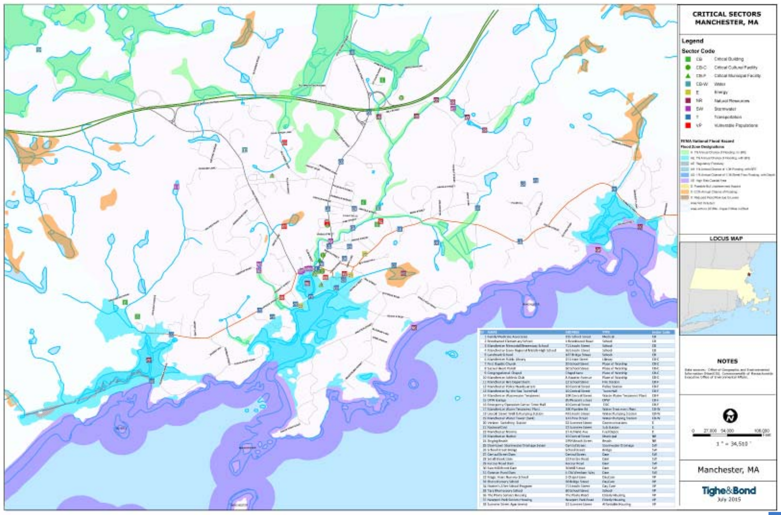

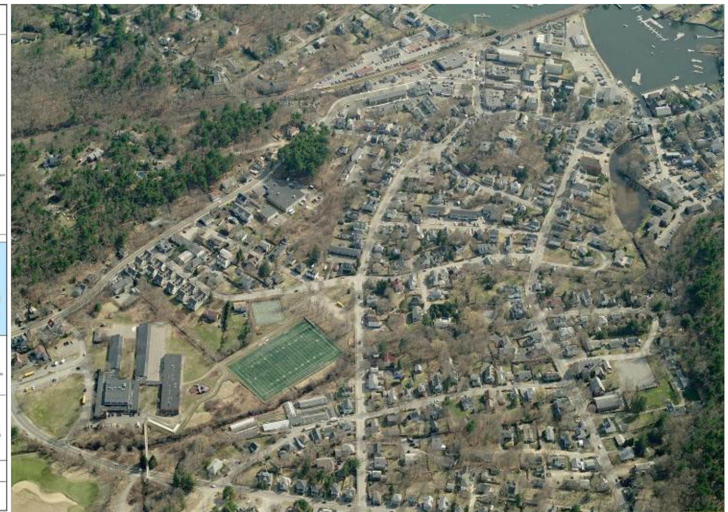

Tighe&Bond

FEMA Hazard Mitigation Plan Enhancement: Task 2 Potential Climate Change Impacts to Manchester-by-the-Sea

Prepared For:

**Town of Manchester-by-the-Sea
Massachusetts**

October 2015

Potential Climate Change Impacts to Manchester-by-the-Sea

TO: Mary Reilly, Manchester-by-the-Sea, Grants Administrator

FROM: Gabrielle Belfit, Jennie Moonan, P.E., Margaret Hernandez

COPY: David Murphy, P.E.

DATE: October 29, 2015

Manchester-by-the-Sea is a small coastal community located on Cape Ann along the North shore of Massachusetts Bay. The coastal area extends for several miles and includes numerous coves and inlets including Manchester Harbor. Sawmill Brook and its tributaries drain rocky uplands, expansive wetlands and developed impervious areas before discharging to the Harbor through a narrow tidal gate. Many areas of the town are subject to flooding during extreme storm events due to the combination of storm surge, hydraulic restrictions from culverts and the tidal gate, stormwater runoff from impervious areas, the channelized stream system, and poor infiltration conditions. Future impacts due to a changing climate, including increased precipitation and sea-level rise, will exacerbate flooding.

The Town of Manchester-by-the-Sea has received a Federal Emergency Management Agency (FEMA) Pre-disaster Mitigation Grant (PDM) to enhance the Town's current Hazard Mitigation Plan (HMP). The tasks include evaluating potential climate change impacts to the Town, and completing a Vulnerability Risk assessment of the Town's critical sectors. This memo summarizes the results of modeling and mapping studies recently completed as part of Task 2 of the grant, to predict where, when and to what degree these future climate impacts may be experienced.

1 Preliminary Assessment

In December 2014, the Town completed a first order "still-water" assessment of properties that have the potential to be impacted due to sea level rise expansion of the existing Federal Emergency Management Agency's (FEMA) 100-year floodplain (Costa, 2012). This method is recommended by the Coastal Zone Management (CZM) StormSmart Coasts program and is consistent with the Massachusetts Climate Change Adaptation (2011) recommendation to expand mapping efforts with respect to predicting impacts from climate change.

The method uses Geographic Information System (GIS) mapping to match the defined FEMA 100-year flood plain base flood elevation to a more accurate Light Detection and Ranging (LiDAR) terrain data, referred to as the "adjusted baseline". Future sea level impacts are then estimated by expanding the adjusted baseline by 1 foot, 2 foot, and 4 foot topographic contours. For the purpose of this exercise, 1 foot was estimated for sea level rise by 2025, 2 feet by 2050 and 4 feet by 2100. This is consistent with the Third National Climate Assessment (Horton et al, 2014) consensus range for sea level rise, applied to this region, of 1 to 4 feet by year 2100 depending on the extent to which the Greenland and West Antarctic Ice Sheet experience significant melting. Along most of the coastal Northeast, sea level rise will exceed global average rise due to local land subsidence. There is additional possibility of even greater sea level rise if Gulf Stream currents are altered (Paris et al, 2012).

Data used in the flood zone expansion exercise included:

- FEMA Flood Insurance Rate Maps (FIRMs) - revised July 16, 2014
- LiDAR topography-2011 Northeast Nation Map LiDAR project
- MassGIS Hurricane Surge Inundation Zones developed by the National Hurricane Center based on the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Storm model data, October 2013
- MassGIS Level 3 Assessor's Parcel Mapping for Manchester-by-the–Sea, Fiscal Year 2013
- MassGIS Building Structures (2-D from 2011-2013 Ortho Imagery), September 2014

Tables 1 and 2 below summarize the mapping exercise for the cumulative parcels that fell within the expanded flood zones.

Table 1
Summary of All Properties Impacted by Flooding w/ Sea Level Rise

Floodplain	Parcels with structures	Cumulative parcels w/structures	Cumulative Value* (Million Dollars)
Adjusted baseline	190	190	$108
1-Foot SLR	16	206	$115
2-Foot SLR	28	234	$130
4 Foot SLR	54	288	$169

*Total assessed primary structure value

There are several limitations inherent in this first order assessment. First, the July 2014

Table 2
Summary of Municipal Properties Impacted by Flooding w/ Sea Level Rise

Parcel ID	Address	Description	Building Value	Flood Zone Expansion: Base	1-Foot	2-Foot	4-Foot
45 0 27	12 Church St	Sewage Treatment Plant Parcel #1	$1,531,600	Y	Y	Y	Y
45 0 28	12 Church St	Sewage Treatment Plant Parcel #2	$33.900	Y	Y	Y	Y
40 0 18	0 Lincoln St	Lincoln Street Well and Pumping Station	$113,300	N	N	N	Y
45 0 23	10 Central St	Town Hall and Police Department	$1,736,300	Y	Y	Y	Y
53 0 36	10 School St	Fire Station	$575,000	Y	Y	Y	Y
17 0 4	119 Beach St	Singing Beach- Bath House and Parking	$138,600	Y	Y	Y	Y
46 0 19	12 Summer St	Affordable Housing	$1,141,300	Y	Y	Y	Y
47 0 6	55 Lincoln St	Elementary School	$4,343,900	N	N	N	Y
22 0 16	17 Tucks Pt Rd	Tuck's Point-Chowder House	$36,100	N	Y	Y	Y
	Total: Primary Structures		**$9,616,100**				
22 0 17	17 Tucks Pt Rd	Tucks Point Rotunda	$20,500 *	Y	Y	Y	Y
11 0 17	113 Summer St	Sweeney Park	$79,200 *	N	N	N	Y
16 0 34	0 Beach St	Masconomo Park	$142,200 *	Y	Y	Y	Y
47 0 04	Norwood St	Coach Field Park	$36,300 *	N	Y	Y	Y
	Total: Secondary Structures:		**$278,200** *				
		TOTAL VALUE	**$9,894,300**				

Values with a * are land value only, no buildings are listed for these parcels.

FEMA FIRM data used in the model has been contested by the Town, and annual chance flood elevations may be reduced by as much as 1 foot in the harbor area and along the eastern coast (Woods Hole Group, August 2015). In this case the method is generally over-predicting sea-level rise impacts. Second, the first order assessment does not account for the impact of hurricane storm surge, wave dynamics or landform responses (such as erosion, breaching or migration); this is a still-water modeling approach that is based on elevations alone. In this case, the method is under-predicting impacts at specific locations.

Finally, the method is not evaluating impacts from upstream sources including flooding created by channel restrictions and increased precipitation due to climate change. A more accurate analysis of the upland area flooding scenarios under future conditions will require a detailed hydraulic analysis to include both impacts of sea level rise, impacts from the culvert and tide gate restrictions, stream channelization and runoff from impervious areas considering future climate conditions.

