APPENDIX

Watershed Master Planning Initiative

Sarasota City

HUC 12 digit: 031002010203

Philippee Creek

Principal Investigator: Frederick Bloetscher, Ph.D., P.E.

Co-Principal Investigators: Weibo Liu, Ph.D., Daniel Meeroff, Ph.D., Diana Mitsova, Ph.D., S. Nagarajan, Ph.D., Hongbo Su, Ph.D., Ramesh Teegavarapu, Ph.D., Zhixiao Xie, Ph.D., Yan Yong, Ph.D., Caiyun Zhang, Ph.D., Ahmet Urusan, Ph.D., Eva Suarez, Ph.D.

Research Assistants: Bishal Dhungana

This resource was funded in part through a grant agreement from the Florida Division of Emergency Management's (FDEM) Bureau of Mitigation, by a grant provided through the Hazard Mitigation Grant Program (HMGP) DR-4337-004-P, as approved by FDEM and the Federal Emergency Management Agency (FEMA) to create and update Watershed Master Plans (WMP) throughout the state of Florida. The views, statements, findings, conclusions, and recommendations expressed herein are those of the authors and do not necessarily reflect the views of the State of Florida, FEMA, or any sub-agencies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. WATERSHED CHARACTERIZATION

For each HUC12 within the community, specific data needs to be acquired and mapped. Collecting historical and up-to-date data from various vital sources is essential for developing a WMP. Among the datasets to acquire are the following:

- Topographic data (LiDAR)
- Relevant waterway locations
- Groundwater levels
- Soils data
- Land use includes vacant land, wetlands, etc.
- Catchment delineations for flood routing

In addition, the FEMA flood maps must be obtained, and the storm of interest must be identified for screening purposes (1-day, 1-year, 5-year, 10-year, and 100-year and 3-day, 25-year and storm event to achieve class 4 in the CRS Manual). In developed areas, many data sources are already available – the key is putting the key datasets in a format that can be queried for screening to identify the priority areas of the watershed. Table 5 summarizes the datasets available at cwr3.fau.edu used to construct this plan.

This watershed master plan is a drill-down of the larger Sarasota Bay- Myakka TMDL region, which involves several HUC 12 sub-watersheds (Figure 1). In Figure 2, the HUC 031002010203 Philippee Creek sub-watershed is zoomed in and Figure 3 shows the communities included in the County.

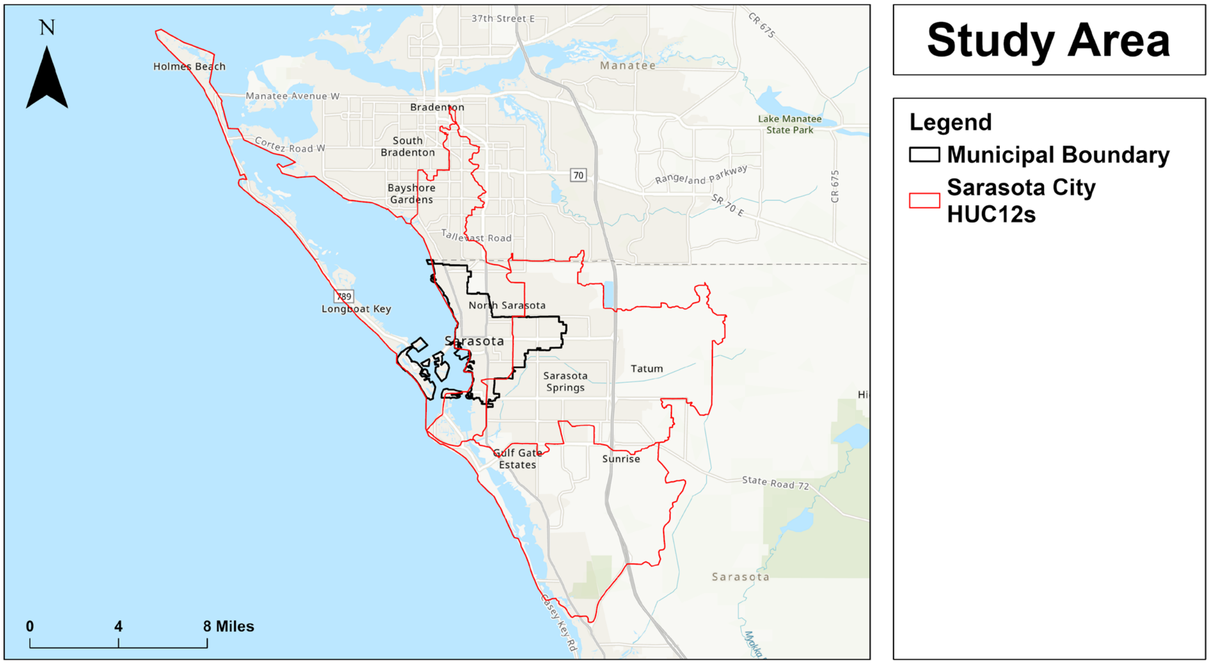

Figure 1. Sarasota City and all HUCs 12-digit sub-watersheds, as generated by FAU CWR3.

Sarasota is a city in and the county seat of Sarasota County, Florida, United States. It is located in Southwest Florida, the southern end of the Greater Tampa Bay Area, and north of Fort Myers and Punta Gorda. Its official limits include Sarasota Bay and several barrier islands between the bay and the Gulf of Mexico. Sarasota is a principal city of the Sarasota metropolitan area. According to the 2020 U.S. census, Sarasota had a population of 54,842. The Sarasota city limits contain several keys, including Lido Key, St. Armands Key, Otter Key, Casey Key, Coon Key, Bird Key, and portions of Siesta Key. Longboat Key is the giant key separating the bay from the gulf. The city limits expanded significantly with the real estate rush of the early twentieth century, reaching almost 70 square miles (180 km^2). The speculation boom began to crash in 1926, and the city limits began to contract, shrinking to less than a quarter of that area. Sarasota has a tropical climate with hot, humid summers and drier winters. The high summer temperatures and humidity regularly push the heat index over 100 °F (38 °C). There are distinct rainy and dry seasons, with the rainy season lasting from March to November and the dry season from December to February. According to the U.S. Census Bureau, the city has a total area of 24.08 square miles (62.4 km^2), of which 14.70 sq mi (38.07 km^2) is land and 9.39 sq mi (24.3 km^2) is water.

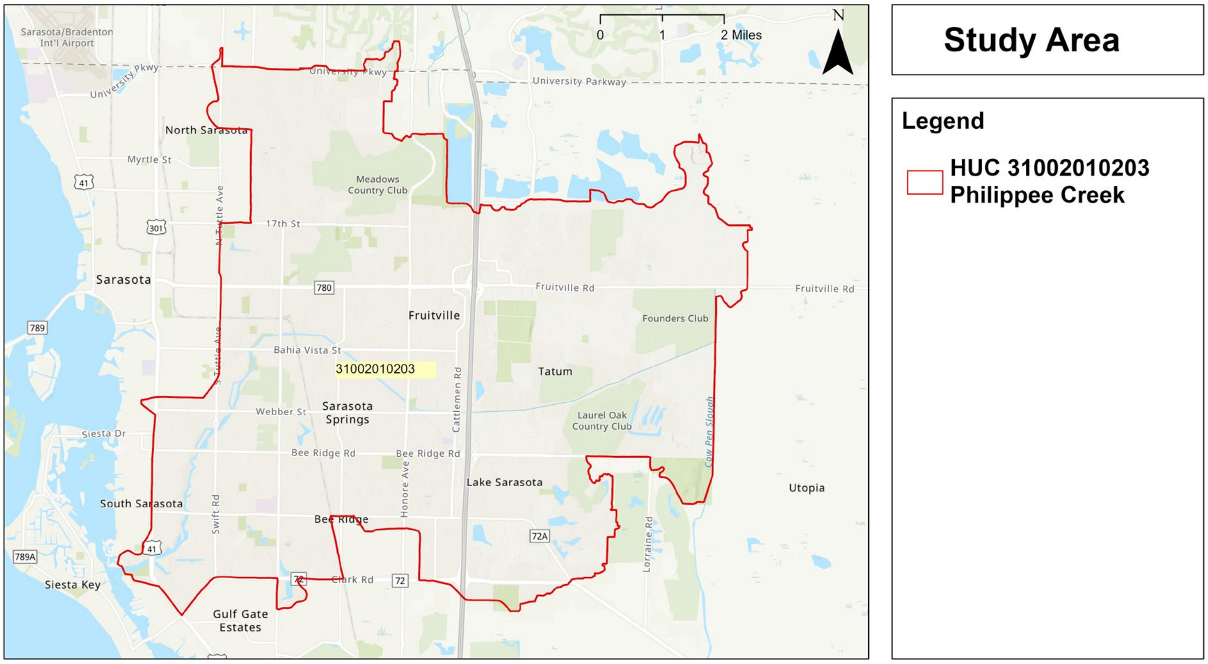

Figure 2. HUC 031002010203 Philippee Creek sub-watershed, as generated by FAU CWR3.

The land use pattern in the Philippe Creek sub-watershed reveals a distinctive landscape. Urban and Built-Up areas dominate at 75.50%, indicating extensive human settlements and significant development. Agriculture contributes 4.05%, representing a portion of the landscape dedicated to farming activities. Transportation, Communication, and Utilities address infrastructure needs at 5.28%. Water and Wetlands collectively account for 11.09%, emphasizing the hydrological features and the presence of wetland ecosystems. Upland Forest contributes 3.94%, adding to the green cover. Barren Land and Rangeland contribute 0.18% and 0.36%, respectively. This diverse land use distribution highlights the dynamic nature of the Philippe Creek sub-watershed.

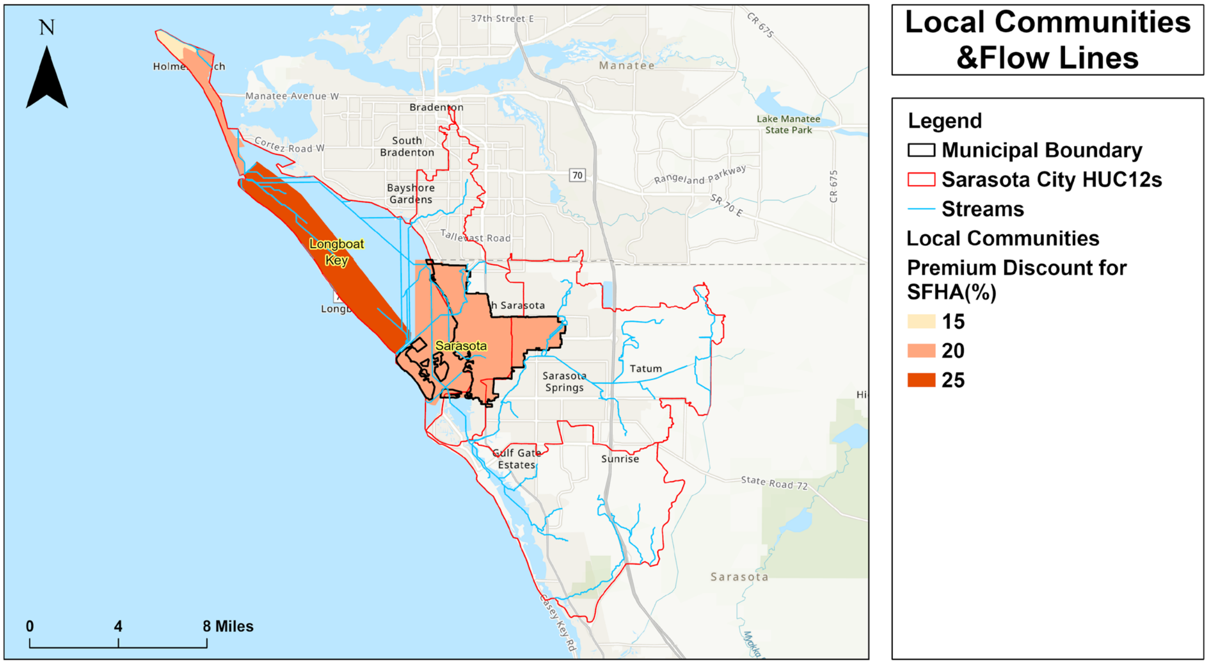

Figure 3. The communities and drainage network in Sarasota City, as generated by FAU CWR3.

Longboat Key is a town in Manatee and Sarasota counties along the central west coast of the U.S. state of Florida, located on and coterminous with the barrier island of the same name. Longboat Key is south of Anna Maria Island, between Sarasota Bay and the Gulf of Mexico. It is almost equally divided between the Manatee and Sarasota counties. Longboat Key was incorporated in 1955 and is part of the Bradenton-Sarasota-Venice, Florida Metropolitan Statistical Area. The town's population was 6,888 at the 2010 census, which decreased from 7,603 at the 2000 census. It increased to 7,505 in the 2020 census. According to the United States Census Bureau, the town has a total area of 16.0 square miles (41.4 km^2), of which 4.1 square miles (10.7 km^2) is land and 11.9 square miles (30.7 km^2), or 74.19%, of which is water.

Bradenton Beach is a city on Anna Maria Island in Sarasota City, Florida, United States. The population was 908 at the 2020 census, down from 1,171 in 2010. It is part of the Bradenton-Sarasota-Venice, Florida Metropolitan Statistical Area. The city occupies the southern part of Anna Maria Island and is one of three municipalities on the island. The others are Holmes Beach in the center and Anna Maria in the north. According to the United States Census Bureau, Bradenton Beach has a total area of 1.19 square miles (3.08 km^2), of which 0.52 square miles (1.35 km^2) are land and 0.67 square miles (1.74 km^2), or 56.55%, are water.

Anna Maria is a city in Sarasota City, Florida, United States. The population was 968 at the 2020 census, down from 1,503 in 2010. The city occupies the northern part of Anna Maria Island and is one of three municipalities. The others are Holmes Beach in the center and Bradenton Beach in the south. Anna Maria is part of the Bradenton-Sarasota-Venice, Florida Metropolitan Statistical Area. According to the United States Census Bureau, the city of Anna Maria has a total area of

0.86 square miles (2.23 km^2), of which 0.74 square miles (1.92 km^2) are land and 0.12 square miles (0.31 km^2), or 14.53%, is water.

Holmes Beach is a city on Anna Maria Island in Sarasota City, Florida, United States. As of the 2020 census, it had a population of 3,010, down from 3,836 at the 2010 census. It is part of the Bradenton-Sarasota-Venice, Florida Metropolitan Statistical Area. The city occupies the central part of Anna Maria Island and is one of three municipalities. The others are Bradenton Beach in the south and Anna Maria in the north. According to the United States Census Bureau, the city has a total area of 1.91 square miles (4.9 km^2), of which 1.68 square miles (4.4 km^2) are land and 0.23 square miles (0.60 km^2), or 12.19%, is water.

A summary of the existing CRS classifications for the communities in the study area is listed in Table 1, based on the FEMA Florida Repetitive Loss List. Non-participants (NP) are recorded by the CRS Program.
A summary of the existing CRS classifications for the communities in the study area is listed in Table 1.

Table 1. Community Rating System eligible communities for Sarasota City as of April 2021.

Community #	Community Name	CRS Class Rating	Premium Discount for SFHA (%)
125150	Sarasota	6	20
125087	Anna Maria	7	15
125091	Bradenton Beach	6	20
125114	Holmes Beach	6	20
125126	Longboat Key	5	25

1.1 Surface Topography

Topography is a key parameter that influences many of the processes involved in flood risk assessment, and thus, up-to-date, high-resolution, high-accuracy elevation data are required. To meet the requirements for FEMA Risk Mapping, Assessment, and Planning (RiskMAP), 1-meter (2015 to present) and 1/9 arc-second (~ 3-meter) (2010 -2015) LiDAR DEMs were acquired. The 1 m × 1 m LiDAR tiles were kriged to create a topographic map of the study area (Figure 4). This accuracy meets the 3DEP Quality Level 2 vertical root mean square error accuracy threshold of ±10 cm for FEMA (Arundel et al., 2015). The LiDAR used for this basin was 2016.

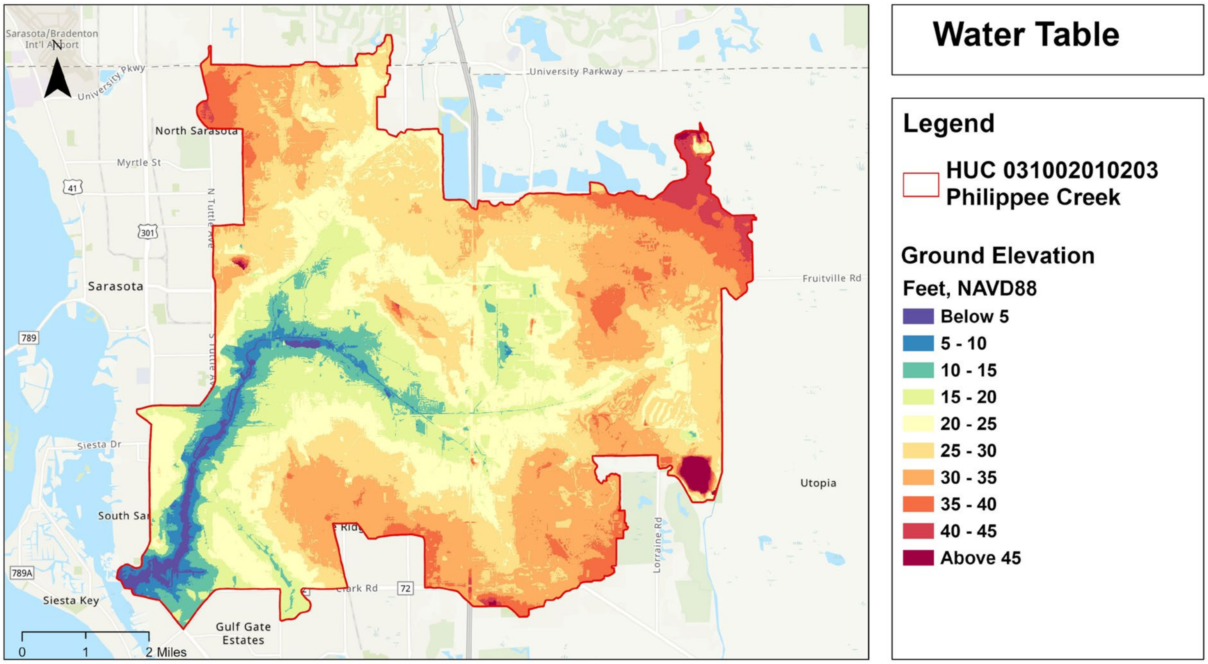

Figure 4. Topographic map of the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

1.1.1 Geomorphological Considerations

Sarasota City in Florida presents a diverse tapestry of geomorphological features shaped by a confluence of natural processes and human interactions. Its coastal expanse, characterized by the southern access to the Tampa Bay estuary and the iconic Sunshine Skyway Bridge, defines its shoreline allure. Inland, a mosaic of geological formations unfolds, encompassing varied terrains from low-lying areas near riverbanks to elevated landscapes. These geomorphological features reflect the historical narrative of human endeavors through remnants like the Braden Castle and sugar mills, coalescing with the natural terrain to paint a diverse and storied landscape within Sarasota City.

The HUC 031002010203 Philippee Creek is in Sarasota City. The land use distribution within the sub-watershed reflects a diverse tapestry of environments. With a blend of water, agricultural expanses, urban areas, and diverse land uses, the Philippee Creek sub-watershed presents a complex and interconnected landscape crucial for both natural ecosystems and human activities within this watershed unit. For context, the FIRM panel index of Sarasota City which includes the study area and surroundings is shown in Figure 5.

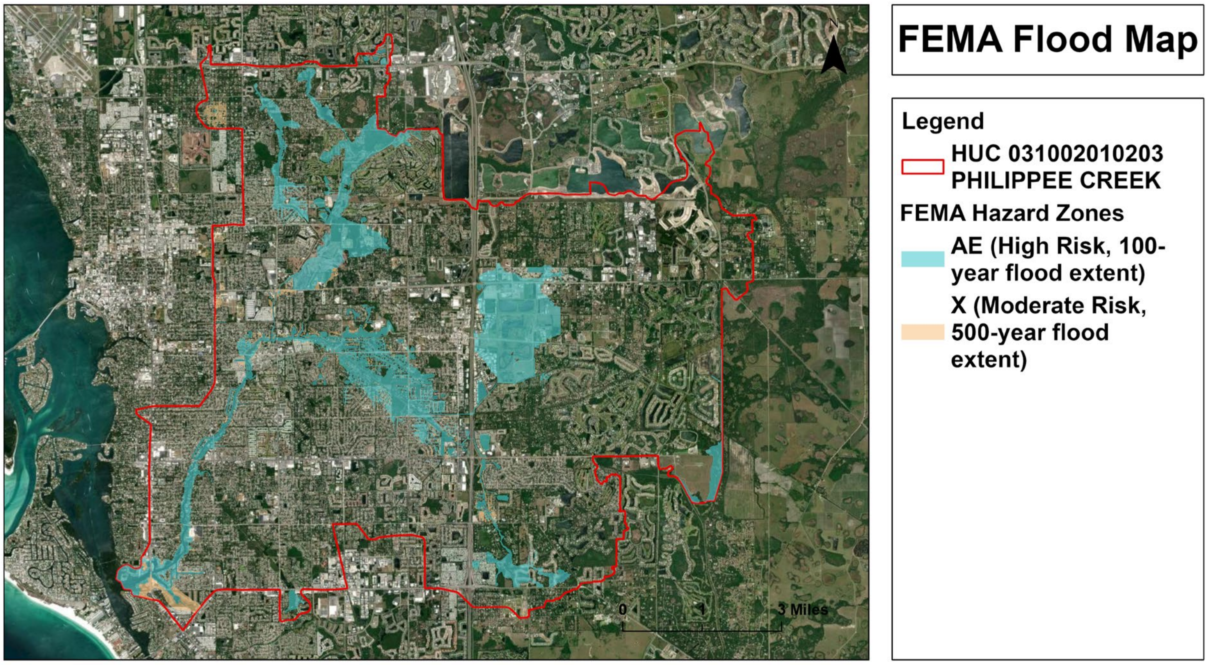

Figure 5. HUC 12 031002010203 Philippee Creek FIRM map (2020), as generated by FAU CWR3.

