feet
- Medium Risk: 0.51 – 2.0 feet
- High Risk: Greater than 2 feet

Note that the table that follows uses the naming conventions below for the "Asset Type" column to help with legibility within the table:

Full Asset Type Name	Condensed Name for Table
Airports	Airports
Communications Facilities	Communications
Electric Production and Supply Facilities	Electric P & S
Emergency Operation Centers	EOCs
Fire Stations	Fire Stations
Health Care Facilities	Health Care
Historical and Cultural Assets	Historic and Culture
Law Enforcement Facilities	Law Enforcement
Local Government Facilities	Local Government
Risk Shelter Inventory	Risk Shelter
Schools	Schools
Solid and Hazardous Waste Facilities	Waste Facilities
Stormwater Treatment Facilities and Pump Stations	Stormwater
Wastewater Treatment Facilities and Lift Stations	WWTF & LS

Not all assets listed are owned or maintained by the City, but they are within or adjacent to the study area and part of the Pinellas countywide asset data available at the time of this analysis.

Table 4-2 - Flood Risk Level for Critical Assets (Storm Surge Flooding)

Asset Group	Asset Type	Index	Asset Name	Regionally Significant	Surge 2040 Int-Low	Surge 2040 Int-High	Surge 2070 Int-Low	Surge 2070 Int-High	Surge 2100 Int-Low	Surge 2100 Int-High
Critical Community & Emergency Facilities	Fire Stations	63153	Station 46		High	High	High	High	High	High
Critical Community & Emergency Facilities	Fire Stations	63257	Station 44		Medium	High	High	High	High	High
Critical Community & Emergency Facilities	Health Care	63063	Palm Garden of Clearwater		Low	Low	Low	Medium	Medium	High
Critical Community & Emergency Facilities	Health Care	63128	Lantern Senior Care					Low	Low	High
Critical Community & Emergency Facilities	Health Care	63132	Glendale House		Medium	Medium	Medium	Medium	Medium	Medium
Critical Community & Emergency Facilities	Health Care	63147	Lincolnshire Assisted Living		Low	Medium	Low	High	High	High
Critical Infrastructure	Communications	63365	Highway Maintenance Yard		High	High	High	High	High	High
Critical Infrastructure	Communications	63373	Wireless Connected Sites/Fuel Dock		High	High	High	High	High	
Critical Infrastructure	Communications	63374	Wireless Connected Sites/Marina		High	High	High	High	High	High
Critical Infrastructure	Electric P & S	63369	NatGas_ngRegulatorStation		Medium	Medium	Medium	High	High	High
Critical Infrastructure	Local Government	63177	US 19 Sub Shop		Medium	Medium	High	High	High	High
Critical Infrastructure	Local Government	63235	Fleet Management U.S. 19 Facility		High	High	High	High	High	High
Critical Infrastructure	Schools	63346	Lakeside Christian School		High	High	High	High	High	High
Critical Infrastructure	Stormwater	63372	Stormwater_swDischarge		Medium	High	High	High	High	High
Critical Infrastructure	Waste Facilities	63205	Sand Key Park		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62973	Marshall Street AWWTF	Yes	Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	62974	Marshall Street AWWTF	Yes	Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	62975	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62976	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62977	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62978	Marshall Street AWWTF	Yes	Low	Medium	Medium	High	High	High

Asset Group	Asset Type	Index	Asset Name	Regionally Significant	Surge 2040 Int-Low	Surge 2040 Int-High	Surge 2070 Int-Low	Surge 2070 Int-High	Surge 2100 Int-Low	Surge 2100 Int-High
Critical Infrastructure	WWTF & LS	62979	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62980	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62981	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62982	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62983	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62984	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62985	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62986	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62987	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62988	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62989	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62990	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62991	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62992	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62993	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62994	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63022	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63023	Marshall Street AWWTF	Yes	Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63024	Marshall Street AWWTF	Yes	Low	Medium	Low	High	High	High
Critical Infrastructure	WWTF & LS	63025	Marshall Street AWWTF	Yes	Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63026	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63027	Marshall Street AWWTF	Yes	Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63028	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63029	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63030	Marshall Street AWWTF	Yes	Low	Low	Low	Medium	High	High
Critical Infrastructure	WWTF & LS	63031	Marshall Street AWWTF	Yes	Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63032	Marshall Street AWWTF	Yes				Medium	Medium	High

Asset Group	Asset Type	Index	Asset Name	Regionally Significant	Surge 2040 Int-Low	Surge 2040 Int-High	Surge 2070 Int-Low	Surge 2070 Int-High	Surge 2100 Int-Low	Surge 2100 Int-High
Critical Infrastructure	WWTF & LS	63033	Marshall Street AWWTF	Yes	Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63050	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63057	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63058	Marshall Street AWWTF	Yes	Low	Medium	Low	Medium	High	High
Critical Infrastructure	WWTF & LS	63059	Marshall Street AWWTF	Yes	Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63060	Marshall Street AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63061	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63062	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63066	LS-37		Medium	Medium	Medium	Medium	High	High
Critical Infrastructure	WWTF & LS	63074	286B7000		Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63076	LS-07		Low	Low	Low	Medium	Medium	High
Critical Infrastructure	WWTF & LS	63090	LS-12		Medium	Medium	Medium	Medium	High	High
Critical Infrastructure	WWTF & LS	63108	LS-B		Low	Low	Low	Medium	Medium	High
Critical Infrastructure	WWTF & LS	63116	277B8150					Low	Low	Medium
Critical Infrastructure	WWTF & LS	63119	LS-03		Low	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63127	LS-09		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63144	LS-10		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63159	LS-V		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63166	317B5200					Low	Medium	High
Critical Infrastructure	WWTF & LS	63169	277B8145		Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63170	LS-03		Low	Medium	Medium	Medium	High	High
Critical Infrastructure	WWTF & LS	63171	LS-32			N/A		Low	Medium	High
Critical Infrastructure	WWTF & LS	63180	LS-07			Low	N/A	Medium	Medium	High
Critical Infrastructure	WWTF & LS	63184	LS-24					Medium	Medium	High
Critical Infrastructure	WWTF & LS	63200	LS-35		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63208	LS-45		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63211	LS-80		High	High	High	High	High	High

Asset Group	Asset Type	Index	Asset Name	Regionally Significant	Surge 2040 Int-Low	Surge 2040 Int-High	Surge 2070 Int-Low	Surge 2070 Int-High	Surge 2100 Int-Low	Surge 2100 Int-High
Critical Infrastructure	WWTF & LS	63228	Clearwater - East AWWTF	Yes	High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63263	316B8042					Low	Medium	High
Critical Infrastructure	WWTF & LS	63264	LS-43		Medium	Medium	Medium	Medium	Medium	High
Critical Infrastructure	WWTF & LS	63265	LS-D		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63266	LS-05		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63270	LS-19		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63271	LS-47							Low
Critical Infrastructure	WWTF & LS	63272	LS-34					Low	Medium	High
Critical Infrastructure	WWTF & LS	63273	LS-T		Medium	Medium	Medium	Medium	High	High
Critical Infrastructure	WWTF & LS	63274	LS-E		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63275	LS-X		Low	Low	Low	Medium	Medium	High
Critical Infrastructure	WWTF & LS	63276	LS-14		Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63277	285A1025		Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63279	LS-16						Low	Low
Critical Infrastructure	WWTF & LS	63280	LS-16							Low
Critical Infrastructure	WWTF & LS	63281	LS-84		Low	Low	Medium	Medium	Medium	Medium
Critical Infrastructure	WWTF & LS	63283	LS-Q							Low
Critical Infrastructure	WWTF & LS	63290	LS-33		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63291	LS-08		Medium	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63292	LS-62		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63293	Wastewater_wwLiftStation		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63294	LS-11		Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63295	LS-20		Medium	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63297	LS-13		Medium	Medium	Medium	Medium	Medium	High
Critical Infrastructure	WWTF & LS	63298	LS-68		Medium	Medium	Medium	Medium	High	High
Critical Infrastructure	WWTF & LS	63299	LS-23		Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63304	271B7155						Low	Low

Asset Group	Asset Type	Index	Asset Name	Regionally Significant	Surge 2040 Int-Low	Surge 2040 Int-High	Surge 2070 Int-Low	Surge 2070 Int-High	Surge 2100 Int-Low	Surge 2100 Int-High
Critical Infrastructure	WWTF & LS	63305	272A5000		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63307	LS-39		Medium	Medium	Medium	Medium	High	High
Critical Infrastructure	WWTF & LS	63308	LS-28		Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63309	LS-26		Medium	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63310	LS-02		Medium	Medium	Medium	High	High	High
Critical Infrastructure	WWTF & LS	63311	LS-01		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63327	LS-50		Medium	Medium	Medium	Medium	Medium	Medium
Critical Infrastructure	WWTF & LS	63338	LS-53		Medium	Medium	Medium	Medium	High	High
Critical Infrastructure	WWTF & LS	63339	179A3000		Medium	Medium	Medium	Medium	Medium	High
Critical Infrastructure	WWTF & LS	63368	Wastewater_wwManhole		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63370	Wastewater_wwManhole		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63371	Wastewater_wwManhole		High	High	High	High	High	High
Transportation and Evacuation Routes	Airports	40141	Clearwater Executive Airport	Yes					Low	Low

