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Community Exposure to Potential Climate-Driven Changes to Coastal-Inundation Hazards for Six Communities in Essex County, Massachusetts

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Cover. Photograph of flooding from the Little River, along Parker Street in Newburyport, Massachusetts, during an April 2004 storm (photograph by Joe Teixeira, courtesy of the Ipswich River Watershed Association and the National Wildlife Federation).

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By Nina Abdollahian, Jamie L. Jones, and Nathan J. Wood

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Contents

Acknowledgments iii
Introduction 1
Methods 1
Community Boundaries 2
Hazard Zones 3
Land Cover and Land Use 4
Populations 5
Economic Assets 5
Critical Facilities and Infrastructure 6
Locally Identified Areas of Concern 6
Salisbury 6
Land Cover and Land Use 6
Populations 10
Economic Assets 11
Critical Facilities and Infrastructure 13
Locally Identified Areas of Concern 13
Conclusion 16
Newburyport 17
Land Cover and Land Use 17
Populations 21
Economic Assets 22
Critical Facilities and Infrastructure 23
Locally Identified Areas of Concern 24
Conclusion 26
Newbury 27
Land Cover and Land Use 27
Populations 31
Economic Assets 32
Critical Facilities and Infrastructure 33
Locally Identified Areas of Concern 34
Conclusion 36
Rowley 37
Land Cover and Land Use 37
Populations 41
Economic Assets 42
Critical Facilities and Infrastructure 43
Locally Identified Areas of Concern 44
Conclusion 46
Ipswich 47
Land Cover and Land Use 47
Populations 51
Economic Assets 52
Critical Facilities and Infrastructure 53
Locally Identified Areas of Concern 54
Conclusion 56

Essex 57
Land Cover and Land Use 57
Populations 62
Economic Assets 63
Critical Facilities and Infrastructure 64
Locally Identified Areas of Concern 65
Conclusion 67
References Cited 68
Appendix 1. Inundation Probability Maps 70

Figures

1. Maps showing six coastal communities in the Great Marsh region of Essex County, Massachusetts, and examples of inundation-probability data and floodwater-depth data for sea-level-rise and storm scenarios provided by Woods Hole Group 3
2. Maps of Salisbury, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070 7
3. Map showing land-cover data for Salisbury, Massachusetts, from the 2011 National Land Cover Database 8
4. Bar graphs showing amounts of developed and undeveloped land and total percentages of developed and undeveloped land in coastal-hazard zones of Salisbury, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070 8
5. Bar graphs showing the area of land classified as conservation lands, endangered species habitats, and priority habitats in the modeled hazard zones of Salisbury, Massachusetts, for 2013, 2030, and 2070 9
6. Pie charts showing distribution (by area) of current land-use classes within hazard zones in Salisbury, Massachusetts, for 2013 and 2070, as well as for all land in Salisbury regardless of hazard zones 10
7. Bar graphs showing resident exposure in Salisbury, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability 11
8. Bar graph showing employee exposure in Salisbury, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability 12
9. Bar graphs showing cumulative value in millions of dollars of business sales volume, total parcels, and building-replacement costs in coastal-hazard zones for Salisbury, Massachusetts 12
10. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in the Town of Salisbury, Massachusetts, as identified by local stakeholders 15
11. Bar graphs showing cumulative percent of total area for areas of concern indicated by local stakeholders in the Town of Salisbury, Massachusetts, in coastal-hazard zones with 1- and 0.2-percent inundation probabilities in 2013, 2030, and 2070, organized by predicted water depth 16
12. Maps of Newburyport, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070 18
13. Map showing land-cover data for Newburyport, Massachusetts, from the 2011 National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2011) 19

14. Bar graphs showing amounts of developed and undeveloped land and total percentages of developed and undeveloped land in coastal-hazard zones of Newburyport, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070 19
15. Bar graphs showing the area of land classified as conservation lands, areas of critical environmental concern, endangered species habitats, priority habitats, and Community Preservation Act locations in the modeled hazard zones of Newburyport, Massachusetts, for 2013, 2030, and 2070 20
16. Pie charts showing distribution (by area) of current land-use classes within hazard zones in Newburyport, Massachusetts, for 2013 and 2070, as well as for all land in Newburyport regardless of hazard zones. 21
17. Bar graph showing resident population exposure in the City of Newburyport, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability 22
18. Bar graph showing employee exposure in Newburyport, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability 23
19. Bar graphs showing the cumulative value in millions of dollars of business sales volume, total parcels, and building-replacement costs in coastal-hazard zones for Newburyport, Massachusetts 23
20. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in Newburyport, Massachusetts, as identified by local stakeholders 25
21. Bar graphs showing cumulative percent of total area for areas of concern indicated by local stakeholders in Newburyport, Massachusetts, in coastal-hazard zones with 0.2- and 1-percent probabilities of occurrence in 2013, 2030, and 2070, organized by predicted water depth 26
22. Map of Newbury, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070 28
23. Map showing land-cover data for Newbury, Massachusetts, from the 2011 National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2011) 29
24. Bar graphs showing amounts of developed and undeveloped land and total percentages of developed and undeveloped land in coastal-hazard zones of Newbury, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070 29
25. Bar graphs showing the area of land classified as conservation lands, areas of critical environmental concern, endangered species habitats, and priority habitats in the modeled hazard zones of Newbury, Massachusetts, for 2013, 2030, and 2070 30
26. Pie charts showing distribution (by area) of current land use classes within hazard zones in Newbury, Massachusetts, for 2013 and 2070, as well as for all land in Newbury regardless of hazard zones 31
27. Bar graph showing resident population exposure in Newbury, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability 32
28. Bar graph showing employee exposure in the Town of Newbury, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability 33
29. Bar graphs showing the cumulative value in millions of dollars of business sales volume, total parcels, and building-replacement costs in coastal-hazard zones for Newbury, Massachusetts 33
30. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in Newbury, Massachusetts, as identified by local stakeholders 35

31. Bar graphs showing cumulative percent of total area for areas of concern indicated by local stakeholders in Newbury, Massachusetts, in coastal-hazard zones with 0.2- and 1-percent probabilities of occurrence in 2013, 2030, and 2070, organized by predicted water depth..... 36
32. Map of Rowley, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070..... 38
33. Map showing land-cover data for Rowley, Massachusetts, from the 2011 National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2011)..... 39
34. Bar graphs showing amounts of developed and undeveloped land and total percentages of developed and undeveloped land in coastal-hazard zones of Rowley, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070..... 39
35. Bar graphs showing the area of land classified as conservation lands, areas of critical environmental concern, endangered species habitats, priority habitats, and Community Preservation Act locations in the modeled hazard zones of Rowley, Massachusetts, for 2013, 2030, and 2070..... 40
36. Pie charts showing distribution (by area) of current land use classes within hazard zones in Rowley, Massachusetts, for 2013 and 2070, as well as for all land in Rowley regardless of hazard zones..... 41
37. Pie chart showing resident population exposure in Rowley, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability..... 42
38. Bar graph showing employee exposure in Rowley, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability..... 43
39. Pie charts showing the cumulative value in millions of dollars of business sales volume, total parcels, and building-replacement costs in coastal-hazard zones for Rowley, Massachusetts..... 43
40. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in Rowley, Massachusetts, as identified by local stakeholders..... 45
41. Bar graphs showing cumulative percent of total area for areas of concern identified by local stakeholders in Rowley, Massachusetts, in coastal-hazard zones with 0.2- and 1-percent probabilities of occurrence in 2013, 2030, and 2070, organized by predicted water depth..... 46
42. Maps of Ipswich, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070..... 48
43. Map showing land-cover data for Ipswich, Massachusetts, from the 2011 National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2011)..... 49
44. Bar graphs showing amounts of developed and undeveloped land and total percentages of developed and undeveloped land in coastal-hazard zones of Ipswich, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070..... 49
45. Bar graphs showing the area of land classified as conservation lands, areas of critical environmental concern, endangered species habitats, and priority habitats in the modeled hazard zones of Ipswich, Massachusetts, for 2013, 2030, and 2070..... 50
46. Pie charts showing distribution (by area) of current land use classes within hazard zones in Ipswich, Massachusetts, for 2013 and 2070, as well as for all land in Ipswich regardless of hazard zones..... 51
47. Bar graph showing resident exposure in the Town of Ipswich, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability..... 52
48. Bar graph showing employee exposure in Ipswich, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability..... 53

49. Bar graphs showing cumulative value in millions of dollars of business sales volume, total parcels, and building-replacement costs in coastal-hazard zones for Ipswich, Massachusetts 53
50. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in the Town of Ipswich, Massachusetts, as identified by local stakeholders 55
51. Bar graphs showing cumulative percent of total area for areas of concern indicated by local stakeholders in the Town of Ipswich, Massachusetts, in coastal-hazard zones with 0.2- and 1-percent probabilities of occurrence in 2013, 2030, and 2070, organized by predicted water depth 56
52. Maps of Essex, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070 58
53. Map showing land-cover data for Essex, Massachusetts, from the 2011 National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2011) 59
54. Bar graphs showing amounts of developed and undeveloped land and total percentages of developed and undeveloped land in coastal-hazard zones of Essex, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070 60
55. Bar graphs showing the area of land classified as conservation lands, areas of critical environmental concern, endangered species habitats, priority habitats, and Community Preservation Act locations in the modeled hazard zones of Essex, Massachusetts, for 2013, 2030, and 2070 61
56. Pie charts showing distribution (by area) of current land use classes within hazard zones in Essex, Massachusetts, for 2013 and 2070, as well as for all land in Essex regardless of hazard zones. 62
57. Bar graph showing resident exposure in the Town of Essex, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability 63
58. Bar graph showing employee exposure in Essex, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability 64
59. Bar graphs showing cumulative value in millions of dollars of business sales volume, total parcels, and building-replacement costs in coastal-hazard zones for Essex, Massachusetts 64
60. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in the Town of Essex, Massachusetts, as identified by local stakeholders 66
61. Bar graphs showing cumulative percent of total area for areas of concern identified by local stakeholders in the Town of Essex, Massachusetts, in coastal-hazard zones with 0.2- and 1-percent probabilities of occurrence in 2013, 2030, and 2070, organized by predicted water depth 67
1-1. Maps of Salisbury, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070 70
1-2. Maps of Newburyport, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070 73
1-3. Maps of Newbury, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070 76
1-4. Maps of Rowley, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070 79
1-5. Maps of Ipswich, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070 82

1-6. Maps of Essex, Massachusetts, coastal-inundation probability showing modeled hazard zones in 2013, 2030, and 2070 85

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Introduction

Understanding if and how community exposure to coastal hazards may change over time is crucial information for coastal managers tasked with developing climate adaptation plans. This report summarizes estimates of population and asset exposure to coastal-inundation hazards associated with sea-level-rise and storm scenarios in six coastal communities of the Great Marsh region of Essex County, Massachusetts. This U.S. Geological Survey (USGS) analysis was conducted in collaboration with National Wildlife Federation (NWF) representatives, who are working with local stakeholders to develop local climate adaptation plans for the Towns of Salisbury, Newbury, Rowley, Ipswich, and Essex and the City of Newburyport (hereafter referred to as communities). Community exposure was characterized by integrating various community indicators (land cover and land use, population, economic assets, critical facilities, and infrastructure) with coastal-hazard zones that estimate inundation extents and water depth for three time periods.

Estimates of community exposure are based on the presence of people, businesses, and assets in hazard zones that are calculated from geospatial datasets using geographic-information-system (GIS) tools. Results are based on current distributions of people and assets in hazard zones and do not take into account projections of human population, asset, or land-use changes over time. Results are not loss estimates based on engineering analysis or field surveys for any particular facility and do not take into account aspects of individual and household preparedness before an extreme event, adaptive capacity of a community during an event, or long-term resilience of individuals and communities after an event. Potential losses would match reported inventories only if all residents, business owners, public managers, and elected officials were unaware of what to do if warned of an imminent threat, failed to take protective measures during an extreme event, or failed to implement any long-term strategies to mitigate potential impacts. This analysis is intended to serve as a foundation for additional risk-related studies, plans, and mitigation efforts that are tailored to local needs. After a summary of the geospatial methods used in the analysis, results are organized by community so that local officials can easily use them in their local adaptation planning efforts.

Methods

Community exposure to coastal-inundation hazards is characterized by integrating geospatial data of scenario-hazard zones with various socioeconomic data to estimate the amount and relative percentage of a specific societal asset in a hazard zone. Societal assets were chosen based on USGS recommendations, discussions with NWF colleagues, and by vetting preliminary asset lists with project

stakeholders in the six coastal communities. This section describes the geospatial data and geoprocessing assumptions for societal assets related to land cover and land use, populations, economic assets, and critical facilities and infrastructure. All socioeconomic data and subsequent exposure estimates reflect current distributions of people and assets and do not include projections of future community growth. Socioeconomic data from the various sources described in this section were considered authoritative, and no additional field verification or map corrections were conducted.

Before analysis, all geospatial data were reprojected to share the same datum (North American Datum of 1983, State Plane, Massachusetts, FIPS 2001 Feet) and projection (Lambert Conformal Conic) to conform to existing geographic information system (GIS) data from the State of Massachusetts's GIS database (MassGIS) (Office of Geographic Information, 2016). Spatial analysis of vector data (for example, Census block polygons and business points) focused on determining whether or not an asset was inside a hazard zone. Slivers of polygons that overlap administrative boundaries and a hazard zone were taken into account during analysis, and final values were adjusted proportionately. The results summarized in this report should be considered first approximations of community exposure and not exhaustive inventories or loss estimates.

Community Boundaries

This study of community exposure to coastal hazards focuses on six communities (Salisbury, Newburyport, Newbury, Rowley, Ipswich, and Essex) in the Great Marsh region of Essex County, Massachusetts (fig. 1*A*). Jurisdictions are delineated by 2015 boundaries provided by MassGIS (Office of Geographic Information, 2016).

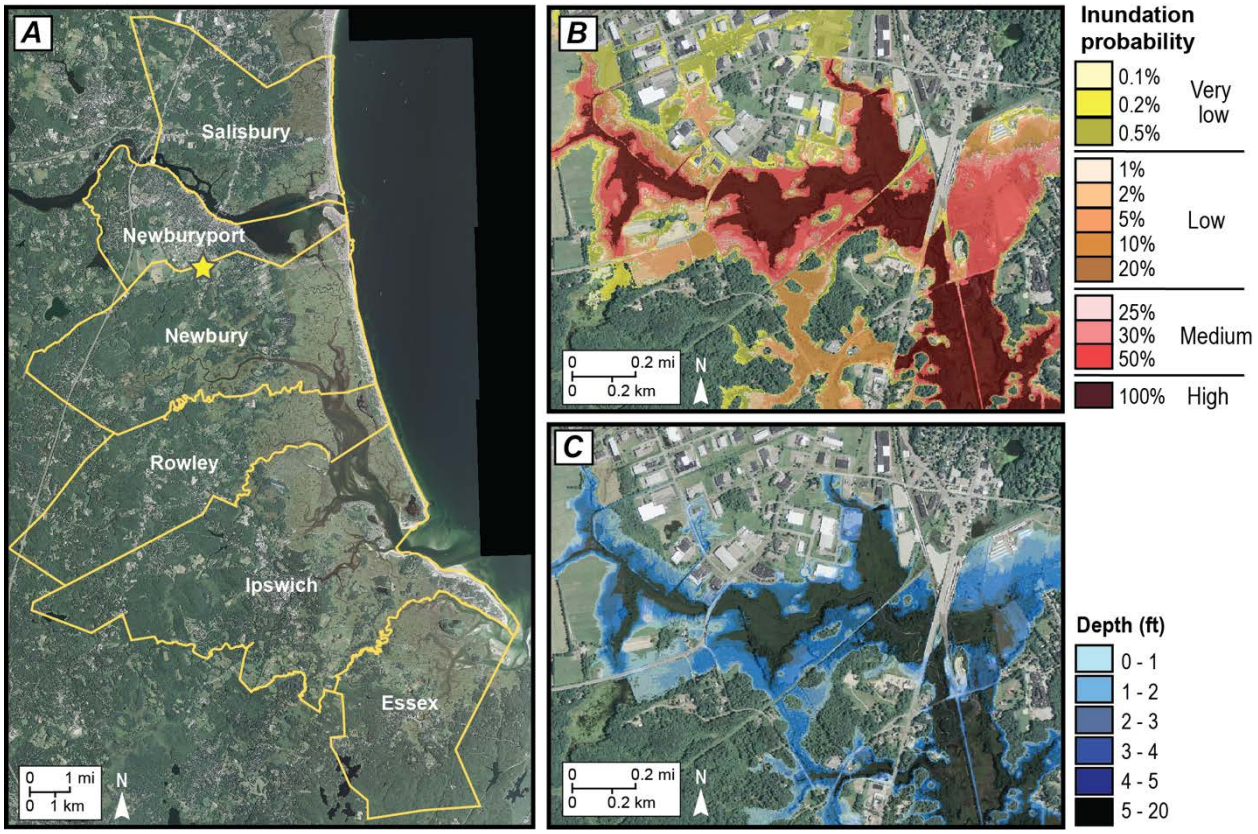

Figure 1. Maps showing (*A*) six coastal communities in the Great Marsh region of Essex County, Massachusetts, and examples of *(B)* inundation-probability data and (*C*) floodwater-depth data for sea-level-rise and storm scenarios provided by Woods Hole Group. The location of the two example maps is noted with a star in *A*. %, percent; ft, feet; mi, mile; km, kilometer.

Hazard Zones

Coastal-inundation hazard zones used in this study were developed and are summarized in geospatial data provided to the USGS by the Woods Hole Group, under contract to the NWF. Methods to develop the various scenario-based hazard zones are described in Kleinfelder (2015). Water-elevation modeling in their analysis was based on a fully optimized Monte Carlo approach to simulate the influence of climate change on sea level, tides, waves, and the track and intensities of tropical (hurricanes) and extratropical (nor'easters) storms. The spatial resolution of modeling efforts varied, ranging from 3.3 to 33 feet (ft) (1 to 10 meters (m)), based on data availability (Kleinfelder, 2015). Sea-level-rise assumptions for 2030 and 2070 hazard zones were 0.66 and 3.39 ft relative to mean sea level, respectively, which represent global sea-level-rise projections for the "highest" scenario by the Intergovernmental Panel on Climate Change (IPCC) (Core Writing Team and others, 2007; Parris and others, 2012).

Two types of hazard zones were included in this analysis—inundation probability (fig. 1*B*) and floodwater depths (fig. 1*C*). Both types of hazard zones were created by the Woods Hole Group for three time periods, including 2013 (representing present day and hereafter referred to as current hazard

zones), 2030, and 2070. For a given time period (current, 2030, and 2070), mapped inundation-probability values ranged from 0.1 to 100 percent with 12 discrete classes. On the basis of discussions with NWF representatives, we grouped the inundation probability values into four categories—high probability (100 percent), medium probability (25, 30, and 50 percent), low probability (1, 2, 5, 10, and 20 percent), and very low probability (0.1, 0.2. and 0.5 percent) (fig. 1*B*)**.** Floodwater depth data were summarized in 1-ft increments for all three time periods (fig. 1*C*) and for 1- and 0.2-percent inundation probabilities (corresponding to 100-year and 500-year storm likelihoods) based on discussions with NWF colleagues. Depth data were coupled with priority assets identified by local stakeholders to characterize the variability in estimated water depths across a specific asset for a specific time period and storm likelihood. Hazard-zone data provided by the Woods Hole Group were considered authoritative, and no additional field verification, model verification, or map corrections were conducted.

Land Cover and Land Use

Describing the patterns of land use and land cover (LULC), particularly patterns of human development, in predicted hazard zones is an important component of an exposure assessment. LULC was characterized using a combination of local and national data. To provide a general description of land cover in hazard zones based on current, 2030, and 2070 storm and sea-level-rise scenarios, we used a subset of the 2011 National Land Cover Database (NLCD), which is based on 30-m spatial resolution Landsat Thematic Mapper digital satellite imagery (Homer and others, 2004, 2012; Multi-Resolution Land Characteristics Consortium, 2011). NLCD data were used to estimate the amount of developed land in hazard zones, using the following three NLCD classes of developed land:

1. *High-intensity developed cells*, which contain 80 to 100 percent impervious surfaces, contain little or no vegetation, and typically represent heavily built-up urban centers, large buildings, and abundant paved surfaces, such as runways and interstate highways;
2. *Medium-intensity developed cells*, which contain 50 to 79 percent impervious surfaces, are a mix of constructed and vegetated surfaces, and typically represent single-family housing units and associated outbuildings; and
3. *Low-intensity developed cells*, which contain 20 to 49 percent impervious surfaces and are similar to medium-intensity developed pixels with the addition of roads and associated trees (Multi-Resolution Land Characteristics Consortium, 2011).

Undeveloped land and wetlands in hazard zones were characterized using the remaining NLCD classes. Other data used to characterize undeveloped land included areas of critical environmental concern, priority habitats, endangered species, conservation lands, and projects related to Massachusetts' Community Preservation Act, all of which were provided by MassGIS (Office of Geographic Information, 2016).

Current land use (as defined by the Massachusetts Department of Revenue) in hazard zones was characterized using land-use descriptions available from MassGIS parcel data (Office of Geographic Information, 2016). Current zoning data, which represents what potential use land in a community could be assigned, were obtained from regional planning organizations (Metropolitan Area Planning Council, Towns of Essex and Ipswich, written commun., 2016; Merrimack Valley Planning Commission, Towns of Newbury, Rowley, and Salisbury and the City of Newburyport, written commun., 2016). Land-use classifications include agricultural/conservation, commercial, government, industrial, religious/charitable/nonprofit, residential, and no classification. Zoning classifications and approaches

varied among the six coastal communities; therefore, we aggregated current zoning into the classes of general, industrial, commercial, residential, agriculture and conservation, and roads for consistency.

Populations

Residential-exposure estimates are based on block-level population counts compiled for the 2010 U.S. Census (U.S. Census Bureau, 2015, 2016) and the extent to which these populations are in coastal-inundation hazard zones for the current, 2030, and 2070 scenarios. Demographic attributes can amplify an individual's sensitivity to hazards (Morrow, 1999; Laska and Morrow, 2007); therefore, in addition to general population counts, we calculated the number of residents in hazard zones according to age (for example, individuals less than 5 and more than 65 years in age) and household structure (for example, renter-occupied households and individuals in group quarters). Additional demographic attributes for residents in hazard zones were characterized using American Community Survey (ACS) 5-year data for 2009–2014, including individuals that may be living in mobile homes, be living in poverty, be unemployed, have no phone, speak mainly English as a second language, have only high-school degrees, have disabilities, or have no vehicles (U.S. Census Bureau, 2016). Discussions of demographic sensitivities are not based on extensive studies of residents in the six Essex County communities, but instead on past social-science research of all types of disasters (for example, earthquakes, tornadoes, and hurricanes). It is not implied that all individuals of a certain group will exhibit identical behavior. The extent of these demographic sensitivities will be influenced by variations in local physical and social context, level of preparedness before an extreme event, ability to respond during an event, and extent and effectiveness of mitigation efforts in the future.

The location and size of other populations were identified using the 2012 Infogroup Employer Database, which is a proprietary database that provides business locations with attributes of employee counts, sales volume, and business type, as defined by the North American Industrial Classification System (NAICS) (Infogroup, 2012). NAICS codes were used to identify community-support businesses (for example, banks, government offices, grocery stores, and religious organizations), dependent-care facilities (for example, child and elderly services, schools, and medical facilities), public venues (for example, accommodations and outdoor venues), and the number of religious and social organizations, as an indicator of social capital. Additional public-venue locations were identified using recreation points, linear features (for example, trails), and areas (for example, scenic land), as identified by geospatial data provided by MassGIS (Office of Geographic Information, 2016).

Economic Assets

Economic analyses for this study focus on three elements of the coastal economy—tax base, the business community, and building replacement value. Current distributions of each dataset were combined with current, 2030, and 2070 coastal-inundation hazard zones to estimate economic exposure. Tax base, as represented by county parcel values, is an attribute of societal vulnerability because cities and counties rely on property taxes for local services. Communities can typically expect disaster-relief aid from external sources, but long-term funds for the restoration of county services typically come from revenue generated by property taxes. If an extreme event destroys property, land values will be reassessed at some point and likely lowered, the community tax base will shrink, and disaster recovery may be more difficult. Current tax-parcel boundaries and value attributes (including land, building, and other) were acquired from MassGIS (Office of Geographic Information, 2016), and the age of the data varied among the six communities, including 2012 (Essex and Ipswich), 2013 (Salisbury), and 2014 (Newbury, Newburyport, and Rowley).

Potential impacts to businesses in each community are determined by calculating the amount and percentage of businesses, employees, and generated sales volumes in the hazard zones using the previously described Infogroup Employer Database. Businesses with fewer than 20 employees were also identified because they have been considered more sensitive to disruptions than larger businesses in past extreme events. Our business counts and descriptions serve as approximations to initiate further discussion because we were unable to verify locational data (latitude and longitude coordinates) for each of the businesses. Building replacement value data were estimated by using cost data by structure occupancy type (adjusted using county modifiers) contained within the Federal Emergency Management Agency's (FEMA) Hazus-MH MR 2.1 loss-estimation application (Federal Emergency Management Agency, 2012). Hazus-MH values are based on general assumptions of building stocks in census designated areas and not based on a site-by-site assessment of actual buildings in a community.

Critical Facilities and Infrastructure

Certain facilities and infrastructure are considered critical for short-term response and long-term recovery of a community following a disaster. As a starting point for discussing these issues, certain facilities were identified using NAICS codes in the 2012 Infogroup Employer Database coupled with local data from MassGIS (Office of Geographic Information, 2016). Critical facilities include those used for public safety purposes (civil-defense facilities, fire stations, and police stations), medical services (ambulances, hospitals, outpatient-care centers, and physician offices), infrastructure maintenance (public-utility offices, public-work offices and storage yards, and transportation hubs) and government functions (courts and legal offices and government offices). Communications towers data were acquired from the 2013 Homeland Security Infrastructure program (HSIP) Gold Dataset (Homeland Infrastructure Foundation-Level Data Subcommittee, 2013). Infrastructure data included roads and railroads, which were acquired from MassGIS (Office of Geographic Information, 2016). Current distributions of each infrastructure dataset were combined with current, 2030, and 2070 coastal-inundation hazard zones to estimate exposure.

Locally Identified Areas of Concern

In 2015, NWF representatives held a series of local meetings with various stakeholders in each of the six communities to discuss vulnerability and resilience to coastal-inundation hazards. During these meetings, participants identified specific areas of concern in their communities where future coastal flooding may have negative impacts. These areas were digitized by the NWF, delivered to the USGS, and then used in the exposure analysis.

Salisbury

Land Cover and Land Use

The Town of Salisbury is approximately 15.4 square miles (mi^2), of which 40 percent (2013) to 45 percent (2070) is in coastal-hazard zones for the three time periods in this analysis (fig. 2; appendix 1). The integration of 2011 land-cover data (fig. 3) and the various hazard zones suggests that 19 to 24 percent of the developed land is in 2013 to 2070 hazard zones, respectively (fig. 4). The highest percentage (41 percent) of the developed land in the hazard zones for each time period is classified as medium-intensity developed, largely representing a mix of rural residential and agriculture areas. Land classified as low-intensity developed represents 32 percent in 2013 and 34 percent in 2070 of the developed land in hazard zones. The remaining 26 percent in 2013 and remaining 24 percent in 2070 of

developed land in hazard zones represents high-intensity developed, such as roads and commercial development. The majority of developed land in hazard zones is in areas considered to have a range of inundation probabilities in current hazard zones, but increasing to high-inundation probabilities in 2030 to 2070 (fig. 4).

The amount of undeveloped land (based on 2011 NLCD data) in coastal-hazard zones is much greater than developed land, but exposure does not vary substantially through time. The majority of undeveloped land is in areas considered to have a high probability of inundation during future storms both today and by 2070. This land also represents approximately 46 to 51 percent of all undeveloped land in Salisbury between 2013 and 2070 (fig. 4). Most of this land is classified as wetlands (85 percent); therefore, it makes sense that much of it would be inundated during storms annually, if not by tides daily.

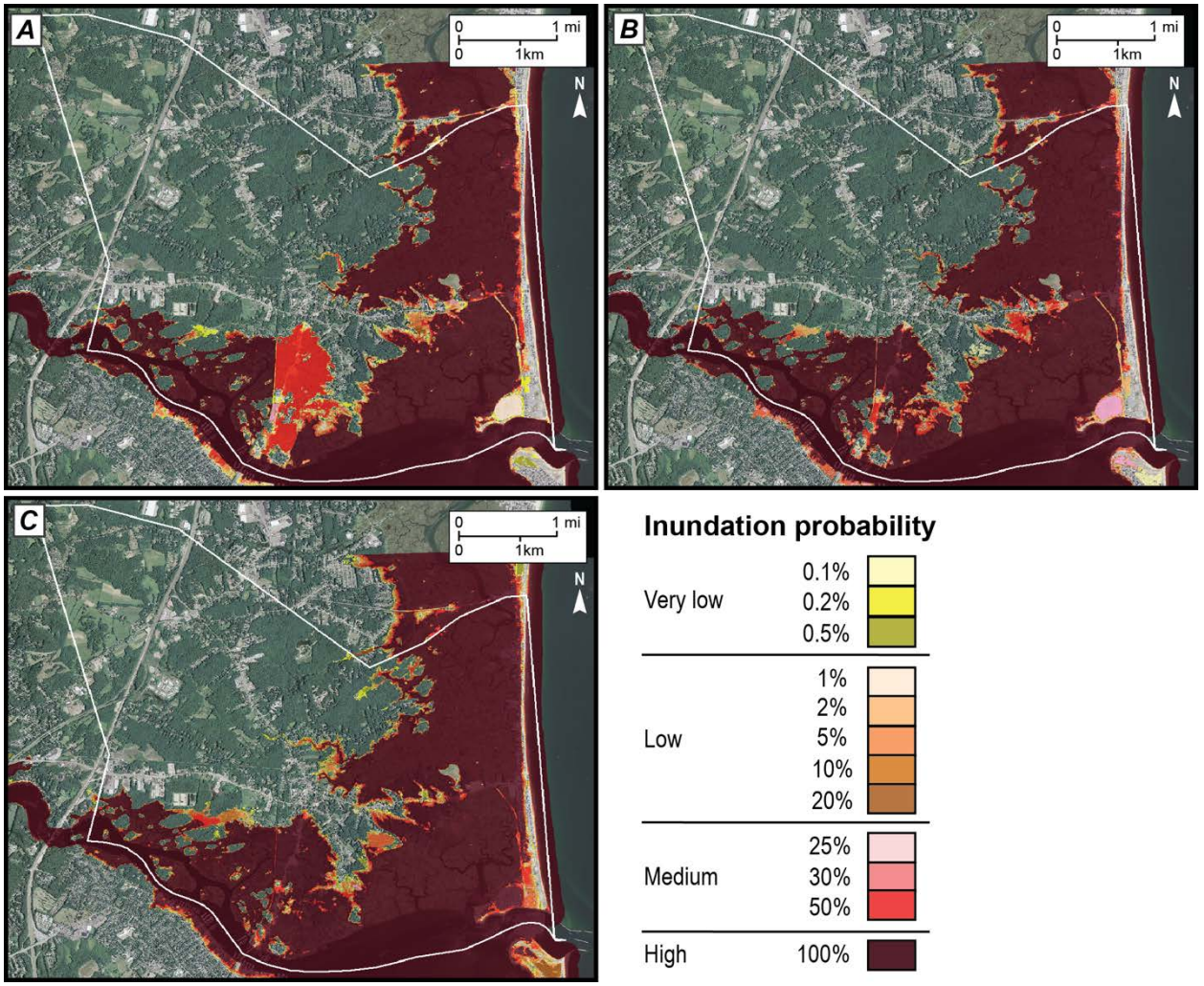

Figure 2. Maps of Salisbury, Massachusetts, coastal-inundation probability showing modeled hazard zones in (*A*) 2013, (*B*) 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). Appendix 1 provides larger versions of each of these maps. %, percent; mi, mile; km, kilometer.

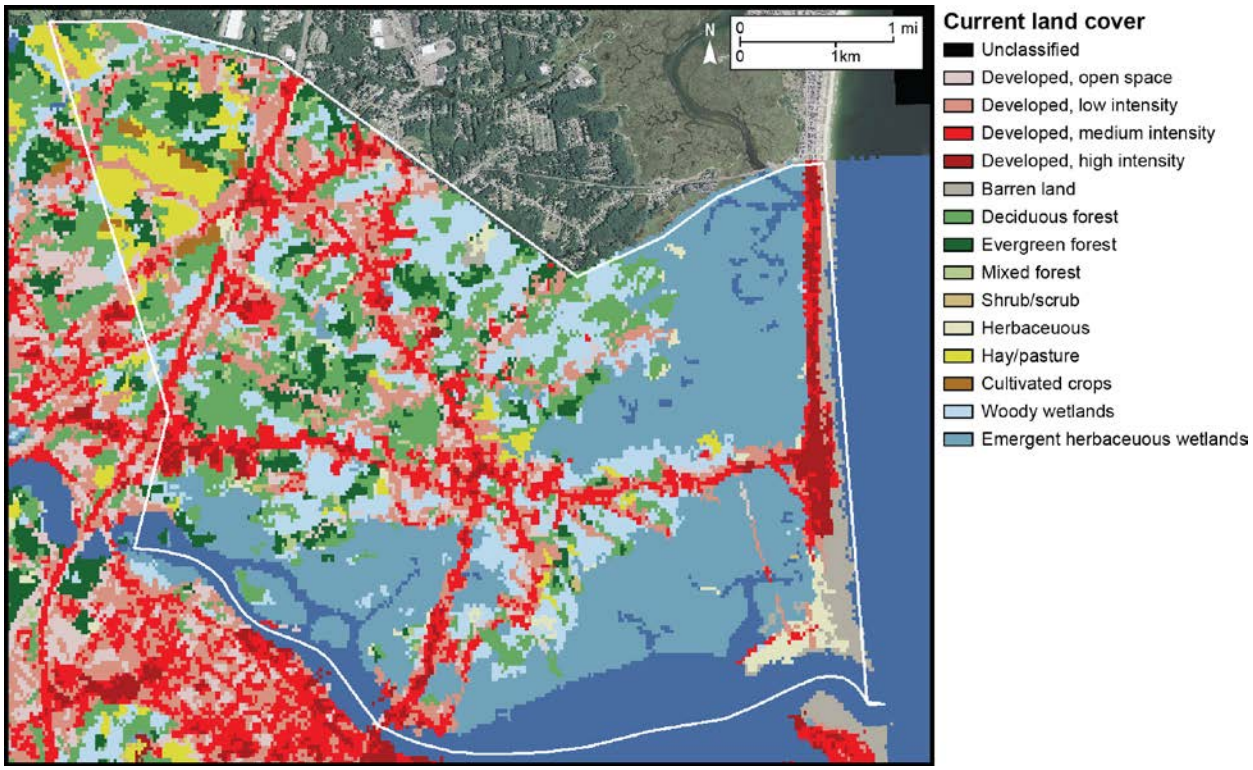

Figure 3. Map showing land-cover data for Salisbury, Massachusetts, from the 2011 National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2011). mi, mile; km, kilometer.

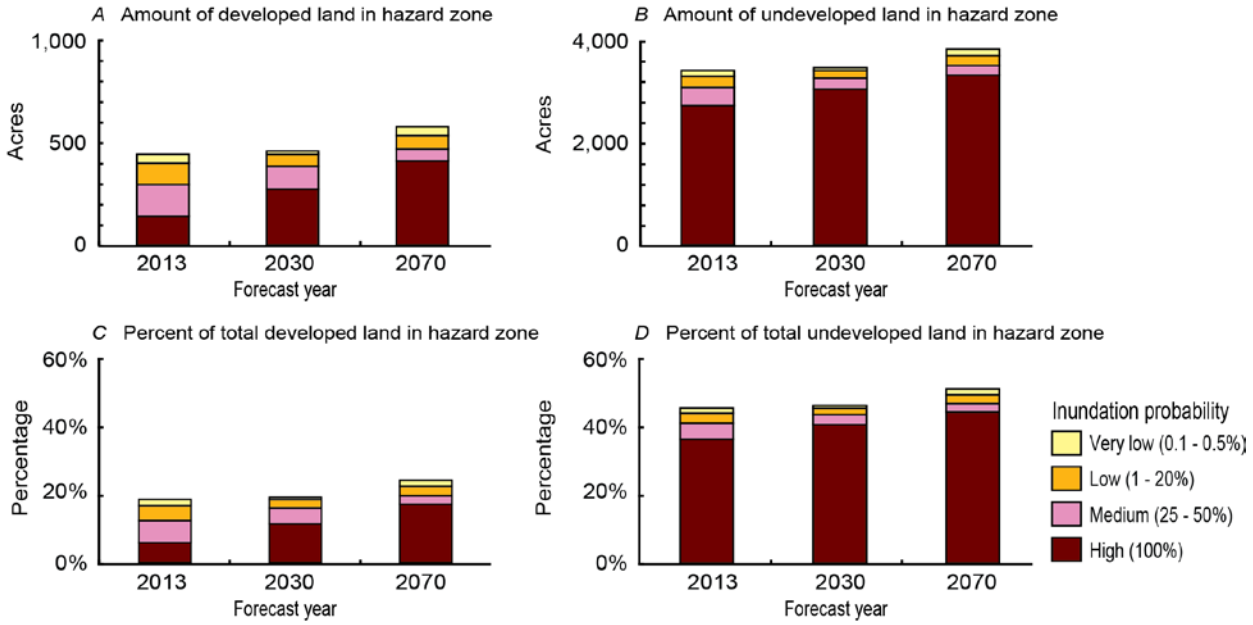

Figure 4. Bar graphs showing amounts of (*A*) developed and (*B*) undeveloped land and total percentages of *(C)* developed and (*D*) undeveloped land in coastal-hazard zones of Salisbury, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070. %, percent.

The modeled hazard zones encompass thousands of acres of conservation lands, areas important to endangered species, and priority habitats (fig. 5). Additional descriptions of each of these environmental designations can be found at MassGIS (Office of Geographic Information, 2016). Seventy-five percent of conservation lands are in current hazard zones, which increases to 83 percent in 2070. The priority habitats and endangered species habitats have larger amounts of land in the hazard zone, on the order of 3,000 acres, with the majority of these areas in high-inundation-probability zones for all three time periods (fig. 5). There are no areas of critical environmental concern or Community Preservation Act locations in Salisbury coastal-hazard zones. The majority of the natural areas in the hazard zones for each time period are considered to have a high probability of inundation, and the remaining areas are distributed evenly between medium, low, very low probability zones, and not in the hazard zone by 2070 (fig. 5). The high probabilities of inundation for these undeveloped conservation areas are a result of the land being predominantly saltmarsh—and thus inundated nearly daily by tides.

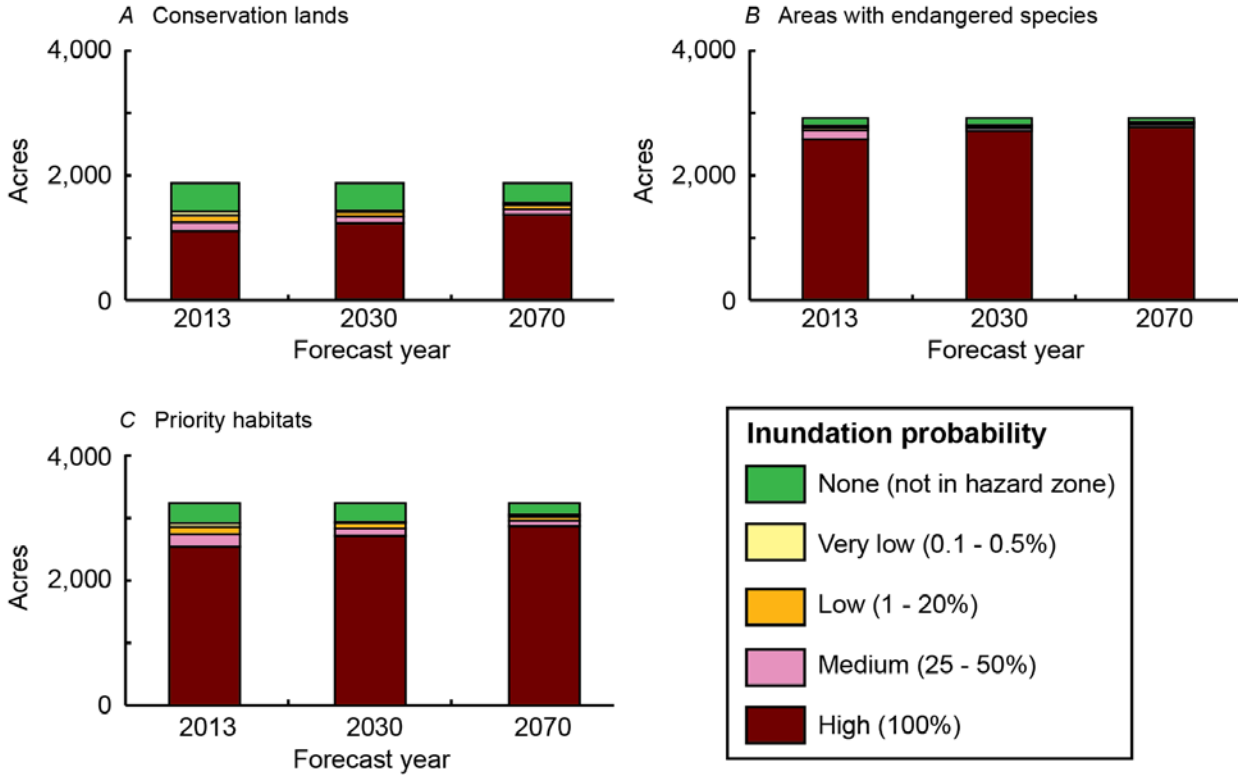

Figure 5. Bar graphs showing the area of land classified as (*A*) conservation lands, (*B*) endangered species habitats, and (*C*) priority habitats in the modeled hazard zones of Salisbury, Massachusetts, for 2013, 2030, and 2070. %, percent.