As part of the FEMA Hazard Mitigation Plan (HMP) enhancement, the Town wished to update the natural hazard risk assessment of critical infrastructure within the town to include climate change impact resulting from sea level rise, storm surge and extreme precipitation. To accomplish this goal, a comparative analysis of over a dozen models was completed and the Coastal Resilience Advisory Group (CRAG) selected three models for use in the HMP enhancement. To complete the analysis, data sets were obtained from each model for three timeframes: 2025, 2050 and 2100. The evaluation process and brief description of the models used are included in Section 2 below. The results of the analysis are presented in Section 3. Section 4 introduces the range of flooding impacts depending on the facility and site conditions, and finally recommendations for a detailed vulnerability risk assessment are presented in Section 5.

2 Climate Change Model Selection

A comparative evaluation of climate change modeling for Manchester-by-the Sea was prepared by Tighe & Bond and presented to the CRAG in August of 2015. The evaluation process involved a preliminary review of more than a dozen climate change models, and a focused comparative evaluation of 8 models including 3 sea level rise models, 3 storm surge models and 2 extreme precipitation models. The evaluation looked at multiple criteria including modeling accuracy, data inputs and level of effort. The climate change models selected by the Town and the CRAG were the Inundation Risk Model (IRM) that includes modules for both sea level rise and storm surge, and the Oyster River Culvert Evaluation Project (ORCEP) for the extreme precipitation model.

A separate watershed assessment using the US Army Corps of Engineers HEC-RAS model was developed for the Sawmill Brook Watershed to capture the inland impacts of increased precipitation on riverine flooding. A brief summary of the three models are included below.

2.1 Sea Level Rise (SLR) and Storm Surge Models

Potential sea level rise and future storm surge predictions for Manchester-by–the-Sea were obtained from the Inundation Risk Model (IRM). The IRM model was developed by Keil Schmid of Geoscience Consultants for the Salem Sound Coast Watch communities in Northeast Massachusetts, including Manchester-by-the-Sea. The model was chosen from a list of 7 sea level rise/storm surge models. The primary objective was to provide easily understandable and self-contained information for decision makers and citizens that incorporates a probabilistic handling of the uncertainties involved in documenting future coastal hazards. This work built on existing models and concepts by providing a unique and intuitive approach to mapping coastal hazard risks. The results are based on probabilities of occurrence of inundation at specific time intervals.

The primary model scenarios are storm surge and sea level rise. Model outputs are shown as risk of inundation presented in percent risk of occurrence ranging from 1% highly unlikely to 99% certain risk. The model outputs do not show water levels or depth of inundation. Data sets include sea level rise at mean high high water, shallow coastal flooding, Category 1 hurricanes and still-water annual storm surge for selected timeframes (2015, 2025, 2050 and 2100). Some data limitations that are worth mentioning: risk defined for sea level rise is not applicable for the 2015 time frame, and the hurricane risk data is only valid for 2015. Time zero data (elevation and tides/water levels) errors are included in the model calculations. The output maps only show flooding from ocean sources, rain and river derived flooding is not included. The output, description of risk and data sources are included in **Table 3.**

Table 3:
IRM Model Outputs, descriptions and data sources

Output	Description of Risk	Data Sources
Sea Level Change	Level is mean higher high water. Risk describes chance of being inundated at least once per day	Sea Level Change NOAA curves are source for future water levels
Shallow Coastal Flooding	Risk describes chance of area being flooded several times a year, where inundation becomes a deterrent to development	
Storm Surge	Risk describes the chance of an area being inundated once a year from coastal storms other than hurricanes (i.e. Nor'easters)	Historic still water surge data (Boston gauge) is used to define surge height
Hurricane/ Category 1	Risk describes chance of area being inundated if a category 1 hurricane is predicted to strike in the area. Rare occurrence	Data from SLOSH model defines hurricane surge height for grid cells

For ease in interpretation of the risk data for the HMP enhancement, the model output was simplified down to four risk categories:

- 1-10% = low risk, highly unlikely to unlikely
- 33% = medium risk, as likely as not
- 66% = medium-high risk, likely
- 90-99% = high, very likely to certain

As mentioned above, there is no Sea Level Rise risk data generated for the 2015 timeframe, and only 2015 includes risk data for the Hurricane SLOSH model output.

2.2 Extreme Precipitation Model

The Oyster River Culvert Analysis Extreme Precipitation Model was selected to model future precipitation conditions. The model will be used to estimate the impact of climate change on the 25 year design storm, and in particular as input into the riverine watershed model described below in Section 2.3.

Tighe & Bond opted to use this model because the Oyster River watershed is located in Durham, New Hampshire, which is approximately 60 miles north of Manchester-by-the-Sea, along the New Hampshire Seacoast. The two areas have a similar climate and elevation, and therefore it is reasonable to anticipate they would experience similar precipitation patterns in the future.

To predict future precipitation patterns, this model considers two greenhouse gas emission scenarios, one more optimistic (A1b) and one more pessimistic (A1f). Each of these scenarios are based off of the climate change estimates on the Intergovernmental Panel on Climate Change's (IPCC) 4th report (2007). The 5th report (2014) projects an optimistic value of 720-1000 ppm carbon dioxide equivalents in 2100; whereas, the pessimistic value is 1000+ ppm carbon dioxide equivalents.

- The A1b scenario assumes a "**b**alanced" global energy mix; i.e. and equal ratio of fossil fuel use to less greenhouse gas intensive sources of energy. This balanced scenario can be viewed as the more optimistic view of climate change's potential impacts in which the atmosphere has approximately 700 ppm of carbon dioxide equivalents by the year 2100.

- The A1fi scenario assumes a "**f**ossil **i**ntensive" global energy mix; i.e. fossil fuels continue to be the primary fuel source. The fossil intensive scenario is the more pessimistic view of climate change's potential impacts in which the atmosphere has approximately 970 ppm of carbon dioxide equivalents by the year 2100.

Tighe & Bond utilized the data in the Oyster River Culvert Analysis to project future precipitation in 2025, 2050, and 2100 for the A1b and A1fi scenarios, with the results shown in **Tables 4-1** and **4-2**. We plotted data points from the 1964 U.S. Weather Bureau, the 2015 Northeast Regional Climate Center (NRCC) data, and the mid-century (2050) Oyster River Study precipitation estimates, and applied a logarithmic trend line to establish data points for $A1_b$ and $A1_{fi}$ conditions in 2025 and 2100.

Table 4-1
$A1_b$ Rainfall Depths for the Sawmill Brook Watershed (24-hour storm) (inches)

Frequency Storm	2025	2050	2100
25-year	6.36	6.86	7.84
50-year	7.42	7.58	7.88
100-year	8.85	9.31	10.69

Table 4-2
$A1_{fi}$ Rainfall Depths for the Sawmill Brook Watershed (24-hour storm)(inches)

Frequency Storm	2025	2050	2100
25-year	6.77	8.35	11.39
50-year	8.19	10.34	14.48
100-year	10.82	12.58	16.82

2.3 Watershed Model

A dynamic watershed model was created for Sawmill Brook to evaluate culvert adequacy and green infrastructure opportunities to reduce flooding in the watershed. The model is essential to evaluate future river flooding conditions due to increased duration and frequency of rainfall under climate change conditions. The model was set up to include the impacts of sea level rise and coastal surge from the IRM model, and utilized the predicted extreme precipitation rates described above to model impacts from climate change. The modeling approach included a complete hydrologic analysis of existing conditions using observed data from previous modeling efforts, recent culvert data gathered by the Town and volunteers, new survey elevations of critical locations, GIS mapping sources for topography, soils and land use. The watershed model was created using the U.S. Army Corps of Engineers Hydraulic Engineering Center's HEC-RAS software to analyze the water surface elevations under present and future conditions. The HEC-RAS model evaluates stream gradient, cross section, and land cover within the channel and overbanks. It also accounts for energy losses through friction, and expansion and contraction at hydraulic structures, such as bridges and culverts.

Tighe & Bond constructed the geometry of the HEC-RAS model based upon a digital terrain model extracted from MassGIS LiDAR data, and then extrapolated cross sections from that data. LiDAR is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing reflected light. LiDAR is used on a plane while flying over land to measure elevations. The LiDAR data was supplemented by survey data from the culvert survey, and other available sources. The model was calibrated for an extreme precipitation event observed in 2006, and supplemented with water surface elevations at Manchester Harbor where flow is restricted due to tidal forces. For more information on the watershed model, please refer to Tighe & Bond Report, Sawmill Brook Culver and Green Infrastructure Analysis Task 4 Report: Evaluation of Locations for Flood Mitigation, October 2015.

Output from the model was used to evaluate inland flooding impacts on facility and site locations as part of the HMP enhancement. The results were quantified by risk of flooding to the facility or site location for each time period modeled.

3 Community Assets and Inundation Analysis

The current Manchester-by-the-Sea HMP includes a listing of 35 identified critical infrastructure facilities and provides a summary of natural hazards impacting these critical facilities. The hazards include FEMA Flood Zones, locally identified areas of flooding, snow fall, and Hurricane Surge Areas. As part of the 2015 HMP enhancement, the list of critical facilities was re-examined and updated to include additional community assets following the guidelines included in the 2012 FEMA Local Mitigation handbook. **Table 5** below summarizes the general community asset categories, relevant critical sectors within each category and the general characteristics that describe why these assets are important to include in a hazard mitigation plan.

