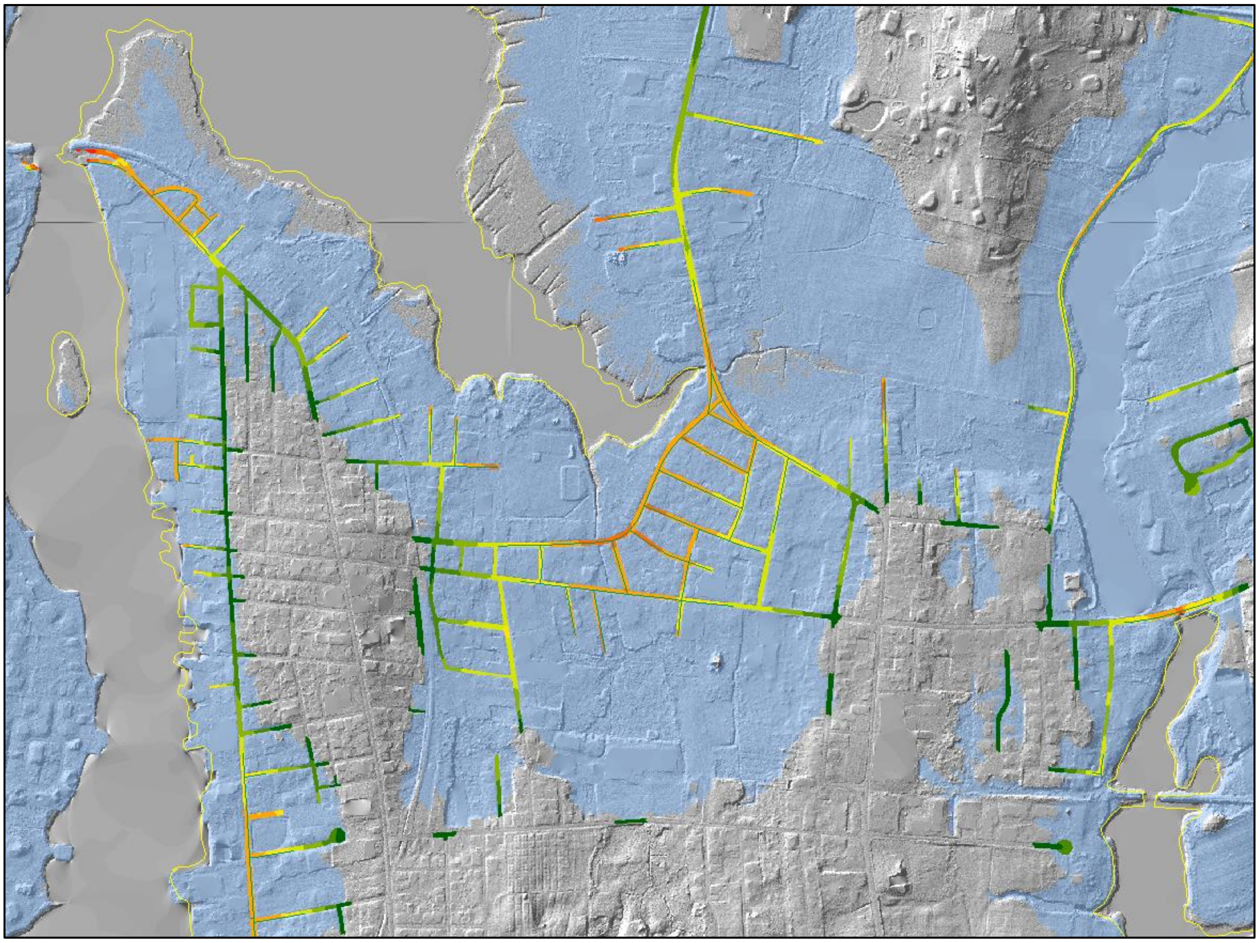
Geospatial Analysis of Sea Level Rise in Warren, Rhode Island



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Executive Summary:

This geospatial analysis of sea level rise for Warren, Rhode Island is a continuation of ongoing storm inundation mitigation planning for the municipality. Warren is a coastal town located in northeastern Rhode Island, abutting Narragansett Bay. Much of the densely populated downtown area of Warren has an elevation below 20- ft above sea level. Due to Warren's low-lying extent, the municipality is vulnerable to the impacts of sea level rise and flooding from storm events. The town is already experiencing regular nuisance flooding under present sea levels, with costly impacts on the town's residences, businesses, and infrastructure.

The URI Coastal Institute (CI), through its **Climate Response Demonstration Site** initiative, has been working with the Town of Warren for several years, collaborating with town officials and others to identify and study adaptation strategies to promote resilience of the community and enhance ecosystem sustainability in the face of climate change. Warren, and neighboring Barrington, make up the "mixed use" demonstration site — one of three sites in the state where the CI is working with community officials and land managers to explore adaptation strategies that address sea level rise and coastal flooding at different locations across the state that were selected to represent shoreline types common in RI (natural areas, urban waterfronts, and mixed-use communities). An important reason leading to the selection of Warren and Barrington as a demonstration site is inundation modeling that reveals extensive low elevation areas of high-density development in this area are especially vulnerable to flooding associated with sea level rise and storm surge.

The goal of this project was to develop a suite of data products to assist town officials in medium and long-term decision making. Products include maps of flooding extent, maps showing density of structural damage, and tabulated data that summarize impacts of flooding (e.g., linear feet of roadway flooded under various scenarios). In addition, this project has resulted in a robust suite of ready-to-use geospatial data layers (both raster and vector data layers) that can be tailored to fit specific future analysis needs. All analyses presented in this report were conducted using ArcGIS Desktop Version 10.6. Selected examples of map products are included as appendices to this report.

The methodology for this study is broken into three distinct geospatial analyses, to examine the effects of sea level rise and storm flooding on:

1) Roadways in Warren, (for all management authorities)

2) Structures in Warren (regardless of ownership), and

3) The density of affected structures in Warren.

Each step in the analysis process built upon the findings of the previous steps and will support future research topics.

The process began with the analysis of roadways, finding that even at current sea levels, potential flooding from extreme storms (e.g., 100-yr return period events) can inundate large segments of the road network, causing portions of the town to be inaccessible by roadway. Further, the 30-year projected sea level rise in the region is expected to be 3 feet above current levels (Rhode Island Coastal Resources Management Council, BeachSAMP 2018). Under these conditions entire neighborhood blocks will become inaccessible under normal tide ranges, and with the addition of a storm surge, neighborhood blocks will be inundated by several feet of flood water.

Floodwater depth on road surface (feet) - Intersection of Market St and Redmond St				
Sea Level Rise Scenario	Mean higher-high water	1-year storm return period	25-year storm return period	100-year storm return period
0 Ft	--	1.37	9.37	12.37
1ft	--	2.37	10.37	--
2ft	0.31	3.37	11.37	14.59
3ft	1.31	4.37	12.37	17.67
5ft	3.30	6.36	14.36	18.27
7ft	5.30	8.36	16.36	19.73
10ft	8.30	11.36	19.36	22.92

The next stage in the analysis was to examine the extent of structural damage for a 100-year storm under three different sea level rise scenarios: current sea level, 2-ft sea level rise, and 5-ft sea level rise. This analysis considered the structure category and damage functions developed by the US Army Corp of Engineers (USACE) as part of the North Atlantic Comprehensive Coastal Study (NACCS). (For example, the NACCS damage functions estimate that a ground level structure with a basement will sustain more damage than an elevated structure without a basement during a coastal flood event.) The analysis finds under current conditions, upwards of 192 structures will be significantly damage (sustaining greater than 50% damage) during a 100-year storm event. With 2-foot and 5-foot sea level rise scenarios, the same 100-year event will cause significant damage (greater than 50% damage) to approximately 380 structures, and 618 structures, respectively.

Count of Damaged structures by Sea Level Rise Scenario, with 100-yr storm			
Sea Level Rise Scenario	<50% structure damage	>50% structure damage	Total
SLR0	643	192	835
SLR2	650	380	1,031
SLR5	722	618	1,340

The final stage of the analysis was to prepare maps showing the density of damaged structures to help identify specific neighborhoods where flood risk is greatest and where the town may want to consider targeted adaptation options such as property buyouts. Warren town officials suggested focusing on Warren census block 305 as a first analysis area due to the common nuisance flooding in this area. As was expected, the analysis confirms that census block 305 (generally between Market St, Everett St, and Child St.) is an area with a higher density of damaged structures, when compared to the rest of Warren. Additionally, the analysis found problem areas along Warren's western boundary and in the southeastern part of town.

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INTRODUCTION

Warren, Rhode Island is a coastal community situated on the northeastern side of Narragansett Bay, located in Bristol County, 9.5 miles southeast of Providence, and borders Massachusetts. While Warren is a geographically small municipality of approximately 6.25 square miles, the town has over 18 miles of waterfront along Narragansett Bay.

