Massachusetts Climate Change and Hazardous Waste Site Screening

Eric Mielbrecht, EcoAdapt[1]
Katelyn Tarrio, Boston University
6 December 2019

Abstract

Communities should expect resilient and sustainable hazardous waste site cleanup, but climate change is challenging current remediation approaches. This research is a first step in informing community leaders, state agencies and remediation managers of the potential vulnerabilities of Massachusetts's hazardous waste sites to climate change-related flooding and inundation. A simple model was developed and GIS tools were used to evaluate the potential vulnerability of a subset of 6,001 high-interest Massachusetts Department of Environmental Protection (MassDEP) listed sites based on their locations relative to FEMA flood hazard map zones, NOAA hurricane surge zones, NOAA sea level rise projections, remediation status, and key community and environmental parameters. 2,388 sites may be exposed to flooding or inundation because they are located within the FEMA 100 year flood risk zones (1% annual chance of flooding), Category 1 or 2 hurricane surge zones, or future one-foot sea level rise inundation zones. When including site sensitivity parameters based on remediation status, 1,707 of these sites showed potentially moderate or high site vulnerability (site vulnerability refactor scores greater than 1.66). When community and environmental sensitivity parameters are added, 2,299 sites showed potentially moderate or high overall vulnerability (overall vulnerability refactor scores greater than 1.66). The user is encouraged to examine results on a site-by-site basis, include local knowledge wherever possible to better understand why a site and adjacent community and environment may be vulnerable, and explore the factors that lead to this vulnerability in order to establish more resilient and sustainable remediation solutions.

Introduction

This research builds on a three-year collaboration spearheaded by the Sustainable Remediation Forum (SURF) that culminated in the report, *Resilient Remediation: Addressing Extreme Weather and Climate Change, Creating Community Value* (Maco et al. 2018). These authors found that climate change can undermine the effectiveness of the original site remediation design and also impact contaminant toxicity, fate and transport, exposure, organism sensitivity, and long-term operation, management, and stewardship of remediation sites. Using principles that address these concerns, researchers from EcoAdapt, Boston University, SURF, MassDEP and the private sector surveyed hazardous waste sites in Massachusetts to identify potential risks to public health and the environment due to climate change-linked extreme weather events and sea level rise caused flooding and inundation. A subset of 6,001 hazardous waste sites were evaluated from a total universe of approximately 50,000 waste sites across the state. The subset of high-interest sites was selected based on several high-risk site characteristics including active site assessment and remediation (e.g. "open" sites), the presence of institutional controls (e.g. activity & use limitations) and the presence of focused risk abatement measures (e.g.

[1] EcoAdapt, P.O. Box 11195, Bainbridge Island, WA 98110. Eric.Mielbrecht@EcoAdapt.org

active exposure pathway mitigation measures). The survey also considered population density, demographics, environmental justice concerns, important community infrastructure, water resources, core wildlife habitat and critical environmental features. The goal is to inform communities adjacent to hazardous waste sites and the MassDEP Bureau of Waste Site Cleanup (BWSC) of potential risks and to provide information that encourages more resilient and sustainable long-term remediation approaches.

National research shows that nearly two million people in the United States live within one mile of one of the 327 Superfund sites in areas vulnerable to sea level rise or prone to folding caused by climate change-related extreme weather. Disadvantaged and minority neighborhoods are often at the greatest risk due to location and availability of resources (Dearen et al. 2017). The 2017 and 2018 hurricane seasons revealed that hazardous waste sites can be inundated by floodwaters, which can result in the release of toxic contaminants (Maco et al. 2018). MassDEP department leaders and community members are curious how extreme weather-related flooding and sea level rise due to climate change may affect that state's contaminated sites.

This research explores the potential exposure of listed hazardous waste sites to flooding and inundation through comparing hazardous waste site locations and projected sea level rise inundation models, hurricane surge models, and Federal Emergency Management Agency (FEMA) flood hazard maps. It also explores the potential sensitivity of sites to this flooding and inundation based on site management remedies and the potential sensitivity of the communities and environment around the sites.

Screening Model

A simple risk-screening model was developed to understand the potential vulnerability of hazardous waste sites and adjacent communities and environment. This was adapted from current climate change vulnerability assessment guidance (Glick et al. 2011). Throughout this project, vulnerability is considered a combination of exposure and sensitivity. Exposure refers to the character, magnitude and rate of climate-related change or impact a site is experiencing or is likely to experience. Sensitivity here refers to the characteristics of a site that confer tolerance or intolerance to changes or impact resulting from the exposure factors investigated. This approach to assessing vulnerability helps identify which site components are likely to be affected, in this case by flooding or sea level rise inundation, and why these components are likely to be vulnerable.

The vulnerability models are summarized below.

> Hazardous Waste Site Vulnerability = Site flooding and Inundation Exposure + Site Sensitivity
>
> Overall Vulnerability = Hazardous Waste Site Vulnerability + Community Sensitivity + Environment Sensitivity

The components of site exposure used are FEMA flood hazard maps (100 year or 1% annual chance, 500 year or 0.2% annual chance, or other FEMA risk zones), coastal hurricane surge zone maps by hurricane intensity, and projected sea level rise inundation maps (the latter two both made available by the National Oceanic and Atmospheric Administration (NOAA)).

Indicators for the potential sensitivity of hazardous waste sites to flooding and sea level rise inundation were derived through consultation with MassDEP staff and available information in MassDEP's hazardous waste site and Reportable Releases Database. This study focused on the following five

parameters considered "high-risk": site status open or closed, active remediation system in place or not, active exposure pathway mitigation measure in place or not, potential imminent hazard exists or not, and critical exposure pathway for human risk exists or not.

The potential sensitivity of communities adjacent to each screened hazardous waste sites was also investigated to better understand the potential for impact to people if a release of contaminants occurred when a site became flooded or inundated. Population density, including elderly and children proportions, environmental justice indices, and proximity of schools and hospitals were considered.

The potential sensitivity of key adjacent environmental receptors and habitats was also investigated to better understand the potential for impact to the environment. Environmental sensitivity was derived from the proximity of areas of critical environmental concern, identified core habitat, BioMap-identified critical natural landscape, and public water supplies (including surface water protection zones, wellhead protection areas, and aquifers).

Methods

Data sources

Hazardous waste site information used for this study were generated by MassDEP and represent the most recent statewide information as of November 2018. Site data include the same information listed in publicly available database files for all regulated waste site cleanup notifications (e.g. site name, address, chemical type, etc.) along with additional site-specifics provided by MassDEP, such as remediation system information and chemical risk classifications[2]. A subset of 6,001 high-interest MassDEP sites were evaluated from a total universe of approximately 50,000 waste sites across the state.

Additional data used in this study were obtained from the Massachusetts Bureau of Geographic Information (MassGIS)[3], the state's official geospatial database. Table 1 lists datasets used along with a description, author name (with informational contributors in parenthesis), year created, date of most recent update and the source; detailed information on data development and version history can be found in links to cited documentation listed in the metadata (Appendix A).

Table 1. Dataset information for variables considered in analysis.

Dataset name	Description	Dataset author (contributor) & Source	Created	Date last updated
FEMA National Flood Hazard Layer	Current effective flood risk boundaries as defined by FEMA; includes all counties in Massachusetts except Berkshire, Franklin, Hampshire and the north western half of Worcester	MassGIS (FEMA) MasGIS data portal[2]	2017	7/25/2017
FEMA Q3 Flood Zones	Flood risk boundaries as defined by Flood Insurance Rate Maps (FIRMs); includes	MassGIS (FEMA)	1997	6/1/2015

[2] https://www.mass.gov/find-out-about-a-contaminated-property
[3] https://www.mass.gov/orgs/massgis-bureau-of-geographic-information

	Berkshire county, Hampshire county and the north western half of Worcester	MasGIS data portal[2]		
Hurricane Surge Inundation Zones	Worst-case hurricane storm surge inundation areas for Category 1 through 4 hurricanes; statewide coverage	MassGIS (U.S. Army Corps of Engineers, New England District) MasGIS data portal[2]	2013	10/23/ 2013
Sea Level Rise Data (Massachusetts)	Inundation zones for 1 through 6 feet of sea level rise for coastal counties in Massachusetts	National Oceanic and Atmospheric Administration (NOAA) MasGIS data portal[2]	2016	2017
Major Watersheds	Full watershed basin delineations (as defined by the United States Geological Survey (USGS) Water Resources Division)	MassGIS (USGS) MasGIS data portal[2]	2000	1/10/2017
2010 US Census Environmental Justice Populations	Block groups meeting the following criteria (developed by the Executive Office of Energy and Environmental Affairs (EOEEA)): 1) >= 25% minority population 2) median household income <= median household income for the state of Massachusetts in 2010 3) >= 25% of households identifying as 'English isolated'	MassGIS (EOEEA) MasGIS data portal[2]	2012	12/11/ 2012
Massachusetts Schools (Pre-K through High School)	Locations of schools listed in the Massachusetts Department of Elementary and Secondary Education (DESE) school profile database; includes public, vocational, technical, private, charter and special education (approved and unapproved) schools	MassGIS MasGIS data portal[2]	2015	6/3/2019
Acute Care Hospitals	Locations of acute care hospitals listed in the Massachusetts Department of Public Health (DPH) database; includes medical-surgical, pediatric, obstetric and maternity beds	MassGIS MasGIS data portal[2]	2009	2018
Areas of Critical Environmental Concern	Boundaries for areas designated as unique concerns by the Secretary of Energy and Environmental Affairs	MassGIS MasGIS data portal[2]	2009	10/16/ 2013

BioMap: 2 Core Habitat	Ecosystem communities designated as necessary for ensuring sustainable persistence of species listed under the Massachusetts Endangered Species Act and the State Wildlife Action Plan	MassGIS (Massachusetts Natural Heritage & Endangered Species Program, The Nature Conservancy) MasGIS data portal[2]	2010	2/28/2011
BioMap2: Critical Natural Landscape	Landscape blocks determined to enhance ecological resilience of intact landscapes as identified by the Massachusetts Natural Heritage & Endangered Species Program	MassGIS (Massachusetts Natural Heritage & Endangered Species Program, The Nature Conservancy) MasGIS data portal[2]	2010	2/28/2011
Public Water Supplies	Locations of public and non-public community surface and groundwater supply sources	MassGIS (Massachusetts Department of Environmental Protection (MassDEP)) MasGIS data portal[2]	1997	4/11/2019
Surface Water Supply Protection Areas	Surface water supply areas designated for protection in the Massachusetts Drinking Water Regulations Act	MassGIS MasGIS data portal[2]	2007	5/15/2017
MassDEP Wellhead Protection Areas (Zone I, Zone II, Interim Areas)	Areas critical for protecting recharge area surrounding public water supply groundwater resources as determined by MassDEP	MassGIS (MassDEP) MasGIS data portal[2]	1999	4/11/2019
US EPA Designated Sole Source Aquifers	Aquifer boundaries designated by the EPA as being a 'sole or principal source' of drinking water for a service area	MassGIS (Department of Conservation and Recreation) MasGIS data portal	1996	
Aquifers	Aquifer boundaries for high, medium and low yield aquifers found in major drainage basins of mainland Massachusetts	MassGIS MasGIS data portal[2]	2007	12/5/2018

US Census Bureau, 2013-2017 American Community Survey 5-Year Estimates	Demographic and housing estimates for each town in Massachusetts, including general populations, populations of adults aged 65 and older and populations of children under 5 years old	US Census Bureau US Census Bureau's American Fact Finder website[4]	2013	2013

Parameters assessed in this study were selected based on relevance to human and environmental risk as well as data availability. Presently, the FEMA National Flood Hazard Layer dataset, along with the FEMA Q3 Paper FIRMs supplement for western Massachusetts and the NOAA Hurricane Surge Inundation Zones were the only statewide flooding assessments available. Similarly, NOAA's sea level rise inundation projection maps were the only spatially explicit, statewide data-layer available. Projected future shifts and expansions of annual flood and storm surge areas are not currently available in a high spatial resolution format for the entire state. Thus, sea level rise is the only projected climate change-linked parameter considered in this analysis.

GIS approach

Hazardous waste site addresses (as listed in MassDEP database files) were converted into geographic coordinates using a geocoding application from the Google Cloud Platform which references Google Maps to locate addresses. Some coordinates retrieved through this method were incorrect due to improper address listings in the original MassDEP database files. To ensure proper mapping locations, site coordinates were filtered and checked for accuracy with the following methods:

1) Sites whose addresses were listed without a number in DEP database files (e.g. "Corner of Erie St and Brookline St") were removed from analysis;
2) A spatial join operation was performed to link geolocated sites with an underlying Massachusetts Communities and Boundaries base layer from MassGIS, and sites whose database-listed city/town did not match the spatially joined city/town were removed from analysis; and
3) A random sample of 15 sites was manually checked for location accuracy.

Sites were referenced by their unique MassDEP-established Routine Tracking Numbers (RTN) throughout analyses to maintain site data consistency. To ensure geospatial consistency, all spatial data were projected to the official projection used by MassGIS: North American Datum 1983 (NAD83) Massachusetts State Plane Coordinate System, Mainland Zone (Fipszone 2001), with units in meters.

Buffer zones were calculated around point locations to spatially represent contaminated areas of a site. A 30-meter radius was calculated around each site, creating an area of roughly 2,827 square-meters (8,492 square-feet) to represent each site (Figure 1). This 30-meter buffer was used as a proxy given actual chemical contamination boundaries are unknown; in general, the 30-meter buffer area captures the property boundaries of many sites, though there is uncertainty in this approximation. Buffer zones were also calculated for environmental and community receptor locations. MassDEP specifies a 152-meter (500-foot) boundary from waste site cleanups for most receptors, and as such this measurement

[4] https://factfinder.census.gov

was used as the buffer radius for select receptor features as represented by MassGIS (whether point or polygon data).

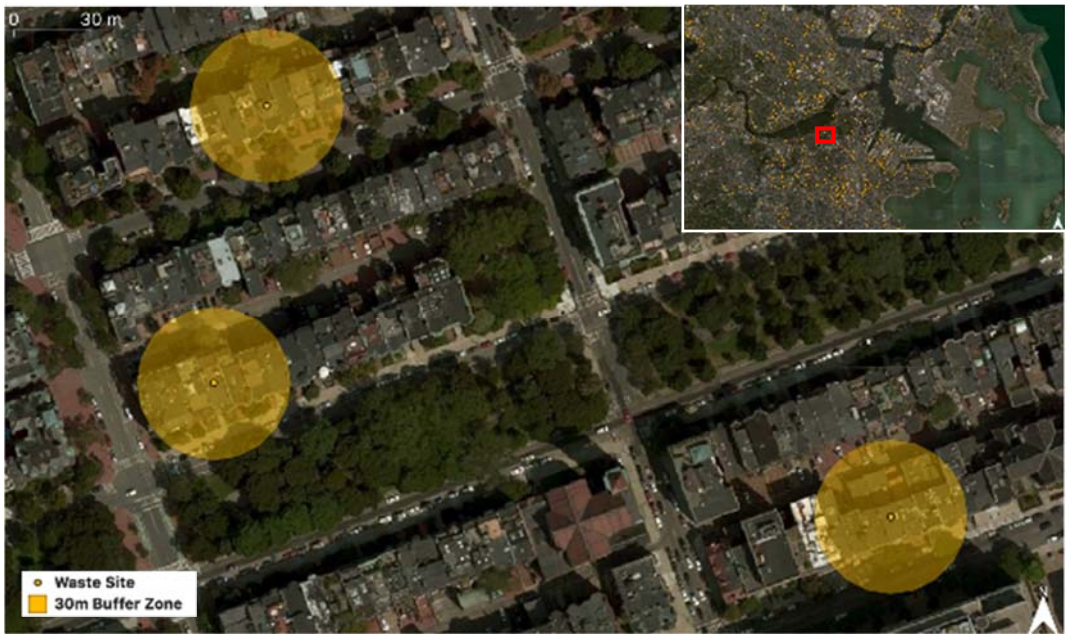

Figure 1. Waste site area approximations in the Back-Bay area of Boston.

Waste site area approximations were then mapped alongside flooding layers and community/environmental buffer zones to identify areas of potential exposure. This overlapping spatial information was extracted and appended to the waste site attribute table to form the final screening table. Occasionally, approximated site boundaries fell within multiple flood zones (Figure *2*), creating a many-to-one relationship; sites of these types were assigned to whichever flood zone label had the highest probability of occurrence (1% versus 0.2% for FEMA flood layers and ascending hurricane categories for storm surge) to conservatively represent flooding exposure. Site proximity to community and environmental receptors was recorded as a binary (yes/no) indicator of whether a site fell within variables with a 500-foot boundary. For receptor data that do not directly concern site approximated area, such as whether the site is located atop an aquifer, receptor attributes were spatially joined to sites from data layers underlying the point data. Population densities were calculated as persons (either general, older adults or children) per square mile of a city or town and appended to sites based on the city or town in which a site was located.

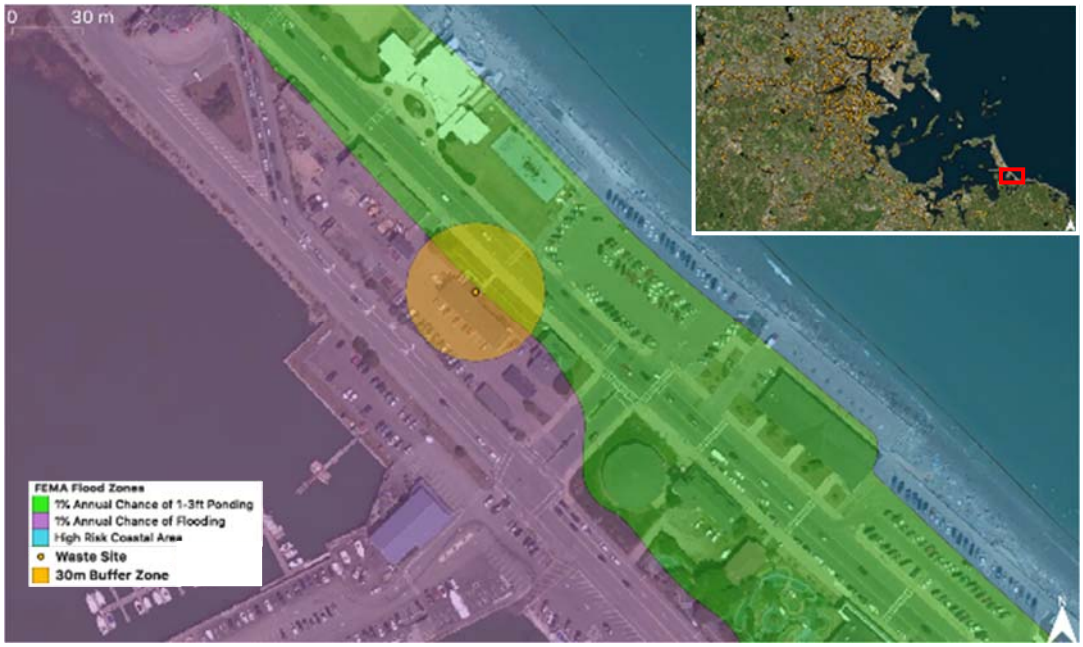

Figure 2. Example of multiple flood zones within site area approximations in the Hull Bay area.

Ranking and Scoring

Vulnerability indices were designed to summarize the multicriteria risk factors at each waste site. As numerous variables assessed in this study are represented in different systems and have different ranges (e.g., 'hurricane categories' for storm surge data, environmental justice block criteria, population densities, etc.), all non-binary information used for vulnerability analyses was reclassified into a common risk scale, with 1 representing the lowest rank (Table *2*).

Flood data were ranked based on inundation likelihood to make all climate data comparable. As outlined in Table 2 current flood risk probabilities were reclassified on a scale of 1 to 3, with all types of 1% likelihood floods (ponding, riverway overflows, etc.) assigned the highest risk score. Hurricane storm surge values were inversely reclassified to represent flooding probability: a Category 1 hurricane has a higher probability of occurrence than a Category 2 hurricane and thus it received the highest score (a 4); a Category 2 hurricane has the second highest occurrence probability of this class, as thus received a score of 3, and so forth. Similarly, projected sea level rise data (which range from 1-6 feet) were inversely scored (i.e., 1-foot sea level rise zones were assigned scores of 6, 2-foot zones were assigned scores of 5, etc.).

