

**Projected Expansion of the Floodplain with Sea Level Rise  
in Dartmouth, Massachusetts**

**Buzzards Bay National Estuary Program and  
Massachusetts Office of Coastal Zone Management**

**Technical Report SLR13-2**

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Data at: <http://www.buzzardsbay.org/floodzone-expansion-slr.html>.

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# **Projected Expansion of the Floodplain with Sea Level Rise in Dartmouth, Massachusetts**

## **Summary**

The Buzzards Bay National Estuary Program (BBNEP) and the Massachusetts Office of Coastal Zone Management evaluated the potential expansion of the 100-year floodplain<sup>1</sup> in Dartmouth, Massachusetts resulting from 1, 2, and 4-foot increases in sea level. A baseline conditions floodplain was developed by adjusting the most landward extent of the 100-year floodplain as mapped by the Federal Emergency Management Agency (FEMA) in their 2009 digital Flood Insurance Rate Map (FIRM) coverages. This boundary was adjusted by matching the FIRM base flood elevations to a highly detailed elevation data set. This adjusted baseline conditions floodplain map was then expanded by adding 1, 2, and 4-foot increases using the same detailed elevation data. Using a 2012 parcel and assessor's data set for the Town of Dartmouth from MassGIS, the number of buildings, their assessed values, and municipal structures were enumerated within these various floodplain expansion scenarios. This evaluation was not meant as a quantification of the impacts of storms with sea level rise, but rather to define an approximate likely geographical expansion of the floodplain, a jurisdictional area used by many state, federal, and municipal agencies and boards.

There are currently 11,835 built upon parcels in the Dartmouth 2012 MassGIS database. Of these, only 520 (4.4%) have the primary structure within the adjusted coastal baseline floodplain of the 100-year storm used in this study. The total primary structure building value of the 520 properties in the adjusted baseline floodplain is \$166.8 million, which is 5.9% of the town's \$2.818 billion total assessed structure value. Ancillary structures (detached garages, sheds, and barns) associated with the 520 properties in the adjusted baseline floodplain total an additional \$12.1 million. The placement of the ancillary structures were not characterized for the sea level rise scenarios.

With a 1 ft sea level rise, 60 parcels with primary structure values totaling \$21.3 million are added to the adjusted baseline floodplain. With a 2-ft sea level rise, an additional 43 parcels worth \$10.7 million are added, and with the 4-ft sea level rise, an additional 113 structures worth \$48.4 million are added. Cumulatively, the baseline to 4-ft sea level rise scenario adds 216 additional built parcels with primary structures worth \$80.4 million in assessed value to the adjusted baseline floodplain.

At a town-wide level, with a 4-ft sea level rise, the percent area of the town in the expanded adjusted baseline floodplain increased from 10.5% to 12.3%. Similarly, the total number of primary structures in the floodplain increased from 4.4% to 6.2% of the total number of primary structures in town, and the property values of primary structures in the floodplain increased from 5.9% to 8.8% of the total town primary structure property value.

Only 10 publicly owned properties with structures totaling \$383,000 are currently in the floodplain. Most of the properties with any appreciable value are town or state-owned beach facility structures. With a 1 and 2-ft sea level rise, no new public buildings are added to the floodplain. However, with the 4-ft sea level rise, the fire station at 10 Bridge Street (building value \$600,000), and the corner of the Town of Dartmouth Emergency Agency offices building on 247 Russells Mills Road (building value \$2.6 million) were added to the floodplain.

The maps resulting from this effort can be used as planning tools to assist the siting and construction of new facilities so that they are less likely to be affected in subsequent decades by sea level rise. These

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<sup>1</sup> That is, the area inundated by a storm with a 1% chance of occurring in any particular year.



maps can also be used as a visual aid to educate municipal officials and the public about the potential impacts of sea level rise, and help set priorities for land acquisition and protection, and help define local climate adaptation strategies

## 1. Introduction

FEMA Flood Insurance Rate Maps (FIRMs) are the basis for federal, state, and local hazard mitigation planning. They are also used to establish the regulatory jurisdiction for mandated flood insurance, and are used by building inspectors, conservation commissions, and other local regulators to establish standards for the siting, construction, and maintenance of buildings, sea walls, and land alteration. This area is commonly referred to as the "100-year floodplain" by insurers, state building regulations, and local bylaws and ordinances. More precisely, FIRMs generally define the area that has a 1% chance or greater of being flooded in any particular year (commonly called the "100-year storm"<sup>2</sup>). In the coastal zone, these floodplain areas may be designated as being either in the Zone V (Velocity or V-zone); which are areas subjected to waves greater than 3 feet during a storm, or Zone A, which are areas subjected to waves less than 3 feet during a storm. Most typically in coastal areas, these two zones are assigned a base flood elevation (BFE). The BFE corresponds to the top of the wave crest during the projected 100-year storm. The methodology for determining these elevations and their boundaries is described in the *Guidelines and Specifications for Flood Hazard Mapping Partners, Volume 1: Flood Studies and Mapping* (FEMA, 2003).