Table 5
Community Asset Categories and Characteristics

FEMA Community Asset Categories	Critical Sectors	Characteristics of Community Assets
People	Schools, Vulnerable Populations, Cultural Facilities	Areas of greater population density, or population with unique vulnerabilities or less able to respond and recover during a disaster.
Built Environment	Critical Municipal Facilities, Water, Wastewater, Energy, Stormwater, Transportation, Cultural Resources	Critical facilities necessary for a community's response to and recovery from emergencies, infrastructure critical for public health and safety, economic viability, or needed for critical facilities to operate.
Economy	Marinas, Downtown Business District	Major employers, primary economic sectors and commercial centers where loss or inoperability would have severe impact on the community and ability to recover from a disaster.

FEMA Community Asset Categories	Critical Sectors	Characteristics of Community Assets
Natural Environment	Natural Resources	Areas that provide protective function to reduce magnitude of hazard impact and increase resiliency. Areas of sensitive habitat that are vulnerable to hazard events, protection of areas that are important to community objectives, such as the protection of sensitive habitat, provide socio-economic benefits, etc.

Together with the CRAG and the Town, a definitive list of 70 community assets were identified as being important to the character and function of Manchester-by-the-Sea. The complete list of facilities and sites are included in **Table 6** and mapped in **Figure 1**.

The current HMP includes many critical sectors included under the People and Built Environment asset categories. Two categories, economy and natural resources, are not included in the current plan version. The CRAG and the Town agreed these were important to consider for a more balanced approach to hazard management.

Natural environments are identified in this handbook as important to: (1) community identity and quality of life, (2) supporting the economy through agriculture, tourism, recreation and protection of clean air and water, and (3) protective functions that reduce hazard impacts and increase resiliency (i.e. absorbing flood waters, providing erosion control, reducing runoff, storm buffers, etc.). Manchester-by-the-Sea has a wealth of coastal and inland natural resources both important for providing resiliency from storm flooding and for the tremendous socioeconomic benefits.

Economic assets were identified as important based on the concept that economic resiliency drives recovery after a disaster. Economic elements unique to Manchester-by-the-Sea include the commuter rail, transporting commuters to the Boston-metro region and ferrying urban beach goers out to Manchester’s waterfront parks and beaches. Also included are marine repair operations that support the fishing and recreational boating community and provide ocean rescue support. Downtown business are also included, where losses or inoperability of these economic sectors would have severe impact on the community to recover from a disaster.

3.1 Inundation Analysis

The model output from the coastal flooding and watershed models were utilized to complete an analysis of the flooding hazards due to climate change for all community assets. The spatial location of each critical sector was evaluated in relation to model output for the four different IRM coastal flood scenarios, and inland flooding from Sawmill Brook based on sea level rise, storm surge and a balanced energy use.

For all community asset categories, if any portion of a parcel, or the linear feature intersected with the modeled inundation areas, it was included as an impacted asset. Developed sites will be examined in closer detail in the Task 3 Risk Vulnerability Analysis to weigh the importance of a partially inundated property. For example, the Landmark school includes inundation areas that impact the site driveway and some auxiliary buildings but not the main campus. The Task 3 will take a closer look at the site to determine the site vulnerability based on the inundation results. **Figure 2** through **Figure 7** and **Table 7** through **Table 10** summarize the results of the inundation analysis for all 70 sites.

Out of the 70 sites, the flooding risks are prevalent at almost all of the listed facilities and sites, if not at the present, at some time in the future.

- The risk of inundation from hurricanes (Category 1 or greater) affects 59% of the community assets (41 out of 70). Hurricane Storm Surge impacts modeled by the IRM are more prevalent for both coastal and inland sites, as compared to the current 2010 HMP risk analysis.
- Inland flooding (modeled with sea level rise and fossil intensive energy use) impacts 43% (30 out of 70) of the locations.
- The risk of inundation due to storm surge affects 33% of the assets (23 out of 70) in the near term (2025), and increases to affect over 50% by 2100.
- The risk of inundation due to shallow coastal flooding affects 31% of the assets (22 out of 70) in the near term (2025) and increases to affect just over 45% of the community assets by 2100.
- Risk of inundation from sea level rise appears the least, and affects only 23% (16 of 70) of the community assets in the near term (2025) and up to 37% (26 out of 70) by 2100.

3.2 Site Selection for Risk and Vulnerability Analysis

The next step in the analysis was to establish a process to narrow down the list of sites for the Task 3 Risk and Vulnerability Analysis (RVA). Sites that were not impacted, or minimally impacted by coastal or inland flooding (2100 impact only), will be kept in the hazard mitigation plan but excluded from the focused RVA. The CRAG and the Town discussed each of the locations with respect to anticipated mitigation value and further reduced the list for the RVA. Sites that were removed and the rational for removal are as follows:

- Manchester Community Center- not a location of refuge
- Manchester Masonic Building- not a location of refuge
- National Grid- 2050 Storm Surge impacts only and mitigation for non-municipally owned utility would be difficult to implement
- MBTA Station- mitigation for state owned transit would be difficult to implement
- Masconomo Park- not a location of refuge, may recommend non-structural mitigation
- Cat Brook- limited adjacent built environment, preservation of open space sufficient
- Beaverdam Swamp- limited adjacent built environment, preservation of open space sufficient
- Cedar Swamp- limited adjacent built environment, preservation of open space sufficient

Remaining assets that were recommended for the RVA include the following locations:

Community Assets: People	**Community Assets: Built Environment**
• Landmark School • Magic Years Nursery School • First Baptist Church • Congregational Church • Summer Street Apartments • The Plains Senior Housing	• Fire Department • Police Department • Town Hall • Manchester Waste Water Treatment Plant • Emergency Operations • Central Street Dam • MBTA Tracks and Bridge • DPW Garage • Lincoln Street Well and Treatment Facility • Downtown Stormwater Drainage • School Street and Bridge • Lincoln Street • Route 127

Community Assets: Economy	Community Assets: Natural Resources
• Manchester Marine • Crocker's Boat Yard • Downtown Business	• Manchester Harbor • Singing Beach • Sawmill Brook • Bennet's Brook • Millets Swamp and Brook

4 Impacts of Climate Change

The updated HMP Community Asset list (Table 6) includes a long list of sites facilities, including but not limited to, public safety complexes, natural resources, schools, senior living residences, and Town-owned buildings. Flooding and sea level rise will impact each of these places in a different way. As a precursor to the Task 3 Vulnerability Assessment, we have brainstormed the impacts flood waters may have on the different facilities and sites. The type of damage that is expected to occur is briefly summarized below.

Site damage may occur at parks and open spaces, natural resources such as beaches and wetlands, and dams. Impacts of flooding include erosion, scour, damage to man-made landscaping and/or native plants, and damage to accessory structures such as fencing, playgrounds, memorials, etc. Some examples are briefly described below:

- Erosion and scour could cause a barrier beach to recede and eventually diminish its ability to protect from sea level rise and wave action.
- The soils and plants of a wetland could become compromised as a result of a flood, which reduces the area's ability to sequester flood waters.
- Dams could sustain structural damage, which can further lead to road damage and ultimately become a public safety issue.
- Damage to accessory structures and landscaping features could be costly items to fix.

Damage may occur to structures and buildings, whether it be a school or a storage tank. Each building or structure should be evaluated to determine what type of damage may occur: structural, non-structural, utility, and content damage. Structural damage would include damage to the load-bearing portions of the building or structure. This damage would likely require evacuation and loss of function of the facility. Non-structural damage includes damage to features such as drywall, painting, flooring, etc. and may require costly repairs, but not necessarily evacuation. Damage to building utilities including water, electrical, and HVAC would require immediate repair and again a loss of function of the facility. Emergency generators may not always be available and with loss of electricity comes loss of communication. These utilities are often located in the basement or subgrade of the building and would be the first area to flood. It should be noted whether or not these facilities also serve as emergency shelters and if they have a backup generator. Damage to the building's contents would include damage to furniture, files, and any other contents such as medical equipment.

Damage to linear features includes damage to roads and public utilities within roadways including electrical, stormwater, water, and wastewater systems. Damage to roads could be detrimental for a number of reasons. During a natural disaster, roadway damage could inhibit the ability of emergency vehicles to access certain areas of the town. After the flood event, roadway damage may hinder economic activity or residents' abilities to travel safely. Damage to public utilities could result in loss of function and loss of service to the public, which in many cases is a public health and/or safety issue. For example, a water main break will result in loss of service and there is also risk of contamination.

5 Recommendations

The results of the Critical Sector Analysis narrowed down the assessment from 70 community assets to 28, based on the location of sites or facilities at risk of flooding due to storm surge, sea level rise and inland flooding, and greater potential for mitigation. This approach will be used to inform the next phase of this project, completing the Vulnerability Risk Assessment. While it is true that some sites or facilities may be considered under multiple asset categories, for the purpose of organizing the recommendations, each site is listed only once.

Six sites were included for people based community assets, predominantly classified with the vulnerable population sector code. In general these sites include areas with greater population density, population with unique vulnerabilities or populations less able to respond and recover during a disaster. Two are municipal properties, two are private and two are non-profit. The CRAG has recommended including all six sites for the Vulnerability Risk Assessment.

Fourteen sites were included for built infrastructure based community assets. All sites are vitally important for public health and safety, including municipal facilities needed to operate the Town's water and sewer, emergency response facilities, critical transportation/evacuation routes and drainage infrastructure. The CRAG recommended including all of these sites in the vulnerability analysis.

