Hydrologic Baseline Conditions and Projected Trends for Kennedy Space Center and the Cape Canaveral Barrier Island Complex

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1 Introduction

1.1 Purpose

The purpose of this document is the creation of a comprehensive collection of data, information and knowledge on the eco-hydrologic setting, and current and predicted (2030 - 2080) hydrologic conditions that will directly and indirectly influence the Kennedy Space Center (KSC) industrial and ecological system. Focus is on identification of existing data sources (web based, published, in-house) and identification of future possible needs. The document will aid in assessment of risks to the National Aeronautics and Space Administration (NASA) and stakeholder missions associated with changing local, regional and global conditions. This living document will allow for rapid updates as new data and improved spatial data (LiDAR elevations, land use, land cover, runoff coefficients, etc.) are accumulated by the Environmental Management Branch (EMB), stakeholders, and supporting staff from the NASA Environmental and Medical Contract (NEMCON) currently managed by Herndon Solutions Group LLC. (HSG).

The report summarizes and visualizes hydrologic conditions supporting long-term trends monitoring, management and regulatory compliance needs, climate risk mitigation, and achievement of KSC and stakeholder's sustainability goals. Future utility may extend to implementation actions of the KSC future development plan, KSC updates to future KSC Environmental Resource Documents (ERD), and the regional multi-agency Indian River Lagoon Health Initiative.

The document is not a comprehensive review of literature regarding the Indian River Lagoon system and KSC. Individuals, interested in such, are encouraged to visit the following web sites and references to explore a plethora of available information on the regional and local ecosystems:

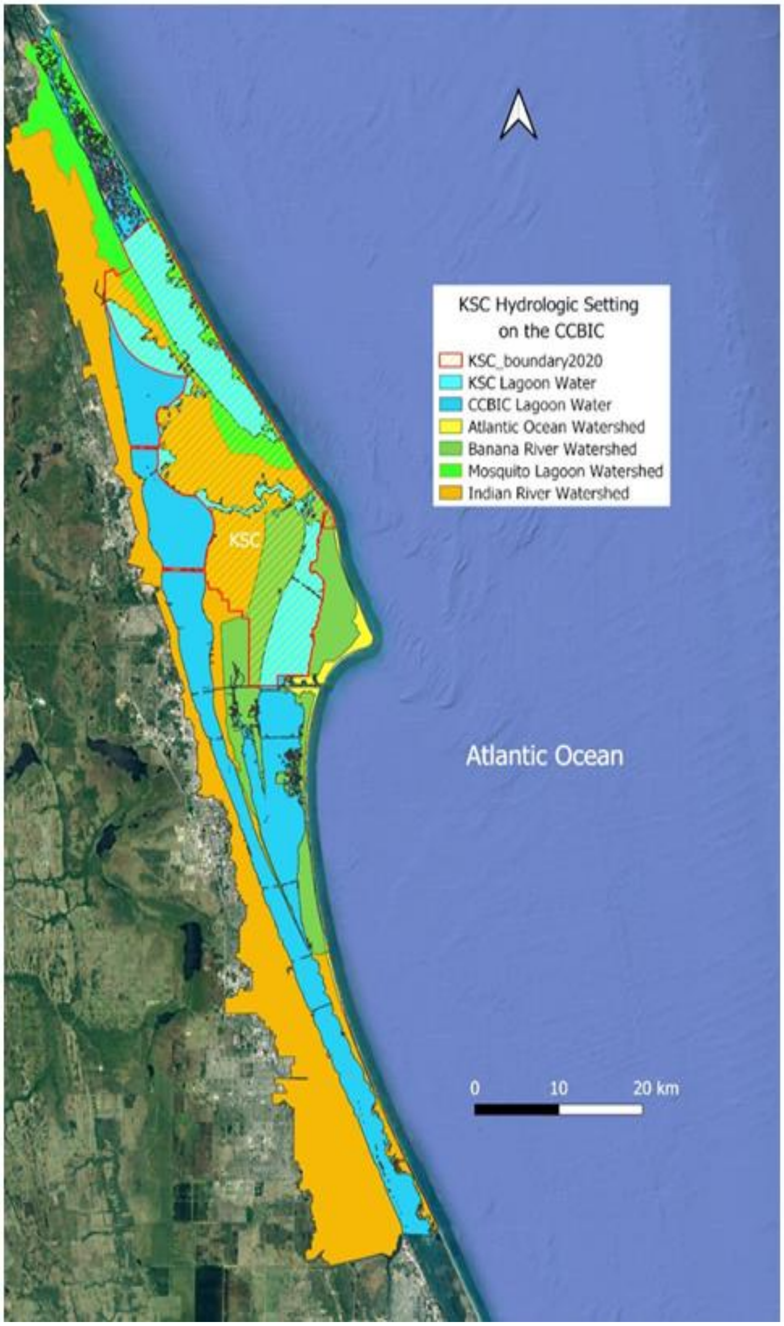
- the Indian River Lagoon Library
  - https://indianriverlagoonnews.org/guide/index.php/Repository,
- the Indian River Lagoon National Estuaries Program
  - https://onelagoon.org/
- the Indian River Lagoon Comprehensive Conservation Management Plan (CCMP)
  - https://onelagoon.org/management-plan/,
- the Kennedy Space Center Environmental Resource Document
  - https://tdksc.ksc.nasa.gov/servlet/dm.web.Fetch/ERD_2020_Rev_G_Environmental_Resources_Document.pdf?gid=1137886&FixForIE=ERD_2020_Rev_G_Environmental_Resources_Document.pdf
- Ecological Impacts of the Space Shuttle Program
  - https://ntrs.nasa.gov/api/citations/20140012489/downloads/20140012489.pdf

From a hydrologic system perspective, KSC is located on an area of the east Central Florida coast known as the Cape Canaveral Watershed (**Figure 1.1**) or the Cape Canaveral Barrier Island

Complex (Foster et al. 2017, Xiao et al. 2018). To minimize possible confusion regarding terminology the following definition is provided and is used throughout the report.

Figure 1.1: The Cape Canaveral Watershed as defined by the United States Geological Survey on the east central Florida coast (https://coast.noaa.gov/ccapatlas).

- Cape Canaveral Barrier Island Complex (CCBIC) - The total drainage basin or area that includes the land surface including uplands, wetlands, sources of surface and groundwater discharge (watershed), and the open water (waterbody) that makeup the Indian River Lagoon (IRL) system between Ponce de Leon and Sebastian Inlets (**Figure 1.2**). The narrow area of the barrier island system that discharges directly to the Atlantic Ocean does not contribute directly to the IRL and that part of the Cape Canaveral Watershed has many separate concerns due to direct interaction with the Atlantic Ocean including tides, waves, and storm-surges.



Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 1.2: Location of the Cape Canaveral Barrier Island Complex (CCBIC) major sub-basins and Kennedy Space Center in the USGS Cape Canaveral watershed.

1.2 Conceptual Model

Conceptual models provide an organizational structure that allow for cataloging and assessing knowledge regarding system interactions and behaviors. A generalized conceptual model for the CCBIC hydrologic system is presented in (**Figure 1.3**). The model describes the continuum defined by the movement of water molecules through the biogeosphere. The cycle is driven by fundamental forces of physics where:

- electromagnetic radiation (light, heat) drives evaporation, photosynthesis and transpiration, and contributes to atmospheric circulation and water vapor condensation
- gravity influences atmospheric and fluid circulation, atmospheric deposition, runoff, soil infiltration, and groundwater movement.

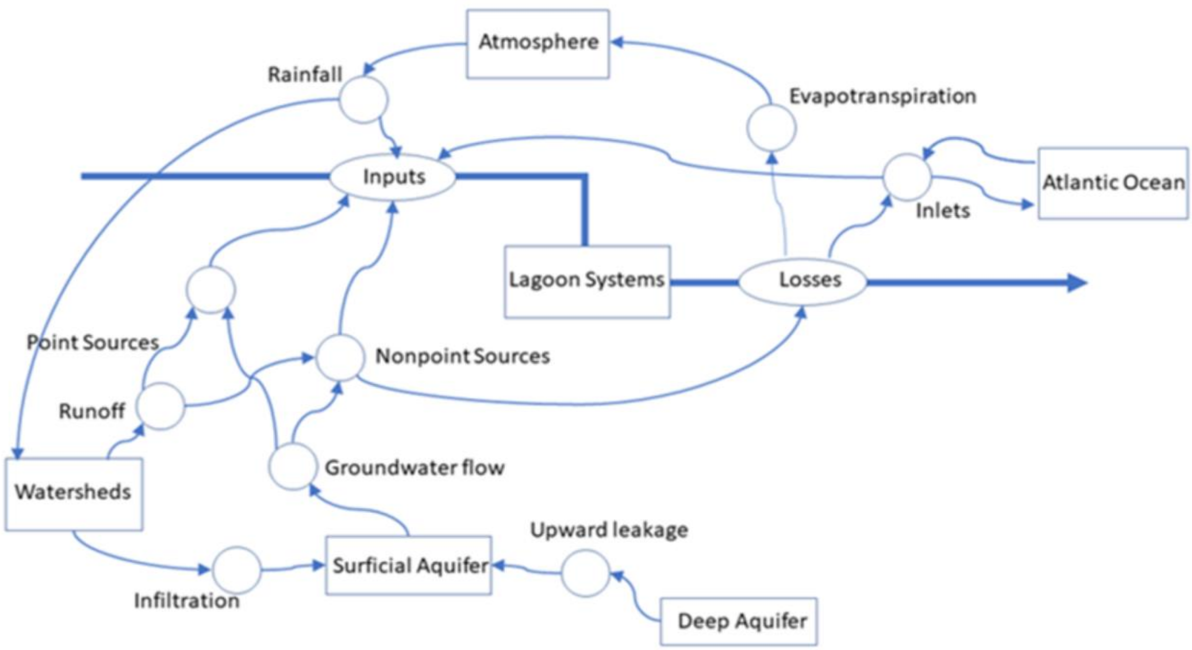


Figure 1.3: Conceptual model depicting hydrologic processes and interactions associated with KSC and the Cape Canaveral Barrier System.

1.3 Document Layout

The chapters in this document are derived primarily from the conceptual model. Together, they provide an overview of local hydrology and past and projected trends. Individually the chapters can be referenced to obtain information on specific model components. The chapters include:

- Cape Canaveral Basin Characteristics
- KSC Basin Characteristics
- Water Levels
- NEXRAD Rainfall
- Evapotranspiration
- Recommendations
- References

1.4 Background Information

The hydrologic cycle is one of the most important processes on earth, linking the atmosphere, geosphere and biosphere through the continuous movement of water molecules. This process controls ecosystem and landscape dynamics around the globe. Influences are felt across all spatial and temporal scales and are especially significant to low-lying coastlines as found at KSC. From a hydrologic perspective, KSC occupies parts of four sub-basins of the Cape Canaveral watershed:

- Mosquito Lagoon,
- Indian River Lagoon,
- Banana River Lagoon, and
- the Atlantic Ocean watershed.

The sub-basins extend along the east central Florida coast from Ponce de Leon inlet in the north to Sebastian inlet in the south (**see Figure 1.2**), a direct line distance of 93 miles (150 km). The relative proportions of the drainage area and surface water bodies which occur inside the KSC Boundary are summarized in Chapter 3.

Local hydrologic conditions in these sub-basins influence:

- the distribution of plant species and communities,
- aquatic and terrestrial primary production,
- habitat quality and food resources,
- wildfire dynamics and controlled burn planning and implementation,
- biogeochemical cycles and movement of nutrients and pollutants,
- soil characteristics, soil erosion and deposition, and
- the NASA KSC and stakeholder missions including both infrastructure, operations, and the workforce experience.

On KSC, hydrology (water), fire, and human alterations were recognized as the major factors influencing natural resources (Hamilton et al.1985). Hydrologic processes influenced by climate, such as rainfall patterns, short-term flooding, storm surges, and long-term sea level rise can alter natural resources and adversely impact facilities and mission critical infrastructure (Rosenzweig et al. 2014).

1.4.1 Geology and Soils

Summaries of the geology and soils of the region are provided in the KSC ERD (ERD 2020) and Space Shuttle Ecological Effects Report (Hall et al.2014). The Florida peninsula had its origins in the creation of the super continent of Pangaea some 300 million years ago (mya) when the North American continental land mass collided with the northwest edge of the African continental plate. During the late Triassic and early Jurassic period, some 200 to 180 mya, tectonic plate movement began rifting Pangaea to create the Atlantic Ocean between America, Europe, and Africa.

The major driving force in the creation of the modern Florida landscape has been the influence of the Ice Age beginning 2.6 mya, and its repeating glacial and inter-glacial periods that produced dramatic fluctuations in sea level and shifts in land elevations. At the maximum of the Wisconsin glaciation about 18 thousand years ago (ka), sea levels were on the order of 100 m lower than at present, and substantial additional areas of Florida were exposed along the Atlantic and Gulf coasts. Adams (2018) postulates Merritt Island and the associated Cape are an abandoned paleodelta formed because of flow reversal in the St. Johns River in response to isostatic uplift of the Florida Plateau in northern Florida some 130-80 ka.

The outer barrier islands are mapped as Holocene in age suggesting that formation began about 7 ka. Cape Canaveral is part of a prograding barrier island complex, the result of southward growth of an original cape at the site of the present False Cape. Multiple dune ridges on Merritt Island and Cape Canaveral indicate periods of deposition and erosion, alternating as sea level varied in relative height. The Atlantic Coastal Ridge, the western boundary of the CCBIC, formed roughly 130-115 ka during the previous Eemian interglacial period prior to the formation of Merritt Island and the associated CCBIC.

Fifty-eight land types and soil series are identified in the Volusia and Brevard County soil surveys (NASA 2003). The KSC Environmental Setting Reference Manual (NASA 2003) presents information on physical properties of regional soil types including particle size, distribution, porosity, permeability, and moisture content. For simplification and management application, the ERD (ERD 2020) presents a table that categorizes the soil types into ten groups (**Figure 1.4**).

Division	Subdivision	Description	Class
Upland	Well-drained	Recent, coastal, alkaline soils – vegetation is coastal dunes, coastal strand, or coastal scrub	Coastal
		Old, inland, acid soils – vegetation is scrub or scrubby flatwoods	Acid Scrub
		Inland, circumneutral soils over coquina – vegetation is scrub or xeric hammock	Coquina Scrub
	Poorly-drained	Acid, sandy soils – vegetation is flatwoods	Flatwoods
		Circumneutral to alkaline soils over coquina or limestone – vegetation is hammock	Hammocks
Wetland	Freshwater	Inland, freshwater soils – vegetation is freshwater marshes or hardwood swamps	Freshwater Wetland
	Saline	Coastal, brackish to saline soils – vegetation is saltmarsh or mangroves	
Agricultural	Scrub soil	Active or abandoned citrus on acid or coquina scrub soils	Citrus Scrub
	Hammock soil	Active or abandoned citrus on hammock soils	Citrus Hammock
Disturbed		Soils modified by construction or filling	Disturbed

Figure 1.4: Soil classifications for Kennedy Space Center. Soils are grouped into ten classes based on similarities in physical properties (source; ERD 2020).

1.4.2 Cultural Eutrophication

Eutrophication is the gradual increase in concentrations of nitrogen, phosphorous and other plant nutrients that occur naturally in an aging aquatic ecosystem with minimal flushing or water replacement. In nature this increase in fertility results from the runoff of nutrients released by the decomposition of organic matter on the adjoining watersheds.

Cultural eutrophication occurs when human activities on the watershed speed up the aging process by introducing nutrients, sediments and other undesirable compounds that degrade ecosystem quality. Human induced degradation of waterbodies is a common phenomenon that has been observed worldwide.

Prior to the 1940s watersheds of the CCBIC were minimally influenced by human disturbance with population estimates suggesting only several thousand residents occupied the basin. At that time hunting, fishing, and some agriculture dominated land-use activities. Beginning with World War II and establishment of Naval Air Station, Banana River human population and associated land-use changes began to accelerate rapidly. (**Figure 1.5**) shows population growth in Brevard County through 2020 resulting from workforce growth stimulated by federal expenditures, real estate development, tourism, and light industry. Note the slight slowdown in growth between 1970 and 1980 with cancellation of the Apollo Program.

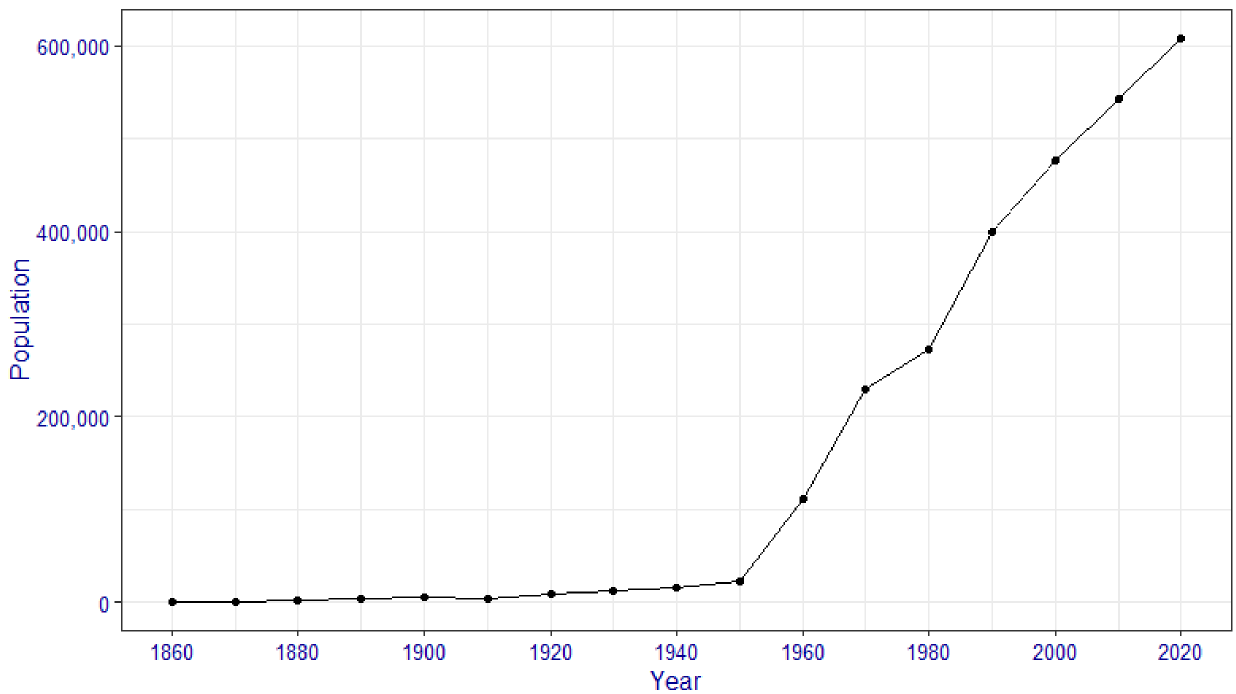


Figure 1.5: Population growth in Brevard County as an indicator cultural eutrophication of the CCBIC Watershed (source; https://worldpopulationreview.com/us-counties/fl/brevard-county-population).

Duncan et al. (2004) found urbanization had expanded as a land-use class from 1% to 26% between 1920 and 1990 with most occurring after 1945 for the CCBIC. NOAA currently operates the nationwide Coastal Change Analysis Program and maintains the C-CAP Land Cover Atlas (https://coast.noaa.gov/ccapatlas/). Between 1996 and 2016 the watershed experienced a 15.2% net increase in developed area with the scrub landcover type being reduced from 21.4 to

11.5 square miles, a 46% loss. Updates to the NOAA Land Cover Atlas should be available in 2022.

1.4.3 Rainfall

A comprehensive summary of rainfall data for KSC can be found in Mailander (1993) and the KSC Environmental Resource Document (ERD 2020) based on several rainfall collecting stations in the region (**Figure 1.6)**. Temporally rainfall shows a wet season June through September and a dry season November through April with October and May being transitional. A spatial component to rainfall at KSC can be seen in the 23-year record from the Tropical Rainfall Mesoscale Monitoring (TRMM) network with dryer conditions along the coast and wetter conditions inland on KSC.

To develop a more complete picture of spatial and temporal rainfall patterns over the basins of the CCBIC this assessment utilizes the NEXRAD hourly rainfall data provided by the St Johns River Water Management District (see Section 5).

Station	Titusville	Merritt Island	CCAFS	NADP Site	LC-39A	Shuttle 1	Patrick
Length of Records (years)	86	75	21	25	12	12	2
January	2.22	2.68	2.39	2.60	2.39	3.21	2.72
February	2.80	2.56	2.91	2.49	2.10	2.43	1.98
March	3.06	2.79	3.41	3.66	2.49	4.28	6.12
April	2.53	2.77	1.30	2.33	2.41	2.38	0.74
May	4.09	3.70	2.77	2.24	2.11	2.54	4.58
June	7.12	6.65	5.74	6.81	4.92	7.14	4.16
July	7.52	5.99	5.17	5.20	2.87	6.23	6.27
August	6.69	5.52	5.41	5.77	4.91	5.67	2.46
September	7.96	7.76	6.48	7.92	6.11	8.03	6.97
October	5.41	6.14	4.32	4.81	4.57	5.29	5.56
November	2.52	2.52	3.24	3.14	2.47	2.75	8.80
December	2.32	0.30	2.00	3.02	2.04	2.16	2.56
Total	54.24	51.38	45.14	49.99	39.39	52.12	52.92

Figure 1.6: Monthly mean rainfall for seven KSC area collecting stations (source: ERD 2020).

1.4.4 Tides and Currents

With the exception of the areas in the vicinity of Ponce de Leon and Sebastian Inlets the CCBIC is considered micro-tidal with tidal ranges on the order of cm to mm. Factors limiting tidal flow in the lagoons include the small openings of the passes compared to the large area of the lagoon, the small volumes of water exchanged with the Atlantic Ocean, the shallow nature of the lagoon, the coefficient of friction with the bottom, the small connection between the Banana River and Indian River at Dragon Point, the complex system of channels in north Mosquito Lagoon and the number and placement of causeways dividing the lagoon into sub-basins (Bilskie 2017, Smith 1993).Currents in the lagoon are dominated by wind driven circulation that cause the lagoon to set-up or set-down depending on conditions. Historic wind roses showing the seasonal wind patterns are presented in (**Figure 1.7**).

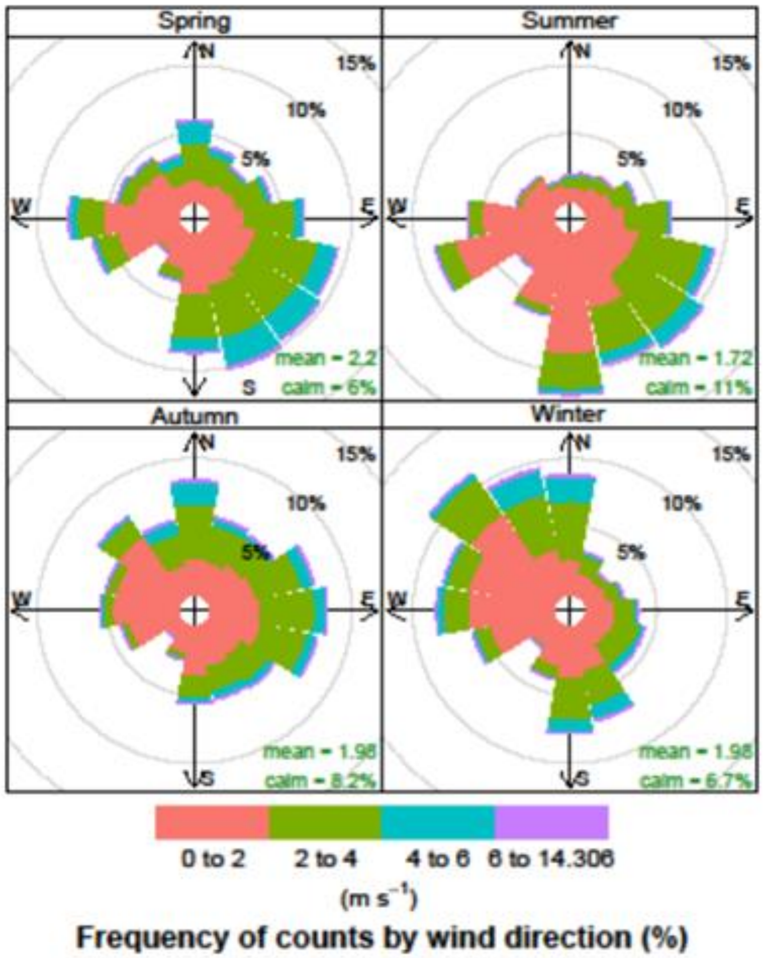


Figure 1.7: Seasonal wind patterns for the KSC area (source; ERD 2020).

1.4.5 Runoff

To develop an understanding of the hydrologic cycle and how it influences natural and man-made features it is imperative to have knowledge on how rainfall on the watershed behaves. When rain falls it can be intercepted, infiltrate to the soil and surficial aquifer, or it can runoff to receiving waterbodies. Primary factors affecting behavior include rainfall intensity and duration, land use, vegetation type and density, soil type and porosity, and slope. A comprehensive GIS and remote sensing study of the runoff coefficient and runoff depth for the entire Indian River Lagoon was published by Bellamy and Cho (2019). Their findings validate the concept that potential runoff coefficients are higher in developed areas near the receiving waterbodies and lower in naturally vegetated isolated areas with low slope. Values across the watersheds ranged between 3 and 100%. Bellamy and Cho (2019) also calculated runoff depth that varied with land cover, land use and precipitation intensity. For their 11-year rainfall interval estimated runoff depth varied from about 1 to 55 inches with a mean of 14 inches. The relationship of runoff depth and rainfall intensity was observable in seasonal trends as well as the longer term El Nino cycle.

1.4.6 Evapotranspiration

Across Florida, evapotranspiration (ET) is generally recognized as the second most important component of the water budget, second only to rainfall, except during droughts when it becomes first(https://www.usgs.gov/science-explorer-results?es=Actual%20Evapotranspiration%20for%20Florida).

ET can be computed as reference, potential, or actual where:

- reference (RET) is estimated from a standard grass surface that is well watered,
- potential (PET) is a measure of the ability of the atmosphere to remove water from a surface when there is ample water such as a lake, and
- actual (AET) is estimated directly for a specific location, vegetation or crop type. There are a host of equations and models that can be utilized to calculate AET since it is dependent on a variety of factors such as soil moisture, depth to water table, humidity, temperature, wind speed, solar insolation, and others. Due to these additional factors AET is typically lower than PET and RET.

The United States Geological Survey (USGS) provides annual spatially gridded (~ 2km) daily estimates of RET and PET for the state of Florida in mm/day. In 2020 the estimated average daily RET and PET rates were 3.62 and 3.63 mm/da, respectively (https://www.usgs.gov/centers/car-fl-water/science/reference-and-potential-evapotranspiration?qt-science_center_objects=0#qt-science_center_objects). Mailander (1990) provided a baseline climate summary document for KSC with PET and AET estimates of 3.33 and 2.6 mm/day for Cape Canaveral in the 1970s. Sanford and Selnick (2013) estimated AET ranged between 2.22 and 2.47 mm/d for Brevard and Volusia counties between 1971 and 2000.

During the last few decades researchers have utilized Eddy Flux systems to monitor ecosystem responses (carbon flux, energy budgets, water exchange, etc.) to climate variables allowing for accurate site-specific estimates of AET. Bracho et al. (2008) reported AET values for scrub oak and pine flatwood at KSC of 2.02 and 2.22 mm/day respectively. Differences were attributed primarily to differences in leaf area and soil moisture.

Watershed scale estimates of ET incorporate satellite data to generate spatially distributed data sets for use in hydrologic modeling and water resource planning. Eddy flux tower data often serve in calibration or data assimilation procedures (Mirza et al. 2015). Utilizing the Gravity Retrieval and Climate Experiment (GRACE) satellite and the GRACE follow-on (GRACE-FO) system, Pascolini-Campbel et al. (2021) estimated that climate change induced heating of the earth produced a 10% increase in global ET between 2003 and 2019. Precipitation on land is increasingly being partitioned into ET instead of runoff. This increase in atmospheric moisture and the resulting increase in rainfall intensity will have significant ecosystem and infrastructure sustainability consequences.

1.4.7 Interactions

The hydrologic cycle represents a continuum of water movement between the atmosphere, geosphere, and biosphere. A simplified representation of the possible paths that water molecules can take are shown in (**Figure 1.8**). Rain falling on the surface can directly impact water bodies or be intercepted by soil, vegetation, and structures on the watershed where it remains until it evaporates. If enough moisture accumulates gravitational forces will overcome capillary action and surface tension and water will move downward as runoff on surfaces with low permeability or through the soil pore spaces into the vadose zone between the water table and land surface. The vadose zone has a water holding capacity that is defined by soil particle size distribution, amount of organic matter, depth to water table and other factors. Water in the vadose zone can return to the atmosphere through evaporation, be absorbed by vegetation and transpired or continue to move downward into the surficial aquifer. Martin et al (2007) provide estimates of terrestrial and marine sources of submarine groundwater discharge (SGD) to the Indian Lagoon suggesting in areas south of Merritt Island and KSC marine SGD is 4 times greater that surface runoff and 2 orders of magnitude greater than terrestrial SGD. No data were found for Banana River, norther Indian River or Mosquito Lagoon.

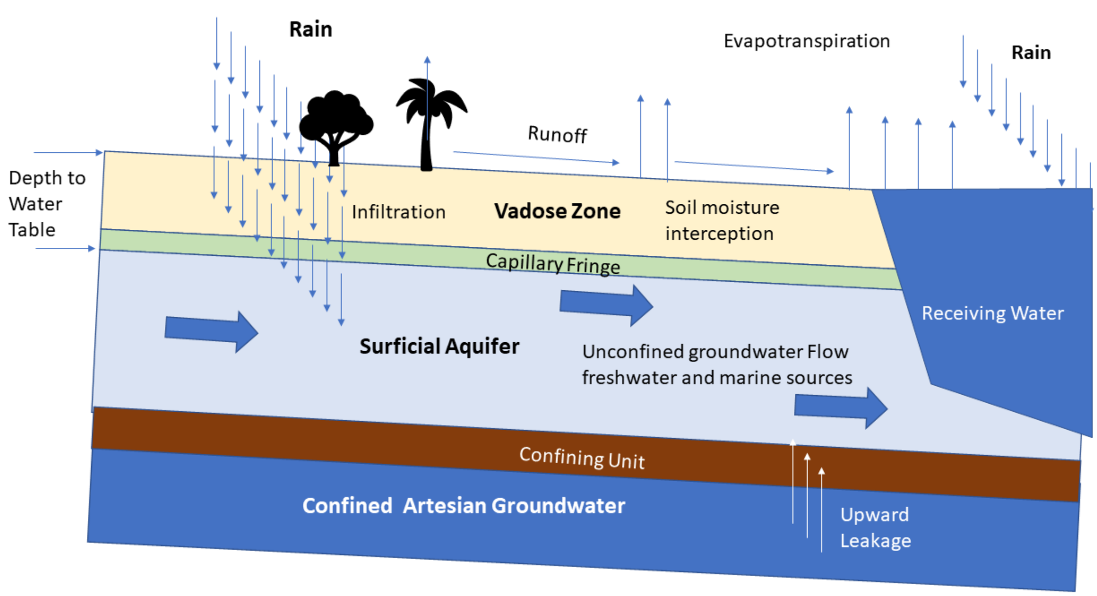
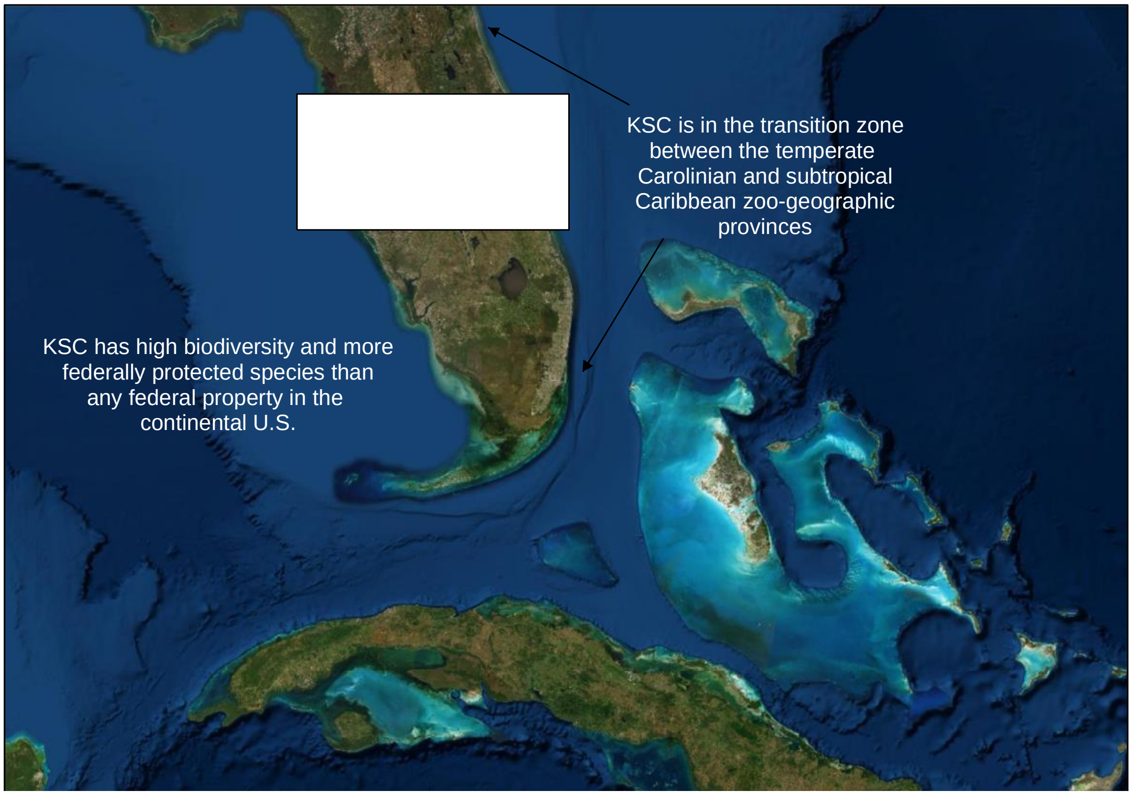


Figure 1.8: Potential water molecule paths of movement in CCBIC basins

1.4.8 Climate

KSC, on the east central Florida coast, is located in the transition zone between the sub-tropical and temperate zoogeographic provinces and has a climate that is similarly intermediate to the two (**Figure 1.9**).



