Statewide Hazard Risk and Vulnerability Assessment for the State of Rhode Island

FINAL REPORT

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Executive Summary

Statewide planning of natural hazard mitigation requires the ability to quantify and analyze a wide variety of hazards and exposures to develop a mitigation strategy and prioritize mitigation investment.

In this study, an approach was developed to perform statewide and regional vulnerability assessment using publicly available data and simple procedures for risk scoring. The approach was based on the NOAA Coastal Services Center "Community Vulnerability Assessment Technique", but expanded and modified to be useful in analyzing entire states. The approach comprises three measures of risk:

- Hazard Risk Scores. These scores represent the risk posed by different natural disasters within each geographic region, regardless of population or development.

- Exposure Risk Scores. These scores represent economic, social, environmental, and critical facilities exposure within each geographic region, regardless of hazard level.

- Combined Risk Scores. These scores represent the product of hazard scores and exposure scores for different hazard/exposure combinations, thus illustrating the intersection of hazard risk with exposed populations and property.

The risk scores are designed to be used in databases and maps generated by Geographic Information Systems (GIS) software. Using the GIS maps of the results, state planners can identify key hazard/exposure combinations and visualize pockets of risk within geographic subregions of the state.

In the state of Rhode Island, the following major findings were identified to guide statewide mitigation planning:

- Vulnerability maps allow visualization of major flood, hurricane, snowstorm, and earthquake hazards in different geographic regions of the state.

- Most of the major hazard scores have large areas of impact in relationship to economic, environmental, social, and critical facilities exposures within the state's small geographic area. This finding suggests that a single disaster could affect much of the state's exposure simultaneously.

- Given the small size of the state, its diverse population, numerous environmental resources, and strong economic development program, all four major areas of

exposure (economic, social, environmental, and critical facilities) must be addressed in order to comprehensively mitigate the risk from these natural hazards.

- Vulnerability maps corroborate existing statewide efforts to adopt the IBC2000 building code, which addresses flooding, hurricanes, snowstorms, and earthquakes using hazard maps. For example, the current building code assigns one uniform snow load value to the entire state. This study suggests higher risk in the northern part of the state, as recognized by higher snow loads in the IBC2000 code for these northern regions.

- Maps and graphics should be used as the basis to improve public awareness of key hazards, especially flooding, hurricanes, snowstorms, and earthquakes

Based on these findings, additional study is recommended to simulate disasters and produce more detailed results, such as potential economic losses, loss of life, and environmental impact. For example, simulation of a single hurricane event could further illustrate the exposure of the state's concentrated resources to one large disaster. Such detailed analysis will also serve to validate and enhance the statewide risk assessment methodology for use in other regions and states.

Overview

Background

This project was funded by the National Oceanic and Atmospheric Administration Coastal Services Center (NOAA CSC) in order to build upon prior efforts to develop a community risk and vulnerability assessment model. These prior efforts are published in an interactive CD-ROM prepared by the NOAA CSC entitled "Community Vulnerability Assessment Tool", NOAA Publication #NOAA/CSC/99044-CD.

The existing Community Vulnerability Assessment Tool was developed for individual communities, such as cities, towns, or counties. The CD-ROM published by NOAA contains an application of this method to New Hanover County, North Carolina, and it has been applied to other communities for use in disaster mitigation planning.

The NOAA CSC, through this study, sought to expand the existing methodology for application on a statewide and regional basis. This expanded geographic study area requires a modified approach, since both the input data and the required results of the study are of a different nature than for an individual community. Furthermore, it is critical that pilot studies be performed to test the practicality and usefulness of the ultimate statewide risk assessment approach.

Thus, the present study incorporates: (1) development of a basic methodology for statewide and regional risk assessment and (2) the application of this approach to the State of Rhode Island, which is currently in the process of updating its State Hazard Mitigation Strategy (409 Plan).

Purpose/Motivation

The motivation for performing hazard and vulnerability assessment at a statewide level stems from the need to create focused policies to address the mitigation of natural hazards on a regional basis. The hazard and vulnerability assessment therefore seeks to answer the following key questions:

- What are the hazards that threaten a given region?
- What are the economic, social, environmental, and critical facilities exposure levels to these hazards, and how are they distributed throughout the region?
- How frequently will damaging events occur, how severe and widespread will the impact be?
- What opportunities exist to mitigate the impact of these events to key exposures?

- How should planning resources and mitigation dollars be allocated among the large number of exposures and hazards to be considered?

While detailed models exist to address individual hazards and exposures, such as earthquake models or hurricane models for economic losses (for example, HAZUS-99, published by the National Institute of Building Sciences and FEMA), no comprehensive quantitative model exists that addresses social, economic, and environmental exposure to multiple disasters within a policymaking framework.

This project aims to provide a generic methodology for evaluating risk levels that is within the capabilities of typical government agencies charged with preparing disaster mitigation plans.

The methodology is tested and applied to two geographic subregions: (1) an individual community, the City of Warwick, RI, and (2) the entire State of Rhode Island.

The benefits of the statewide risk assessment are multifold, including:

- Building awareness of risk and vulnerability
- Mobilizing stakeholders and promote communication
- Prioritizing mitigation investment to areas of most demand
    - Hazards
    - Exposures
    - Regions
- Collecting data to guide community-specific studies

Note that the results of the statewide risk assessment are necessarily limited in application to a regional basis. The intent is to provide risk measures on an aggregate basis, as opposed to risk at individual locations. Aggregate level risk measures can be used to identify and prioritize more localized and detailed risk assessment of critical exposures and hazards.

Scope of Work

The project comprised the following five tasks:

1. **Detailed task plan**

Prepare a detailed task plan for completing Tasks 2,3,4, and 5 for the appropriate project officer at the NOAA Coastal Services Center.

2. **Develop framework for a Statewide Hazard Risk and Vulnerability Assessment for the State of Rhode Island.**

Develop the framework for a Statewide Hazard Risk and Vulnerability Assessment for the State of Rhode Island. The assessment should build upon the methodology developed by the Coastal Services Center in the Community Vulnerability Assessment Tool. New Hanover County, North Carolina. NOAA/CSC/99044-CD. CD-ROM. Charleston, SC: NOAA Coastal Services Center, 1999.

3. **Develop Pilot Community Risk and Vulnerability Assessment for Warwick, RI.**

The framework for a Statewide Hazard Risk and Vulnerability Assessment for the State of Rhode Island developed in Task 2 should be applied to Warwick, RI.

4. **Conduct the Statewide Hazard Risk and Vulnerability Assessment for the State of Rhode Island.**

Apply the methodology developed in Task 2 to the state of Rhode Island. Prepare maps, charts, and tables of results.

5. **Demonstration of Results**

Prepare a brief written summary of the work performed and present the results to the appropriate project office at the Coastal Services Center prior to June 30, 2001.

Methodology for Statewide Vulnerability Assessment

Overview of Approach

Figure 1 below shows a general flowchart of the methodology developed for this study.

Regions and Subregions

The first step in the process is to define the study region and select subregions for analysis. Analysis of risk measures is performed at the subregion level, and then subregion scores are aggregated together through summation to measure overall risk to the study region (or any other combination of subregions desired).

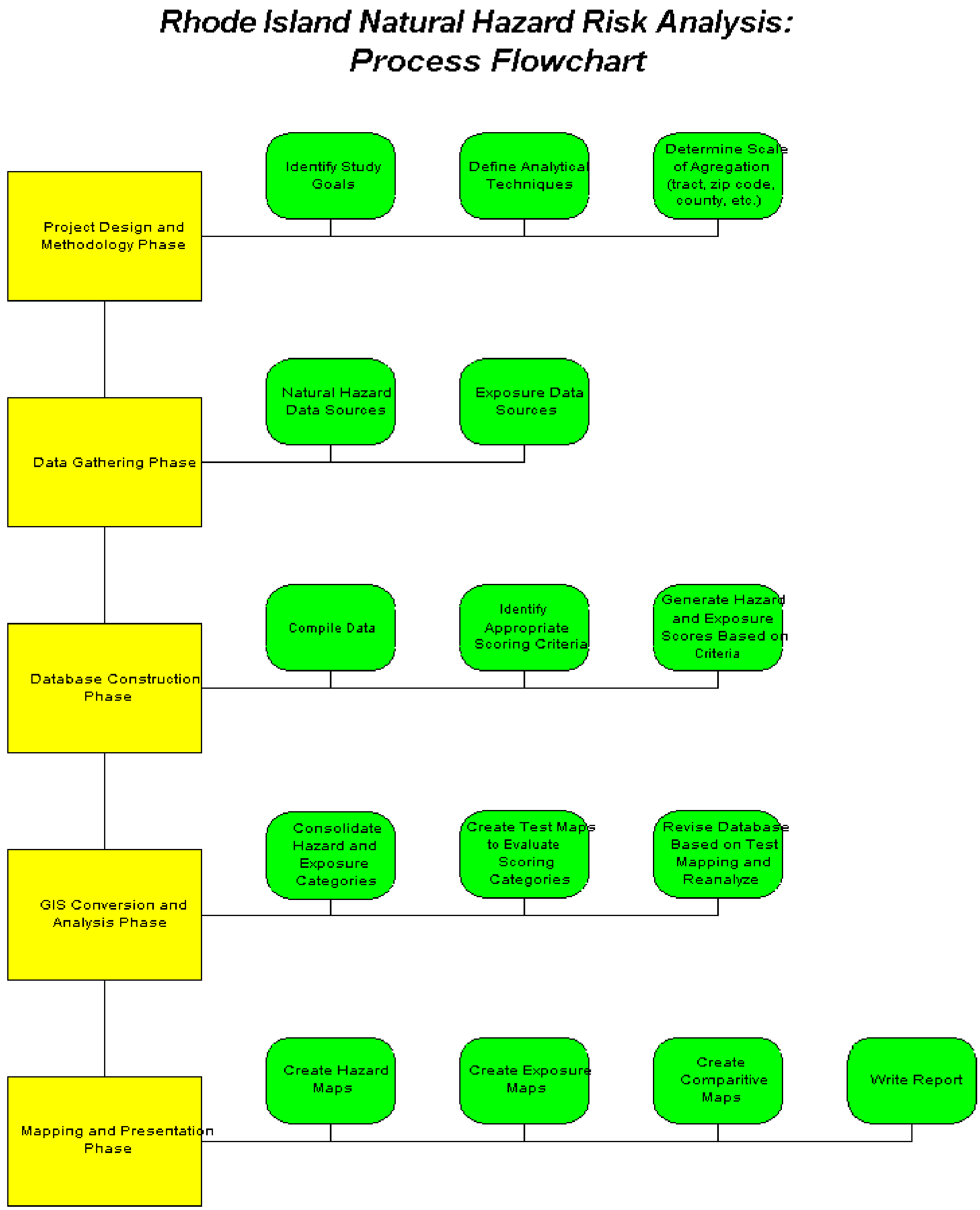
Using the approach described in this report, the study region can theoretically be of any size, ranging from an individual community to an entire country. The main constraint on the study region chosen is that it must be divisible into standardized geographic subregions that are mutually exclusive and collectively exhaustive (i.e., subregions must not overlap, and when added together they must represent the entire region of interest).

Regions and subregions selected in the analysis process provide a critical link between statewide planning and community level planning. Statewide analysis of combined subregions can be used to identify communities with high mitigation needs. Data collected in the statewide analysis can then be directly incorporated into community level mitigation planning. Conversely, community-level data can be used to validate results from the statewide analysis. For example, we have taken flood data collected from a community-specific study of the City of Warwick and used it as a validation case for the statewide results.

For the purposes of this study, the study region was the State of Rhode Island, and subregions were selected to be census tracts. Other subregions that could be used include zip codes and counties. If smaller subregions are chosen, higher resolution can be obtained in mapping risk measures. However, this consideration must be balanced with the availability of data for these subregions.

In the case of Rhode Island, adequate data exists at the census tract level for hazards and exposure for our purposes. In addition, census tracts allow flexibility for aggregation into cities, counties, and other regional combinations for further study.

Figure 1


Rhode Island Natural Hazard Risk Analysis:
Process Flowchart
Project Design and Methodology Phase
Identify Study Goals
Define Analytical Techniques
Determine Scale of Agregation (tract, zip code, county, etc.)
Data Gathering Phase
Natural Hazard Data Sources
Exposure Data Sources
Database Construction Phase
Compile Data
Identify Appropriate Scoring Criteria
Generate Hazard and Exposure Scores Based on Criteria
GIS Conversion and Analysis Phase
Consolidate Hazard and Exposure Categories
Create Test Maps to Evaluate Scoring Categories
Revise Database Based on Test Mapping and Reanalyze
Mapping and Presentation Phase
Create Hazard Maps
Create Exposure Maps
Create Comparitive Maps
Write Report

Hazard Type Identification

The second step in the process is to determine the hazard types for consideration. The list should be comprehensive and include any hazard type with a reasonable probability of occurring within the study region in a given one year period. However practical limits exist on data availability that may limit consideration of certain hazard types.

The sources for hazard type identification can include emergency management personnel, building officials, weather officials, seismologists, engineers, insurance professionals, and others with knowledge of potential disasters that can impact a region.