Three sites were included for economy based community assets, including two marine business locations and the downtown business area. The downtown business will be limited to locations that would be impacted by storm surge or sea level rise by the year 2050, which correlates to buildings at the 15 foot land surface elevation. Pending further discussion with the Downtown Business Association, the CRAG recommends including these two facilities and downtown business area for the Vulnerability Risk Assessment. The CRAG further recommended that the economic aspects of transportation corridors listed under built environment community assets is considered in the Vulnerability Risk Assessment.

Five sites were included for natural resource based community assets. Based on the diversity of natural resources, importance to the community and areas providing tremendous socio-economic benefits, the CRAG recommended including all of these sites.

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Table 6 - Critical Facilities/Sites

COMMUNITY ASSET	ID	NAME	ADDRESS	Sector Code
People	P-1	Brookwood Elementary School	1 Brookwood Road	CB
	P-2	Manchester Memorial Elementary School	71 Lincoln Street	CB
	P-3	Manchester Essex Regional Middle High School	36 Lincoln Street	CB
	P-4	Landmark School	167 Bridge Street	CB
	P-5	Magic Years Nursery School	3 Chapel Lane	VP
	P-6	Hornet's After School Program	71 Lincoln Street	VP
	P-7	Tara Montessori School	60 School Street	VP
	P-8	The Plains Seniors Housing	The Plains Road	VP
	P-9	Newport Park Seniors Housing	Newport Park Road	VP
	P-10	Summer Street Apartments	12 Summer Street	VP
	P-11	Mancester Community Center	Beach Street	VP
	P-12	Manchester Public Library	15 Union Street	CB-C
	P-13	First Baptist Church	20 School Street	CB-C
	P-14	Sacred Heart Parish	58 School Street	CB-C
	P-15	Congregational Chapel	Chapel Lane	CB-C
	P-16	Masconomo Park	60 Beach St	P
	P-17	Sweeney Park	113 Summer St	P
	P-18	Manchester Historical Society	10 Union Street	CB-C
	P-19	Coach Field Playground	Norwood & Brook	P
	P-20	Surf Park	Raymond Street	P
	P-21	First Parish Church	Town Common	CB-C
	P-22	Manchester Masonic Bldg	26 Central street	VP
	P-23	Essex Country Club	153 School Street	P

Table 6 - Critical Facilities/Sites

COMMUNITY ASSET	ID	NAME	ADDRESS	Sector Code
Built Environment	B-1	Manchester Fire Department	12 School Street	CB-F
	B-2	Manchester Police Headquarters	10 Central Street	CB-F
	B-3	Manchester-by-the-Sea Town Hall	10 Central Street	CB-F
	B-4	Manchester Wastewater Treatment	12 Church Street	CB-F
	B-5	DPW Garage	85 Pleasant Street	CB-F
	B-6	Emergency Operation Center Town Hall	10 Central Street	CB-F
	B-7	Manchester Wastewater Treatment Plant Parcel #2	12 Church Street	CB-W
	B-8	Lincoln Street Well & Pumping Station	40 Lincoln Street	CB-W
	B-9	Manchester Water Tower (tank)	139 Pine Street	CB-W
	B-10	Verizon- Switching Station	52 Summer Street, Unit R	E
	B-11	National Grid	21 Summer Street	E
	B-12	Vulnerable UST's		E
	B-13	Downtown Stormwater Drainage Sytem	Central Street	SW
	B-14	School Street Bridge	School Street	SW
	B-15	Central Street Dam	Central Street	SW
	B-16	Small Brook Dam	22 Forster Road	SW
	B-17	Forster Road Dam	Forster Road	SW
	B-18	Saw Mill Brook Dam	30 Mill Street	SW
	B-19	Gorman Pond Dam	4 Old Wenham Way	SW
	B-20	MBTA Tracks/Bridge		T
	B-21	Route 127		T
	B-22	School Street		T
	B-23	Pine Street		T
	B-24	Lincoln Street		T

Table 6 - Critical Facilities/Sites

COMMUNITY ASSET	ID	NAME	ADDRESS	Sector Code
Economy	E-1	MBTA Station	Beach Street	T
	E-2	Manchester Marine	17 Ashland Ave	CB
	E-3	Crocker's Boat Yard	15 Ashland Ave	CB
	E-4	Downtown Businesses		CB
Natural Resources	N-1	Manchester Harbor	10 Central Street	NR
	N-2	Singing Beach	199A Beach Street	NR
	N-3	Black Beach (Barrier Beach)		NR
	N-4	White Beach (Barrier Beach)		NR
	N-5	Eaglehead Swamps and Ponds		NR
	N-6	Chubb Creek and marsh		NR
	N-7	Kettle Cove and Clark Pond		NR
	N-8	Cat Brook		NR
	N-9	Millet's Swamp and Brook		NR
	N-10	Sawmill Brook		NR
	N-11	Bennet's Brook and Marsh		NR
	N-12	Causeway Brook		NR
	N-13	Dexter Pond		NR
	N-14	Winthrop Field		NR
	N-15	Beaverdam Swamp	School St.	NR
	N-16	Cedar Swamp	School St.	NR
	N-17	Maple Swamp	Pine St.	NR
	N-18	Long Hill Conservation Area		NR
	N-19	Wolf Trap Marsh		NR

Sector Code Key:

CB	Critical Building	P	Parks
CB-C	Critical Cultural Facility	SW	Stormwater
CB-F	Critical Municipal Facility	T	Transportation
CB-W	Water	VP	Vulnerable Populations
E	Energy	NR	Natural Resources

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Table 7 - Community Asset: People (Vulnerable Populations, Cultural Facilities and Parks)

Risk of Flooding for 2015, 2025, 2050 and 2100 scenarios

RISK KEY: None, Low, Med, Med-High, High

ID	NAME	ADDRESS	Sector Code	Flood Zone Elevation NAVD-88 (ft)	IRM Sea Level Rise				IRM Shallow Coastal Flooding				IRM Storm Surge				IRM Hurricane / Cat 1				Upland Flooding Impacts			
					2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100
P-1	Brookwood Elementary School	1 Brookwood Road	CB	14	N/A													N/A	N/A	N/A				
P-2	Manchester Memorial Elementary School	71 Lincoln Street	CB	15	N/A													N/A	N/A	N/A				
P-3	Manchester Essex Regional Middle High School	36 Lincoln Street	CB		N/A													N/A	N/A	N/A				
P-4	Landmark School	167 Bridge Street	CB	14	N/A													N/A	N/A	N/A				
P-5	Magic Years Nursery School	3 Chapel Lane	VP	13	N/A													N/A	N/A	N/A				
P-6	Hornet's After School Program	71 Lincoln Street	VP	15	N/A													N/A	N/A	N/A				
P-7	Tara Montessory School	60 School Street	VP		N/A													N/A	N/A	N/A				
P-8	The Plains Seniors Housing	The Plains Road	VP		N/A													N/A	N/A	N/A				
P-9	Newport Park Seniors Housing	Newport Park Road	VP		N/A													N/A	N/A	N/A				
P-10	Summer Street Apartments	12 Summer Street	VP	11	N/A													N/A	N/A	N/A				
P-11	Mancester Community Center	Beach Street	VP	11	N/A													N/A	N/A	N/A				
P-12	Manchester Public Library	15 Union Street	CB-C		N/A													N/A	N/A	N/A				
P-13	First Baptist Church	20 School Street	CB-C	11	N/A													N/A	N/A	N/A				
P-14	Sacred Heart Parish	58 School Street	CB-C		N/A													N/A	N/A	N/A				
P-15	Congregational Chapel	Chapel Lane	CB-C	13	N/A													N/A	N/A	N/A				
P-16	Masconomo Park	60 Beach St	P	11	N/A													N/A	N/A	N/A				

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Table 7 - Community Asset: People (Vulnerable Populations, Cultural Facilities and Parks)

RISK KEY: None | Low | Med | Med-High | High

Risk of Flooding for 2015, 2025, 2050 and 2100 scenarios

ID	NAME	ADDRESS	Sector Code	Flood Zone Elevation NAVD-88 (ft)	IRM Sea Level Rise				IRM Shallow Coastal Flooding				IRM Storm Surge				IRM Hurricane / Cat 1				Upland Flooding Impacts			
					2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100
P-17	Sweeney Park	113 Summer St	P	15	N/A													N/A	N/A	N/A				
P-18	Manchester Historical Socie	10 Union Street	CB-C		N/A													N/A	N/A	N/A				
P-19	Coach Field Playground	Norwood & Brook	P	12	N/A													N/A	N/A	N/A				
P-20	Surf Park	Raymond Street	P	14	N/A	*Outside of area for model results*												N/A	N/A	N/A				
P-21	First Parish Church	Town Common	CB-C	15	N/A													N/A	N/A	N/A				
P-22	Manchester Masonic Bldg	26 Central street	VP	11	N/A													N/A	N/A	N/A				
P-23	Essex Country Club	153 School Street	P	15	N/A													N/A	N/A	N/A				

Table 8 - Community Asset: Built Environment (Critical Buildings, Infrastructure and Transportation Cooridors)