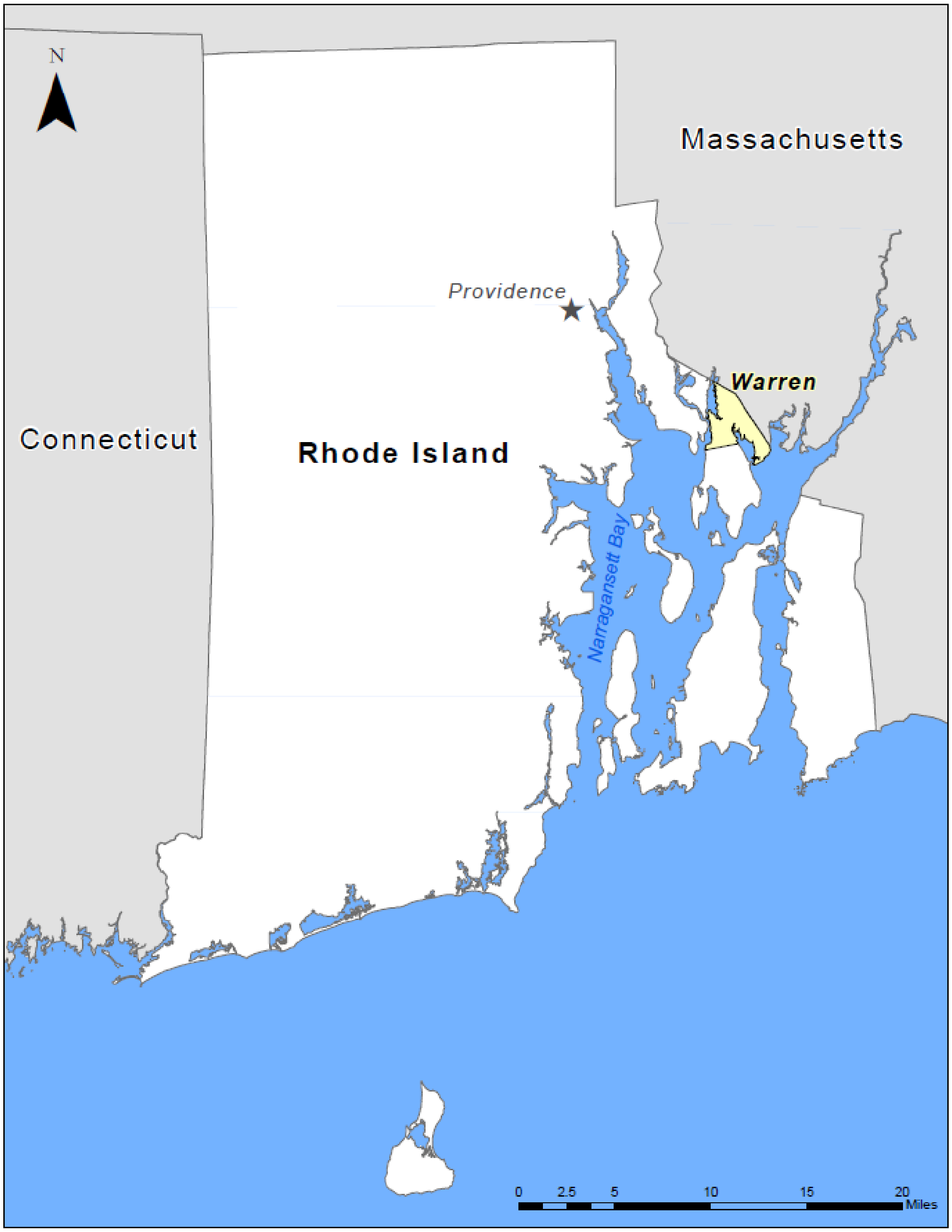


Figure 1- Warren location map.

The town of Warren has been proactive in planning for sea level rise and inundation from coastal storm events. Warren is already experiencing effects of flooding and storm inundation under current sea levels. During periods of extremely high tide or “king tides,” a reverse storm flow can cause sea water to percolate up from storm drains onto the roadways. Because large portions of the town are low-lying (i.e., less than 20’ above sea level) even minor storms can cause significant flooding in town.

Images- At the intersection of Market Street and Redmond Street, Vehicles traveling west on Market street through flood water. Photo credit: Janet Freedman.

This analysis of sea level rise and storm surge contributes to ongoing work at the University of Rhode Island's Coastal Institute (CI), as part of its Climate Response Demonstration Site initiative. This project leverages and builds on the extensive modeling and analysis of flooding in the state developed as part of the Shoreline Change Special Area Management Plan, called BeachSAMP for short (Rhode Island Coastal Resources Management Council, 2018). BeachSAMP is an extensive document detailing the effects of sea level rise and storm surge on Rhode Island's coastline for the purpose of informing state and local decision makers to guide medium- and long-term decision making. As a result of the 2018 BeachSAMP project, several geospatial data layers were produced from models of sea level rise and storm surge. These resulting data layers are collectively referred to as "STORMTOOLS," they are available free to the public in the form of GIS raster layers for download, or as online interactive map viewers from the STORMTOOLS website. STORMTOOLS geospatial data was the starting point for this more detailed examination of Warren Rhode Island. All analyses were conducted using in ArcGIS Desktop Version 10.6

ROADWAY ANALYSIS

The geospatial analysis on the effects of sea level rise in Warren began with an evaluation of the road network within the town, regardless of management authority. The analysis aimed to identify roads that would be inundated by floodwater under present and future sea level rise conditions, and to what extent. Several roadways are slated for re-pavement by Rhode Island Department of Transportation (RIDOT) in the coming years. Given the projected rise in sea level for the region, the town and state are evaluating whether resurfacing roadways at their current elevation is warranted, as storm inundation will increasingly cause these roads to be submerged and inaccessible at regular intervals.

Roadway Analysis Data sources

Two important data sources were used for the road analysis: (i) STORMTOOLS Sea level rise raster geodatabases, and (ii) Roads_Polygons. STORMTOOLS sea level rise raster geodatabases were developed by the University of Rhode Island, Environmental Data Center and RICRMC. STORMTOOLS data layers show inundation from 0ft, 1ft, 3ft, 5ft, 7ft, and 10ft sea level rise scenarios, with each geodatabase also containing storm flooding at various return periods/ flood envelopes for each given sea level rise scenario. (See table 1).

Table 1- STORMTOOLS Data Layers

STORMTOOLS Sea Level Rise Geodatabase and Storm Return Periods provided by University of Rhode Island, Environmental Data Center- Base data used for all analyses (roads and structures)	
STORMTOOLS Sea Level Rise Geodatabase	Storm Return Periods/ flood envelopes within Geodatabase
0ft	Base Flood Elevation (BFE) Mean Higher-High Water (MHHW), 1 Year, 3 Year, 5 Year, 10 Year, 25 Year, 50 Year, 100 Year, Surge 100 Year, Total Depth 100 Year, Wave 100 Year.
1ft	Mean Higher-High Water (MHHW), 1 Year, 3 Year, 5 Year, 10 Year, 25 Year, 50 Year, 100 Year
2ft	Base Flood Elevation (BFE) Mean Higher-High Water (MHHW), 1 Year, 3 Year, 5 Year, 10 Year, 25 Year, 50 Year, 100 Year, Surge 100 Year, Total Depth 100 Year, Wave 100 Year.
3ft	Base Flood Elevation (BFE) Mean Higher-High Water (MHHW), 1 Year, 3 Year, 5 Year, 10 Year, 25 Year, 50 Year, 100 Year, Surge 100 Year, Total Depth 100 Year, Wave 100 Year.
5ft	Base Flood Elevation (BFE) Mean Higher-High Water (MHHW), 1 Year, 3 Year, 5 Year, 10 Year, 25 Year, 50 Year, 100 Year, Surge 100 Year, Total Depth 100 Year, Wave 100 Year.
7ft	Base Flood Elevation (BFE) Mean Higher-High Water (MHHW), 1 Year, 3 Year, 5 Year, 10 Year, 25 Year, 50 Year, 100 Year, Surge 100-year, Total Depth 100 Year, Wave 100 Year.
10ft	Base Flood Elevation (BFE) Mean Higher-High Water (MHHW), 1 Year, 3 Year, 5 Year, 10 Year, 25 Year, 50 Year, 100 Year, Surge 100 Year, Total Depth 100 Year, Wave 100 Year.

Roads_Polygons were supplied by MainStreetGIS, LLC., the company that provides GIS services and products to the Town of Warren. Roads_Polygons are a polygon layer which covers the entire footprint of the road surface for all roadways in Warren. This polygon layer does not include parking lots, sidewalks, bike paths or private driveways.

Roadway Analysis Methods

The Roadway analysis was conducted in two parts: Part 1 created a raster dataset representing the depth of floodwater on the roadway for a given SLR/storm scenario. Part 2 created a line feature of the flooded roadways used to calculate the linear feet of flooded roads. Both parts used ArcGIS model builder to run the analysis.

Part 1

First, each of the geodatabases representing SLR/storm scenarios listed in Table 1 were brought into model builder and the “Iterate Rasters” tool was used to repeat the model for every scenario. A “Parse Path” tool was used to maintain the naming convention for each storm return period. Next, “Extract by Mask” was used to extract each flood layer to the Roads_Polygon layer. This operation resulted in flooding scenarios clipped only to the footprint of flooded roadways in Warren. The resulting dataset was choppy and peppered due to the raster cell size of 3.28 feet by 3.28 feet, with individual pixels of a given value completely surrounded by pixels of a uniform value. To smooth the dataset, a “Focal Statistics” tool was used to average each cell with its circular neighborhood of 3 cells. The resulting raster was smoother, however the “Focal Statistics” operation extended the raster footprint 3 cells beyond the extent of the road surface in all directions. To remedy this, an additional “extract by mask” operation was used to bring the smooth raster back to the footprint of the roadway. Finally, during this last “extract by mask” step, a parallel “contour” operation was conducted to create breaklines to demarcate the flood water depth in 0.2 ft intervals on the road surface. (Figure2)

Final Output Products of analysis:

- Flood depth rasters on roadways for every Sea Level Rise Scenario and Flood return Period (73 rasters in total)
- Break lines in 0.2ft intervals (polyline features) for every Sea Level Rise Scenario and Flood return Period (73 rasters in total)