For the purposes of this study, the following hazard types were considered based on the experience of the project team:

- Floods
- Extreme Wind (Nor'easters and Hurricanes)
- Snowstorms
- Hailstorms
- Tornadoes
- Earthquakes
- Temperature Extremes

These hazards were judged to have a reasonable probability of occurring within the study region in a given one-year period.

Define Analytical Requirements

This step consisted of determining the appropriate techniques for computing risk measures. The following key requirements guided selection of the risk scoring system used in this study:

- Use of basic Community Vulnerability Assessment Tool approach, but expanded to better model statewide and regional risk
- Ability to compare and contrast different hazards and exposures
- Ability to aggregate individual risk measures into summary risk measures through algebraic summation

- Ability to utilize publicly available, non-proprietary data for analysis
- Flexibility for incorporation of diverse categories of hazards and exposures
- Linkage to established standards for hazards, such as model building codes, to ensure validity of results and parallelism with established practices in hazard mitigation

Data Collection

The following table outlines sources for data collection that were identified early in the project to guide the study.

Table 1. Data Collection

Category	Data Types	Possible Data Sources
Hazards	Extreme Wind Events, Flood, Nor'easter, Earthquake, Snow/Ice, Temperature Extremes, Tornado, Environmental Hazards	National Hurricane Center FEMA, NOAA, National Weather Service, United States Geological Survey, National Climatic Data Center RIGIS (online GIS database for State of Rhode Island) National Flood Insurance Program (NFIP) Insurance Companies
Critical Facilities	Shelters, Schools, Hospitals and Nursing Homes, Fire and Rescue, Police, Utilities Communications, Transportation, Government	Rhode Island Building Commissioner Rhode Island Department of Administration Rhode Island Department of Transportation RIGIS (online GIS database for State of Rhode Island)

Category	Data Types	Possible Data Sources
Critical Populations	Minority Populations Households below poverty level Population over age 65 Single parent with child families Population with no high school diploma Households with public assistance income Housing units with no vehicle available Rental units	U.S. Census Rhode Island Department of Administration RIGIS (online GIS database for State of Rhode Island) Red Cross
Economic Centers	Hotels/Motels, Agriculture, Construction, Manufacturing, Transportation, Wholesale and Retail, Services, Finance/Insurance, Real Estate	United States Economic Census Rhode Island Economic Development Corporation Rhode Island League of Cities and Towns Rhode Island Department of Transportation RIGIS (online GIS database for State of Rhode Island)
Environmental Resources	Hazardous Materials, Toxic Release Sites, Oil Facilities Ports, Marinas, Discharge Sites Scenic Vistas Beach Erosion and Shoreline Change	Rhode Island Department of Environmental Management Rhode Island Coastal Resources Management Council RIGIS (online GIS database for State of Rhode Island)

Category	Data Types	Possible Data Sources
Mitigation Opportunities	Policy Status, Undeveloped Land, Population Projections, Land Cover Change, Zoning	Rhode Island Department of Environmental Management Rhode Island Building Commissioner RIGIS (online GIS database for State of Rhode Island)

Hazard, Exposure, and Combined Risk Scoring

The approach used for this project involves three types of risk scores: hazard scores, exposure scores, and combined scores. Each of the three risk scores describe different aspects of the vulnerability in a given region:

- **Hazard Scores**. Hazard scores measure the average impact of different hazard types in a region. The hazard score in a region is a function of the geography and natural recurrence of disasters over time in an area. Thus, hazard scores are inherent to a region and theoretically cannot be lowered through mitigation or other intervention. A hazard score is computed for each hazard type and each subregion considered. Hazard scores can be combined within a subregion or across multiple subregions to evaluate aggregate hazard risk levels.

- **Exposure Scores**. Exposure scores measure the level of assets, populations, or resources within a given region. The exposure score is a function of the built environment, demographics, and environmental uses of a given region. Exposures scores can be combined within a subregion or across multiple subregions to evaluate aggregate exposure levels.

- **Combined Scores**. Combined scores represent the product of individual hazard and exposure scores, measuring the effects of hazards on the exposure of a given region. Combined scores are useful results for policymaking and risk mitigation, as they indicate the key hazard/exposure combinations that exist in a region. Combined risk scores are calculated for each subregion, and can then be aggregated to measure overall scores for the study region or other combinations of subregions by summation.

Note that the significance of the scores is relative in nature. A given score does not correspond to a dollar loss level or other direct measure of risk. Instead, the risk scores are intended to provide a framework for understanding the aggregate distribution of hazard and exposure combinations across a study region. Detailed analysis of direct risk measures, such as dollar loss, can be conducted for the key hazard/exposure combinations identified by this approach, using software like HAZUS.

Hazard Score

Overview of Scoring Procedure

Scoring Approach

The hazard score for each hazard type is computed using the following formula:

HAZARD SCORE = (FREQUENCY SCORE) * (AREA IMPACT SCORE)*

(INTENSITY SCORE)

The individual factors in the hazard score are:

- Frequency Score. This score is a measure of how often a given hazard occurs, in terms of number of events per year.
- Area Impact Score. This score is a measure of how much geographic area would be affected by a hazard event, in terms of either gross area or relative area (see discussion below).
- Intensity Score. This score is a measure of the level of intensity of a hazard. For each hazard, a different measure is used, based on the type of forces that characterize the hazard (e.g. wind for a hurricane, ground shaking for an earthquake).

The procedure for determining each component of the hazard score is described below.

Frequency Score

Frequency scores are based on the average number of events per year of the hazard type.

Five levels of frequency are considered, based on commonly used benchmarks in both the insurance and building design fields. Table 2 summarizes the frequency score and subjective description of each frequency level.

Table 2. Frequency Lookup Table

Return Period (years)	Frequency Score	Number of events per year	Subjective Description
1	5	1	Frequently recurring hazards, multiple recurrences in one lifetime
50	4	0.02	Typically occurs at least once in lifetime of average building
100	3	0.004	25% chance of occurring at least once in lifetime of average building
500	2	0.002	10% chance of occurring at least once in lifetime of average building
1000	1	0.001	Highly infrequent events, like maximum considered earthquake

Area Impact Score

Two methods of determining area impact score were used, depending on the type of hazard distribution (see description of individual hazards below):

- Relative Area Impact. This method relates the area impact score to the percentage of a subregion impacted by the event considered (such as the % area of a census tract). Scoring for this method is shown in Table 3 below.

- Absolute Area Impact. This method relates the area impact score to the average impact in square miles of the event considered. The scores used are shown in Table 4 below.

Table 3: Area Impact Lookup Table, Relative Method

Relative Area Impact (% subregion covered)	Score	Subjective Description
0	0	No affected area - 0% impact
0.1	1	10% tract impact
0.25	2	25% tract impact
0.5	3	50% tract impact
0.75	4	75% tract impact
1	5	100% tract impact

Table 4. Area Impact Score, Absolute Method

Absolute Area Impact (sq. miles)	Score
0	0
0.001	1
0.01	2
0.1	3
1	4
10	5

Intensity Score

To determine intensity scores, an intensity measure was selected for each hazard type, as follows:

- Extreme Wind (Nor'easters and Hurricanes): 3-sec gust windspeed (mph) and wind pressure on buildings (psf)
- Earthquake: Spectral acceleration (1-sec), %g

- Tornado: Fujita scale
- Flood: Base Flood Elevation (ft)
- Hail: Particle size (in)
- Snow: Snowfall (in)
- Extreme Temperature: Heating and cooling degree days

For each hazard type, the intensity measure was related to a lookup table of intensity scores ranging from 1 (lowest intensity) to 5 (highest intensity). The intensity scores therefore provided a somewhat uniform method of relating intensities from very different hazards.

NOTE: These intensity measures are intended for use in the Northeast region of the U.S. only. Different relative intensities should be considered for other regions of the country.

Extreme Wind (Nor'easter and Hurricane)

Extreme wind hazards were analyzed using an approach that is consistent with ASCE 7-98, "Design Loads for Buildings and Other Structures". ASCE 7-98 serves as the basis for building codes throughout the United States and employs a generally accepted procedure for determining wind force levels for design of buildings.

The frequency of winds used for design is typically 100 years, and therefore this frequency level was selected for wind analysis in this study. Because of the large geographic nature of hurricanes and nor'easters, the area impact score used was 5 in all cases.

Extreme wind intensity scores were based on a combination of geographic windspeed distribution and wind pressure figures, both of which are taken from ASCE 7-98. This process consisted of two steps:

The first step was to determine the average wind speed that a tract was likely to experience in a 100 year hurricane event. This varies across the state and was divided into three categories. These categories were 90-100 miles per hour wind speeds, 100-110 miles per hour wind speeds, and 110 – 120 miles per hour wind speed. The windspeed for each tract was taken from ASCE 7-98 Figure **6-1c,** "Basic Wind Speed – Mid and Northern Atlantic Hurricane Coastline", and corresponds to the 3-sec gust windspeed at 33 ft above ground for Exposure C category (see description of categories below).

The second step was to determine the average degree of exposure within each census tract. The exposure score is determined by the ground cover, topography, and constructed features of a tract and is labeled as A, B, C, or D. The exposure categories were taken from the ASCE 7-98 building code, and are standard categories used in the design of buildings nationwide:

- Exposure A is applied to large city centers with buildings averaging over 70' in height. All tracts with a population of over 10,000 people were classified as Exposure A.
- Exposure B is for urban and suburban areas. Tracts with populations between 2,500 and 10,000 people were classified as Exposure B.
- Exposure C is for open terrain, with populations of less than 2,500.
- Exposure D is for flat, unobstructed areas exposed to wind flowing over water. All tracts within one mile of the ocean were classified as Exposure D.

NOTE: The application of these exposures is very coarse. In actuality, individual sites within a census tract may have widely varying exposures. However, for the purposes of this study, which focuses on statewide levels of risk, an average exposure for each census tract was judged to be sufficient for the analysis of each census tract.

Once the exposure category and wind speeds were determined, these values were used in a matrix (shown in Table 5) to determine the average force of wind pressure that would affect a typical building, in pounds per square foot. For example, if a tract has an exposure of category B and is in a 110 mile per hour wind speed zone, the average pressure would be approximately 20 pounds per square foot. This measurement corresponds to the ASCE 7-98 method for determining hurricane forces on structures.

Finally, the value of wind pressure determined was entered into Table 6 below, which resulted in a score of 1 to 5 for extreme wind intensity score. Higher wind pressure levels are assigned higher intensity scores. Thus, the extreme wind hazard score for a census tract is proportional to the average wind pressure experienced by buildings within that census tract for a building code level wind event.

Table 5. Basic Pressure, Simplified Method (based on ASCE 7-98), psf

	Windspeed (3 sec gust)			
Exposure	90	100	110	120
A	12.6	15.3	18	21.6
B	14	17	20	24
C	19.6	23.8	28	33.6
D	23.24	28.22	33.2	39.84

Table 6. Intensity Score Lookup Table based on Pressure

Pressure (psf)	Intensity Score
<12	0
12	1
15	2
20	3
25	4
>30	5

Earthquake

Earthquake scoring was computed with the aid of HAZUS-99, FEMA's software for hazard and loss estimation from earthquakes. To determine the earthquake score, the following process was followed:

- A single earthquake frequency level was selected as a basis for analysis. For the purposes of this study, all scores were based on a 500 year recurrence event. Note that other return periods could also be used to determine earthquake hazard scores, but the 500 year event was selected as most representative of a "design basis" earthquake frequency for the state of Rhode Island based on the judgment of the project team.

- HAZUS was then used to calculate the average spectral accelerations for each census tract, using a 500 year probabilistic event for the state of Rhode Island. The HAZUS output included maps of spectral acceleration and numerical tables corresponding to the maps. The spectral acceleration values output by HAZUS account for the major factors that influence ground motions in an earthquake, including soil types and distance from earthquake sources.

- Area Impact scores were taken to be 5 for all Rhode Island census tracts due to the complete coverage which would occur during a statewide earthquake event.

- Intensity scores were constructed using spectral acceleration, in units of gravitational acceleration, for a 1 second period building. These values were created using judgment, such that they would be consistent with hazard levels used in building codes for earthquake design.

- Finally, frequency, area impact, and intensity scores were multiplied together to determine the earthquake hazard score for each census tract.

Table 7. Earthquake Intensity Score

Spectral Acceleration (1sec), g	Intensity Score	Subjective Description
0	0	No effects
0.005	1	Felt indoors, light vibration
0.01	2	Indoors, strong vibration
0.025	3	Outdoors, house shakes
0.05	4	Walls crack, ground waves
0.1	5	Violent, building structures damaged

Hailstorm

Hail frequency scores were based on historic data for hail events over the last 50 years. Area impact was computed using an absolute scale for an area of 1 square mile. Intensity scores were based on particle size of the worst case recorded event in a census tract, as shown in the table below.

Table 8. Hail (Particle Size, in)

Particle Size (in)	Intensity Score	Subjective Description
0	0	No Effect
0.5	1	Foliage damaged
1	2	Cars dented
2	3	Windows smashed
3	4	Moderate Injuries
4	5	Serious injury & damage

Severe Snowstorms

Snowstorms were also calculated on the basis of a historical record from the NWS. Area impact was determined using a relative scale due to the nature of the hazard. Intensity was determined by the depth of snowfall of the worst case event recorded in a census tract, as outlined in the table below.