Risk of Flooding for 2015, 2025, 2050 and 2100 scenarios

RISK KEY: None | Low | Med | Med-High | High

ID	NAME	ADDRESS	Sector Code	Flood Zone Elevation NAVD-88 (ft)	IRM Sea Level Rise				IRM Shallow Coastal Flooding				IRM Storm Surge				IRM Hurricane/ Cat 1				Upland Flooding Impacts			
					2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100
B-1	Manchester Fire Department	12 School Street	CB-F	11	N/A													N/A	N/A	N/A				
B-2	Manchester Police Headquarters	10 Central Street	CB-F	11	N/A													N/A	N/A	N/A				
B-3	Manchester-by-the-Sea Town Hall	10 Central Street	CB-F	11	N/A													N/A	N/A	N/A				
B-4	Manchester Wastewater Treatment	12 Church Street	CB-F	11	N/A													N/A	N/A	N/A				
B-5	DPW Garage	85 Pleasant Street	CB-F		N/A													N/A	N/A	N/A				
B-6	Emergency Operation Center Town Hall	10 Central Street	CB-F	11	N/A													N/A	N/A	N/A				
B-7	Manchester Wastewater Treatment Plant Parcel #2	12 Church Street	CB-W	11	N/A													N/A	N/A	N/A				
B-8	Lincoln Street Well & Pumping Station	40 Lincoln Street	CB-W	15	N/A													N/A	N/A	N/A				
B-9	Manchester Water Tower (tank)	139 Pine Street	CB-W		N/A													N/A	N/A	N/A				
B-10	Verizon- Switching Station	52 Summer Street, Unit R	E		N/A													N/A	N/A	N/A				
B-11	National Grid	21 Summer Street	E	11	N/A													N/A	N/A	N/A				
B-12	Vulnerable UST's		E		N/A	Requires specific analysis												N/A	N/A	N/A				
B-13	Downtown Stormwater Drainage Sytem	Central Street	SW		N/A	Requires specific analysis												N/A	N/A	N/A				
B-14	School Street Bridge	School Street	SW		N/A	Requires specific analysis												N/A	N/A	N/A				
B-15	Central Street Dam	Central Street	SW	11	N/A													N/A	N/A	N/A				
B-16	Small Brook Dam	22 Forster Road	SW		N/A	Requires specific analysis												N/A	N/A	N/A				

Table 8 - Community Asset: Built Environment (Critical Buildings, Infrastructure and Transportation Cooridors)

Risk of Flooding for 2015, 2025, 2050 and 2100 scenarios

RISK KEY: None | Low | Med | Med-High | High

ID	NAME	ADDRESS	Sector Code	Flood Zone Elevation NAVD-88 (ft)	IRM Sea Level Rise				IRM Shallow Coastal Flooding				IRM Storm Surge				IRM Hurricane/ Cat 1				Upland Flooding Impacts			
					2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100
B-17	Forster Road Dam	Forster Road	SW		N/A	Requires specific analysis												N/A	N/A	N/A				
B-18	Saw Mill Brook Dam	30 Mill Street	SW		N/A	Requires specific analysis												N/A	N/A	N/A				
B-19	Gorman Pond Dam	4 Old Wenham Way	SW		N/A	Requires specific analysis												N/A	N/A	N/A				
B-20	MBTA Tracks/Bridge*		T		N/A													N/A	N/A	N/A				
B-21	Route 127*		T		N/A													N/A	N/A	N/A				
B-22	School Street *		T		N/A													N/A	N/A	N/A				
B-23	Pine Street*		T		N/A													N/A	N/A	N/A				
B-24	Lincoln Street *		T		N/A													N/A	N/A	N/A				

* Note: Impacts shown may cover any portion of the transportation cooridor.

Table 9 - Community Asset: Economy (Commuter Rail and Businesses)

Risk of Flooding for 2015, 2025, 2050 and 2100 scenarios

RISK KEY:

None	Low	Med	Med-High	High

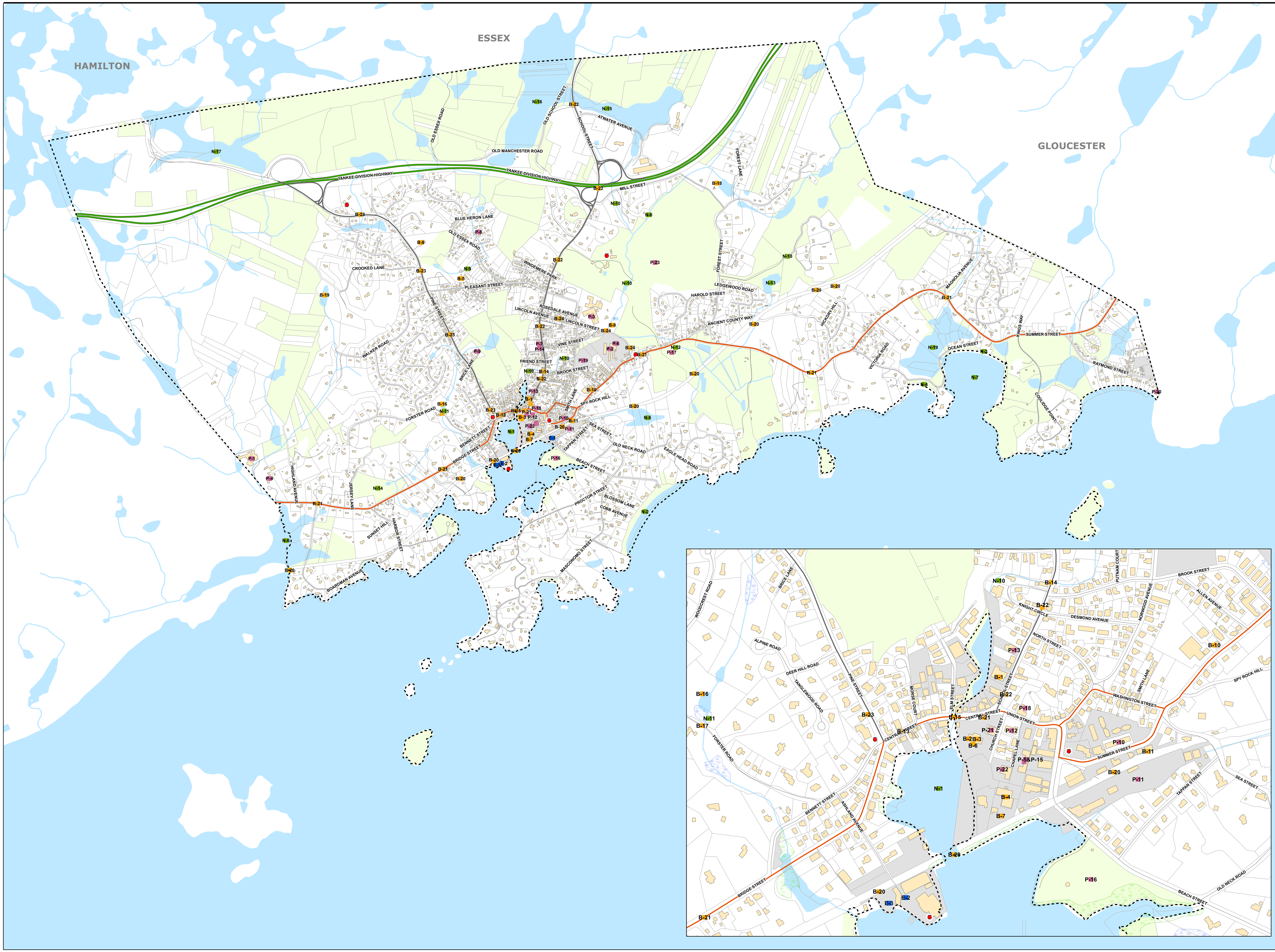
ID	NAME	ADDRESS	Sector Code	Flood Zone Elevation NAVD-88 (ft)	IRM Sea Level Rise				IRM Shallow Coastal Flooding				IRM Storm Surge				IRM Hurricane / Cat 1				Upland Flooding Impacts			
					2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100
E-1	MBTA Station	Beach Street	T	12	N/A													N/A	N/A	N/A				
E-2	Manchester Marina	17 Ashland Ave	CB	11	N/A													N/A	N/A	N/A				
E-3	Crocker's Boat Yard	15 Ashland Ave	CB	11	N/A													N/A	N/A	N/A				
E-4	Downtown Businesses		CB		N/A	Requires specific analysis												N/A	N/A	N/A				

Table 10 - Community Asset: Natural Resources

Risk of Flooding for 2015, 2025, 2050 and 2100 scenarios

RISK KEY: None | Low | Med | Med-High | High

ID	NAME	ADDRESS	Sector Code	Flood Zone Elevation NAVD-88 (ft)	IRM Sea Level Rise				IRM Shallow Coastal Flooding				IRM Storm Surge				IRM Hurricane / Cat 1				Upland Flooding Impacts			
					2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100	2015	2025	2050	2100
N-1	Manchester Harbor	10 Central Street	NR	11	N/A													N/A	N/A	N/A				
N-2	Singing Beach	199A Beach Street	NR	14	N/A													N/A	N/A	N/A				
N-3	Black Beach (Barrier Beach)		NR		N/A	*Outside of area for model results*												N/A	N/A	N/A				
N-4	White Beach (Barrier Beach)		NR		N/A	*Outside of area for model results*												N/A	N/A	N/A				
N-5	Eaglehead Swamps and Ponds		NR		N/A													N/A	N/A	N/A				
N-6	Chubb Creek and marsh		NR		N/A													N/A	N/A	N/A				
N-7	Kettle Cove and Clark Pond		NR		N/A	*Outside of area for model results*												N/A	N/A	N/A				
N-8	Cat Brook		NR		N/A													N/A	N/A	N/A				
N-9	Millet's Swamp and Brook		NR		N/A													N/A	N/A	N/A				
N-10	Sawmill Brook *		NR		N/A													N/A	N/A	N/A				
N-11	Bennet's Brook and Marsh *		NR		N/A													N/A	N/A	N/A				
N-12	Causeway Brook		NR		N/A													N/A	N/A	N/A				
N-13	Dexter Pond		NR		N/A													N/A	N/A	N/A				
N-14	Winthrop Field		NR		N/A													N/A	N/A	N/A				
N-15	Beaverdam Swamp	School St.	NR		N/A													N/A	N/A	N/A				
N-16	Cedar Swamp	School St.	NR		N/A													N/A	N/A	N/A				