The most common land use in the hazard zones is classified as governmental and ranges from 43 percent in 2013 to 41 percent in 2070 of all land in the hazard zone (fig. 6). The high percentage of government land use in hazard zones is disproportionate to the community as a whole, where it only represents 25 percent of land use by area (fig. 6*C*). The second most common use of land in the coastal-hazard zones is classified as residential, which ranges from 28 percent in 2013 to 30 percent in 2070. In all three hazard zones (that is, 2013, 2030, and 2070), the majority of the parcel area is in areas classified as having a high probability of inundation. All of the remaining land uses in the hazard zones each represent less than 10 percent by area, such as religious, charitable, or nonprofit, agriculture and conservation, and industrial.

Zoning data, determined by community planners, suggests that residential areas represent the highest percentage of land in coastal-hazard zones, ranging from 93 percent in 2013 to 92 percent in 2070, respectively. The remaining zoning types (commercial, agriculture and conservation, and industrial) in the hazard zones each represent less than 10 percent by area.

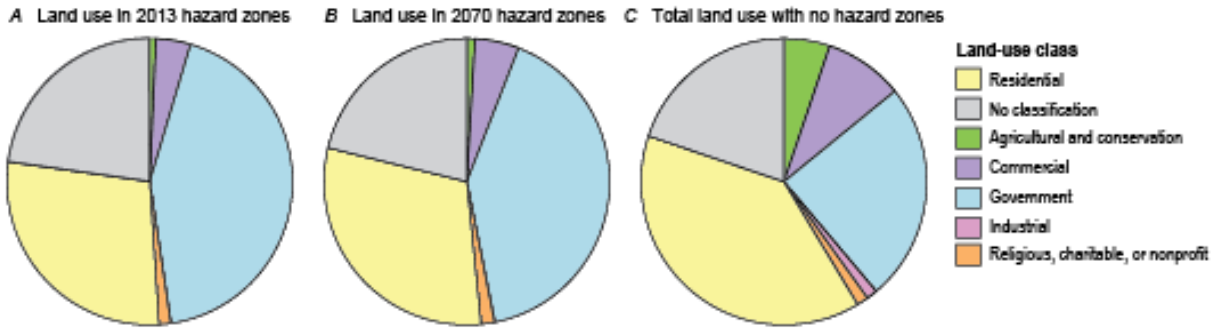

Figure 6. Pie charts showing distribution (by area) of current land-use classes within hazard zones in Salisbury, Massachusetts, for (*A*) 2013 and (*B*) 2070, as well as for (*C*) all land in Salisbury regardless of hazard zones.

Populations

The number of Salisbury residents living in the coastal-hazard zones ranges from 1,827 in 2013 to 2,707 in 2070, representing 22 to 33 percent, respectively, of the 8,282 total residents of Salisbury (fig. 7). This estimate is based solely on changes in the extent of the hazard zones, as resident distributions are based on 2010 population counts. The greatest increase in residential exposure among the three time periods is associated with the high-inundation-probability zone. The majority of residents in current hazard zones are located in areas classified as having a high (100 percent) inundation probability (549 residents). By 2070, the number of residents living in the highest hazard zone is estimated to nearly triple to 1,635 residents due to changes in the extent of hazard zones, whereas the number of residents in the medium, low, and very low probability zones are not estimated to increase substantially.

All demographic percentages describing residents in hazard zones were relatively stable (+/- 1 percent) across the three time periods. Demographic results relative to 2070 hazard zones suggest that less than 5 percent of the residents in the hazard zones are living in mobile homes, living under the poverty line, unemployed, lack a phone, speak English as a second language, under 5 years in age, living in institutionalized group quarters, or without a vehicle. Greater than 5 percent of the residents in the hazard zones have disabilities (12 percent), are more than 65 years in age (18 percent), live in renter-occupied households (19 percent), and have only a high-school degree (38 percent).

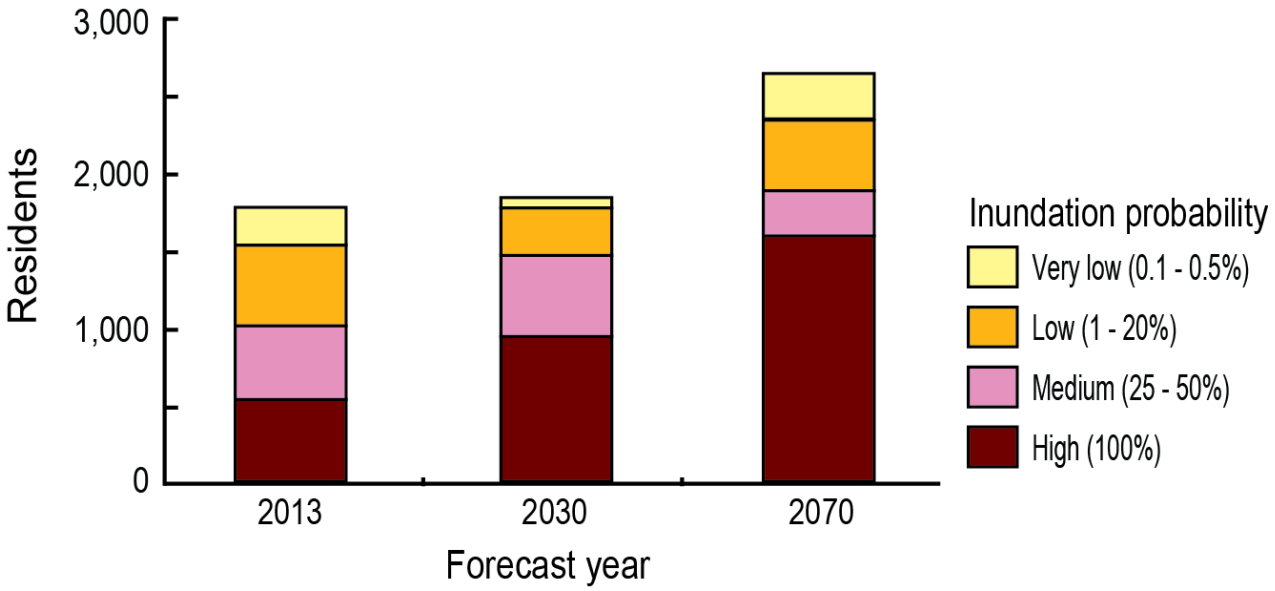

Figure 7. Bar graphs showing resident exposure in Salisbury, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

An analysis of other population data suggests several types of nonresidential groups are threatened by coastal-inundation hazards. Dependent-care facilities in hazard zones include 4 sites (medical facilities) in the 2013 low-probability zone and increases to 6 facilities in 2070, including 4 sites in areas with high inundation probability, 1 site in an area with a low inundation probability, and another site in an area with very low inundation probability. Public venues in coastal-hazard zones include one site (an amusement and theme park) in the 2013 medium-probability zone and increasing to 10 sites by 2070 (1 in a high-probability zone, 5 in the medium-probability zone, 2 in the low-probability zone, and 2 in the very low probability zone). Recreation data indicate that coastal-hazard zones with high probabilities of inundation contain one to two canoe access points, 0.32 to 5.3 miles (mi) of roads and trails, and 1,784 to 2,110 acres of recreational areas (referred to as scenic land), where ranges represent 2013 and 2070 values. There are no religious and civic organizations in the coastal-hazard zone.

Economic Assets

The number of Salisbury employees working in coastal-hazard zones ranges from 410 in 2013 to 617 in 2070, representing 12 to 18 percent, respectively, of the 3,394 employees that were in the community (fig. 8). As was the case with the resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zone and not projected changes in employee distributions. In 2013, most employees in these hazard zones are in areas classified as having a low (1–20 percent) inundation probability (215 employees). By 2070, 376 employees are at businesses in the high (100 percent) probability zone, with additional employees in zones classified as medium (166), low (59), and very low (16) inundation probability. Sales volume exposure for private-sector businesses ranges from $73 million in 2013 to as much as $102 million in 2070 (fig. 9*A*). None of the businesses in the various hazard zones were classified as related to natural resources. The number of businesses likely to have a significant customer presence (for example, retail) in coastal-hazard zones ranges from 58 businesses in 2013 to 75 businesses in 2070. The number of these businesses with fewer than 20 employees (a group

typically more sensitive to disruptions) ranges from 90 in 2013 to 123 in 2070, representing 21 and 28 percent, respectively, of the Salisbury business community.

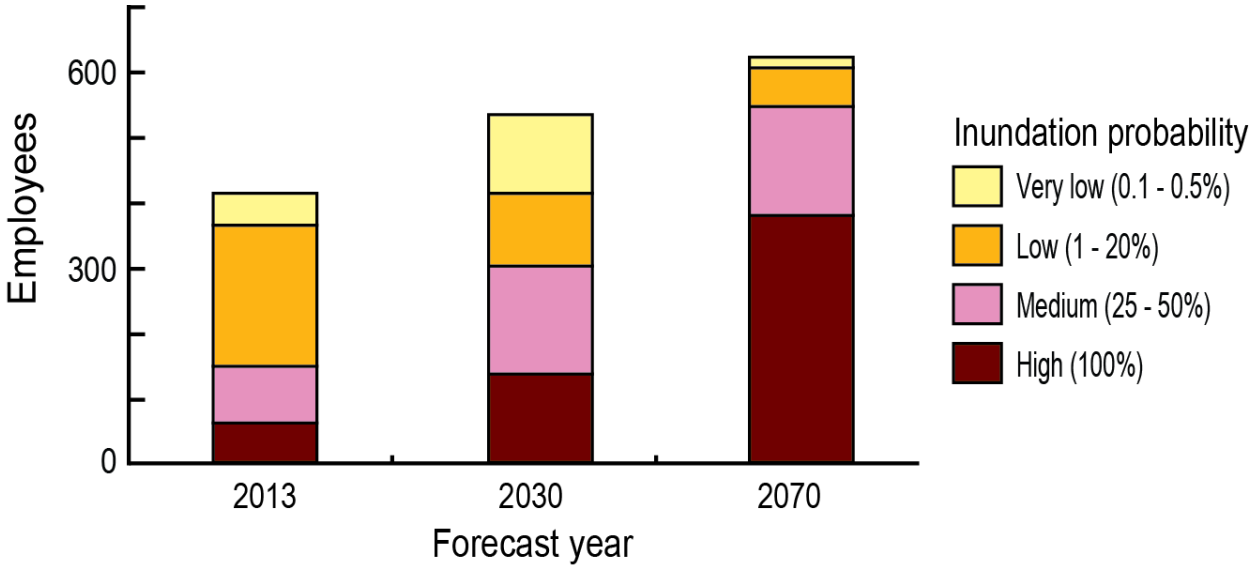

Figure 8. Bar graph showing employee exposure in Salisbury, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

Similar to sales volume, the amount of parcel values and building-replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value for parcels in coastal-hazard zones ranges from approximately $377 million in 2013 hazard zones to approximately $574 million in 2070 hazard zones, representing 25 to 38 percent of the community's tax base between the two time periods (fig. 9*B*). The majority of tax-parcel value in hazard zones is associated with building value for 2013 and 2030 (50 percent, respectively) and land value for 2070 (50 percent), with the remainder associated with content value. Based on building-stock data in the FEMA Hazus-MH 2.2 database (Federal Emergency Management Agency, 2016), estimated building-replacement values range from $389 million for the 2013 hazard zone to $514 million for 2070 hazard zone (fig. 9*C*). For all three time periods, the majority of potential building-replacement values are in areas classified as high probability of inundation.

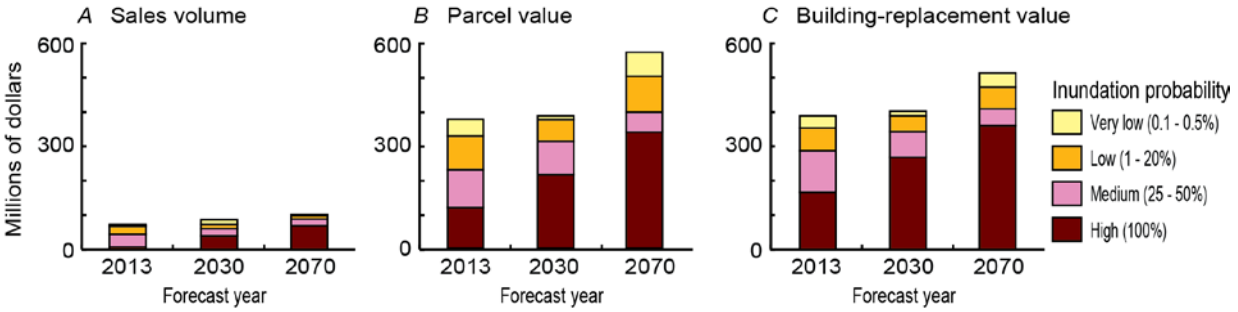

Figure 9. Bar graphs showing cumulative value in millions of dollars of (*A*) business sales volume, (*B*) total parcels, and (*C*) building-replacement costs in coastal-hazard zones for Salisbury, Massachusetts. %, percent.

Critical Facilities and Infrastructure

Results indicate that coastal-hazard zones in Salisbury contain no composting-operation sites, small waste-transfer stations, public-work offices and storage yards, public-water-supply sources, transmission lines, Massachusetts Bay Transportation Authority (MBTA) parking-lot locations, or park-and-ride lots. Three critical facilities are in areas classified as low (government office and first-responder facility) and very low (police station) inundation probability in 2013, respectively, which become high-probability zones by 2070. One transportation hub is in an area with a very low probability of inundation in 2013 that rises to a medium probability by 2070. Three public-utility stations (including a marina and a gas station) are in coastal-hazard zones, distributed evenly between medium to very low probability zones in 2013 and primarily in the high-probability zone for 2070. Two underground storage tanks are in the hazard zones, with the probability of inundation increasing from medium (1) and low (1) in 2013 to high (2) in 2070. No tier-classified oil and hazardous-material release/disposal sites are in the hazard zones, although one site with a declared activity and use limitation is in an area considered to have a very low inundation probability in 2013 that becomes medium probability in 2070. With regard to infrastructure, results suggest that there are approximately 18 mi of roads and rail in 2013 hazard zones (primarily in the low-probability zone) that increases to 19 mi by 2070 (primarily in the medium-probability zone).

Locally Identified Areas of Concern

Local stakeholders identified several "areas of concern" in Salisbury (fig. 10). Based on a comparison of these areas with predicted hazard zones for current conditions, 2030, and 2070, the following observations can be made of the exposure of these areas to coastal-inundation hazards.

- Route 1A is estimated to have 100 percent of its area inundated by varying floodwater depths by storms today, in 2030, and in 2070, for both 1- and 0.2-percent inundation probabilities (fig. 11). Water depths over the majority of the asset are estimated to be on the order of 1 to 20 ft from 2013 to 2030 but become more consistently 5 to 20 ft in 2070 coastal-hazard zones for both storm scenarios.
- The estimated extent of inundation for Salisbury Beach at Broadway ranges from 49 to 53 percent (by area with ranges corresponding to 1- and 0.2-percent inundation probabilities, respectively) in 2013 with exposure percentages rising to 80 to 94 percent of the asset by 2070. Floodwater depths over the majority of the asset are estimated to be on the order of 1 to 20 ft for all time periods and storm probabilities.
- Salisbury Barrier Beach has an estimated extent of inundation and floodwater depths ranging from 32 to 36 percent by area and 1 to 20 ft in 2013 hazard zones for the 1- and 0.2-percent inundation probabilities. By 2070, this barrier is estimated to be 55 to 61 percent exposed (by area) with depths ranging from about 5 to 20 ft for both scenarios.
- North End Boulevard has estimated floodwater depths from 1 to 20 ft in the 2013 and 2030 hazard zones and increases to about 5 to 20 ft in the 2070 hazard zones for both 1- and 0.2-percent inundation probabilities.
- The sewage pumping station is estimated to have approximately 98 percent of its area in coastal-hazard zones from 2013 to 2070 for both storm scenarios. Estimated floodwater depths range from 2 to 20 ft for the 1-percent inundation probability and 3 to 20 ft for the 0.2-percent-inundation probability between 2013 and 2030 with an increase to about 5 to 20 ft in 2070 for both scenarios.

- The seawall at 32 1st street and the low-lying residential area bordering Black River Marsh have similar exposure profiles in that coastal-hazard zones are estimated to cover 97 to 100 percent and 98 to 100 percent (by area with ranges corresponding to 1- and 0.2-percent inundation probabilities) of the two assets, respectively, in 2013 with exposure percentages rising to 100 percent for both assets by 2070. The estimated floodwater depths for the two assets over time exhibit a range from 1 to 20 ft from 2013 to 2030, and the seawall exposure increases to about 3 to 20 ft, whereas the low lying residential continues to range from 1 to 20 ft by 2070 for the 1-percent inundation probability. Estimated depths for the 0.2-percent inundation probability for the two assets are similar in that depths range from 1 to 20 ft from 2013 to 2030 and increase to about 5 to 20 ft by 2070.
- Dunes east of the southern end of Atlantic Avenue, north of the beach center and east of Ocean Front South, are not in forecasted coastal-hazard zones. Nonetheless, local officials and planners have indicated the dune assets are likely to be impacted by erosion that would then lead to coastal inundation, which is plausible, but gauging the potential of erosion is outside the scope of this analysis.

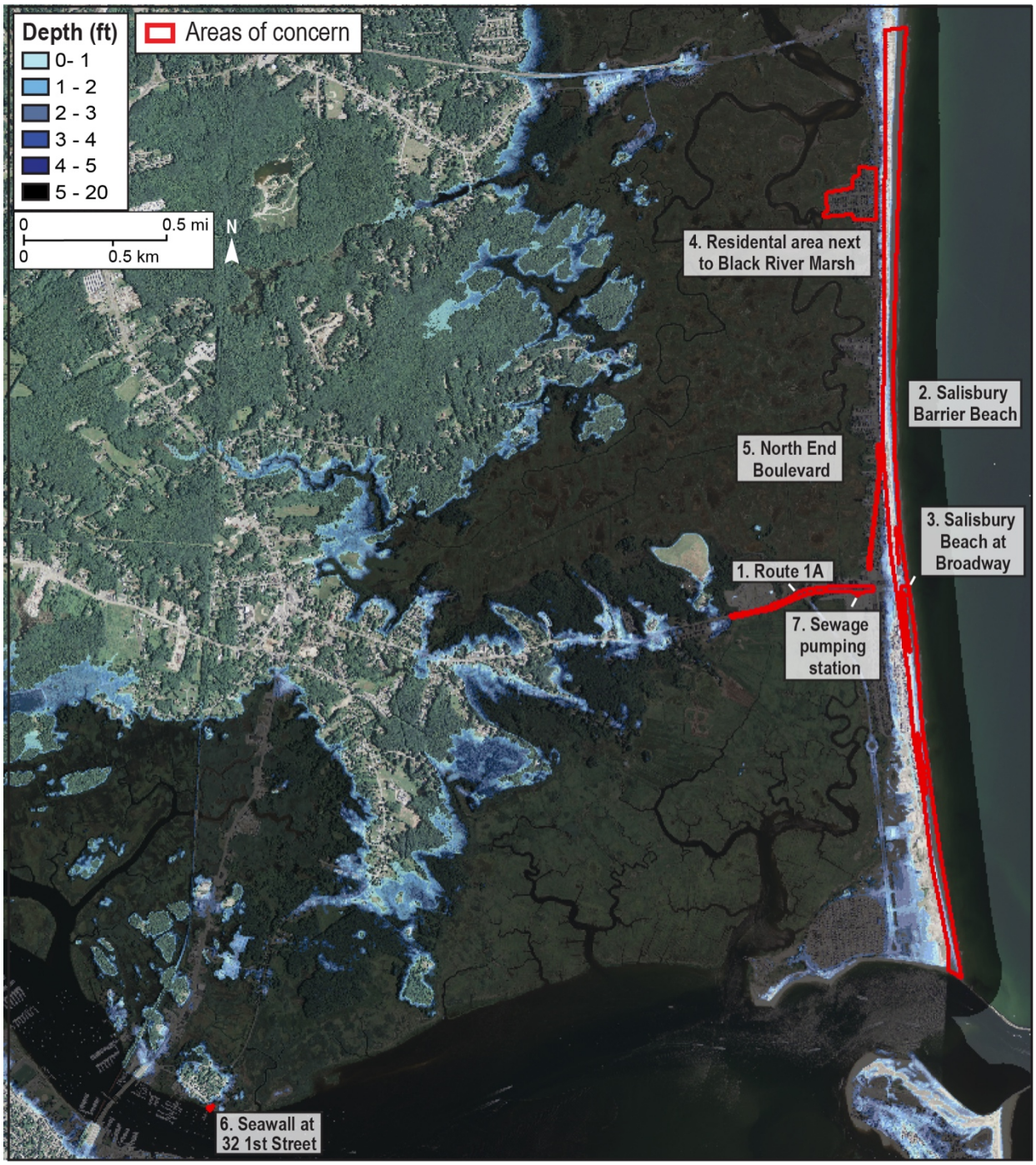

Figure 10. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in the Town of Salisbury, Massachusetts, as identified by local stakeholders. Areas of concern associated with dunes east of the southern end of Atlantic Avenue, north of the beach center and east of Ocean Front South, are located within Salisbury Beach at Broadway (site 3). ft., feet; mi, mile; km, kilometer.

Figure 11. Bar graphs showing cumulative percent of total area for areas of concern indicated by local stakeholders in the Town of Salisbury, Massachusetts, in coastal-hazard zones with 1- and 0.2-percent inundation probabilities in 2013, 2030, and 2070, organized by predicted water depth. Dunes east of the southern end of Atlantic Avenue, north of the beach center and east of Ocean Front South, are not in hazard zones. %, percent; ft., feet.

Conclusion

Understanding how the Town of Salisbury is vulnerable to coastal hazards will help local and State officials decide where to focus future planning efforts and how to allocate resources to mitigate the impacts of coastal hazards. Results indicate significant variations in amounts and percentages of community assets exposed to climate-driven coastal hazards. The Town of Salisbury's maximum coastal-hazard zone (the total area exposed to potential inundation from sea-level rise and storm surge) includes 24 percent of total developed land and 51 percent of total undeveloped land by 2070. The majority of exposed land in Salisbury (85 percent of land) is in the high-inundation-probability zone. The maximum hazard zone also is projected to contain approximately 2,707 residents (33 percent of total), 617 employees (18 percent of total), and numerous community businesses, public venues, dependent-care facilities, and recreational area by 2070. There are also demographic groups in the Town of Salisbury that may be more sensitive to future threats and therefore may need extra preparedness training, such as residents that have disabilities (12 percent of exposed residential population), are more than 65 years in age (18 percent of exposed residential population), live in renter-occupied households (19 percent of exposed residential population), and only have a high-school degree (38 percent of

exposed residential population). The amount of exposed parcel and building-replacement values increase approximately 13 percent (parcel) and 11 percent (building replacement) in the high-probability zone by 2070. Although the overall area exposed increases by only 6 percent, the within-area distribution of exposed assets changes over time to include more high-probability exposure. The maximum hazard zone also is projected to contain approximately 7 critical facilities, including 1 government office, 1 police station, 1 first-responder facility, 1 transportation hub, and 3 public-utility stations by 2070. In addition, approximately 19 mi of roads and rail (21 percent of roads and rail) would be exposed in the maximum hazard zone by 2070. The depth analysis indicates that at a 0.2- and -1 percent storm-surge probability, the seawall at 32 1st Street has the highest area in hazard zones. In addition, predicted inundation heights may be primarily 5 to 20 ft for the majority of the assets by 2070.

Newburyport

Land Cover and Land Use

The City of Newburyport is approximately 8.34 mi^2, of which 7 percent (2013) to 14 percent (2070) of it is in coastal-hazard zones for the three time periods in this analysis (fig. 12; appendix 1). The integration of 2011 land-cover data (fig. 13) and the various hazard zones suggests that 5 to 13 percent of the developed land is in 2013 to 2070 hazard zones, respectively. The highest percentage (45 percent in 2013 to 52 percent in 2070) of the developed land in the hazard zones is classified as medium-intensity developed, largely representing a mix of rural residential and agriculture areas. Land classified as low-intensity developed represents 36 percent in 2013 and 31 percent in 2070 of the developed land in hazard zones. The remaining 19 percent in 2013 to 17 percent in 2070 of developed land in hazard zones represents high-intensity developed, such as roads and commercial development. The majority of developed land in hazard zones is in areas considered to have a high (100 percent) probability of inundation (fig. 14).

The amount of undeveloped land (based on 2011 NLCD data) in coastal-hazard zones is much greater than developed land but exposure does not vary substantially through time. The majority of undeveloped land is in areas considered to have a high probability of inundation during future storms both today and by 2070. This land also represents approximately 10 to 15 percent of undeveloped land in Newburyport between 2013 and 2070 (fig. 14). Most of this land is classified as wetlands (59 percent); therefore, it makes sense that much of it would be inundated during storms, if not on a near daily occurrence.

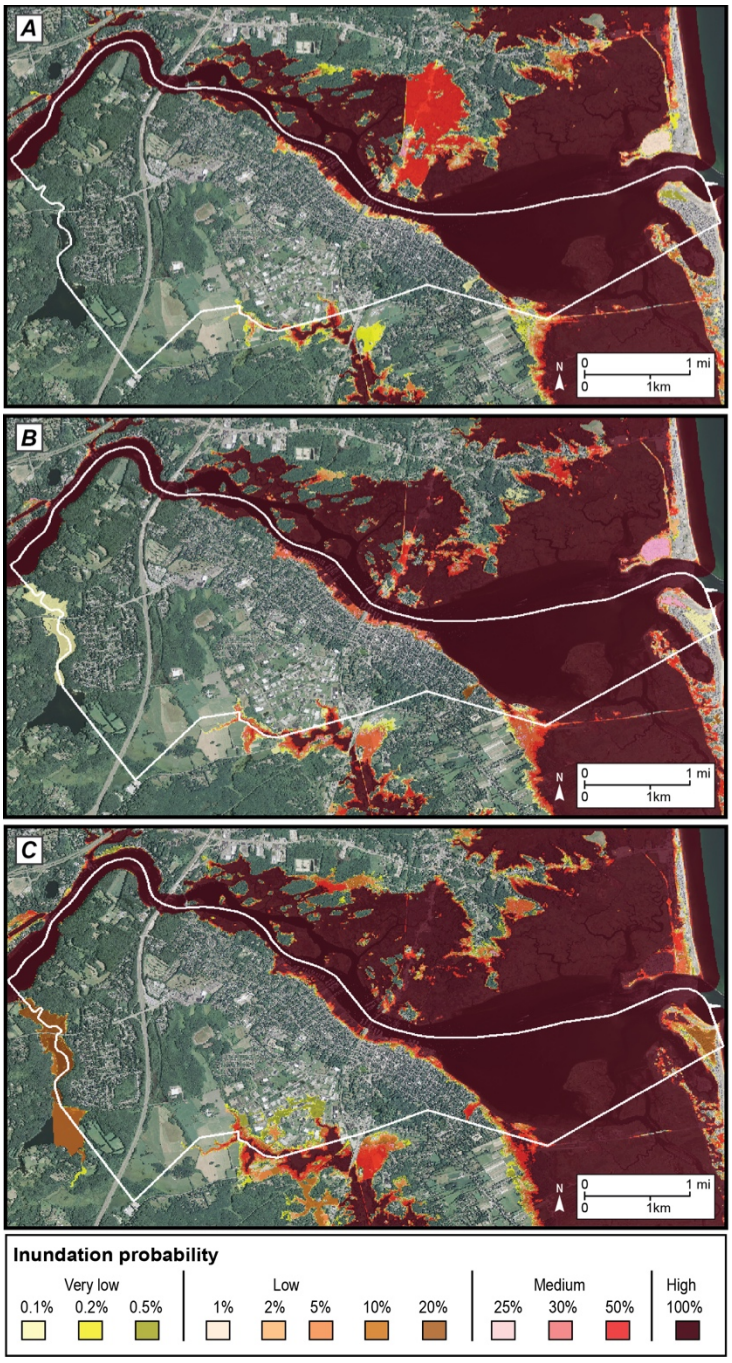

Figure 12. Maps of Newburyport, Massachusetts, coastal-inundation probability showing modeled hazard zones in (*A*) 2013, (*B*) 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). Appendix 1 provides larger versions of each of these maps. %, percent; mi, mile; km, kilometer.

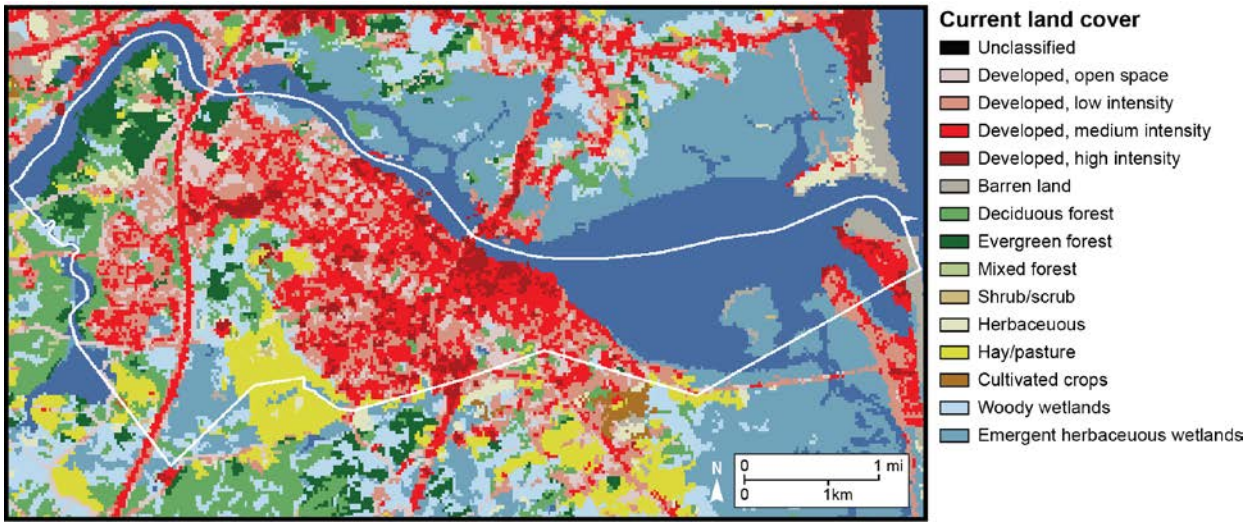

Figure 13. Map showing land-cover data for Newburyport, Massachusetts, from the 2011 National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2011). mi, mile; km, kilometer.

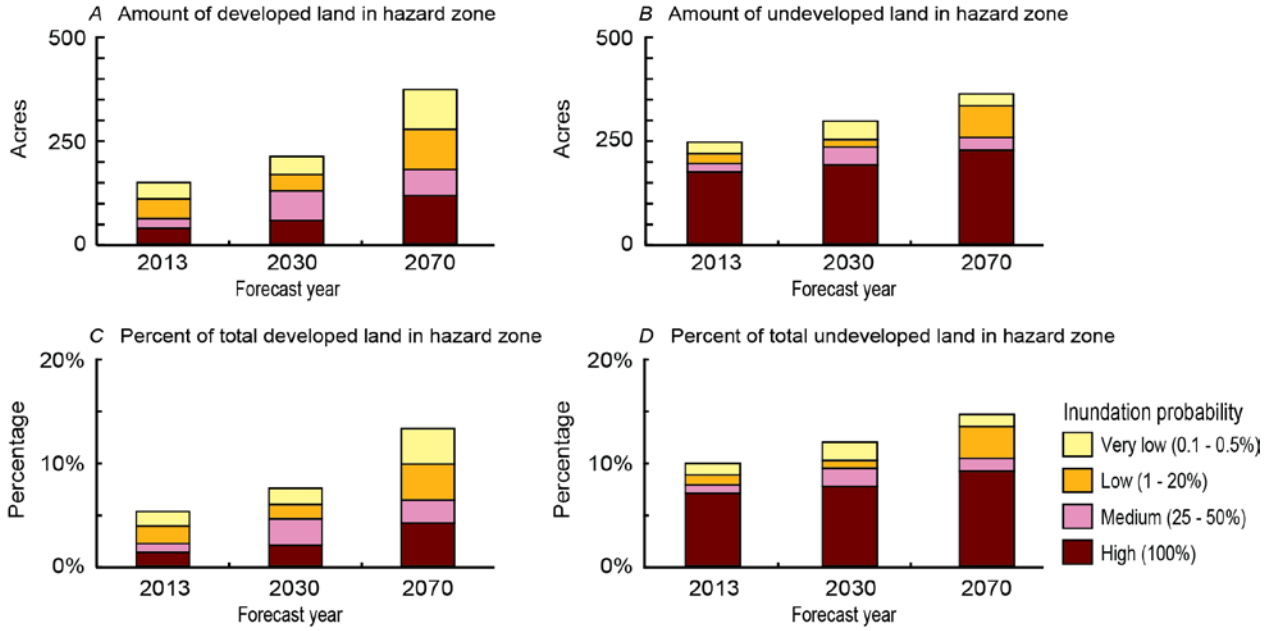

Figure 14. Bar graphs showing amounts of (*A*) developed and (*B*) undeveloped land and total percentages of (*C*) developed and (*D*) undeveloped land in coastal-hazard zones of Newburyport, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070. %, percent.

The modeled hazard zones encompass thousands of acres of conservation lands, areas important to endangered species, and priority habitats (fig. 15). Additional descriptions of each of these environmental designations can be found at MassGIS (Office of Geographic Information, 2016). Conservation lands have the least amount of land in the coastal-hazard zones, from 6 percent in 2013 and increasing to 12 percent in 2070. Ninety-eight percent of identified areas of critical environmental concern are in current hazard zones, which increases to 100 percent in 2070. Endangered species habitats and priority habitats have larger amounts of land in the hazard zones, on the order of 500 acres,

with the majority of these areas in high-inundation-probability zones for all three time periods (fig 15). In addition, Community Preservation Act locations have less than 5 percent exposure to coastal hazards until 2070 with 13 percent of locations in the hazard zones (fig. 15*E*).

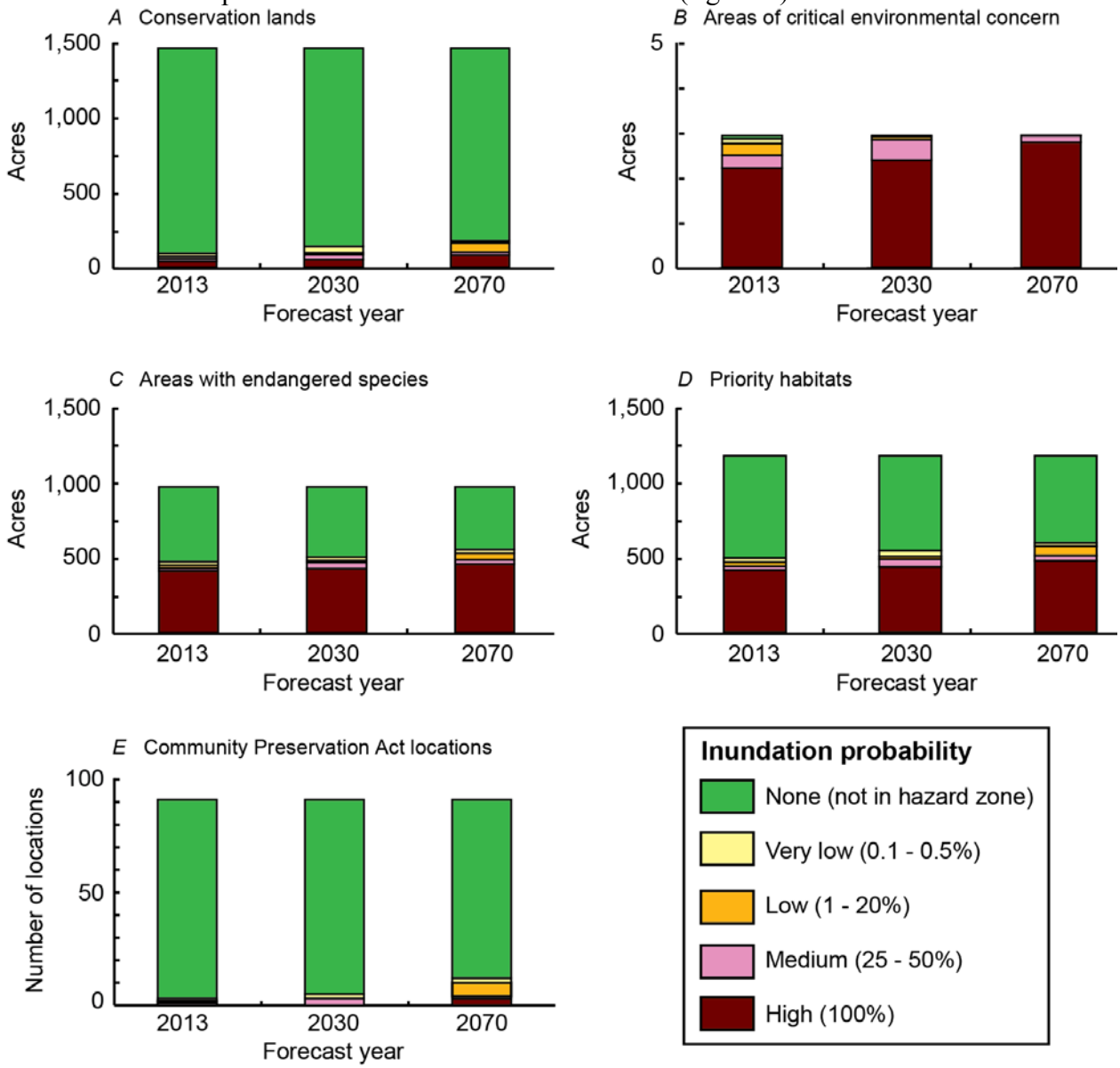

Figure 15. Bar graphs showing the area of land classified as (*A*) conservation lands, (*B*) areas of critical environmental concern, (*C*) endangered species habitats, (*D*) priority habitats, and (*E*) Community Preservation Act locations in the modeled hazard zones of Newburyport, Massachusetts, for 2013, 2030, and 2070. %, percent.

With regard to land use in hazard zones, the largest amount of land lacks a land-use classification and ranges from 79 percent in 2013 to 68 percent in 2070, respectively (fig. 16). The highest amount of land in coastal-hazard zones with a land-use classification is classified as commercial, which ranges from 10 percent in 2013 to 9 percent in 2070. All of the remaining land uses in the hazard zone each represent less than 10 percent by area, such as religious, charitable, or nonprofit, agriculture and conservation, government, residential, and industrial. The high percentage of land in the

hazard zone that lacks a land-use classification (68–79 percent) is disproportionate to the community as a whole, where it only represents 49 percent of land use by area (fig. 16*C*).

Current zoning, determined by community planners, suggests that most affected area in the coastal-hazard zones would be land zoned for agriculture and conservation, ranging from 57 percent in 2013 to 43 percent in 2070, respectively. Land zoned for residential purposes is the second highest, by area, ranging from 17 percent in 2013 to 24 percent in 2070 of all land in the hazard zones. The remaining zoning types (commercial and industrial) in the hazard zones each represent less than 20 percent by area.

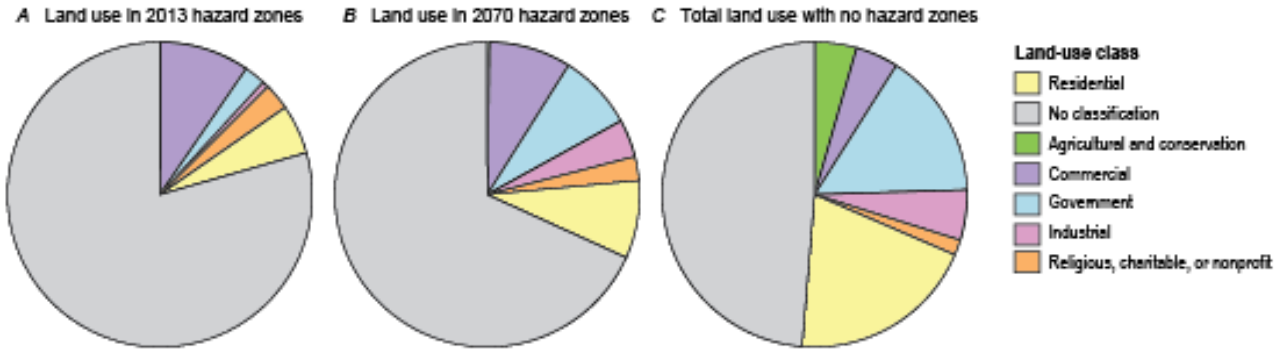

Figure 16. Pie charts showing distribution (by area) of current land-use classes within hazard zones in Newburyport, Massachusetts, for (*A*) 2013 and (*B*) 2070, as well as for (*C*) all land in Newburyport regardless of hazard zones.

Populations

The number of Newburyport residents living in the coastal-hazard zones ranges from 250 in 2013 to 1,206 in 2070, representing 1 to 7 percent, respectively, of the 17,416 total residents in Newburyport (fig. 17). This estimate is based solely on changes in the extent of the hazard zones, as resident distributions are based on 2010 population counts. The greatest increase in residential exposure among the three time periods is associated with the low-inundation-probability zone. The majority of residents in current hazard zones are located in areas classified as having a very low (0.1–0.5 percent) inundation probability (143 residents). By 2070, the number of residents living in hazard zones is estimated to be in the low-probability (1–20 percent) zone (514 residents) due to changes in the extent of hazard zones, whereas the number of residents in 2070 in the high, medium, and very low probability zones are also estimated to increase but to a lesser degree (fig. 17).

All demographic percentages describing residents in hazard zones were relatively stable (+/- 1 percent) among the three hazard scenarios (current, 2030, and 2070). Demographic data suggest that there are no residents in the coastal-hazard zones across the three time periods that live in mobile homes or live in institutionalized group quarters. Less than 5 percent of the residents in the hazard zones speak English as a second language, are less than 5 years in age, are unemployed, lack a phone, or lack vehicles. Greater than 5 percent of the residents in the hazard zones are living under the poverty line (7 percent), have disabilities (11 percent), live in renter-occupied households (17 percent), are more than 65 years in age (19 percent), or only have a high-school degree (20 percent).