4.1.2.8 Rainfall (Pluvial and Fluvial) Flooding – 100-Year Event - 2040 Planning Horizon

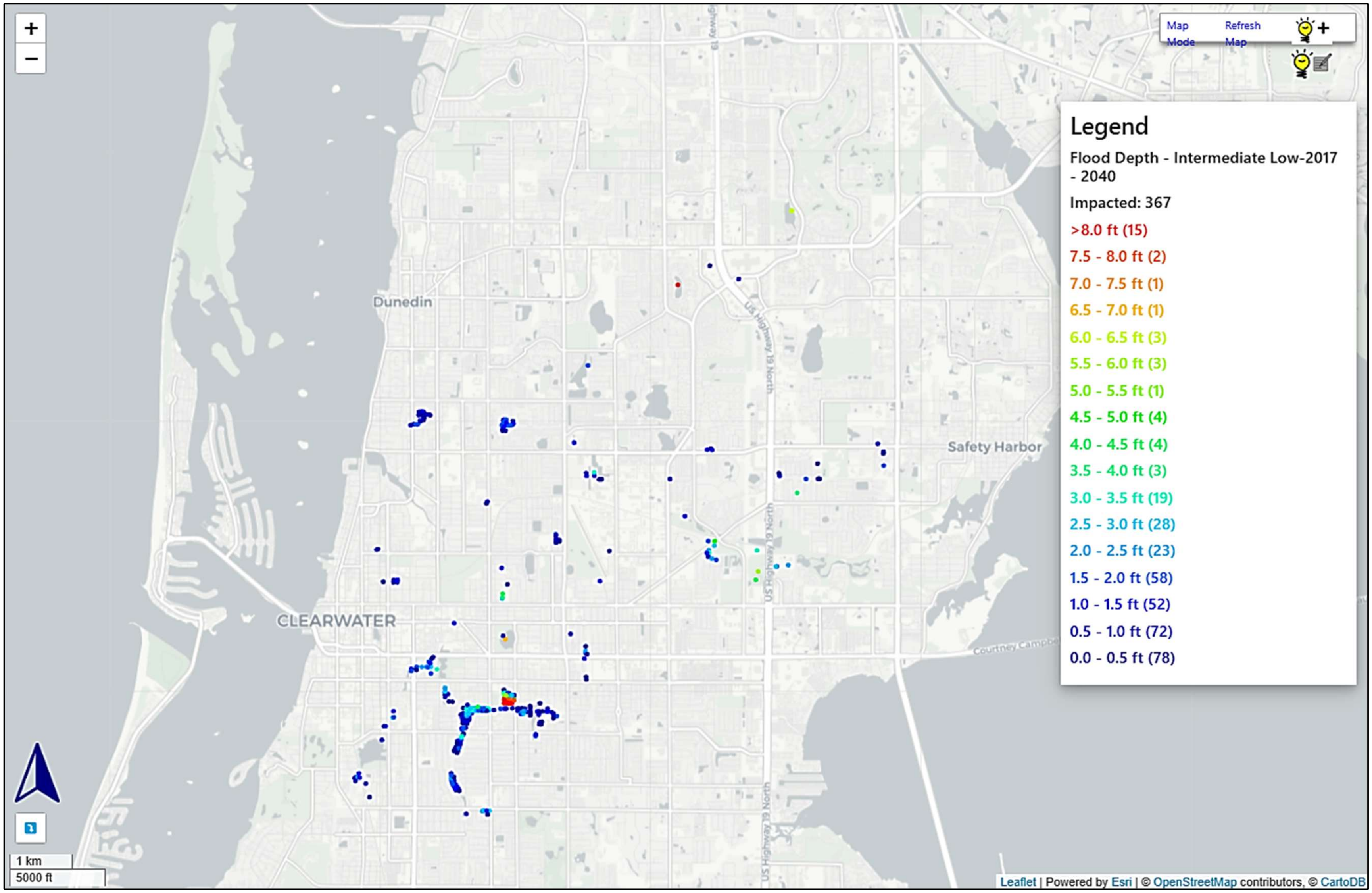


Figure 4-25 - Rainfall Impacts – 100-Year - 2040

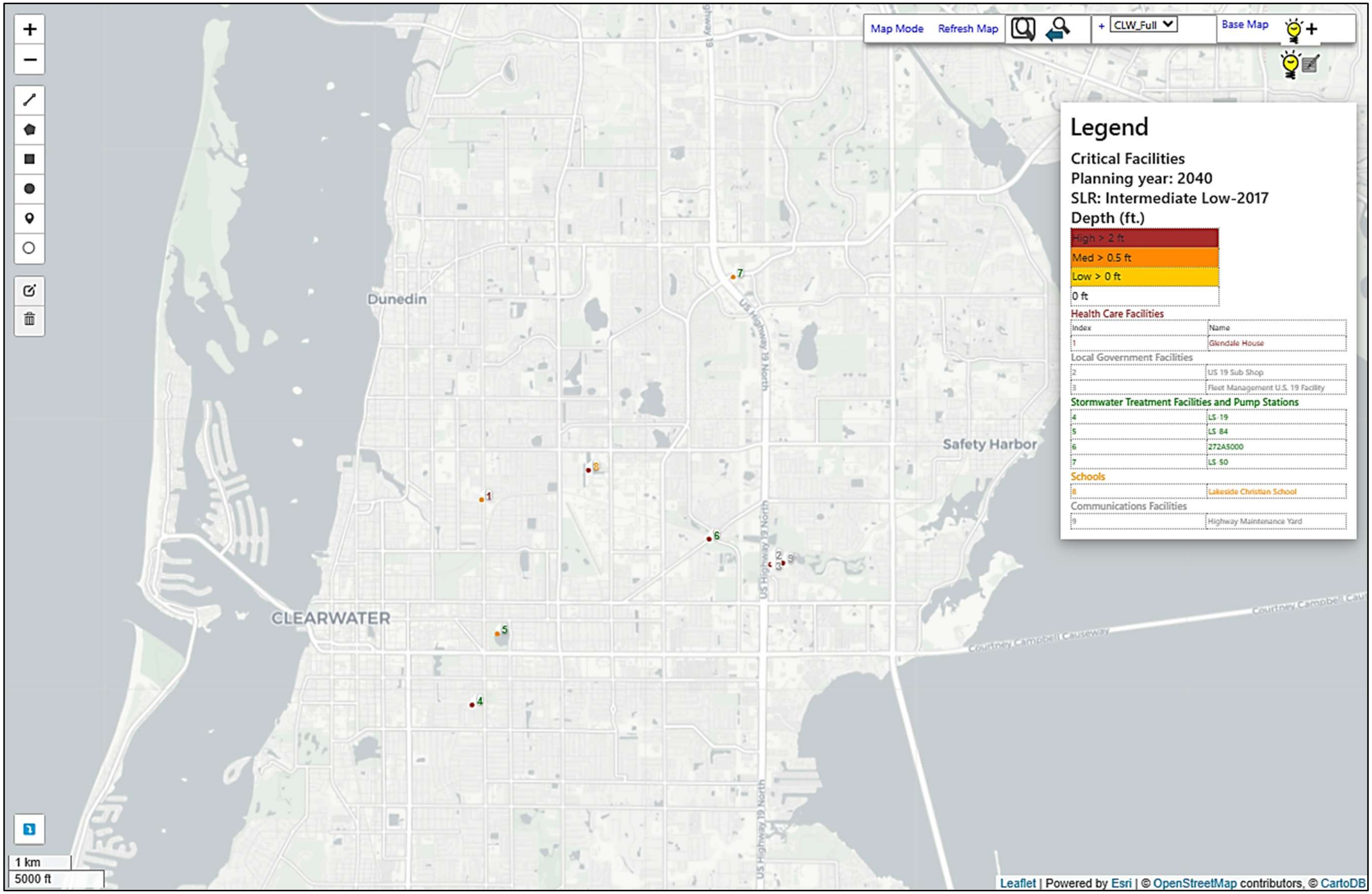


Figure 4-26 - Rainfall - 2040 - 100-Year Event; Impacted Critical Assets

4.1.2.9 Rainfall (Pluvial and Fluvial) Flooding – 100-Year Event - 2070 Planning Horizon

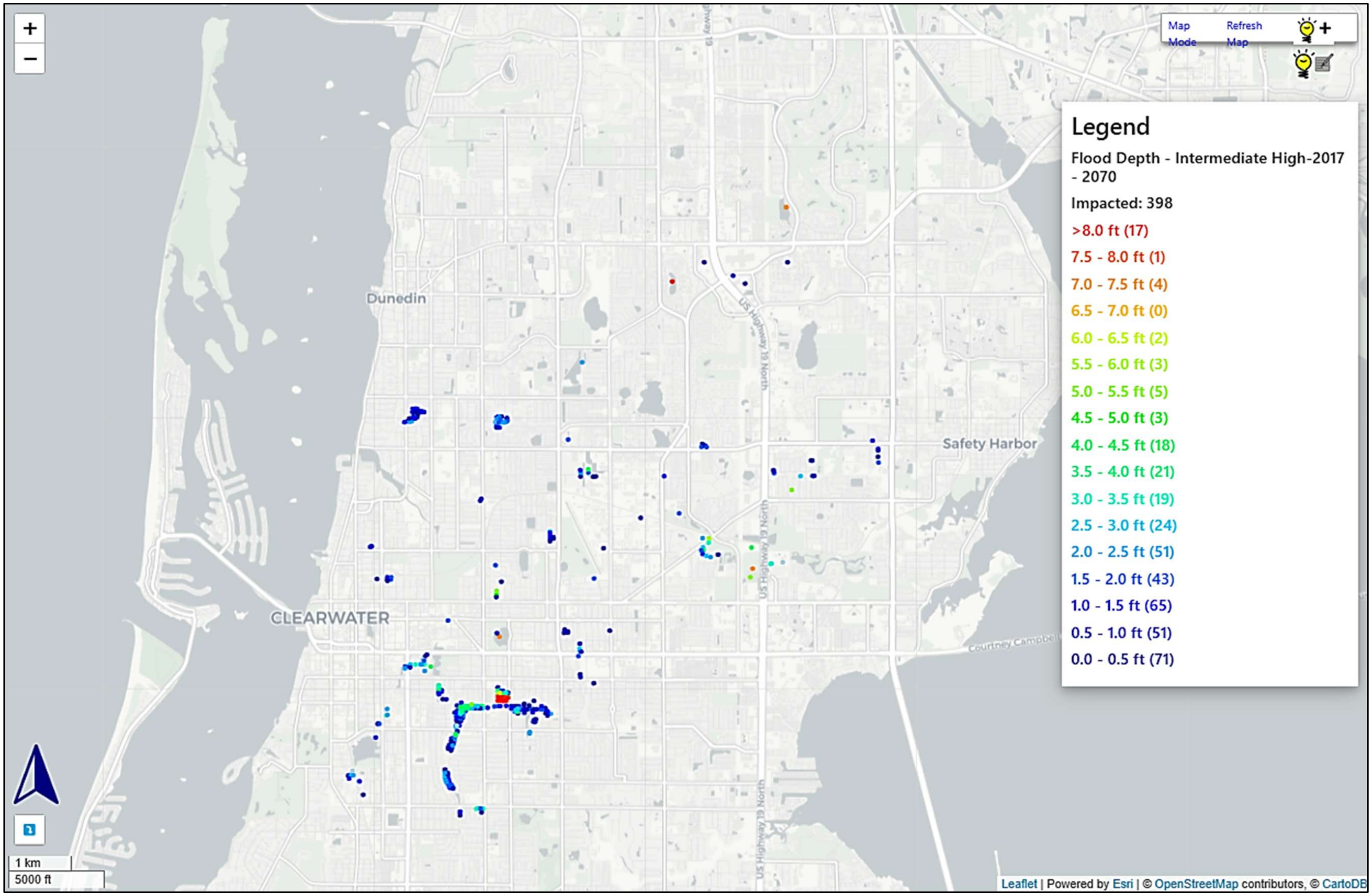


Figure 4-27 - Rainfall Impacts – 100-Year - 2070

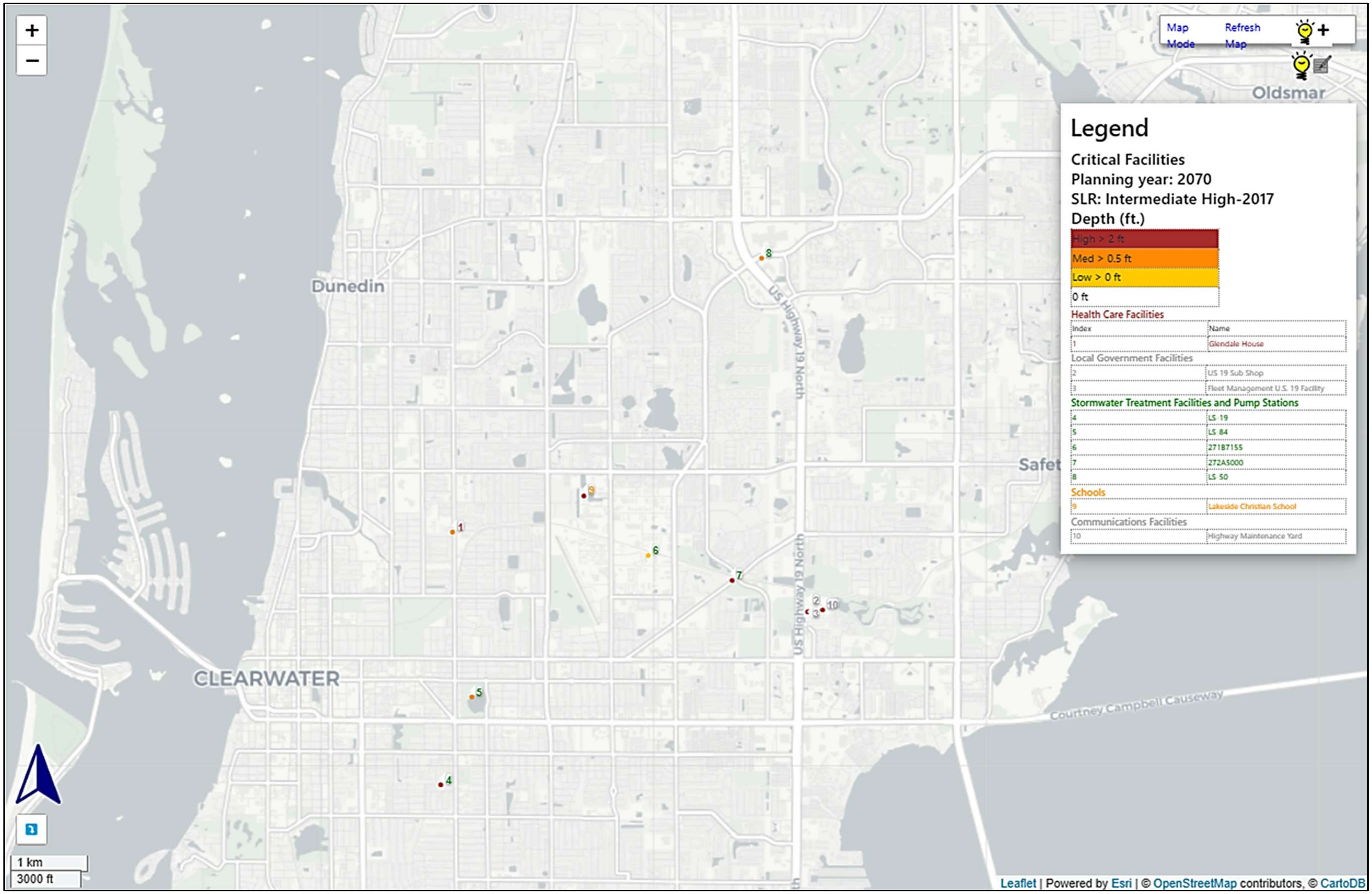


Figure 4-28 - Rainfall - 2070 - 100-Year Event; Impacted Critical Assets

4.1.2.10 Rainfall (Pluvial and Fluvial) Flooding – 100-Year Event - 2100 Planning Horizon

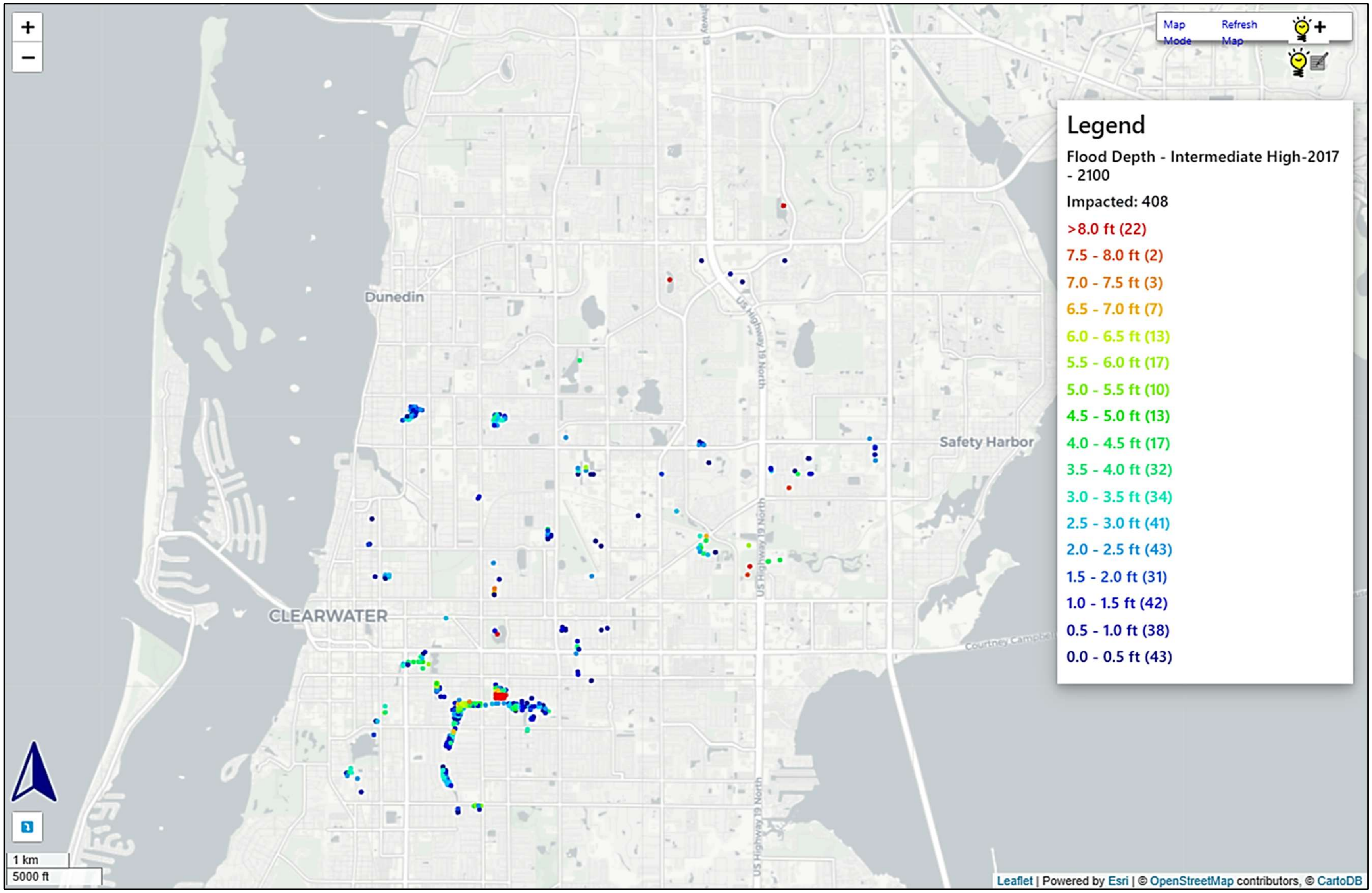


Figure 4-29 - Rainfall Impacts – 100-Year - 2100

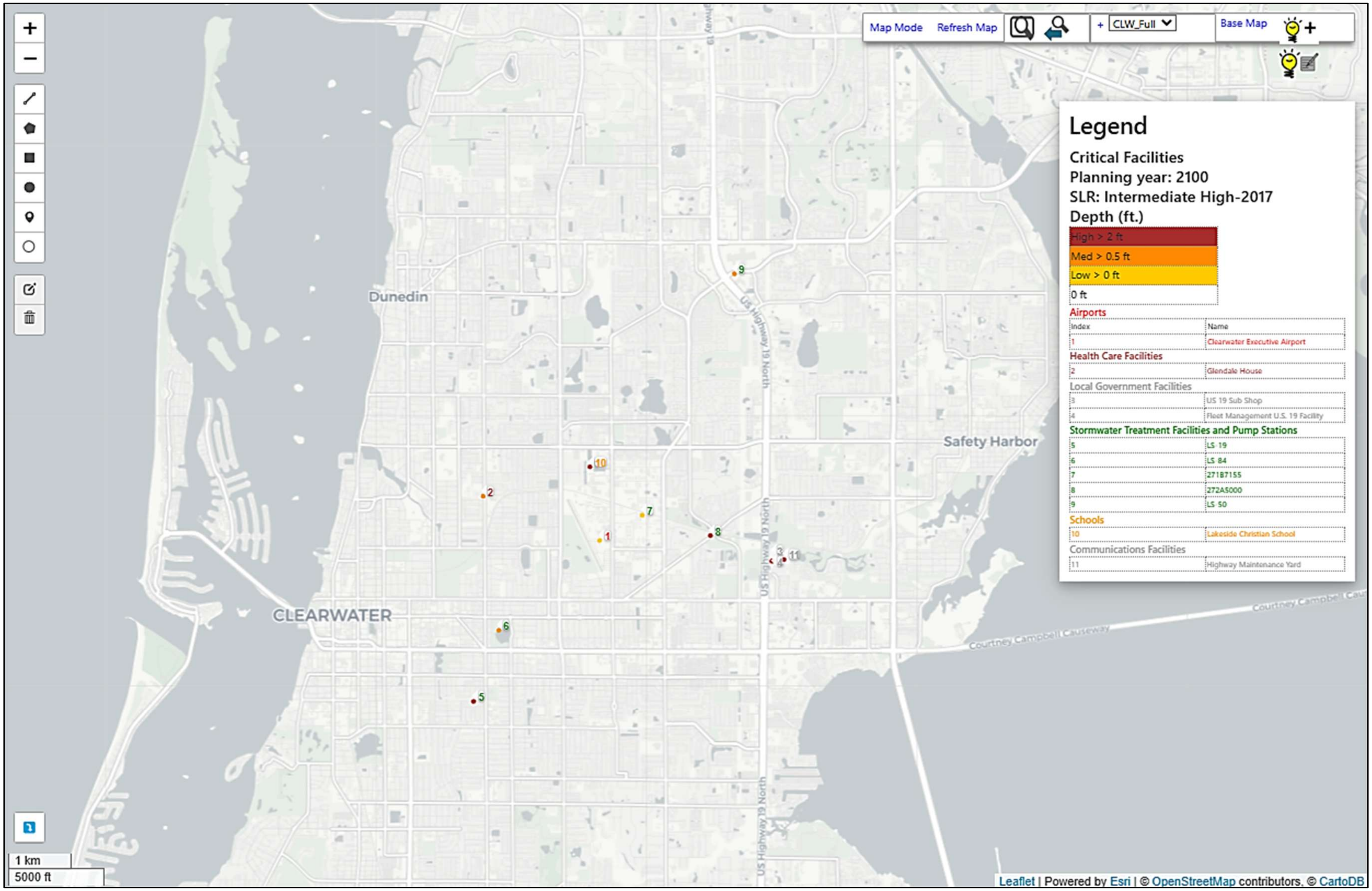


Figure 4-30 - Rainfall - 2100 - 100-Year Event; Impacted Critical Assets

4.1.2.11 Rainfall (Pluvial and Fluvial) Flooding – 500-Year Event - 2040 Planning Horizon

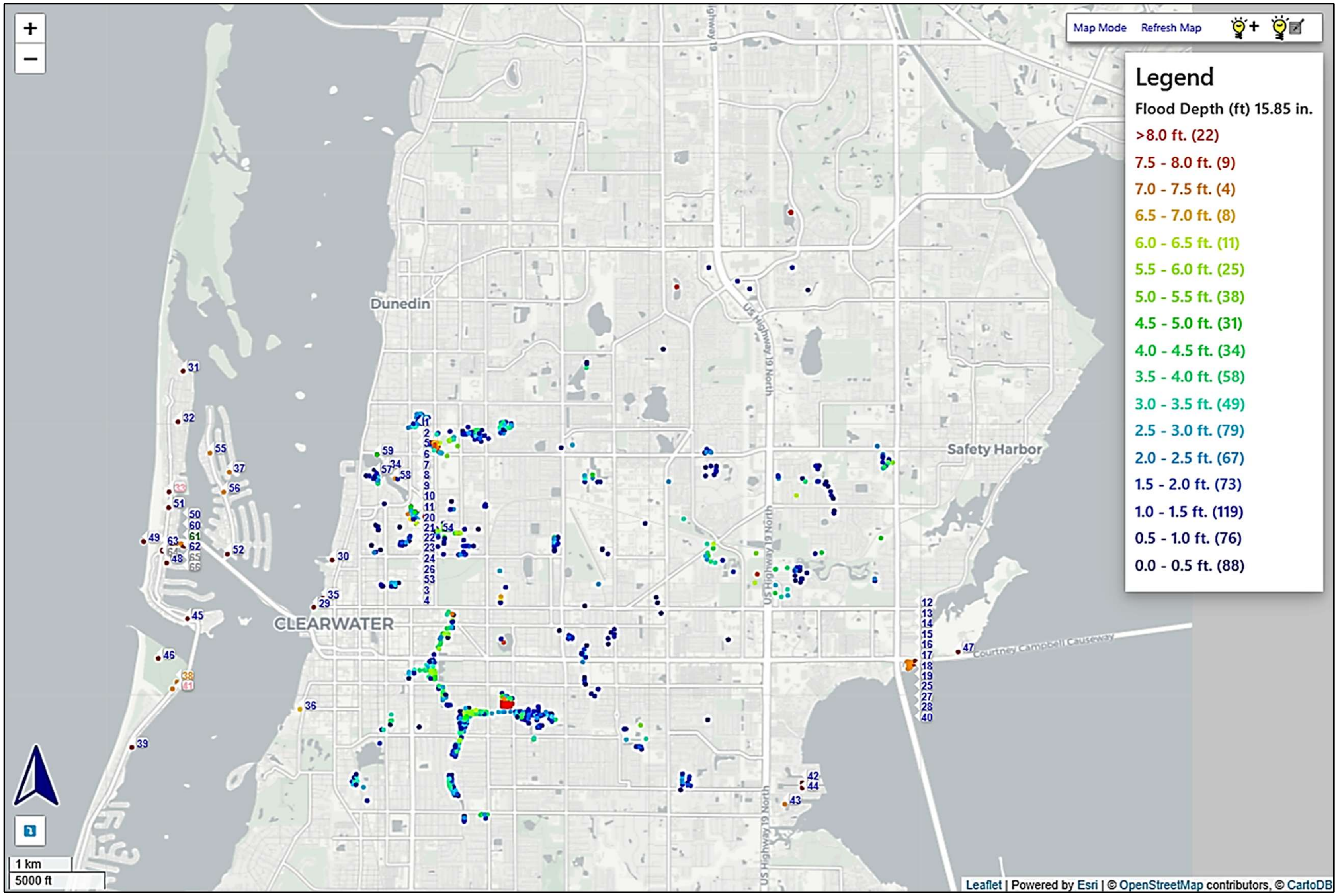


Figure 4-31 - Rainfall Impacts – 500-Year – 2040

4.1.2.12 Rainfall (Pluvial and Fluvial) Flooding – 500-Year Event - 2070 Planning Horizon

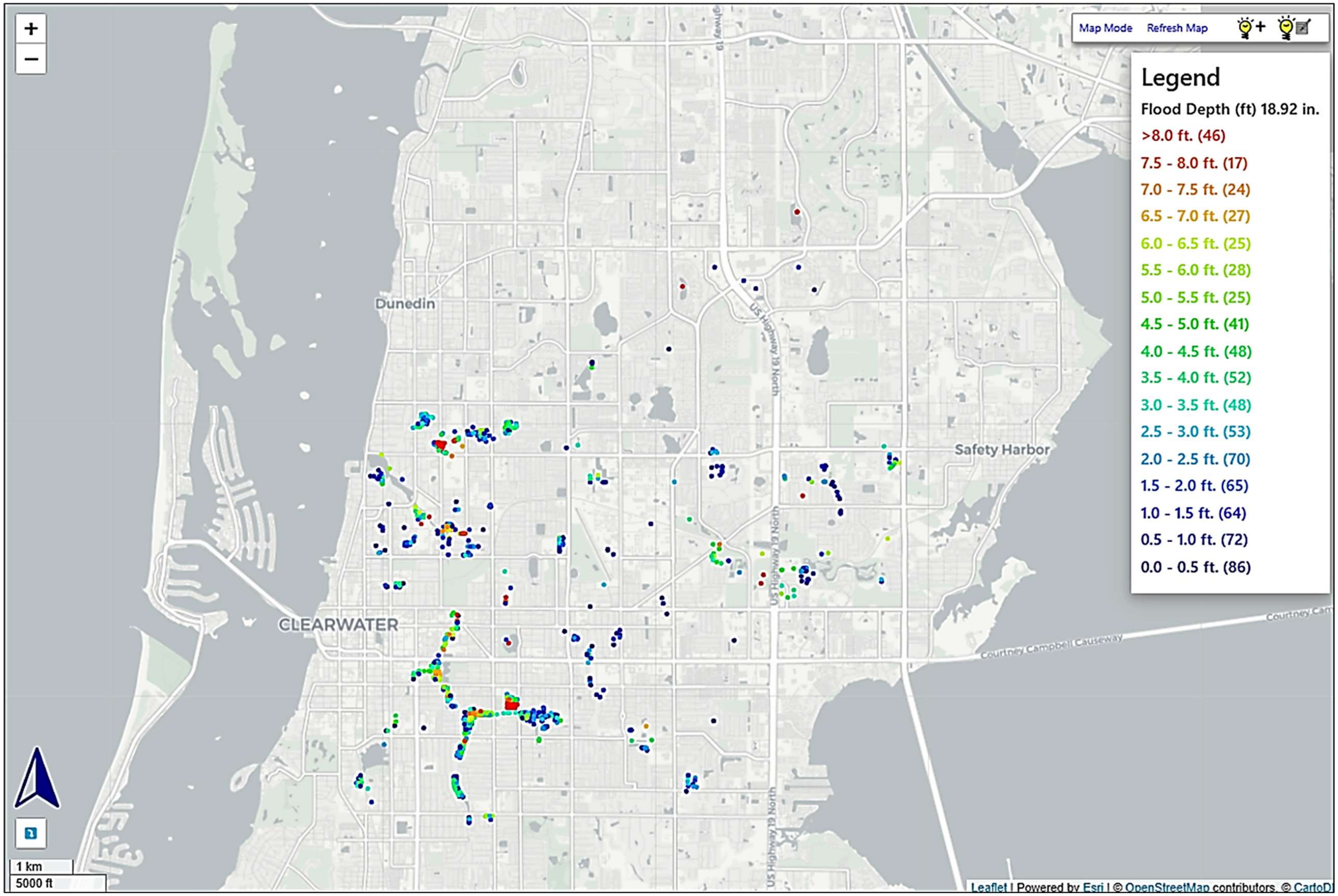


Figure 4-32 - Rainfall Impacts – 500-Year – 2070

4.1.2.13 Rainfall (Pluvial and Fluvial) Flooding – 500-Year Event - 2100 Planning Horizon

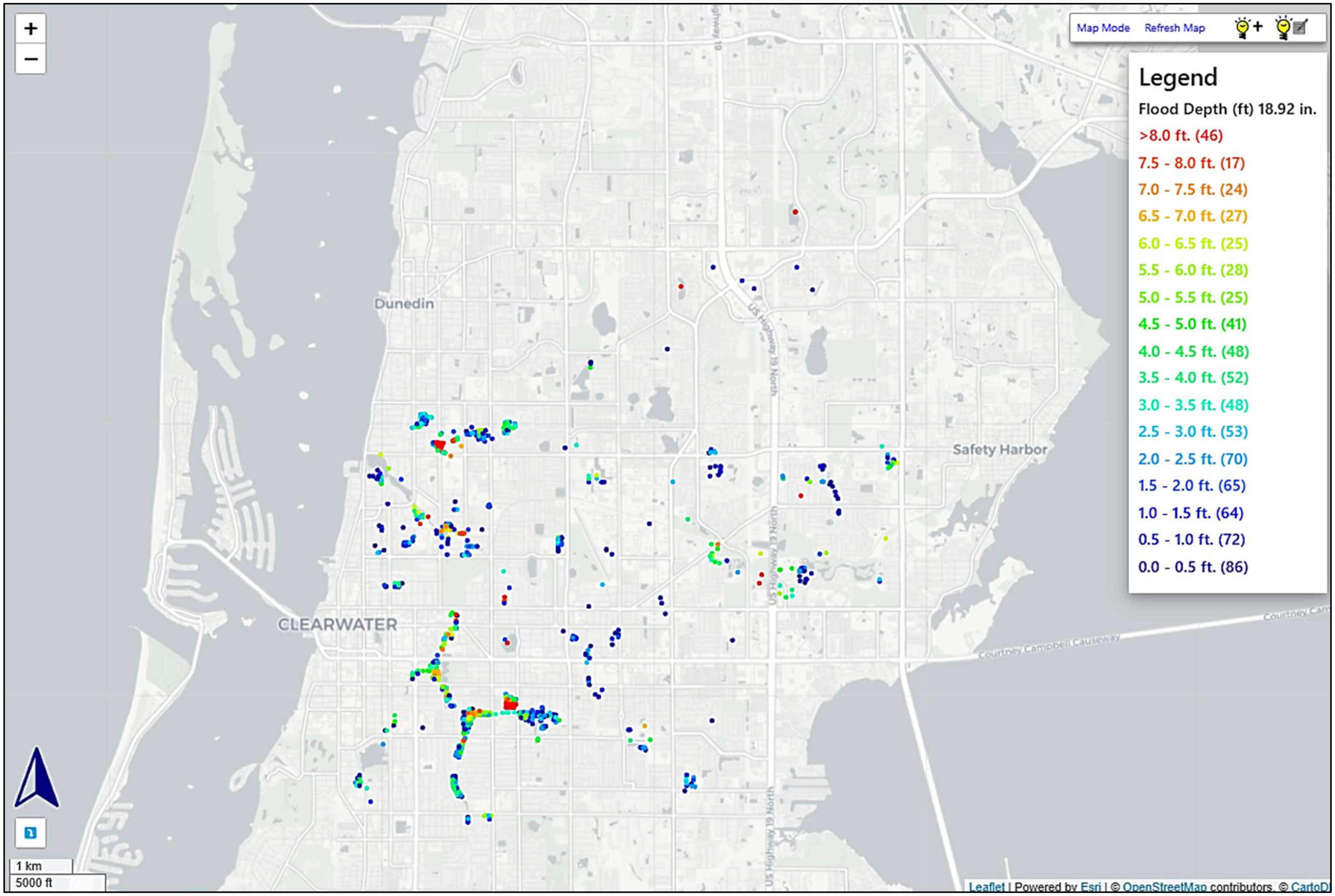


Figure 4-33 - Rainfall Impacts – 500-Year – 2100

4.1.2.14 Rainfall (Pluvial and Fluvial) Flooding – Critical Asset Summary Table

The flood risk table below is intended to show the sensitivity of the critical assets studied in this project (406 total). The assets that are exposed to future rainfall flooding (100-Yr and 500-Yr for all planning horizons) alone is shown below. Regionally significant assets, particularly water treatment facilities and the Clearwater Executive Airport, could be impacted at the 2040 planning horizon in a 500-Yr rain event. The flood risk identified (high, medium, or low) is based on the following flood depths:

- Low Risk: 0.1 – 0.5 feet
- Medium Risk: 0.51 – 2.0 feet
- High Risk: Greater than 2 feet

Note that the table that follows uses the naming conventions below for the “Asset Type” column to help with legibility within the table:

Full Asset Type Name	Condensed Name for Table
Airports	Airports
Communications Facilities	Communications
Electric Production and Supply Facilities	Electric P & S
Emergency Operation Centers	EOCs
Fire Stations	Fire Stations
Health Care Facilities	Health Care
Historical and Cultural Assets	Historic and Culture
Law Enforcement Facilities	Law Enforcement
Local Government Facilities	Local Government
Risk Shelter Inventory	Risk Shelter
Schools	Schools
Solid and Hazardous Waste Facilities	Waste Facilities
Stormwater Treatment Facilities and Pump Stations	Stormwater
Wastewater Treatment Facilities and Lift Stations	WWTF & LS

Not all assets listed are owned or maintained by the City, but they are within or adjacent to the study area, and part of the Pinellas countywide asset data available at the time of this analysis.

Table 4-3 - Flood Risk Level for Critical Assets (Pluvial and Fluvial Flooding)

Asset Group	Asset Type	Index	Asset Name	Regionally Significant	Rain 100Yr 2040	Rain 100Yr 2070	Rain 100Yr 2100	Rain 500Yr 2040	Rain 500Yr 2070	Rain 500Yr 2100
Critical Community & Emergency Facilities	Health Care	63132	Glendale House		Medium	Medium	Medium	Medium	Medium	High
Critical Community & Emergency Facilities	Health Care	63138	Clearwater Center					High	High	High
Critical Infrastructure	Communications	63365	Highway Maintenance Yard		High	High	High	High	High	High
Critical Infrastructure	Local Government	63177	US 19 Sub Shop		Medium	High	High	High	High	High
Critical Infrastructure	Local Government	63235	Fleet Management U.S. 19 Facility		High	High	High	High	High	High
Critical Infrastructure	Schools	63346	Lakeside Christian School		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	62974	Marshall Street AWWTF	Yes				Medium	Medium	High
Critical Infrastructure	WWTF & LS	62976	Marshall Street AWWTF	Yes				High	High	High
Critical Infrastructure	WWTF & LS	62977	Marshall Street AWWTF	Yes				High	High	High
Critical Infrastructure	WWTF & LS	62979	Marshall Street AWWTF	Yes				High	High	High
Critical Infrastructure	WWTF & LS	62980	Marshall Street AWWTF	Yes				Medium	High	High
Critical Infrastructure	WWTF & LS	62981	Marshall Street AWWTF	Yes				High	High	High
Critical Infrastructure	WWTF & LS	62983	Marshall Street AWWTF	Yes				Medium	High	High
Critical Infrastructure	WWTF & LS	62984	Marshall Street AWWTF	Yes				High	High	High
Critical Infrastructure	WWTF & LS	62985	Marshall Street AWWTF	Yes				High	High	High
Critical Infrastructure	WWTF & LS	62986	Marshall Street AWWTF	Yes				High	High	High
Critical Infrastructure	WWTF & LS	63057	Marshall Street AWWTF	Yes				High	High	High
Critical Infrastructure	WWTF & LS	63060	Marshall Street AWWTF	Yes				High	High	High
Critical Infrastructure	WWTF & LS	63159	LS-V					High	High	High
Critical Infrastructure	WWTF & LS	63184	LS-24					High	High	High
Critical Infrastructure	WWTF & LS	63264	LS-43					Low	Low	Medium
Critical Infrastructure	WWTF & LS	63270	LS-19		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63271	LS-47					High	High	High
Critical Infrastructure	WWTF & LS	63281	LS-84		Low	Medium	Medium	Medium	Medium	High

Asset Group	Asset Type	Index	Asset Name	Regionally Significant	Rain 100Yr 2040	Rain 100Yr 2070	Rain 100Yr 2100	Rain 500Yr 2040	Rain 500Yr 2070	Rain 500Yr 2100
Critical Infrastructure	WWTF & LS	63283	LS-Q					High	High	High
Critical Infrastructure	WWTF & LS	63285	LS-U					High	High	High
Critical Infrastructure	WWTF & LS	63298	LS-68					High	High	High
Critical Infrastructure	WWTF & LS	63299	LS-23					High	High	High
Critical Infrastructure	WWTF & LS	63304	271B7155			N/A	Low	Medium	Medium	Medium
Critical Infrastructure	WWTF & LS	63305	272A5000		High	High	High	High	High	High
Critical Infrastructure	WWTF & LS	63309	LS-26					Medium	Medium	Medium
Critical Infrastructure	WWTF & LS	63311	LS-01					High	High	High
Critical Infrastructure	WWTF & LS	63327	LS-50		Medium	Medium	Medium	Medium	Medium	Medium
Critical Infrastructure	WWTF & LS	63330	LS-48					Low	Low	Medium
Transportation and Evacuation Routes	Airports	40141	Clearwater Executive Airport	Yes			Low	Low	Medium	Medium

Structure Impacts due to Acute Flood Exposure

The results presented in sections 4.1.2.1 - 4.1.2.14 reveal some clear patterns in exposure to acute flood events through the 21st century. They include:

- The barrier island is under the most widespread threat, with exposure to flooding in all scenarios and all planning periods. Floods are impacting a larger percentage of buildings in this geography.
- Stevenson Creek-both upper and lower sections-also represents a source of high flood risk, with potential for flood intensifying throughout the century.
- The tributary of Allens Creek at the southeastern side of the City is also an area of high flood risk, particularly in the area of Nursery road.
- Structures around North Bayshore Blvd on the eastern side of the city are also under intensifying risk over the course of the century.
- Various other pockets of high flood risk are spread across the city and intensify in risk over the century.
- Comparing the storm surge results for the least and most extreme scenarios-95th percentile 2040 with 2017 intermediate-low SLR vs. 95th percentile 2100 planning year with 2017 intermediate-high SLR - the total at-risk buildings ranges from 3,126 to 4,936. Most significantly, 40% of the nearly 5,000 structures (approximately 2,000 structures) in the 2100 int-high scenario are estimated to have depths greater than 8 feet while the 2040 int-low scenario has 24 structures or 1%.

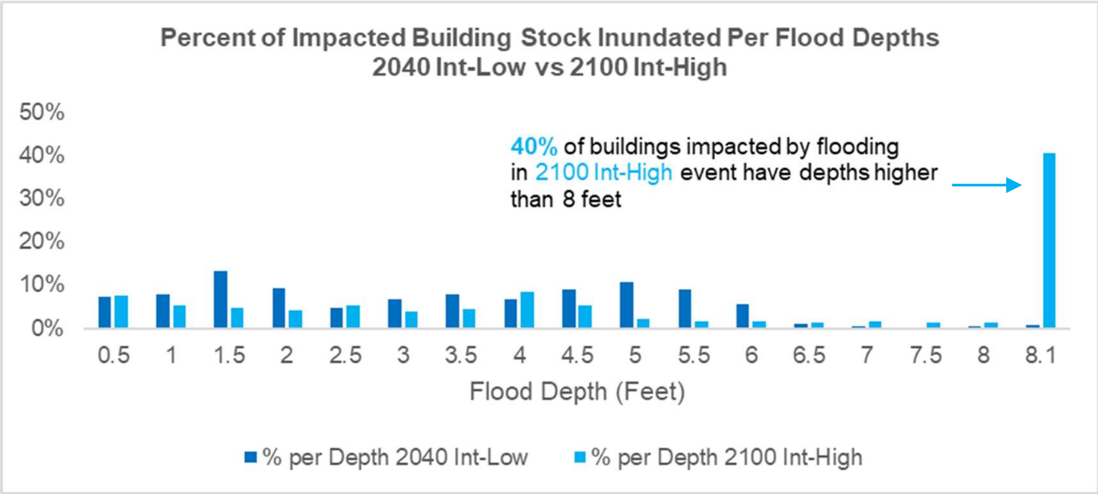


Figure 4-34 - Comparison of 2040 Int-Low and 2100 Int-High Buildings Inundated per Depth of Flooding

4.1.3 Stormwater and Transportation Exposed to Future Flood Conditions

One of the key sets of assets provided at the start of the study was a collection of stormwater assets. These assets were used in conjunction with transportation assets to create a set of tracking points that could be used to geospatially understand where flooding was occurring, how deep it may get at those locations, and what disruptions this may cause for residents and businesses as they try to navigate the city's transportation network.

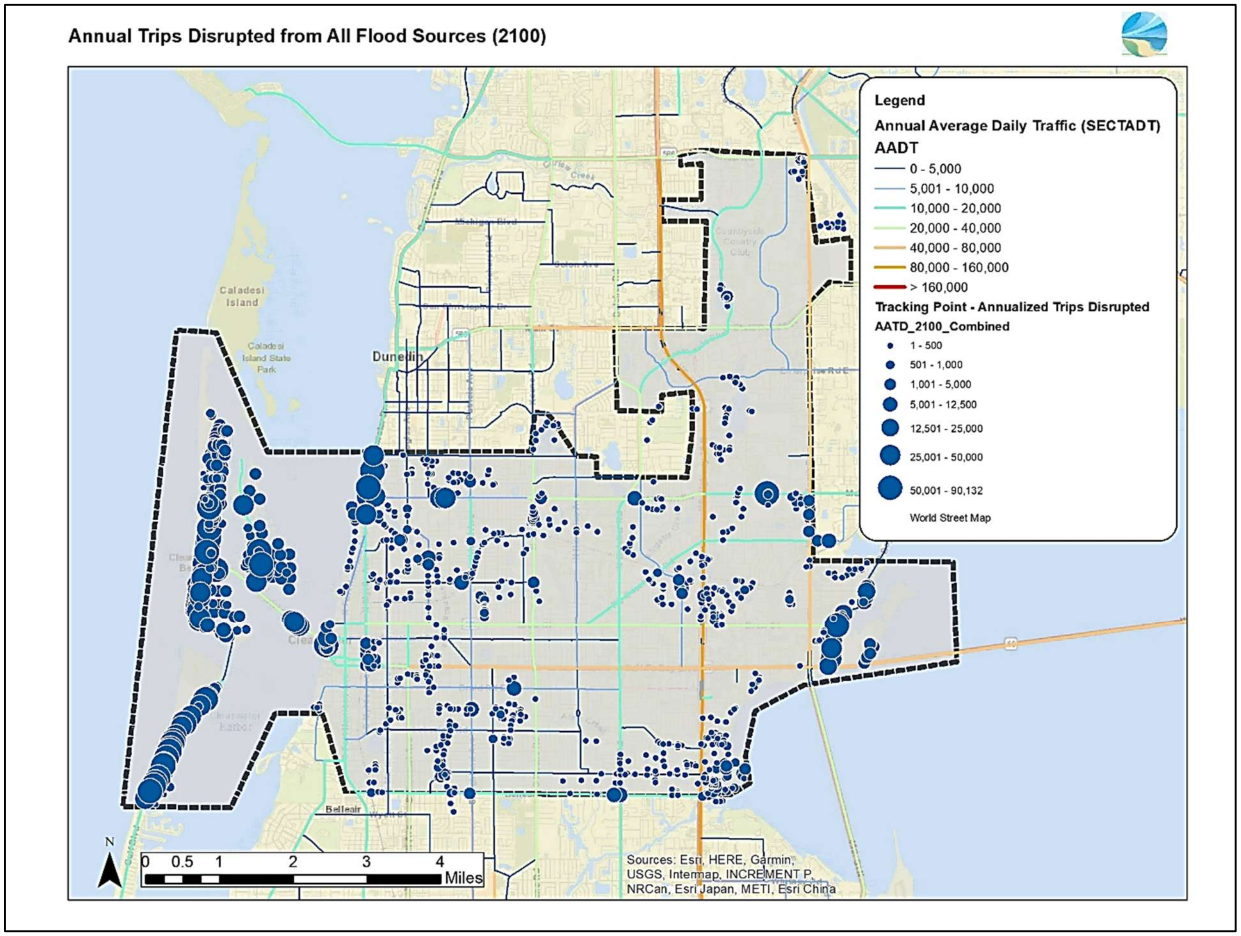


Figure 4-35 - Trips disrupted from all flood events (2100)

4.2 Heat Exposure

Note: Evaluations of heat impacts to the City was beyond the scope of the FDEP grant and not part of the required deliverables.

As seen within the Exposure and Climate Drivers section of the report, increases in temperature are expected to be experienced across the city. To provide an assessment of what parts of the city are expected to incur more impacts from the increase in temperatures, a model was developed to utilize the downscaled local temperature projections along with existing spatial data of shaded locations and buildings. The model uses the locations of buildings to identify how many days throughout the year that the spot can expect to receive a maximum temperature (Max T) above 90 degrees Fahrenheit. The buildings have been analyzed for trees in the area around the building, and the Max T is adjusted down based on tree percentage. The amount of reduction maxes out at 5 degrees and is linearly related to a linear, distance-weighted estimate of tree percentage based on the tree percentage raster, which has results at 30-meter grid cells. The tree percentage of the cell right over the structure's centroid gets the highest weight, the grid cells in the square of cells one cell distance out from the centroid gets the next highest weight, and the grid cells in the next concentric square gets a low weight. If the weighted tree percent is 1.0, the Max T is reduced 5 degrees. If the tree percentage is zero, then the Max T is not reduced at all. The maps below show the results per each planning horizon (2040, 2070, and 2100) and each climate projection (2017 intermediate-low and 2017 intermediate-high).

4.2.1 Citywide Heat Exposure

Results from the model are summarized as follows:

2040 Planning Horizon

- There are 10,081 study locations where temperatures are increasing in the number of days that experience maximum temperatures greater than 90 degrees when existing shade conditions are accounted for.
- All locations are within the category of 1-25 days per year.

2070 Planning Horizon

- There are 14,603 study locations where temperatures are increasing in the number of days that experience maximum temperatures greater than 90 degrees when existing shade conditions are accounted for.
- Of those locations, the majority of locations (9,244) are within the category of 76-100 days per year.

2100 Planning Horizon

- There are 17,446 study locations where temperatures are increasing in the number of days that experience maximum temperatures greater than 90 degrees when existing shade conditions are accounted for.
- Of those locations, most locations (9,262) are within the category of 176-200 days per year.

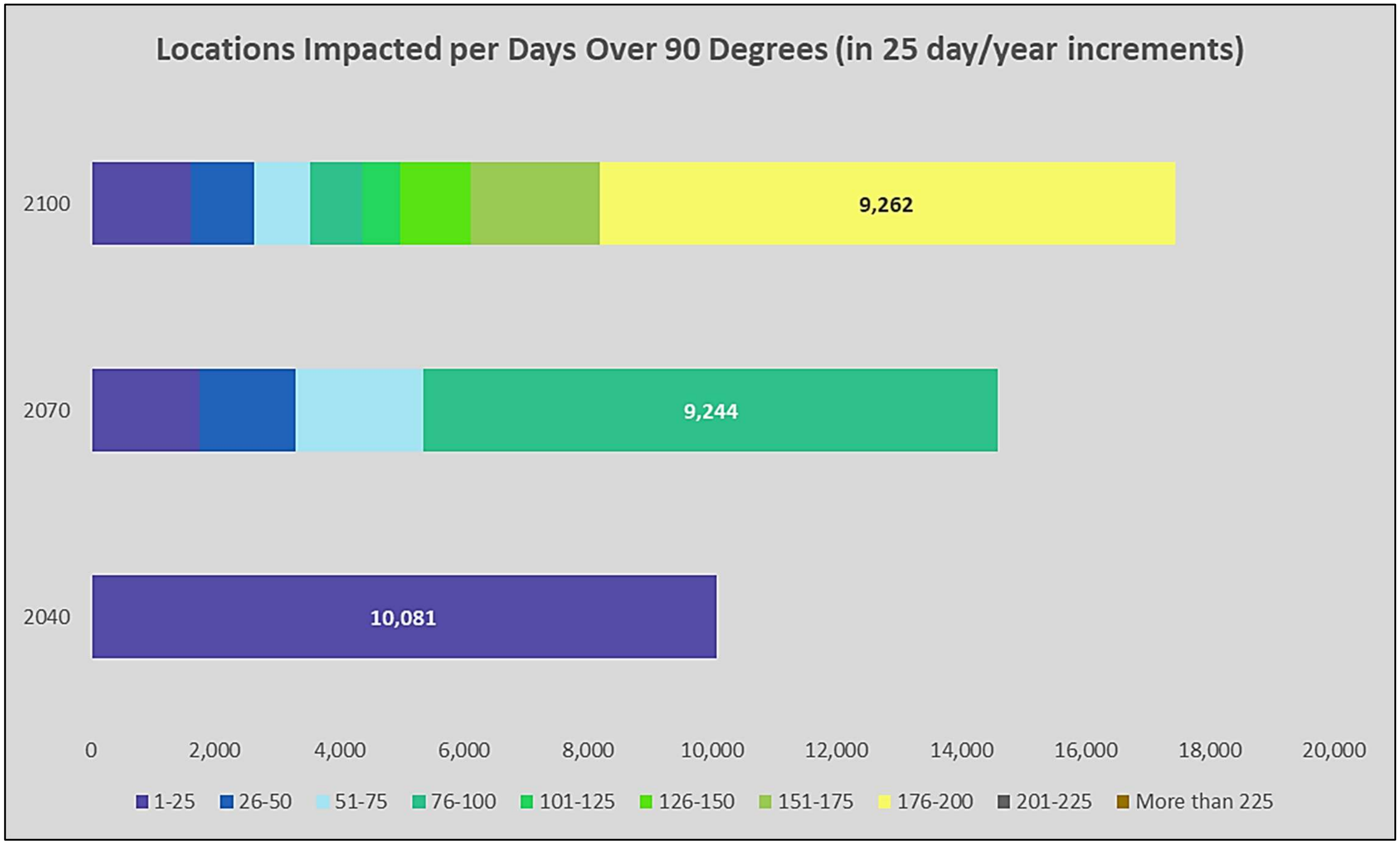


Figure 4-36 - The number of locations expected to experience increasing days of temperature greater than 90 degrees for each planning horizon (2040, 2070, 2100).