Source: ESRI, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1.9: The Cape Canaveral Barrier Island system and Kennedy Space Center are located in a transitional climate that is primarily sub-tropical but has experienced periodic temperate conditions such as hard freezes that limit the northern range of sub-tropical species.

Mailander (1990) and the KSC ERD (NASA 2020) provide baseline climate summaries that describe the region as mostly subtropical with short, mild winters and hot, humid summers, with no recognizable spring or fall seasons. Warm weather, usually beginning in late April, prevails for about 9 months of the year. Typically, dawns are slightly cloudy or hazy, with little wind, and temperatures near 70 degrees Fahrenheit (°F). During the day the temperature rises into the 80s and 90s °F. Occasional cool days occur in November, but winter weather starts in January and extends through February and March. These last two months are usually windy and temperatures range from about 40 °F at night to 75 °F during the daytime (Mailander 1990**).** (**Figure 1.**) displays the long-term temperature trend for east central Florida. This upward trend in temperature is attributed primarily to increasing emissions of greenhouse gasses and manmade changes in global carbon pools.

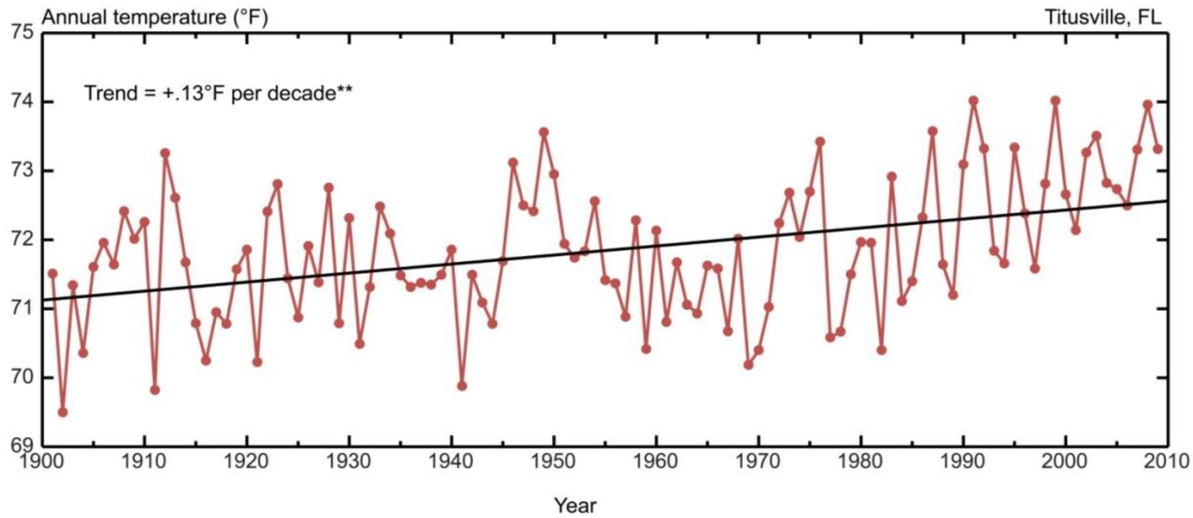


Figure 1.10: Long-term annual average temperature trend for Titusville Florida. The rising temperatures correlate with increasing global population growth, urbanization, rising atmospheric CO_2 levels, and other factors altering long-term global carbon budgets (National Climate Data Center).

The dominant sub-tropical weather pattern (May to October) is characterized by southeast winds, which travel clockwise around the Bermuda High. This pattern, in addition to almost daily sea breezes, brings moisture over the warmer land mass. As the air warms it rises producing almost daily thundershowers thus creating the summer wet season. Approximately 70 percent of the average annual rainfall occurs during this period. Weather patterns in the dry season (November to April) are influenced by cold continental air masses. Rains occur when these masses move over the Florida peninsula and meet warmer air. In contrast to localized, heavy thundershowers in the wet season, rains are light and tend to be uniform in distribution during the dry season (Mailander 1990).

2 Cape Canaveral Barrier Island Complex (CCBIC)

2.1 Purpose

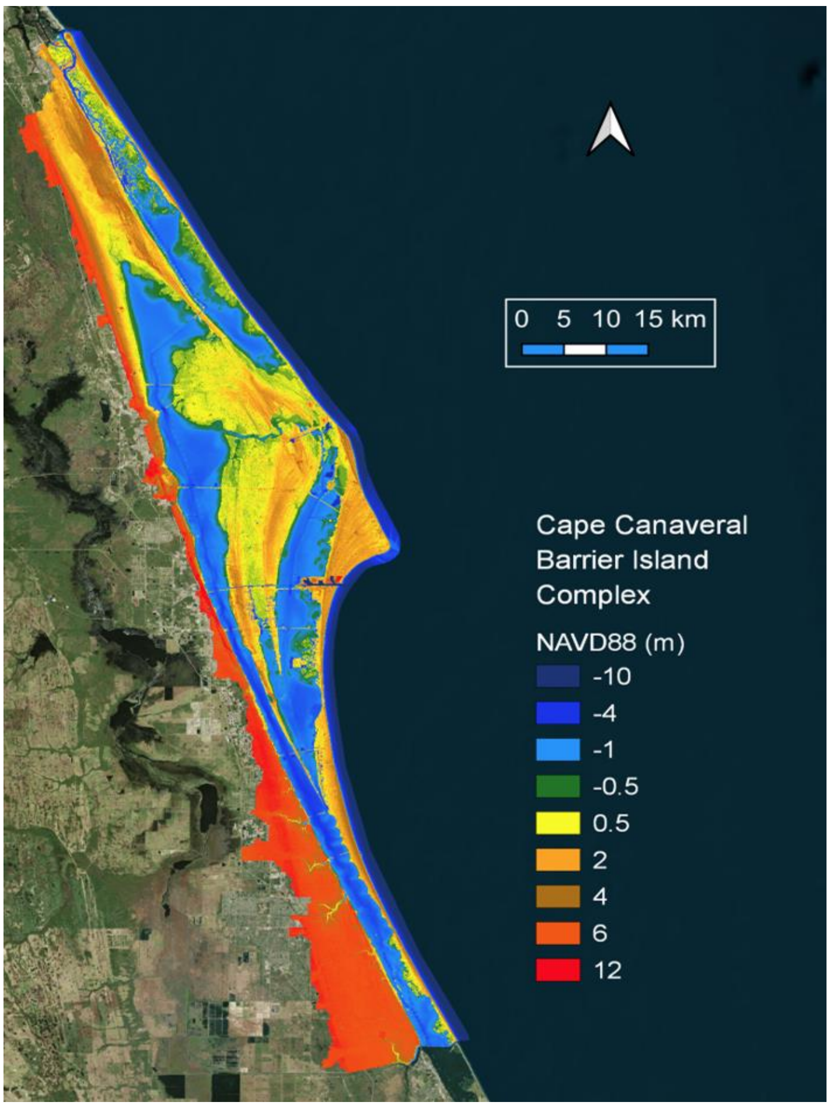
This section develops data descriptions and summary statistics on current baseline attributes of the entire CCBIC. Included are:

- basin area
- basin elevation statistics
- watershed area
- watershed elevation statistics
- waterbody area
- waterbody bottom elevation statistics

- waterbody volume
- watershed to waterbody ratio

2.2 Cape Canaveral Barrier Island Basin

The CCBIC basin covers approximately 195,500 ha based on boundaries from the St. Johns River Water Management District. The basin is bounded on the north by Ponce de Leon Inlet, the east by the Atlantic Ocean, the south by the Sebastian Inlet and the west by the Atlantic Coastal Ridge system developed after sea levels rose with the retreat of the Eminem ice sheet between 130,000 and 115,000 ya. The relative topography and bathymetry of the CCBIC basin is shown in (**Figure 2.1**) based on NOAA continuously updated digital elevation model (CUDEM) data (https://coast.noaa.gov/htdata/raster2/elevation/NCEI_ninth_Topobathy_2014_8483/).



Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 2.1: Elevations of the Cape Canaveral Barrier Island Complex (CCBIC) on the east central Florida coast.

Waterbody bottom and watershed elevation data summary statistics with the CCBIC data re-sampled to a 3 m pixel size are shown in (**Table 2.1**). This re-sampling produced a minimum elevation of -11.53 m and a maximum elevation of 25.43 m in the 195,495 ha basin.

Table 2.1: Descriptive Statistics for the Cape Canaveral Barrier Island Complex (CCBIC) LiDAR derived digital elevation model.

Group	Category	Pixels	Average Elevation (m)	Median Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Hectares (ha)	Percent of CCBIC
CCBIC	Waterbody	80,840,763	-1.60	-1.53	-11.53	-0.10	72,756.69	37.22
CCBIC	Watershed	136,375,882	3.38	2.25	-0.10	25.43	122,738.29	62.78
CCBIC	Basin	217,216,645	1.53	0.63	-11.53	25.43	195,494.98	100.00

Descriptive statistics based on the NOAA Coastal Change Analysis Program Continually Updated Digital Elevation Model for the Cape Canaveral Watershed with a 3 m pixel. Vertical datum = NAVD88m.

The average CCBIC basin elevation is 1.53 m and the median elevation is 0.63 m (**Figure 2.2**). The higher elevations beginning at approximately 5 m represent primarily the Atlantic Coastal Ridge along the west side of the basin.

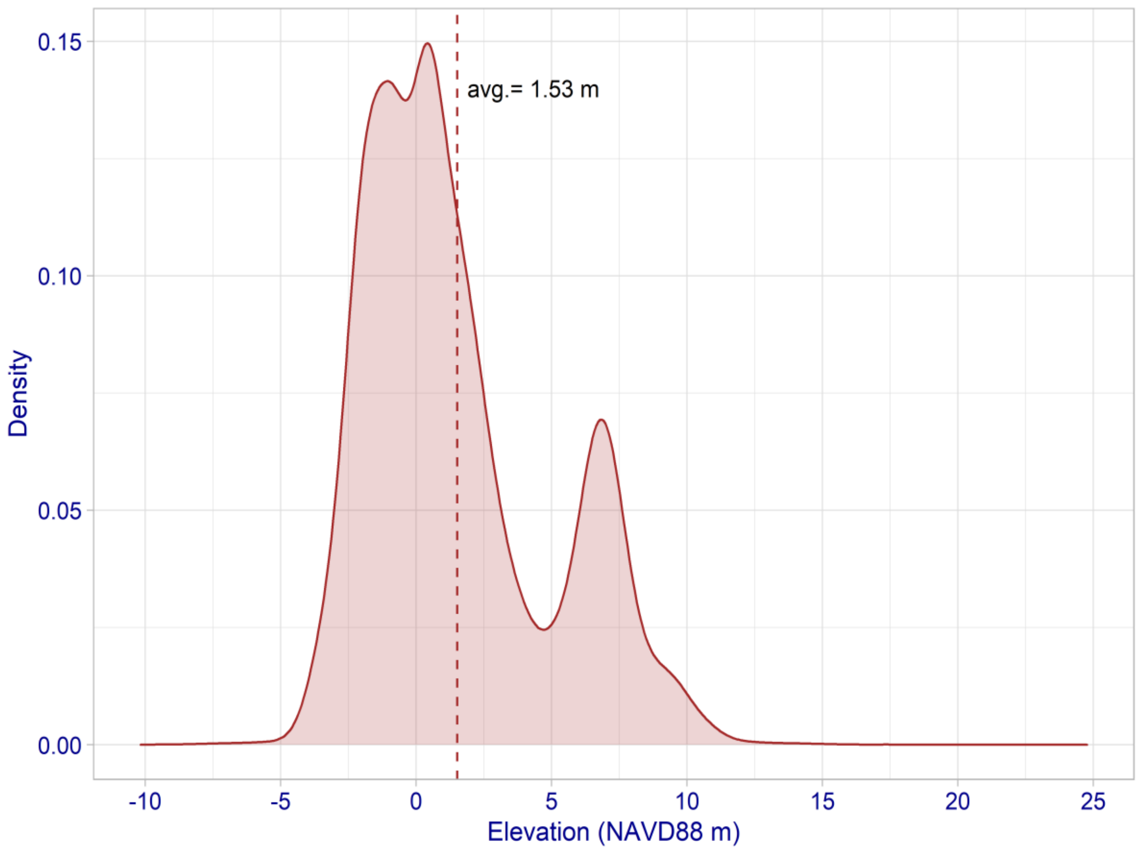


Figure 2.2: Cape Canaveral Barrier Island Complex (CCBIC) elevation density distribution.

The cutoff between the CCVIC basin waterbody and watershed is defined as -0.1 m elevation or the recent average lagoon water level between 1997-2020. The waterbody bottom elevation averages -1.60 m and the watershed elevation average is 3.38 m (**Figure 2.3**).

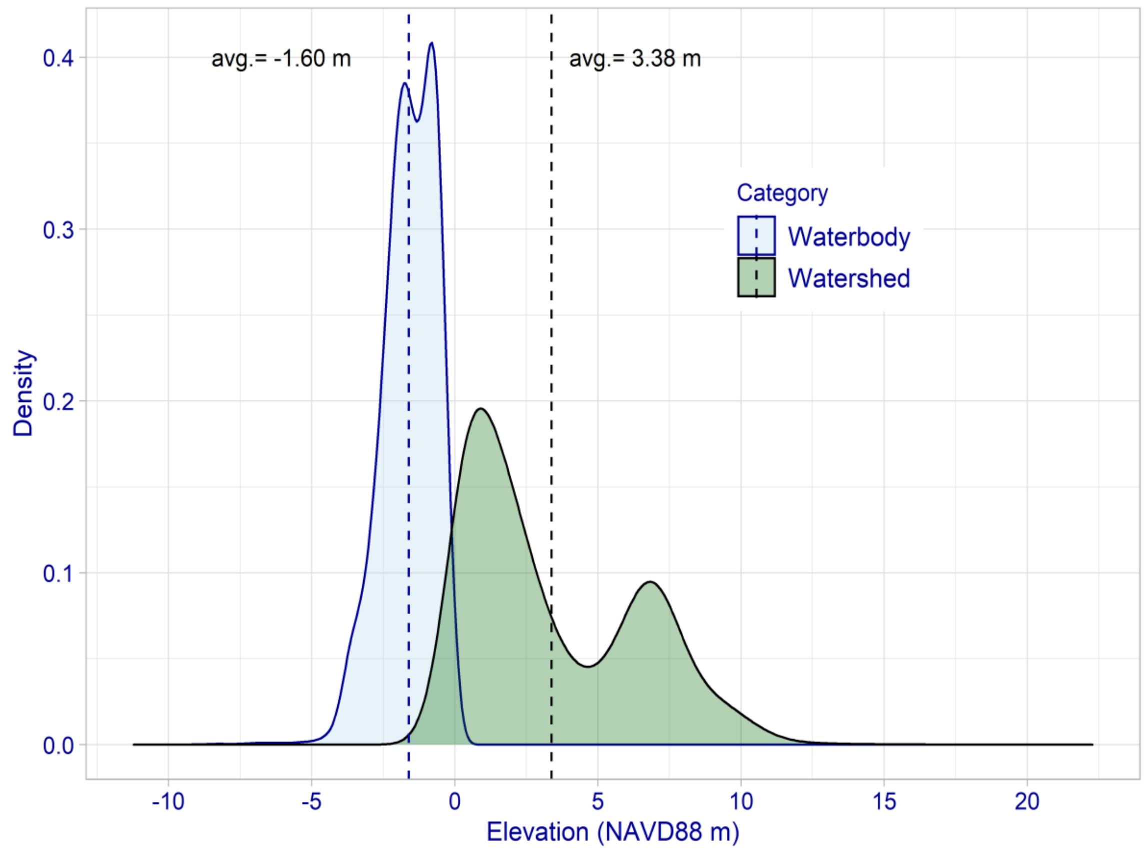


Figure 2.3: Cape Canaveral Barrier Island Complex (CCBIC) waterbody and watershed elevation density distribution.

(**Figure 2.4**) provides a visualization of the relative areas of the CCBIC Basin, waterbody, and watershed. The watershed to waterbody ratio is 1.69 to 1 and the volume of the lagoon between Ponce de Leon and Sebastian Inlets is 116,572 ha m. Volume is expressed in terms of equivalent hectares one meter deep (ha m).

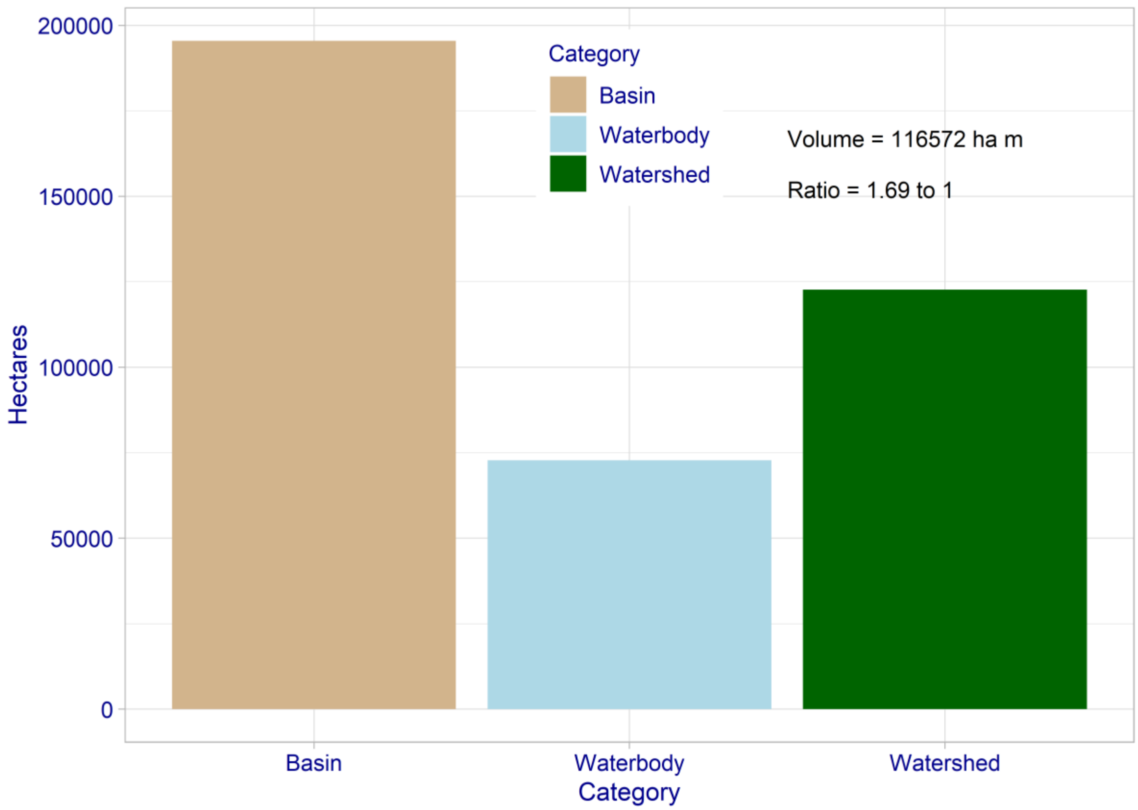
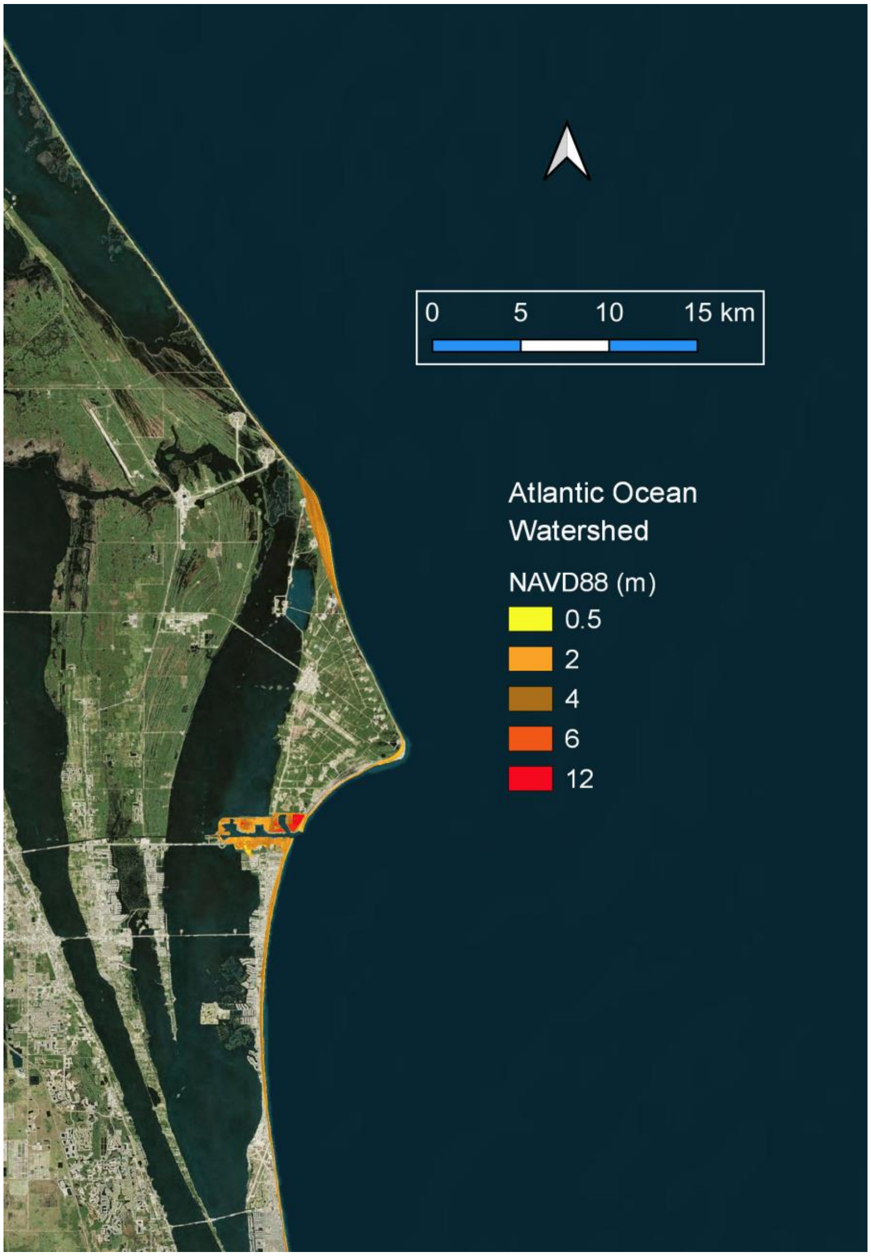


Figure 2.4: Cape Canaveral Barrier Island Complex (CCBIC) component areas (ha), watershed to waterbody ratio, and waterbody volume (ha m).

2.2.1 Atlantic Ocean Watershed

This section develops data descriptions and summary statistics on current attributes of the coastal watershed of the CCBIC that drains to the Atlantic Ocean. This consists primarily of the east side of the dune line and beach. No analyses of data for the Atlantic Ocean waterbody are included. Erosion from rising sea levels and storm surge are continuing to reduce the width of this watershed and anthropogenic activities such as beach nourishment and dune construction are being utilized to manage shoreline retreat.

The Atlantic Ocean watershed covers approximately 2,259 ha when using a mean high water elevation of 0.33 m as the seaward boundary. The area is bounded on the north by Ponce de Leon Inlet, the east by the Atlantic Ocean, the south by the Sebastian Inlet and the west by the coastal dune line with the exception of Port Canaveral and the prograding area at the False Cape. The watershed elevation is shown in (**Figure 2.5**).



Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 2.5: Extent of the Atlantic Ocean Watershed of the CCBIC on the east central Florida coast.

Atlantic Ocean watershed elevation data summary statistics are shown in (**Table 2.2**). The maximum elevation is 15.31 m with a mean of 3.18 m across the 2,259-ha watershed.

Table 2.2: Descriptive Statistics for the Atlantic Ocean watershed LiDAR derived digital elevation model.

Group	Category	Pixels	Average Elevation (m)	Median Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Hectares	Acres
AO	Watershed	2,510,451	3.18	2.94	0.33	15.31	2,259.41	5,583.1

Descriptive statistics based on the NOAA Coastal Change Analysis Program Continually Updated Digital Elevation Model for the Cape Canaveral Watershed with a 3 m pixel. Minimum Elevation = Mean High Water Level estimated for 2015-2020 of 0.33m. Vertical datum = NAVD88m.

The Atlantic Ocean watershed elevation is mostly below 6 m with an average of 3.18 m (**Figure 2.6**).

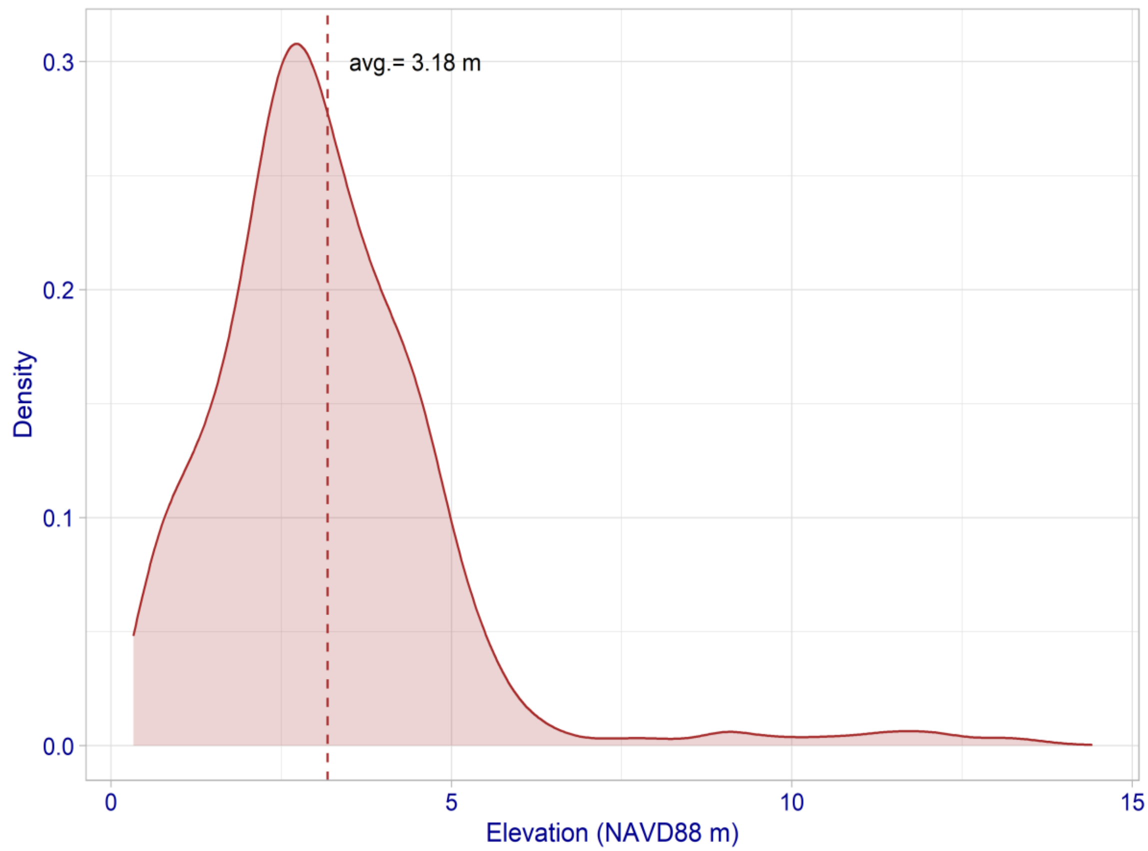
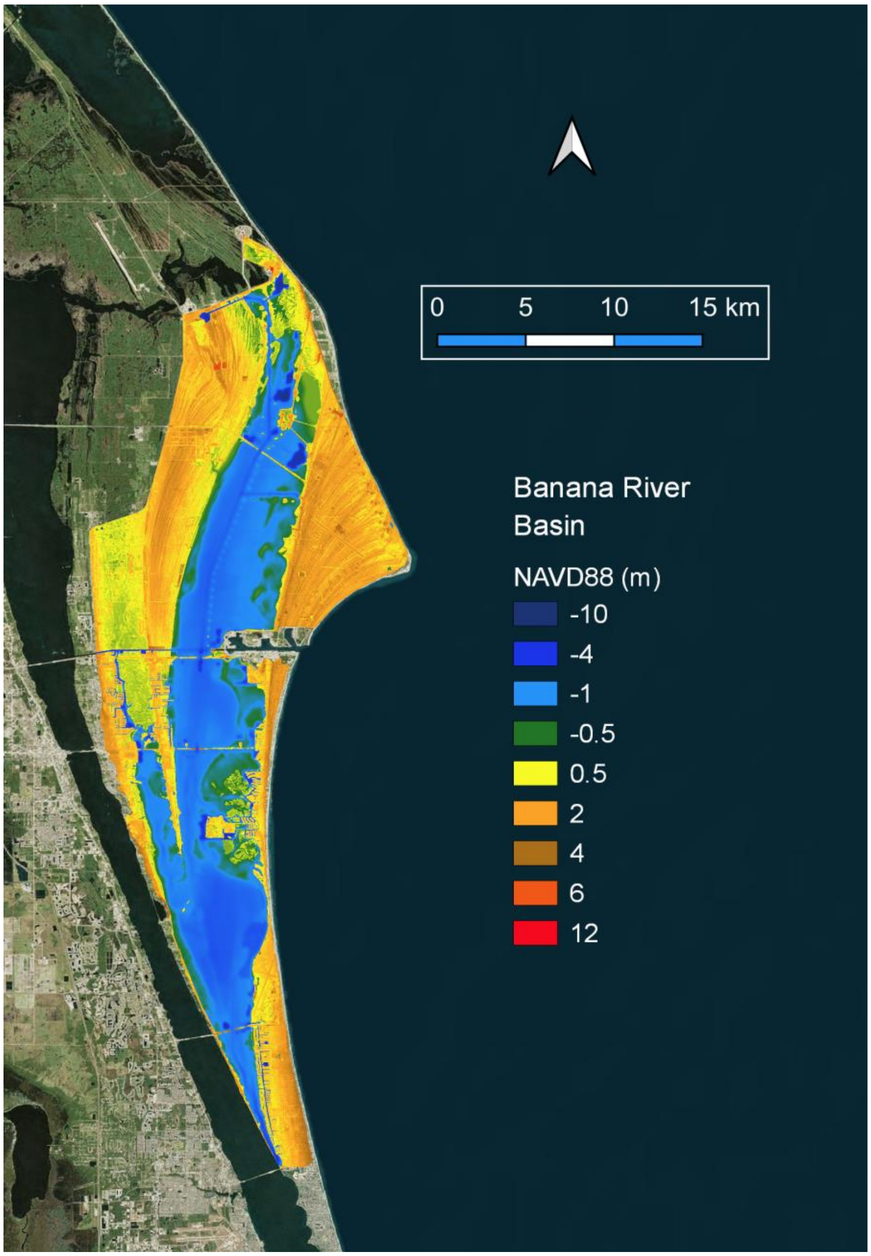


Figure 2.6: Atlantic Watershed Elevation density distribution.

2.2.2 Banana River Basin

The Banana River Basin is bounded on the north by the NASA Crawlerway and Pads 39A and 39B, the east by the Atlantic Ocean beach barrier island with the Cape Canaveral Space Force Station and a string of coastal communities, and the west by Merritt Island. The south end of the lagoon connects to the Indian River through Carters Cut, a small pass at Dragon Point and the Eau Gallie Causeway. The pass narrows to ~135 m wide averaging 3.6 m deep providing a cross sectional area of approximately 500 square meters limiting water exchange between the Banana and Indian River lagoons. The relative elevation of the Banana River Basin is shown in (**Figure 2.7**).



Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 2.7: The Banana River Basin on the east central Florida coast.