To characterize community and environmental factors, a simple model was constructed in which binary (yes-1/no-0) variables were summed together. The non-binary receptors of population density and environmental justice designations were reclassified in a similar way to climate data (Table *2*). Population density factors (people per square mile) for the surrounding city/town of a site were reclassified based on a standard five-number summary of population data distribution (the boxplot method); these descriptive statistics were calculated statewide for comparability and were assigned on a 1 to 3 scale, with 1 indicating 'low' population density and 3 representing 'high' population density. For environmental justice criteria, communities surrounding a site were reclassified with a social vulnerability scale from 1 to 3, where a score of 1 indicates a community block with a single

disadvantage factor (i.e., low income *or* minority *or* English isolated), 2 indicates blocks at a disadvantage for two criteria, and 3 indicates all three criteria impact a block.

The five site sensitivity factors derived from the MassDEP hazardous waste site information database were binary in nature (yes-1/no-0) and simply summed for each location. These were: site status open or closed, active remediation system in place or not, active exposure pathway mitigation measure in place or not, potential imminent hazard exists or not, and critical exposure pathway for human risk exists or not.

Table 2. Risk factor scoring scheme for non-binary variables.

	Reclassification scoring					
Score	**6** (highest risk)	**5**	**4**	**3**	**2**	**1** (lowest risk)
Flooding	NA	NA	NA	1% floods (includes: High Risk Coastal Areas, Regulatory Floodways, 1% Annual Chance of Flooding, with or without BFE, 1% Annual Chance of 1-3ft Sheet Flow Flooding or Ponding)	0.2% Annual Chance of Flooding	Reduced Risk from Levee
Hurricane Storm Surge	NA	NA	Category 1 Hurricane (most likely)	Category 2 Hurricane (moderately likely)	Category 3 Hurricane (less likely)	Category 4 Hurricane (least likely)
Sea Level Rise Inundation	1ft Sea Level Rise	2ft Sea Level Rise	3ft Sea Level Rise	4ft Sea Level Rise	5ft Sea Level Rise	6ft Sea Level Rise
Environmental Justice Criteria	NA	NA	NA	Minority & Income & English Isolation	Minority & Income, or Minority & English Isolation, or Income & English Isolation	Minority (M) or Income (I) or English Isolation (E)
Population Density (General, Adults 65+, Children <5)	NA	NA	NA	Population Density >75th Quartile	Population Density in the Interquartile Range	Population Density <25th Quartile

After all variables were converted into common risk scores, exposure, sensitivity and vulnerability indices were calculated according to the definitions listed in Box 1. Score sums were refactored and standardized on a zero to five scale for equal weighting when combining. No distinction was made between the relative importance of any specific environmental, social or site-specific feature as the ultimate goal of this study's screening is to provide a data record of site information. Higher numeric scores are only meant to suggest which waste sites should be investigated further for site-specific adaptation measures.

Box 1. Explanations of exposure, sensitivity and vulnerability indices and scores.

Flooding Exposure = ∑ Ranked flooding risk zones (FEMA NFHL, Q3 Flood zones, Hurricane storm surge zones) a site is exposed to. (Theoretical range 1-7, 0 indicates no exposure determined. Results range 0-7.)

Future Sea Level Rise Exposure = ∑ Ranked sea level rise inundation zones a site is exposed to. (Theoretical range 1-6, 0 indicates no exposure determined. Results range 0-6.)

Environmental Sensitivity = ∑ Binary indicators for protected environmental areas and water resource boundaries in close proximity to a site. (Theoretical range 1-10, 0 indicates no sensitivity determined. Results range 0-7.)

> Environmental Receptor Sensitivity = ∑ Binary indicators for 500ft zones (Area of Critical Environmental Concern, Public Water Supplies, Surface Water Protection Zones, Wellhead Protection Zone (I and II), Interim Wellhead Protection Area) + ∑ Binary indicators for immediate zones (BioMap Core Habitat, BioMap Critical Natural Landscape, Sole Aquifers, High/Medium Yield Aquifers)

Environmental Sensitivity Refactor = (Environmental Sensitivity score ÷ maximum Environmental Sensitivity score) x 5. (Range 1-5, 0 indicates no sensitivity determined.)

Community Receptor Sensitivity = ∑ Binary indicators for social risk factors in surrounding community of a site. (Theoretical range 1-14, 0 indicates no sensitivity determined. Results range 3-17.)

> Community Receptor Sensitivity = ∑ Binary indicators for social risk factors (Population density, Density of adults aged 65+, Density of children age 0-5, Environmental Justice Indices) + ∑Binary indicators for 500ft zones (Schools k-12, Acute Care Hospitals)

Community Sensitivity Refactor = (Community Sensitivity score ÷ maximum Community Sensitivity score) x 5. (Range 1-5, 0 indicates no sensitivity determined.)

Community-Environmental Refactor = [(Community Sensitivity Refactor + Environmental Sensitivity Refactor) ÷ (maximum Community Sensitivity Refactor + maximum Environmental Sensitivity Refactor)] x 5.

Site Climate Exposure = Flooding Exposure + Future Sea Level Rise Exposure. (Theoretical range 1-13, 0 indicates no exposure determined. Results range 0-13.)

Site Climate Exposure Refactor = (Site Climate Exposure score ÷ maximum Site Climate Exposure score) x 5. (Range 1-5, 0 indicates no exposure determined.)

Site Sensitivity = ∑ Binary indicators for site risk factors (open status, active remediation system in place, active exposure pathway mitigation measures status, potential imminent hazard classification, critical exposure pathway for human risk classification). (Theoretical range 1-5, 0 indicates no sensitivity determined. Results range 0-4.)

Site Sensitivity Refactor = Site Sensitivity + 1. (Range 1-5)

Site Vulnerability* = Site Climate Exposure + Site Sensitivity. (Theoretical range 1-18, 0 indicates no vulnerability determined. Results range 0-14.)

*Sites with Climate Exposure scores of 0 receive Site Vulnerability score of 0.

Site Vulnerability Refactor = [(Site Climate Exposure Refactor + Site Sensitivity Refactor) ÷ (maximum Site Climate Exposure Refactor + maximum Site Sensitivity Refactor)] x 5. (Range 1-5, 0 indicates no exposure determined.)

Results Summary

The results summary presented here is general and considers all 6,001 hazardous waste sites. The user is encouraged to examine the screening results on a site-by-site basis to better understand how attributes come together as climate exposure, site sensitivity, community sensitivity and environmental sensitivity scores, and finally as summed or refactored site and overall vulnerability rankings. The rankings are only relative within these screening results. Users are encouraged to include local site knowledge and other data relevant to locations of interest and customize the vulnerability models to meet their own needs.

Site Climate Exposure

Site exposure ranking indicates the relative frequency or magnitude of flooding or inundation a site may endure. Sixty hazardous waste sites of 6,001 were identified as likely to see the highest exposure to flooding and inundation (Site Climate Exposure score of 13, the maximum). These sites are located within currently designated FEMA 100 year flood risk zones (1% annual chance of flooding), Category 1 hurricane surge zones, and are also susceptible to one foot or more of future sea level rise. The additive nature of this combined exposure suggests these sites may see impacts soon if not already.

A total of 2,388 sites are located within one or more of the following flood and inundation zones and can be considered at some risk: within the FEMA 100 year flood risk zones (1% annual chance of flooding), Category 1 or 2 hurricane surge zones, or future one foot sea level rise inundation zones. These sites show a wide range of exposure combinations and exposure scores. According to the screening results, 999 sites are within current FEMA 100 year flood risk zones, 1,220 sites are within current Category 1 or 2 hurricane surge zones, and 72 sites are within one foot sea level rise inundation zones.

More than half of the sites (3,613 sites) are predicted to see no exposure to flooding or inundation based on the project's screening parameters. Where no flooding or inundation exposure was predicted, site vulnerability and overall vulnerability was considered negligible and give a score of zero. However, results are based on the limited data used in this screening and other possibly relevant site-level information was not considered. Therefore they should not be considered risk free sites.

Site Sensitivity

Sensitivity ranking considers characteristics that may make a site more vulnerable to flooding or inundation (e.g. high risk). A combination of factors were considered when determining site sensitivity and each was weighted equally. Sites with multiple sensitivity characteristics present were considered more sensitive than those with fewer. Site sensitivity scores ranged between zero and four, with five the theoretical maximum. Table 3 shows the distribution of these characteristics among sites. There were 2,532 sites with the lowest sensitivity ranking (zero). Sites with sensitivity scores of zero still remain sensitive to flooding or inundation but are likely less sensitive than sites with higher sensitivity scores.

Table 3. Number of sites by intersection of site sensitivity characteristics considered.

	Open Site	Active Remediation System in Place	Active Exposure Pathway Mitigation Measure	Critical Exposure Pathway Identified	Imminent Hazard Present
Open Site	3156	149	56	92	171
Active Remediation System in Place	-	427	17	11	11
Active Exposure Pathway Mitigation Measure	-	-	95	9	13
Critical Exposure Pathway	-	-	-	92	16
Imminent Hazard Present		-	-	-	171

Hazardous Waste Site Vulnerability

The site vulnerability score combines site exposure and site sensitivity scores, and sites receiving higher vulnerability scores are likely at greater risk for uncontrolled contaminant release due to flooding or inundation. Initial site exposure and site sensitivity scores were refactored for equivalent weighting, and site vulnerability score results were standardized on a zero to five scale.

Throughout the state, 2,388 sites were ranked with some potential site vulnerability (site vulnerability refactor scores greater than zero), and 1,707 sites showed potentially moderate or high site vulnerability (scores greater than 1.66). 161 sites showed potentially high site vulnerability (scores greater than 3.33). These were in Essex (56), Suffolk (45), Boston area (21), Bristol (14), Middlesex (9), Barnstable (4), Norfolk (6), Nantucket (2), Plymouth (2), and Dukes (2) counties. Figure 3 shows the frequency distribution of site vulnerability scoring. Appendix B shows site locations and site vulnerability scores for Massachusetts. More than half of the sites (3,613 sites) are predicted to see no exposure to flooding or inundation based on the project's screening parameters, and are anticipated to have very low

vulnerability (zero score). However, results are based on the limited data used in this screening and other possibly relevant site-level information could result in higher vulnerability scores.

Figure 3. Hazardous waste site vulnerability (refactored) frequency distribution. (No exposure = site vulnerability refactor scores of zero [n=3,613]; Low Vulnerability = scores between 0 and 1.66 [n=681]; Moderate Vulnerability = scores between 1.67 and 3.33 [n=1546]; High Vulnerability = site vulnerability scores between 3.34 and 5 [n=161])

Hazardous Waste Site Overall Vulnerability with Community and Environment Sensitivity

Overall vulnerability as represented in this screening is a limited first step in understanding how vulnerable the community and the environment may be to a possible uncontrolled release of contaminants due to a hazardous waste site being flooded or inundated. Each community will have a better understanding of the sensitivity of its people and environment than what can be determined from state-wide datasets as used here. Therefore, screening results presented are only intended to demonstrate how a few indices could be used to explore potential impacts to nearby neighborhoods and key environmental components. Please review the methods used and apply local knowledge before relying on these generalized vulnerability screening results.

Overall vulnerability combines potential community and environment sensitivity with site vulnerability, and suggests a vulnerability of the hazardous waste site to flooding and of the surrounding area to the impacts of a possible uncontrolled release of contaminants if such flooding were to occur. Refactored community sensitivity scores ranged from 1.2 to 5.0. Refactored environmental sensitivity scores ranged from 0 to 5.0. Refactored overall vulnerability scores ranged from 0 to 5.0.

Throughout the state, 2,388 sites were ranked with some potential overall vulnerability (overall vulnerability refactor score greater than zero), and 2,299 sites showed potentially moderate or high overall vulnerability (scores greater than 1.33). 385 sites showed potentially high overall vulnerability (scores greater than 3.33). These were in Boston area (103), Suffolk (82), Middlesex (81), Essex (74), Bristol (20), Norfolk (8), Barnstable (7), Plymouth (4), Dukes (2), Worcester (2), Hampden (1) and Nantucket (1) counties. Figure 4 shows the frequency distribution of overall site vulnerability scoring. Appendix B shows site locations and overall vulnerability scores for Massachusetts. More than half of

the sites (3,613 sites) are predicted to see no exposure to flooding or inundation based on the project's screening parameters, and are anticipated to have very low overall vulnerability (zero score). However, results are based on the limited data used in this screening and other possibly relevant site-level information could result in higher vulnerability.

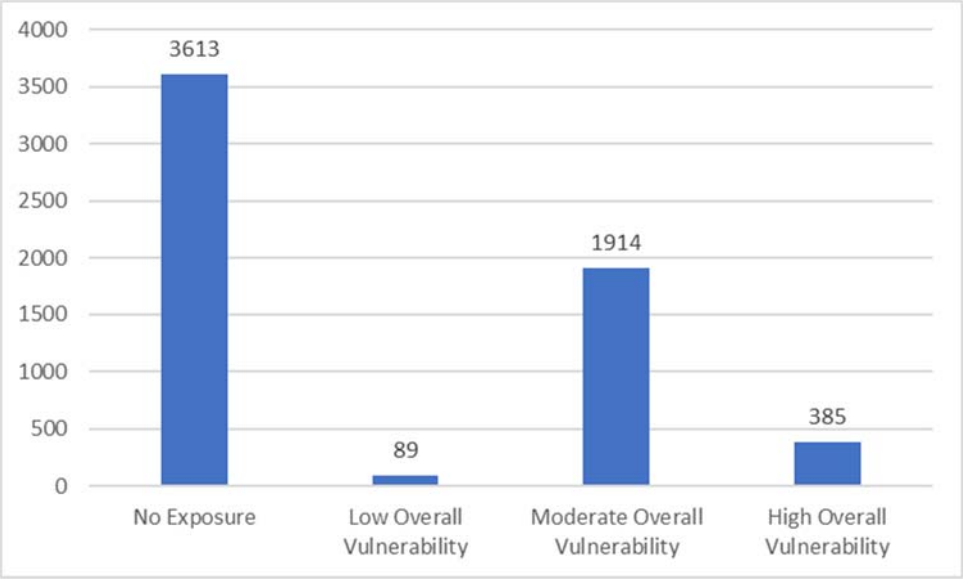

Figure 4. Overall Vulnerability with Community and Environmental Sensitivity frequency distribution. *(No exposure = site overall vulnerability refactor scores of zero [n=3,613]; Low Vulnerability = scores between 0 and 1.66 [n=89]; Moderate Vulnerability = scores between 1.67 and 3.33 [n=1914]; High Vulnerability = site vulnerability scores between 3.34 and 5 [n=385])*

Overall vulnerability ranking alone does not reveal much about a site. However, working backward from the overall vulnerability score to the exposure and sensitivity scores, and the attributes that make up each, can provide the user a way to better understand what is driving vulnerability. Is the site location very likely to flood? Is a contaminant management remedy not yet in place? Could a contamination management remedy be overwhelmed? Is the proximity of a drinking water source a worry? Are people nearby facing numerous challenges that would make responding to an uncontrolled release difficult? These screening results are intended to assist a user in initiating a systematic investigation to develop adaptation actions to reduce overall vulnerability.

How to Use the Screening Results Table

The screening results are the main output of this project (Appendix C). Data in this table are meant to be manipulated by data analysists and GIS specialists, and users are encouraged to build custom results relevant to their needs. The screening results table included attributes not used in the exposure, sensitivity and vulnerability scoring presented but may be relevant when investigating individual sites. Users should become familiar with the definitions of attributes within the MassDEP Bureau of Waste Site Cleanup Reportable Releases Database and the other datasets used before manipulating data for their needs. The screening results are also available in Excel format.

Limits to Results Use

Results presented in this report and accompanying screening results table are based on a limited analysis using a simple vulnerability model using existing datasets that are either publicly available or were provided to the project's researchers. The project researchers made their best efforts to locate recent and complete data, but no on-the-ground site investigations were made. It is likely that site-level information relevant to this investigation exists but was not included. The user is encouraged to include local site knowledge and other data relevant to their situation and customize the vulnerability models to meet their own needs. The user is also encouraged to review the methods and assumptions used to be sure they meet expectations before relying on the screening results.

Acknowledgements

We are grateful for the initial development of these ideas by Katlyn Tarrio and Rick Reibstein of Boston University, and the creative input of the project team which included Barbara Maco of the Sustainable Remediation Forum, Thomas Potter of MassDEP Bureau of Waste Site Cleanup, Rick Reibstein of Boston University, Cathy Rockwell of Woodward & Curran, Inc., and Lara Hansen of EcoAdapt. Thank you also to the Sustainable Remediation Forum for providing funding and for seeing value in this pioneering work.

Citations

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Appendix A

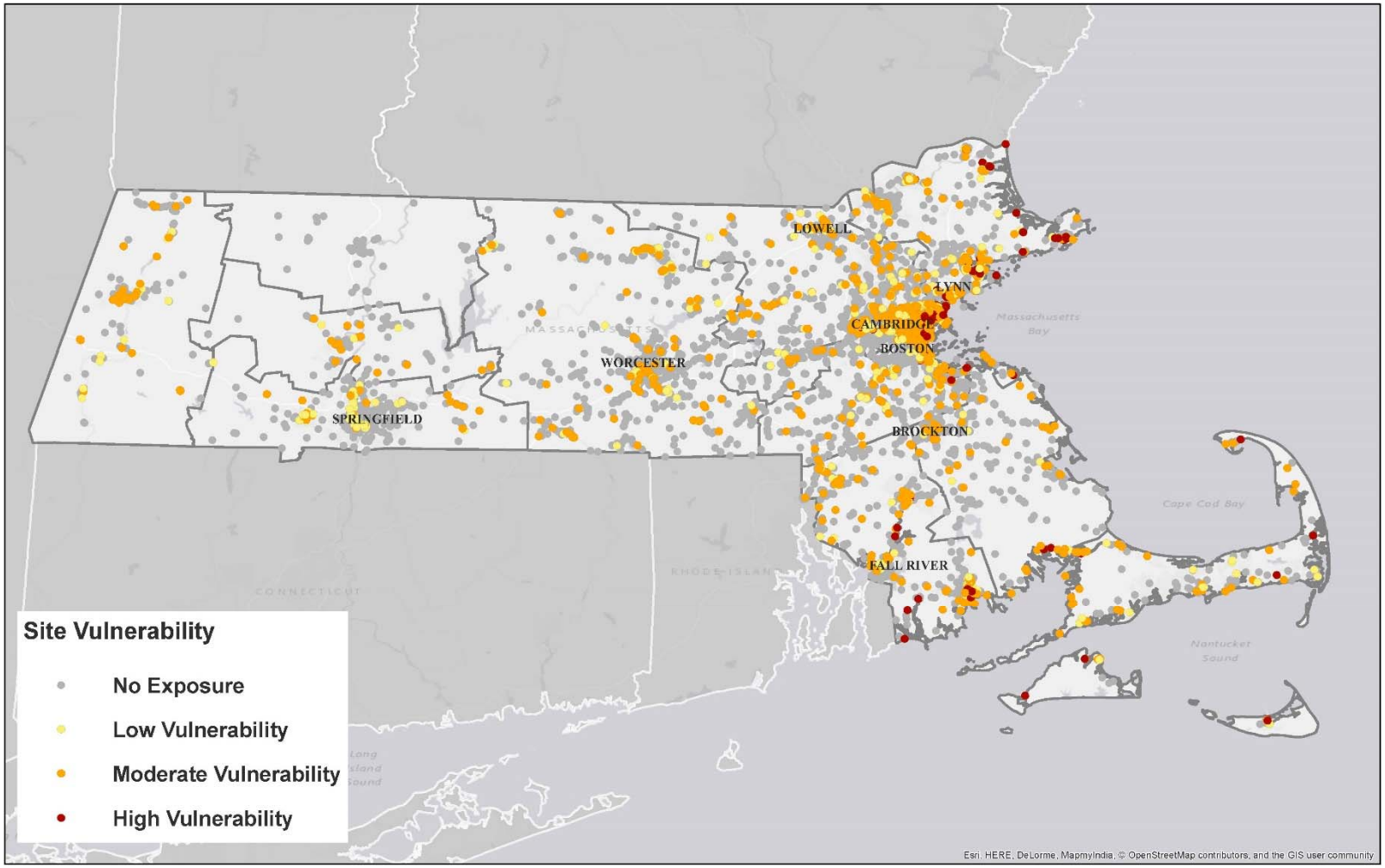
Screening Results Table Attribute Metadata and Data Sources