The predicted landward limit of the floodplain, as depicted in the FEMA FIRMs, corresponds to a specific real-world elevation as defined by the BFE. The FIRMs prepared by FEMA are in fact an approximate depiction of which properties are in or out of the specified floodplain elevation. While the FEMA FIRMs are generally good for broadly defining which homes are in or out of the jurisdictional floodplain, the maps are limited by the quality of topographic data that is available. Whether a particular structure near a mapped BFE boundary is actually in the floodplain can only be determined definitively by actual field surveys. In fact, FIRMs can be amended based on such field investigations, and often are.

In 2009 and 2011, FEMA updated the FIRMs in Bristol and Plymouth counties based on recent LiDAR<sup>3</sup> surveys, contracted by FEMA or United States Geological Survey (USGS), and limited new coastal engineering analyses<sup>4</sup>. The basis of the changes in the maps are summarized in Flood Insurance Studies for each county available on the FEMA website<sup>5</sup>. Due to funding limitations, FEMA was unable to do new engineering analyses for all portions of each community. These new maps have

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<sup>2</sup> Many scientists and regulators encourage the use of the term "1% storm" or "1% storm floodplain", over "100-year storm" or "100-year storm floodplain", because of public misconceptions that a 100-year storm only occurs once in one hundred years. However, because the term "100-year floodplain" is so pervasive in regulations, in news reports, and the public vernacular, we used it here instead of the less commonly used term "1% floodplain."

<sup>3</sup> Light Detection And Ranging (also abbreviated LiDAR and LADAR) is an optical remote sensing technology that can measure the distance to a target by illuminating it with pulse of light from a laser.

<sup>4</sup> As part of FEMA's Map Modernization project, the 2009 Flood Insurance Rate Maps for Dartmouth have a new datum, NAVD88, or North American Vertical Datum of the 1988-2001 Tidal Epoch. In Dartmouth, the "old" elevation value for 0.0 feet using the National Geodetic Vertical Datum of 1929, or NGVD29 is equal to minus 0.817 feet NAVD88 (calculated for Apponagansett Bay at [http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert\\_con.prl](http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl)). In addition, the new maps show increased flood elevations in many areas that reflect improved flood hazard models, landscape changes, and better land elevation measurements.

<sup>5</sup> Go to: <https://msc.fema.gov>

increased precision and reliability, although like any data set, they are subject to errors in interpretation and processing of the elevation data as described below.

For this study, we considered only the landward-most extent of the FIRM 100-year storm floodplain, and the published BFE, to define the adjusted baseline floodplain. We then expanded this adjusted baseline floodplain by adding 1, 2, and 4-ft. to the BFE (whether A or V zone). The extrapolations were based on a digital data set of estimated bare earth elevations established by a 2007 aerial survey using LiDAR technology that was obtained from FEMA (from (CDM-Smith 2008 study) and which was used in part to prepare the 2009 updated Bristol and Plymouth County FIRMs.

The selected 1, 2, and 4-ft elevation increases in this study were chosen as convenient management elevation markers. The relative sea level rise rate documented for Woods Hole, MA has been 10.3 inches per century since 1932<sup>6</sup>. The international consensus range for sea level rise, applied to this region, is 1 to 4.5 feet by year 2100<sup>7</sup>. However, some other studies with alternative scenarios with more expanded Greenland and Antarctic glacier melting, or changes in the North Atlantic gyre predict higher local sea level rise rates. We thus leave open ended how quickly the 1, 2, and 4-ft elevation increases may occur.

## 2. Methods

In this study, ArcGIS<sup>®</sup> software by Esri (ArcMap Desktop versions 9.3 and 10.1) was used to manipulate the various existing digital data sets, with some additional analysis completed in spreadsheets using pivot table functions. No field collection of data or ground truthing was required for this analysis. We used a 2007 LiDAR study contracted by FEMA, and described in detail in CDM-Smith's *Mapping Activities for Plymouth and Bristol Counties, Massachusetts. Task Order 18 Activity 1--Topographic Data Development / Acquisition Summary Report*. These LiDAR data were provided to the Buzzards Bay NEP as both 2-ft contour lines, and as digital elevation models in the form of Triangular Irregular Network (TIN) raster files. To a limited degree, for certain floodplain expansion areas we also used 2011 Northeast National Map LiDAR project data<sup>8</sup>. In general, the precision of the LiDAR data is 1 cm, but the accuracy is approximately 6 inches over the entire southeast study area, and the relative accuracy over a small geographic area along the same flight path is considerably better<sup>9</sup>.