Banana River Basin waterbody and watershed elevation data summary statistics based on the NOAA continuously updated digital elevation model are shown in (**Table 2.3**). The average elevation of the waterbody bottom is -1.56 m and the average elevation for the watershed is 1.53 m. The minimum elevation of -11.53 m and the maximum elevation of 17.9 m are associated with areas dredged for fill material and construction and the KSC landfill, respectively.

Table 2.3: Descriptive Statistics for the Banana River Basin LiDAR derived digital elevation model.

Group	Category	Pixels	Average Elevation (m)	Median Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Hectares	Acres
BR	Waterbody	21,673,473	-1.56	-1.44	-11.53	-0.10	19,506.13	48,200.61
BR	Watershed	25,767,857	1.53	1.52	-0.10	17.91	23,191.07	57,306.30
BR	Basin	47,441,330	0.12	0.24	-11.53	17.91	42,697.20	105,506.91

Descriptive statistics based on the NOAA Coastal Change Analysis Program Continually Updated Digital Elevation Model for the Cape Canaveral Watershed with a 3 m pixel. Vertical datum = NAVD88m.

Most of the Banana River Basin elevation lies below 2.5 m elevation and averages 0.12 m (**Figure 2.8**).

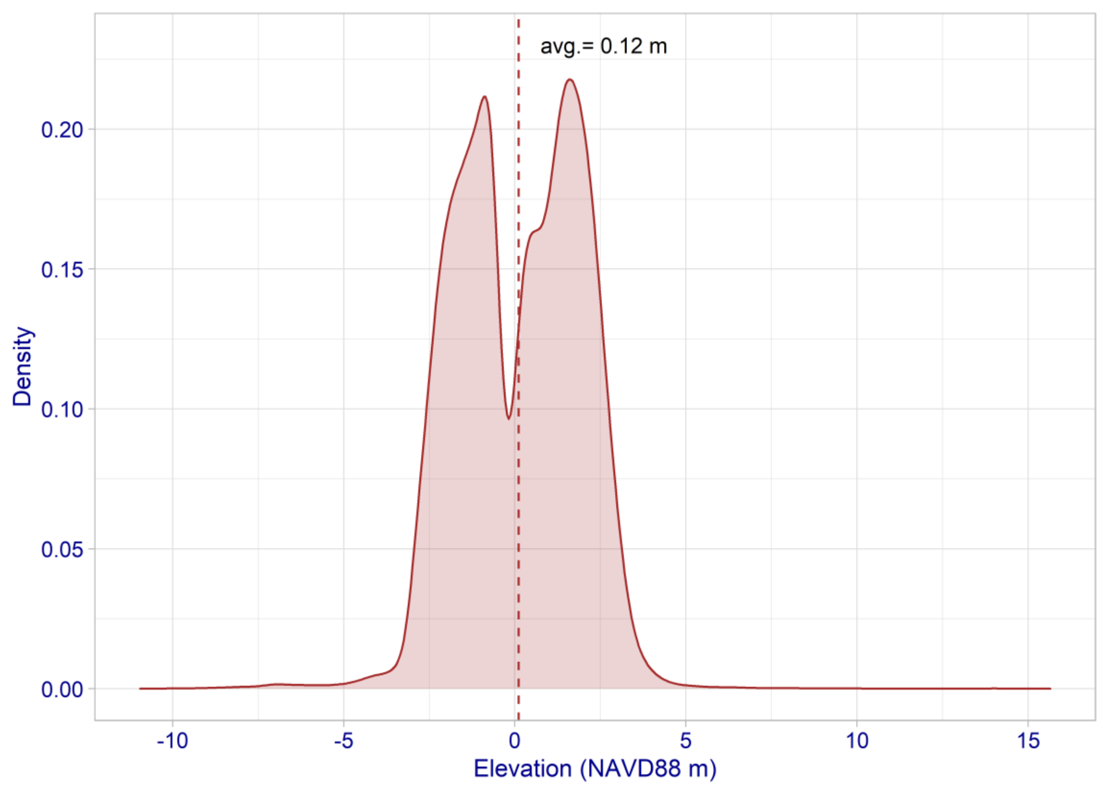


Figure 2.8: Banana River Basin elevation density distribution.

Banana River Basin waterbody bottom and watershed elevations are shown using a value of -0.1 m elevation for the recent average water level between 1997-2020 (**Figure 2.9**).

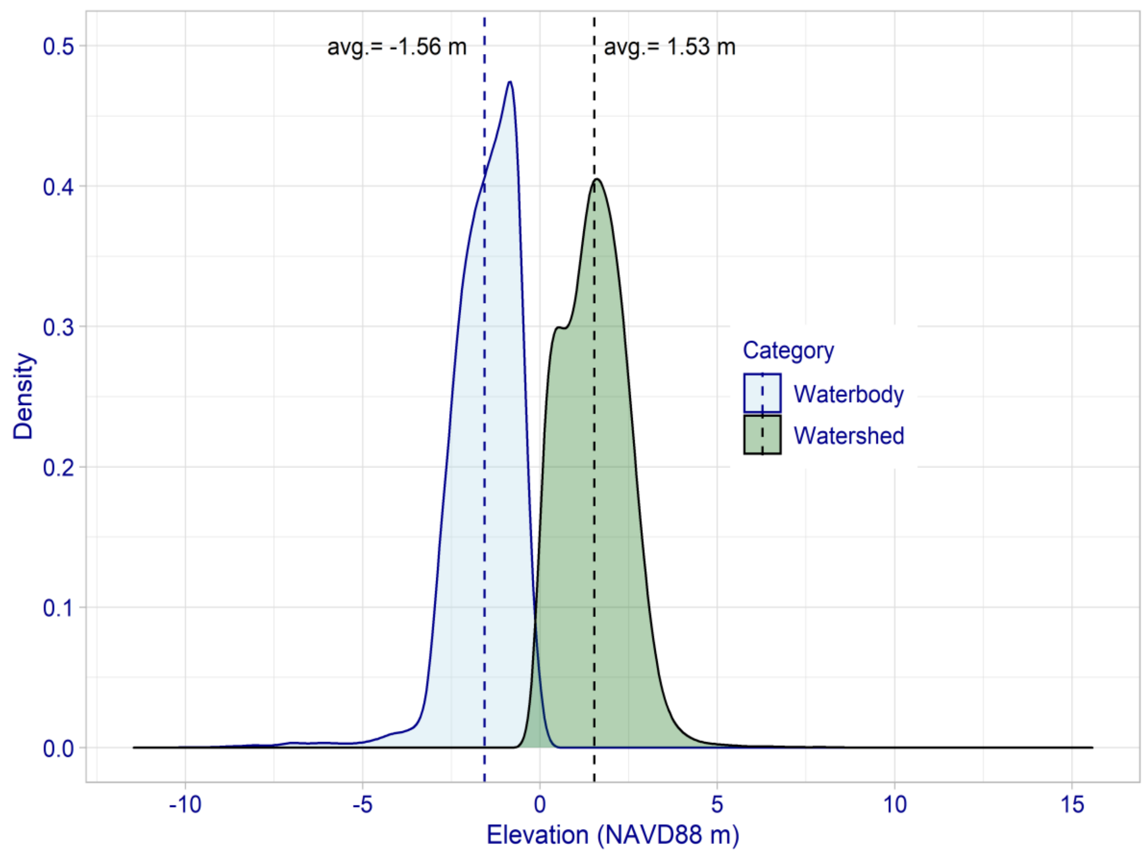


Figure 2.9: Banana River Basin elevation density distribution by watershed and waterbody.

(**Figure 2.10**) provides a visualization of the relative areas of the basin, watershed and waterbody. The watershed to waterbody ratio is only 1.19 to 1 and the volume of the lagoon is estimated at 30495 ha m. Volume is expressed in terms of equivalent hectares one meter deep (ha m).

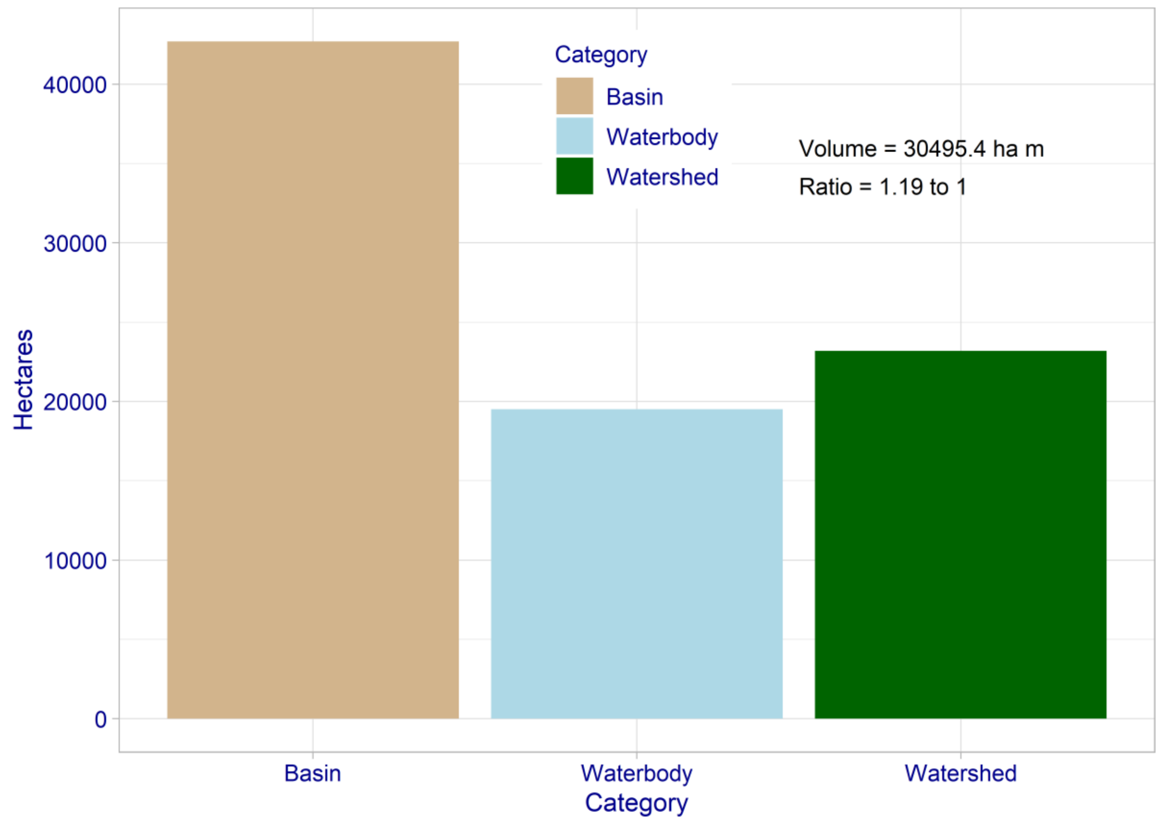
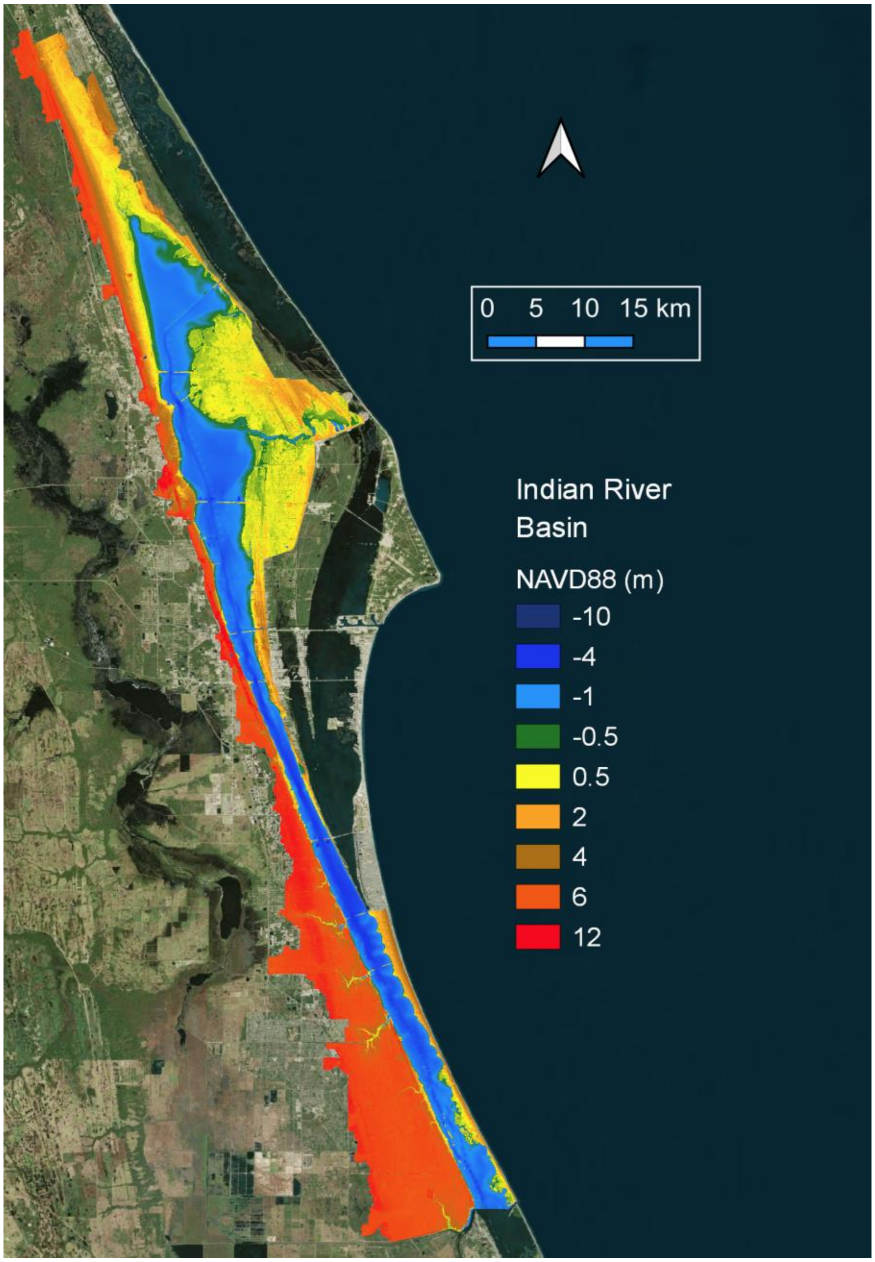


Figure 2.10: Banana River Basin component areas (ha), watershed to waterbody ratio, and waterbody volume (ha m).

2.2.3 Indian River Basin

The Indian River Basin is bounded on the north by the Turnbull Creek, the east by Merritt Island and the Atlantic Ocean beach barrier island, the south by the Sebastian River and Sebastian Inlet and the west by the Atlantic Coastal Ridge along the Florida mainland. The relative elevation of the Indian River Basin is shown in (**Figure 2.11**).



Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 2.11: The Indian River Basin on the east central Florida coast.

Waterbody bottom and watershed elevation data summary statistics for the Indian River basin are shown in (**Table 2.4**). The basin covers approximately 118,845 ha with a minimum waterbody elevation of -8.4 m and a maximum elevation of 25.43 m.

Table 2.4: Descriptive Statistics for the Indian River Basin LiDAR derived digital elevation model.

Group	Category	Pixels	Average Elevation (m)	Median Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Hectares (ha)	Percent of CCBIC
IR	Waterbody	43,247,059	-1.74	-1.71	-8.4	-0.10	38,922.35	19.91
IR	Watershed	88,802,868	4.29	4.56	-0.1	25.43	79,922.58	40.88
IR	Basin	132,049,927	2.32	1.03	-8.4	25.43	118,844.93	60.79

Descriptive statistics based on the NOAA Coastal Change Analysis Program Continually Updated Digital Elevation Model for the Cape Canaveral Watershed with a 3 m pixel. Vertical datum = NAVD88m.

The Indian River Basin average elevation is 2.32 m and the median is 1.03 m (**Figure 2.12**).

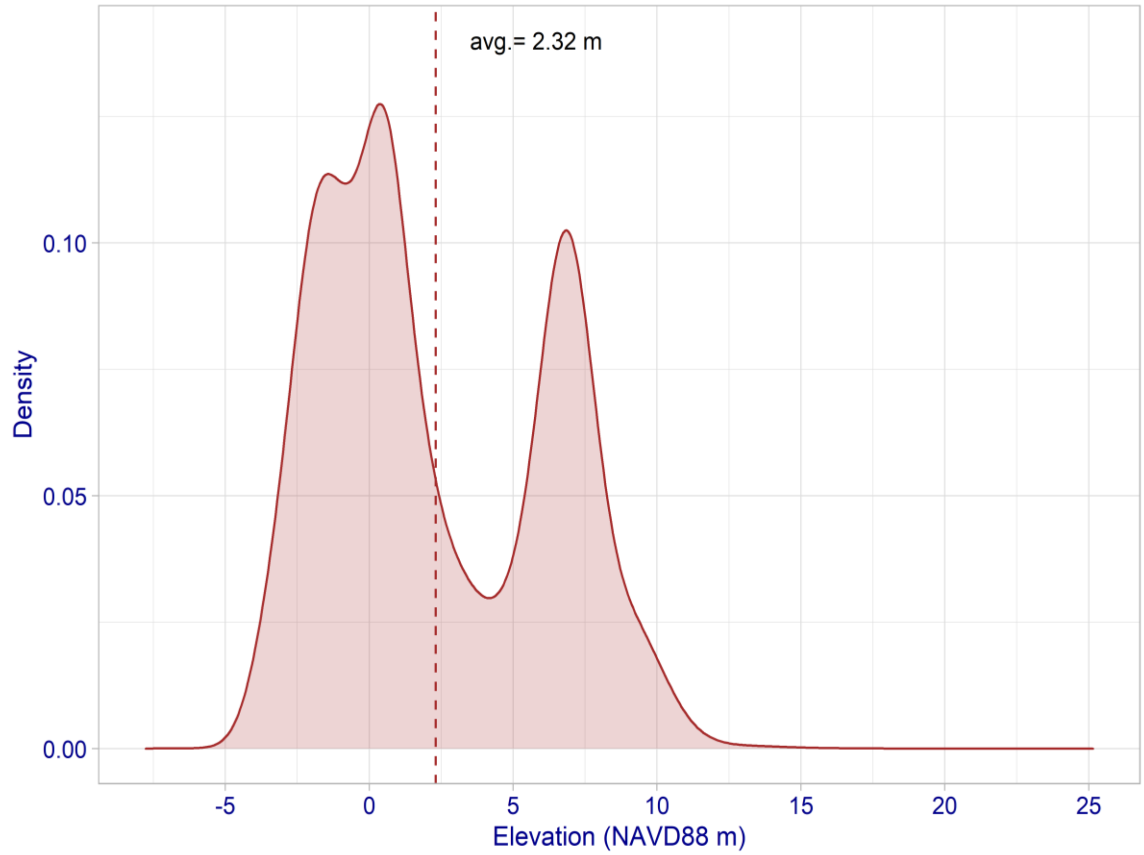


Figure 2.12: Indian River Basin elevation density distribution.

Indian River waterbody bottom and watershed elevations are shown using a value of -0.1 m elevation for the recent average water level between 1997-2020. The average waterbody elevation is -1.74 m and the average watershed elevation is 4.29 m (**Figure 2.13**).

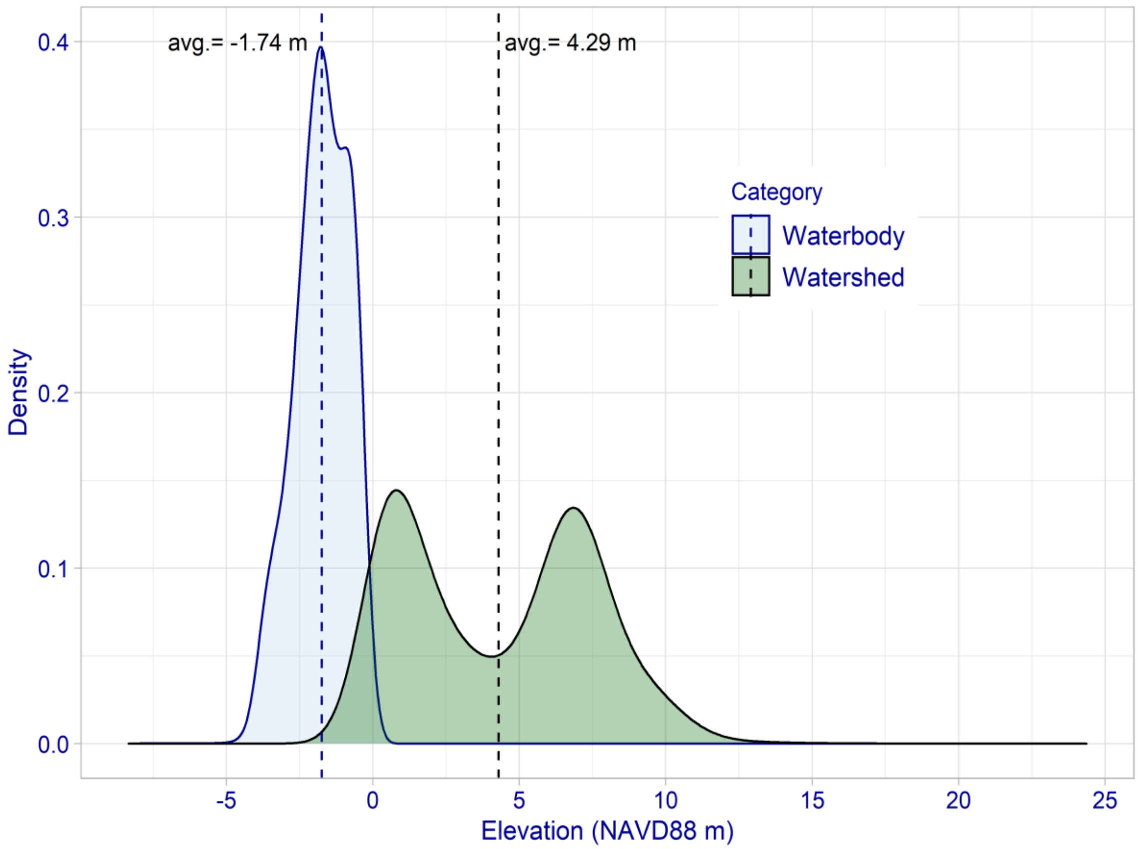


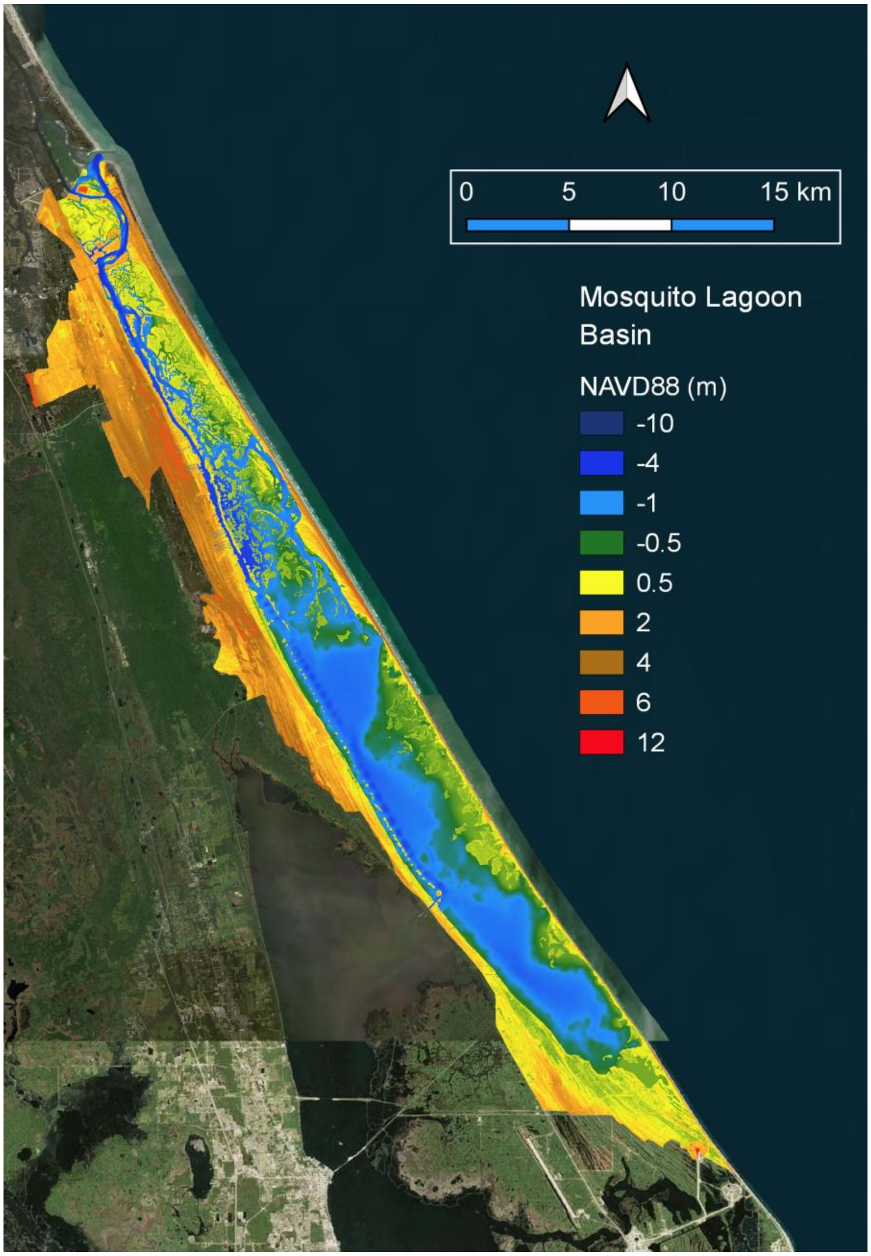
Figure 2.13: Indian River Basin elevation density distribution by watershed and waterbody.

(**Figure 2.14**) provides a visualization of the relative areas of the basin, watershed and waterbody. The watershed to waterbody ratio is only 1.19 and the volume of the lagoon between Ponce de Leon and Sebastian Inlets (30495 ha m). Volume is expressed in terms of equivalent hectares one meter deep (ha m).

Figure 2.14: Indian River Basin component areas (ha), watershed to waterbody ratio, and waterbody volume (ha m).

2.2.4 Mosquito Lagoon Basin

The Mosquito Lagoon Basin is bounded on the north by Ponce de Leon Inlet, the east but the Atlantic Ocean beach barrier island, the south by Pads 39A and 39B, west by the Atlantic Coastal Ridge and Florida mainland. The south end of the lagoon connects to the Indian River through Haulover Canal. The relative topography and bathymetry of the Mosquito Lagoon Basin is shown in (**Figure 2.15**).



Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO;

Figure 2.15: The Mosquito Lagoon Basin on the east central Florida coast.

Bathymetry and Watershed elevation data summary statistics are shown in (**Table 2.5**). The basin covers approximately 35,134 ha with 15,890 ha of waterbody and 19,245 ha watershed.

Table 2.5: Descriptive Statistics for the Mosquito Lagoon Basin LiDAR derived digital elevation model.

Group	Category	Pixels	Average Elevation (m)	Median Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Hectares (ha)	Percent of CCBIC
ml	Waterbody	15,889,908	-1.27	-1.01	-7.18	-0.10	14,300.92	7.32
ml	Watershed	19,244,896	1.69	1.36	-0.10	20.61	17,320.41	8.86
ml	Basin	35,134,804	0.36	0.07	-7.18	20.61	31,621.32	16.18

Descriptive statistics based on the NOAA Coastal Change Analysis Program Continually Updated Digital Elevation Model for the Cape Canaveral Watershed with a 3 m pixel. Vertical datum = NAVD88m

The Mosquito Lagoon elevation density distribution is shown in (**Figure2.16**). Most of the area lies below 2.5 m elevation with a basin average of 0.36 m.

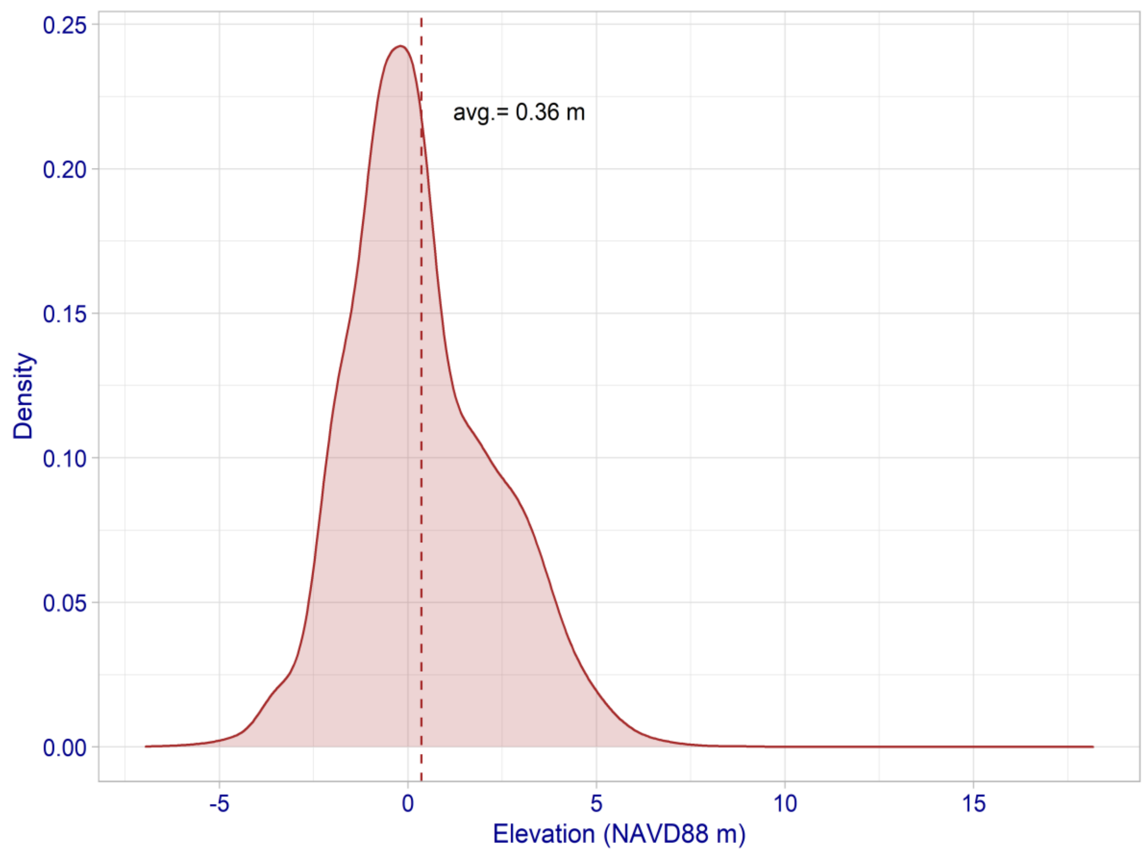


Figure 2.16: Mosquito Lagoon elevation density distribution.

Mosquito Lagoon waterbody bottom and watershed elevations are shown using a value of -0.1 m elevation for the recent average water level between 1997-2020. The average waterbody elevation is -1.27 m and the average watershed elevation is 1.69 m (**Figure 2.17**).

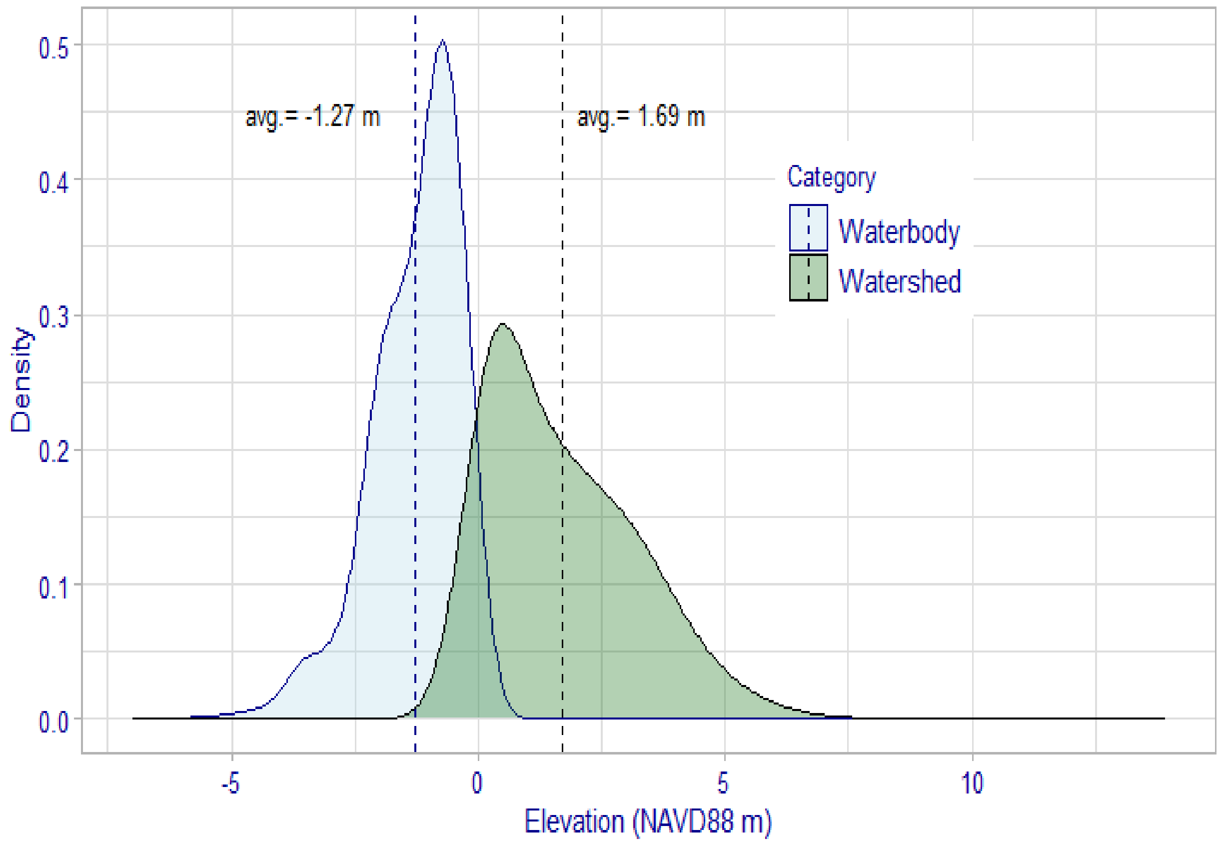


Figure 2.17: Mosquito Lagoon Basin elevation density distribution by watershed and waterbody.

