Sea-Level Rise Inundation Assessment for the City of Rockledge Stormwater System

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List of Acronyms

AHW – Annual High Water

DEM – Digital Elevation Model

DEP – Florida Department of Environmental Protection

ECFRPC – East Central Florida Regional Planning Council

ECFRRAP – East Central Florida Regional Resilience Action Plan

GIS – Geographic information systems

LMSL – Local Mean Sea Level

MHHW – Mean higher high water

NAVD88 – North American Vertical Datum of 1988

NOAA – National Oceanographic and Atmospheric Administration

NTDE – National Tidal Datum Epoch

SHW – Seasonal High Water

USACE – United States Army Corps of Engineers

Introduction and Background

The City of Rockledge is a coastal municipality in Brevard County located on a relatively high ridge area between the estuarine Indian River Lagoon (which forms most of the City's eastern boundary) and the extensive freshwater marshes of the upper St. Johns River (located to the west of the City). Originally incorporated in 1887, Rockledge has the distinction of being the oldest municipality within Brevard County. The U.S. Census Bureau (2018) population estimate for Rockledge is 27,715 on a land area of 12.15 square miles, at a density of ~2,281 people per square mile. The City of Cocoa is located directly north of Rockledge and the Viera communities of unincorporated Brevard County are located to the south, making Rockledge part of an extensive and growing urban corridor between the Indian River and St. Johns River in Brevard County.

This report provides the results of a sea-level rise vulnerability assessment for stormwater infrastructure within the City of Rockledge, as developed through funding provided by the Florida Department of Environmental Protection's Florida Coastal Management Program. The general rationale for conducting sea-level rise vulnerability assessments is that sea-level rise poses a wide array of short-term and long-term concerns for natural ecosystems, private property, and public infrastructure within Florida's coastal communities (Butler et al. 2016). However, the specific rationale for conducting detailed evaluations of stormwater systems is that there is a high degree of consensus that stormwater drainage systems can be very vulnerable to even small increments of sea-level rise and, in many cases, are already experiencing visible impacts (Evans et al. 2016; Gambill et al. 2017; Evans et al. 2019). These vulnerabilities stem from the fact that stormwater infrastructure is inherently located at low points within the landscape, often is located underground in a way that can interact with tidal groundwater systems, and – particularly within older municipal systems – can have direct hydrologic connections to estuarine and ocean surface waters.

The most visible evidence of these vulnerabilities can be seen within some coastal communities around Florida – and elsewhere across the country and world – that have experienced an increased occurrence of what are commonly referred to as "sunny day," "nuisance," or "shallow coastal" floods. The term sunny day flood is a colloquialism that describes a tidal flooding event that isn't associated with rainfall or a wind storm event that, at least historically, would be a more typical cause of flood conditions (i.e., the flooding can occur on an otherwise sunny day). Other terms such as nuisance flooding or shallow coastal flooding more broadly indicate that this type of tidal flooding may also occur at night, even though events that occur during the day are more readily observed and documented by the media and general public (Sweet et al. 2018).

A shallow coastal flooding event typically occurs when the water elevation of a large high tide (sometimes called a "king tide") is sufficient to push tidewater up-gradient into low-lying roads and yard. Coastal stormwater systems often serve as an important conduit for shallow coastal flooding, with saltwater *discharges* frequently observed within low-lying stormwater inflow structures that would normally serve as the drainage points for rainwater. It is apparent that sea-level rise is the primary reason for the increased occurrence of shallow coastal flooding events in Florida and other areas of the world (Sweet et al. 2017).