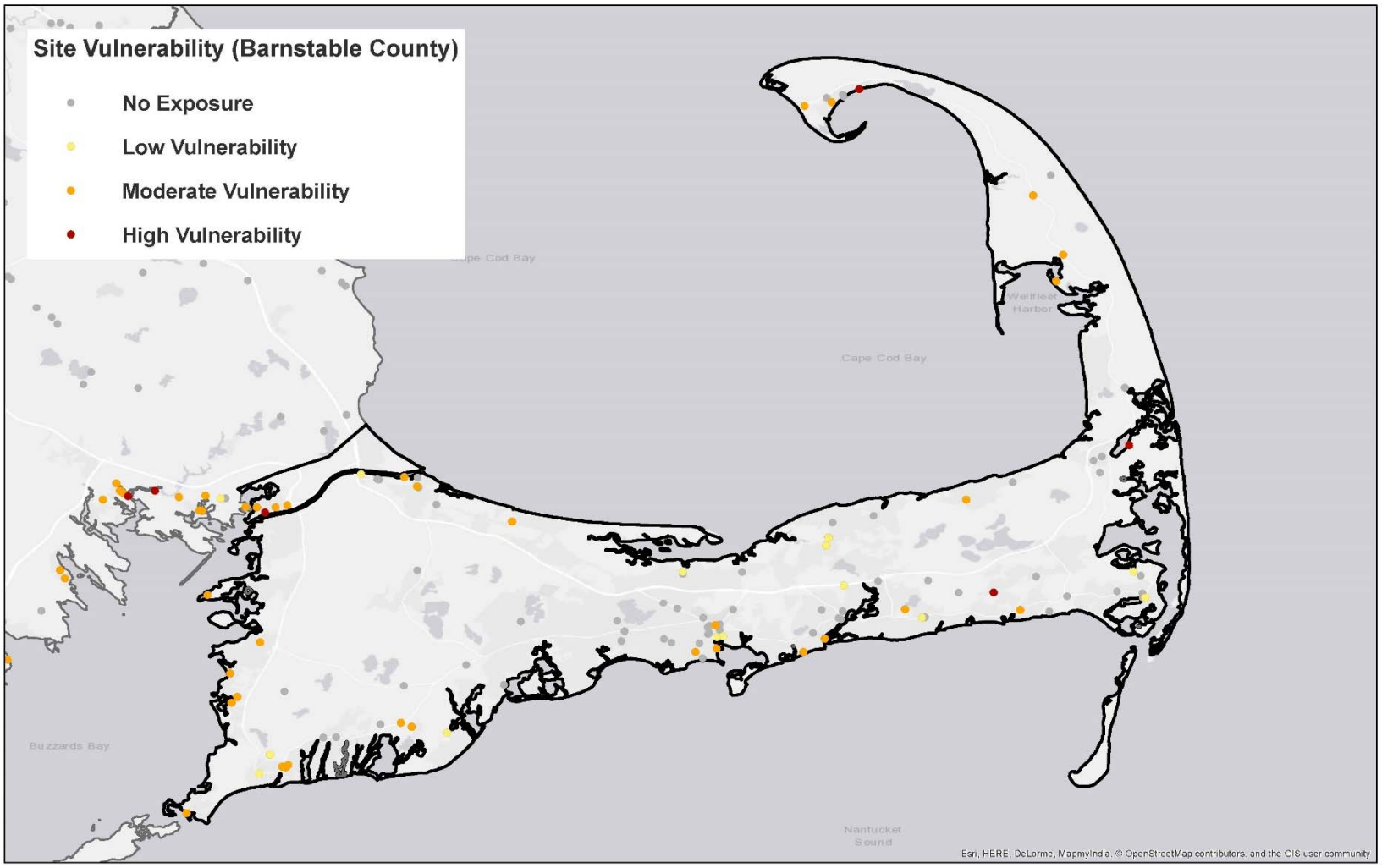
Attribute type	Attribute	Definition	Notes
Site information	RTN	Routine Tracking number	
	Site_Name	Site location information	
	Release_Address	Site location information	
	City_Town	Site location information	
	County	Site location information	
	State	Site location information	
	Census_town_code	US Census Place or county subdivision FIPS code	
	Reporting_Category	When site needs to be reported to DEP	
	Notification_Date	Date site was first reported to MassDEP	
	Current_Date	Date a site was listed as its current compliant status	
	Phase	Phase of cleanup process	
	Compliance_Status	Where site currently stands in cleanup process	
	RAO_Class	Release Action Outcome	
	Chemical_Type	Category of chemical spilled	
	Open_site	Is site on Open site list as of November 2018?	
	ARS	Is site on ARS list as of November 2018?	
	AEPMM	Is site on an Active Exposure Pathway Mitigation Measures list as of November 2018?	
	AUL	Is site on AUL list as of November 2018?	
	Open_sites_Tier_class	Tier classification of open sites	Open sites only
	Open_sites_CEP	Critical exposure pathway for human risk?	Open sites only
	Open_sites_Potential_IH	Potential imminent hazard?	Open sites only
	ARS_Ground_Water	Site contains ground water remediation system?	ARS sites only
	ARS_Sparging	Site contains Air Sparging system?	ARS sites only
	ARS_SVE	Site contains Soil Vapor Extraction remediation system?	ARS sites only
	ARS_DualPhase	Site contains Dual phase remediation system?	ARS sites only
	Remedy_Number	Number of remediation systems at site	ARS sites only
	ARS_Currently_Operating	Is remediation system active?	ARS sites only
	Fed_Potential_IH	Potential imminent hazard?	RCRA/DPS/Superfund sites only
	Fed_Status	Federal status (RCRA, superfund, FUD, etc)?	RCRA/DPS/Superfund sites only
Climate	Flood	"Dominant" FEMA National Flood Hazard Layer zone	"Dominant" = highest probability
	Q3_Flood	"Dominant" PAPER FIRM flood zone	"Dominant" = highest probability; For some towns in Western MA not covered by FEMA NFHL
	Hurricane	"Dominant" hurricane inundation zone	"Dominant" = highest probability
	SLR_1ft	Is site within flood zone?	
	SLR_2ft	Is site within flood zone?	
	SLR_3ft	Is site within flood zone?	
	SLR_4ft	Is site within flood zone?	
	SLR_5ft	Is site within flood zone?	
	SLR_6ft	Is site within flood zone?	
Community Receptor	Watershed	Name of surrounding watershed	
	Pop_density	People per square mile	
	Older_pop_density	Adults over 65 per square mile	
	Children_density	Children under 5 per square mile	
	EJ	Environmental Justice criteria	
	School	Is site within 500 feet of a school?	
	Hospital	Is site within 500 feet of an acute care hospital?	
	ACECS	Is site within 500 feet of an Area of Critical Environmental Concern?	
Environment receptors	BioMap_Core_Habitat	Is site within a Core Habitat?	
	BioMap_Critical_Natural_Landscape	Is site within a Critical Natural Landscape?	
	Public_water_supplies	Is site within 500 feet of a public water supplies?	
	Surface_Water_Protection_Zones	Is site within 500 feet of a surface water protection zones?	
	Wellhead_Protection_Zone1	Is site within 500 feet of a Zone 1 wellhead protection zone?	
	Wellhead_Protection_Zone2	Is site within 500 feet of a Zone 2 wellhead protection zone?	
	Interim_Wellhead_Protection_Area	Is site within 500 feet of an Interim wellhead protection area?	
	Sole_Aquifers	Is site atop an EPA designated sole aquifer?	
	Aquifers_High_Med_Yield	Is site atop a high or medium yield aquifer?	
Scoring scheme	pop_rank	Rank of 1-3 of vulnerability, with 3 being most vulnerable	Population density over 75th quartile = highest risk (3), in the IQR = second highest (2), under 25th quartile = lowest risk (1)
	old_rank	Rank of 1-3 of vulnerability, with 3 being most vulnerable	Older adult density over 75th quartile = highest risk (3), in the IQR = second highest (2), under 25th quartile = lowest risk (1)
	child_rank	Rank of 1-3 of vulnerability, with 3 being most vulnerable	Child density over 75th quartile = highest risk (3), in the IQR = second highest (2), under 25th quartile = lowest risk (1)
	EJ_rank	Rank of 1-3 of vulnerability, with 3 being most vulnerable	MIE = highest risk (3), ME or MI or IE = second highest (3), just I, E or M = lowest (1)
	flood_rank	Rank of 1-3 of vulnerability, with 3 being most vulnerable	1% floods ("VE: High Risk Coastal Area", "AE: Regulatory Floodway", "AE: 1% Annual Chance of Flooding, with BFE", "A: 1% Annual Chance of Flooding, no BFE", "AO: 1% Annual Chance of 1-3ft Sheet Flow Flooding, with Depth") = highest risk (3); 0.2% flood ("X: 0.2% Annual Chance of Flooding" = second highest (2), 'reduced risk from levee' = lowest (1)
	q3flood_rank	Rank of 1-3 of vulnerability, with 3 being most vulnerable	* same as flood_rank
	hurricane_rank	Rank of 1-4 of vulnerability, with 4 being most vulnerable	Hurricane category 1 = highest risk (4), category 2 = second highest (3), category 3 = second lowest (2), category 4 = lowest (1)
Sensitivity/Vulnerability	Flooding_Exposure	Summation of flood (FEMA) and hurricane/surge scores	Theoretical maximum score = 7 (e.g. site in category 1 hurricane zone AND 1% flood zone)
	Future_Sea_Level_Rise_Exposure	Number of SLR zones a site is located in, with 6 being the highest	Theoretical maximum score = 6 (e.g. is at risk for 1 ft sea level rise, i.e. most near term)
	Environment_Sensitivity	Summation of binary indicators for protected environmental areas and water resources	Theoretical maximum score = 10
	Community_receptors	Summation of population density/EJ scores and indicators for school/hospital proximity	Theoretical maximum score = 14
	Site_Climate_Exposure	Summation of Flooding_Exposure and Future_Sea_Level_Rise_Exposure	Theoretical maximum score = 13
	Site_Sensitivity	Summation of whether site is: 1) open, 2) has an ARS, 3) has an AEPMM, 4) is an imminent hazard and 5) has a CEP status	Theoretical maximum score = 5 (e.g. site is open, has an ARS, is a 'potential imminent hazard', has a 'critical exposure pathway' and has an AEPMM)
	Site_Vulnerability	Summation of Overall_Climate_Exposure and Site_Sensitivity	Theoretical maximum score = 18
	Overall_Vulnerability	Summation of Site_Vulnerability and Environment/Community receptors	Theoretical maximum score = 45
Sensitivity/Vulnerability Refactoring	Site_Climate_Exposure_Refactor	[Site_Climate_Exposure / max(Site_Climate_Exposure)] * 5	
	Comm_refactor	[Community_receptors / max(Community_receptors)] * 5	
	Env_refactor	[Environment_Sensitivity / max(Environment_Sensitivity)] * 5	
	Comm_env_refactor	[Comm_refactor + Env_refactor / max(Comm_refactor+Env_refactor)] * 5	
	site_sensitivity_refactor	Site_Sensitivity +1	
	site_vulnerability_refactor	[(Site_Climate_Exposure_Refactor + site_sensitivity_refactor / max(Site_Climate_Exposure_Refactor + site_sensitivity_refactor)] * 5	
	overall_vuln_refactor	[site_vulnerability_refactor + Comm_env_refactor) / max(site_vulnerability_refactor + Comm_env_refactor)] * 5	

Attribute type	Attribute	Source	Documentation links
Site information	RTN	MassDEP database files	
	Site_Name	MassDEP database files	
	Release_Address	MassDEP database files	
	City_Town	MassDEP database files	
	County	MassDEP database files	
	State	MassDEP database files	
	Census_town_code	MassDEP database files	
	Reporting_Category	MassDEP database files	
	Notification_Date	MassDEP database files	
	Current_Date	MassDEP database files	
	Phase	MassDEP database files	
	Compliance_Status	MassDEP database files	
	RAO_Class	MassDEP database files	
	Chemical_Type	MassDEP database files	
	Open_site	MassDEP database files	Information provided by MassDEP
	ARS	MassDEP database files	
	AEPMM	MassDEP database files	
	AUL	MassDEP database files	
	Open_sites_Tier_class	MassDEP database files	
	Open_sites_CEP	MassDEP database files	
	Open_sites_Potential_IH	MassDEP database files	
	ARS_Ground_Water	MassDEP database files	
	ARS_Sparging	MassDEP database files	
	ARS_SVE	MassDEP database files	
	ARS_DualPhase	MassDEP database files	
	Remedy_Number	MassDEP database files	
	ARS_Currently_Operating	MassDEP database files	
	Fed_Potential_IH	MassDEP database files	
	Fed_Status	MassDEP database files	
Climate	Flood	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-fema-national-flood-hazard-layer?_ga=2.135552887.771566741.1557433901-443446499.1554227867
	Q3_Flood	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-fema-q3-flood-zones-paper-firms?_ga=2.135552887.771566741.1557433901-443446499.1554227867
	Hurricane	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-hurricane-surge-inundation-zones?_ga=2.135552887.771566741.1557433901-443446499.1554227867
	SLR_1ft	NOAA	
	SLR_2ft	NOAA	
	SLR_3ft	NOAA	https://coast.noaa.gov/slrdata/
	SLR_4ft	NOAA	
	SLR_5ft	NOAA	
	SLR_6ft	NOAA	
Community Receptor	Watershed	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-major-watersheds?_ga=2.132389704.771566741.1557433901-443446499.1554227867
	Pop_density	US Census ACS 2013-2017 estimates	https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_17_5YR_DP05&prodType=table
	Older_pop_density	US Census ACS 2013-2017 estimates	
	Children_density	US Census ACS 2013-2017 estimates	
	EJ	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-2010-us-census-environmental-justice-populations
	School	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-massachusetts-schools-pre-k-through-high-school?_ga=2.174948196.771566741.1557433901-443446499.1554227867
	Hospital	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-acute-care-hospitals?_ga=2.106191557.771566741.1557433901-443446499.1554227867
Environment receptors	ACECS	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-areas-critical-environmental-concern?_ga=2.174948196.771566741.1557433901-443446499.1554227867
	BioMap_Core_Habitat	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-biomap2?_ga=2.174948196.771566741.1557433901-443446499.1554227867
	BioMap_Critical_Natural_Landscape	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-biomap2?_ga=2.174948196.771566741.1557433901-443446499.1554227867
	Public_water_supplies	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-public-water-supplies?_ga=2.131937097.771566741.1557433901-443446499.1554227867
	Surface_Water_Protection_Zones	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-surface-water-supply-protection-areas-zone-b-c?_ga=2.131937097.771566741.1557433901-443446499.1554227867
	Wellhead_Protection_Zone1	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-massdep-wellhead-protection-areas-zone-ii-zone-i-iwpa?_ga=2.173888485.771566741.1557433901-443446499.1554227867
	Wellhead_Protection_Zone2	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-massdep-wellhead-protection-areas-zone-ii-zone-i-iwpa?_ga=2.173888485.771566741.1557433901-443446499.1554227867
	Interim_Wellhead_Protection_Area	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-massdep-wellhead-protection-areas-zone-ii-zone-i-iwpa?_ga=2.173888485.771566741.1557433901-443446499.1554227867
	Sole_Aquifers	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-epa-designated-sole-source-aquifers?_ga=2.68483927.771566741.1557433901-443446499.1554227867
	Aquifers_High_Med_Yield	MassGIS	https://docs.digital.mass.gov/dataset/massgis-data-aquifers?_ga=2.173888485.771566741.1557433901-443446499.1554227867
Scoring scheme	pop_rank		
	old_rank		
	child_rank		
	EJ_rank		
	flood_rank		
	q3flood_rank		
	hurricane_rank		
Sensitivity/Vulnerability	Flooding_Exposure		
	Future_Sea_Level_Rise_Exposure		
	Environment_Sensitivity		
	Community_receptors		
	Site_Climate_Exposure		
	Site_Sensitivity		
	Site_Vulnerability		
	Overall_Vulnerability		
Sensitivity/Vulnerability Refactoring	Site_Climate_Exposure_Refactor		
	Comm_refactor		
	Env_refactor		
	Comm_env_refactor		
	site_sensitivity_refactor		
	site_vulnerability_refactor		
	overall_vuln_refactor		

Appendix B

Hazardous Waste Site Vulnerability. (No exposure = site vulnerability refactor scores of zero [n=3,613]; Low Vulnerability = scores between 0 and 1.66 [n=681]; Moderate Vulnerability = scores between 1.67 and 3.33 [n=1546]; High Vulnerability = site vulnerability scores between 3.34 and 5 [n=161])