1.1.2 Waterway Features

An understanding of river- and stream-channel geomorphic responses to various human-caused and natural disturbances is important for effective management, conservation, and rehabilitation of rivers and streams to accommodate multiple, often conflicting, needs. Channel changes may have implications for the protection of property and structures, water supply, navigation, and habitat. The channel-bank erosion that accompanies natural channel migration on a flood plain represents a constant threat to property and structures located in or near the channel. Various anthropogenic and natural disturbances introduce additional instability to which rivers and streams adjust. Human-caused disturbances include reservoirs, channelization, in-channel sand and gravel extraction, and urbanization. A common natural disturbance is a flood or major storm event.

The health of coastal ecosystems relies on robust communities of sea grasses, oyster beds, and mangroves for juvenile fish and other species. Important issues to evaluate the health of the watershed in the coastal zone are the emergent and submerged lands. The Ocean lies to the west of HUC 12 031002010203 Philippee Creek, which directly affects the ground and surface water of area. Due to the direct interference with the ocean, the rising sea level rise will have a significant threat to this sub-watershed, potentially causing adverse impacts within the region. Figure 6 shows the bathymetry for the coastal zone. Note the waters in the Gulf are relatively shallow near shore which increases wave action from storm events.

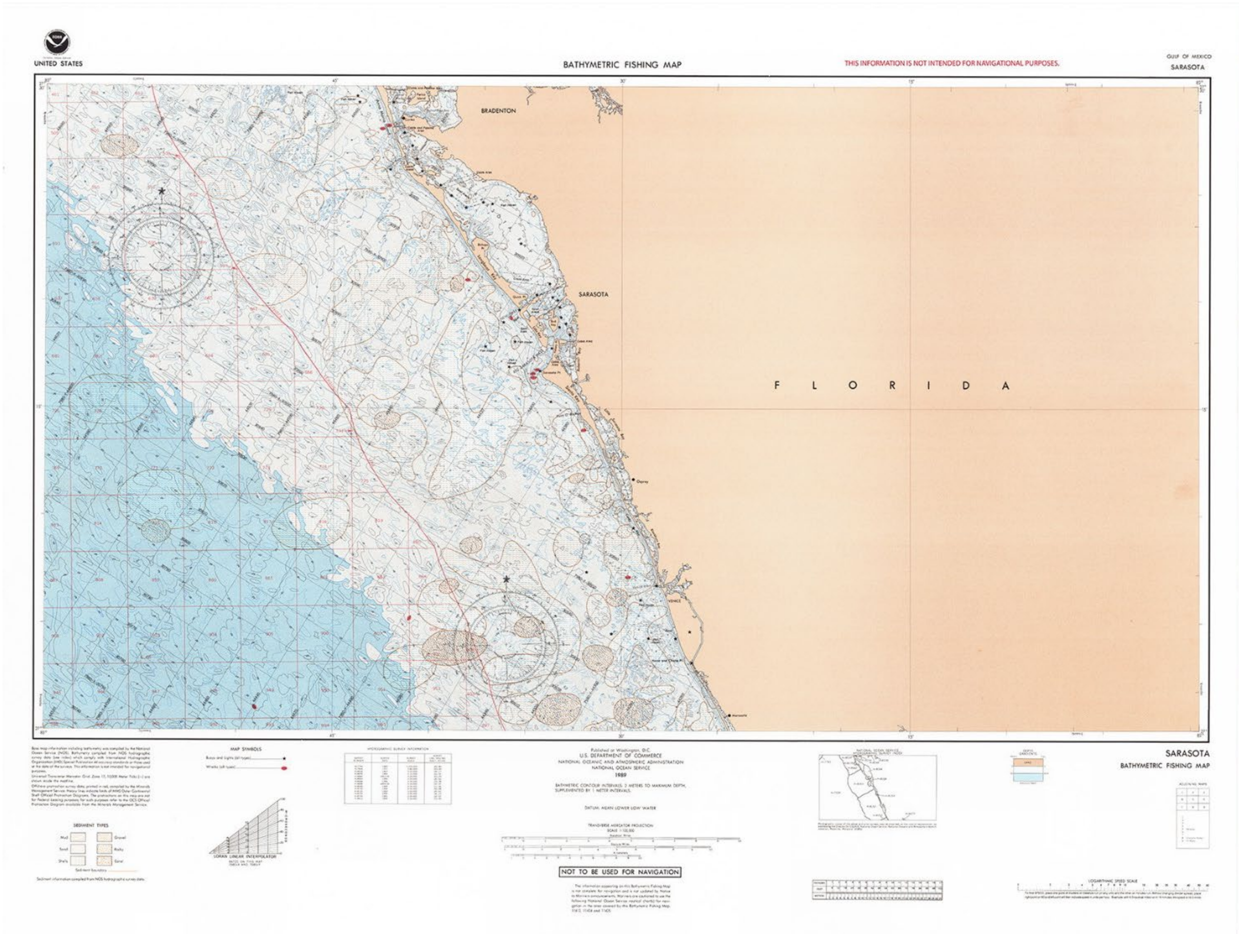

Figure 6. Bathymetry map of the shore of Sarasota City, FL. and surrounding counties of Manatee and Port Charlotte. (https://www.ncei.noaa.gov/maps/bathymetry/)

Numerous tributaries exist throughout both the freshwater and estuarine portions of the watershed and can influence overall hydrology of the area depending on rainfall and regional hydrological conditions. The major flow paths of the sub-watershed calculated using Arc Hydro are mapped. (Figure 7).

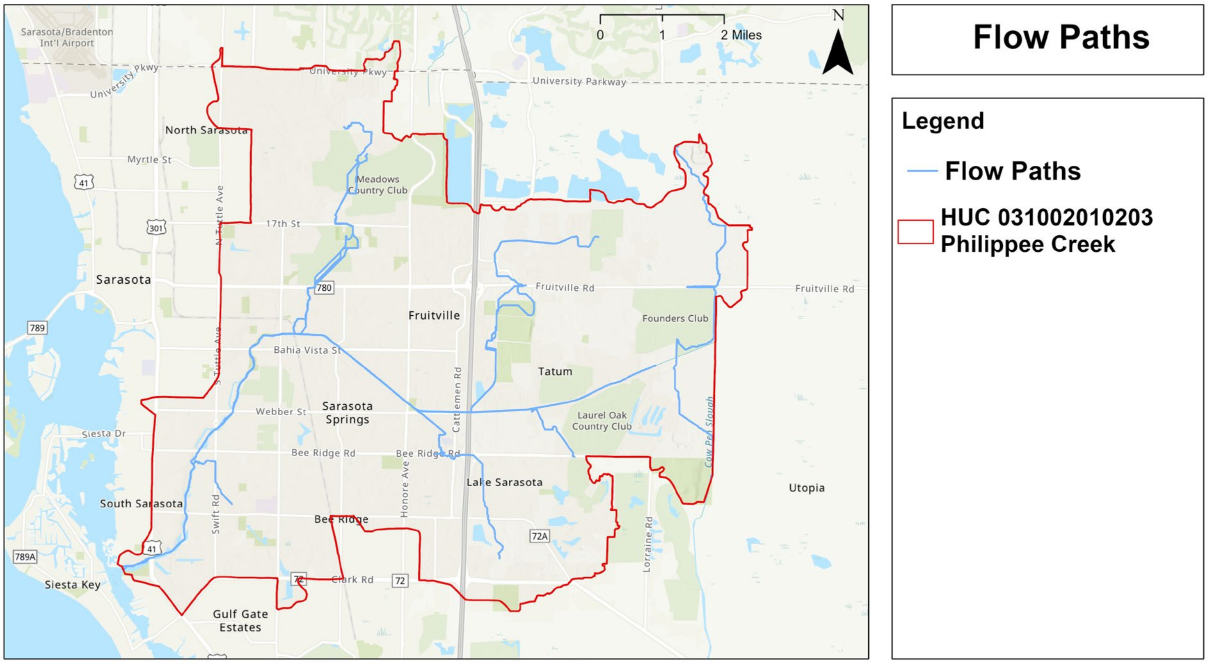

Figure 7. Flow paths for HUC 031002010203 Philippee Creek sub-watershed (SWFWMD.gov), as generated by FAU CWR3.

1.1.3 Hydrologic Boundaries

The geographic area of the subject sub-watershed should be clearly defined to ensure that implementing the WMP will address all the major sources and causes of impairments and threats. Although there is no rigorous definition or delineation of this concept, one way to identify the geographic extent of the watershed master planning effort is to consult the United States Geological Survey (USGS) map of hydrologic units. A hydrologic unit is part of a watershed mapping classification system showing various areas of land that contribute surface water runoff to designated outlet points, such as lakes or stream segments. USGS designates drainage areas as sub-watersheds (including smaller drainages) numbered with 12-digit hydrologic unit codes (HUCs), nested within watersheds (10-digit HUCs). These are combined into larger drainage areas called subbasins (8 digits), basins (6 digits), and subregions (4 digits), which make up the large regional drainage basins (2 digits).

Region>>Subregion>>Basin>>Sub-basin>>Watershed>>Sub-watershed

The major water bodies in the sub-watershed are the Intracoastal Waterway with the associated lakes and canals:

- Phillippi Creek
- Lime Lake
- Hudson Bayou

Given that stream flow data are critical for estimating flooding, Figure 8 shows the historical streamflow in the basin. Note the summer rainy season creates the surge in June to September. Such data are useful in assessing relationships between precipitation and streamflow, potentially an important indicator of watershed development.

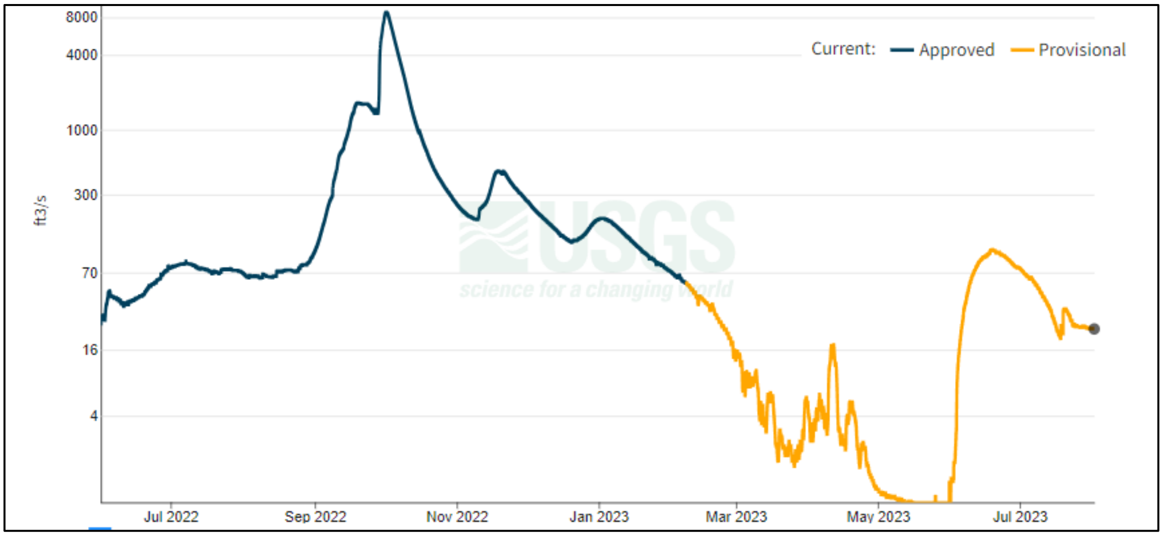

Figure 8. Average streamflow for Myakka River at control near Laurel FL - 02298880 Surface-Water, June 2022 to July 2023). Data retrieved from USGS Water Data Services: https://waterdata.usgs.gov/monitoring-location/02298880/#parameterCode=00060&showMedian=false&startDT=2022-06-01&endDT=2023-08-01

1.2 Groundwater

In this region of Florida, there is a direct interaction between groundwater and surface water. In addition to low land elevations and topographic relief, the groundwater and surface water are controlled by the canals, rivers, and tides. Since there is a limited number of groundwater monitoring stations, the strong relationship between groundwater and surface water was leveraged to develop a 99^{th}- percentile surface of the water table elevation for mapping purposes. To establish a common date for modeling, the recorded groundwater table elevations were sorted in ascending order to determine the 98^{th} - 100^{th} percentile date of occurrence in Excel®, following the procedure detailed in Romah (2011). This procedure was automated for this effort using a python code to process the groundwater data more efficiently. Outliers and anomalous groundwater levels in the database are initially identified (e.g., catastrophic storm events) and replaced by region-specific mean values based on observations available from the nearest well. Missing date-specific data are estimated using simple temporal interpolation based on observations available in time. If a station (or monitoring well) data contains large amounts of missing data, it is not used in the generation of the groundwater surface.

The uppermost formation generally encountered along the Sarasota City coast is the Anastacia Formation. The Anastasia Formation is composed of interbedded sands and coquinoidal limestones, with orangish brown sediments, and coquina of whole and fragmented mollusk shells in a matrix of sand often cemented by calcite. Sands occur as light gray to tan and orangish brown, unconsolidated to moderately hardened, un-fossiliferous to very fossiliferous beds. The Anastasia Formation forms part of the surface aquifer system (https://mrdata.usgs.gov/geology/state/sgmc-unit.php?unit=FLPSa%3B0).

Once a common time period is determined across the majority of shallow groundwater wells, canal data can be gathered for that common date (and two days prior, in the event the canals were deliberately lowered). Data is obtained from the SWFWMD DBHYDRO site for surface waters (https://www.SWFWMD.gov/science-data/dbhydro) and as generated by FAU CWR3 at cwr3.fau.edu. Between stations, an ArcGIS tool permits a line to be drawn to replicate the canals and establish points in a gradient between stations. The same is true for the ocean, but it is a constant head boundary. The canals form boundary conditions for the screening tool on the edges of the basin and affect localized groundwater. The tide issue is resolved by using the common date for high tide. An additional surficial wells were noted across the area (Figure 9) and, in conjunction with the surface water stations, were used to Multiple Linear Regression a groundwater-surface layer for the basin across the HUC 031002010203 Philippee Creek boundary (Figure 10).

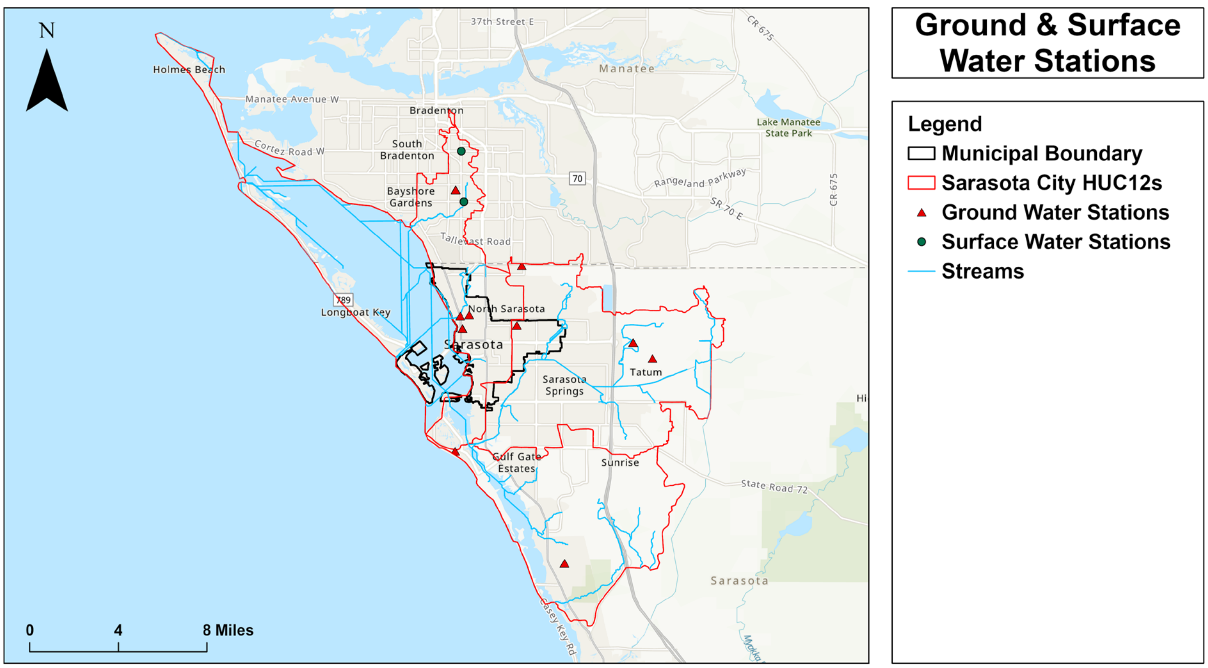

Figure 9. Ground & Surface Water Stations with drainage network for Sarasota City, as generated by FAU CWR3.

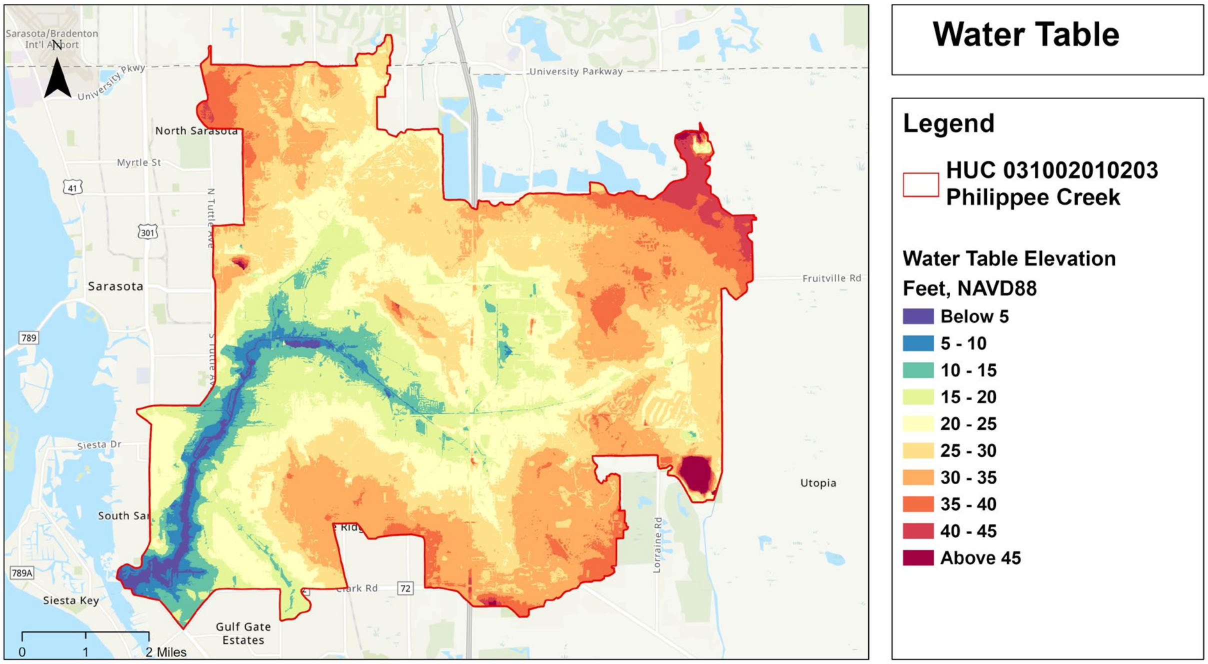

Figure 10. Elevation of the top of the surface groundwater layer for the HUC 031002010203 Philippee Creek created by multiple linear regression analysis – elevation NAVD88, as generated by FAU CWR3.

1.3 Surface Water/Tides

Historically, surface water and tides have been an important factor in determining how much freshwater is delivered, how fast this water enters wetlands and estuaries, and the quality of that water. Evapotranspiration and rainfall do not coincide (Figure 11), which makes water supply planning difficult (Bloetscher, 1995).

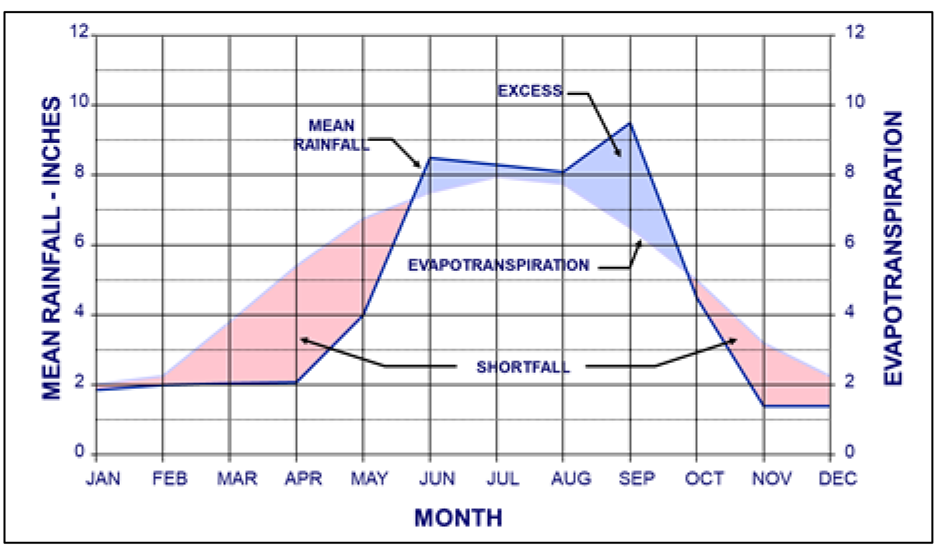

Figure 11. Comparison of rainfall and evapotranspiration for SW Florida (Bloetscher, 1995).

Many stations are located along canals and rivers, which assists in determining the water levels across open and connected surface water bodies. As shown in Figure 9, there are many stations with observations available. Data outside the study area was needed to properly Multiple Linear Regression across the boundary of the basin for the groundwater layer, adding another 40 points to the project. This is because the study area is primarily developed. All daily mean surface water level observations on the common date (October 29, 2017) were gathered from monitoring stations in the DBHYDRO database.

