Coastal Vulnerability Assessment: City of St. Augustine, Florida

Contract # C1469
Florida Department of Economic Opportunity

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EXECUTIVE SUMMARY

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

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

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

- Mean Higher High Water (MHHW), which defines the highest daily high tide, representing the limit of where land is "wetted" on a daily basis and has very limited use.
- Nuisance flooding – defined as a minor flood event that occurs monthly, often resulting in the flooding of roads.
- The 1% annual chance flood, also known as the 100-yr recurrence interval flood, which defines the Special Flood Hazard area depicted on Federal Emergency Management Agency Flood Insurance Rate Maps. Such an event has a 1% chance of occurring any given year, and a 26% chance of occurring over a 30-year timeframe.

The study assessed the vulnerability of the city to these existing flood conditions with an incremental approach. This involved gradually increasing sea level at half-foot increments to identify "tipping points" in vulnerability. This approach was used to assess the city's existing and future coastal flooding vulnerability. The study established cartographic layers of each coastal flood type and SLR scenario combination. The amount, changes in land area subject to each flood condition, and projected flooding "hotspots" were identified. The flood cartographic layers were then overlaid on the city's GIS data to assess vulnerability of buildings, roads, bridges, water treatment facilities, as well as historical and archeological resources. The city's vulnerability to saltwater intrusion was also evaluated. The essential results of these assessments are summarized below:

How much more flooding is expected?

- Of the three flood types evaluated, nuisance flooding has the largest potential to impact St. Augustine in the near term. An additional 500 acres of land are vulnerable to nuisance flooding with 1 ft of SLR. This scenario could occur as early as the 2030's or as late as 2100, depending on the degree of SLR acceleration.
- Present-day areas subject to nuisance flooding are expected to be flooded almost daily by tides with 1.5 ft of SLR, which could occur as early as the 2040's or after 2100.
- 3 ft of SLR would make today's nuisance flood equivalent to today's 1% annual chance flood, in terms of the area flooded. This situation could occur in the 2060's with high acceleration, or after 2100 with low acceleration of SLR.

- The 1% annual chance floodplain is projected to increase slowly after the first 1.5 ft of SLR. At this point, the 1% floodplain inundates most of downtown St. Augustine and is relatively constrained by topographic gradients on the west side of the City.
- In addition to increased flood extent and depth, SLR also increases the frequency of coastal flood events. The future higher water day-to-day water levels allow smaller, more frequent floods to impact larger areas. For example, despite the relatively small amount of growth of the 1% annual chance flood, it is estimated that a flood equal to today's event will occur twice as often with 1 ft of SLR.

What are the major pathways for future flooding?

- Major pathways for propagation of floodwaters into St. Augustine include the following areas, designated by streets:
    - Downtown: Cordova Street, vicinity of Riberia Street, King Street and Orange Street.
    - North: vicinity of Althea Street, Beacon Street and East Park Avenue, Ocean Boulevard, Vista Cove Road and down Douglas Avenue from the north.
    - East: Gerado Street, Flagler Boulevard, Arricola Avenue, Dolphin Drive and Coquina Avenue.
- Increasing flood protection where these streets come to the shoreline, or preventing backflow to these areas would reduce future flooding.

How will building vulnerability to flooding change?

- Buildings vulnerable to nuisance flooding increase by 17 fold with 1 ft of SLR.
- Buildings vulnerable to daily tidal flooding increase by 24 fold with 2.5 ft of SLR. Such a condition could occur as soon as the 2050's or after 2100, depending on SLR acceleration.

How will road vulnerability to flooding change?

- With 1.5 ft of SLR, 30% of the road network is affected by nuisance flooding. This finding suggests that even with low levels of SLR, nuisance flooding will cause increased public inconveniences, suggesting a shift from occasional to frequent road closures. Such a condition could occur as early as the 2040s and as late as 2100, depending on SLR acceleration.
- With 3 ft of SLR, over 50% of the road network is affected by nuisance flooding, a notable finding given the frequency of this flood type. This condition is projected to occur as early as the 2060s or after 2100, depending on the degree of SLR acceleration.
- The frequency of road flooding is also expected to increase. Roads are currently only inundated for a few days out of the year – this has the potential to increase to up to 90 days a year under the 1.5 ft SLR scenario, and to 365 days with the 3.0 ft SLR scenario.

How will Historic District vulnerability to flooding change?

- Buildings located in the City's historic districts are presently not exposed to nuisance flooding.
- Vulnerability is projected to increase with 1 to 1.5 ft of SLR, a condition that is projected to occur between the 2040s and 2100.
- In such a scenario, 20-50% of the structures in the Lincolnville, Model Land Company, St. Augustine Town Plan, Abbot Tract, Castillo de San Marcos, and the pending National Park Service historic districts are projected to be vulnerable to nuisance flooding.
- The most vulnerable are Castillo de San Marco, the Model Land, and the pending National Park Service districts.

How will SLR impact archeological zones and cemeteries?

- Most cemeteries and archeological zones are vulnerable to the 1% annual chance event, even under baseline conditions.
- For daily tidal flooding with SLR, most cemeteries have limited vulnerability to flooding until SLR reaches 3 ft. The vulnerability of archeological zones to tidal inundation is mixed – several sites are exposed under existing conditions. Overall vulnerability increases with SLR.
- Nuisance flooding is already impacting over 60% of designated archeological zones in the City. All designated sites will be subject to this type of flooding with 1.5 ft of SLR. On the other hand, only one of twelve cemeteries are presently exposed to nuisance flooding. – only one of 11 designated areas. This increases to 50% with 2 ft of SLR and 100% with 3.5 ft of SLR.

How will bridge vulnerability to flooding change?

- Presently, bridges and approaches are only vulnerable to flooding at the 1% annual chance recurrence interval.
- Bridges and approaches become vulnerable to nuisance flooding with 1 ft of SLR, and to daily tidal flooding at 2.5 ft of SLR.
- Approximately 50% of the city's bridges are vulnerable to nuisance flooding with 2 ft of SLR.

How will sea level rise impact water and wastewater treatment facilities?

- The St. Augustine Water Plant is not vulnerable to any flood hazard or SLR combination examined by this study effort.
- The St. Augustine Wastewater Treatment Plant has limited vulnerability to flooding under existing conditions. Major vulnerability to the 1% annual chance event is noted with just 1 ft of SLR. The site would have increasing vulnerability to nuisance flooding with sea level increases between 2 and 4 ft. Major vulnerability to nuisance flooding becomes apparent with 5 ft of SLR.

What are the Anticipated Changes in the St. Augustine Water Table?

- The city is vulnerable to saltwater intrusion because of its location within a high-salinity zone and unique hydrogeological setting.
- St. Augustine's local groundwater network may be useful for long-term monitoring of rising water-table driven by SLR.

1. OVERVIEW

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

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

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2. PROJECT SCOPING

2.1. *Initial Questionnaire*

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

The questionnaire asked the following eight questions:

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

   Response: The study should clearly convey the risks/vulnerabilities the City is facing including how it may impact historic/cultural resources, residents, businesses, tourism, and redevelopment. Then establish what strategies the City may adopt including their potential impacts as well. The study should be accessible for residents to read and understand.

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

   Response: The study should focus on two (2) areas that are important to the City. The historic downtown area and the surrounding historic neighborhoods with an emphasis on aging infrastructure and historic/cultural resources.

3. Should the study focus on particular infrastructure (e.g. due to aging, proximity to hazard, etc.)? If so, please describe.

   Response: The City owns and operates water, sewer and stormwater utilities. The storm and sanitary sewer infrastructure should be focused on due to age and proximity to tidal rivers. The storm sewer collection system is very old, tidally influenced, undersized and not designed efficiently. The sanitary sewer system (pump stations and collection) is very old and suffers from inflow and infiltration which is exasperated further during high tide events. However, the City is interested in infrastructure in general including transportation, power, natural gas, communications, etc. One common infrastructure theme is old age.

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

   Response: No

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

   Response: No

6. What data do you have about the community to help characterize the built environment and natural assets?

   ☒ *Parcel data*
   (can be obtained at the St. Johns County Property Appraisers website, http://www.sjcpa.us/)
   ☒ *Building footprints*
   (can be obtained at the St. Johns County Property Appraisers Website, http://www.sjcpa.us/)
   ☒ *Roads*
   (can be obtained at the St. Johns County website, http://www.co.stjohns.fl.us/gis/DataDepotDisclaim.aspx)
   ☒ *Above/underground utilities*
   (City provided storm, sewer and water data via ftp site)
   ☒ *Others (please list)*
   Historic property registry shapefile
   Zoning shapefile
   Historic Preservation Zone shapefile
   Neighborhood shapefile
   LiDAR – available from St. Johns County
   2014 Aerials – available from St. Johns County Property Appraisers
   FEMA Floodplain Maps
   St. Johns County Flood Insurance Study

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

   Response: Need a little more time to discuss and compile a list of community participants.

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

a.) Internal Stakeholders –
David Birchim, Planning and Building Director
Martha Graham, Public Works Director
James "JC" Costeira, Fire Chief/Emergency Manager
John Regan, City Manager
Tim Shields, Facilities
Bill Mendez, Engineering Manager

b.) External Stakeholders –
St. Johns County (SJC) Emergency Management
SJC Growth Management Department
SJC Office of Economic Development
SJC Chamber of Commerce
Castillo de San Marcos National Monument (NPS)

Flagler College
Flagler Hospital
Anastasia and Fort Mose State Parks
Guana Tolomato Matanzas National Estuarine Research Reserve (GTMNERR)
University of Florida (UF)
City Neighborhood Associations
Florida Department of Transportation (FDOT)

2.2. *Design Meeting*

The purpose of the design meeting was to frame the problems faced by the City with respect to coastal resilience, and to identify analysis products that would support the adaptation planning process. The design meeting also served as a forum to discuss and identify the flood event types and SLR scenarios for use the vulnerability assessment with the City representatives. The breakout sessions during the January 2016 design meeting revealed a number of key issues, identified by attendees representing the City and the Florida DEO. Discussion also served to identify additional datasets that could be leveraged to assess issues. A synopsis of the design meeting follows, with a full summary provided in Appendix B.

Priority issues included:

- Realistic options for adapting the city's historical resources to SLR.
- Realistic options for adapting the city at large while also managing aging infrastructure.
- Understanding tipping points for when facilities and buildings will be compromised.
- Positioning the city to obtain funding for planning (master planning, capital improvement planning).

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

2.3. *Work Plan*

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

3. MAPPING OF SEA LEVEL RISE CONDITIONS

Geospatial coverages were created for each combination of flood event type and sea level rise (SLR). The coverages allowed a visual assessment of how future flooding would increase with each condition. Further, the data allowed an assessment of the amount of land subject to flooding for each scenario. The information was then used to identify noteworthy future tipping points in flood conditions and major pathways of flooding in St. Augustine. A summary of the methodologies for mapping SLR conditions are presented first, followed by the results of the analysis. For further detail on the analytical approach, please refer to Appendix A.

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

The first step for mapping SLR was to establish SLR scenarios in consultation with the community during the design meeting. Through that effort, it was decided that the community preferred an incremental water level approach - where existing water level conditions are raised at specified increments from present day to the highest SLR projection considered. Two future time-frames were considered for the bases of the SLR projections. A relatively short-term horizon approximately 30 years from today (2045), and a relatively long-term horizon 70 years from today (2085). These time horizons relate to municipal planning as shown in Table 1.

Table 1. Identified time horizons and relevance to municipal planning and infrastructure.

Life Cycle Alignment	Time Horizon/ Time Period	Relevance	Use
Municipal Planning	20-40 years 2035-2055	Comprehensive Plan & Outcomes Short end of Commercial and Utility life-cycles	Vulnerability assessment Key planning value Basis for evaluation of all adaptation strategies
Critical Infrastructure/ Long-term awareness	50-80 years 2065-2085	Utility Infrastructure life-cycles Transportation infrastructure lifecycles Residential structure lifecycles	Secondary vulnerability assessment to provide insight into long-term risk Basis for long-term infrastructure decisions Evaluate cost-effectiveness of additional protection for adaptable resilience strategies

The range of SLR projections was established from the NOAA SLR scenarios for the U.S. (NOAA 2012). Relative SLR projections from Mayport, FL based on the NOAA guidance were retrieved from the U.S. Army Corps of Engineers Sea-Level Change Curve Calculator (http://www.corpsclimate.us/ccaceslcurves.cfm, USACE 2016). The Mayport gauge location was selected as it was the closest to St. Augustine. Projected SLR values for the short- and long-term horizons are provided in Table 2.

Table 2. SLR projections at Mayport, FL gage based on NOAA/NCA Projections. Increases are in units of feet relative to local mean sea level and calculated from the mid-point of the existing National Tidal Datum Epoch (1992).

Time Horizon	Low[1]	Intermediate-Low[2]	Intermediate-High[3]	High[4]
Short-term (2045)	0.4	0.7	1.2	1.9
Long-term (2085)	0.7	1.5	3.2	5.2

The full range of SLR projections at the two time frames is 0 to 5 ft. The consensus at the Design Meeting was to assess vulnerability through an incremental approach to allow for identification of tipping points in the City's vulnerability. In consultation with the community representatives, the desired increment was identified as 0.5 ft. Each SLR increment assessed, and the projected earliest date of occurrence by NOAA SLR curve are shown below:

Table 3. SLR increments considered for the assessment and earliest date they could occur relative to each NOAA SLR curve.

SLR	Low	Intermediate-Low	Intermediate-High	High
Feet	**Year**	**Year**	**Year**	**Year**
0.5	2050	2035	2020	2015
1.0	>2100	2060	2040	2030
1.5	>2100	2085	2050s	2040s
2.0	>2100	>2100	2060s	2040s
2.5	>2100	>2100	2070s	2050s
3.0	>2100	>2100	2080s	2060s
3.5	>2100	>2100	2090	2070s
4.0	>2100	>2100	2090s	2070s
5.0	>2100	>2100	2090s	2080s

Coastal flood event types including tidal, nuisance and high to low recurrence interval storm surge were discussed with the community at the design meeting. The community selected tidal, nuisance and the 1% annual chance flood – information on each is presented in Table 4:

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

[1] NOAA Low scenario: represents a continuation of historical observations.
[2] NOAA Intermediate-Low scenario: based primarily on the upper end of the IPCC Fourth Assessment Report.
[3] NOAA Intermediate-High scenario: represents the upper end of global projections modeled by semi-empirical methods.
[4] The NOAA High scenario: derived from an estimation of potential change with maximum possible glacier and ice sheet loss by the end of the century.

Table 4. Sources of flood hazard types selected for the St. Augustine vulnerability assessment.

Flood Type	Description	Frequency	Water Elevation	Source
Mean Higher High Water (MHHW)	The higher daily high tide elevation, defining the limit of what land is essentially "inundated" or has very limited use.	Daily	~2 ft NAVD88	NOAA VDatum software
Nuisance Flooding	Areas frequently flooded by tides and/or small coastal storms. Results in shallow flooding, which may disrupt or limit use.	12-17 times a year	3.75 ft NAVD88	Tidal gauge analysis and coordination with community
1% annual chance flood event	Areas subject to flooding by significant coastal storms. Defines the Special Flood Hazard Area as delineated on Federal Emergency Management Agency Flood Insurance Rate Maps. Also known as the "Base Flood".	~26% chance in 30 years	Range from 6-10 ft	Preliminary FEMA FIS update for St. Johns County, FL.

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

SLR increases water elevations relative to land, resulting in larger and deeper floods. Vulnerability to these future conditions varies by each flood type and local land elevations. The mapping layers produced for each flood type and SLR scenario were reviewed to gain a better understanding of how each flood type would change with SLR. This included a review of the sequence of increasing flooding, from today's condition (baseline) through 5 ft of SLR (in half-foot increments) for each flood event type. Figure 1 provides a summary of the amount of land area vulnerable to flooding compared to total land area in St. Augustine, which is also provided in tabular format (Table 5).

Change in the flooded area for the three flood types is shown in Figure 2. This illustration clearly shows the differential rate of change for each flood type with increasing SLR scenario. Nuisance flooding grows the fastest, followed by MHHW, and then the 1% annual chance floodplain.

- MHHW: Present day MHHW elevations are approximately 1.5 ft lower than nuisance flooding. Once this difference is made up for with sea level rise (2040's, at earliest based on the highest projection [Table 3]), MHHW grows at a similar rate as nuisance flooding, increasing by 1.5 times with 4 ft of SLR.

- Nuisance Flooding: Of the three flood types evaluated, nuisance flooding has the largest potential for increase with SLR. Particular attention should be given to this because, while at present these events currently only cause minor inconveniences such as road closures, impacts will become more frequent and flooding will also become deeper, resulting in increased damages. The rate of growth is fairly linear with increasing SLR scenario. Results show 200-300 acres per 0.5 ft of SLR for lower levels of SLR (0-1 ft), and increases to 350-400 acres per 0.5 ft of SLR (1.5 – 3.5 ft). Areas impacted will increase by 1.5 times with 3 to 3.5 ft of SLR.

- 1% Annual Chance Floodplain: The 1% floodplain experiences slow growth after the first 1.5 ft of SLR. At this point, the 1% floodplain inundates most of downtown St. Augustine and is relatively constrained by topographic gradients on the west side of the city. Further growth becomes more limited with increasing SLR due to these conditions (Figure 2). The area impacted increases 1.2 times with 5 ft of SLR.

Table 5. Total flooded area for each event type and SLR combination.