Table 9. Snowstorm (Depth, in)

Depth (in)	Intensity Score	Subjective Description
0	0	Ground visible
3	1	Moderate cover
6	2	Thick ground cover
9	3	Trees collapse
12	4	Roads impassable
>24	5	Light structural damage

Temperature Extremes

The frequency scores for temperature extremes are based upon seasonal averages over a 50 year period. The area impact scores were statewide, thus resulting in consistent scores of 5. Intensity scores were determined by the difference between the number of heating degree days and cooling degree days. These values were evaluated per the table below.

Table 10. Temp Extremes (Heating Deg. Days - Cooling Deg. Days)

Degree Days	Intensity Score	Subjective Description
0	0	No temp. extremes
100	1	Light variation
1000	2	Medium variation
2500	3	Serious temperatures
7500	4	Cold/Heat Wave

10000	5	Frigid/Burning Temp.

Tornado

Frequency values were derived from historic tornado data over a 30 year period, culled from the National Weather Service Severe Weather Center. Area impact was computed based on the average length and width of the damage path, as cited also by the National Weather Service. Finally, Intensity scores were based on the Fujita Scale, as illustrated below.

Table 11. Tornado (Fujita Scale)

Fujita Scale	Intensity Score	Subjective Description
0	0	Light damage
1	1	Moderate damage
2	2	Significant damage
3	3	Severe damage
4	4	Devastating damage
5	5	Incredible damage

Flooding

Flood frequency was based on the 100 and the 500 year flood events as follows:

- A 100-year frequency flood score was determined for each census tract by taking the % area covered by flood zone A (for the area impact score) and the average base flood elevation (for the intensity score, see Table 12 below).

- A 500 year frequency flood score was determined for each census tract by taking the % area covered by flood zone X500 (for the area impact score) and the average base flood elevation (for the intensity score, see Table 12 below).

The flood hazard score was determined by averaging these two scores together.

Note that flood area impact scores were analyzed using both relative and absolute area figures. For the final study, relative area covered was chosen because it more accurately measured the potential damage caused to small tracts while not biasing scores towards their favor. However, both absolute and relative area figures are included in the database for different types of analysis if deemed desirable at a later date.

Table 12. Flood (BFE, Base Flood Elevation, ft)

Base Flood Elevation	Intensity Score	Subjective Description
0	0	No effect
14	1	Light flooding
18	2	Moderate flooding
20	3	Moderate-heavy flooding
22	4	Heavy Flooding
24	5	Severe Flooding

Exposure Score

Exposure includes all populations and assets that may be at risk from the natural hazards described above.

The exposures considered were divided into four major groups:

1) **Critical Facilities** includes marinas, emergency shelters, schools, hospitals, fire and rescue stations, police stations, water treatment or sewage processing plants, railroad stations and airports, and government facilities.

2) **Social Vulnerability** includes the population density, as well as tract-wide percentages on the percent of non-whites, of families below the poverty line, of elderly populations, of those with no high schooling, disabled adults, people on public assistance, those with no vehicles, renters, and percentage of non-english speakers. These categories correspond to social groups tracked by the U.S. Census, and were selected on this basis only.

3) **Environmental Resources** include the presence of rare species habitats, scenic vistas, and CERCLIS sites.

4) **Economic Values** include the value of construction, light manufacturing, wholesale, hotels and motels, agricultural lands, professional / technical programs, retail, banking, and domestic properties.

Overview of Scoring Procedure

The exposure score for each subregion was calculated using the following formula:

EXPOSURE SCORE = (EXPOSURE TYPE SCORE) *

(IMPORTANCE FACTOR)

The two factors that make up the exposure score are:

- **Exposure Type Score**. For each type of exposure, a lookup table was developed to relate some measure of the exposure value (such as population, dollar value, or number of facilities) to a common exposure index. In each case, a score of 1 corresponds to the lowest amount of exposure, and a score of 5 corresponds to the highest amount of exposure. Table 14 summarizes the different exposure type scores used in this study.

- **Importance Factor.** A factor, ranging from 0.85 to 1.3, was used to account for the critical nature of some types of exposure. This approach was developed such that it was consistent with national building code standards, which assign a higher importance factor to critical facilities.

Table 13. Importance Factors for Exposure Scores

Occupancy Category	Importance Factor
I	0.85
II	1
III	1.2
IV	1.3

Table 14. Occupancy Categories

Occupancy	Category
Fire, Police, Medical Facilities	IV
Emergency Shelters (including some school buildings)	IV
Environmental CERCLIS sites	III
Major industrial sites	III
Schools (non-Emergency Shelters)	III
Other public utilities	II
Other structures	II

Once the scores for each sub-category of exposure were calculated, they were added together to evaluate the overall score for the exposure type. For example, to determine the overall Environmental Resources score, the scores of each of its subcomponents (scenic vistas, CERCLIS sites, and endangered species scores) were added. (note: CERCLIS is the online information database that lists sites covered under the CERCLA, or Comprehensive Environmental Response, Compensation, and Liability Act) The end result is an absolute score that allows comparison of relative environmental exposure factors between tracts.

Using this method, summary scores must be normalized by the number of sub-categories considered in order to compare the overall scores from different exposure types. Because each category has a varying number of sub-categories, each of which adds to the tract's final score, the summary scores are higher for those exposure types with more sub-categories considered. In other words, if there were 12 types of critical facilities counted and only 2 social factors counted, the absolute score for critical facilities would be much higher than the social score. Thus, the overall scores were divided by the number of sub-categories considered in order to provide normalized exposure scores for environmental, critical facilities, social vulnerability, and economic exposure.

Table 15. Lookup Tables for Exposure Scoring

Number of Sites	Lookup Table Score
0	0
1	1
2	2
3	3
4	4
5	5

Property Value	Value Score
0	0
500000	1
1000000	2
5000000	3
10000000	4
25000000	5

% Total Population	Lookup Table Score
0.00	0
5.00	1
15.00	2
25.00	3
35.00	4
45.00	5

Population Density (people/sq. mile)	Lookup Table Score
0	0
100	1
500	2
1500	3
5000	4
10000	5

Critical Facilities

- Marinas: The number of marinas was determined from the RIGIS "Marinas.shp" file. The Occupancy Code for marinas is II, resulting in a score of 1 in the ASCE 7-98 modifier column.

- Shelters: Shelter information came from the RIGIS file, "Public Safety.shp". The number of shelters was used to determine the basic exposure score in Table 15. This value was then multiplied by the shelter's Occupancy Code score of 1.3, resulting in a total exposure score.

- Schools: School information came from the RIGIS file, "Schools.shp". The number of schools was used to determine the basic exposure score in Table 15. This value was then multiplied by a school's Occupancy Code modifier score of 1.2, resulting in a total exposure score.

- Hospitals: Hospital information came from the RIGIS file, "Hospitals.shp". The number of hospitals was used to determine the basic exposure score in Table 15. This value was then multiplied by the hospital's Occupancy Code modifier score of 1.3, resulting in a total exposure score.

- Fire and Rescue Stations: Fire and Rescue information came from the RIGIS file, "Public Safety.shp". The number of stations was used to determine the basic exposure score in Table 15. This value was then multiplied by the station's Occupancy Code modifier score of 1.3, resulting in a total exposure score.

- Police Stations: Police Station information came from the RIGIS file, "Public Safety.shp". The number of stations was used to determine the basic exposure score in Table 15. This value was then multiplied by the station's Occupancy Code modifier score of 1.3, resulting in a total exposure score.

- Water Supply Points: Water supply point information came from the RIGIS files, "Sewer Pumping Points.shp" and "Water Pumping Points.shp". The number of points was used to determine the basic exposure score in Table 15. This value was then multiplied by the station's Occupancy Code modifier score of 1.2, resulting in a total exposure score.

- Rail Road Stations and Airports: Railroad station and airport information came from the RIGIS file, "Airports.shp". The number of stations was used to determine the basic exposure score in Table 15. This value was then multiplied by the station's Occupancy Code modifier score of 1.2, resulting in a total exposure score.

- Government Facilities: This information came from the RIGIS file, "Public Safety.shp". It includes local, state, and federal office buildings. The number of facilities was used to determine the basic exposure score in Table 15. This value was then multiplied by the station's Occupancy Code modifier score of 1.2, resulting in a total exposure score.

Final Scores: The exposure scores for each of these categories was then added up and divided by 10, the total number of Critical Facility subcategories, for a normalized score.

Social Vulnerability

NOTE: All Social Factor scores were derived from the RIGIS file "Census1.shp". Social categories were chosen to represent different types of populations that would be at risk in a natural hazard situation.

- Population Density: Persons per square mile figures were extracted from the RIGIS database. This value was then compared to the Percent Population in Table 15 to yield an exposure score.

- Non-White: This score represents the percentage of non-white persons relative to the total population in each tract. This value was compared to the Percent Population in Table 15 to yield an exposure score.

- Family Below the Poverty Level: This score represents the percentage of families in each tract whom are below the poverty level. This value was compared to the Percent Population in Table 15 to yield an exposure score..

- Over 65: This score represents the percentage of elderly people in each tract. This value was compared to the Percent Population in Table 15 to yield an exposure score.

- Disabled Adults: This score represents the percentage of disabled adults in each tract. This value was compared to the Percent Population in Table 15 to yield an exposure score.

- No High School: This score represents the percentage of the total population in each tract that has not completed high school. This value was compared to the Percent Population in Table 15 to yield an exposure score.

- Public Assistance: This score represents the percentage of the total population of each tract who are on public assistance. This value was compared to the Percent Population in Table 15 to yield an exposure score.

- No Vehicle: This score represents the percentage of the total population of each tract who do not have access to a private vehicle. This value was compared to the Percent Population in Table 15 to yield an exposure score.

- Rental Units: This score represents the percentage of the total population of each tract who live in rental units. This value was compared to the Percent Population in Table 15 to yield an exposure score.

- Non-English Speaking: This score represents the percentage of the total population of each tract who cannot speak English. This value was compared to the Percent Population in Table 15 to yield an exposure score.

Final Scores: The exposure scores for each of these categories was then added up and divided by 10, the total number of Social Factors subcategories, for a normalized score.

Environmental Exposure

- CERCLIS Sites: CERCLIS is the online information database that lists sites covered under the CERCLA, or Comprehensive Environmental Response, Compensation, and Liability Act. Information for this category came from the "CERCLIS.shp" RIGIS file. This value then used the Number of Facilities Lookup in Table 15 to determine a preliminary score. This score was then multiplied by the lookup table value of the ASCE 98 Occupancy Code, which is 1.2 for CERCLIS sites, resulting in a final CERCLIS environmental resources exposure score.

- Rare Species: Information for this category came from the RIGIS file, "Rare Species.shp". This is described as the "estimated habitat and range of rare species and noteworthy natural communities". This file is a polygon file, which often overlapped many census tracts. To quantify this, it was necessary to clip the habitat polygons along the lines of each census tract border, resulting in a number of smaller habitat polygons contained within each tract. The number of polygons was counted and used as a rough proxy for the rare species habitat in a given tract. This value was recorded was compared to the Number of Facilities Lookup in Table 15 to determine the exposure score.

- Scenic Vistas: Information for this category came from the RIGIS file, "Scenic Areas.shp". This file is described as defining "areas in RI designated by the RIDEM as noteworthy or distinctive landscapes or views". Similar to the Rare Species file, this came in polygon format. The same method was used to break it apart and quantify their influence on a given tract as above. These values were recorded, then compared to the Number of Facilities Lookup in Table 15 to determine the exposure score.

Final Scores: The exposure scores for each of these categories was then added up to calculate an absolute Environmental Resources exposure score. This was then divided by 3 to compute a normalized score.

Economic Exposure

NOTE: All of the following information came from the 1997 Rhode Island Economic Census, which uses a Zip Code level of analysis. It was necessary to determine how many and which census tracts were in each zip code and then divide the total figure for a code by the number of tracts within it. Thus if a zip code had $1 million dollars in construction property in it, and it contained 10 census tracts, than the value for each tract would be $100,000 for the purposes of this analysis. Because the resolution of this data is lower, the figures included should not be taken as absolute. The following categories are those used by the U.S. Census Bureau to code business types across the country.

The procedure for calculating the scoring of each sub-category is identical. For each category, there are 4 quantities considered.

- Number of establishments in each tract
- Total value for all establishments in that category, for the entire zip code .
- Total value of establishments divided by the number of census tracts found within the zip code, resulting in a per tract valuation of each category
- The final value is the actual exposure score, which was determined by taking the valuation per tract and using the Property Value Lookup in Table 15 shown above.

Each individual economic category is described below:

- **Construction**: The US Census defines this category as "establishments primarily engaged in the construction of buildings and other structures, heavy construction (except buildings), additions, alterations, reconstruction, installation, and maintenance and repairs."
- **Manufacturing**: The US Census defines this category as "establishments that are engaged in the mechanical, physical, or chemical transformation of materials, substances, or components into new products."
- **Wholesale**: The US Census defines this category as "establishments engaged in wholesaling merchandise, generally without transformation, and rendering services incidental to the sale of merchandise."

- **Hotels/Motels**: The US Census defines this category as "establishments providing customers with lodging and/or prepared meals, snacks, and beverages for immediate consumption."

- **Agriculture**: This category is defined as businesses that are involved with or dependant upon the growing, harvesting, producing, or processing food and food-stuffs from the land.