The graphic above illustrates that not only are the amount of days/year with high temperatures increasing, but also the number of locations is increasing; and most of the locations are experiencing the worst of the temperature increases. This is shown spatially by the maps on the following pages.

4.2.1.1 Year 2040 Locations with Days Greater than 90 Degrees (2017 Projections)

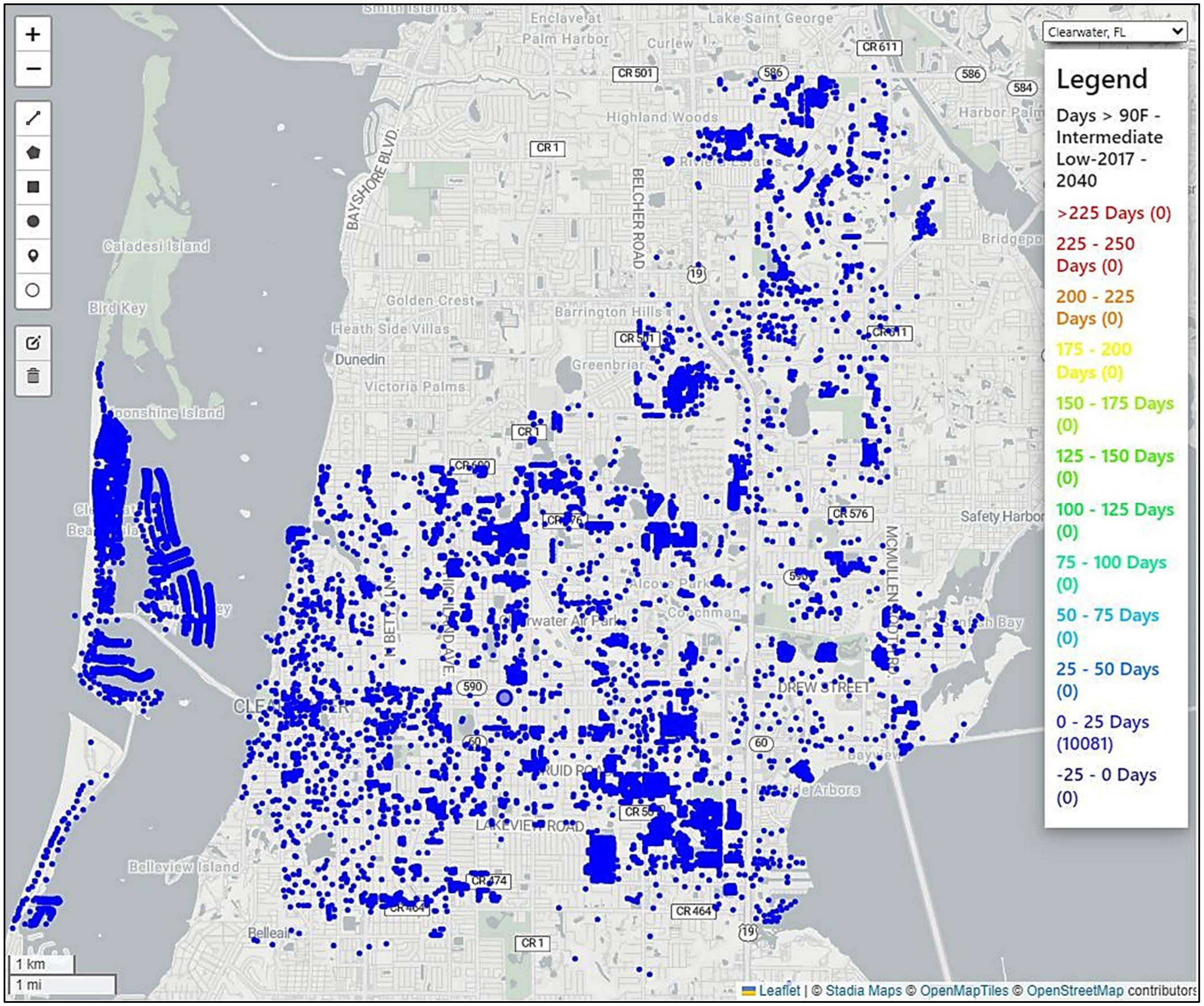


Figure 4-37 - Heat impacts at building locations using the 2017 projections (Year 2040).

4.2.1.2 Year 2070 Locations with Days Greater than 90 Degrees (2017 Projections)

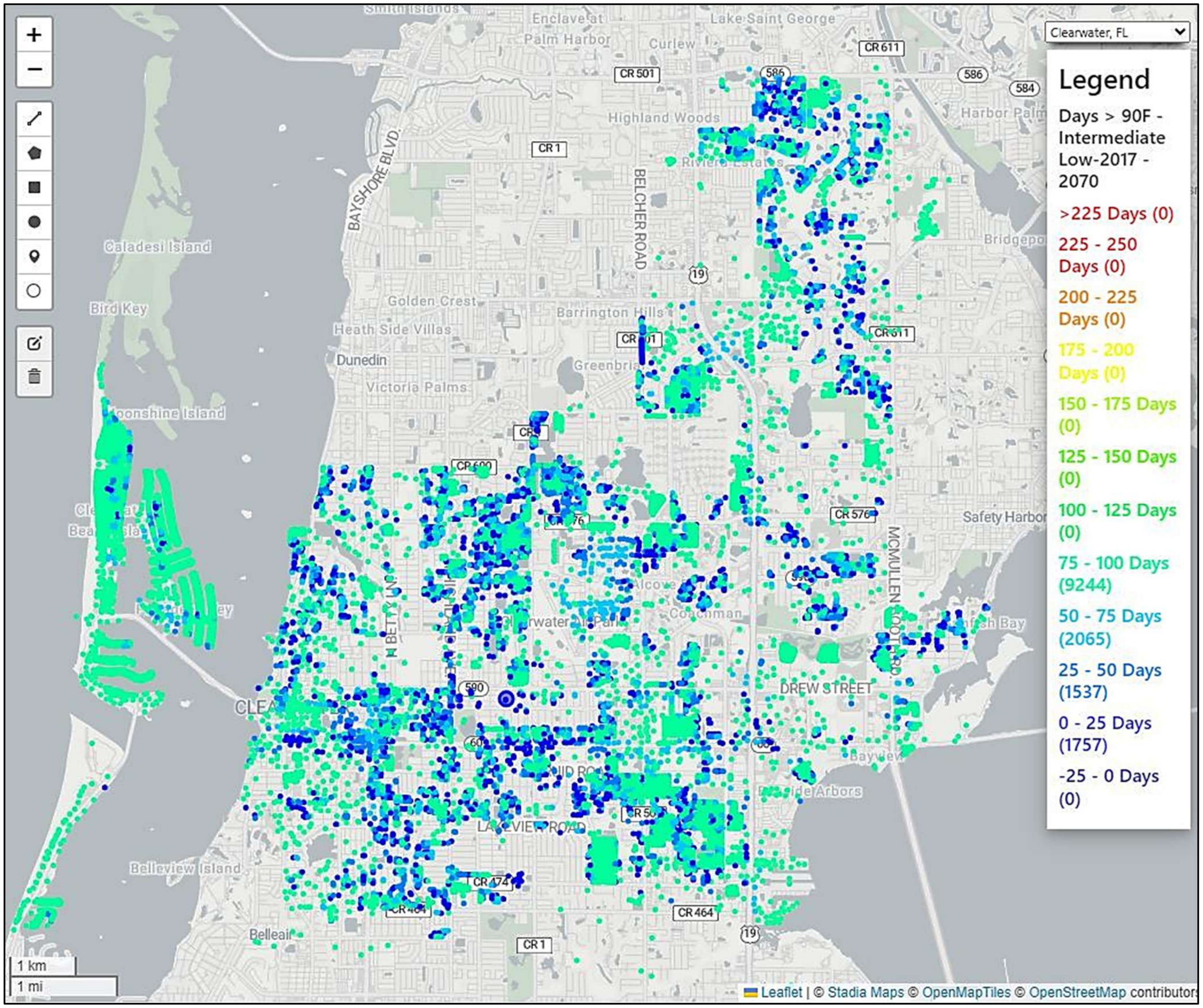


Figure 4-38 - Heat impacts at building locations using the 2017 projections (Year 2070).

4.2.1.3 Year 2100 Locations with Days Greater than 90 Degrees (2017 Projections))

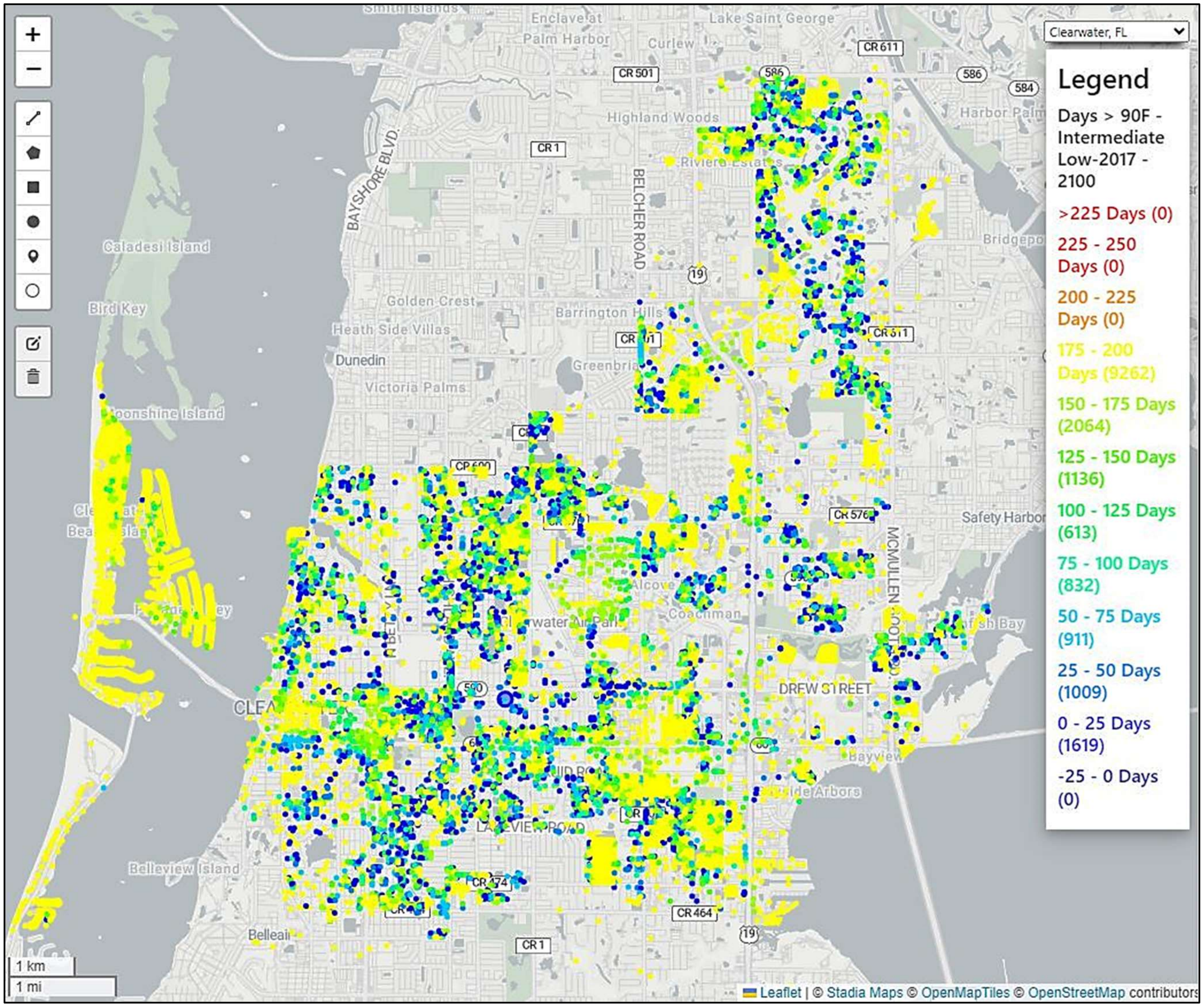


Figure 4-39 - Heat impacts at building locations using the 2017 projections (Year 2100).

ADAPTATION PLANNING WITH SCENARIOS

5. Developing Scenarios

Although the grant is focused on identifying exposure and sensitivity to climate hazards, the City is utilizing the project to also begin the adaptation planning process that tests mitigation actions aimed at reducing the potential consequences of increased flooding and heat. To facilitate this part of the project, the Project Action Team (PAT) held a series of meetings to understand how the tool evaluates costs and benefits, and what areas of the community should be tested with the tool.

5.1 Stakeholder Sessions

Getting Together to Make Informed Decisions
A series of in-person and virtual sessions were held to help determine what scenarios (adaptation actions and areas of interest) to study further with the tool.

The PAT was first introduced to the scenario development process during a regular virtual meeting. Following the session, the PAT determined that it would be more beneficial to hold an in-person meeting where maps could be marked up together, and consensus reached on what scenarios to test. The in-person meeting resulted in deeper discussion within the PAT and it was requested to get additional input from other city staff before finalizing the 10 scenarios.

The first discussion dealt with how to assess the city within the context of the study. Would it be beneficial to look at the scenarios through the lens of existing geographical subdivisions of the community such as watersheds, land use types/planning corridors, stormwater maintenance areas, etc.? The second major consideration of the scenario development process was the climate hazards that would need to be evaluated. The final major consideration was the identification of what type of mitigation/adaptation action(s) should be tested via the different scenarios.

5.1.1 Geographical Planning Considerations

The PAT was presented with some basic geographies to consider based on the results of the exposure and sensitivity analyses. The areas most exposed to flood hazards were the barrier islands, Stevenson Creek (particularly the northern portion where it enters Clearwater Harbor), and along Tampa Bay. The first thought was to evaluate whether the Clearwater 2045 land use plan contained study areas that would overlap these same clusters.

In reviewing the Clearwater 2045, the following exhibits from the plan were used to frame the discussion:

- QP 1. Framework-which established the city's Neighborhoods; Corridors; Activity, Mixed-Use, and Neighborhood Centers; and Hercules Employment District.

- QP 4. Historical Sites- which shows sites listed in the National Register of Historical Places; site listed in Florida Master Sites List, and the Harbor Oaks Historical District.

- CCM 5. CSA & CHHA-which shows the limits of the Category 1 Hurricane Surge (synonymous with the Coastal High Hazard Area in Florida Statutes); the Coastal Storm Area; FEMA Velocity Zones; and the Category 5 Hurricane Boundary.

- CCM 8. Evacuation Routes-which identifies the hurricane evacuation routes within the city.

In addition to exhibits from the Clearwater 2045 Plan, the group also discussed whether to develop scenarios for geographies based on watersheds, the engineering atlas, economic development areas, neighborhood revitalization strategy areas, and social justice areas.

5.1.2 Adaptation/Mitigation Actions

The major benefit of utilizing the City Simulator tool is the ability to test a portfolio of user-selected measures to gain insight on what actions can produce a high return on investment, what is the magnitude of costs to implement measures, and how to prioritize potential capital expenditures.

These actions to mitigate or adapt to climate impacts were categorized into the following four categories during the discussions.

- Increase Awareness
  - Additional sensors
  - Survey/catalog finished floor elevations (FFEs)
  - Increase frequency of inspections
  - Resilience awareness campaign
  - Public surveys

- Policy and Planning
  - Future land use planning
  - Prevent building within floodplain/hazard areas
  - Land acquisition
  - Increasing freeboard
  - Floodproofing
  - Resiliency bond financing

- Infrastructure Improvements
  - Stormwater drainage
  - Culvert/bridge improvements
  - Stormwater parks
  - Enhance telecommunication systems

- Physical Countermeasures
  - Elevate buildings
  - Structure acquisitions
  - Raise streets
  - Add/raise seawalls
  - Tree plantings

The tool mostly utilizes the last category, physical countermeasures, as implementable actions to be tested within the community. Some of the other adaptation options can be implemented via policy assumptions selected within the tool. The PAT chose to test all of the physical countermeasures within the final selected scenarios.

5.1.3 Selecting Scenarios

After multiple virtual sessions were facilitated to discuss the baseline results and how they might be evaluated in the scenario process, an in-person meeting was held to select the initial scenarios. The following graphic identifies the scenarios chosen and highlights their location, the actions to be evaluated, and the value that it has to the study in relation to actions being considered by the city.

Table 5-1 - Scenarios developed by the Project Action Team to be assessed within the tool.

Scenario #	Geography of Interest	Actions to Evaluate	Value to the Study
1	Stevenson Creek	Elevate roads; Acquire structures	High exposure to flooding; ongoing studies in the area.
2	Citywide	Increase tree coverage	City has Greenprint 2.0 plan for sustainability and intends to mitigate for heat exposure.
3	Barrier Islands	Elevate seawalls	High exposure to flooding; ongoing studies in the area.
4	Coastal Zone 3	Elevate roads	High exposure to flooding; ongoing studies in the area.
5	Barrier Islands	Elevate structures	High exposure to flooding; ongoing studies in the area.
6	Citywide	Acquire structures	Help the city identify good candidates for acquisition due to high return on investment.
7	Hercules and US 19 Corridors	Acquire structures	These are economic development areas of interest.
8	Coastal Zone 1, Central Business District, and North Greenwood	Acquire structures; Add tree coverage	These are income-impacted areas where the City is currently investing in improvements.
9	SR 60, Drew Street, and S. Missouri (Alt 19)	Stormwater improvements; Tree coverage; Density changes	These are future investment corridors with expected redevelopment activities.
10	Citywide	Elevate structures	Help the city identify good candidates for elevation due to high return on investment.

5.1.4 Scenario Analysis

The tool was designed to provide results that prioritize potential projects based on the generated cost-benefit ratio within costs constraints selected by the user. To help compare scenarios, the tool provides a losses avoided value compared to estimated costs to implement the actions. The city's guidance was for results to be provided in a manner that accounted for listing of all projects (with a benefit costs ratio greater than 1), if cost was not an option (e.g., the full estimate of costs necessary to implement), and then also at 25% intervals under the threshold.

* Note that this aspect of the City Simulator tool provides statistics at $5 million cost increments. The tool assumes a minimum spend of $1 million dollars, so the tool can report costs and projects at $1M, $6M, $11M, up to total estimated costs. The curve will flatten out at the end when all benefits are maximized.

The image below provides a sample of the interactive chart that is produced when the scenario is evaluated.

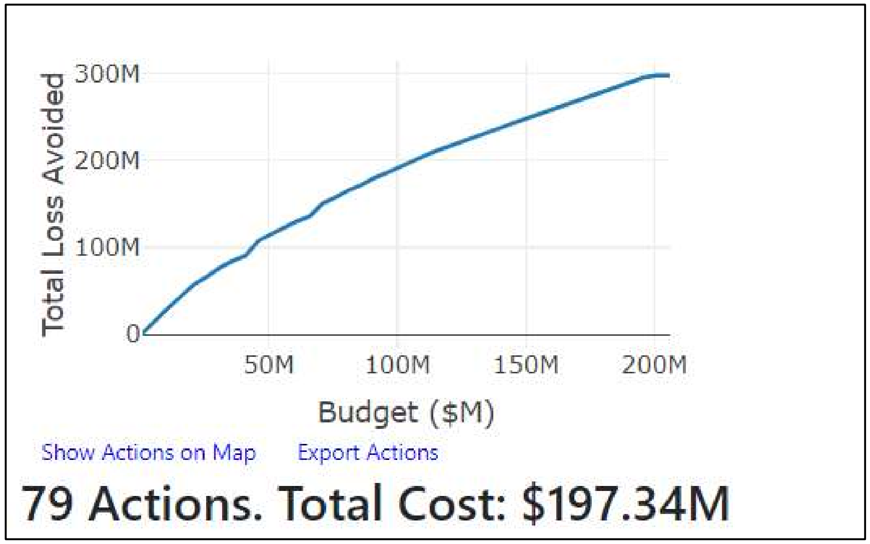


Figure 5-1 - Sample budget to losses avoided curve created for each scenario

The tool lets user click on a particular budget cost ($1M through total estimate at $5M intervals) and will then provide a list of the projects that provide the best return on investments. The user can also see all of these results on a map. By clicking any of the proposed projects suggested by the tool, the map will zoom to the location of the project. Additionally, an export function lets those results be saved as a comma delimited text file that can be further analyzed in another software of the user's choice, such as excel, GIS, or a database program.

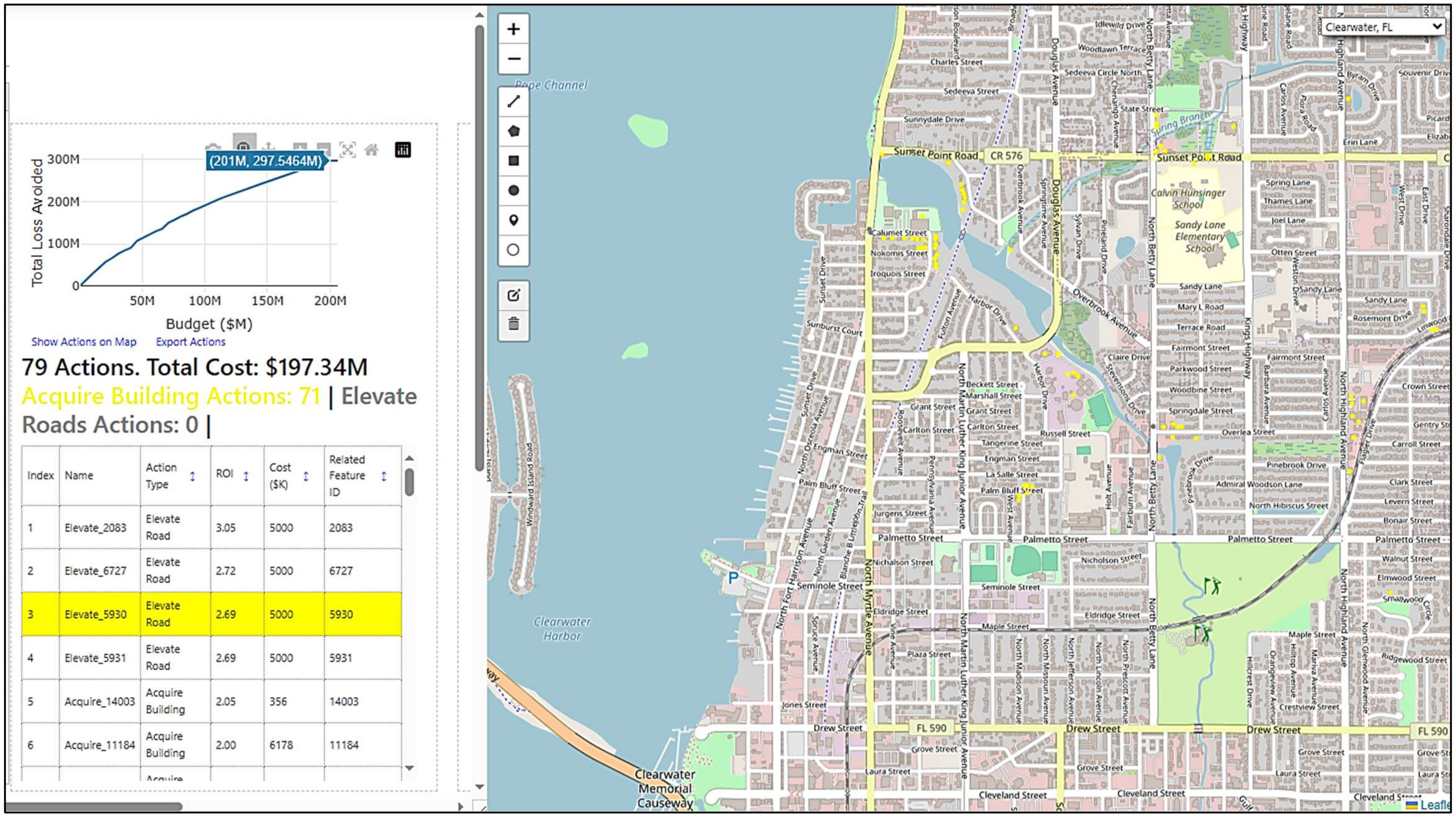


Figure 5-2- Sample tool screenshot showing cost curve, table of actions listed by return-on-investment (ROI) score, and map of action locations.

5.1.5 Methodologies utilized in assessing mitigation/adaptation actions

5.1.5.1 Elevating Roads

The cost for elevating roads is estimated as a function of average annual daily trips (AADT) as follows:

- AADT > 100,000; $100M
- AADT > 20,000; $20M
- AADT > 10,000; $10M
- Otherwise; $5M

Losses avoided: losses are estimated by multiplying the number of disrupted trips avoided from elevating by a value per disrupted trip avoided factor.

Default value per trip avoided: $2 per trip.

Disrupted trips are calculated in the desktop City Simulator software and brought over as an attribute of each stormwater node when the digital twin is loaded.

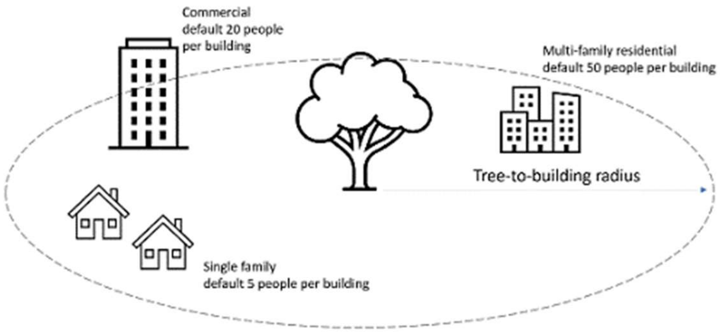
Value per trip avoided: the value can be calculated as a function of the redundancy of routes in the vicinity of the stormwater node. If this has not been calculated, then the default value is used.

5.1.5.2 Tree Planting Model

The tool assumes a $500 per tree cost for planting new trees. The tree planting benefit model works by having the tool find all locations where a tree may potentially be planted. This includes all sidewalks, protected areas, and recreational areas. It then estimates the number of people who get shade from the tree per day. It does this by finding all buildings within a radius of approximately 200 feet, and summing the number of agents either working or living in the buildings. If the agents have not been populated, it assumes 20 people per commercial building, 50 people per multi-family residential building, and 5 people per single family residential building.

The method then estimates benefit as:

The number of people shaded per day
times
The percentage of people who actually walk past the tree
times
The monetary benefit per day per person
times
The number of days in the simulation that the tree is planted.



The default assumptions are:

- 10% of people walk past the tree
- $0.01 benefit per day per person
- 180 days per year of benefit given seasonaility.

5.2 Scenario 1: Stevenson Creek

Scenario Setup:

Geography:

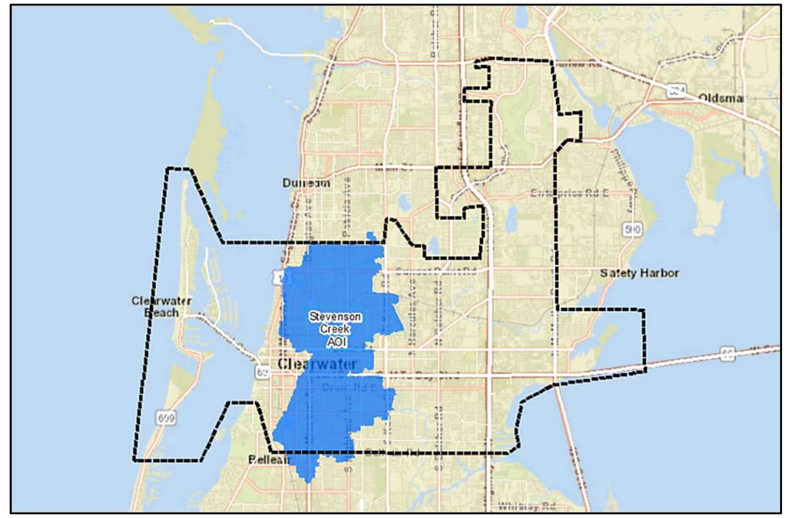
Stevenson Creek Watershed

Actions to Evaluate:

- Elevate Roads
- Acquire Structures

Value to the Community:

This geography is one with high exposure to tidal and rainfall flooding. There are also ongoing studies in the area that may be able leverage results of the analysis.



This scenario, and all others included in this document, are in support of a high-level planning exercise to begin evaluating the complexities of future hazard conditions. These scenarios are not meant to imply that the City is intending to perform these actions.

The Stevenson Creek scenario provides an opportunity to evaluate what the estimated costs and benefits are if flood-exposed roads were elevated, and flood-exposed structures were acquired. The watershed is approximately 7.5 square miles in size (the portion within the city limits) with baseline results of 1,594 structures exposed to at least some level of flood depths per future conditions. These structures are experiencing flooding as either increases in tidal surge or from increased rainfall events.

Stakeholder participants noted that the citywide flood exposure maps showed large clusters of structures within the watershed making it a good candidate for further analysis. It was also noted that the city has additional projects ongoing or about to begin that might also benefit from a deeper understanding of the flood vulnerabilities and opportunities to mitigate. This watershed's footprint also overlaps with areas designated as underserved communities and the city chose to develop an additional scenario to look specifically at some of the impacts in those areas.

Depth Distribution Graphic

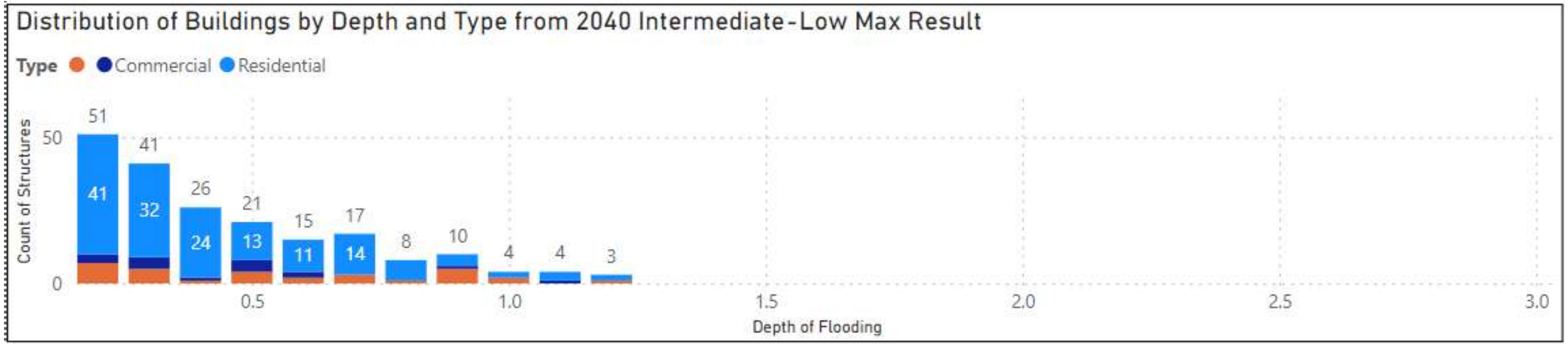


Figure 5-3- Distribution of structures (by flood depth in feet) within the Stevenson Creek AOI, using the 2040 Intermediate-Low Max Surge results.