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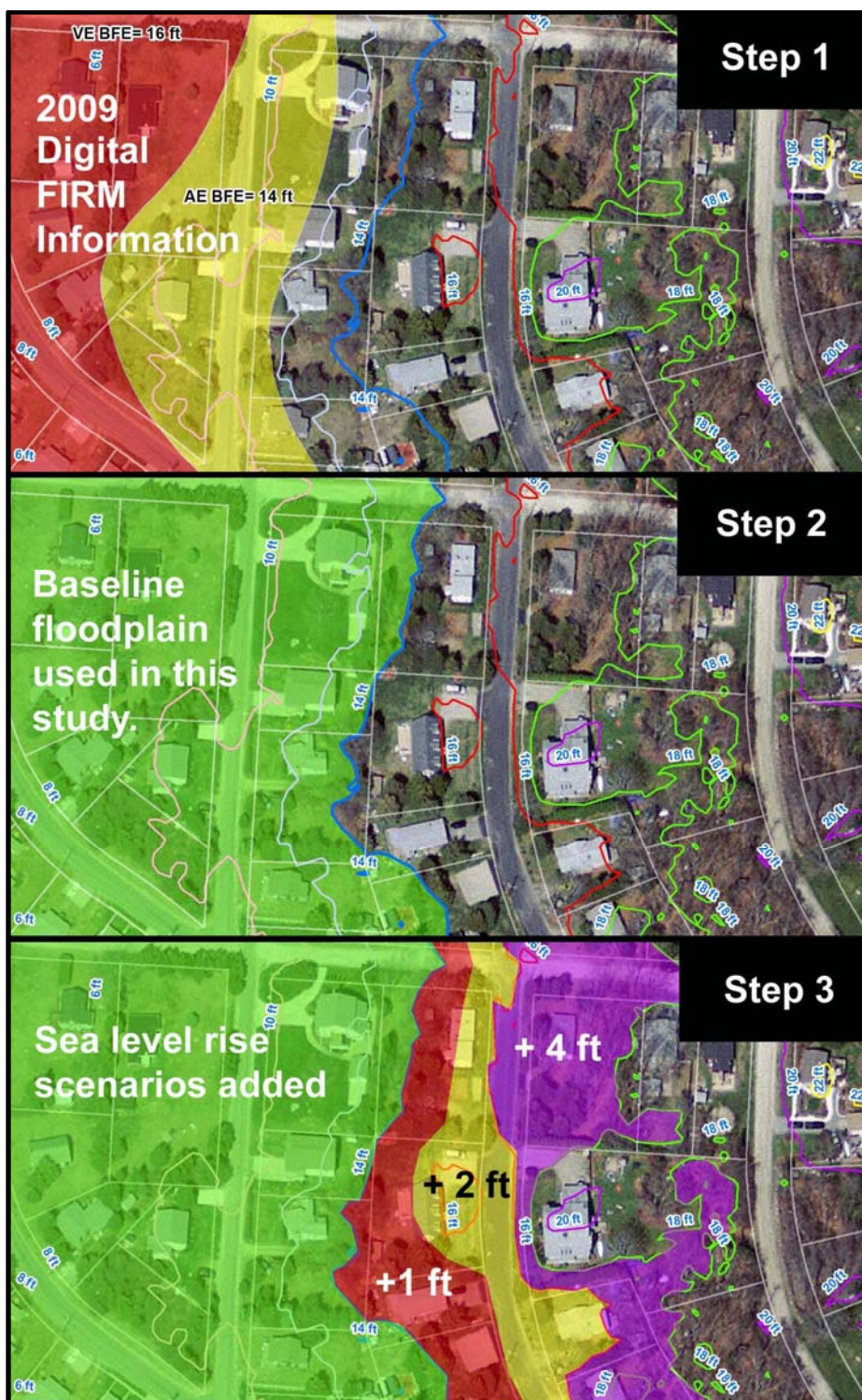
<sup>6</sup> Data available at [http://tidesandcurrents.noaa.gov/sltrends/sltrends\\_station.shtml?stnid=8447930](http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8447930). This is the average rate for the period 1932 to 2006.

<sup>7</sup> IPCC, 2007.

<sup>8</sup> LiDAR for the Northeast (ARRA LiDAR Task Order, USGS Contract: G10PC00026, Task Order Number: G10PD02143, Task Order Number: G10PD01027), project meets U.S. Geological Survey National Geospatial Program Base LiDAR Specification, Version 12, see USGS (2009). Note that dates of LiDAR coverages collected under this contract range from 2009 to 2012.

<sup>9</sup> USGS, 2008





## Comments

The adjusted baseline floodplain developed for this study was based on the base flood elevations and other information contained in the 2009 FIRM digital data set. At this site, the base flood elevation of the AE Zone or the 100-year storm was designated as 14 ft.

To ensure consistency of comparisons among the data sets, an adjusted baseline floodplain was created for this study by precisely matching its boundary to the LiDAR contour elevations. In this case, the adjusted boundary was matched to the 14-ft LiDAR based contour line (blue line).

The process was continued for the 1, 2, and 4-ft sea level rise scenarios. If any portion of a house was in the new boundary, it was included in that sea level rise scenario. A house that crossed multiple boundaries was assigned to the lowest elevation.

**Fig. 1. Summary of approach for defining expanding floodplains for each of the sea level rise scenarios.** Step 1: The landward most base flood elevations for a 100-year storm from 2009 digital FIRM data were compared to LiDAR contours (or digital elevation models). Step 2: An adjusted baseline floodplain area was defined (shaded green) for the purposes of this study. Step 3: The adjusted baseline floodplain was expanded for the 1-ft (shaded red), 2-ft (shaded yellow), and 4-ft (shaded magenta) sea level rise scenarios.