- **Professional/Technical Services:** The US Census defines this category as "establishments with payroll that specialize in performing professional, scientific, and technical activities for others. These activities require a high degree of expertise and training. The establishments in this sector specialize according to expertise and provide services to clients in a variety of industries and, in some cases, to households. Activities performed include: legal advice and representation; accounting, bookkeeping, and payroll services; architectural, engineering, and specialized design services; computer services; consulting services; research services; advertising services; photographic services; translation and interpretation services; veterinary services; and other professional, scientific, and technical services."

- **Retail**: The US Census defines this category as "establishments engaged in retailing merchandise, generally without transformation, and rendering services incidental to the sale of merchandise."

- **Financial**: The US Census defines this category as "establishments of firms with payroll primarily engaged in financial transactions (transactions involving the creation, liquidation, or change in ownership of financial assets)and/or in facilitating financial transactions."

- **Domestic**: Domestic property is all privately owned property within which people reside.

Final Scores: The exposure scores for each of these categories were added up to obtain an absolute Economic Value exposure score. This score was then divided by 8 to achieve a normalized score.

Combined Score

Combined scores were determined using the following formula:

COMBINED SCORE = (HAZARD SCORE) * (EXPOSURE SCORE)

A combined score was determined for each hazard/exposure combination at the census tract level. Statewide combined scores for each hazard/exposure combination were then determined by summing the census tract combined scores.

To study combined scores, tables and maps were created for the following quantities in each census tract:

- Total Absolute Hazard Score * Total Absolute Exposure Score
- Individual Hazard Scores * Total Absolute Exposure Score (i.e., seven tables, one for each hazard type)
- Individual Exposure Scores * Total Absolute Hazard Score (i.e., four tables, one for each exposure category)
- Individual Hazard Score * Individual Exposure Score (for several select groupings of hazards/exposures)

These tables allow the user to study the geographic distribution of combined scores for each individual exposure (subjected to all combined hazards), for each individual hazard (impacting all combined exposures), and for several key hazard/exposure combinations.

In addition, the following tables were created for the entire state, aggregating census tract scores to the statewide level:

- Individual Hazard Score * Individual Exposure Score (for every combination)
- Total Absolute Exposure * Total Absolute Hazard

These tables can be sorted and allow the user to determine the maximum individual hazard/exposure combinations on a statewide basis.

Mitigation Opportunities Analysis

The mitigation opportunities analysis is the interpretation of hazard, exposure, and combined score results in order to identify and prioritize actions to lower overall risk and improve preparedness to natural disasters.

Each state or region will have a different approach to this process, which should involve all important stakeholders in government and the private sector. The following approach was employed for this study, and is suggested for application in statewide level studies (higher resolution studies, such as community vulnerability assessments, should employ a more focused mitigation opportunities analysis such as that described in the NOAA CD-ROM):

- Determine the top exposure scores (e.g. the top 5)
- Prepare maps of top exposures multiplied by total hazard scores
- Determine the top hazard scores statewide (e.g. the top 2)
- Prepare maps of top hazards multiplied by total exposure scores
- Determine the top hazard/exposure combinations (e.g., the top 20 combined scores statewide)
- Create maps of top hazard/exposure combinations for the entire state.
- Determine distribution of key hazard/exposure combination scores by subregions.
- Consider statewide preparedness actions to handle social vulnerabilities identified for key hazards
- Consider statewide physical risk reduction measures (such as building code improvements) for hazards affecting critical facilities and economic exposures
- Encourage localized risk mitigation strategy development in high-scoring subregions
- Prepare more detailed studies, such as HAZUS-99 loss estimation models, for high scoring hazard/exposure combinations to better understand risk

Warwick Pilot Results

The methodology was applied to perform a vulnerability assessment of census tracts in the city of Warwick as a pilot study. Results from this analysis are discussed in the attached report (submitted under separate cover) entitled "Warwick Pilot Study".

State of Rhode Island Results

Mapping Information

Two sets of maps were created to represent the data, relative maps and absolute maps. Relative maps present hazard, exposure, and combined scores on a five step colored scale from "Lowest" to "Highest". This allows for greater ease in interpretation of any given map, but presents a problem when comparing "Highest" and "Lowest" scores between different maps. This problem is due to the fact that a "Highest" value on one map may not represent the same range of scores as a "Highest" value on another map.

For example, on the Relative Flood Hazard Map, a "Higher" value represents a Hazard Score of 19 to 27. The lowest score is 0 and the highest score is 45. However, on the Relative Hurricane Hazard Map, a "Higher" value represents a Hazard score of 61 to 80. In the first case, the interval between each category is 8, where the interval between each category in the later case is 19. Thus the descriptive category "Higher" will not mean the same thing between two maps, which may graph data of different scales with different intervals between each interpretive category.

In order to allow for comparison between maps, a set of absolute maps were created that graphed hazard, exposure, and comparison scores on a uniform scale and with equal intervals between each category. These maps have a ten step colored scale and an equal interval of 10 between each category. While absolute maps allow for comparability between hazard and exposure categories, they are often much less descriptive since the range of scores for some categories are quite small compared to others.

Both relative maps and absolute maps are included to allow for a greater variety of interpretation and analysis.

Hazard Scores

Hazard Scores were determined for each census tract based on the methodology described above. Table 16 shows the hazard scores tabulated for each of the seven hazards considered, as well as the total hazard score and average hazard score for each census tract. In addition, statewide totals are shown at the bottom of the table.

The attached maps in Appendix C show the distribution of hazard scores throughout the state. In addition, a summary map of all hazards is shown for ease of reference.

Table 16. Hazard Scores for Rhode Island Communities (sum of census tracts)

Town	AREA (sq.miles)	Wind Score	Flood Score	Earthquake Score	Tornado Score	Hail Score	Snow Score	Temperature Extreme Score	Total Score	Average Score
Barrington Total	10.3	860.0	234.0	420.0	112.0	280.0	600.0	560.0	3066.0	438.0
Bristol Total	11.2	1200.0	135.0	480.0	128.0	320.0	400.0	640.0	3303.0	471.9
Burrilville Total	57.1	960.0	63.0	510.0	136.0	340.0	850.0	680.0	3539.0	505.6
Central Falls Total	1.3	740.0	36.0	300.0	80.0	200.0	500.0	400.0	2256.0	322.3
Charlestown Total	41.7	680.0	144.0	210.0	56.0	140.0	175.0	280.0	1685.0	240.7
Coventry Total	62.3	1160.0	81.0	480.0	128.0	320.0	550.0	640.0	3359.0	479.9
Cranston Total	28.9	3820.0	360.0	1950.0	520.0	1300.0	3250.0	2600.0	13800.0	1971.4
Cumberland Total	28.1	1180.0	117.0	600.0	160.0	400.0	1000.0	800.0	4257.0	608.1
East Greenwich Total	16.3	720.0	63.0	270.0	72.0	180.0	225.0	360.0	1890.0	270.0
East Providence Total	13.9	2720.0	225.0	1410.0	376.0	940.0	2350.0	1880.0	9901.0	1414.4
Exeter Total	58.3	240.0	0.0	90.0	24.0	60.0	75.0	120.0	609.0	87.0
Foster Total	51.8	180.0	18.0	120.0	32.0	80.0	200.0	160.0	790.0	112.9
Glocester Total	56.8	500.0	27.0	240.0	64.0	160.0	400.0	320.0	1711.0	244.4
Hopkinton Total	44.0	600.0	54.0	210.0	56.0	140.0	175.0	280.0	1515.0	216.4
Jamestown Total	13.8	480.0	54.0	180.0	48.0	120.0	150.0	240.0	1272.0	181.7
Johnston Total	24.3	1180.0	18.0	510.0	136.0	340.0	850.0	680.0	3714.0	530.6
Lincoln Total	19.0	740.0	45.0	360.0	96.0	240.0	600.0	480.0	2561.0	365.9
Little Compton Total	23.0	160.0	18.0	60.0	16.0	40.0	50.0	80.0	424.0	60.6
Middletown Total	13.7	800.0	36.0	300.0	80.0	200.0	250.0	400.0	2066.0	295.1
Narragansett Total	16.9	1180.0	198.0	390.0	104.0	260.0	325.0	520.0	2977.0	425.3
New Shoreham Total	11.0	300.0	27.0	90.0	24.0	60.0	75.0	120.0	696.0	99.4
Newport Total	9.2	1880.0	306.0	720.0	192.0	480.0	600.0	960.0	5138.0	734.0
North Kingstown Total	45.3	1760.0	297.0	690.0	184.0	460.0	575.0	920.0	4886.0	698.0
North Providence Total	5.8	1400.0	81.0	690.0	184.0	460.0	1150.0	920.0	4885.0	697.9
North Smithfield Total	24.7	480.0	27.0	210.0	56.0	140.0	350.0	280.0	1543.0	220.4
Pawtucket Total	8.8	4880.0	117.0	2160.0	576.0	1440.0	3600.0	2880.0	15653.0	2236.1
Portsmouth Total	27.3	1120.0	216.0	420.0	112.0	280.0	350.0	560.0	3058.0	436.9
Providence Total	18.7	10980.0	486.0	5850.0	1560.0	3900.0	9750.0	7800.0	40326.0	5760.9
Richmond Total	40.7	200.0	18.0	90.0	24.0	60.0	75.0	120.0	587.0	83.9
Scituate Total	54.7	500.0	99.0	270.0	72.0	180.0	450.0	360.0	1931.0	275.9
Smithfield Total	27.7	920.0	72.0	420.0	112.0	280.0	700.0	560.0	3064.0	437.7
South Kingstown Total	63.5	1580.0	171.0	540.0	144.0	360.0	450.0	720.0	3965.0	566.4
Tiverton Total	30.8	880.0	54.0	330.0	88.0	220.0	275.0	440.0	2287.0	326.7
Warren Total	7.5	800.0	198.0	330.0	88.0	220.0	275.0	440.0	2351.0	335.9
Warwick Total	36.9	5400.0	684.0	2400.0	640.0	1600.0	2875.0	3200.0	16799.0	2399.9
West Greenwich Total	51.4	240.0	0.0	90.0	24.0	60.0	75.0	120.0	609.0	87.0
West Warwick Total	8.1	1480.0	99.0	660.0	176.0	440.0	925.0	880.0	4660.0	665.7
Westerly Total	31.5	1880.0	189.0	570.0	152.0	380.0	475.0	760.0	4406.0	629.4
Woonsocket Total	7.9	2260.0	99.0	1110.0	296.0	740.0	1850.0	1480.0	7835.0	1119.3

Exposure Scores

Exposure Scores were determined for each census tract based on the methodology described above. Table 17 shows the exposure scores tabulated for each of the exposures considered, as well as the total exposure score and normalized score for each census tract. Exposure scores are summarized by individual exposure subcategories as well as major categories (environmental, economic, social, and critical facilities). In addition, statewide totals are shown at the bottom of the table.

The attached maps in Appendix C show the distribution of summary exposure scores (environmental, economic, social, and critical facilities) throughout the state. In addition, a summary map showing all exposures is shown for ease of reference.

Exposure scores were also summarized by community. The community level results were obtained by adding the census tract exposure scores together. These maps are also shown in Appendix C.

Table 17. Rhode Island Exposure Scores by Community (sum of census tracts)