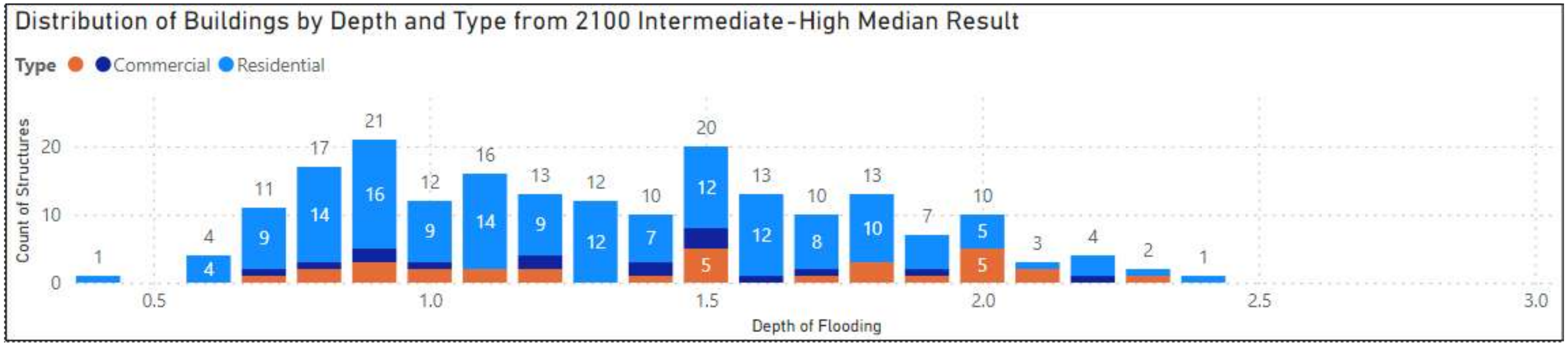


Figure 5-4 - Distribution of structures (by flood depth in feet) within the Stevenson Creek AOI, using the 2100 Intermediate-High Max Surge results.

The images above help to show how the structures within the Stevenson Creek AOI will become more inundated over time. At the 2040 planning horizon, the structures that are exposed to tidal surge flooding are generally at a foot or less, with most exposed to less than half a foot of water. At the 2100 planning horizon, the structures are now experiencing flood depths of half a foot to 2.5 feet. The map below provides additional context as to where the structures are being exposed to flooding under any of the scenarios.

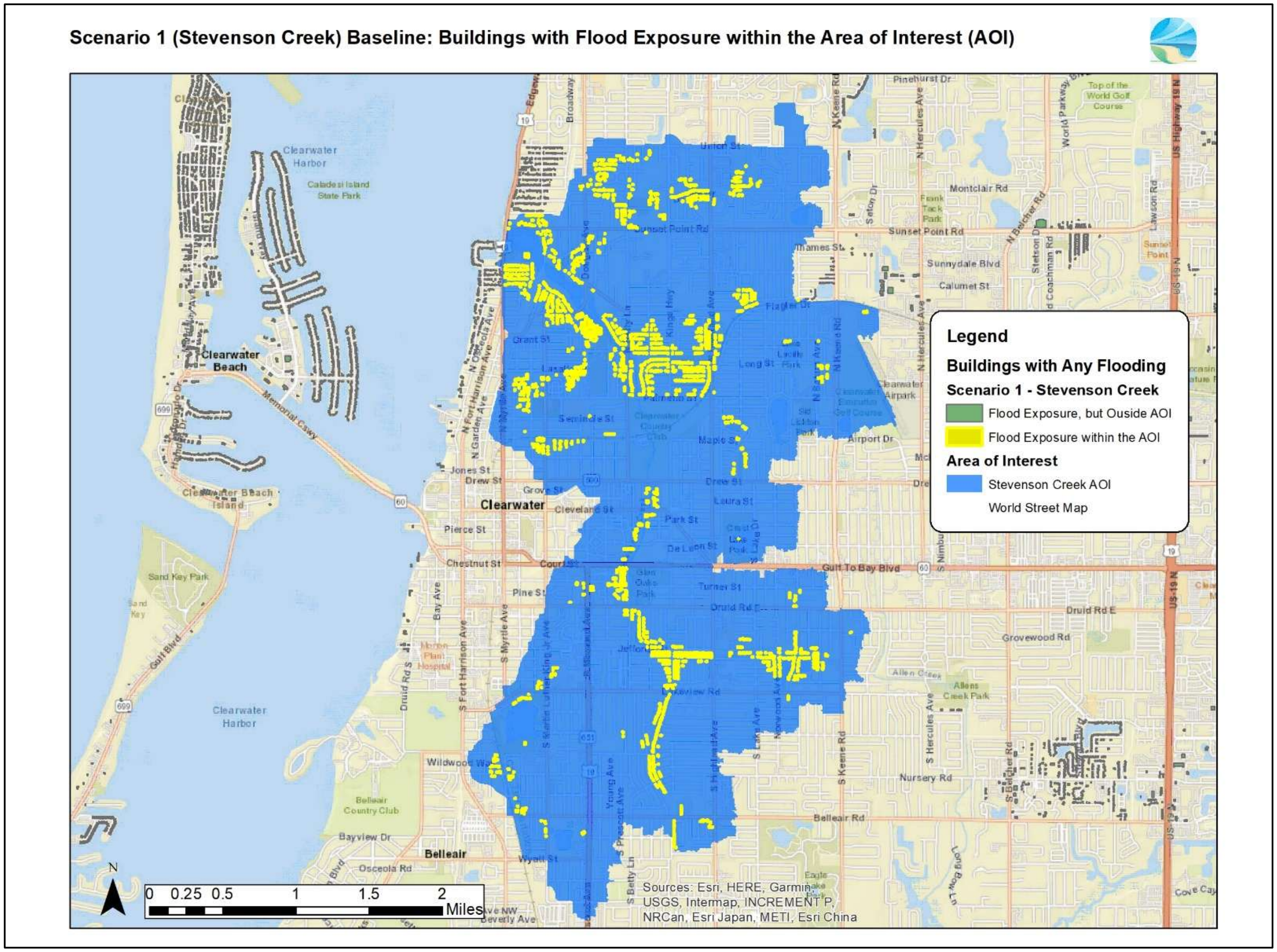


Figure 5-5 - Structures within the Stevenson Creek Watershed that are exposed to future flooding.

5.2.1 Preliminary Results

It is estimated that benefits to the Stevenson Creek watershed from elevating roads and acquiring structures are maximized when approximately $200 million is spent on the 79 projects that show a positive cost to benefit ratio. Implementing these projects is estimated to avoid $297 million in damages. The are recommended for this scenario that evaluated both acquiring structures and elevating roads within the Stevenson Creek watershed. Recommended projects by type per allocation of funding are identified below.

Full Cost Estimate

- Cost of implementation: $197, 340,000
- Number of Projects: 79 Projects
    - Elevate Roads: 8 Projects
    - Acquire Buildings: 71 Projects

75% of Cost Estimate

- Cost of implementation: $145,600,000
- Number of Projects: 44 Projects
    - Elevate Roads: 8 Projects
    - Acquire Buildings: 36 Projects

50% of Budget

- Cost of implementation: $101,000,000
- Number of Projects: 35 Projects
    - Elevate Roads: 5 Projects
    - Acquire Buildings: 30 Projects

25% of Project Costs

- Cost of implementation: $51,000,000
- Number of Projects: 22 Projects
    - Elevate Roads: 4 Projects
    - Acquire Buildings: 18 Projects

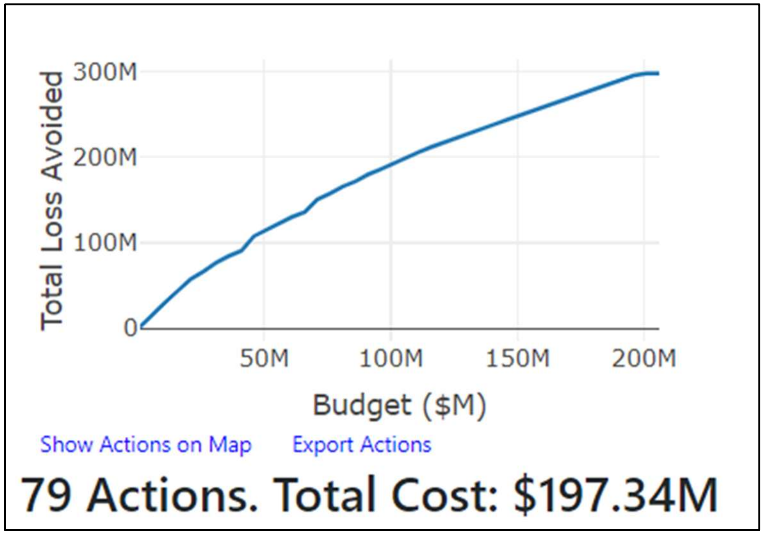


Figure 5-6: Cost to benefit curve generated within the City Simulator tool for the Stevenson Creek scenario.

5.2.1.1 Results Discussion

The results indicate that all projects with a positive (greater than 1) cost-benefit ratio could be done for approximately $197.34M with a benefit of $297.55M in losses avoided.

Table 5-2 - Scenario 1 - Summary of All Projects with a Positive ROI (Greater than 1)

Action Types	Sum of Cost	Count of Projects	Average ROI
Acquire Building	$147,342,000	71	1.28
Elevate Road	$50,000,000	8	2.01
Grand Total	**$197,342,000**	**79**	**1.35**

As shown within the preliminary discussion results above, the distribution of projects (what roads to elevate and what structures to acquire) vary based on the funding that may be available to spend on the mitigation actions.

5.2.1.2 Limitations of Scenario and Opportunities for Improvement

The tool is using elevation data from a LiDAR 2017 base as well as assumptions on the finished floor heights (Ground plus 1 foot for residential finished floor elevation [FFE] estimate and ground plus 0.5 feet for FFE of commercial structures) relative to the LiDAR. Collecting finished floor elevations would greatly improve the projected results. The tool is currently estimating the cost of elevating roads as a function of trips disrupted (see methodology in 4.1.5 above). Using improved data to approximate cost of road would better inform the results per scenario.

The map of the scenario's area of interest above also shows that using a different geographic extent to test may be more practical when reviewing the cluster of flood-exposed structures, particularly in the northern portion of the watershed. There are many structures in the Coastal Zone 1 watershed that are along Clearwater Harbor, and adjacent to the AOI, that might want to be studied collectively to address implementation considerations like public engagement, shared infrastructure and easements, road closures, etc.

Additionally, the City may wish to build from the preliminary results to drill down more specifically into the watershed to look at city-owned property opportunities, social equity within the neighborhoods, and opportunities to align resilient actions with already established capital planning and land use visions.

5.3 Scenario 2: Increase Tree Coverage

Scenario Setup:

Geography:

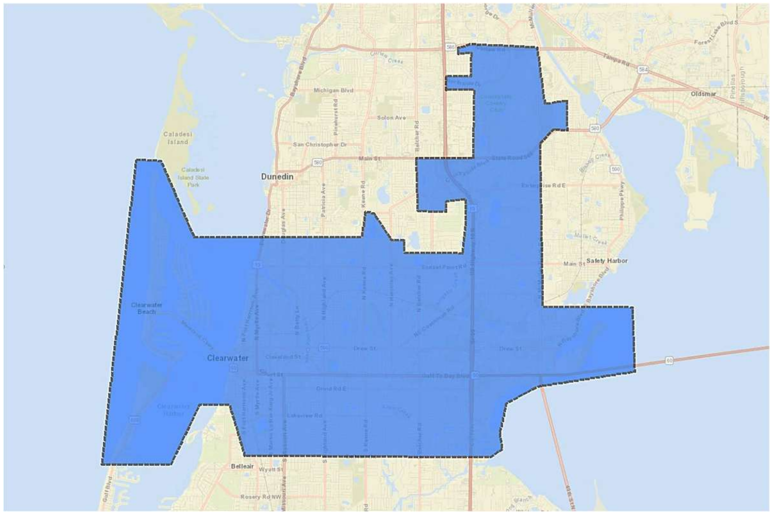
Citywide

Actions to Evaluate:

- Tree plantings

Value to the Community:

Heat exposure citywide is of great concern to the project stakeholders. It was recommended that the tool be used to evaluate locations where providing additional shade has the potential to lower temperatures..



Scenario 2 provides an opportunity to evaluate where the city might benefit most from tree plantings relative to shade and lowering temperatures. The scenario utilizes temperature findings from the exposure and sensitivity processes as well as a tree benefit model (see methodology from 4.1.5).

Stakeholder participants noted that the heat and temperature findings provided opportunities to further evaluate how the city invests in trees and sustainability actions. The model is intended to provide a starting point for how to prioritize geographies that may most benefit from the additional plantings and to build upon the existing tree inventory. As this is a planning level tool, it is intended to provide insights into what locations may most benefit from shade when considering the simulation of people that live or work in an area based on demographic data. Any guidance provided by this document would need to be further evaluated when considering implementation. For example, some tree plantings may not be physically possible in locations, and some locations may not be recommended for plantings per advice of landscape architects.

5.3.1 Preliminary Results

Scenario 2 was a citywide assessment of investment in tree plantings and resulted in 7,248 planting locations with an estimated cost of $3.62M and avoided damages estimated of $5.1M.

Full Cost Estimate

- Cost of implementation: $3,620,000
- Number of Projects: 7,248 Projects

Note that relative to other mitigation/adaptation actions, the cost of trees is relatively affordable. Thus, the tool's budget increments of $5 million provide less insight on the count of actions at smaller percentages budget. The graphic on the following page provides the spatial allocation of where the city would receive the most heat reduction benefits by planting trees.

Figure 5-7: Cost to benefit curve generated within the City Simulator tool for scenario 2.

5.3.1.1 Results Discussion

The results indicate that all projects with a positive (greater than 1) cost-benefit ratio could be done for approximately $3.6M, with a benefit of $5.1M in losses avoided when tree plantings are implemented across the city as shown below.

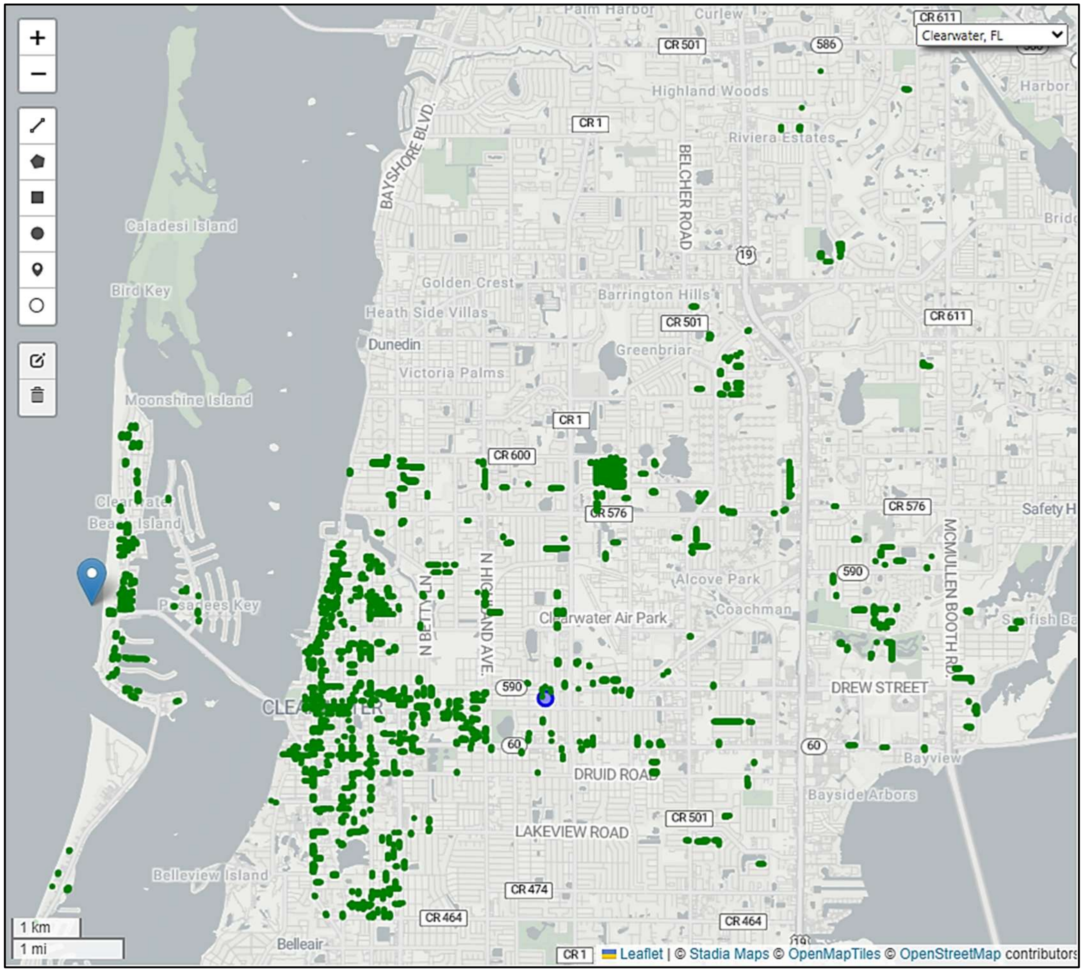


Figure 5-8 - Tree plantings investments citywide (100% budget)

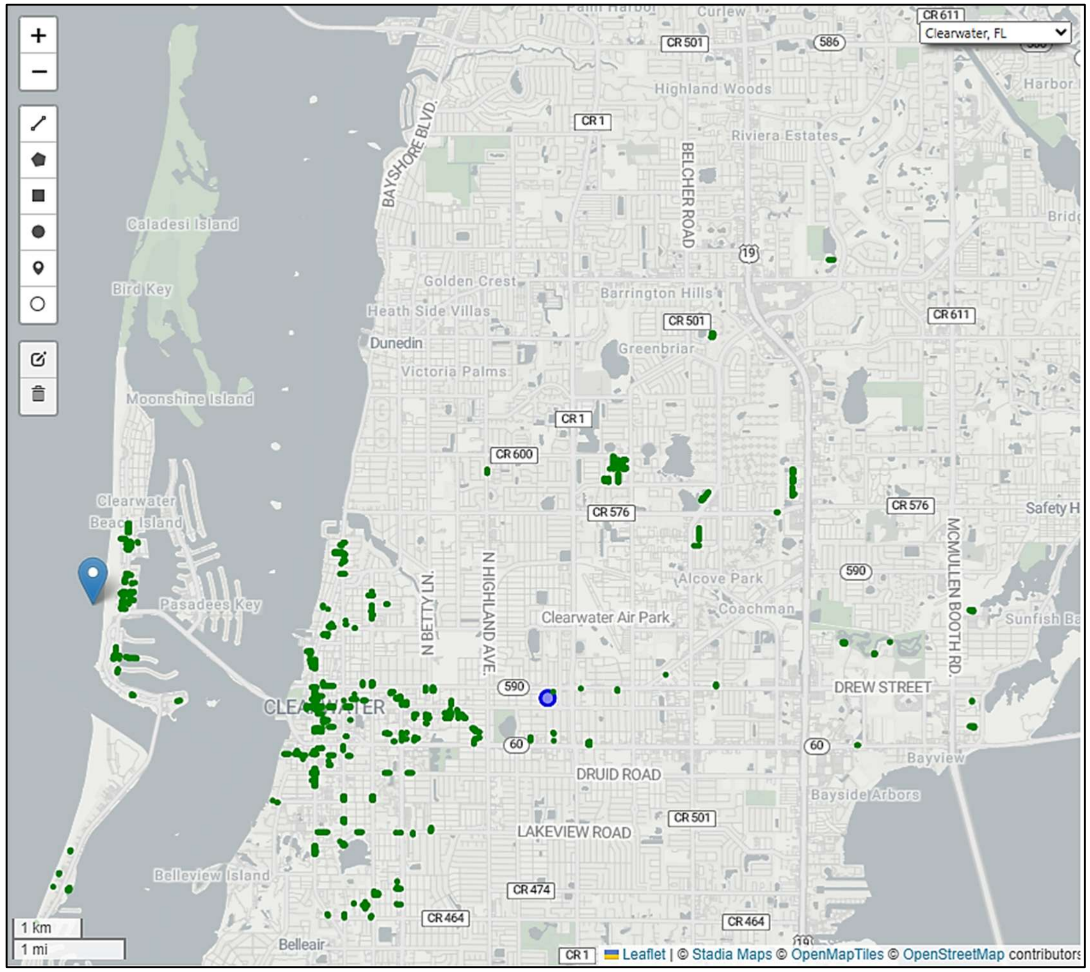


Figure 5-9 - Tree plantings with highest ROI citywide (20% budget)

5.3.1.2 Limitations of Scenario and Opportunities for Improvement

Scenario 11 was added to help refine how the city can further evaluate opportunities to add tree plantings across the community. The model makes use of the city's parcel fabric and demographics to estimate relative benefits to tree planting locations per the methodology identified in 4.1.5. The City should consider building upon the model with information from the existing tree inventory regarding probable types of trees to be planted, estimate of shade/temperature decrease per type, and costs to install (currently a flat amount in the model).

5.4 Scenario 3: Elevate Seawalls

Scenario Setup:

Geography:

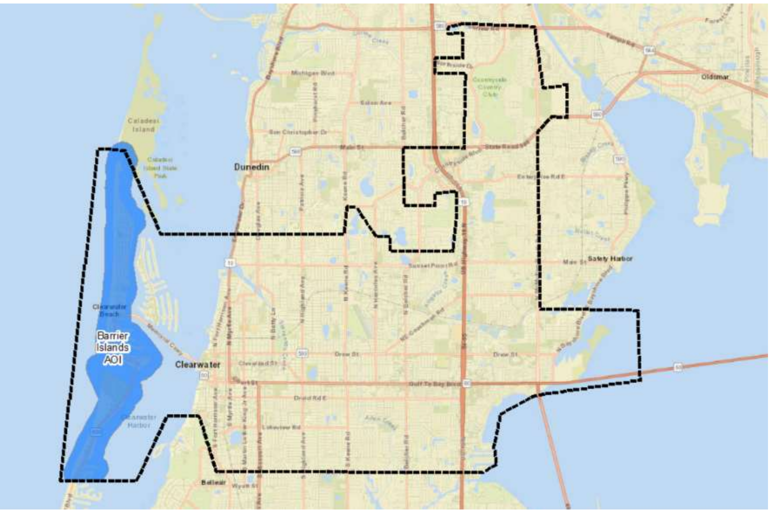
Barrier Islands

Actions to Evaluate:

- Elevate Seawalls

Value to the Community:

The City's barrier islands have structures with some of the most frequent flood occurrences under today's conditions. Stakeholders thought there would be value in looking at reductions in losses if walls were raised..



Scenario 3 was developed to evaluate what additional protection might be offered by elevating seawalls from their current elevation (approximately 3-feet) to 5 feet. The barrier islands are impacted by tidal flooding under today's conditions and minor storms. It was also noted that the city has additional projects ongoing or about to begin that might also benefit from a deeper understanding of the flood vulnerabilities and opportunities to mitigate. It is also important to recognize that most of the seawalls are private and not owned/maintained by the city. This planning tool is designed to facilitate the discussion of possible actions that the community may want to consider when evaluating actions that can reduce flood damages.

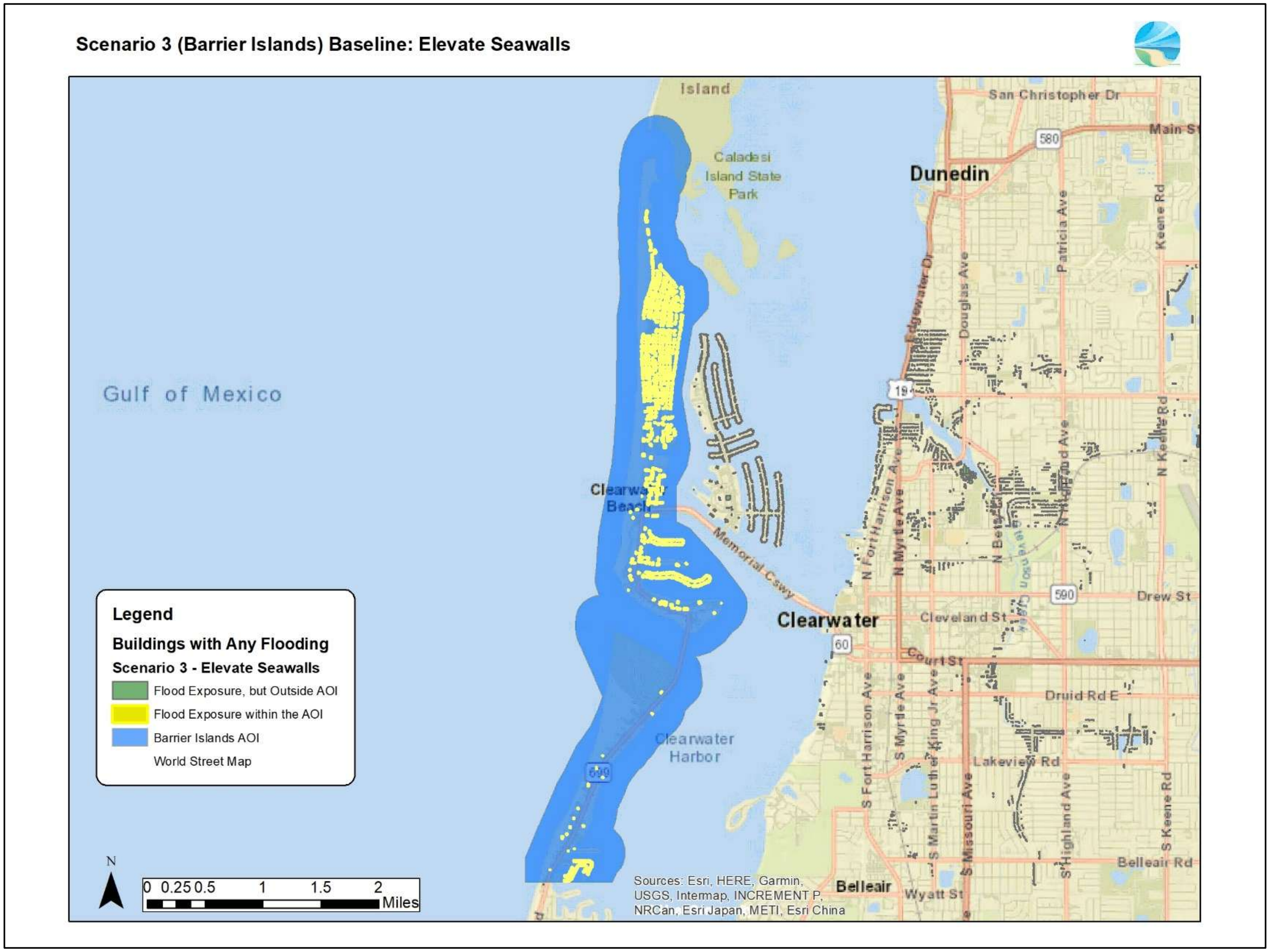
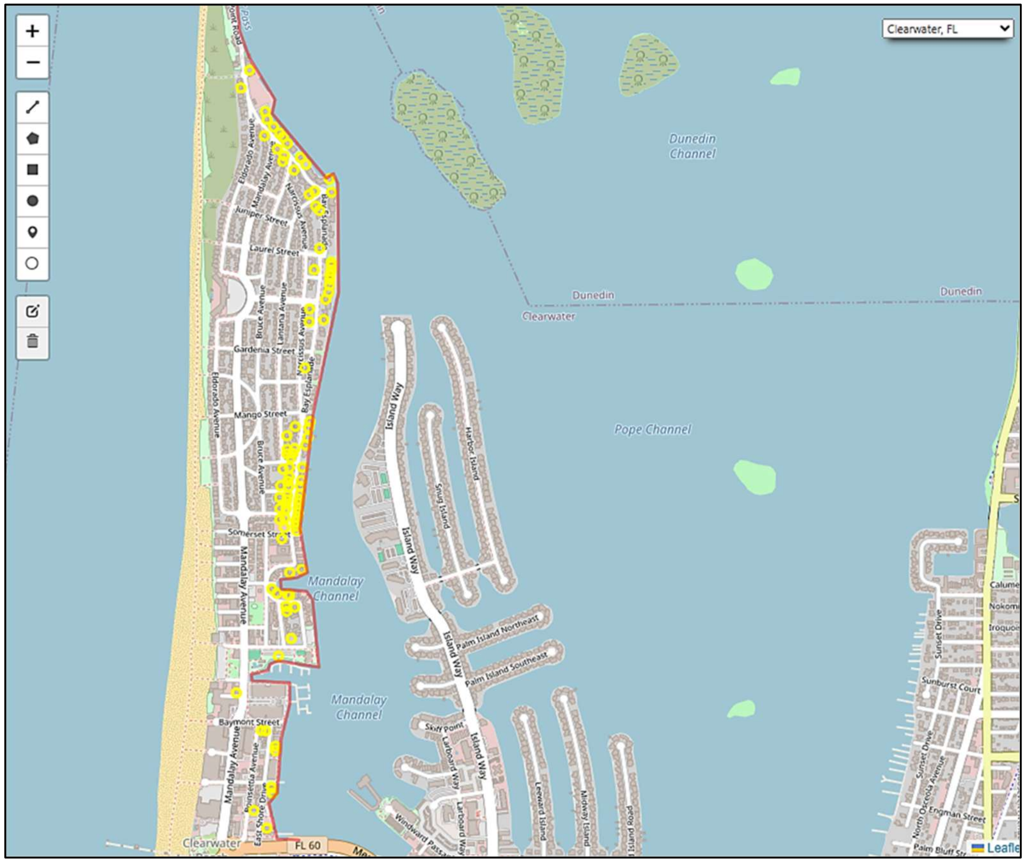


Figure 5-10 - Structures within the Barrier Islands Area of Interest that are exposed to future flooding.

5.4.1 Preliminary Results

The tool currently allows the user to draw a seawall, select the elevation, and then returns statistics relative to the length of seawall, approximate cost, and structures protected. For the Barrier Islands scenario, 4 seawall segments were developed to test their potential effectiveness. Each seawall was set to 5-feet NAVD88.

Segment 1-North Beach (North of SR.60/Gulf to Bay)



Structures Protected

- 96

Length of Seawall

- Approximately 15,065 feet

Cost

- Lower Bound: $2,259,750
- Upper Bound: $30,131,00

Note that the tool provides a cost output that references the most conservative (highest) estimate of $2,000 per linear foot which is typical in commercial or high-erosion areas.

Residential projects can be anywhere from $150 to $600 per linear foot.

Thus, this segment could range in costs from $2.25M to $30.13M.