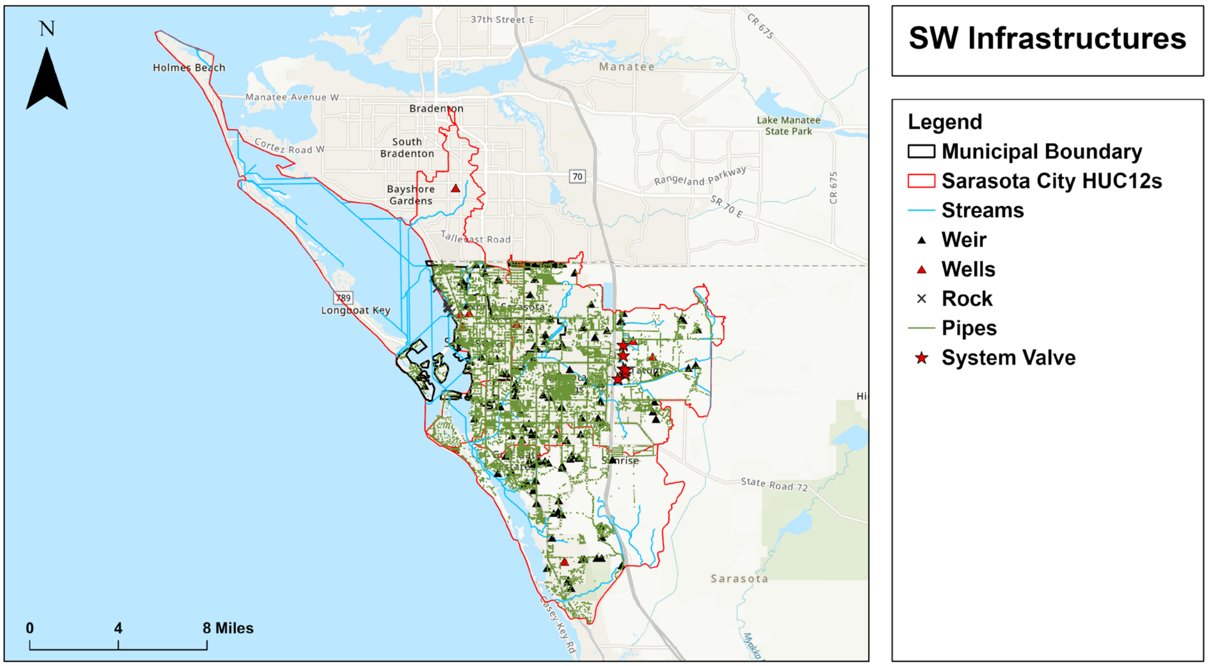

Figure 12. Location of major watershed level stormwater infrastructure in Sarasota City (used in modeling with Cascade 2001) (SWFWMD, 2020), as generated by FAU CWR3.

While the topography (Section 1.1) and native soil (Section 1.4) create an environment that is highly permeable and capable of infiltrating significant percolation into the soil, changes in land use and land cover have resulted in water falling on impervious areas, where the water collects in pools or runs off rapidly, in direct contrast to the natural condition. This runoff flowing over impermeable regions can lead to larger scale flooding.

Tidal data can be gathered from NOAA tidal gages and other gages monitored by local governments. The location of tide gauges is important to ensure they accurately depict tides, as opposed to inland waters. To set a boundary for the coastal areas, the high tide on the common date of 10/29/2017 was chosen. Figure 13 shows the tide gages in Florida. The Fort Myers tide station was used for this exercise.

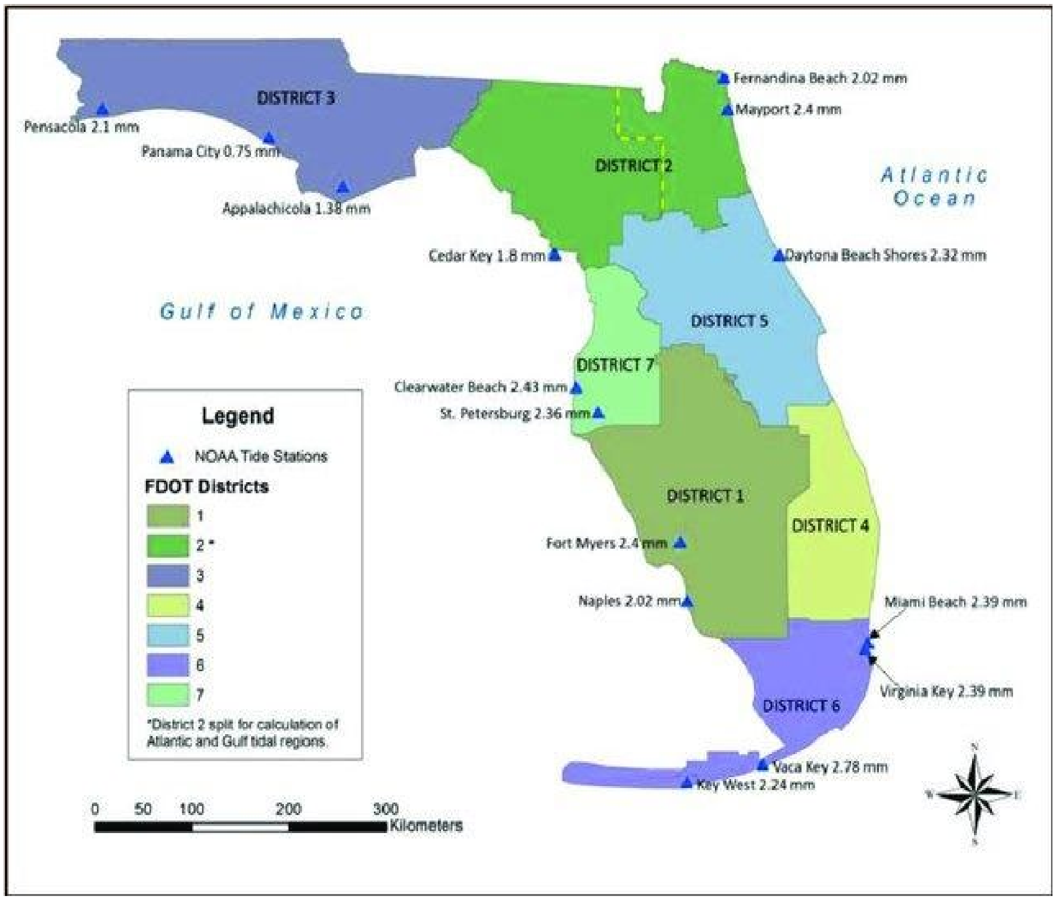

Figure 13. Locations of Florida tidal stations maintained by NOAA in FDOT Districts (https://www.researchgate.net/publication/330637496_Sea_Level_Rise_Projection_Needs_Capacities_and_Alternative_Approaches_Sea_Level_Rise_Projection_Needs_Capacities_and_Alternative_Approaches/Figures?lo=1).

1.4 Soils

Soil can store water if there is adequate distance between the topographic surface and the groundwater, and the soil types can absorb the water. Soil storage capacity is the volume of soil pores in the unsaturated zone that is available to store infiltrated stormwater (Gregory et al., 1998). Throughout Florida, it is common to have large-volume storm events that fill the voids in the unsaturated zone as shown in Figure 14.

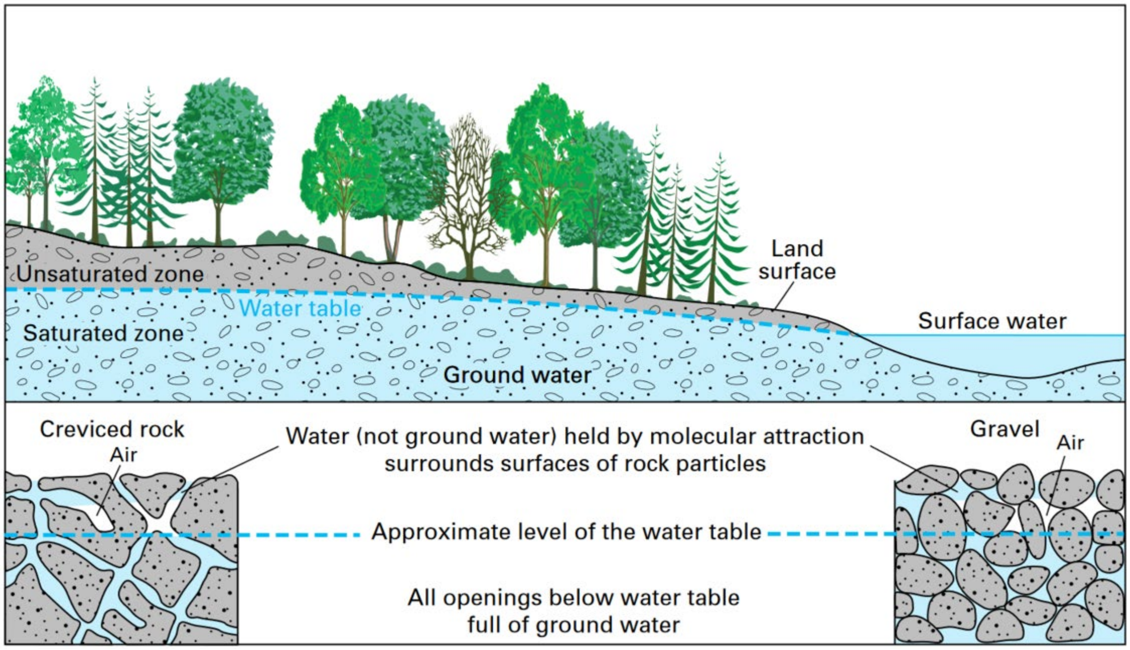

Figure 14. Zones where underground water exists (USGS, 2020).

The unsaturated zone is the portion of the subsurface above the water table that contains soil/rock and air and water in its pores as shown in Figure 15. This zone affects the rate at which the aquifer is recharged by controlling water movement from the surface of the land downward towards the aquifer. During rain events, the soil voids fill up quickly resulting in the water table rising to the surface, and the surplus rainfall becomes runoff.

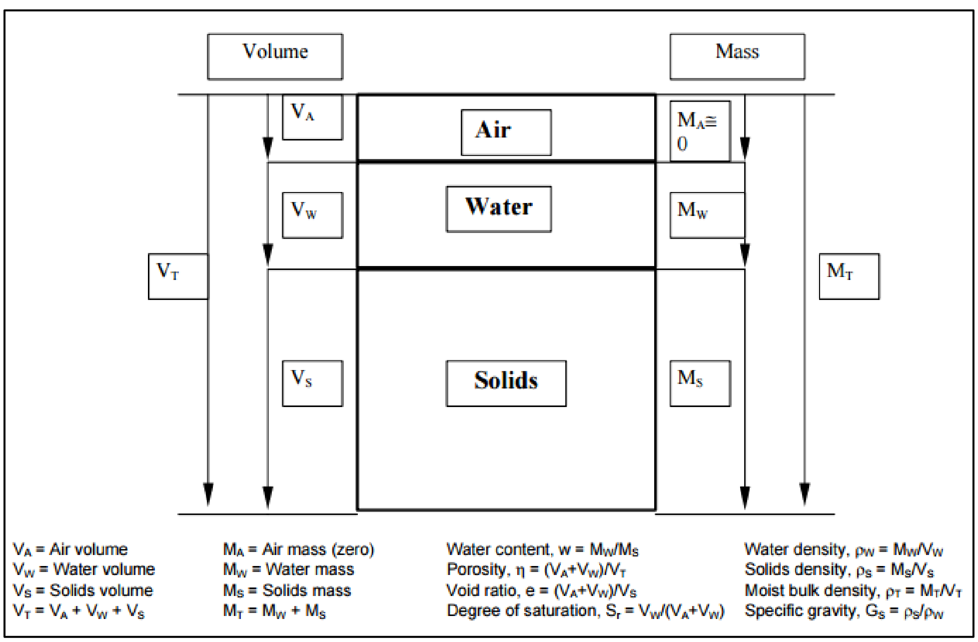

Figure 15. Saturated zone soil phase diagram and definitions (Gregory et al., 1998).

Soil data is available from the United States Department of Agriculture (USDA) or other agencies in the form of maps that can be incorporated as a GIS layer. The Gridded SSURGO (gSSURGO) dataset from USDA is chosen. This dataset is similar to the standard product from USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database, but is in the Environmental Systems Research Institute, Inc. (ESRI®) file geodatabase format. A file geodatabase allows for statewide or even Conterminous United States (CONUS) tiling of data. The gSSURGO dataset contains all the original soil attribute tables in SSURGO. All spatial data are stored within the geodatabase instead of externally as separate shape files. Both SSURGO and gSSURGO are considered products of the National Cooperative Soil Survey (NCSS). Figure 16 shows the unsaturated zone found by the difference between the groundwater elevation layer and surface topography.

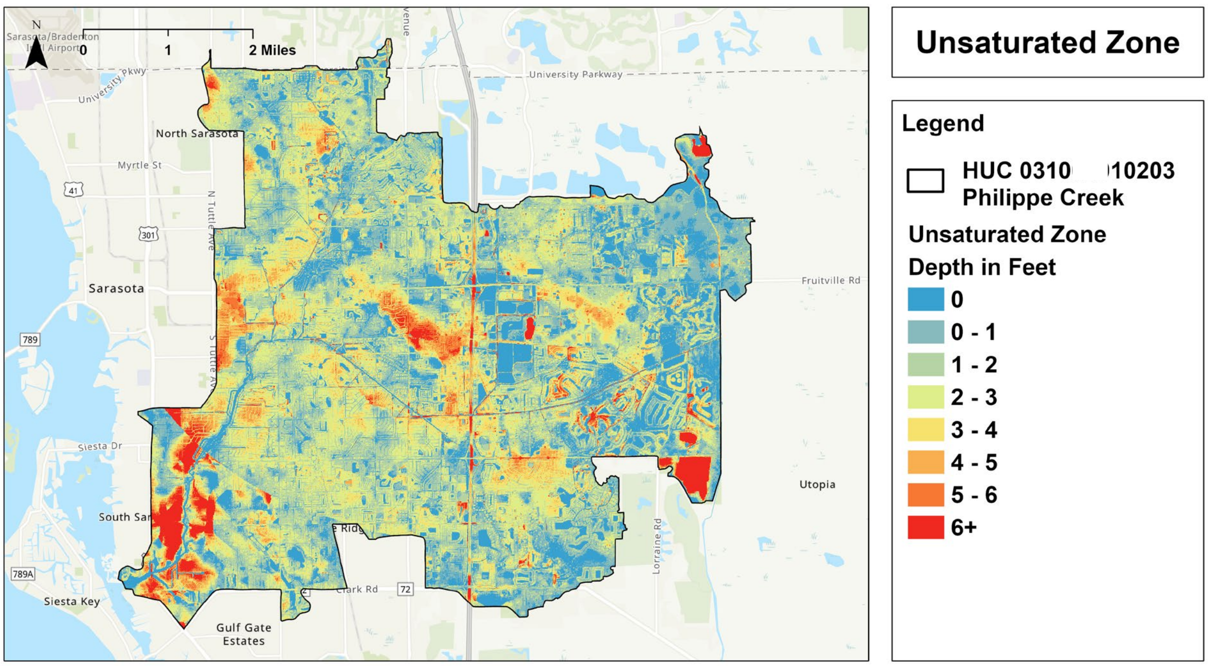

Figure 16. Unsaturated zone map for HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

The available water storage from USDA derived for the soil layer (0-150 cm or 0-5 ft) statewide is shown in Figure 17, which covers most of Florida with a spatial resolution of 10 m. The unit is in cm. As a result of applying this layer to the study area (Figure 18), the estimated soil storage capacity can be illustrated. Much of the basin has significant soil storage capacity.

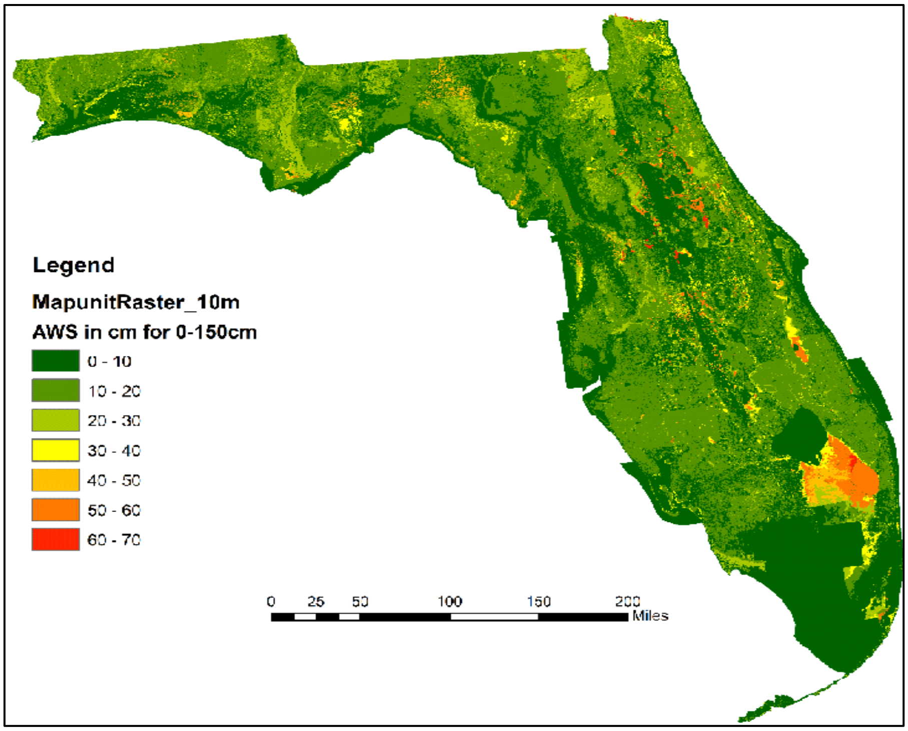

Figure 17. Available water storage derived from the gSSURGO soil database for all of Florida, as generated by FAU CWR3.

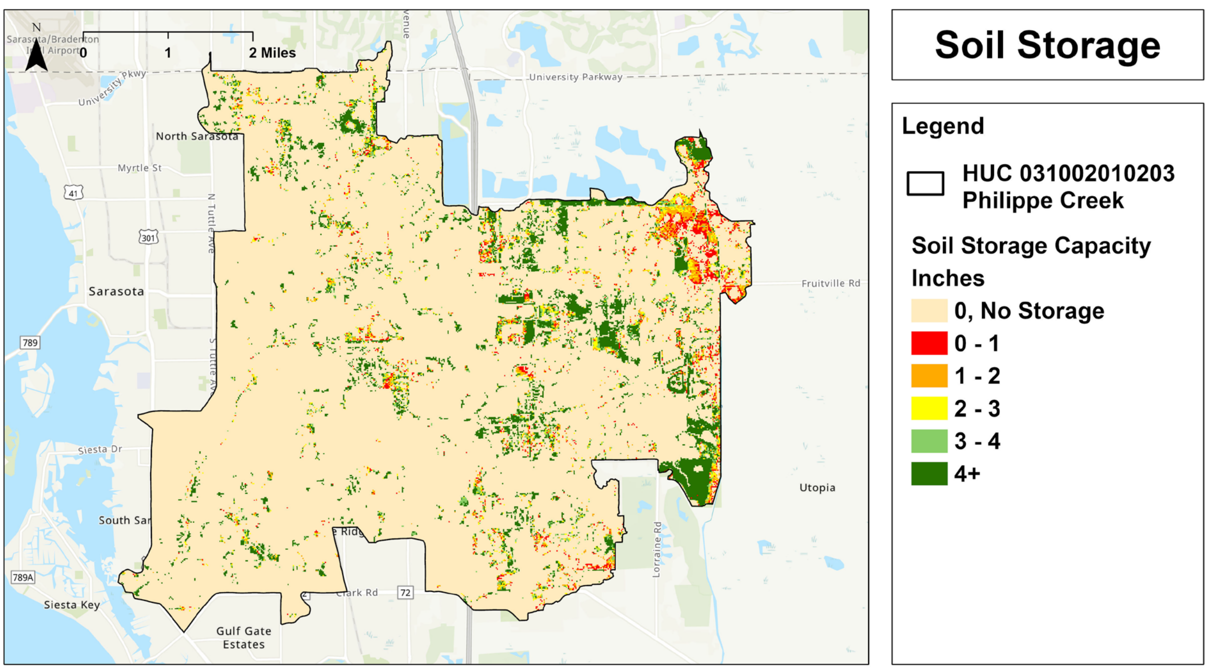

Figure 18. Water storage capacity of soil (inches) for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

Lastly, Figure 19 shows the water holding capacity for the basin, which refers to the capacity of a particular soil texture to retain water against the force of gravity.

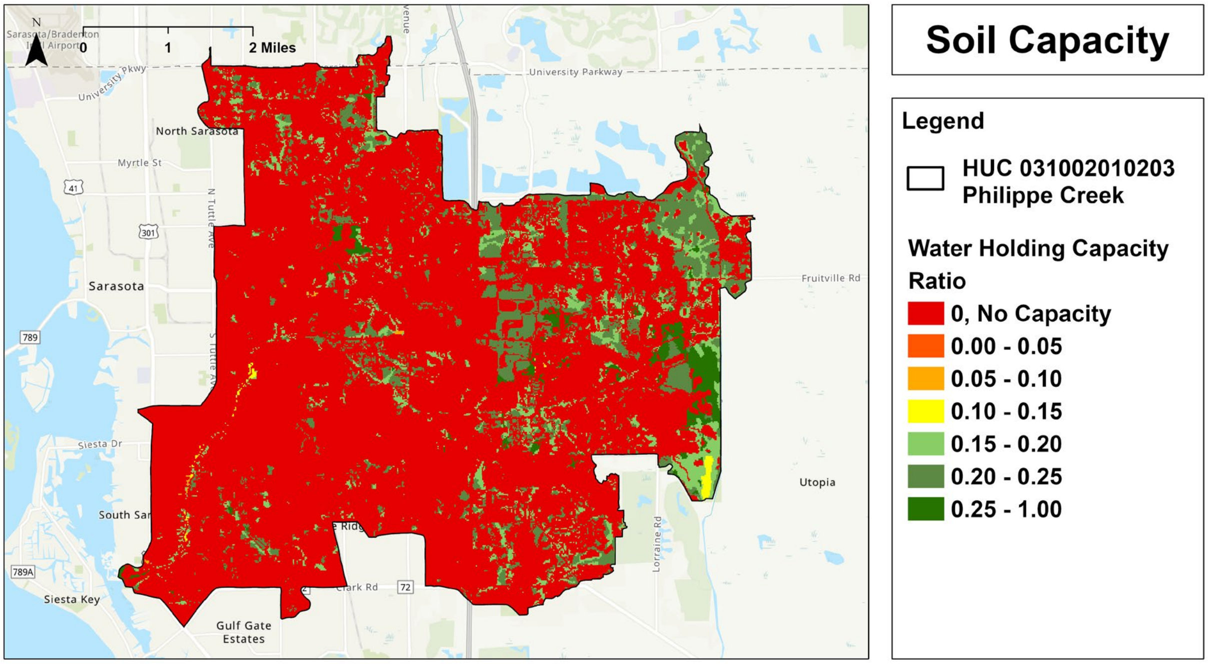

Figure 19. Water holding capacity of soil (ratio) for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

1.5 Land Cover

The USGS produces the NLCD of nationwide data on land cover at a 30-m resolution with a 16-class legend based on a modified Anderson Level II classification system. NLCD is coordinated through the 10-member Multi-Resolution Land Characteristics Consortium (MRLC) to provide digital land cover information nationwide. For the conterminous United States, NLCD 2016 contains 28 different land cover products characterizing land cover and land cover change across 7 epochs from 2001-2016, urban imperviousness and urban imperviousness change across 4 epochs from 2001-2016, tree canopy and tree canopy change across 2 epochs from 2011-2016 and western U.S. shrub and grassland areas for 2016 (Figure 20).