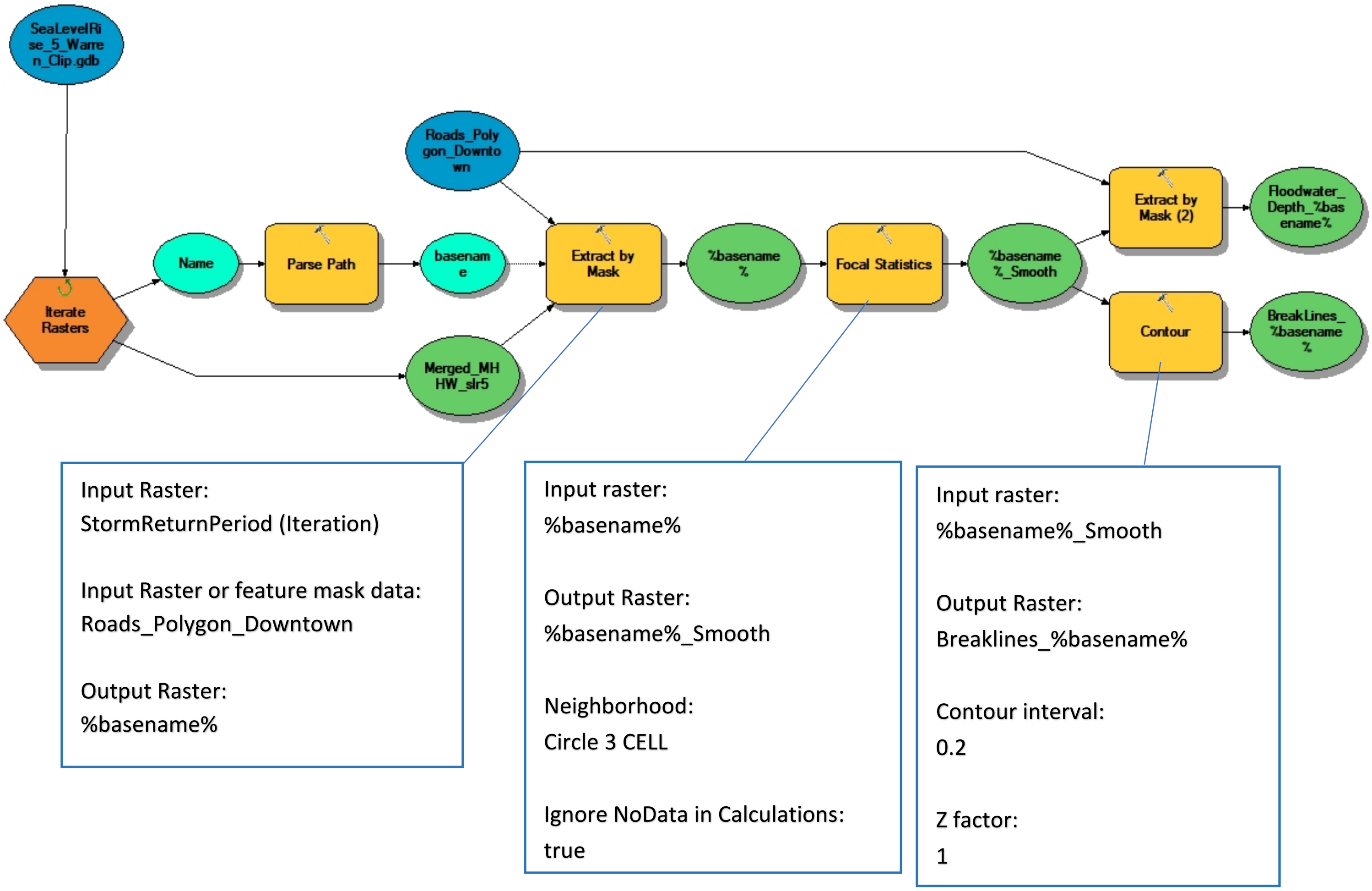


Figure 2 - Roadway Analysis Model (Part1)

<u>Part 2,</u>

Model builder only allows one Iteration tool to be used per model, therefore, to calculate the length of flooded roadways under each SLR/storm scenario, a second model was created titled FloodedRds_Pt2. First, the "Iterate Raster" tool was used to create layers flooded road length layers for every storm return period. Next, "Parse Path" was used to maintain the naming convention. Next, an "INT" tool was used to convert the raster from decimal format to integer format, to comply with the parameters for the next step in the model. This next step is to convert the raster to polygon using a "raster to polygon" tool. The final step is to clip roads to the extent of the raster polygon using the "clip" tool. (Figure 3)

This model produces the length of liner feet of flooded roadway for each SLR/storm scenario in the form of a line feature. The length of flooded roadway is found in the attribute table for each data layer. Some roads are multi-part features, so sorting the attributes table by road name is important to understand the full linear length of flooded roads. (Figure 4)

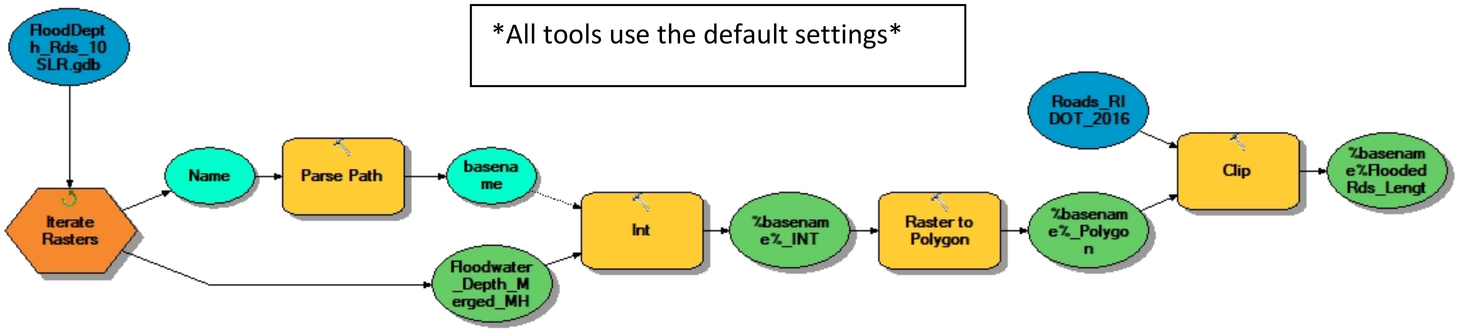
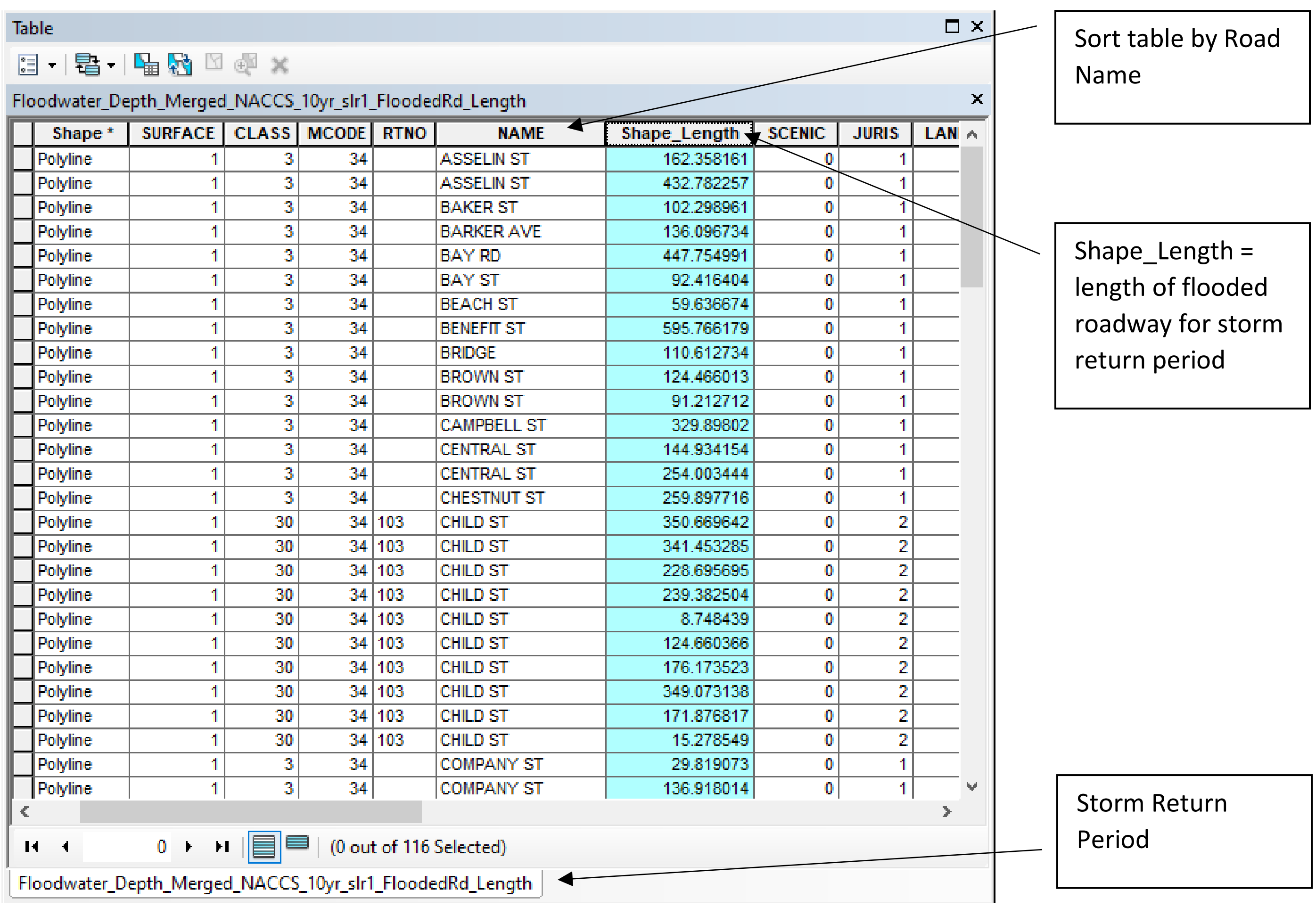


Figure 3- Roadway Analysis Model (Part 2)