(**Figure2.18**) provides a visualization of the relative areas of the basin, watershed and waterbody for Mosquito Lagoon. The watershed to waterbody ratio is only 1.19 and the lagoon volume is 18,109 ha m.

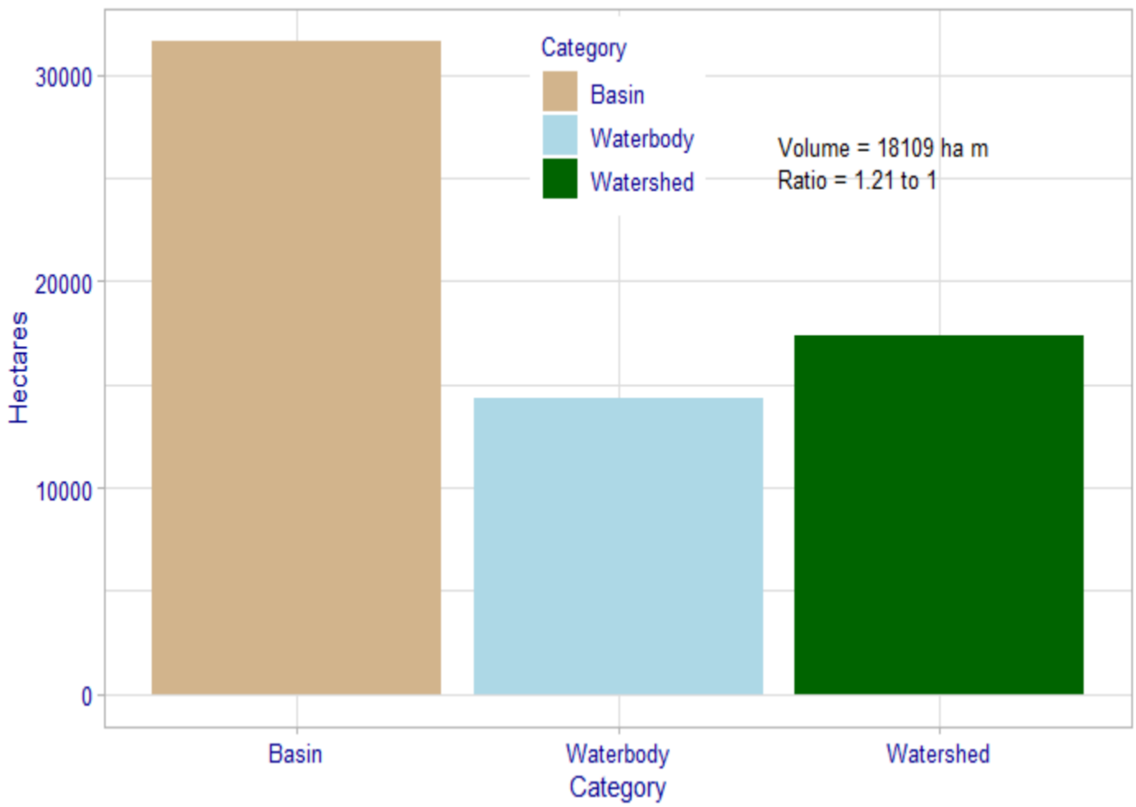


Figure 2.18: Mosquito Lagoon Basin component areas (ha), watershed to waterbody ratio, and waterbody volume (ha m).

3 KSC Portions of the CCBIC

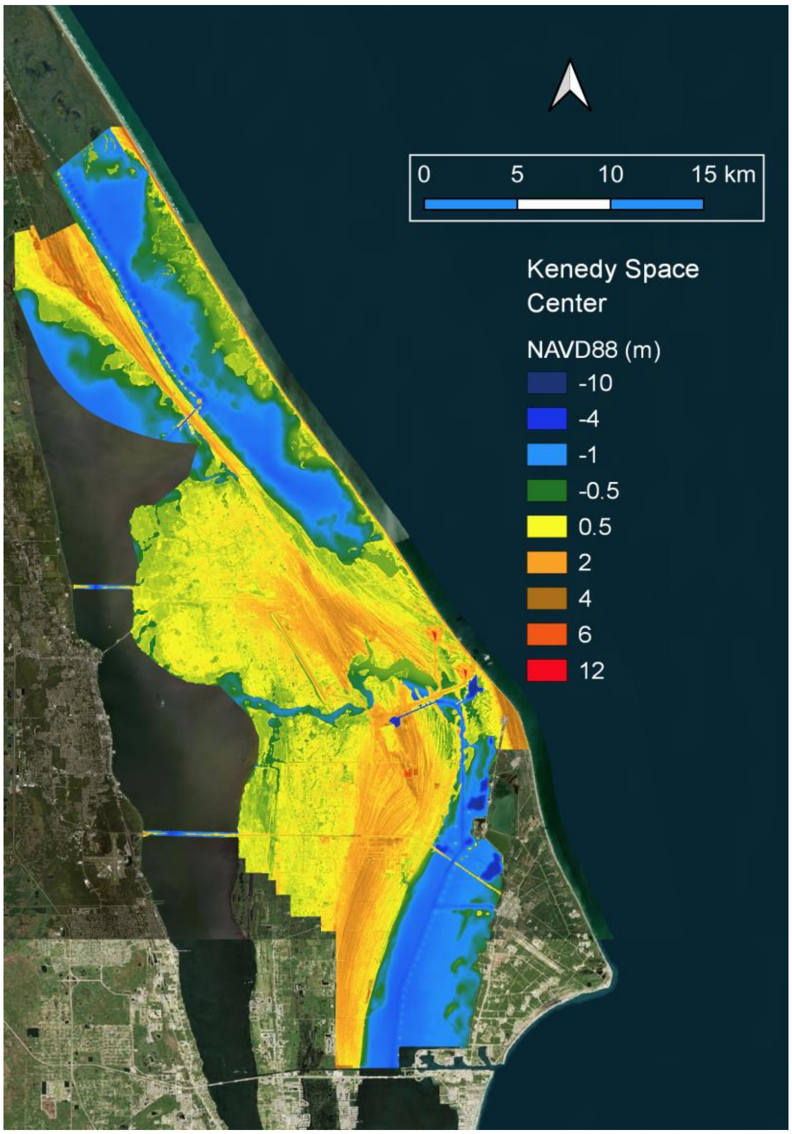
3.1 Purpose

This section develops data descriptions and summary statistics on current baseline attributes of the portions of the CCBIC that fall within the KSC property boundary. Included are:

- basin area
- basin elevation statistics
- watershed area
- watershed elevation statistics
- waterbody area
- waterbody bottom elevation statistics
- waterbody volume
- watershed to waterbody ratio

3.2 KSC CCBIC Basin Components

KSC is in the northern region of the CCBIC covering approximately 57000 ha or 29% of the 195, 295 ha basin including portions of the watersheds and waterbodies of the Atlantic Ocean, Banana River, Indian River and Mosquito Lagoon (**Figure 3.1**).



Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 3.1: The Kennedy Space Center Basin on the east central Florida coast.

Waterbody bottom and watershed elevation data summary statistics for KSC based on the NOAA continuously updated digital elevation model (CUDEM) for the Cape Canaveral watershed are shown in (**Table 3.1**).

Table 3.1: Descriptive statistics for the Kennedy Space Center (KSC) portion of the CCBIC LiDAR derived digital elevation model.

Group	Category	Pixels	Average Elevation (m)	Median Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Hectares (ha)	Percent of KSC
KSC	Waterbody	25,610,472	-1.18	-0.97	-10.17	-0.10	23,049.42	40.56
KSC	Watershed	37,533,295	0.99	0.71	-0.10	16.11	33,779.97	59.44
KSC	Basin	63,143,767	0.11	0.19	-10.17	16.11	56,829.39	100.00

Descriptive statistics based on the NOAA Coastal Change Analysis Program continually updated digital elevation model for the basins within KSC using a 3 m pixel. Datum = NAVD88.

The Kennedy Space Center Basins elevation density distribution is shown in (**Figure3.2**). Most of the area lies below 2.5 m elevation.

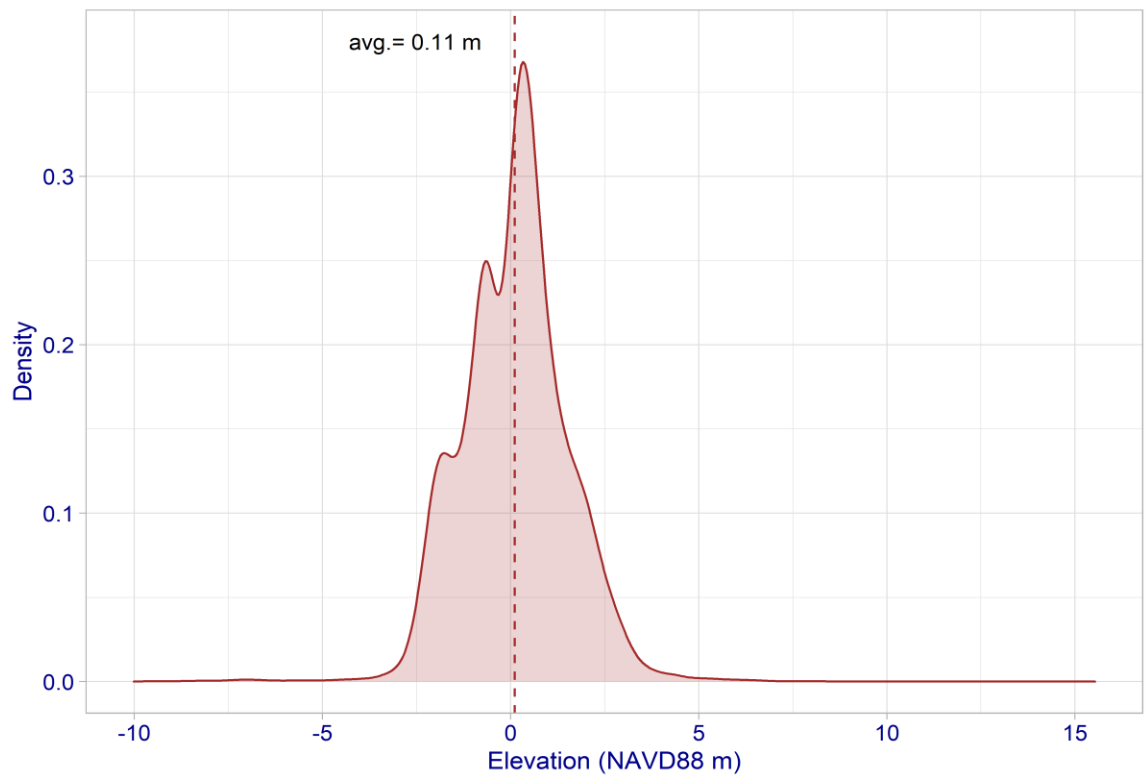


Figure 3.2: Kennedy Space Center Basin elevation density distribution.

Comparison of the waterbody bottom and watershed elevations for all KSC are shown in (**Figure 3.3**) using a value of -0.1 m elevation for the recent average annual water level between 1997-2020.

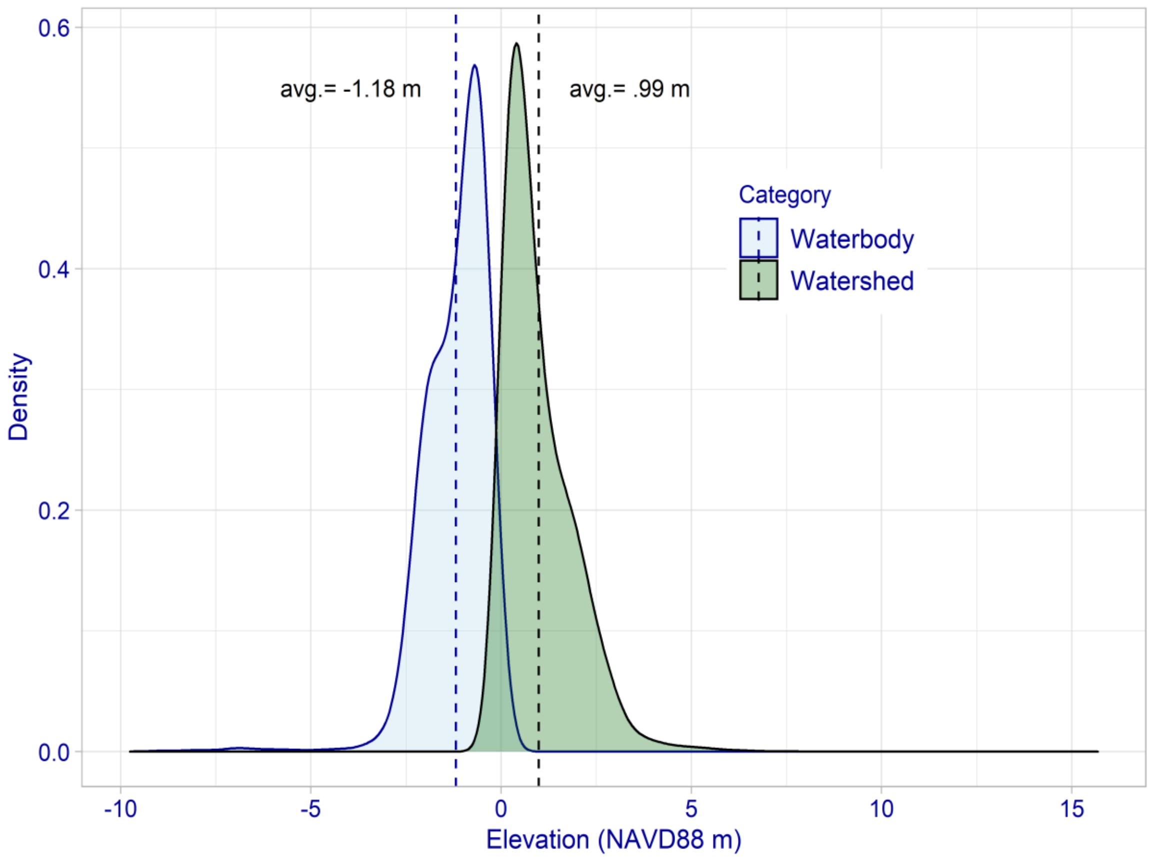


Figure 3.3: Kennedy Space Center elevation density distribution by watershed and waterbody.

(**Figure 3.4**) provides a visualization of relative areas of the basin, watershed and waterbody. The watershed to waterbody ratio is low at 1.47 and the volume of the lagoons around KSC is 27,303.58 ha m.

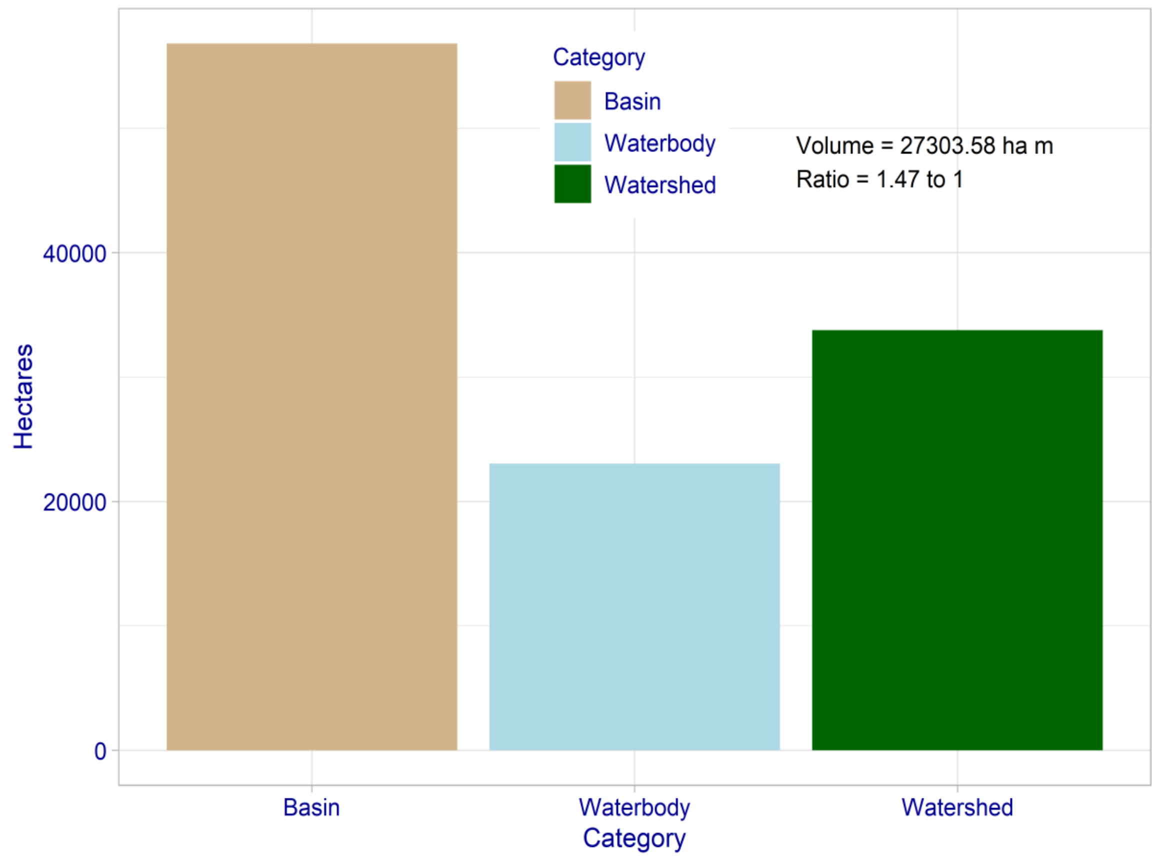
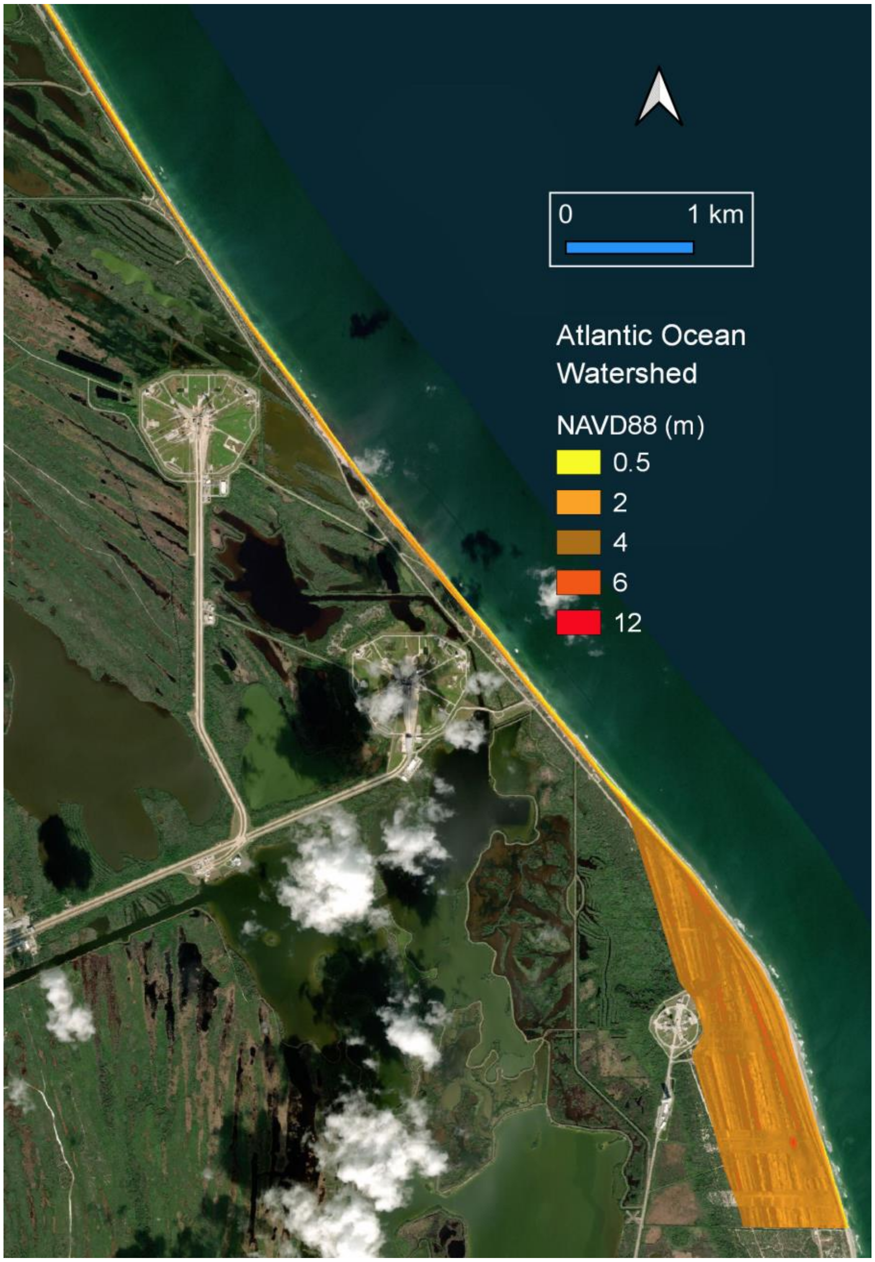


Figure 3.4: Kennedy Space Center Basin component watershed to waterbody ratio and waterbody volume (ha m).

3.2.1 KSC Atlantic Ocean Watershed

This section develops data descriptions and summary statistics on current attributes of the coastal watershed of KSC that drains to the Atlantic Ocean. This narrow area includes primarily the east side of the dune line and beach. Erosion from rising sea levels and storm surge has breached the dune in several locations and reduced the width of the watershed in most areas. NASA KSC has implemented a coastal protection program to protect valuable critical launch infrastructure along the Atlantic coast.

The KSC Atlantic Watershed covers approximately 2259 ha. The relative elevations are shown in (**Figure 3.5**) with the widest area associated with prograding beach at the historic False Cape region.



Source: ESRI, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3.5: Example of the Atlantic Watershed of KSC near launch pads 39A and 39B on the east central Florida coast.

Watershed elevation data summary statistics based on the NOAA continuously updated digital elevation model (CUDA) for the Atlantic watershed are shown in (**Table 3.2**).

Table 3.2: Descriptive Statistics for the KSC portion of the Atlantic Ocean Watershed LiDAR derived digital elevation model.

Group	Category	Pixels	Average Elevation (m)	Median Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Hectares (ha)	Percent of KSC
AOKSC	Watershed	374,976	2.99	3.17	0.33	8.28	337.48	0.59

Descriptive statistics based on the NOAA Coastal Change Analysis Program continually updated digital elevation model for the Cape Canaveral Watershed with a 3 m pixel. Datum = NAVD88m

The KSC Atlantic Watershed has an average elevation of 2.99 m (**Figure 3.6)**.

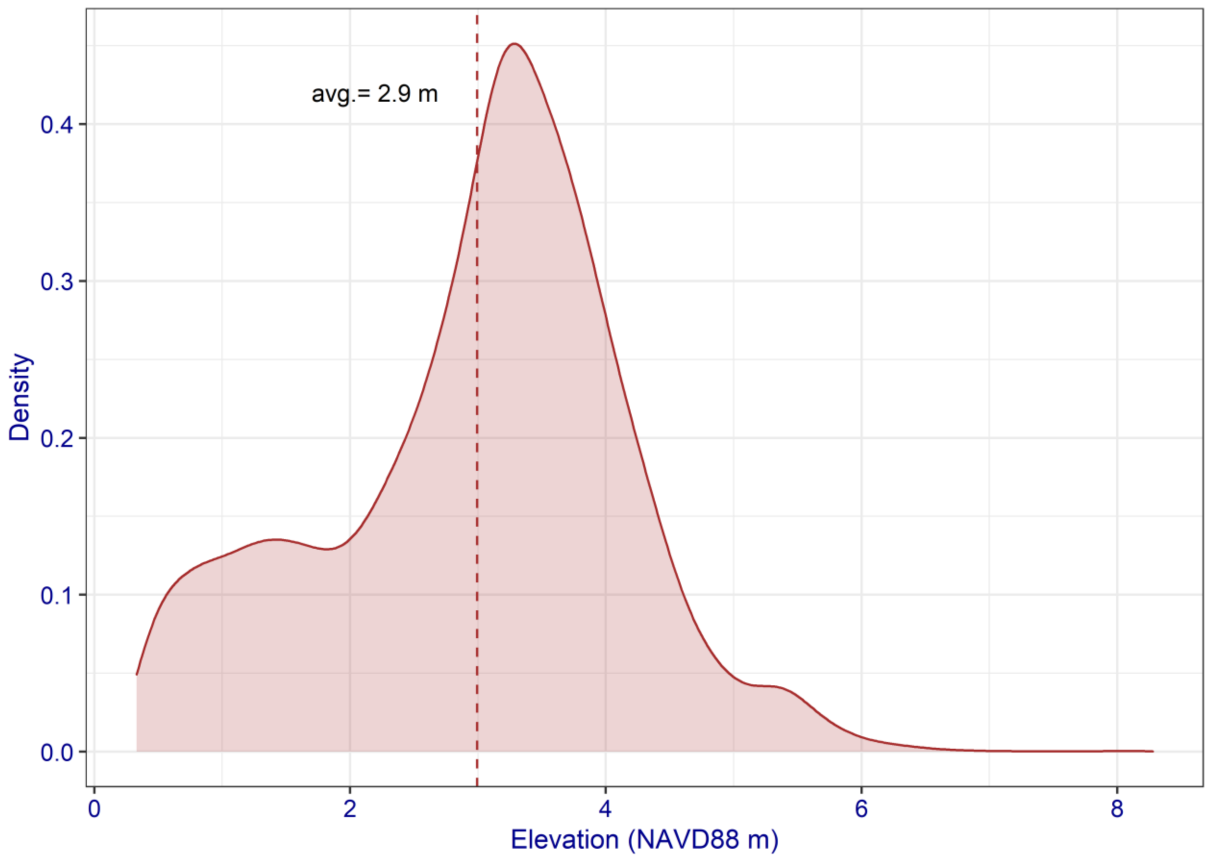
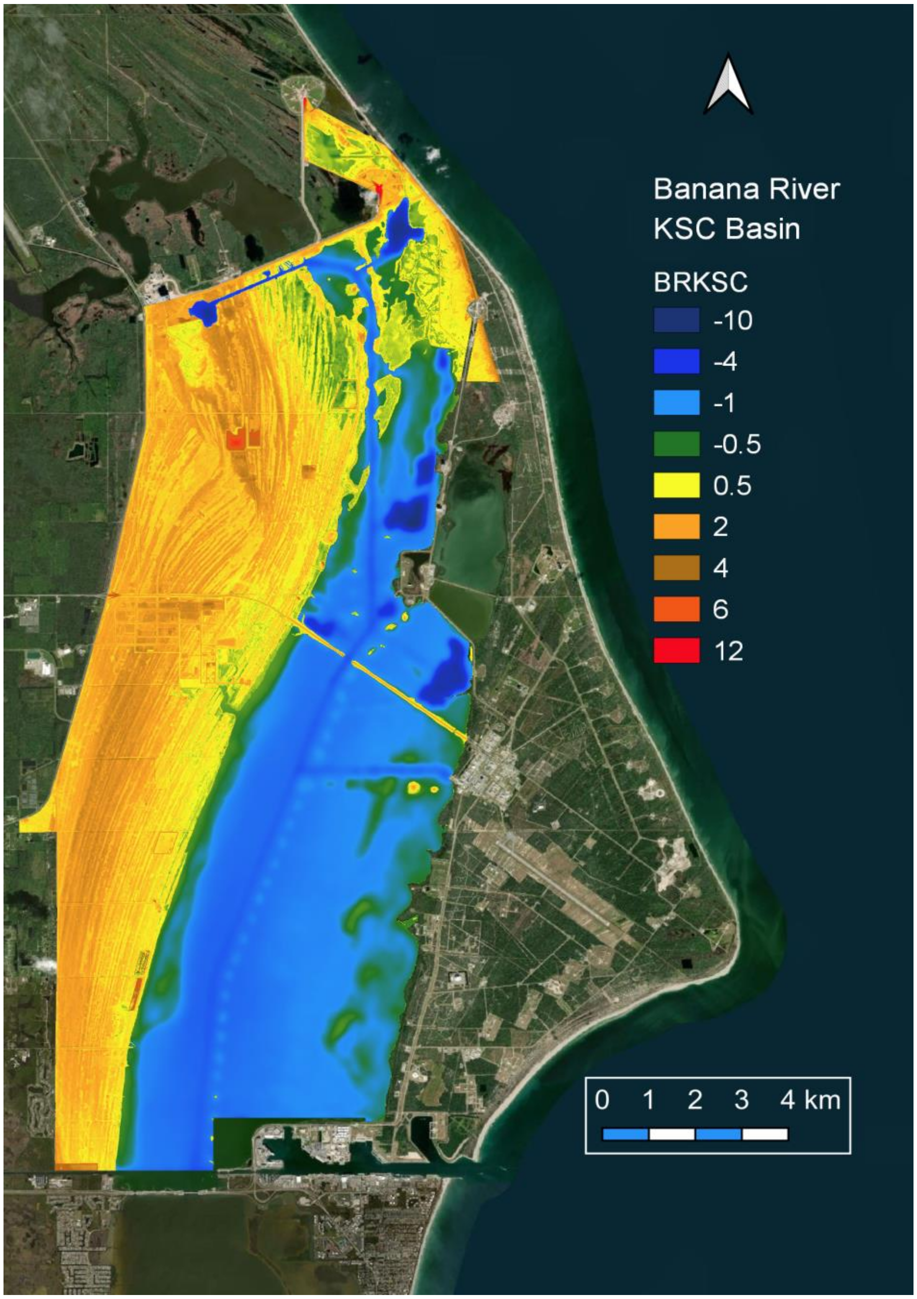


Figure 3.6: KSC Atlantic Watershed elevation density distribution.

3.2.2 KSC Banana River Basin

Inside KSC the Banana River Basin is bounded on the north by the NASA Crawlerway and Pad 39A, the east by the Atlantic Ocean beach barrier island with the Cape Canaveral Space Force

Station, the west by KSC and Merritt Island. The south end of the KSC portion of the Banana River lagoon stops just north of the barge canal and Port Canaveral. The relative elevations of the KSC Banana River Basin is shown in (**Figure 3.7**) based on existing LiDAR data.



Source: ESRI, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3.7: The Banana River Basin inside KSC property line on the east central Florida coast.

Waterbody bottom and watershed elevation data summary statistics for the Banana River Basin are shown in (**Table 3.3**).

Table 3.3: Descriptive Statistics for the KSC portion of the Banana River Basin LiDAR derived digital elevation model

Group	Category	Pixels	Average Elevation (m)	Median Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Hectares (ha)	Percent of KSC
BRKSC	Waterbody	8,410,342	-1.51	-1.32	-10.17	-0.10	7,569.31	13.32
BRKSC	Watershed	8,379,003	1.51	1.46	-0.10	15.62	7,541.10	13.27
BRKSC	Basin	16,789,345	-0.01	-0.11	-10.17	15.62	15,110.41	26.59

Descriptive statistics based on the NOAA Coastal Change Analysis Program Continually Updated Digital Elevation Model for the Cape Canaveral Watershed with a 3 m pixel. Datum = NAVD88m,

Most of the KSC Banana River Basin lies below 2.5 m elevation with a basin average of -0.01 m (**Figure 3.8**).