COMMUNITY ASSETS

LEGEND

Community Assets

- Built Environment
- Economy
- Natural Environment
- People
- Underground Storage Tanks (B-12)
- Downtown Businesses (E-4)
- Buildings
- Waterbodies
- Open Space
- Town Boundary

LOCUS MAP

0 500 1,000 2,000 Feet

1 " = 1,000 '

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

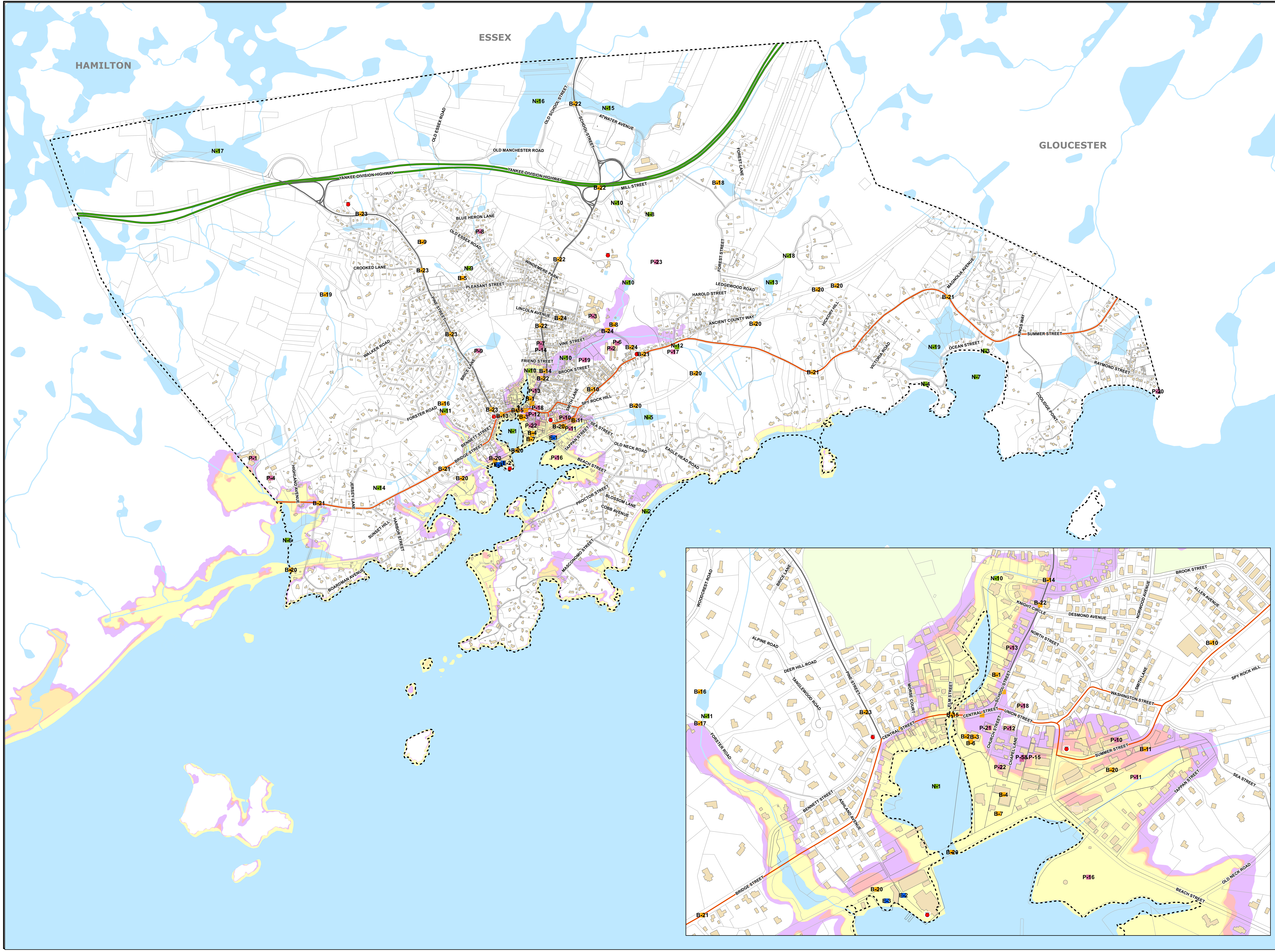
Potential Climate Change Impacts to Manchester-by-the-Sea, MA

Tighe&Bond

Sept. 2015

FIGURE 1

G:\GIS\MA\ManchesterMA\avproj\20150929CriticalSectors



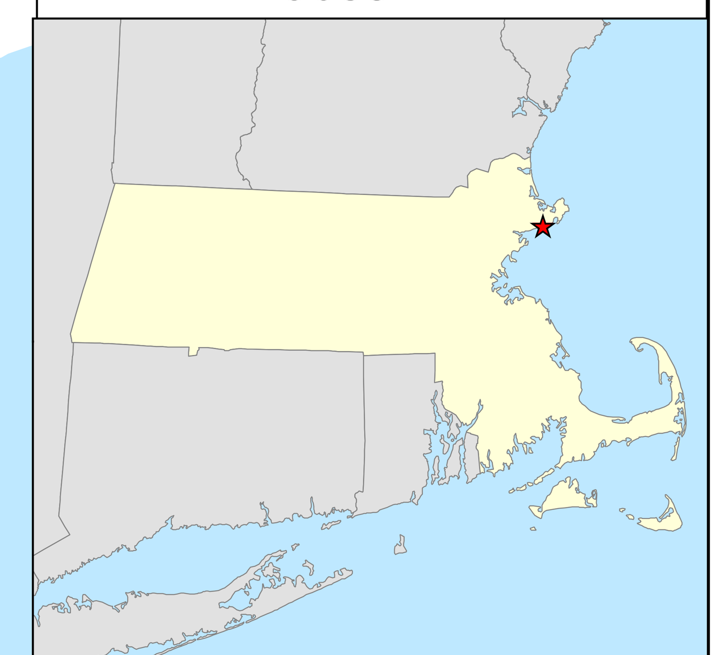
IRM STORM SURGE

LEGEND

Community Assets

- Built Environment
- Economy
- Natural Environment
- People
- Underground Storage Tanks (B-12)
- Downtown Businesses (E-4)
- Buildings
- Waterbodies
- 2015 IRM Storm Surge
- 2025 IRM Storm Surge
- 2050 IRM Storm Surge
- 2100 IRM Storm Surge
- Town Boundary

LOCUS MAP



N

0 500 1,000 2,000 Feet

1 " = 1,000 '

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Potential Climate Change Impacts to Manchester-by-the-Sea, MA

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FIGURE 2

G:\GIS\MA\ManchesterMA\avproj\20150929CriticalSectors

IRM HURRICANE CATEGORY 1

LEGEND

Community Assets

- Built Environment
- Economy
- Natural Environment
- People
- Underground Storage Tanks (B-12)
- Downtown Businesses (E-4)
- Buildings
- Waterbodies
- 2015 IRM CAT 1 Hurricane

LOCUS MAP

0 500 1,000 2,000 Feet

1 " = 1,000 '

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Potential Climate Change Impacts to Manchester-by-the-Sea, MA