For the parcel and structure values, we used 2012 MassGIS Level 3 parcel data and assessors records<sup>10</sup>. To assign the placement of building locations within the parcels, we used a draft MassGIS database of building footprints based on a 2011 aerial survey<sup>11</sup>. Because a single parcel may have more than 1 structure, points were automatically generated for the largest structure on each parcel using the Geospatial Modeling Environment Software<sup>12</sup>. Generally, the largest structure is the primary structure, but during the review of the placement of the label points within the structure with respect to the floodplain, point placement was adjusted as necessary to correspond to the apparent primary structure<sup>13</sup>.



**Fig. 2. Mapping Base Flood Elevations (BFEs) with odd numbered values.** In areas where the base flood elevation was set to an odd number value and elevation contours wide spaced, the TIN raster digital elevation model files were coded to match the same base flood elevation boundaries. In this image, a floodplain scenario (shaded green, right) was used to estimate a 17-ft contour (colored magenta).

<sup>10</sup> Available at: <http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/l3parcels.html>. Last download 1/8/2013.

<sup>11</sup> Courtesy Paul Nutting, MassGIS.

<sup>12</sup> Geospatial Modeling Environment (Version 0.7.2.1) (c) Hawthorne L. Beyer 2009-2012 . Available at: [www.spatial ecology.com](http://www.spatial ecology.com), email: [hawthorne@spatial ecology.com](mailto:hawthorne@spatial ecology.com).

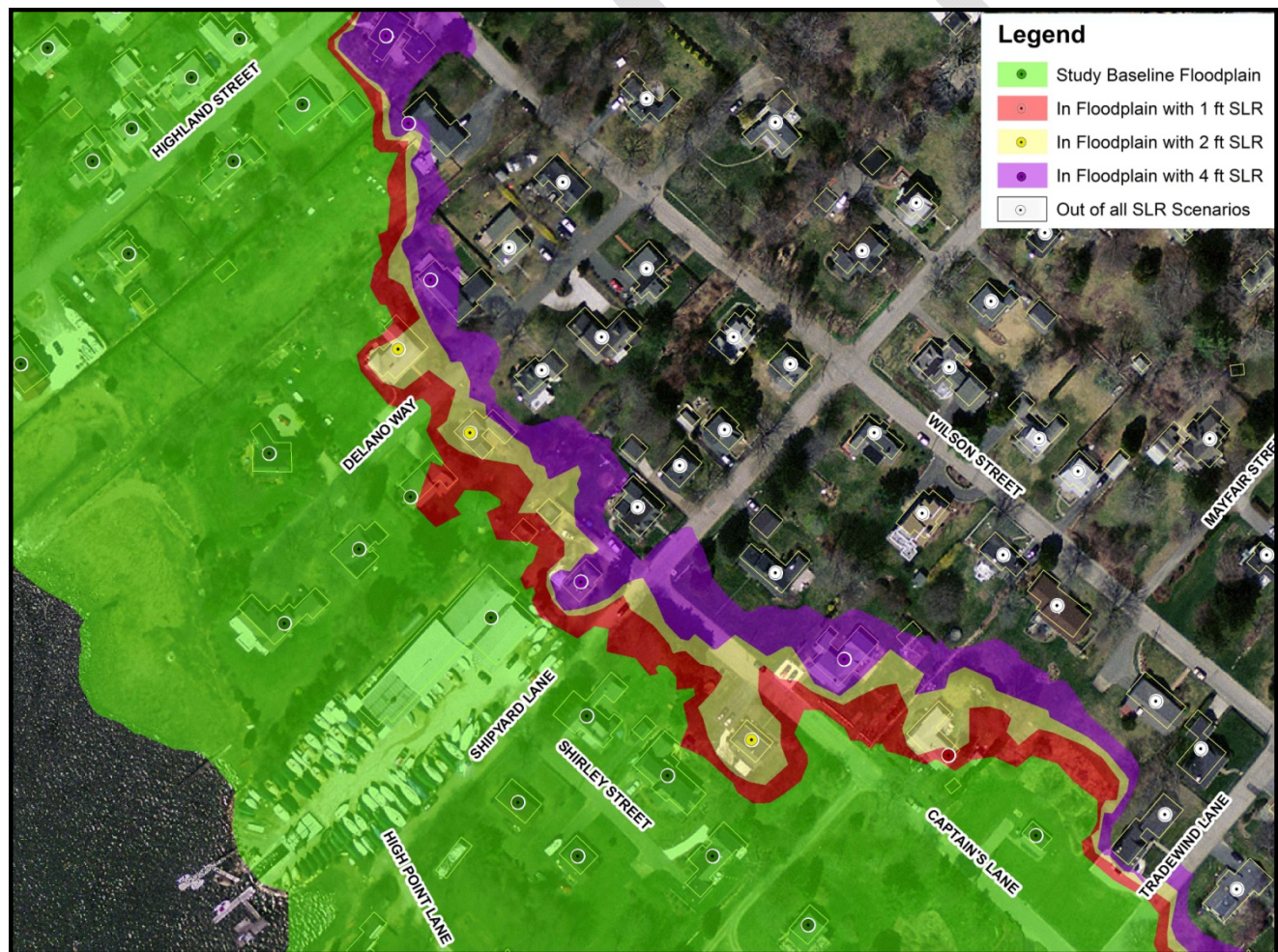
<sup>13</sup> For example, a point was moved in one instance from a large barn to the residence, which was easily discerned by features such as cows, driveways, vehicles, and apparent architecture.