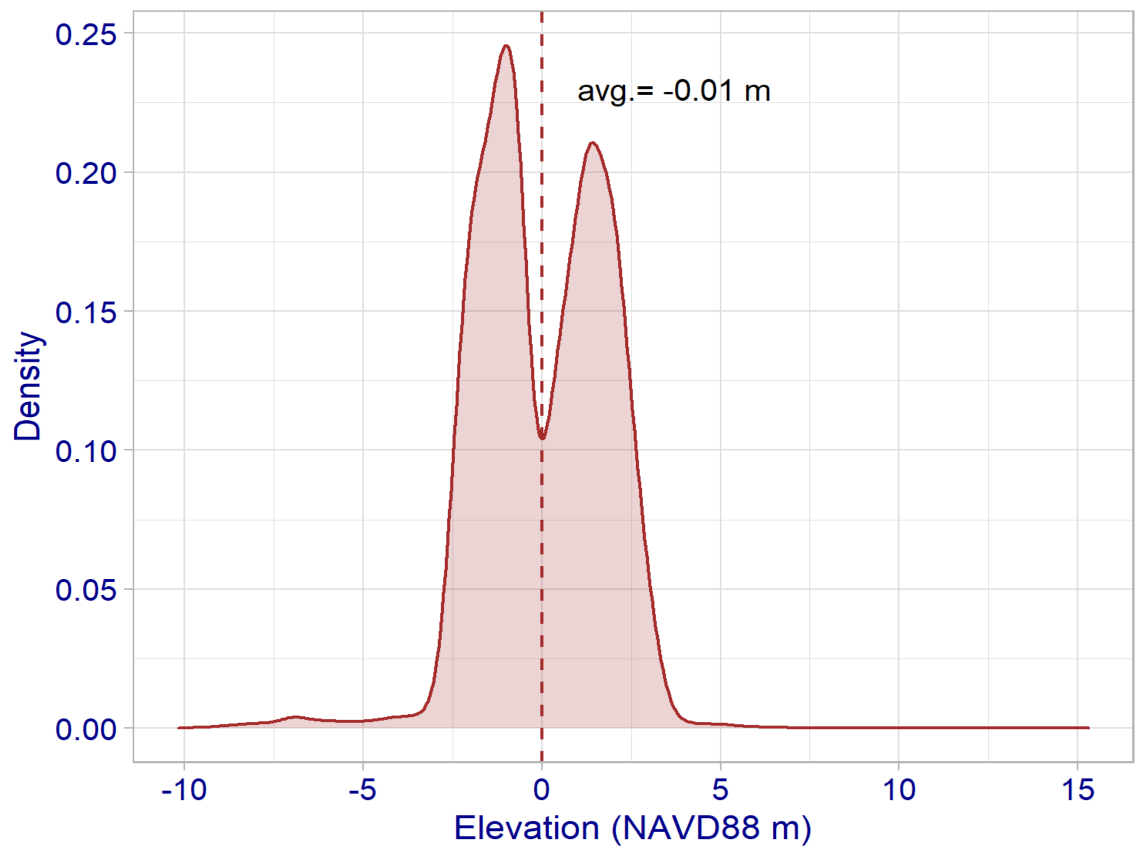


Figure 3.8: KSC Banana River Basin elevation density distribution.

Waterbody bottom and watershed elevation are -1.51 m and 1.51 m, respectively (**Figure 3.9**).

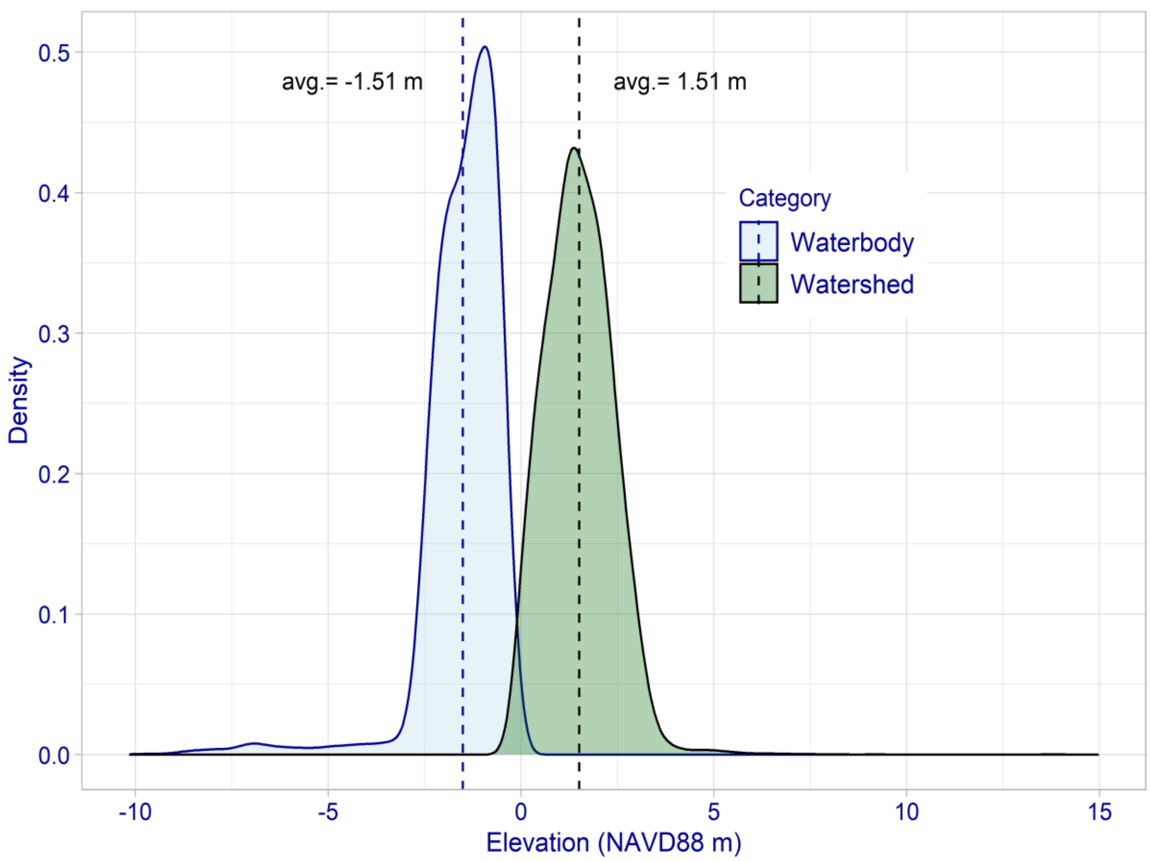


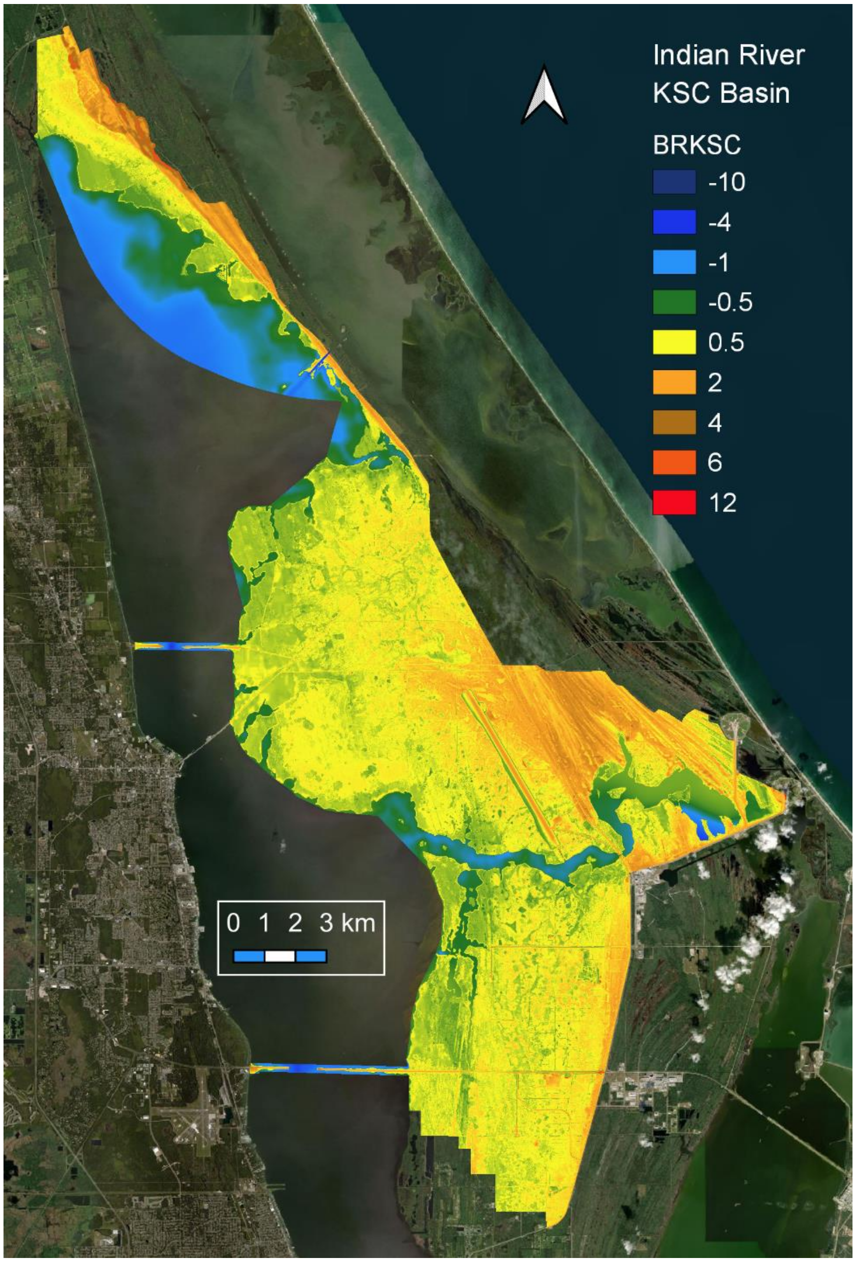
Figure 3.9: KSC Banana River Basin elevation density distribution by watershed and waterbody.

(**Figure 3.10**) provides a visualization of the relative areas of the basin, watershed, and waterbody. The watershed to waterbody ratio is 0.99 and the volume of the KSC portion of the Banana River lagoon is estimated at 11,451.3 ha m.

Figure 3.10: Relationship of KSC Banana River Basin component elevations, watershed to waterbody ratio, and waterbody Volume (ha m).

3.2.3 KSC Indian River Basin

Inside KSC the Indian River Basin is bounded on the north by Turnbull Creek, the east by KSC and Merritt Island, and the west by open lagoon water, the south end of the KSC portion of the basin follows the KSC property line across Merritt Island stopping north of the barge canal. The relative elevation of the KSC portion of the Indian River Basin is shown in (**Figure 3.11**).



Source: ESRI, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3.11: The Indian River Basin inside KSC property on the east central Florida coast.

Waterbody bottom and watershed elevation data summary statistics for the KSC portion of the Indian River Basin are shown in (**Table 3.4**).

Table 3.4: Descriptive Statistics for the KSC portion of the Indian River Basin LiDAR derived digital elevation model.

Group	Category	Pixels	Average Elevation (m)	Median Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Hectares (ha)	Percent of KSC
irkscIC	Surface Water	5,826,959	-0.79	-0.65	-4.86	-0.10	5,244.26	9.23
irkscIC	Watershed	21,690,517	0.76	0.54	-0.10	13.54	19,521.47	34.35
irkscIC	Basin	27,517,476	0.43	0.38	-4.86	13.54	24,765.73	43.58

Descriptive statistics based on the NOAA Coastal Change Analysis Program continually updated digital elevation model for the Cape Canaveral Watershed with a 3 m pixel. Datum = NAVD88m

The KSC Indian River Basin elevation density distribution is shown in (**Figure 3.12**). Most of the area lies below 2.5 m elevation and the overall average elevation is 0.43 m.

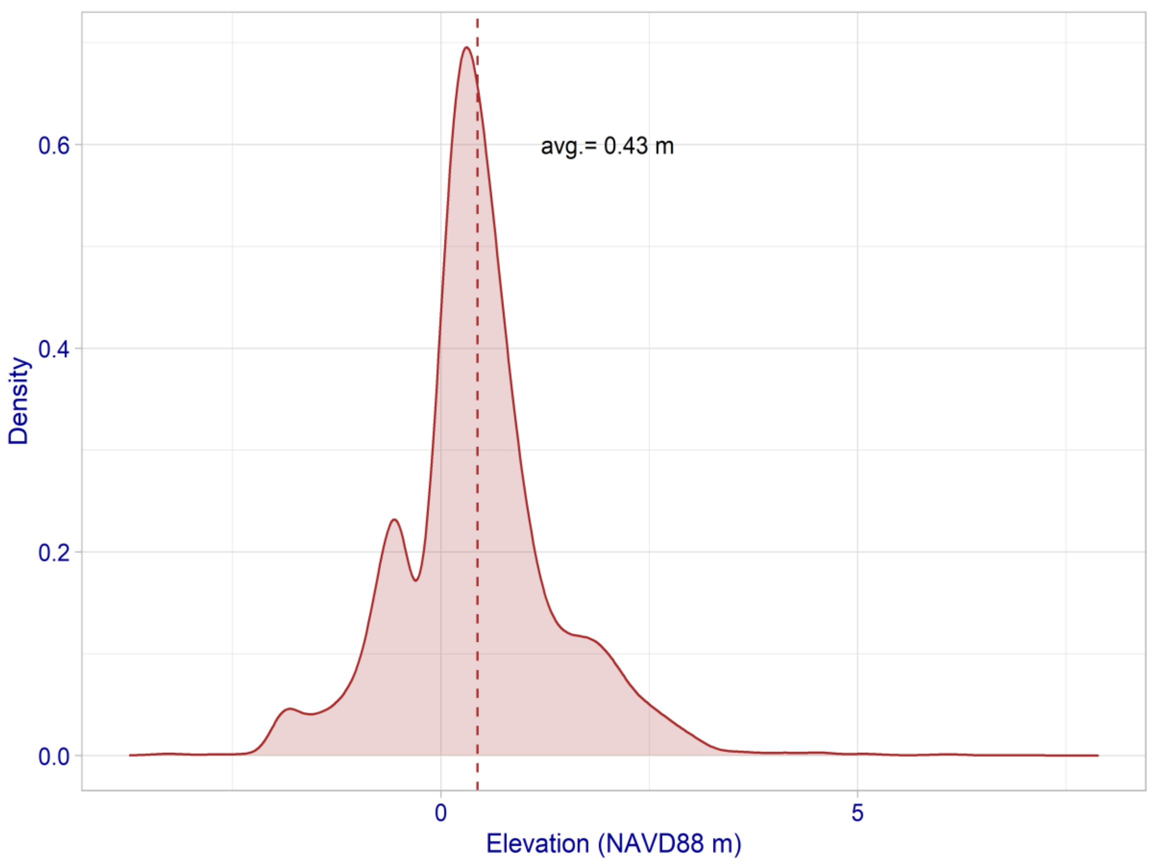


Figure 3.12: KSC Indian River Basin elevation density distribution.

Waterbody bottom and watershed elevation density distributions are shown in (**Figure 3.13**) using a value of -0.1 m NAVD88 elevation for the average lagoon water level.

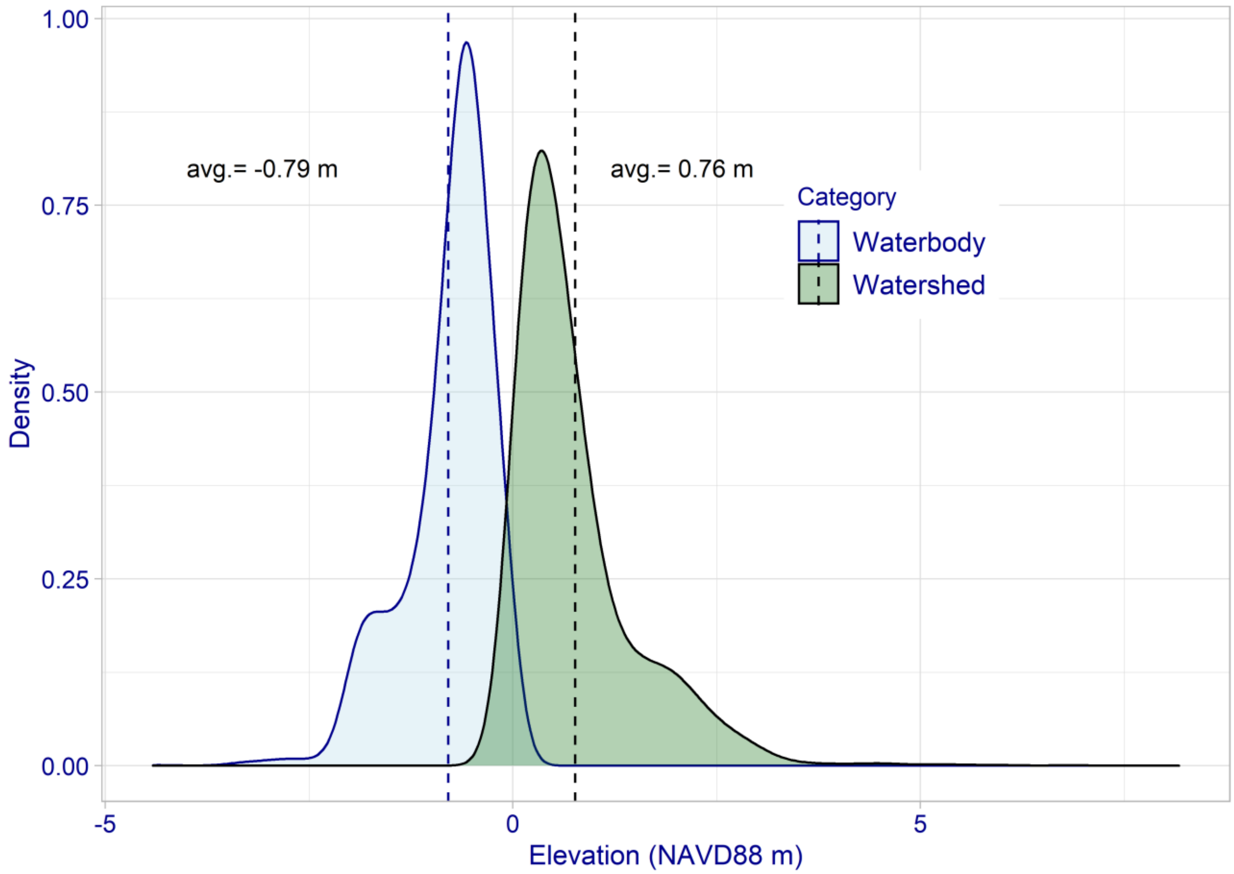


Figure 3.13: KSC Indian River Basin elevation density distribution by watershed and waterbody.

(**Figure 3.14**) provides a visualization of the relative areas of the KSC portion of the Indian River basin, watershed and waterbody. The watershed to waterbody ratio is only 3.72 to 1 and the lagoon volume is estimated at 4,145 ha m. Volume is expressed in terms of equivalent hectares one meter deep (ha m). The relatively high watershed to waterbody ratio is a function of the limited western KSC boundary location.

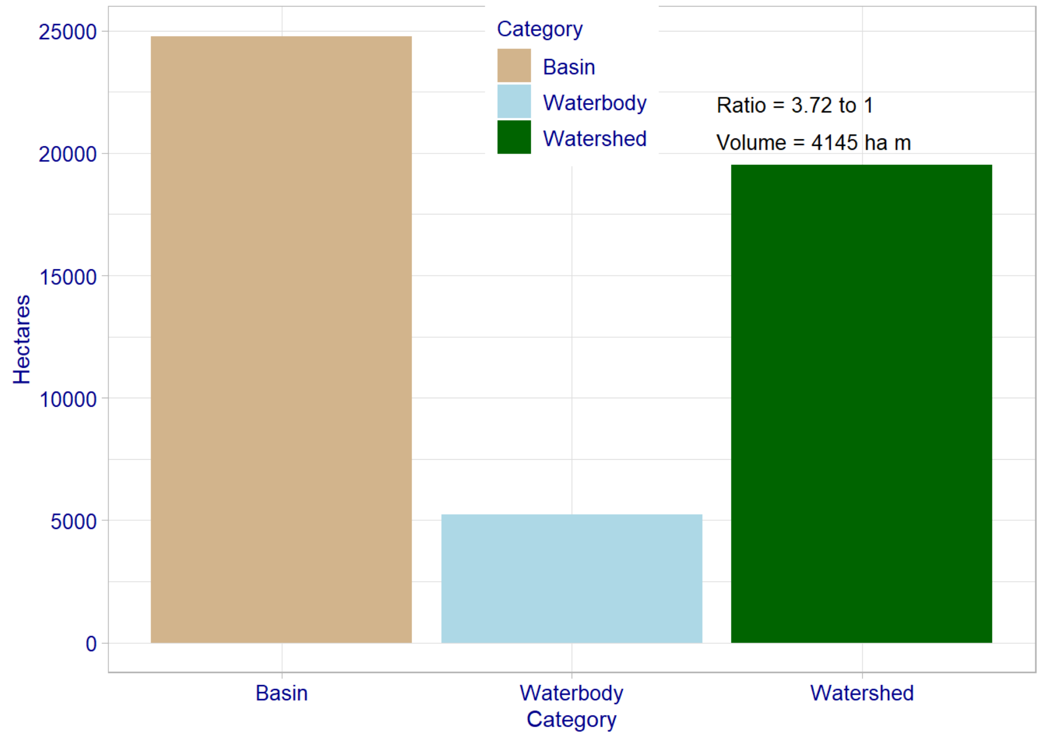
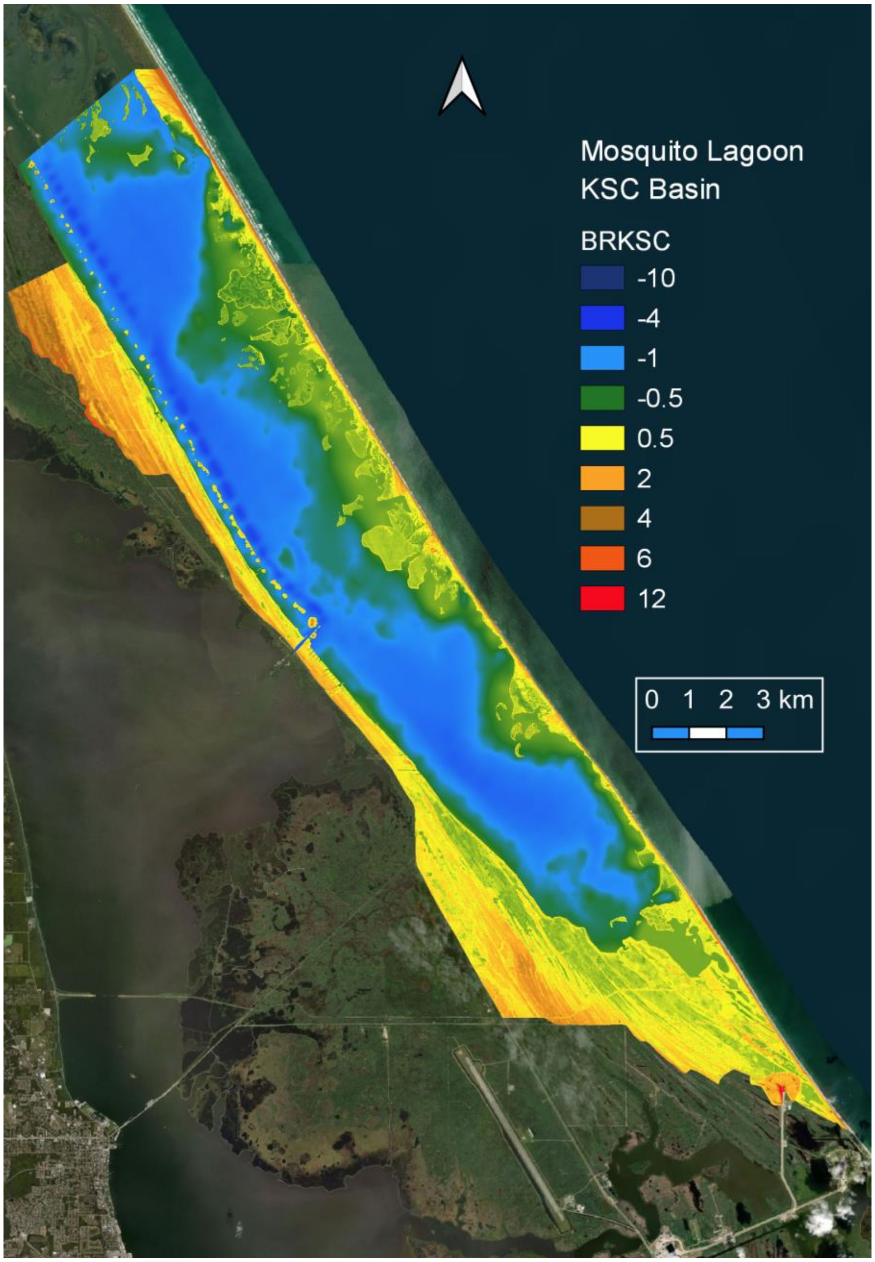


Figure 3.14: Relationship of KSC Indian River Basin component elevations (NAVD88 m), watershed to waterbody ratio, and waterbody Volume (ha m).

3.2.4 KSC Mosquito Lagoon Basin

Inside KSC the Mosquito Lagoon Basin is bounded on the north by oyster and mangrove islands, the east by the Canaveral barrier island, the west by Merritt Island and the Atlantic Coast Ridge, and the south by KSC Pads 39A and 39B. The relative elevation of the KSC Mosquito Lagoon Basin is shown in (**Figure 3.15**) based on existing LiDAR data.



Source: ESRI, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3.15: The KSC portion of the Mosquito Lagoon Basin on the east central Florida coast.

Waterbody bottom and watershed elevation data summary statistics are shown in (**Table 3.4**).

Table 3.4: Descriptive statistics for the KSC Mosquito Lagoon Basin LiDAR derived digital elevation model

Group	Category	Pixels	Average Elevation (m)	Median Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Hectares (ha)	Percent of KSC
MLKSC	Surface Water	11,366,812	-1.14	-0.95	-3.94	-0.10	10,230.13	18.00

Group	Category	Pixels	Average Elevation (m)	Median Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Hectares (ha)	Percent of KSC
MLKSC	Watershed	7,089,514	0.98	0.67	-0.10	16.11	6,380.56	11.23
MLKSC	Basin	18,456,326	-0.33	-0.52	-3.94	16.11	16,610.69	29.23

Descriptive statistics based on the NOAA Coastal Change Analysis Program Continually Updated Digital Elevation Model for the Cape Canaveral Watershed with a 3 m Pixel. Datum = NAVD88m.

The KSC Mosquito Lagoon Basin mostly lies below 2.5 m elevation with an overall average of -0.33 m (**Figure 3.16**).

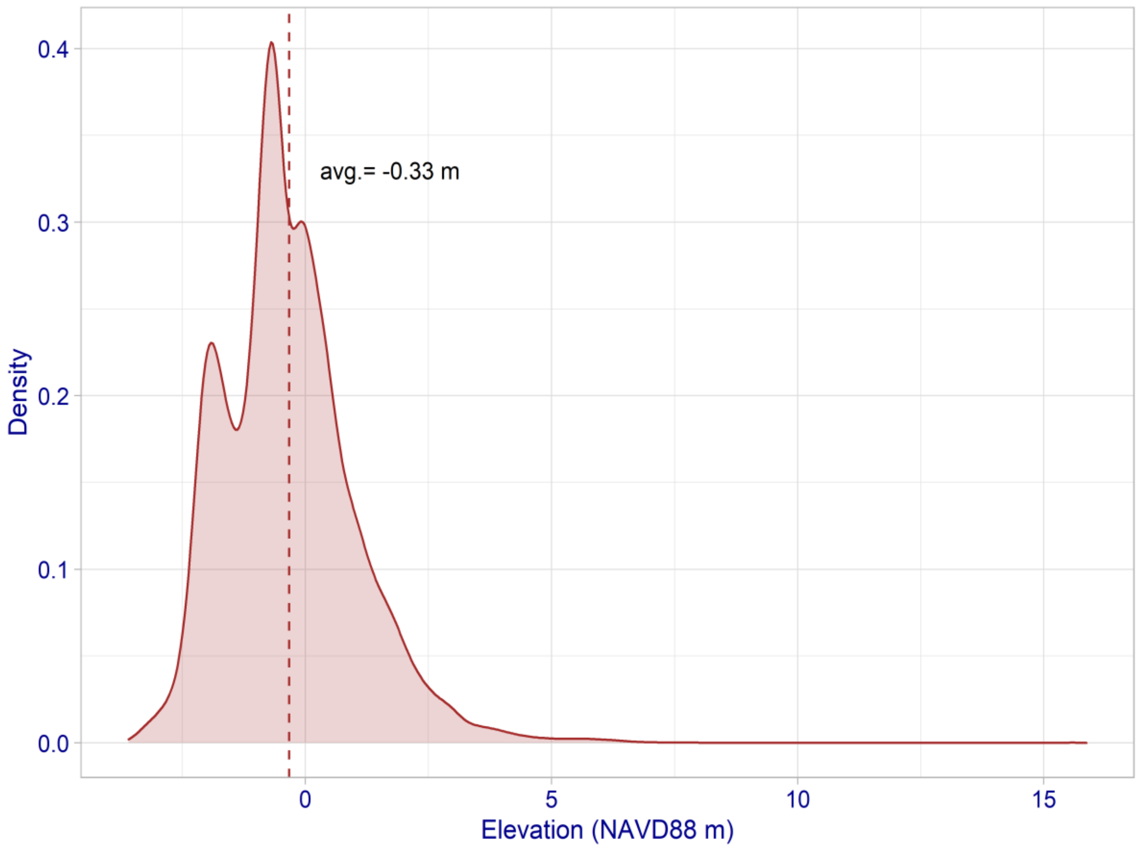


Figure 3.16: KSC Mosquito Lagoon Basin elevation density distribution.

The KSC Mosquito Lagoon bottom elevation averages -1.14 m and the watershed elevation averages 0.98 m (**Figure 3.17**).

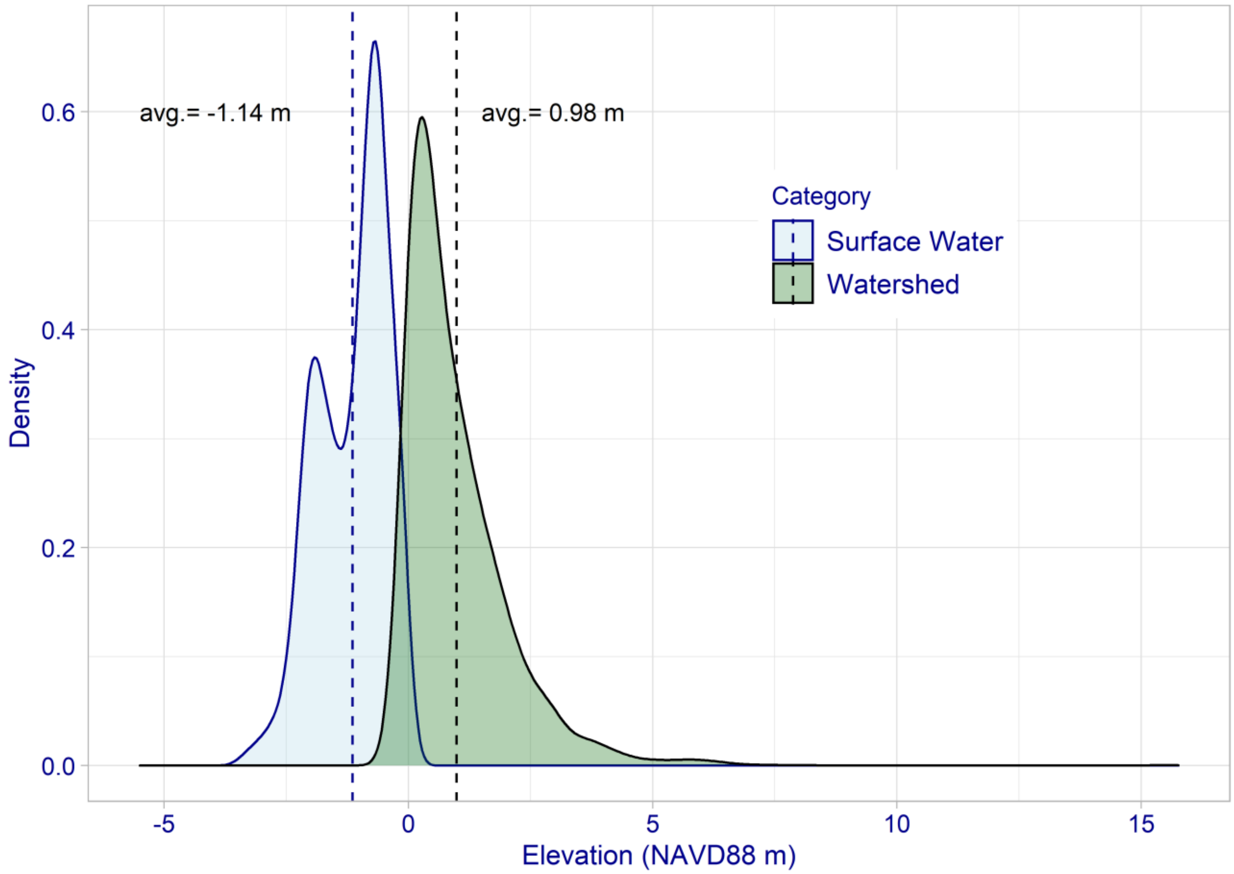


Figure 3.17: KSC Mosquito Lagoon Basin elevation (NAVD88 m) density distribution by watershed and waterbody.