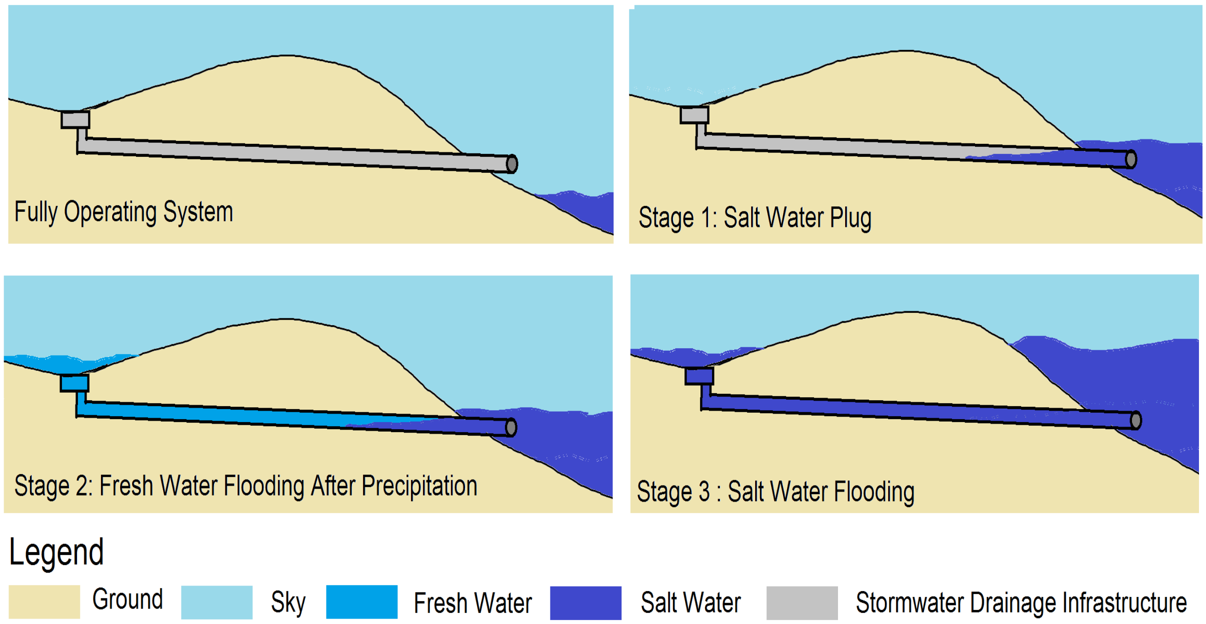
Although most shallow coastal flooding events currently cause little property damage and have relatively minor impacts (hence, the use of the term "nuisance" flood), these events are nevertheless a quite serious and troubling indication that a coastal stormwater drainage system is completely inundated by tidewater. Indeed, the presence of shallow coastal flooding indicates that a coastal stormwater system originally designed and constructed to function under an assumption of historic sea level conditions is now subject to rising water levels well outside of the original engineering design parameters. Put another way, a stormwater system that is inundated by tidewater infiltration, as indicated by discharges of saltwater from stormwater inflow points into roads and yards, can provide very little to no effective drainage of rainwater runoff. Accordingly, shallow coastal flooding events indicate the potential for increased risks of stormwater-driven flood damage during a large rainfall event that may coincide with a king tide or other elevated coastal water condition (see, e.g., Titus et al. 1987; Spanger-Siegfried et al. 2014).

Fortunately, shallow coastal flooding is not yet prevalent or widespread in all of Florida's coastal communities, and communications with local officials indicate that very little shallow coastal flooding has been observed to date within the City of Rockledge. Various factors including differential tide ranges, geologic substrate, ground elevation profiles, and engineering interventions within individual stormwater drainage systems all contribute to the extent of shallow coastal flooding that any given community experiences (Sweet et al. 2018). The geographic position of Rockledge on a fairly high coastal ridge in an area of the Indian River with a very small tidal amplitude gives it a very low risk profile for visible shallow coastal flooding impacts under current sea level conditions, or even under high end sea-level rise projection scenarios over the next several decades.

However, sea-level rise can have substantial impacts on the functioning of a coastal stormwater system well before the point at which tidewater is observed to discharge from stormwater inlets. As the elevation of receiving water bodies and groundwater table rises, tidewater can more readily enter pipes, ditches, and other drainage features within a coastal community's stormwater system (Figure 1). Intrusion of tidewater into these infrastructure features incrementally reduces the volumetric drainage potential of conventional gravity-driven stormwater systems, even if the extent of the intrusion is not sufficient to produce tidewater discharge from inlet structures. Increased saltwater intrusion into stormwater systems also can often promote rapid growth of fouling organisms and result in deposition of tide-deposited marine debris within the stormwater system (Bloetscher et al. 2011. All of these impacts typically result in higher maintenance costs and, if the infrastructure is not maintained diligently, can further reduce the functionality of the stormwater drainage system. Over time, the net effect can be a significant loss of drainage potential that may increase the risks of rainfall-driven flood damages to private property and public infrastructure. Avoidance of such impacts typically will require substantial investments to upgrade impacted stormwater systems.

With this background, the overall purpose of this study was to provide a baseline inventory and rapid assessment of current and potential future vulnerabilities within the City of Rockledge's stormwater management system. This assessment is intended to serve as a planning tool that may be used to inform general flood resilience policies and capital improvement priorities within the City of Rockledge's stormwater system over the next decade. However, we stress that the analyses and visualizations provided within this report are for planning purposes only and should not be used as a primary basis for site-level engineering, design, or construction.