SLR Increment	Flooded Area (acres)		
	MHHW	Nuisance	1.0%
0	3,778	4,238	6,260
0.5	3,975	4,462	6,603
1	4,061	4,753	6,842
1.5	4,177	5,155	7,110
2	4,321	5,513	7,271
2.5	4,564	5,859	7,429
3	4,892	6,209	7,539
3.5	5,322	6,596	7,632
4	5,683	6,906	7,702
4.5	6,022	7,146	7,766
5	6,390	7,323	7,822

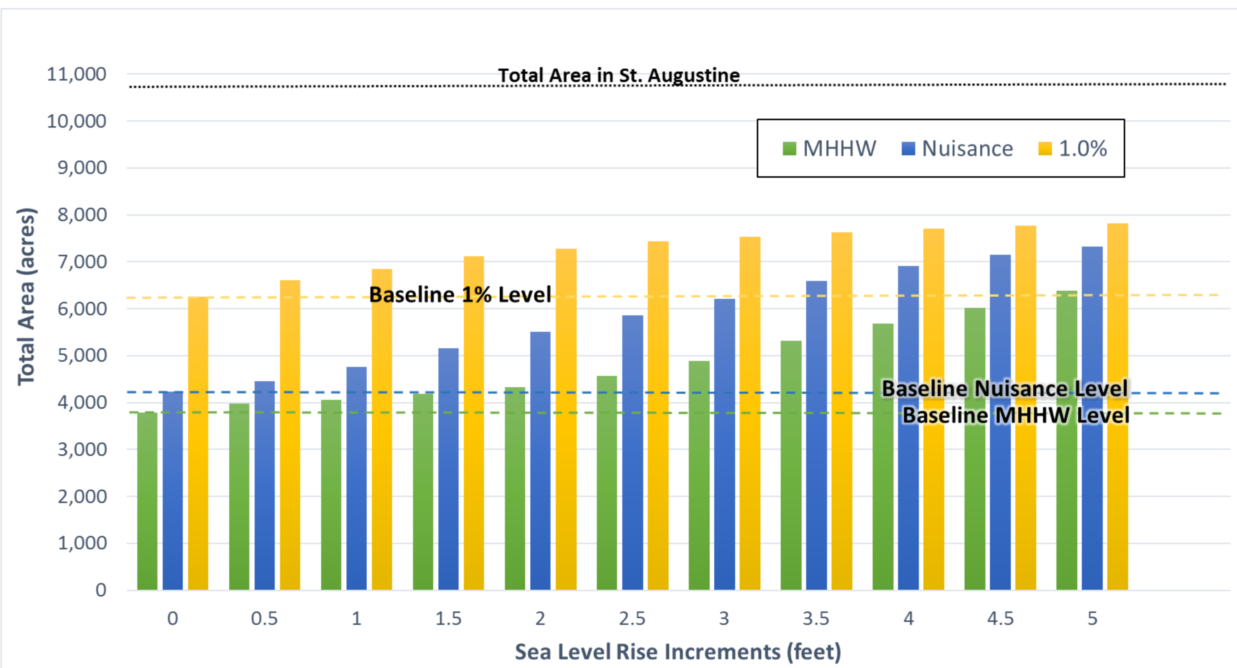


Figure 1. Total amount of floodplain area in St. Augustine under different flood hazard type – SLR scenarios. The black dotted line represents the total amount of land area in St. Augustine that can be used as a means to view how non-floodplain land area still exists under different scenarios. The yellow dotted line represents the baseline 1% annual chance event, the blue dotted line represents the baseline nuisance flood event level, and the green dotted line represents the baseline MHHW level.

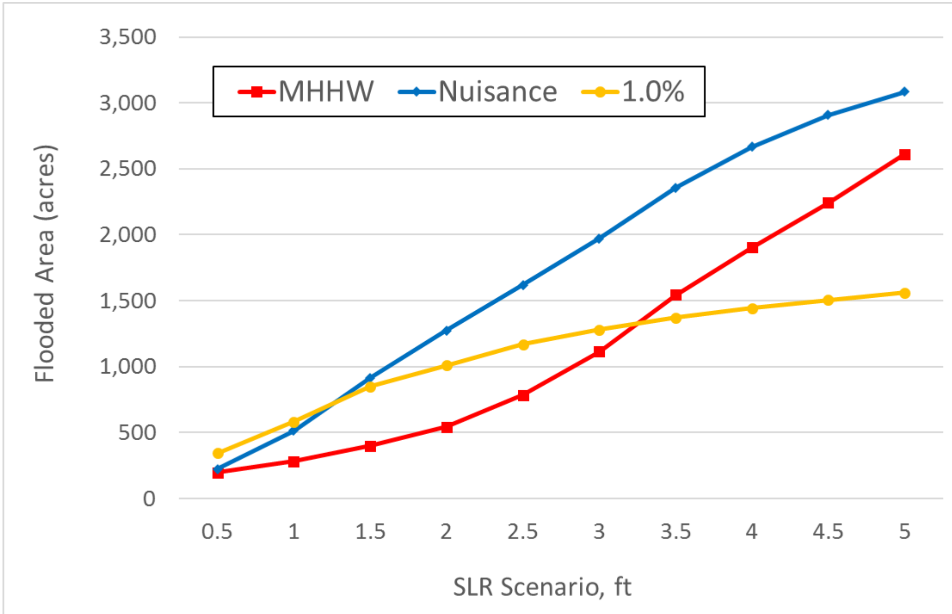


Figure 2. Changes in flooded area by flood type. Note rapid growth of nuisance flood areas, which is shared by MHHW after 2 ft of SLR. The 1% annual chance floodplain experiences slow growth after 1.5 ft of SLR.

Potential tipping points in the progression of increasing SLR was of key interest to the City. These are highlighted below:

- 1.5 ft of SLR (Low: >2100; Intermediate-Low: 2085; Intermediate-High: 2050s; High 2040s):
  - MHHW becomes equivalent to current nuisance. This trend is evident in Figure 1 because the green bar (MHHW) reaches the same level as the baseline nuisance level, which is depicted by the blue dotted line. Of the three flood hazard types, MHHW increases the inundated area most dramatically with each SLR scenario.
  - At 1.5 ft of SLR, nuisance flooding becomes persistent in multiple streets and low-lying areas surrounding Matanzas River, Salt Run, and the San Sebastian River.
- 2 ft of SLR (Low: >2100; Intermediate-Low: >2100; Intermediate-High: 2060s; High 2040s):
  - A possible tipping point for MHHW with 2 ft of SLR, after which the amount of inundated area begins to accelerate (Figure 2).
  - With 2 ft of SLR, the majority of downtown and North Davis Shores becomes inundated (Figure 4).
- 3 ft of SLR (Low: >2100; Intermediate-Low: >2100; Intermediate-High: 2080s; High 2060s):
  - At 3 feet, nuisance becomes equivalent to current 1%. Nuisance flooding is important because as relative sea levels increase, it no longer takes a strong storm event to cause significant flooding.

Snapshots of increased flooding at the identified tipping point SLR increments are shown in Figures 3, 4, and 5 for MHHW, Nuisance and 1% annual chance flood conditions, respectively.

3.3. *Where are the Major Flood Pathways in St. Augustine?*

Flood pathways were identified in order understand the major areas of new flood incursion into the community as a result of SLR. Flood pathways were identified by reviewing the changing flood extents and identifying locations where flooding propagates inland to increase the overall flood extent. The major flood pathways are illustrated for the East, North, and Downtown areas of the city in Figures 6, 7, and 8, respectively.

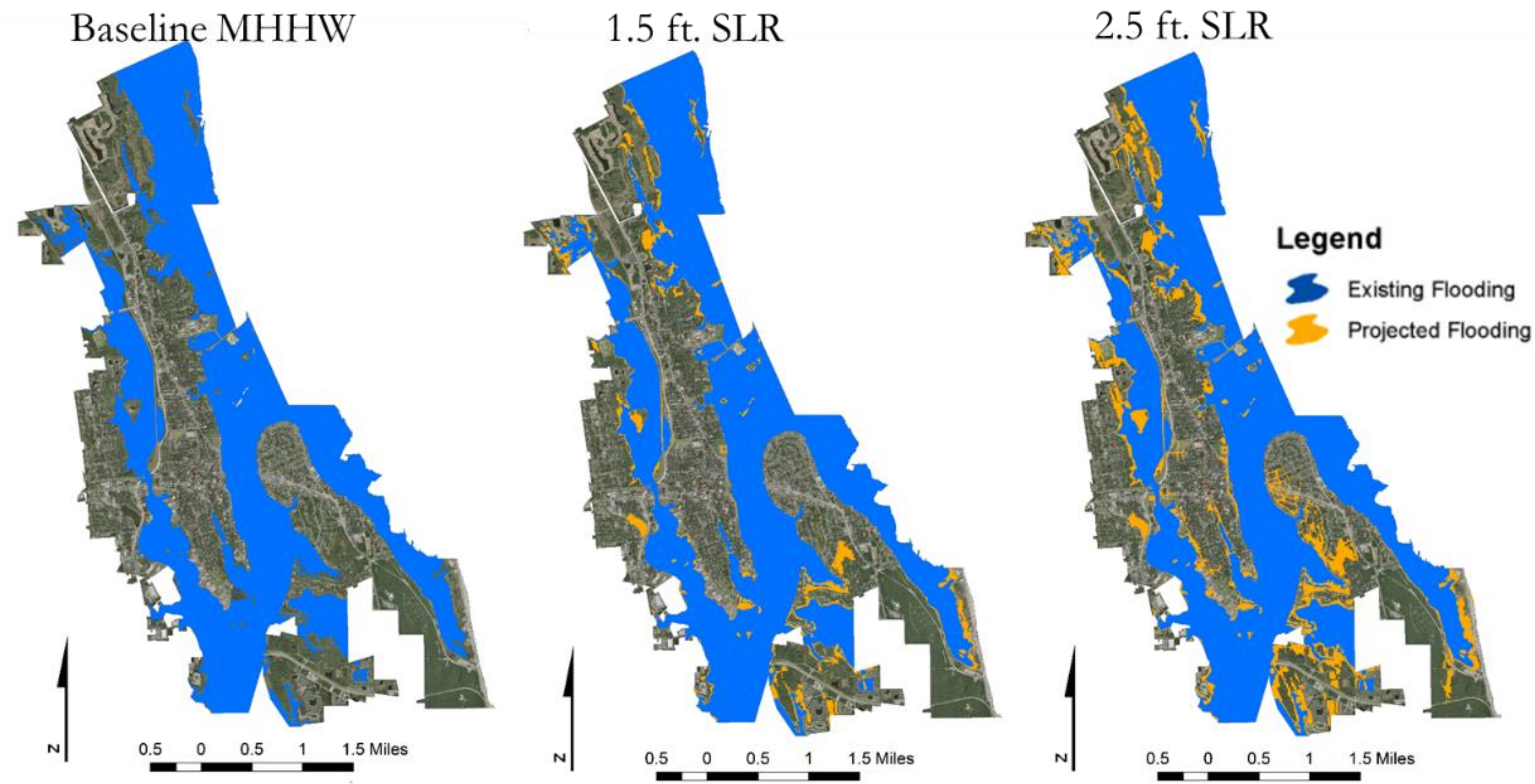


Figure 3. Changes in MHHW inundation under baseline MHHW, 1.5 ft SLR, and 2.5 ft SLR scenarios. These areas would be expected to be "wetted" by tides on a daily basis.

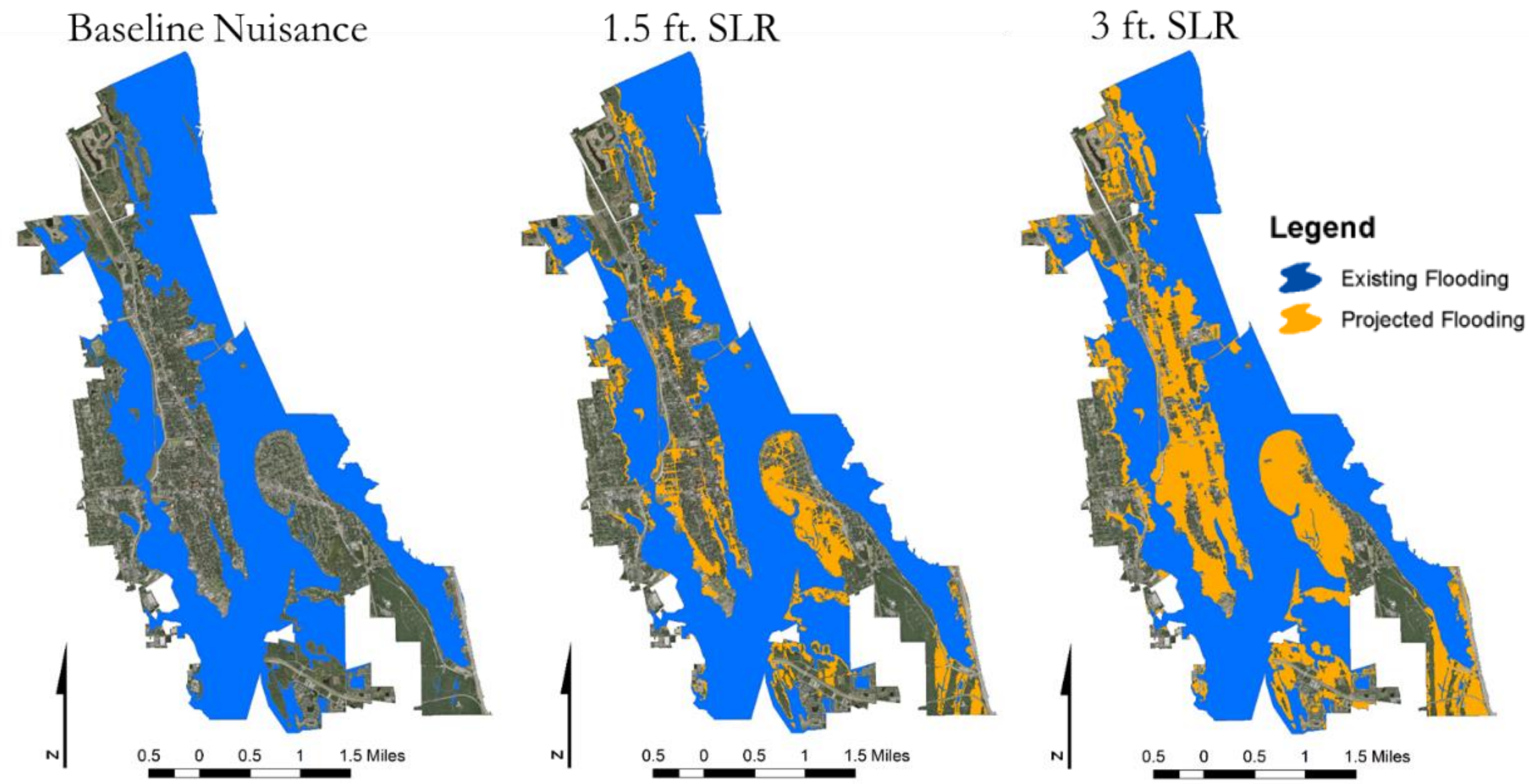


Figure 4. Changes in nuisance flood extents with 1.5 ft SLR, and 2.5 ft SLR scenarios. Current nuisance flooding is 3.75 ft Under the 3 ft SLR scenario, nuisance flooding becomes equivalent to the current 1% flood extent.

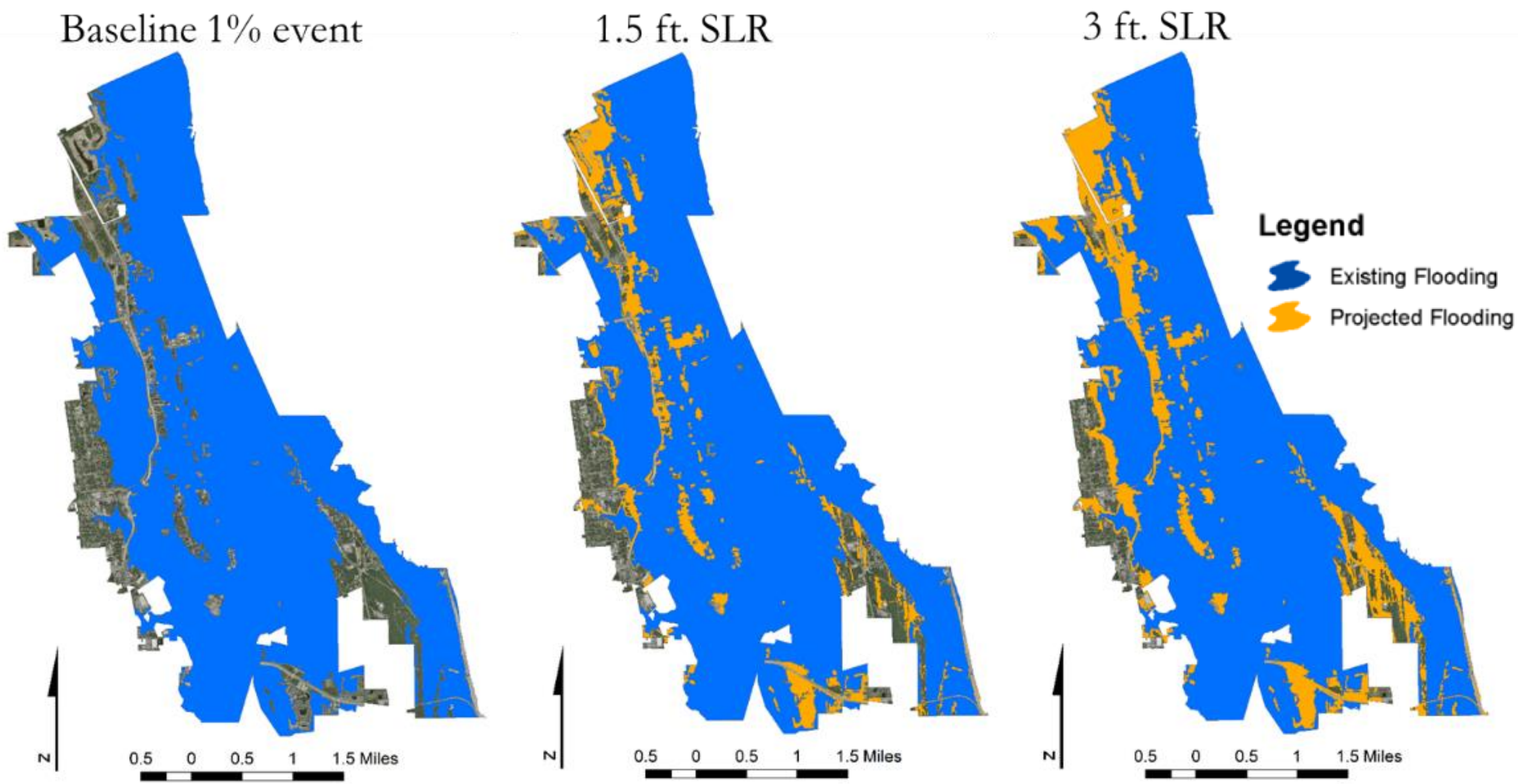


Figure 5. Changes in the 1% annual chance floodplain. The 1% event currently affects much of the city. As sea level rises, the 1% annual chance floodplain expands over the full historic district. But is relatively constrained by topographic gradients to the west.