(**Figure 3.18**) provides a visualization of the relative areas of the KSC portion of the basin, watershed and waterbody. The watershed to waterbody ratio is only 0.624 to 1 and the volume of the KSC portion of the lagoon is estimated at 11,705 ha m.

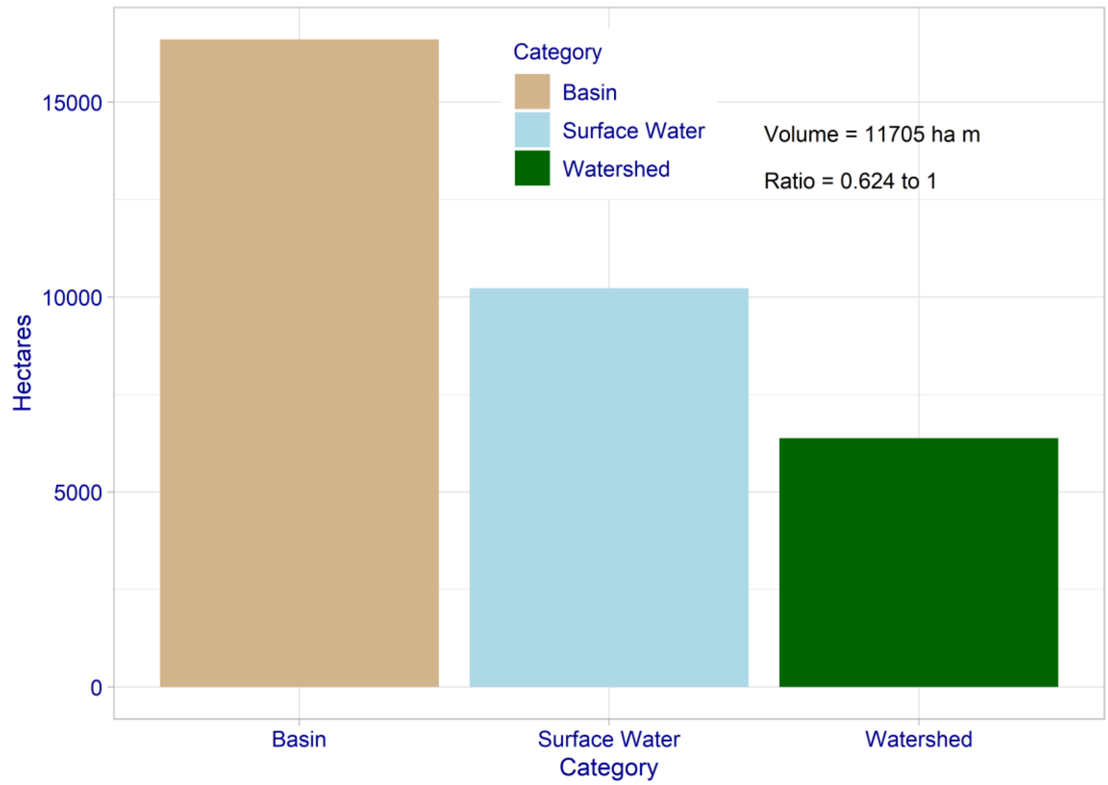


Figure 3.18: Relationship of KSC Mosquito Lagoon Basin component elevations, watershed to waterbody ratio, and waterbody volume (ha m).

4 Water Levels

4.1 Purpose

This section develops data descriptions and summary statistics on current baseline attributes of water levels on the CCBBIC between 1996 and 2020 utilizing several data sources including:

- Trident Pier NOAA station 8721604, 1966-2020.
  https://tidesandcurrents.noaa.gov/stationhome.html?id=8721604
- Haulover Canal USGS Haulover Canal station 02248380, 1966-2020
  https://waterdata.usgs.gov/nwis/inventory/?site_no=02248380&agency_cd=USGS
- Shallow groundwater wells in Tel-4 EMB Dates.
- Gravity Retrieval and Climate Experiment (GRACE and GRACE-Follow On) satellites JPL 2002-2020.
  https://grace.jpl.nasa.gov/data/get-data/

Water level data are presented for the Atlantic Ocean at Port Canaveral in the vicinity of KSC, the Indian River Lagoon system at Haulover Canal between the Indian River and Mosquito

Lagoon, the KSC surficial aquifer in the KSC Tel-4 region, and the open Atlantic Ocean adjacent to Cape Canaveral using the Grace/GRACE-FO Monthly Mass Grid 1165.

Current water level data collection sites are shown in (**Figure 4.1**). To address trends in sea level rise annual data are used to minimize influences of short term fluctuations such as tides and wind driven changes. Effects of infrequent high-water events are assessed by examining the mean of the top one or five percent of annual high-water events (99^{th} or 95^{th} quantile).

Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 4.1: Locations of surface water (Trident Pier and Haulover Canal), and water table (Tel-4) monitoring sites in the vicinity of Kennedy Space Center.

4.2 Surface Water

Summary statistics for the Trident Pier and Haulover Canal water level recordings between 1996 and 2020 are shown in (**Tables 4.1 and 4.2**). The mean difference between the ocean (-0.25 m) and lagoon (-0.17 m) was 0.08 m or about 3 inches. When looking at extreme events, the 1 percent of days each year with the highest water levels (99th quantile), the mean difference between the ocean (0.16 m) and lagoon (0.21 m) was 0.05 m or about 2 inches. The maximum daily average high water for Trident Pier occurred in 2019 (0.27 m) and the maximum for Haulover Canal occurred in 2017 (0.41 m). High water values in east central Florida are most often associated with low pressure windy tropical cyclone driven storm surges.

Table 4.1: Twenty-five-year annual trends and statistics for daily average water levels measured at the Trident Pier in Port Canaveral, 1996-2020.

Year	Number of Records	Mean Water Level (m)	Median Water Level (m)	Minimum Water Level (m)	Maximum Water Level (m)	99th quantile (m)	Standard Deviation (m)
1996	366	-0.36	-0.39	-0.63	0.15	0.01	0.14
1997	365	-0.30	-0.31	-0.56	-0.04	-0.09	0.10
1998	365	-0.33	-0.34	-0.60	-0.04	-0.11	0.11
1999	365	-0.25	-0.26	-0.53	0.35	0.14	0.14
2000	366	-0.27	-0.29	-0.55	0.09	0.05	0.13
2001	365	-0.30	-0.31	-0.58	0.20	0.11	0.14
2002	365	-0.28	-0.30	-0.56	0.21	0.05	0.14
2003	365	-0.31	-0.33	-0.59	0.14	0.07	0.15
2004	366	-0.32	-0.35	-0.56	0.47	0.13	0.14
2005	365	-0.24	-0.26	-0.58	0.17	0.13	0.14
2006	365	-0.30	-0.31	-0.61	0.02	-0.03	0.11
2007	365	-0.25	-0.27	-0.62	0.23	0.16	0.15
2008	366	-0.28	-0.30	-0.68	0.35	0.18	0.17
2009	365	-0.25	-0.27	-0.60	0.13	0.11	0.18
2010	365	-0.29	-0.31	-0.53	0.06	0.01	0.12
2011	365	-0.28	-0.31	-0.57	0.22	0.14	0.15
2012	366	-0.23	-0.24	-0.56	0.40	0.19	0.15
2013	365	-0.23	-0.25	-0.51	0.22	0.14	0.14
2014	365	-0.18	-0.18	-0.41	0.17	0.11	0.11

Year	Number of Records	Mean Water Level (m)	Median Water Level (m)	Minimum Water Level (m)	Maximum Water Level (m)	99th quantile (m)	Standard Deviation (m)
2015	365	-0.17	-0.19	-0.48	0.35	0.25	0.15
2016	366	-0.17	-0.19	-0.45	0.33	0.26	0.14
2017	365	-0.19	-0.23	-0.46	0.40	0.25	0.16
2018	365	-0.23	-0.24	-0.44	0.17	0.04	0.11
2019	365	-0.12	-0.16	-0.39	0.30	0.27	0.15
2020	366	-0.16	-0.18	-0.48	0.34	0.22	0.14
Total Data Set	9,132	-0.25	-0.27	-0.68	0.47	0.16	0.15

Descriptive statistics based on the NOAA Trident Pier station 8721604. Datum = NAVD88m.

Table 4.2: Twenty-five-year annual trends and statistics for daily average water levels measured at Haulover Canal, 1996-2020

Year	Number of Records	Mean Water Level (m)	Median Water Level (m)	Minimum Water Level (m)	Maximum Water Level (m)	99th quantile (m)	Standard Deviation (m)
1996	366	-0.24	-0.25	-0.55	0.22	0.05	0.11
1997	351	-0.19	-0.19	-0.38	0.01	-0.02	0.08
1998	352	-0.23	-0.24	-0.42	0.06	-0.03	0.09
1999	353	-0.16	-0.18	-0.36	0.29	0.19	0.13
2000	364	-0.19	-0.22	-0.43	0.12	0.08	0.12
2001	365	-0.20	-0.22	-0.46	0.21	0.18	0.14
2002	362	-0.18	-0.18	-0.41	0.09	0.06	0.12
2003	360	-0.21	-0.22	-0.51	0.11	0.06	0.12
2004	366	-0.23	-0.25	-0.54	0.21	0.11	0.13
2005	365	-0.16	-0.19	-0.40	0.26	0.19	0.13
2006	365	-0.24	-0.25	-0.44	0.00	-0.03	0.10
2007	365	-0.18	-0.20	-0.43	0.20	0.15	0.14
2008	359	-0.20	-0.24	-0.49	0.38	0.22	0.16
2009	357	-0.19	-0.16	-0.56	0.15	0.14	0.17
2010	365	-0.22	-0.23	-0.42	0.02	0.00	0.09
2011	346	-0.20	-0.22	-0.48	0.29	0.20	0.14
2012	366	-0.17	-0.17	-0.46	0.12	0.06	0.12

Year	Number of Records	Mean Water Level (m)	Median Water Level (m)	Minimum Water Level (m)	Maximum Water Level (m)	99th quantile (m)	Standard Deviation (m)
2013	362	-0.17	-0.20	-0.37	0.14	0.11	0.11
2014	348	-0.10	-0.12	-0.35	0.24	0.19	0.10
2015	346	-0.08	-0.12	-0.43	0.36	0.33	0.16
2016	366	-0.11	-0.11	-0.35	0.25	0.23	0.11
2017	364	-0.11	-0.14	-0.46	0.41	0.36	0.16
2018	365	-0.15	-0.14	-0.48	0.11	0.07	0.09
2019	361	-0.05	-0.06	-0.39	0.28	0.26	0.12
2020	366	-0.08	-0.10	-0.41	0.32	0.30	0.14
Total Data Set	9,005	-0.17	-0.18	-0.56	0.41	0.21	0.14

Descriptive statistics based on the Haulover Canal station 02248380. Datum = NAVD88m.

(**Figures 4.2 and 4.3**) display the water elevation data in box plot format showing the median, 25th and 75 quartiles and outliers for each year. Outliers are defined as 1.5 times the interquartile range. Outliers or extreme values are more common at the Atlantic Ocean site with most frequent occurrence July through October. The Haulover Canal data show more extreme values in August.

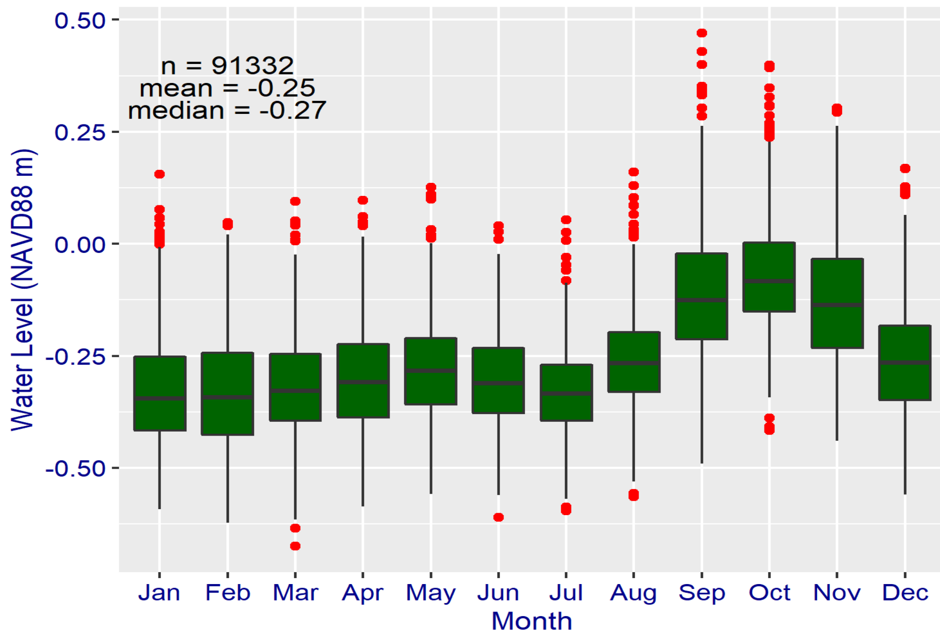


Figure 4.2: Box plot of annual daily average water elevation at Trident Pier, 1996-2020.

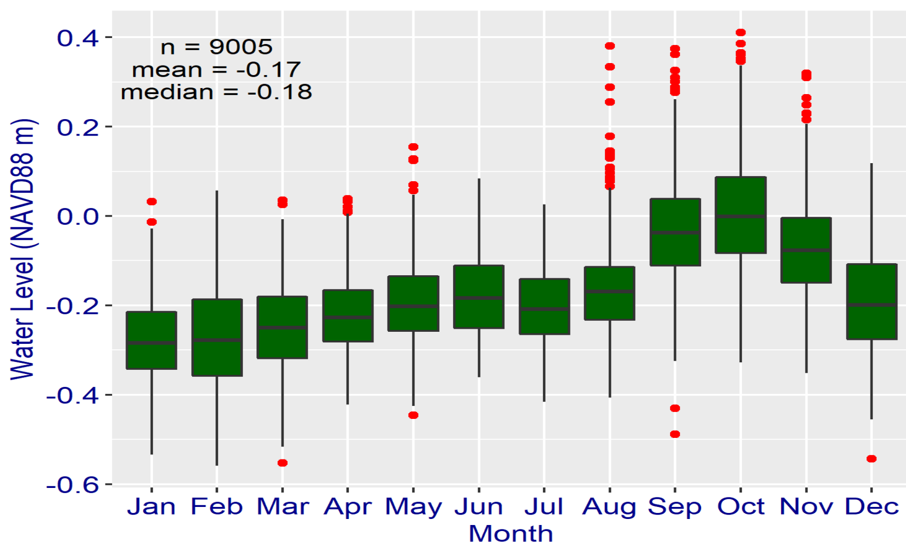


Figure 4.3: Box plot of annual daily average water elevation at Haulover Canal, 1996-2020.

(**Figure 4.4**) displays the 25-year trend in annual surface water elevations for the period 1996 through 2020. There is a high degree of correlation between trends in the Atlantic Ocean water levels and the lagoon water levels (r^2=0.93). Daily the Atlantic Ocean experience diurnal tides with some influence of wind speed and direction. In the CCBIC tidal influences are physically limited to areas near the passes. Wind driven circulation has the greatest influence on short term daily to weekly water levels near KSC. Between 1996 and 2020 the Atlantic Ocean and surrounding lagoons rose 2002 and 2020about 0.18 m or 7 inches.

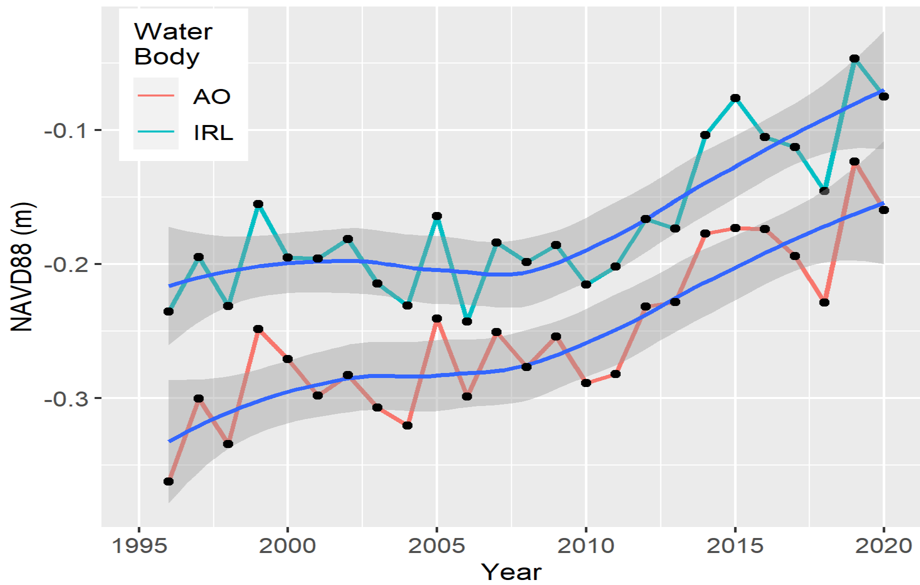


Figure 4.4: Twenty-five-year annual water level trends for the Atlantic Ocean and Indian River Lagoons near Kennedy Space Center.

As with the annual trend, the monthly lagoon water level is correlated to monthly patterns in sea level (**Figure 4.5**). Factors driving this pattern include seasonal thermal expansion and contraction, changing wind patterns, changing current speeds, and continental ice melt. Minimum water levels are observed January through July with maxima September to November.

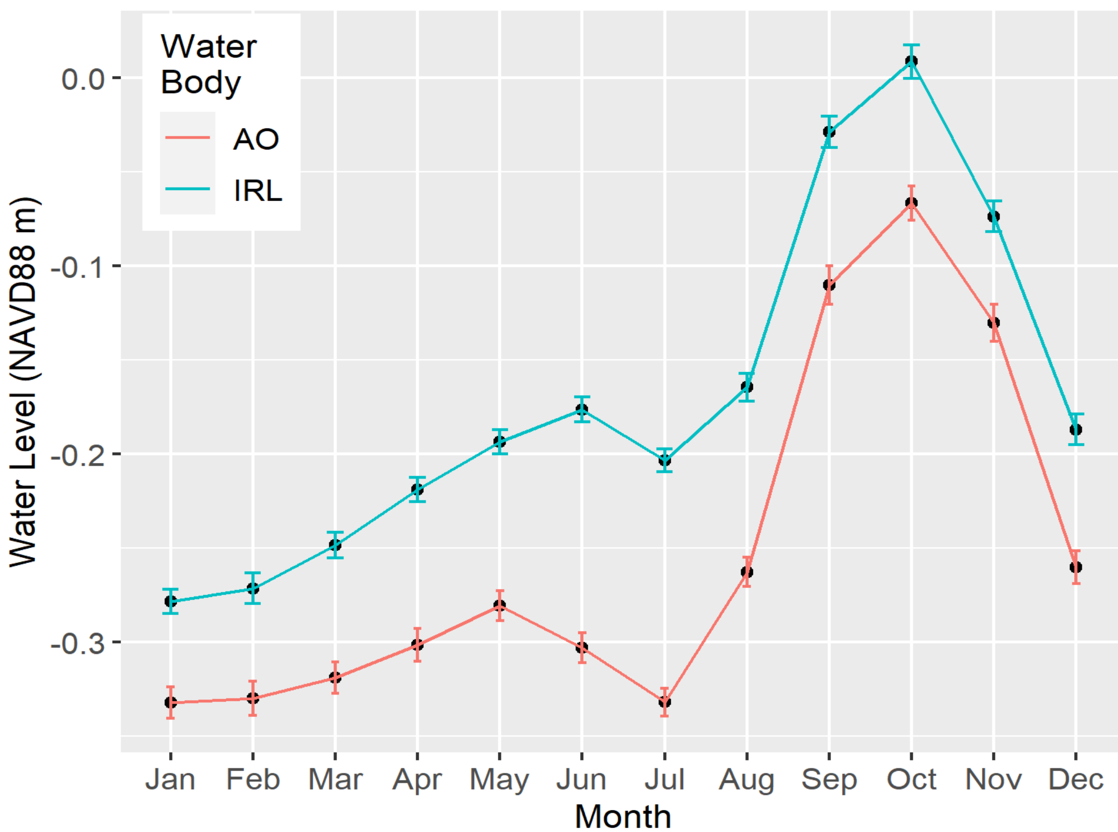


Figure 4.5: Monthly Atlantic Ocean and CCBIC Lagoon levels based on twenty-five years of data, 1996-2020.

(**Figure 4.6**) presents the Haulover Canal water elevation density distributions for two distinct 5-year periods, 1996-2000 and 2016-2020. These data suggest that changing climate is changing water elevation by altering the data distribution in a non-linear fashion. The lower 5th quantile has increased only .05 m, the median of the 5-year pooled distributions has increased by .1 m and the 95th quantile has increased by .16 m.

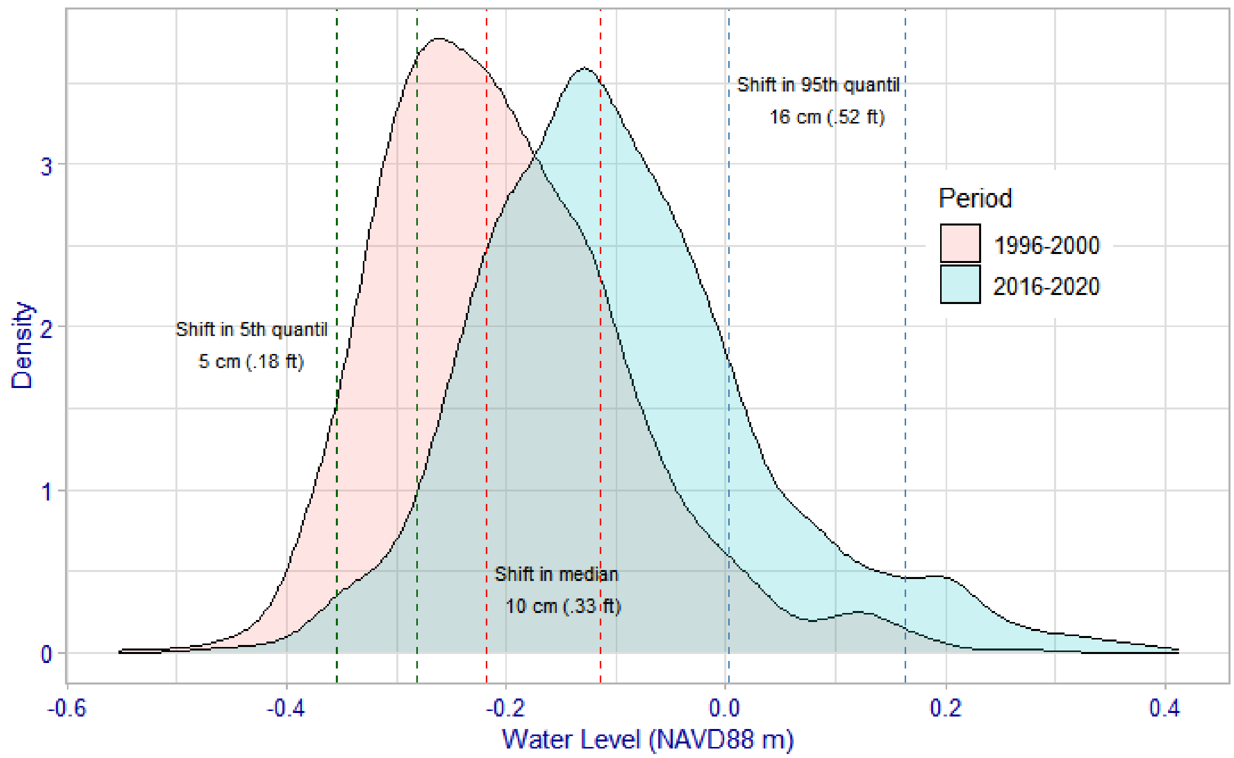


Figure 4.6: Cape Canaveral Barrier Island Complex (CCBIC) elevation (NAVD88 m) density distribution for two five-year periods, 1996-2000 and 2016-2020. The data distributions appear to be changing in a non-linear fashion.

4.3 Gravity Retrieval and Climate Experiment (GRACE)

The NASA and German Space Agency Gravity Retrieval and Climate Experiment (GRACE and GRACE-FO) satellites track the movement of water mass around the earth as it produces fluctuations in the gravity field. Results from 2002 to present are shown in (**Figure 4.7)** based on changing mass on the mascon grid cell 1165 located directly east of Cape Canaveral. Mass is expressed as cm of water and the open ocean increased about 5.9 cm (2.8 in) in that 19-year period. Which is 60% of the relative rise measured at the Trident Pier of 12 cm (4.7 in).

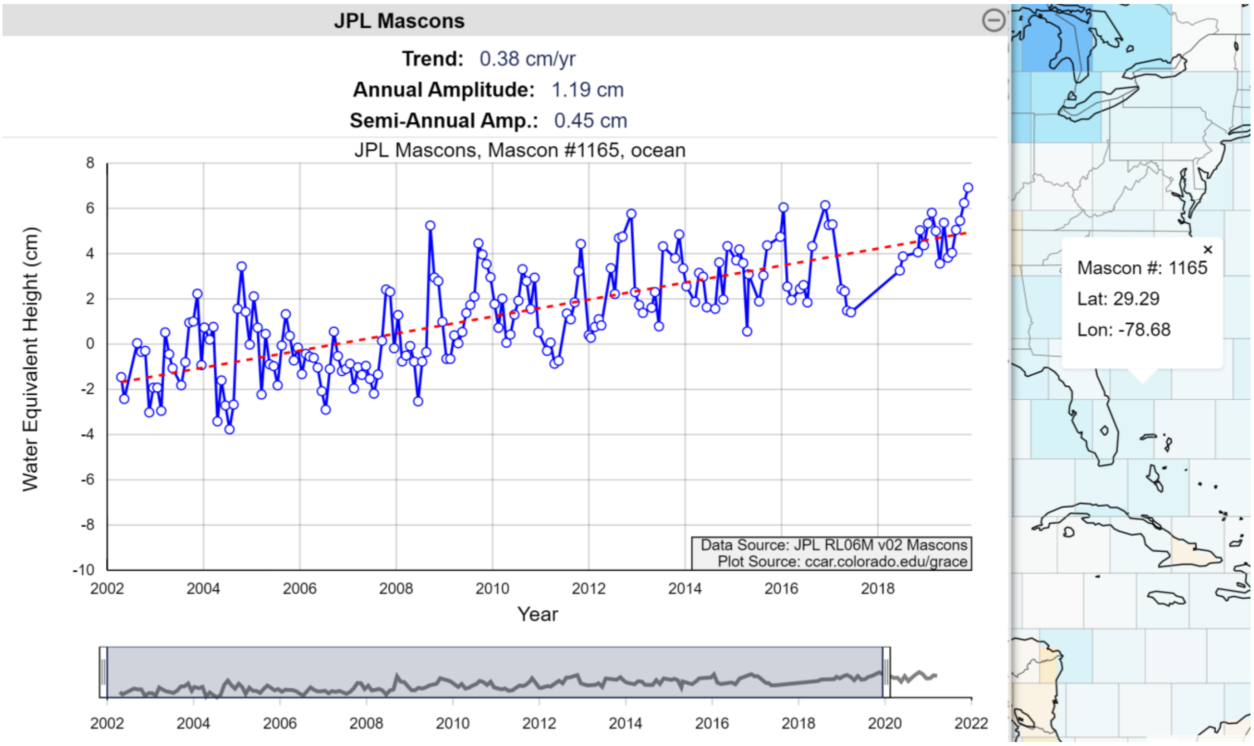


Figure 4.7: Gravity Retrieval and Climate Experiment (GRACE) sea level rise results for mascon 1165 located east of Cape Canaveral.

4.4 Surficial Aquifer

The surficial aquifer of the CCBIC and especially KSC and the barrier island systems represents a unique resource that influences plant community distributions in low lying and wetland areas, and the salinity and nutrient regimes of the regional waterbodies. Rainfall infiltration represents the primary water source to the surficial aquifer; however, upward leakage from the lower confined artesian aquifer has been reported but not spatially quantified (USGS). Results of monitoring depth to water table between 2010 and 2020 in the Tel-4 area are shown in (**Figure 4.8**). Minimum water levels are observed March through May and maximum water levels occur in September and October. These minimum and maximum periods correspond closely with patterns observed in seasonal rainfall data and the seasonal sea and lagoon levels.

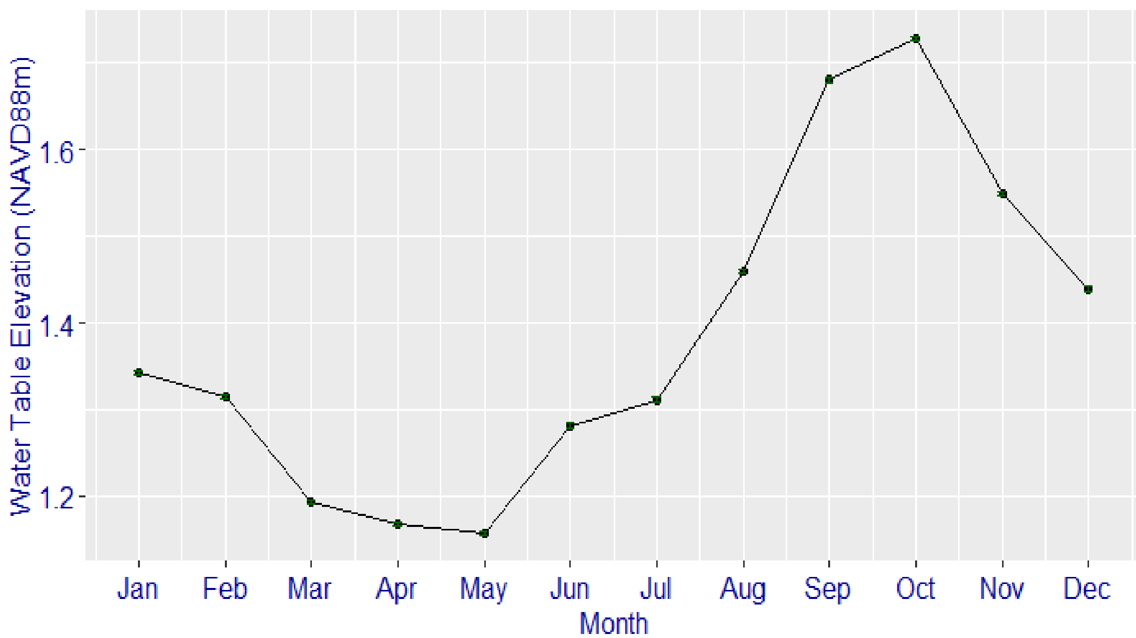
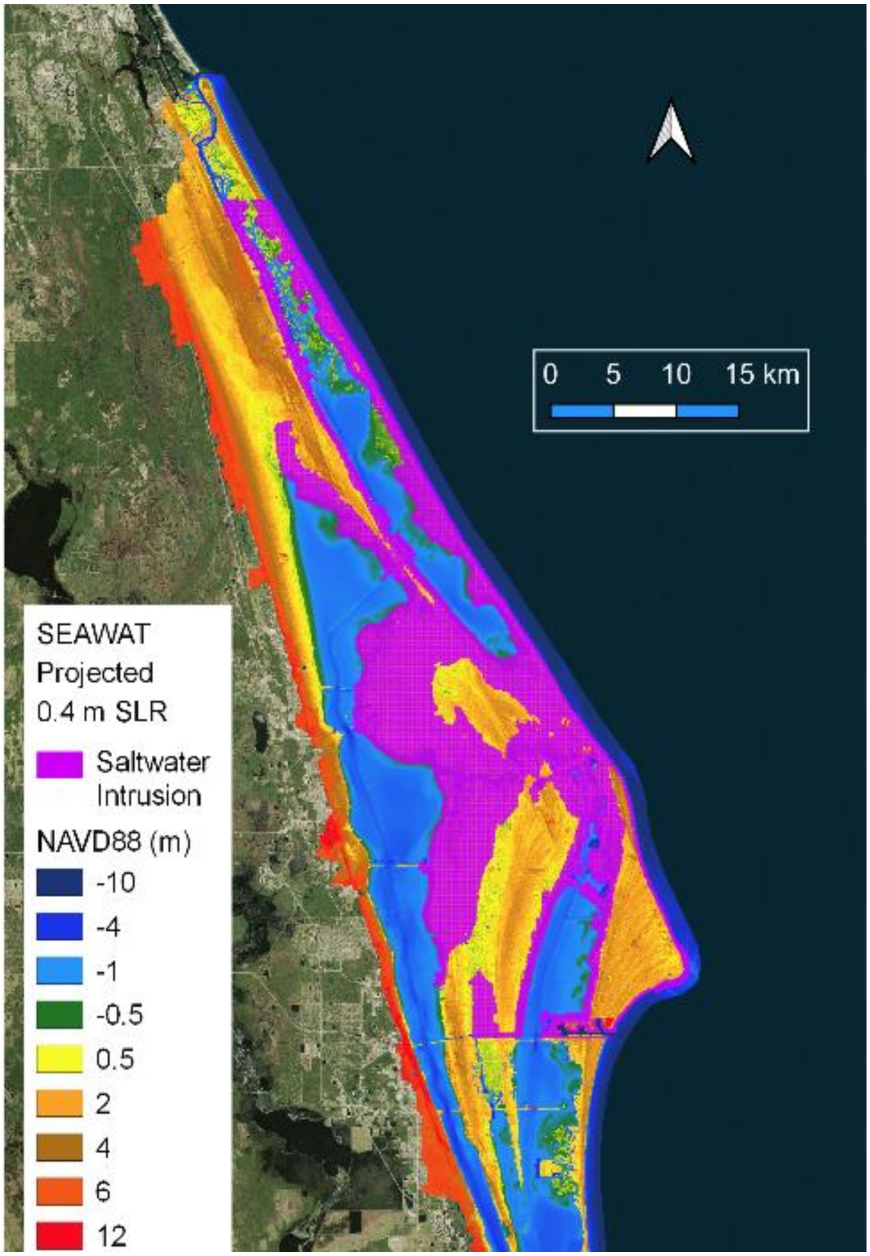


Figure 4.8: Monthly water table elevations for the surficial aquifer in the Tel-4 region of KSC.