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FIGURE 3

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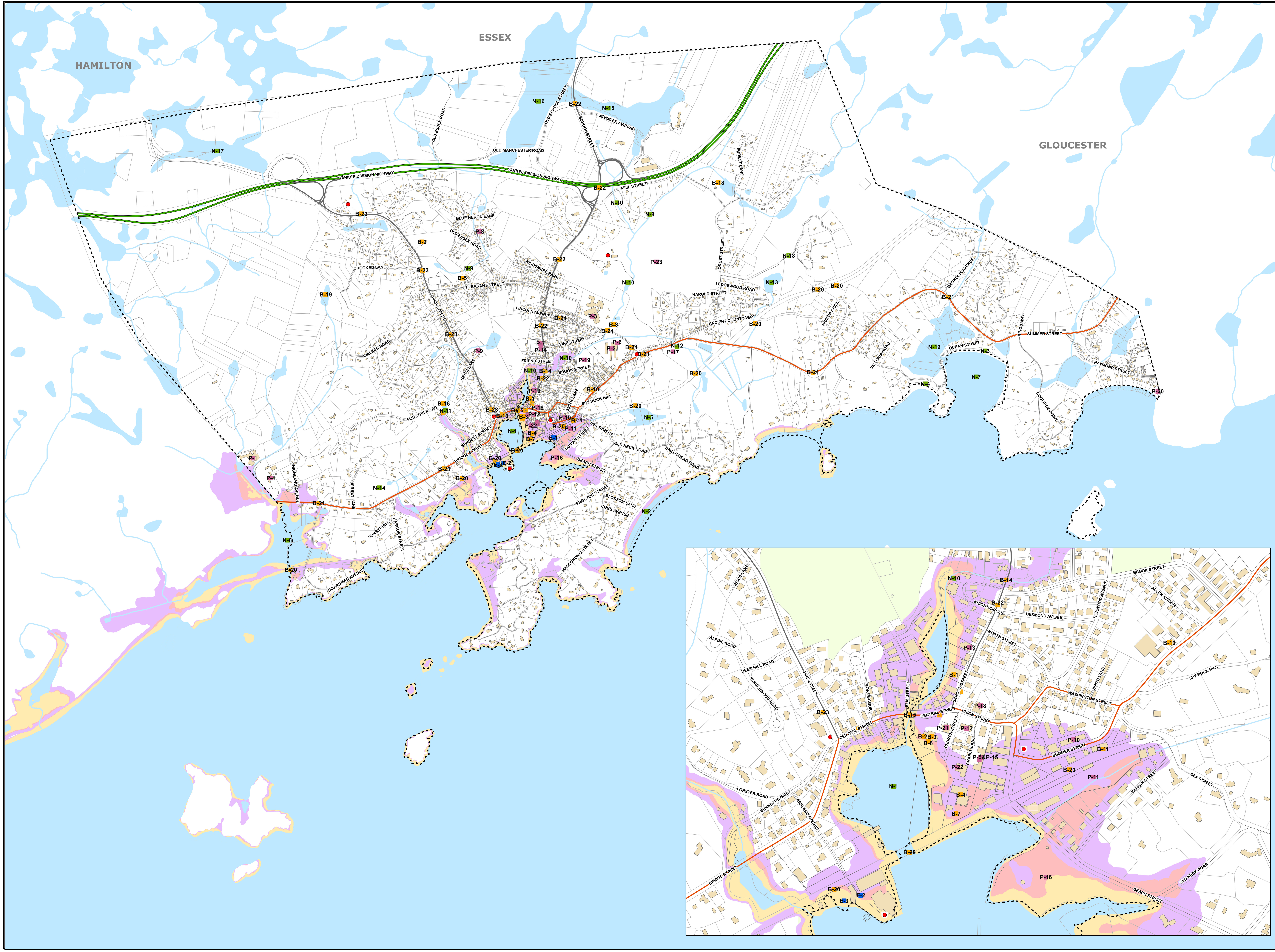
IRM SEA LEVEL RISE



LEGEND

Community Assets

- Built Environment
- Economy
- Natural Environment
- People
- Underground Storage Tanks (B-12)
- Downtown Businesses (E-4)
- Buildings
- Waterbodies
- 2025 IRM Sea Level Rise
- 2050 IRM Sea Level Rise
- 2100 IRM Sea Level Rise
- Town Boundary

LOCUS MAP

0 500 1,000 2,000 Feet

1 " = 1,000 '

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Potential Climate Change Impacts to Manchester-by-the-Sea, MA

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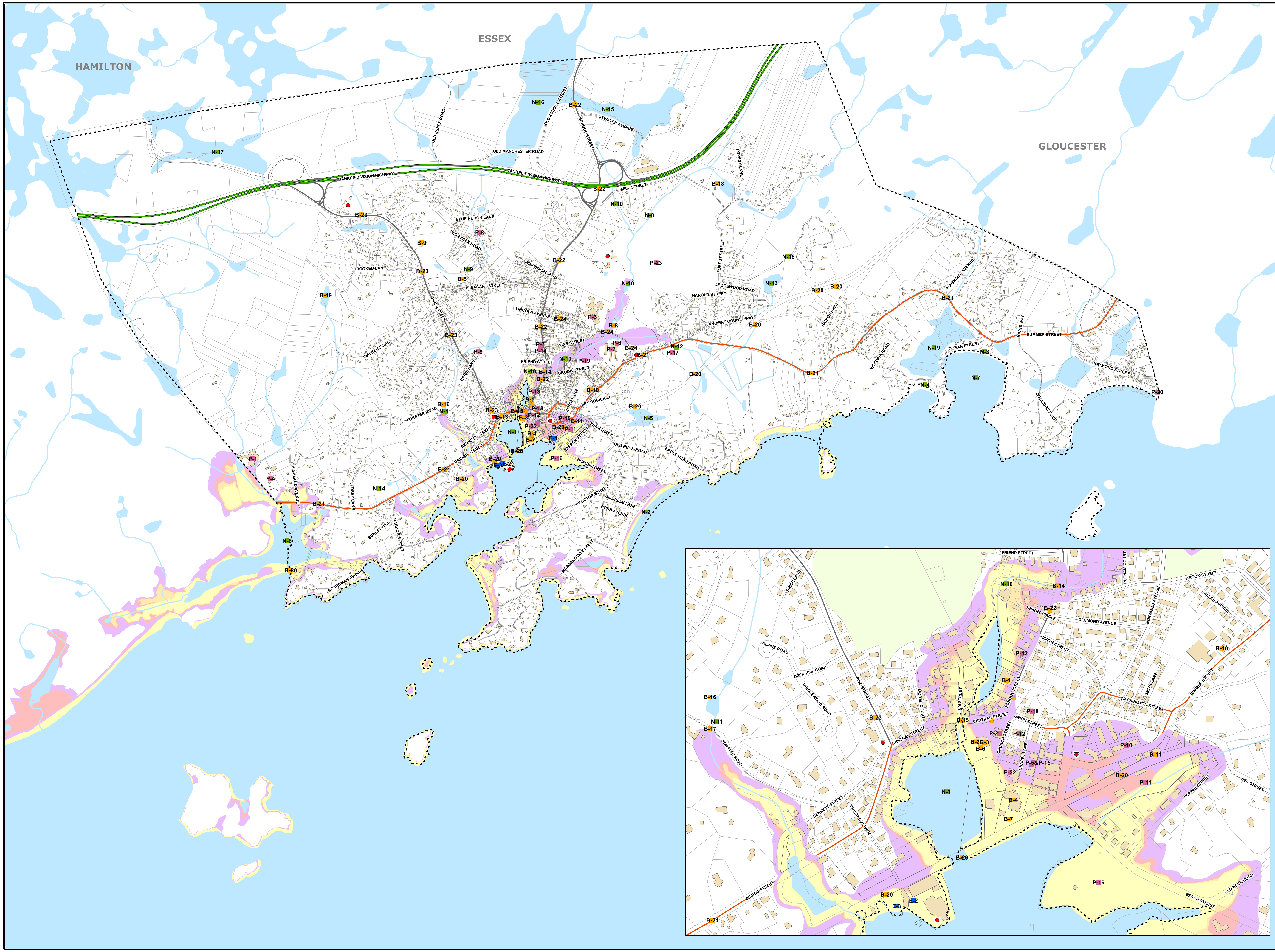
FIGURE 4

G:\GIS\MA\ManchesterMA\avproj\20150929CriticalSectors



IRM SHALLOW COASTAL FLOODING

LEGEND

Community Assets

- Built Environment
- Economy
- Natural Environment
- People
- Underground Storage Tanks (B-12)
- Downtown Businesses (E-4)
- Buildings
- Waterbodies
- 2015 IRM Shallow Coastal Flooding
- 2025 IRM Shallow Coastal Flooding
- 2050 IRM Shallow Coastal Flooding
- 2100 IRM Shallow Coastal Flooding
- Town Boundary

LOCUS MAP

0 500 1,000 2,000 Feet

1 " = 1,000 '