Shape *	SURFACE	CLASS	MCODE	RTNO	NAME	Shape_Length	SCENIC	JURIS	LAN
Polyline	1	3	34		ASSELIN ST	162.358161	0	1	
Polyline	1	3	34		ASSELIN ST	432.782257	0	1	
Polyline	1	3	34		BAKER ST	102.298961	0	1	
Polyline	1	3	34		BARKER AVE	136.096734	0	1	
Polyline	1	3	34		BAY RD	447.754991	0	1	
Polyline	1	3	34		BAY ST	92.416404	0	1	
Polyline	1	3	34		BEACH ST	59.636674	0	1	
Polyline	1	3	34		BENEFIT ST	595.766179	0	1	
Polyline	1	3	34		BRIDGE	110.612734	0	1	
Polyline	1	3	34		BROWN ST	124.466013	0	1	
Polyline	1	3	34		BROWN ST	91.212712	0	1	
Polyline	1	3	34		CAMPBELL ST	329.89802	0	1	
Polyline	1	3	34		CENTRAL ST	144.934154	0	1	
Polyline	1	3	34		CENTRAL ST	254.003444	0	1	
Polyline	1	3	34		CHESTNUT ST	259.897716	0	1	
Polyline	1	30	34	103	CHILD ST	350.669642	0	2	
Polyline	1	30	34	103	CHILD ST	341.453285	0	2	
Polyline	1	30	34	103	CHILD ST	228.695695	0	2	
Polyline	1	30	34	103	CHILD ST	239.382504	0	2	
Polyline	1	30	34	103	CHILD ST	8.748439	0	2	
Polyline	1	30	34	103	CHILD ST	124.660366	0	2	
Polyline	1	30	34	103	CHILD ST	176.173523	0	2	
Polyline	1	30	34	103	CHILD ST	349.073138	0	2	
Polyline	1	30	34	103	CHILD ST	171.876817	0	2	
Polyline	1	30	34	103	CHILD ST	15.278549	0	2	
Polyline	1	3	34		COMPANY ST	29.819073	0	1	
Polyline	1	3	34		COMPANY ST	136.918014	0	1	

Figure 4- Attributes table listing the length of inundated roadway for a given sea level rise scenario.

Roadway Analysis Results

The results of the analysis depict the extent and depth of the flooded roadways in Warren for a given sea level rise scenario and storm return period. Table 5 below, displays a selection of floodwater depths at the intersection of Market Street and Redmond Street under various flooding conditions. This same table is found as Appendix 1 to this report. Appendix 2 contains the length of affected roadways that experience flooding under a 1-year return period event at different SLR horizons. Figure 5 displays a map of the intersection of Market St, and Redmond St.

By default, the resulting raster datasets are in a stretched symbology, and range in value from negative values to positive values of 999. For better visualization and interpretation of the data, a classified symbology was applied. Using a defined interval classification method and data exclusion of values greater than 30 will help to narrow the results and make the data more useful for decision making.

Table 2- Results of roadway analysis for a section of Warren, RI.

Floodwater depth on road surface (feet) - Intersection of Market St and Redmond St				
Sea Level Rise Scenario	Mean higher-high water	1-year storm return period	25-year storm return period	100-year storm return period
0 Ft	--	1.37	9.37	12.37
1ft	--	2.37	10.37	--
2ft	0.31	3.37	11.37	14.59
3ft	1.31	4.37	12.37	17.67
5ft	3.30	6.36	14.36	18.27
7ft	5.30	8.36	16.36	19.73
10ft	8.30	11.36	19.36	22.92

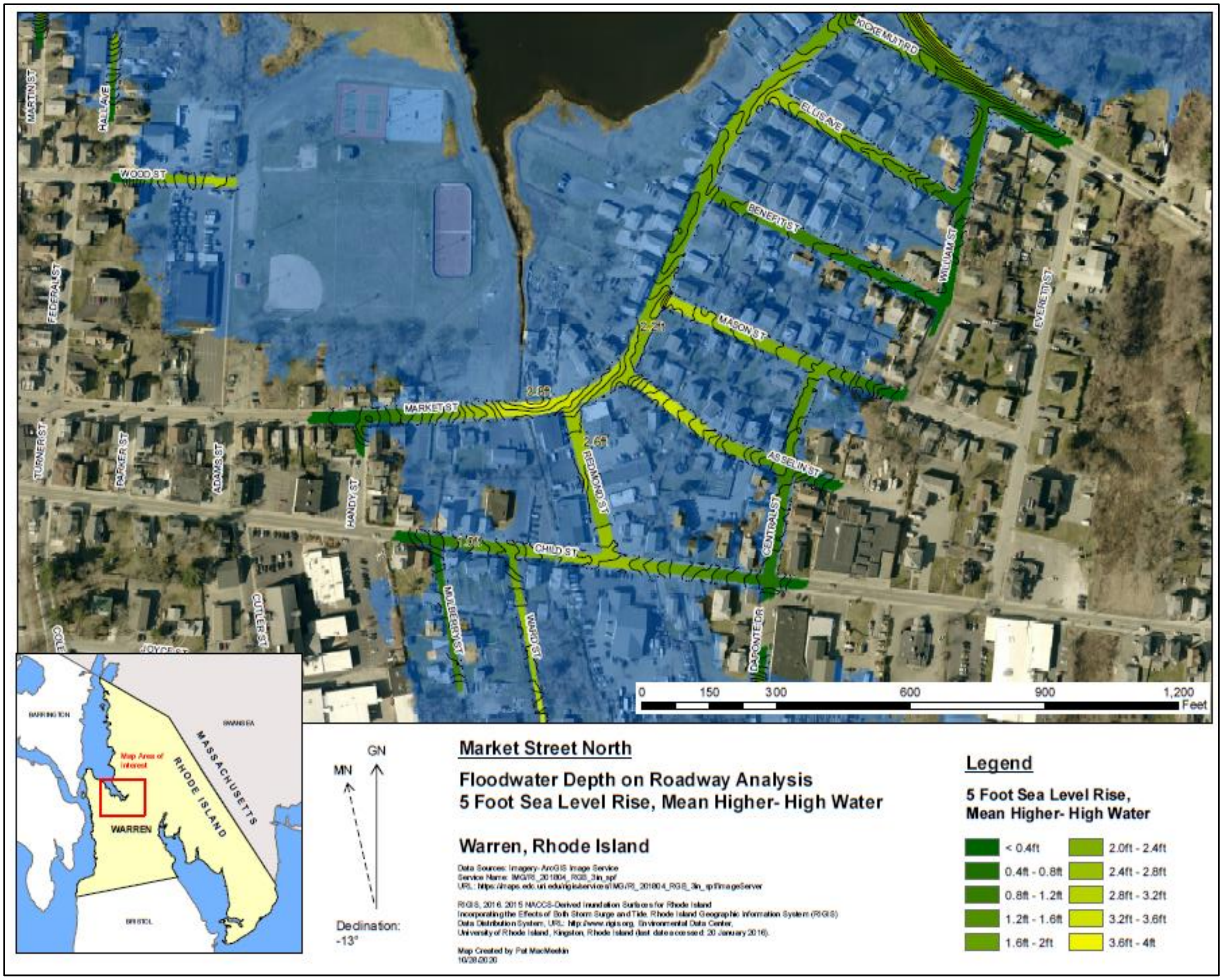
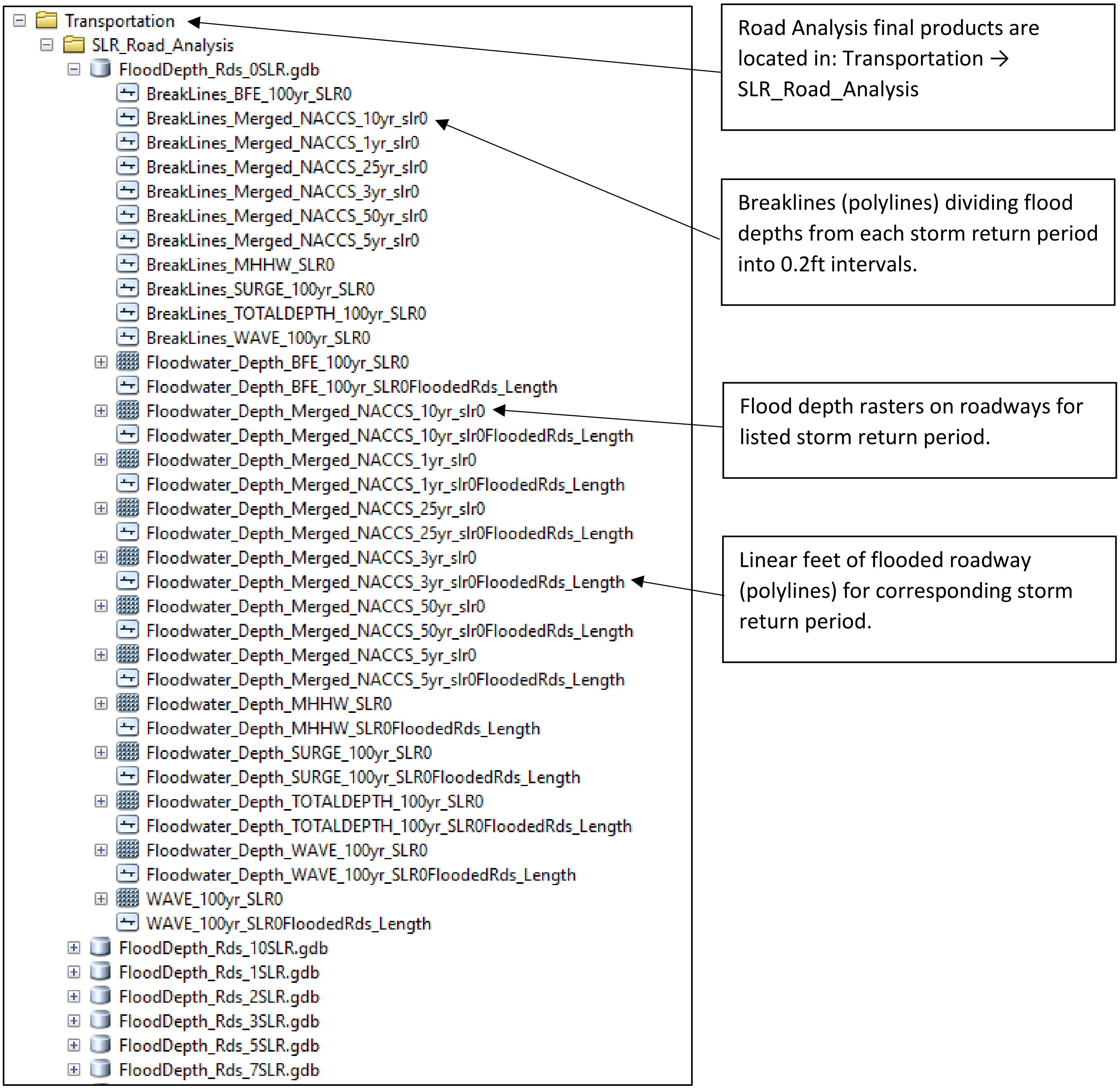


Figure 5- Roadway analysis, Intersection of Market St, and Redmond St. at map center.