Figure 1: Stages of coastal stormwater system impact from sea-level rise. Image credit, Emily Niederman.



Data and Methods

Stormwater Dataset

The basic approach for this study was to utilize a comprehensive geographic information systems (GIS) inventory of stormwater infrastructure, as supplied to the project team by the City of Rockledge, to develop a series of assessments for current and future tidewater penetration into the stormwater system. This inventory contains a series of 266 control structures, 465 manhole structures, 2,437 inlet structures, 2,134 end-of-pipe structures, and approximately 68 linear miles of underground pipes and culverts. Most structures within the inventory have survey quality elevation data for the bottom of structures (i.e., invert elevation), as well as survey quality elevation data for the top of structure (i.e., ground elevation). For those structures without a top of structure elevation listed within the original dataset, we estimated ground elevation by extracting the relevant point elevation values from the University of Florida GeoPlan Center's (2013) statewide digital elevation model (DEM). Any missing elevations for the bottom of structure were estimated by subtraction of structure depth, if available in the dataset, from top of structure elevation as measured by survey data or, in cases where survey data wasn't available, the extracted DEM ground elevation value. For structures without a bottom elevation and no reported depth value, the bottom elevation value is reported as "null" and no bottom of structure assessments were performed. All elevation data from both ground surveys and the DEM are standardized as feet relative to the North American Vertical Datum of 1988 (NAVD88).

Water Level Thresholds

Following the approach of Evans et al. (2019) for a sea-level rise assessment in the City of Satellite Beach, we utilized the NOAA VDatum 3.4 tool (Yang et al. 2012) develop a baseline mean sea level (MSL) elevation datum – as currently defined by the 1992 National Tidal Datum Epoch (NTDE) – for the

Indian River Lagoon at Rockledge. Through this VDatum assessment, the 1992 base MSL for the Indian River at Rockledge was estimated at -0.65 ft NAVD88. Also following Evans et al. (2019), we estimated a "seasonal high water" (SHW) value of 1 ft above MSL and an "annual high water" (AHW) value of 1.42 ft above MSL for the Indian River at Rockledge. The SHW value is an estimate of a water level that may be equaled or exceeded over about a 2-week period within a given year, while AHW is an estimate of a water level that may be equaled or exceeded over a 24-hour period within a given year. We do note that the SHW and AHW values estimates used here were not developed specifically at the Indian River in Rockledge, but instead are calculated from historic tide gauge data at Carters Cut in the Banana River and more recent water level gauge data at the SR192 Bridge at the Indian River in Melbourne.

To develop an assessment of future water level conditions, we added increments of projected sea-level rise for the years 2020, 2040, 2070, and 2100 to the 1992 baseline values for MSL, SHW, and AHW. Following the recommendations from the East Central Florida Regional Resilience Action Plan (ECFRPC 2018), we used the United States Army Corps of Engineers (USACE) "High" sea-level rise curve from 2013 as a lower bound, and the National Oceanographic and Atmospheric Administration (NOAA) "High" sea-level rise curve from 2017 as a higher bound. A summary of these water level thresholds across all years and sea-level rise curves is provided in Table 1.

Inundation Assessments

An inundation assessment using all water level thresholds in Table 1 was developed for all stormwater features within the City of Rockledge. This inundation assessment included two components for each water level threshold:

1) An estimated depth of water within the bottom of structure. Absent any adaptation action, the presumed impact of tidewater infiltration into the bottom of these structure is reduced volumetric drainage capacity within the stormwater system.

2) An estimated depth of water above the top of the structure. Absent any adaptation action, the presumed impact of tidewater at elevations above the top of the structure is discharge of tidewater from the stormwater structure into adjacent low-lying areas within the City of Rockledge.

Table 1: Water level thresholds by sea-level rise projection scenario for the Indian River Lagoon at Rockledge, FL. All values are as feet relative to NAVD88.