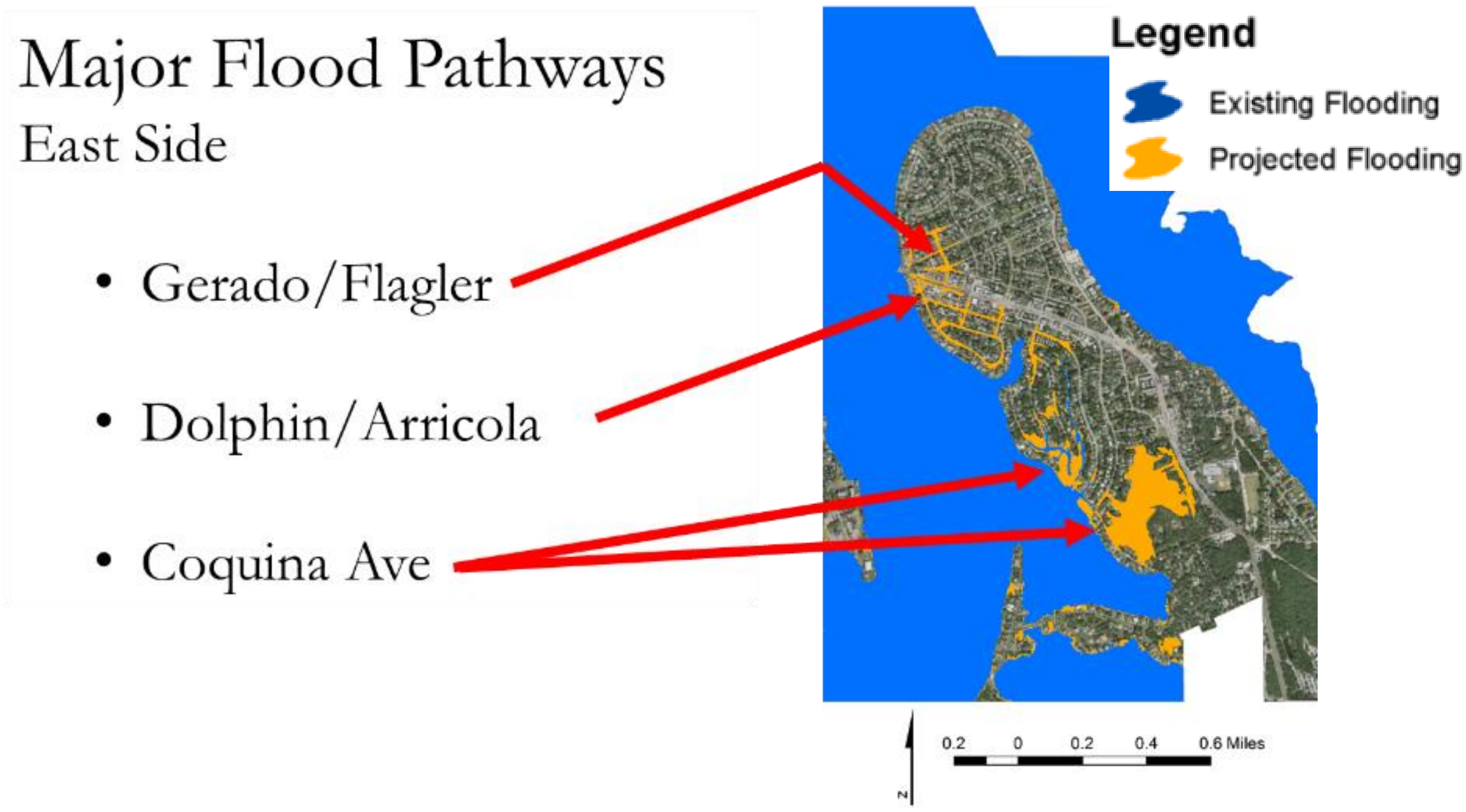


Figure 6. Locations of flood intrusion on the eastern side of St. Augustine.

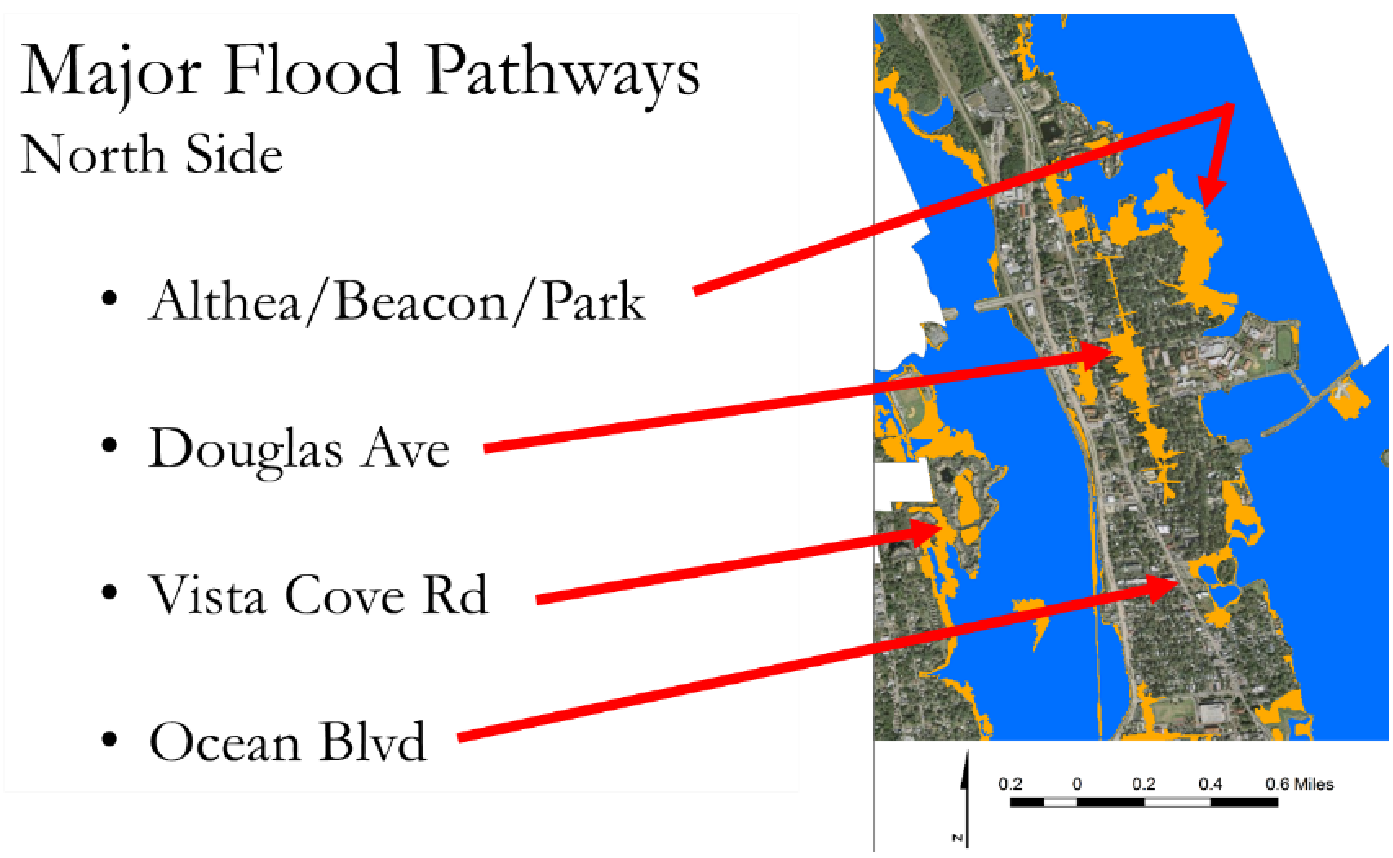


Figure 7. Locations of flood intrusion on the north side of St. Augustine.

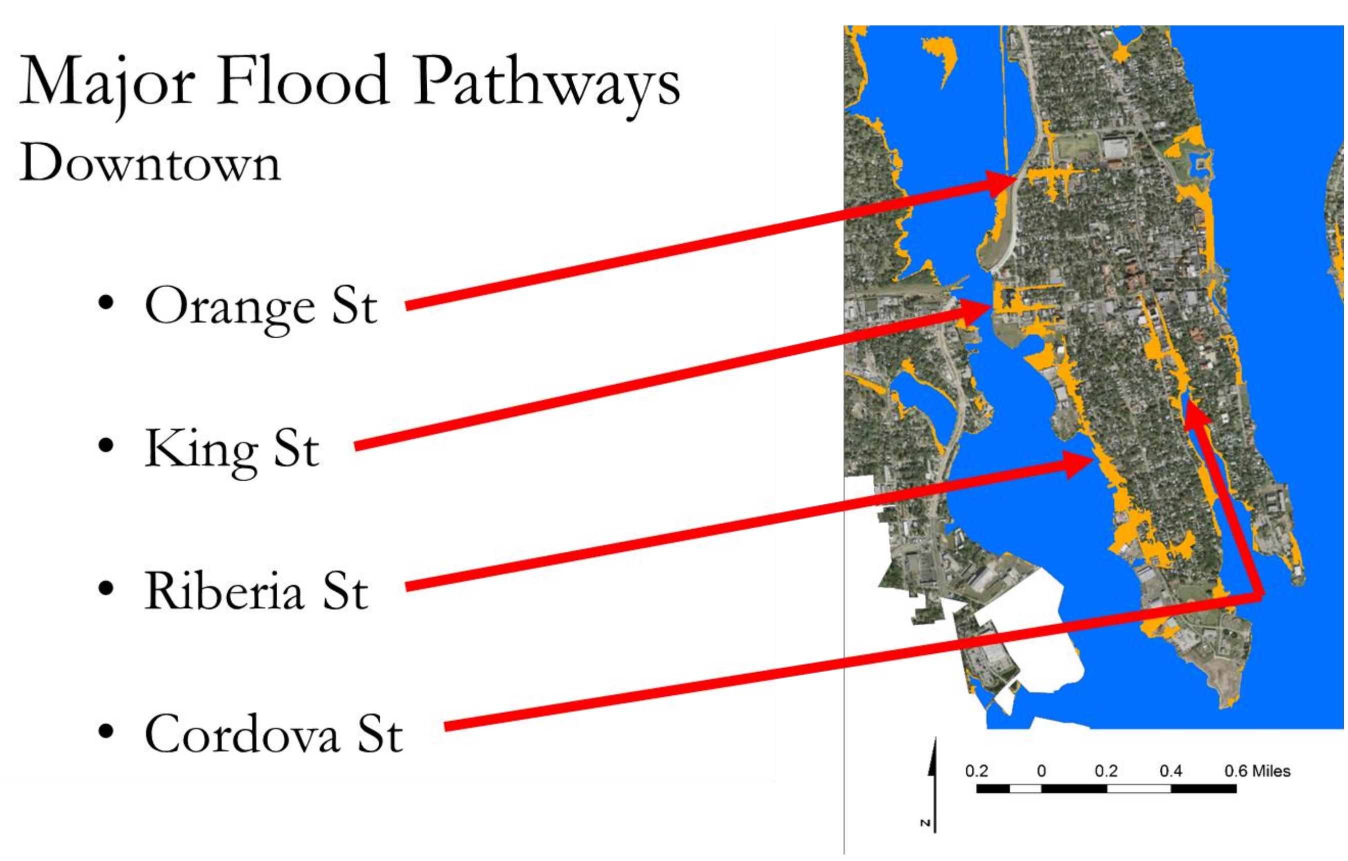


Figure 8. Locations of flood intrusion in the downtown area of St. Augustine.

3.4. *How will Sea Level Rise Change Flood Frequency?*

Changes in the recurrence interval for the 1% annual chance flood, also known as the 100-yr recurrence interval flood, were evaluated to understand how SLR will affect flood frequencies, which were characterized using recurrence intervals. Changes in recurrence intervals were calculated using a tool developed for the Federal Transit Administration. A representative existing 1% flood recurrence elevation of 6.9 ft was entered into the tool along with each SLR increment to return the estimated reduction in recurrence interval.

Table 4 compares existing recurrence interval against estimated recurrence intervals under different SLR increments. For example, if SLR increases by 2-feet above the existing condition we can expect the 100-yr event to become a 5-yr event. Alternatively stated, this means areas currently having a 1% chance of flooding annually could be expected to now have a 20% of flooding annually if 2 ft of SLR were to occur.

Nuisance flood frequency for city roads is discussed in Section 4.1.1.

Table 6. Reductions in recurrence intervals under SLR scenarios.

Existing Recurrence Interval, years; (Percent annual chance)	SLR Increment, feet above existing condition									
	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
	Estimated Recurrence Interval, years									
10 (10%)	4	2	1	1	1	1	1	1	1	1
50 (2%)	16	5	2	1	1	1	1	1	1	1
100 (1%)	71	50	16	5	2	1	1	1	1	1
500 (0.2%)	334	223	149	100	71	50	16	5	2	1

4. VULNERABLITY ASSESSMENT

The objective of the vulnerability assessment was to identify infrastructure impacted by sea level rise (SLR) scenarios and to summarize key impacts. The vulnerability assessment focused on four main components:

Table 7.Vulnerability assessment items.

Component	Metrics
Roads	• Percent of network affected by scenario • Days inundated for road segments
Infrastructure	• Bridges, Water/Wastewater
Historic Resources	• Structures impacted
Archaeological Resources	• Percent of archaeological zone or cemetery affected by scenario
Groundwater impacts	• Local and regional response to SLR

4.1. *Road Vulnerability Assessment*

To address the road vulnerability component of the assessment, the St. Augustine road network was first segmented into small, discreet segments. Each segment was assigned an elevation from the Digital Elevation Model in the GIS framework. Future flood vulnerability as well as the frequency and duration of flooding was assessed using the NOAA inundation tool. This resulted in a look-up table of expected flood frequency and duration by SLR increment. The final step of the analysis was to relate the table to road segments. Road segments were selected by location using the nuisance flood extent polygons and then attributed with flood frequency values. The amount of roads (length and percent of total) in the community subject to nuisance flood frequency were then summarized by SLR increment. Further information on aspects of the approach is provided in Appendix A.

4.1.1. How will Sea Level Rise Impact Flooding of the Road Network?

With respect to percentage of road network affected by the three flood hazard types, three main trends were identified - discussed below and shown graphically in Figure 9.

- With 1.5 ft of SLR, 30% of the road network is affected by nuisance flooding. This shows that even with low levels of SLR, nuisance flooding will cause public inconveniences, such as occasional to frequent road closures.
- With 2 ft of SLR, there is a possible tipping point for MHHW, where the percent of road network flooded grows quickly for MHHW with increasing SLR increments. This tipping point is likely a result of the current design standards to which roads are built or a fairly uniform elevation across the affected areas.
- With 3 ft of SLR, over 50% of the road network is affected by nuisance flooding.
- At 5 ft of SLR, approximately 80% of the road network is impacted by nuisance flooding. Although nuisance flooding on roadways may currently be a relatively minor inconvenience for the City's transportation system, any acceleration of SLR will further reduce the time between flood events and will intensify the impacts of flooding on the road network; potential impacts would include more frequent or permanent road closures, compromised infrastructure, and possibly even incapacitation of entire routing options for the area.

The amount of roads (length and percent of total) in St. Augustine subject to nuisance flood frequency are summarized by SLR increment in Table 8.

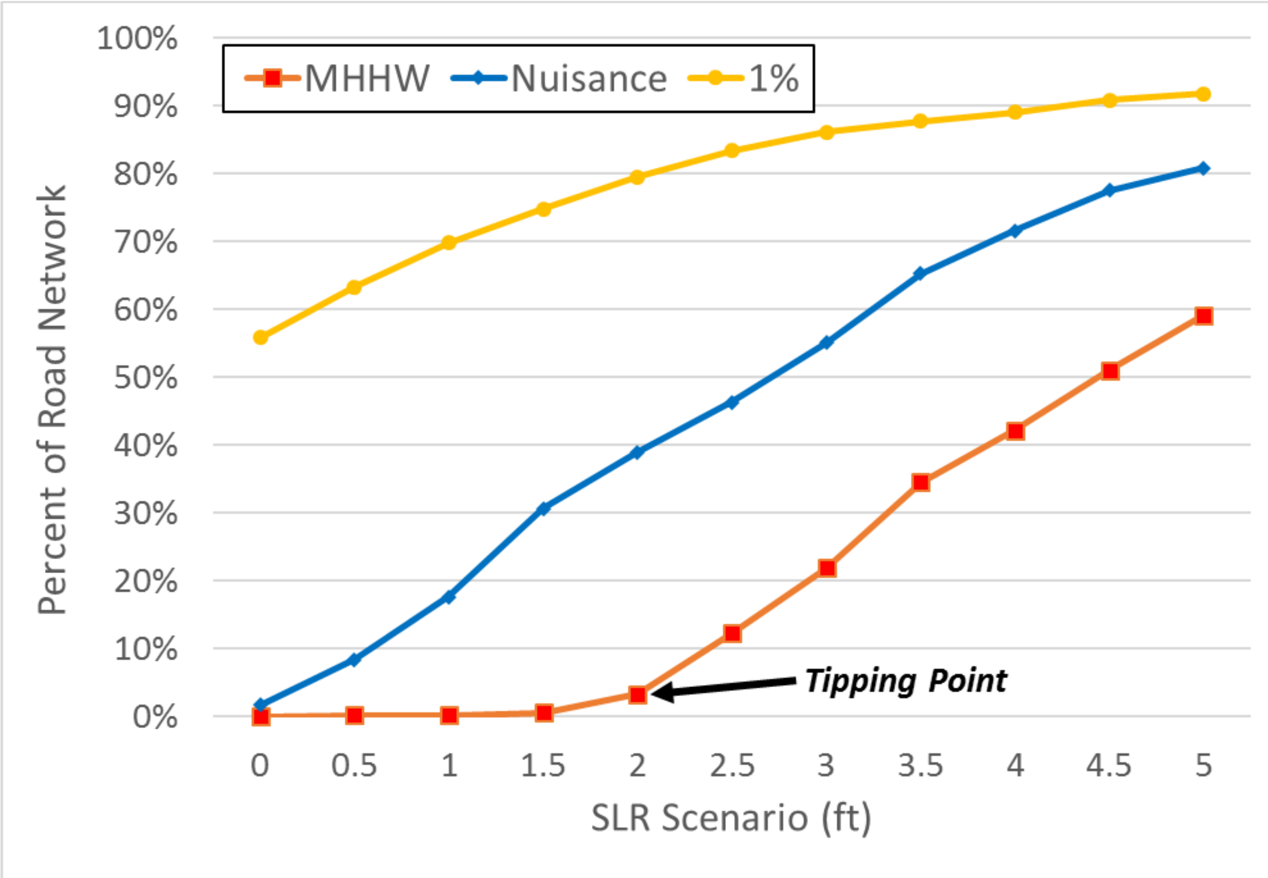


Figure 9. Percent of road network affected by MHHW, nuisance, and the 1% flood level for each SLR increment.