The base flood elevations from the FIRMs released by FEMA for Dartmouth in 2009 were overlain on the detailed LiDAR contour data (Fig. 1) and digital elevation models (Fig. 2). Typically, the LiDAR 2-ft elevation contour lines were adequate to estimate expansion or adjustments of the boundaries of each sea level rise scenario. However, where land slopes were slight, and the base flood elevation was set to an odd-number value, the digital elevation model TIN raster images were often used to visually estimate the respective new floodplain boundaries, (see Fig. 2). In this way, an adjusted baseline floodplain was defined and used as the initial conditions for the purposes of this study allowing for more meaningful and precise comparisons among the sea level rise scenarios.

This adjusted baseline floodplain was then expanded to account for 1, 2, and 4-foot sea level rises. This was done by using the LiDAR elevations, and the BFEs identified on the FIRMs to which was added each sea level rise scenario (see Fig. 1). Thus, if the BFE on the FIRM was specified as 14 feet for a site, the boundary of the baseline floodplain would be expanded to the 18-ft LiDAR contour in the 4-ft sea level rise scenario.

This is a simplified approach, and a more accurate approach would involve predictions of erosion and



**Fig. 3. Structure Assignment in Floodplain Expansion Areas with Different Sea Level Rise Scenarios.** Multiple structures (outlined in yellow), if present on a parcel, were converted to label points representing the position of the largest structure. If no structure was present on the GIS coverage, a label point was created for the parcel. The position of these points were used to initially place the primary structure in a flood zone scenario. If several scenarios crossed the footprint of a house, the point location was adjusted to place the building in the lowest elevation zone.



landform change, and detailed engineering analyses to determine how much the flood elevations would rise along the coast given the submergence of land in the new floodplain areas, but such an effort was beyond the scope of this study.

After the floodplain scenario boundaries were created, the precise placement of the primary structure was assigned to a floodplain scenario (or out of the floodplain). In the first step, to approximate the locations of primary structures, a centroid label point was created for each parcel to represent the location of primary structure. The position of these points, representing the vulnerability of the structures to sea level rise, was carefully examined on aerial photograph base maps for all parcels crossed by a sea level rise scenario. The positions of these points were moved to precisely coincide with the house footprint. If a house was crossed by several floodplain scenarios, the point was placed in the lowest elevation scenario as illustrated in Fig. 3. Secondary or ancillary detached structures were ignored, and the property building value was assigned to the main structure, typically the primary residential structure. On some parcels, there are multiple detached or attached dwelling units, and 3 of these parcels were bisected by a floodplain in Dartmouth (e.g. the large condominium complex on.

Once the position of structures was set relative to the sea level rise scenarios, the position of these points were converted to x y coordinates for each parcel, matched to the assessor's database file<sup>14</sup>, which was imported into ArcGIS<sup>®</sup>. This extra step captured those parcels where many tax records (and multiple structures and owners) exist on one parcel, as is the case with parcels containing condominiums. The new point data set (containing assessor's data and sea level rise scenario location) was then evaluated<sup>15</sup> to quantify the number and value of primary structures in each floodplain scenario. The resulting data set was processed in an Excel spreadsheet, and a pivot table was used to quantify building data using various classifications of structures by floodplain scenario.

Various quality control and data validation approaches were implemented to ensure the accuracy of the data following the protocols described above. These validation techniques included check sum approaches to ensure property counts and values and other data are not inadvertently double counted or omitted. Additional information on the methods, the QAPP, and the digital data sets related to this study area available at the Buzzards Bay NEP website: <http://www.buzzardsbay.org/floodzone-expansion-slr.html>.