	Mean Sea Level	Season High Water	Annual High Water
1992 - Baseline	-0.65	0.35	0.77
2020 – USACE High	-0.15	0.85	1.27
2020 – NOAA High	0.15	1.15	1.57
2040 – USACE High	0.57	1.57	1.99
2040 – NOAA High	1.20	2.20	2.62
2070 – USACE High	2.20	3.20	3.62
2070 – NOAA High	3.82	4.82	5.24
2100 – USACE High	4.50	5.50	5.92
2100 – NOAA High	7.83	8.83	9.25

Results

The full suite of results for this stormwater system vulnerability assessment is contained in a series of appendices that provide close-up visualizations impacts for each water level scenario across fifteen section panels within the City of Rockledge. A summary guide to these map appendices is provided as Table 2. For aid in map interpretation, we also developed tables to summarize gross numbers and overall percentages of identified stormwater structure vulnerability to tidewater infiltration in the City of Rockledge (Tables 3-8).

Summaries for bottom of structure vulnerability are provided in Table 3 (Local Mean Sea Level), Table 4 (Seasonal High Water), and Table 5 (Annual High Water). These bottom of structure results indicate that current to near-term (i.e., 2020 water levels) tidewater infiltration within the Rockledge stormwater system is very isolated, with most of the current to near-term identified impact associated with the bottom of control structures that, in many cases, are designed to slow and detain water flow. Tidewater infiltration into the bottom of structures varies by sea-level rise projection scenario, but less than 2% of the structures within the Rockledge stormwater system are projected to have medium-term tidewater infiltration at the high bound of the 2070 NOAA High sea-level projection (4.47' above 1992 water levels).

Summaries for top of structure vulnerability are provided in Table 6 (Local Mean Sea Level), Table 7 (Seasonal High Water), and Table 8 (Annual High Water). These results for top of structure inundation indicate that very small percentages of the stormwater infrastructure within the City of Rockledge are vulnerable to current or near-term tidal flooding. However, one inlet and four end structures do show vulnerability top of structure inundation under 2020 AHW conditions for both the USACE and NOAA sea-level rise projection scenarios (Figures 2a & 2b). As shown in Figure 2a, the inlet showing potential impact under near-term AHW events is located at the intersection of Sweet St. and Rockledge Dr. End structures showing potential overtopping during near-term AHW events are all outfalls into the Indian River located along Rockledge Dr. Potentially impacted outfalls along Rockledge Dr. with intersection locations near Hardee Dr., Fernwood Dr., and Orange Ave. are shown in Figure 2a. A potentially impacted outfall on Rockledge Dr. to the north of Coquina Rd. is shown in Figure 2b.

Discussion and Recommendations

The City of Rockledge has a very active stormwater management program that is funded through a local stormwater utility fee structure. The City currently requires most new construction to implement stormwater controls that are sufficient to maintain pre-development conditions for a 100-year rainfall event, which exceeds minimum state standards for stormwater management. A number of large stormwater facilities – including the Barton Park Stormwater Facility, Eyster Stormwater Facility, Larry Schultz Stormwater Park, Robert A. Anderson Stormwater Park, and the Wynona and Ernie Morris Park – provide the storage and treatment capacity for meeting this stringent 100-year standard across the City. Other stormwater projects such as installation of numerous baffle boxes along the Indian River and extensive street sweeping have recently been implemented within the City for the purposes of water quality mitigation.The database inventory of stormwater structures, as provided to the project team in a GIS format, is impressively thorough and updated regularly for the purpose of actively maintaining and managing the stormwater system.

The overall results of this sea-level rise vulnerability assessment suggest that the stormwater system within the City of Rockledge has very isolated vulnerability to tidewater flooding under current to near-term conditions. However, a high rate of sea-level rise would be expected to result in increasing tidewater impacts that impact the functioning of the stormwater system located directly along the Rockledge Dr. corridor. While these impacts should be monitored, field visits to Rockledge Dr. and communications with the City's stormwater management staff indicate that other consequences of higher waters in the Indian River – particularly wave action erosion along the shoreline and roadbed of Rockledge Dr. – are likely to pose higher short-term to medium-term risks to waterfront property and infrastructure than chronic flooding from tidewater infiltration.

The primary near-term recommendation from this vulnerability assessment is for the City of Rockledge's Public Works personnel to maintain a field database of observed tidal flooding impacts within the City's stormwater system. Such impacts could include observations of fouling from estuarine organisms within low-lying outfall points into the Indian River, as well as any observations of tidewater flooding during high water events. Due to the relatively high elevations within most of Rockledge, we stress that the risks of direct tidal flooding from the stormwater system into streets, yards, or other property and infrastructure are very localized or associated with extreme storm surge and/or very high long-term scenarios of sea-level rise. However, clogging of outfall pipes with fouling organisms or other marine debris could have the potential to cause rainwater back-up, particularly with large precipitation events. Risks of these back-up events can be greatly reduced through regular inspection and maintenance to identify and remove such drainage system impediments.