Table 8. Mileage and percentage of road network affected by nuisance flood level for each SLR increment.

SLR Scenario, ft	Flood Elevation, ft NAVD88	Length of Road Affected, mi	Percent of Network
0	3.75	1.64	2%
0.5	4.25	8.41	8%
1	4.75	17.74	18%
1.5	5.25	30.82	31%
2	5.75	39.22	38%
2.5	6.25	46.60	46%
3	6.75	55.47	55%
3.5	7.25	65.77	65%
4	7.75	72.10	72%
4.5	8.25	78.12	78%
5	8.75	81.38	81%

In terms of number of days of inundation in St. Augustine, roads are currently (i.e. 0 ft SLR) only flooded for a few days out of the year. Days of road flooding increase to up to 90 days/year under the 1.5 ft SLR scenario, and up to 365 days/year under the 3.0 ft SLR scenario (Figure 9). Sections of roads that are inundated for significant periods of time might experience general deterioration and corrosion of infrastructure not designed to withstand frequent to constant inundation or salt-water exposure.

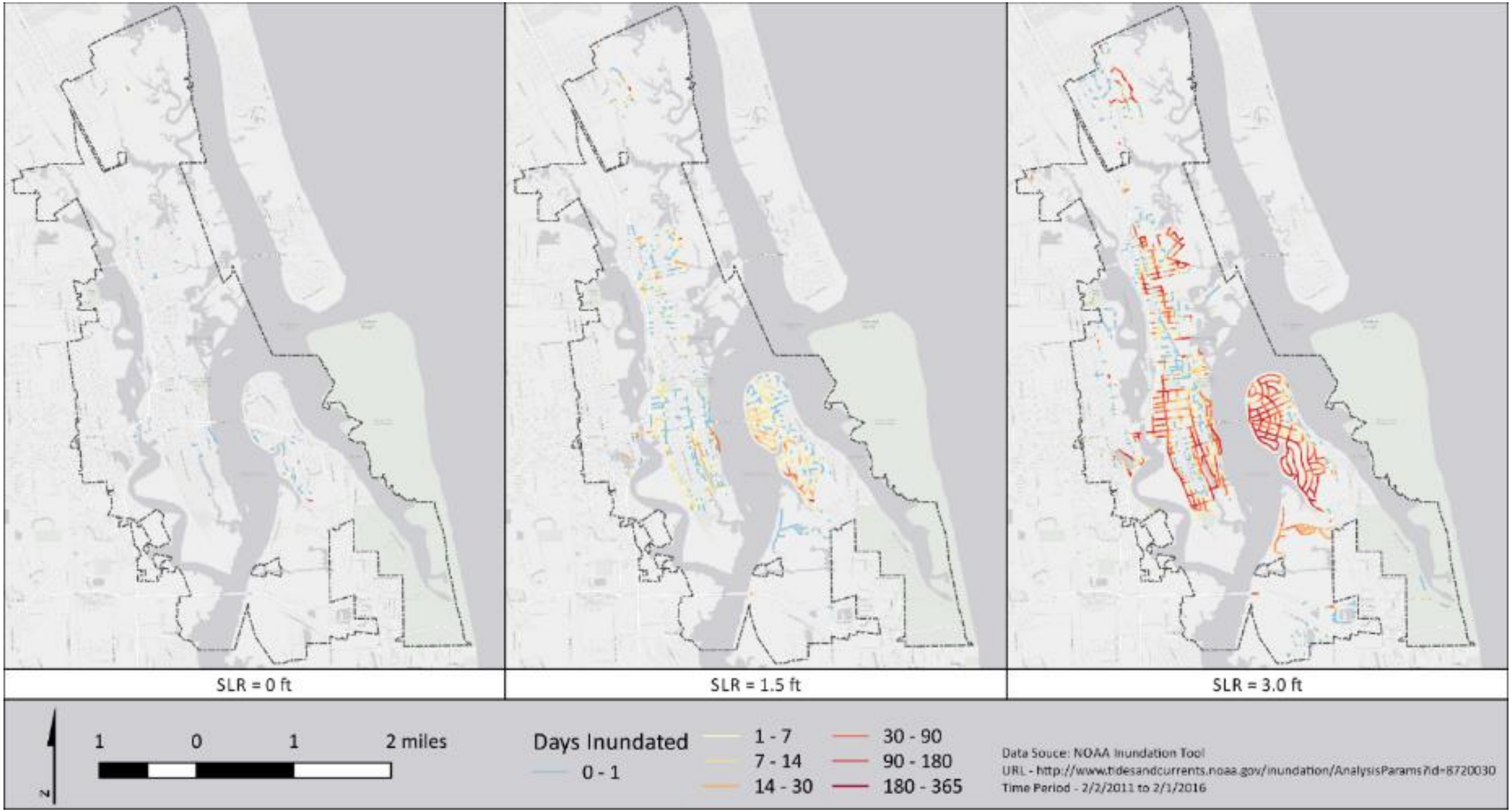


Figure 10. The vulnerability of the road network to nuisance flooding increases significantly from present day conditions with 1.5 and 3 ft of SLR.

4.2. *How will Sea Level Rise Impact Bridge Vulnerability?*

Bridge vulnerability to the different flood hazard types with sea level rise was evaluated in order to identify future changes in the functionality of bridges and associated access routes. It should be noted that bridge deck elevation data was not provided as part of this study. Exposure was evaluated against each flood type and scenario by using a GIS overlay approach, where the mapped floodplain extents were overlaid on top of the asset; this methodology is described in more detail in the Technical Appendix. This approach was implemented in order to identify possible "tipping points" for infrastructure vulnerabilities. When bridge approaches were inundated, the entire bridge was classified as impacted.

Based on the bridge vulnerability analysis, the research team identified a possible tipping point for MHHW around 2 ft of SLR (Figure 7). This tipping point is probably a function of current bridge design standards. For example, if most bridges in St. Augustine were constructed at 2 ft above present-day MMHW elevations, once the water surface surpasses this elevation, bridge approaches will begin to flood more frequently and penetrate further up the bridge approach with increasing sea levels.

Nuisance flooding begins to reduce the number of passable bridges even under low SLR increments (i.e. beginning at 0.5 ft of SLR). At 5 ft of SLR, 7 bridges in St. Augustine become impassable. The steady increase in number of impassable bridges with nuisance flooding and SLR is due to the fact that acceleration in sea level rise reduces the timing between flood events, thus increasing the frequency at which bridge approaches are inundated.

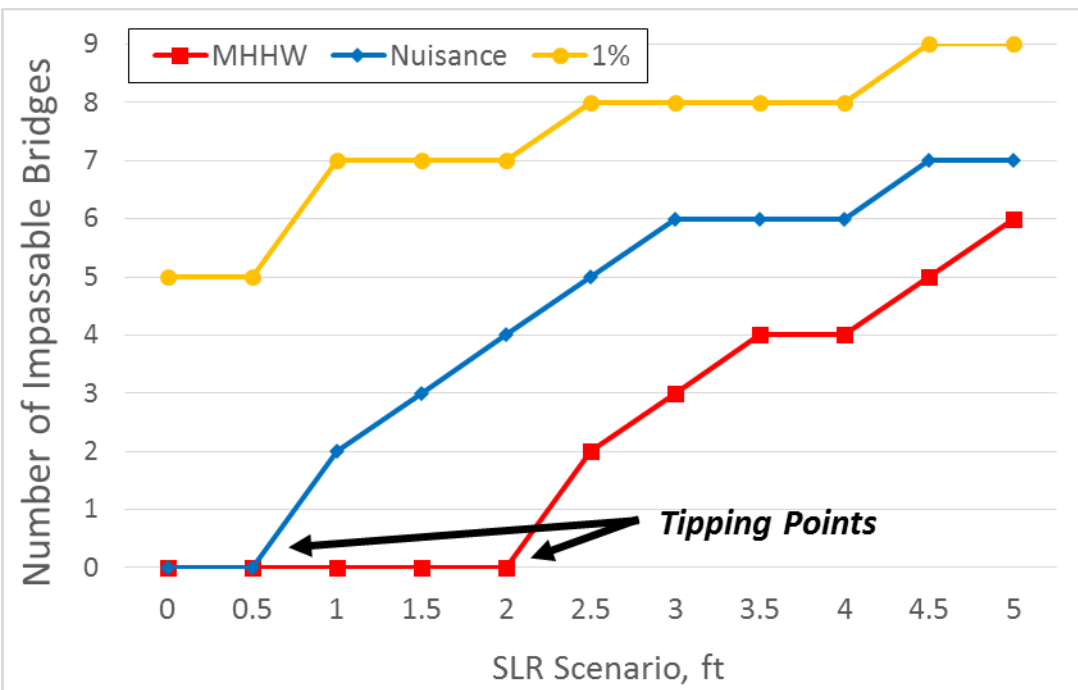


Figure 11. Number of bridges transitioned to impassable by MHHW, nuisance, and the 1% flood level in each SLR scenario.

Under present day conditions (i.e. SLR = 0), the 1% annual chance flood event already impacts bridge passability; specifically, resulting in 5 impassable bridges in the city. With 5 ft of SLR, the 1% event is predicted to result in 4 additional bridges that cannot be accessed. Noted changes in bridge functionality are more attributed to the approaches being flooded rather that total inundation of the bridge. In instances of bridge approaches being flooded, the bridge was classified as unusable no matter how high the span. In terms of bridge functionality during nuisance flood event with SLR, four bridges transition from passable to non-functioning under the 1.5 ft scenario, and two additional bridges become non-functioning under the 3.0 ft SLR scenario (Figure 12).

For bridge functionality during 1% annual chance event with SLR, two bridges transition from passable to non-functioning under the 1.5 ft SLR scenario, and one additional bridge becomes non-functioning under the 3.0 ft SLR scenario (Figure 13). A full tabular summary of bridge vulnerability is provided in Table 9.

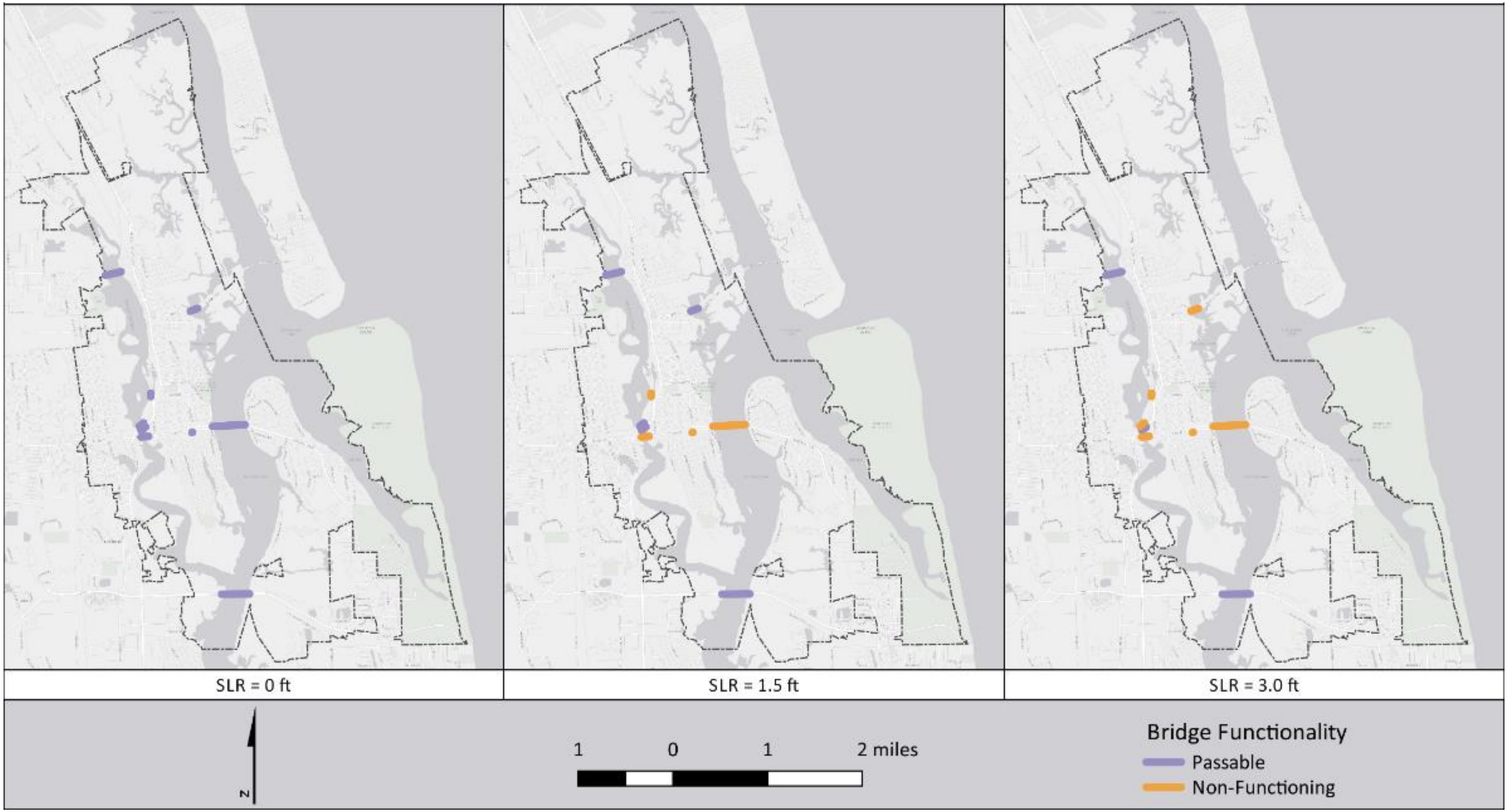


Figure 12. Bridge vulnerability to the nuisance flood event with SLR.

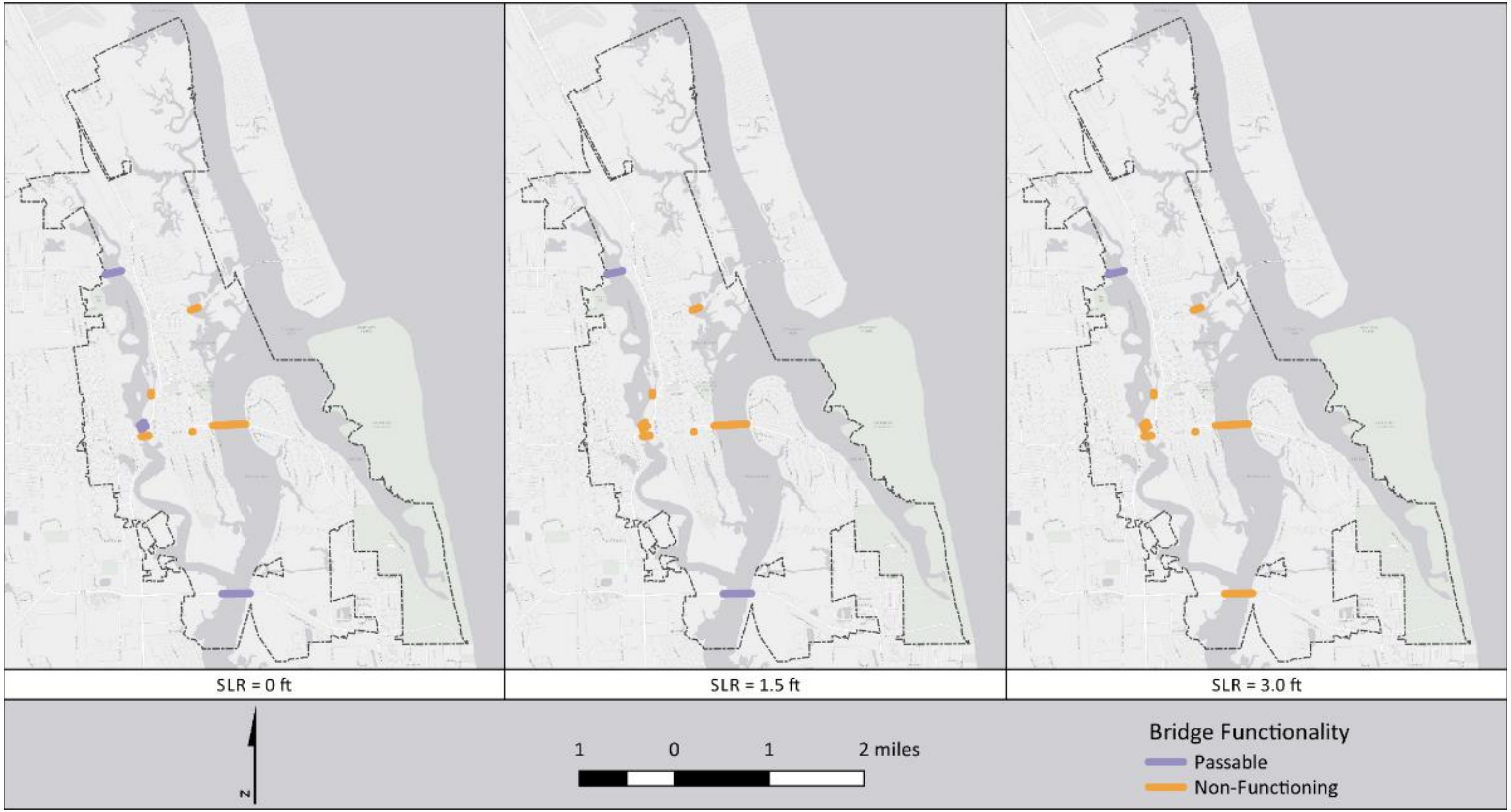


Figure 13. Bridge vulnerability to the 1% annual chance event with SLR.