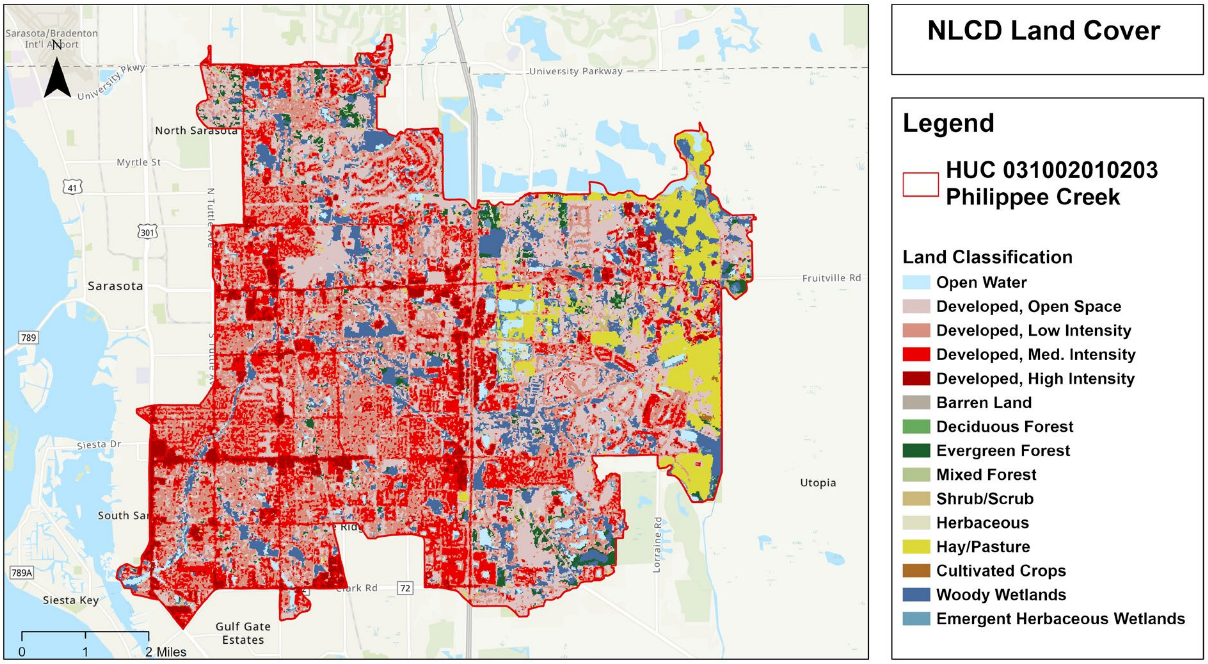

Figure 20. Land use in the HUC 031002010203 Philippee Creek (from the NLCD 2016 database), as generated by FAU CWR3.

The SWFWMD dataset is derived from the Florida Land Use Cover Classification System (FLUCCS), which is digitized by photointerpretation on county-based aerial photography with varying resolution in the 4 in - 2 ft pixel range. The NLCD2016 has a 30-meter resolution derived from Landsat imagery. Hence, the NLCD maps appear much coarser and pixelated compared to the SWFWMD maps. The land cover/land use map for the study area used the SWFWMD dataset. A close-up view is provided in Figure 21.

Based on the 2023 Florida Geographic Data Library (FGDL) (https://fgdl.org/fgdlmap/) the land use map for HUC 031002010203 sub-watershed is shown in Figure 21.

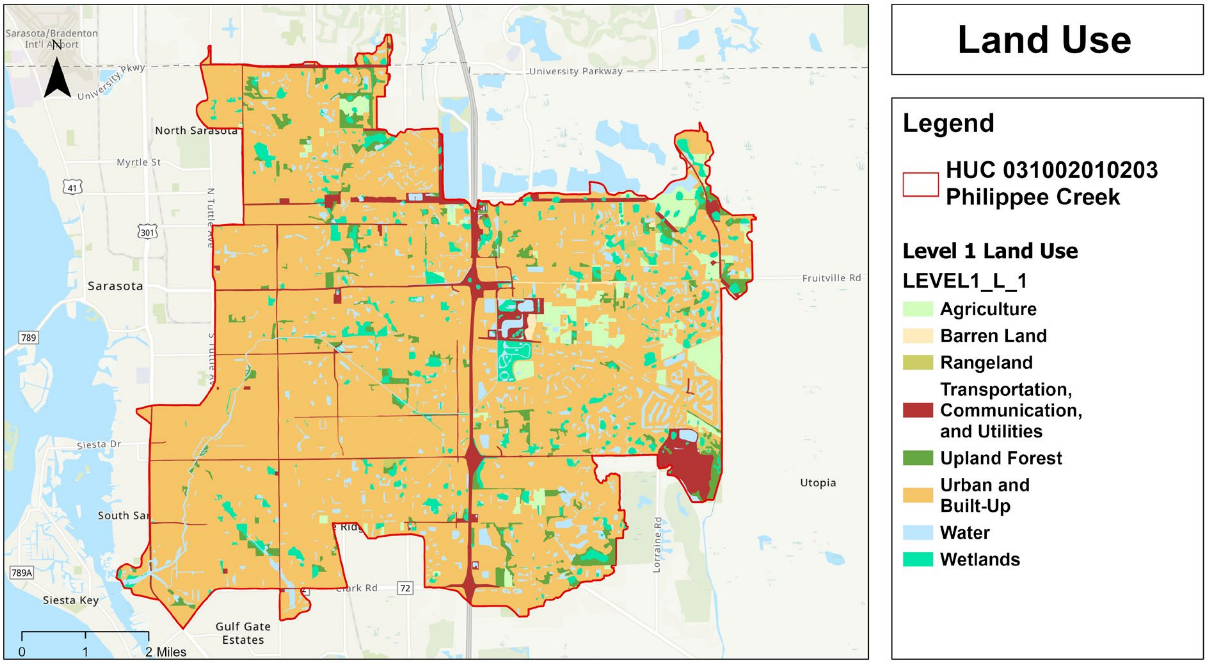

Figure 21. Land use in the HUC 031002010203 Philippee Creek (from the SWFWMD 2014-2016 database), as generated by FAU CWR3.

Based on the 2023 Florida Geographic Data Library (FGDL) (https://fgdl.org/fgdlmap/) the land use data for HUC 031002010203 Philippee Creek is shown in Table 2.

Table 2. Land use for HUC 031002010203 Philippee Creek sub-watershed (NLCD 2016).

Land use description	Percentage
Agriculture	4.05%
Barren Land	0.18%
Rangeland	0.36%
Transportation, Communication and Utilities	5.28%
Upland Forest	3.94%
Urban and Built Up	75.50%
Water	6.01%
Wetlands	5.08%
Total	100.00%

For modeling purposes, the values on Table 3 were used as needed as applied to the future land use maps. The future land use maps need to be used for the final land cover, as adjusted for future stormwater improvements set by regulatory standards.

Table 3. Roughness and CN Values for Each Land Use Code.

DOR Code	Use	Impervious %	Roughness
0	Vacant	0	0.4
1	Single Family	29	0.25
2	Mobile homes	21	0.05
4	Condos	60	0.05
7	Vacant –to be developed	0	0.4
8	Multifamily	60	0.05
TH 101	Townhomes	91	0.025
94	Road Right-of-Ways	50	0.08
	Open water	100	n/a
All others	Commercial, etc.	50	0.07

1.6 Precipitation

Rainfall used in the screening tool is based on the SWFWMD 3-day, 25-year storm, but can be modified for any rainfall event using the accumulated rainfall table obtained from NOAA Atlas 14 Point Precipitation Frequency Estimates (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html). Figure 22 shows the 3-day, 25-year rainfall map based on the NOAA Atlas 14 dataset for the whole state.

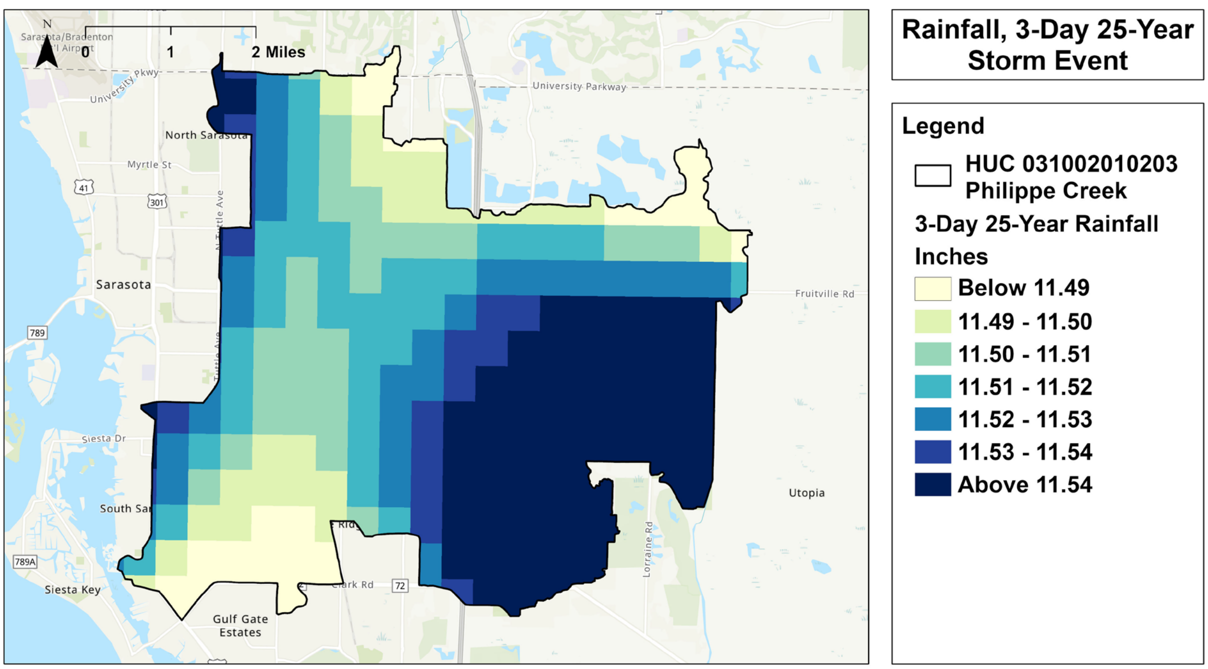

Figure 22. Rainfall distribution map across the HUC 031002010203 Philippee Creek for 3-day, 25-year storm, as generated by FAU CWR3.

The historical monthly rainfall differences between several DBHYDRO stations from 01/01/2010 to 03/21/2021 are shown in Figure 23.

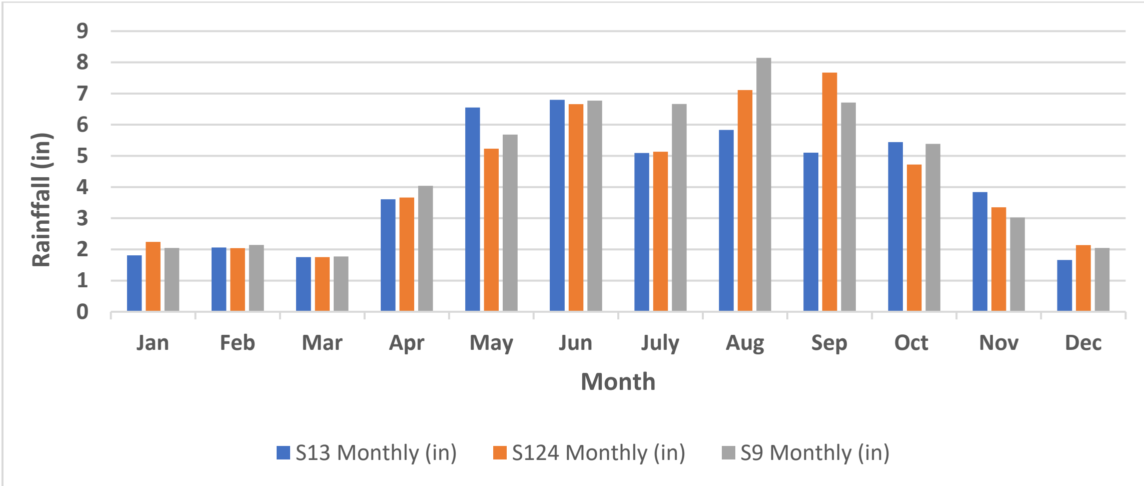

Figure 23. Variation of monthly rainfall at three locations (SWFWMD, DBHYDRO accessed 03/11/2021) showing generally consistent rainfall across the HUC 031002010203 Philippee Creek.

1.7 Open Space

Open space is defined as areas that are exempted from development. Generally, this means one or more of the following qualifiers exist:

1. Land that is valuable for recreation, forestry, fishing, or conservation of wildlife or natural resources
2. Land that is a prime natural feature of the state's landscape, such as a shoreline or ridgeline
3. Land that is habitat for native plant or animal species listed as threatened, endangered, or of special concern.
4. Land that is a relatively undisturbed example of an uncommon native ecological community
5. Land that is important for enhancing and conserving the water quality of lakes, rivers, and coastal water
6. Land that is valuable for preserving local agricultural heritage
7. Proximity to urban areas or areas with open space deficiencies and underserved populations
8. Vulnerability of land to development
9. Stewardship needs and management constraints.
10. Preservation of forest land and water bodies that naturally absorb significant amounts of carbon dioxide.

Permanent protection of sensitive areas can provide critical water quality protection and can be achieved through partnerships with landowners, municipalities, land trusts and state agencies. There is limited land in the study area that has been protected via acquisition by federal, state, or local agencies, has conservation easements or is designated as wetlands or areas of critical concern. Agricultural land and other land cover will come from the land cover map (in Section 1.5). Added to this will be the water bodies discussed in Section 1.9, which serves a related condition to open space.

1.8 Impervious Areas

Impervious areas do not permit the infiltration of rainfall to groundwater, and because the water cannot infiltrate, it runs off faster. Faster runoff means that flows to water bodies and storm sewers occur faster and with higher peaks. The result is a disruption of the natural and potentially the planned hydrology. Impervious areas include pavement, buildings, and other areas that reduce runoff capacity. In other words, developed areas have much higher imperviousness than open spaces that are natural or agricultural.

The NLCD provides nationwide data on land cover and land cover change at a 30-m resolution with a 16-class legend based on a modified Anderson Level II classification system. Systematically aligned over time, the database offers the ability to understand both current and historical land cover and land cover change to enable assessment of trends. Using the NLCD 2016 dataset, a layer was created by using only three categories out of the 13 to identify impervious areas such as primary roads in urban areas, secondary roads in urban areas, and tertiary roads in urban areas. The new layer was then converted to match the 3-meter spatial resolution from the DEM and the standard State Plane Coordinate system. Figure 24 shows the impervious areas derived from the NLCD 2016 as updated by the future land use map.

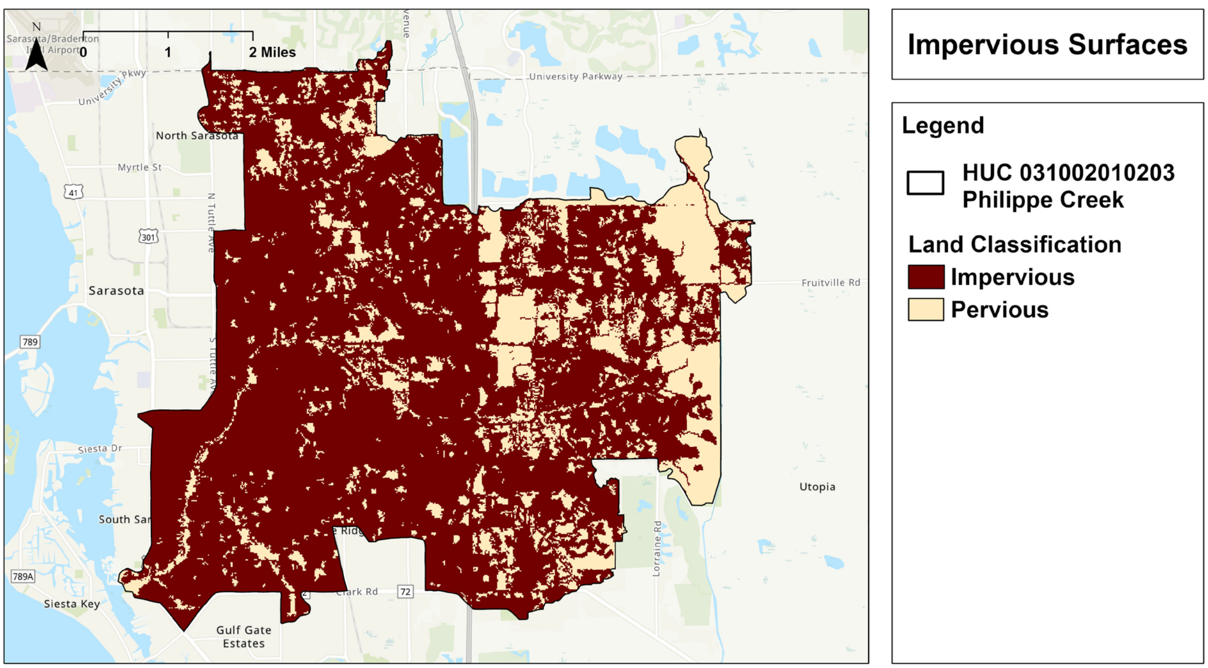

Figure 24. Impervious area map for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

1.9 Water bodies

Water bodies were defined in the statewide land use land cover dataset to set soil water holding capacity to zero in model simulations (Figure 25). Note that tiny water bodies may be missing from the maps. Soils were discussed previously in Section 1.4.

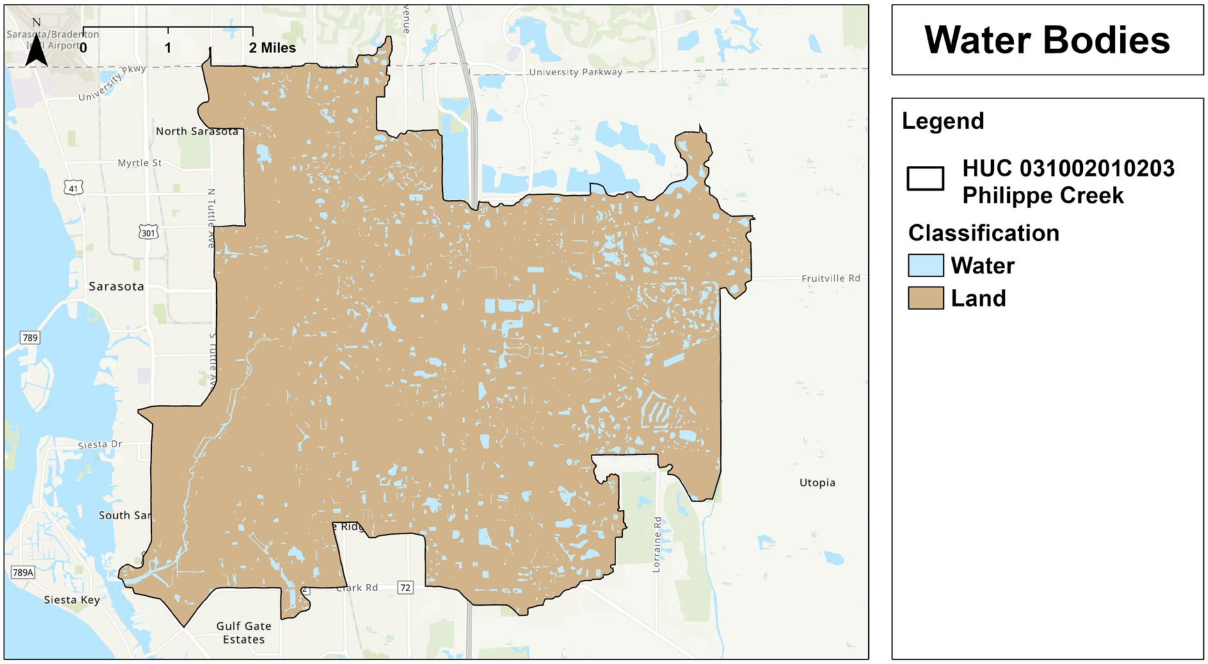

Figure 25. Water bodies map for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

1.10. Natural Resources

Understanding the study area's natural resources is critical to identifying potential sources of water quality degradation and areas to designate for conservation, protection, and restoration. One possible goal of watershed master planning is to protect terrestrial wildlife, aquatic habitat, and buffer zones. USGS maintains important sources of information on physical and geographical features as well as soil and mineral resources, surface and ground water resources, topographic maps, and water quality monitoring data. The USDA's Natural Resources Inventory (NRI) (www.nrcs.usda.gov/technical/NRI) is a survey of information on natural resources on non-federal land in the United States that captures data on land cover and land use, soil erosion, prime farmland soils, wetlands, habitat diversity, erosion, conservation practices, and related items. Since 2001, the NRI has been updated continually with annual releases of NRI data from all 50 states. The information provided can be used for addressing agricultural and environmental issues down to the county or cataloging unit level. Therefore, this data can be used to determine erosion and site-specific soil characteristics for certain land uses such as croplands, pasturelands, forestlands, etc., but the data is typically provided as inventories, not GIS layers.

1.11 Demographics

Demographics data is important for determining several key indicators for watershed master planning such as the ability to pay for improvements, social justice issues, land acquisition costs, property/land use, and communication strategies. The US Census has databases at the census tract level. Based on the census data for the study area, Table 4 outlines population and racial composition demographics.

Table 4. Demographics and Housing Characteristics of selected communities within the HUC Sarasota City, noting that only portions of these communities are within the sub-watershed (US Census 2010).