As part of the NASA Headquarters Climate Adaptation Science Investigators (CASI) project, the University of Central Florida Coastal Hydroscience Analysis Modeling and Predictions (CHAMPS) lab conducted a surficial aquifer study to assess potential saltwater intrusion impacts associated with sea level rise and storm surges. Xiao et al. (2018) found a water table rise of 0.4 m can produce significant saltwater intrusion into the surficial aquifer as a result of both inundation and density equilibrium processes at the freshwater saltwater boundary (**Figure 4.9**).



Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 4.9: Simulated saltwater intrusion in the surficial aquifer based on a 0.4 m rise in lagoon water levels.

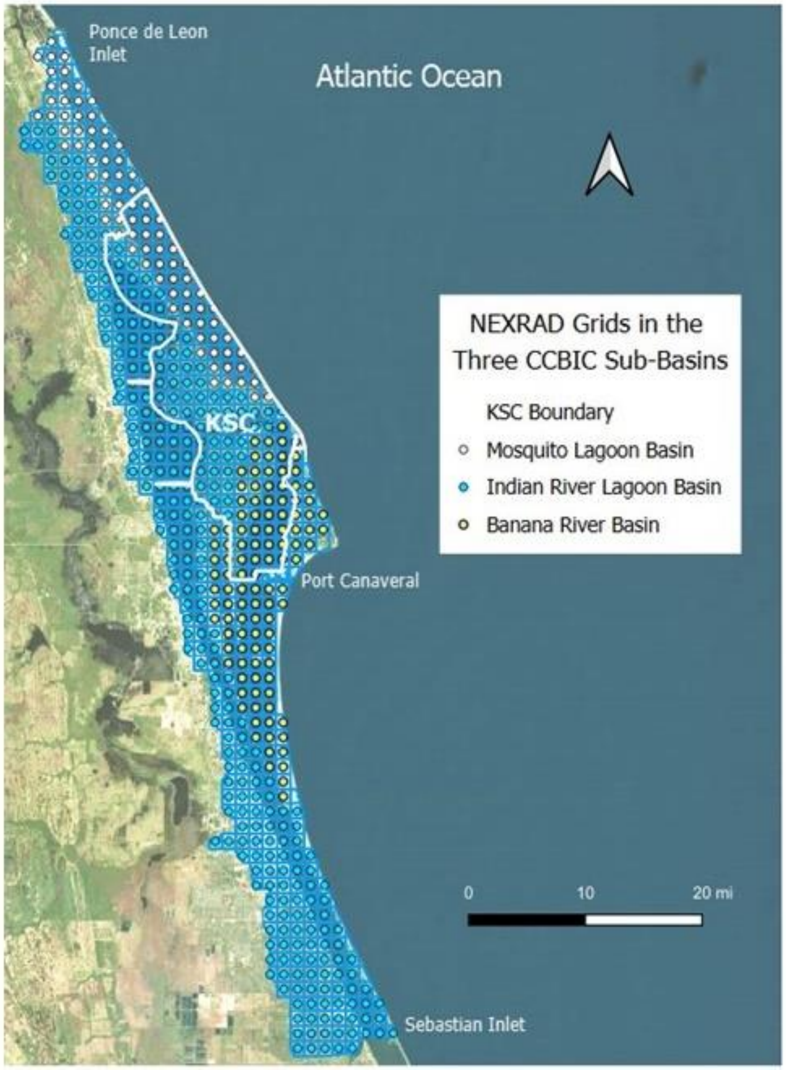
5 Rainfall

5.1 Purpose

This section develops data descriptions and summary statistics on current baseline attributes of rainfall on the CCBIC between 1996 and 2020 utilizing the NEXRAD derived gauge adjusted hourly rainfall data provided by the St. Johns River Water Management District. Unlike point gauges, this dataset gives full coverage of KSC and the entire basin utilizing a 2 km grid cell system. Data can be obtained from the Kennedy Long Term Ecological portal (https://kltep.ksc.nasa.gov/mettools/nexrad/nexrad.php) or the St. John River Water Management District site (http://webapub.sjrwmd.com/agws10/radrain/).

5.2 NEXRAD

A detailed discussion of the complexities and biases associated with measuring rainfall for use in hydrologic studies can be found in Sun et al. (2021) and a comprehensive comparison of NEXRAD data with gauge data can be found in Licata et al. (2009). Their assessment found NEXRAD data overestimates the volume of low rainfall (< 0.1 inch/hr) events and underestimates high rainfall events (>1.0 inch/hr). On average, NEXRAD produced results that were 95% of the calibrated gauge data. Variability was higher in the summer thunderstorm season than in the winter with broadly distributed frontal passage rainfall events. Tancreto (2004) conducted a runoff simulation study comparing the uses of NEXRAD rainfall data with interpolated rain gauge data and the HEC-HMS model to simulate USGS stream gauge runoff data from watersheds in the St. Johns River Basin. Generally, the NEXRAD data performed better than the interpolated data with improvement being attributed to better watershed spatial coverage. (**Figure 5.1**) displays the distribution of 528 NEXRAD grid cells across the CCBIC.



Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 5.1: Relationship of the NEXRAD grid to the Cape Canaveral Barrier Island Complex (CCBIC), the three associated sub-basins, Banana River, Indian River and Mosquito Lagoon and KSC on the east central Florida coast.

Each grid cell has a unique number that can be utilized to select rainfall data from the NEXRAD data base (**Figure 5.2**).

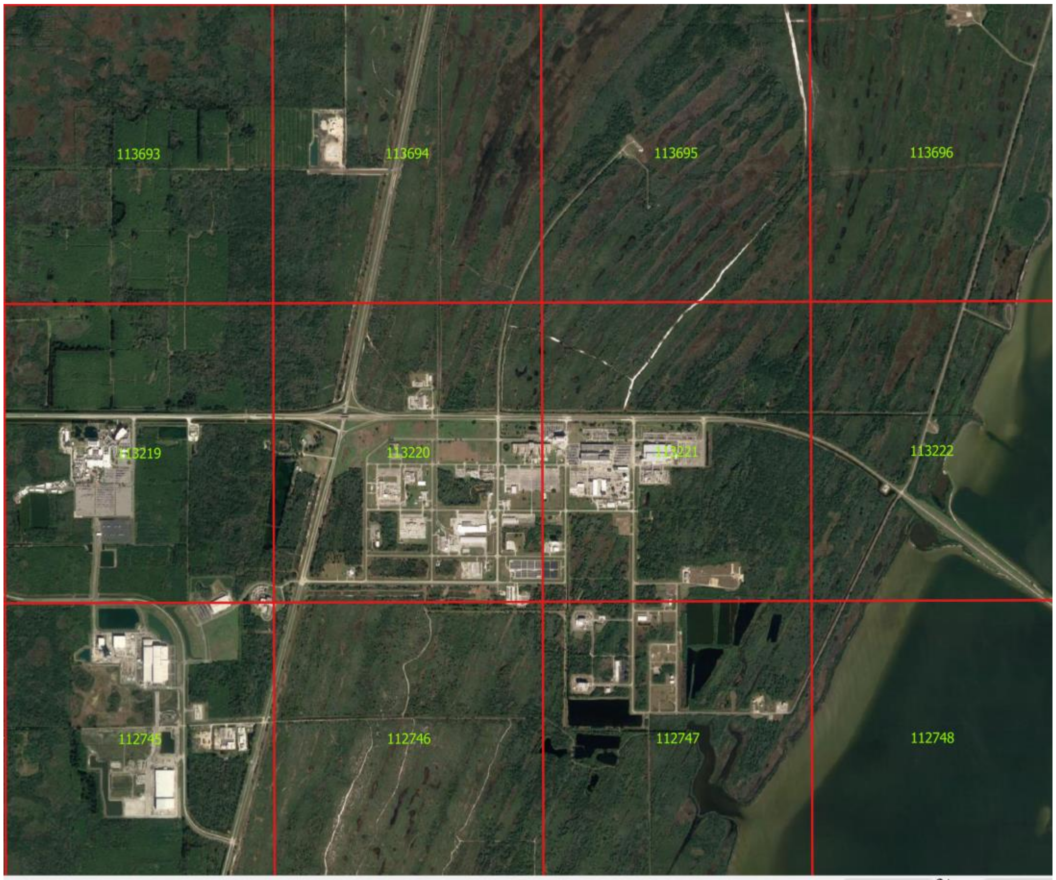


Figure 5.2: Examples of NEXRAD grid cells with identifying numbers covering the KSC Industrial area.

(**Table 5.1**) presents summary statistics by basin for the 25-year NEXRAD rainfall dataset. There are 528 grid cell centers that fall with the CCBIC boundary. Average annual rainfall was 46.19 inches. The minimum annual rainfall within the CCBIC basin was 19.13 inches and the maximum annual value was 139.96 inches.

Table 5.1: NEXRAD rainfall summary statistic for KSC and the basins of the Cape Canaveral Barrier Island Complex (CCBIC) 1996-2020.

Basin	NEXRAD Cells	Sample Size	Average Annual Rainfall (in)	Median Annual Rainfall (in)	Minimum Annual Rainfall (in)	Maximum Annual Rainfall(in)	Standard Deviation
Atlantic Ocean	9	225	43.95	43.32	22.41	119.45	11.45
Banana River	113	2,825	43.82	42.55	20.09	121.92	11.12
Indian River	317	7,925	47.47	47.26	20.07	139.96	10.68

Basin	NEXRAD Cells	Sample Size	Average Annual Rainfall (in)	Median Annual Rainfall (in)	Minimum Annual Rainfall (in)	Maximum Annual Rainfall(in)	Standard Deviation
Mosquito Lagoon	89	2,225	44.89	44.78	19.13	68.71	9.34
CCBIC	528	13,200	46.19	45.78	19.13	139.96	10.70
KSC	150	3,750	44.47	44.39	19.13	87.04	9.58

Descriptive statistics based on the St. Johns River Water Management District rain gauge adjusted NEXRAD data

Figure 5.3 shows a boxplot of the NEXRSAD data by year. Recall the dashed line represents the median, the box extends between the 25th and 75th percentile and the whiskers represent the 1st and 99th percentile. The outliers begin at ± 1.5 * inner quartile range. Of importance is the absence of an increasing trend in extreme events often predicted by climate change models. The driest year was 2000, the year Florida "Burned" and the wetest year was 2005.

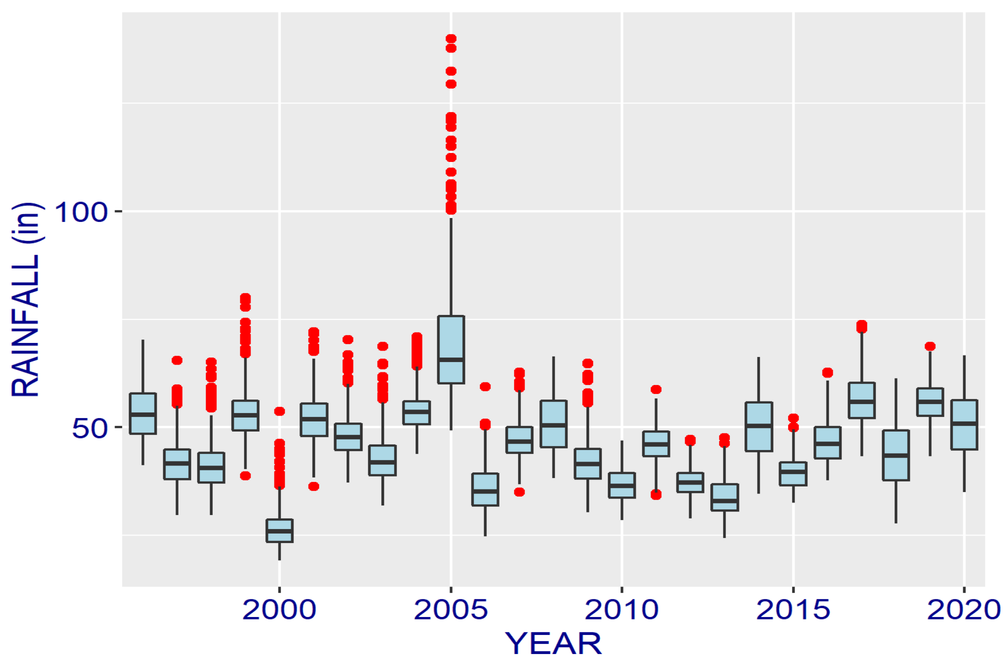


Figure 5.3: Box plot of Cape Canaveral Barrier Island Complex (CCBIC) NEXRAD rainfall (in) data by year across all 528 CELLS.

The NEXRAD annual rainfall density distributions for the 4 basin boundaries are shown in **Figure 5.4.** Based on the annually combined data set there appears to be a no differences between the basins.

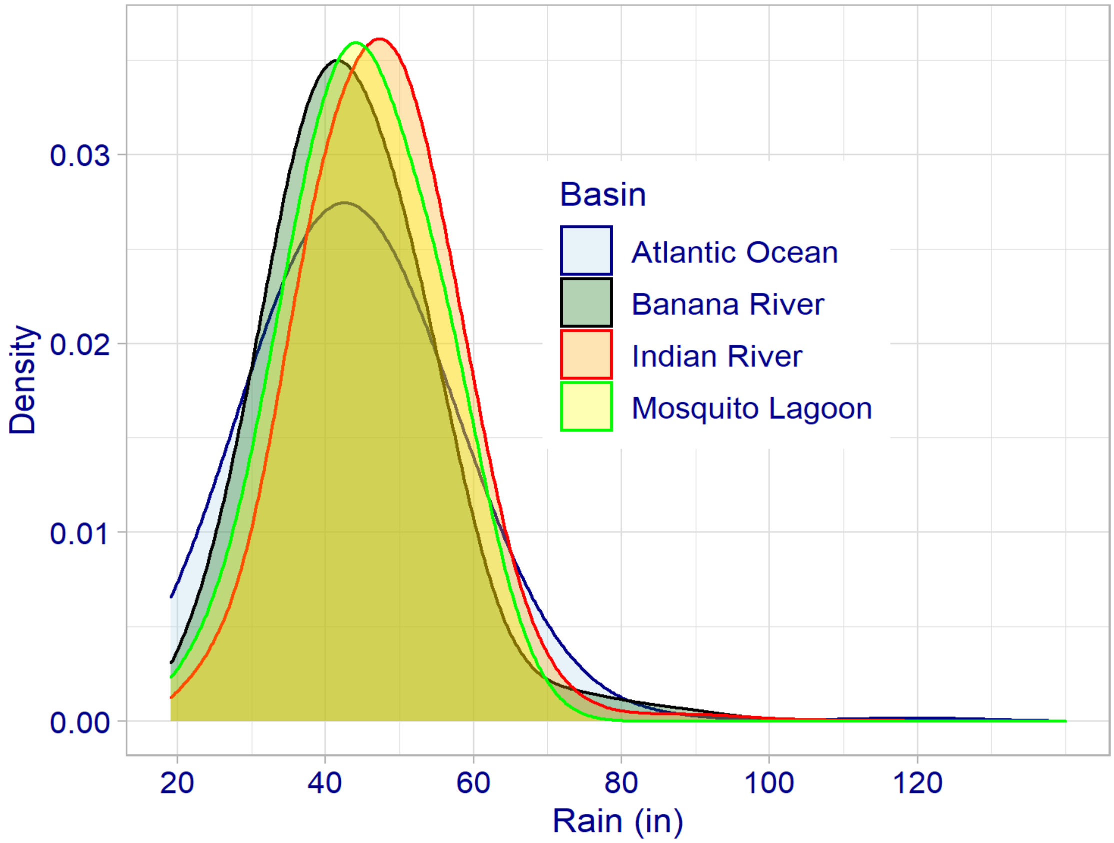


Figure 5.4: CCBIC basins annual NEXRAD rainfall density distributions.

(**Figure 5.5**) displays the temporal annual 25-year trends in rainfall between the 4 basins. The overall temporal pattens are very similar between the basins.

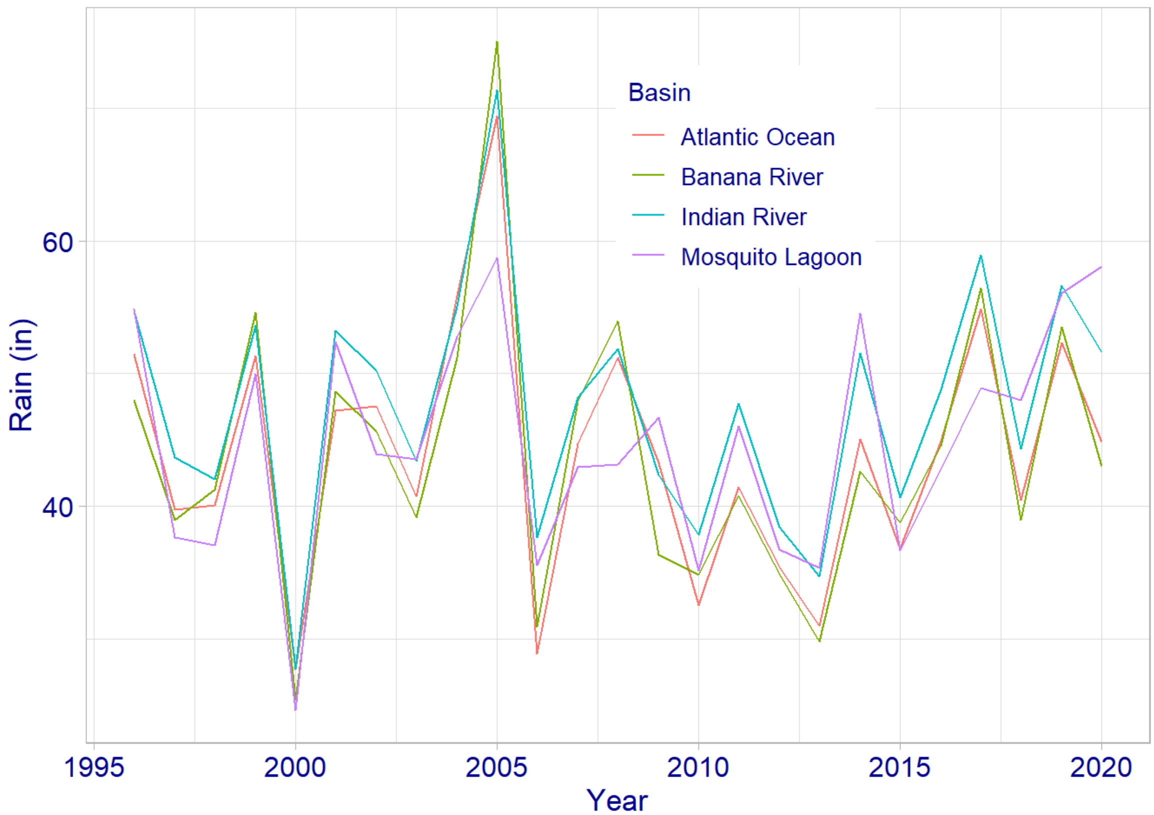


Figure 5.5: Temporal 25-year annual rainfall trends for the basins of the CCBIC.

To test the overall utility of the NEXRAD data, a comparison was made with the National Weather Service long-term rainfall gauge monitoring station in Titusville, Florida (**Figure 5.6**). The annual total rainfall from the gauge was compared to the annual total estimated for all the CCBIC grid cells and for only the grid cell (116056) that contained the station. The gauge data and NEXRAD data follow the annual pattern of rainfall closely; however, the gauge data averaged 9.8 % higher than the NEXRAD data from the grid cell overlapping the gauge station.

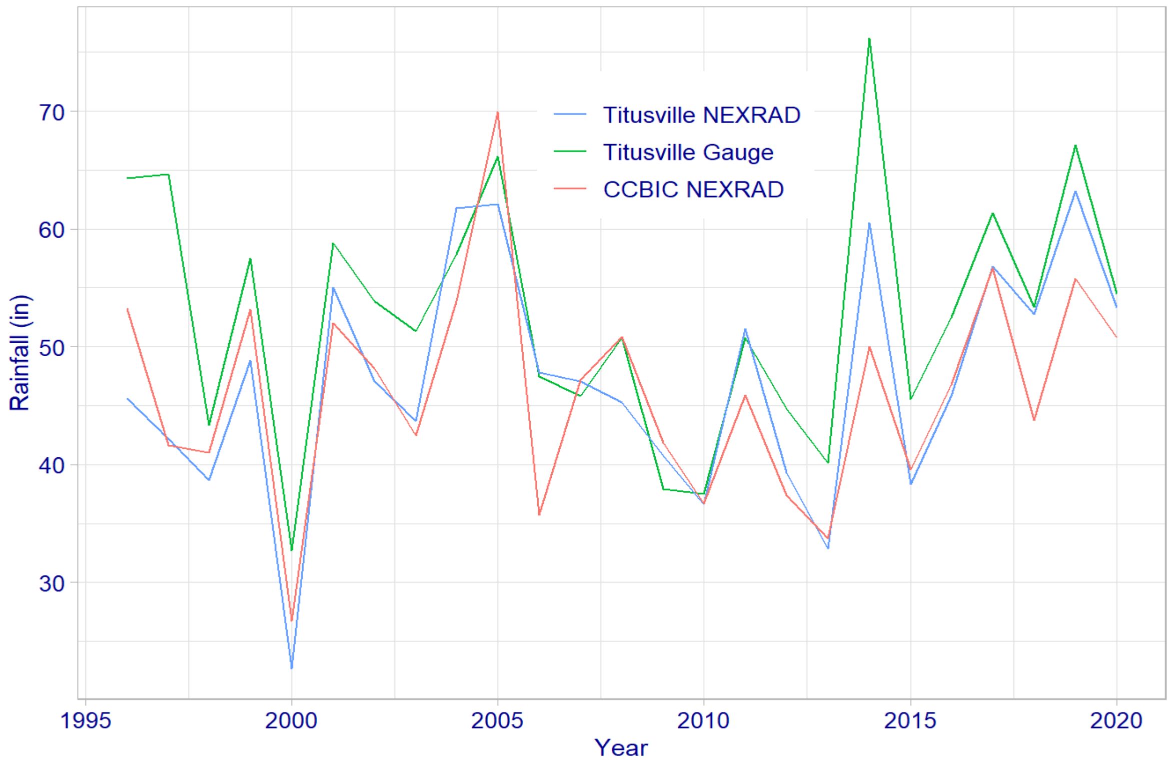


Figure 5.6: Comparison of the Titusville National Weather Service long-term rainfall gauge station with the NEXRAD estimated annual rainfall for the entire CCBIC and the grid cell that contains the Titusville rain station.

The monthly average total rainfall pattern with 95% confidence intervals is shown in (**Figure 5.7**) As previously observed (ERD 2020, Mailander 1990) regional rainfall displays an average monthly total minimum between 2-3 inches November through April transitioning in May to a 4 month period of average total maxima between 5 and 7 inches with a declining transition in the October time frame.

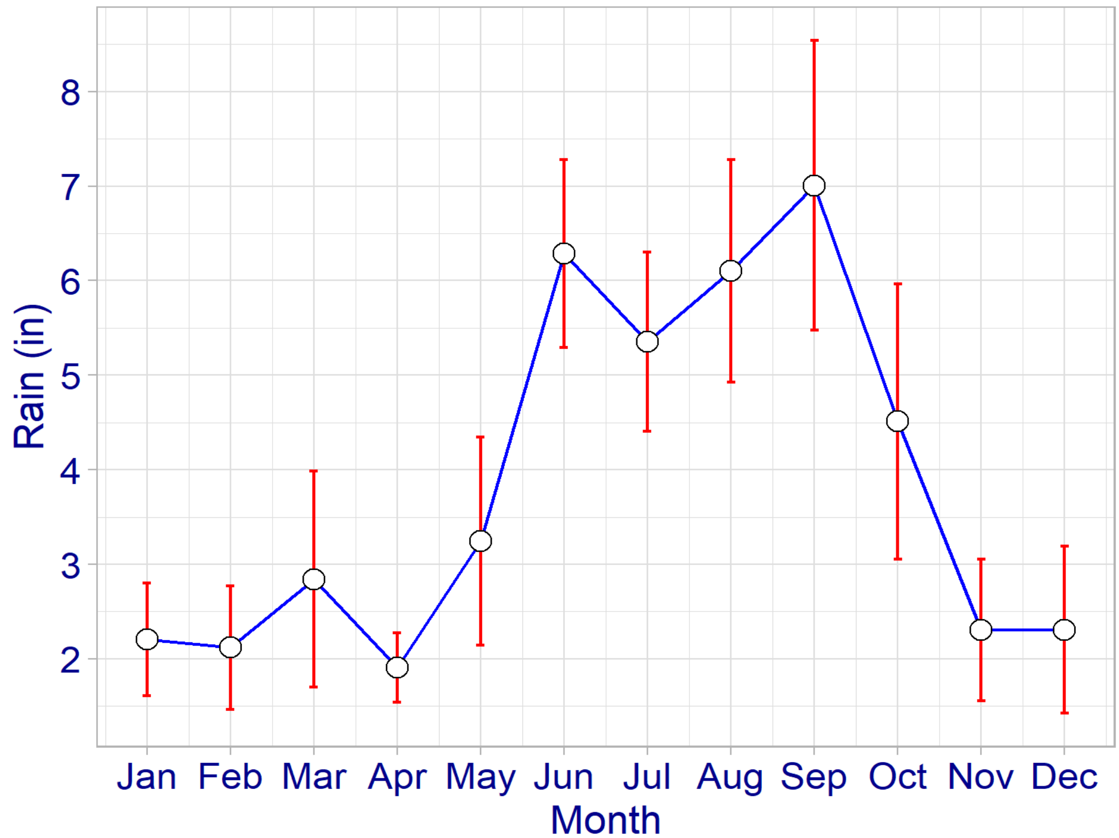
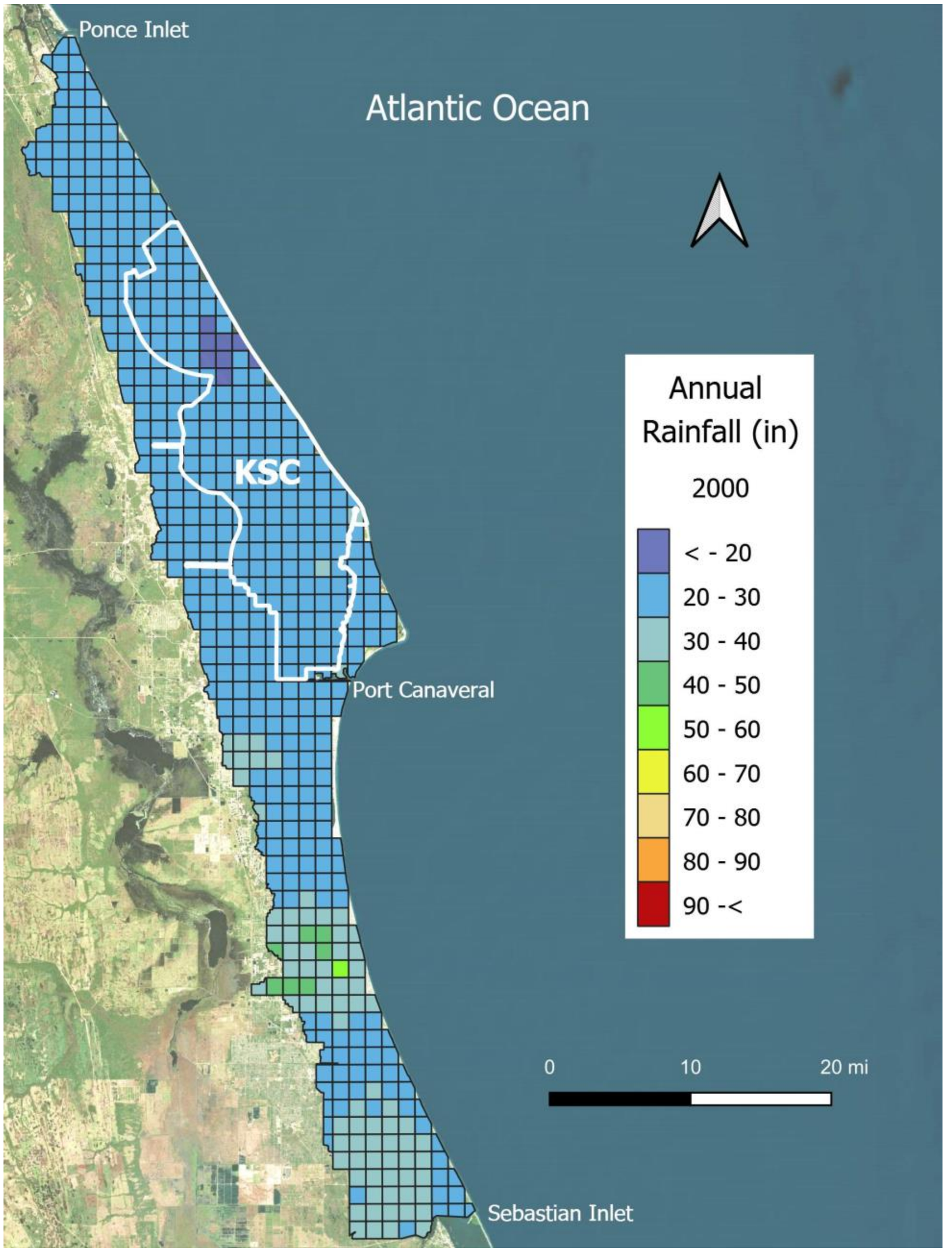


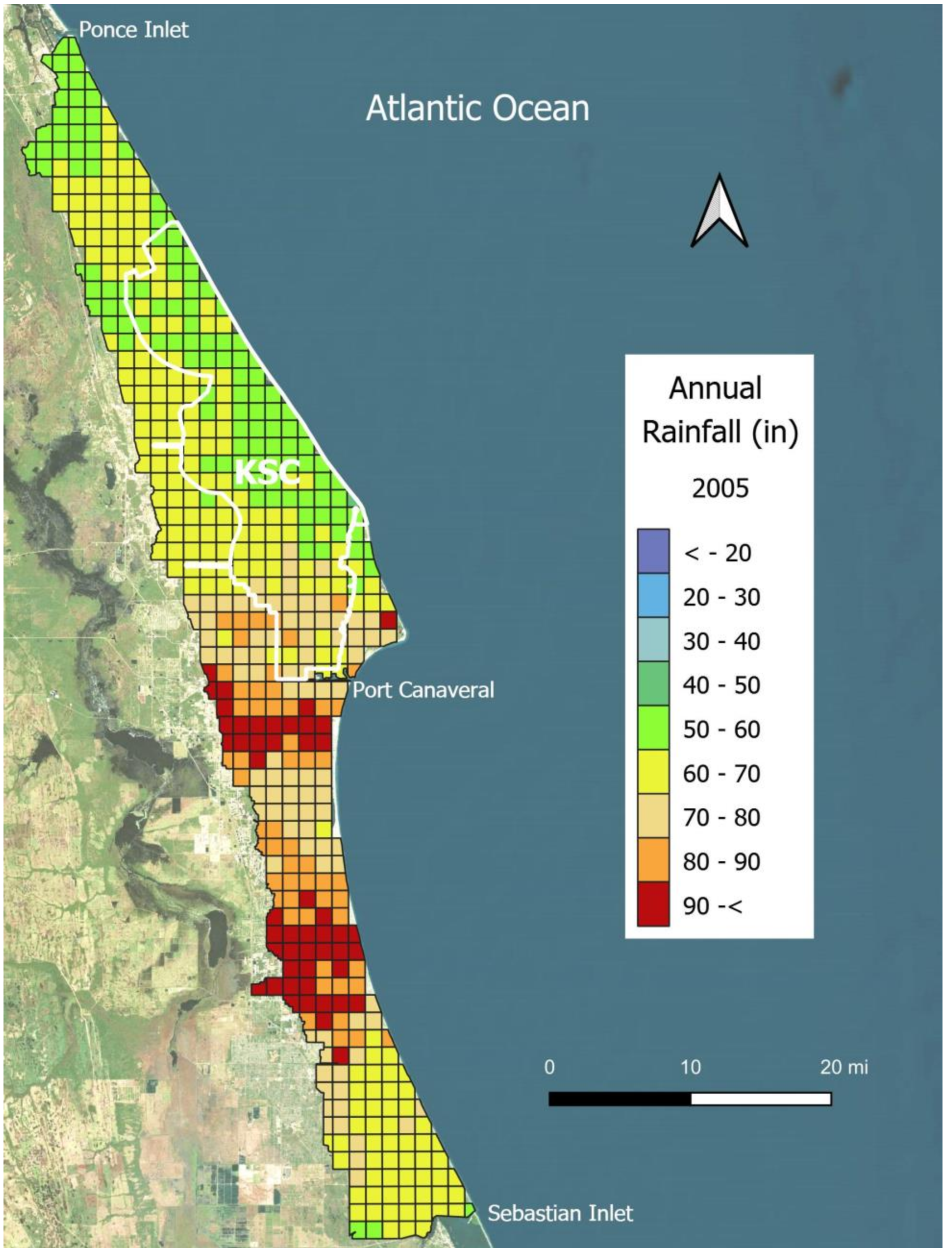
Figure 5.7: Monthly pattern of CCBIC NEXRAD average total rainfall data and 95% confidence intervals between 1996 and 2021.