Site Vulnerability (Barnstable County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
Cape Cod Bay
Wellfleet Harbor
Cape Cod Bay
Buzzards Bay
Nantucket Sound
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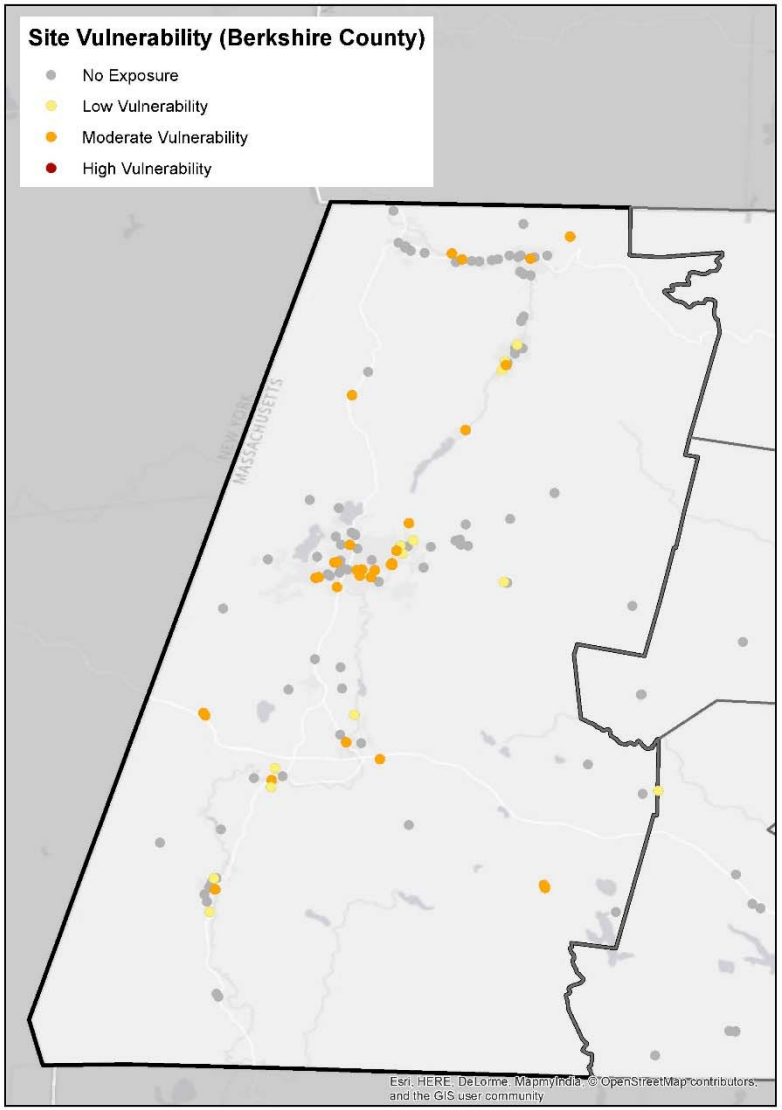
Site Vulnerability (Berkshire County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
NEW YORK
MASSACHUSETTS
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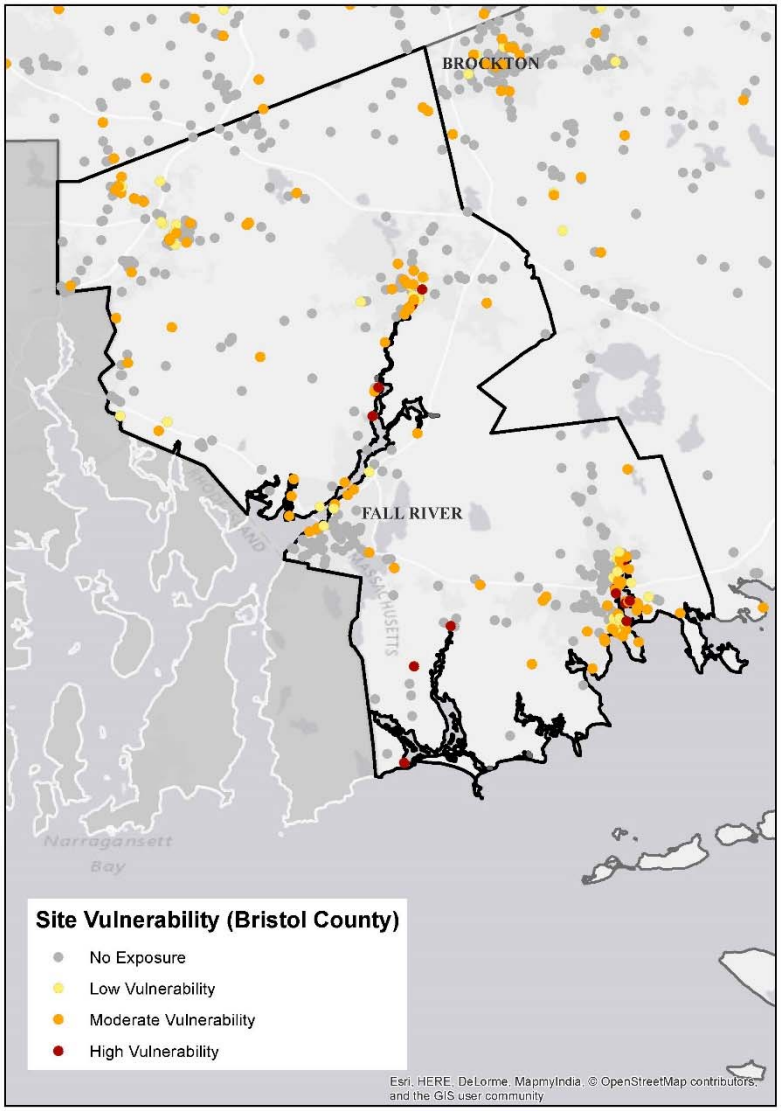
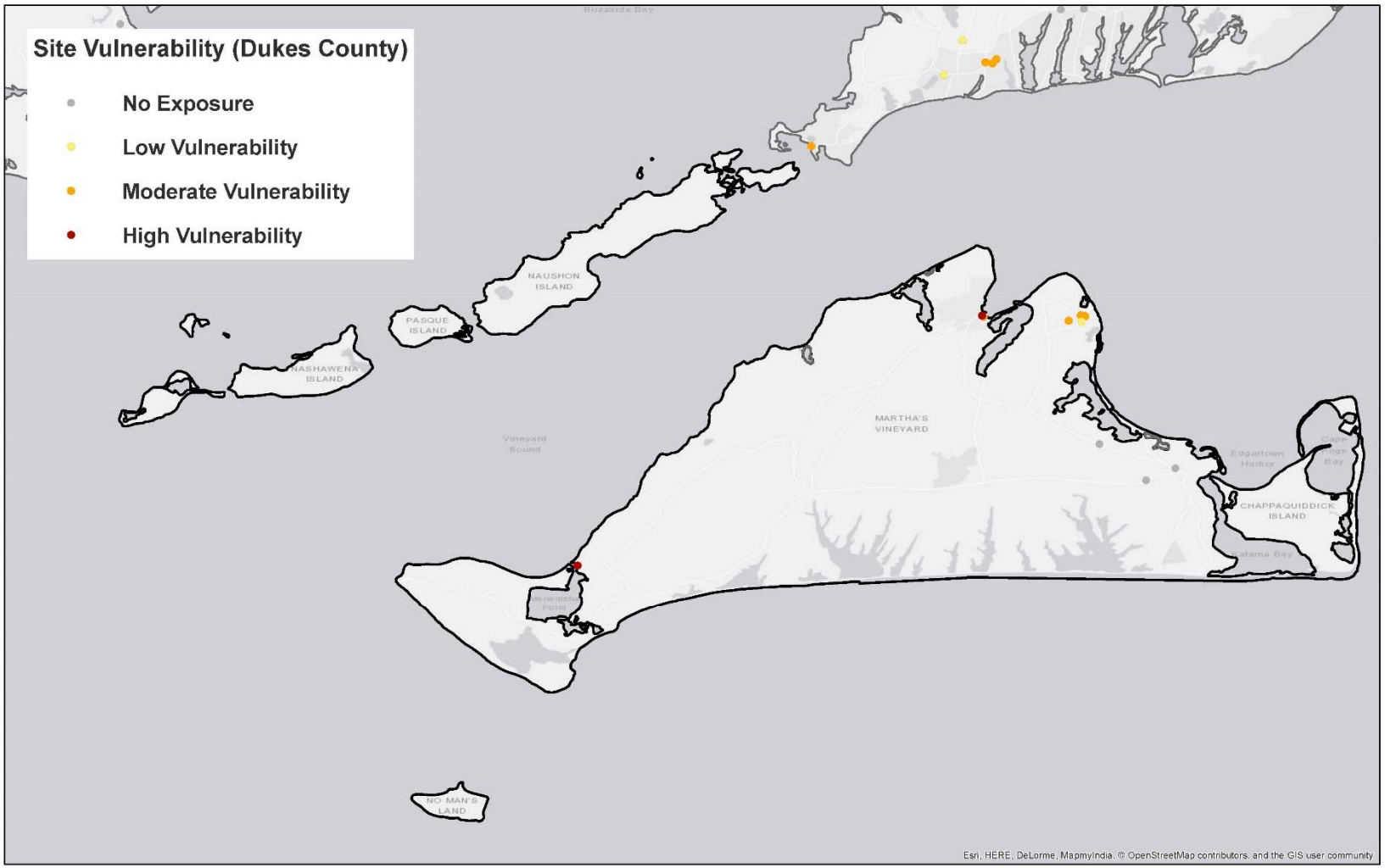

BROCKTON
FALL RIVER
Narragansett Bay
Site Vulnerability (Bristol County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community