Figure 5-11: Segment 1 - North Beach seawall elevation simulation

Segment 2-South Beach (South of SR.60/Gulf to Bay south to Clearwater Pass Bridge)

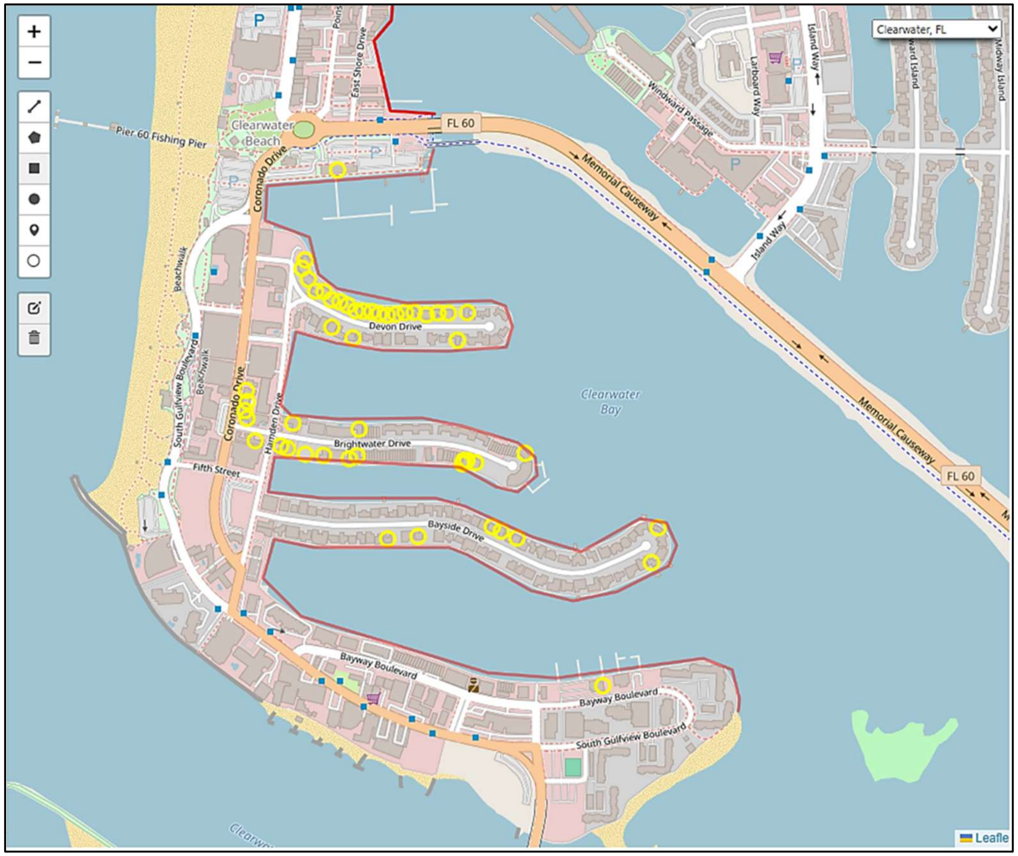


Figure 5-12: Segment 2 - South Beach seawall elevation simulation

Structures Protected

- 50

Length of Seawall

- Approximately 19,415 feet

Cost

- Lower Bound: $2,912,250
- Upper Bound: $38,830,000

Note that the tool provides a cost output that references the most conservative (highest) estimate of $2,000 per linear foot which is typical in commercial or high-erosion areas.

Residential projects can be anywhere from $150 to $600 per linear foot.

Thus, this segment could range in costs from $2.91M to $38.83M.

Segment 3-South Beach (Clearwater Pass Bridge south to 1400 Gulf Blvd)

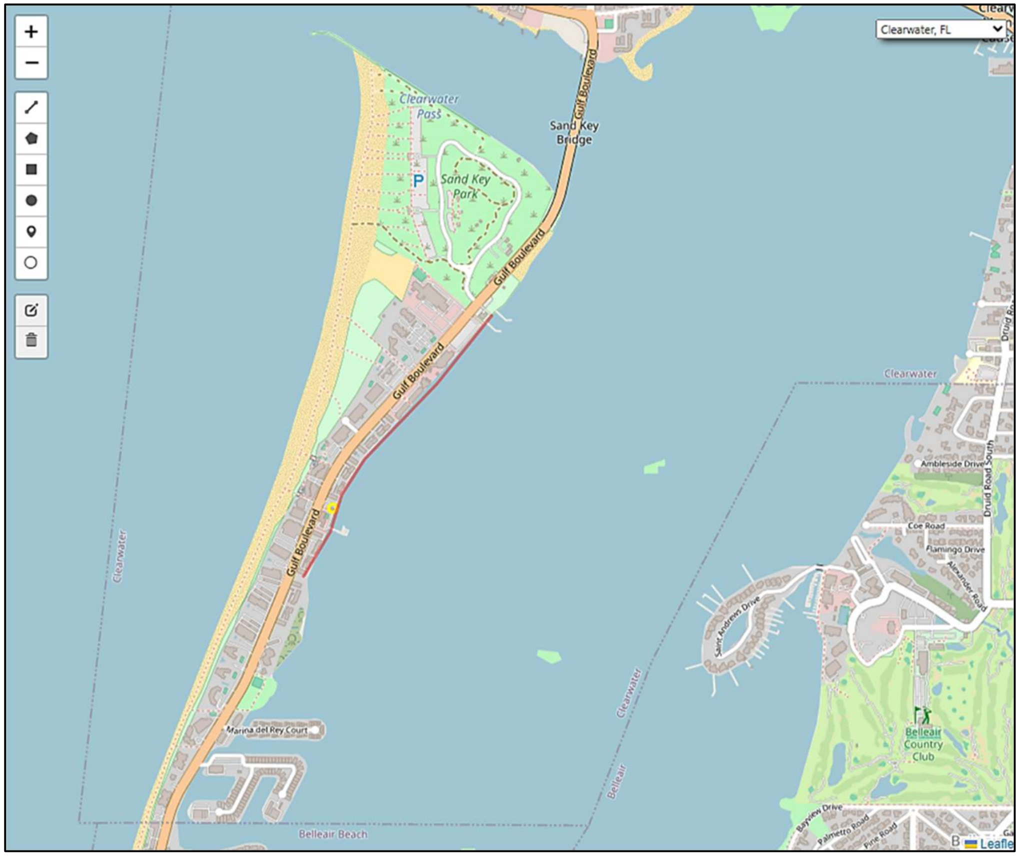


Figure 5-13: Segment 3 - South Beach seawall elevation simulation

Structures Protected

- 2

Length of Seawall

- Approximately 4,343 feet

Cost

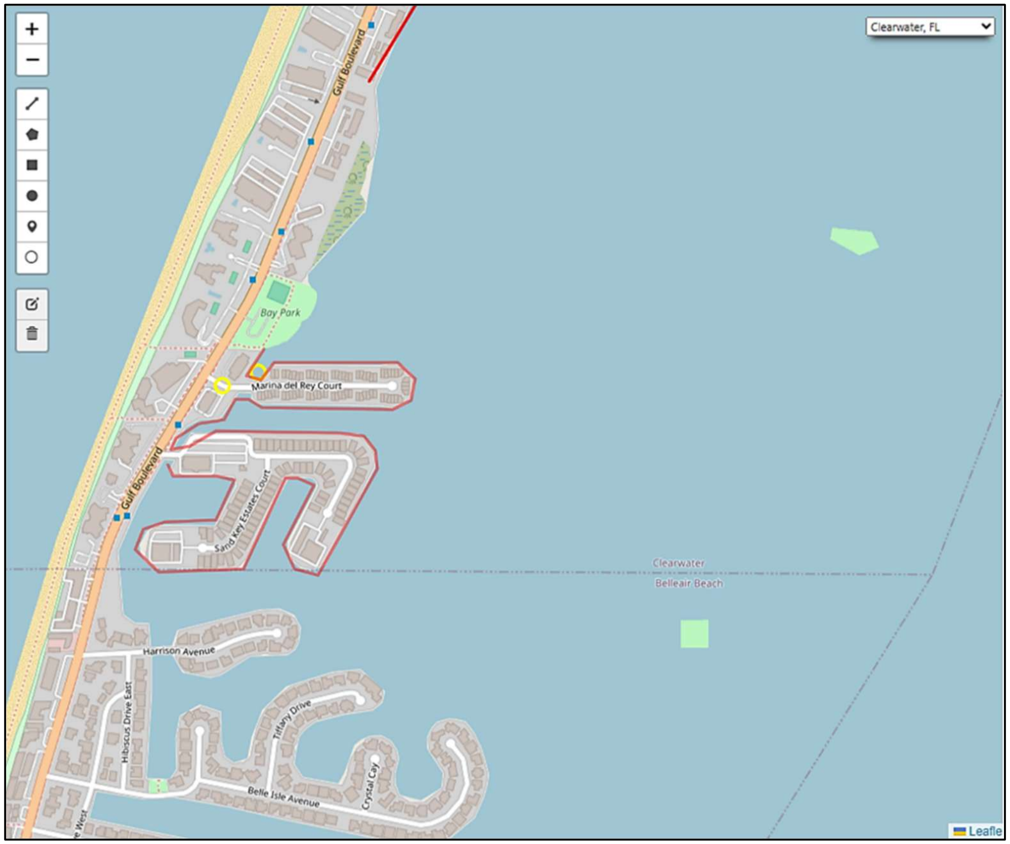
- Lower Bound: $651,450
- Upper Bound: $8,686,000

Note that the tool provides a cost output that references the most conservative (highest) estimate of $2,000 per linear foot which is typical in commercial or high-erosion areas.

Residential projects can be anywhere from $150 to $600 per linear foot.

Thus, this segment could range in costs from $651K to $8.67M.

Segment 4-North Beach (North of SR.60/Gulf to Bay)



Structures Protected
- 2

Length of Seawall
- Approximately 9,754 feet

Cost
- Lower Bound: $1,463,100
- Upper Bound: $19,508,000

Note that the tool provides a cost output that references the most conservative (highest) estimate of $2,000 per linear foot which is typical in commercial or high-erosion areas.

Residential projects can be anywhere from $150 to $600 per linear foot.

Thus, this segment could range in costs from $1.46M to $19.51M.

Figure 5-14: Segment 4 - South Beach seawall elevation simulation

5.4.1.1 Results Discussion

The results show that the scenario of raising the seawall an additional 2 feet (above the estimated average height of 3 feet) to a total of 5-feet would protect the most structures in the North Beach portion of the Barrier Islands study area. Many of these structures are private and not owned/maintained by the city. Close to 100 structures would receive additional protection under the scenario. The segment to the south of SR.60/Gulf to Bay south to Clearwater Pass Bridge also has the potential to protect an additional 50 structures but includes a longer segment of seawall, meaning a lower cost-benefit. However, the results show that the segment 2 could be shortened as the southernmost portion of the segment only protects one additional structure. The two southernmost segments have very limited benefit per the current model results.

5.4.1.2 Limitations of Scenario and Opportunities for Improvement

As with the results of all scenarios, better assessment of finished floor elevation [FFE] estimates would greatly improve the insights provided by the tool. The tool is currently limited to identifying structures protected by the seawall but is not capable of additional quantification of benefits. Furthermore, estimated costs of repair are challenging for seawalls as cost for seawalls vary greatly, where typically the low end for a minor wall might be $500 per linear foot (LF) and a more robust, but short, seawall may be $2,000/LF or more. That would be just the wall and related elements, not any other upland improvements. The costs are dependent on the following:

- Height of wall
- Soils in location (i.e., locations with high presence of organic layers will be more expensive and robust)
- Material of seawall and cap (concrete, steel, vinyl, FRP, etc.)
- Are tie-rods needed? If so, costs would increase further.

As a note, our engineers indicate that there are not a lot of conventional ways to add elevation to a seawall. Most current designs generally account for some future elevating of the seawalls, but most existing seawalls are not designed to take added load attributed to elevation. Adding 2 feet or more to a seawall will likely require a new wall, or possibly a stepped wall, which would be set back slightly from the existing wall. It is unlikely to see appreciable savings by “elevating” vs building a new wall to achieve the added seawall elevation.

5.5 Scenario 4: Coastal Zone 3

Scenario Setup:

Geography:

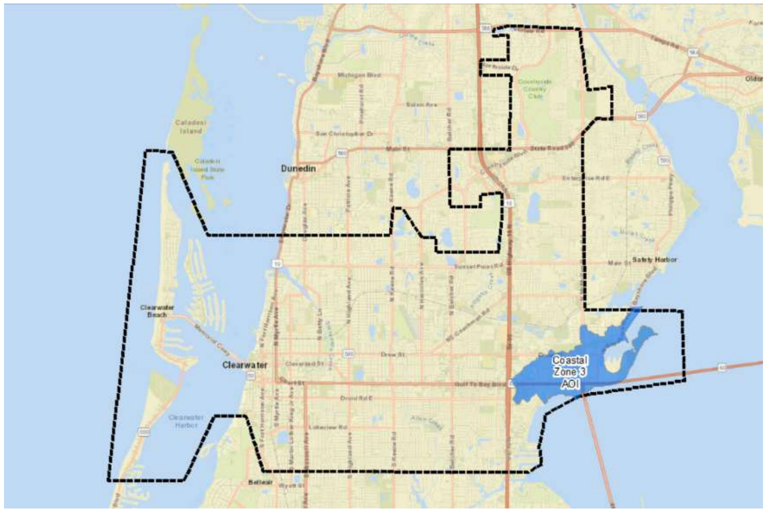
Coastal Zone 3

Actions to Evaluate:

- Elevate Roads

Value to the Community:

This geography is one with high exposure to tidal and rainfall flooding. There are also ongoing studies in the area that may be able leverage results of the analysis.



The Coastal Zone 3 scenario provides an opportunity to evaluate what the estimated costs and benefits are if flood-exposed roads were elevated. The watershed is approximately 1.6 square miles in size with baseline results of 153 structures exposed to at least some level of flood depths per future conditions. These structures are experiencing flooding as either increases in tidal surge or from increased rainfall events.

Stakeholder participants noted that the citywide flood exposure maps showed large clusters of structures within the watershed making it a good candidate for further analysis. It was also noted that the City has additional projects ongoing or about to begin that might also benefit from a deeper understanding of the flood vulnerabilities and opportunities to mitigate. As seen in the graphic on the following page, this area also has the potential to have significant transportation impacts along Bayshore Drive that may need to be mitigated.

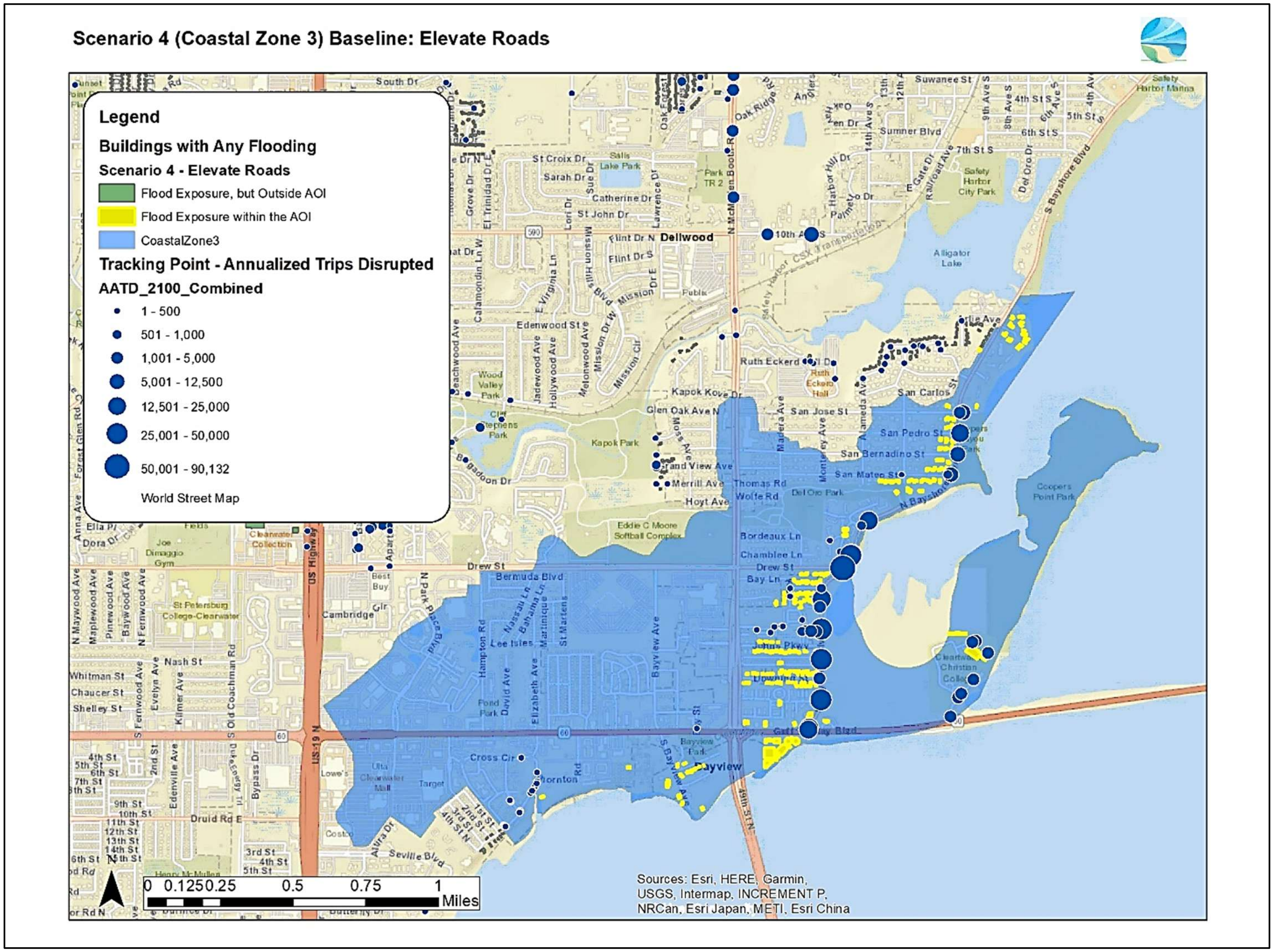


Figure 5-15 - Structures and tracking points within the Coastal Zone 3 Watershed that are exposed to future flooding.

5.5.1 Preliminary Results

It is estimated that benefits to the Coastal Zone 3 watershed from elevating roads are maximized when approximately $70 million is spent on the 14 road elevation projects that show a positive cost to benefit ratio. Implementing these projects is estimated to avoid $213 million in damages. Recommended projects per allocation of funding are identified below).

100% of Potential Costs (All projects)

- Cost of implementation: $71,000,000
- Number of Projects: 14 Projects

75% of Project Costs

- Cost of implementation: $50,000,000
- Number of Projects: 10 Projects

50% of Project Costs

- Cost of implementation: $35,000,000
- Number of Projects: 7 Projects

25% of Project Costs

- Cost of implementation: $16,000,000
- Number of Projects: 3 Projects

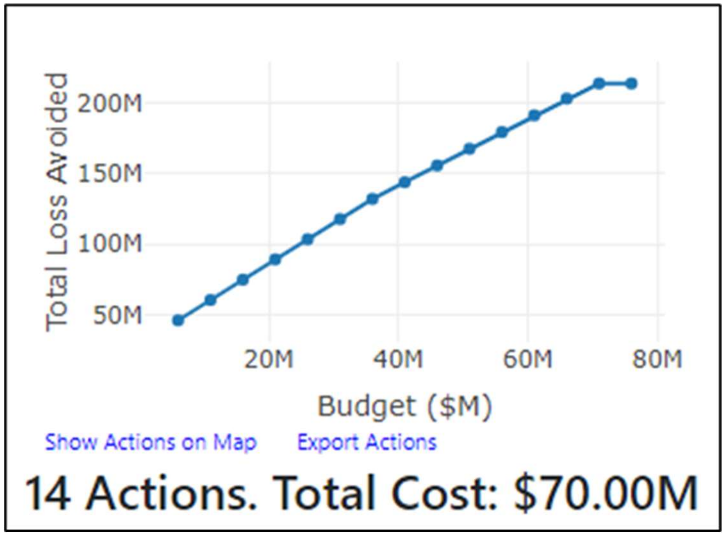


Figure 5-16: Cost to benefit curve generated for scenario 4.

5.5.1.1 Results Discussion

The image below is the 25% budget scenario, which helps to illustrate the potential priority projects where there is the greatest return on investment. The map shows the three road segments that the city may wish to further assess in Coastal Zone 3.

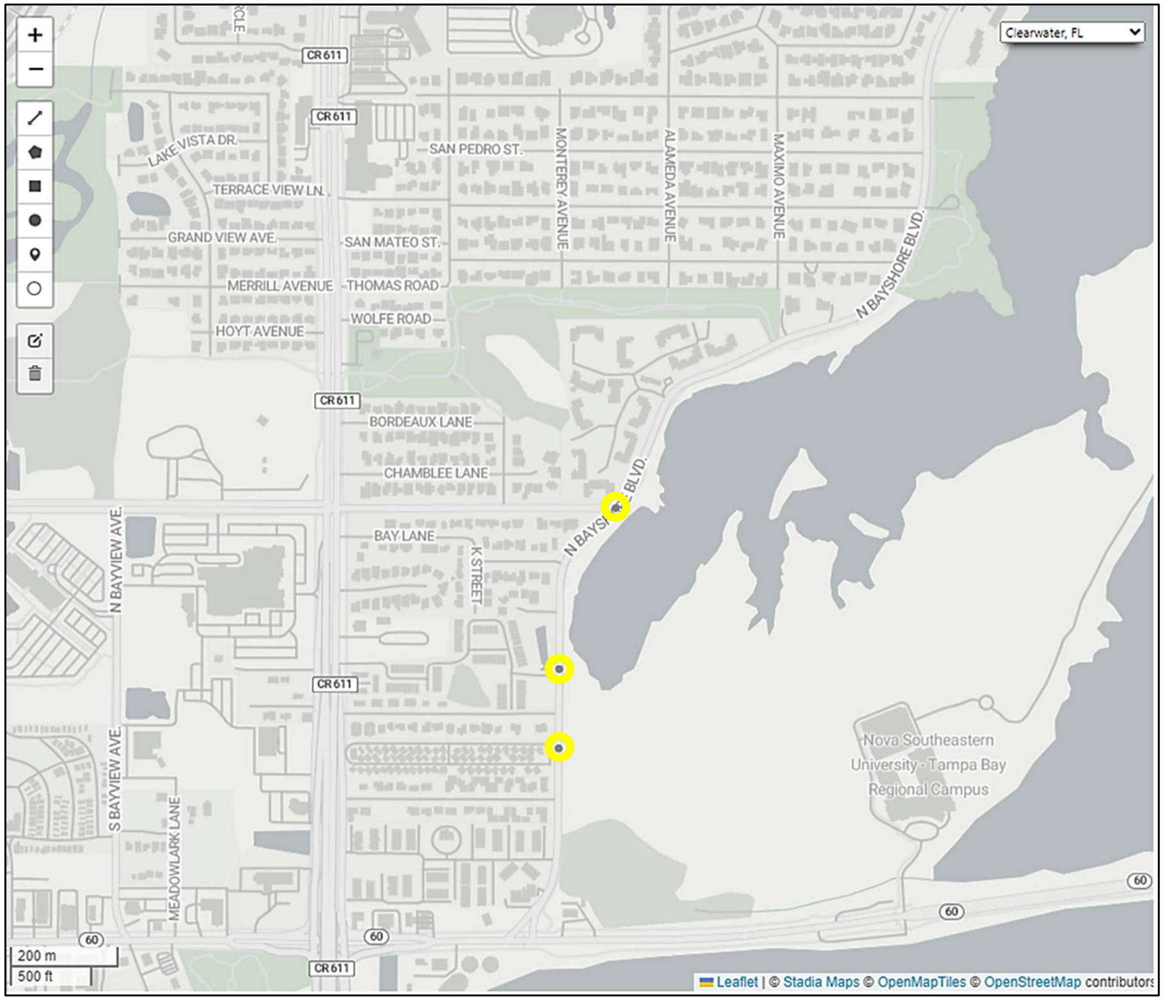


Figure 5-17 - Road elevation projects (dark grey dots) with the best ROI per the 25% budget scenario.

5.5.1.2 Limitations of Scenario and Opportunities for Improvement

The tool is using elevation data from a LiDAR 2017 base as well as assumptions on the finished floor heights (Ground plus 1 foot for residential finished floor elevation [FFE] estimate and ground plus 0.5 feet for FFE of commercial structures) relative to the LiDAR. Collecting finished floor elevations would greatly improve the projected results. The tool is currently estimating the cost of elevating roads based on a function of average annual daily trips. Using better data to approximate cost of road would better inform the results per scenario.

5.6 Scenario 5: Elevate Structures on Barrier Islands

Scenario Setup:

Geography:

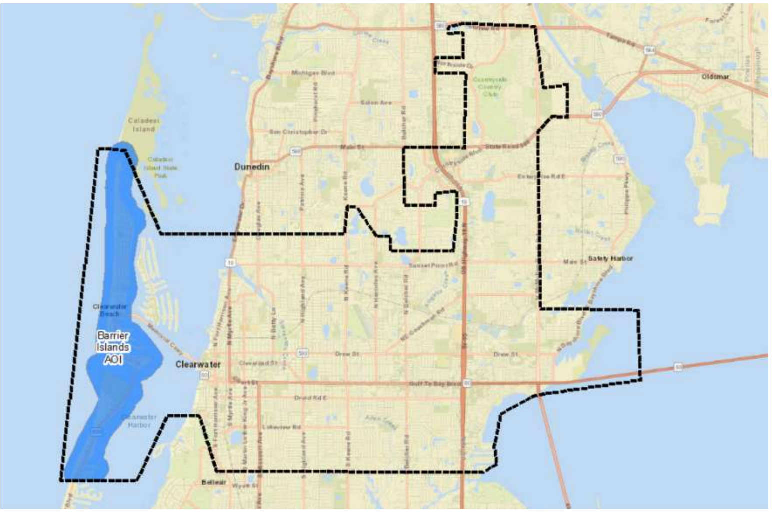
Barrier Islands

Actions to Evaluate:

- Elevate Structures

Value to the Community:

This geography is one with high exposure to tidal flooding. There are also ongoing studies in the area that may be able leverage results of the analysis.



As indicated in Scenario 3 above, the Barrier Islands area of interest is very susceptible to current and future flood events with approximately 1,000 structures at risk. To further evaluate options for protecting the community, the stakeholders decided to evaluate how elevating structures could benefit the area.

5.6.1 Preliminary Results

It is estimated that benefits from elevating structures within the barrier islands are maximized when approximately $88 million is spent on 602 projects that show a positive cost to benefit ratio. Implementing these projects is estimated to avoid $240 million in damages. Recommended projects per allocation of funding are identified below.

100% of Potential Costs (All projects)
- Cost of implementation: $88, 053,000
- Number of Projects: 602 Projects

75% of Project Costs
- Cost of implementation: $66,000,000
- Number of Projects: 428 Projects

50% of Project Costs
- Cost of implementation: $45,967,000
- Number of Projects: 294 Projects

25% of Project Costs
- Cost of implementation: $25, 997,000
- Number of Projects: 15 Projects

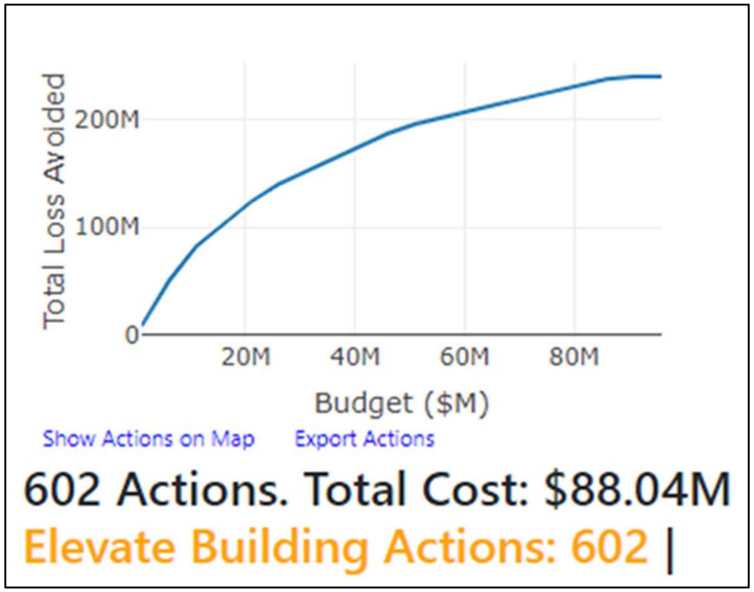


Figure 5-18: Cost to benefit curve generated for scenario 5.

5.6.1.1 Results Discussion

The biggest takeaway from the initial results is probably the location of projects. The image below is the 25% scenario, meaning if only $21 million of the estimated $88 million needed to elevate structures, the largest benefit to cost is for these 90 properties along Clearwater Harbor north and south of SR60.

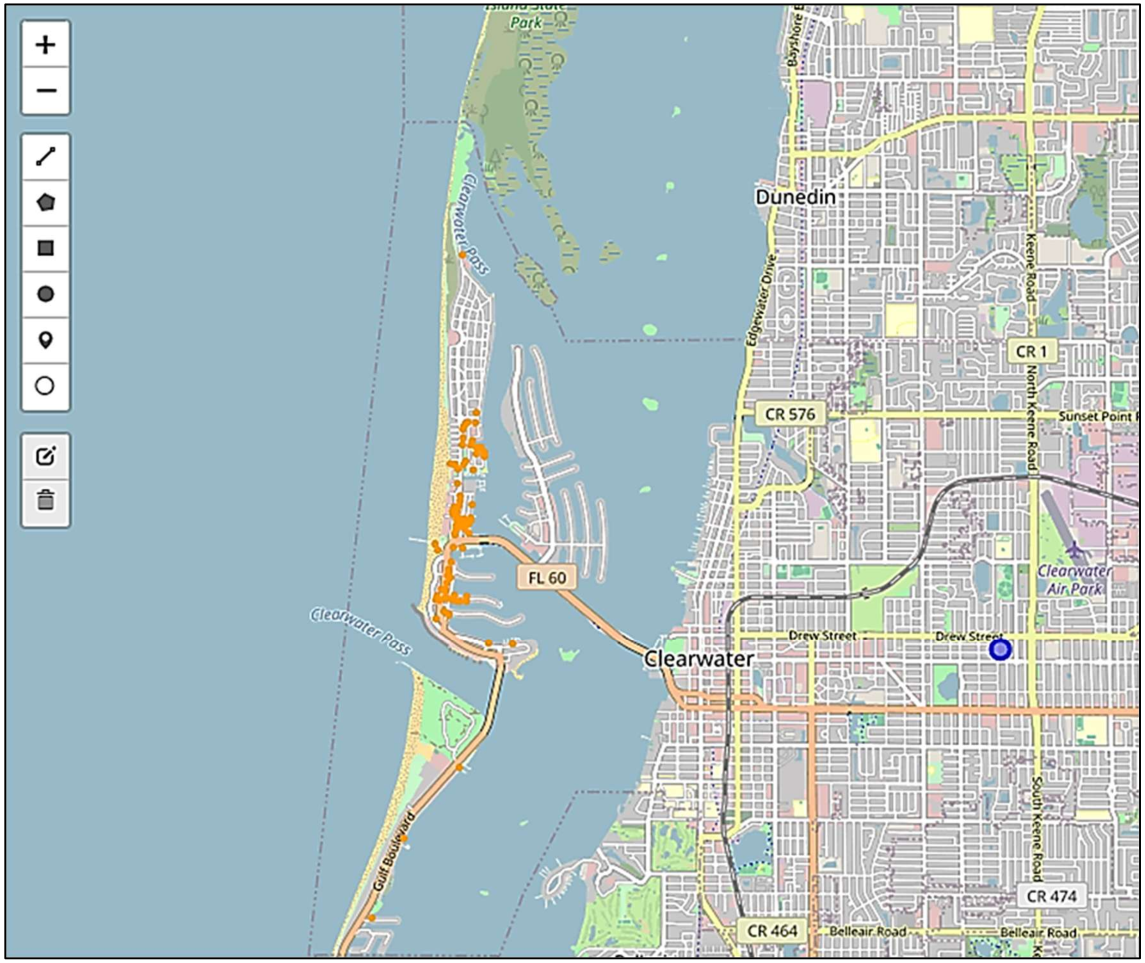


Figure 5-19 - 25% budget recommendation for Scenario 5 (Elevate structures on the Barrier Islands)

5.6.1.2 Limitations of Scenario and Opportunities for Improvement

As with the results of all scenarios, better assessment of finished floor elevation [FFE] estimates would greatly improve the insights provided by the tool. It would also benefit to understand realistic expectations of elevations due to different foundation types, associated costs per type of elevation, and limitations of elevations due to zoning requirements. Future iterations of the model may want to apply a different weighting to consider repetitive losses and severe repetitive losses when evaluating benefit to cost figures. There are 57 repetitive loss properties and 8 severe repetitive loss properties within the area of interest. The city could look at this area in more detail as well as other repetitive loss locations to develop a repetitive loss area analysis which could give them additional credit under the Activity 510 of FEMA's Community Rating System (CRS).