Figure 6- Final outputs from road analysis:



FLOOD RISK ANALYSIS (CERI ANALYSIS)

The next phase of this analysis used the STORMTOOLS Coastal Environmental Risk Index (CERI) to evaluate risk of flooding to structures within the town of Warren. This analysis made use of damage functions developed by the US Army Corps of Engineers (USACE) and applied to structures inside the flood envelope in Warren.

Flood Risk Data sources

The flood risk analysis incorporated one major data source, the STORMTOOLS "Barrington, Bristol, Warren structural risk layer". The Barrington, Bristol, Warren structural risk layer displays point features for each structure in the three neighboring towns. These datasets represent output from the STORMTOOLS Coastal Environmental Risk Index (CERI) for the three towns. The data show point features attributed with estimates of structural damage from models of flooding from 100-year storm events. Three layers were provided, point features representing addressed structures and attributed with the percent of structure damage for a 100-year storm in combination with: 0 ft sea level rise, 2 ft sea level rise, and 5 ft sea level rise. In the attributes table of each layer, the "MOST" column represents the percentage of structural damage for that particular scenario. For example, a point with a "MOST" value of 55.20, means 55.20% of the structure will be damaged for a given sea level rise scenario. Additionally, the "MOST" values consider the structure category as described by the Army Corp of Engineers (ACOE) North Atlantic Comprehensive Coastal Study (NACCS) (Spaulding et al., 2019).

Table 3- Flood risk data sources (CERI data)

Data Source layers- GIS file name and data representation (all damage functions)	
GIS Data Layer (Point Feature Class)	Data Representation (Point Feature Class)
BBW_RISK_100yr_SLR0_agol	Structures damaged by **0 ft Sea Level Rise**, 100-year storm return period (Clipped to Warren)
BBW_RISK_100yr_SLR2_agol	Structures damaged by **2 ft Sea Level Rise**, 100-year storm return period (Clipped to Warren)
BBW_RISK_100yr_SLR5_agol	Structures damaged by **5 ft Sea Level Rise,** 100-year storm return period (Clipped to Warren)

Flood Risk Part 1- Structural Point Analysis

The Structural flood risk analysis was divided into two parts. Part one examined which individual structures would be affected by a given sea level rise/storm return period scenario, and to what extent the structure would be damaged. Part two examined the location density of these structures to help identify areas of town where there is a more urgent need for mitigation.

Structural Point Analysis, Part 1 Methods:

First, each of the three structure damage layers- BBW_Risk_100yr_SLR0_agol, BBW_Risk_100yr_SLR2_agol, BBW_Risk_100yr_SLR5_agol, were clipped to the extent of the town boundary, in order to only display structures within Warren. Next, a symbology was applied to the "MOST" attribute to display the points into 4 groups of 25% intervals. The information from this symbology step is displayed in Table 4 below. To narrow the analysis results to a more manageable data set, the following definition query was applied: “MOST”>49.99. This resulted in a layer which only displayed structures sustaining 50% or greater structural damage for a given scenario.

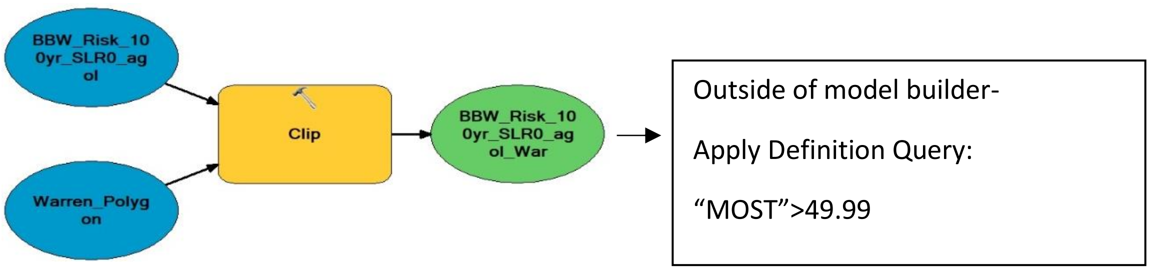


Figure 7- CERI damage function model

Structural Point Analysis, Part 1 Results:

This analysis was primarily a manipulation of symbology, with some basic clipping and filtering steps to narrow the processing extent and results. The analysis resulted in two sets of layers. The first set of layers displays a point for every structure sustaining any amount of damage (all damage functions). There is one layer for each sea level rise scenario at a 100-year storm return period (three layers- 0 ft SLR, 2 ft SLR, and 5ft SLR). This first set of data was used to produce maps displaying damaged structures by intervals of 25% damage function to create four groups with corresponding maps for each group (<24.99%, 25% - 49.99%, 50% - 74.99%, >75%).

Table 4- count of damaged structures by damage interval

Count of damaged structures in census block 305 by precent structural damage category (Structures)					
Sea Level Rise Scenario	<24.99%	25% - 49.99%	50% - 74.99%	>75%	Total
0 ft Sea Level Rise, 100-year storm return period	129	221	106	4	460
2 ft Sea Level Rise, 100-year storm return period	138	204	189	18	550
5 ft Sea Level Rise, 100-year storm return period	166	193	237	108	704

The next set of layers displays a point for every structure sustaining greater than 49.99% damage for each sea level rise scenario at a 100-year storm return period. (three layers- 0 ft SLR, 2 ft SLR, and 5ft SLR). Again, corresponding maps were created for each scenario. Mapping the extent of structures that could experience this level of damage is important because it provides the town with geospatial data showing structures that may be required to be brought up to current floodplain management standards (under FEMA's "50% rule") in the event of a large storm.

This map series also includes a count of the total structures damaged by a given sea level rise scenario. The count was obtained by sorting the "MOST" column in the attributes table of for the given BBW_RISK_100yr_SLR[ ]_agol layer and grouping the records by in intervals of 25% to create 4 groups (0% - 24.99%, 25% - 49.99%, 50% - 74.99%, 75% - 100%).

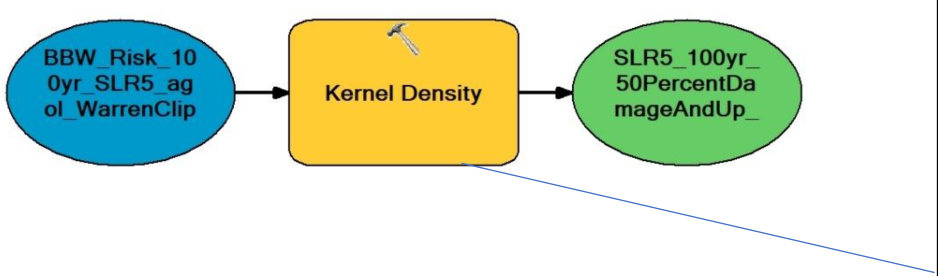
Flood Risk Part 2- Density Analysis:

Building on the structural damage analysis, a density analysis was conducted to measure and identify areas of the town where structures would sustain greater than 50% damage. This information can then be used by town managers to identify areas of the town where flood risk is greatest and where the town may want to consider targeted adaptation options such as property buyouts target formulate a plan for mitigation. The general methodology for this density analysis was outlined by Nicole Leporacci in her 2016 URI MESM report "A Quantitative Assessment of Sea Level Rise and Storm Inundation on Rhode Island Coastal" (Leporacci, 2016).

Density Analysis, Part 2 Methods:

This part of the analysis utilized only the datasets displaying greater than 49.99% damage function for each sea level rise scenario at a 100-year storm return period (layers using the definition query "MOST">49.99). Each of these data layers were brought into model builder, and a "Kernel Density" tool was used to calculate the density of structures damaged by storm surge per square miles. The kernel density tool calculates a "magnitude per unit area from point or polyline features using a kernel function to fit a smoothly tapered surface to each point" (ESRI 2017). This tool takes the point features, spreads them across the processing extent (in this case the town of Warren), and returns a density value based on the spatial relationship of each point to every other point. (Environmental Systems Research Institute, 2016). In this application, the output is a raster where each cell represents the density of structures (in units per sq. mile), which can be used to identify hot spots of potential flood damage.

Figure 8- Kernel Density Model



Output Cell Size:
5

Area Units:
SQUARE MILES

Output values are:
Densities

Method:
PLANAR

Density Analysis, Part 2 Results:

The outputs from the Kernel density analysis display a heat map of the density of damaged structures, with hot colors (red and orange) representing high density of structures sustaining greater than 49.99% damage, and cooler colors (greens) representing lower density of structures sustaining greater than 49.99% damage.