### 3. Results

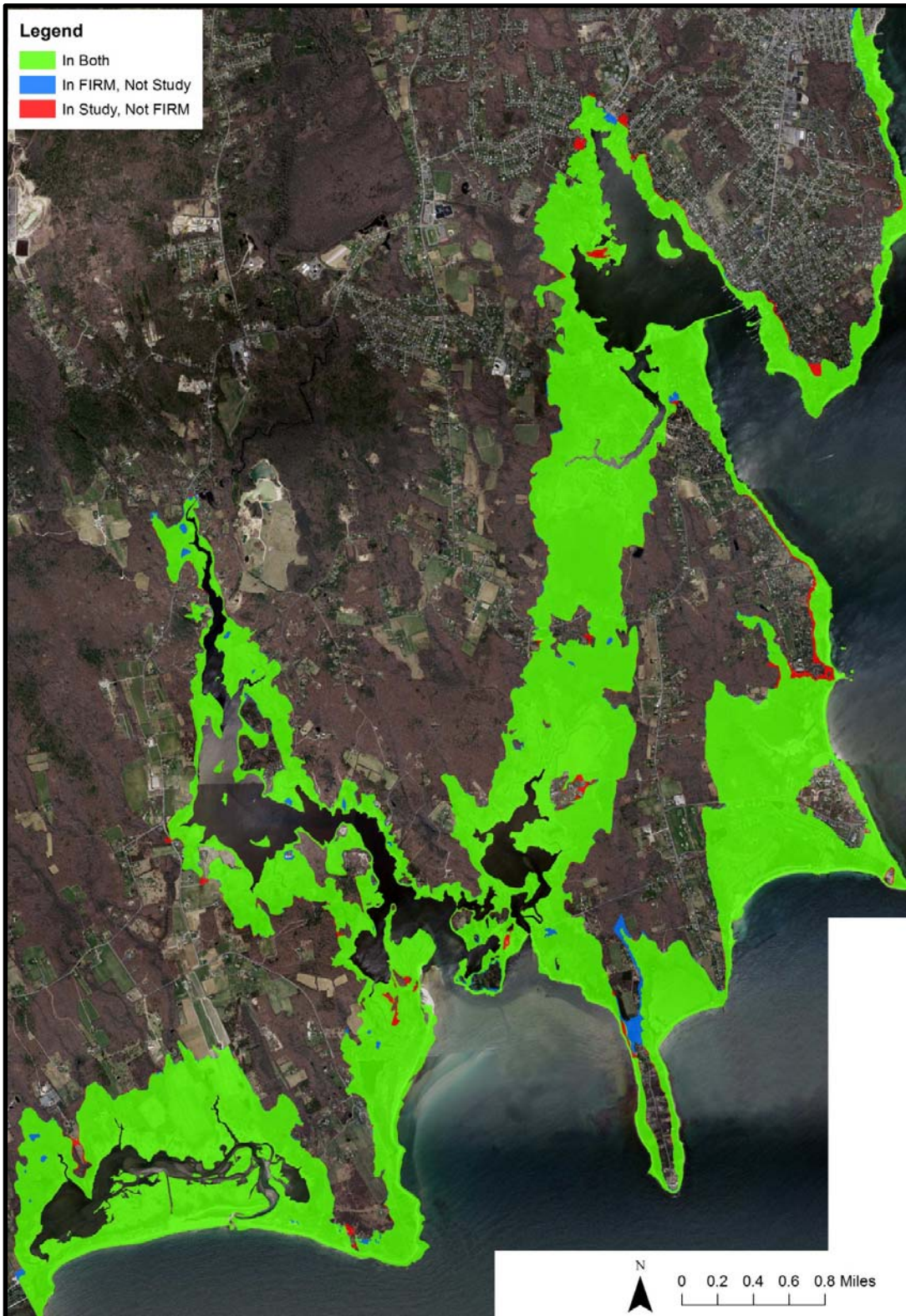
Fig. 4 shows the difference between the FIRM 100-year floodplain (i.e. a storm with a 1% chance of occurring in a particular year) and the adjusted baseline floodplain used in this study. There were 16 parcels with primary structures within the FIRM 100-year floodplain, but not within the adjusted baseline floodplain used in this study, and 41 built parcels primary structures within the adjusted baseline floodplain used in this study, but not within the FIRM 100-year floodplain.

Within the baseline floodplain there were 28 properties with structures that did not have a "building" value assigned in the database. Most of these properties appeared to be companion lots with barns, sheds, etc. These properties were assigned the value in the "Other" building value in the database to ensure each identified primary structure had an assessed value assigned.

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<sup>14</sup> The data sets were logically joined using the "LOC\_ID" variable in the two data sets.

<sup>15</sup> The shapefile's dbf files was imported into Excel and analyzed in a pivot table.



**Fig. 4. Comparison of FIRM 100-yr Floodplain to Adjusted Baseline Floodplain in Dartmouth.** Figure shows the adjusted baseline floodplain conditions adopted in this study, and how it differed from the 2009 FIRMs 100-year (1% annual risk) coastal floodplain. Inland floodplain areas were excluded from the analysis.



Fig. 5 shows a town-wide overview of the adjusted baseline floodplain and the various sea level rise scenarios. Appendix A has detailed maps of this analysis. As shown in Table 1, there are 520 parcels with building structures in the adjusted baseline floodplain used in this study, out of a town-wide total of 11,835 built parcels, or 4.4% of the total. The total building value of the primary structure of these 520 properties in the floodplain is \$166.8 million, which is 5.9% of the \$2.818 billion in primary structure assessed value in the Town. The location of ancillary structures (detached garages, sheds, and barns) were not evaluated in this study, but for the 520 properties in the baseline floodplain, these ancillary structures had an assessed value that totaled \$12.1 million (7.2% additional value). Thus, the value of all structures (primary and ancillary) in the baseline floodplain is closer to \$178.9 million.