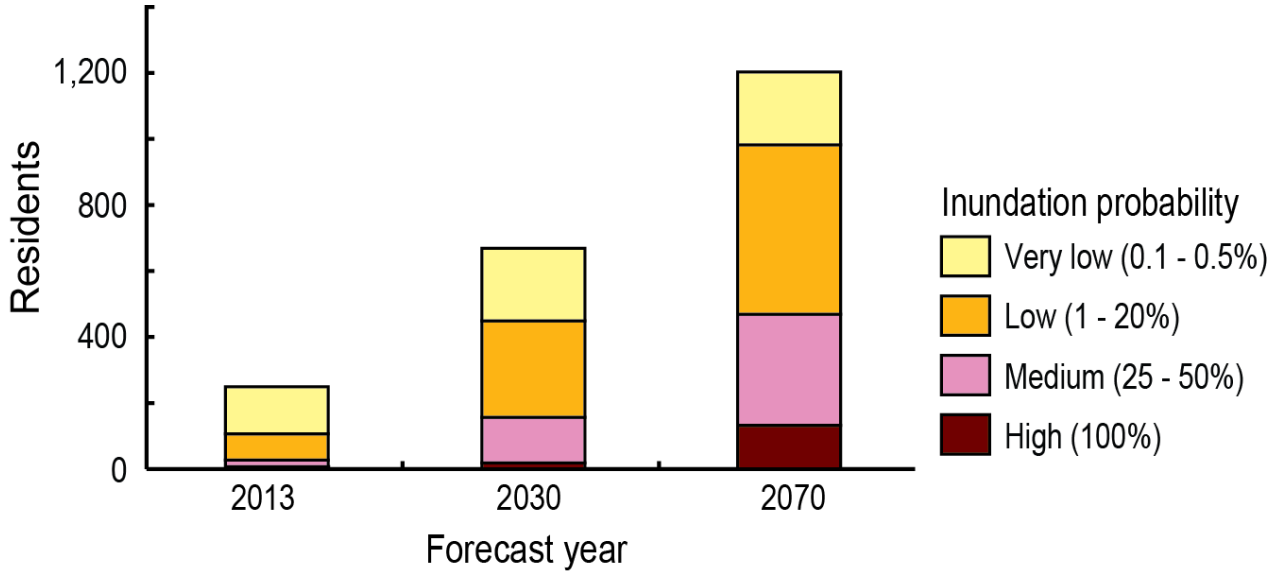

Figure 17. Bar graph showing resident population exposure in the City of Newburyport, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

An analysis of other population data suggests several types of nonresidential groups are threatened by coastal-inundation hazards. Public venues in coastal-hazard zones include five sites (marinas and museums) in 2013 (primarily in medium and very low probability zones) that increase to 10 sites in 2070 (high (3), medium (2), low (4), and very low (1) probability zones). One religious and civic organization is in the 2013 high-probability zone, and this increases to 3 sites in the 2070 high (1) and very low (2) probability zones. There are no dependent-care facilities in 2013 coastal-hazard zones, but this increases to one site in the 2030 very low probability zone and 18 sites by 2070 (primarily very low probability zones). Recreation data indicate that coastal-hazard zones with high probabilities of inundation contain a farmer's market, 0.01 to 0.91 mi of roads and trails, and 203 to 250 acres of recreational areas (referred to as scenic land), where ranges represent 2013 and 2070 values.

Economic Assets

The number of Newburyport employees working in coastal-hazard zones ranges from 484 in 2013 to 2,580 in 2070, representing 3 to 18 percent, respectively, of the 14,016 employees in the community (fig. 18). As was the case with resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zones and not projected changes in employee distributions. In 2013, most employees in these hazard zones are in areas classified as having a low (1–20 percent) inundation probability (427 employees). By 2070, 1,481 employees are at businesses in the very low (0.1–0.5 percent) probability zone, with additional employees in zones classified as high (470), medium (165), and low (464) inundation probability. Sales volume exposure for private-sector businesses ranges from $91.5 million in 2013 to as much as $489.1 million in 2070 (fig, 19*A*). None of the businesses in the various hazard zones were classified as related to natural resources. The number of businesses likely to have a significant customer presence (for example, retail) in coastal-hazard zones ranges from 7 businesses in 2013 to 121 businesses in 2070. The number of these businesses with fewer than 20 employees (a group typically more sensitive to disruptions) ranges from 16 in 2013 to 189 in 2070, representing 1 percent (2013) to 14 percent (2070) of the Newburyport business community.

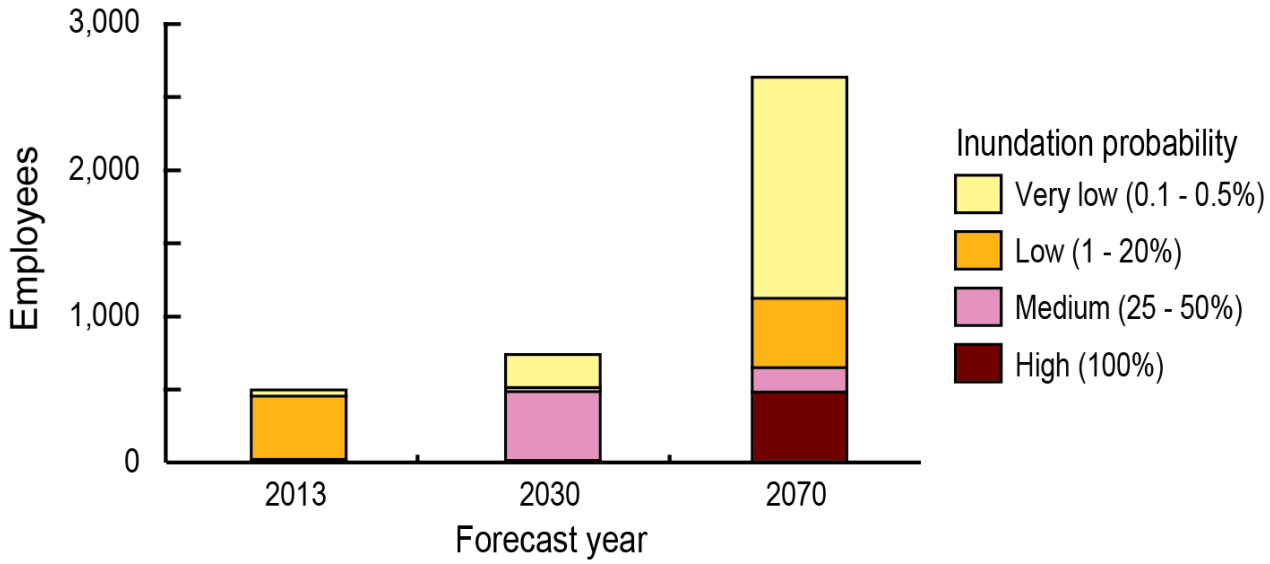

Figure 18. Bar graph showing employee exposure in Newburyport, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

Similar to sales volume, the amount of parcel values and building-replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value for parcels in coastal-hazard zones ranges from approximately $165 million in 2013 hazard zones up to approximately $475 million in 2070 hazard zones, representing 5 to 13 percent of the community's tax base between the two time periods (fig. 19*B*). The majority of tax-parcel value in hazard zones is associated with land value for 2013 and 2030 (50 and 52 percent, respectively), and building value for 2070 (52 percent). Based on building-stock data in the FEMA Hazus-MH 2.2 database (Federal Emergency Management Agency, 2016), estimated building-replacement values range from $145 million for the 2013 hazard zones to as much as $362 million for 2070 hazard zones (fig. 19*C*). The majority of potential building-replacement values are in areas classified as very low probability of inundation in 2013 as great as low probability of inundation in 2070.

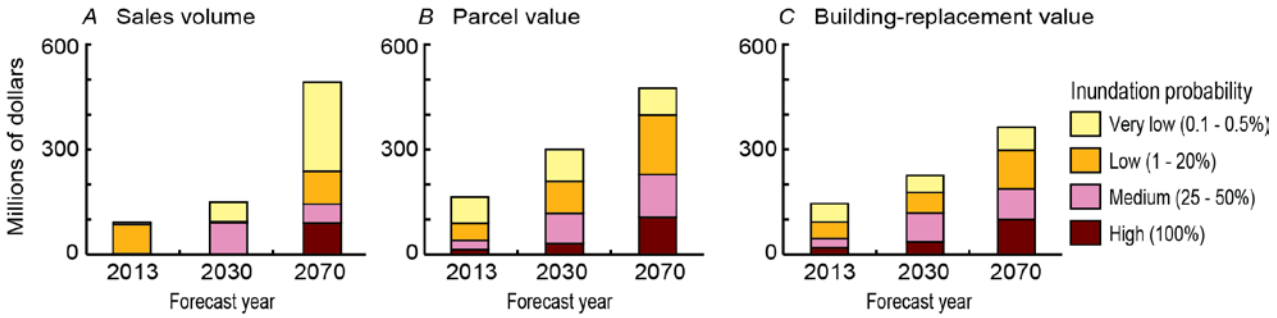

Figure 19. Bar graphs showing the cumulative value in millions of dollars of (*A*) business sales volume, (*B*) total parcels, and (*C*) building-replacement costs in coastal-hazard zones for Newburyport, Massachusetts. %, percent.

Critical Facilities and Infrastructure

Results indicate there are no composting-operation sites, small waste-transfer stations, public-work offices and storage yards, first-responder facilities, town halls, communication towers, public-water-supply sources, MBTA parking-lot locations, or park-and-ride lots located in the coastal-hazard zones in Newburyport. Two government offices (a legislative body and a police station) are in 2013

coastal-hazard zones, which increase to 8 offices by 2070. These government offices are in hazard zones initially classified as low-probability-inundation zones in 2013 and gradually increase between high (2), medium (1), low (2), and very low (3) probability zones by 2070. One transportation hub is found in the 2030 low-probability zone and increases to two hubs (an airport and a trucking hub) in the 2070 very low and medium-probability coastal-hazard zones. Coastal-hazard zones contain several public-utility stations, ranging from 7 sites in 2013 (distributed evenly between low and very low probability zones and representing 14 percent of the community's total) to 11 in 2070 (primarily in the high-probability zone and representing 22 percent of the community's total). One underground storage tank is in the hazard zones, with the probability of inundation increasing from low in 2013 to high in 2070. One tier-classified oil and hazardous-waste release/disposal site is in a low-probability zone in 2013 and a high-probability zone by 2070). Three sites with a declared activity and use limitation are in 2013 hazard zones (two very low probability and one high probability), increasing to six sites in 2070, spanning all probability zones. With regard to infrastructure, results suggest that there are approximately 4.3 mi of roads and rail in 2013 hazard zones (primarily in the low-probability zone) that increases to 8.1 mi by 2070 (primarily in the medium-probability zone). No transmission lines are exposed in 2013 in Newburyport, but 0.15 mi of transmission lines are in 2070 hazard zones.

Locally Identified Areas of Concern

Local stakeholders identified several "areas of concern" in Newburyport (fig. 20). Based on a comparison of these areas with predicted hazard zones for current conditions, 2030, and 2070, the following observations can be made of their exposure to coastal-inundation hazards.

- The wastewater treatment plant is estimated to have 0 to 5 percent (by area with ranges corresponding to 1- and 0.2-percent probability storms, respectively) of its area to be inundated by varying floodwater depths of a storm today, for both the 1- and 0.2-percent probability storms (fig. 21). These percentages rise to 93 to 98 percent for the two storm probabilities by 2070. Floodwater depths over the majority of the asset are estimated to be on the order of 0 to 20 ft from 2013 to 2030 with an increase to 1 to 20 by 2070 for both storm scenarios.
- The estimated extent of inundation for the Plum Island turnpike ranges from 54 to 66 percent (by area with ranges corresponding to 1- and 0.2-percent probability storms, respectively) in 2013 with exposure percentages rising to 89 to 90 percent by 2070. The estimated floodwater depths for the turnpike range from 1 to 20 ft from 2013 to 2030, which increases to primarily 5 to 20 ft in 2070.
- Artichoke Pond is estimated to have minimal exposure in the various coastal-hazard zones (0 percent in 2013 and 2030) but increases substantially for the pond in 2070, with estimated floodwater depths that range primarily from 5 to 20 ft for both storm scenarios (fig. 21).
- Estimated depths exhibit similar trends for Merrimack River jetty system (A) and (B) (fig. 21), in that coastal-hazard zones are estimated to cover 31 to 32 percent and 52 to 54 percent (by area with ranges corresponding to 1-and 0.2-percent-probability storms, respectively) of the two assets in 2013 with exposure percentages rising to 32 and 60 percent to 64 percent of the assets by 2070. Estimated floodwater depths have similar distributions for the two assets over time and among storm probabilities, in that depths exhibit a range from 1 to 20 ft in 2013 and 2030 hazard zones but become more consistently 5 to 20 ft in 2070 hazard zones for both storm scenarios.
- Cashman Park has estimated floodwater depths of 1 to 20 ft in 2013 and 2030 hazard zones, and these depths increase to 4 to 20 ft in the 2070 hazard zones for both storm scenarios (fig. 21).
- Scotland Road has the least area that is estimated to be inundated in the various hazard zones, with no exposure from 2013 to 2030 but an increase in exposure from 75 to 100 percent by 2070

(by area with ranges corresponding to 1- and 0.2-percent probability storms, respectively); estimated floodwater depths are generally 4 ft or less.

- Water Street and Central Waterfront have similar exposure profiles in that coastal-hazard zones are estimated to cover 11 to 17 percent and 38 to 48 percent (by area with ranges corresponding to 1- and 0.2-percent probability storms, respectively) of the two assets in 2013 with exposure percentages rising to 74 to 89 percent and 85 to 91 percent of the assets by 2070. The estimated floodwater depths are generally 4 ft or less for the 1-percent-probability storm scenario from 2013 to 2030, which increases to primarily 5 to 20 ft by 2070 for both assets. Estimated depths are about 1 to 20 ft for the 0.2-percent-probability storm scenario from 2013 to 2070 for both storm scenarios.
- Bartlett Spring Pond is not located in any of the forecasted coastal-hazard zones.

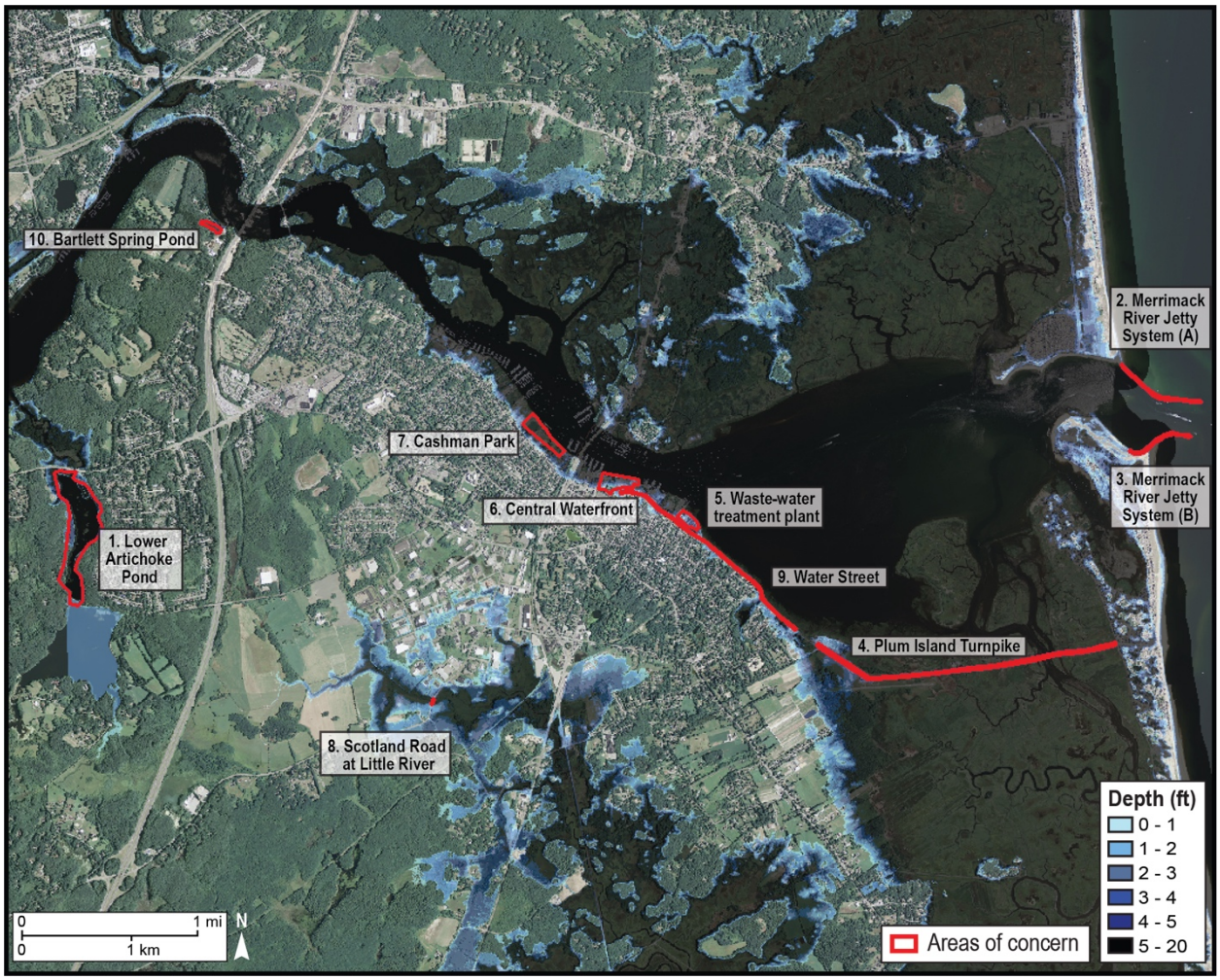

Figure 20. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in Newburyport, Massachusetts, as identified by local stakeholders. ft., feet; mi, mile; km, kilometer.

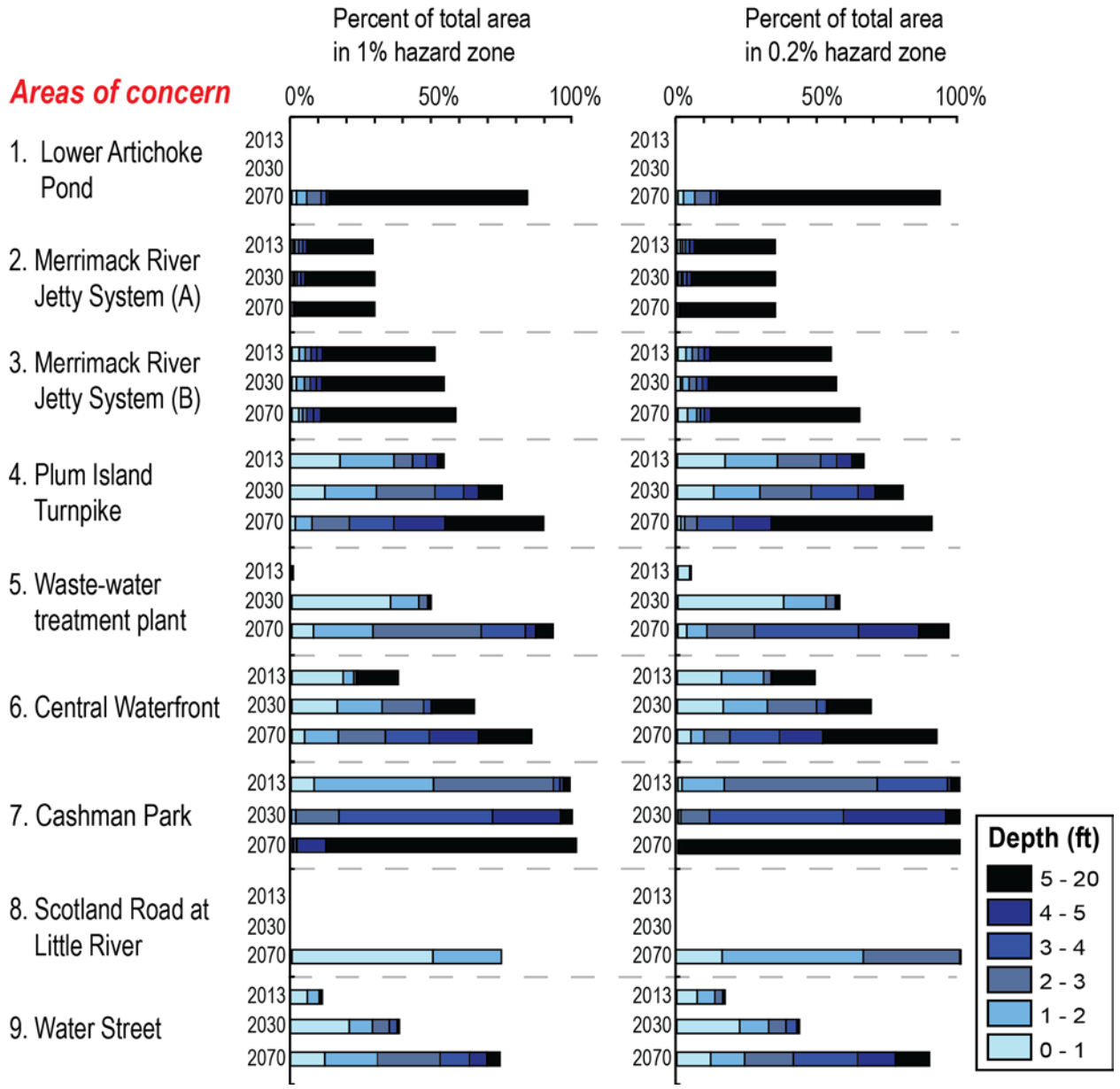

Figure 21. Bar graphs showing cumulative percent of total area for areas of concern indicated by local stakeholders in Newburyport, Massachusetts, in coastal-hazard zones with 0.2- and 1-percent probabilities of occurrence in 2013, 2030, and 2070, organized by predicted water depth. Bartlett Spring Pond was identified as an area of concern but is not predicted to be in any of the hazard zones. %, percent; ft., feet.

Conclusion

Understanding how the City of Newburyport is vulnerable to coastal hazards will help local officials decide where to focus future planning efforts and how to allocate resources to mitigate the impacts of coastal hazards. Results indicate significant variations in amounts and percentages of community assets exposed to potential climate-driven coastal hazards with regards to land cover and land use, populations, economic assets, and critical facilities and infrastructure. The City of Newburyport maximum coastal-hazard zone (the total area exposed to potential inundation from sea-level rise and storm surge) includes 13 percent of total developed land and 15 percent of total

undeveloped land by 2070. The majority of land in Newburyport hazard zones is in the high-inundation-probability zone (47 percent of land). The maximum hazard zone would also contain approximately 1,206 residents (7 percent of total), 2,580 employees (18 percent of total), and numerous community businesses, public venues, dependent-care facilities, religious or civic organizations, and recreational area by 2070. There are also demographic groups in the City of Newburyport that may be more sensitive to future threats and therefore may need extra preparedness training, such as residents that live under the poverty line (7 percent of exposed residential population), have disabilities (11 percent of exposed residential population), live in renter-occupied households (17 percent of exposed residential population), are more than 65 years in age (19 percent of exposed residential population), and have only a high-school degree (20 percent of exposed residential population). The amount of exposed parcel and building-replacement values increase approximately 8 percent (parcel) and 7 percent (building replacement) in the high-inundation-probability zone by 2070. Although the overall area exposed increases by only 7 percent, the within-area distribution of exposed assets changes over time to include more high-probability exposure. The maximum hazard zone would also contain approximately 21 critical facilities, including 8 government offices, 2 transportation hubs, and 11 public-utility stations by 2070. In addition, approximately 8.1 mi of roads and rail (8 percent of roads and rail) would be exposed in the maximum hazard zone by 2070. The depth analysis determined that at a 0.2- and 1-percent storm-surge probability, Cashman Park has the largest area in hazard zones. In addition, predicted inundation heights may be 1 to 20 ft for the majority of the assets by 2070.

Newbury

Land Cover and Land Use

The Town of Newbury is approximately 23.2 mi^2, of which 37 percent (2013) to 45 percent (2070) of it is in coastal-hazard zones for the three time periods in this analysis (fig. 22; appendix 1). The integration of 2011 land-cover data (fig. 23) and the various hazard zones suggests that 21 to 29 percent of the developed land is in 2013 to 2070 hazard zones, respectively. The highest percentage (75 percent in 2013 to 70 percent in 2070) of the developed land in the hazard zones for each time period are classified as low-intensity developed, largely representing rural residential areas. Land classified as medium-intensity developed represents 23 percent in 2013 and 27 percent in 2070 of the developed land in hazard zones. The remaining 2 percent in 2013 to 3 percent in 2070 of developed land in hazard zones represents high-intensity developed, such as roads and commercial development (fig. 24). For each time period, the majority of developed land in hazard zones is in areas considered to have a high (100 percent) probability of inundation.

The amount of undeveloped land (based on 2011 NLCD data) in coastal-hazard zones is much greater than developed land but exposure does not vary substantially through time. The majority of undeveloped land is in areas considered to have a high probability of inundation during future storms. This land also represents approximately 39 to 47 percent of undeveloped land is in 2013 to 2070 hazard zones (fig. 24). Most of this land is classified as wetlands (82 percent); therefore, it makes sense that much of it would be inundated during storms, if not on a near daily occurrence.

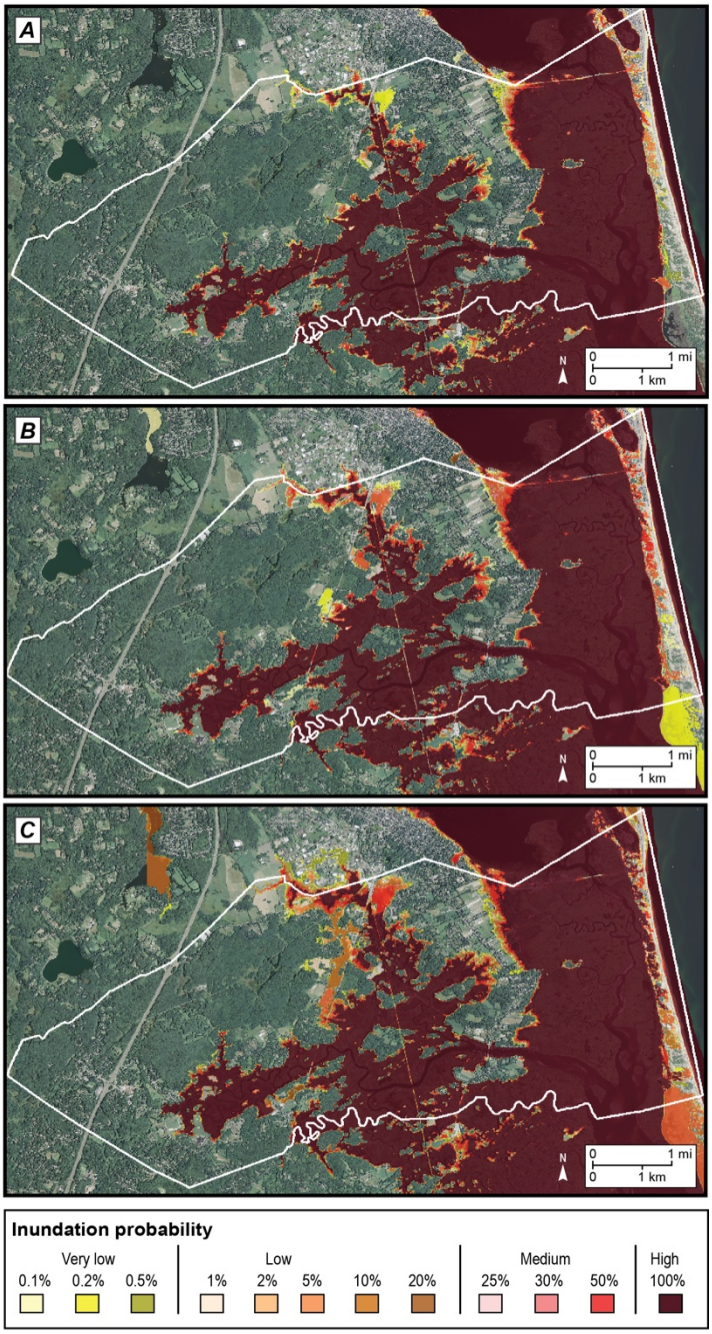

Figure 22. Map of Newbury, Massachusetts, coastal-inundation probability showing modeled hazard zones in (*A*) 2013, *(B)* 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). Appendix 1 provides larger versions of each of these maps. %, percent; mi, mile; km, kilometer.

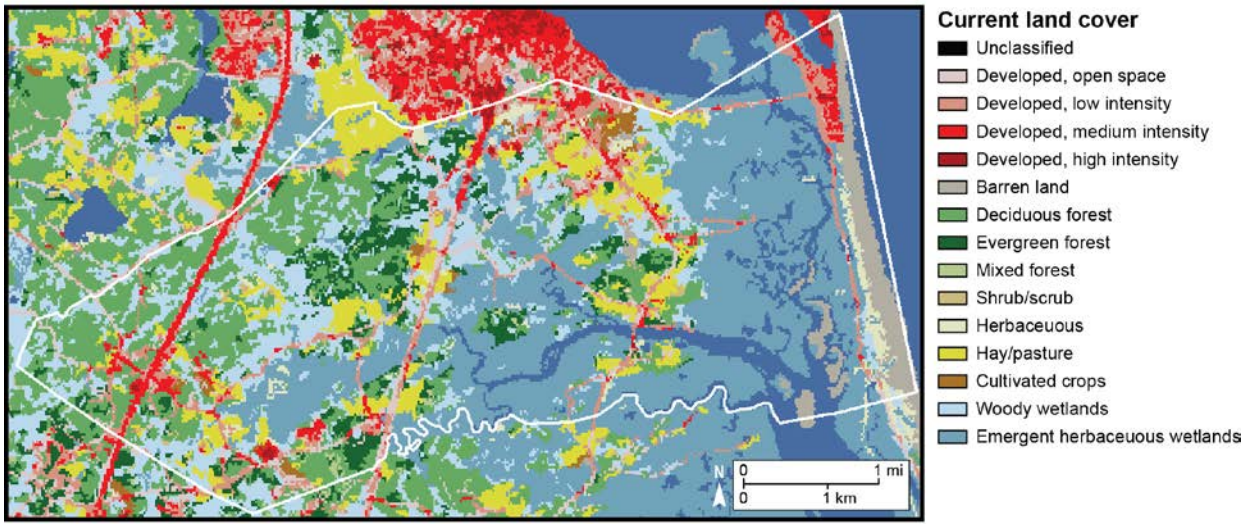

Figure 23. Map showing land-cover data for Newbury, Massachusetts, from the 2011 National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2011). mi, mile; km, kilometer.

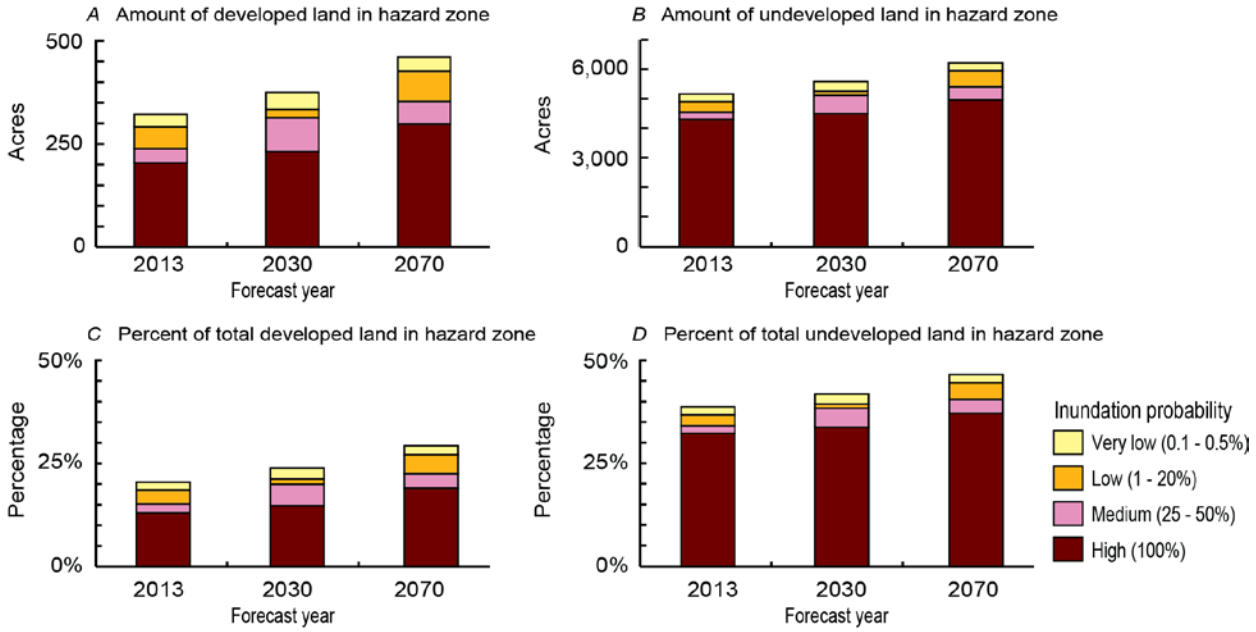

Figure 24. Bar graphs showing amounts of (*A*) developed and (*B*) undeveloped land and total percentages of (*C*) developed and (*D*) undeveloped land in coastal-hazard zones of Newbury, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070. %, percent.

The modeled hazard zones encompass thousands of acres of conservation lands, areas important to endangered species, and priority habitats (fig. 25). Additional descriptions of each of these environmental designations can be found at MassGIS (Office of Geographic Information, 2016). Fifty-one percent of conservation lands (by area) are in current hazard zones, which increases to 58 percent in 2070. Similar percentages are estimated for areas with endangered species (59 percent of land in 2013 to 66 percent of land in 2070) and priority habitats (61 percent in 2013 to 67 percent in 2070). Higher

percentages are estimated for areas of critical environmental concern, where 88 percent in 2013 to 94 percent in 2070 of these areas are in hazard zones for the three time periods (fig. 25). The high probabilities of inundation for these undeveloped conservation areas are a result of the land being predominantly salt marsh—and thus inundated on a nearly daily occurrence. Finally, there are no Community Preservation Act locations in predicted coastal-hazard zones for Newbury.

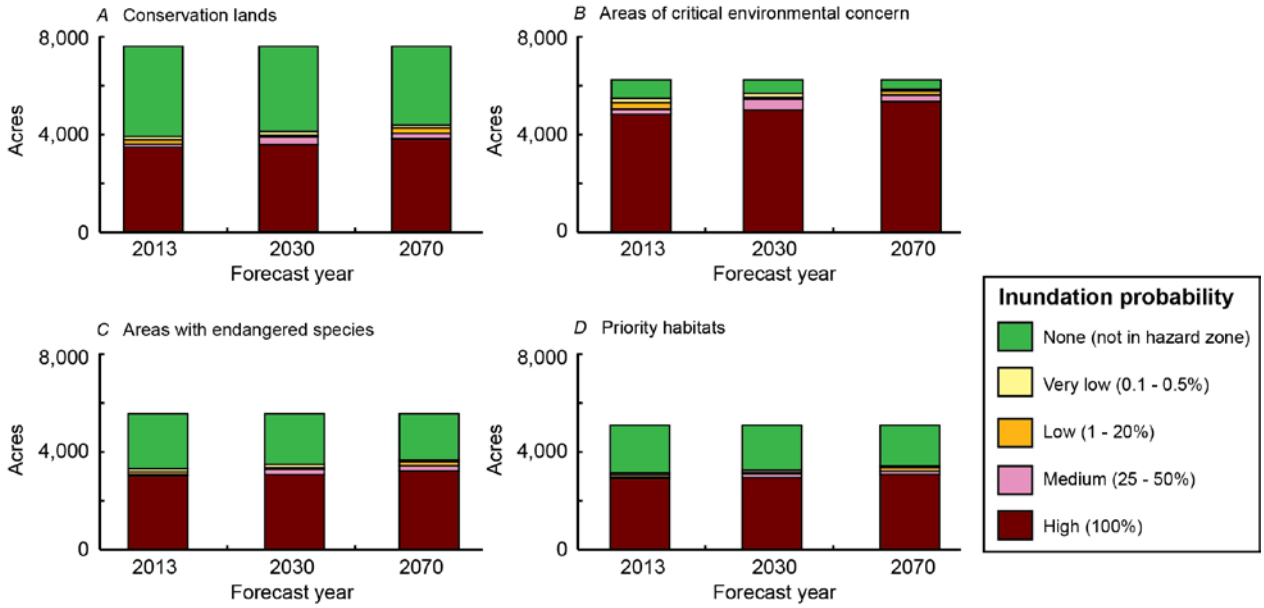

Figure 25. Bar graphs showing the area of land classified as (*A*) conservation lands, (*B*) areas of critical environmental concern, (*C*) endangered species habitats, and (*D*) priority habitats in the modeled hazard zones of Newbury, Massachusetts, for 2013, 2030, and 2070. %, percent.

The most common land use in the hazard zones is considered governmental and ranges from 28 percent in 2013 to 23 percent in 2070 (fig. 26). The second largest area of land in the coastal-hazard zones lack classification and ranges from 19 percent in 2013 to 22 percent in 2070. Land classified as agriculture and conservation ranges from 20 percent in 2013 to 18 percent in 2070. All of the remaining land uses in the hazard zones each represent less than 20 percent by area, such as commercial, religious, charitable, or nonprofit, residential, and industrial. Current zoning, determined by community planners, indicates that land zoned as residential represents 97 percent in 2013 to 96 percent in 2070 of all land in hazard zones. The remaining zoning types (commercial, industrial, and agriculture and conservation) in the hazard zones each represent less than 10 percent by area.

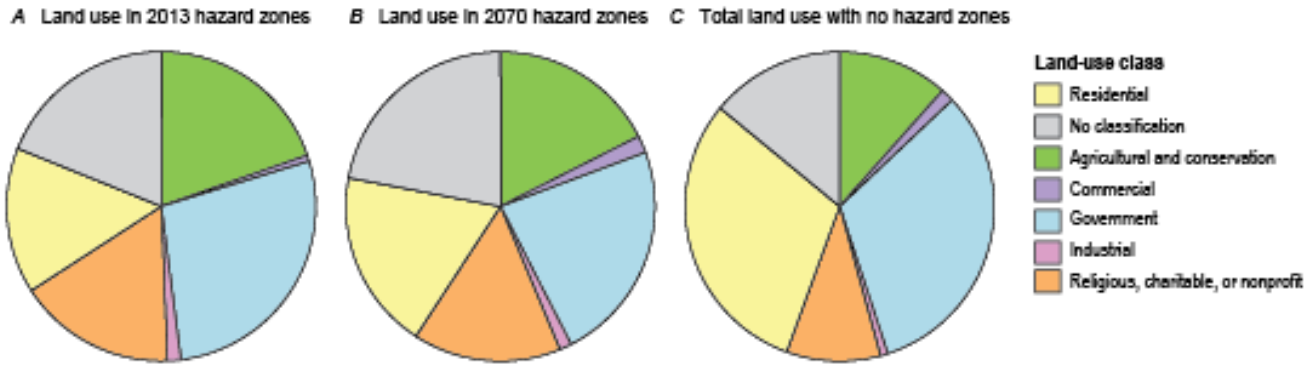

Figure 26. Pie charts showing distribution (by area) of current land use classes within hazard zones in Newbury, Massachusetts, for (*A*) 2013 and (*B*) 2070, as well as for (*C*) all land in Newbury regardless of hazard zones.

Populations

The number of Newbury residents living in the coastal-hazard zones ranges from 572 in 2013 to 1,154 in 2070, representing 9 to 17 percent, respectively, of the 6,666 total residents in Newbury (fig. 27). This estimate is based solely on changes in the extent of the hazard zones, as resident distributions are based on 2010 population counts. The greatest increase in resident exposure among the three time periods is associated with the high-inundation-probability zone. The majority of residents in current hazard zones are located in areas classified as having very low (0.1–0.5 percent) inundation probability (189 residents). By 2070, the current number of residents in hazard zones is estimated to be in the high-probability (100 percent) zone (412 residents) due to changes in the extent of hazard zones, whereas the number of residents in 2070 in the medium, low, and very low probability zones are not estimated to increase substantially.

All demographic percentages describing residents in hazard zones were relatively stable (+/- 1 percent) across the three time periods. Demographic data suggest that there are no residents in the coastal-hazard zones across the three time periods that live in mobile homes or lack a phone. Less than 5 percent of the residents in the hazard zones speak English as a second language, live in group quarters, are less than 5 years in age, or lack vehicles. Greater than 5 percent of the residents in the hazard zones are unemployed (6 percent), live under the poverty line (8 percent), are in renter-occupied households (11 percent), have disabilities (14 percent), are more than 65 years in age (16 percent), or only have a high-school degree (26 percent).

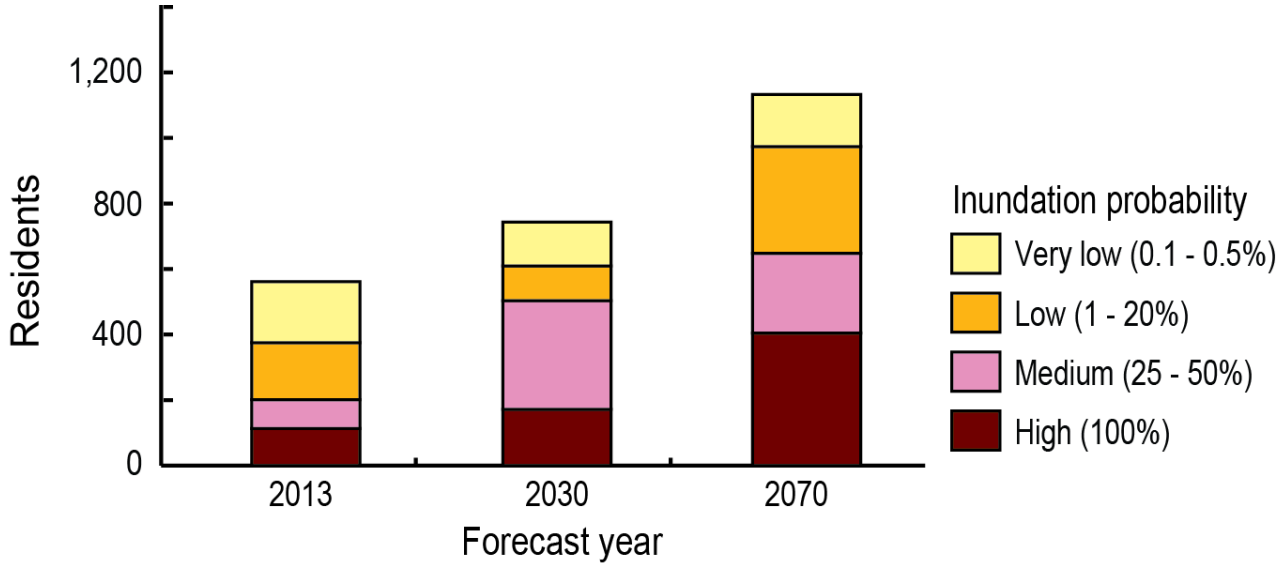

Figure 27. Bar graph showing resident population exposure in Newbury, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

An analysis of other population data suggests several types of nonresidential groups are threatened by coastal-inundation hazards. Public venues in coastal-hazard zones include two sites (a marina and a stable) in the 2013 low and very low probability zones that end up in high-probability zones in 2030 and 2070. Dependent-care facilities in hazard zones include a medical facility in the 2013 very low probability zone and increases to 4 medical facilities in 2070 in areas classified as high (1), medium (1) and very low (2) probability zones. Recreation data indicate that coastal-hazard zones with high probabilities of inundation contain a canoe access point in the various hazard zones, 0 to 0.18 mi of roads and trails, and 4,781 to 5,419 acres of recreational areas (referred to as scenic land), where ranges represent 2013 and 2070 values. There are no religious or civic organizations in the coastal-hazard zone.