Table 9. Bridge vulnerability to all flood event SLR scenario combinations. "O" denotes bridge and/or bridge approaches were open or only partially inundated for the selected condition. "F" indicates that the bridge or bridge approaches were fully inundated. In some cases, shallow flooding under the "F" condition would allow the bridge to remain passable.

Bridge Name	MHHW											Nuisance flooding											1% annual chance flood										
	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
San Sebastian Bridge North	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	F	F
FEC Bridge at San Sebastian River North	O	O	O	O	O	F	F	F	F	F	F	O	O	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
FEC Railroad Bridge	O	O	O	O	O	O	O	O	O	O	F	O	O	O	O	O	O	F	F	F	F	F	O	O	F	F	F	F	F	F	F	F	F
San Sebastian Bridge South	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	F	F	O	O	F	F	F	F	F	F	F	F	F
Coate's Bridge	O	O	O	O	O	O	O	F	F	F	F	O	O	O	O	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
Bridge of Lions	O	O	O	O	O	O	F	F	F	F	F	O	O	O	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
Mickler O'Connell Bridge	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	F	F	F	F	F	F
King Street	O	O	O	O	O	F	F	F	F	F	F	O	O	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
Vilano Causeway	O	O	O	O	O	O	O	O	O	F	F	O	O	O	O	O	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
Total Count Per Scenario	**0**	**0**	**0**	**0**	**0**	**2**	**3**	**4**	**4**	**5**	**6**	**0**	**0**	**2**	**3**	**4**	**5**	**6**	**6**	**6**	**7**	**7**	**5**	**5**	**7**	**7**	**7**	**8**	**8**	**8**	**8**	**9**	**9**

4.3. *How will Sea Level Rise Impact Building Vulnerability?*

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

The following trends were identified as an outcome of the building vulnerability assessment, which are graphically represented in Figure 14:

- MHHW:
  - At 2.5 ft of SLR, the number of vulnerable buildings increase by 24 fold over existing vulnerability.
  - With 5 ft of SLR, MHHW becomes equivalent to the current 1% annual chance event.
- Nuisance flooding:
  - With 1 ft of SLR, the number of buildings increase by 17 times the existing vulnerability. This is a possible tipping point for nuisance flooding.
  - As sea level increases 1 and 1.5 ft above current conditions, fold increases triple.
  - Between 3 and 3.5 ft of SLR, the number of buildings exposed to nuisance flooding becomes equivalent to the current 1% annual chance event
- 1% annual chance flooding:
  - Building vulnerability is already high and slowly increases with SLR.

Through all flood types, buildings will be subject to more frequent and deeper floods with SLR.

Table 10. Fold-increases in building vulnerability counts across flood types with increasing SLR scenario. For example, we could expect 1.5 ft of SLR to result in 40 times as many buildings impacted by nuisance flooding than currently impacted by the same event today.

SLR Increment	Flood Type		
	MHHW	Nuisance	1%
0.5	1.1	4.8	1.1
1	1.3	17.5	1.2
1.5	2.0	40.0	1.2
2	5.5	62.9	1.3
2.5	23.6	79.4	1.3
3	69.5	98.0	1.3
3.5	131.3	114.1	1.4
4	182.6	123.9	1.4
4.5	228.6	129.1	1.4
5	271.0	133.7	1.4

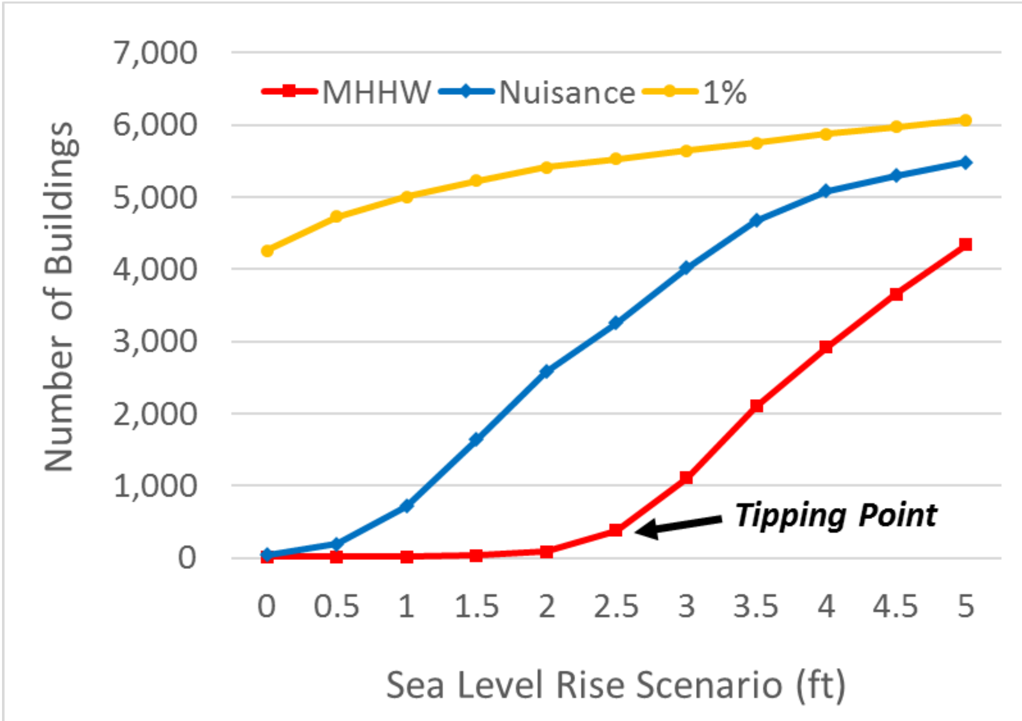


Figure 14. Number of buildings (commercial, residential and municipal) affected by MHHW, nuisance, and the 1% flood level in each SLR scenario.

4.4. *How will Sea Level Rise Impact National Register Historic District Vulnerability?*

In St. Augustine, there are approximately 2,550 historic structures. Exposure was evaluated against each flood type and scenario by using a GIS overlay approach, where the mapped floodplain extents were overlaid on top of the historical structures - this methodology is described in more detail in the Appendix A.

The study effort identified the following trends as a result of the National Register Historic District vulnerability assessment, which are graphically represented in Figure 15 and spatially illustrated in Figure 16 and Figure 17:

- With 1 ft of SLR, there is a tipping point for nuisance flooding where vulnerability begins to increase rapidly.
- With 2.5 ft of SLR, there is a tipping point for MHHW.
- With 3 ft of SLR, nuisance flooding intrudes on 80% of listed National Register areas.
- Under most SLR scenarios (including the baseline), the 1% annual chance event inundates most buildings within Historic Districts.

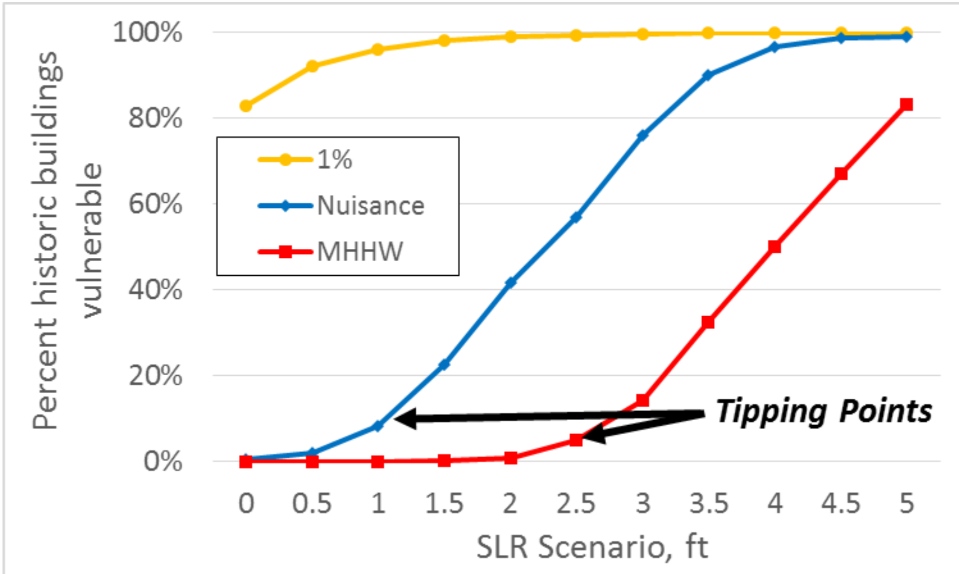


Figure 15. Percentage of buildings within Historic Districts affected by MHHW, nuisance, and the 1% flood level in each SLR scenario.

St. Augustine's historic districts have negligible vulnerability to a nuisance event, as defined by this study, under today's conditions (Figure 17). Vulnerability quickly increases as SLR raises water levels 1.5 ft over existing conditions. Lincolnville, Model Land Company, St. Augustine Town Plan, Abbot Tract, Castillo de San Marcos, and the pending National Park Service historic districts are projected to have 20-50% of their structures vulnerable to flooding in such a condition. The North City historic district is least vulnerable to this condition, with less than 5% of buildings exposed to flooding (Figure 17).

Under a further increase in sea level to 2.5 ft, a nuisance flood would significantly impact most of the downtown historic districts. 75-100% of buildings in the Castillo de San Marco, Model Land, and the pending National Park Service districts are projected to be vulnerable to nuisance flooding under this condition. The Spanish Coquina Quarries district is projected to have the least exposure, with only 5-10% of the building stock vulnerable to nuisance flooding. In general, the impacts from recurrent coastal flooding will result in more harm in these areas given the age of the structures, generally lower first floor elevations, and the additional weathering as a result of frequent inundation to saltwater.

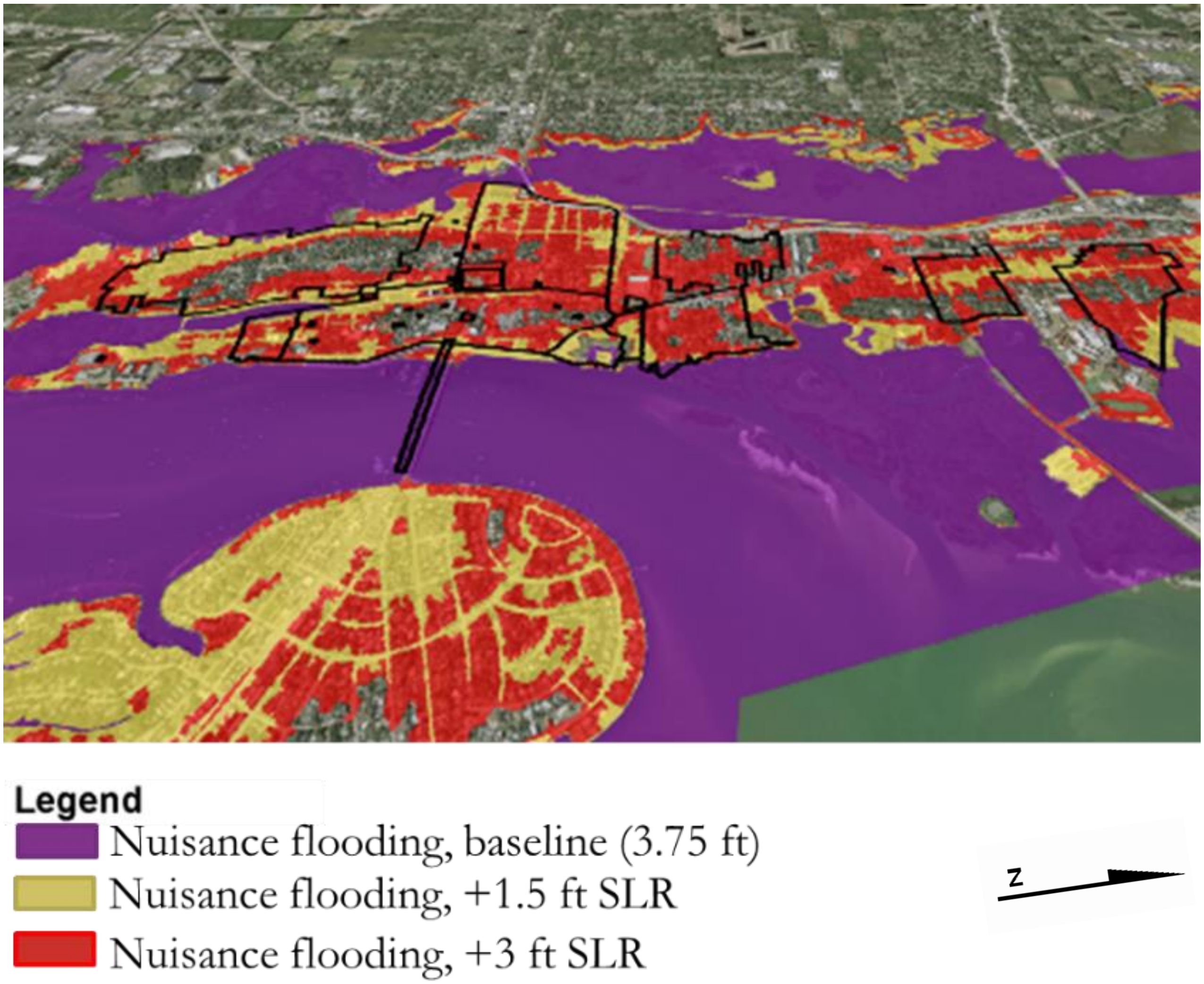
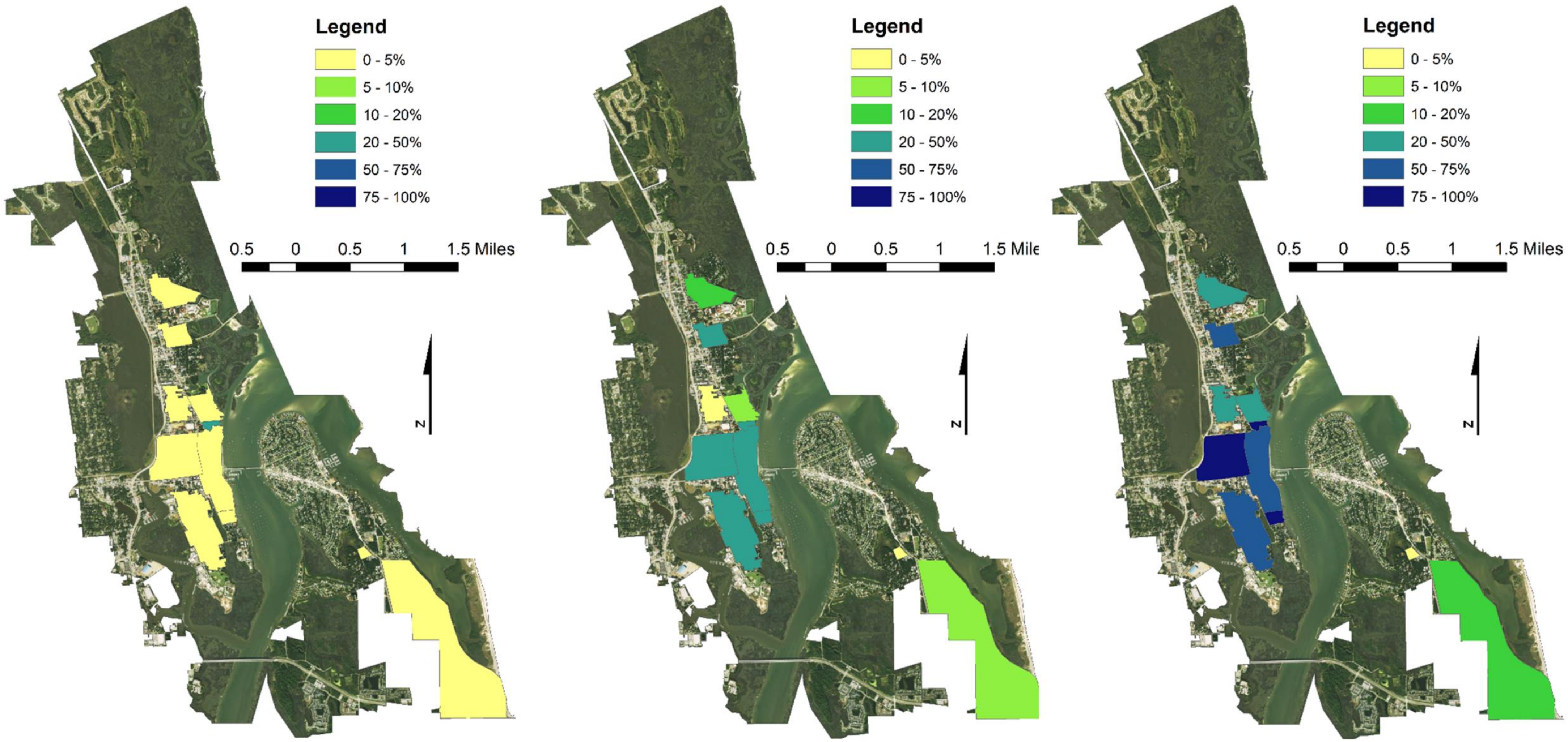


Figure 16. Map depicting flood extents within St. Augustine Historic Districts.