5.7 Scenario 6: Acquisition of Structures Citywide

Scenario Setup:

Geography:

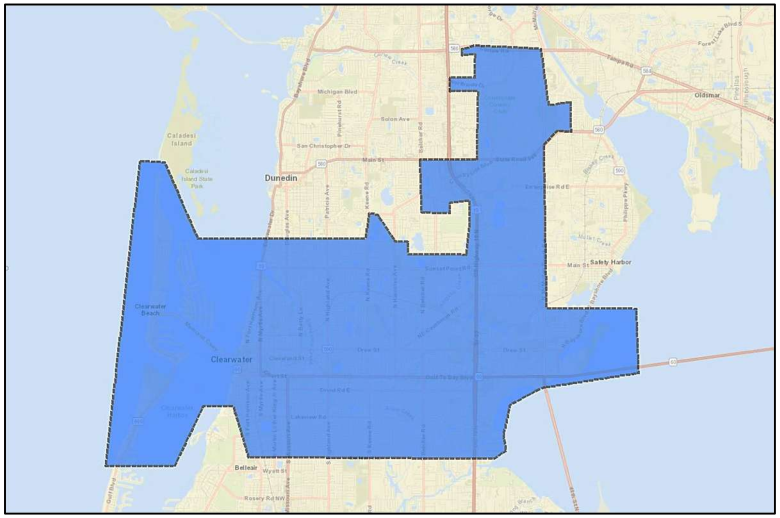
Citywide

Actions to Evaluate:

- Acquire Structures

Value to the Community:

Grant funds are available to protect structures from flooding. The City is interested in identifying locations of structures that may be good candidates for acquisitions..



The most effective form of mitigation is to remove the asset from its exposure to the hazard. Within the city limits, there are approximately 4,600 structures with potential for flood exposure. This assessment will look at the costs and losses avoided that are expected by acquiring structures across the city.

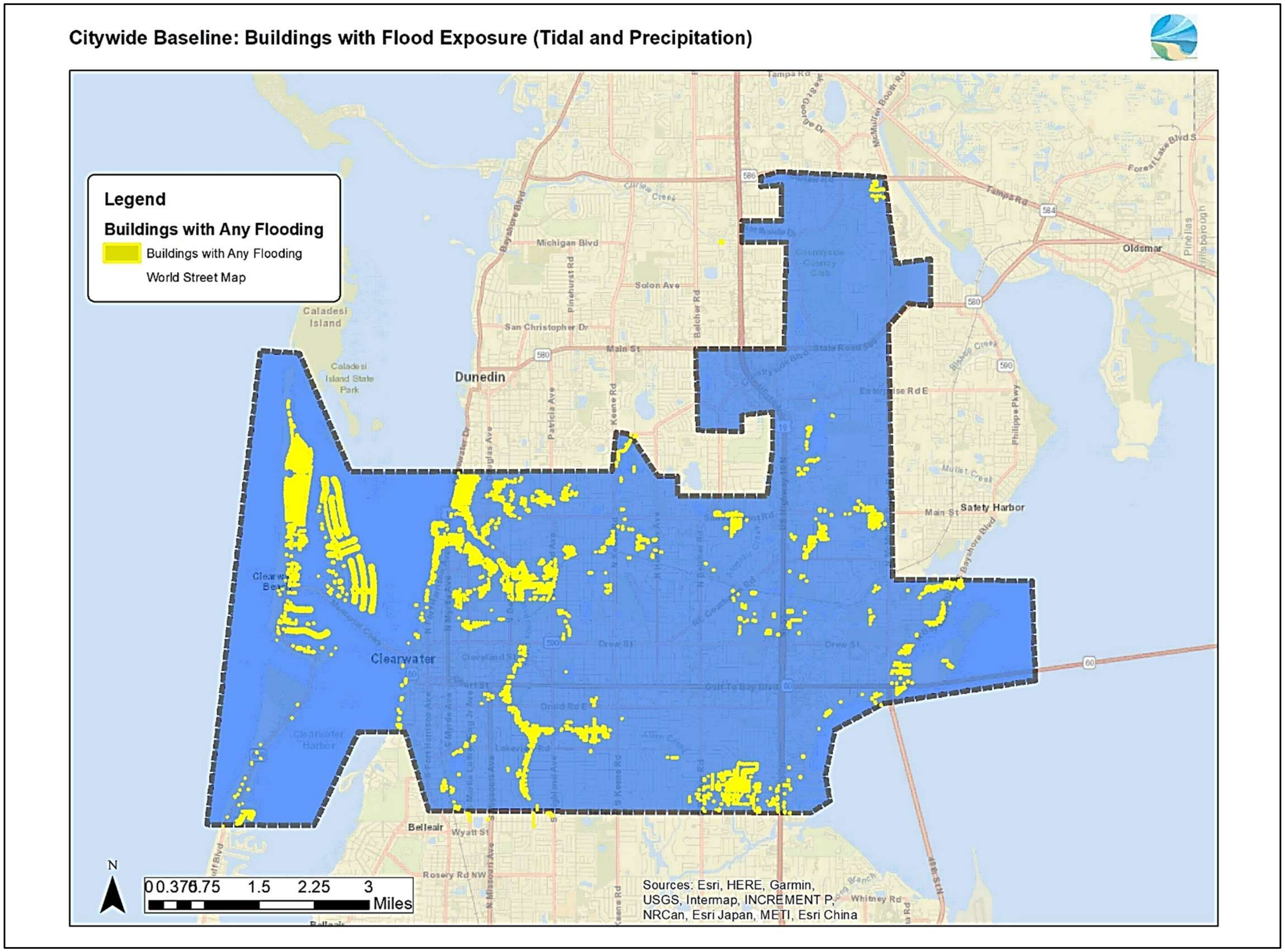


Figure 5-20-Citywide structures that are exposed to future flooding.

5.7.1 Preliminary Results

It is estimated that benefits from acquiring structures across the city are maximized when approximately $1.5 billion is spent on 1,282 projects that show a positive cost to benefit ratio. Implementing these projects is estimated to avoid $2.45 billion in damages. Recommended projects per allocation of funding are identified below.

100% of Potential Costs (All projects)
- Cost of implementation: $1,522,228,000
- Number of Projects: 1,282 Projects

75% of Project Costs
- Cost of implementation: $1,140,000,000
- Number of Projects: 830 Projects

50% of Project Costs
- Cost of implementation: $761,000,000
- Number of Projects: 423 Projects

25% of Project Costs
- Cost of implementation: $381,000,000
- Number of Projects: 271 Projects

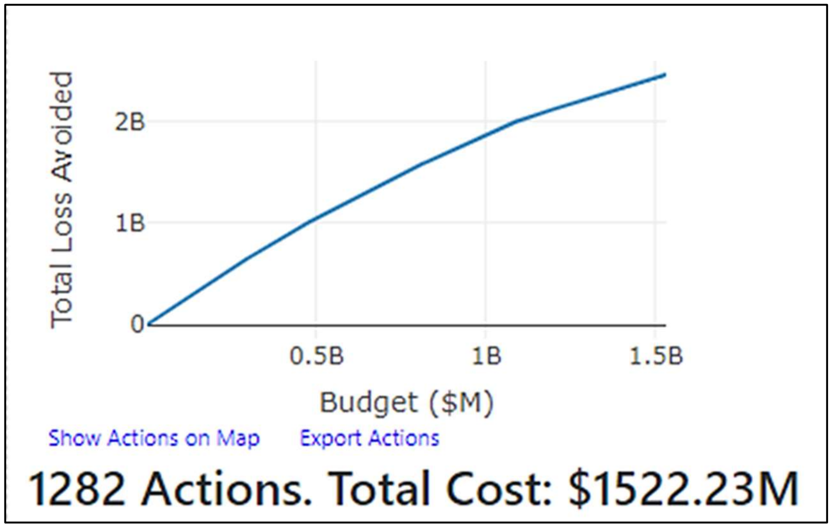


Figure 5-21: Cost to benefit curve generated for acquisitions of structures citywide.

5.7.1.1 Results Discussion

The image below is the 25% scenario, which helps to illustrate the potential priority projects where there is the greatest return on investment. The map helps to show some of the distinct clusters where the city may wish to further assess the viability of acquiring structures in these geographies.

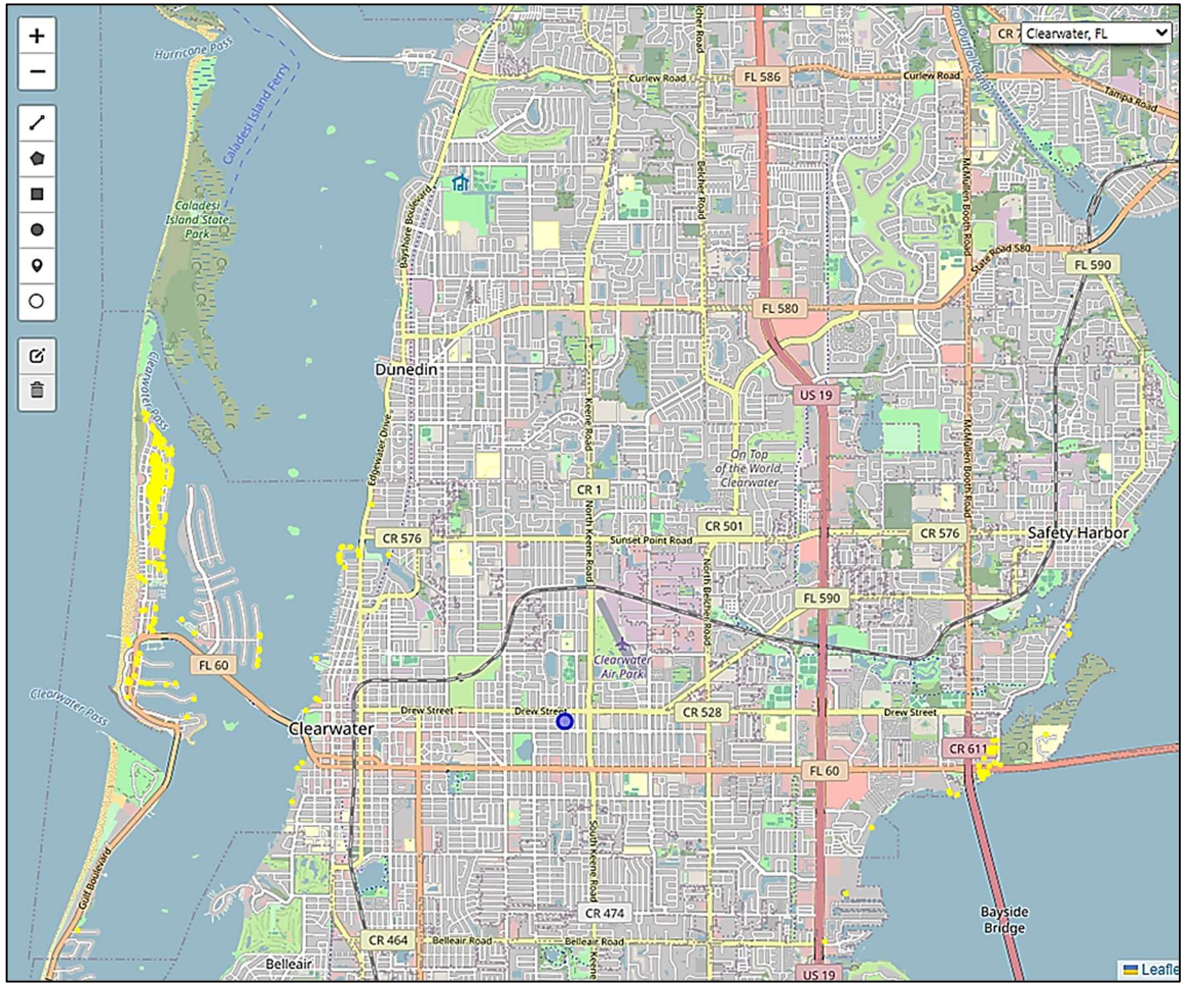


Figure 5-22 - Structures (yellow dots) with the highest ROI for the 25% budget citywide acquisition scenario.

5.7.1.2 Limitations of Scenario and Opportunities for Improvement

As with the results of all scenarios, better assessment of finished floor elevation [FFE] estimates would greatly improve the insights provided by the tool. It would also benefit to understand realistic expectations of acquisitions based on public sentiment, costs associated with relocations, and focusing on specific clusters of acquisition targets where the area could be turned into a regional stormwater pond or other community amenity. Future iterations of the model may want to apply a different weighting to consider repetitive losses and severe repetitive losses when evaluating benefit to cost figures for acquisitions.

5.8 Scenario 7: Hercules and US 19 Corridors

Scenario Setup:

Geography:

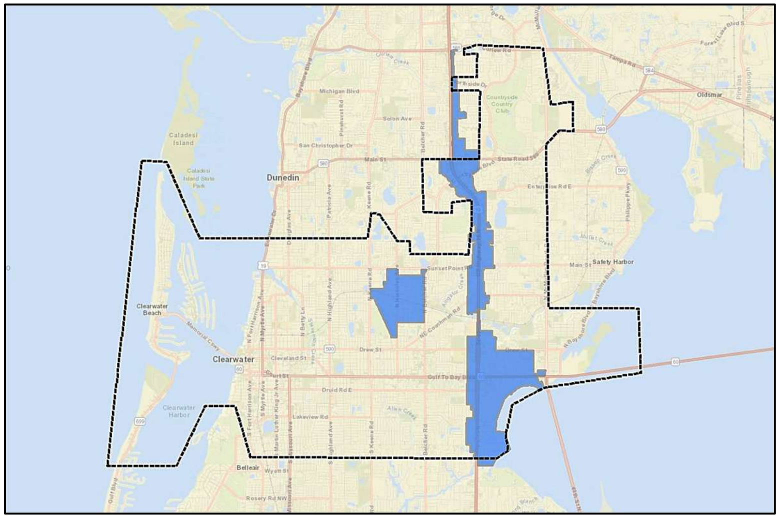
Hercules and US 19

Actions to Evaluate:

- Acquire Structures

Value to the Community:

City staff indicated that there are ongoing plans for additional investment into these areas and thus it would be helpful to understand what flood vulnerable structures would be best candidates for acquisition..



The Hercules and US 19 corridors were selected by the project action team to evaluate these areas that are expected to receive investment for economic redevelopment. The locations are part of the Clearwater 2045 Plan and elaborated on within Goal QP 2 (Quality Places) of that document. The area has approximately 80 structures exposed to flooding from additional climate projections of rainfall and sea level rise.

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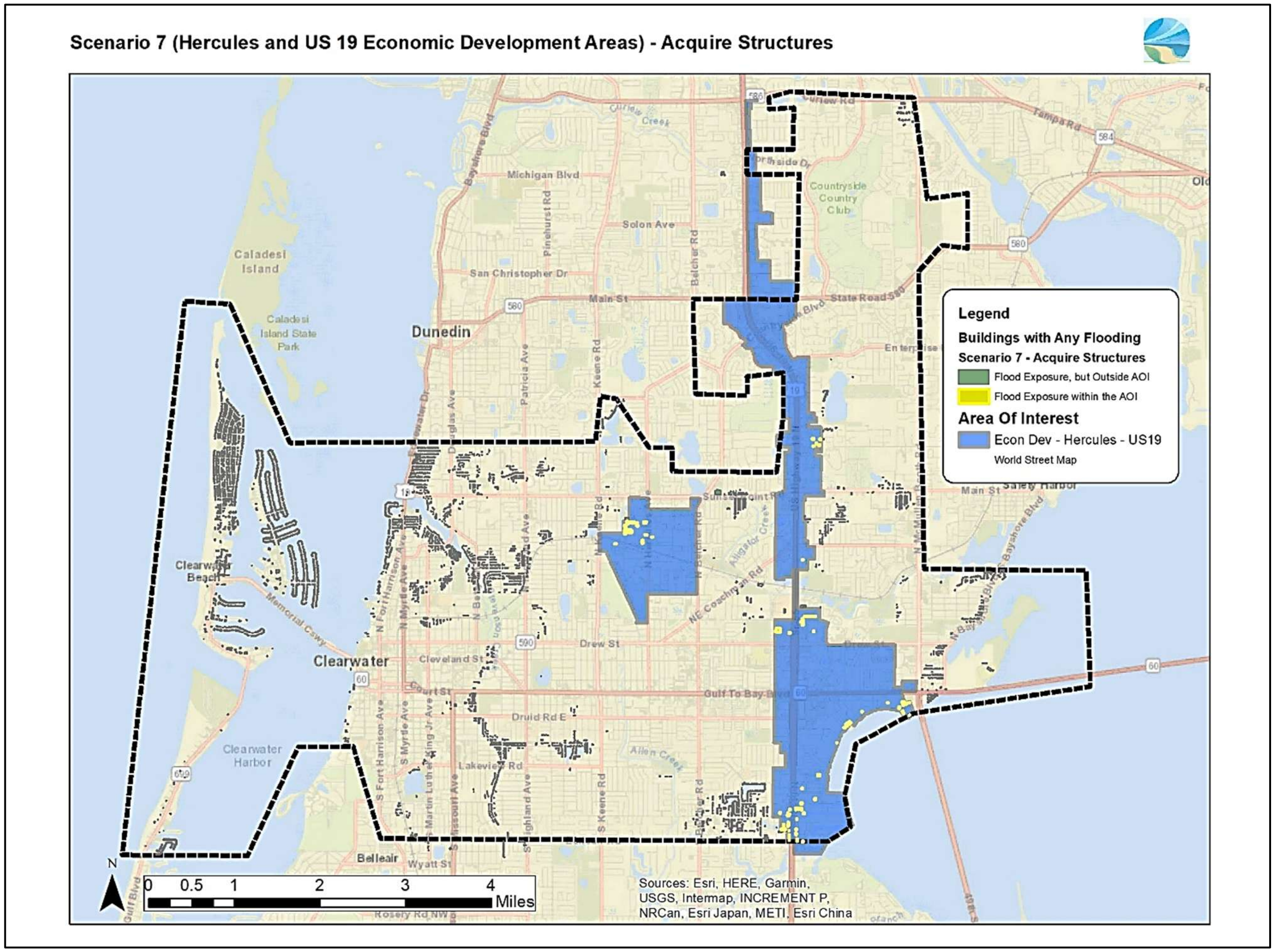


Figure 5-23 - Structures within the US 19 and Hercules economic development areas that are exposed to future flooding.

5.8.1 Preliminary Results

It is estimated that benefits from acquiring structures within the US 19 and Hercules economic redevelopment areas are maximized when approximately $26.35 million is spent on 8 acquisition projects that show a positive cost to benefit ratio. Implementing these projects is estimated to avoid $43.17 million in damages. Recommended projects per allocation of funding are identified below.

100% of Potential Costs (All projects)
- Cost of implementation: $26, 350,000
- Number of Projects: 8 Projects

75% of Project Costs
- Cost of implementation: $19,760,000
- Number of Projects: 7 Projects

50% of Project Costs
- Cost of implementation: $14,580,000
- Number of Projects: 5 Projects

25% of Project Costs
- Cost of implementation: $5, 950,000
- Number of Projects: 5 Projects

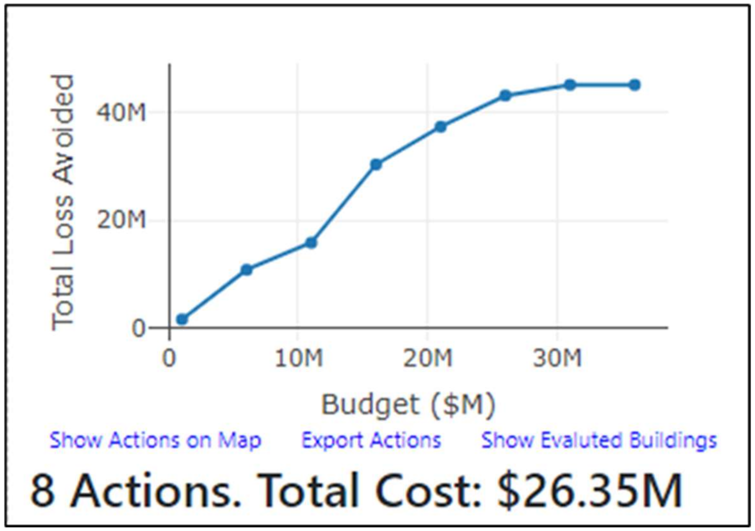


Figure 5-24: Cost to benefit curve generated for scenario 7.

5.8.1.1 Limitations of Scenario and Opportunities for Improvement

As this scenario's area of interest includes some areas along Tampa Bay, the recommended actions are skewed towards those areas where there is more instances of projected flood damages and thus higher return on investment. If the intent of the assessment was to have a more thorough understanding of relative risk and return on investment within those areas away from the coast, the geographical extents of the area of interest could be re-delineated to better capture the intent.

5.9 Scenario 8: Coastal Zone 1, Central Business District and N Greenwood

Scenario Setup:

Geography:

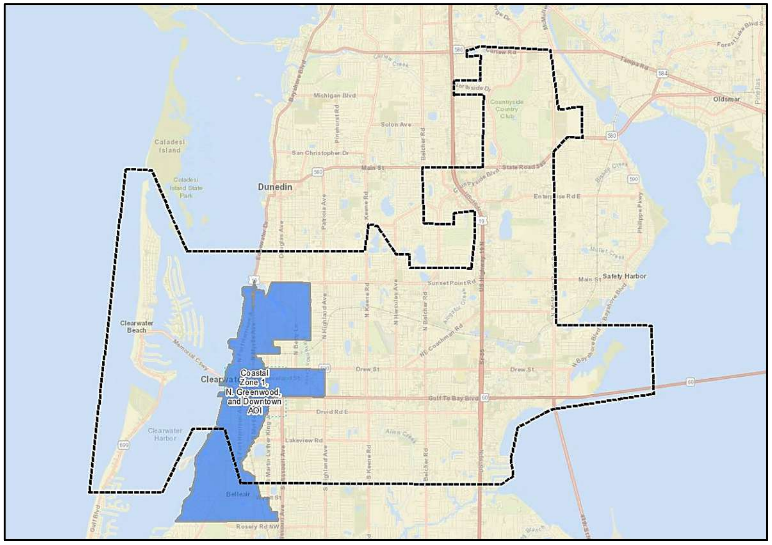
Downtown, N. Greenwood, and along Clearwater Harbor within the Coastal Zone 1 watershed

Actions to Evaluate:

- Tree Plantings
- Acquire Structures

Value to the Community:

This is an area of ongoing redevelopment and includes some of the more socially vulnerable portions of the City. Analysis of heat reduction and acquisitions..



The Project Action Team developed a scenario that evaluated the North Greenwood Community Redevelopment Area, the Downtown District, and Coastal Zone 1, as a combined geography where reinvestment is ongoing and social vulnerabilities have been identified. The scenario provides an opportunity to evaluate what the estimated costs and benefits are if flood-exposed structures were acquired, and additional trees were planted to reduce heat exposure.

During the original presentation of scenario results, the combined geography was causing the tool to produce questionable results or crashing the program. The project team chose to re-evaluate the project as three sperate scenarios:

- Scenario 8a-Just North Greenwood (Acquire structures and add trees)
- Scenario 8b-Just Central Business District (Acquire structures and add trees)
- Scenario 8c-Coastal Zone 1 (Acquire structures and add trees)

These additional scenarios are presented in Section 6-Refined Scenarios. The baseline map of flood exposure for the scenario is provided on the next page.

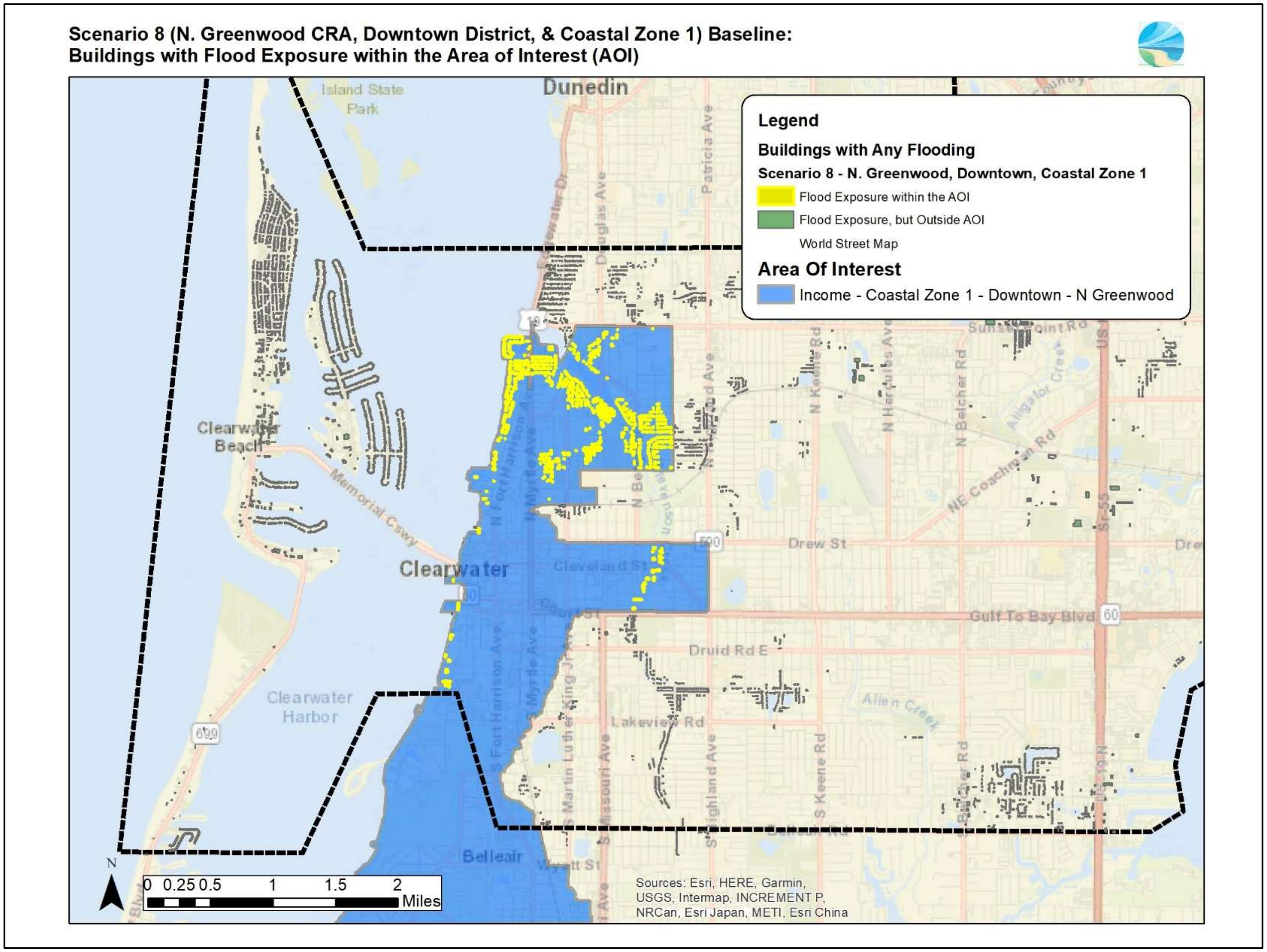


Figure 5-25 - Structures within the N. Greenwood/Downtown/Coastal Zone 1 AOI that are exposed to future flooding.

5.10 Scenario 9: Sr.60, Drew St., and S. Missouri (Alt 19)

Scenario Setup:

Geography:

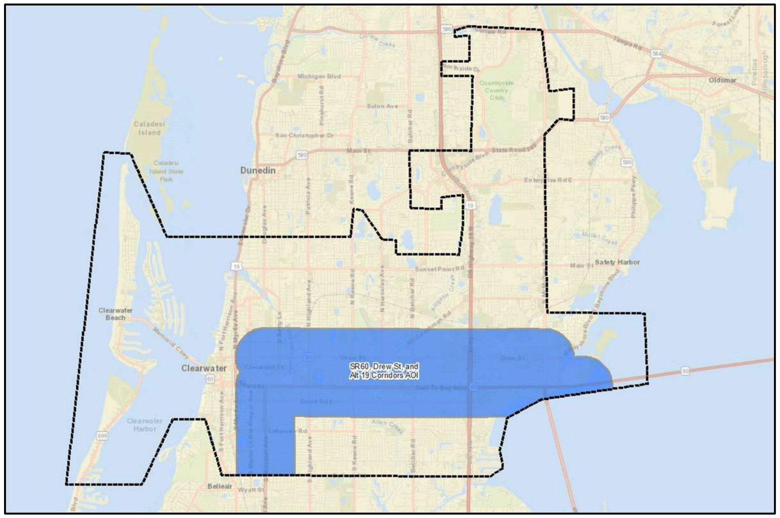
Central City

Actions to Evaluate:

- Stormwater Improvements
- Tree Coverage
- Density Changes

Value to the Community:

The City wanted to analyze these areas that are future investment corridors with expected redevelopment..



The Project Action Team developed a scenario that evaluated the State Road 60 (SR 60), Drew Street, and S. Missouri Avenue (Alternate 19 or Alt 19), as a combined geography where investment is planned for these corridors. The scenario provides an opportunity to evaluate what the estimated costs and benefits if additional trees were planted to reduce heat exposure as well as policy changes were implemented.

During the original presentation of scenario results, the combined geography and mixture of hard and soft mitigation actions was causing the tool to produce questionable results or crashing the program. The decision was made to focus on some of the tree planting options as part of the citywide assessment of heat. The following maps highlight the flood exposure within the area of interest as well as beneficial tree planting locations.