Town	Area (sq. miles)	Critical Facilities Score	Normalized Score	Social Score	Normalized Social Score	Environmental Score	Normalized Environmental Score	ECONOMIC SCORE	Normalized Economic Score	Total Exposure Score	Normalized Total Exposure Score
Barrington Total	10.31	74.6	7.5	104.0	10.4	6.0	2.0	308.0	38.5	492.6	123.2
Bristol Total	11.21	62.7	6.3	224.0	22.4	4.6	1.5	384.0	48.0	675.3	168.8
Burrilville Total	57.05	74.4	7.4	164.0	16.4	13.8	4.6	363.0	45.4	615.2	153.8
Central Falls Total	1.30	52.5	5.3	238.0	23.8	1.2	0.4	50.0	6.3	341.7	85.4
Charlestown Total	41.72	46.7	4.7	57.0	5.7	14.2	4.7	147.0	18.4	264.9	66.2
Coventry Total	62.28	122.5	12.3	161.0	16.1	38.4	12.8	372.0	46.5	693.9	173.5
Cranston Total	28.87	265.7	26.6	896.0	89.6	14.2	4.7	1473.0	184.1	2648.9	662.2
Cumberland Total	28.14	89.5	9.0	212.0	21.2	19.8	6.6	380.0	47.5	701.3	175.3
East Greenwich Total	16.32	45.5	4.6	79.0	7.9	4.2	1.4	243.0	30.4	371.7	92.9
East Providence Total	13.95	165.6	16.6	711.0	71.1	14.0	4.7	1004.0	125.5	1894.6	473.7
Exeter Total	58.33	34.3	3.4	20.0	2.0	13.8	4.6	63.0	7.9	131.1	32.8
Foster Total	51.83	33.6	3.4	20.0	2.0	19.6	6.5	64.0	8.0	137.2	34.3
Glocester Total	56.79	60.4	6.0	57.0	5.7	15.4	5.1	159.0	19.9	291.8	73.0
Hopkinton Total	43.98	22.9	2.3	54.0	5.4	13.2	4.4	150.0	18.8	240.1	60.0
Jamestown Total	13.81	22.0	2.2	43.0	4.3	9.4	3.1	156.0	19.5	230.4	57.6
Johnston Total	24.35	66.5	6.7	210.0	21.0	22.4	7.5	442.0	55.3	740.9	185.2
Lincoln Total	18.98	96.7	9.7	131.0	13.1	20.4	6.8	354.0	44.3	602.1	150.5
Little Compton Total	22.96	8.8	0.9	14.0	1.4	11.6	3.9	44.0	5.5	78.4	19.6
Middletown Total	13.72	56.6	5.7	114.0	11.4	12.4	4.1	160.0	20.0	343.0	85.8
Narragansett Total	16.85	97.5	9.8	120.0	12.0	6.2	2.1	271.0	33.9	494.7	123.7
New Shoreham Total	10.96	17.0	1.7	19.0	1.9	5.2	1.7	75.0	9.4	116.2	29.1
Newport Total	9.16	135.4	13.5	338.0	33.8	11.2	3.7	552.0	69.0	1036.6	259.2
North Kingstown Total	45.33	94.0	9.4	186.0	18.6	22.6	7.5	451.0	56.4	753.6	188.4
North Providence Total	5.78	66.7	6.7	321.0	32.1	2.4	0.8	238.0	29.8	628.1	157.0
North Smithfield Total	24.72	61.1	6.1	66.0	6.6	23.6	7.9	119.0	14.9	269.7	67.4
Pawtucket Total	8.85	222.6	22.3	1257.0	125.7	8.2	2.7	1748.0	218.5	3235.8	809.0
Portsmouth Total	27.35	53.5	5.4	106.0	10.6	16.6	5.5	310.0	38.8	486.1	121.5
Providence Total	18.75	790.3	79.0	3873.0	387.3	22.2	7.4	3511.0	438.9	8196.5	2049.1
Richmond Total	40.71	36.8	3.7	20.0	2.0	19.6	6.5	58.0	7.3	134.4	33.6
Scituate Total	54.75	60.1	6.0	53.0	5.3	13.0	4.3	165.0	20.6	291.1	72.8
Smithfield Total	27.75	61.0	6.1	123.0	12.3	16.6	5.5	290.0	36.3	490.6	122.7
South Kingstown Total	63.50	183.3	18.3	175.0	17.5	28.6	9.5	445.0	55.6	831.9	208.0
Tiverton Total	30.83	39.5	4.0	110.0	11.0	11.0	3.7	264.0	33.0	424.5	106.1
Warren Total	7.50	54.0	5.4	155.0	15.5	5.4	1.8	253.0	31.6	467.4	116.9
Warwick Total	36.88	259.1	25.9	815.0	81.5	17.0	5.7	1713.0	214.1	2804.1	701.0
West Greenwich Total	51.40	30.8	3.1	18.0	1.8	18.6	6.2	75.0	9.4	142.4	35.6
West Warwick Total	8.11	87.6	8.8	319.0	31.9	4.8	1.6	550.0	68.8	961.4	240.4
Westerly Total	31.48	70.6	7.1	216.0	21.6	7.2	2.4	361.0	45.1	654.8	163.7
Woonsocket Total	7.93	236.5	23.7	703.0	70.3	5.8	1.9	666.0	83.3	1611.3	402.8

Combined Scores

The Combined Scores were determined for each census tract based on the methodology described above. Every combination of individual exposure and hazard was considered for each individual census tract, resulting in a total of 273 combined scores for each census tract. For analysis purposes, these scores were combined into statewide aggregates and are summarized in Table 18.

In addition, the attached maps in Appendix C show the distribution of combined scores throughout the state for the following combinations.

- Total Absolute Hazard Score * Total Absolute Exposure Score
- Individual Hazard Scores * Total Absolute Exposure Score (i.e., seven maps, one for each hazard type)
- Individual Exposure Scores * Total Absolute Hazard Score (i.e., four maps, one for each exposure category)
- Individual Hazard Score * Individual Exposure Score (for illustrative purposes, elderly populations at snow risk and schools at earthquake risk)

In addition, a summary map showing all of these combinations together is shown for ease of reference.

STATEWIDE SUMMARY TABLE OF COMBINED SCORES

Exposure		Hazard Wind	Flood	Earthquake	Tornado	Hail	Snow	Temperature
Critical Facilities	**Marinas**	5300	1386	1980	528	1320	1925	2640
	Shelter	163202	13619	73320	19552	48880	104618	97760
	Schools	53880	4082	24120	6432	16080	32940	32160
	Hospitals	1612	47	702	187	468	1008	936
	Fire	16250	1650	6825	1820	4550	8580	9100
	Police	4290	374	1716	458	1144	2113	2288
	Water	27360	3812	11736	3130	7824	15180	15648
	Railroad	720	32	252	67	168	240	336
	Government	2712	281	1116	298	744	1290	1488
	Critical Facilities Sum	275326	25284	121767	32471	81178	167893	162356
	Critical Facilities Average	27533	2528	12177	3247	8118	16789	16236
Social Vulnerability	**Population (total)**	165940	12969	76770	20472	51180	112425	102360
	Nonwhite	38500	1539	19440	5184	12960	31375	25920
	Poverty	32640	1899	15750	4200	10500	24725	21000
	Over 65	90660	8073	41130	10968	27420	59125	54840
	Disabled	44800	3582	20850	5560	13900	30225	27800
	No High School	152820	10899	70800	18880	47200	105900	94400
	Public Assistance	43460	2628	20550	5480	13700	31500	27400
	No Vehicle	29320	2151	13860	3696	9240	21350	18480
	Renters	191820	15426	88170	23512	58780	128775	117560
	Non-English Speakers	15940	693	7740	2064	5160	12550	10320
	Social	805900	59859	375060	100016	250040	557950	500080
	Social Normalized	80590	5986	37506	10002	25004	55795	50008
Environmental	**CERCLIS sites**	21288	2441	9072	2419	6048	11970	12096
	Protected Species	15760	1314	6270	1672	4180	7025	8360
	Scenic Vistas	1680	153	690	184	460	800	920
	Environmental Sum	38728	3908	16032	4275	10688	19795	21376
	Environmental Average	12909	1303	5344	1425	3563	6598	7125
Economic	**Construction**	132920	12060	59490	15864	39660	82200	79320
	Manufacturing	120860	10044	54750	14600	36500	77600	73000
	Wholesale	132540	11223	60330	16088	40220	85975	80440
	Hotels	242440	21618	109230	29128	72820	153400	145640
	Agriculture	45940	4248	20310	5416	13540	26850	27080
	Service	105320	9594	46500	12400	31000	63375	62000
	Retail	256220	22086	115380	30768	76920	163275	153840
	Financial	105420	9216	47070	12552	31380	66225	62760
	Dom	89840	8514	39870	10632	26580	53550	53160
	Economic Sum	1231500	108603	552930	147448	368620	772450	737240
	Economic Average	153938	13575	69116	18431	46078	96556	92155
TOTALS	**Total Exposure**	2351454	197654	1065789	284210	710526	1518088	1421052
	Average Total Exposure	587864	49413	266447	71053	177632	379522	355263

Mitigation Opportunities

The risk scoring maps were presented to numerous planners, businesspeople, and state officials in order to identify mitigation opportunities. These meetings included:

1. Several meetings with Pamela Pogue, State Flood Plain Coordinator and Project Impact Coordinator.

2. Presentation to the Rhode Island Statewide Hazard Mitigation Planning Committee 2/2001.

3. Presentation to the Rhode Island Showcase State Hazard Assessment Committee 2/2001. This committee consisted of state officials, representatives from FEMA, major utilities, the insurance industry, and private business.

4. Presentation to insurance industry representatives 3/24/2001 at Amica Mutual Insurance, one of the largest property insurers in Rhode Island.

5. Presentation to Rhode Island Showcase State Steering Committee 8/1/2001

Each of these meetings yielded mitigation opportunities that will be pursued by the state. The mitigation opportunities can be divided into two broad categories:

1. Macroscopic policy initiatives. Based on the overall hazard and risk assessment results, several key initiatives were identified to mitigate key hazard/exposure combinations. These initiatives include:

    a. Statewide adoption of IBC2000 building code. The new building code includes provisions for improved design of buildings for hurricanes/extreme wind events, earthquakes, floods, and snowstorms that are consistent with the hazard levels identified in this study. The new code provides a major improvement in hazard-based design when compared to the existing code (BOCA 1996 with State Amendments). For example, the existing code uses a uniform snow load throughout the state, whereas hazard maps and the experience of the project team suggest a higher potential loading for northern parts of the state.

    b. Encourage responsible development of high risk coastal areas.

    c. Foster public awareness of disaster risk, focusing on flood, hurricane, snowstorm, and earthquake risk.

2. Microscopic/focused mitigation programs

a. Accelerate development of community hazard mitigation plans in high-risk communities identified in this report.

b. Review NFIP policy concentration in high-risk flood census tracts, and encourage further participation in program

All of these mitigation opportunities will be incorporated in the state hazard mitigation plan (409 Plan) being prepared by the Rhode Island Emergency Management Agency concurrent with this vulnerability assessment.

In addition, the following areas were identified for further study:

1. Further evaluation of Warwick flood for critical facilities, social, environmental, and economic exposure

2. Need additional study of nursing homes, day care centers, assisted living facilities under critical facilities category

3. Need additional study of tourism industry exposure to hurricane events. This analysis should include seasonal hazard scores, with higher hurricane hazards during peak tourist season. RIEDC maintains data on the tourist population

4. Suggest preparation of scenario analyses for key hazards and economic exposures for detailed losses. For example, simulate a repeat of the 1938 hurricane and compute economic losses statewide. Similarly, a flood analysis for a 500 year flood could be performed to compute total economic losses within flooded areas

5. Environmental study could include analysis of shoreline change maps in relationship to hurricane and coastal flooding hazards.

Commentary on Approach and Results

The following issues related to the technical methodology and results were identified during the course of this study:

1. Census tract scaling issue for economic data. Particularly for economic data, census tracts tend to distort the results due to differences in size (e.g. Lincoln has only 2 census tracts, so these come up with very high economic exposure scores due to large expanse of area covered, while individual census tract in Providence come up lighter). To address this issue, it is recommended that exposure results be summarized at the community level for output maps. These maps have been included in Appendix C for comparison with the census tract level data.

2. Missing data for individual census tracts can skew the final combined hazard/exposure results. For example, some census tracts were found to be missing in the exposure databases used for this study. The combined results therefore indicate lower levels of risk in these missing census tracts, suggesting a false level of variation in risk within the region. For this reason, census tract level results should be used with care and consideration for this issue when viewing the final results. In situations where this effect is pronounced, it is recommended that community-level results be used in lieu of census-tract level results.

3. Link between community and statewide data. Ideally, data collected on a community level would be incorporated into the statewide analysis. However, since different levels of detail exist in each community for exposure data, it may be impossible to directly incorporate much of the community-level information. For example, one community may have information on the exact location of every emergency shelter, while an adjacent community may only know the total number of shelters within the community. It is recommended, however, that the detailed community level data be used for local validation of the results (see below). If detailed information is desired for incorporation directly into the statewide analysis, an alternative procedure might be to use an "information quality factor" for each community in order to account for the differences in data resolution. Communities with higher resolution of data should receive a lower risk score (for example, by using a lower quality factor), due to the improved knowledge of assets at risk. This issue was explored during this study using sensitivity analysis, but quality factors were not used in the final results.

4. Need for localized validation. Statewide results may suggest very high levels of risk in individual census tracts. However, it is recommended that a detailed analysis be performed to validate any such conclusion. In this study, we have performed detailed validation of flood hazard risk in the City of Warwick on a higher resolution scale in order to validate the statewide results.

References

- "Community Vulnerability Assessment Tool", NOAA Publication #NOAA/CSC/99044-CD, National Oceanic and Atmospheric Administration Coastal Services Center, Charleston, SC, 2000.
- "Minimum Design Loads for Buildings and Other Structures", Publication ASCE 7-98, American Society of Civil Engineers, Reston, VA, 2000.
- HAZUS 99 Technical Manual, Federal Emergency Management Agency, Washington, DC 1999.

- HAZUS 99 MapInfo Version, Eastern Region Build 257, Federal Emergency Management Agency, Washington, DC 1999.

- HAZUS 99 MapInfo Version Supplemental Data, CD #65 Rhode Island Vol. DT65.V02, Federal Emergency Management Agency, Washington, DC 1999.

- "International Building Code (IBC2000)", International Code Council, Inc., March 2000

- **The Rhode Island Geographic Information System (RIGIS)** is a consortium of government and private organizations employing computer and communications technology to manage and use a collective data base of comprehensive geographically related information. See URL at http://www.planning.state.ri.us/GIS/GISHOME.HTM.

APPENDIX A The Saffir-Simpson Hurricane Scale

(From: TPC/National Hurricane Center - http://www.nhc.noaa.gov/aboutsshs.html)

The Saffir-Simpson Hurricane Scale is a 1-5 rating based on the hurricane's present intensity. This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf in the landfall region. Note that all winds are using the U.S. 1-minute average.

Category One Hurricane:

Winds 74-95 mph (64-82 kt or 119-153 km/hr). Storm surge generally 4-5 ft above normal. No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage. Hurricanes Allison of 1995 and Danny of 1997 were Category One hurricanes at peak intensity.