Site Vulnerability (Dukes County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
NAUSHON ISLAND
PASQUE ISLAND
NASHAWENA ISLAND
MARTHA'S VINEYARD
Vineyard Sound
Edgartown Harbor
CHAPPAQUIDDICK ISLAND
NO MAN'S LAND
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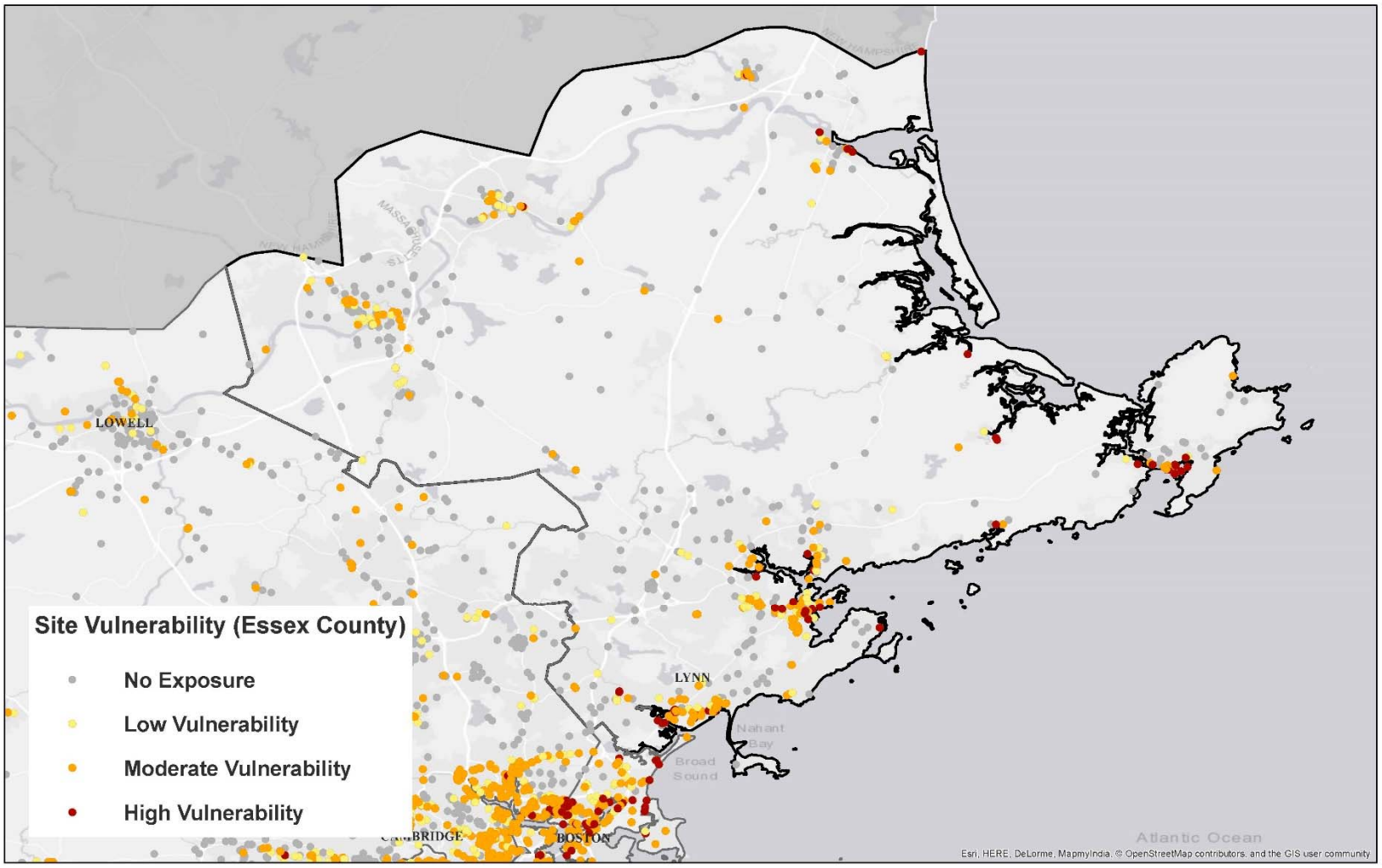
Site Vulnerability (Essex County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
LOWELL
LYNN
Nahant Bay
Broad Sound
BOSTON
Atlantic Ocean
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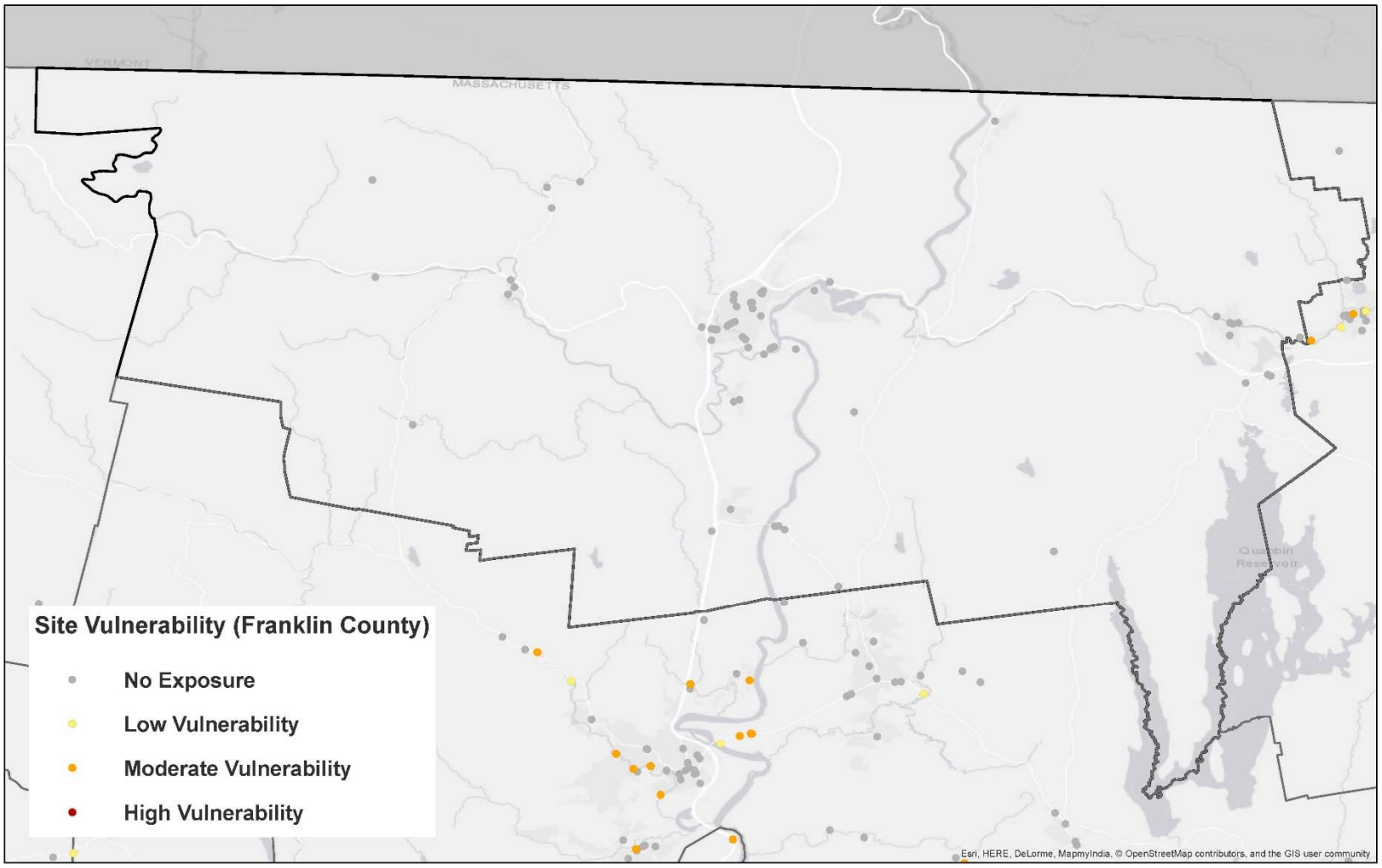
MASSACHUSETTS
Site Vulnerability (Franklin County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
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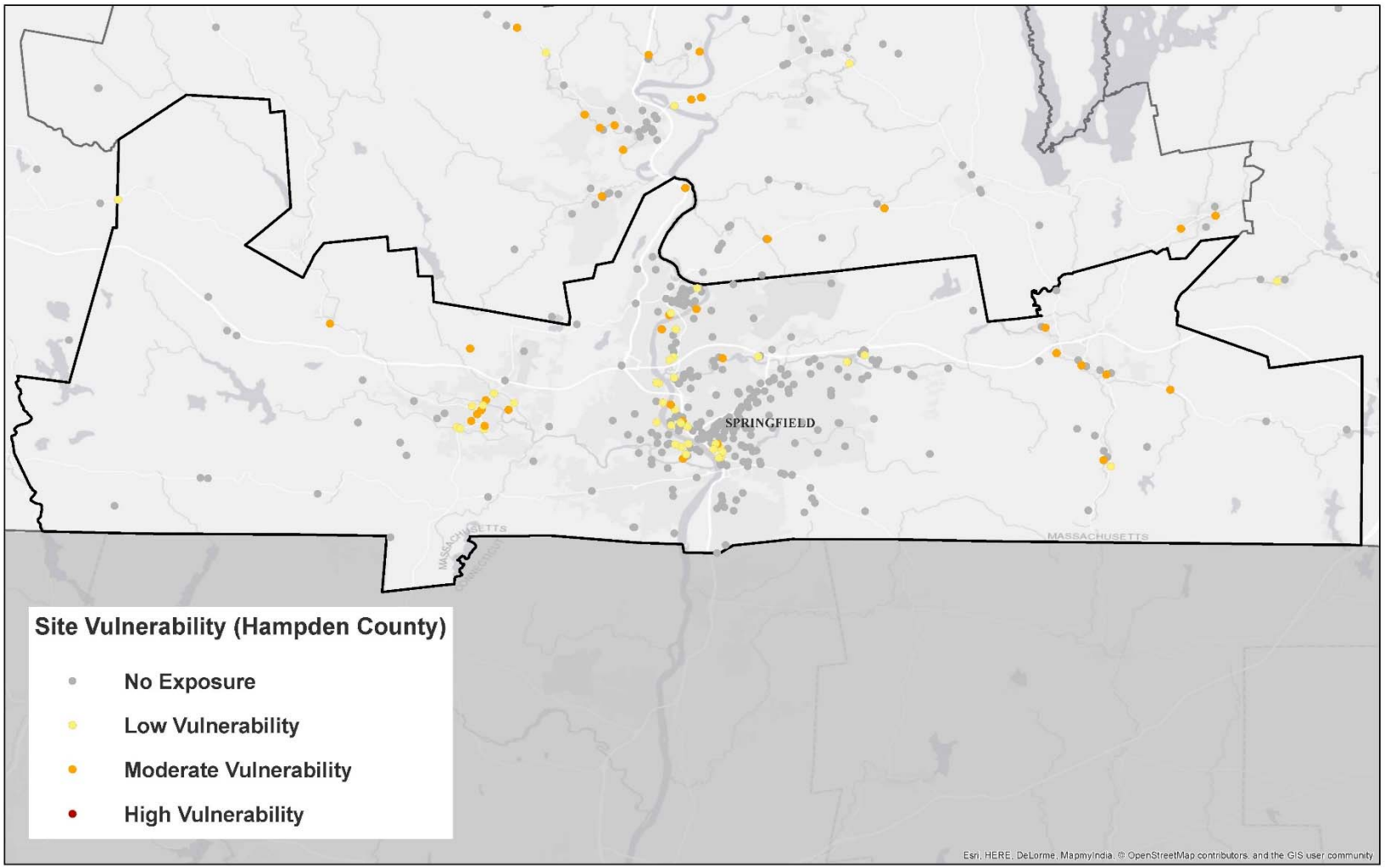
SPRINGFIELD
MASSACHUSETTS
MASSACHUSETTS
Site Vulnerability (Hampden County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
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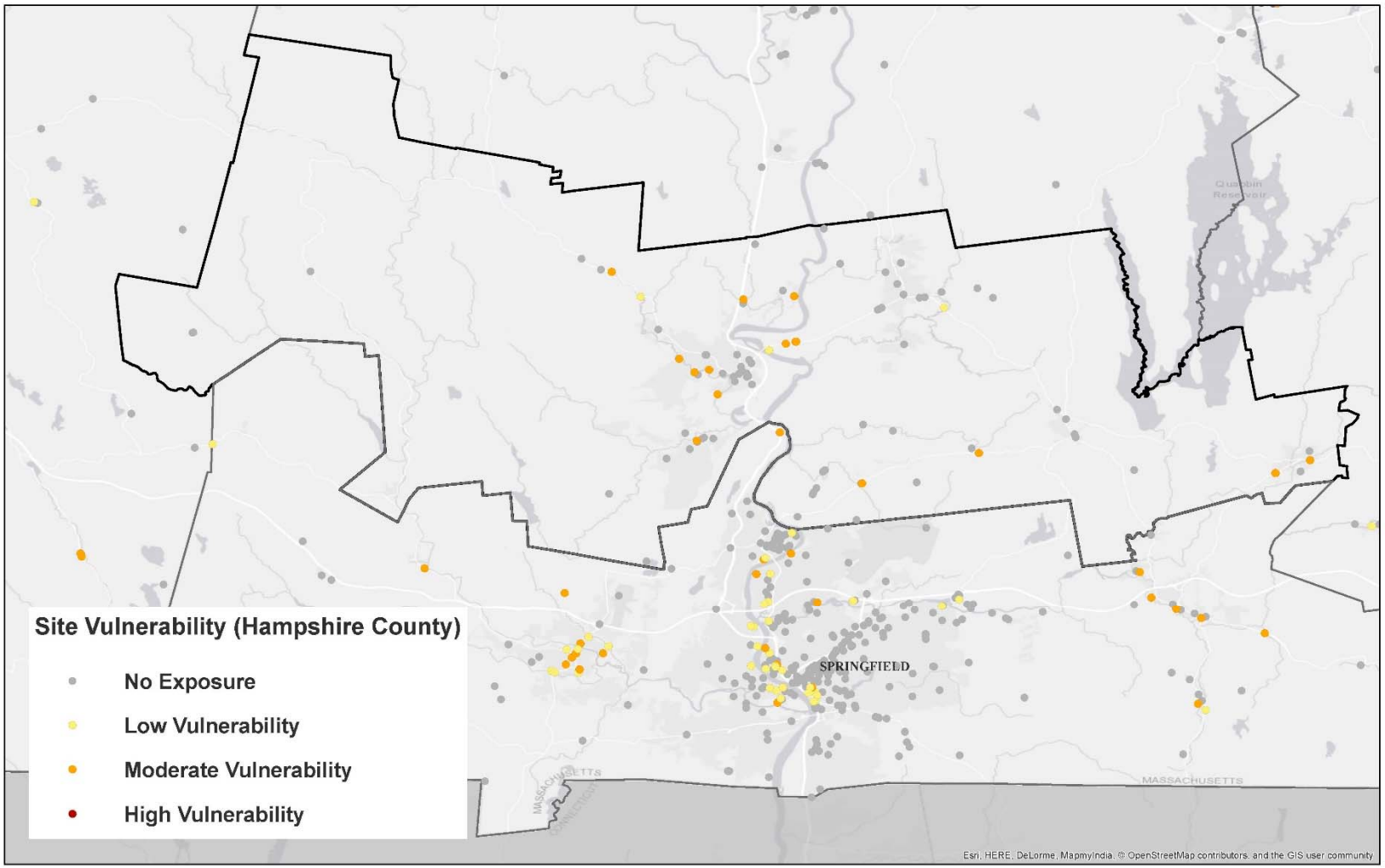
Site Vulnerability (Hampshire County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
SPRINGFIELD
MASSACHUSETTS
MASSACHUSETTS
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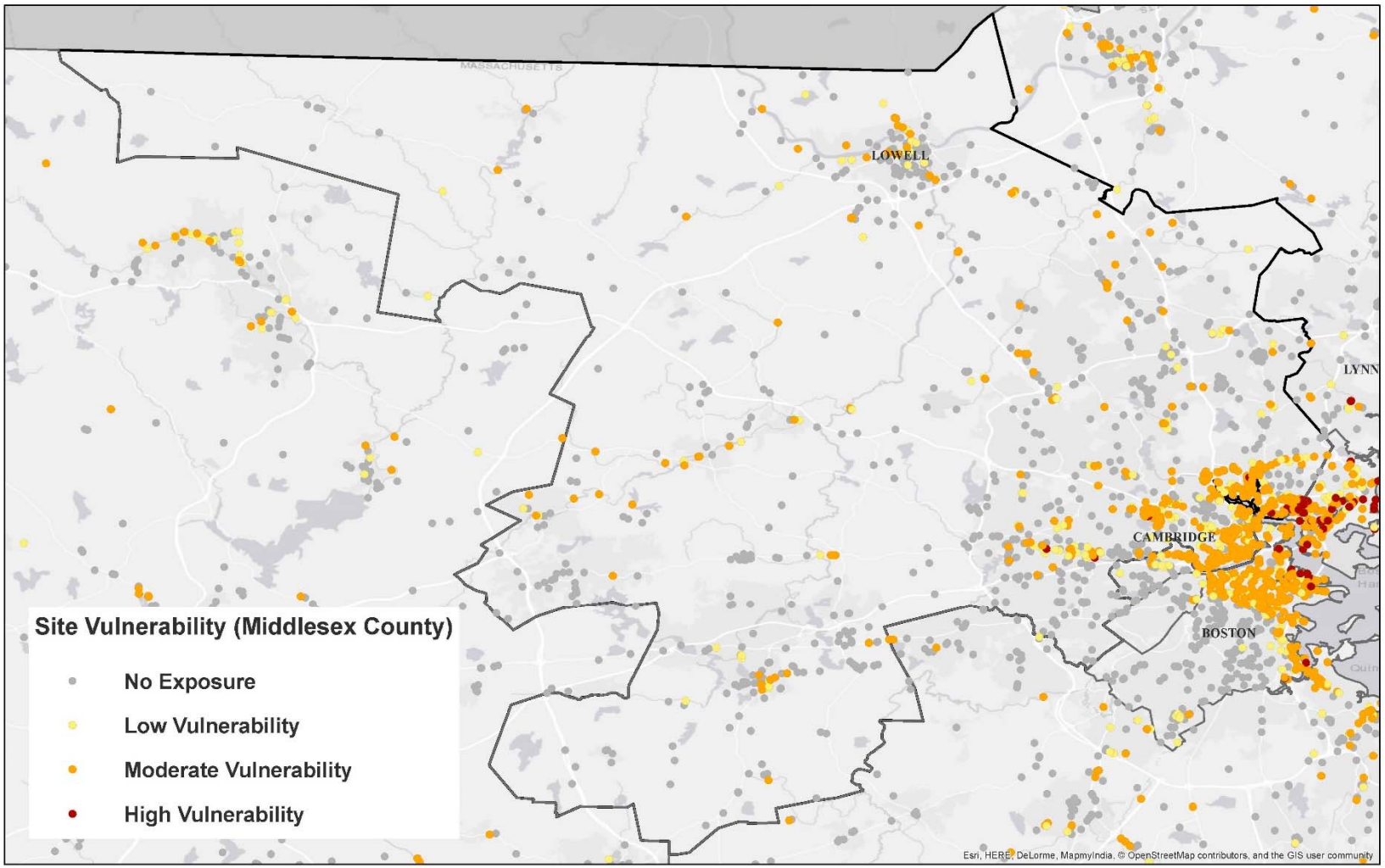
Site Vulnerability (Middlesex County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
LOWELL
LYNN
CAMBRIDGE
BOSTON
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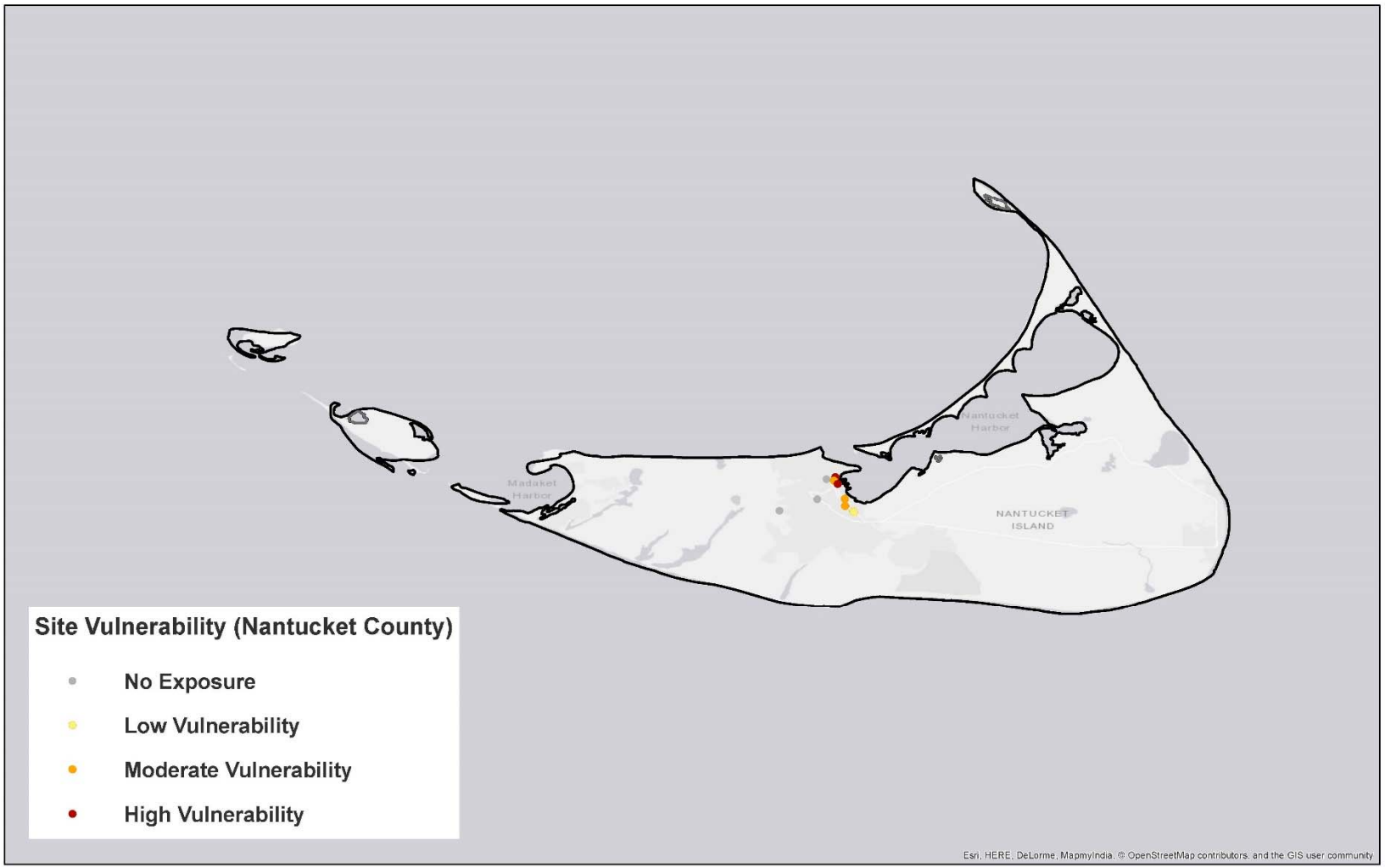
Site Vulnerability (Nantucket County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