Economic Assets

The number of Newbury employees working in coastal-hazard zones ranges from 98 in 2013 to 349 in 2070, representing 6 to 20 percent, respectively, of the 1,751 employees in the community (fig. 28). As was the case with resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zones and not on projected changes in employee distributions. In 2013, most employees in these hazard zones are in areas classified as having a very low (0.1–0.5 percent) inundation probability (55 employees). By 2070, 165 employees are at businesses in the medium (25–50 percent) probability zone, with additional employees in zones classified as high (89), low (83), and very low (12) inundation probability. Sales volume exposure for private-sector businesses ranges from $8 million in 2013 to as much as $36 million in 2070 (fig. 29*A*). None of the businesses in the various hazard zones were classified as related to natural resources. The number of businesses likely to have significant customer presences (for example, retail) in coastal-hazard zones ranges 10 businesses (6 in the medium-probability zone, 2 in the low-probability zone, and 2 in the very low probability zone) to 18 businesses in 2070 hazard zones (8 in the high-probability zone, 3 in the medium-probability zone, 6 in low-probability zone, and 1 in the very low probability zones). The number of these businesses with fewer than 20 employees (a group typically more sensitive to disruptions) ranges from 15 in 2013 to 33 in 2070, representing 6 percent (2013) to 14 percent (2070) of the Newbury business community.

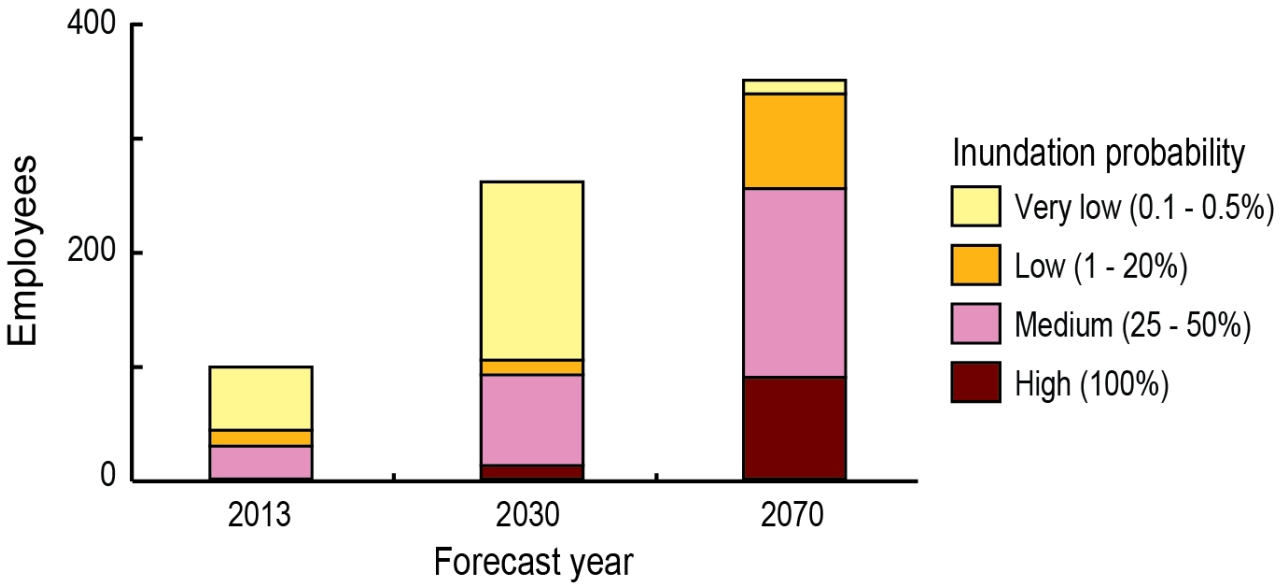

Figure 28. Bar graph showing employee exposure in the Town of Newbury, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

Similar to sales volume, the amount of parcel values and building-replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value for parcels in coastal-hazard zones ranges from approximately $191 million in 2013 hazard zones up to approximately $345 million in 2070 hazard zones, representing 14 to 25 percent of the community's tax base between the two time periods (fig. 29*B*). The majority of tax-parcel value in hazard zones is associated with land value for all three time periods (66, 61, and 60 percent, respectively), with the remainder associated with building/content value. Based on building-stock data in the FEMA Hazus-MH 2.2 database (Federal Emergency Management Agency, 2016), estimated building-replacement values range from $119 million for the 2013 hazard zones up to $206 million for 2070 hazard zones (fig. 29*C*). For all three time periods, the majority of potential building-replacement values are in areas classified as high probability of inundation.

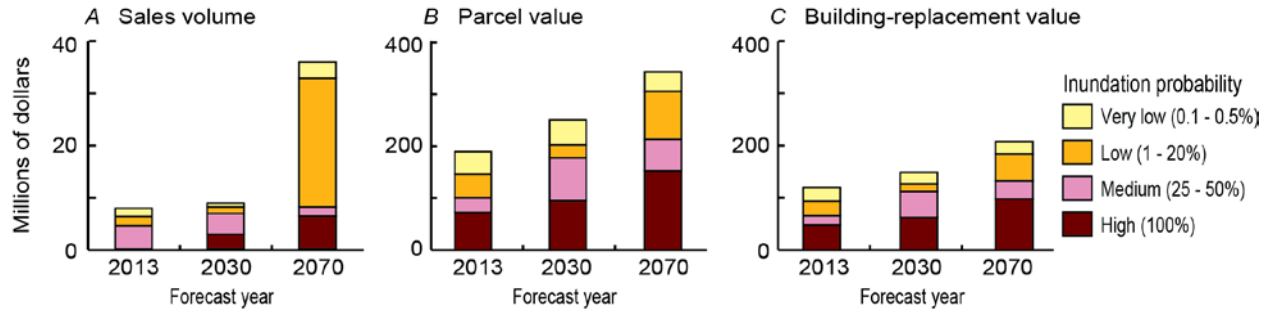

Figure 29. Bar graphs showing the cumulative value in millions of dollars of (*A*) business sales volume, (*B*) total parcels, and (*C*) building-replacement costs in coastal-hazard zones for Newbury, Massachusetts. %, percent.

Critical Facilities and Infrastructure

Results indicate that coastal-hazard zones in Newbury contain no composting-operation sites, small waste-transfer stations, public-work offices and storage yards, first-responder facilities, government offices, no tier-classified oil and hazardous-material release/disposal sites, public-water-

supply sources, MBTA parking-lot locations, or park-and-ride lots. An airport and a trucking hub are not in current hazard zones but are in low-probability inundation-hazard zones for 2030 and 2070. One communication tower is in a high-probability inundation-hazard zone for 2030 and 2070. One underground storage tank is in an area of low-inundation probability for 2070 hazard zones but not in 2013 or 2030 zones. With regard to infrastructure, results suggest that there are approximately 13 mi of roads and rail in 2013 hazard zones (primarily in the low-probability zone) that increases to 17 mi by 2070 (primarily in the medium-probability zone). Approximately 0.48 mi of transmission lines are in hazard zones, with exposure spanning primarily from low to high probability in 2013 and increasing to primarily high in 2070.

Locally Identified Areas of Concern

Local stakeholders identified several "areas of concern" in Newbury (fig. 30). Based on a comparison of these areas with predicted hazard zones for current conditions, 2030, and 2070, the following observations can be made of their exposure to coastal-inundation hazards.

- Ninety-nine percent (by area) of the groin jetty at Plum Island Boulevard is in hazard zones associated with 4 to 20 ft of flooding for both the 1-and 0.2-percent-probability storm scenarios for all time periods (fig. 31). Floodwater depths over the majority of the asset increase to approximately 5 to 20 ft by 2070.
- Estimated floodwater depths exhibit similar trends for the sewage pumping station and Pine Island Road. Coastal-hazard zones are estimated to cover 100 percent (by area for both 1-and 0.2-percent-probability storm scenarios) of the two assets from 2013 to 2070. Estimated depths have similar distributions for the two assets over time and among storm probabilities, in that depths exhibit a range from 1 to 5 ft in 2013 and 2030 hazard zones but become more consistently 5 to 20 ft in 2070 hazard zones for both storm scenarios.
- Similar trends are also exhibited with Central Street Dam, Route 1, and Cottage Road. The coastal-hazard zones are estimated to cover 18 to 24 percent, 45 to 48 percent, and 49 to 53 percent (by area with ranges corresponding to 1- to 0.2-percent-probability storms, respectively) of the three assets in 2013 with exposure percentages rising to 49 to 63 percent, 57 to 66 percent, and 75 to 86 percent of the assets by 2070. Estimated floodwater depths have similar distributions for the three assets over time and among storm probabilities, in that depths will exhibit at least 1 to 2 ft in 2013 and at least 1 to 4 ft by 2030 but become more consistently 5 to 20 ft in 2070 hazard zones for both storm scenarios (fig. 31).
- The estimated extent of inundation and water depths for Triton Middle and High School and Lord Timothy Dexter Industrial Green are the smallest of the areas of concern in hazard zones (fig. 31). Coastal-hazard zones are estimated to cover 0.2 to 0.3 percent and 1.5 to 2 percent in 2013 for both storm scenarios with exposure percentages rising to 1 to 3 percent and 9 to 24 percent by 2070. Floodwater depths for the middle and high school are estimated to be 1 to 5 ft from 2013 to 2030, which increases to 1 to 20 ft by 2070 for both storm scenarios. Lord Timothy Dexter Industrial Green is estimated to have floodwater depths of 1 to 20 ft from 2013 to 2070 for both hazard scenarios.
- Newbury Elementary School, Newburyport Train Station, and the dam at the intersection of River and Forest Streets are not located in any of the forecasted coastal-hazard zones—although they may be subject to inland freshwater flooding, but that analysis is outside the scope of this report.

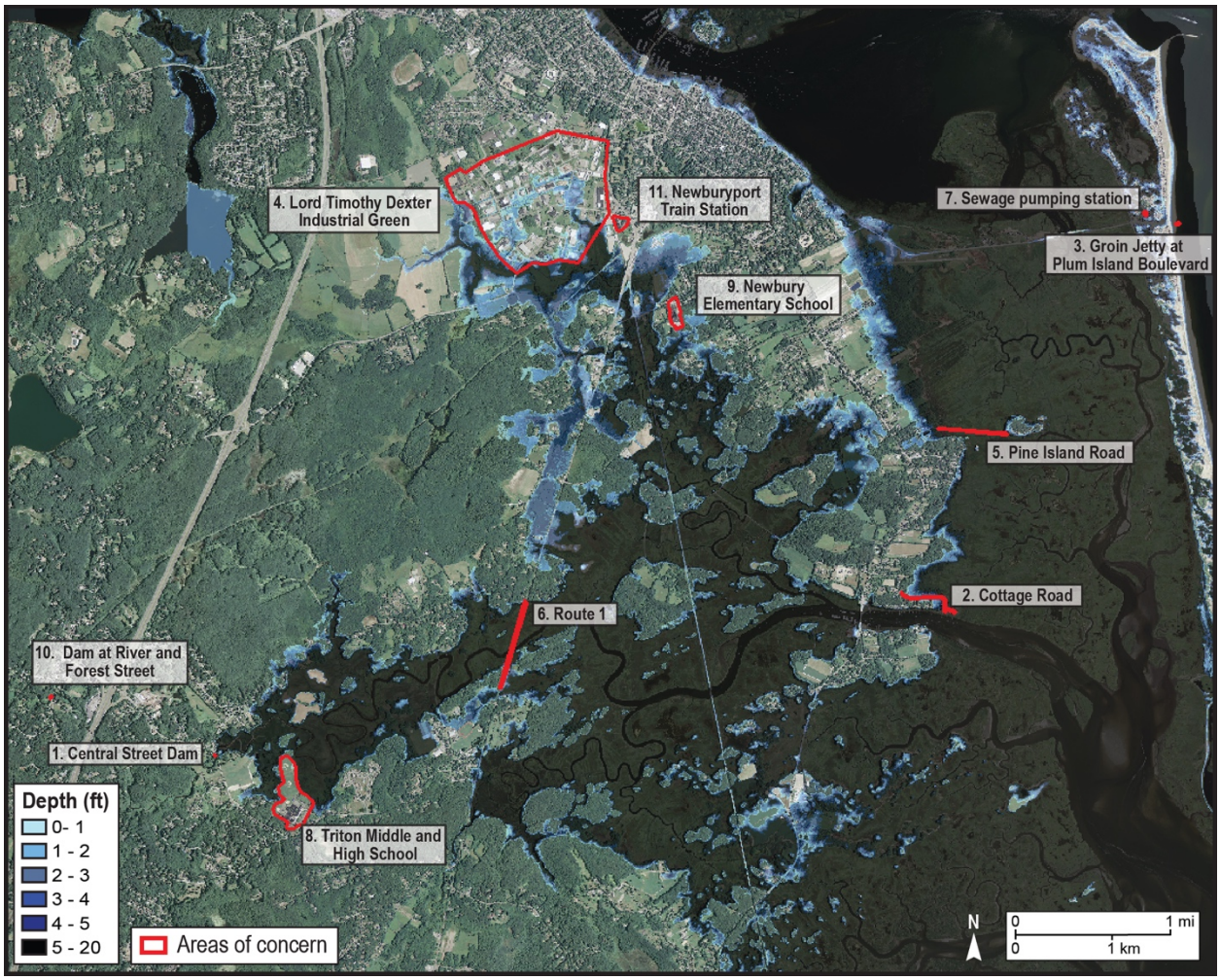

Figure 30. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in Newbury, Massachusetts, as identified by local stakeholders. ft., feet; mi, mile; km, kilometer.

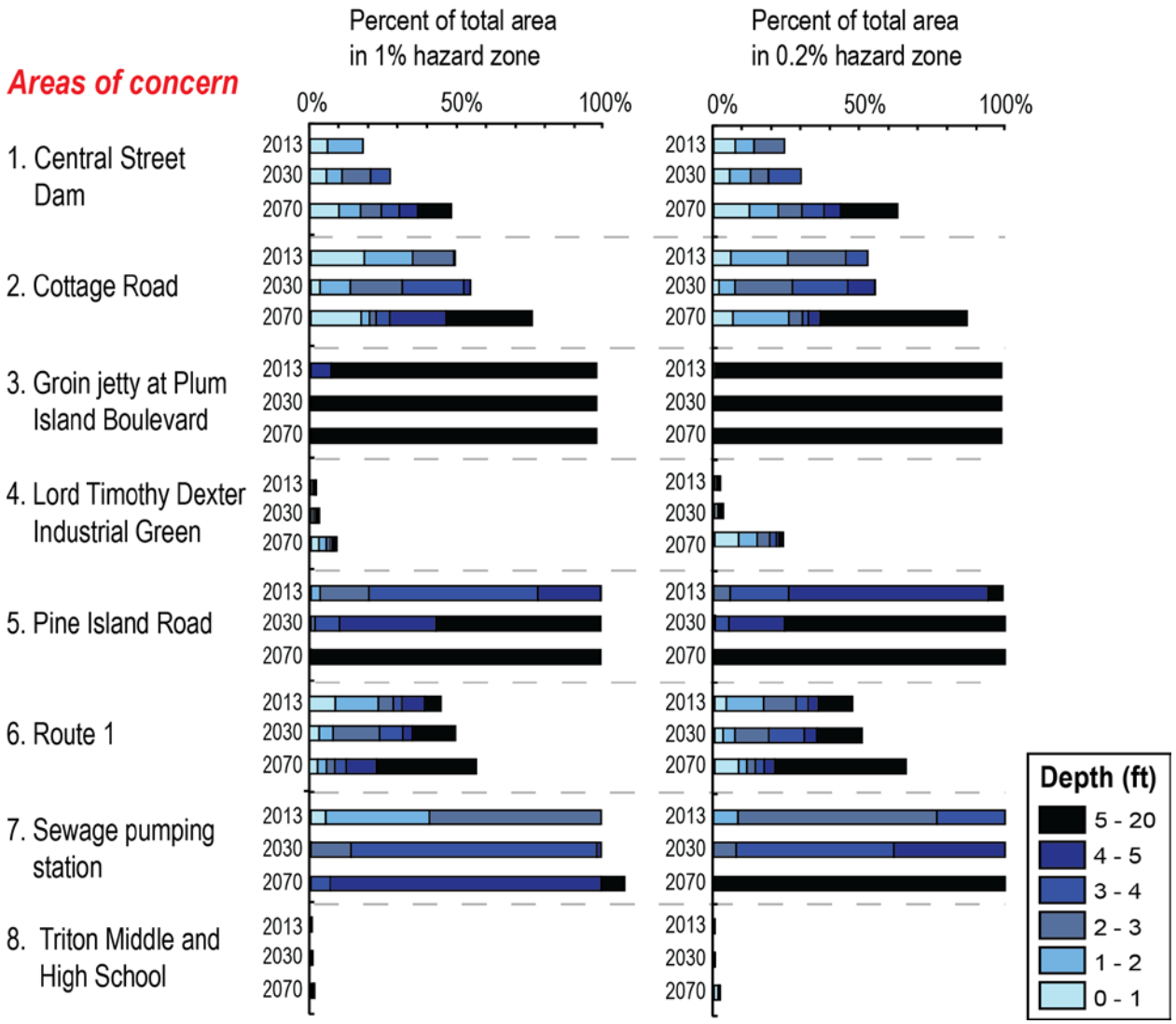

Figure 31. Bar graphs showing cumulative percent of total area for areas of concern indicated by local stakeholders in Newbury, Massachusetts, in coastal-hazard zones with 0.2- and 1-percent probabilities of occurrence in 2013, 2030, and 2070, organized by predicted water depth. The following areas of concern are not in hazard zones: Newbury Elementary School, Newburyport Train Station, and the dam at the intersection of River and Forest Streets. %, percent; ft., feet.

Conclusion

Understanding how the Town of Newbury is vulnerable to coastal hazards will help local officials decide where to focus future planning efforts and how to allocate resources to mitigate the impacts of coastal hazards. Results indicate significant variations in amounts and percentages of community assets exposed to climate-driven coastal hazards with regards to land cover and land use, populations, economic assets, and critical facilities and infrastructure. The Town of Newbury's maximum coastal-hazard zone (the total area exposed to potential inundation from sea-level rise and storm surge) includes 29 percent of total developed land and 47 percent of total undeveloped land by 2070. The majority of exposed land in Newbury is in the high-inundation-probability zone (79 percent of land). The maximum hazard zone would also contain approximately 1,154 residents (17 percent of total), 349 employees (20 percent of total), and numerous community businesses, public venues,

dependent-care facilities, and recreational areas by 2070. There are also demographic groups in the town of Newbury that may be more sensitive and therefore may need extra preparedness training, such as residents that are unemployed (6 percent of exposed residential population), live under the poverty line (8 percent of exposed residential population), live in renter–occupied households (11 percent of exposed residential population), have disabilities (14 percent of exposed residential population), are more than 65 years in age (16 percent of exposed residential population), and residents with only a high-school degree (26 percent of exposed residential population). The amount of exposed-parcel and building-replacement values increase approximately 11 percent (parcel) and 10 percent (building replacement) in the high-probability inundation zone by 2070. Although the overall area exposed increases by only 8 percent, the within-area distribution of exposed assets changes over time to include more high-probability exposure. The maximum hazard zone would also contain approximately three critical facilities, including two transportation hubs and one communications tower by 2070. In addition, approximately 17 mi of roads and rail (17 percent of roads and rail) would be exposed in the maximum hazard zone by 2070. The depth analysis indicates at a 0.2- and 1-percent storm-surge probability, Pine Island Road has the largest area in hazard zones, with predicted inundation heights of 5 to 20 ft by 2070 (fig. 31).

Rowley

Land Cover and Land Use

The Town of Rowley is approximately 18.1 mi^2, of which 20 percent (2013) to 25 percent (2070) of it is in coastal-hazard zones for the three time periods in this analysis (fig. 32; appendix 1). The integration of land-cover data (fig. 33) and the various hazard zones suggests that 3 to 4 percent of the developed land is in 2013 to 2070 hazard zones, respectively (fig. 34). The highest percentage (89 percent in 2013 to 90 percent in 2070) of the developed land in the hazard zones for each time period is classified as low-intensity developed, largely representing rural residential areas. Land classified as medium-intensity developed represents the remaining 11 percent in 2013 and 10 percent in 2070 of the developed land in hazard zones. The majority of developed land in hazard zones for each time period, regardless of type, is in areas considered to have a high (100 percent) probability of inundation.

The amount of undeveloped land (based on 2011 NLCD data) in coastal-hazard zones is much greater than developed land but exposure does not vary substantially through time. The majority of undeveloped land is in areas considered to have a high probability of inundation during future storms. Approximately 22 to 27 percent of undeveloped land is in 2013 to 2070 hazard zones (fig. 34). Most of this land is classified as wetlands (84 percent); therefore, it makes sense that much of it would be inundated during storms, if not on a near daily occurrence.

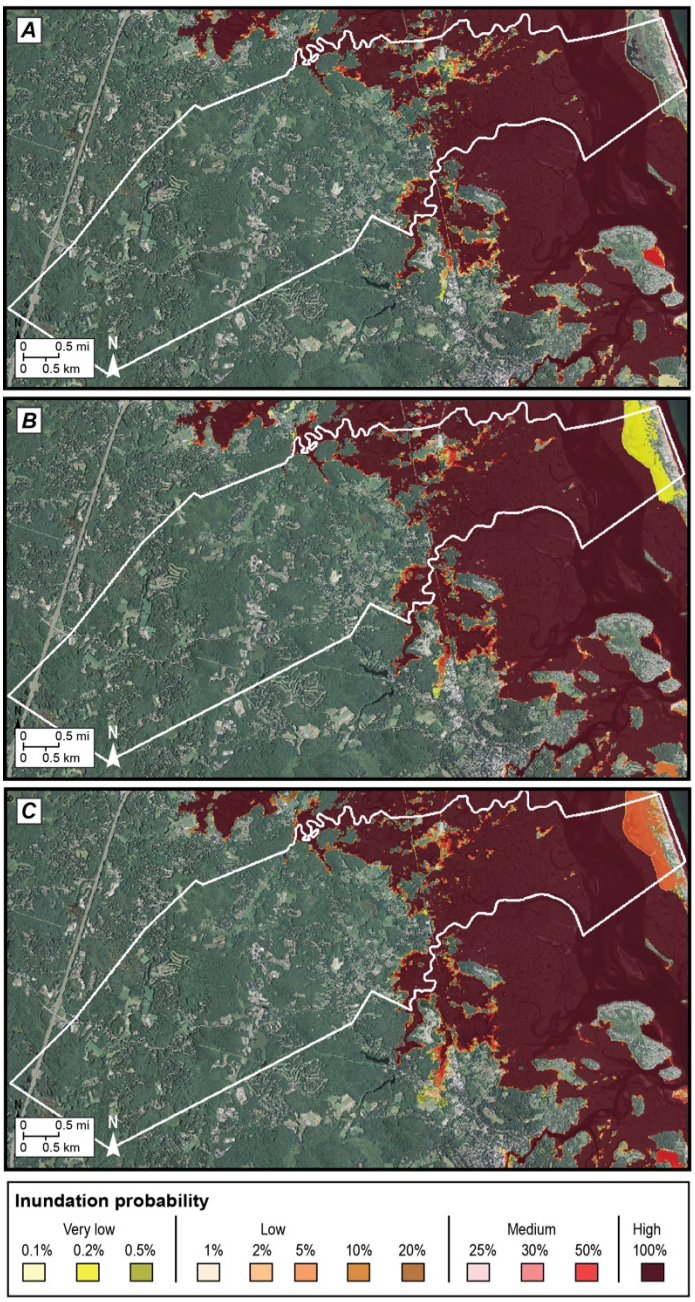

Figure 32. Map of Rowley, Massachusetts, coastal-inundation probability showing modeled hazard zones in (*A*) 2013, (*B*) 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). Appendix 1 provides larger versions of each of these maps. %, percent; mi, mile; km, kilometer.

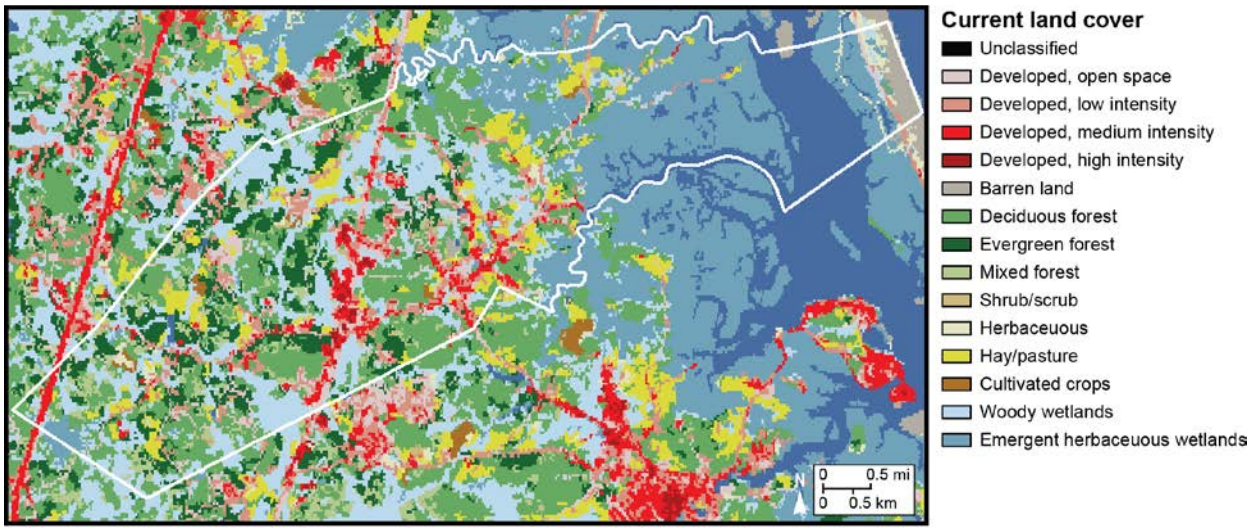

Figure 33. Map showing land-cover data for Rowley, Massachusetts, from the 2011 National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2011). mi, mile; km, kilometer.

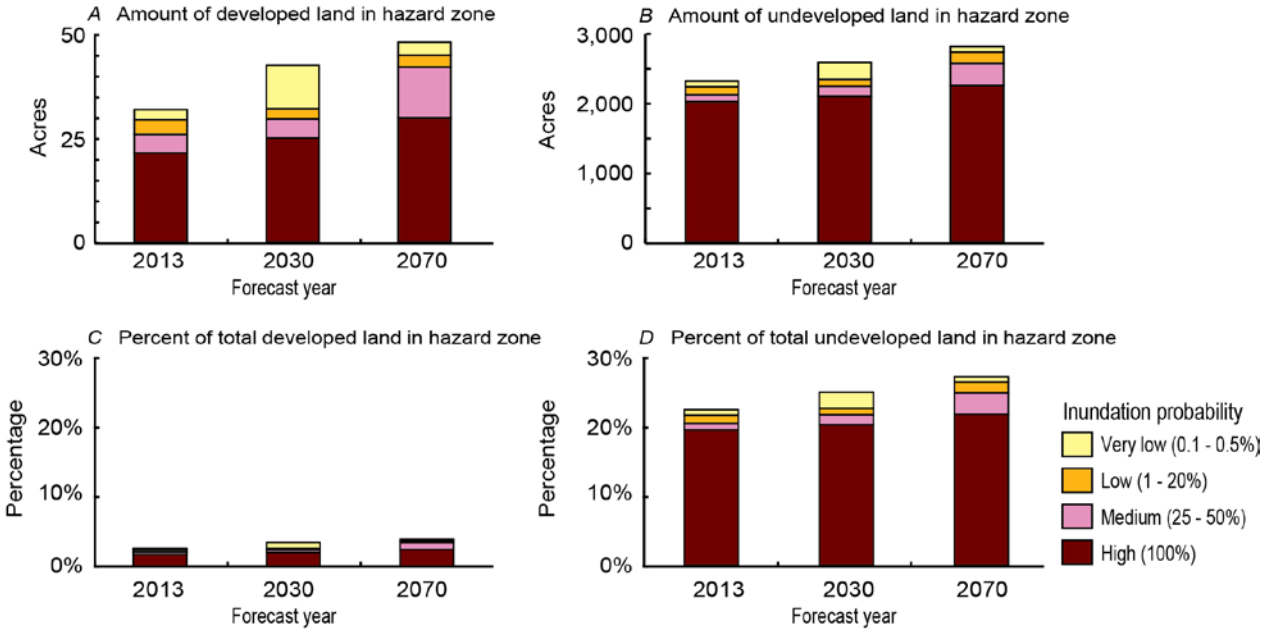

Figure 34. Bar graphs showing amounts of (*A*) developed and (*B*) undeveloped land and total percentages of (*C*) developed and (*D*) undeveloped land in coastal-hazard zones of Rowley, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070. %, percent.

The modeled hazard zones encompass thousands of acres of conservation lands, areas important to endangered species, and priority habitats (fig. 35). Additional descriptions of each of these environmental designations can be found at MassGIS (Office of Geographic Information, 2016). Forty-two percent of conservation lands are in current hazard zones, which increases to 53 percent by 2070. The endangered species habitats and priority habitats have approximately 2,000 acres of land in the coastal-hazard zone with majority of the area in the high-inundation-probability zones for all three time periods. Areas of critical environmental concern has the largest amount of land in the coastal-hazard

zones, on the order of 2,700 acres, with the majority of the area in the high-inundation-probability zones for all three time periods. (fig. 35). In contrast, less than 3 percent of Community Preservation Act locations are in current coastal-hazard zones and increase to only 5 percent by 2070. The majority of the natural areas in the hazard zones for each time period are considered to have a high probability of inundation and the majority of the remaining areas are not in the hazard zone (fig. 35). The high probabilities of inundation for these undeveloped conservation areas are a result of the land being predominantly salt marsh—and thus inundated on a nearly daily occurrence.

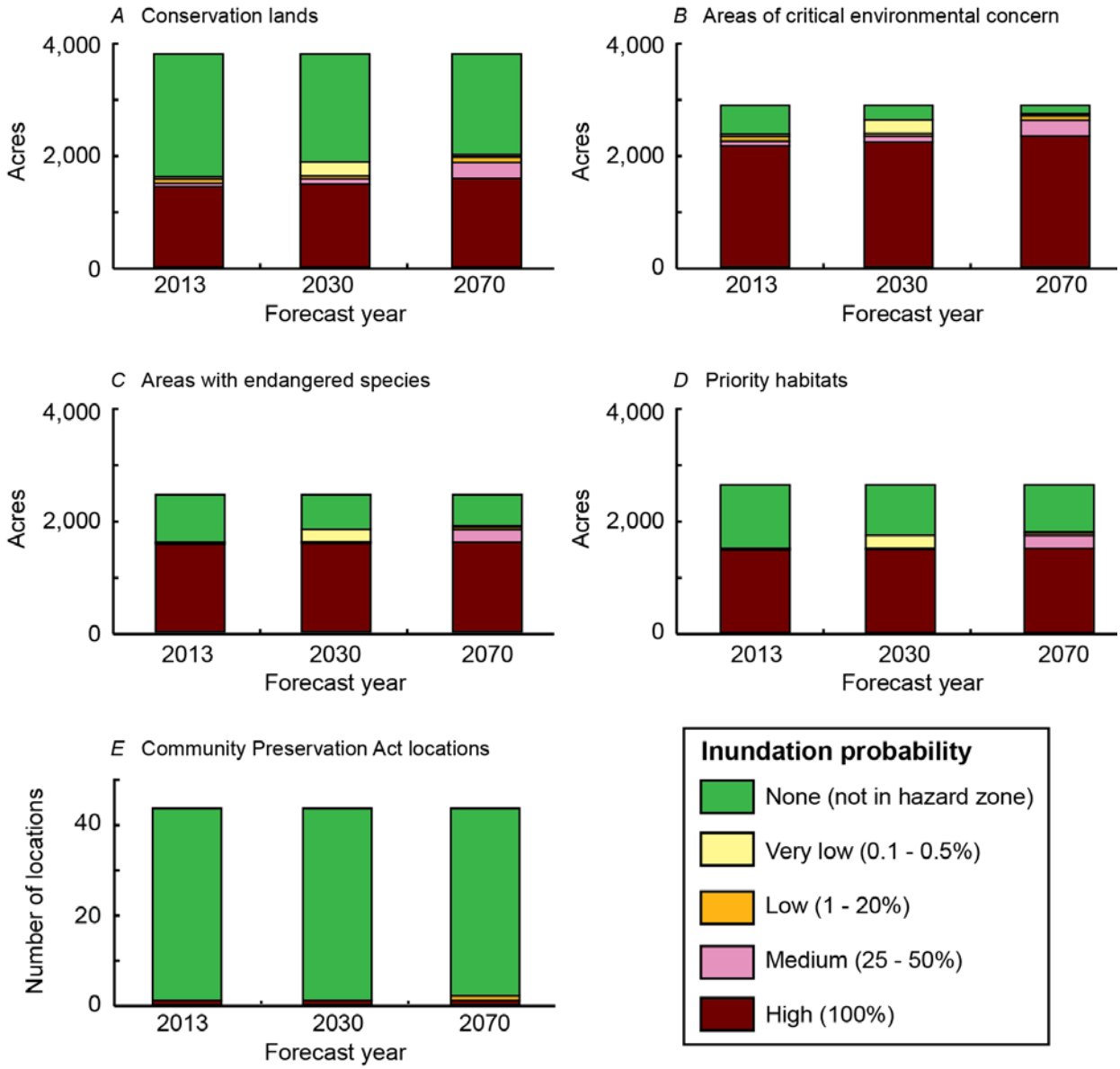

Figure 35. Bar graphs showing the area of land classified as (*A*) conservation lands, (*B*) areas of critical environmental concern, (*C*) endangered species habitats, (*D*) priority habitats, and (*E*) Community Preservation Act locations in the modeled hazard zones of Rowley, Massachusetts, for 2013, 2030, and 2070. %, percent.

The most common land use in the hazard zone is considered governmental and ranges from 20 percent in 2013 to 38 percent in 2070, respectively (fig. 36). The second largest area of land in the coastal-hazard zones lacks classification and ranges from 33 percent in 2013 to 24 percent in 2070.

Land classified as religious, charitable, or nonprofit uses range from 19 percent in 2013 to 15 percent in 2070. Residential land use ranges from 14 percent in the 2013 hazard zone and 12 percent in the 2070 hazard zone. In all three hazard zones (that is, 2013, 2030, and 2070), the majority of the parcel area is in areas classified as having a high probability of inundation. All of the remaining land uses in the hazard zone each represent less than 10 percent by area, such as agriculture and conservation, residential, and industrial. Current zoning, determined by community planners, suggests that most affected areas in the coastal-hazard zones is land zoned for agriculture and conservation purposes and ranges from 100 percent in 2013 to 99 percent in 2070, respectively. The remaining zoning types (commercial, industrial, and residential) in the hazard zone each represent less than 1 percent by area.

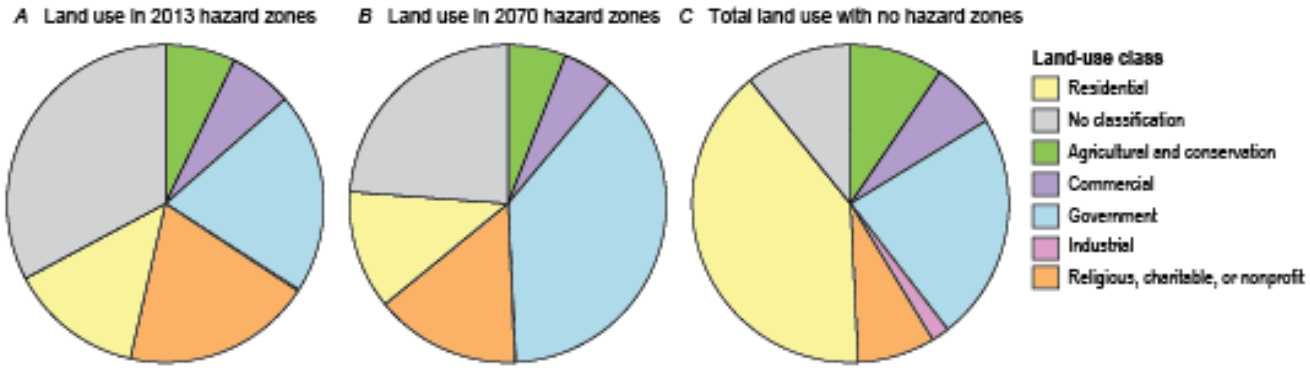

Figure 36. Pie charts showing distribution (by area) of current land use classes within hazard zones in Rowley, Massachusetts, for (*A*) 2013 and (*B*) 2070, as well as for (*C*) all land in Rowley regardless of hazard zones.

Populations

The number of Rowley residents living in coastal-hazard zones ranges from 108 in 2013 to 151 in 2070, representing 2 to 3 percent, respectively, of the 5,856 total residents in Rowley (fig. 37). This estimate is based solely on changes in the extent of the hazard zones, as resident distributions are based on 2010 population counts. The majority of the residents in current hazard zones are located in areas classified as having a low (1–20 percent) inundation probability (57 residents). The greatest increase in residential exposure among the three time periods is associated with the high-inundation-probability zone (102 residents in 2070).

All demographic percentages describing residents in hazard zones were relatively stable (+/- 1 percent) across the three time periods. Demographic data suggest that there are no residents in the coastal-hazard zones across the three time periods that live in mobile homes or lack a phone. Less than 5 percent of the residents in the hazard zones speak English as a second language, are unemployed, are less than 5 years in age, or lack vehicles. Greater than 5 percent of the residents in the hazard zones are in renter-occupied households (9 percent), are living in institutionalized group quarters (11 percent), are living under the poverty line (15 percent), have disabilities (20 percent), are more than 65 years in age (23 percent), or only have a high-school degree (45 percent).

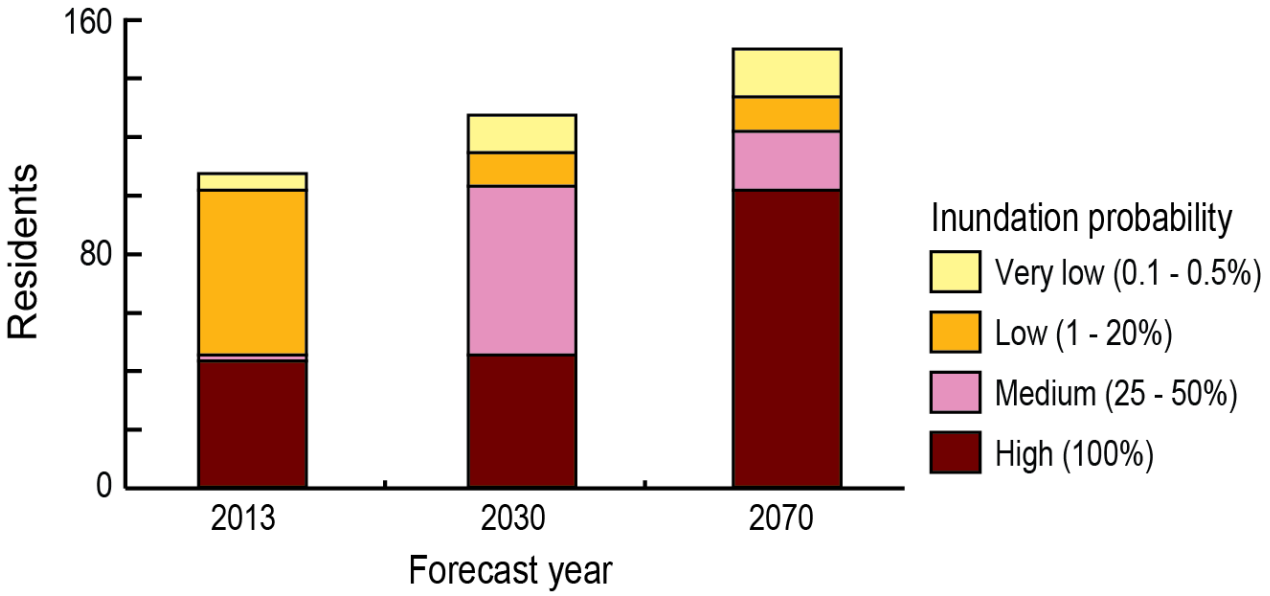

Figure 37. Pie chart showing resident population exposure in Rowley, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

An analysis of other population data suggests several types of nonresidential groups are not in coastal-hazard zones, including dependent-care facilities (for example, child and elderly services, schools, and medical facilities), religious or civic organizations, or public venues in the various hazard zones. Recreation data indicate that coastal-hazard zones with high probabilities of inundation contain 2,239 acres in 2013 to 2,486 acres in 2070 of recreational areas (referred to as scenic land).