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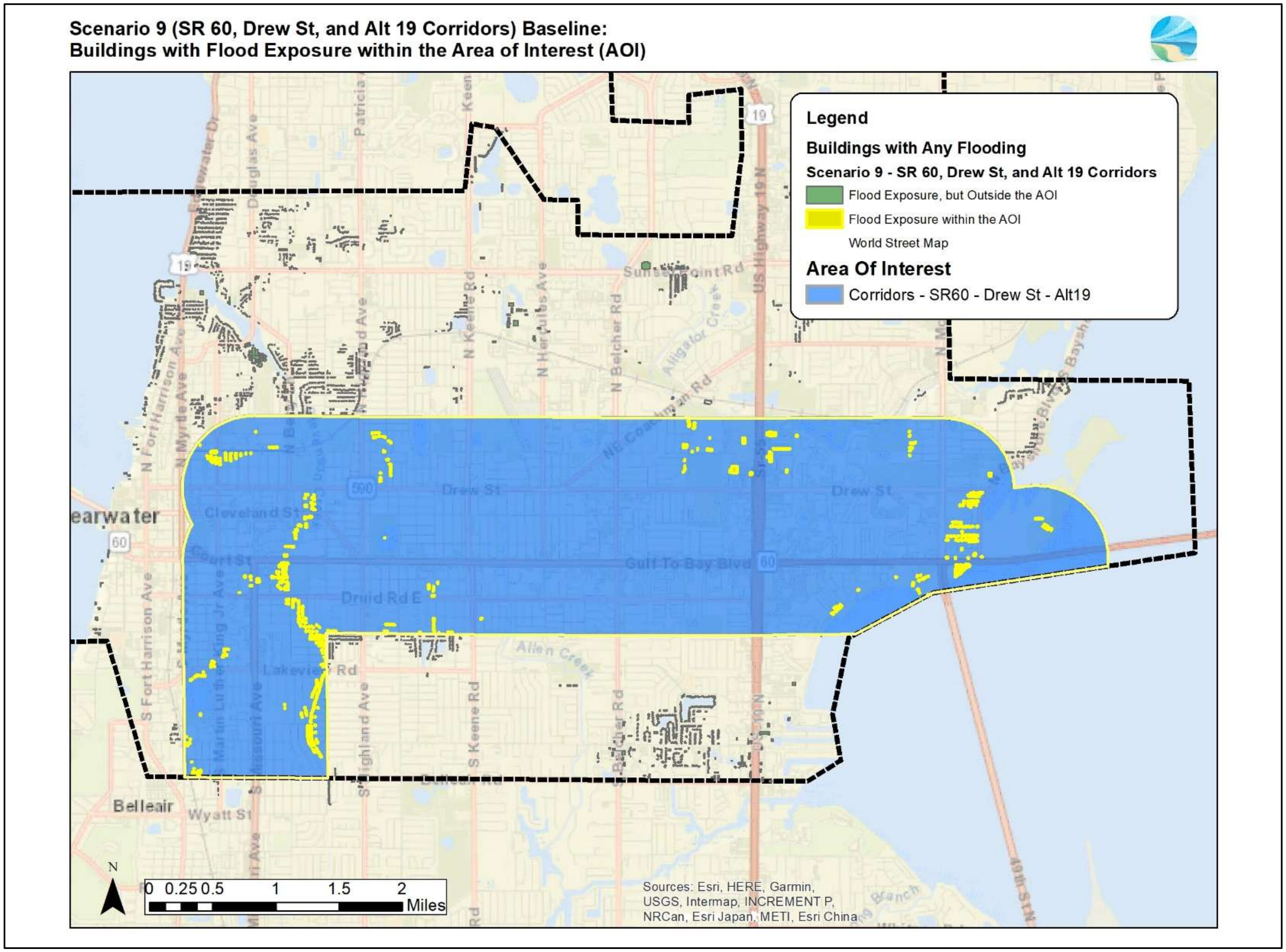


Figure 5-26 - Structures within the SR60, Drew St, and US 19 corridors that are exposed to future flooding.

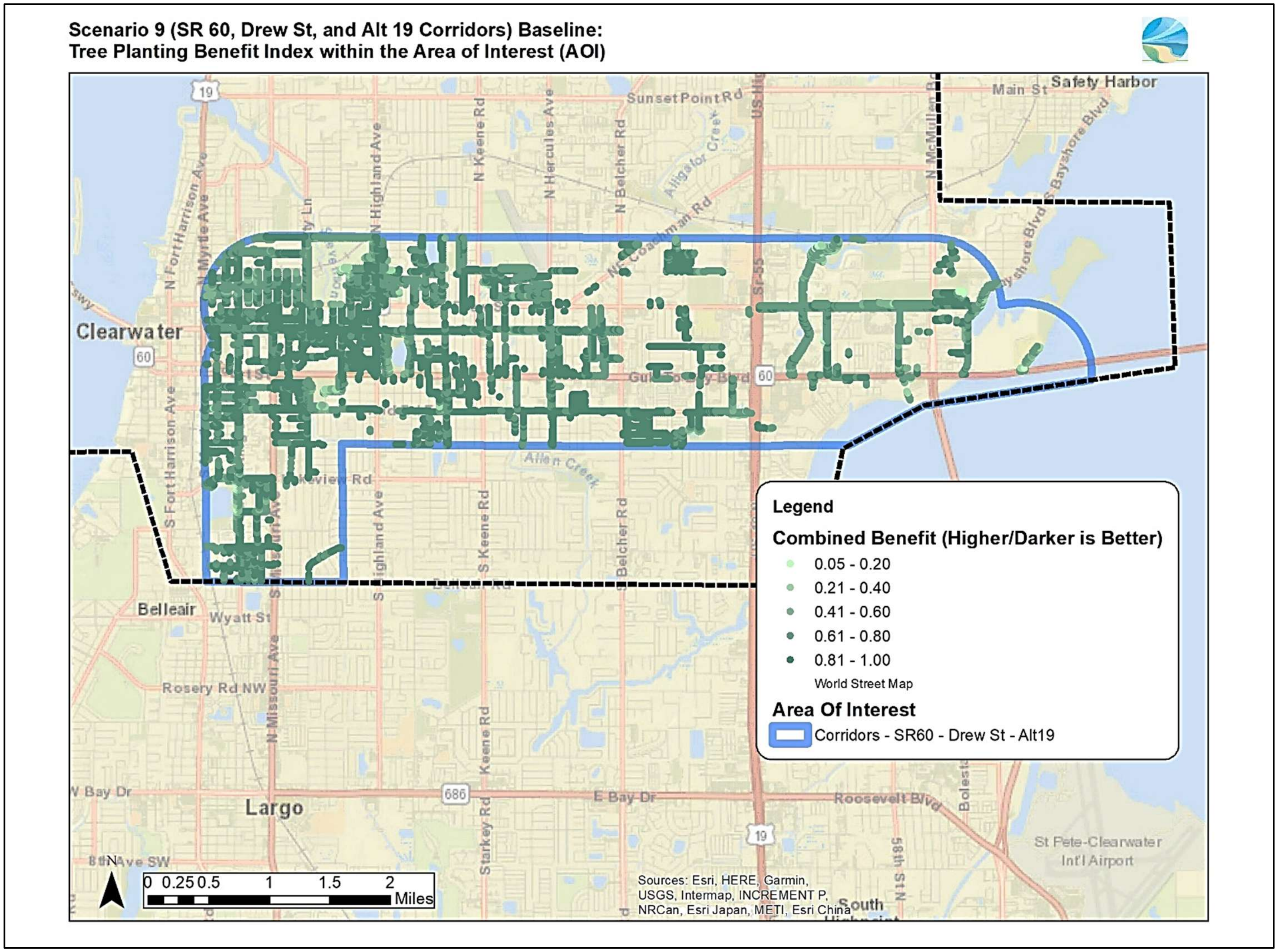


Figure 5-27 - Tree Benefit Index within the Scenario 9 (Investment Corridors) AOI

5.11 Scenario 10: Elevate Structures Citywide

Scenario Setup:

Geography:

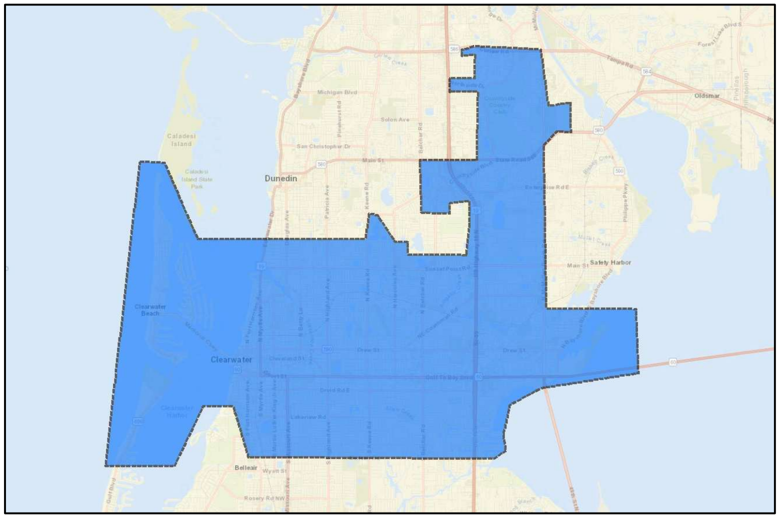
Citywide

Actions to Evaluate:

- Elevate Structures

Value to the Community:

There are clusters of flood vulnerable structures across the city. Stakeholders were interested in understanding where the best candidates for elevation were located within all areas..



As mentioned in Scenario 6 (Citywide Flood Structure Acquisitions), the most effective form of mitigation is to remove the asset from its exposure to the hazard. Elevating structures is not as effective as acquisition since the structural foundation will still have some exposure to the flood hazard and occupants of the structure will still be impacted when traveling through potentially flooded areas. Additionally, acquisitions of clustered properties would allow the City to repurpose the land whereas elevations will not. Within the city limits, there are approximately 4,600 structures with potential for flood exposure. This assessment will look at the costs and losses avoided that are expected by elevating structures across the city.

5.11.1 Preliminary Results

It is estimated that benefits from elevating structures across the city are maximized when approximately $141.1 million is spent on 837 elevation projects that show a positive cost to benefit ratio. Implementing these projects is estimated to avoid $389.3 million in damages. Recommended projects per allocation of funding are identified below.

100% of Potential Costs (All projects)

- Cost of implementation: $141,090,000
- Number of Projects: 837 Projects

75% of Project Costs

- Cost of implementation: $106,000,000
- Number of Projects: 587 Projects

50% of Project Costs

- Cost of implementation: $71,000,000
- Number of Projects: 365 Projects

25% of Project Costs

- Cost of implementation: $36,000,000
- Number of Projects: 135 Projects

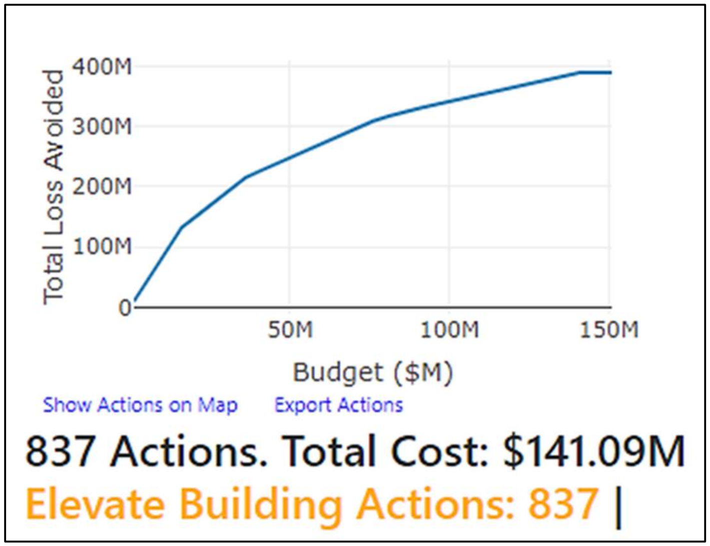


Figure 5-28: Cost to benefit curve generated for scenario 10.

5.11.1.1 Results Discussion

The image below is the 25% scenario, which helps to illustrate the potential priority projects where there is the greatest return on investment. The map helps to show some of the distinct clusters where the city may wish to further assess the viability of elevating structures in these geographies.

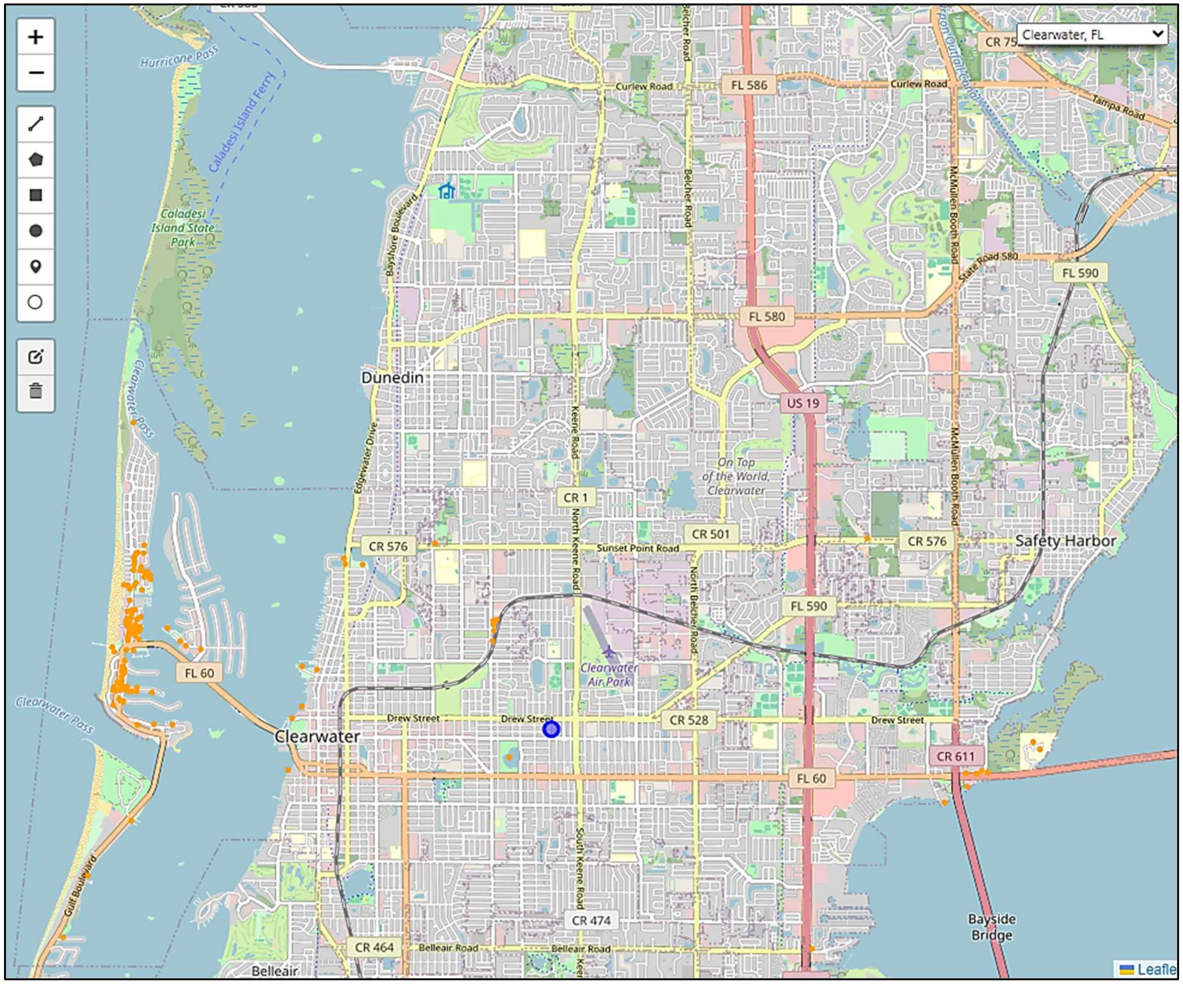


Figure 5-29 - Structures (orange dots) with the highest ROI for the 25% budget citywide acquisition scenario.

5.11.1.2 Limitations of Scenario and Opportunities for Improvement

As with the results of all scenarios, better assessment of finished floor elevation [FFE] estimates would greatly improve the insights provided by the tool. It would also benefit to understand realistic expectations of elevations based on public sentiment and better differentiation of costs associated with elevation per type of structure and/or location. Future iterations of the model may want to apply a different weighting to consider repetitive losses and severe repetitive losses when evaluating benefit to cost figures for elevations.

6. Refined Scenarios

Following the development of the 10 scenarios, the consultant team provided preliminary results to City leadership and the PAT. At the meeting, the stakeholders discussed the findings from the preliminary scenarios and decided to refine 5 of the initial scenarios (resulting in a total of 15 unique scenarios developed for the project). The refined scenarios are listed below:

- Scenario 1-Report out impact to bridges within the Stevenson Creek AOI
- Scenario 8a-Just North Greenwood (Acquire structures and add trees)
- Scenario 8b-Just Central Business District (Acquire structures and add trees)
- Scenario 8c-Coastal Zone 1 (Acquire structures and add trees)
- Scenario 11-Identify tree deserts (Focus on right of way/City property)

The findings from the refined scenarios are presented in the sections below.

6.1 Refined Scenario 1: Stevenson Creek with Bridges

Scenario Setup:

Geography:

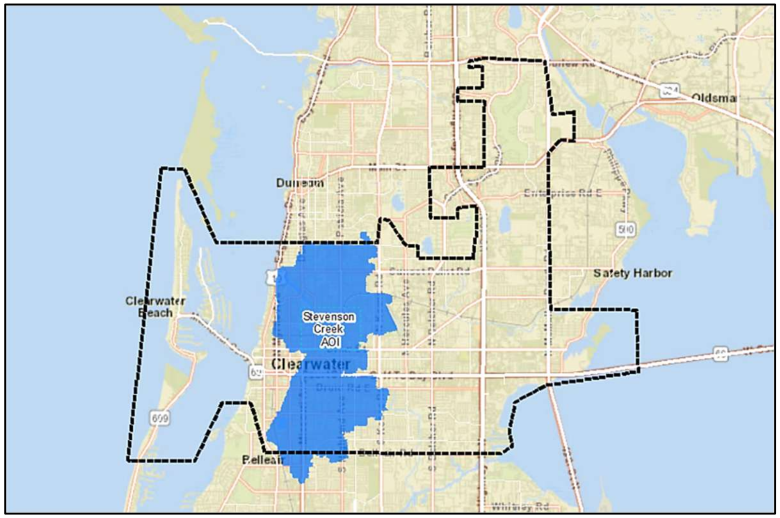
Stevenson Creek Watershed

Actions to Evaluate:

- Bridge vulnerability

Value to the Community:

This geography is one with high exposure to tidal and rainfall flooding. There are also ongoing studies in the area that may be able leverage results of the analysis.



Following the presentation of initial scenario results, the PAT looked to evaluate the Stevenson Creek area for impacts to bridges. The city’s transportation GIS featureset identifies 99 bridges across the community. There are 24 bridges located within the Stevenson Creek watershed. To estimate deck elevations for the bridges, elevation information was extracted from the DEM for each of the vertices in the shape of the bridge polygon. The highest one was used as the deck elevation.

6.1.1.1 Results Discussion

The tool is not currently capable of delivering the same type of metrics for bridge evaluations as for other scenarios. The current capabilities showed three structures were exposed to potential inundation.

- Belleview Blvd/Stevenson Creek
- Belleair Road/Rice Lake
- Douglas Ave/Stevenson Creek

Improvements to bridges would likely need coordination with the County and/or State/Federal agencies depending on ownership of the bridge and surrounding infrastructure. This planning level tool provides a starting point for further evaluation and would need more planning, design, and cost information to fully evaluate benefits.

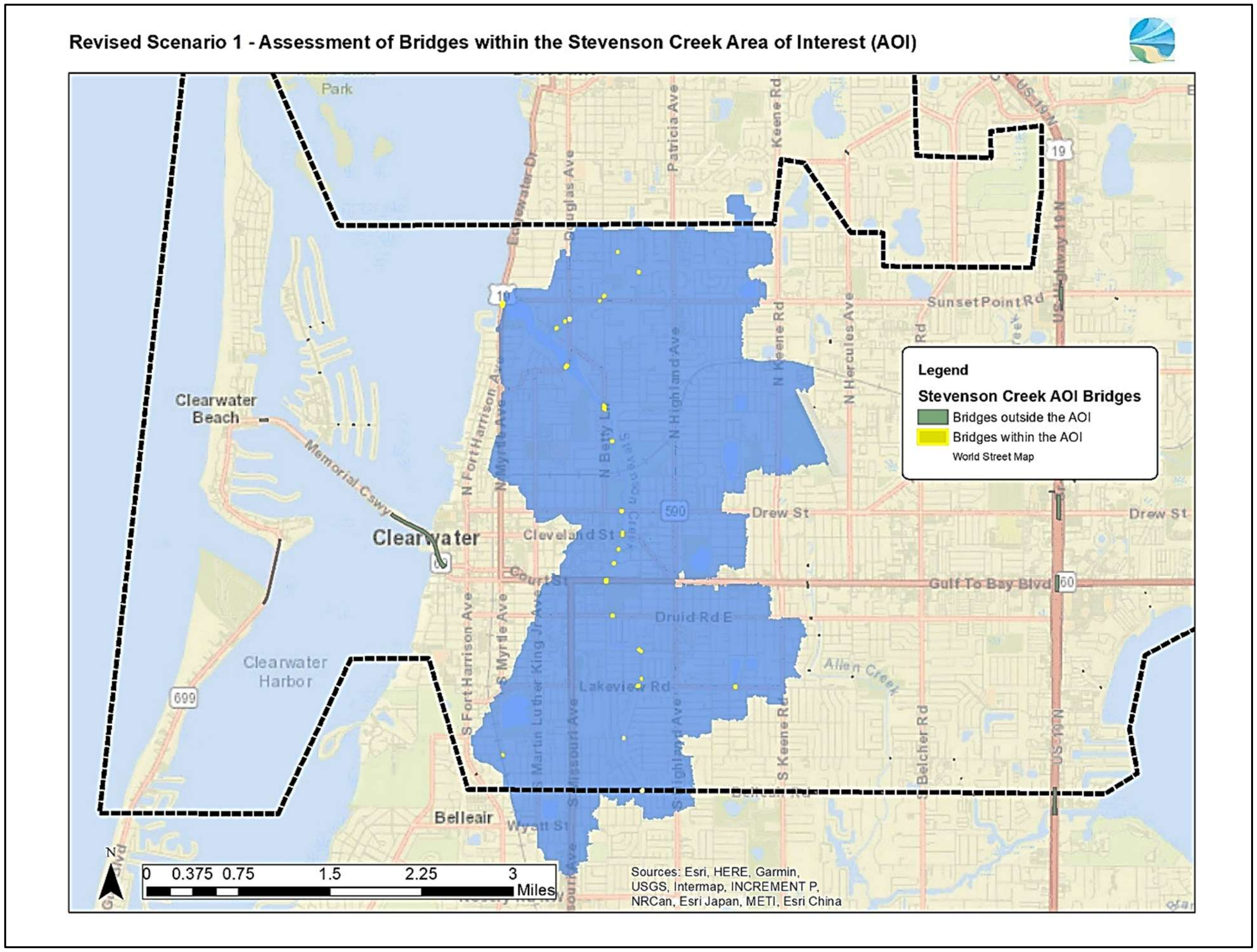


Figure 6-1 - Bridges within Stevenson Creek AOI

Outside of the area of interest, the tool showed potential impacts to the following six bridges: Coopers Point/Old Tampa Bay North Bridge; Coopers Point/Old Tampa Bay South Bridge; Windward Passage/Clearwater Harbor W Bridge; Windward Passage/Clearwater Harbor E Bridge; Windward Passage/Clearwater Harbor M Bridge; and Harbor Passage/Clearwater Harbor E Bridge.

6.2 Refined Scenario 8a: North Greenwood

Scenario Setup:

Geography:

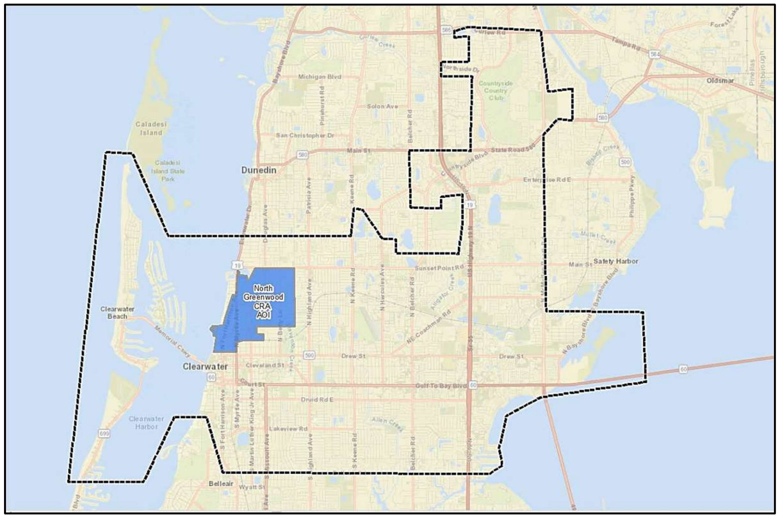
North Greenwood Community Redevelopment Area

Actions to Evaluate:

- Acquire Structures
- Plant Trees

Value to the Community:

This is an area of ongoing redevelopment and includes some of the more socially vulnerable portions of the City. Analysis of heat reduction and acquisitions.



The scenario 8a was derived from the original Scenario 8. Scenario 8a evaluates acquiring structures and adding trees within the North Greenwood Community Redevelopment Area. The refined scenario provides an opportunity to evaluate what the estimated costs and benefits are if flood-exposed structures were acquired, and potential tree plantings are considered.

6.2.1 Preliminary Results

It is estimated that benefits from elevating structures within the N Greenwood AOI are maximized when approximately $76 million is spent on the 1,184 projects that show a positive cost to benefit ratio. The simulation estimates that if all of these projects were implemented today that approximately $98 million in flood damages to these buildings would be avoided over the 2020-2100 time frame. This estimate is based on FEMA Hazus depth-damage curves, which translate the depth of flooding over the building's first floor elevation (FFE) to cost of repairs as a percentage of the building's replacement cost. Recommended projects per allocation of funding are identified below.

100% of Potential Costs (All projects)

- Cost of implementation: $76,350,000
- Number of Projects: 1,184 Projects
  - Tree Plantings: 1,141 Projects
  - Acquire Buildings: 43 Projects

75% of Project Costs

- Cost of implementation: $56,000,000
- Number of Projects: 926 Projects
  - Tree Plantings: 901 Projects
  - Acquire Buildings: 25 Projects

50% of Project Costs

- Cost of implementation: $36,000,000
- Number of Projects: 869 Projects
  - Tree Plantings: 851 Projects
  - Acquire Buildings: 18 Projects

25% of Project Costs

- Cost of implementation: $21,000,000
- Number of Projects: 952 Projects
  - Tree Plantings: 919 Projects
  - Acquire Buildings: 33 Projects

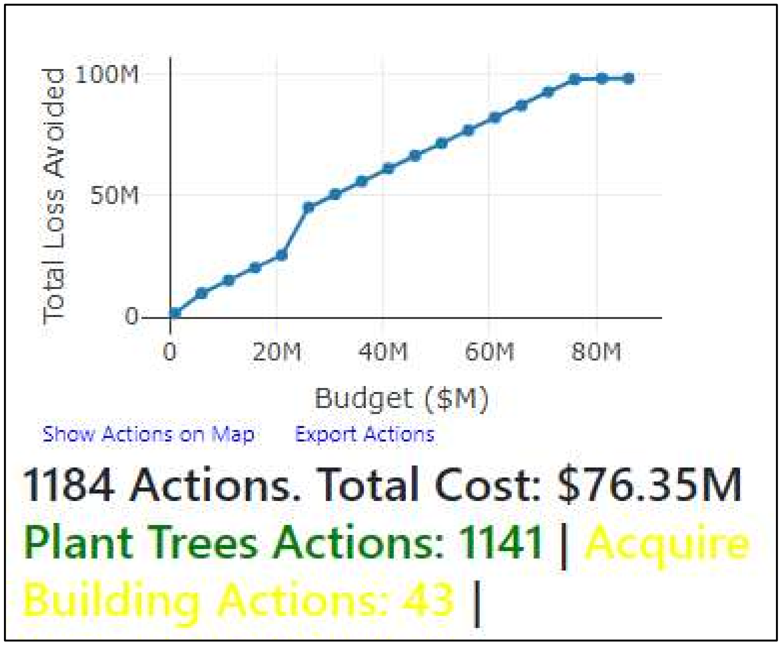


Figure 6-2: Cost to benefit curve scenario 8a.

6.2.1.1 Results Discussion

The map below provides findings at the 25% total cost budget, which can be a proxy for highest priority areas as these represent potential actions with the highest return on investment. Note that the tool visualizations are being improved to include boundaries to represent the area of interest (AOI), but not currently available. GIS data for the project does include the boundaries.

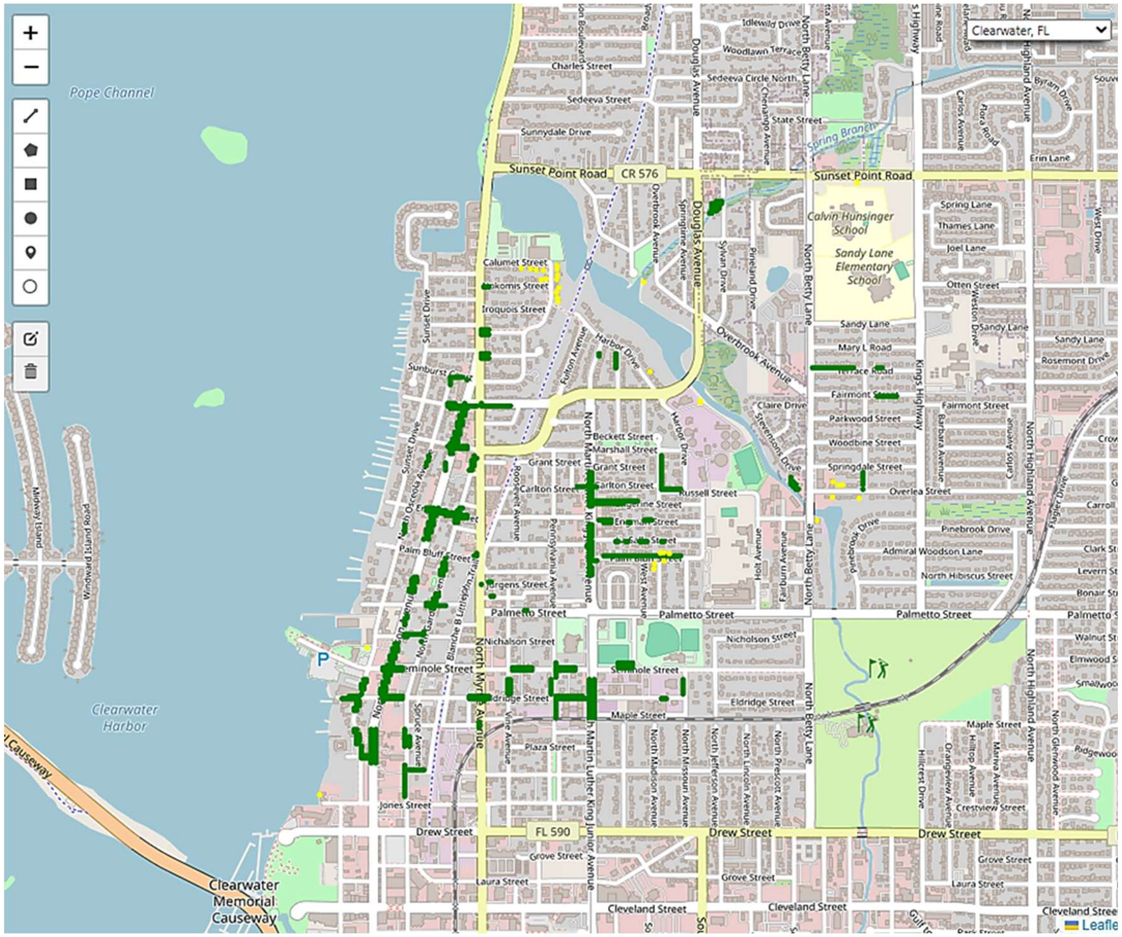


Figure 6-3 - Scenario 8a (N. Greenwood) highest ROI for acquisition (yellow dots) and tree plantings (green).