Category Two Hurricane:

Winds 96-110 mph (83-95 kt or 154-177 km/hr). Storm surge generally 6-8 feet above normal. Some roofing material, door, and window damage of buildings. Considerable damage to shrubbery and trees with some trees blown down. Considerable damage to mobile homes, poorly constructed signs, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of the hurricane center. Small craft in unprotected anchorages break moorings. Hurricane Bonnie of 1998 was a Category Two hurricane when it hit the North Carolina coast, while Hurricane Georges of 1998 was a Category Two Hurricane when it hit the Florida Keys and the Mississippi Gulf Coast.

Category Three Hurricane:

Winds 111-130 mph (96-113 kt or 178-209 km/hr). Storm surge generally 9-12 ft above normal. Some structural damage to small residences and utility buildings with a minor amount of curtain wall failures. Damage to shrubbery and trees with foliage blown off trees and large tress blown down. Mobile homes and poorly constructed signs are destroyed. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the hurricane center. Flooding near the coast destroys smaller structures with larger structures damaged by battering of floating debris. Terrain continuously lower than 5 ft above mean sea level may be flooded inland 8 miles (13 km) or more. Evacuation of low-lying residences with several blocks of the shoreline may be required. Hurricanes Roxanne of 1995 and Fran of 1996 were Category Three hurricanes at landfall on the Yucatan Peninsula of Mexico and in North Carolina, respectively.

Category Four Hurricane:

Winds 131-155 mph (114-135 kt or 210-249 km/hr). Storm surge generally 13-18 ft above normal. More extensive curtain wall failures with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3-5 hours before arrival of the hurricane center. Major damage to lower floors of structures near the shore. Terrain lower than 10 ft above sea level may be flooded requiring massive evacuation of residential areas as far inland as 6 miles (10 km). Hurricane Luis of 1995 was a Category Four hurricane while moving over the Leeward Islands. Hurricanes Felix and Opal of 1995 also reached Category Four status at peak intensity.

Category Five Hurricane:

Winds greater than 155 mph (135 kt or 249 km/hr). Storm surge generally greater than 18 ft above normal. Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All shrubs, trees, and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the hurricane center. Major damage to lower floors of all structures located less than 15 ft above sea level and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5-10 miles (8-16 km) of the shoreline may be required. Hurricane Mitch of 1998 was a Category Five hurricane at peak intensity over the western Caribbean. Hurricane Gilbert of 1988 was a Category Five hurricane at peak intensity and is the strongest Atlantic tropical cyclone of record.

APPENDIX B: The Fujita Scale

(From the Tornado Project - http://www.tornadoproject.com/fscale/fscale.htm#fscale table)

F-Scale Number	Intensity Phrase	Wind Speed	Type of Damage Done
F0	Gale tornado	40-72 mph	Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; damages sign boards.
F1	Moderate tornado	73-112 mph	The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	Significant tornado	113-157 mph	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light object missiles generated.
F3	Severe tornado	158-206 mph	Roof and some walls torn off well constructed houses; trains overturned; most trees in fores uprooted
F4	Devastating tornado	207-260 mph	Well-constructed houses leveled; structures with weak foundations blown off some distance; cars thrown and large missiles generated.
F5	Incredible tornado	261-318 mph	Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 meters; trees debarked; steel re-inforced concrete structures badly damaged.
F6	Inconceivable tornado	319-379 mph	These winds are very unlikely. The small area of damage they might produce would probably not be recognizable along with the mess produced by F4 and F5 wind that would surround the F6 winds. Missiles, such as cars and refrigerators would do serious secondary damage that could not be directly identified as F6 damage. If this level is ever achieved, evidence for it might only be found in some manner of ground swirl pattern, for it may never be identifiable through engineering studies

5. Relative Environmental Exposure Map

IV. **Combined Scores by Census Tract**

1. Hazard Scores Multiplied by Combined Exposure Scores
    a. Flood Exposure Scores
    b. Earthquake Exposure Scores
    c. Hail Exposure Scores
    d. Hurricane Exposure Scores
    e. Snow Exposure Scores
    f. Combined Exposure Scores

2. Exposure Scores Multiplied by Combined Hazard Scores
    a. Critical Facilities Hazard Scores
    b. Social Hazard Scores
    c. Economic Hazard Scores
    d. Environmental Hazard Scores

V. **Detailed Hazard/Exposure Combinations by Census Tract**

1. Schools at Earthquake Risk
2. Elderly Population at Snow Risk

APPENDIX C: Hazard, Exposure, and Combined Score Maps

I. **Hazard Scores by Census Tract**

1. Relative Hazard Map Comparison
2. Relative Flood Hazard Map
3. Relative Hail Hazard Map
4. Relative Hurricane Hazard Map
5. Relative Earthquake Hazard Map
6. Relative Snow Hazard Map
7. Relative Temperature Extreme Hazard Map
8. Relative Combined Hazard Map

II. **Exposure Scores by Census Tract**

1. Combined Relative Exposure Maps
2. Relative Critical Facilities Exposure Map
3. Relative Social Exposure Map
4. Relative Economic Exposure Map
5. Relative Environmental Exposure Map
6. Relative Combined Exposure Map

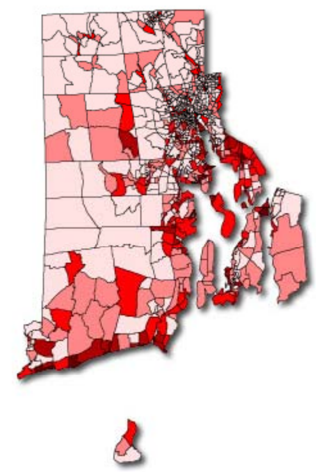
III. **Exposure and Hazard Scores by Community**

1. Combined Relative Exposure Maps
2. Relative Critical Facilities Exposure Map
3. Relative Social Exposure Map
4. Relative Economic Exposure Map

Relative Hazard Map Comparison

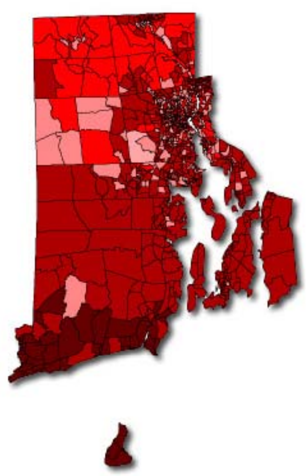
Illustrates the Distribution of Relative Hazards Through-Out Rhode Island