Madaket Harbor
Nantucket Harbor
NANTUCKET ISLAND
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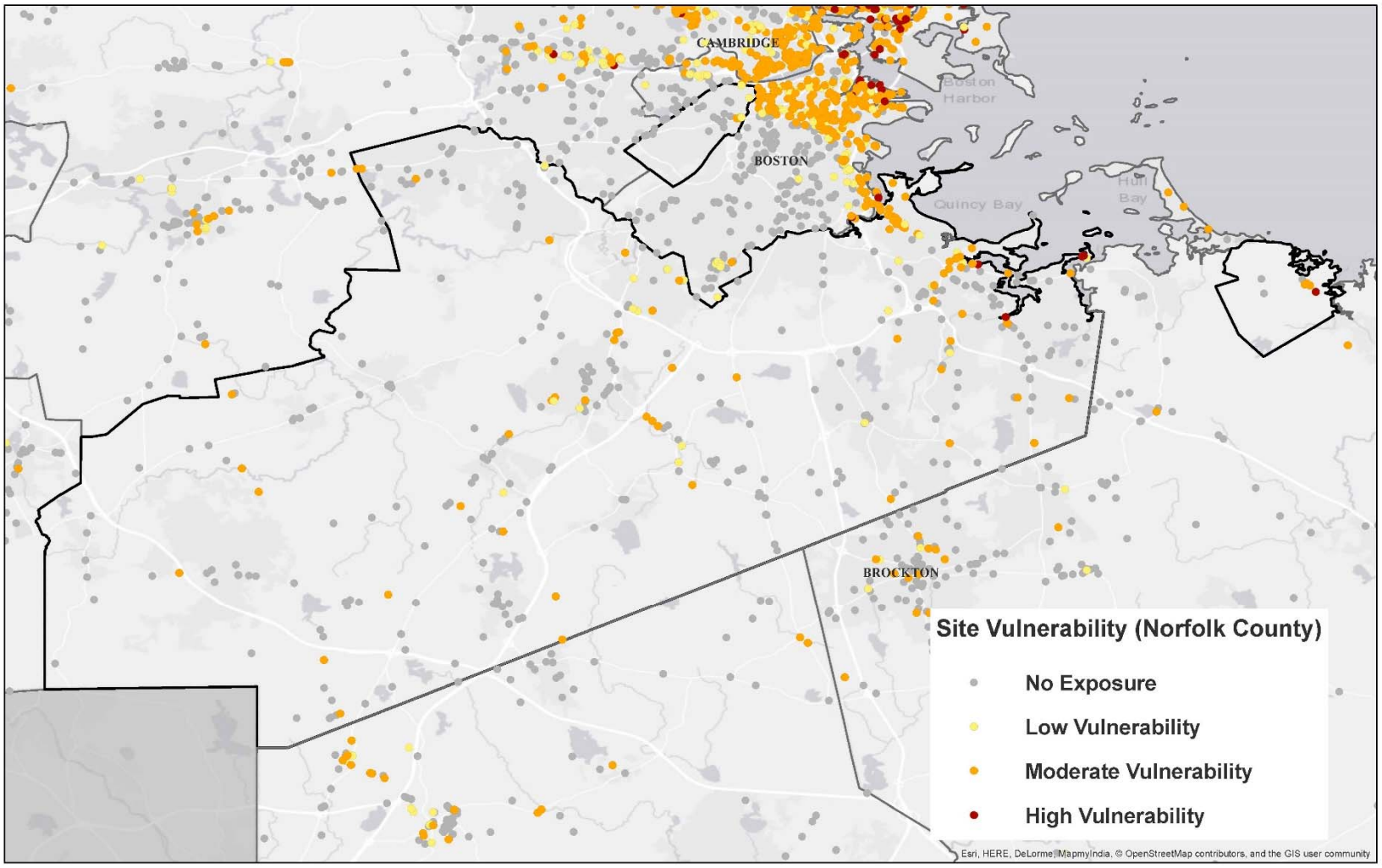
CAMBRIDGE
BOSTON
Boston Harbor
Quincy Bay
Hull Bay
BROCKTON
Site Vulnerability (Norfolk County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
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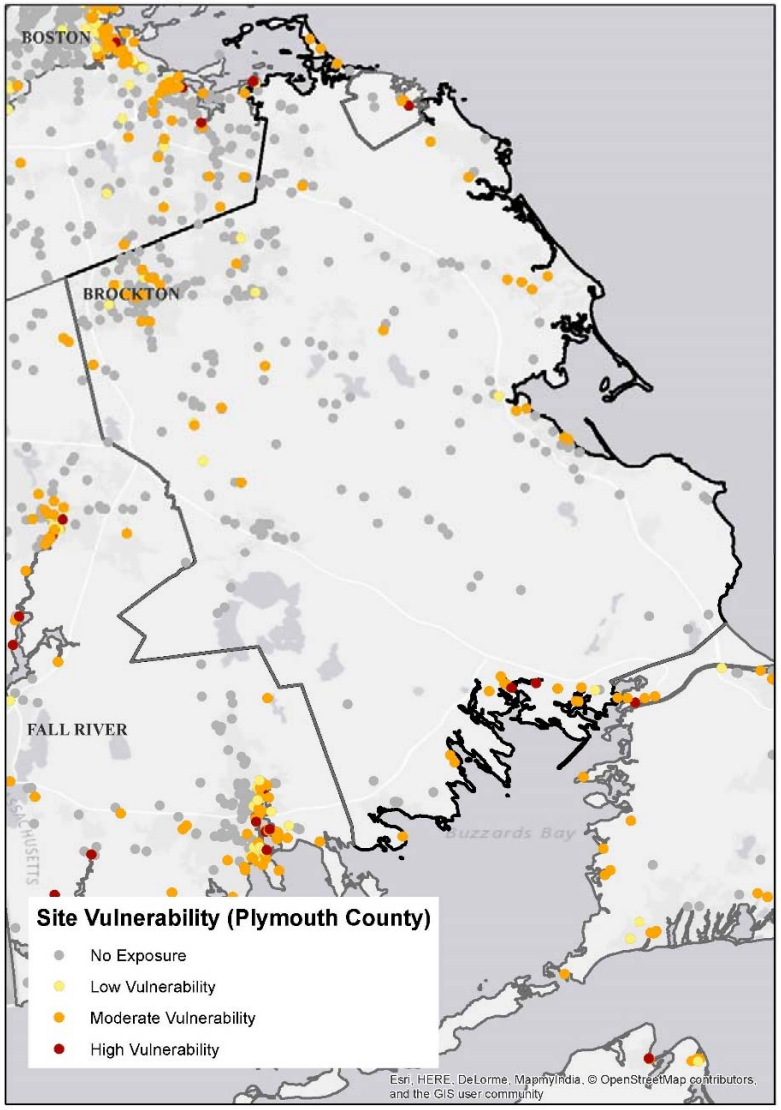
BOSTON
BROCKTON
FALL RIVER
Buzzards Bay
Site Vulnerability (Plymouth County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
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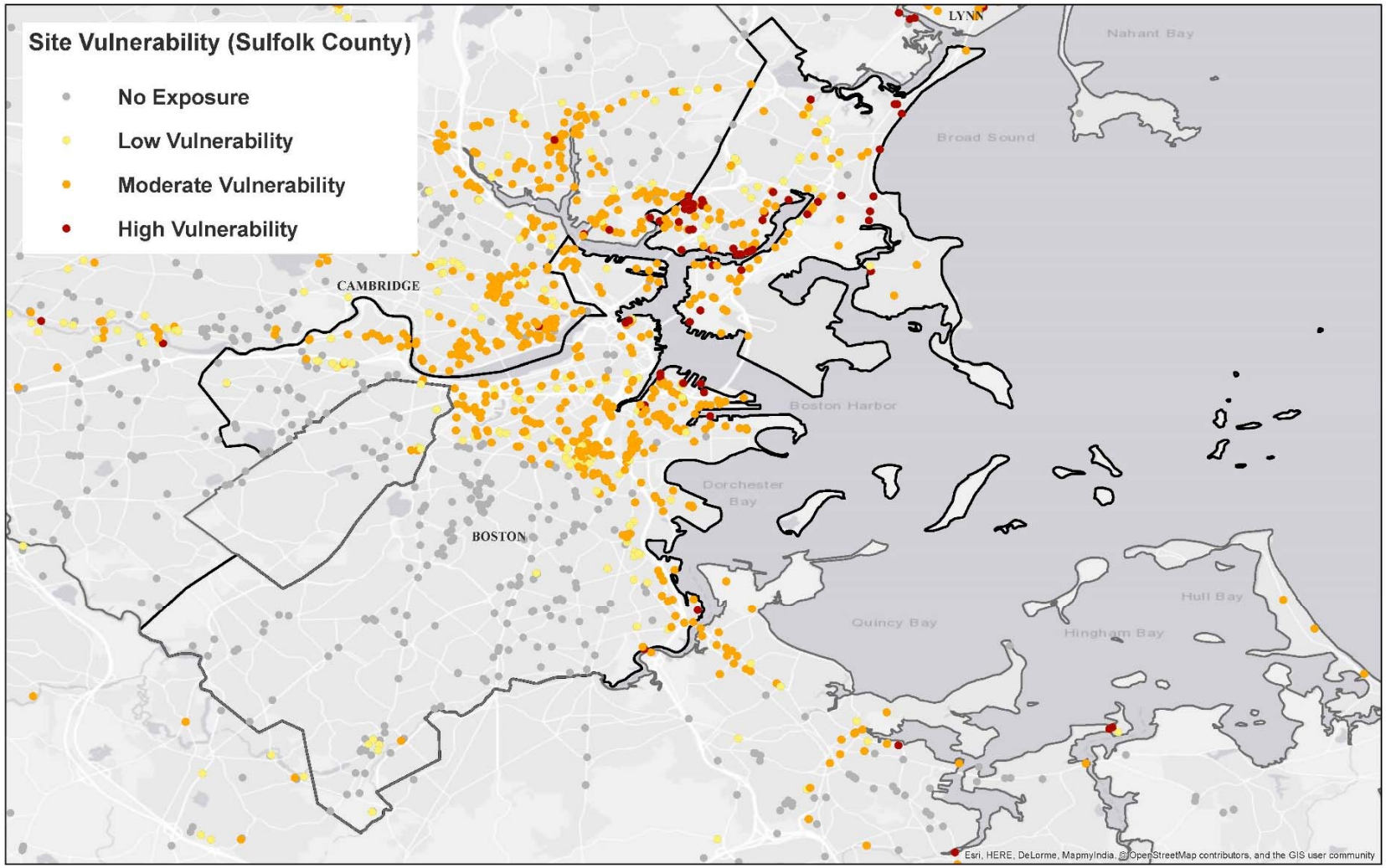
Site Vulnerability (Sulfolk County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
LYNN
Nahant Bay
Broad Sound
CAMBRIDGE
Boston Harbor
Dorchester Bay
BOSTON
Hull Bay
Quincy Bay
Hingham Bay
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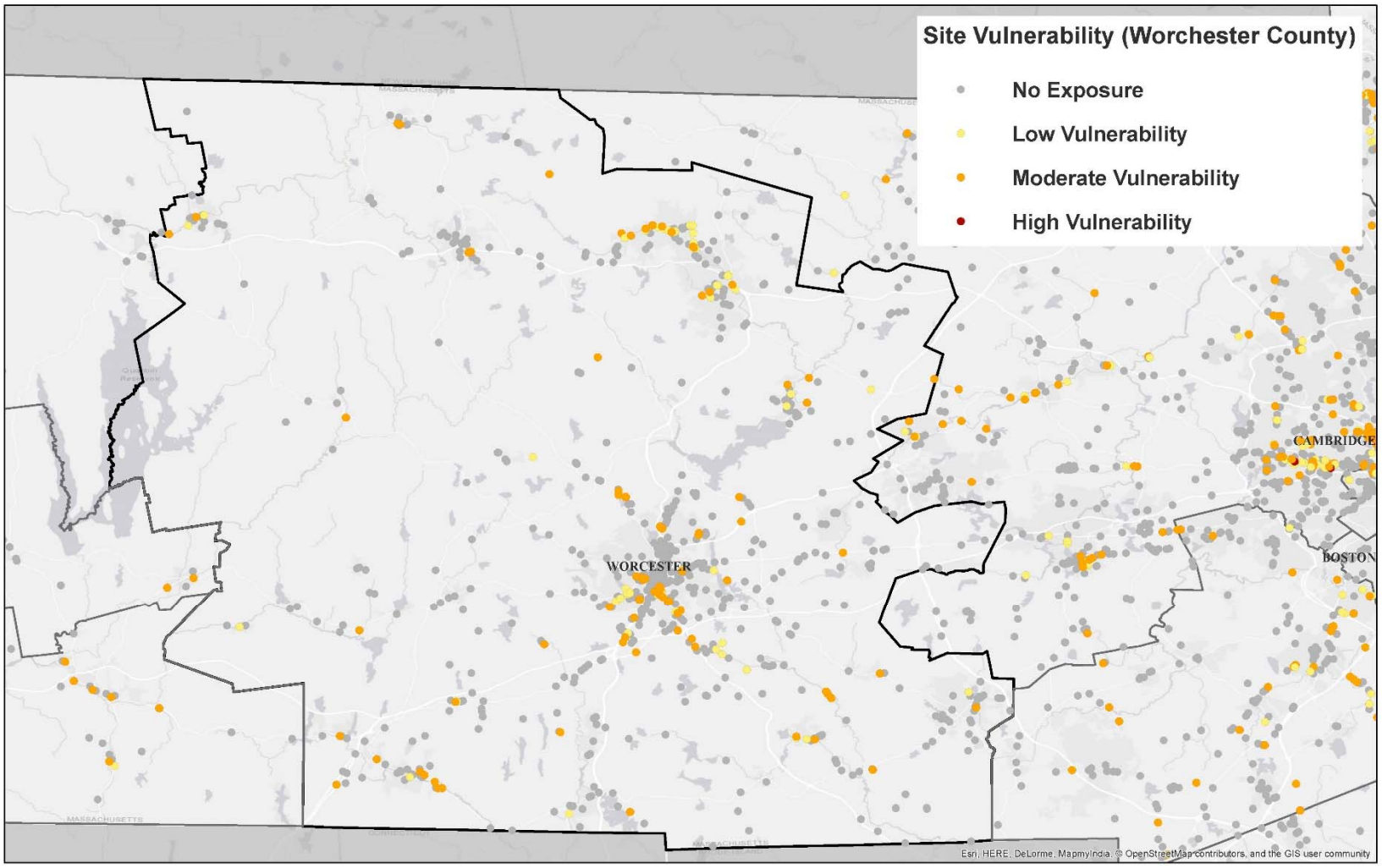
Site Vulnerability (Worchester County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
WORCESTER
CAMBRIDGE
BOSTON
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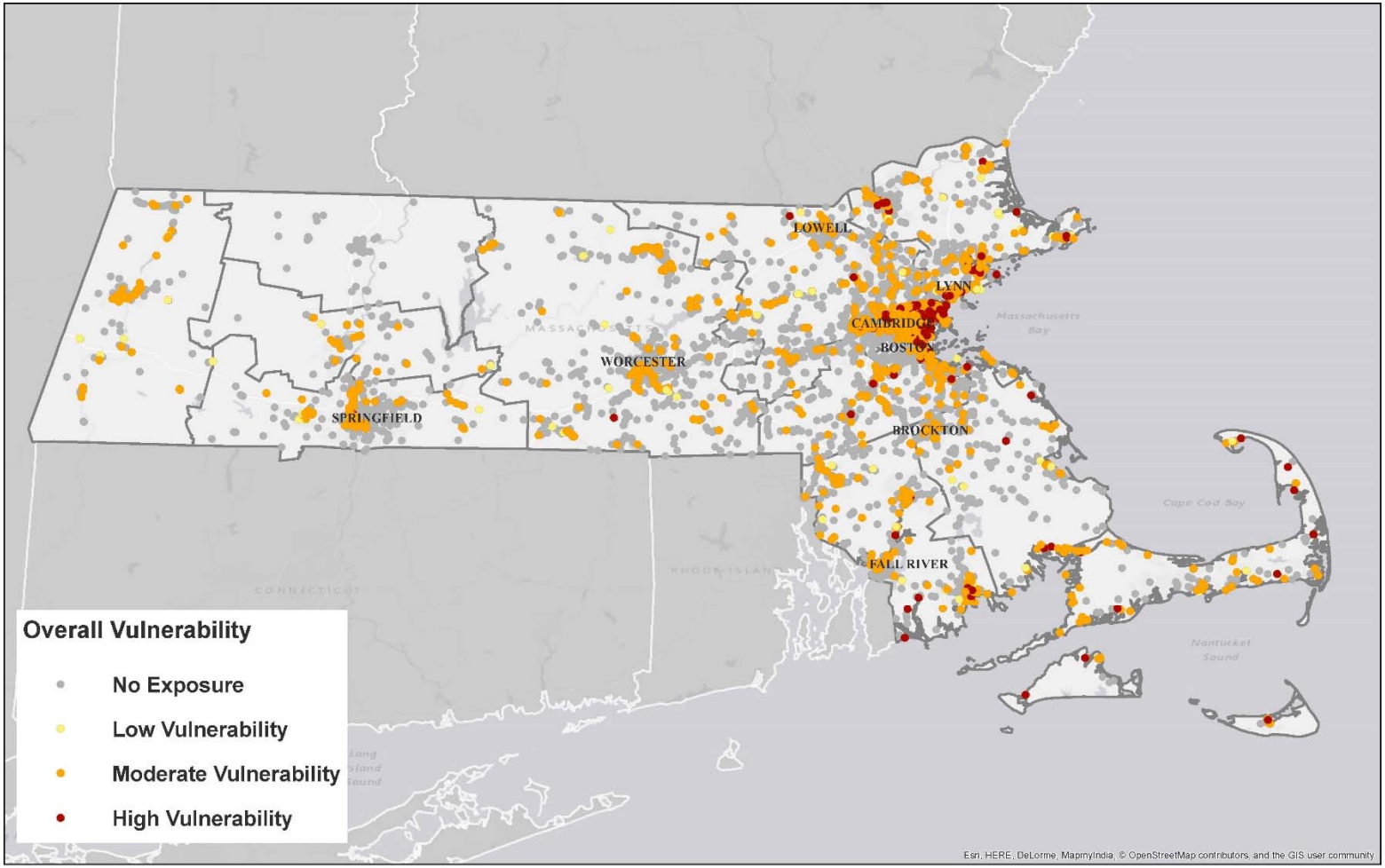
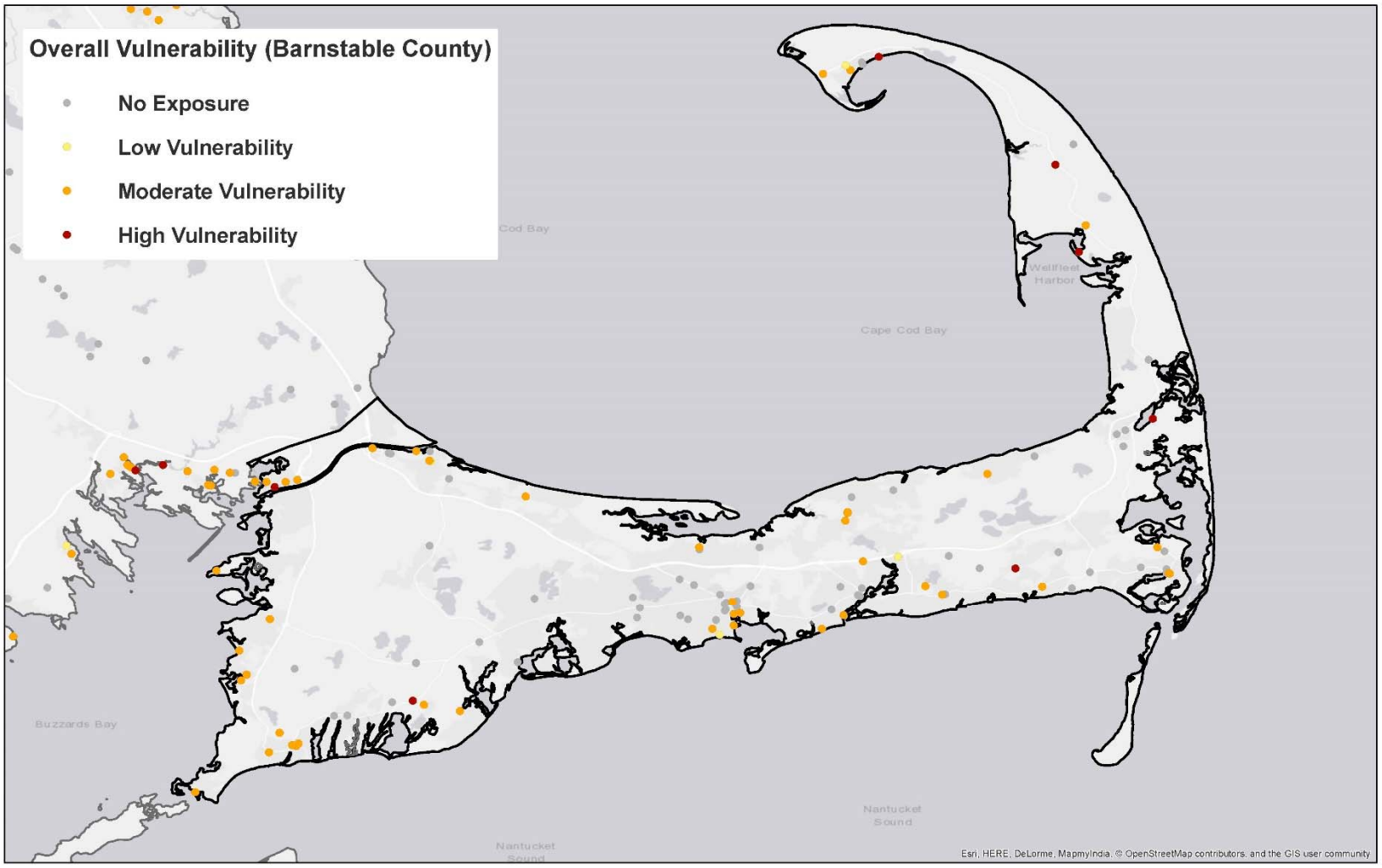
Hazardous Waste Site Overall Vulnerability with Community and Environment Sensitivity. (No exposure = site overall vulnerability refactor scores of zero [n=3,613]; Low Vulnerability = scores between 0 and 1.66 [n=89]; Moderate Vulnerability = scores between 1.67 and 3.33 [n=1914]; High Vulnerability = site vulnerability scores between 3.34 and 5 [n=385])