SLR = 0 ft. SLR = 1.5 ft. SLR = 2.5 ft.

Figure 17. Percentage of buildings within the St. Augustine Historic Districts affected by nuisance flooding under representative shorter term SLR scenarios.

4.5. *How will Sea Level Rise Impact Water and Wastewater Treatment Facility Vulnerability?*

This study evaluated the vulnerability of water and wastewater treatment facilities to different flood hazard types with SLR in order to identify key SLR flood elevation thresholds that begin to significantly impact facility structures. Flooded water treatment facilities face a threat of contamination due to saltwater intrusion and flood waters impairing infrastructure. Wastewater treatment facilities that are frequently inundated may experience structural damages that lead to releases of untreated waste. Flood damage would be costly to both types of facilities in terms of threat to public health and financial lost.

The study did not find that the St. Augustine Water Plant was vulnerable to flooding to the identified events and SLR scenarios. This facility is fairly insulated from the impacts of flooding as it is situated outside of the 1% annual chance floodplain.

The St. Augustine Wastewater Treatment Plant, however, is more vulnerable to flooding; the northern portion of the facility tends to flood first, followed by a slower encroachment of water from all sides of the southern portion (Figure 18). Under baseline conditions (i.e. SLR = 0), the facility is relatively insulated from the impacts of MHHW and nuisance flooding because it is protected by berms and adjacent wetlands (shaded blue area in Table 11). However, MHHW with 3.5 ft of SLR leads to some flood encroachment on the 3 structures located within the northern portion of the facility. The structures are impacted by a nuisance flood event with only 2 ft of SLR. With a nuisance flood event and 4.5 ft of SLR and a 1% annual chance event and only 1 ft of SLR, the flood extent propagates across the road and begins to impact the structures located in the center of the facility. With a nuisance flood event with 5 ft of SLR or a 1% annual chance with only 1.5 ft of SLR, the entire facility is impacted by flooding.

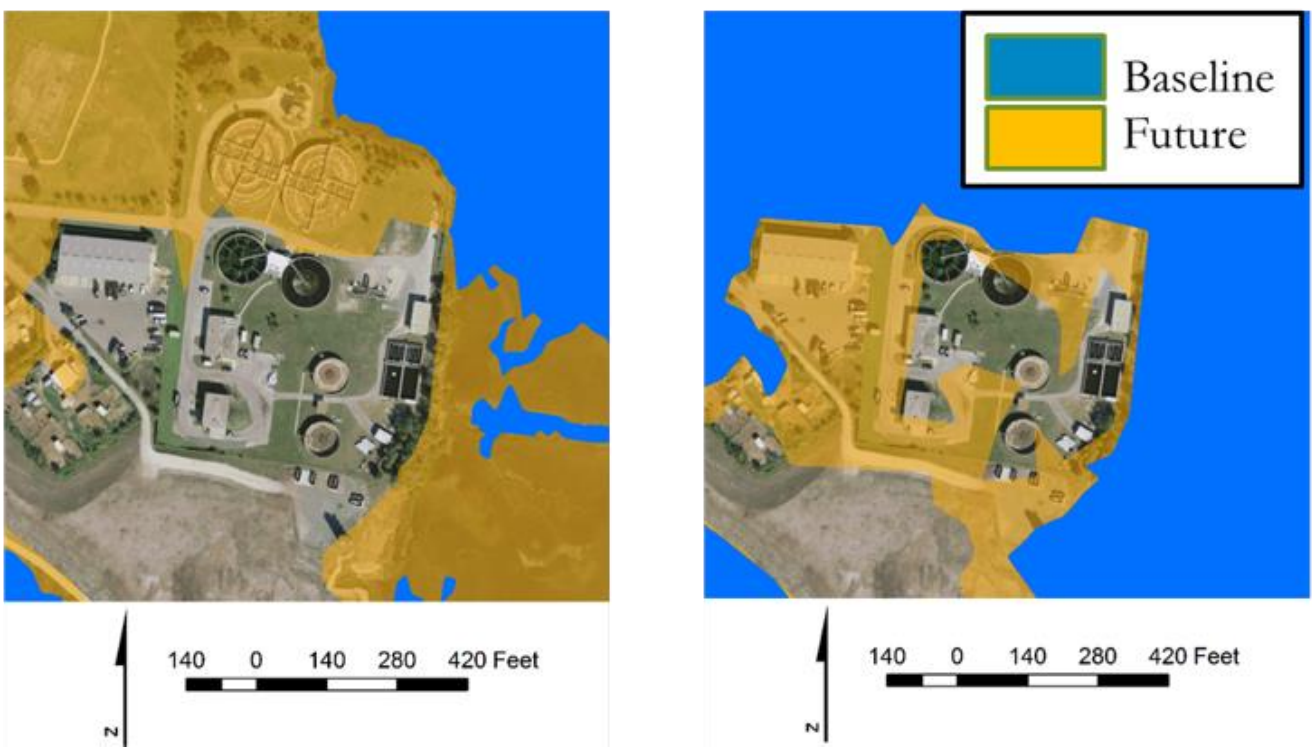


Figure 18. Wasterwater treatment plant structure exposure tipping points to MHHW + 5 ft SLR (left) and to the 1% Event + 1.0 ft SLR (right).

Table 11. Vulnerability of St. Augustine Wastewater Treatment Plant to each flood type and SLR scenario.

SLR Flood Elevation in Feet	MHHW	Nuisance	1%
0	None	None	Some
0.5			
1.0			Major
1.5			Total
2.0		Some	
2.5			
3.0			
3.5	Some		
4.0			
4.5		Major	
5.0		Total	

Legend	
None	No flood impact
Some	Impact to some structures (<=3)
Major	Impact to the majority of structures
Total	Total encroachment

4.6. *How will Sea Level Rise Impact Archaeological Resource Vulnerabilities?*

In St. Augustine, there are 17 archaeological zones and 12 cemeteries (Figure 19). Mapped floodplain extents were overlaid on top of archeological resources in order to compute the percentage of area inundated under the different flood hazard types and SLR scenarios.

The overall takeaways from the archeological resource vulnerability assessment are:

- Congregation of Sons of Israel Cemetery is not vulnerable to flooding for any flood event and SLR combinations.
- For MHHW with SLR, most cemeteries and archeological resources are not vulnerable to flooding impacts under low SLR scenarios; however, impacts steadily grow under higher SLR scenarios.
- Most cemeteries in St. Augustine are not exposed from nuisance flooding under baseline conditions; however, some archeological zones are already impacted by these events. As sea level rise accelerates, the timing between nuisance flood events will shorten and archeological resources will begin to experience increased flood effects, with some zones becoming completely inundated even under low amounts of SLR.
- Most cemeteries and archeological zones are vulnerable to the 1% annual chance event, even under baseline conditions; with increasing SLR, these impacts increase rapidly.
- Many archeological zones and cemeteries experience large, sudden jumps in extent of flooding, which are likely a result of archeological resources with fairly uniform elevations; once a threshold elevation is reached, the majority of area is vulnerable to inundation.

The following sub-sections assess vulnerability of both archeological zones and cemeteries to each flood type with increasing SLR.

Figure 19. Archeological zones and cemeteries located in St. Augustine. For graphic simplicity, note that not all cemeteries are labeled.

4.6.1. Mean Higher High Water with Sea Level Rise

For MHHW under baseline conditions (i.e. SLR = 0 ft), some archeological zones are fairly insulated from the impacts of flooding under low SLR scenarios; for example, Zone II C, Zone II D, Zone II E, and Zone II F do not experience any flooding until 1.5 ft of SLR. However, other archeological zones steadily grow in percentage of inundated area with increasing SLR; for example, Zone IA goes from having only 1% of total area inundated to almost 90% of total area inundated with 5 ft of SLR (Table 12).

For MHHW under baseline conditions (i.e. SLR = 0 ft), most of the cemeteries in St. Augustine area fairly insulated from the impacts of flooding., with the exception of the Nombre de Dios Cemetery that experiences 6% of total area inundated. Many of the cemeteries remain insulated from flooding impacts even under high SLR scenarios, with the exception of a few cemeteries that become completely inundated beginning at 4 ft of SLR (Table 13).

Table 12. Percentage of inundated area in St. Augustine archeological zones with MHHW plus SLR. Row becomes blue when zone is completely inundated.

Zone	Sea Level Rise Increment (Feet)										
	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Zone I A	1%	2%	2%	2%	3%	11%	20%	31%	48%	70%	89%
Zone I B	0%	0%	1%	4%	8%	13%	25%	38%	55%	69%	78%
Zone I C	23%	25%	27%	28%	30%	34%	46%	63%	74%	83%	90%
Zone I D	31%	32%	33%	34%	39%	48%	54%	60%	68%	75%	81%
Zone I E	51%	61%	70%	78%	79%	80%	81%	85%	87%	90%	92%
Zone II A	6%	8%	8%	9%	11%	13%	17%	32%	47%	61%	75%
Zone II B	50%	52%	53%	56%	62%	71%	83%	100%			
Zone II C	0%	0%	0%	0%	1%	6%	17%	26%	36%	50%	80%
Zone II D	0%	0%	0%	0%	2%	8%	11%	30%	37%	46%	59%
Zone II E	0%	0%	0%	0%	0%	0%	4%	17%	39%	80%	92%
Zone II F	0%	0%	0%	0%	0%	0%	0%	55%	100%		
Zone II G	38%	39%	39%	40%	40%	41%	43%	43%	45%	47%	48%
Zone II H	0%	17%	20%	20%	27%	29%	35%	38%	45%	52%	57%
Zone III A	8%	8%	8%	8%	9%	14%	26%	37%	51%	65%	75%
Zone III B	19%	22%	23%	24%	25%	28%	31%	40%	43%	47%	52%
Zone III C	3%	4%	4%	4%	4%	6%	8%	11%	14%	17%	21%
Zone III D	45%	49%	50%	51%	54%	57%	61%	64%	68%	71%	74%

Table 13. Percentage of inundated area in St. Augustine cemeteries with MHHW plus SLR. Row becomes blue when zone is completely inundated.

Cemetery	Sea Level Rise Increment (Feet)										
	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Congregation of Sons of Israel Cemetery	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Flagler Family Tombs	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%	10%
Franciscan Monastery Cemetery	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
Gen. William W. Loring Memorial	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	
Government House Hospital Cemetery	0%	0%	0%	0%	0%	0%	19%	42%	79%	100%	
Nombre de Dios Cemetery	6%	6%	8%	12%	14%	20%	30%	36%	42%	47%	58%
Nuestra Senora de la Soledad Cemetery	0%	0%	0%	0%	0%	0%	0%	5%	13%	27%	53%
OC Lightner Gravestone	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
Old Huguenot Cemetery	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
St. Augustine National Cemetery	0%	0%	0%	0%	0%	0%	8%	13%	20%	54%	100%
St. Augustine Parish Cemetery	0%	0%	0%	0%	0%	2%	7%	38%	98%	100%	
Tolomato Cemetery	0%	0%	0%	0%	0%	0%	0%	47%	100%		

4.6.2. Nuisance Flooding with Sea Level Rise

For nuisance flooding under baseline conditions (i.e. SLR = 0 ft), many archeological zones are already experience substantial flooding. With increasing SLR, the timing between nuisance flood events will decrease and archeological zones will begin to experience larger portions of inundated land, some zones becoming completely inundated even under low amounts of SLR; for example, Zone II B becomes completely inundated with 2 ft of SLR (Table 14).

Table 14. Percentage of inundated area in St. Augustine archeological zones with nuisance flooding plus SLR. Row becomes blue when zone is completely inundated.

Zone	Sea Level Rise Increment (Feet)										
	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Zone I A	3%	7%	16%	26%	38%	60%	81%	94%	97%	97%	97%
Zone I B	6%	10%	17%	30%	47%	62%	71%	82%	96%	100%	
Zone I C	29%	32%	36%	55%	69%	79%	86%	91%	94%	95%	97%
Zone I D	38%	43%	52%	58%	66%	72%	78%	86%	93%	98%	100%
Zone I E	79%	80%	81%	84%	87%	89%	92%	94%	96%	99%	100%
Zone II A	10%	12%	15%	27%	41%	54%	70%	84%	97%	99%	100%
Zone II B	58%	65%	79%	96%	100%						
Zone II C	1%	3%	11%	22%	31%	42%	61%	90%	100%		
Zone II D	0%	3%	9%	18%	33%	39%	50%	73%	88%	100%	
Zone II E	0%	0%	0%	9%	27%	56%	90%	96%	99%	100%	
Zone II F	0%	0%	0%	23%	82%	100%					
Zone II G	40%	41%	42%	43%	44%	47%	48%	67%	84%	97%	99%
Zone II H	0%	28%	33%	36%	41%	49%	53%	57%	61%	65%	69%
Zone III A	8%	10%	19%	32%	44%	58%	70%	79%	90%	97%	99%
Zone III B	26%	28%	32%	38%	41%	45%	49%	53%	56%	59%	65%
Zone III C	5%	5%	6%	9%	12%	16%	19%	23%	28%	33%	37%
Zone III D	53%	56%	59%	62%	66%	70%	72%	75%	79%	82%	84%

For nuisance flooding under baseline conditions (i.e. SLR = 0 ft), many cemeteries in St. Augustine are insulated from the impacts of flooding, with the exception of Nombre de Dios Cemetery with 13 % of total land area already flooded. The Congregation of Sons of Israel Cemetery remains resilient under all SLR scenarios because of its high elevation. However, there appears to be a tipping point for other cemeteries, such as the Franciscan Monastery Cemetery that transitions from 24% of total area flooded with 3.5 ft of SLR to complete inundation with 4 ft of SLR. These large jumps in extent of flooding is likely a result of cemeteries with fairly uniform elevations; once a threshold elevation is reached, the majority of area is vulnerable to inundation (Table 15).

Table 15. Percentage of inundated area in St. Augustine cemeteries with nuisance flooding plus SLR. Row becomes blue when zone is completely inundated.

Cemetery	Sea Level Rise Increment (Feet)										
	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Congregation of Sons of Israel Cemetery	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Flagler Family Tombs	0%	0%	0%	0%	0%	0%	0%	53%	77%	85%	99%
Franciscan Monastery Cemetery	0%	0%	0%	0%	0%	0%	0%	24%	100%		
Gen. William W. Loring Memorial	0%	0%	0%	0%	0%	14%	100%				
Government House Hospital Cemetery	0%	0%	0%	26%	55%	92%	100%				
Nombre de Dios Cemetery	13%	16%	27%	33%	39%	45%	52%	59%	70%	100%	
Nuestra Senora de la Soledad Cemetery	0%	0%	0%	4%	6%	16%	34%	44%	100%		
OC Lightner Gravestone	0%	0%	0%	0%	0%	0%	0%	100%			
Old Huguenot Cemetery	0%	0%	0%	0%	0%	0%	97%	100%			
St. Augustine National Cemetery	0%	0%	0%	9%	16%	30%	83%	100%			
St. Augustine Parish Cemetery	0%	0%	4%	13%	47%	100%					
Tolomato Cemetery	0%	0%	0%	14%	100%						

4.6.3. 1% Annual Chance Event with Sea Level Rise

For the 1% annual chance event under baseline conditions (i.e. SLR = 0 ft), a significant portion of archeological zones already experience inundation. For example, Zone II B and Zone II F are already completely inundated during a 1% annual chance event. With 2.5 ft of SLR, most archeological zones are completely (or almost completely) inundated (Table 16).

For the 1% annual chance event under baseline conditions (i.e. SLR = 0 ft), most of the cemeteries in St. Augustine area already completely flooded, with the exception of the Congregation of Sons of Israel Cemetery that is insulated from the impacts of all SLR scenarios (Table 17).

Table 16. Percentage of inundated area in St. Augustine archeological zones for the 1% annual chance event with SLR. Row becomes blue when zone is completely inundated.

Zone	Sea Level Rise Increment, ft										
	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Zone I A	89%	96%	96%	97%	98%	98%	99%	99%	100%		
Zone I B	79%	93%	100%								
Zone I C	90%	93%	95%	96%	98%	100%					
Zone I D	86%	94%	99%	100%							
Zone I E	92%	94%	97%	100%							
Zone II A	83%	97%	99%	100%							
Zone II B	100%										
Zone II C	75%	97%	100%								
Zone II D	62%	81%	97%	100%							
Zone II E	86%	96%	99%	100%							
Zone II F	100%										
Zone II G	45%	60%	70%	83%	91%	97%	99%	99%	99%	99%	99%
Zone II H	53%	58%	62%	65%	68%	74%	80%	86%	88%	88%	89%
Zone III A	74%	83%	93%	99%	100%						
Zone III B	60%	63%	66%	71%	75%	80%	84%	87%	89%	90%	92%
Zone III C	21%	25%	30%	35%	39%	49%	55%	61%	65%	71%	77%
Zone III D	68%	72%	74%	77%	82%	84%	87%	90%	94%	97%	99%

Table 17. Percentage of inundated area in St. Augustine cemeteries for the 1% annual chance event with SLR. Row becomes blue when zone is completely inundated.