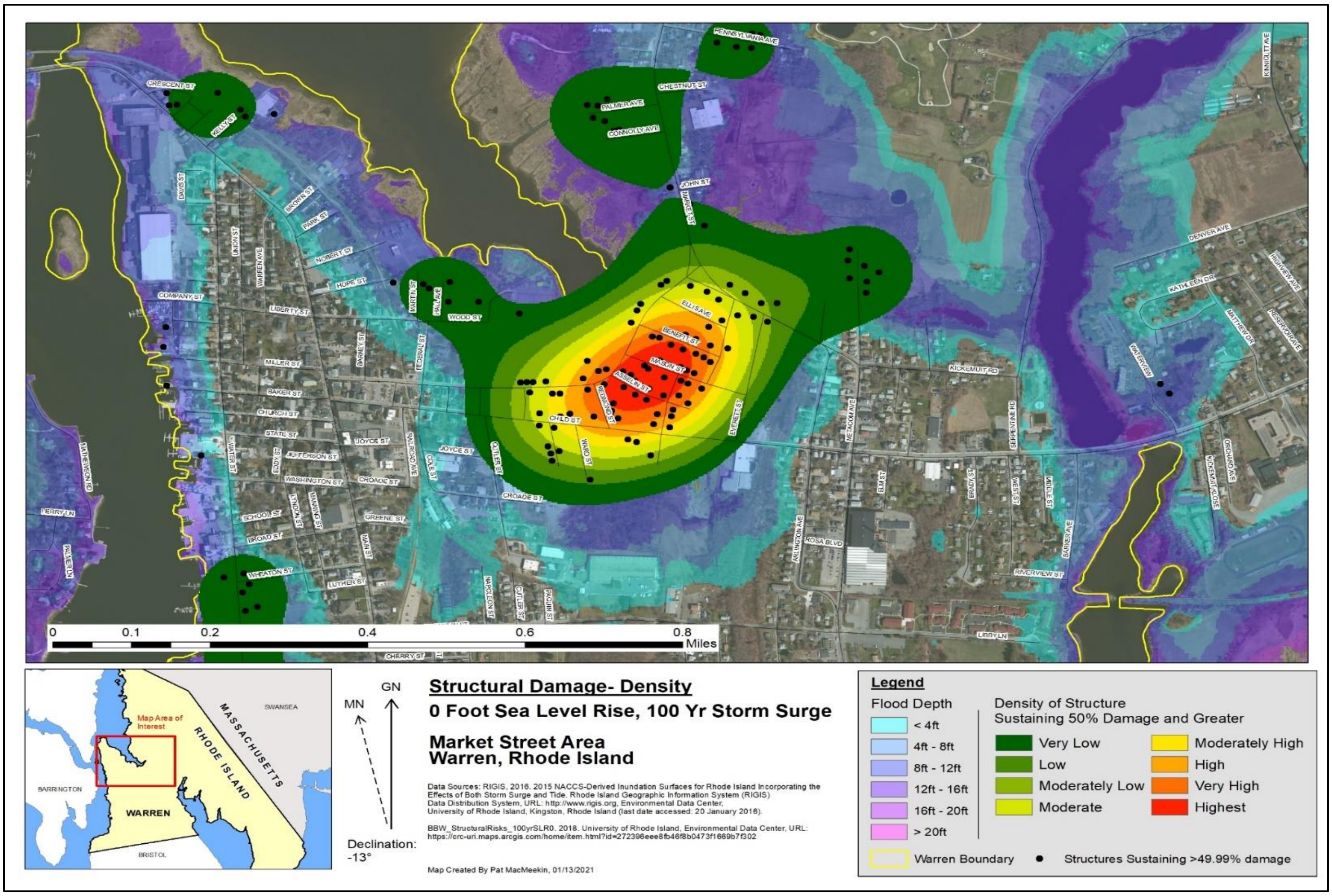


Figure 9- Density Analysis Results (Map)

NEXT STEPS

The STORMTOOLS geospatial layers developed by URI, and the analysis methods of this report, provide groundwork for future analysis. The methodology detailed in this report is easily transferable to other adjacent municipalities to increase the footprint of detailed storm inundation information for the region. Specifically, for Warren, logical next steps are to combine the three individual analysis areas (roads analysis, and the two structural damage analyses) to identify locations where it seems most urgent to consider and implement appropriate flood mitigation practices. Possible examples are to identify feasible emergency egress routes for first responders and public evacuations, or to help inform the placement of flood mitigation infrastructure.

References:

Documents:

Environmental Systems Research Institute. (2016). *Understanding density analysis—Help | ArcGIS for Desktop*. https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/understanding-density-analysis.htm

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Online Linkage:
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Download: https://crc-uri.maps.arcgis.com/home/item.html?id=272396eee8fb46f8b0473f1669b7f302.

Appendix 1- Floodwater depth on Road Surface

Floodwater depth on road surface (feet)- Intersection of Market St and Redmond St				
Sea Level Rise Scenario	Mean higher-high water	1-year storm return period	25-year storm return period	100-year storm return period
0 Ft	--	1.37	9.37	12.37
1ft	--	2.37	10.37	--
2ft	0.31	3.37	11.37	14.59
3ft	1.31	4.37	12.37	17.67
5ft	3.30	6.36	14.36	18.27
7ft	5.30	8.36	16.36	19.73
10ft	8.30	11.36	19.36	22.92

Appendix 2- List of Flooded Roads, and linear feet of flooded roads for given sea level rise and storm return period.

0 Foot Sea Level Rise,
1-year storm return interval

ROAD NAME	LINEAR FEET
ASSELIN ST	352.45
BRIDGE	51.71
CAMPBELL ST	66.85
CHILD ST	420.32
CONNOLLY AVE	59.52
COUNTY RD	48.26
CRESCENT ST	230.75
ELLIS AVE	245.86
HALL AVE	30.09
KICKEMUIT RD	449.21
MAIN ST	491.00
MARKET ST	1404.36
MASON ST	374.20
METACOM AVE	241.83
PALMER AVE	101.72
PARKER AVE	20.23
PATTERSON AVE	78.61
REDMOND ST	362.78
SAINT THERESA DR	31.57
SCHOOLHOUSE RD	17.81
SERPENTINE RD	37.56
SHIPYARD LN	15.32
WARD ST	384.31
WATER ST	513.30
WOOD ST	180.25

A complete list of flooded roads and linear feet is available on the in the products section of the data outputs from this report:

On project external hard drive:

→Products →Flooded_Rds_List

Appendix 2- List of Flooded Roads, and linear feet of flooded roads for given sea level rise and storm return period.

1 foot sea level rise,
1- year storm return interval,

ROAD NAME	LINEAR FEET
ASSELIN ST	480.17
BAKER ST	43.85
BAY RD	259.56
BEACH ST	21.84
BENEFIT ST	299.50
BRIDGE	66.26
CAMPBELL ST	194.21
CENTRAL ST	235.42
CHESTNUT ST	53.96
CHILD ST	883.02
COMPANY ST	97.24
CONNOLLY AVE	109.67
COUNTY RD	53.30
CRESCENT ST	421.16
DAPONTE DR	38.56
ELLIS AVE	435.57
HAILE ST	41.75
HALL AVE	96.12
JOHNSON ST	30.32
KICKEMUIT RD	939.77
LAUREL LN	37.02
LINCOLN AVE	15.89
LONGWHARF DR	98.66
MAIN ST	764.05
MAPLE ST	2.84
MARKET ST	2239.53
MARTIN ST	44.55
MASON ST	514.17
METACOM AVE	277.99
MILL ST	200.43
MULBERRY ST	121.09
PALMER AVE	147.50
PARKER AVE	52.90
PATTERSON AVE	144.65
PENNSYLVANIA AVE	27.41
READ AVE	9.29
REDMOND ST	362.78
SAINT THERESA DR	58.27
SCHOOLHOUSE RD	305.74
SERPENTINE RD	667.61

ROAD NAME	LINEAR FEET
SHIPYARD LN	15.19
THOMPSON ST	158.78
WARD ST	416.86
WATER ST	1187.81
WESTMINSTER ST	256.56
WILLIAM ST	18.97
WOOD ST	235.41

A complete list of flooded roads and linear feet is available on the in the products section of the data outputs from this report:

On project external hard drive:

→Products →Flooded_Rds_List

Appendix 2- List of Flooded Roads, and linear feet of flooded roads for given sea level rise and storm return period.

3 Foot Sea Level Rise
1-year storm return interval

ROAD NAME	LINEAR FEET
ASSELIN ST	595.14
BAKER ST	87.20
BARKER AVE	95.38
BAY RD	439.17
BAY ST	11.71
BEACH ST	49.92
BENEFIT ST	595.77
BRIDGE	103.98
BROWN ST	192.11
CAMPBELL ST	306.21
CENTRAL ST	396.07
CHESTNUT ST	209.11
CHILD ST	1775.83
COMPANY ST	171.60
CONNOLLY AVE	202.50
COUNTY RD	61.70
CRESCENT ST	421.16
DAPONTE DR	232.47
ELLIS AVE	500.72
EVERETT ST	314.74
HAILE ST	94.88
HALL AVE	307.65
HANDY ST	251.10
HOPE ST	24.66
JOHN ST	18.94
JOHNSON ST	118.53
KELLY ST	179.34
KICKEMUIT RD	1305.18
KINNICUTT AVE	86.69
LAUREL LN	85.05
LINCOLN AVE	139.40
LONGWHARF DR	265.10
MAIN ST	944.88
MAPLE ST	36.36
MARKET ST	2713.69
MARTIN ST	193.20
MASON ST	734.29
METACOM AVE	344.33
MILL ST	200.43
MULBERRY ST	328.18

ROAD NAME	LINEAR FEET
NOBERT ST	109.46
PALMER AVE	301.63
PARK ST	172.04
PARKER AVE	109.13
PATTERSON AVE	210.06
PENNSYLVANIA AVE	544.73
READ AVE	163.40
REDMOND ST	362.78
RIVERVIEW ST	45.72
ROSELAND AVE	216.96
SAINT THERESA DR	144.09
SCHOOLHOUSE RD	714.74
SERPENTINE RD	2829.59
SHIPYARD LN	15.19
THOMPSON ST	222.62
WARD ST	416.86
WATER ST	1676.36
WATERVIEW	17.38
WESTMINSTER ST	256.56
WHEATON ST	108.87
WILLIAM ST	686.35
WOOD ST	332.30