Economic Assets

The number of Rowley employees in coastal-hazard zones ranges from 4 in 2013 to 10 in 2070, representing 0.2 to 0.4 percent, respectively, of the 2,443 employees in the community (fig. 38). As was the case with resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zones and not projected changes in employee distributions. In 2013, employees working at businesses in hazard zones are in areas classified as having a very low (0.1–0.5 percent) inundation probability (4 employees). By 2070, analysis indicates that there are 6 employees at businesses in areas classified as very low (0.1–0.5 percent) probability zones, with additional 4 employees in areas classified as high-inundation probability. Sales volume exposure for private-sector businesses ranges from $0.7 million in 2013 up to $1.6 million in 2070 (fig. 39*A*). None of the businesses in the various hazard zones were classified as related to natural resources. The number of businesses likely to have a significant customer presences (for example, retail) in coastal-hazard zones range from 1 business in 2013 in very low probability zones to 2 businesses in 2070 hazard zones (1 in high probability and 1 in very low probability zones). Some of the businesses in the hazard zones have fewer than 20 employees (1 in 2013 and 3 in 2070), representing 0.4 percent in 2013 to 1.1 percent in 2070 of the Rowley business community.

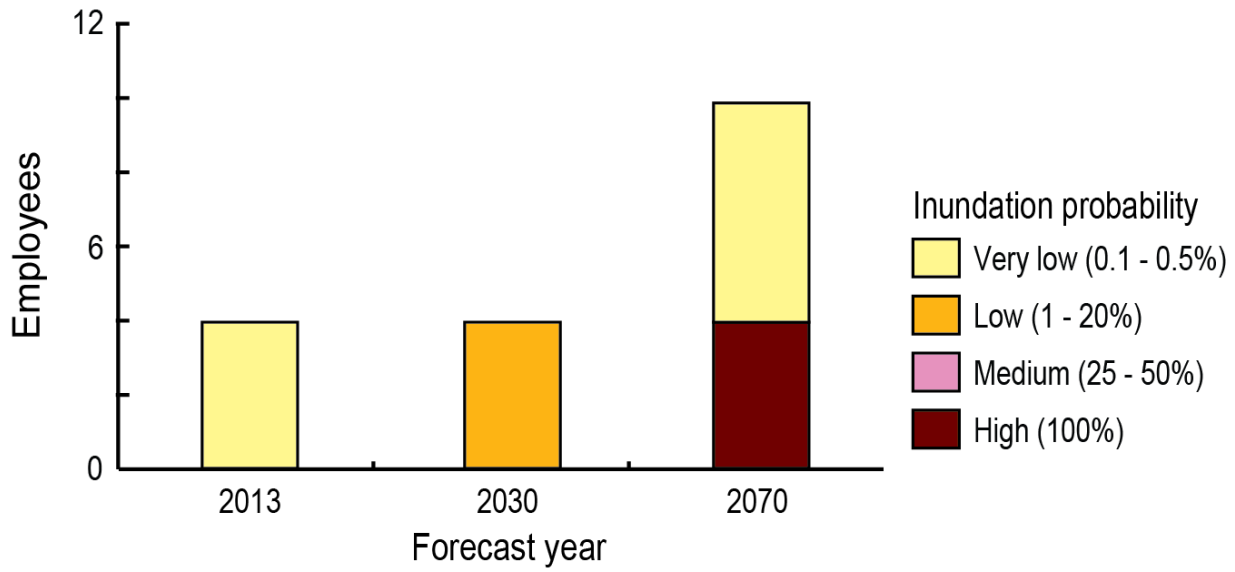

Figure 38. Bar graph showing employee exposure in Rowley, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

Similar to sales volume, the amount of parcel values and building-replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value for parcels in coastal-hazard zones ranges from approximately $12.8 million in 2013 hazard zones to as much as approximately $21.4 million in 2070 hazard zones, representing 1 to 2 percent of the community's tax base between the two time periods (fig. 39*B*). The majority of tax-parcel value in hazard zones is associated with land value for all three time periods (62, 60, and 57 percent, respectively), with the remainder associated with building/content value. Based on building-stock data in the FEMA Hazus-MH 2.2 database (Federal Emergency Management Agency, 2016), estimated building-replacement values range from $22.3 million for the 2013 hazard zones up to $31 million for 2070 hazard zones (fig. 39*C*). For all three time periods, the majority of potential building-replacement values are in areas classified as high probability of inundation.

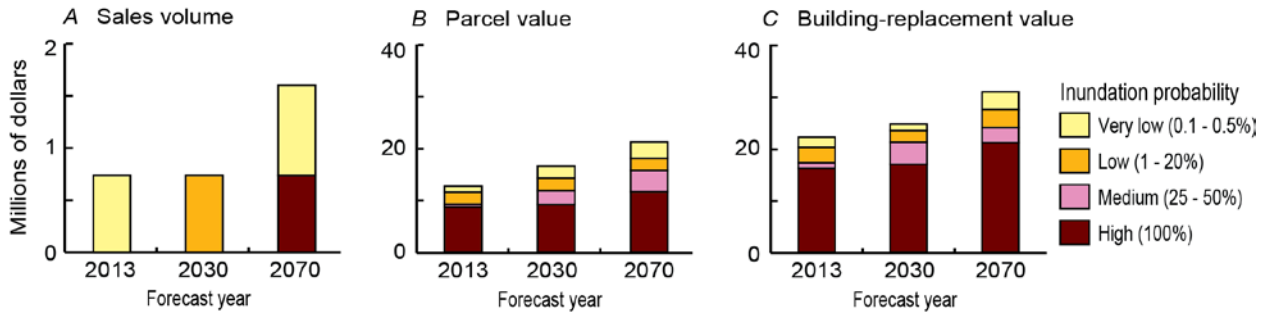

Figure 39. Pie charts showing the cumulative value in millions of dollars of (A) business sales volume, (B) total parcels, and (C) building-replacement costs in coastal-hazard zones for Rowley, Massachusetts. %, percent.

Critical Facilities and Infrastructure

Results indicate that Rowley coastal-hazard zones contain no government offices, public-utility stations, first-responder facilities, communication towers, transportation hubs, public-work offices and

storage yards, public-water-supply sources, MBTA parking-lot locations, transmission lines, park-and-ride lots, solid-waste composting operations or small waste-transfer stations, underground storage tanks, tier-classified oil and hazardous-material release/disposal sites, or oil and hazardous-material release/disposal sites. With regard to infrastructure, results suggest that there are approximately 3.7 mi of roads and rail in 2013 hazard zones (distributed evenly across all four probability zones) that increases to 6.2 mi by 2070 (distributed evenly across all four probability zones).

Locally Identified Areas of Concern

Local stakeholders identified several "areas of concern" in Rowley (fig. 40). Based on a comparison of these areas with predicted hazard zones for current conditions, 2030, and 2070, the following observations can be made of their exposure to coastal-inundation hazards.

- Plum Island Beach and Stackyard Road have the largest areas in estimated inundation-hazard zones for both storm scenarios and over all three time periods. The estimated floodwater depths for Stackyard Road for current hazard zones are primarily 5 ft or less, but increase to primarily 5 to 20 ft in 2070 hazard zones. Estimated floodwater depths for Plum Island Beach range from 1 to 20 ft from 2013 to 2070 with depths primarily at 5 to 20 ft for both storm scenarios (fig. 41).
- The communications tower has less area that is estimated to be inundated from the coastal-hazard zones. In 2013 and 2030, the maximum floodwater depths are 3 ft or less but increase to 4 to 5 ft by 2070 for the 0.1-percent storm scenario and 5 to 20 ft in the 0.2-percent storm scenario.
- The Jewell Mill Dam at Glen Street has minimal exposure to hazard zones (0 percent, by area, in 2013 and 2030) but increases moderately in 2070.
- Hillside Street Culvert at Tributary to Mill River, Route 133 at Bach elder Brook, Newbury Road, and Rowley Town Well #3 at Boxford Road are not in coastal-hazard zones used in this study.

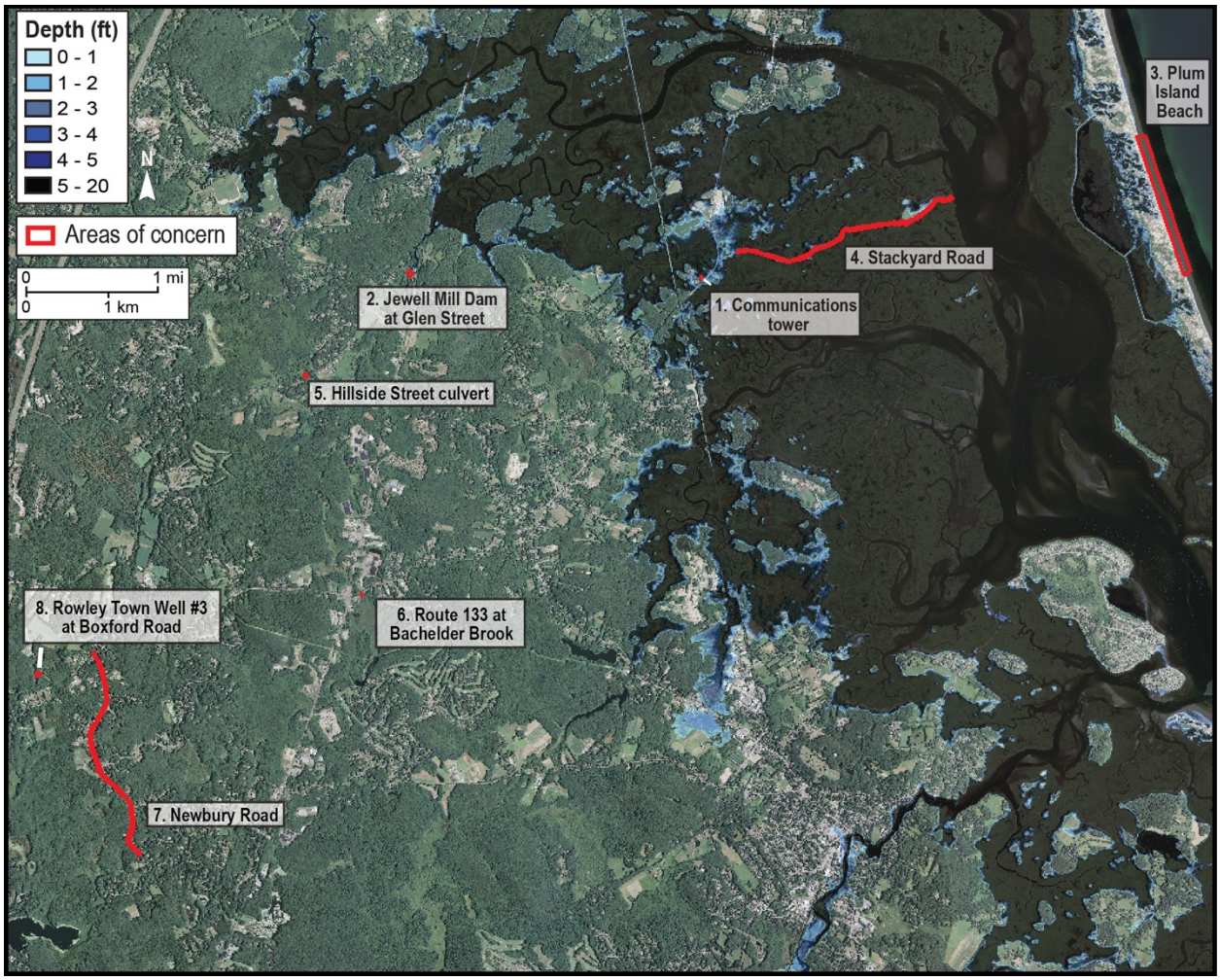

Figure 40. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in Rowley, Massachusetts, as identified by local stakeholders. ft., feet; mi, mile; km, kilometer.

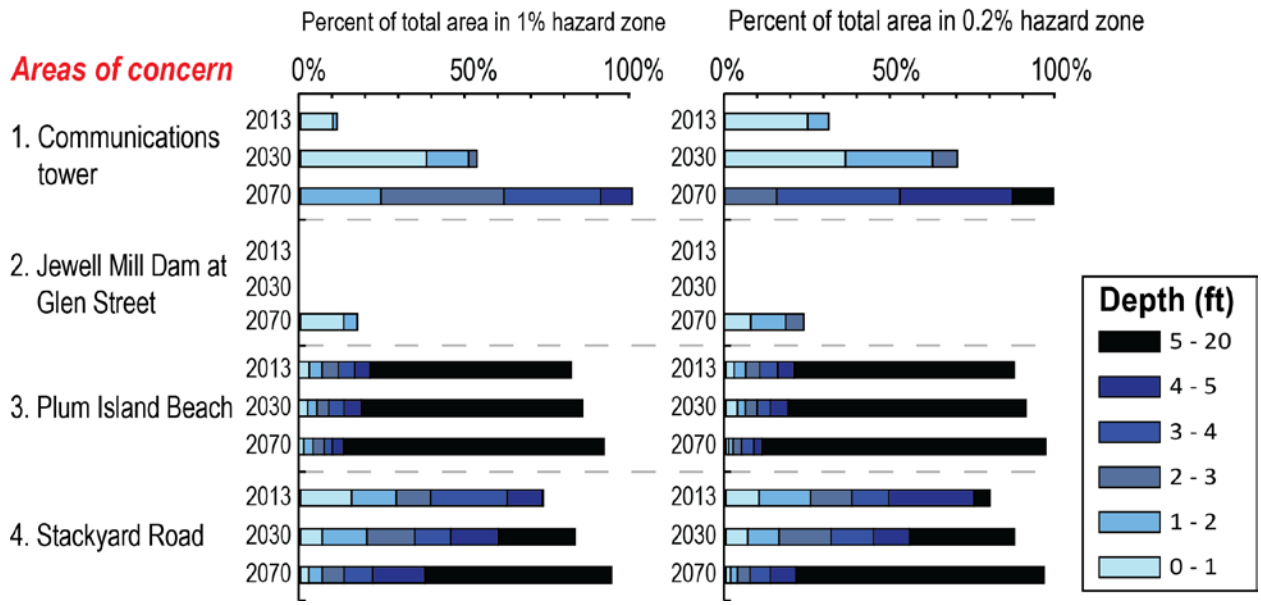

Figure 41. Bar graphs showing cumulative percent of total area for areas of concern identified by local stakeholders in Rowley, Massachusetts, in coastal-hazard zones with 0.2- and 1-percent probabilities of occurrence in 2013, 2030, and 2070, organized by predicted water depth. The following areas of concern are not in coastal-hazard zones: Hillside street culvert, Route 133, Newbury Road, and the Rowley Town Well #3. %, percent; ft., feet.

Conclusion

Understanding how the Town of Rowley is vulnerable to coastal hazards will help local and State officials decide where to focus future planning efforts and how to allocate resources to mitigate the impacts of coastal hazards. Results indicate significant variations in amounts and percentages of community assets exposed to climate-driven coastal hazards with regards to land cover and land use, populations, economic assets, and critical facilities and infrastructure. The Town of Rowley maximum coastal-hazard zone (the total area exposed to potential inundation from sea-level rise and storm surge) includes 4 percent of total developed land and 27 percent of total undeveloped land by 2070. The majority of exposed land in Rowley is in the high-inundation-probability zone (80 percent of land). The maximum hazard zone would also contain approximately 151 residents (3 percent of total), 10 employees (0.4 percent of total), and 2,845 acres of recreational area by 2070. There are also demographic groups in the Town of Rowley that may be more sensitive to future threats and therefore may benefit from targeted risk-reduction efforts, such as residents that live in renter–occupied households (9 percent of exposed residential population), live in institutionalized group quarters (11 percent of exposed residential population), live under the poverty line (15 percent of exposed residential population), have disabilities (20 percent of exposed residential population), are more than 65 years in age (23 percent of exposed residential population), or only have a high-school degree (45 percent of exposed residential population). The amount of exposed parcel and building-replacement values increase approximately 1 percent in the high-probability inundation zone by 2070. Although the overall area exposed increases by only 5 percent, the within-area distribution of exposed assets changes over time to include more high-probability exposure. Critical facilities are not exposed to coastal hazards, whereas approximately 6.2 mi of roads and rail (8 percent of roads and rail) would be exposed in the maximum hazard zone by 2070. The depth analysis determined that at a 0.2- and 1-percent probability

of a storm surge, the areas of concern with the largest areas in hazard zones are Plum Island Beach and Stackyard Road, with predicted inundation heights of 5 to 20 ft by 2070.

Ipswich

Land Cover and Land Use

The Town of Ipswich is approximately 32 mi^2, of which 25 percent (2013) to 30 percent (2070) of it is in coastal-hazard zones for the three time periods in this analysis (fig. 42; appendix 1). The integration of 2011 land-cover data (fig. 43) and the various hazard zones suggests that 6 to 9 percent of the developed land is in 2013 to 2070 hazard zones, respectively (fig. 44). The highest percentage (53 percent in 2013 to 2070) of the developed land in the hazard zones for each time period is classified as low-intensity developed largely representing rural residential areas. Land classified as medium-intensity developed represents 46 percent in 2013 and 43 percent in 2070 of the developed land in hazard zones. The remaining 1 percent in 2013 to 5 percent in 2070 of developed land in hazard zones represents high-intensity developed, such as roads and commercial development. For each time period, the majority of developed land in hazard zones is in areas considered to have a high (100 percent) probability of inundation (figs. 44*A* and *C*).

The amount of undeveloped land (based on 2011 NLCD data) in coastal-hazard zones is much greater than developed land but exposure does not vary substantially through time. The majority of undeveloped land is in areas considered to have a high probability of inundation during future storms both today and by 2070. This land also represents approximately 28 to 33 percent of all undeveloped land in Ipswich between 2013 and 2070 (figs. 44*B* and *C*). Most of this land is classified as wetlands (79 percent); therefore, it makes sense that much of it would be inundated during storms, if not on a near daily occurrence.

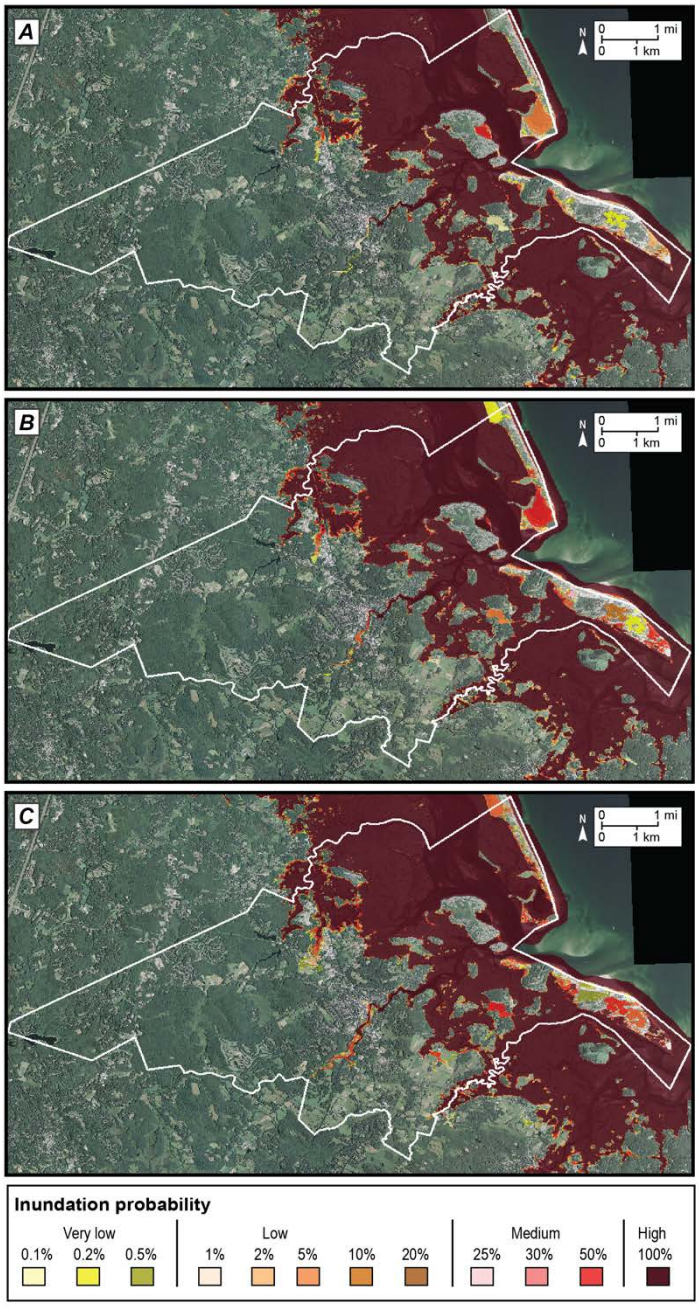

Figure 42. Maps of Ipswich, Massachusetts, coastal-inundation probability showing modeled hazard zones in *(A)* 2013, *(B)* 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). Appendix 1 provides larger versions of each of these maps. %, percent; mi, mile; km, kilometer.

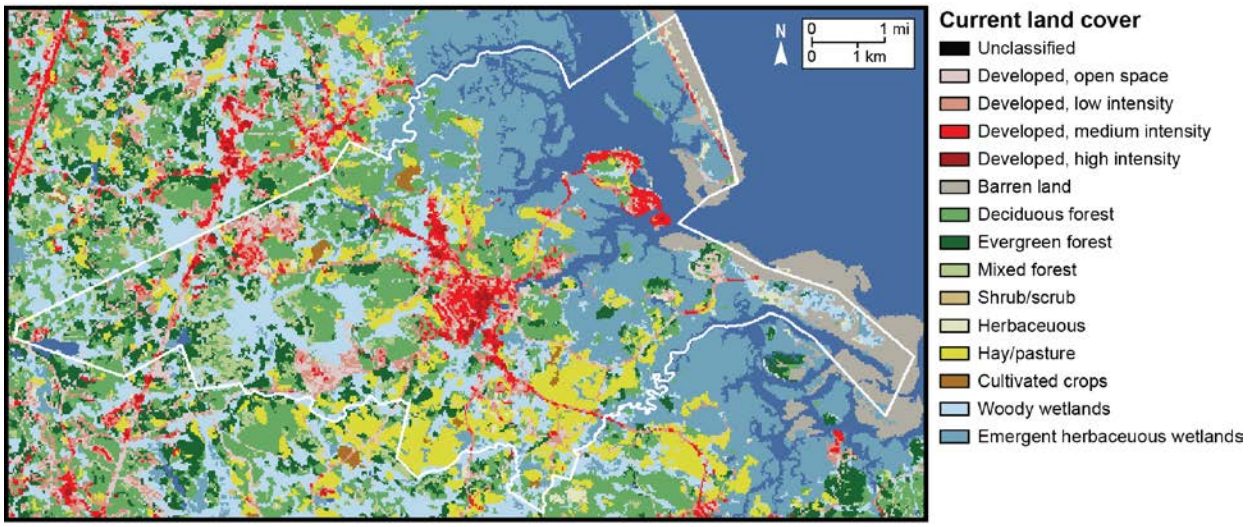

Figure 43. Map showing land-cover data for Ipswich, Massachusetts, from the 2011 National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2011). mi, mile; km, kilometer.

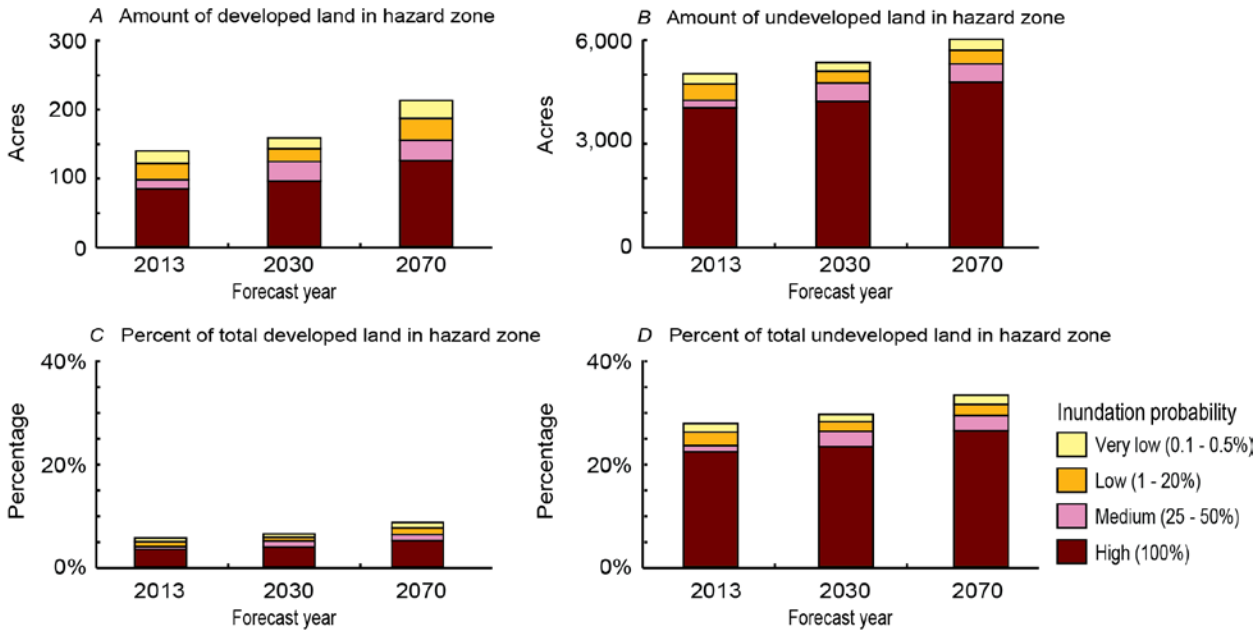

Figure 44. Bar graphs showing amounts of (*A*) developed and (*B*) undeveloped land and total percentages of (*C*) developed and (*D*) undeveloped land in coastal-hazard zones of Ipswich, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070. %, percent.

Modeled hazard zones encompass thousands of acres of conservation lands, areas important to endangered species, and priority habitats (fig. 45). Additional descriptions of each of these environmental designations can be found at MassGIS (Office of Geographic Information, 2016). Thirty-two percent of conservation lands are in current hazard zones, which increases to 38 percent by 2070. The endangered species habitats and priority habitats each have approximately 4,000 acres of land in the coastal-hazard zones with majority of the area in the high-inundation probability zone. The areas of critical environmental concern have the largest amount of land in the hazard zones, on the order of 5,000 acres, with majority of this area in the high-inundation-probability zones for all three time

periods. (figs. 45*A–D*). The majority of the natural areas in the hazard zones for each time period are considered to have a high probability of inundation and the majority of the remaining areas are not in the hazard zone (fig. 45). Finally, there are no Community Preservation Act locations exposed to coastal hazards in Ipswich.

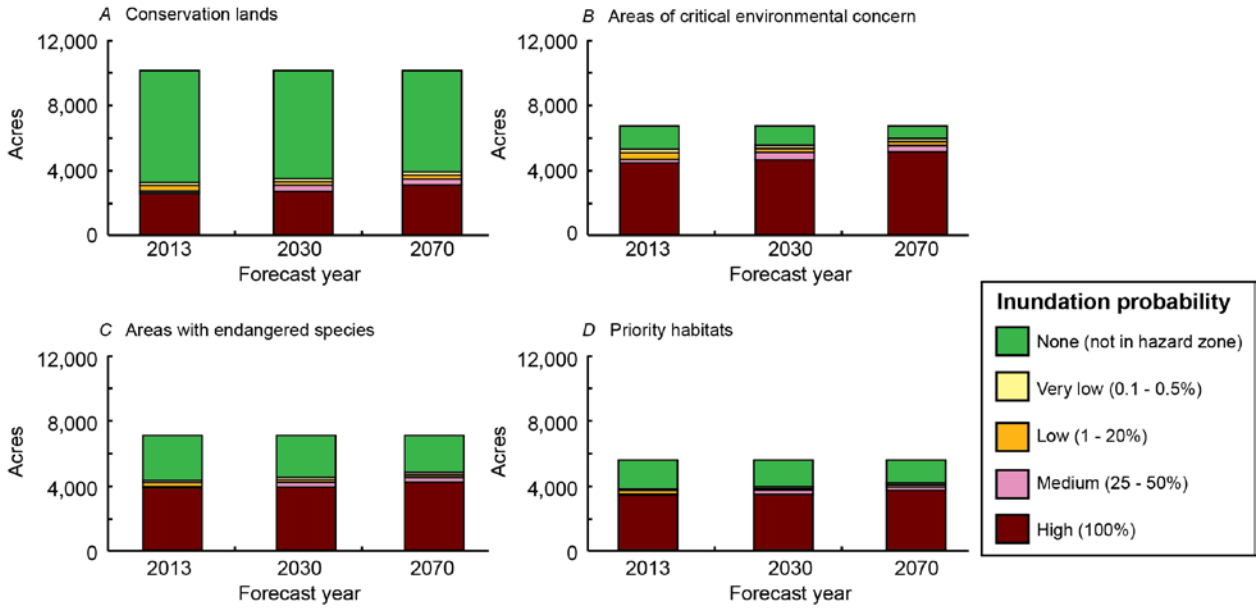

Figure 45. Bar graphs showing the area of land classified as (*A*) conservation lands, (*B*) areas of critical environmental concern, (*C*) endangered species habitats, and (*D*) priority habitats in the modeled hazard zones of Ipswich, Massachusetts, for 2013, 2030, and 2070. %, percent.

The most common land use in the hazard zone is classified as government and ranges from 47 percent in 2013 to 39 percent in 2070, respectively, of all land in the hazard zone (fig. 46). The second most common use of land in the coastal-hazard zones is classified as residential, which ranges from 31 percent in 2013 to 26 percent in 2070, and the third as religious, charitable, or nonprofit, which ranges from 8 percent in 2013 to 20 percent in 2070. In all three hazard zones (that is, 2013, 2030, and 2070), the majority of the parcel area is in areas classified as having a high probability of inundation. All of the remaining land uses in the hazard zone each represent less than 10 percent by area, such as agriculture and conservation, commercial, and industrial. The high percentage of government land use in hazard zones is somewhat disproportionate to the community as a whole, where it represents 35 percent of land use by area (fig. 46*C*).

Zoning data, determined by community planners, suggests that areas zoned rural and residential would be the most affected area relative to coastal-hazard zones ranging from 99 percent in 2013 to 98 percent in 2070, respectively. The remaining zoning types (commercial, industrial, and residential) in the hazard zone each represent less than 10 percent by area.

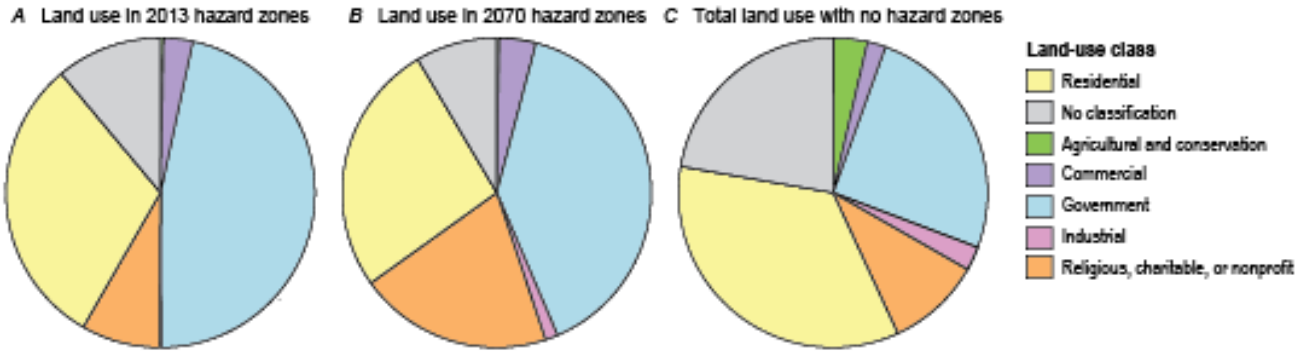

Figure 46. Pie charts showing distribution (by area) of current land use classes within hazard zones in Ipswich, Massachusetts, for (*A*) 2013 and (*B*) 2070, as well as for (*C*) all land in Ipswich regardless of hazard zones.

Populations

The number of Ipswich residents living in the coastal-hazard zones ranges from 237 in 2013 to 492 in 2070, representing 2 to 4 percent, respectively, of the total 13,174 total residents of Ipswich (fig. 47). This estimate is based solely on changes in the extent of the hazard zones, as resident distributions are based on 2010 population counts. The greatest increase in residential exposure among the three time periods is associated with the high-inundation-probability zone. The majority of residents in current hazard zones are located in areas classified as having a high (100 percent) inundation probability (107 residents). By 2070, the number of residents living in the highest hazard zones is estimated to increase to 195 residents due to changes in the extent of hazard zones, whereas the numbers of residents in the medium, low, and very low probability zones are not estimated to increase as substantially.

All demographic percentages describing residents in hazard zones were relatively stable (+/- 1 percent) across the three time periods. Demographic results relative to 2070 hazard zones suggest that none of the residents in the coastal-hazard zones across the three time periods reside in mobile homes. Less than 5 percent of the residents in the hazard zones are living in institutionalized group quarters, speak English as a second language, are unemployed, lack a phone, are less than 5 years in age, or lack vehicles. Greater than 5 percent for residents in the hazard zones include individuals that are living under the poverty line (7 percent), have disabilities (10 percent), are in renter-occupied households (12 percent), are more than 65 years in age (17 percent), and only have a high-school degree (22 percent).

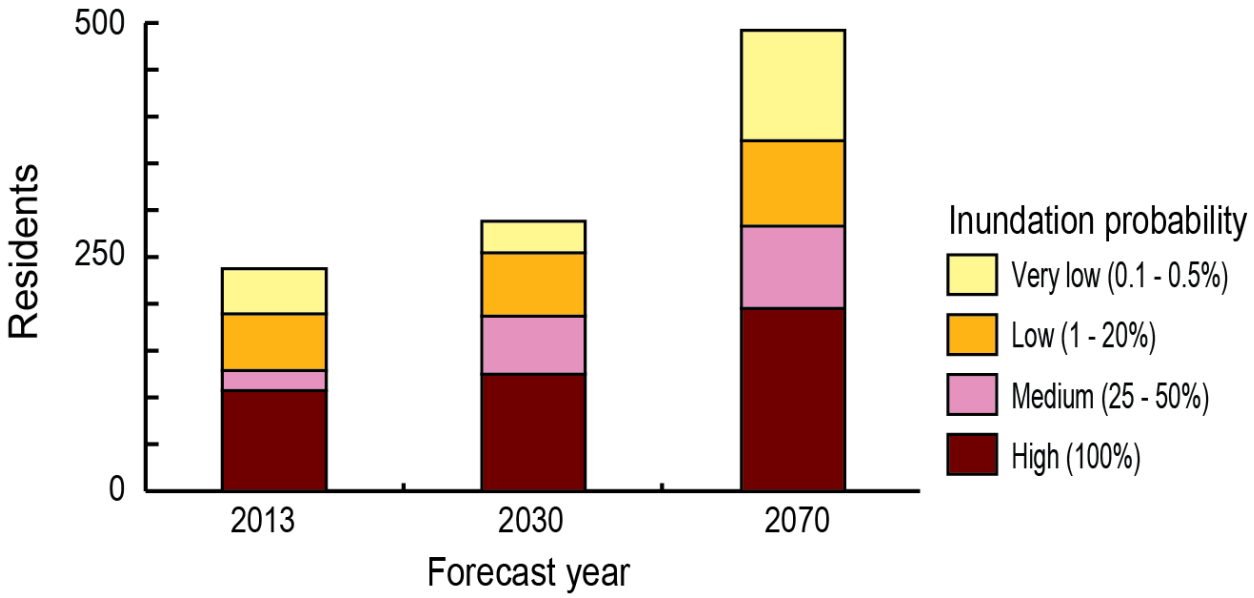

Figure 47. Bar graph showing resident exposure in the Town of Ipswich, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

An analysis of other population data suggests several types of nonresidential groups are in coastal-hazard zones. Dependent-care facilities in the hazard zones include one site (medical facility) in the 2013 high-probability zone that increases to 14 facilities (medical facilities) in 2070 (primarily in the low-probability zone). Recreation data indicate that coastal-hazard zones with high probabilities of inundation contain Ipswich's Farmers Market, 0 to 0.62 mi of recreational trails, and 4,448 to 5,189 acres of recreational areas (referred to scenic land), where ranges represent 2013 and 2070 values. There are no religious or civic organizations and no public venues (for example, hotels and motels, and marinas) in the coastal-hazard zone.

Economic Assets

The number of Ipswich employees working in the coastal-hazard zones ranges from 100 in 2013 to 457 in 2070, representing 2 to 9 percent, respectively, of the 5,086 employees in the community (fig. 48). As was the case with resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zones and not projected changes in employee distributions. In 2013, most employees in these hazard zones are in areas classified as having a high (100 percent) inundation probability (45 employees). By 2070, 224 employees are at businesses in the low-probability (1-20 percent) zone, with additional employees in zones classified as high (100), medium (16) and very low (117) inundation probability. Sales volume exposure for private-sector businesses ranges from $19.5 million in 2013 up to $48.1 million in 2070 (fig. 49*A*). None of the businesses in the various hazard zones were classified as related to natural resources. The number of businesses likely to have a significant customer presence (for example, retail) in coastal-hazard zones ranges from 20 businesses in 2013 to 56 businesses in 2070. The number of these businesses with fewer than 20 employees (a group typically more sensitive to disruptions) ranges from 26 in 2013 to 85 in 2070, representing 4 and 14 percent, respectively, of the Ipswich business community.

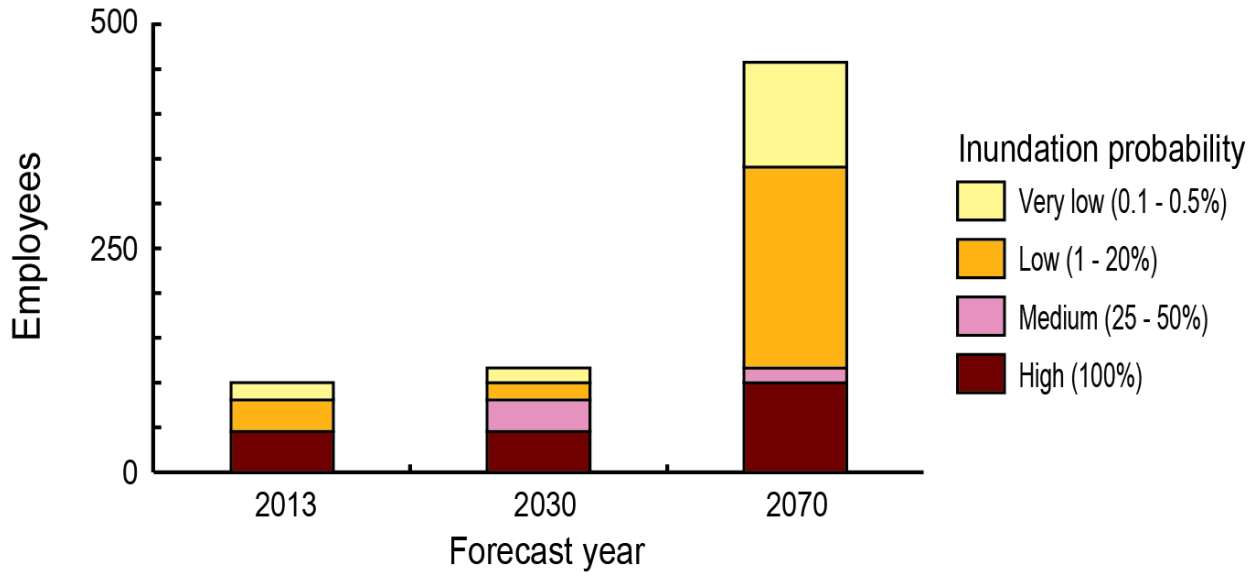

Figure 48. Bar graph showing employee exposure in Ipswich, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

Similar to sales volume, the amount of parcel values and building-replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value for parcels in coastal-hazard zones ranges from approximately $83.9 million in 2013 hazard zones to approximately $155.3 million in 2070 hazard zones, representing 3 to 6 percent of the community's tax base between the two time periods (fig. 49*B*). The majority of tax-parcel value in hazard zones is associated with land value for all three time periods (67, 70, and 65 percent, respectively), with the remainder associated with building/content value. Based on building-stock data in the FEMA Hazus-MH 2.2 database (Federal Emergency Management Agency, 2016), estimated building-replacement values range from $79 million for the 2013 hazard zones to $154.4 million for 2070 hazard zones (fig. 49*C*). For all three time periods, the majority of potential building-replacement values are in areas classified as high probability of inundation.

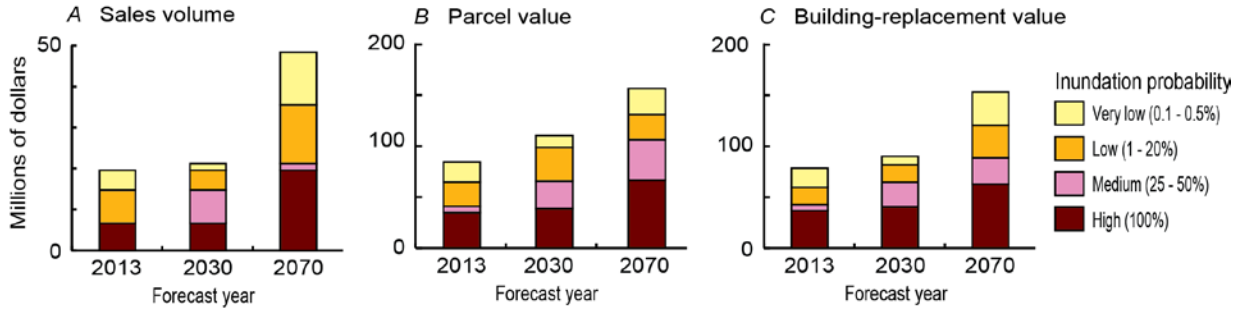

Figure 49. Bar graphs showing cumulative value in millions of dollars of (*A*) business sales volume, (*B*) total parcels, and (*C*) building-replacement costs in coastal-hazard zones for Ipswich, Massachusetts. %, percent.

Critical Facilities and Infrastructure

Results indicate that coastal-hazard zones in Ipswich contain no composting-operation sites, small waste-transfer stations, underground storage tanks, tier-classified oil and hazardous-material release/disposal sites, oil and hazardous-material release/disposal sites with a declared activity and use limitation, public-water-supply sources, transmission lines, MBTA parking-lot locations, park-and-ride

lots, government offices, public-utility stations, first-responder facilities, communication towers, transportation hubs, or public-work offices and storage yards. With regard to infrastructure, results suggest that there are approximately 8.1 mi of roads and rail in 2013 hazard zones (distributed evenly between low to very low probability zones) that increases to 9.9 mi by 2070 (primarily in medium-probability zones).