Cemetery	Sea Level Rise Increment (Feet)										
	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Congregation of Sons of Israel Cemetery	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Flagler Family Tombs	11%	59%	71%	95%	100%						
Franciscan Monastery Cemetery	0%	100%									
Gen. William W. Loring Memorial	100%										
Government House Hospital Cemetery	100%										
Nombre de Dios Cemetery	63%	73%	100%								
Nuestra Senora de la Soledad Cemetery	53%	100%									
OC Lightner Gravestone	100%										
Old Huguenot Cemetery	100%										
St. Augustine National Cemetery	100%										
St. Augustine Parish Cemetery	100%										
Tolomato Cemetery	100%										

4.7. *Aquifer and Water Table Changes*

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

4.7.1. What are the Primary Mechanisms of Saltwater Intrusion?

In the coastal zone, the water table typically lies above mean sea level and groundwater flows from higher elevation inland areas toward lower elevation coastal areas. This natural movement of freshwater towards the ocean prevents saltwater from intruding into coastal aquifers by maintains the position of the interface between freshwater and saltwater (Barlow 2003). However, observations of long-term declines in the potentiometric surface and increases in chloride concentrations associated with saltwater intrusion are increasing concerns in northeastern Florida. The principal areas of saltwater intrusion in the Floridan aquifer system in northeastern Florida have been in Duval and St. Johns County (Spechler 1994). The inland movement of the saltwater interface in northeast Florida is due to a combination of factors, including:

- Lateral encroachment from the ocean due to excessive water withdrawals from coastal aquifers that share a hydraulic connection with the sea (i.e. pumping-induced saltwater intrusion).
- Upconing of saline water from deeper zones in the aquifer.
- Fractures in coastal rock formation creating conduits for saline intrusion (Figure 20).
- Short and long-term sea level changes (tidal fluctuations and SLR) inducing saltwater interface migration and water table rise.

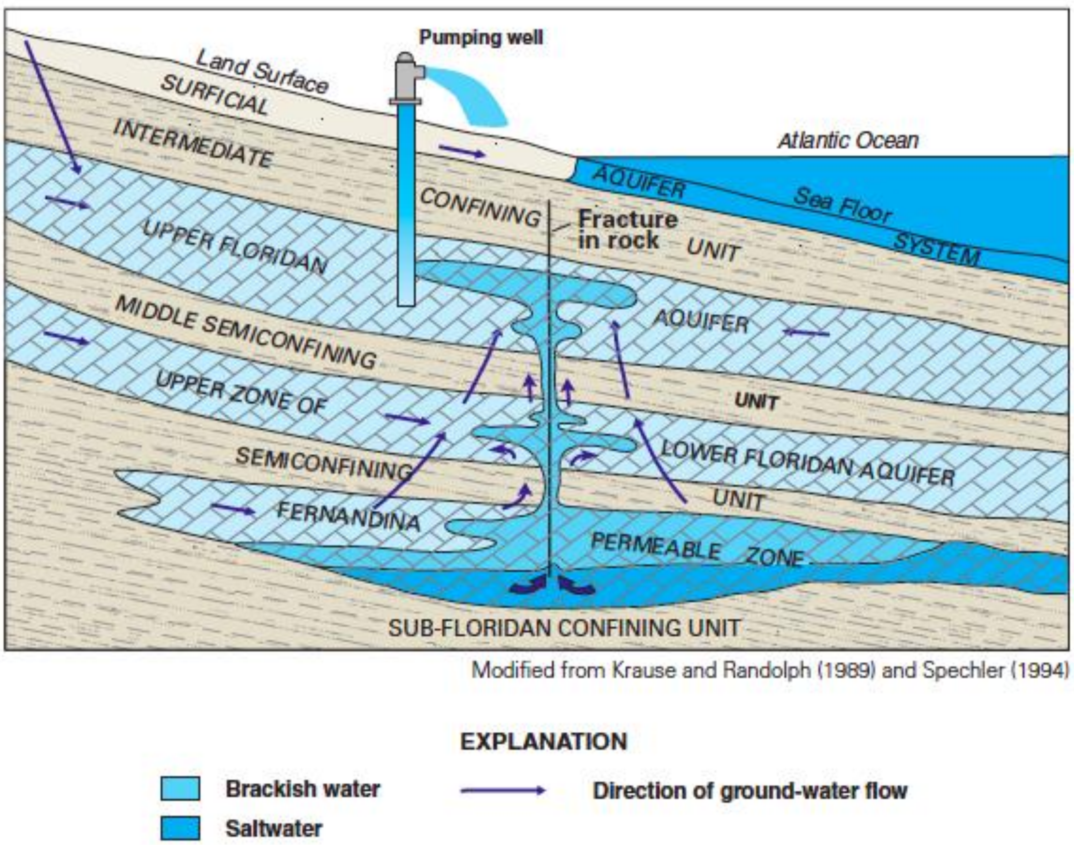


Figure 20. Model of saltwater leakage along fractures in the Floridan aquifer system in northeastern Florida. These fractures provide preferential conduits for saline water to flow upward into freshwater zones in response to groundwater pumping in the upper aquifers. Figure obtained from Barlow (2003).

Local hydrogeology studies of the Floridan aquifer system attribute the majority of observed saltwater intrusion to Mechanism 4 where upward movement of saline water is occurring along both vertical and horizontal fractures or joints and solution collapse features such as the paleokarst features in the Upper Floridan aquifer (Spechler 2002). Mechanism 1 also plays an important role as industrial and agricultural expansion and population growth in northeastern Florida have resulted in significant increases in water withdrawals form the Florida aquifer system, resulting in pumping-induced saltwater intrusion (Spechler 1994).

Information on trends in salinity, chloride concentrations, and the potentiometric surface of the Florida aquifer system provides insight into potential vulnerabilities of the system to SLR and saltwater intrusion. St. Augustine is situated within a high-salinity zone of the aquifer system, defined as areas having greater than 10,000 mg/L of total dissolved solids and generally associated with coastal areas of high-permeability (Williams and Kuniansky 2015). Saltwater intrusion into freshwater aquifers in northeastern Florida has resulted in observable increases in groundwater chloride concentrations (Williams and Kuniansky 2015). Maps of chloride concentrations in the Upper and Lower Floridan aquifers illustrate the general transition zone between fresh and saltwater (Barlow 2003). Chloride concentrations in the Upper Floridan aquifer are generally related to proximity to the coast and groundwater flow. In areas where the upper confining unit is thin or absent, recharge and groundwater circulating is high. These areas of high permeability results in groundwater that readily dissolves the carbonate rocks that compose the aquifer system, creating conduits that transmit and store tremendous volumes of groundwater. Chloride concentrations tend to be low (less than 250 mg/L) in these areas where high groundwater circulation is high. Conversely, where the groundwater flow system is tightly confined, concentrations in the aquifer tend to be higher (Barlow 2003). Additional information and maps of chloride concentrations and the potentiometric surface are included in the Technical Appendix.

4.7.2. What are the Anticipated Changes in the St. Augustine Water Table?

While well-field withdrawals and fractures in the aquifer sediments are major drivers of the inland migration of the saltwater interface in the Floridan aquifer system, sea-level rise has the potential to exacerbate the extent and magnitude of saltwater intrusion (Langevin and Zygnerski 2013). Sea-level rise accelerates the migration of the salt-freshwater interface and lifts the water table closer to the ground surface, resulting in a form of coastal flooding called groundwater inundation (Rotzoll and Fletcher 2012). Groundwater inundation originates from below the land surface as sea-level rise and/or heavy rainfall lift the water table to an elevation that penetrates the land surface with groundwater, which can consist of freshwater, saltwater, or brackish water. Over time, continuing declines in the potentiometric surface resulting from decreased rainfall or increased water use

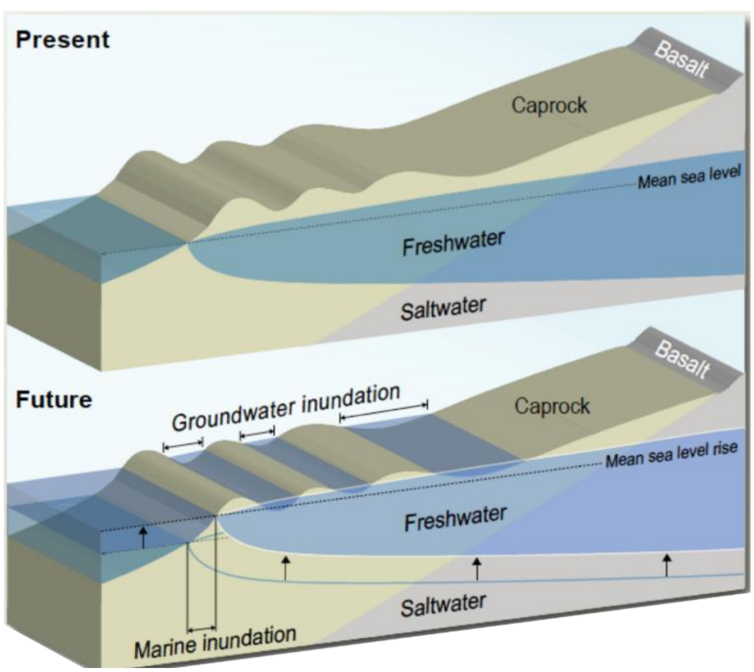


Figure 21. Conceptual diagram of groundwater inundation, obtained from Rotzoll and Fletcher (2012).

coupled with accelerated rates or relative SLR in northeastern Florida have the potential to shift the natural balance between recharge and discharge. For example, during times of simultaneous sea-level driven water table rise and pumping-induced potentiometric surface decline, the increase in vertical head difference might induce accelerated rates of saltwater intrusion. Furthermore, the permeable nature of the surficial aquifer system in St. Johns County, especially in areas along the coast where sediments consist of limestone, make St. Augustine more susceptible to sea-level driven water table rise and saltwater contamination. An in-depth qualitative analysis of anticipated changes in the water table in St. Augustine would require a long-term groundwater-level monitoring network with dense coverage in order to study past trends and forecast future scenarios.

5. DISCUSSION

The results of the City of St. Augustine's Vulnerability Assessment provide quantitative and qualitative building blocks for the next phase of the project, Adaptation Planning. The City's staff were instrumental in providing feedback throughout the project from the questionnaire, to the design meeting, to the review of draft results. In order to focus the assessment, the City chose to quantify how much land could be lost to inundation by different flood hazard types with SLR, identify major pathways of flooding in St. Augustine, evaluate how SLR will change flood frequency, and to assess possible vulnerabilities to the built environment and the sub-surface environment (i.e. the aquifer system underlying the City of St. Augustine). The uncertainties associated with sea level rise require the city to take a pragmatic approach as to how it proceeds with addressing the vulnerabilities identified in this report. This report is not meant to identify all possible future impacts from sea level rise but helps to prioritize those issues most concerning to the city staff at the present time and may serve as a starting point for additional vulnerabilities as the science changes and more planning resources become available. The results of this report and the documentation of the planning process throughout will be captured as part of the State's Community Resiliency Initiative and thus help other communities facing stressors from sea level rise.

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APPENDIX A: TECHNICAL APPROACH

A-1 Flood Hazard Elevations

The mean higher high water datum (MHHW) tidal datum is defined by NOAA as the "The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch." In practice, elevations below this datum are typically "wetted" or "near-wetted" by tides on a daily basis by the higher high tide. A base, "present day" MHHW surface was established using the NOAA VDatum software, which provided for a continuous, spatially variable value across the community geography. The surface was created by first establishing a regular point grid over the study area. The point grid was then input into the VDatum software to return the MHHW elevation relative to NAVD88, the datum of the topographic base. The base coverage output from VDatum was limited to "water" areas, and did not intersect the topographic at the MHHW elevation. This was corrected by extrapolating the coverage until intersection was consistently achieved throughout the county.

Nuisance flooding was defined in the design meeting as a level of flooding that occurred 12-17 times a year. In present day, this flood type results in shallow flooding of roads which limits use. NOAA reports a nuisance flood elevation of 2.38 ft at the Mayport FL NWLON (Station ID 8720218). Given discussion with the community, consensus was that this value was too low.

Review of water levels record at Mayport indicated that there are not regular instances where the water level goes above 4 ft elevation on a regular basis. Similar review at Fernandina did show regular instances of water levels exceeding 4 ft; however this location is further away and has a slightly higher tidal range as compared to St. Augustine. It had been noted at the design meeting that onshore winds and accompanying waves tend to pump water into the inlet and raise the water level as it piles up against the historical St. Augustine peninsula. This process likely explains the difference between the observed water levels at Mayport. A series of initial nuisance flood delineations were made in 0.25 ft increments from 3.5 to 4.5 ft. A nuisance elevation of 3.75 ft was established as the best baseline value for nuisance flooding through these pictorials in conjunction with the reported levels from the tidal stations.

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

A-2 Implementation of SLR Conditions

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

A-3 Flood Layer Production

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

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

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

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

A-4 Road Vulnerability Assessment

To complete the road vulnerability assessment, St. Augustine road network data available from the City GIS resources were densified into 100 ft sections, split, and then each segment was then attributed with minimum ground elevation values from the study digital elevation model. Although segments were densified to 100 ft, individual segments were more on the order of 30 ft due to line geometry. Values were exported to an attribute table and then summary statistics were performed to generate road elevation probability and cumulative density functions.

Flood vulnerability was assessed using the NOAA inundation tool, using NWLON station 8720030 at Fernandina Beach. The tool was unavailable at St. Augustine, Fernandina Beach was a suitable location given that the St. Augustine station (8720576) is a subordinate station with established tidal ratios to Fernandina. The NOAA inundation tools allows a five-year window query window to establish water level exceedance counts and duration to a specific elevation. Exceedance values were established at 0.1 m (~0.33 ft) increments using a reference 5-year time period 2/2/2011 to 2/1/2016. Elevations were related to St. Augustine using the NOAA-established high-tide ration of 0.75 (relative to MLLW – e.g. 1 m (MLLW) at Fernandina is 0.75 m (MLLW) at St. Augustine. Results of this analysis are shown in Figure A-1.

It should be noted that, based on this analysis the nuisance flood level, defined as 3.75 feet should not have received any flooding during the five years from 2/2/2011 to 2/1/2016. From observations this is known to be not the case. This suggests that there is some mechanism for surge/runup in St. Augustine which is not captured in the NOAA tidal relationships. Given this, it is likely that the results underpredict the potential frequency of flooding for existing and future conditions.

The final step of the analysis was to relate the table to road segments. Road segments were selected by location using the nuisance flood extent polygons and then attributed with flood frequency values. The amount of roads (length and percent of total) in the community subject to nuisance flood frequency were then summarized by SLR increment (Figure 22).

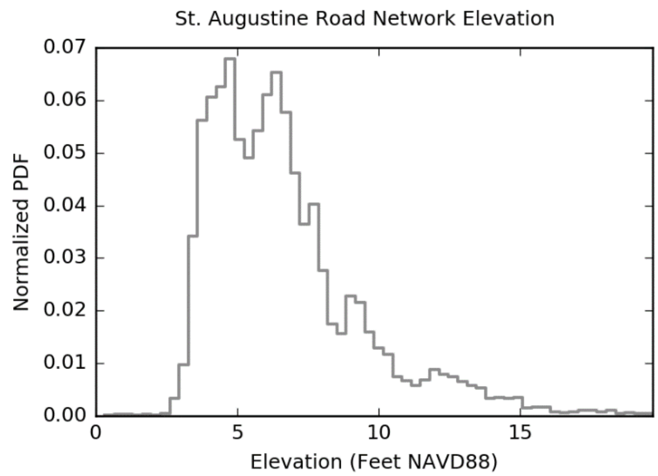

Figure A-1. St. Augustine road network elevation, probability density function.

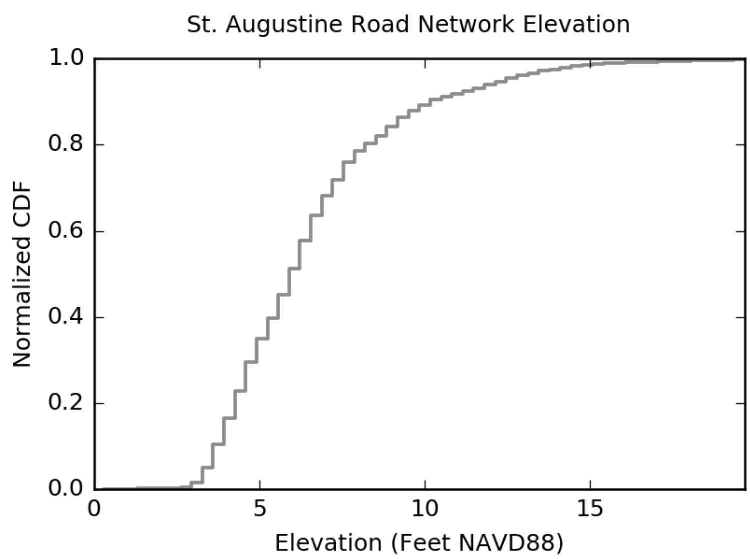

Figure 23. St. Augustine road network elevation, cumulative distribution function.

A-5 GIS Overlay on buildings and infrastructure:

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

A-6 Groundwater Impacts

A-6.1 Hydrogeological Setting

The city of St. Augustine is situated within the St. Johns River Water Management District (SJRWMD). The hydrogeology of the area consists of two main aquifer units: the surficial aquifer system and the Floridan aquifer system. The Floridan aquifer system, composed chiefly of limestone and dolomite, behaves as one aquifer over much of its extent; although, the system is subdivided vertically into upper and lower permeable zones: the Upper and Lower Floridan aquifers, which are separated by both confining and semiconfining units that control the movement of water between the two aquifers (Figure 1; Barlow 2003; Spechler 2002; Belaineh et. al 2011; Williams and Kuniansky 2015). In St. Augustine, the surface of the Upper Floridan aquifer system is composed primarily of Oscala Limestone or equivalent sediments (Williams and Kuniasky 2015). The surface of the Upper Floridan is also characterized as a paleokarstic plain exhibiting erosion and collapse features. Seismic reflection investigation in St. Johns County also revealed the presence of buried collapse and other karstic features (Spechler 2002). These unique hydrogeological features provide conduits of high vertical hydraulic conductivity, promoting hydraulic connectivity between fresh groundwater and more saline zones within the aquifer system and the bordering marine environment (Spechler 2002).

The surficial aquifer, or water table aquifer, that overlies the Floridan aquifer system is generally unconfined and consists mostly of sand and locally contains gravel and sandy limestone. Along the coast extending from St. Augustine southward to Palm Beach County, limestone composed of cemented shells and quartz sand form a laterally extensive permeable zone, which is the principle water-producing unit in the surficial aquifer system (Spechler 1994). Within the SJRWMD, the surficial aquifer ranges in thickness from approximately 25 to 50 feet, forming a thin irregular blanket of terrace and alluvial sands that serve as an important sink layer for temporary storage of groundwater that ultimately recharge the underlying Floridan aquifer system (Williams and Kuniansky 2015).