Overall Vulnerability (Barnstable County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
Cod Bay
Wellfleet Harbor
Cape Cod Bay
Buzzards Bay
Nantucket Sound
Nantucket Sound
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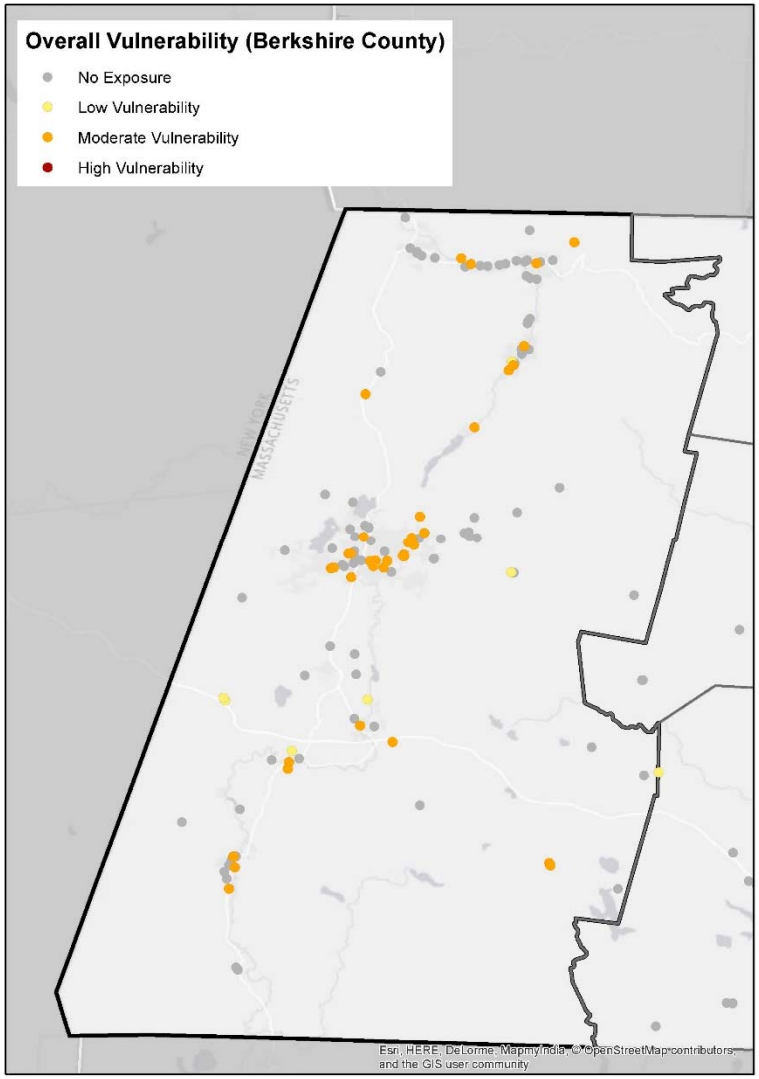
Overall Vulnerability (Berkshire County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
NEW YORK
MASSACHUSETTS
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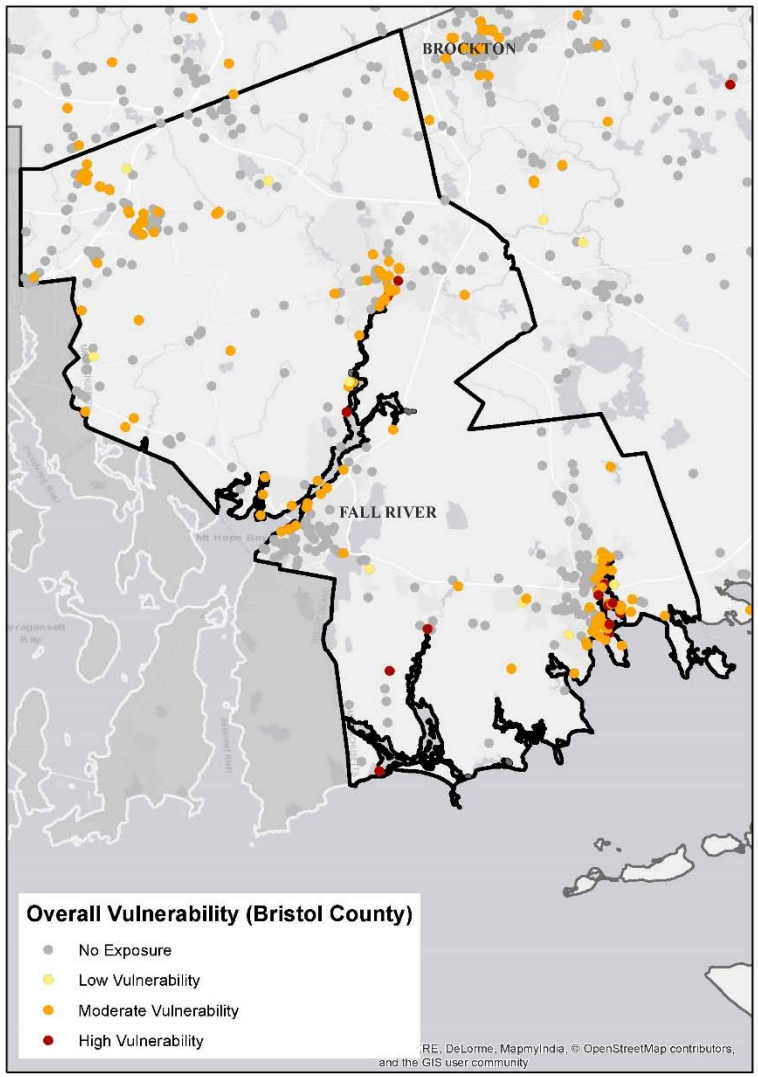
BROCKTON
FALL RIVER
Overall Vulnerability (Bristol County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
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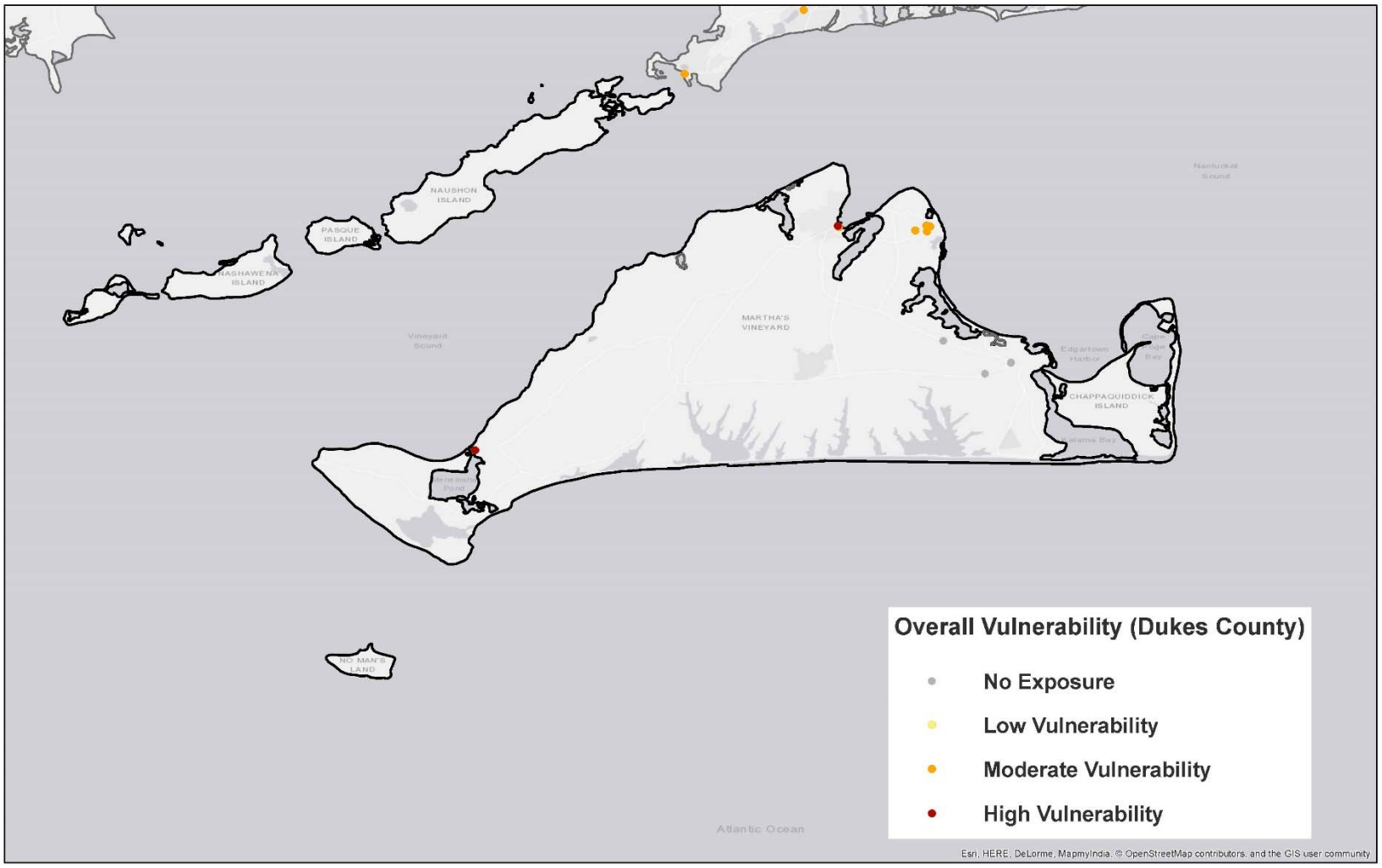
NAUSHON ISLAND
PASQUE ISLAND
NASHAWENA ISLAND
MARTHA'S VINEYARD
CHAPPAQUIDDICK ISLAND
NO MAN'S LAND
Vineyard Sound
Nantucket Sound
Atlantic Ocean
Overall Vulnerability (Dukes County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
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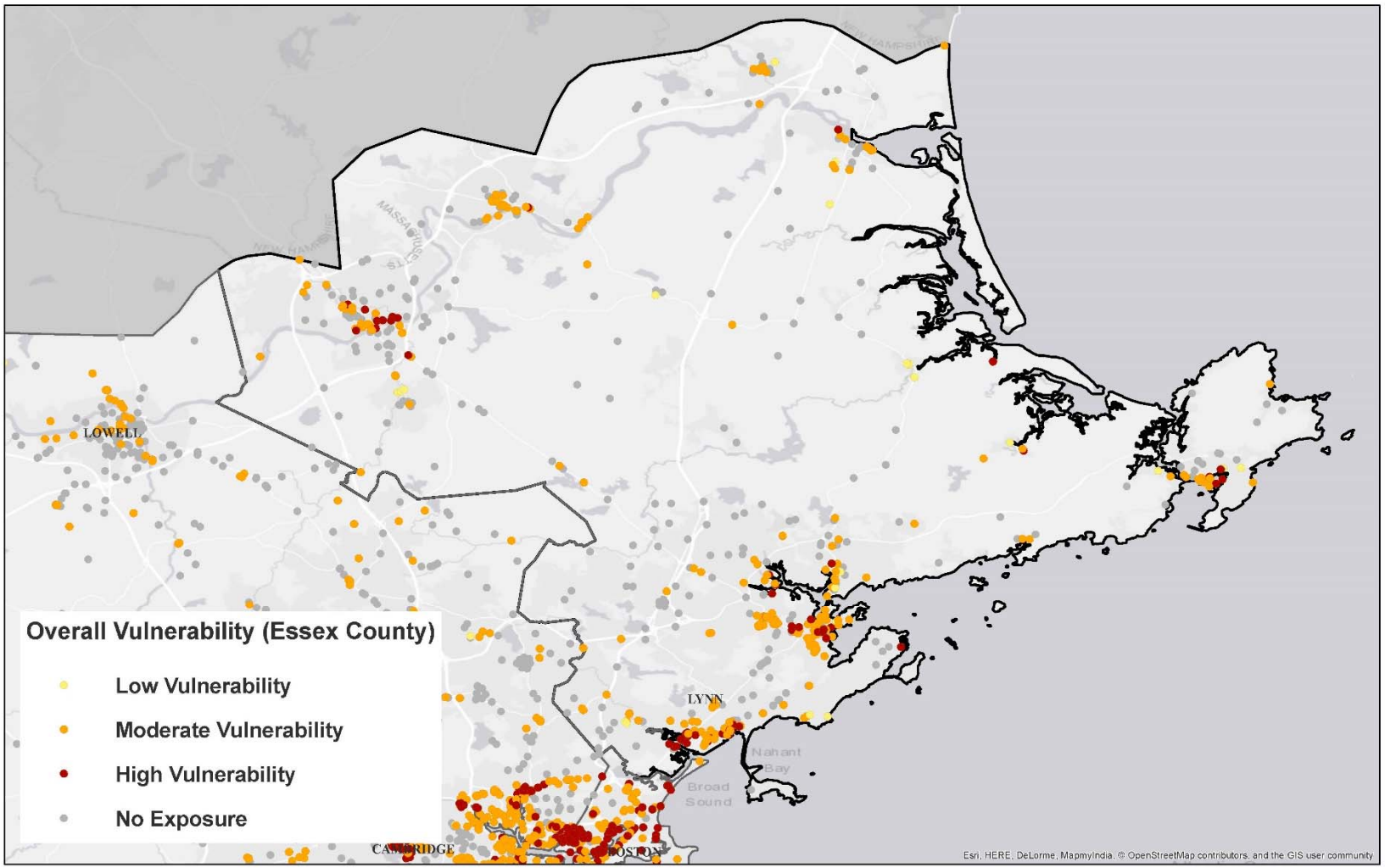
Overall Vulnerability (Essex County)
Low Vulnerability
Moderate Vulnerability
High Vulnerability
No Exposure
LOWELL
LYNN
Nahant Bay
Broad Sound
CAMBRIDGE
BOSTON
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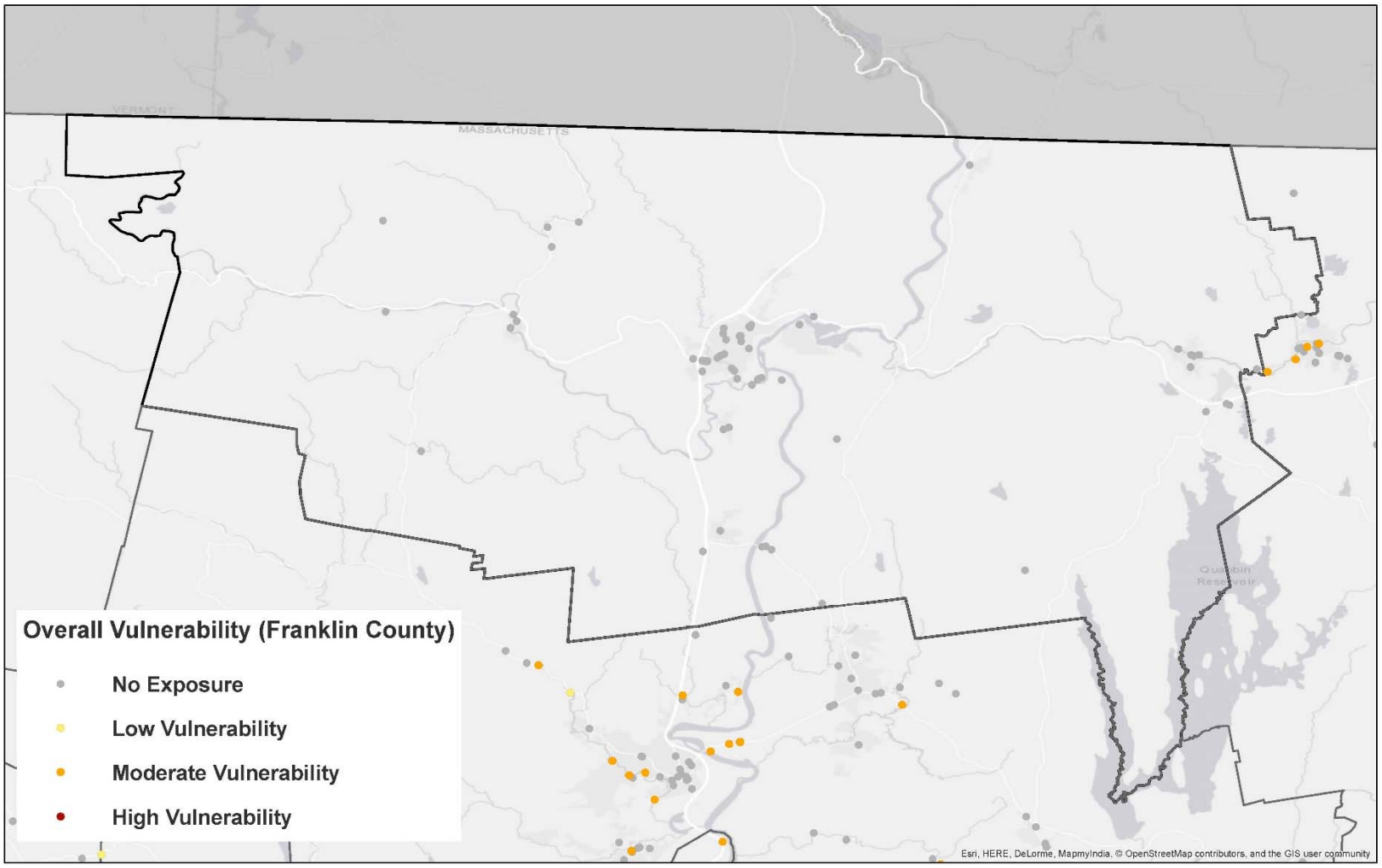
MASSACHUSETTS
Overall Vulnerability (Franklin County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
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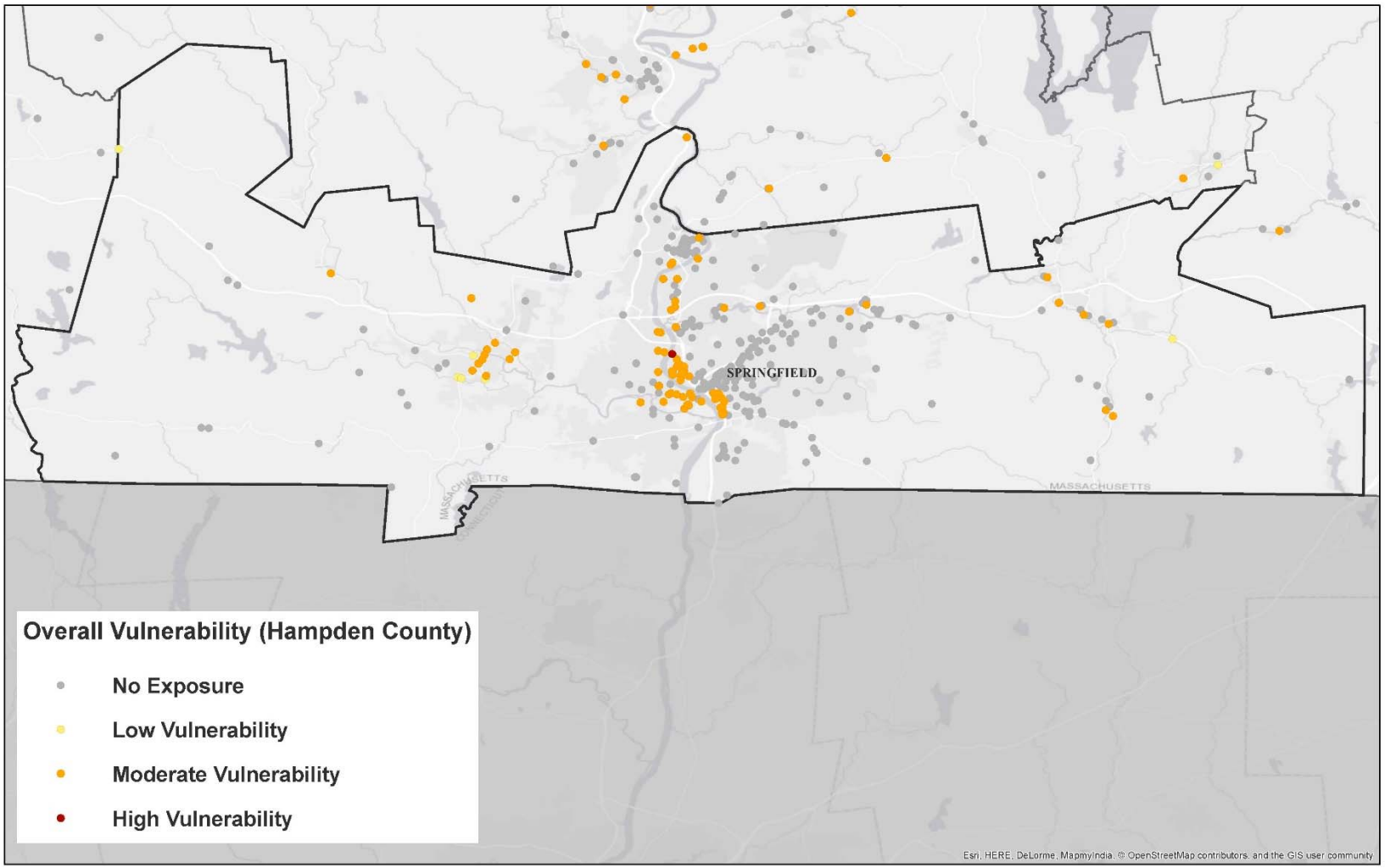
SPRINGFIELD
MASSACHUSETTS
MASSACHUSETTS
Overall Vulnerability (Hampden County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
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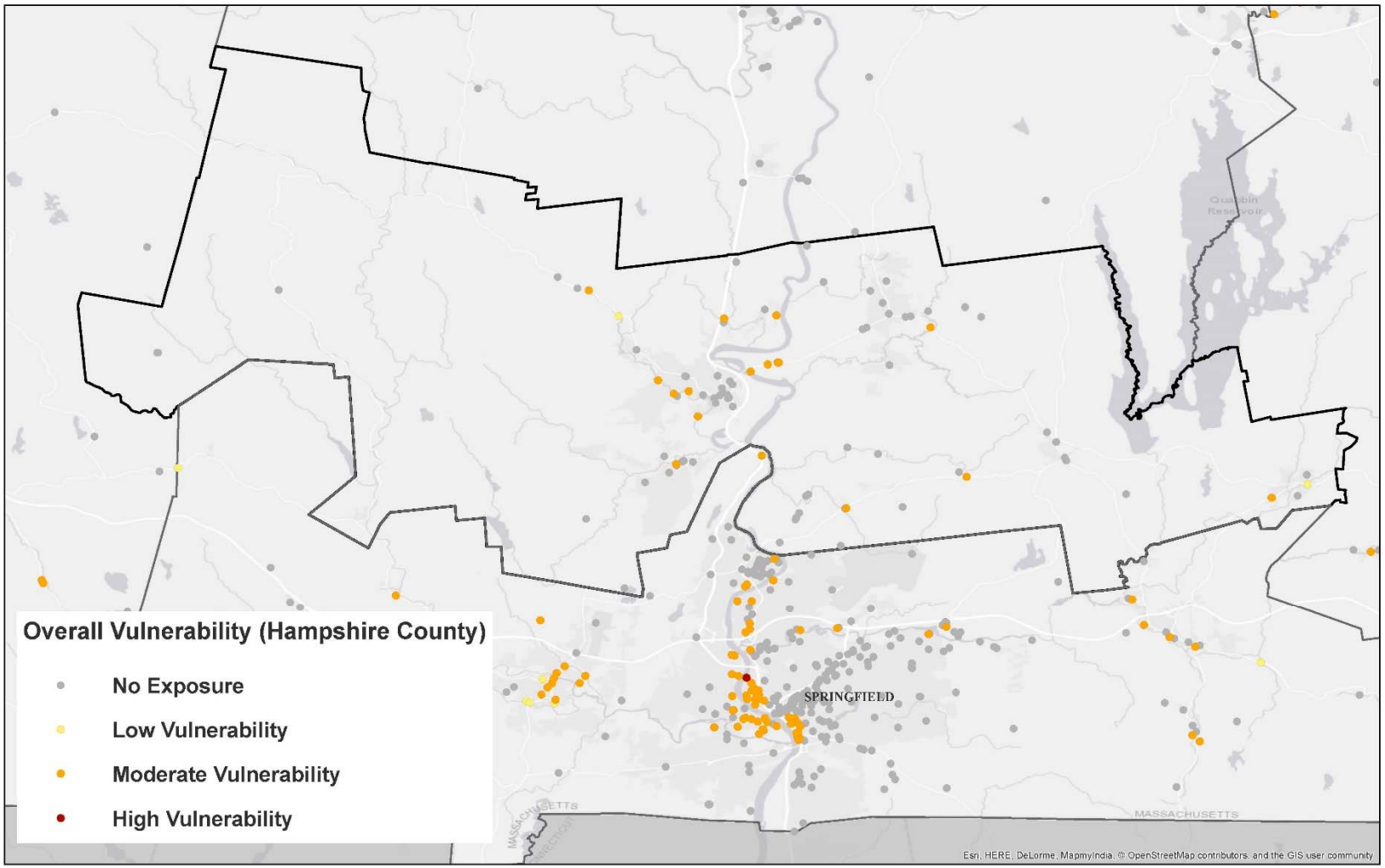
Overall Vulnerability (Hampshire County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
SPRINGFIELD
MASSACHUSETTS