Locally Identified Areas of Concern

Local stakeholders identified several "areas of concern" in Ipswich (fig. 50). Based on a comparison of these areas with predicted hazard zones for current conditions, 2030, and 2070, the following observations can be made of their exposure to coastal-inundation hazards.

- Jeffery's Neck Road is estimated to have 73 to 84 percent (by area with ranges corresponding to 1- and 0.2-percent-probability storm scenarios, respectively) of its area to be inundated by varying water depths by storms today, for both the 1-and 0.2-percent-probability storm scenarios (fig. 51). These percentages rise to 96 and 98 percent for the two storm probabilities by 2070. Floodwater depths are estimated to be on the order of 1 to 20 ft from 2013 to 2030 with an increase to primarily 5 to 20 ft by 2070 for both storm scenarios.
- Estimated floodwater depths exhibit similar trends for Downtown Ipswich and Crane Beach. Coastal-hazard zones are estimated to cover 50 to 54 percent (by area with ranges corresponding to 1- and 0.2-percent-probability storm scenarios, respectively) of Downtown Ipswich in 2013 with exposure percentages rising to 84 to 89 percent of the asset by 2070. Estimated floodwater depths have similar distributions for the two assets over time and among storm probabilities, in that depths exhibit a range from 1 to 20 ft in 2013 and 2030 zones but become more consistently 5 to 20 ft in 2070 hazard zones for both storm scenarios.
- The estimated extent of inundation for Crane Beach ranges from 64 to 70 percent by area, respectively, for all time periods for the two storm scenarios.
- Estimated floodwater depths exhibit similar trends for Labor-in-Vain Road, Clark Beach, and Clark Pond. All three assets have estimated water depths of 5 ft or less in 2013 and 2030 hazard zones, but increase to 5 to 20 ft in the 2070 hazard zones for both storm scenarios. Clark Beach and Clark Pond have the largest areas estimated to be inundated for both storm scenarios and over all three time periods (fig. 51).
- Estimated floodwater depths exhibit similar trends for the sewage pumping station, Pavilion Beach, and Argilla Road at Fox Creek. Coastal-hazard zones are estimated to cover 63 to 74 percent, 81 to 89 percent, and 71 to 81 percent (by area with ranges corresponding to 1-and 0.2-percent-probability storm scenarios, respectively) of the three assets in 2013 with exposure percentages rising to 88 to 91 percent, 99 to 100 percent, and 100 percent of the asset by 2070. Estimated depths have similar distributions for the sewage pumping station and Pavilion Beach, in that depths exhibit a range from 1 to 20 ft in 2013 and 2030 zones, whereas Argilla Road exhibits a range from 1 to 4 ft but become more consistently 5 to 20 ft in 2070 hazard zones for both storm scenarios over time.
- Choate Bridge has less area that is estimated to be inundated in the coastal-hazard zones but estimated floodwater depths are much greater at 5 to 20 ft even for 2013 hazard zones.
- Route 1A at Muddy Run, South Main Street, and County Road at Saltonstall Brook all have similar exposure profiles in that exposure is minimal (< 1 percent by area in 2013 and 2030), but increases moderately for Route 1A and County Road and substantially for South Main Street in 2070.
- Linebrook Road at Bull Brook is not located in any of the forecasted coastal-hazard zones.

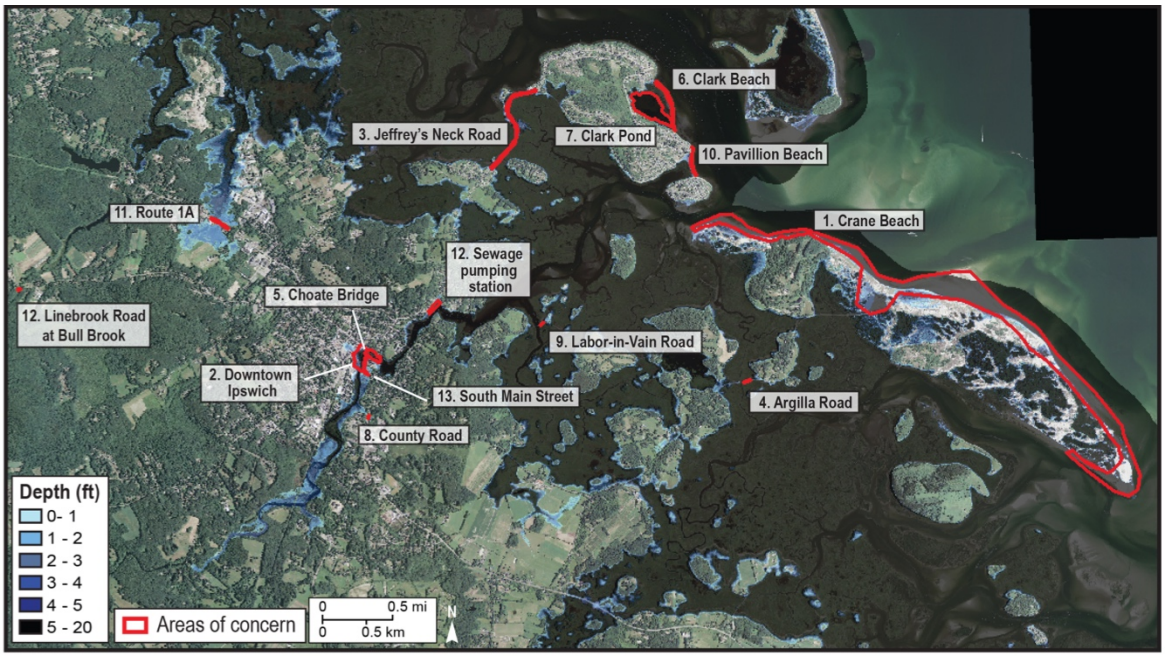

Figure 50. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in the Town of Ipswich, Massachusetts, as identified by local stakeholders. ft., feet. mi, mile; km, kilometer.

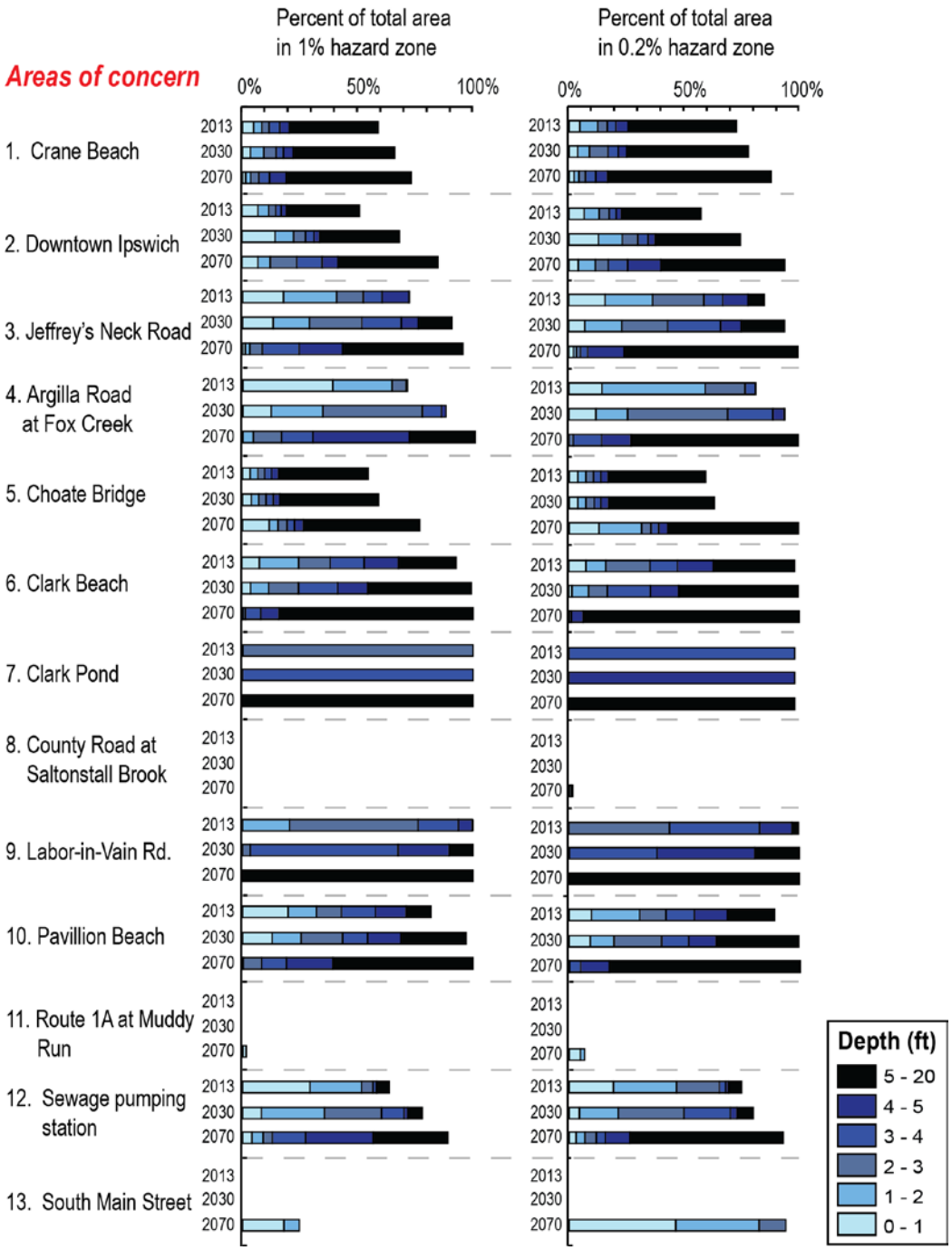

Figure 51. Bar graphs showing cumulative percent of total area for areas of concern indicated by local stakeholders in the Town of Ipswich, Massachusetts, in coastal-hazard zones with 0.2- and 1-percent probabilities of occurrence in 2013, 2030, and 2070, organized by predicted water depth. The following area of concern is not in the hazard zones: Linebrook Road at Bull Brook. %, percent; ft., feet.

Conclusion

Understanding how the Town of Ipswich is vulnerable to coastal hazards will help the local and State officials decide where to focus future planning efforts and how to allocate resources to mitigate the impacts of coastal hazards. Results indicate significant variations in amounts and percentages of

community assets exposed to climate-driven coastal hazards with regards to land cover and land use, populations, economic assets, and critical facilities and infrastructure. The Town of Ipswich's maximum coastal-hazard zone (the total area exposed to potential inundation from sea-level rise and storm surge) includes 30 percent of total developed land and 33 percent of total undeveloped land by 2070. The majority of exposed land in Ipswich (79 percent of land in hazard zones) is in the high-inundation-probability zone. The maximum hazard zone also is projected to contain approximately 492 residents (4 percent of total), 457 employees (9 percent of total), and numerous community businesses, dependent-care facilities, and recreational area by 2070. There are also demographic groups in the Town of Ipswich that may be more sensitive to future threats and therefore may need extra preparedness training, such as residents that living under the poverty line (7 percent of exposed residential population), have disabilities (10 percent of exposed residential population), live in renter–occupied households (12 percent of exposed residential population), more than 65 years in age (17 percent of exposed residential population), and residents with only a high-school degree (22 percent of exposed residential population). The amount of exposed parcel and building-replacement values increase approximately 3 percent (parcel) and 4 percent (building replacement) in the high-probability inundation zone by 2070. Although the overall area exposed increases by only 5 percent, the within-area distribution of exposed assets changes over time to include more high-probability exposure. Critical facilities are not exposed to coastal hazards, whereas approximately 9.9 mi of roads and rail (7 percent of roads and rail) would be exposed in the maximum hazard zone by 2070. The depth analysis determined that at a 0.2- and 1-percent probability of a storm surge, Clark Pond has the largest area in the maximum inundation zone. In addition, predicted inundation heights may be 5 to 20 ft for the majority of the assets by 2070.

Essex

Land Cover and Land Use

The Town of Essex is approximately 14 mi^2, of which 27 percent (2013) to 30 percent (2070) of it is in coastal-hazard zones for the three time periods in this analysis (fig. 52; appendix 1). The integration of 2011 land-cover data (fig. 53) and the various hazard zones suggests that 12 to 20 percent of the developed land is in 2013 to 2070 hazard zones, respectively (fig. 54). The highest percentage (62 percent in 2013 to 60 percent in 2070) of the developed land in the hazard zones for each time period is classified as low-intensity developed largely representing rural residential areas. Land classified as medium-intensity developed represents 28 percent (2013) to 31 percent (2070) of the developed land in hazard zones. The remaining 10 percent in 2013 and 8 percent in 2070 of developed land in hazard zones represents high-intensity developed, such as roads and commercial development. For each time period, the majority of developed land in hazard zones is in areas considered to have a high (100 percent) probability of inundation and the remaining areas are split fairly evenly across medium, low, and very low probabilities of inundation (fig. 54*A*). Of all land cover in the coastal-hazard zones, developed land makes up 3 to 4 percent of total exposure from 2013 to 2070 (fig. 54*C*).

The amount of undeveloped land (based on 2011 NLCD data) in coastal-hazard zones is much greater than developed land, but exposure does not vary substantially through time. The majority of undeveloped land is in areas considered to have a high probability of inundation during future storms both today and by 2070. This land also represents approximately 27 to 30 percent of undeveloped land in Essex between 2013 and 2070 (figs. 54*B* and *D*). Most of this land is classified as wetlands (89 percent); therefore, it makes sense that much of it would be inundated during storms, if not on a near daily occurrence.

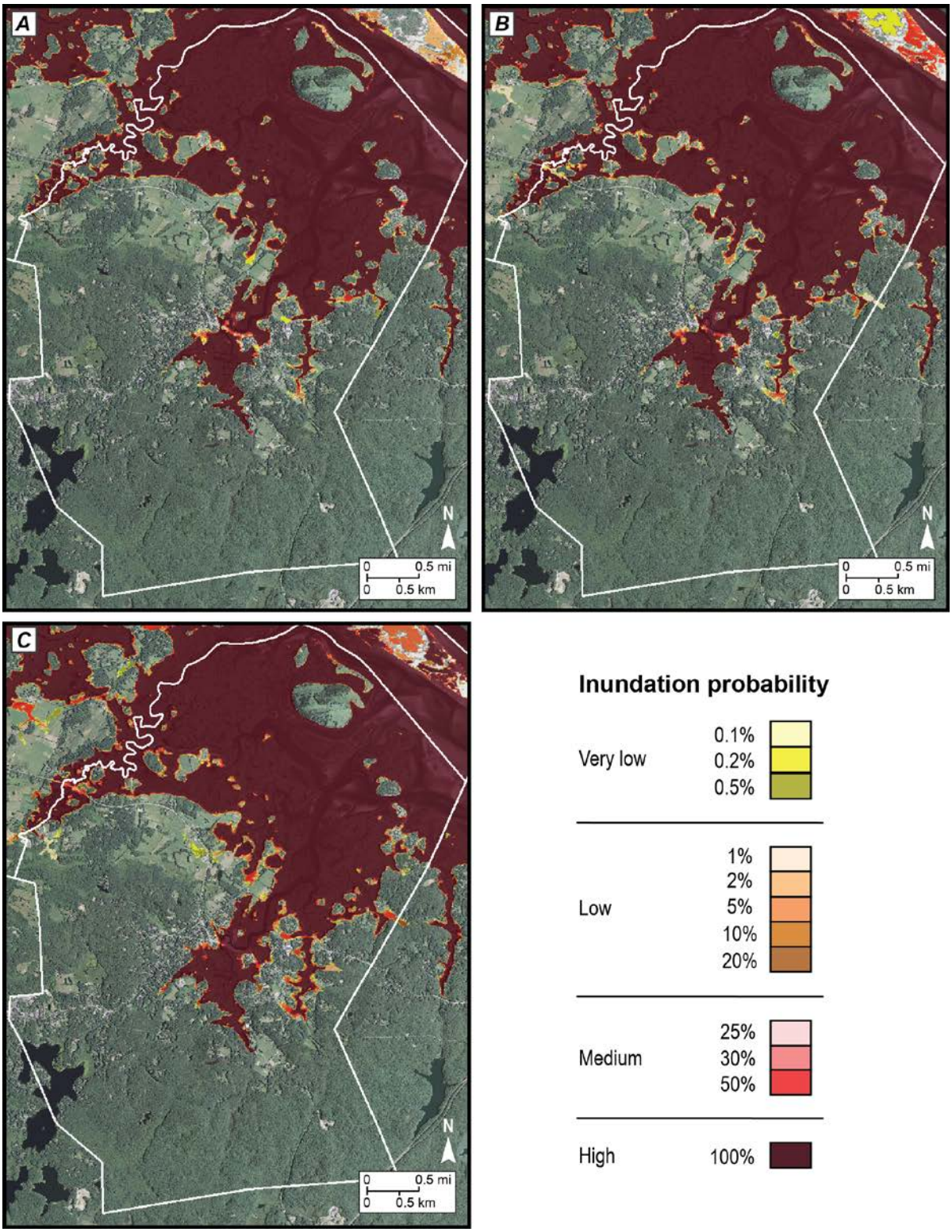

Figure 52. Maps of Essex, Massachusetts, coastal-inundation probability showing modeled hazard zones in *(A)* 2013, (*B*) 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). Appendix 1 provides larger versions of each of these maps. %, percent mi, mile; km, kilometer.

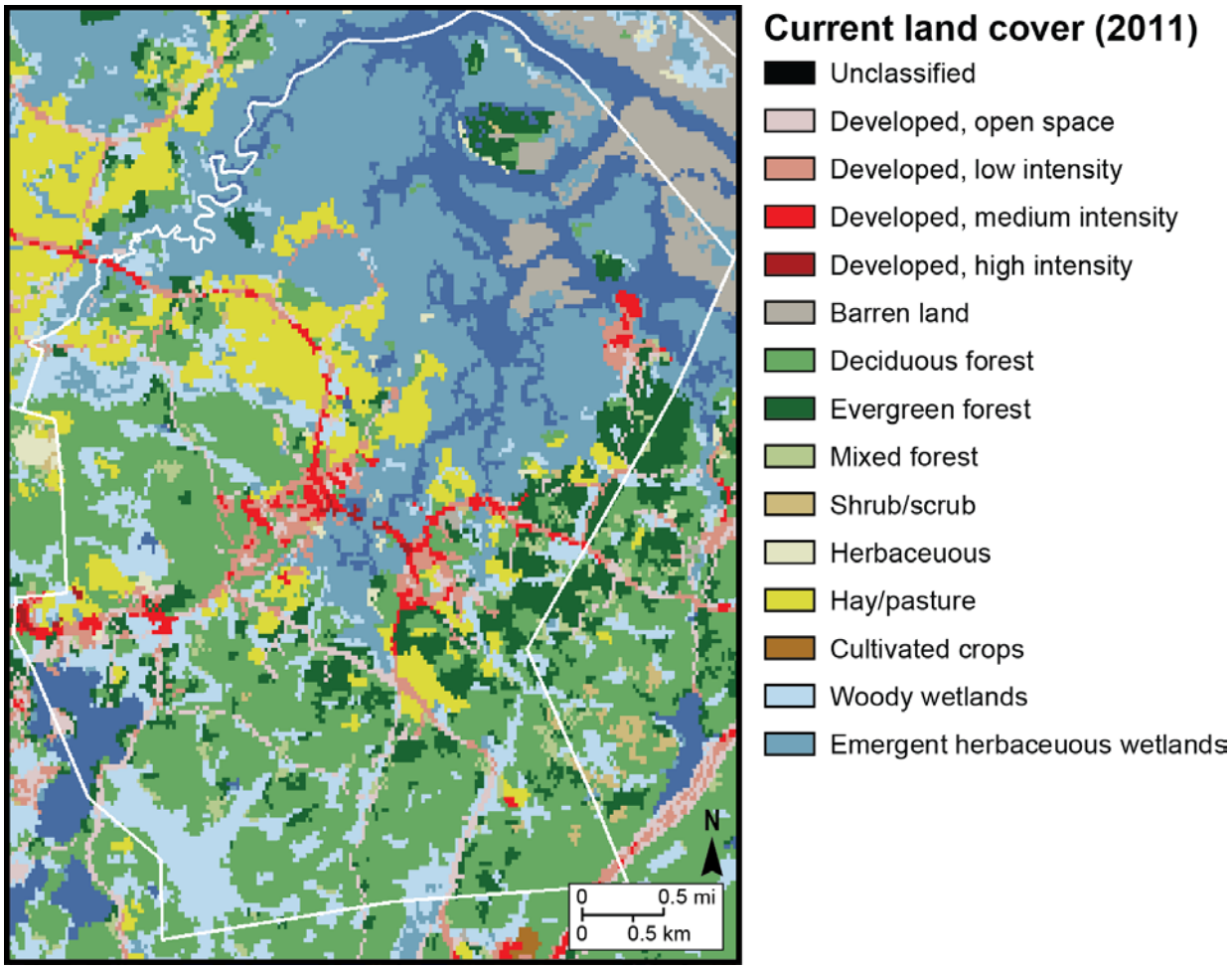

Figure 53. Map showing land-cover data for Essex, Massachusetts, from the 2011 National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2011). mi, mile; km, kilometer.

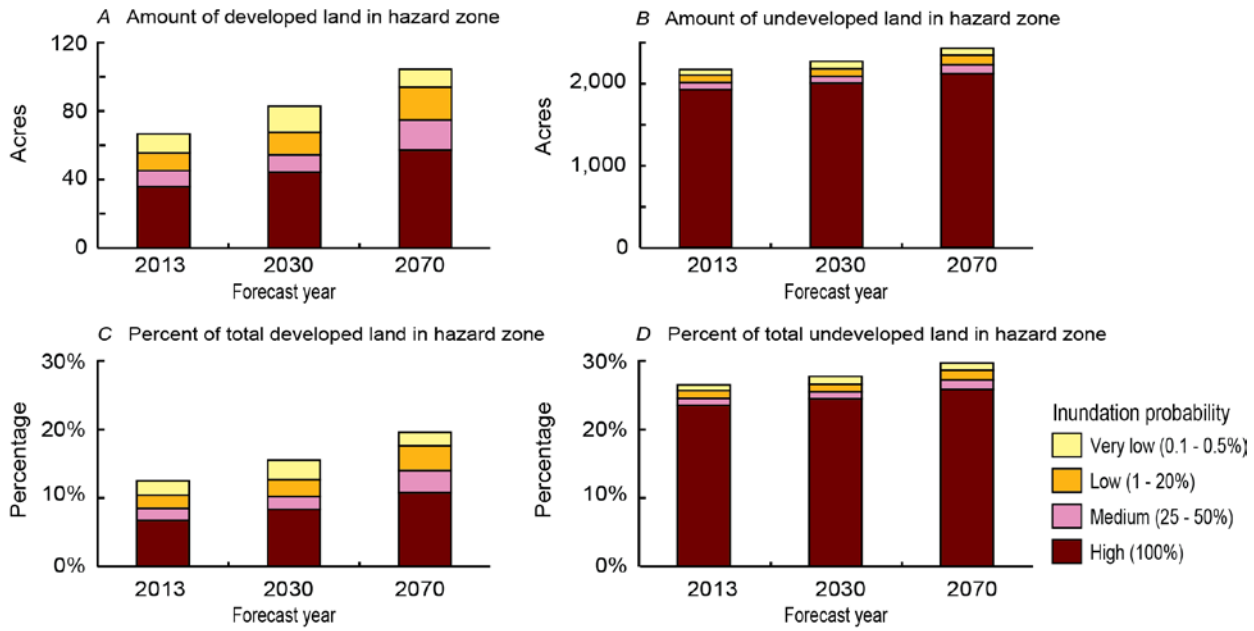

Figure 54. Bar graphs showing amounts of (*A*) developed and (*B*) undeveloped land and total percentages of (*C*) developed and (*D*) undeveloped land in coastal-hazard zones of Essex, Massachusetts, expressed by inundation probability in 2013, 2030, and 2070. %, percent.

Modeled hazard zones encompass thousands of acres of conservation lands, areas important to endangered species, and priority habitats (fig. 55). Additional descriptions of each of these environmental designations can be found at MassGIS (Office of Geographic Information, 2016). Forty-four percent of conservation lands are in current hazard zones, which increases to 48 percent by 2070 (fig. 55*A*). Among environmental assets, areas of critical environmental concern have the largest amount of land in the hazard zones, on the order of 2,300 acres, with majority of the area in the high-inundation-probability zones for all three time periods (fig. 55*B*). The inundation extent for endangered species habitats (65 percent) and priority habitats (72 percent) do not change from 2013 to 2070 (figs. 55*C* and *D*). In addition, approximately 10 percent of Community Preservation Act locations are in coastal-hazard zones, which increase to 64 percent in 2070 (fig. 55*E*). The majority of the natural areas in the hazard zones for each time period are considered to have a high probability of inundation, and the majority of the remaining areas are not in the hazard zone (fig. 55). The high probabilities of inundation for these undeveloped conservation areas are a result of the land being predominantly salt marsh—and thus inundated on a nearly daily occurrence.

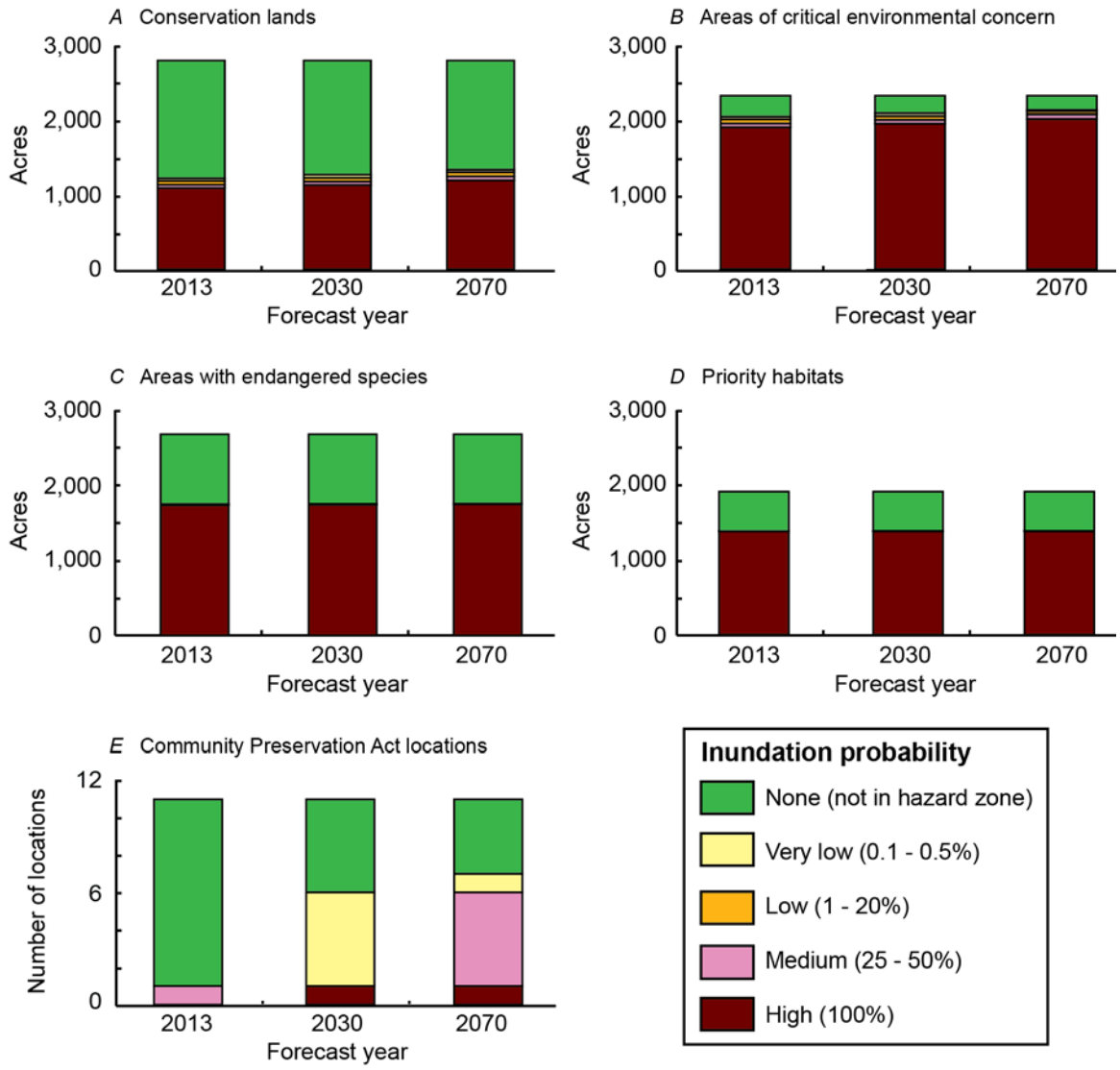

Figure 55. Bar graphs showing the area of land classified as (*A*) conservation lands, (*B*) areas of critical environmental concern, (*C*) endangered species habitats, (*D*) priority habitats, and (*E*) Community Preservation Act locations in the modeled hazard zones of Essex, Massachusetts, for 2013, 2030, and 2070. %, percent.

The most common land use in hazard zones is classified as residential and ranges from 62 percent in 2013 to 64 percent in 2070, respectively, of all land in the hazard zone (fig. 56). The second most common use of land in hazard zones is classified as religious, charitable, or nonprofit, which ranges from 19 percent in 2013 to 17 percent in 2070. In all three hazard zones (that is, 2013, 2030, and 2070), the majority of the parcel area is in areas classified as having a high probability of inundation. All of the remaining land uses in the hazard zone each represent less than 10 percent by area, such as agriculture and conservation, commercial, government, and industrial. The high percentage of residential land use in hazard zones is slightly disproportionate to the community as a whole, where it represents 54 percent of land use by area (fig. 56*C*).

Zoning data, determined by community planners, suggests that areas zoned "general" represent the largest amount of land in coastal-hazard zones, ranging from 92 percent in 2013 to 89 percent in 2070, respectively. The remaining two zoning types (industrial and road) in the hazard zone each represent less than 10 percent by area.

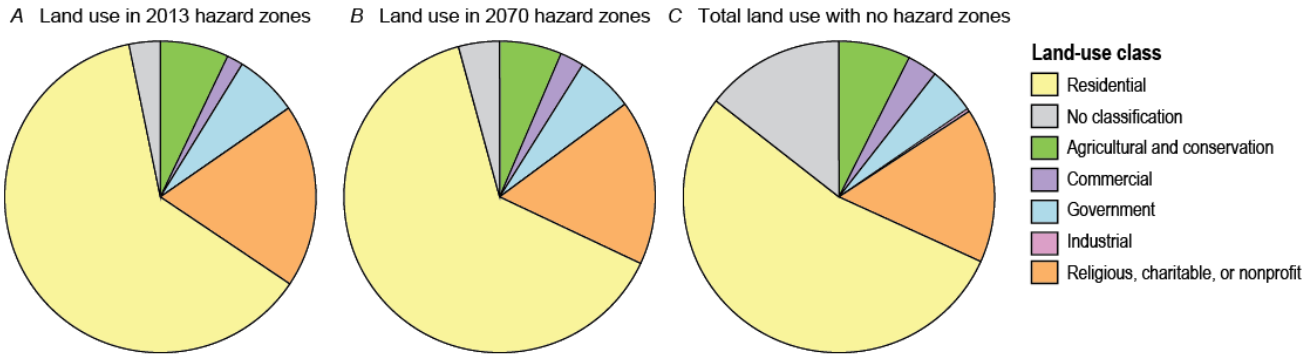

Figure 56. Pie charts showing distribution (by area) of current land use classes within hazard zones in Essex, Massachusetts, for (*A*) 2013 and (*B*) 2070, as well as for all land in Essex regardless of hazard zones.

Populations

The number of Essex residents living in the coastal-hazard zones ranges from 181 in 2013 to 331 in 2070, representing 5 to 9 percent, respectively, of the total 3,504 total residents in Essex (fig. 57). This estimate is based solely on changes in the extent of the hazard zones, as resident distributions are based on 2010 population counts. The majority of residents in current hazard zones are located in areas classified as having a low (1–20 percent) inundation probability (57 residents). The greatest increase in residential exposure among the three time periods is associated with the high-inundation-probability zone. By 2070, the number of residents living in the highest hazard zones is estimated to be 159 residents due to changes in the extent of hazard zones, whereas the numbers of residents in the medium, low, and very low probability zones are not estimated to increase substantially.

All demographic percentages describing residents in hazard zones were relatively stable (+/-1 percent) across the three time periods. Demographic results relative to 2070 hazard zones suggest that none of the residents in the coastal-hazard zones across the three time periods are in mobile homes, living under the poverty line, have disabilities, speak English as a second language, or are living in institutionalized group quarters. Less than 5 percent of the residents in the hazard zones are unemployed, lack a phone, are in renter-occupied households, are less than 5 years in age, or lack vehicles. Greater than 5 percent of residents in the hazard zones include individuals that are more than 65 years in age (18 percent) and residents with only a high-school degree (31 percent).

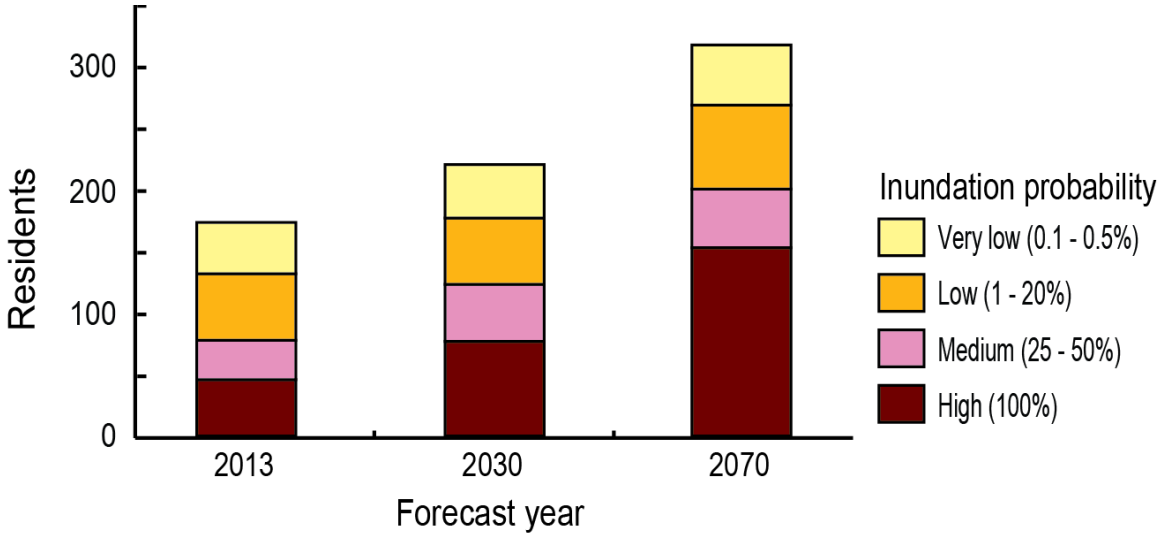

Figure 57. Bar graph showing resident exposure in the Town of Essex, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

An analysis of other population data suggests several types of nonresidential groups are in coastal-hazard zones. Public venues in hazard zones include two sites (hotels and motels, and marinas) in the 2013 medium-probability zone that end up in the high-probability zones in 2030 and 2070 and an additional venue (bed-and-breakfast inns) in the very low probability zone in 2070. Recreation data indicate that coastal-hazard zones with high probabilities of inundation contain no recreation access points but do contain 0 to 0.62 mi of recreational trails and 1,977 to 2,224 acres of recreational areas (referred to as scenic land), where ranges represent 2013 and 2070 values. There are no dependent-care facilities (for example, child and elderly services, schools, and medical facilities) and no religious or civic organizations in the coastal-hazard zones.

Economic Assets

The number of Essex employees working in coastal-hazard zones ranges from 142 in 2013 to 191 in 2070, representing 10 to 14 percent, respectively, of the 1,410 employees in the community (fig. 58). As was the case with resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zones and not projected changes in employee distributions. In 2013, most employees in these hazard zones are in areas classified as having a low (1–20 percent) inundation probability (105 employees). By 2070, 142 employees are at businesses likely to be in the high (100 percent) probability zone, with additional employees in zones classified as medium (1), low (45), and very low (3) inundation probability. Sales volume exposure for private-sector businesses ranges from $11.3 million in 2013 to as much as $16.4 million in 2070 (fig. 59*A*). None of the businesses in the various hazard zones were classified as related to natural resources. The number of businesses likely to have significant customer presence (for example, retail) in coastal-hazard zones ranges from 11 businesses in 2013 to 15 businesses in 2070. The number of these businesses with fewer than 20 employees (a group typically more sensitive to disruptions) ranges from 24 in 2013 to 33 in 2070, representing 12 and 17 percent, respectively, of the Essex business community.

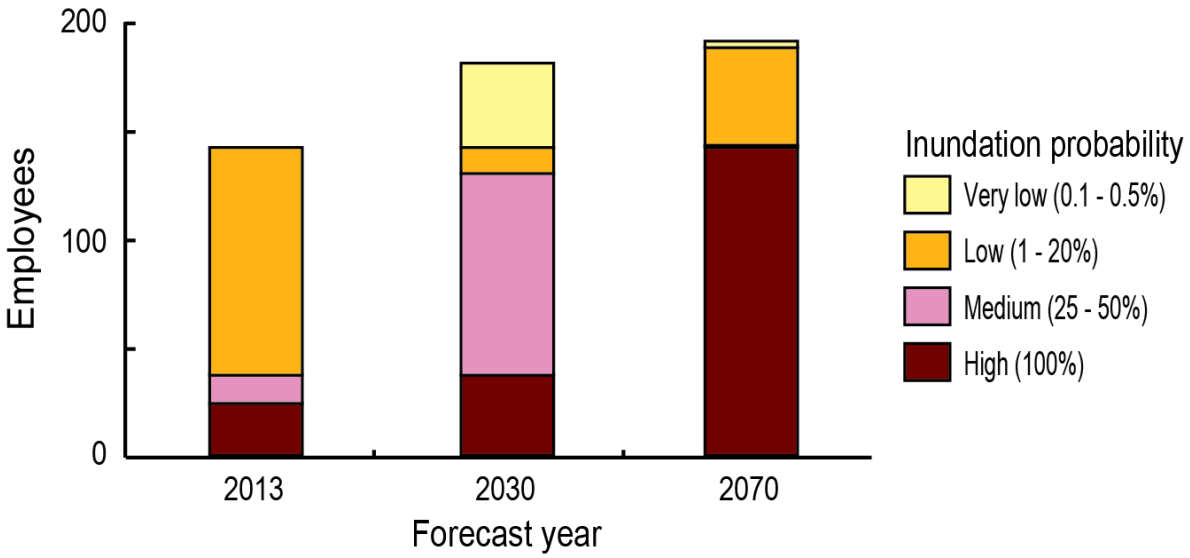

Figure 58. Bar graph showing employee exposure in Essex, Massachusetts, to storm-surge scenarios for 2013, 2030, and 2070, organized by inundation probability. %, percent.

Similar to sales volume, the amount of parcel values and building-replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value for parcels in coastal-hazard zones ranges from approximately $76.5 million in 2013 hazard zones up to approximately $125.1 million in 2070 hazard zones, representing 10 to 16 percent of the community's tax base between the two time periods (fig. 59*B*). The majority of tax-parcel value in hazard zones is associated with land value for all three time periods (65 percent (2013), 65 percent (2030), and 63 percent (2070), respectively), with the remainder associated with building/content value. Based on building-stock data in the FEMA Hazus-MH 2.2 database (Federal Emergency Management Agency, 2016), estimated building-replacement values range from $55.6 million for the 2013 hazard zones to $87.7 million for 2070 hazard zone (fig. 59*C*). For all three time periods, the majority of potential building-replacement values are in areas classified as high probability of inundation.

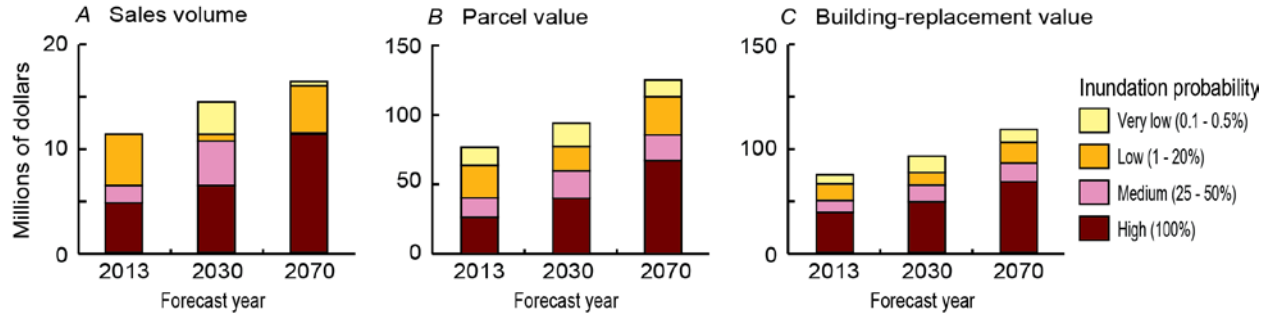

Figure 59. Bar graphs showing cumulative value in millions of dollars of (*A*) business sales volume, (*B*) total parcels, and (*C*) building-replacement costs in coastal-hazard zones for Essex, Massachusetts. %, percent.

Critical Facilities and Infrastructure

Results indicate that coastal-hazard zones in Essex contain no composting-operation sites, small waste-transfer stations, public-work offices and storage yards, public-water-supply sources, transmission lines, MBTA parking-lot locations, park-and-ride lots, first-responder facilities, town halls, communication towers, or transportation hubs. One executive office, a public finance office, and three

legislative bodies are in areas classified as low-probability inundation zones in 2013 that become medium-probability zones in 2030, and ultimately high-probability zones by 2070. Two public-utility stations (commercial property) are in the coastal-hazard zones, distributed evenly between low and very low probability zones in 2013 to five stations primarily in low-probability zones in 2070. One underground storage tank is in the hazard zones, with the probability of inundation increasing from very low in 2013 to medium in 2070. One tier-classified site is found in the low-probability hazard zone in 2013 and increases to high probability in 2070. There are no declared activity and use limitation sites exposed in 2013 with an increase to three sites in the 2070 low-probability zone. With regard to infrastructure, results suggest that there are approximately 2.4 mi of roads and rail in 2013 hazard zones (distributed evenly between medium to very low probability zones) that increases to 3.3 mi by 2070 (distributed evenly across all four probability zones).