Table A-1. Generalized hydrogeological units of the St. Johns River Basin, modified from Belaineh et. al 2011.

<table>
<tr><th>Geologic Age</th><th>Stratigraphic Unit</th><th colspan="2">Hydrogeological Unit</th><th>Lithologic Description</th></tr>
<tr><td>Pleistocene and Holocene (5.3 Ma to present)</td><td>Pleistocene and Holocene deposits</td><td colspan="2">Surficial aquifer system</td><td>Sand, shell, and clay lenses</td></tr>
<tr><td>Pliocene (5.3 to 2.6 Ma)</td><td>Late Miocene or Pliocene deposits</td><td colspan="2" rowspan="2">Intermediate aquifer system (intermediate confining unit and intermediate aquifer)</td><td rowspan="2">Clay, marl, and discontinuous beds of sand, shell, dolomite and limestone</td></tr>
<tr><td>Miocene (23 to 5.3 Ma)</td><td>Hawthorn Formation</td></tr>
<tr><td rowspan="3">Eocene (56 to 34 Ma)</td><td>Oscola and Suwannee Limestone</td><td rowspan="3">Floridan aquifer system</td><td>Upper Floridan (upper and lower zones)</td><td>Very porous limestone</td></tr>
<tr><td>Avon Park Formation</td><td>Middle semiconfining unit</td><td>Leaky, low permeability limestone and dolomite</td></tr>
<tr><td>Oldsmar Formation</td><td>Lower Floridan aquifer</td><td>Porous limestone</td></tr>
<tr><td>Paleocene (65 to 56 Ma)</td><td>Cedar Keys Formation</td><td colspan="2">Sub-Floridan confining unit</td><td>Low permeability anhydrite beds</td></tr>
</table>

A-6.2 Chloride Concentrations and the Potentiometric Surface

Chloride concentrations in the SJRWMD are illustrated in Figure A-3, with highest concentrations (greater than 1000 mg/L) along the St. Johns River and the southeastern extent of St. Augustine. Research suggests that the anomalously high chloride concentration in these areas is a result of two main processes: (1) residual seawater that entered the aquifer during the Pleistocene when sea level was higher (at least 25 feet higher than present sea levels), which has not been completely flushed out by modern freshwater and (2) brackish water flowing upward from the underlying Floridan aquifer along fracture zones and conduits within the aquifer system (Spechler 2001; Belaineh et. al 2011).

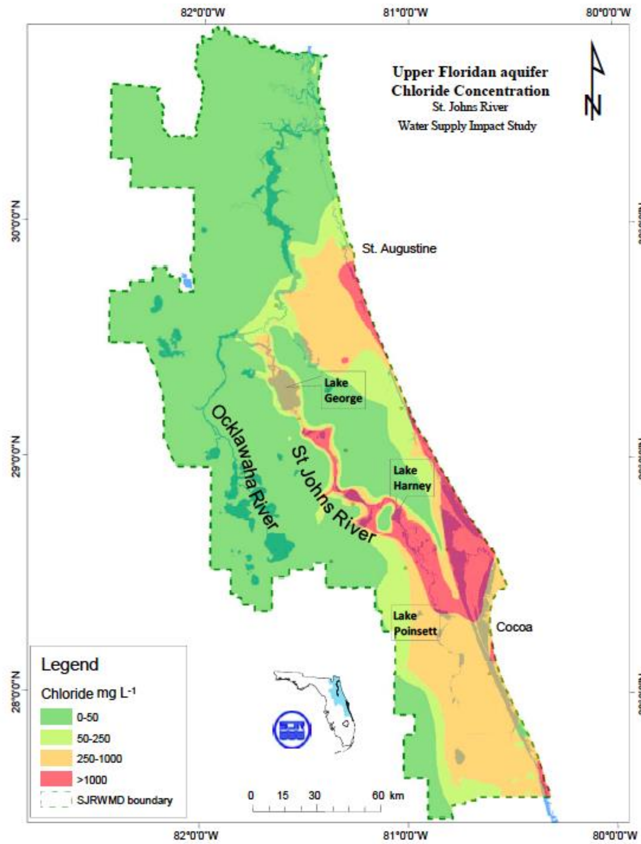

Figure A-3. Chloride concentration of the Upper Floridan aquifer within SJRWMD, obtained from Belaineh et. al (2011).

The potentiometric surface is an imaginary surface to which water from an artesian aquifer (under confining conditions) will rise in tightly cased wells that penetrate the aquifer (Spechler 2002), illustrating the top of the groundwater surface in an aquifer. Potentiometric surface maps are similar to water table maps as both show the horizontal direction and gradient of groundwater flow; however, water table maps show the level of saturation in the unconfined aquifer whereas a potentiometric surface does not represent the physical top of water table but rather the potential energy that is available to move groundwater.

The SJRWMD records trends in potentiometric surface in the Floridan aquifer system. The generalized configuration of the present potentiometric surface for the Floridan aquifer in the SJRWMD is shown in Figure A-4, representing conditions in March 2016 (between seasonal high and seasonal low water levels). In March 2016, the potentiometric surface underlying St. Augustine ranged from 10 to 20 feet above sea level. It should be noted that the potentiometric surface of the Upper Floridan aquifer is constantly fluctuating in response to seasonal variations in rainfall and groundwater withdraws (Spechler 2002); therefore, Figure A-4 represents a discrete snapshot in time. However, long-term observations show a gradual decline in the potentiometric surface of the Floridan aquifer system at a rate of approximately one-third to three-fourths foot per year as a result of increased pumping in northeastern Florida (Williams and Kuniansky 2015). Figure A-5 illustrates recent annual change in the potentiometric surface from March 2015 to March 2016. During this time, the potentiometric surface declined between 0 and -4 feet in St. Johns County. Depressions in potentiometric surfaces are often associated with an increase potential for movement of saline water into freshwater zones due to an increase in the vertical head difference between zones (Spechler 2002; Williams and Kuniansky 2015).

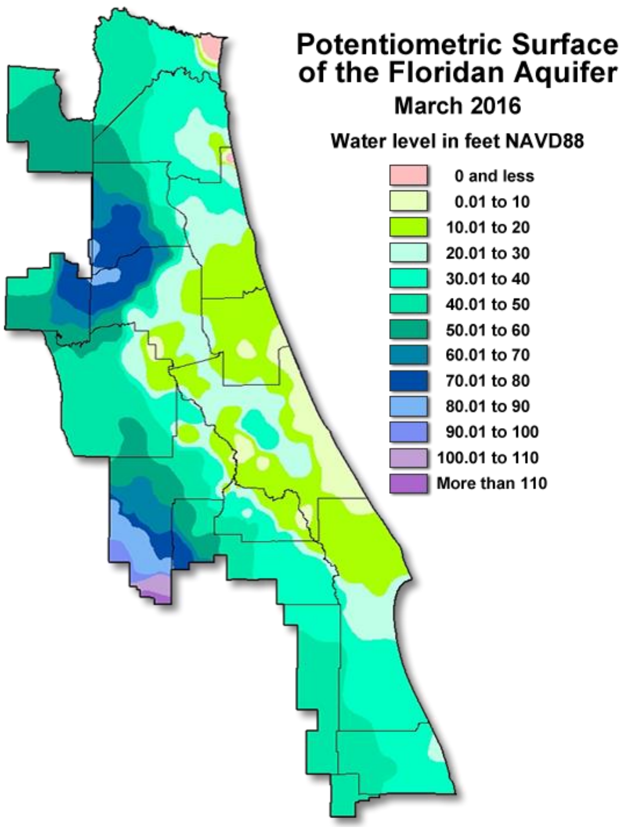

Figure A-4. Potentiometric surface of the Floridan Aquifer in March 2016. Figure obtained from the SJRMD using measured water levels in wells. Units represent the level to which the water in the confined aquifer would rise within a well, in height above mean sea level (or NAVD88 vertical datum).

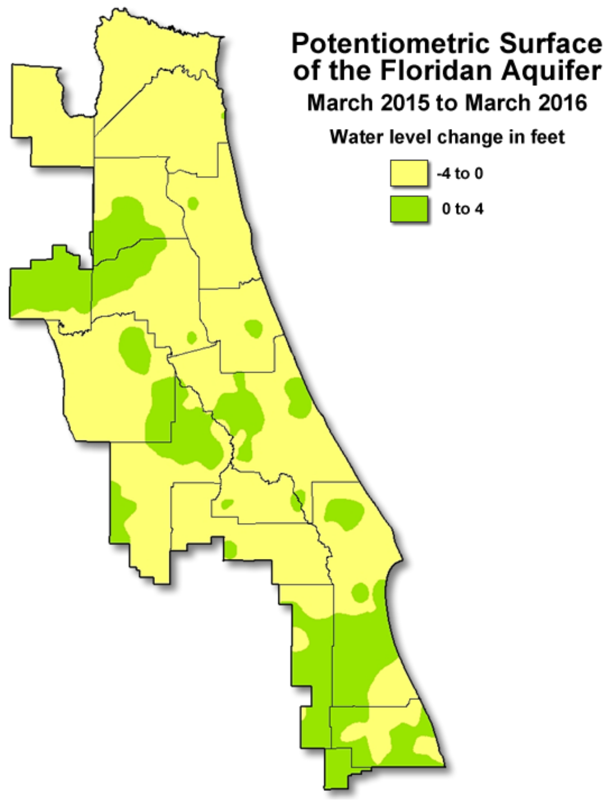

Figure A-5. Change in potentiometric surface of the Floridan Aquifer from March 2015 to March 2016. Figure obtained from the SJRMD using measured water levels in wells. Units represent the level to which the water in the confined aquifer would rise within a well, in height above mean sea level (or NAVD88 vertical datum).

APPENDIX B: DESIGN MEETING

Attendees:

Name	Organization	Contact
Martha Graham	City of St. Augustine	mgraham@citystaug.com
Reuben Franklin	City of St. Augustine	rfranklin@citystaug.com
Bill Mendez	City of St. Augustine	bmendez@citystaug.com
David Birchim	City of St. Augustine	dbirchim@citystaug.com
Jenny Wolfe	City of St. Augustine	jwolfe@citystaug.com
Sean Reiss	Florida Department of Economic Opportunity	Sean.Reiss@deo.myflorida.com
Brian Batten Krista Rand Chris Zambito	Dewberry	bbatten@dewberry.com krand@dewberry.com czambito@dewberry.com

Priorities:

- Realistic options for adapting the city's historical resources to sea level rise
- Realistic options for adapting the city at large while also managing aging infrastructure
- Understanding tipping points for when facilities and buildings will be compromised
- Positioning the city to obtain funding for planning (master planning, capital improvement planning)

Breakout Session Action Items:

Preservation of Historical and Archaeological Resources Action Items
Identify threats to historic resources • Needs: SLR maps • State historical resources point files are obtained from FL DHR • St. Augustine supplies historical zoning • (Optional): Reuben has a point file with a non-comprehensive catalogue of state elevation certificates
Obtain elevations of historic assets • St. Augustine will apply for funding • FL DEO may be able to provide funding through community planning technical assistance grants
Develop a methodology to show the value of historical and archaeological resources • Jenny provides a document produced by FL concerning the economic value of historical resources • County visitor information can provide a source of economic value of tourism • FL DEO may be able to provide funding through community planning technical assistance grants
Identify low impact, engineering-based adaptation options • Jenny provides the standards related to historic preservation (which must also be considered) • St. Augustine supplies GIS of historical districts • St. Augustine supplies records of recorded structures • Jenny supplies GIS of downtown archaeology • Needs: a list of options

Discussion

- Many historical resources are low lying or below grade and the city needs a clear idea of what their resources are
- The city struggles with modern building codes: FEMA rules, floodplain management, and preservation rules are often at odds
- The city does not want to lose their national historical treasures, which are integral to the city's identity
- The economy is based on tourism focused on these historical treasures
- Downtown buildings on the National Historic Register are a special concern
- The Historic Architecture Review Board (HARB) has to approve any changes to buildings or sites before permitting
- Adaptation of roadways and other infrastructure should not negatively impact historic resources
- It would be useful to assign a financial value to these resources to support protection through grant applications
- How much can we lose before losing the value of our community?
- 47 Cordova St. property *has* been successfully elevated; this is a historical structure, so there is precedent
- Is there a point at which moving or elevating a structure degrades its status as a historical resource?
- HARB has shown some flexibility in allowing floodproofing on new construction, but with respect to hazard mitigation, does not prefer one method over another for historical resources

Financial Planning for Adaptation Action Items

Examine fee-based strategies to protect historical resources

- Follow-up with Sean about whether other communities have used Adaptation Action areas for fee assessment
- Needs: adaptation cost estimates

Identify federal and state cost-sharing opportunities

- One option may include FL DEP Coastal Partnership
- Needs: other funding opportunities

Enhance county and regional relationships on matters of regional resilience

- City of St. Augustine pursues
- Needs: guidance on conducting a workshop with the county or other partners

Identify documentation that would support meeting climate change/resilience requirements in grants (especially federal)

- Needs: guidance

Discussion

- Discovering what types of funding may be available for St. Augustine is one of the reasons the city joined the pilot
- The city is defined as a "disadvantaged city" based on population versus the number of tax-exempt properties (e.g. historic or institutions such as Flagler College and the Florida School for the Deaf and the Blind), although some state properties voluntarily contribute
- General fund revenue is very low and there are negligible tax mechanisms to collect from tourists

- The stormwater user fee is based on impervious area, but only funds a bare bones staff and budget. Raise?
- Community Redevelopment Areas may provide funds for adaptation activities
- For planning projects with the State Division of Historical resources, matching funds are required
- Federal funds for projects affecting historical resources require mitigation analysis
- If property values decline (due to SLR), the result will be declining fees from this source
- Can fee schedules be adjusted?
- Can Adaptation Action Areas be instituted and used as the basis for fee assessment?
- The seawall repair headed by FEMA was an overly lengthy process
- Is the USACE a potential funding resource? The State?
- It will be important to gain commitment to adaptation on a regional scale
- Will developing a sea level strategy plan help the city qualify for funds?

Conservation Action Items
Create development incentives and entitlements related to conservation • Planning and Building pursues
Identify professionals or university support for a city-wide greenhouse gas and energy audit • Planning Office pursues • University of Florida may be a useful resource
Discussion
• Appealing activities may ultimately involve activities such as low impact development (city promotes this) and lowering fuel consumption and greenhouse gas emissions • Runoff could be managed through limiting impervious area, onsite retention and rain barrels • Potential partners include St. John County, citizens, the city government, college, hospitals, and schools • Uncertain of public reception to conservation initiatives • Some institutions in the community are very proactive on conservation • The city recycling program took a while to catch on, but is now popular. This is city-run • It would be useful to have goals or targets in mind to explain how potential fee increases will be used • Low-hanging fruit may include more recyclable carryout containers • Realistically, the impact on SLR will be negligible • Gaining public involvement and support will be essential • Energy conservation: LED lighting products that fit historic preservation guidelines of providing "warm" light do exist • Expectation is that regulatory standards will come mainly from the federal level

Infrastructure Action Items
Show the economic valuation of the loss of infrastructure • Martha can provide a baseline valuation • Needs: maps of at-risk infrastructure

Risk-based asset adaptation prioritization

- Needs: adaptation recommendations

Identify funding sources for master planning and capital improvement planning that includes sea level rise

- St. Augustine pursues
- Needs: maps (made for other tasks) will be used to support the planning

Develop a tidal inundation traffic tool

- Needs: feasibility of incorporating an existing NOAA tool
- Needs: possible shortcuts to developing a traffic tool

Consider effects on Lake Maria Sanchez project's level of services

- St. Augustine will review the project using maps (made for other tasks)

Discussion

- The city has aging infrastructure in a low-lying coastal area.
- Road elevations at many locations are not above the 100-year flood event
- Stormwater backs up and inundates, taking capacity away from the system
- Pumping stations are aging
- Water distribution systems are composed of old pipe, principally galvanized steel, being replaced gradually with PVC
- Some important water facilities are
    - The wastewater treatment plant next to the Matanzas River
    - The water treatment plant, which is further inland
    - There are seven wells pumping from the Floridan Aquifer, on which reverse osmosis is performed
    - Some septic tanks exist, but mostly at higher elevations
- Transportation facilities include
    - Downtown parking garage
    - Fleet maintenance facilities
    - City Hall
    - Two city-owned cell towers
- Some infrastructure is shared or owned by other entities. US1, A1A and San Marco are DOT-owned, and the outfalls for these roads are shared by the city
- What is utility vulnerability to saltwater intrusion?
- How far inland is SLR expected to contribute to saltwater intrusion?
- It may be useful to work toward decentralizing the utility systems through the master planning and capital improvement planning
- Archaeology regulations and needs must also be considered
- Options like shared cares and decentralizing transportation may be desirable
- Communications and power providers are FPL, Comcast, AT&T, Verizon and Teco Gas.
- The city can provide a baseline valuation of their infrastructure

APPENDIX C: LESSONS LEARNED

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

- Scoping the Vulnerability Assessment
  - Going through an iterative process (questionnaire, kickoff discussion, facilitated design meeting) was helpful to gather feedback from multiple stakeholders and focus the community's priorities.
  - Less is more. The vulnerability assessment is technical in nature and limited funding constrains the complexity of analysis that can be performed for each assessment. Once draft results were presented, it was clear that the participants would rather have detailed discussions for a few assessments as opposed to limited-detailed discussions of many assessments.

- Data Quality/Availability
  - Limitations in data, such as finished floor elevations, resulted in how some of the assessments could be performed.

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

- Opportunities to Build on the Vulnerability Assessment
  - An economic analysis of the impacts of the discussed flood events would be helpful to the community.
  - Due to limitations in the available data and budget, impacts from the changes in depth of flooding was not possible. The City may want to invest additional resources to identify finished floor elevations and perform an improved vulnerability analysis, such as a depth-damage assessment. This would allow them to quantify impacts further and look to ancillary impacts such as potential changes to flood insurance and building codes.