Earthquake Hazard Scores

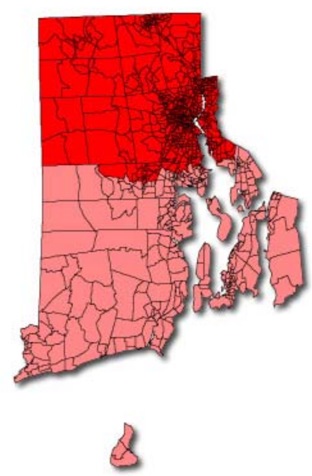


Flood Hazard Scores

Hail Hazard Scores

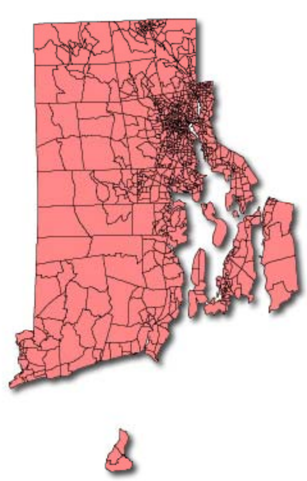


Hurricane Hazard Scores

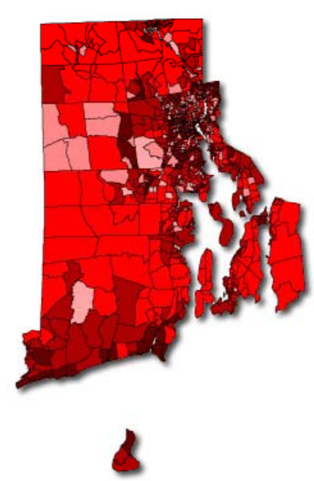


Snow Hazard Scores

Temperature Extremes Hazard Scores



Tornado Hazard Scores



Combined Hazard Scores

Combined Hazard Risk

- Lowest
- Lower
- Moderate
- High
- Highest

N

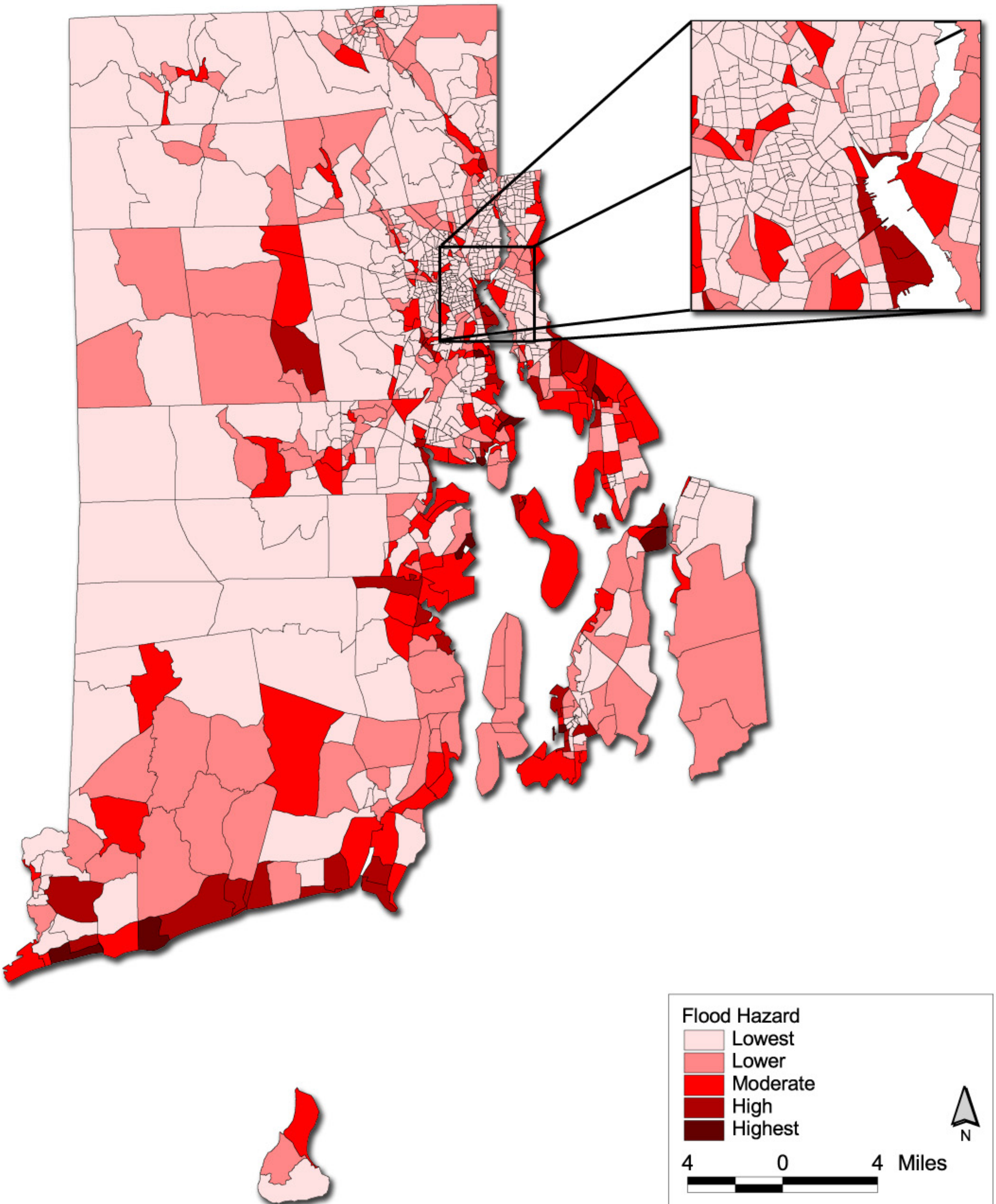
4 0 4 8 Miles

Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Relative Flood Hazard Map

Based on NFIP Flood Zones AE through X500

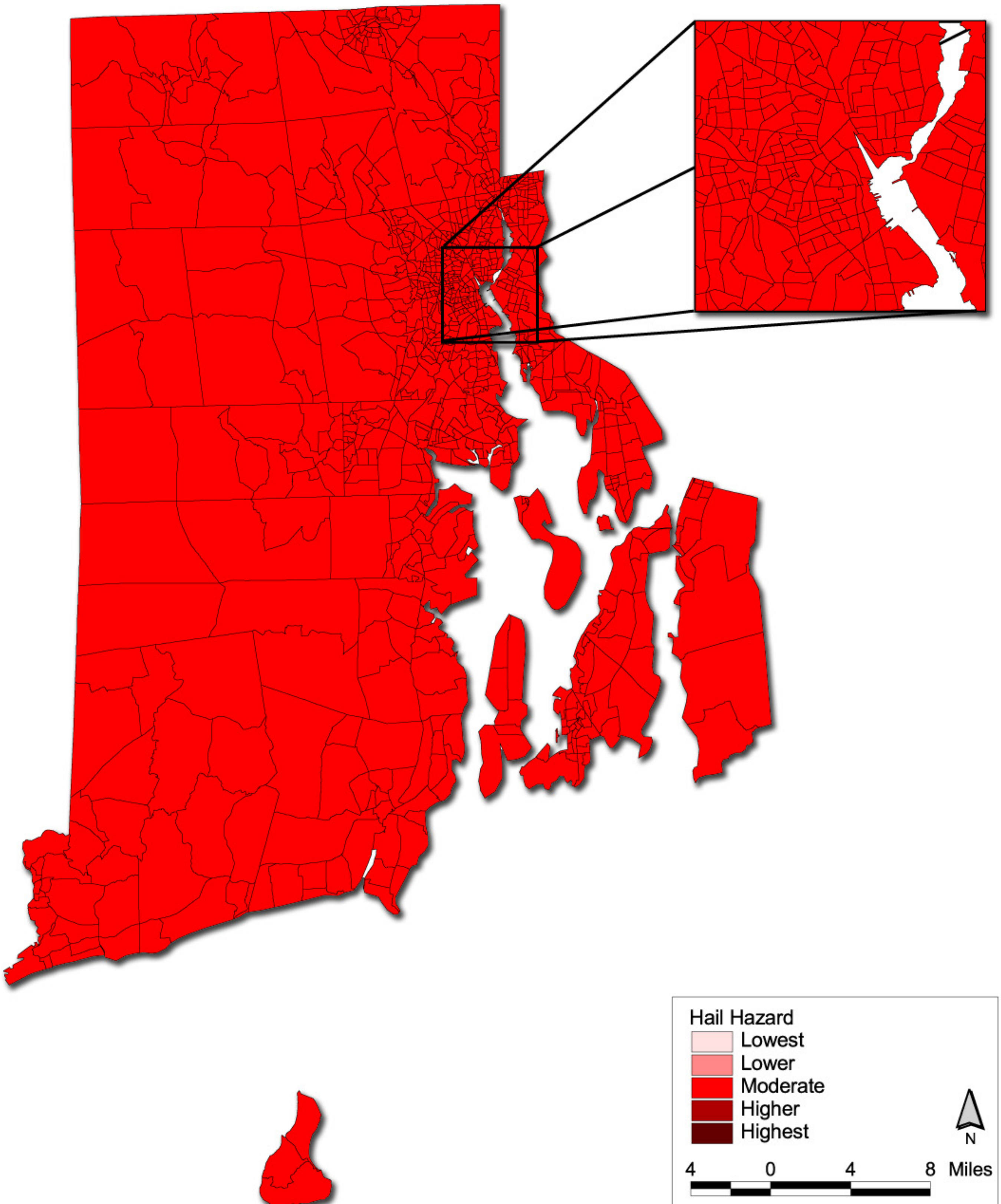


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Relative Hail Hazard Map

Based on Particle Size in Inches

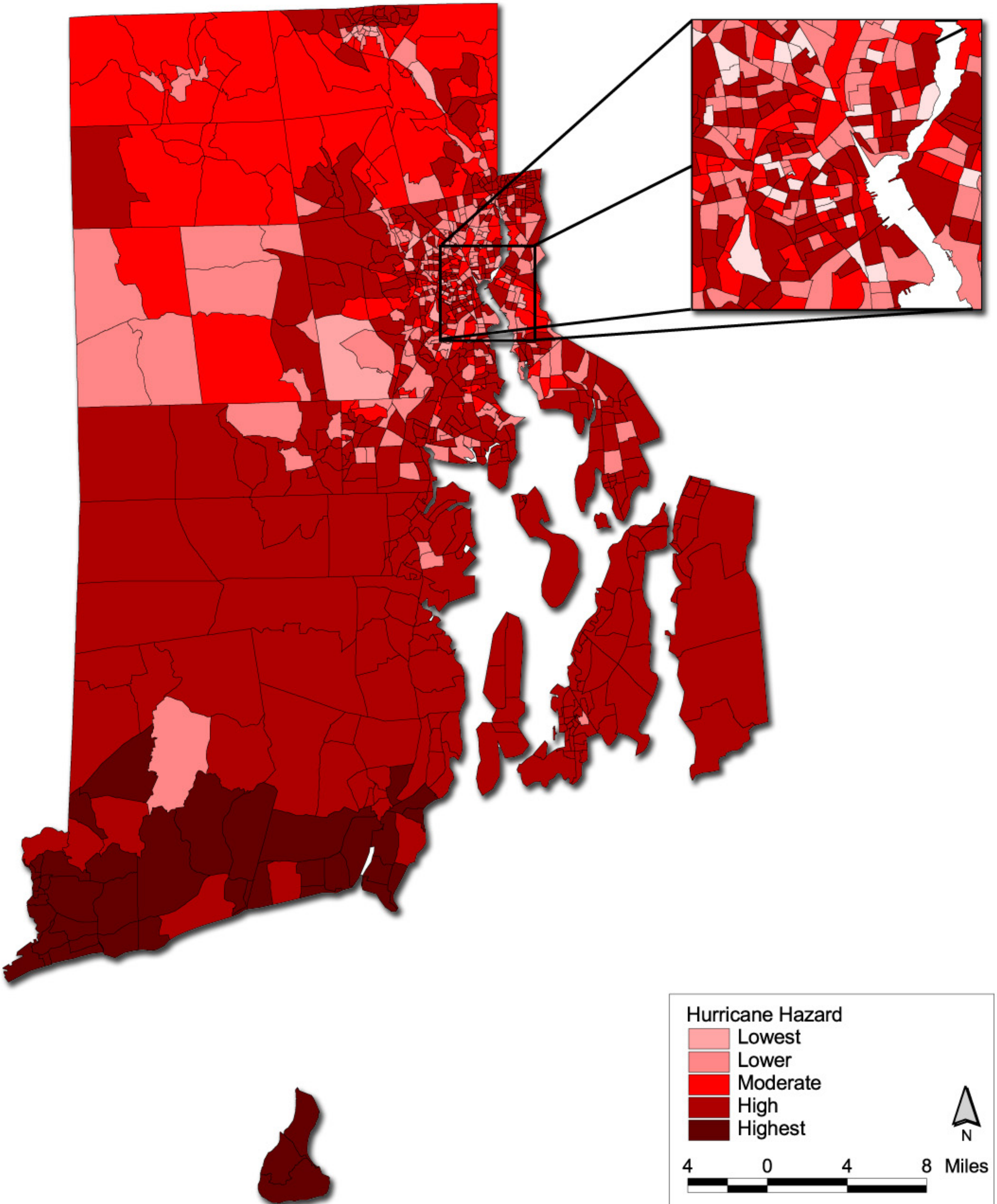


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Relative Hurricane Hazard Map

Based on Saffir Simpson hurricane windspeeds

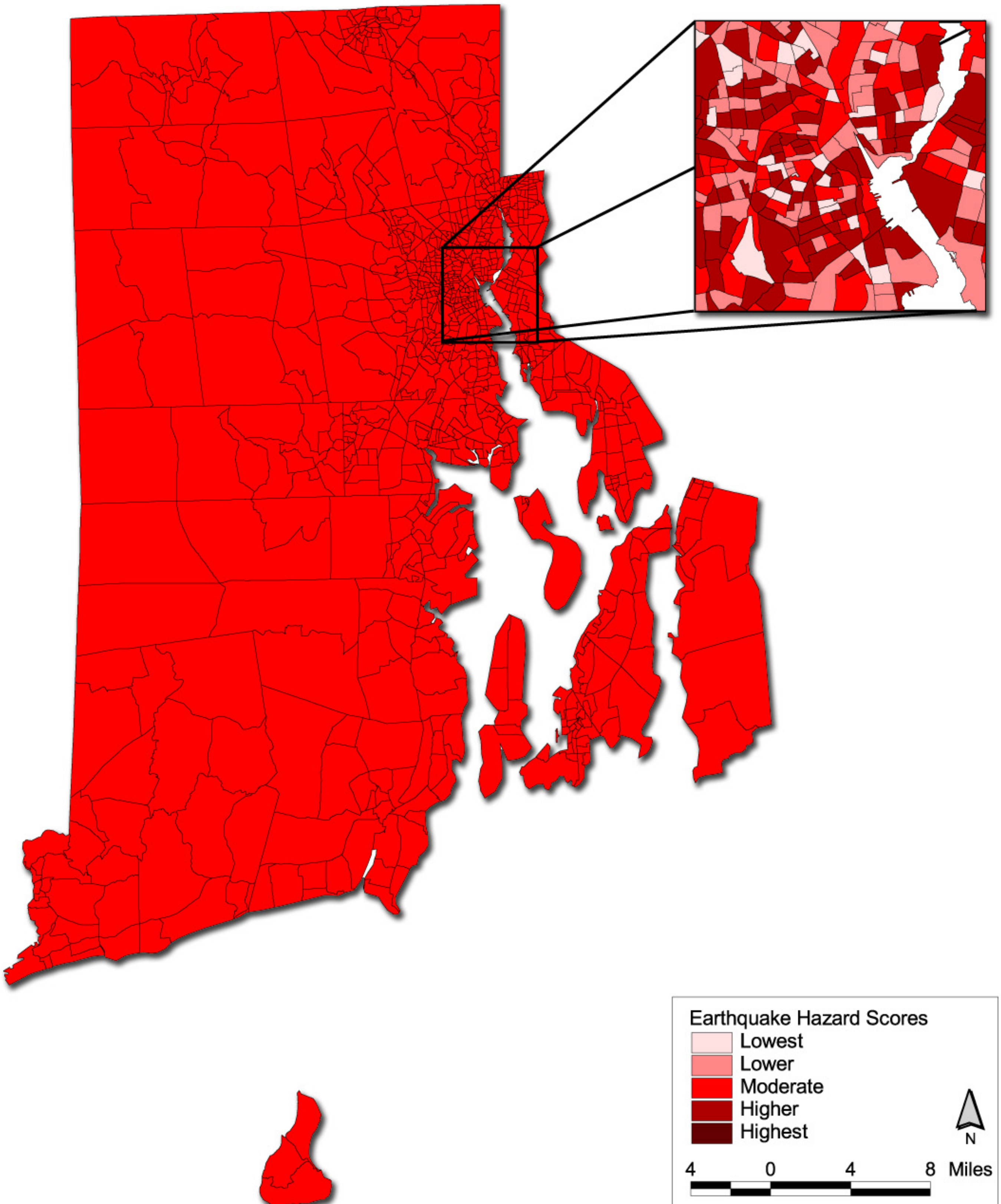


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Relative Earthquake Hazard Map

Based on MMI Spectral Acceleration (G-force/1 sec)