Locally Identified Areas of Concern

Local stakeholders identified several "areas of concern" in Essex (fig. 60). Based on a comparison of these areas with predicted hazard zones for current conditions, 2030, and 2070, the following observations can be made of their exposure to coastal-inundation hazards.

- Crane Beach is estimated to have 74 to 78 percent (with ranges corresponding to 1- and 0.2-percent-probability storm scenarios, respectively) of the beach's area inundated by varying water depths by storms today (fig. 61). These percentages rise to 86 and 88 percent for the two storm probabilities by 2070. Floodwater depths over the majority of the asset are estimated to be on the order of 5 to 20 ft for all time periods and storm probabilities.
- Estimated floodwater depths exhibit similar trends for the intersection of Conomo Point Road and Robbins Island Road and the intersection of the Main Street Causeway and Woodman's Beach. Coastal-hazard zones are estimated to cover 40 to 44 percent and 43 to 54 percent (by area with ranges corresponding to 1- and 0.2-percent-probability storm scenarios, respectively) of the two assets in 2013 with exposure percentages rising to 58 to 63 percent and 76 to 79 percent of the assets by 2070. Estimated depths have similar distributions for the two assets over time and among storm probabilities, in that depths exhibit a range from 1 to 20 ft in 2013 and 2030 zones but become more consistently 5 to 20 ft in 2070 hazard zones for both storm scenarios.
- The estimated extent of inundation at the intersection of Eastern Avenue and Ebben Creek ranges from 14 to 45 percent by area and is generally less than 1 foot in floodwater depths in current hazard zones for the two storm scenarios. By 2070, this intersection is estimated to have the highest percent exposure by area for the 0.2-percent storm scenario and second only to Crane Beach for the 1-percent storm scenario. Floodwater depths at this site are also estimated to increase from 1 to 2 ft in the 2013 and 2030 hazard zones to a range of 1 to 20 ft by 2070.
- The ball fields and playground behind Town Hall and Richdale's Gas Station are estimated to have floodwater depths of generally 5 ft or less in the 2013 and 2030 hazard zones for both storm scenarios. Estimated water depths for the 1-percent-probability scenario increase to 5 to 20 ft for the ball fields and playground and increase to 4 to 5 ft for Richdale's Gas Station by 2070 (fig. 61). Estimated water depths for the 0.2-percent-probability scenario increase to 5 to 20 ft for both assets by 2070.
- The Landing Road culvert has less area that is estimated to be inundated in the various hazard zones, while floodwater depths are at 5 to 20 ft for the current hazard zone.

- The Apple Street culvert and the intersection of Eastern Avenue and Grove Street have similar exposure profiles in that exposure is minimal (0 percent in 2013 and 2030) but increases moderately for the street intersection and substantially for the culvert in 2070.

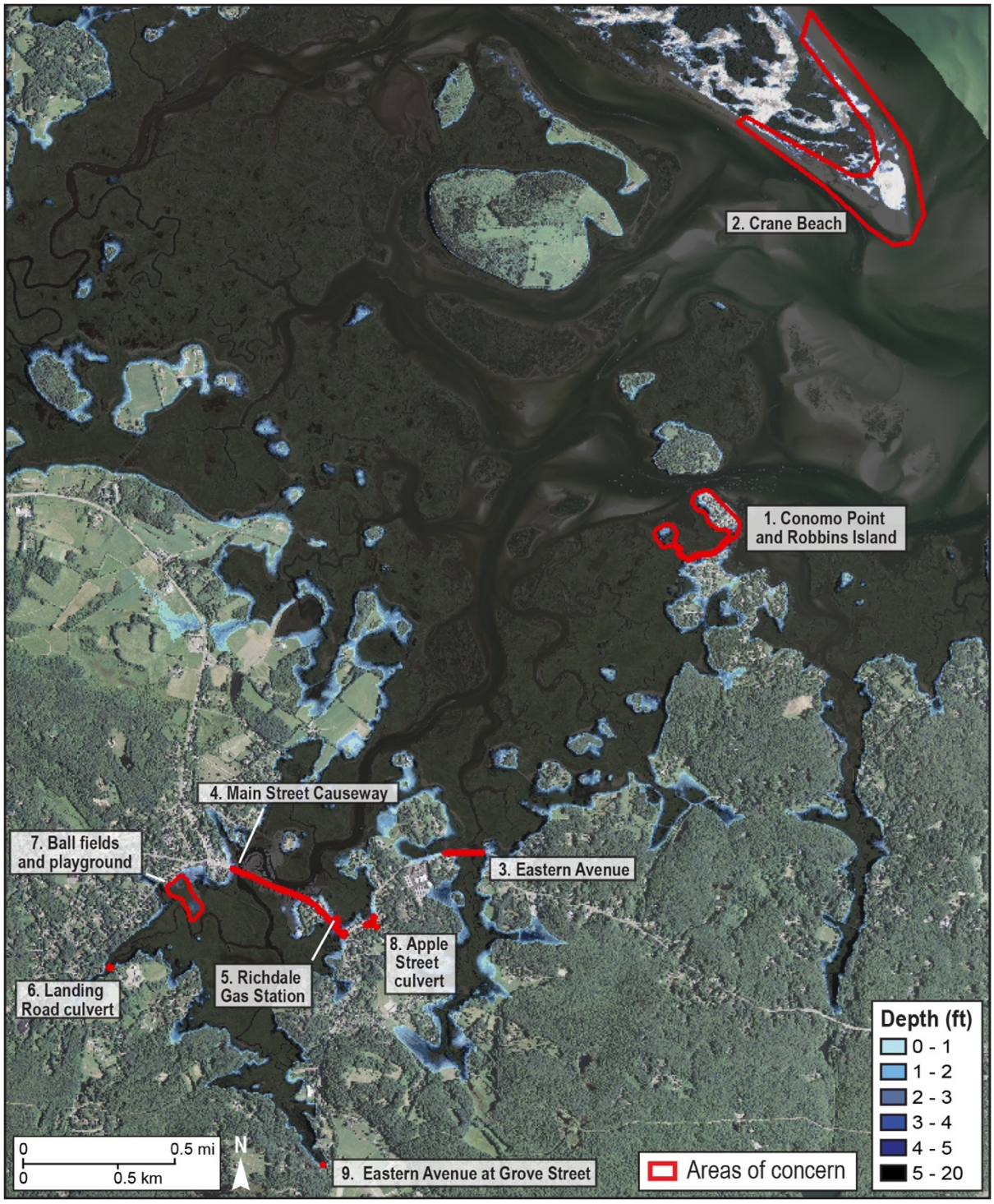

Figure 60. Map showing inundation depth (in 0.5-foot increments) at a 1-percent probability (~100-year storm) as delineated by the Woods Hole Group, in addition to areas of concern in the Town of Essex, Massachusetts, as identified by local stakeholders. ft., feet; mi, mile; km, kilometer.

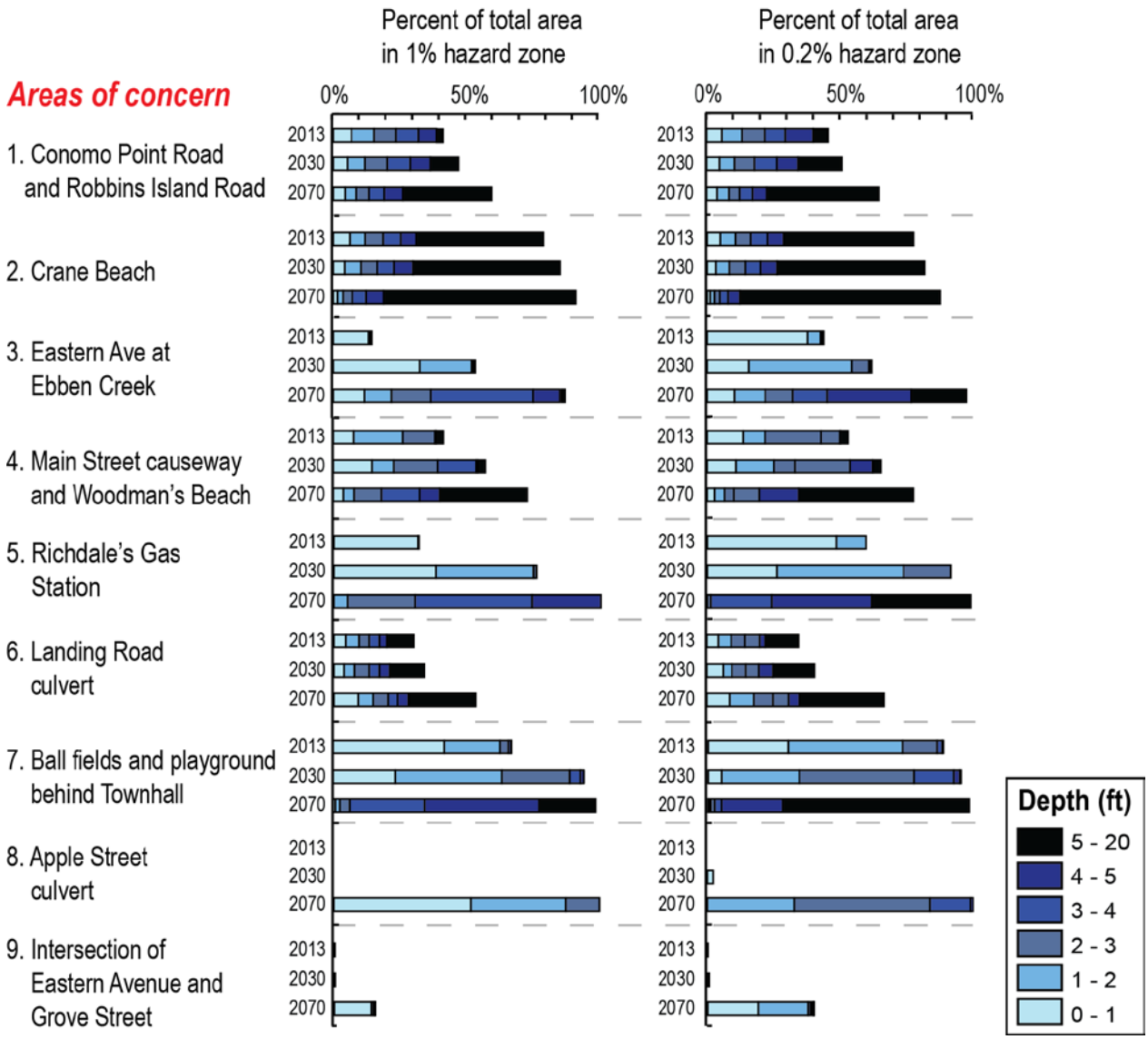

Figure 61. Bar graphs showing cumulative percent of total area for areas of concern identified by local stakeholders in the Town of Essex, Massachusetts, in coastal-hazard zones with 0.2- and 1-percent probabilities of occurrence in 2013, 2030, and 2070, organized by predicted water depth. %, percent; ft., feet.

Conclusion

Understanding how the Town of Essex is vulnerable to coastal hazards will help the local and State officials decide where to focus future planning efforts and how to allocate resources to mitigate the impacts of coastal hazards. Results indicate significant variations in amounts and percentages of community assets exposed to climate-driven coastal hazards with regards to land cover and land use, populations, economic assets, and critical facilities and infrastructure. The Town of Essex maximum coastal-hazard zone (the total area exposed to potential inundation from sea-level rise and storm surge) includes 20 percent of total developed land and 30 percent of total undeveloped land by 2070. The majority of exposed land in Essex (86 percent of land) is in the high-inundation-probability zone. The maximum hazard zone also is projected to contain approximately 331 residents (9 percent of total), 191 employees (14 percent of total), and numerous community businesses, public venues, and recreational

area by 2070. There are also demographic groups in the Town of Essex that may be more sensitive to future threats and therefore may need extra preparedness training, such as residents that are more than 65 years in age (18 percent of exposed residential population) and residents with only a high-school degree (31 percent of exposed residential population). The amount of exposed parcel and building-replacement values increase by approximately 6 percent in the high-probability inundation zone by 2070. Although the overall area exposed increases by only 3 percent, the within-area distribution of exposed assets changes over time to include more high-probability exposure. The maximum hazard zone also is projected to contain approximately 10 critical facilities, including 5 government offices, and 5 public-utility stations by 2070. In addition, approximately 3.3 mi of roads and rail (7 percent of roads and rail) would be exposed in the maximum hazard zone by 2070. The depth analysis indicates that at a 0.2- and 1-percent storm-surge probability, Richdale's Gas Station has the largest area in the maximum inundation zone. In addition, predicted inundation heights may be 5 to 20 ft for majority of the assets by 2070.

References Cited

Core Writing Team, Pachauri, R.K. and Reisinger, A., eds., 2007, Climate change 2007—Synthesis report; Contribution of working groups I, II, and III to the fourth assessment report of the Intergovernmental Panel on Climate Change: IPCC, Geneva, Switzerland, Intergovernmental Panel on Climate Change, 104 p.

Federal Emergency Management Agency, 2016, Hazus: Federal Emergency Management Agency Web page, accessed January 22, 2016, at https://www.fema.gov/hazus.

Federal Emergency Management Agency, 2012, Multi-hazard loss estimation methodology—Flood Model—Hazus®-MH user manual: Department of Homeland Security Mitigation Division, p. 1–569, accessed January 22, 2016, at https://www.fema.gov/media-library/assets/documents/24609.

Homeland Infrastructure Foundation-Level Data Subcommittee, 2013, HIFLD Subcommittee home page: Homeland Infrastructure Foundation-Level Data Subcommittee Web site, accessed January 21, 2016, at https://gii.dhs.gov/HIFLD/.

Homer, C., Huang, C., Yang, L., Wylie, B., and Coan, M., 2004, Development of a 2001 National Landcover Database for the United States: Photogrammetric Engineering and Remote Sensing, v. 70, no. 7, p. 829–840.

Homer, C.H., Fry, J.A., and Barnes C.A., 2012, The National Land Cover Database: U.S. Geological Survey Fact Sheet 2012–3020, 4 p. [Also available at http://pubs.usgs.gov/fs/2012/3020/.]

Infogroup, 2012, Employer database: Infogroup online dataset, accessed September 23, 2015, at http://referenceusagov.com/Static/Home.

Kleinfelder, 2015, Coastal climate change vulnerability assessment and adaptation plan—City of Gloucester, MA: Kleinfelder project report for the City of Gloucester, accessed January 22, 2016, at http://gloucester-ma.gov/DocumentCenter/View/3416.

Laska, S., and Morrow, B., 2007, Social vulnerabilities and Hurricane Katrina—An unnatural disaster in New Orleans: Marine Technology Society Journal, v. 40, no. 4, p. 16–26.

Morrow, B., 1999, Identifying and mapping community vulnerability: Disasters, v. 23, no. 1, p. 1–18.

Multi-Resolution Land Characteristics Consortium, 2011, National Land Cover Database 2011 (NLCD2011): Multi-Resolution Land Characteristics Consortium Web site, accessed May 23, 2016, at http://www.mrlc.gov/nlcd2011.php.

Office of Geographic Information (MassGIS), 2016, MassGIS datalayers: Commonwealth of Massachusetts, Office of Geographic Information Web site, accessed January 22, 2016, at

http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/layerlist.html.
Parris, A., Bromirski, P., Burkett, V., Cayan, D., Culver, M., Hall, J., Horton, R., Knuuti, K., Moss, R., Obeysekera, J., Sallenger, A., and Weiss, J., 2012. Global sea level rise scenarios for the US National Climate Assessment: National Oceanic and Atmospheric Administration Tech Memo OAR CPO-1, 37 p.
U.S. Census Bureau, 2015, Cartographic boundary shapefiles: U.S. Census Bureau Web page, accessed May 23, 2016, at http://www.census.gov/geo/maps-data/data/tiger-cart-boundary.html.
U.S. Census Bureau, 2016, American FactFinder: U.S. Census Bureau Web page, accessed May 23, 2016, at http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml.
U.S. Department of Agriculture, 2015, Geospatial data gateway: U.S. Department of Agriculture Web site, accessed December 1, 2015, at https://gdg.sc.egov.usda.gov/.

Appendix 1. Inundation Probability Maps

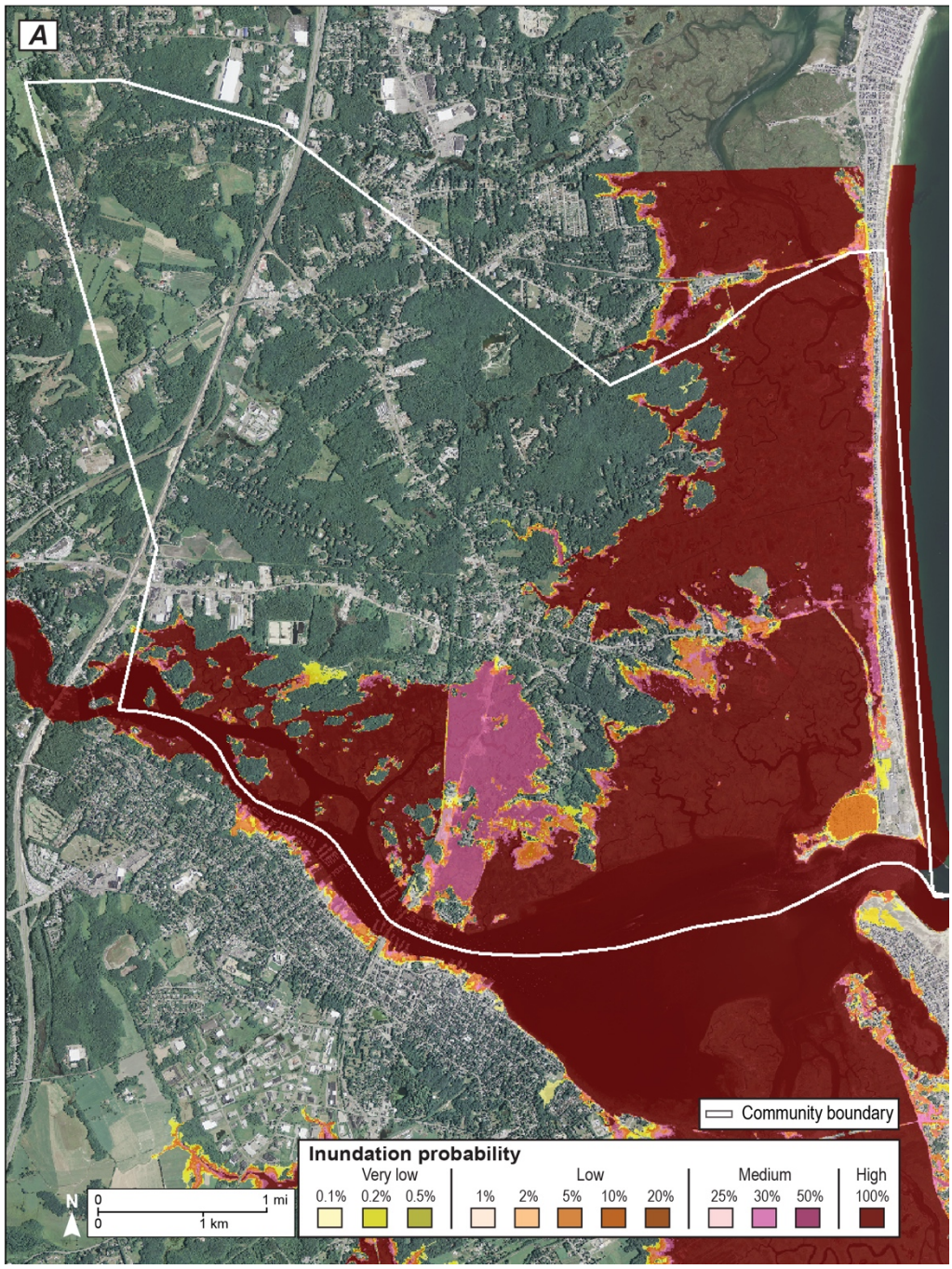

Figure 1-1. Maps of Salisbury, Massachusetts, coastal-inundation probability showing modeled hazard zones in (*A*) 2013, (*B*) 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). %, percent; mi, mile; km, kilometer.

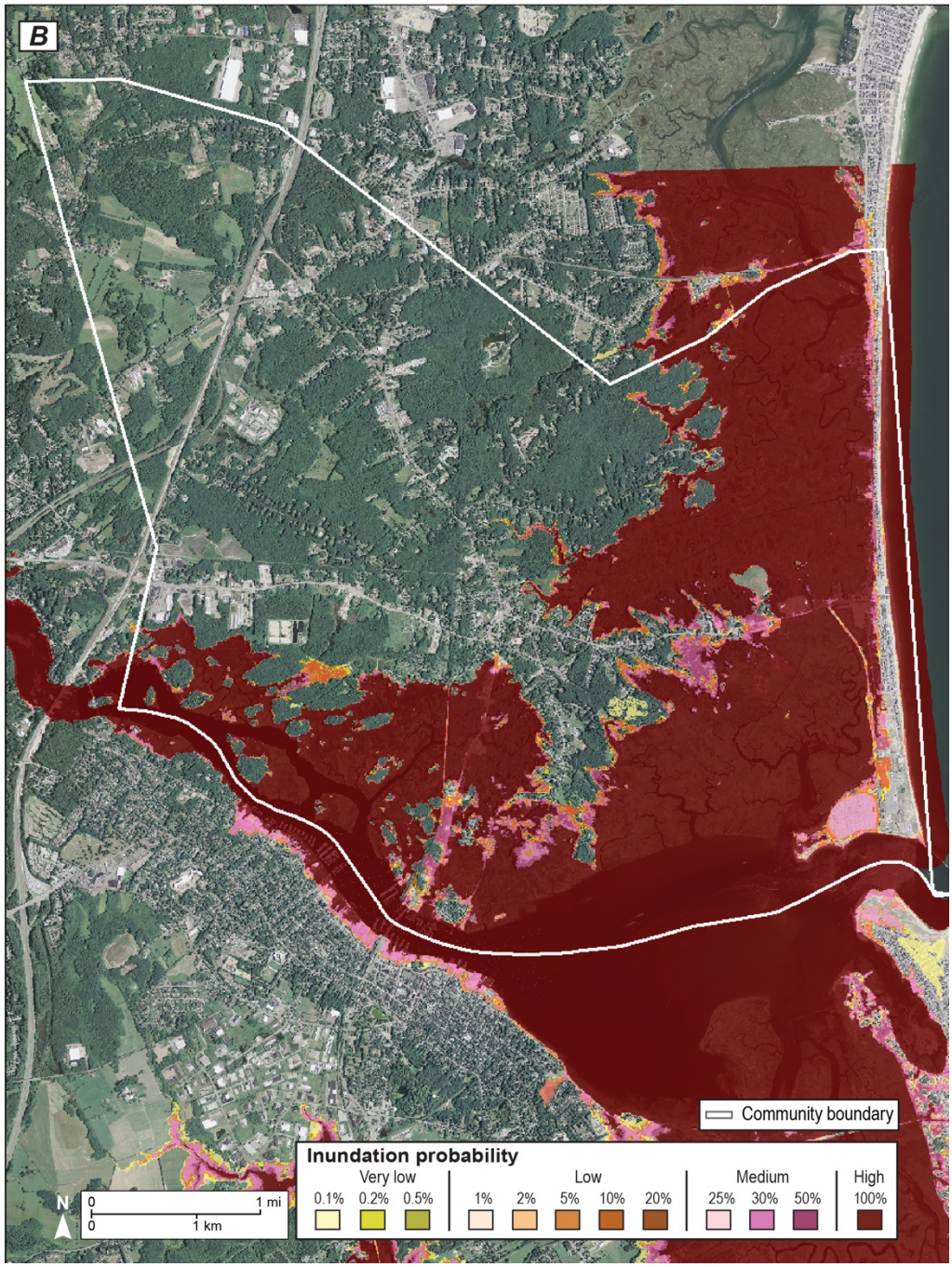

Figure 1-1.—Continued

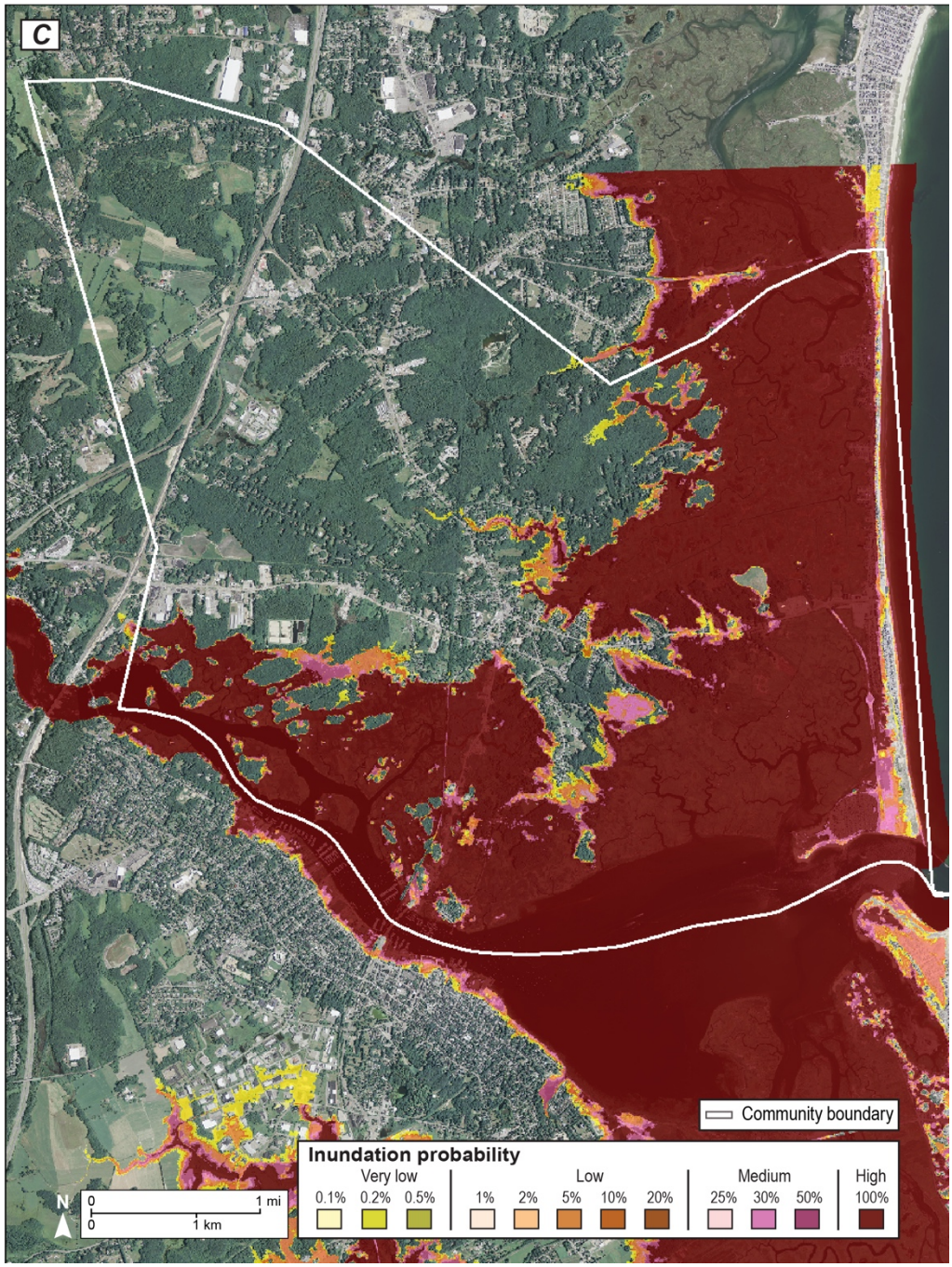

Figure 1-1.—Continued

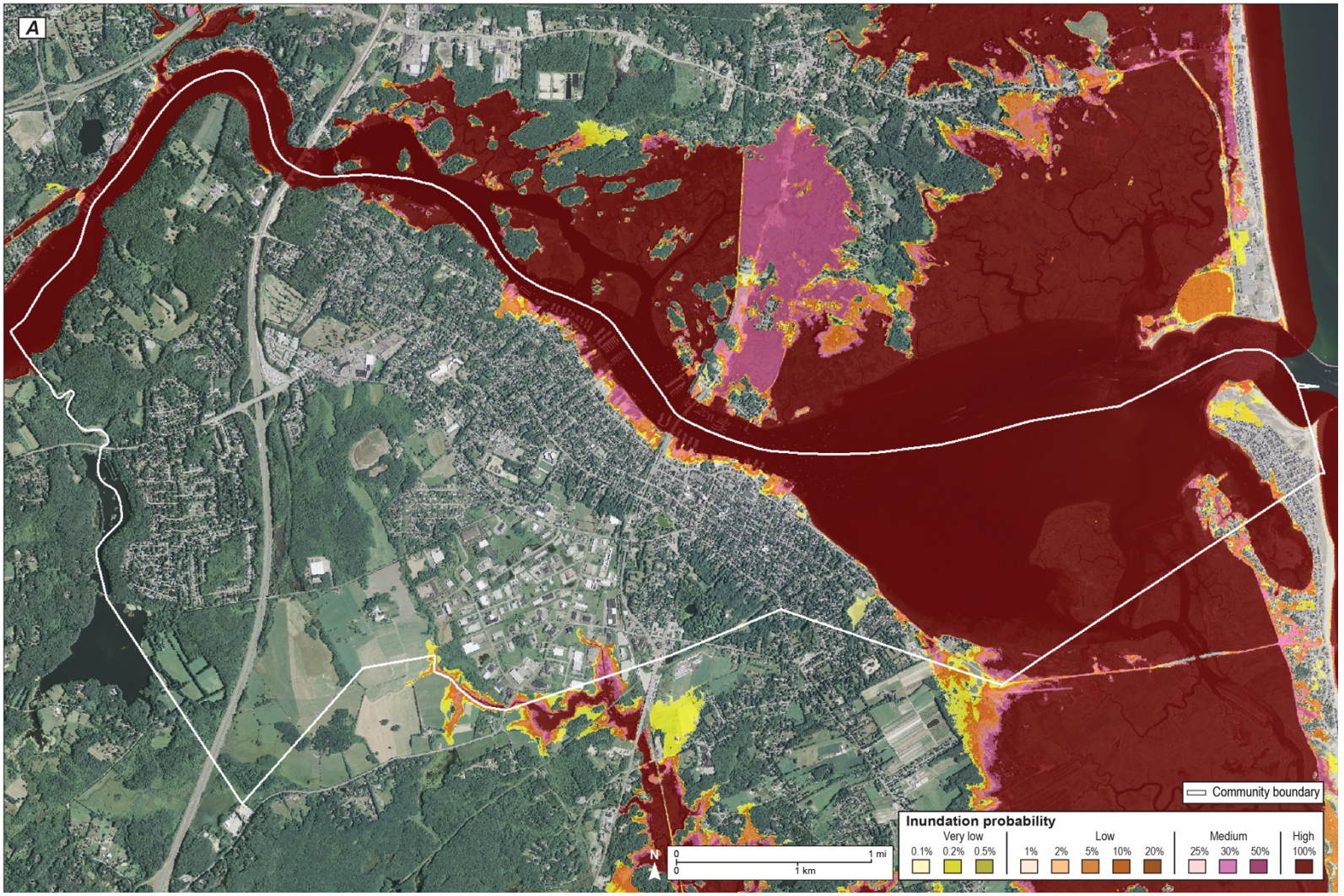

Figure 1-2. Maps of Newburyport, Massachusetts, coastal-inundation probability showing modeled hazard zones in (*A*) 2013, (*B*) 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). %, percent; mi, mile; km, kilometer.

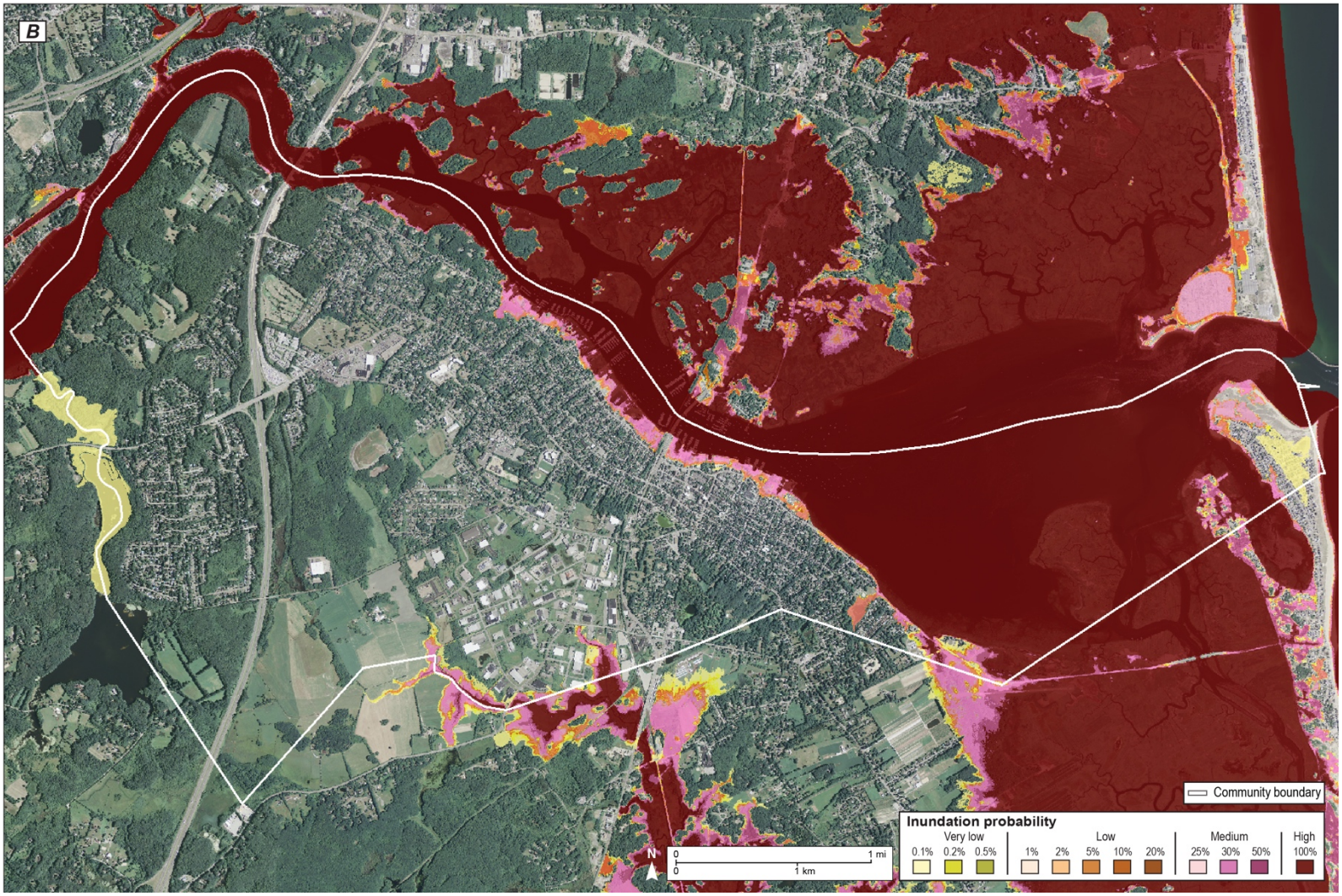

Figure 1-2.—Continued

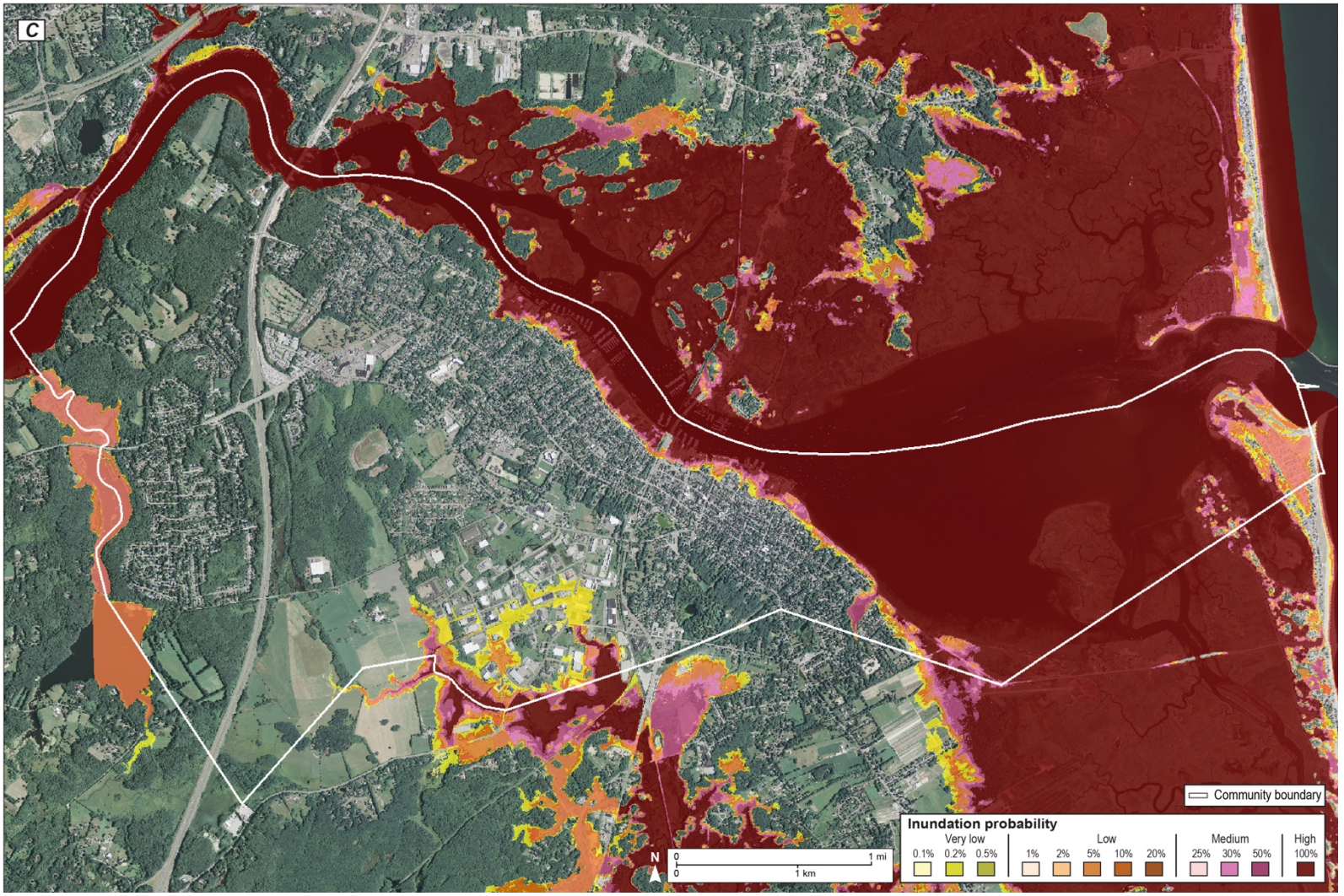

Figure 1-2.—Continued

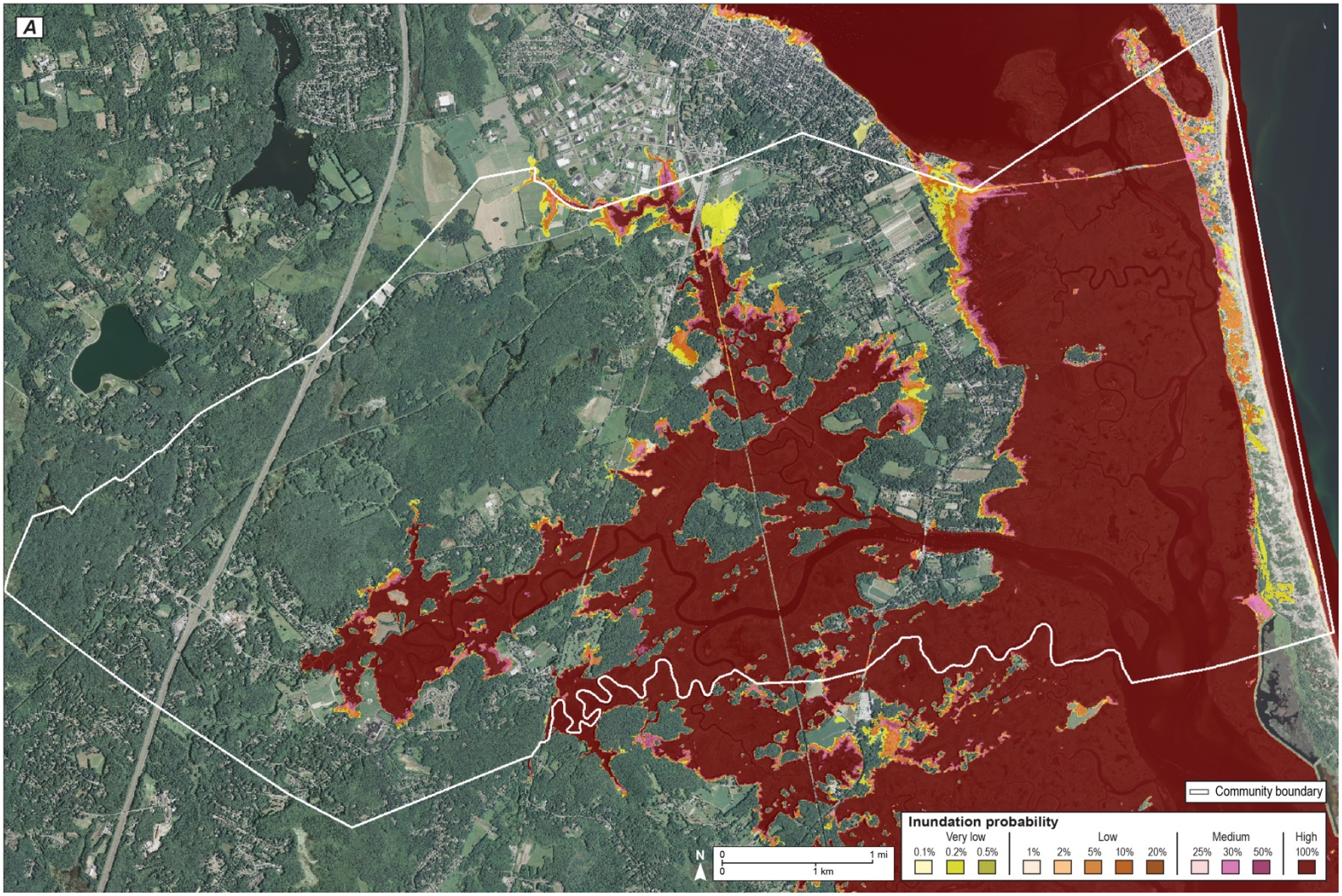

Figure 1-3. Maps of Newbury, Massachusetts, coastal-inundation probability showing modeled hazard zones in (*A*) 2013, (*B*) 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). %, percent; mi, mile; km, kilometer.