Demographic Parameter	**Sarasota**	**Palmetto**	**Bradenton Beach**	**Anna Maria**	**Holmes Beach**	**Longboat Key**
Area in square miles	24.1	5.79	1.19	0.86	1.91	16
Population	54,842	13,323	908	968	3,010	7,505
No. of Households	23,984	4,796	484	551	1,617	4,106
Med. Household Income	$62,615	$50,762	$65,536	$85,729	$78,311	$121,797
Median Age	49	49	68	65	64	71
White	66.16%	64.32%	93.06%	94.32%	92.86%	94.52%
Black, African American	12.39%	10.08%	1.00%	0.31%	0.17%	0.41%
American Indian, Native	0.52%	0.65%	0.22%	0.00%	0.13%	0.23%
Asian	3.08%	0.73%	0.55%	0.83%	1.06%	1.17%
Another Race	7.38%	13.05%	0.11%	0.62%	0.53%	0.64%
Two or More Races	10.41%	11.11%	5.07%	3.93%	5.22%	3.00%
Hispanic or Latino (Regardless of Race)	17.92%	28.18%	3.52%	3.01%	3.42%	2.36%

Source: US Census Bureau 2020 and Zip-codes.com

1.12 Stormwater Infrastructure Inventory

SWFWMD and USACE infrastructure exert a far larger impact at the watershed level compared to local infrastructure on the waterways indicated on Figure 26. Key stormwater assets for the study area:

- Pumping stations
- Culverts
- Canals
- Spillways.

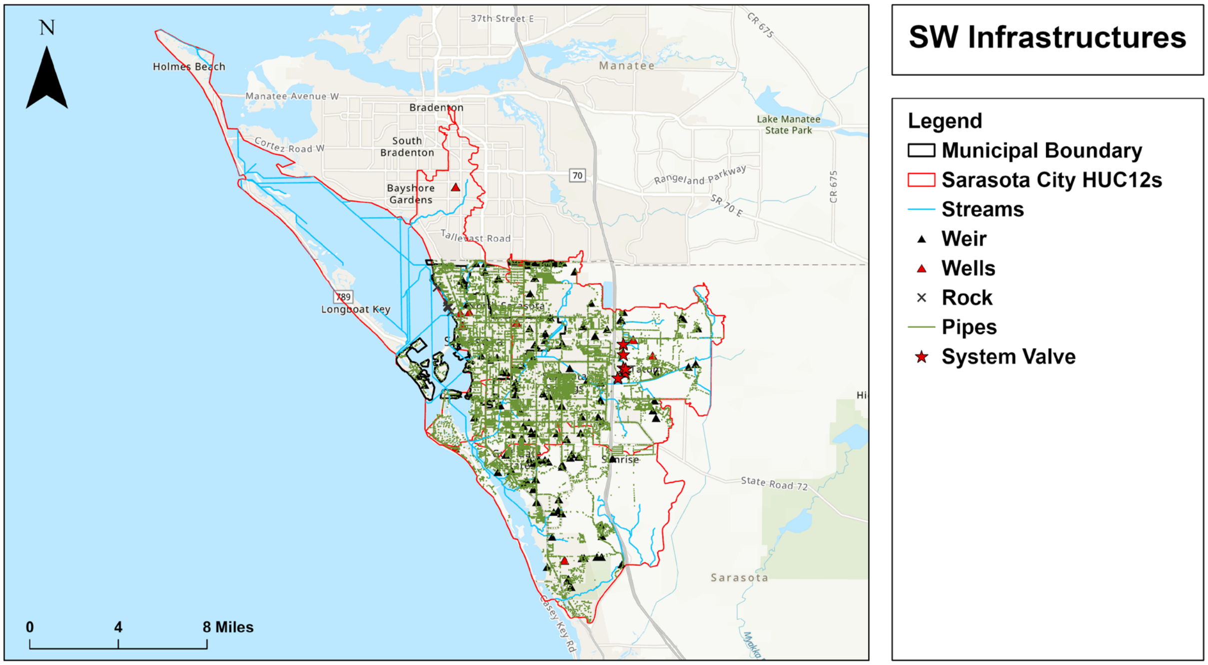

Figure 26. United States Army Corps of Engineers (USACE) and SWFWMD infrastructure in Sarasota City, as generated by FAU CWR3.

Local community stormwater systems consist of drainage ditches, storm sewers, retention ponds and other facilities constructed to store runoff or carry it to a receiving stream, lake, ocean, or other waterbody. Other man-made features include yards and swales that collect runoff and direct it to the sewers and ditches. When most of these systems were built, they were typically designed to handle the amount of water expected during a 10-year storm. Larger storms overload them, and the resulting backed-up sewers and overloaded ditches produce shallow flooding. Another urban drainage problem occurs in the areas protected by levees. Being in floodplains, they are flat and do not drain naturally, especially when a levee blocks the flow to the river. To drain these areas, channels have been built and pumps installed to mechanically move the water past the levee. Often, these man-made systems do not have the capacity to handle heavy rains or intense storms.

Another challenge with stormwater infrastructure is related to recordkeeping. It is not uncommon for stormwater data to be incomplete in most jurisdictions and completely lacking in others. Quality of data differs from jurisdiction to jurisdiction; some are in GIS formats, while others are paper maps or as-builts that represent the infrastructure at a macroscale level. The condition of the assets may be lacking, and the maintenance history may not be available either. Stormwater assets may have been installed with no records, especially in rural areas, farm fields, and private property.

The HUC 031002010203 Philippee Creek stormwater program operates through its boundaries. The sub-watershed has a GIS map of all stormwater elements. The stormwater structures include catch basins, curb inlets, culverts, canals, swales, pump stations, ditches, and manholes. The stormwater system must maintain compliance with the stormwater regulations, which require record-keeping, policy development, inspections, and maintenance.

- Best landscape practice.
- Control car washing contribution to pollution.
- Enforce the Stormwater Pollution Prevention Plan (SWPPP) by site evaluation, assessment, erosion and sediment controls, preventive maintenance, certification and inspection reporting for construction sites and city planning.
- Implement a hazardous material elimination system.
- Eliminate illicit dumping.
- Proactive and reactive catch basin inspections and maintenance.
- Street sweeping to control debris.
- Maintain swales to help prevent stormwater pollution flooding.

1.13 Data Gaps

FAU has developed comprehensive databases to address the information needed for vulnerability assessment. These are included in Table 5. The data can be used to model the impacts of flood routing during the storm of interest. As a result, the modeling pieces (discussed in Chapter 2) will include the following:

- Flood response model results (Cascade 2001)
- Flood risk/hazard mapping
- Vulnerability assessments to identify areas of concern for future repetitive losses.

There is only one data gap for the area – existing stormwater infrastructure records are incomplete. However, for the purposes of this plan, this data gap does not limit the findings as there are two scales: 1) the sub-watershed level and 2) community hotspots. A neighborhood-level vulnerability assessment will require the local infrastructure inventor.

Table 5. List of datasets collected by FAU as of List of datasets collected by FAU for the project

Data Category	**Dataset Name**	**Original Source**	**Spatial Coverage/ Resolution**	**Temporal Coverage/ Resolution**	**Link to the Dataset on our Server (physical location)**	**Dataset size and Format**	**Native or FAU Processed dataset**
	USGS_NED	USGS	Part of Florida, raster image in 1 m	Created by USGS in 2016	\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\LiDAR_DEM\DEM_1m	3.28G bytes, raster images	Native
	USGS_NED	USGS	Part of Florida, raster image in 3m	Created by USGS	\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\LiDAR_DEM\DEM_3m	40.9G bytes, raster images	Native
	USGS_DEM	USGS	Florida, Raster data in 10m	Created by USGS	\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\USGS_DEM	22.6 G bytes, raster images	Native
	DEM_3m_merged	USGS	3m in tiff		\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\LiDAR_DEM\DEM_3m_merged	186G bytes, raster images	FAU Processed
Topography	SRTM_30m	NASA	30m Raster		\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\LiDAR_DEM\SRTM_30m_UCF_Chang	607M bytes, raster images	Native
	USGS_3DEP	USGS	Sarasota County, raster image in 1 meter	2018-2020	\\engsynws01.eng.fau.edu\Project_working\Users\Geosciences\Dataset\DEM_1m\Sarasota\serasota_menatee_dem_feet	53G bytes, raster images	Mosaiced by FAU

Data Category	Dataset Name	Original Source	Spatial Coverage/ Resolution	Temporal Coverage/ Resolution	Link to the Dataset on our Server (physical location)	Dataset size and Format	Native or FAU Processed dataset
Groundwater	FL_GW	Southwest FL Water Management District	Florida, Geodatabase	Daily, 1980-2020	\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\FL_GW\SWFWMD_GeoDatabase	27.9 G bytes, Geodatabase	Native
Surface Water and Tides	FL_SW	Southwest Florida Water Management District	Southwest of Florida, site observations	Daily, since 2000	\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\FL_SW\	74.5M bytes, in excel and dbf	Native
Soil	FL_Soil	FY2019 USDA Soil SSURGO gSSURGO) Database https://sdmdataaccess.nrcs.usda.gov/	Florida, Raster data is in 10m	Released by USDA in 2019	\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\FL_soil Processed data for water holding capacity ratio is at: \\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\FL_soil\aws0_150_whc1.tif	107G bytes, both vector and raster	FAU Processed
Land Cover	USGS_LC	USGS	Conterminous United States, raster format, 30m derived from satellite	Created by USGS in 2016 (Most recent)	\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\USGS_LC\NLCD_2016_Land_Cover_L48_20190424	20G bytes, raster	Native
	Impervious Surface	USGS	Florida, 30m derived from satellite	Created by USGS in 2016 (Most recent)	\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\Impervious\NLCD_2016_Impervious_descriptor_L48_20190405\	24.6G Bytes, Raster Image	FAU Processed

Data Category	Dataset Name	Original Source	Spatial Coverage/ Resolution	Temporal Coverage/ Resolution	Link to the Dataset on our Server (physical location)	Dataset size and Format	Native or FAU Processed dataset
	Open Space	USGS	Florida, 30m derived from satellite	Created by USGS in 2016 (Most recent)	\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\FL_LCLU\NLCD2016_OpenSpace\	21G bytes, raster	FAU Processed
Precipitation Records	FL_NOAA14_Precipitation	NOAA Atlas 14 Database	Florida, raster in 800m	Most recent release from NOAA	\\engsynws01.eng.fau.edu\Project_mastercopy\Datasets\FL_NOAA14_Precipitation\se25y3d_inch.tif	34 M bytes, raster images	FAU Processed, 3-day 25-year and 3-day 100-year

2. ASSESSMENT OF VULNERABLE AREAS

Defining flood risk due to compounding hydrographic influences is the central concern of a WMP effort. Modeling and assessment of vulnerability for the study area focused on the combination of a high water table, heavy rainfall, and impervious urban conditions that can lead to localized nuisance flooding events. Through previous surveys conducted with local officials, the number of days of continuous nuisance flooding that the public will tolerate before that flooding is considered destructive is about 4 days.

For a large study area, small parts may be most at risk. The key is to identify where further study might be needed. A screening tool accomplishes this goal applied to the sub watershed scale to designate areas that are susceptible to periodic flooding events. Utilizing the information collected and analyzed in Chapters 1 and 2, and comparing it to data in Chapter 3, vulnerability can be assessed.

2.1 Historical and Existing Challenges

There are a series of historical challenges in the west coast of Florida, including the HUC 031002010203 Philippee Creek including the following:

- Control of discharges to the Gulf of Mexico, which cause ecosystem damage, harmful algal blooms, and other water quality issues for the coastal ocean.
- Flooding near coastal ocean.
- Development adjacent to the floodplain.
- Water supply and flood protection are intertwined, opposing issues throughout the basin.
- Reconciling local and regional planning efforts.

Pressure for development in the western portion of the basin exacerbates effort to protect open space for land percolation of water. While regulations are in place to reduce the influx of stormwater, the challenges will continue with development.

2.1.1 Existing Management Efforts in the Watershed

The entire basin is controlled by the SWFMWD and USACE with the intent of reducing flooding within the district boundaries. Local governments have local stormwater utility infrastructure and planning/policy tools to reduce future flood potential as discussed in Chapter 3. Most of the major projects to date have been District driven. Much of that plan's focus, however, was on addressing water quality issues.

2.1.2 Critical Target Areas Identification

By modeling the Philippee Creek flood response to a series of rainfall events and sea levels (plus king tides), and further classifying flood risk as the probability of inundation, it is possible to identify critical target areas. These areas are particularly vulnerable to flooding and are subject to further study through a scaled-down modeling approach. The screening tool is first applied at the greater watershed level to provide an initial risk assessment focused on the hydrologic response to a rainfall event given the unique characteristics and features of the sub-watershed or study area. The process is discussed later in Section 2.2 with results presented in Section 2.5.

2.1.3 Potential Preservation Areas

Sarasota City has a plan for limited land acquisition along the coast and in the sloughs throughout the County. No other communities in the HUC 031002010203 Philippee Creek have such plans. It is unclear what further effort is needed until the storage acreage completes construction and begins operation and monitoring.

2.2 Vulnerability Maps

2.2.1 Screening Tool

The screening tool utilizes topographic data from various sources (Section 1.1), water table elevations (Section 1.2) and surface water gauges (Section 1.3) downloaded from the SWFWMD DBHYDRO website, tidal information for coastal areas obtained from the NOAA Current & Tides website (Section 1.3), soil maps obtained from the USDA (Section 1.4), and another key dataset as described previously in Chapter 1. The design storms are discussed in Section 1.6. The reason this is critical is that to do any modeling (as required by the CRS program), a screening tool should be used to identify regions with a high risk of inundation based on multiple collected datasets and hydrological models. Figure 27 shows how the GIS layers interface in the tool and how they are combined for spatial analysis.

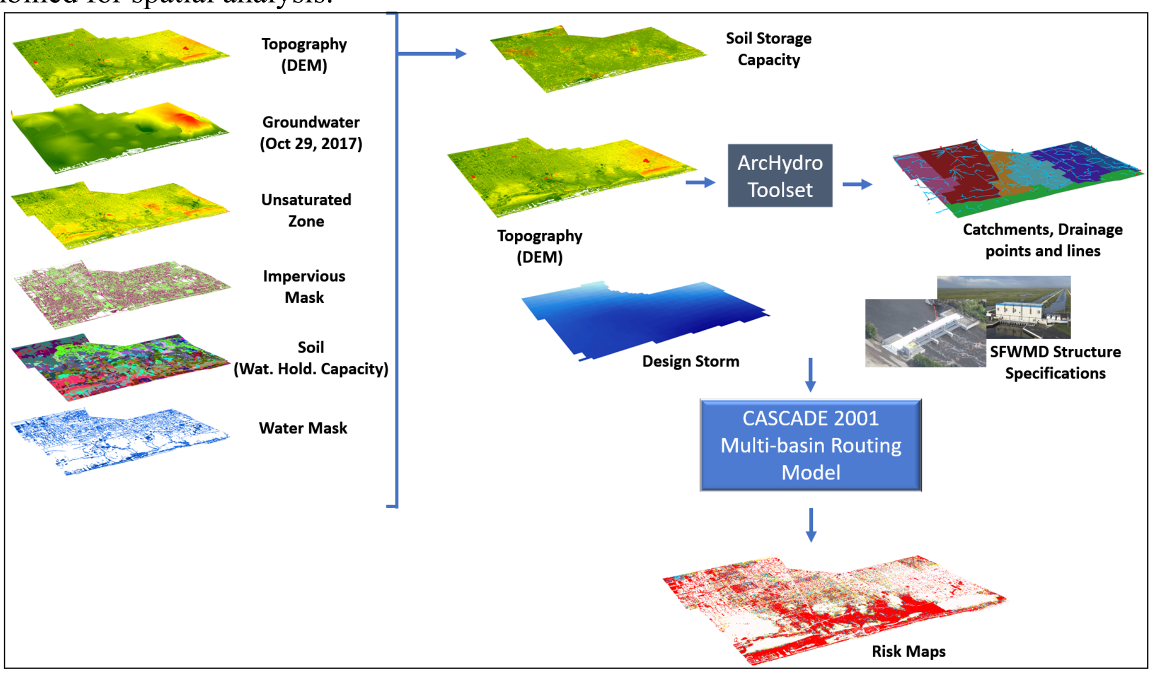

Figure 27. Screening tool methodology for creating flood risk maps.

The model chosen for this screening tool is Cascade 2001, which is a multi-basin hydrologic/hydraulic routing model developed by the SWFWMD. The model permits the investigator to run different storm events to determine flooding scenarios. The boundaries are critical for basin studies and must be chosen carefully. The following data layers collected in the prior section are processed to develop the input files for Cascade 2001:

- Topography
- Soils
- Development intensity
- Groundwater elevations
- Surface water/Outlet locations

The software creates a glass box where water rises to a certain level and then decreases. Running the simulation requires defining the basin (HUC or sub-HUC) and input of the following data:

- Area
- Portion of area above a given elevation
- Initial groundwater stage
- Longest travel time for the runoff to reach the most distance point of discharge
- Ground storage as estimated from the USDA gridded National Soil Survey Geographic Database (gNATSGO)

  Ground storage ≈ (Water holding capacity) × (Surface elevation – GW elevation)
  = 2 × (AWS for a soil layer of 0-150 cm) / 150cm × (Surface elevation – GW elevation)

- Available water storage (AWS) for a soil layer of 0-150 cm
- Average amount of precipitation that can be stored in the soil layer

The output from the model is an elevation surface that can be used to develop a flood map for the study area (Figure 28), which shows the spatial distribution of probabilities of flooding during the modeled 1-day, 100-year storm event.

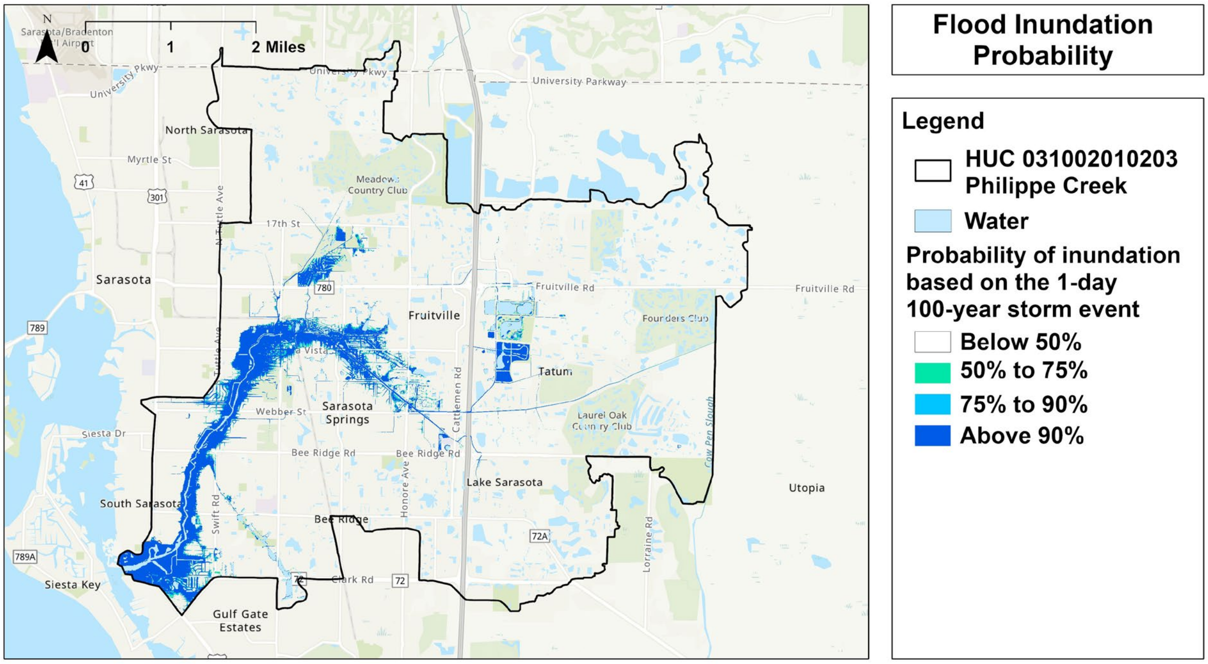

Figure 28. Probability of flood risk map during the modeled 1-day, 100-year storm event for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

Just because a property is shown to flood does not mean it always floods. The flood maps can be compared to the repetitive loss properties uploaded to the GIS platform as a separate layer, as shown in Section 2.5.

2.2.2 Identification of Vulnerable Area

Given these assumptions and the Cascade 2001 outputs, the goal of this methodology is to produce a spatially-temporally quantified understanding of nuisance-destructive flood potential in the study area given observed values. Risk is a function of compounding geo-hydrological features, namely, surface water, groundwater, topography, build-out, and time of year. A GIS-based algorithm and spatial interpolation generated layers of the greatest observable hydrographic surfaces. These outputs were then compared with high resolution topographic LiDAR data to develop digital elevation models that reflect the observed risk landscape. These models can then be combined into Cascade 2001 to produce vector and volume information, in combination with soils, vegetation and impervious surfaces, allowing the observed model outputs to be extrapolated into a more predictive context.

To evaluate flood vulnerability at this scale, the analysis starts with a binary flooding surface (0 = below 50% chance of flooding; 1 = above 50% flooding) based on output from the screening tool for a specified design storm. Next, attributes of that raster based on "VALUE = 1" query are extracted using Extract by Attributes tool. Then the Batch Project tool was used to map critical facilities data to the common coordinate system (NAD83 UTM Zone 17N), unit = meters. Then a field was added using Add Field for [PriorityTier] = assigned Tier #1-6 value from the DOR codes and [Area_sqmeter]. The critical facilities layers were then merged into a single layer to calculate the polygon geometry for [Area_sqmeter] using the Merge tool. Next, Zonal Statistics as Table is used to calculate the SUM of flooded values ("VALUE = 1") within each critical parcel. Output table has fields for SUM (i.e., total # of flooded pixels per critical parcel) and AREA in map units of square meters (since each pixel in the flooding surface has a cell size of 3-meters by 3-meters, each area is equal to the SUM value multiplied by 9 m^2). Using the Join Field tool, the SUM and AREA fields are joined to the merged critical facilities layer based on a key attribute, first renaming these fields for clarity (e.g., AREA_FLOODED_3d25y). Once all field data is included, the next step involves using Export Table to export the dataset as a CSV file. Note that non-flooded parcels have zero flooded area, so they receive a <Null> value from the zonal statistics tool. To replace null values with zeros, we use Calculate Field in the attribute table along with the following Python expression (replacing the respective field name): "0 if !AREA_FLOODED_3d25y! is None else !AREA_FLOODED_3d25y!". Next, the CSV file is saved as an Excel Workbook (.xlsx). The Range is converted to an Excel Table, and the columns are rearranged in the desired order. Finally, the "percent-flooded" columns are calculated as follows:

- PCT_FLOODED_3d25y = ([@[AREA_FLOODED_3d25y]]/[@[TotalArea_sqmeter]])*100
- PCT_FLOODED_1d100y = ([@[AREA_FLOODED_1d100y]]/[@[TotalArea_sqmeter]])*100

After this calculation, the table is sorted to show the higher priority tiers and higher percent-flooded values first. To reduce the number of critical facilities shown in the final table, a filter was created to show only critical facilities with 10% or more flooded area in the parcel during both storm events. Records with duplicate parcel ID numbers were removed from the table. The results of this procedure are discussed in Section 2.5 of this document.