With a 1-ft sea level rise, 60 parcels with primary structure values totaling \$21.3 million are added to the adjusted baseline floodplain. With a 2-ft sea level rise, an additional 43 parcels worth \$10.7 million are added, and with the 4-ft sea level rise, an additional 113 structures worth \$48.4 million are added. Cumulatively, the baseline to 4-ft sea level rise scenario adds 216 additional built parcels with primary structures worth \$80.4 million in assessed value to the adjusted baseline floodplain.

At a town-wide level, with a 4-ft sea level rise, the percent area of the town in the expanded adjusted baseline floodplain increased from 10.5 % to 12.3% (Fig. 6, top). Similarly, the total number of primary structures in the floodplain increased from 4.4% to 6.2% of the total number of primary structures in town (Fig. 6, middle), and the property values of primary structures in the floodplain increased from 5.9% and 8.8% of the total town primary structure property value (Fig. 6, bottom).

**Table 1. Expansion of floodplain with different sea level rise (SLR) scenarios.** Totals are for the parcels with the primary structure building values greater than zero using a MassGIS Level 3 2012 assessor's records and parcel database<sup>16</sup>.

Floodplain	parcels with structures	cumulative parcels w/ structures	value of primary structures*	cumulative value of primary structures
Adjusted baseline	520	520	\$166,763,600	\$166,763,600
1-ft SLR	60	580	\$21,299,700	\$188,063,300
2-ft SLR	43	623	\$10,715,000	\$198,778,300
4-ft SLR	113	736	\$48,430,900	\$247,209,200
Outside of coastal floodplain	11,099	11,835	\$2,570,573,100	\$2,817,782,300
Net change baseline to +4ft		216		\$80,445,600
Percent change baseline to +4ft		41.5%		48.2%

\* = total assessed primary structure value

<sup>16</sup> MassGIS 2012 Level 3 parcel data set downloaded at: <http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/ftpl3parcels.html> (accessed 10 January 2013). Town-wide, 246 of 11,185 parcels (mostly companion parcels to an adjacent lot) had no "building" value assigned to them in the assessor records (i.e. no primary structure). In these cases, the "other" structure value in the assessor's data was assigned to the structure so that every built parcel had a structure value assigned to it. Only 28 such parcels were located in any one of the floodplain scenarios.



**Fig. 5. Overview of the Town of Dartmouth showing changes in expansion of floodplain boundaries with various sea level rise scenarios over the adjusted baseline floodplain. Note that some changes are too small to see at this scale. See detailed maps in Appendix A.**



With respect to public properties, only ten publicly owned properties have structures in the adjusted baseline floodplain. With the 1 and 2-ft sea level rise scenarios, no additional publicly owned structures will be added, but in the case of the 4-ft rise scenario, the fire station at 10 Bridge Street (building value \$600,000), and the corner of the Town of Dartmouth Emergency Agency offices building at 247 Russells Mills Road (building value \$2.6 million) were added to the adjusted baseline floodplain. Table 2 shows a complete list of public properties and their building values in the adjusted baseline floodplain as defined by this study, and the 4-ft sea level rise.

<b>Table 2. Public properties in the various sea level rise scenarios.</b>						
<b>Parcel ID</b>	<b>Owner1</b>	<b>Structure</b>	<b>Site Address</b>	<b>Bldg Val</b>	<b>Other Val</b>	<b>Value for Study</b>
<b>Baseline</b>						
10_6	Mass. Common.	State Bathing Beach Facility, Demarest Lloyd	Barneys Joy Rd	\$0	\$115,500	\$115,500
139_183	Town Of Dartmouth	Single Family Home, Tax Acquisition?	12 Rogers St	\$89,000	\$1,600	\$89,000
134_41	Town Of Dartmouth	Jones Park Beach Buildings	70 St John St	\$50,900	\$4,800	\$50,900
90_10	Town Of Dartmouth	Round Hill Beach Facility	Smith Neck Rd	\$33,100	\$0	\$33,100
139_181	Town Of Dartmouth	unknown structure at Rogers St (pump station?)	Rogers St	\$0	\$22,500	\$22,500
23_46	Town Of Dartmouth	Russells Mills Landing Park building	50 Horseneck Rd	\$0	\$21,200	\$21,200
121_86	Town Of Dartmouth	unknown	Captains Lane	\$0	\$18,000	\$18,000
111_11	Town Of Dartmouth	unknown	77 Gulf Rd	\$0	\$16,000	\$16,000
127_71	Town Of Dartmouth	unknown	270 Russells Mills Rd	\$0	\$9,100	\$9,100
117_8	Town Of Dartmouth	unknown	Water St	\$0	\$1,800	\$1,800
	<b>Total</b>			<b>\$173,000</b>	<b>\$210,500</b>	<b>\$377,100</b>
<b>4-ft SLR</b>						
132_1	Town Of Dartmouth	Dartmouth Emergency Management Agency	247 Russells Mills Rd	\$2,556,200	\$209,200	\$2,556,200
117_170	Dartmouth Fire District 1	Fire Station	10 Bridge St	\$599,900	\$18,000	\$599,900
	<b>Total</b>			<b>\$3,156,100</b>	<b>\$227,200</b>	<b>\$3,156,100</b>