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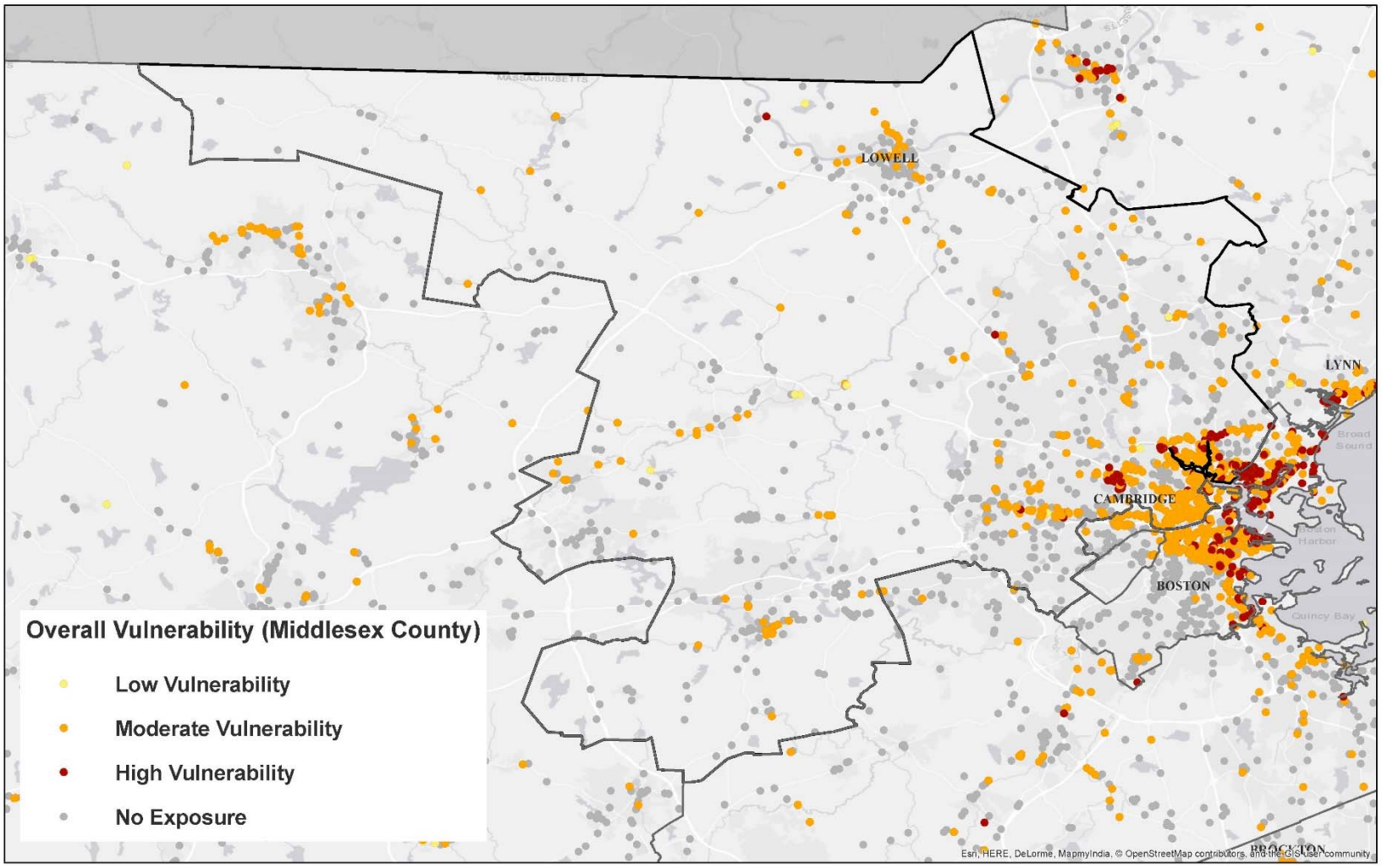
Overall Vulnerability (Middlesex County)
Low Vulnerability
Moderate Vulnerability
High Vulnerability
No Exposure
LOWELL
LYNN
CAMBRIDGE
BOSTON
Broad Sound
Quincy Bay
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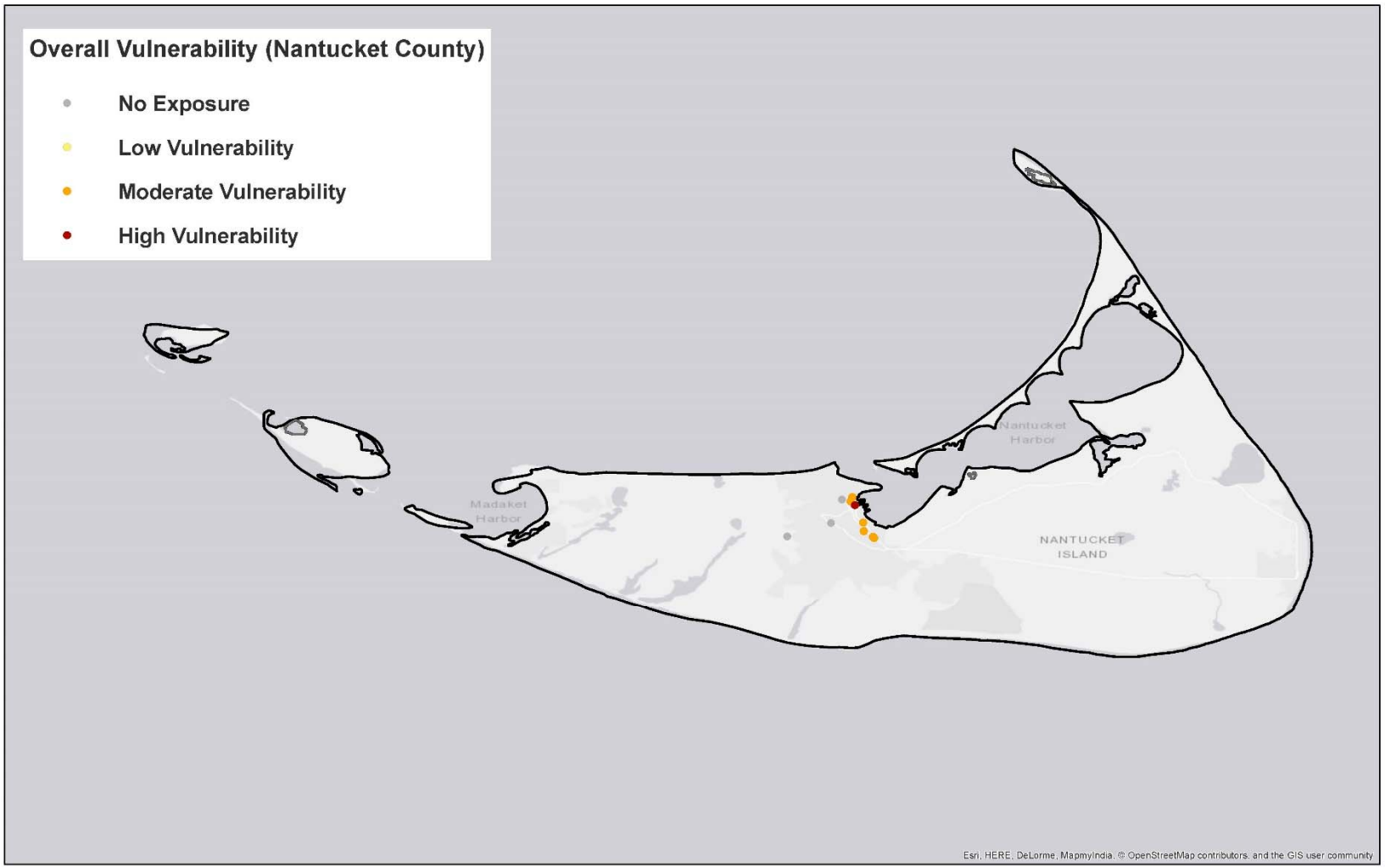
Overall Vulnerability (Nantucket County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
Madaket Harbor
Nantucket Harbor
NANTUCKET ISLAND
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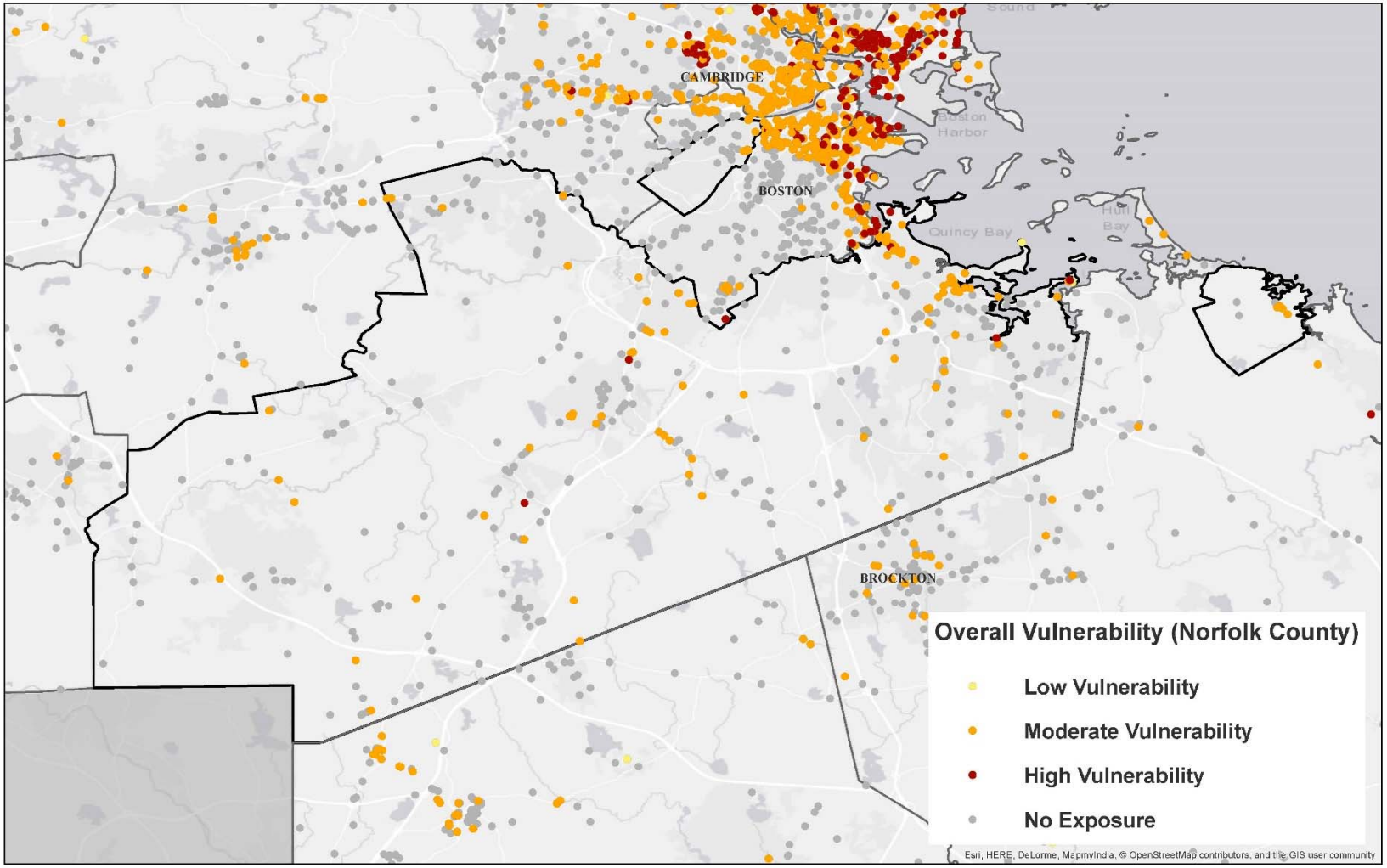
CAMBRIDGE
BOSTON
Boston Harbor
Quincy Bay
BROCKTON
Overall Vulnerability (Norfolk County)
Low Vulnerability
Moderate Vulnerability
High Vulnerability
No Exposure
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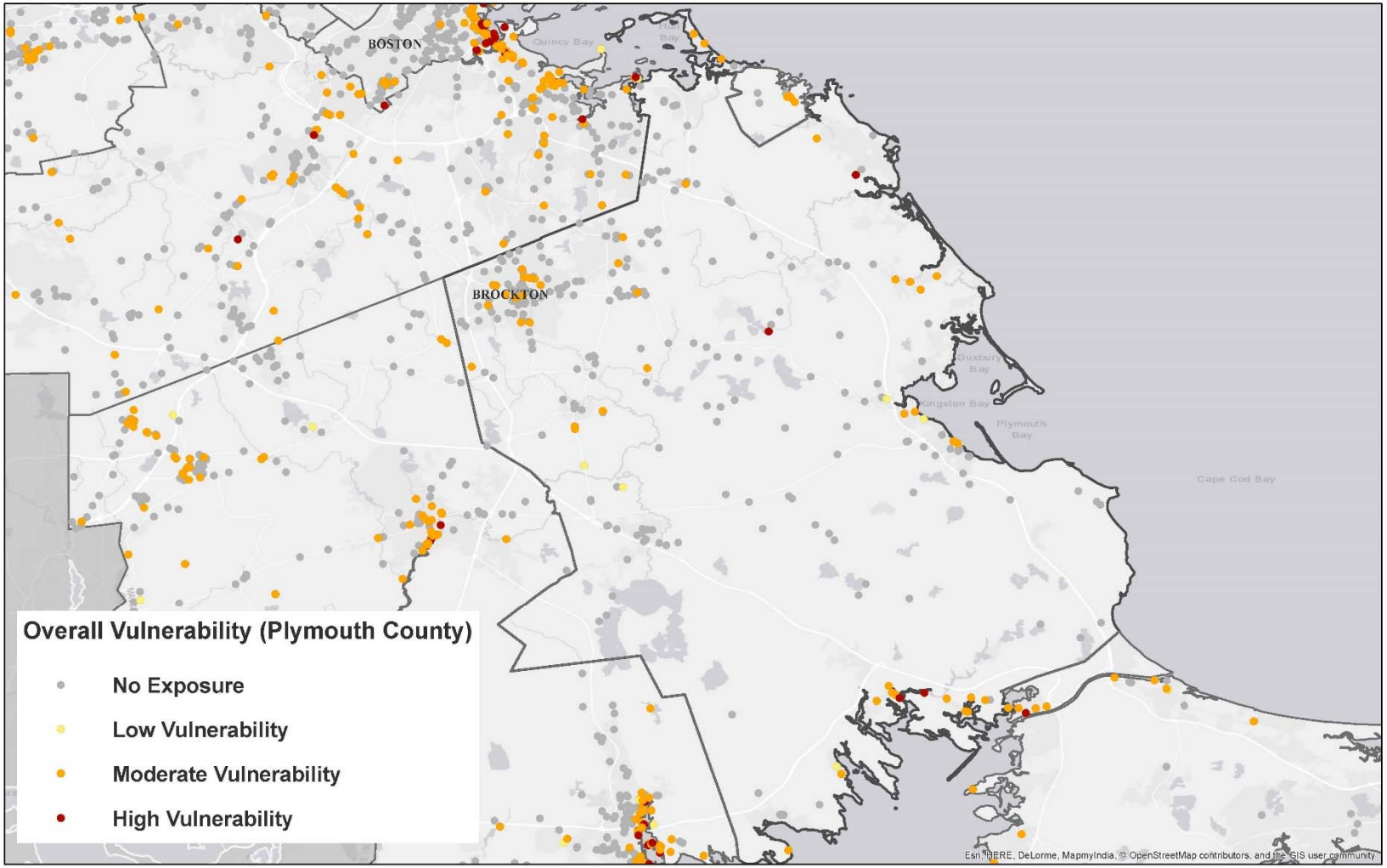
BOSTON
BROCKTON
Quincy Bay
Duxbury Bay
Plymouth Bay
Cape Cod Bay
Overall Vulnerability (Plymouth County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
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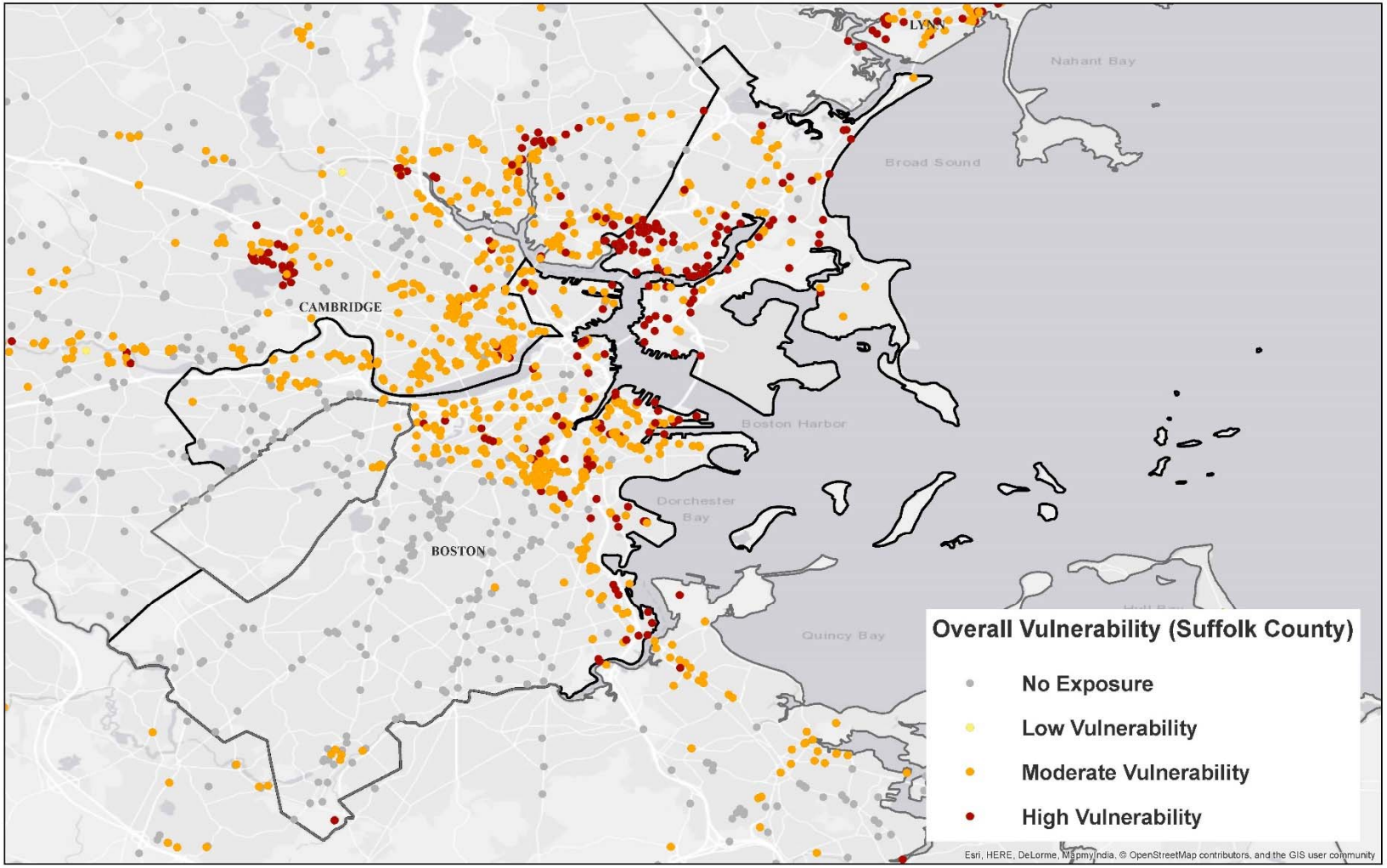
LYNN
Nahant Bay
Broad Sound
CAMBRIDGE
Boston Harbor
Dorchester Bay
BOSTON
Quincy Bay
Overall Vulnerability (Suffolk County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
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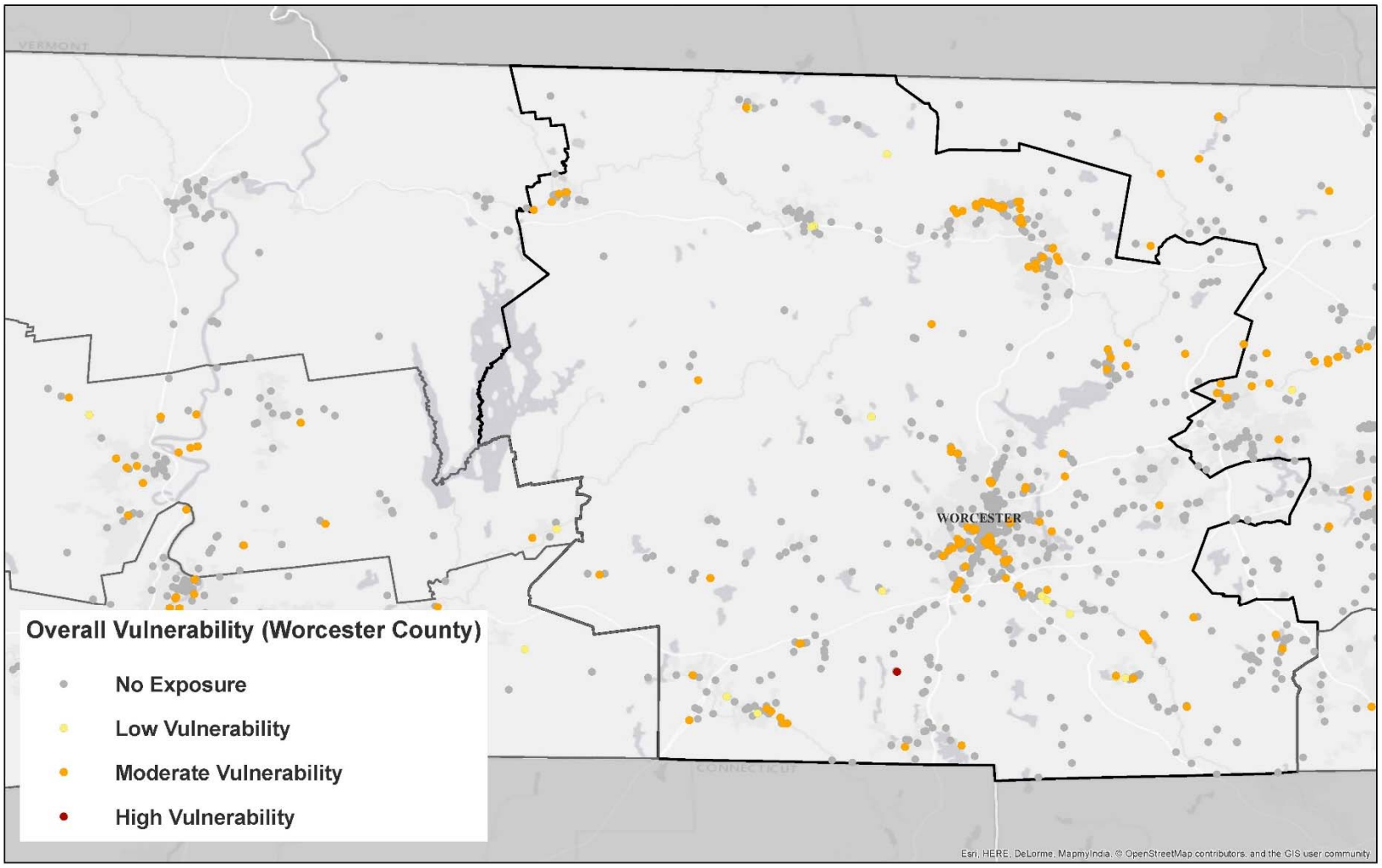
VERMONT
WORCESTER
CONNECTICUT
Overall Vulnerability (Worcester County)
No Exposure
Low Vulnerability
Moderate Vulnerability
High Vulnerability
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Appendix C

Tabulated Results

The screening results table file, “MA Sites Screening Results Table 6December19.xlsx”
Contact Eric Mielbrecht for access to the data table if it is not available for download with this report. (Eric.Mielbrecht@EcoAdapt.org)