With respect to dams and levees, for purposes of the NFIP, FEMA only recognizes systems that meet, and continue to meet, minimum design, operation, and maintenance standards that are consistent with comprehensive floodplain management criteria. The Code of Federal Regulations, Title 44, Section 65.10 (44 CFR 65.10) describes the information needed for FEMA to determine if a levee system reduces the risk from the 1% annual chance flood. FEMA has accredited levees and Provisionally Accredited Levees (that have a specified timeframe to obtain the necessary data to confirm the levee's certification status). If a levee system no longer meets Section 65.10, FEMA will de-accredit the levee system and issue an effective FIRM showing the levee-impacted area as a SFHA. FEMA coordinates its programs with USACE, who may inspect, maintain, and repair levee systems. USACE has authority under Public Law 84-99 to supplement local efforts to repair flood control projects that are damaged by floods. Like FEMA, USACE provides a program to allow public sponsors or operators to address levee system maintenance deficiencies. Failure to do so within the required timeframe results in the levee system being placed in an inactive status in the USACE Rehabilitation and Inspection Program. Levee systems in an inactive status are not eligible for rehabilitation assistance under Public Law 84-99. FEMA coordinated with USACE, the local communities, and other organizations to compile a list of levees that exist within Broward County for the FIS. There are no levees/dams listed in the sub-watershed study area.

2.3 Future Challenges of Sea Level Rise and Climate Change

Global observations from satellites and long-term data collection have made it possible to document and analyze patterns in the Earth's climate. Scientific analysis of the impact of these changes has helped to improve the understanding of future flood hazard driving forces and long-term impacts on human activities and watershed master planning (http://www.research.noaa.gov/climate/t_observing.html). Examples of impacts are rising global average air and ocean temperatures, increased and earlier snow and ice melt, shorter subtropical rainy seasons, shifted seasons, sea level rise and greater variations in temperature and precipitation (IPCC, 2013; Freas et al., 2008; Marshall et al., 2004; Bloetscher et al., 2010). Marshall et al. (2004) specifically focused on the Florida peninsula to predict changes in rainfall and warmer temperatures but interspersed lower low temperatures due to the potential loss of wetlands.

43 shows the accumulated precipitation average prior to 1973 versus 1994. Marshall et al. (2004) state that "because sea breezes are driven primarily by contrasting thermal properties between the land and adjacent ocean, it is possible that alterations in the nature of land cover of the peninsula have had impacts on the physical characteristics of these circulations." Their modeling suggests that land use changes have reduced total rainfall by 12% since 1900, probably because of the loss of wetlands. This confirms the finding of Pielke (1999) who reported that "development has exacerbated their severity since landscape changes over south Florida have already appeared to have reduced average summer rainfall by as much as 11%" (Pielke, 1999). Future changes in climate will add to the existing impacts, at a time when the population of the state is expected to nearly double by 2030. Additional research and high-resolution climate modeling for the Florida peninsula and local jurisdictions is needed to help guide long-term plans like WMPs.

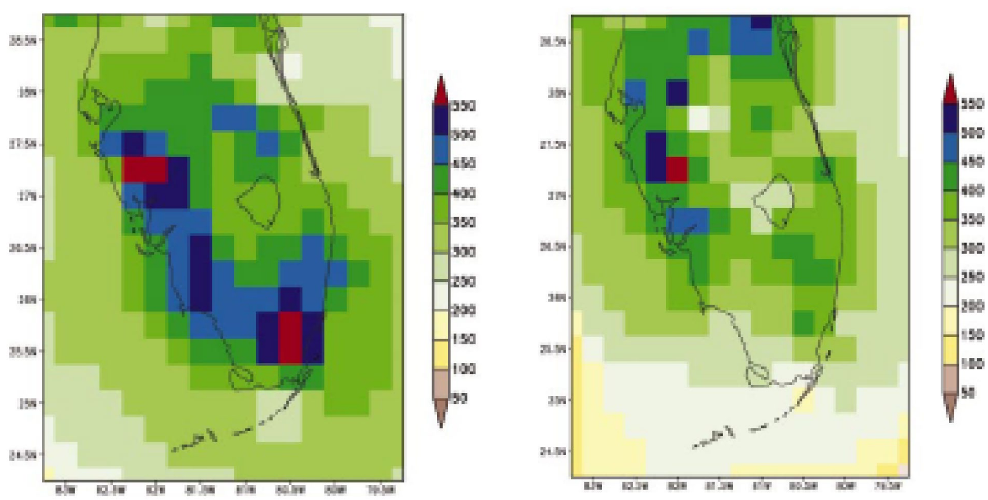

Figure 29. Accumulated precipitation 1973 (left) and 1994 (right) (Marshall et al., 2004)

Marshall et al. (2004) report that "while there is a great deal of spatial variability in these values, the results show that daytime maximum generally increased with the use of the 1993 land cover." When converted to heat flux, Marshall et al. (2004) noted that "the latent heat flux difference exhibits a consistent decrease of nearly 10% of the grid-average pre-1900 value." Figure 30Figure 30 shows the change in average rainfall and the change in average temperature from 1924 to 2000. Note the reversed trend (higher temperatures and lower rainfall), which means groundwater inputs are reduced (Marshall et al., 2004) leading to the conclusion that land use changes (loss of wetlands) contribute to the higher variability of temperature.

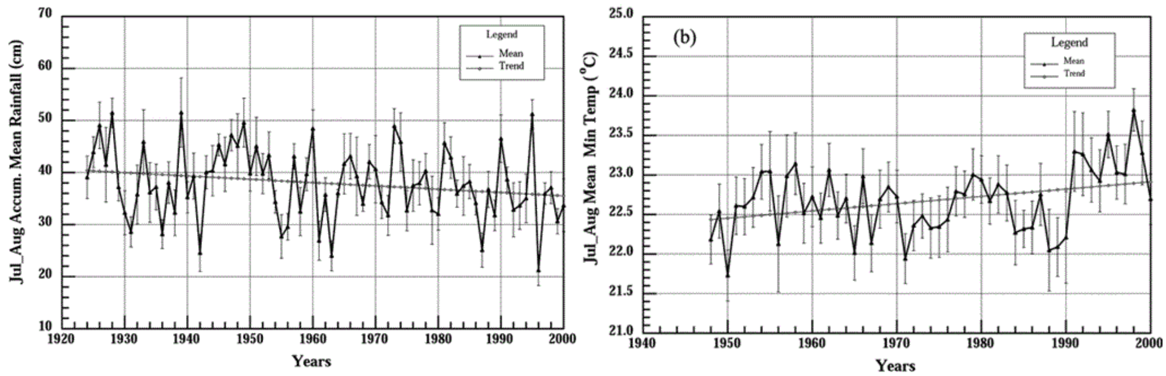

Figure 30. Change in average rainfall and change in average temp 1924 to 2000. Note the reversed trend, which means groundwater input variability is lessened (Marshall et al., 2004)

Climate change is likely to: 1) threaten the integrity and availability of fresh water supplies and 2) increase the risk of flooding, not only in the low-lying coastal areas, but also in the interior flood plains. Other issues include a) saltwater intrusion, which may be intensified by sea level rise, b) prolonged droughts that will contribute to water supply shortages and wildfires, and c) heavier rains during the rainy season and higher hurricane storm surge, which may increase the risk due to flooding. More frequent and damaging floods are likely to become an ever-increasing problem as sea level continues to rise because of: a) increasing groundwater table elevations and surface water gage heights, b) reduced groundwater seepage through the aquifer to the ocean, c) increasingly compromised stormwater drainage systems, and d) more frequent inundation of barrier islands and coastal areas.

NOAA and IPCC (2013) predictions suggest that by 2100, global temperatures will be on the order of 2-3°C (3-5°F) higher and sea levels will rise by up to 3 feet. Accompanying these drivers are potential changes in storm frequency and intensity, desertification, population migration, ocean acidification and coastal flooding (IPCC, 2007), exacerbated by the land cover and land use changes, which are substantially impacted by the fluxes, timing and quality of precipitation (Adrians et al., 2003; Scanlon et al., 2005; Marshall et al., 2004; Salmun and Molod, 2006), and leading to changes in the timing of peak flows and volumes (Richey and Costa-Cabral, 2006).

An outcome of these climatic patterns is that during the past 140 years, an increase in sea levels has been observed (Bloetscher, 2012), a worrying pattern since sea level rise is a permanent phenomenon, that can be catastrophic to low lying areas in the long-term. The question is how much and how soon? Various studies (Bindoff et al., 2007; Domingues et al., 2008; Edwards, 2007; Gregory, 2008; Vermeer and Rahmstorf, 2009; Jevrejeva, Moore and Grinsted, 2010; Bloetscher, 2010, 2011; IPCC, 2007; Heimlich et al., 2009) indicate large uncertainty in projections of sea level rise by 2100. Gregory et al. (2012) note that during the last two decades, the global rate of sea level rise has been larger than the 20th-century time-mean, and Church et al. (2011) suggested that the cause was increased rates of thermal expansion, glacier mass loss, and ice discharge from icesheets. Gregory et al. (2012) suggested that there may also be increasing contributions to global sea level rise from the effects of groundwater depletion, reservoir impoundment, and loss of storage capacity in surface waters due to siltation. Measurements of Florida's east coast (Maul, 2008) show an average rate of sea level rise of 2.27 ± 0.04 mm per year from 1915 to 1992 based on tide gauge readings. Analyzing the tidal gauge readings for Florida shows that:

1. Florida average sea level rise is 2.10 ± 0.49 mm/yr
2. All but one location is within the 95% confidence limit range (the exception is Panama City where there is evidence of submergence and other land-based issues)
3. None of the Florida sea level rise rates differ statistically.
4. Average global sea level rise for 1920-2000 was 2.0 mm/yr – within 95% confidence limit for Florida locations.

From 1929 to 1992, over eight inches of sea (Figure 31), with another 6 inches added since 1992, which is already having significant impacts on coastal communities where population growth has increased the need for improved flood management strategies (Bloetscher, 2008; Parkinson, 2010; Zhang et al., 2011, 2011a; NFIP, 2011; Schmidt et al., 2011; Warner et al., 2012).

As a result, the SFRCCC (2015) adopted USACE's methodology to derive scenarios of sea level change intermediate to high rates of sea level rise for years 2030 (3" to 7") and 2060 (9" to 24") as the consensus projection to guide future planning in Southeast Florida. The path keeps increasing – now 14 inches since 1929 (Figure 31. Increasing tides and projected future increase – 99th percentile (FAU developed map based on tidal stations at Key West and Key Biscayne, FL – data on FAU server).) caused by thermal expansion of the ocean and melting ice caps (Jevrejeva et al., 2010; Vermeer and Rahmstorf, 2009). Sea level rise is a major concern since nearly half the US population lives within 50 miles of the coast, involving most major commercial, residential, and economic enterprises.

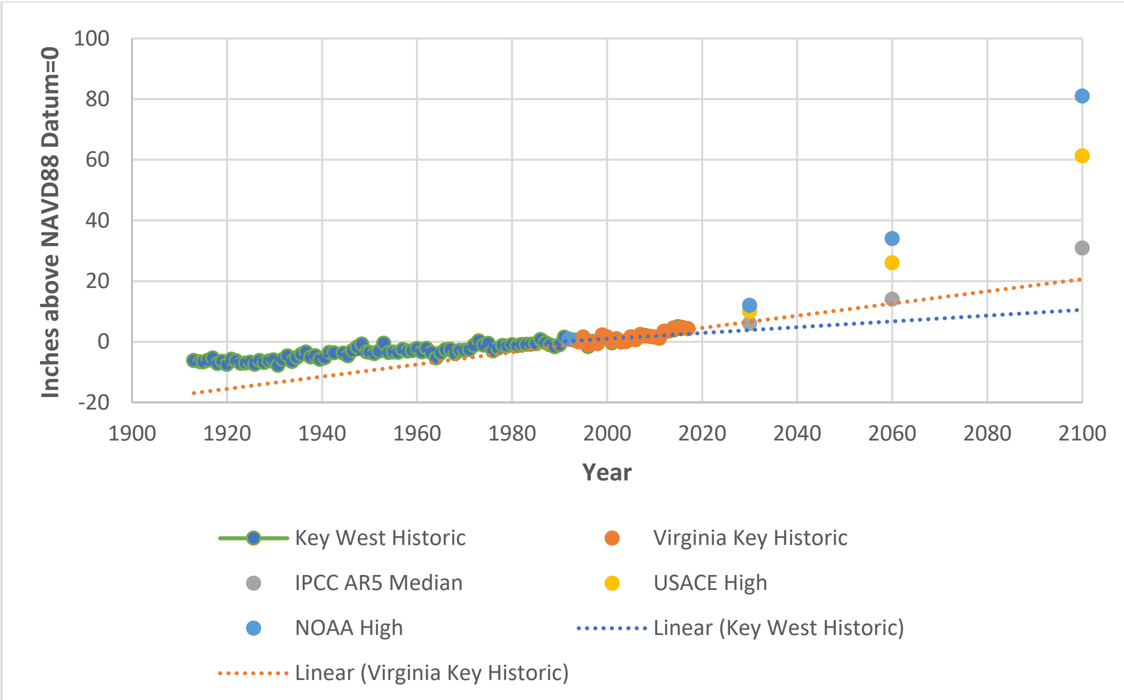

Figure 31. Increasing tides and projected future increase – 99th percentile (FAU developed map based on tidal stations at Key West and Key Biscayne, FL – data on FAU server).

NOAA (2017) outlines five scenarios for sea level rise. The NFIP proposes the use of the intermediate high projection, which is 1.2 meters or 4 ft from current sea level elevations (Figure 32. Graphic of sea level rise projections from NOAA (2017)), and the Southeast Florida Regional Climate Compact (SFRCC, 2011) projection recommended by its scientific working group for years 2030 (3” to 7”) and 2060 (9” to 24”).

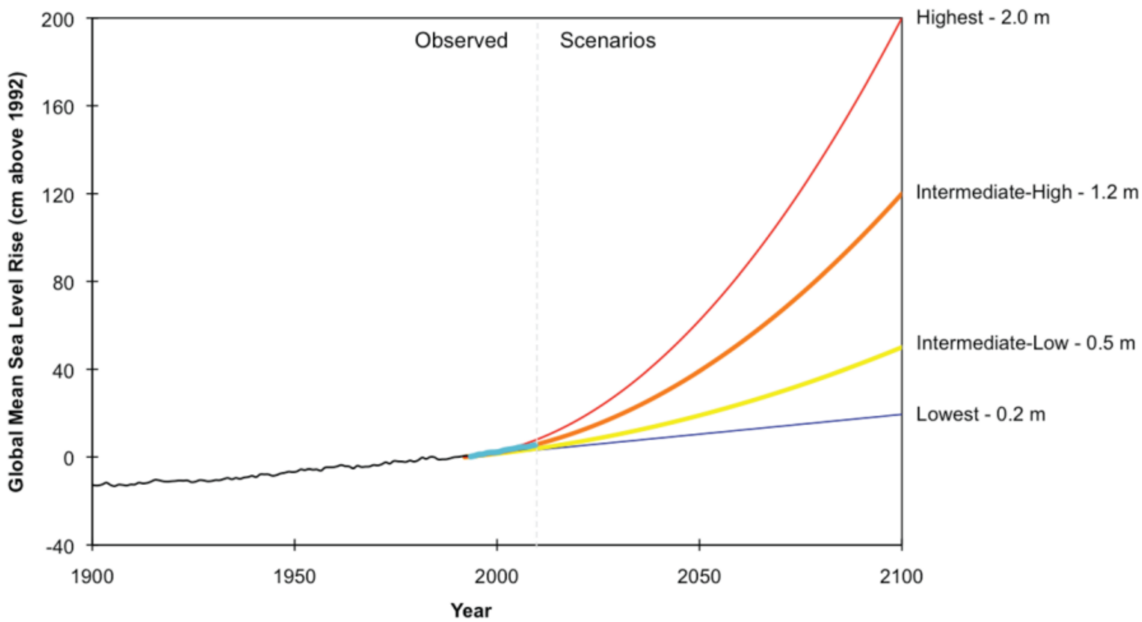

Figure 32. Graphic of sea level rise projections from NOAA (2017) (https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf)

As sea level rises, access to roads, bridges, rail, and transit could be at risk of flooding, causing the effects of sea level rise to spread indirectly throughout the entire transportation network, affecting the overall system performance. For example, the flooding of a critical road or facility access can cause a shifting of traffic flow causing congested conditions in other roadways that are not actually flooded. Since the roadway network would be unable to carry the traffic demand, the system would experience operational failure; as a result, causing travel times and delays. Moreover, the inundation of critical access could cause transportation connectivity problems to essential infrastructure like ports or airports. Transportation infrastructure relies on the effectiveness of flood control and stormwater drainage systems for the transportation corridors. Road integrity relies on adequate drainage. The increased risk of severe flooding in Florida's low-lying terrain can adversely affect transportation infrastructure along the coastline; roads can be inundated, and roadway beds can be damaged. Sea level rise will cause increased water table levels (FDOT, 2012), as regional water tables cannot exist naturally below mean high tide (2 feet in Florida). Adding 3 feet of sea level rise on top of groundwater would compound the risk of flooding in low-lying areas. Road bases below 5 feet NVGD would become saturated under this scenario, likely causing premature base failure. As soil storage capacity is diminished due to rising groundwater elevations associated with sea level rise, the potential for more frequently flooded roadways would likely damage pavements (FDOT, 2012). Hence sea level rise must be accounted for in WMPs in coastal areas. To allow flexibility in the analysis due to the range of increases within the different time periods, an approach that uses incremental increases of 1, 2, and 3 feet of sea level rise is suggested for modeling. The increments can work as threshold values in planning considerations in terms of allowing planners the ability to know ahead of time where the next set of vulnerable areas will be, to allow for a proactive response approach that can be matched to the observed future rates. Sea level rise is a major concern since nearly half the US population lives within 50 miles of the coast, involving most major commercial, residential, and economic enterprises. The effects of 5ft sea level rise and 1-day 100-year storm event for HUC 031002010203 Philippee Creek sub-watershed is shown in Figure 40.

2.4 Modeling Results

The design storm simulation determined that approximately 24% of Sarasota City's total area, or 4.72 square miles, has ground surface elevations below the maximum headwater height, and would therefore be expected to be inundated during a 3-day 25-year design storm (see Figure 33). For comparison, approximately 28% of City's total area, or 5.53 square miles, would be expected to be inundated during a 1-day 100-year design storm (see Figure 36). Approximately 20% of City's total area, or 4.03 square miles, would be expected to be inundated during a 1-day 10-year design storm (Figure 35). Finally, approximately 19% of City's total area, or 3.88 square miles, would be expected to be inundated during the 1-day 5-year storm (see Figure 34). Table 6 compares the four events.

Table 6. Sarasota City expected to be inundated by the event.

Event	Area with probability of inundation below 50% (sq. miles)	Area with probability of inundation above 50% (sq. miles)	Area with probability of inundation below 50% (%)	Area with probability of inundation above 50% (%)
1-day 100-year	5.53	10.17	72.93%	27.70%
3-day 25-year	4.72	10.98	76.35%	23.65%
1-day 10-year	4.03	11.67	79.82%	20.18%
1-day 5-year	3.88	11.82	80.59%	19.41%

Figure 33 to Figure 36 are a series of maps that depict the risk of flooding in the basin based on following scenarios:

1. 3-day 25-year storm event (Figure 33)
2. Sea level rise of 5 ft + 3-day 25-year storm event (Figure 34)
3. 1-day 5-year storm (Figure 34)
4. Sea level rise of 5 ft + 1-day 5-year storm (Figure 36)
5. 1-day 10-year storm (Figure 35)
6. Sea level rise of 5 ft + 1-day 10-year storm (Figure 38)
7. 1-day 100-year storm (Figure 36)
8. Sea level rise of 5 ft + 1-day 100-year storm (Figure 40)

In all cases, flooding is noted along the river line and wetlands. With the increase of sea level rise reaching 5 feet, we can see that the inundation moves towards the inland areas, causing significant loss of property. The sea level rise of that amount is not going to be in effect soon, probably not in next 100 years but from a sustainable point of view, this might be a best time to establish a planning strategy by the County and SWFWMD to develop significant efforts to protect property. As this sub-watershed lies in a lower elevation and connected to ocean, king tide of 2.6 feet and sea level rise together might exacerbate the situation.