We also recommend that future updates to the City of Rockledge's Stormwater Master Plan should include more detailed assessments of drainage system functionality for a 25-year horizon of future sea-level rise and, perhaps more importantly, any amplification in local precipitation event frequency that may be associated with climate change. More intense rainfall events in combination with rising sea levels could potentially produce elevated risk of local stormwater flooding beyond those developed through the inundation assessments in this current report. We further note that installation and monitoring of a long-term water level gauge in the Indian River near Rockledge would provide more confidence in coastal water level datums, particularly if field conditions indicate more substantial tidal and stormwater flooding impacts than projected through our current assessment.

Table 2: Map series appendix list by water level threshold assessment for stormwater infrastructure in the City of Rockledge

Water Level Threshold	Appendix Number
2020 – Mean Sea Level, USACE High	Appendix 1
2020 – Seasonal High Water, USACE High	Appendix 2
2020 – Annual High Water, USACE High	Appendix 3
2020 – Mean Sea Level, NOAA High	Appendix 4
2020 – Seasonal High Water, NOAA High	Appendix 5
2020 – Annual High Water, NOAA High	Appendix 6
2040 – Mean Sea Level, USACE High	Appendix 7
2040 – Seasonal High Water, USACE High	Appendix 8
2040 – Annual High Water, USACE High	Appendix 9
2040 – Mean Sea Level, NOAA High	Appendix 10
2040 – Seasonal High Water, NOAA High	Appendix 11
2040 – Annual High Water, NOAA High	Appendix 12
2070 – Mean Sea Level, USACE High	Appendix 13
2070 – Seasonal High Water, USACE High	Appendix 14
2070 – Annual High Water, USACE High	Appendix 15
2070 – Mean Sea Level, NOAA High	Appendix 16
2070 – Seasonal High Water, NOAA High	Appendix 17
2070 – Annual High Water, NOAA High	Appendix 18
2100 – Mean Sea Level, USACE High	Appendix 19
2100 – Seasonal High Water, USACE High	Appendix 20
2100 – Annual High Water, USACE High	Appendix 21
2100 – Mean Sea Level, NOAA High	Appendix 22
2100 – Seasonal High Water, NOAA High	Appendix 23
2100 – Annual High Water, NOAA High	Appendix 24

Figure 2a: Stormwater inlets and end structures showing potential top elevation inundation under 2020 annual high water (AHW) conditions, City of Rockledge (northern extent)

Figure 2b: Stormwater end structures showing potential top elevation inundation under 2020 annual high water (AHW) conditions, City of Rockledge (southern extent)

Table 3: Projected bottom of structure inundation at local mean sea level (LMSL), as adjusted by sea-level rise projection scenario, for the City of Rockledge stormwater system

	# Control Structures	% Control Structures	# Manholes	% Manholes	# Inlets	% Inlets	# End Structures	% End Structures
2020 – USACE High	6	2.3%	1	0.2%	2	0.1%	3	0.1%
2020 – NOAA High	6	2.3%	1	0.2%	2	0.1%	4	0.2%
2040 – USACE High	8	3.0%	1	0.2%	2	0.1%	8	0.4%
2040 – NOAA High	8	3.0%	1	0.2%	3	0.1%	12	0.6%
2070 – USACE High	9	3.4%	3	0.6%	6	0.2%	16	0.7%
2070 – NOAA High	10	3.8%	6	1.3%	15	0.6%	27	1.3%
2100 – USACE High	11	4.1%	8	1.7%	21	0.9%	29	1.4%
2100 – NOAA High	12	4.5%	13	2.8%	43	1.8%	56	2.6%

Table 4: Projected bottom of structure inundation at seasonal high water (SHW), as adjusted by sea-level rise projection scenario, for the City of Rockledge stormwater system

	# Control Structures	% Control Structures	# Manholes	% Manholes	# Inlets	% Inlets	# End Structures	% End Structures
2020 – USACE High	8	3.0%	1	0.2%	2	0.1%	11	0.5%
2020 – NOAA High	8	3.0%	1	0.2%	3	0.1%	12	0.6%
2040 – USACE High	8	3.0%	1	0.2%	5	0.2%	14	0.7%
2040 – NOAA High	9	3.4%	3	0.6%	6	0.2%	16	0.7%
2070 – USACE High	10	3.8%	5	1.1%	11	0.5%	20	0.9%
2070 – NOAA High	11	4.1%	9	1.9%	21	0.9%	30	1.4%
2100 – USACE High	11	4.1%	10	2.1%	25	1.0%	34	1.6%
2100 – NOAA High	13	4.9%	16	3.4%	52	2.1%	82	3.8%