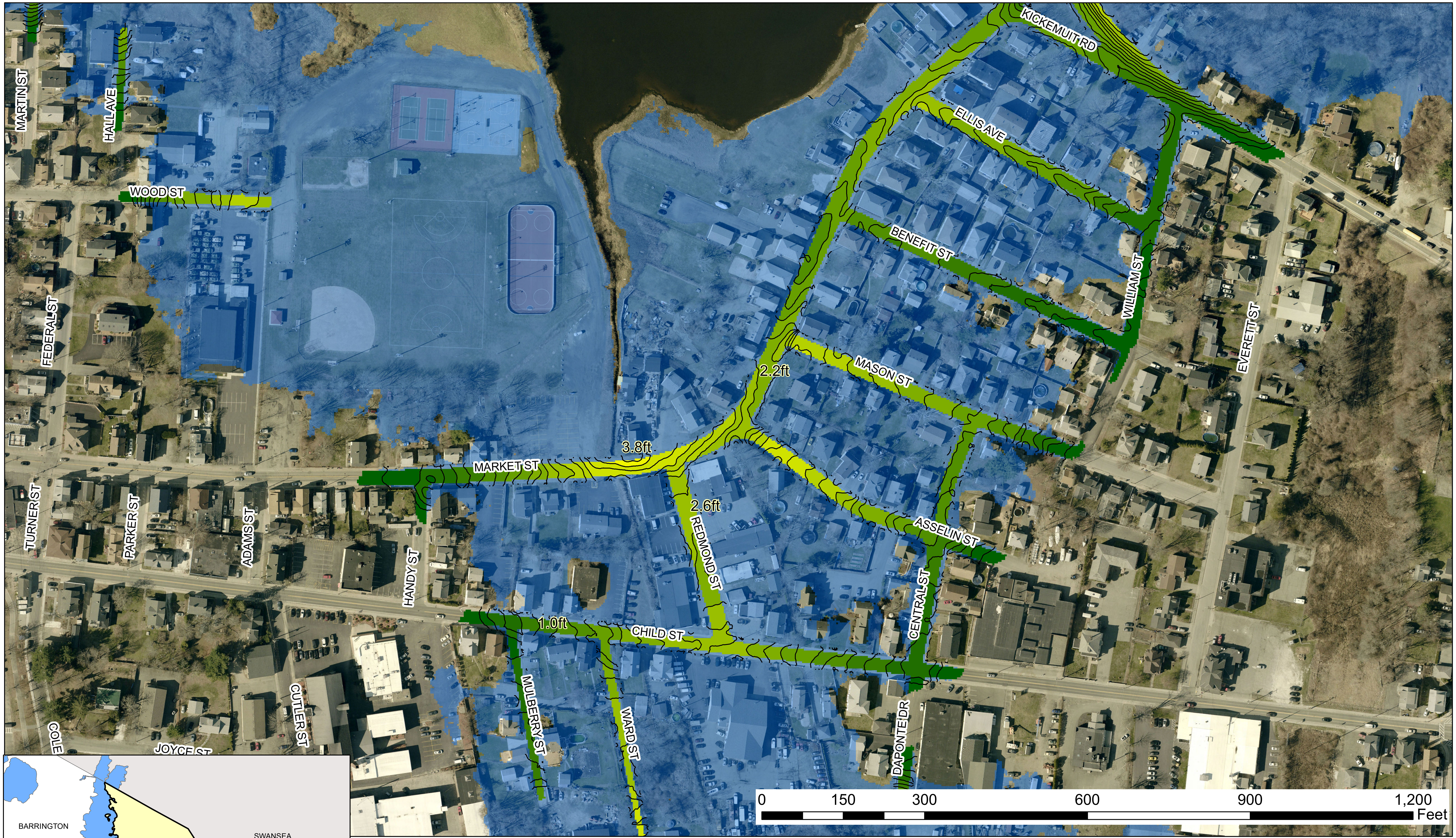
A complete list of flooded roads and linear feet is available on the in the products section of the data outputs from this report:

On project external hard drive:

→Products →Flooded_Rds_List

Appendix 3- Count of damaged structures by damage category

Count of damaged structures in census block 305 by precent structural damage category (Structures)					
Sea Level Rise Scenario	<24.99%	25% - 49.99%	50% - 74.99%	>75%	Total
0 ft Sea Level Rise, 100-year storm return period	129	221	106	4	460
2 ft Sea Level Rise, 100-year storm return period	138	204	189	18	550
5 ft Sea Level Rise, 100-year storm return period	166	193	237	108	704



GN

MN

Declination:
-13°

Market Street North

Floodwater Depth on Roadway Analysis
5 Foot Sea Level Rise, Mean Higher- High Water

Warren, Rhode Island

Data Sources: Imagery- ArcGIS Image Service
Service Name: IMG/RI_201804_RGB_3in_spf
URL: https://maps.edc.uri.edu/rigis/services/IMG/RI_201804_RGB_3in_spf/ImageServer

RIGIS, 2016. 2015 NACCS-Derived Inundation Surfaces for Rhode Island
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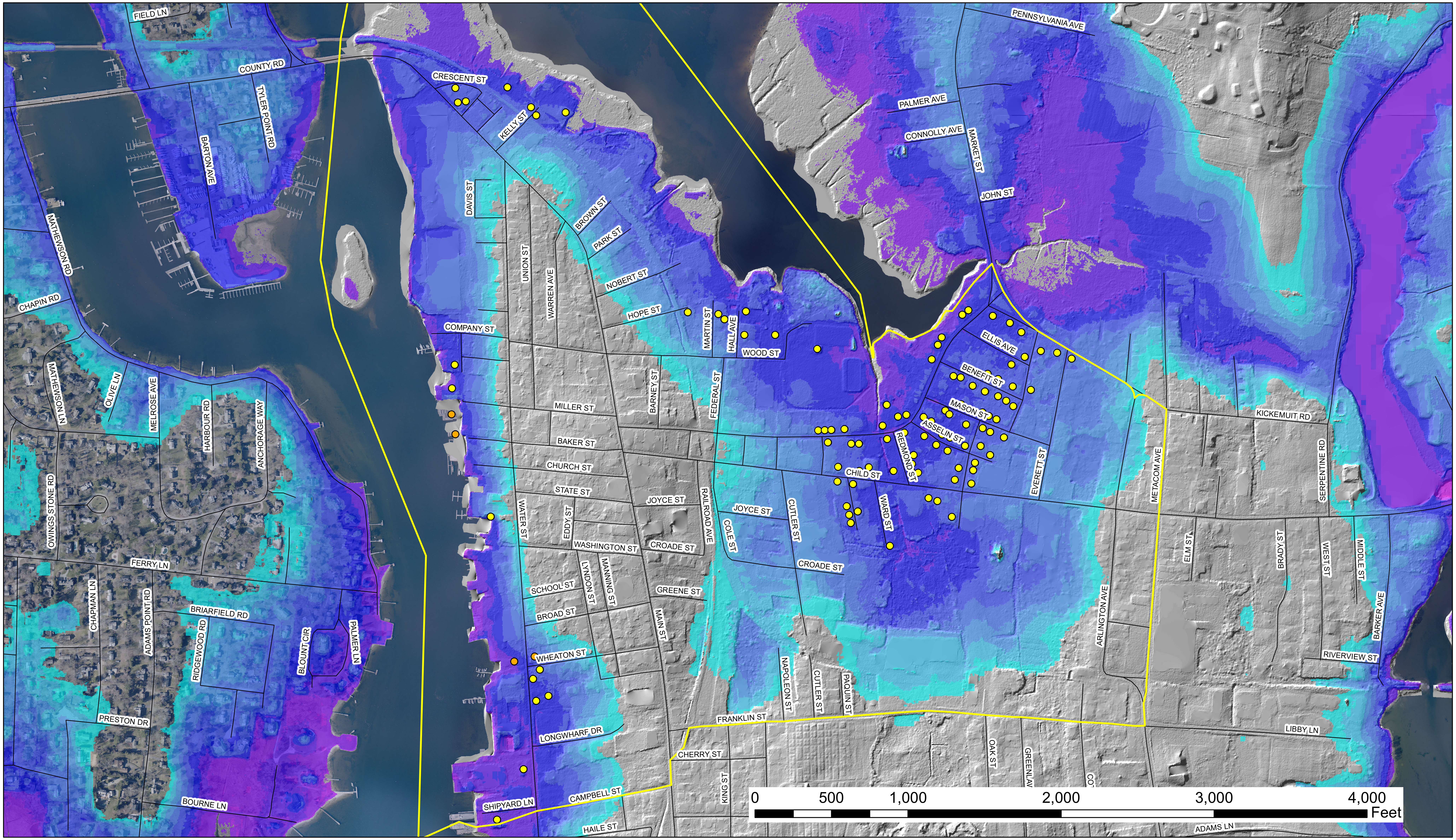
University of Rhode Island, Kingston, Rhode Island (last date accessed: 20 January 2016).

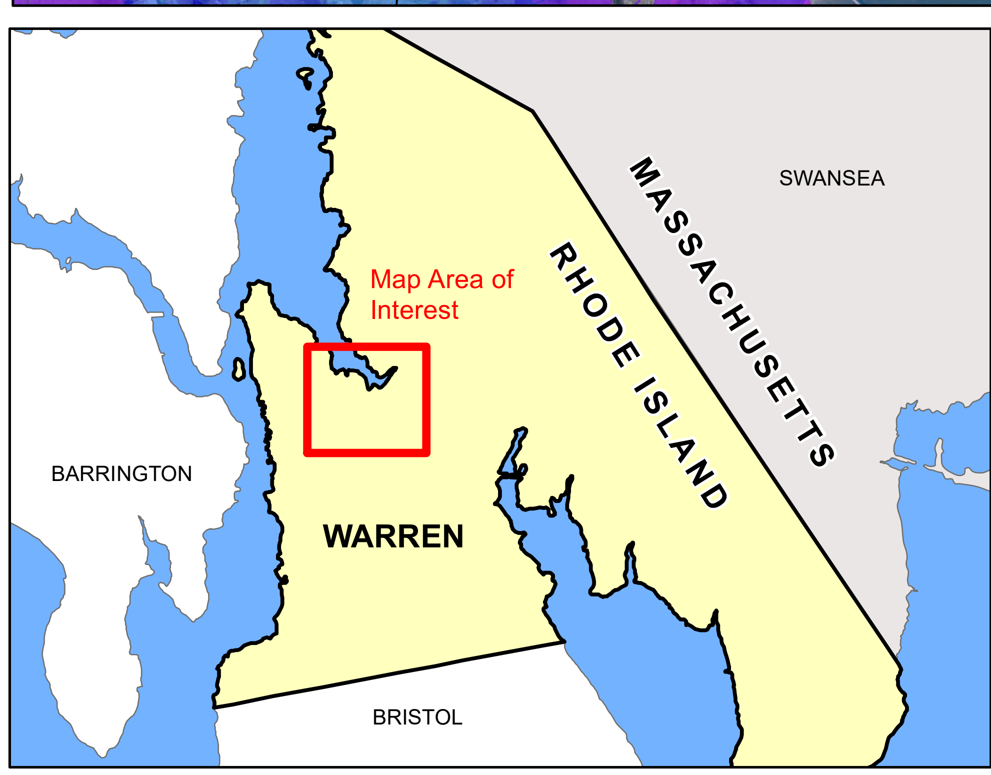
Map Created by Pat MacMeekin
10/28/2020

Legend

5 Foot Sea Level Rise, Mean Higher- High Water

- < 0.4ft
- 0.4ft - 0.8ft
- 0.8ft - 1.2ft
- 1.2ft - 1.6ft
- 1.6ft - 2ft
- 2.0ft - 2.4ft
- 2.4ft - 2.8ft
- 2.8ft - 3.2ft
- 3.2ft - 3.6ft
- 3.6ft - 4ft