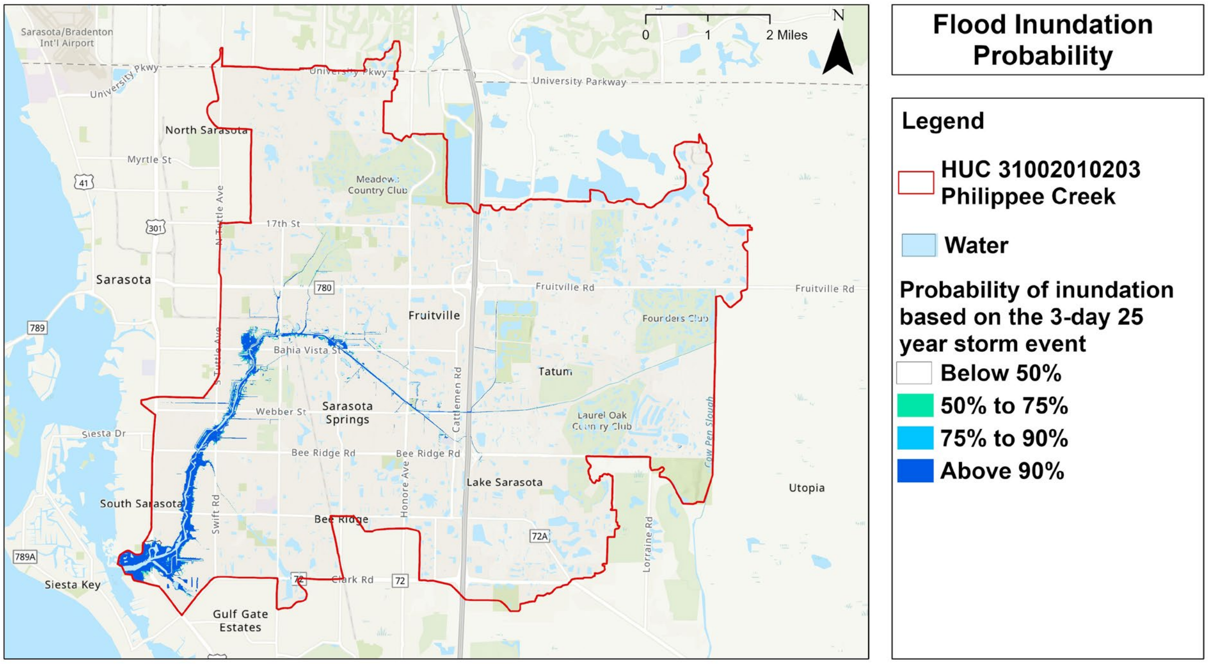

Figure 33. Probability of inundation based on 3-day, 25-year storm for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

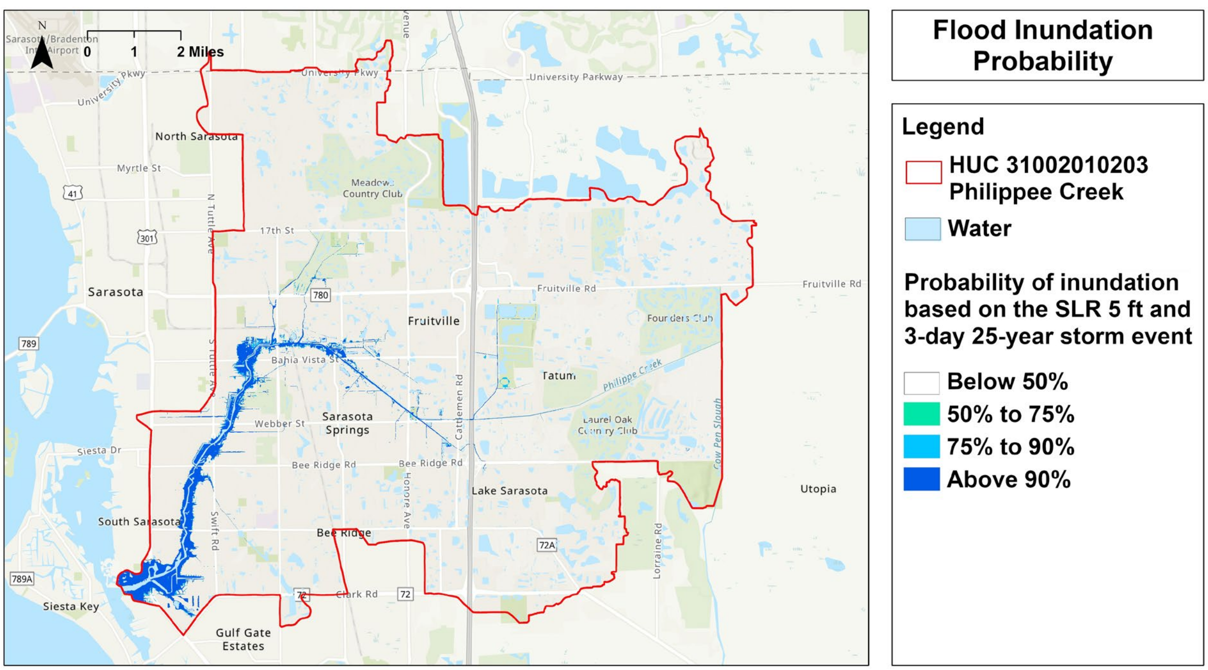

Figure 34. Probability of inundation based on 5 ft sea level rise and 3-day, 25-year storm for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

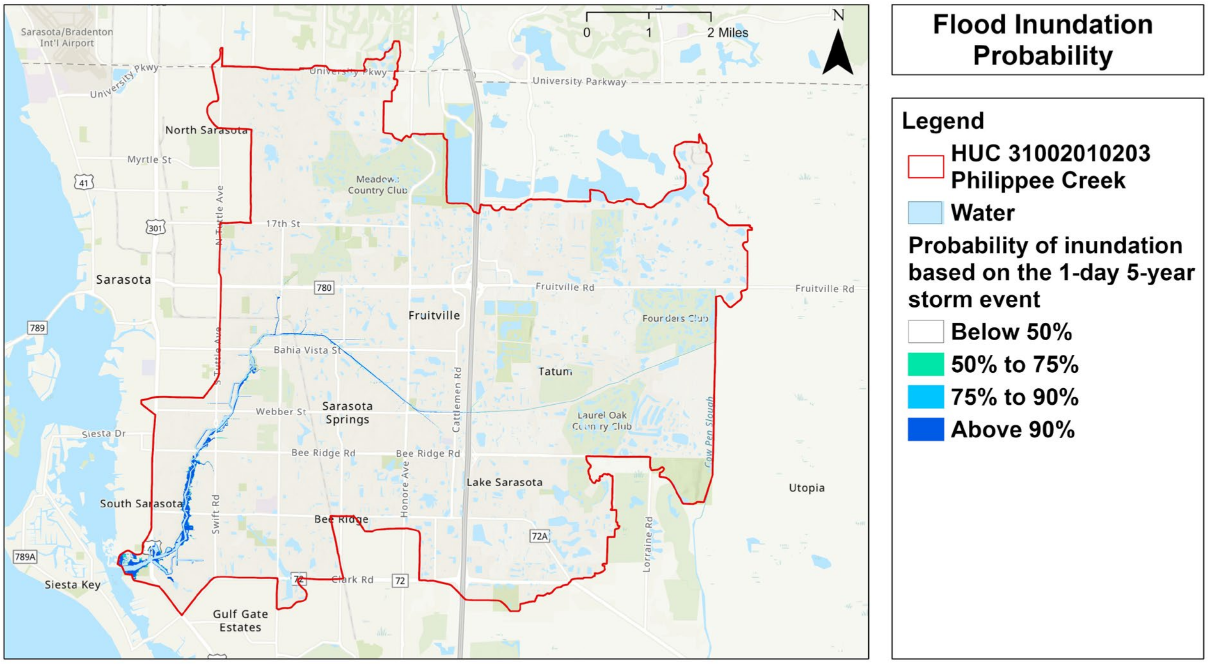

Figure 35. Probability of inundation based on 1-day, 5-year storm for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

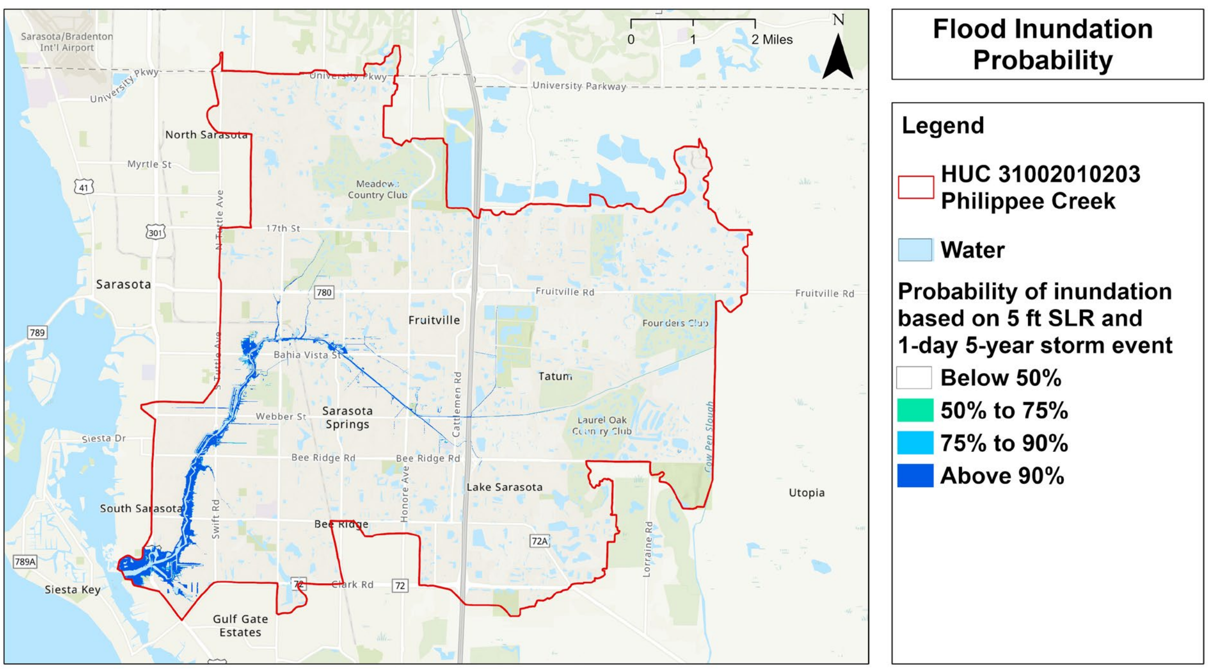

Figure 36. Probability of inundation based on 5 ft sea level rise and 1-day, 5-year storm for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

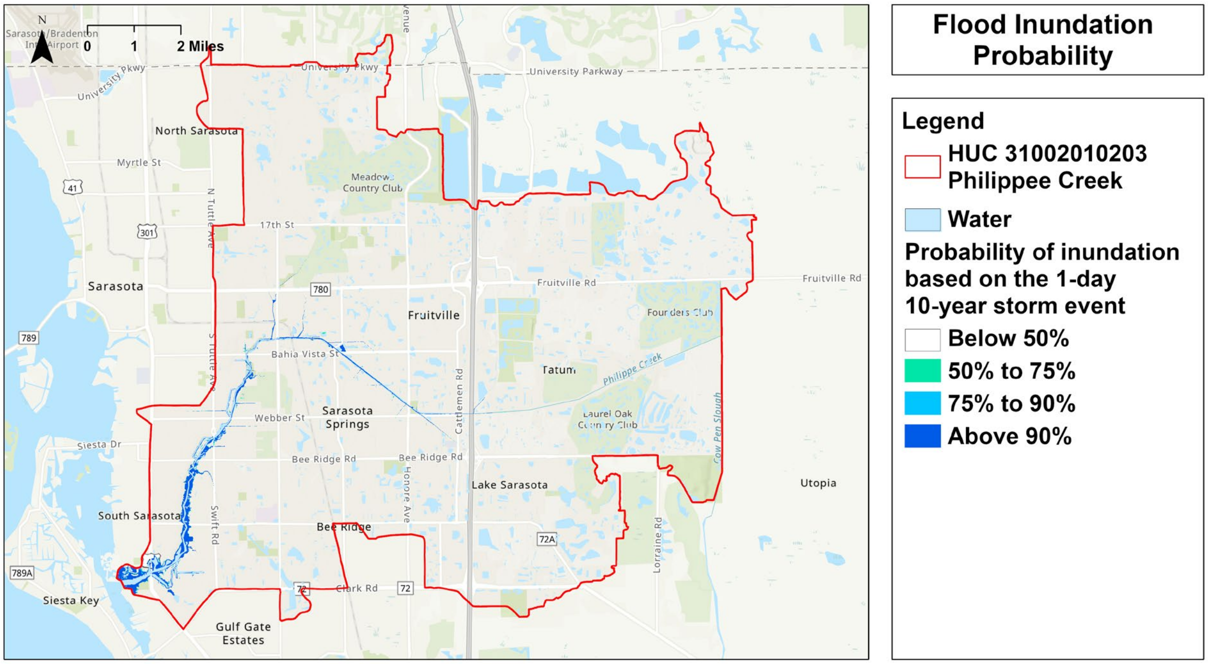

Figure 37. Probability of inundation based on 1-day, 10-year storm for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

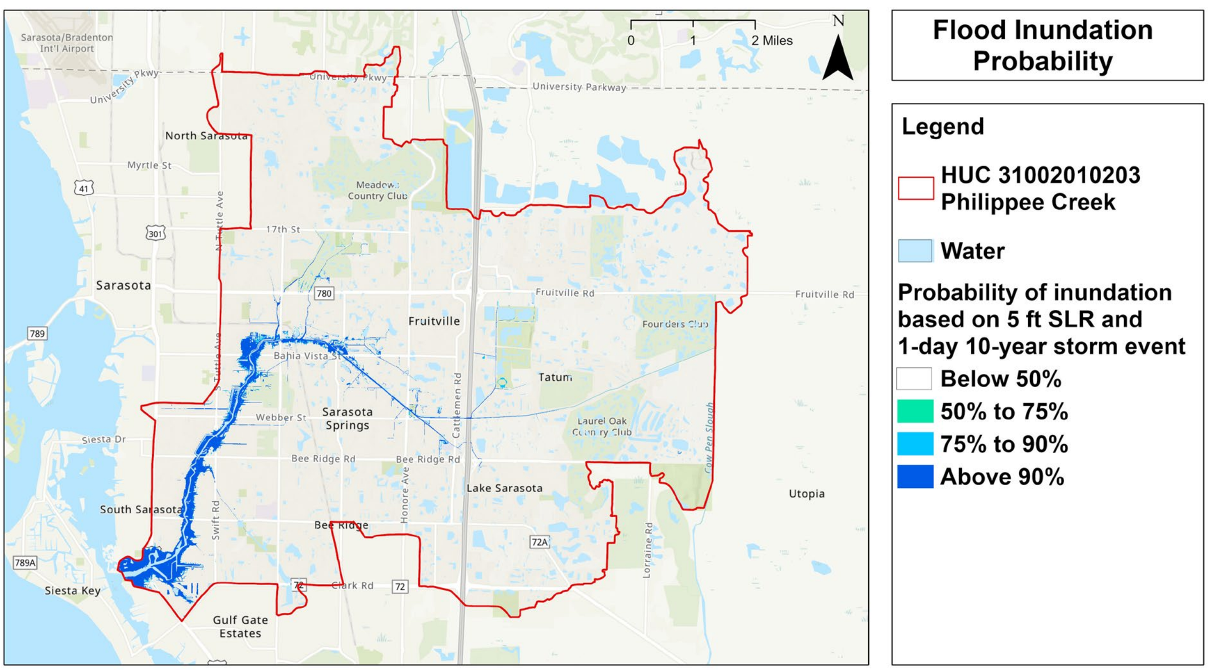

Figure 38. Probability of inundation based on 5 ft sea level rise and + 1-day, 10-year storm for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

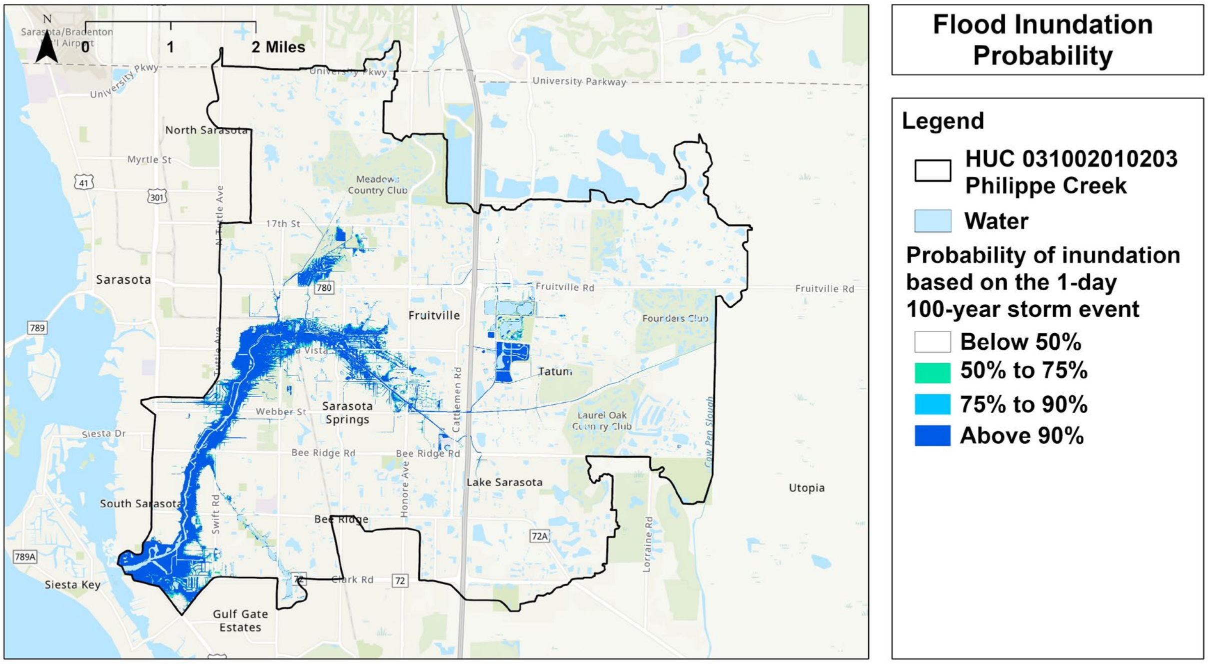

Figure 39. Probability of inundation based on 1-day, 100-year storm for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

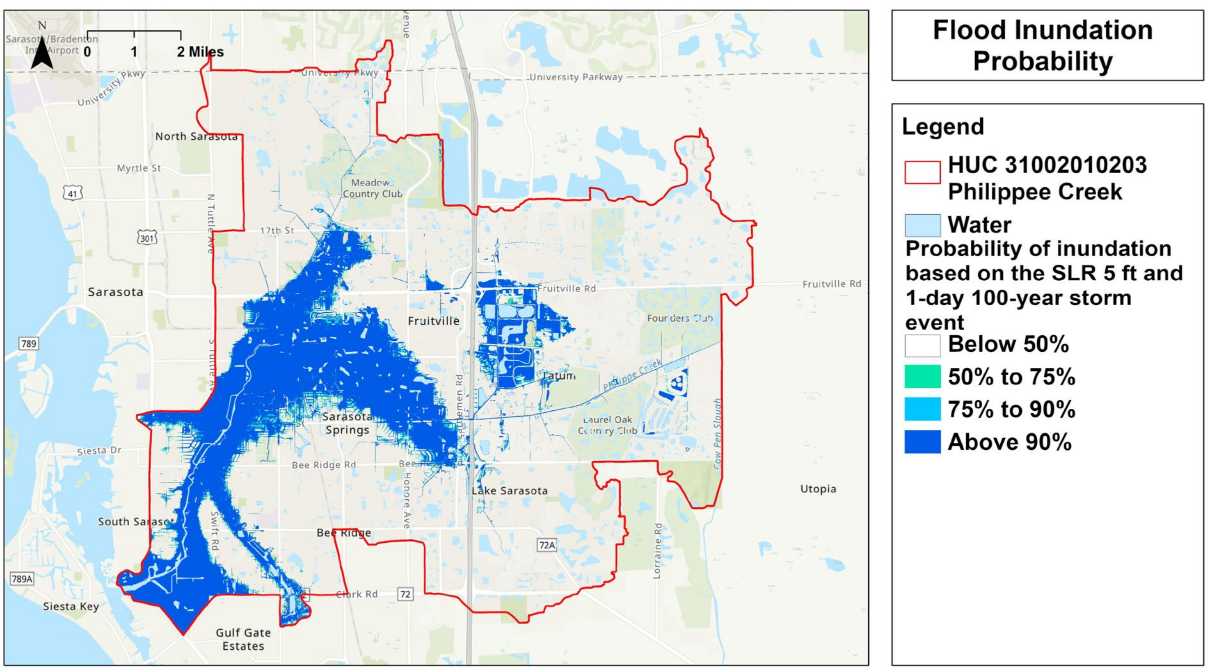

Figure 40. Probability of inundation based on 5 ft sea level rise and 1-day, 100-year storm for the HUC 031002010203 Philippee Creek, as generated by FAU CWR3.

2.5 Risk and Vulnerability

The screening tool modeling exercise from the prior section identified areas within the communities that are vulnerable to flooding. Higher priority concerns should be those properties or assets that are considered essential and need to be kept in service during a flooding event. The major regional issues in the greater watershed are the C43 reservoir and capital projects associated with the SWFWMD plans for controlling discharges that impact the ecosystem in the west end of the watershed. Hence regional water management districts and USACE projects have higher priority due to the larger area served. All other improvements are distinctly local. To help with prioritization, the following is suggested:

1. Tier 1. Critical facility protection (water, sewer, public safety, hospitals, schools, power).
2. Tier 2. Essential services (groceries, pharmacies, roadways)
3. Tier 3. Economic centers.
4. Tier 4. At-risk communities.
5. Tier 5. Other urban/suburban property
6. Tier 6. Agriculture/public property/vacant/undeveloped

Table 7 outlines the US Department of Revenue (DOR) codes from the property appraiser's office and assigns an associated priority level to each parcel. Note that for residential property, identifying at-risk communities (income, age, disability, health) requires a further drilldown to the neighborhood level (i.e., wealthy neighborhoods with few older, poor health individuals would have a lower priority than at risk communities, which generally have lower value housing and denser development). In the latter case, more people are impacted, and those people have less ability to mitigate risk. Based on these priorities, the relative risk priority DOR land use codes were evaluated based on a scale of 1 to 6, where 1 is high priority (more vulnerable) and 6 is the least priority (least vulnerable).

Table 7. Department of Revenue (DOR) land use codes, as generated by FAU CWR3.