6.3 Refined Scenario 8b: Central Business District

Scenario Setup:

Geography:

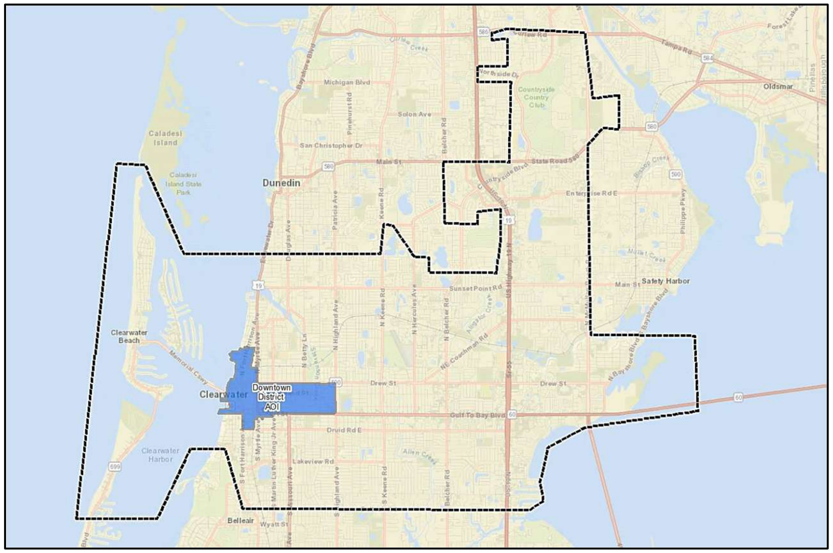
Central Business District

Actions to Evaluate:

- Acquire Structures
- Tree Plantings

Value to the Community:

There are clusters of flood vulnerable structures across the city. Stakeholders were interested in understanding where the best candidates for elevation were located within all areas..



The scenario 8b was derived from the original Scenario 8. Scenario 8b evaluates acquiring structures and adding trees within the Downtown District. The refined scenario provides an opportunity to evaluate what the estimated costs and benefits are if flood-exposed structures were acquired, and potential tree plantings are considered. As indicated with other scenarios, the

6.3.1 Preliminary Results

It is estimated that benefits from elevating structures within the Downtown District AOI are maximized when approximately $9 million is spent on 1,572 projects that show a positive cost to benefit ratio. Implementing these projects is estimated to avoid $17.8 million in damages. Recommended projects per allocation of funding are identified below.

100% of Potential Costs (All projects)

- Cost of implementation: $9,000,000
- Number of Projects: 1,572 Projects
    - Tree Plantings: 1,568 Projects
    - Acquire Buildings: 4 Projects

75% of Project Costs

- Cost of implementation: $6,000,000
- Number of Projects: 1,569 Projects
    - Tree Plantings: 1,568 Projects
    - Acquire Buildings: 1 Project

50% of Project Costs

- Cost of implementation: $4,500,000
- Number of Projects: 1,569 Projects
    - Tree Plantings: 1,568 Projects
    - Acquire Buildings: 1 Project

25% of Project Costs

- Cost of implementation: $2,000,000
- Number of Projects: 1,568 Projects
    - Tree Plantings: 1,568 Projects
    - Acquire Buildings: 0 Projects

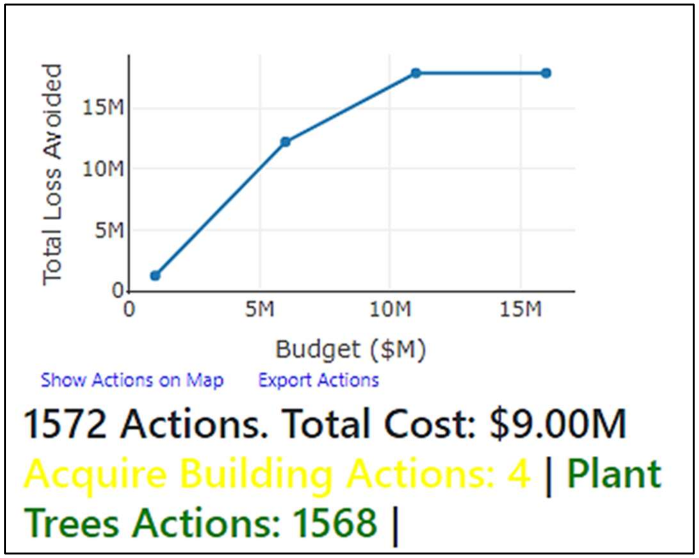


Figure 6-4: Cost to benefit curve generated for scenario 8b.

6.3.1.1 Results Discussion

The map below provides findings at the 25% total cost budget, which can be a proxy for highest priority areas as these represent potential actions with the highest return on investment.

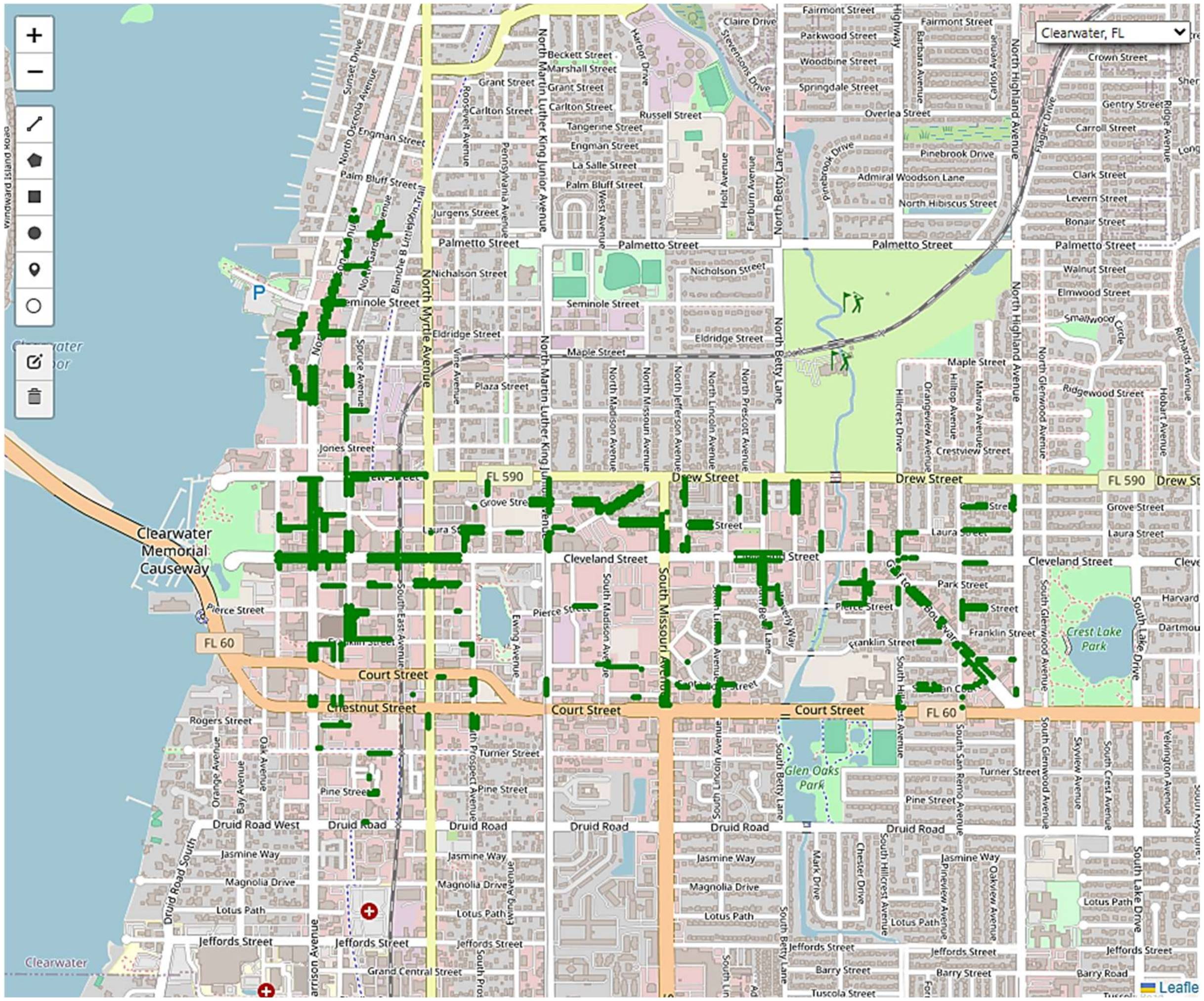


Figure 6-5 - Scenario 8b (Downtown District) highest ROI for acquisition and tree plantings (green dots)

6.4 Refined Scenario 8C: Coastal Zone 1

Scenario Setup:

Geography:

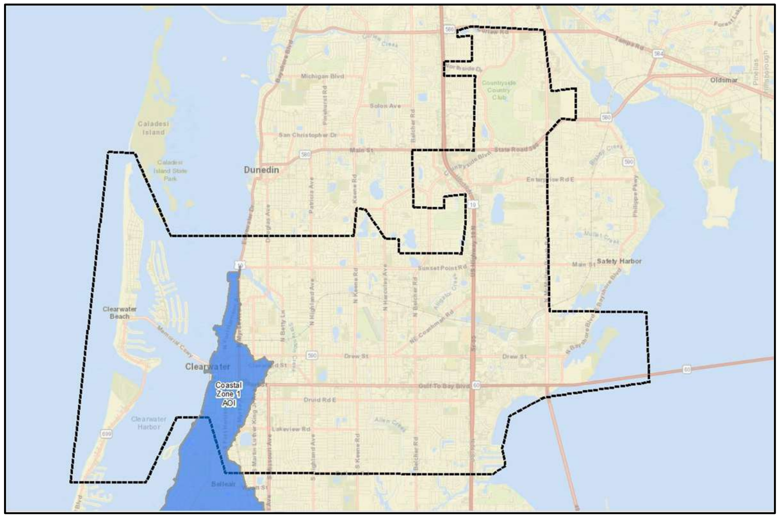
Coastal Zone 1

Actions to Evaluate:

- Acquire Structures
- Tree Plantings

Value to the Community:

This is an area of ongoing investment that is also including areas of social vulnerability.



The scenario 8c was derived from the original Scenario 8. Scenario 8c evaluates acquiring structures and adding trees within the Coastal Zone 1 watershed. The refined scenario provides an opportunity to evaluate what the estimated costs and benefits are if flood-exposed structures were acquired, and potential tree plantings are considered. As noted with other tree planting scenarios above, this planning level tool is intended to provide insights into what locations may most benefit from shade when considering the simulation of people that live or work in an area based on demographic data. Any guidance provided by this document would need to be further evaluated when considering implementation. For example, some tree plantings may not be physically possible in locations, and some locations may not be recommended for plantings per advice of landscape architects.

6.4.1 Preliminary Results

It is estimated that benefits from elevating structures within the Coastal Zone 1 AOI are maximized when approximately $65 million is spent on 2,111 projects that show a positive cost to benefit ratio. Implementing these projects is estimated to avoid $120.36 million in damages. Recommended projects per allocation of funding are identified below.

100% of Potential Costs (All projects)

- Cost of implementation: $65, 040,000
- Number of Projects: 2,111 Projects
  - Tree Planting: 2,058 Projects
  - Acquire Buildings: 53 Projects

75% of Project Costs

- Cost of implementation: $51,000,000
- Number of Projects: 922 Projects
  - Tree Planting: 889 Projects
  - Acquire Buildings: 33Projects

50% of Project Costs

- Cost of implementation: $31,000,000
- Number of Projects: 1,161 Projects
  - Tree Planting: 1,154 Projects
  - Acquire Buildings: 7 Projects

25% of Project Costs

- Cost of implementation: $16, 000,000
- Number of Projects: 1,222 Projects
  - Tree Planting: 1,215 Projects
  - Acquire Buildings: 7 Projects

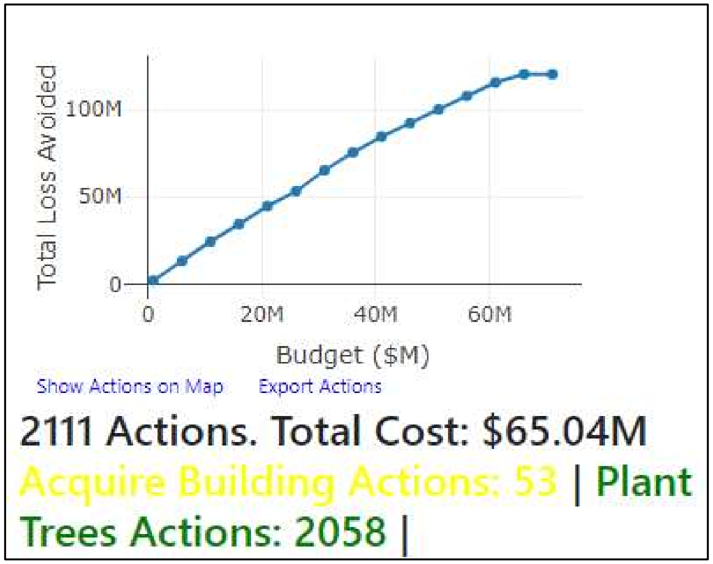


Figure 6-6 - Cost to benefit curve generated for scenario 8c.

6.4.1.2 Results Discussion

The map below provides findings at the 25% total cost budget, which can be a proxy for highest priority areas as these represent potential actions with the highest return on investment.

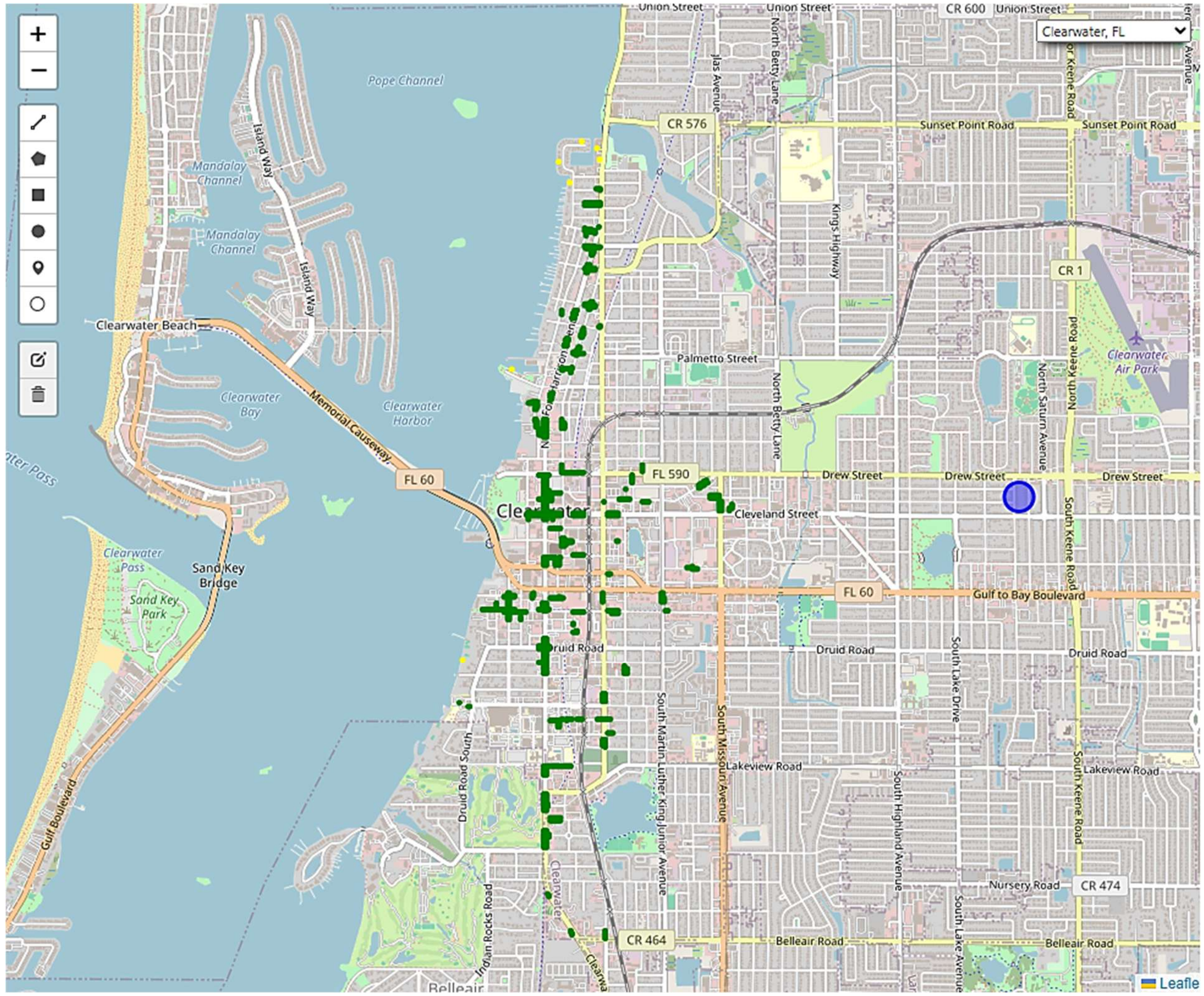


Figure 6-7 - Scenario 8c (Coastal Zone 1) highest ROI for acquisition (yellow dots) and tree plantings (green dots).

6.5 Scenario 11: Identify Tree Deserts

Scenario Setup:

Geography:

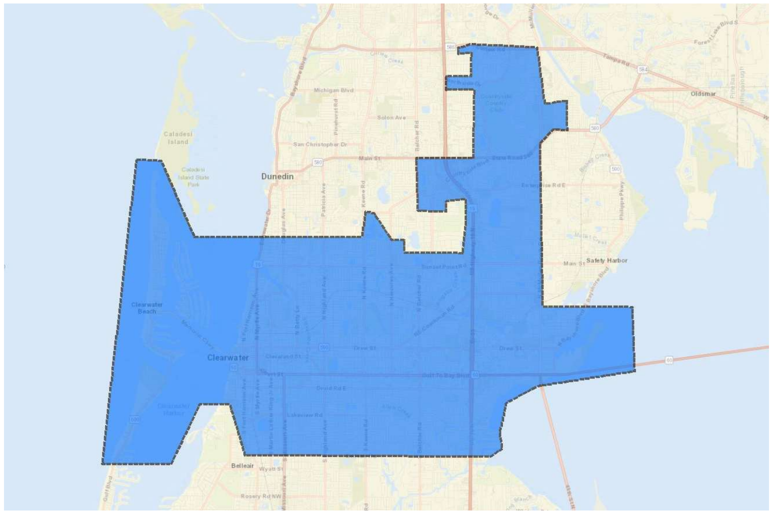
Citywide

Actions to Evaluate:

- Tree Plantings

Value to the Community:

Stakeholders asked if the tree assessment could be refined to better address shade impacts. It was recommended to refine the model to areas along streets and city properties..



The findings from Scenario 2 helped to open up a larger conversation amongst the PAT regarding the opportunities to plant trees and provide additional shade and equity benefits through them. The recommendations were to look at refinements that might be possible within the existing budget, particularly with regard to better identifying realistic locations. The model methodology identified in 5.1.5.2 was created to help improve the return-on-investment calculations. The findings shown in Scenario 2 utilize the new ROI scoring compared to the initial results provided to the PAT in February of 2024. Furthermore, to help the PAT with prioritizing the locations, a combined benefit index was created. The map of the citywide tree planting locations, using the combined benefit index, is provided on the following page.

As noted previously, this is a planning level tool that is designed to provide insights into what locations may most benefit from shade when considering the simulation of people that live or work in an area based on demographic data. Any guidance provided by this document would need to be further evaluated when considering implementation. For example, some tree plantings may not be physically possible in locations, and some locations may not be recommended for plantings per advice of landscape architects.

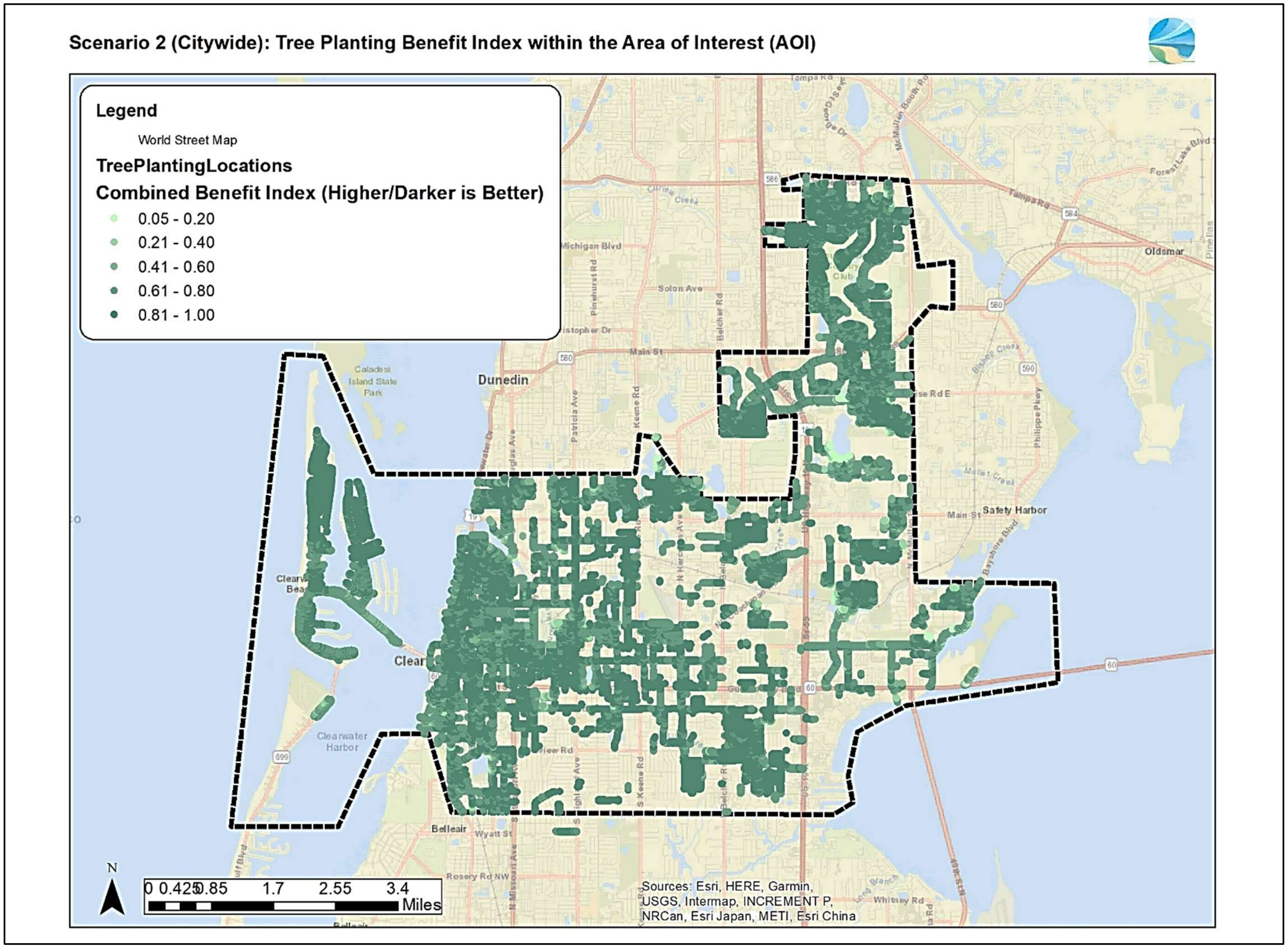


Figure 6-8 - Structures within the Stevenson Creek Watershed that are exposed to future flooding.

6.5.1.1 Results Discussion

Scenario 11 did not result in a cost-based metric. The cost-based metric was captured in Scenario 2. However, the approach to deriving the budget-to-losses avoided shown in Scenario 2 results was updated in this report, compared to results shown to the PAT at the February 2024 meeting. The February meeting with the PAT mentioned the need to better adjust the spatial locations that are likely to have trees (such as along sidewalks, rights-of-way) and develop another factor besides cost when evaluating locations. The outcome/result of Scenario 11 is the development of a tree planting benefit index resulting in a map and GIS featureset that the city can use in future planning discussions.

6.5.1.2 Limitations of Scenario and Opportunities for Improvement

The model makes use of the city's parcel fabric and demographics to estimate relative benefits to tree planting locations per the methodology identified in 5.1.5.2. The City should consider building upon the model with information from the existing tree inventory regarding probable types of trees to be planted, estimate of shade/temperature decrease per type, and costs to install (currently a flat amount in the model).

7. Recommendations from the Technical Advisory (TAC) Committee

The TAC met with members of the Project Action Team virtually on August 13, 2024, to review the project findings. The TAC made the following recommendations for the city to consider when building upon the study findings.

- Although the Clearwater Beach station does not have statistically different projections of future sea level rise than the St. Petersburg station, the Tampa Bay Client Science Advisory Panel (CSAP) is using the St. Petersburg station as the preferred gauge due to a longer period of record. The recommendation from the TAC is to use the St. Petersburg station in future studies so that the region is using one consistent station.

- The study could be expanded to evaluate surface water models for water quality and include groundwater modeling.

- Use the study to emphasize public opportunities like rain gardens and individual property protection actions (tree plantings, flood insurance, structural improvements) as well as regional solutions such as what was done at Kapok Park, which included acquisition of repetitive loss structures and converted the area to a regional park with flood control elements.

- Consider including land acquisition costs to evaluate opportunities for new or additional stormwater retention and treatment needs.

- The City could consider going after grant funding to expand upon visualization and educational outreach opportunities that communicate study findings and help residents understand what impacts might be like at an individual property.

APPENDICES

Appendix A. Summary of Project Engagement

The TAC was created to be a more external group that included representatives of outside stakeholders as well as city representatives that were not active in the detailed activities being coordinated through the PAT. This group included individuals representing, the regional transportation agency (Forward Pinellas), regional planning (Tampa Bay Regional Planning Council), environmental (Tampa Bay Estuary Program), Pinellas County sustainability and resilience, and city leadership.

Meeting ID	Date	Items Covered	PAT	TAC
Intro Presentation	09/22/2022	Staff introductions and project goals.	X	
Data Needs	10/06/2022	Description of layers used in the model, layers requested per the grant, contacts for data.	X	
Intro Meeting for PAT and the TAC (TAC Meeting #1)	11/15/2022	Introduce participants, project goals, the City Simulator model, and project road map.	X	X
Intro to the Model	12/08/2022	Walk through of model components, project and data assumptions, digital twin requirements, hazard data availability.	X	
PAT Meeting 5	01/17/2023	Review of initial parcel, land use, and transportation data converted for use in the model.	X	
PAT Meeting 6	02/14/2023	Review of updated parcel and transportation data, review of climate drivers, and hazard data.	X	
TAC Meeting #2	02/24/2023	Review of project requirements, data collected and processed to date, actions to be simulated, and approach for climate drivers.	X	X

Meeting ID	Date	Items Covered	PAT	TAC
Project Leads Meeting	09/06/2023	Introduce project to new sustainability lead, provide update on baseline model run, and update on climate models	X	
PAT Meeting 7	10/19/2023	Provide update on baseline model run, update on climate models, provide approach for heat modeling and metrics.	X	
Findings Meeting 1	11/07/2023	Review of climate simulations, temperature projections, sea level rise projections, flood impacts to buildings and transportation networks, and heat exposure.	X	
Findings Meeting 2	11/28/2023	Review of trips disrupted by simulated coastal flooding, heat impacts on individuals, projected energy usage by building.	X	
Scenario Planning	12/15/2023	In-person meeting to evaluate baseline results and select adaptation scenarios to simulate.	X	
Scenario Planning #2	01/31/2024	In-person meeting with City leadership stakeholders to refine scenarios to be evaluated.	X	
Scenario Planning #3	02/23/2024	In-person meeting with City leadership stakeholders to refine scenarios to be evaluated.	X	
Public Meeting	03/20/2024	Public meeting to present preliminary results. The meeting was held as part of the Environmental Advisory Board's regular meeting. Meetings are open to the public and are held in Council Chambers on the first floor of the Main Library, located at 100 N. Osceola Ave. Media coverage of the event helped to communicate the project and provided another mechanism to receive input on the findings.		

Meeting ID	Date	Items Covered	PAT	TAC
TAC Meeting #3	08/13/24	Hybrid meeting with in-person and virtual attendance to review the final sensitivity results and to solicit comments from the TAC regarding suggested improvements for future efforts.	X	X
Public Meeting	09/16/24	The final results of the city's vulnerability assessment were presented to the Clearwater City Council at 1:30 p.m. Monday, Sept. 16. The meeting was open to the public for comments.		

Appendix B. Reports and Data Sources Referenced in the Document

The following documents and tools were referenced in this report:

Reference Name	Type	Link to Reference	Location in the Report
Greenprint 2.0	Sustainability Plan	Clearwater Greenprint - City of Clearwater (myclearwater.com)	Executive Summary
Census Data (Clearwater City Profile)	Demographic Data	2022	Section 1: Community Profile
NOAA Coastal Inundation Site	Climate Data	tool	Section 1: Climate Trends
NOAA Sea Level Rise Trends	Climate Data	Tool	Section 1: Climate Trends
Pinellas County Water Atlas	Climate Data	tool	Section 1: Climate Trends
Atlas 14 Precipitation Data	Climate Data	PF Map: Contiguous US (noaa.gov)	Section 2: Future Rainfall
Forecasting Climate Change Induced Shift in Storm Intensity and Frequency in Florida	Climate Modeling Methods	Link	Section 2: Future Rainfall
IPCC Future Climate Change	Climate Data	https://ar5-syr.ipcc.ch/topic_futurechanges.php	Section 2: Future Rainfall
National Weather Service (NOAA)-Tampa Bay Climate Normals	Climate Data	ASOS Climate Normals (weather.gov)	Section 2: Future Temperature

Reference Name	Type	Link to Reference	Location in the Report
LOCA Temperature Data	Climate Data	Link	Section 2: Future Temperature
Recommended Projections of Sea Level Rise in the Tampa Bay Region (2019)	Climate Modeling Methods	Link	Section 2: Future Sea Level
NOAA 2022 Sea Level Rise Technical Report	Climate Modeling Methods	View or Download	Section 2: Future Sea Level
USACE South Atlantic Coastal Study (Coastal Hazards System)	Climate Data and Modeling Methods	CHS (dren.mil)	Section 2: Surge Predictions
Clearwater 2045 Comprehensive Plan Update	Land Use Plan	Clearwater 2045	Section 4: Scenario Development

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