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

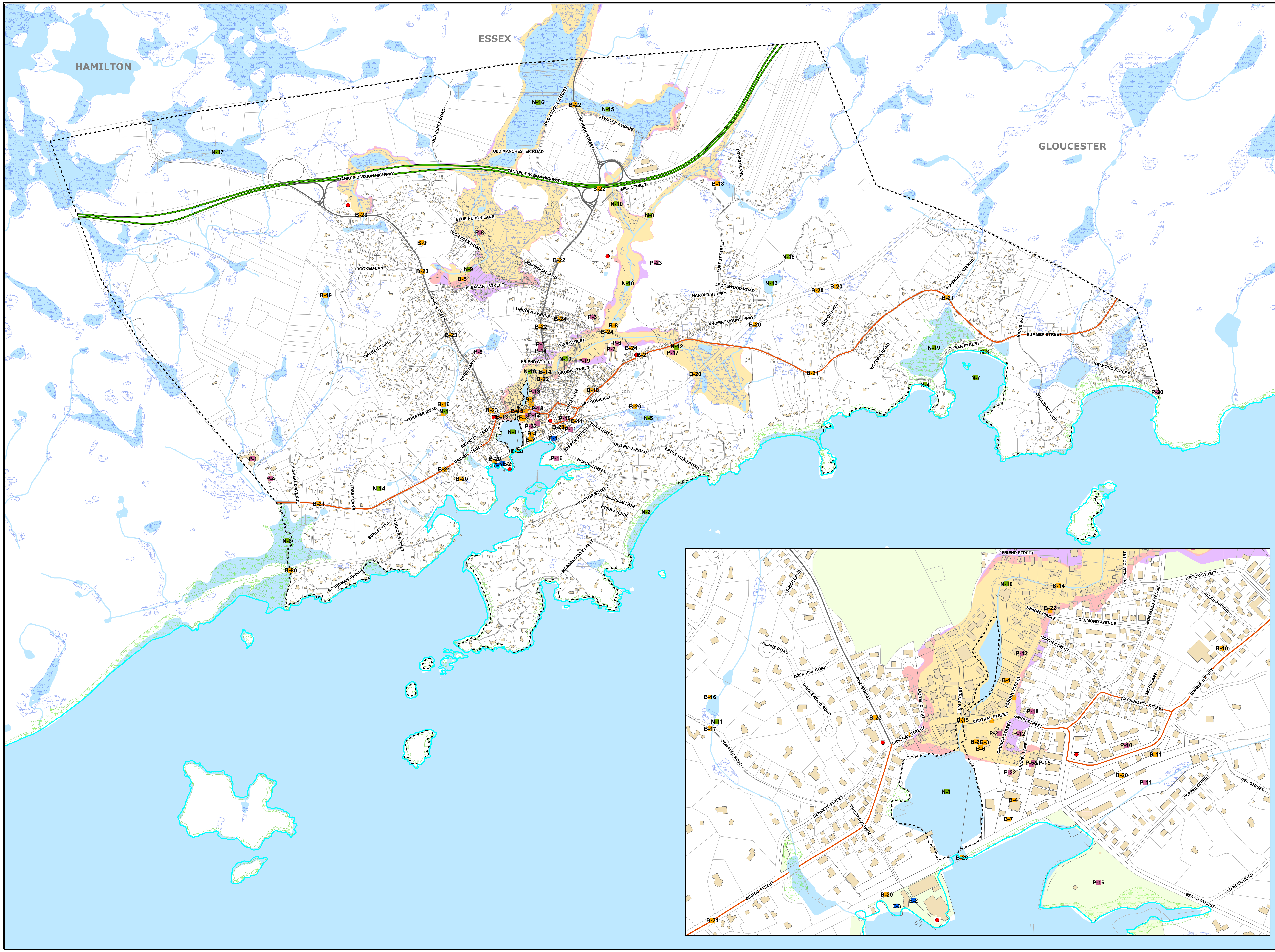
Potential Climate Change Impacts to Manchester-by-the-Sea, MA

Tighe&Bond

Sept. 2015

FIGURE 5

INLAND FLOODING BASED ON SEA LEVEL RISE & FOSSIL INTENSIVE ENERGY USE

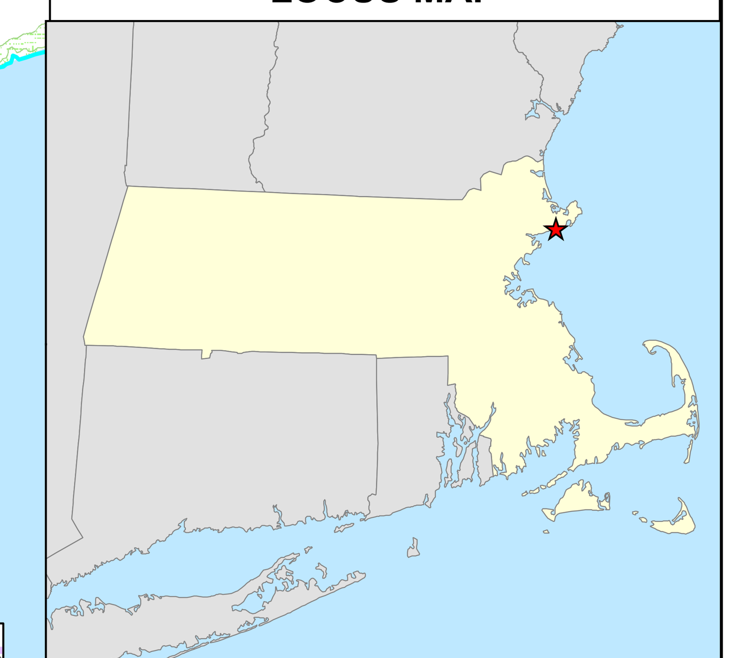


LEGEND

Community Assets

- Built Environment
- Economy
- Natural Environment
- People
- Underground Storage Tanks (B-12)
- Downtown Businesses (E-4)
- Buildings
- Inland Wetlands
- Coastal Wetlands
- Waterbodies
- 2025 Flooding
- 2050 Flooding
- 2100 Flooding
- Town Boundary

LOCUS MAP



0 500 1,000 2,000 Feet

1 " = 1,000 '

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Potential Climate Change Impacts to Manchester-by-the-Sea, MA

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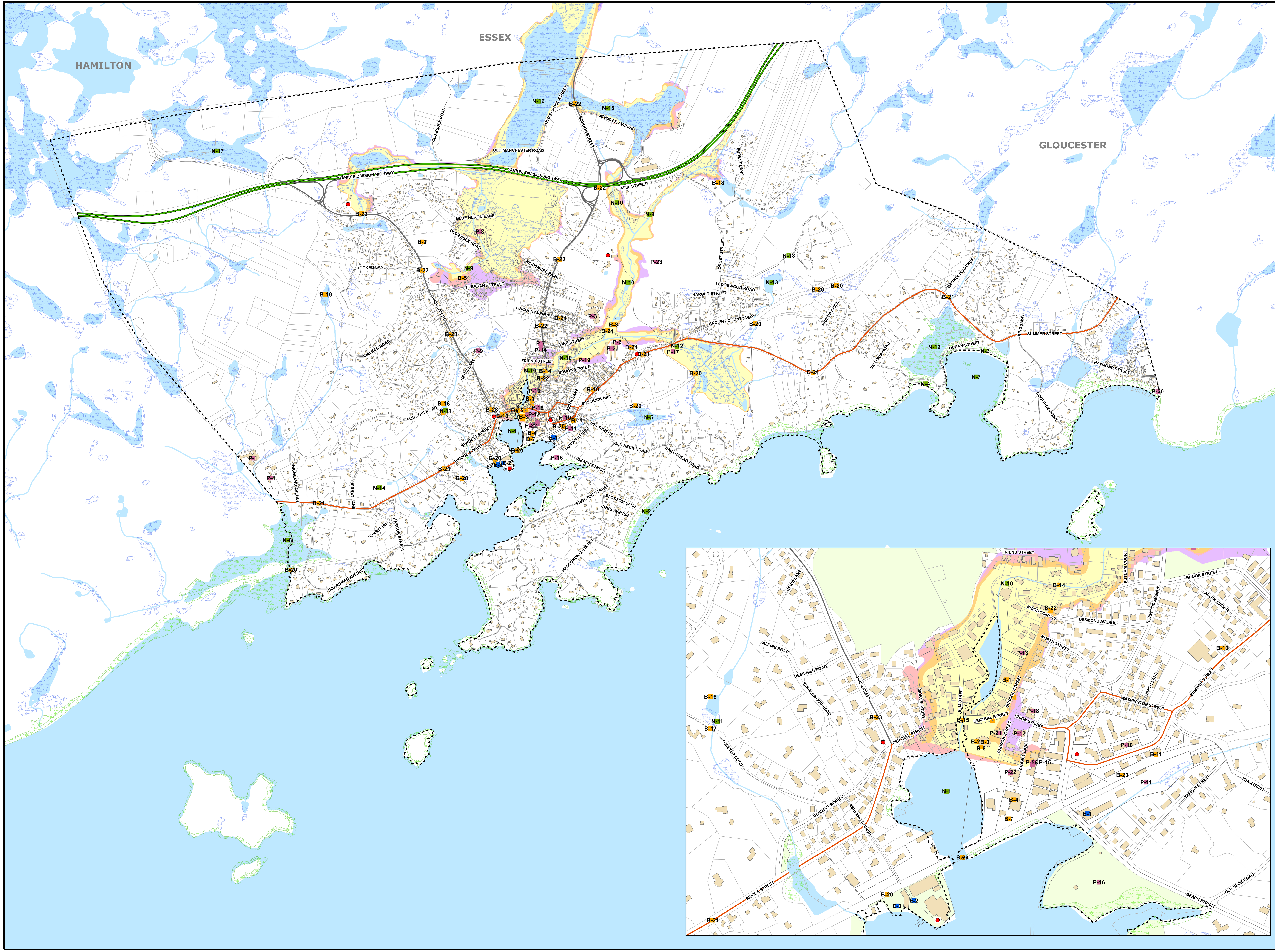
Sept. 2015

FIGURE 6

G:\GIS\MA\ManchesterMA\avproj\20150929CriticalSectors



INLAND FLOODING BASED ON STORM SURGE & FOSSIL INTENSIVE ENERGY USE

LEGEND

Community Assets

- Built Environment
- Economy
- Natural Environment
- People
- Underground Storage Tanks (B-12)
- Downtown Businesses (E-4)
- Buildings
- Inland Wetlands
- Coastal Wetlands
- Waterbodies
- 2025 Flooding
- 2015 Flooding
- 2050 Flooding
- 2100 Flooding
- Town Boundary

LOCUS MAP

0 500 1,000 2,000 Feet

1 " = 1,000 '

NOTES

Data sources: Town of Manchester-by-the-Sea, Office of Geographic and EnvironmentalInformation (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs.

Potential Climate Change Impacts to Manchester-by-the-Sea, MA

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FIGURE 7