DOR (use code)	Description	Priority
0	Vacant Residential	6
1	Single Family Residential	5
2	Mobile Homes	4
3	Multi-Family >9 units	4
4	Residential Condo	5

DOR (use code)	Description	Priority
5	Cooperatives	5
6	Retirement homes	4
7	Misc. Residential	5
8	Multi-Family <10	4
9	Residential Common Area	6
10	Vacant Commercial	6
11	One-Story Stores	3
12	Mixed Use Store	4
13	Department Store	3
14	Supermarket	2
15	Regional Shopping Center	3
16	Community Shopping Center	3
17	Office Non-Professional	3
18	Service Multi-Story	3
19	Professional Services Building	3
20	Terminals	3
21	Restaurant	3
22	Drive-in	5
23	Financial	2
24	Insurance company offices	3
25	Repair service shops (excluding automotive), radio and t.v. repair, refrigeration service, electric repair, laundries, laundromats	3
26	Laundry	3
27	Service Station	3
28	Mobile Home Sales, Parking Lot, Mobile Home Parks	5
29	Wholesale outlets, produce houses, manufacturing outlets	3
30	Florists, greenhouses	6
31	Drive-in Theater	5
32	Auditoriums/Indoor Theaters	5
33	Bar	5
34	Skating Rinks, Poolhalls, Bowling Alleys	5
35	Tourist Attractions	5
36	Camps	6

DOR (use code)	Description	Priority
37	Racehorse, auto, and dog tracks	6
38	Golf Course	6
39	Hotel	3
40	Vacant Industrial	6
41	Light Manufacturing	4
42	Heavy manufacturing	3
43	Lumber yards, sawmills, planning mills	6
44	Fruit, vegetables, and meat packing	3
45	Canneries, distilleries, and wineries	5
46	Other food processing, candy factories, bakeries, potato chip factories	5
47	Mineral processing, phosphate processing, cement plants, refineries, clay plants, rock and gravel plants	5
48	Warehouse Distribution	5
49	Open Storage	6
50	Improved agricultural	6
51	Cropland soil capability class i	6
52	Cropland	6
53	Cropland soil capability class iii	6
54	Timberland - site index 90 and above	6
55	Timberland - site index 80 to 89	6
56	Timberland - site index 70 to 79	6
57	Timberland - site index 60 to 69	6
59	Timberland not classified by site index to pines	6
60	Grazing land soil capability class i	6
61	Grazing land soil capability class ii	6
62	Grazing land soil class 3	6
63	Grazing Land	6
66	Orchard	6
67	Poultry	6
68	Dairies, feed lots	5
69	Ornamentals	6
70	Vacant without Features	6
71	Church	5

DOR (use code)	Description	Priority
72	Private School	3
73	Private Hospital	2
74	Home for the Aged	4
75	Orphanage	4
76	Cemetery	6
77	Club, Hall	5
78	Convalescent Homes	4
79	Cultural organizations	5
80	Vacant Government	6
81	Military	6
82	Military, Forest, Parks	6
83	Public School	1
84	Public College	1
85	Public hospitals	1
86	County	1
87	State, other than military, forests, parks, recreational areas, colleges, hospitals	6
88	Federal	6
89	Municipal	1
90	Leasehold interests (government-owned property leased by a non-governmental lessee)	6
91	Utility	1
92	Mining lands, petroleum lands, or gas lands	6
93	Subsurface rights	6
94	Right of Way	6
95	Submerged, lakes	6
96	Sewage Disposal	1
97	Outdoor recreational or parkland, or high-water recharge subject to classified use assessment	6
98	Centrally assessed	6
99	Other Non-Agricultural Acreage	6
100	Parcels with no values	6
102	Parcels with no values (water)	6
103	Parcels with no values (row)	2

Having assigned the risk priority from 1 to 6 in the DOR codes and the percentage of the parcel that floods during the applicable design storm, properties that are more critical to the function of the community can be identified. The methodology is to first convert the DOR code priority tier to its inverse scale by the following equation:

Consequence of risk factor = 7 – DOR Code Priority Tier

The flood risk factor from the screening tool is interpreted based on flooding probability. We take all parcels in tiers #1-4 that have a greater than 50% chance of flooding during a particular design storm and calculate the percent of the parcel that would flood during that event. The percentage is converted to a 6-point scale termed as the Flood Risk Factor, as follows:

Table 8. Flood Risk Factor

Percent of Parcel Flooded	Flood Risk Factor
90-100%	6
80-89%	5
70-79%	4
60-69%	3
50-59%	2
<50%	1

The priority is further developed by assigning 75% of the importance to the consequence of flooding and 25% importance to flood risk, or three times the importance to the consequence of flooding to come up with a composite score as follows:

Flood Risk Factor × 25% + Consequence of Risk Factor × 75% = Composite Score

Example:

$1 \times 25\% + 6 \times 75\% = 4.75$

Those higher priority properties that received the higher composite score are where the mitigation strategies and financial resources should focus first.

2.5.1 Results

Figure 41 depicts the HUC 031002010203 Philippee Creek sub-watershed priority of land uses (parcels classified as 1 to 6 tiers), showing the critical facilities that should receive priority. Figure 42 illustrates the flood map with 5-ft sea level rise and 1-day 100-year overlayed on property consequence factors (tiers). Figure 43 illustrate the composite score for the HUC, which is the result of the calculations explained above, pinpointing parcels that should be prioritized. It is overlayed with 1-day 100-year inundation.

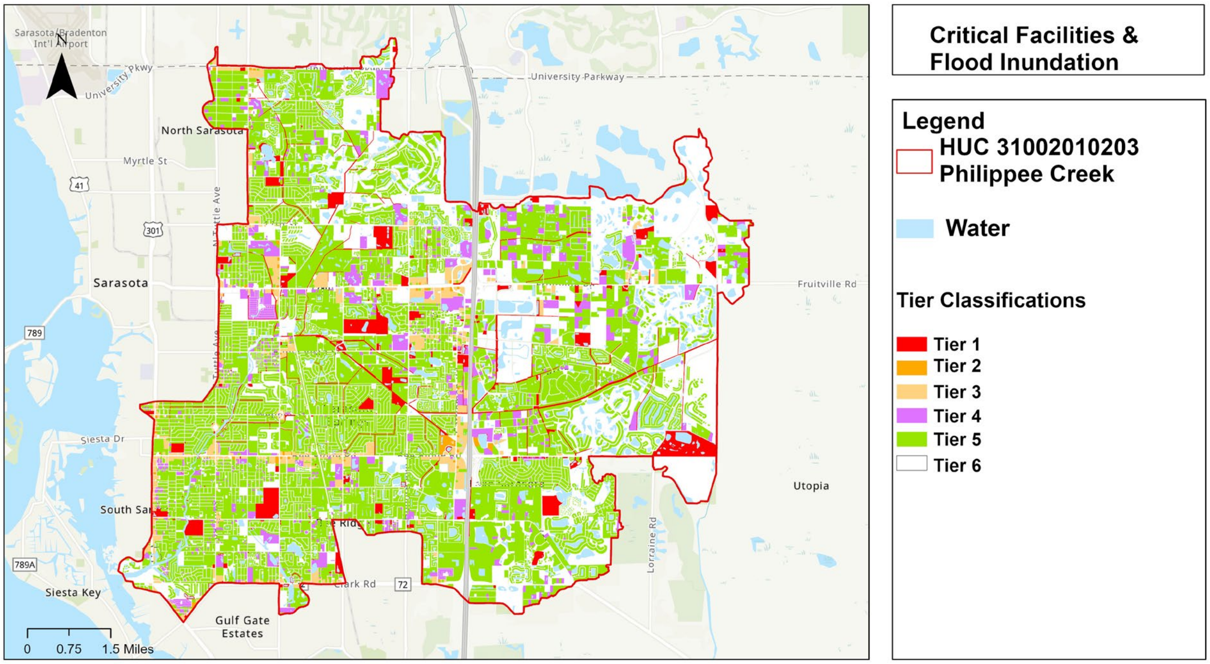

Figure 41. Priority of land uses (Property consequence factor) in the tiers from Table 6 based on land use from the Sarasota City Property Appraiser's office, as generated by FAU CWR3.

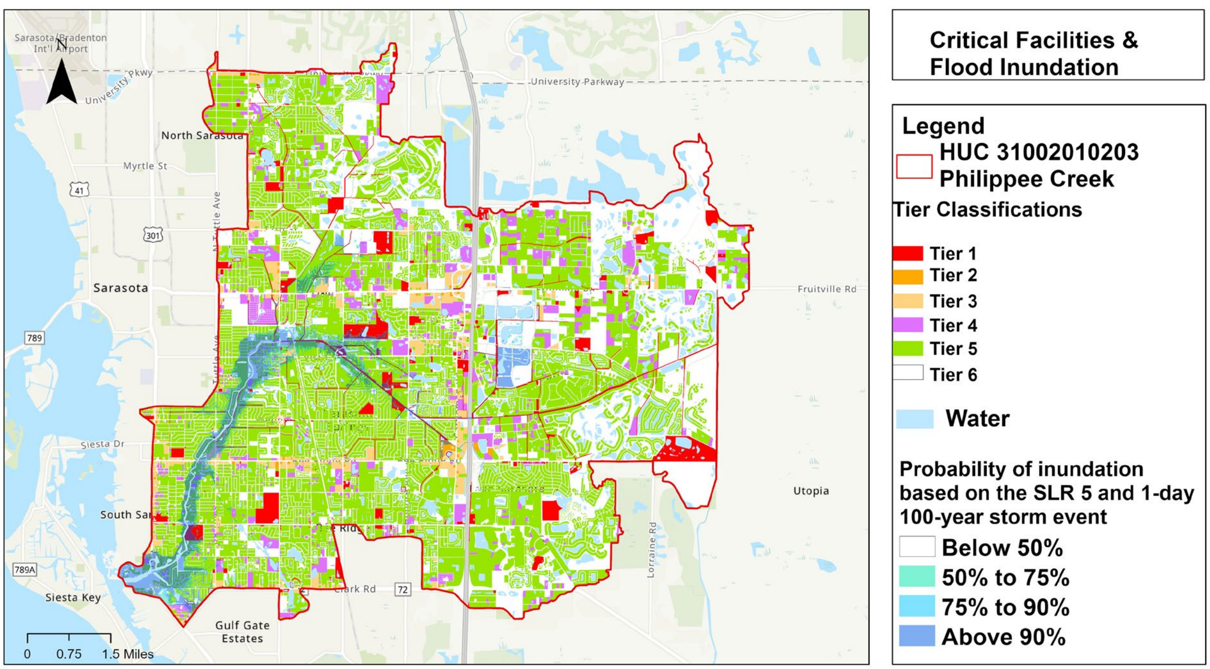

Figure 42. 5 ft Sea level rise and 1-day 100-year flood inundation map and property consequence factors together on one map, as generated by FAU CWR3.

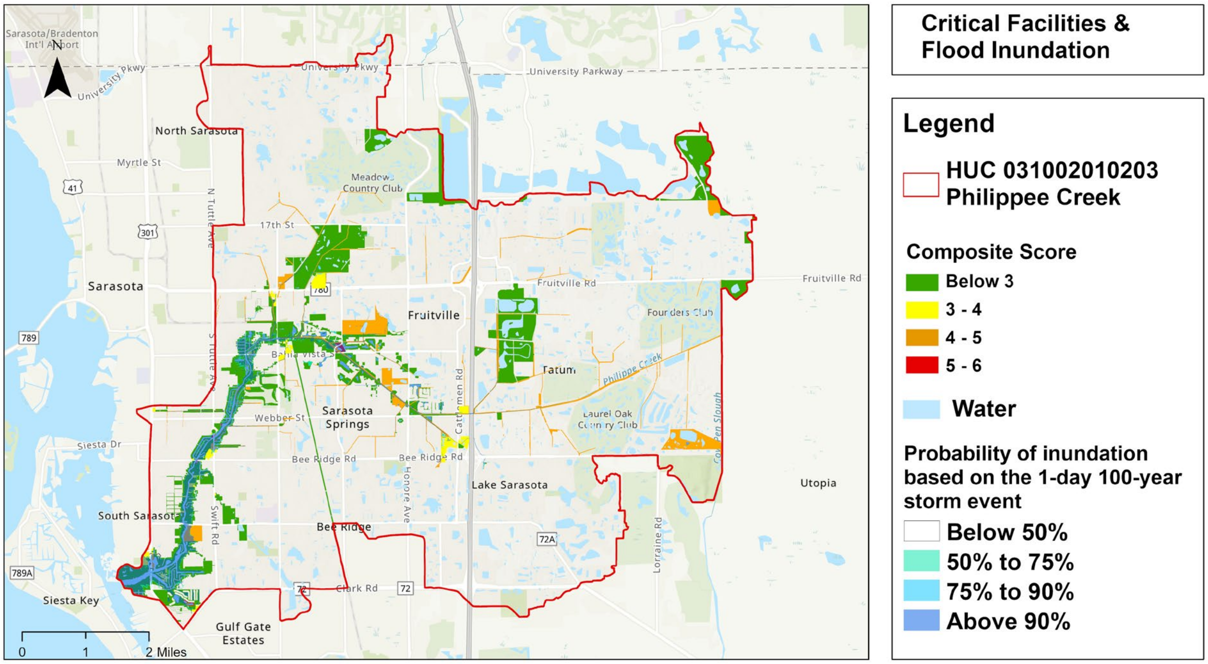

Figure 43. Probability of inundation based on 1-day 100-year and composite score together, as generated by FAU CWR3.

2.5.3 Repetitive Loss Property Map

A Repetitive Loss (RL) property is a building that has had two or more loss or damage due to a specific hazard, such as floods, hurricanes, or other natural disasters, over $1,000 each, paid by the National Flood Insurance Program (NFIP) within any ten-year period since 1978. There are currently more than 122,000 RL properties nationwide (FEMA, 2005).

These data are essential for assessing the vulnerability of certain areas to recurrent losses and for developing strategies to mitigate the risks. However, due to privacy concerns, the data cannot be openly shared with the public. For this reason, the data were converted into a hot spot analysis map. These maps, instead of identifying the specific location of the repetitive loss properties, highlight clusters of repetitive loss claims and areas where the probability of repetitive losses is higher than would be expected by random chance. In other words, it helps pinpoint locations that have a higher concentration of properties prone to repetitive losses. Figure 44 indicates the results from hot spot analysis in point data, showing aggregated counts, and raster data, showing the estimated probability of repetitive loss.

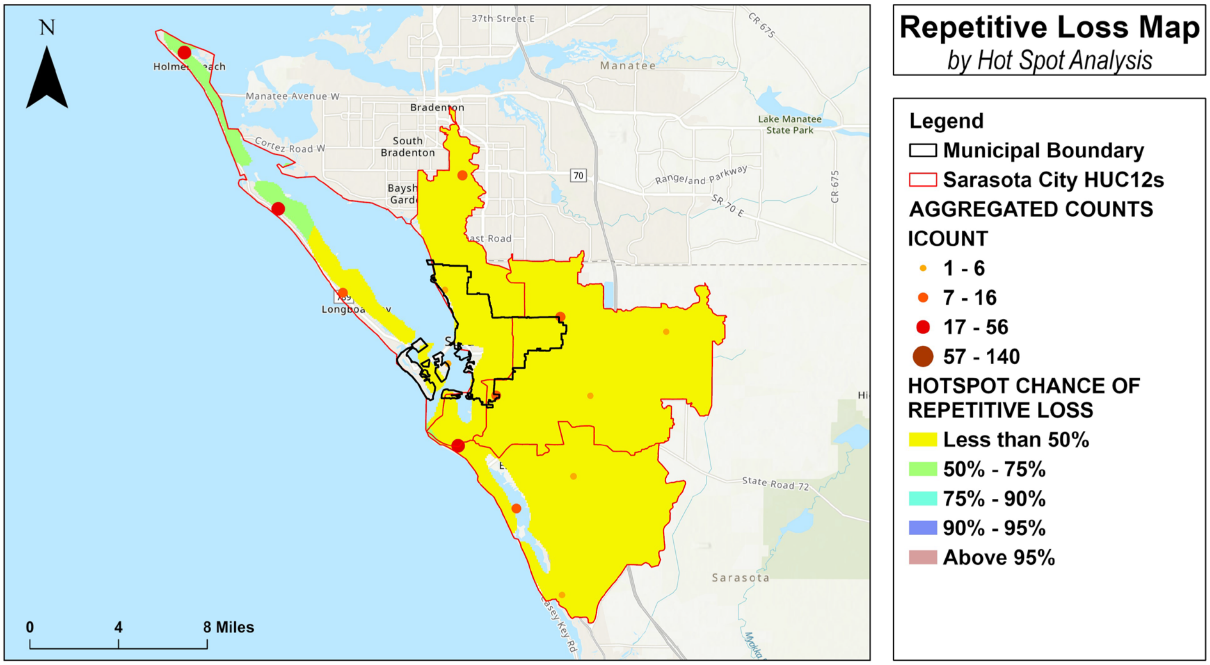

Figure 44. Repetitive Loss map for Sarasota City by Hot Spot Analysis, as generated by FAU CWR3.

2.5.4 Impacted Adjustment Areas

In the evaluation of flood risk management strategies within the framework of the National Flood Insurance Program Community Rating System (CRS), the concept of impact adjustment plays a pivotal role in determining the extent to which CRS-credited activities or elements influence the vulnerability of a community's Special Flood Hazard Area (SFHA) and the structures located within it. It's important to note that while the usual results of impact adjustment are related to the SFHA area, in this specific analysis, it was used 1-day 100-years storm event inundation area performed by FAU instead.

In this context, the following table presents a breakdown of the impact adjustment calculations for a 1-day 100-years storm event inundation. The values are expressed in acres and depict the areas of interest as well as the deductions considered in the evaluation process.

The outcomes of these calculations provide valuable insights into the impact adjustment scenarios:

With ALL State Lands:

This scenario reflects the remaining inundation area after accounting for deductions A, B, and C. It represents the effect of CRS-credited activities without considering the influence of state lands in managing flood risks.

With NO State Lands:

In this case, the remaining inundation area is determined by considering all deductions, including state lands (both open space and not open space).

These calculations highlight the dynamic nature of impact adjustment within the CRS framework. By accurately gauging the influence of individual elements, the system ensures that credit allocations align closely with a community's efforts in flood risk mitigation.

Table 9. Impacted Adjustment Areas for HUC 031002010203, as generated by FAU CWR3.

AREAS	ACRES
HUC-12 Sub-watershed: 031002010203	36145.13
All of the 1-day 100-years storm event inundation	**984.39**
Subtract	
A. Bodies of Water in 1-day 100-years inundation > 10 acres	217.00
B. Federal Land in 1-day 100-years inundation > 10 acres	0.00
C. Reservation/Tribal Land in 1-day 100-years inundation > 10 acres	0.00
D. State Land in 1-day 100-years inundation > 10 acres that is open space	0.00
E. State Land in 1-day 100-years inundation > 10 acres that is NOT open space	0.00
The remainder is either:	
With ALL State Lands: All of the 1-day 100-years inundation minus (A+B+C) or	767.39
With NO State Lands: All of the 1-day 100-years inundation minus (A+B+C+D+E)	767.39

2.5.5 Solutions

Chapter 5 of the Watershed Master Plan for Sarasota City describes a list of possible gray and green stormwater strategies to combat flooding that can be implemented as solutions for the county. The same solutions can also be applied at the HUC level, including HUC 031002010203. A summary of these flood mitigation strategies is listed in Table 10.

Table 10. List of possible gray and green stormwater strategies to combat flooding.

Strategy Class	Implementation Strategy	Applications	Benefits	Cost	Barriers to Implementation
Green	Rainwater harvesting	Local, small scale, easily implemented in developed areas	Protects property, treats runoff	Under $5,000	Limited volume disposed of, so many are needed, maintenance
Gray	Pervious paving	Parking lots, patios, driveways, anything except paved roads due to traffic loading	Reduces roadway and parking lot flooding	$10-20/sf, requires bumpers and sub-base to maintain paver integrity	Must be maintained via vacuuming or the perviousness fades after 2-3 years

Strategy Class	Implementation Strategy	Applications	Benefits	Cost	Barriers to Implementation
Green	Detention	Common for new development, but difficult to retrofit; limited to open areas	Removes water from streets, reduces flooding	$200K/ac	Land availability, maintenance of pond, discharge location Uses up land that could otherwise be developed
Gray	Exfiltration Trench	Any low-lying area where stormwater collects and the water table is more than 3 ft below the surface; densely developed areas where retention is not available, roadways	Excess water drains to aquifer, some treatment provided	$250/ft	Significant damage to roadways for installation, maintenance needed, clogging issues reduce benefits
Gray	Central sewer installation	All areas where there are septic tanks. Mostly a water quality issue	Public health benefit of reducing discharges to lawns, canals, and groundwater from septic tanks	$15,000 per household	Cost, assessments against property owners, property rights issues
Green	Flood prone property acquisition	Regional agency - could be any low-lying areas	Removes flood prone areas from risk	$2K-$100K/ac depending on whether it is already developed	Difficult to implement if occupied, issues with willing sellers, cost, lack of funds for acquisition

Strategy Class	Implementation Strategy	Applications	Benefits	Cost	Barriers to Implementation
Gray	Pump stations	Any low-lying area where stormwater collects, and there is a place to pump the excess stormwater to such as a canal; common for developed areas	Removes water from streets, reduces flooding	Start at $1.5 to 5 million each, number unclear without more study	NPDES permits, maintenance cost, land acquisition, discharge quality
Gray	Armored sewer systems	Any area where gravity sanitary sewers are installed	Keeps stormwater out of sanitary sewer system and reduces potential for disease spread from sewage overflows	$500/manhole	Limited expense beyond capital cost
Gray	Sea walls	Barrier islands and downtown coastal areas	Protects property	$1200/ft	Private property rights, neighbors
Policy	Changes in land use	Applicable universally	Achieves flood risk mitigation by adjusting permitted land use	Low but may incur private property rights conflicts and litigation	Private property rights conflicts and litigation
Gray	Roadway base protection	Low-lying areas, coastal communities	Protects roads and access routes	$1 million per plane-mile	Cost, adjacent properties become uninsurable
Policy	Enhanced elevation of buildings	Developers would implement this for new construction	Reduced flood risk	Varies	Potential issues with building, structure or latticework, and existing homes that are not elevated

2.5.6 Drilldowns

The process of identifying potential mitigation measures to implement begins with narrowing down the feasible engineering alternatives using threshold criteria and quantifiable selection criteria that include measures of effectiveness, cost, and added benefit to the community. The toolbox describes a variety of strategies that could be used to improve potential flood management conditions. They are community-specific and most require significant engineering and planning to determine the most efficient configuration to achieve the community's goals. Hard infrastructure systems are usually the first systems to be impacted because they are built at lower elevations than the finished floor of structures. In addition, many infrastructure systems are located within the roadways (water, sewer, stormwater, power, phone, cable tv, internet, etc.). At present, most roadway base courses are installed above the water table. If the base stays dry, the roadway surface will remain stable. As soon as the base is saturated, the roadway can deteriorate.

Catastrophic flooding should be expected during heavy rain events if there is nowhere for the runoff to go. The vulnerability of infrastructure will require the design of more resistant and adaptive infrastructure and network systems. This will, in turn, involve the development of new performance measures to assess the ability of infrastructure systems to withstand flood events and to enhance resilience standards and guidelines for the design and construction of facilities. Specifically, considerations include retrofitting, material protective measures, rehabilitation, and in some cases, the relocation of facilities to accommodate sea-level rise impacts. As they are related, groundwater is, similarly, expected to have a significant impact on flooding in these low-lying areas because of the loss of soil storage capacity. Evapotranspiration in low-lying areas with high groundwater will become more important which is why ecologically based stormwater management that employs natural native vegetation will become more important over time in certain communities.

All the drilldowns for this sub-watershed can be found in chapter 5 of master plan.