GN

MN

Declination: -13°

Percent Structural Damage > 50%

0 Foot Sea Level Rise, 100 Yr Storm Surge

Census Block 305
Warren, Rhode Island

Data Sources: RIGIS, 2016. 2015 NACCS-Derived Inundation Surfaces for Rhode Island Incorporating the Effects of Both Storm Surge and Tide. Rhode Island Geographic Information System (RIGIS) Data Distribution System, URL: http://www.rigis.org, Environmental Data Center, University of Rhode Island, Kingston, Rhode Island (last date accessed: 20 January 2016).

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Map Created By Pat MacMeekin, 11/24/2020

Legend

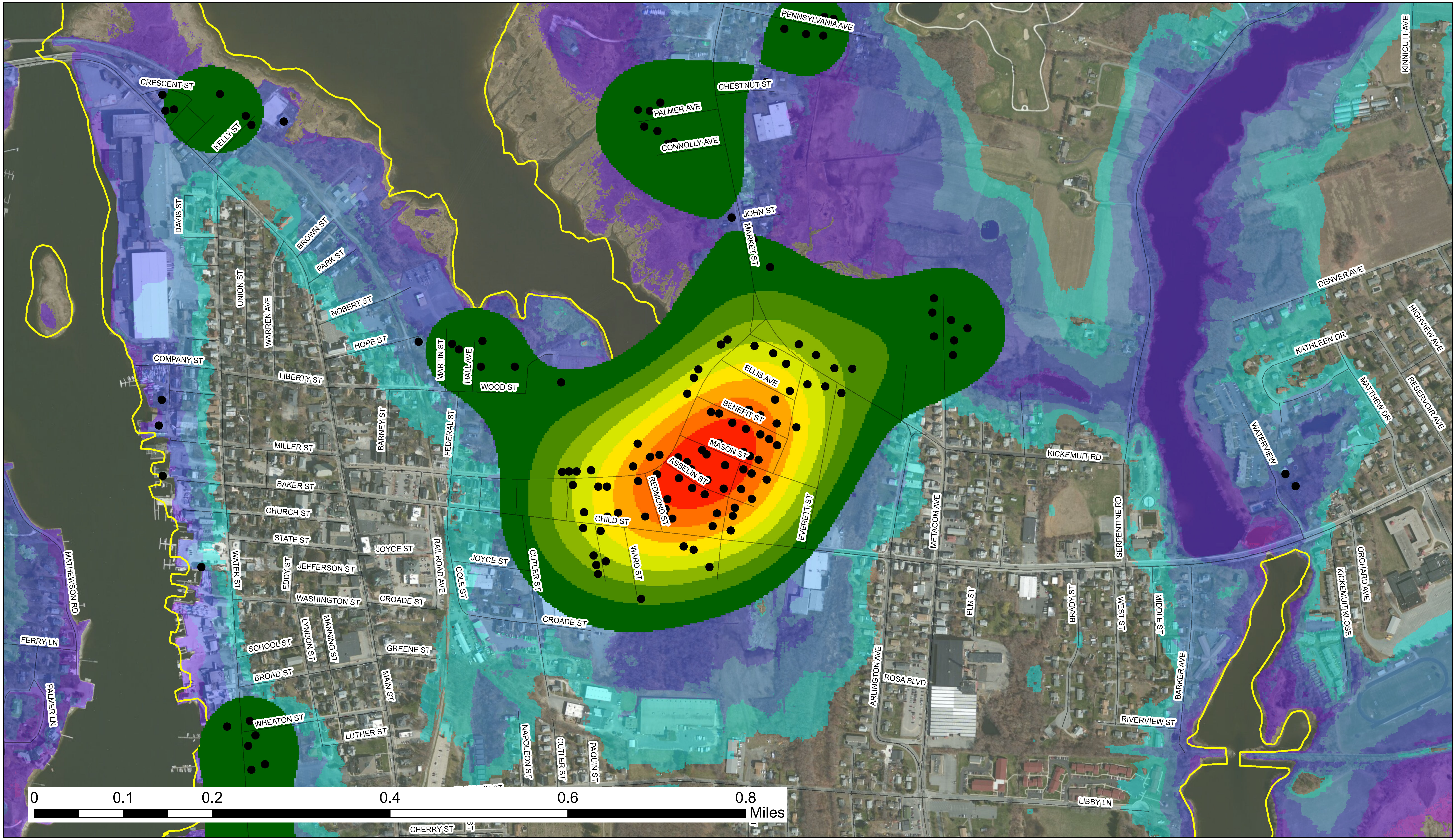
Flood Depth

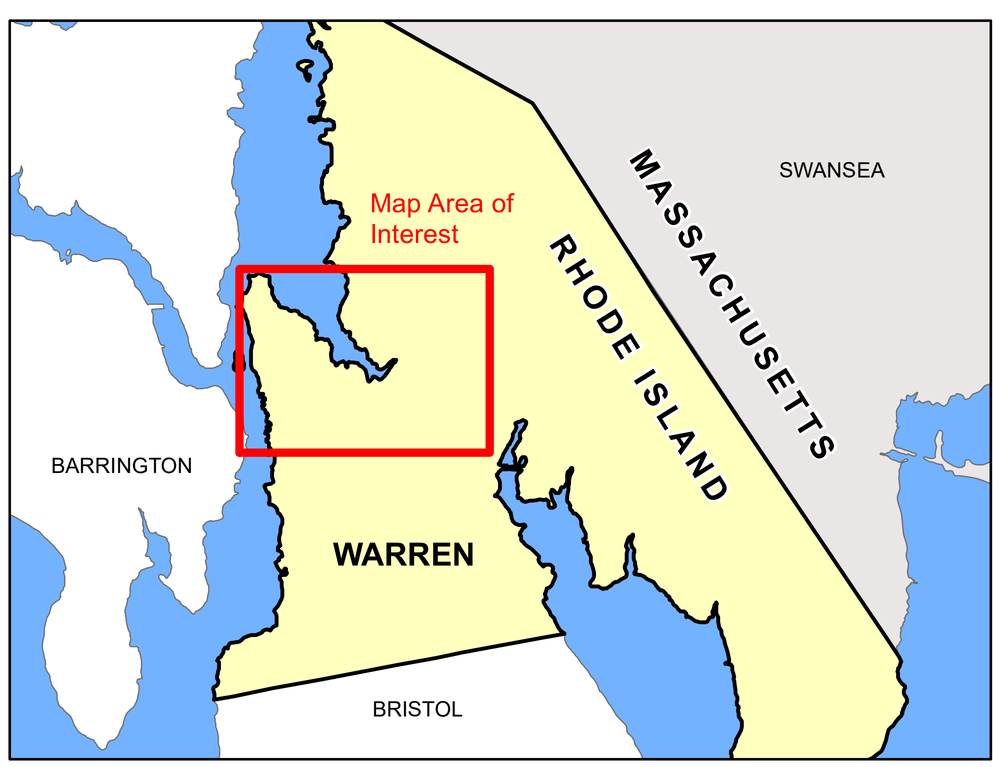
- <2 ft
- 2 ft - 4 ft
- 4 ft - 6 ft
- 6 ft - 8 ft
- 8 ft - 10 ft
- 10 ft - 12 ft
- 12 ft - 14 ft
- 14 ft - 16 ft
- 16 ft - 18 ft
- 18 ft - 20 ft
- 20 ft - 22 ft

Warren Census Block 305

Percent Structural Damage In Map Extent

	Count
50% - 75%	84
75% - 100%	4
	Total 88





GN
MN

Declination: -13°

Structural Damage- Density

0 Foot Sea Level Rise, 100 Yr Storm Surge

Market Street Area
Warren, Rhode Island

Data Sources: RIGIS, 2016. 2015 NACCS-Derived Inundation Surfaces for Rhode Island Incorporating the Effects of Both Storm Surge and Tide. Rhode Island Geographic Information System (RIGIS) Data Distribution System, URL: http://www.rigis.org, Environmental Data Center, University of Rhode Island, Kingston, Rhode Island (last date accessed: 20 January 2016).

BBW_StructuralRisks_100yrSLR0. 2018. University of Rhode Island, Environmental Data Center, URL: https://crc-uri.maps.arcgis.com/home/item.html?id=272396eee8fb46f8b0473f1669b7f302

Map Created By Pat MacMeekin, 11/24/2020

Legend

Flood Depth
- < 4ft
- 4ft - 8ft
- 8ft - 12ft
- 12ft - 16ft
- 16ft - 20ft
- > 20ft

Density of Structure Sustaining 50% Damage and Greater
- Very Low
- Low
- Moderately Low
- Moderate
- Moderately High
- High
- Very High
- Highest

Warren Boundary

Structures Sustaining >49.99% damage