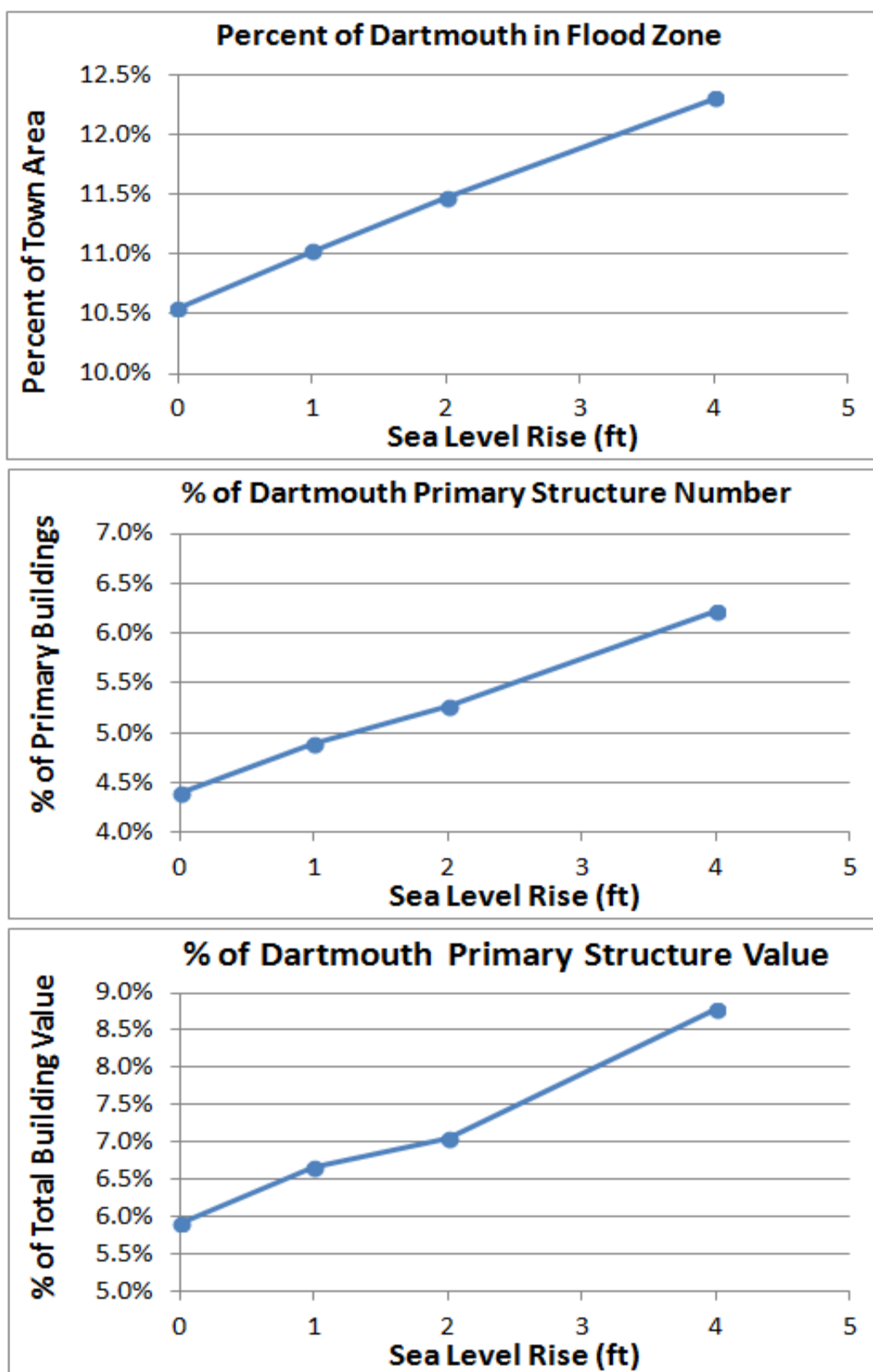


Fig. 6. Percent change in town area within the floodplain (top), percent of total primary structures in the floodplain (middle), and percent of total primary structure value in the floodplain (bottom) for each of the sea level rise scenarios (baseline conditions = 0 ft).



## Discussion

There are a number of uncertainties in the analysis presented. If future storms are more severe than in the past, the actual extent of inundation could be greater than described here. Second, this analysis did not consider the elevation of the landscape or elevation of the buildings. Buildings near the elevational margins of a floodplain tend to have minimal flooding compared to properties close to shore and at lower elevations. For these reasons, the maps should be used as general planning tools by public officials and residents about where to construct future structures to minimize their susceptibility to storms with sea level rise, and future liabilities associated with flood insurance. They also can help identify areas that may subsequently enter the jurisdictional regulated area known as the 100-year floodplain that is used by many agencies. In this way, municipal officials and the public could also use these maps to identify sites for open space and habitat protection rather than for construction of public facilities. Other ways this data can be used are described in the Massachusetts Climate Change Adaptation Report (EEA, 2011).

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**Appendix A.** Detailed maps showing the expanded floodplain boundaries under the various sea level rise scenarios. The locations of the detailed panel maps can be determined using the key below.