Table 5: Projected bottom of structure inundation at annual high water (AHW), as adjusted by sea-level rise projection scenario, for the City of Rockledge stormwater system

	# Control Structures	% Control Structures	# Manholes	% Manholes	# Inlets	% Inlets	# End Structures	% End Structures
2020 – USACE High	8	3.0%	1	0.2%	5	0.2%	14	0.7%
2020 – NOAA High	8	3.0%	1	0.2%	5	0.2%	14	0.7%
2040 – USACE High	9	3.4%	3	0.6%	6	0.2%	16	0.7%
2040 – NOAA High	9	3.4%	5	1.1%	8	0.3%	18	0.8%
2070 – USACE High	10	3.8%	6	1.3%	15	0.6%	27	1.3%
2070 – NOAA High	11	4.1%	9	1.9%	24	1.0%	34	1.6%
2100 – USACE High	11	4.1%	10	2.1%	28	1.1%	37	1.7%
2100 – NOAA High	16	6.0%	16	3.4%	62	2.5%	106	5.0%

Table 6: Projected top of structure inundation at local mean sea level (LMSL), as adjusted by sea-level rise projection scenario, for the City of Rockledge stormwater system

	# Control Structures	% Control Structures	# Manholes	% Manholes	# Inlets	% Inlets	# End Structures	% End Structures
2020 – USACE High	0	0.0%	0	0.0%	0	0.0%	1	0.0%
2020 – NOAA High	0	0.0%	0	0.0%	0	0.0%	1	0.0%
2040 – USACE High	0	0.0%	0	0.0%	0	0.0%	3	0.1%
2040 – NOAA High	0	0.0%	0	0.0%	1	0.0%	4	0.2%
2070 – USACE High	0	0.0%	0	0.0%	1	0.0%	5	0.2%
2070 – NOAA High	0	0.0%	0	0.0%	1	0.0%	9	0.4%
2100 – USACE High	1	0.4%	0	0.0%	4	0.2%	12	0.6%
2100 – NOAA High	5	1.9%	3	0.6%	25	1.0%	23	1.1%

Table 7: Projected top of structure inundation at seasonal high water (SHW), as adjusted by sea-level rise projection scenario, for the City of Rockledge stormwater system

	# Control Structures	% Control Structures	# Manholes	% Manholes	# Inlets	% Inlets	# End Structures	% End Structures
2020 – USACE High	0	0.0%	0	0.0%	0	0.0%	4	0.2%
2020 – NOAA High	0	0.0%	0	0.0%	0	0.0%	4	0.2%
2040 – USACE High	0	0.0%	0	0.0%	1	0.0%	4	0.2%
2040 – NOAA High	0	0.0%	0	0.0%	1	0.0%	5	0.2%
2070 – USACE High	0	0.0%	0	0.0%	1	0.0%	8	0.4%
2070 – NOAA High	1	0.4%	0	0.0%	4	0.2%	13	0.6%
2100 – USACE High	1	0.4%	0	0.0%	6	0.2%	20	0.9%
2100 – NOAA High	8	3.0%	9	1.9%	27	1.1%	24	1.1%

Table 8: Projected top of structure inundation at annual high water (AHW), as adjusted by sea-level rise projection scenario, for the City of Rockledge stormwater system

	# Control Structures	% Control Structures	# Manholes	% Manholes	# Inlets	% Inlets	# End Structures	% End Structures
2020 – USACE High	0	0.0%	0	0.0%	1	0.0%	4	0.2%
2020 – NOAA High	0	0.0%	0	0.0%	1	0.0%	4	0.2%
2040 – USACE High	0	0.0%	0	0.0%	1	0.0%	5	0.2%
2040 – NOAA High	0	0.0%	0	0.0%	1	0.0%	7	0.3%
2070 – USACE High	0	0.0%	0	0.0%	1	0.0%	9	0.4%
2070 – NOAA High	1	0.4%	0	0.0%	6	0.2%	19	0.9%
2100 – USACE High	3	1.1%	1	0.2%	10	0.4%	22	1.0%
2100 – NOAA High	9	3.4%	9	1.9%	27	1.1%	24	1.1%

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