Examples of the spatial distribution of annual rainfall across the CCBIC are shown in (**Figures 5.7 to 5.9**). These figures display the 2000 drought year, the 2005 extreme wet year and the 2020 year covering the range of spatial variability within the current data set.



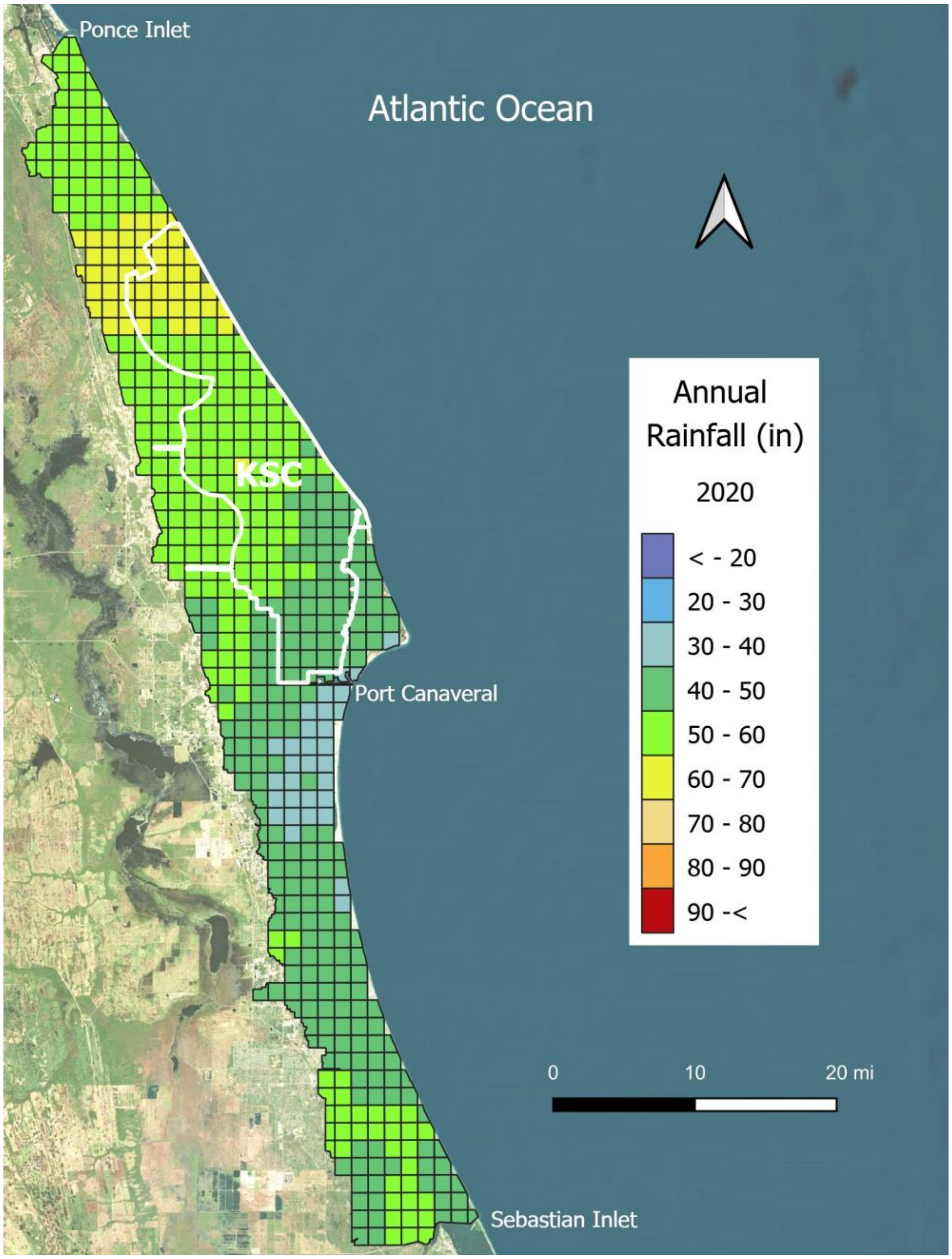
Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 5.7: Spatial distribution of NEXRAD measured total annual rainfall during the drought year of 2000.



Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 5.8: Spatial distribution of NEXRAD measured total annual rainfall during the extreme wet year of 2005.



Source: @2021 Microsoft Bing Virtual Earth, Earthstar Geographic SIO

Figure 5.9. Spatial distribution of NEXRAD measured total annual rainfall during the moderate rainfall year of 2020.

To see a movie displaying the annual spatial rainfall pattern for the CCBIC and KSC between 1996 and 2020 double click on the icon below. To pause, slowdown or speed up the movie place the cursor on the movie application window to raise the tool bar.

CCBIC and KSC NEXRAD RAINFALL 1996-2020.mp4

6 Evapotranspiration

6.1 Purpose

This section provides a brief overview of the USGS Caribbean-Florida Water Science Center (CFWSC) regional reference evapotranspiration (RET) and potential evapotranspiration (PET) data that covers the CCBIC and KSC. The data for 1985 – 2020 can be downloaded from https://www.usgs.gov/centers/car-fl-water/science/reference-and-potential-evapotranspiration?qt-science_center_objects=0#qt-science_center_objects.

6.2 Data Processing

Mecikalski et al. (2018) provide a description of how they utilized the GOES satellite estimates of solar insolation, RET, and PET to compute a 2-km resolution daily model for the State of Florida (**Figure 6.1**).

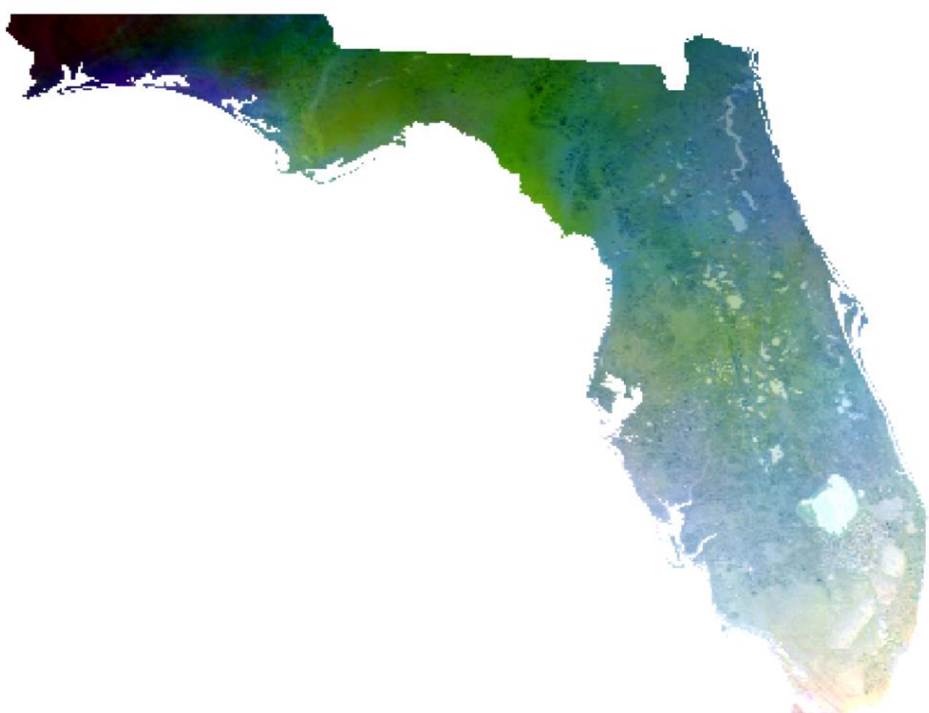


Figure 6.1: Example of the USGS Caribbean-Florida Water Science Center reference evapotranspiration (RET) and potential evapotranspiration (PET) download for the State of

Florida, 2020 (https://www.usgs.gov/centers/car-fl-water/science/reference-and-potential-evapotranspiration?qt-science_center_objects=0#qt-science_center_objects).

The USGS data include the parameters shown in (**Tale 6.1**).

Table 6.1: Data types in each annual file available from the USGS Caribbean-Florida Water Science Center.

Column	Definition
date	Date data representation
latitude	Latitude of Pixel value
longitude	Longitude of Pixel value
pixel	Pixel ID number
PET	Potential ET (mm/day)
RET	Reference ET (mm/day)
solar	Solar Radiation - Daily Insolation (MegaJoules/sq meter/day)
RHmax	Maximum Relative Humidity for day (%)
RHmin	Minimum Relative Humidity for day (%)
Tmax	Maximum Temperature for day (C)
Tmin	Minimum Temperature for day (C)
Win	Wind Speed (meters/second)

Using these data in conjunction with the data in (**Table 6.2**) the actual monthly ET (AET) value for different land cover types can be calculated for use with ecological and hydrologic models.

Table 6.2: Monthly actual (AET) to reference (RET) ratios for several land-cover types in east-central Florida basins.

Month	Forest	Grass	Marsh	Water	Ridge	Urban	Agriculture
January	0.7616	0.6356	0.7790	0.9335	0.4523	0.7584	0.7790
February	0.7442	0.6453	0.8604	0.9550	0.4762	0.6936	0.8604
March	0.7542	0.6264	0.9619	1.0278	0.5282	0.5915	0.9619
April	0.6736	0.6465	0.9294	1.0543	0.5519	0.5385	0.9294
May	0.6699	0.4590	0.9692	1.0744	0.6194	0.5419	0.9692
June	0.6258	0.6434	1.0208	1.1016	0.7832	0.6741	1.0208
July	0.7640	0.8365	0.9701	1.1195	0.7889	0.6920	0.9701
August	0.8309	0.8846	0.9504	1.1760	0.8186	0.7423	0.9504
September	0.8142	0.9241	0.9268	1.1415	0.7334	0.6680	0.9268
October	0.8434	0.8481	0.9769	1.1469	0.6250	0.7302	0.9769
November	0.9187	0.7769	0.8902	1.0970	0.4891	0.7424	0.8902

Month	Forest	Grass	Marsh	Water	Ridge	Urban	Agriculture
December	0.7764	0.7503	0.7937	1.0420	0.5272	0.7476	0.7937

Source: Sepulveda (2018).

7 Infrastructure and Management

7.1 Purpose

This section provides a brief discussion of hydrologic infrastructure and hydrologic management actions supporting of surface water permitting, flood control, and natural resource management.

7.2 Overview

Hydrologic infrastructure of the CCBIC includes, ditches, canals, retention and detention ponds, sewage treatment facilities, storm drains, settling boxes, managed wetlands and other approaches to control volume, flow rates, and water quality for beneficial reasons. The Florida Department of Environmental Protection (DEP), the St. Johns River Water Management District, county and municipal governments, natural resource managers, not-for-profit organizations and private citizen groups are all involved. The DEP oversees the holistic Total Maximum Daily Loads (TMDL) Program utilizing the following steps as described in https://floridadep.gov/dear/water-quality-evaluation-tmdl/content/total-maximum-daily-loads-tmdl-program:

1. Assess the quality of surface waters-are they meeting water quality standards? (Surface Water Quality Standards - Chapter 62-302)

2. Determine which waters are impaired-that is, which ones are not meeting water quality standards for a particular pollutant or pollutants. (Impaired Waters Rule (IWR) - Chapter 62-303)

3. Establish and adopt, by rule, a TMDL for each impaired water for the pollutants of concern-the ones causing the water quality problems. (TMDLs - Chapter 62-304)

4. Develop, with extensive local stakeholder input, Basin Management Action Plans (BMAPs) that....

    a. Implement the strategies and actions in the BMAP

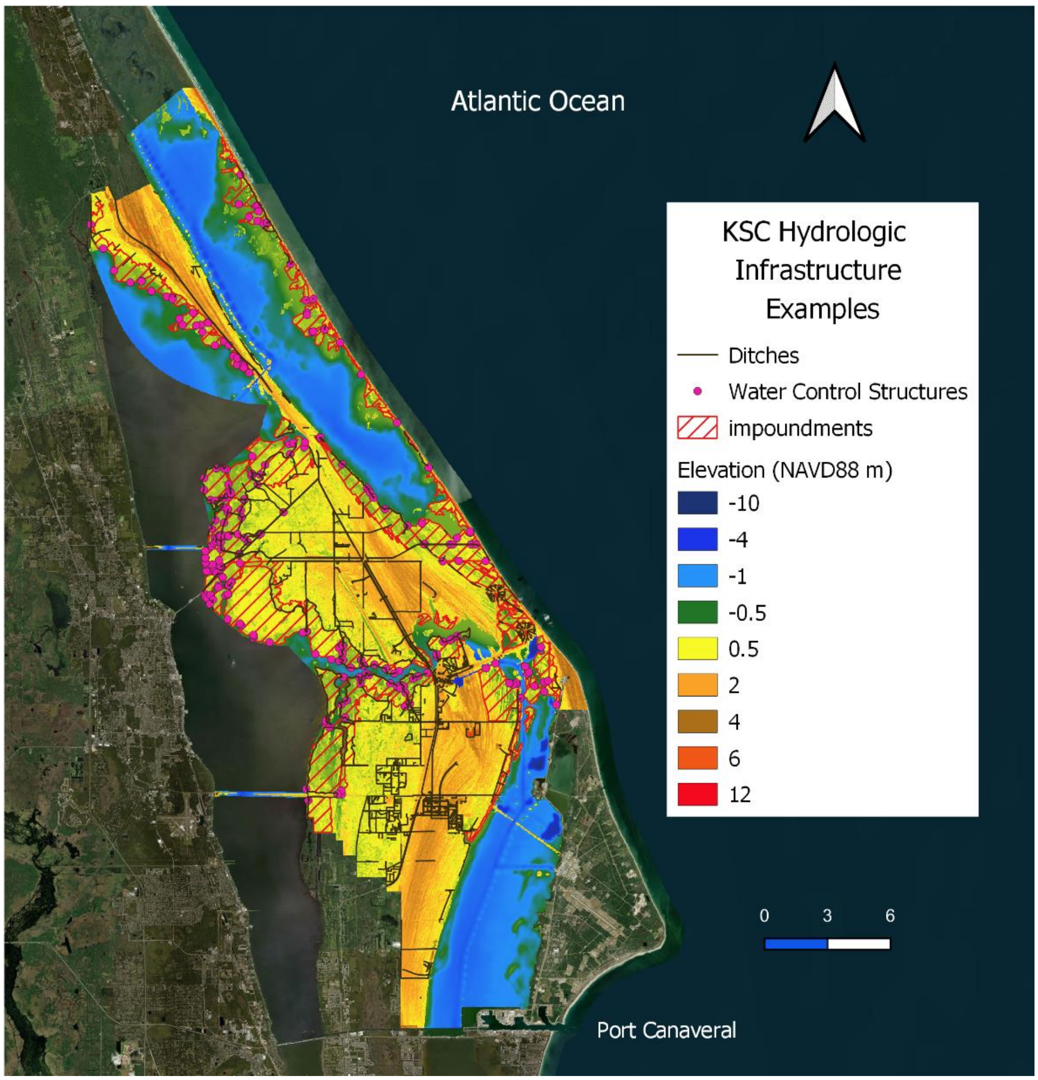
    b. Measure the effectiveness of the BMAP, both continuously at the local level and through a formal re-evaluation every five years.

    c. Adapt-change the plan and change the actions if things aren't working

    d. Reassess the quality of surface waters continuously

Detailed discussions of the KSC surface water permitting and management and groundwater remediation activities can be found in (ERD 2020).

(Figure 7.1) shows the general distribution of hydrologic infrastructure across KSC and their locations relative to land elevation and the Banana River, Indian River and Mosquito Lagoon. Included are stormwater ditches, culverts, detention basins, impoundments, and water control structures. A more detailed view is shown in a closeup of the LC39 area near the Turning Basin **(Figure 7.2)** Rising water tables and possibly more frequent storms and intense rainfall events projected for a changing climate will impact maintenance cost and operational performance associated with this infrastructure.



Source: ESRI, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 7.1: Spatial distribution of the hydrologic infrastructure within the KSC boundary and relationships to the Banana River, Indian River, and Mosquito Lagoon.

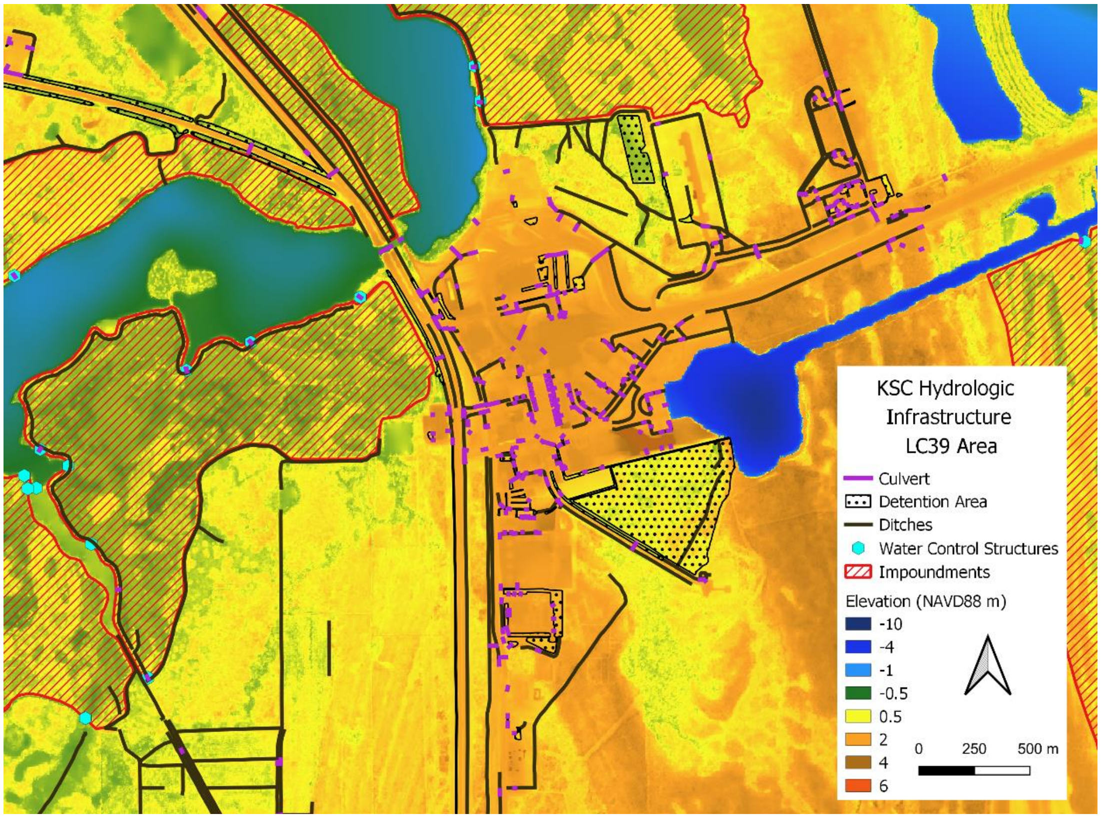


Figure 7.2: Hydrologic infrastructure in the LC39 area utilized to manage stormwater, water quality, and wildlife habitat. Note the large number of culverts to support movement of water off the impervious surfaces associated with buildings, parking lots and roads.

8 Climate

8.1 Purpose

This section provides a summary of projected climate trends for the CCBIC and KSC. The KSC ERD (ERD 2020) provides more detailed information.

8.2 Projections

Comprehensive reviews of the science, modeling, forecast, risks, adaptation, and sustainability needs can be found in the U. S. National Climate Assessment (https://nca2018.globalchange.gov/) and the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (https://www.ipcc.ch/assessment-report/ar6/). In a warming planet, the CCBIC and KSC will transition deeper into the sub-tropical and away from the temperate zoogeographic province. Projected trends based on literature and the downscaled forecast for KSC provided by the Goddard Institute for Space Studies based on modeling performed as part of the World Climate Institute Climate Model Inter Comparison Project (CMIP-3) are summarized in (**Table 8.1**).

Table 8.1: Summary of projected climate change forecast for the CCBIC and KSC.

Climate Feature	**Projected Change**
Warm temperatures	Increase in the number of days above 90 °F
Cool temperatures	Reduction in the number of days below 40 °F with fewer less intense periods of freezing temperatures
Rainfall	Possibly fewer events but more intense due to increasing atmospheric moisture with warming temperatures
Evapotranspiration	Increasing with warming temperatures and longer growing seasons
Tropical Storms	Increasing frequency and intensity possible
Water Tables (sea level, lagoon level, surficial aquifer)	Continuing to rise, rate dependent on ice melt, changing ocean currents, and increased rainfall potential.
Water Management (wetlands, stormwater, saltwater intrusion)	More complex due to more intense rainfall, storm surge, control system inundation

(Table 8.2 and Figure 8.1) present results of the USACOE Sea-Level Change Curve Calculator (Version 2021.12) for relative sea level rise at the Trident Pier NOAA station (Sea-Level Curve Calculator (army.mil)). Based on examination of the water level curve fitted polynomial shown for the Trident Pier mean sea level **(Figure 4.4).** Water level shave risen .14 m between 200 and 2020 indicating the region is firmly on the NOAA 2017 intermediate trajectory for relative sea level change.

Table 8.2: Data for the Trident Pier relative sea level change scenarios based on the NOAA et al. 2017 methodology.

All values are expressed in meters

Year	NOAA2017 VLM	NOAA2017 Low	NOAA2017 Int-Low	NOAA2017 Intermediate	NOAA2017 Int-High	NOAA2017 High	NOAA2017 Extreme
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.03	0.04	0.07	0.09	0.10	0.11
2020	0.00	0.07	0.09	0.14	0.18	0.21	0.23
2030	0.01	0.12	0.15	0.22	0.31	0.38	0.42
2040	0.01	0.16	0.20	0.31	0.43	0.55	0.63
2050	0.01	0.20	0.25	0.41	0.60	0.78	0.91
2060	0.01	0.24	0.31	0.53	0.78	1.04	1.25
2070	0.02	0.29	0.37	0.67	1.00	1.36	1.64
2080	0.02	0.32	0.42	0.81	1.25	1.73	2.10
2090	0.02	0.35	0.46	0.96	1.52	2.11	2.60
2100	0.02	0.37	0.51	1.13	1.83	2.58	3.18

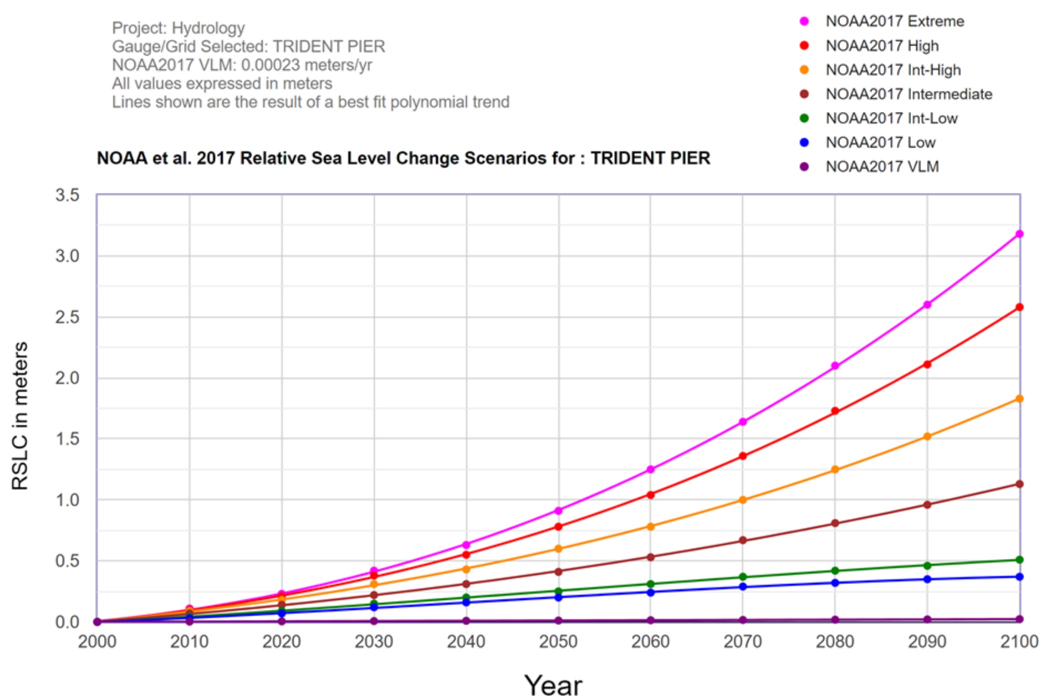


Figure 8.1: Plots of the Trident Pier relative sea level change calculations for the period 2000 to 2100.

The Ecological Monitoring team developed an ArcGIS based water level rise (bathtub) model as part of the NASA Headquarters funded CASI project in 2014. (**Figure 8.2**) shows the area of KSC that, will potentially be inundated by a water level rise of 1 m with a starting basis elevation of -0.23 m NAVD88 in the year 2000. This figure does not include any of the dynamic factors influencing shoreline locations such as erosion, marsh accretion, or man-made projects to protect facilities or habitats.

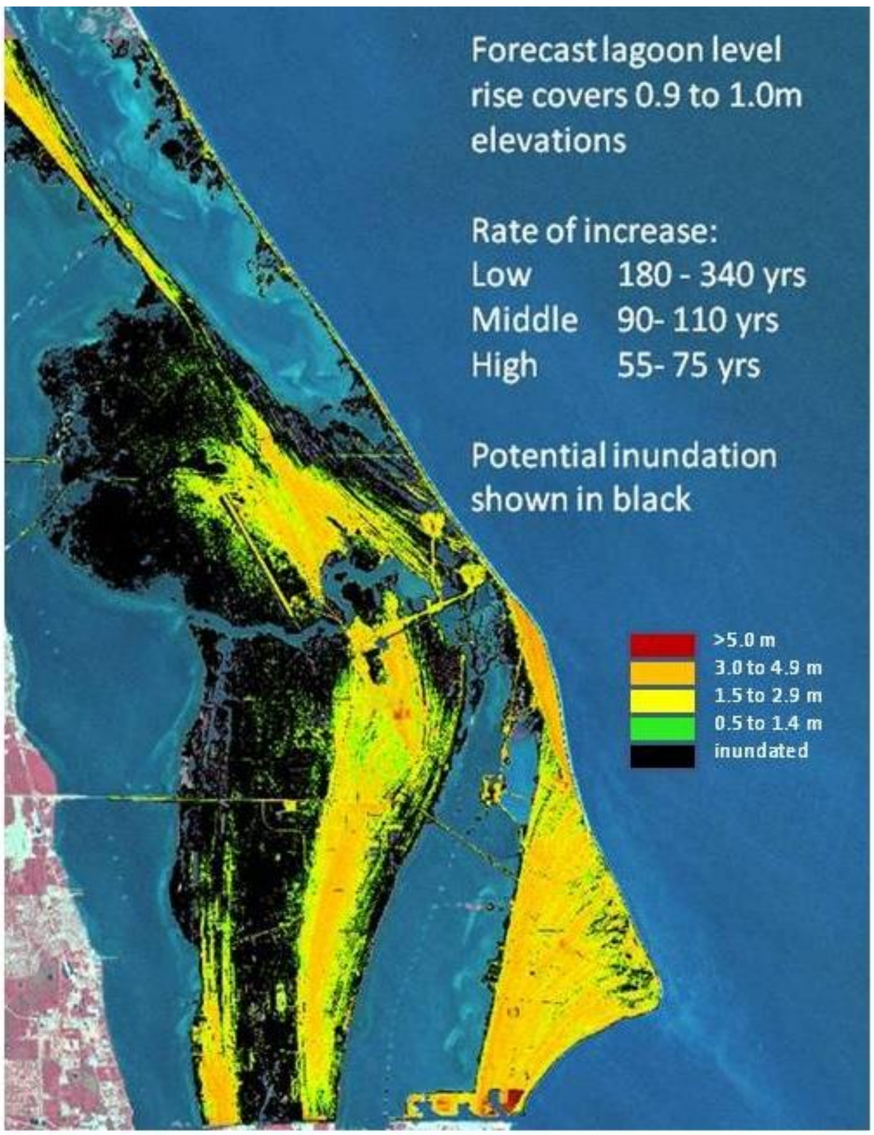


Figure 8.2: Projected areas of inundation on KSC based on a 1 m rise in the water table. Rates of increase were developed by the Goddard Institute for Space Studies.

9 Conclusions and Recommendations

9.1 Conclusions

Extensive data and information are available for defining the baseline hydrology of the CCBIC and KSC. In combination with a growing body of site-specific data, KSC managers and stakeholders can more easily address risk from climate change and develop management strategies to enhance resilience and sustainability of facilities and natural resources.

9.2 Recommendations

The following recommendations are provided for EMB consideration.

- The current Lidar elevation data and basin boundary files provide good first approximations of the baseline watershed and waterbody areas and elevations. When available from NOAA, the new CUDEM dataset that will include the new 2019-2020 LiDAR should be incorporated in the EMB database to continue improving quality.

- The CCBIC major sub-basin and KSC sub-basin boundaries should be reviewed and updated to allow for improved understanding of KSC contributions (volume and chemistry) to receiving waters (IRL health initiative concept, TMDL and BMAP improvements).

- Evapotranspiration (ET) represents the second most important component of the hydrologic cycle next to rainfall and is most important during drought. The USGS Caribbean-Florida Water Science Center (CFWSC) provides CCBIC/KSC estimates of reference ET (RET) and potential ET (PET). They also have developed a method to calculate land-cover based actual ET (AET) utilizing AET to RET ratios developed from eddy flux estimates of AET in different land cover types. It is recommended that this approach be applied to the KSC landscape utilizing their data and data available from the various past and ongoing eddy flux studies being conducted on KSC.

- Work with Indian River Lagoon stakeholders to develop a better understanding of the volumes, chemistry, and sources of subsurface discharges. These data are critical to understanding lagoon hydrology, surface water quality, and lagoon health trends.

- Develop information on effects of water level rise on KSC water control structures, existing drainage system and stormwater management systems.

- Support reviews of state and federal regulations and executive orders that impact KSC management decisions related to ecohydrology, climate change, and associated operational activities such as facility siting, land use, emissions, and NEPA documentation.

- Continue providing input to stakeholders and reviewing KSC hydrology related climate and sustainability projects.

- Continue to support the hydrologic activities associated with FDEP storm water and TMDL monitoring and management and the regional Indian River lagoon Health initiative.

- Establish a second water table monitoring site in the Happy Creek region to ensure understanding of trends across the KSC property.

- Establish a water level monitoring process to assess utility of Haulover Canal measurements for monitoring long-term (weeks to years) trends in the isolated Banana River.

- Continue to update KLTEP to make this information available to management and stakeholders.

- Continue monitoring the numerous data portals that distribute CCBIC and KSC relevant information on ecohydrology. Where approved, utilize that data to update the EMD data and knowledge base to ensure scientifically sound informed management decisions. These data portals include, but because of the continually evolving nature of the web, are not limited to:

NOAA Coastal Change Analysis Program-
LIDAR CUDEM, Land use and land cover change
https://coast.noaa.gov/digitalcoast/data/home.html

Trident Pier water levels
https://tidesandcurrents.noaa.gov/stationhome.html?id=8721604

USACOE
Sea level Rise Projections
https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html

USGS Water Resource
Haulover Canal water levels
https://waterdata.usgs.gov/usa/nwis/uv?site_no=02248380

Evapotranspiration and Climate parameters
https://www.usgs.gov/centers/car-fl-water/science/

St Johns River Water Management District
Land-cover, NEXRAD Rainfall
https://www.sjrwmd.com/data/

Northwest Alliance for Computational Science and Engineering PRISM Climate Group

Climate parameters

https://prism.oregonstate.edu/projects/gallery_view.php?state=FL

World Climate Research Institute

Advances in global circulation modeling, Climate Model Intercomparison Project (CMIP)

https://public.wmo.int/en/programmes/world-climate-research-programme

NASA-Climate Change

Sea level rise, global temperatures, water mass movement, Evapotranspiration

https://climate.nasa.gov/

Evapotranspiration: Watching Over Water Use | NASA

Indian River Lagoon

Home - Indian River Lagoon (onelagoon.org)

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