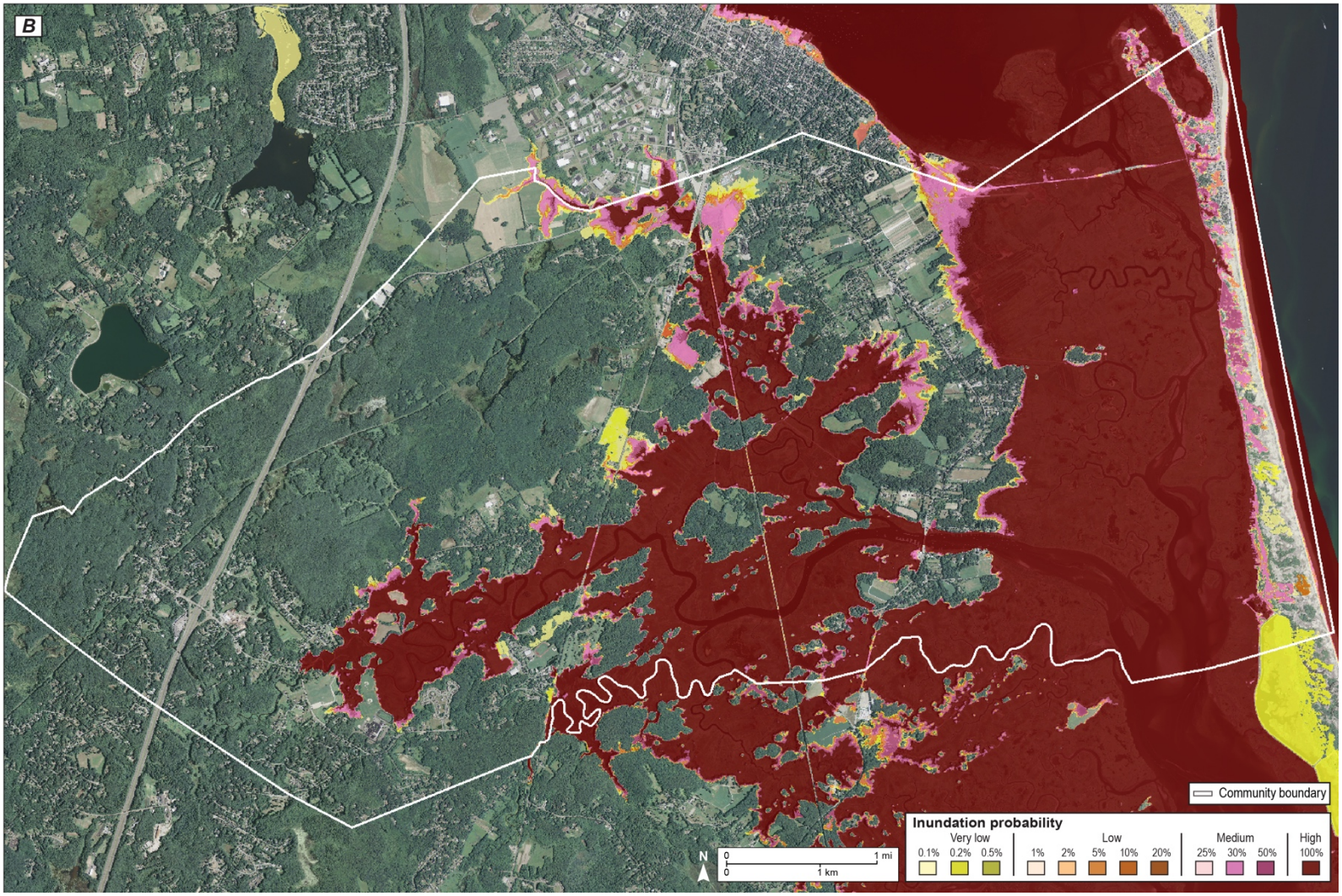

Figure 1-3.—Continued

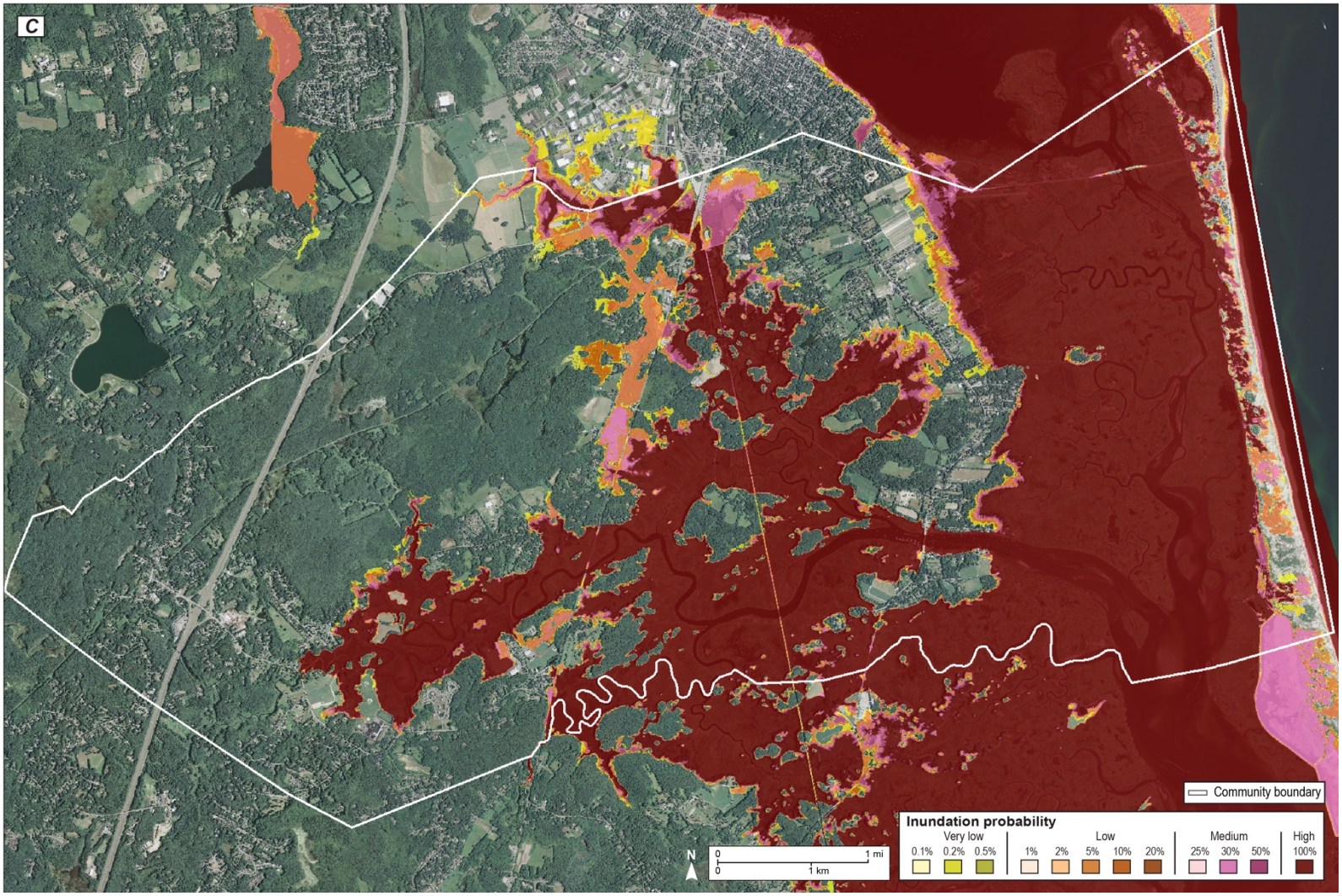

Figure 1-3.—Continued

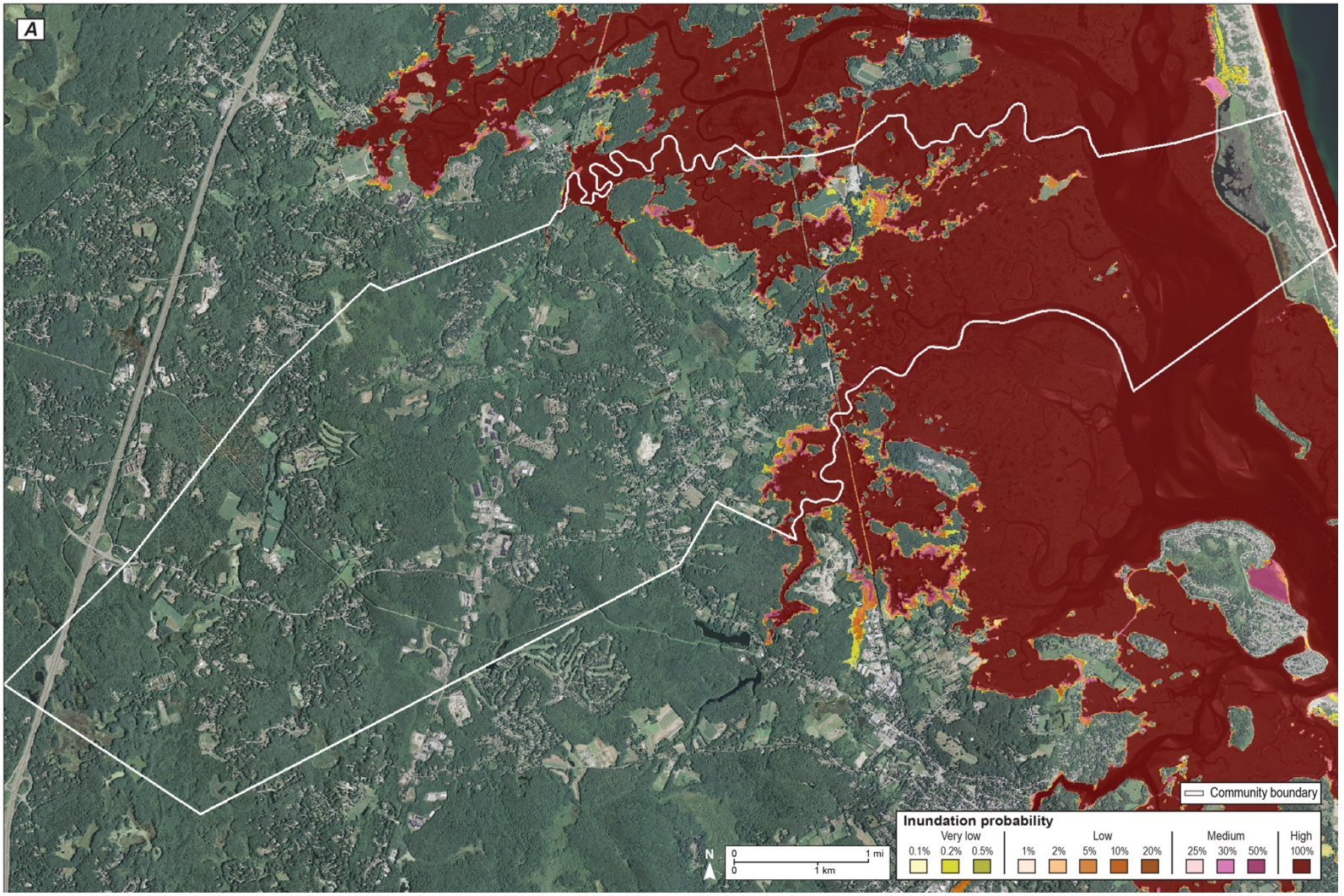

Figure 1-4. Maps of Rowley, Massachusetts, coastal-inundation probability showing modeled hazard zones in (*A*) 2013, (*B*) 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). %, percent; mi, mile; km, kilometer.

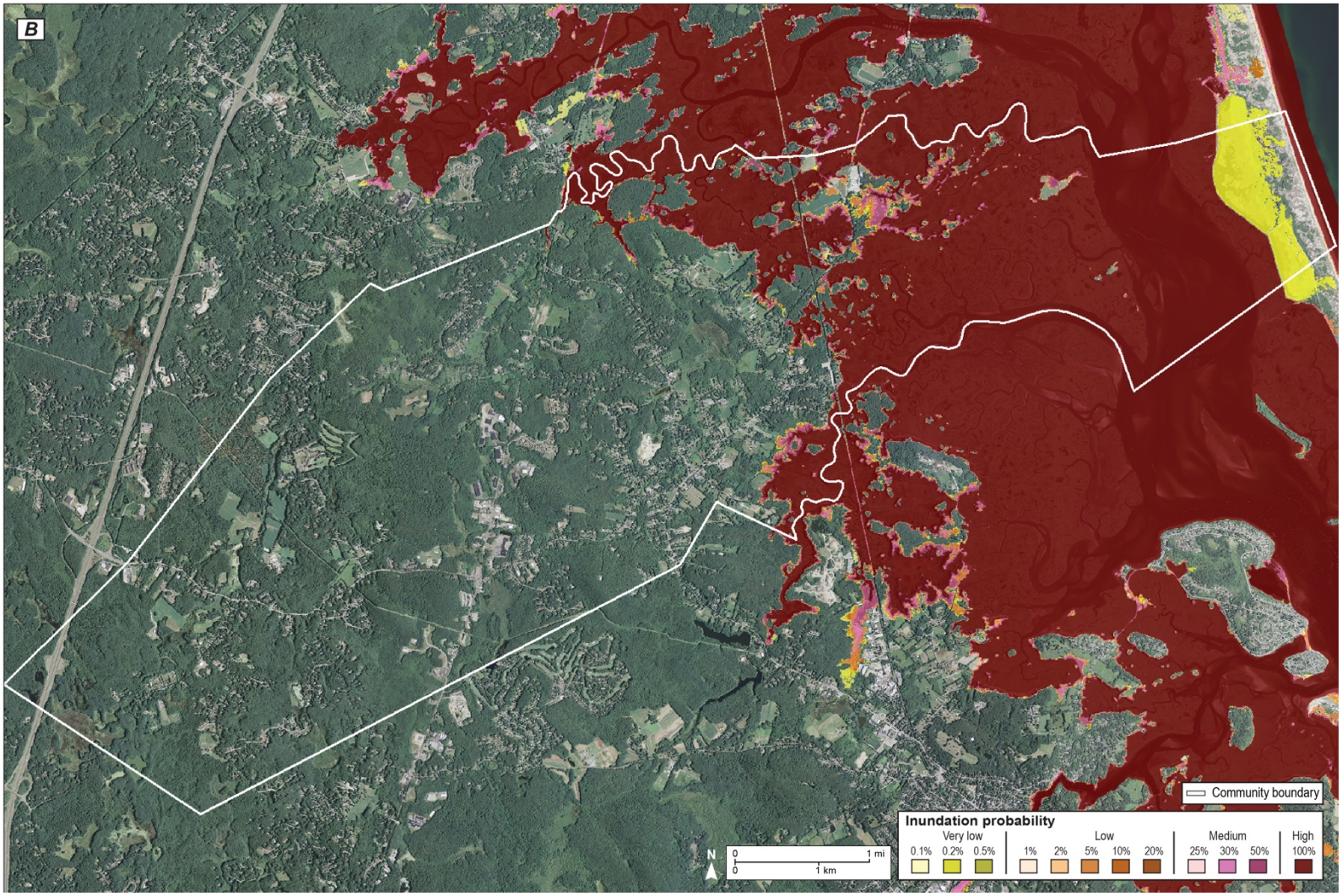

Figure 1-4.—Continued

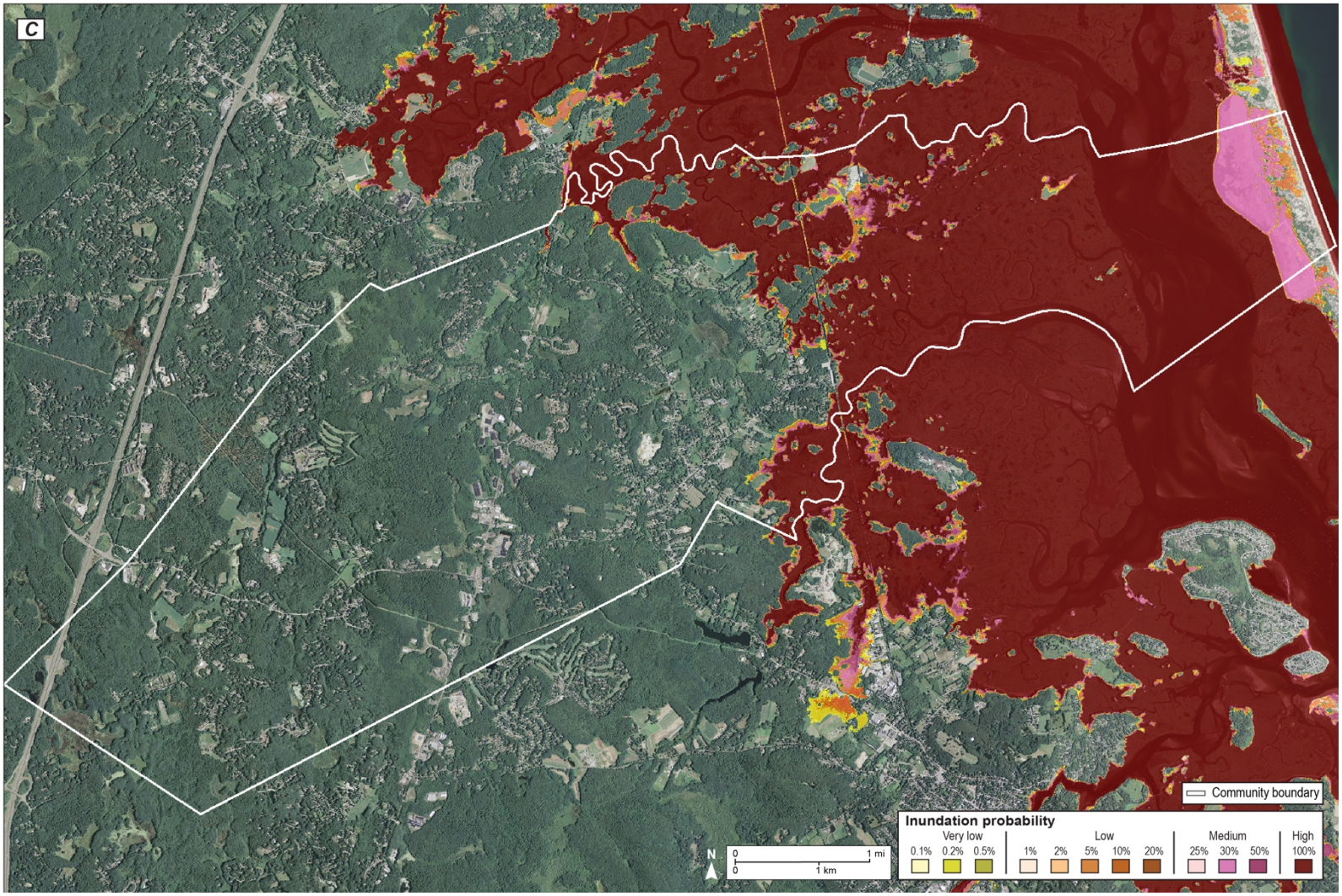

Figure 1-4.—Continued

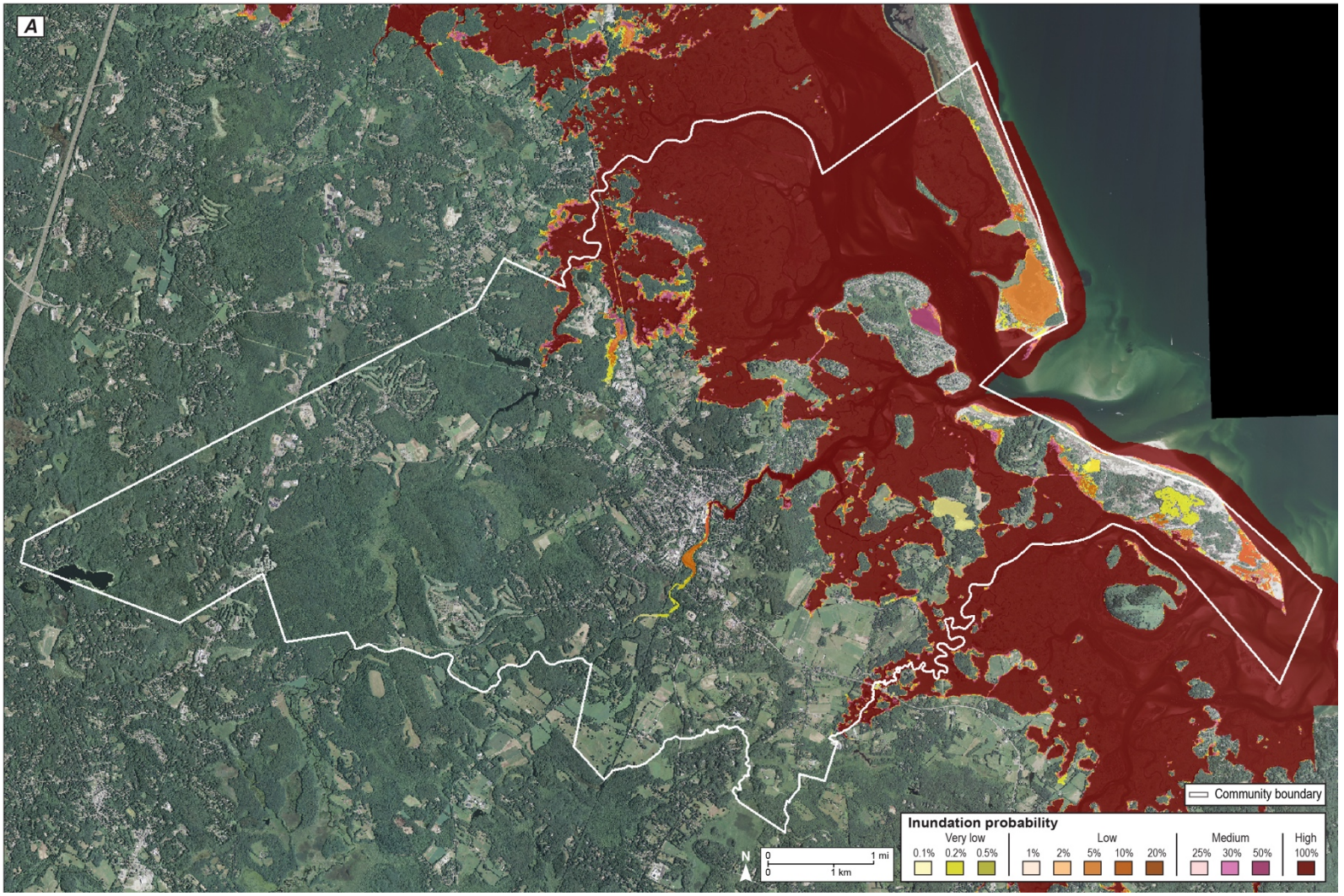

Figure 1-5. Maps of Ipswich, Massachusetts, coastal-inundation probability showing modeled hazard zones in (*A*) 2013, (*B*) 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). %, percent; mi, mile; km, kilometer.

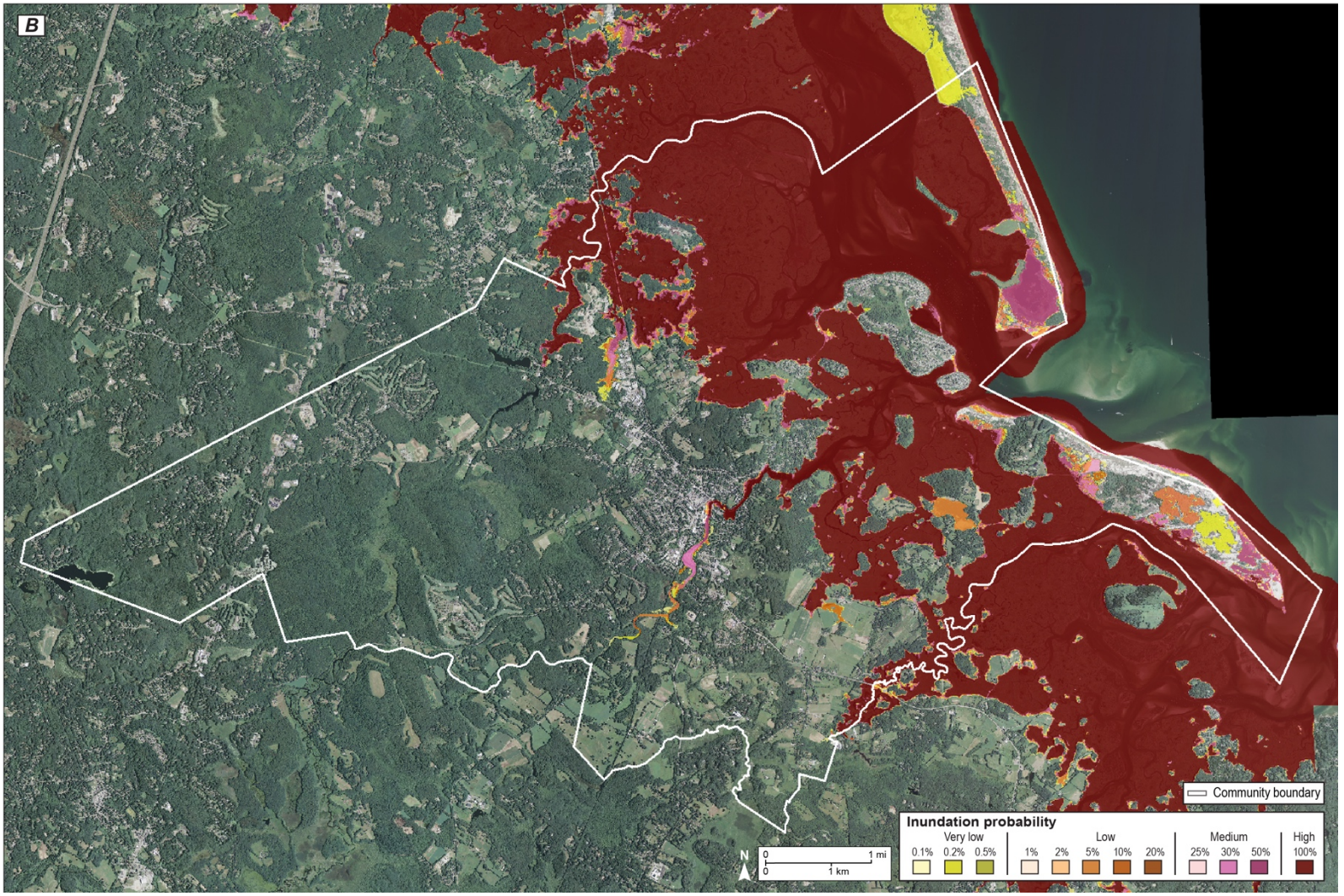

Figure 1-5.—Continued

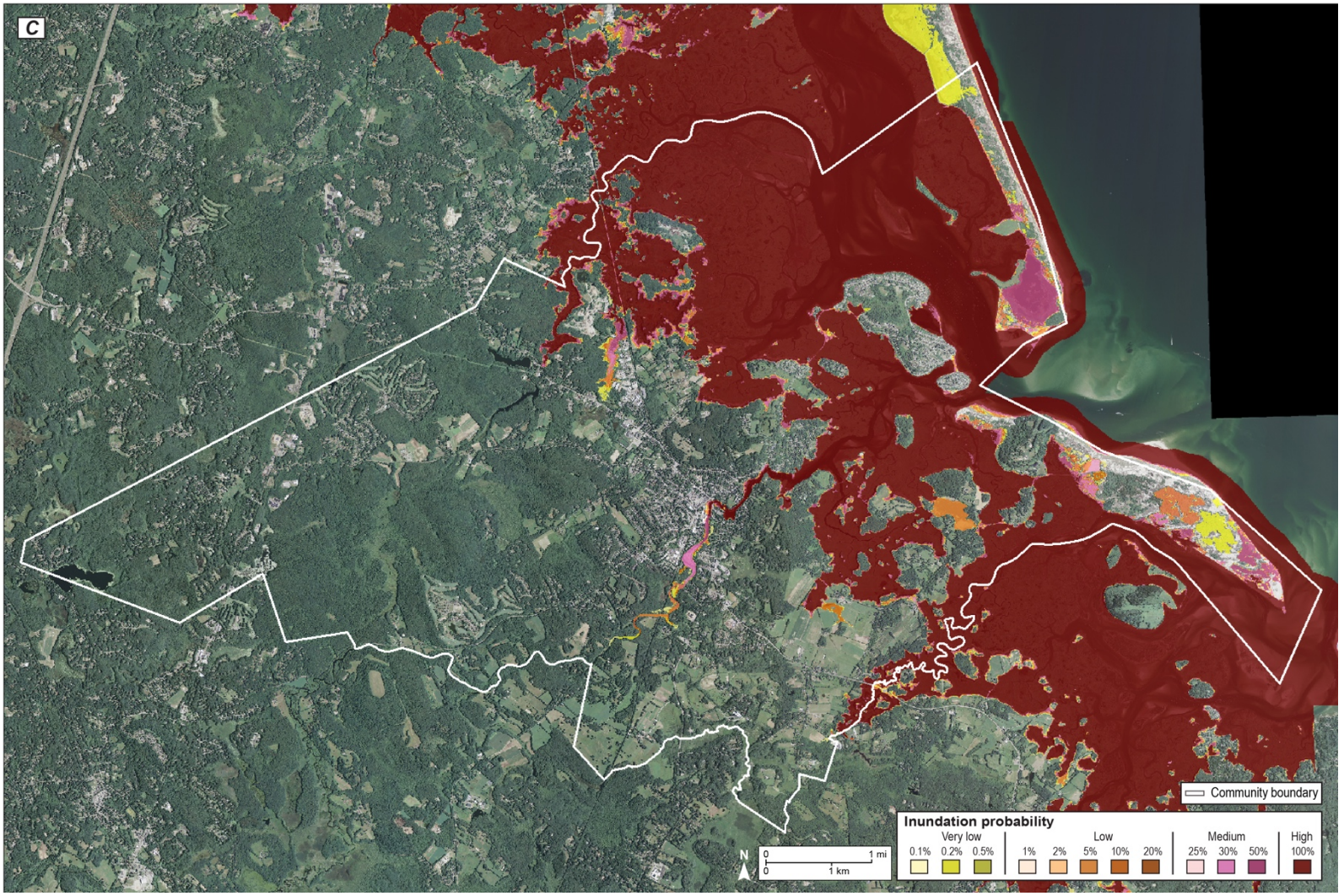

Figure 1-5.—Continued

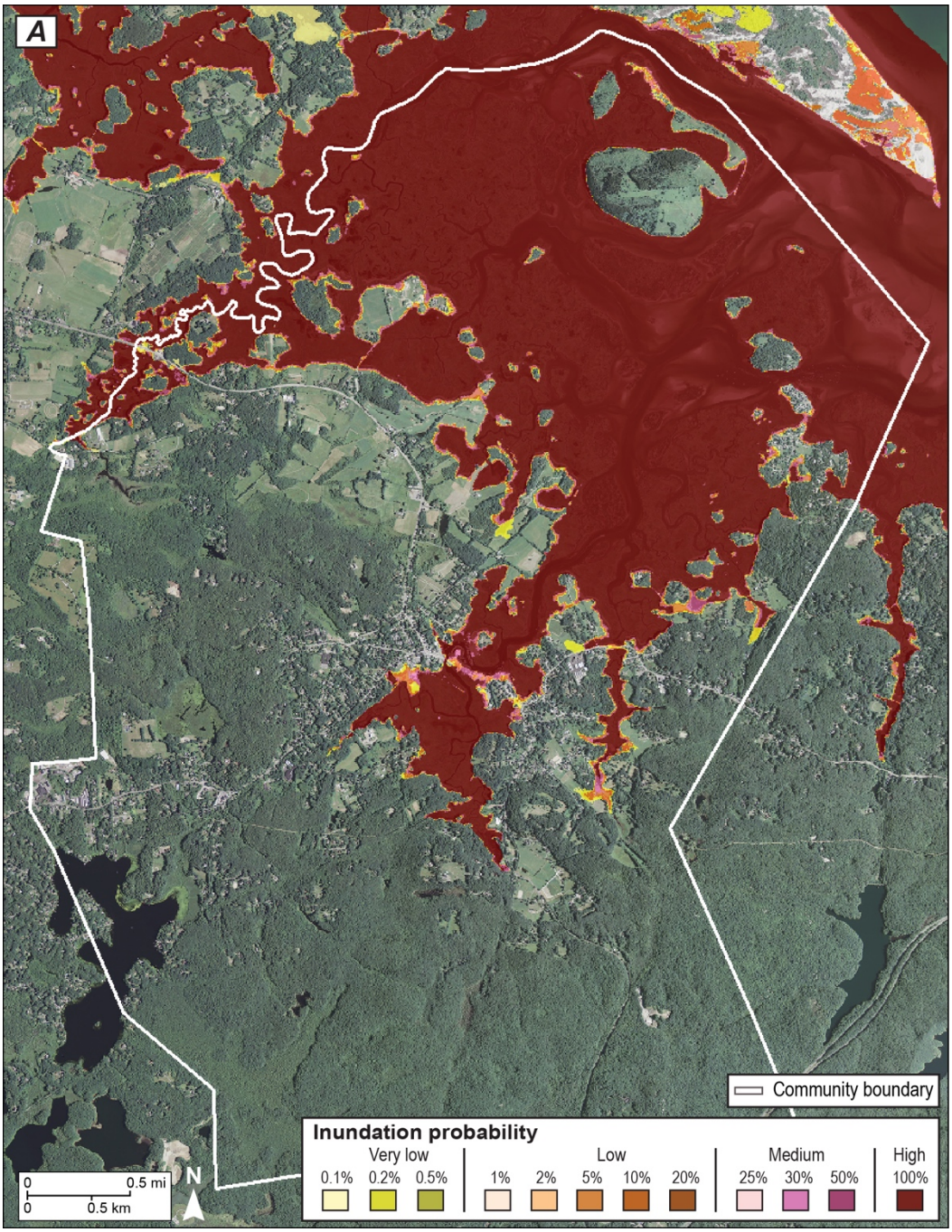

Figure 1-6. Maps of Essex, Massachusetts, coastal-inundation probability showing modeled hazard zones in (*A*) 2013, (*B*) 2030, and (*C*) 2070. Background imagery in each figure is 2014 data from the National Agriculture Imagery Program (U.S. Department of Agriculture, 2015). %, percent; mi, mile; km, kilometer.

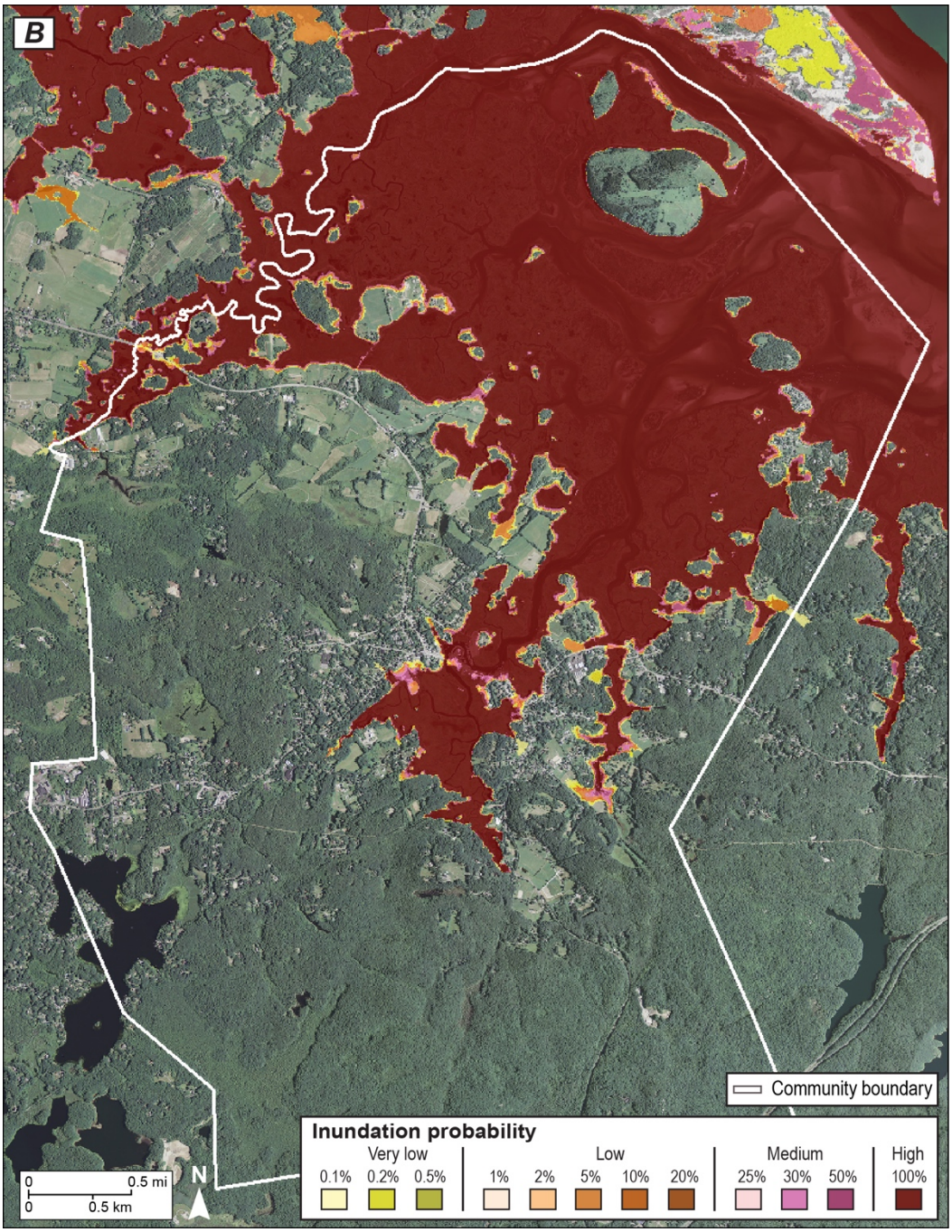

Figure 1-6.—Continued

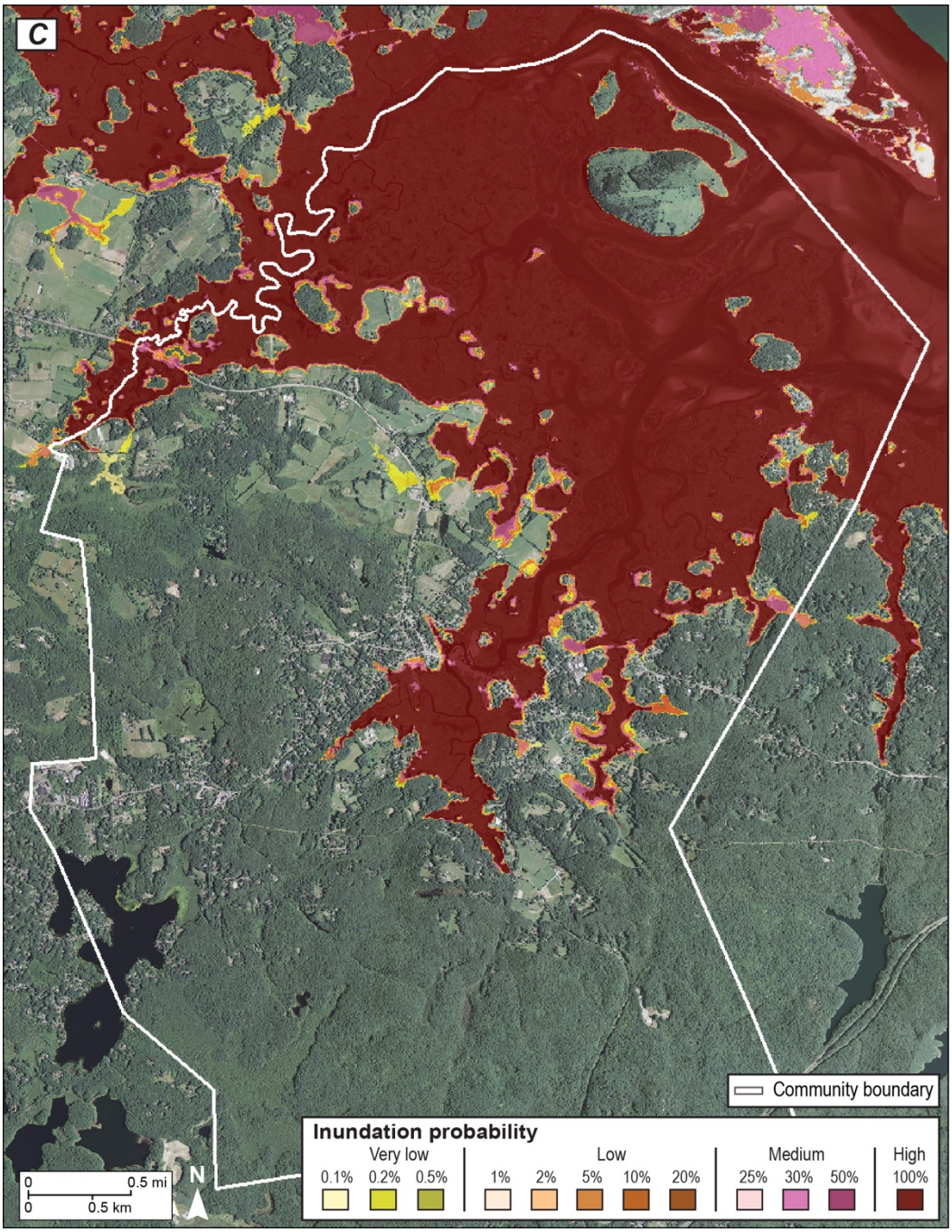

Figure 1-6.—Continued

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