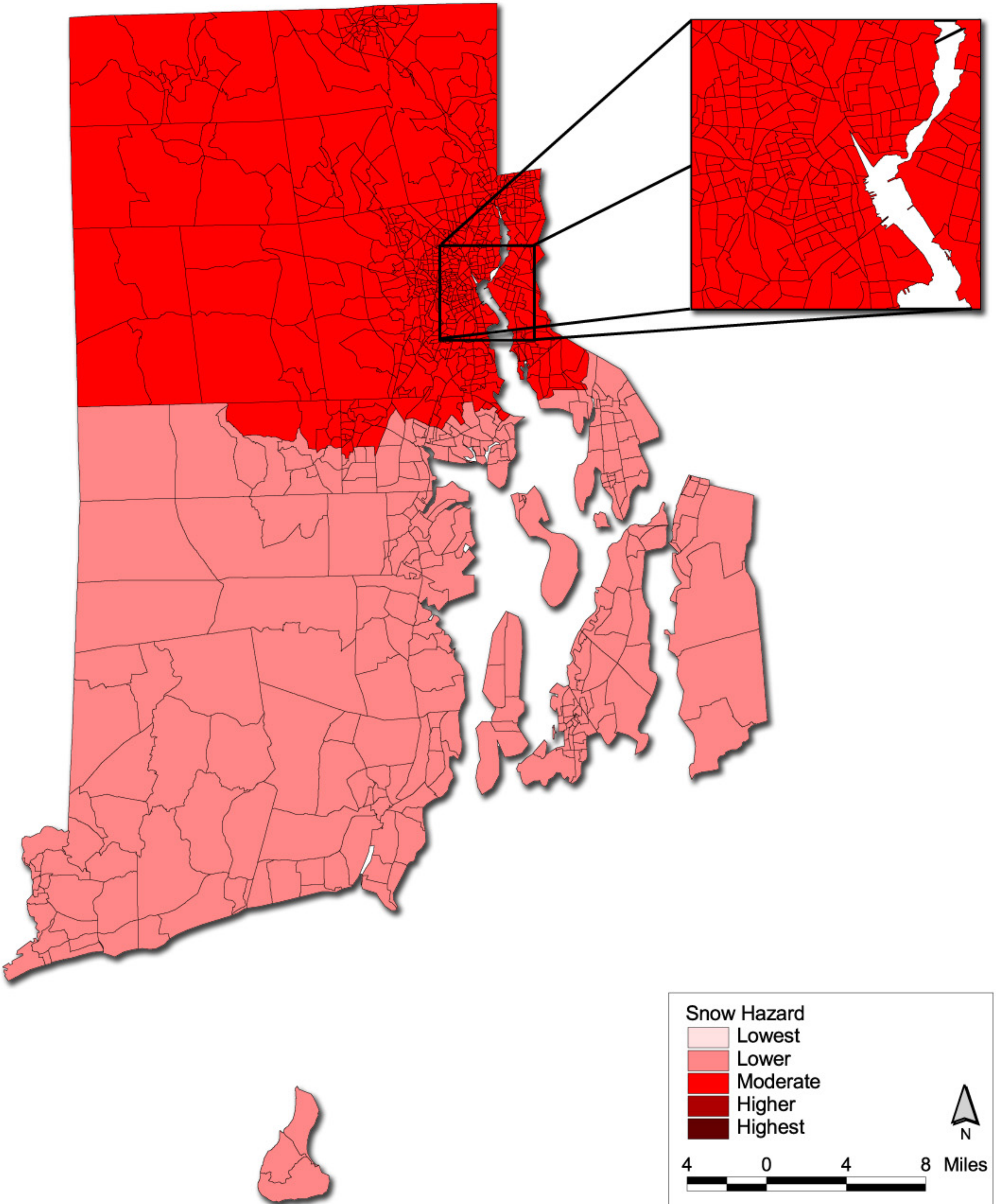


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Relative Snow Hazard Map

Based on average annual depth in inches

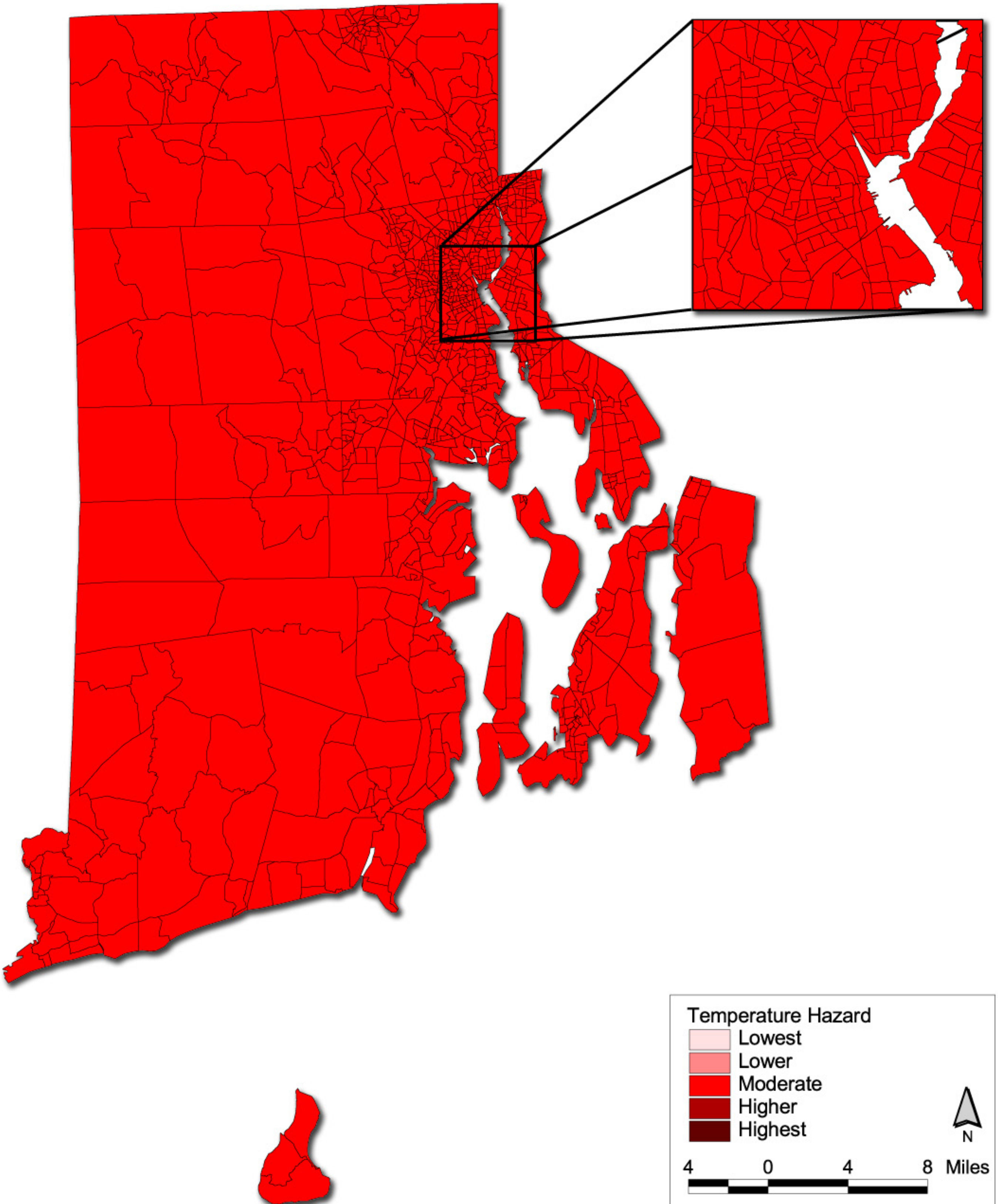


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Relative Temperature Hazard Map

Based on heating degree days minus cooling degree days

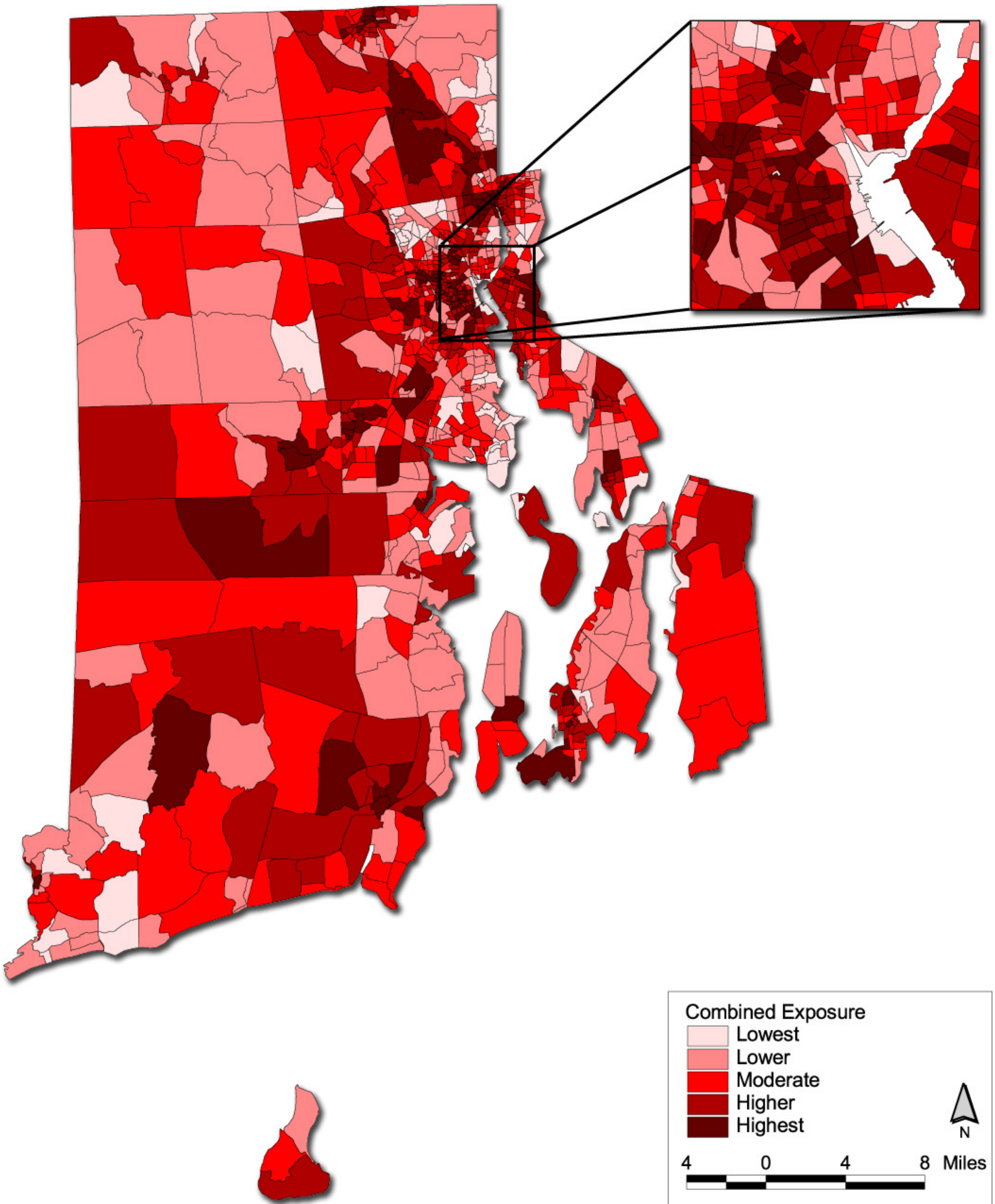


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Combined Relative Exposure Map

Based on combined critical facilities, social, environmental, and economic exposure scores.

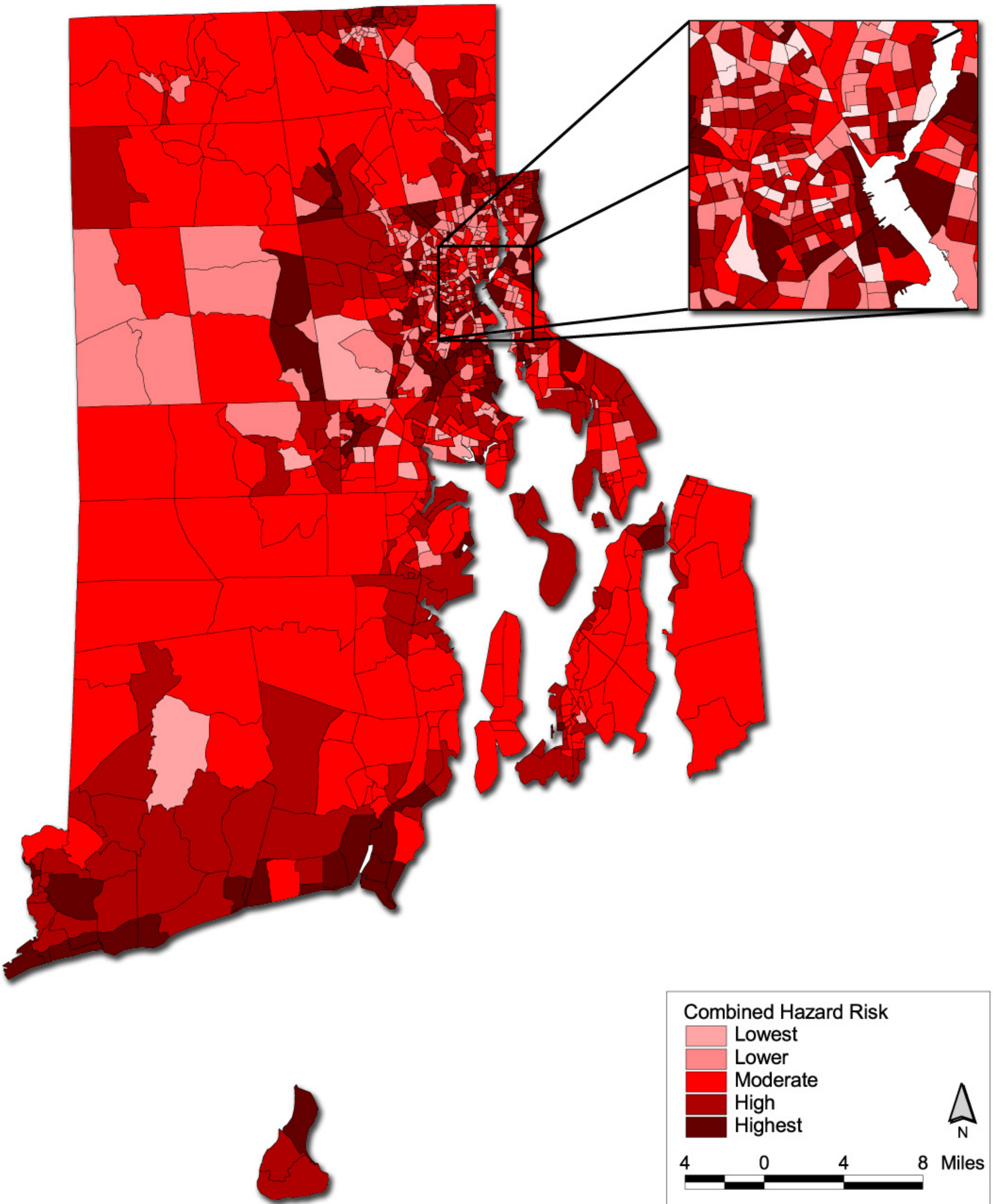


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Combined Relative Hazard Map

Sum of all hazard scores

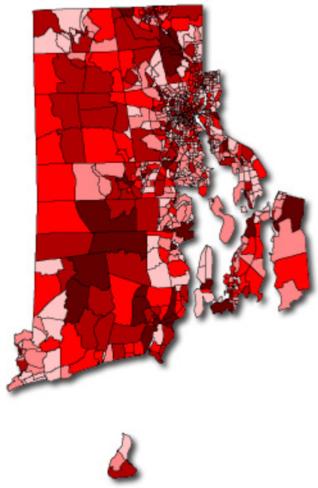


Source: Rhode Island Natural Hazard & Exposure Database

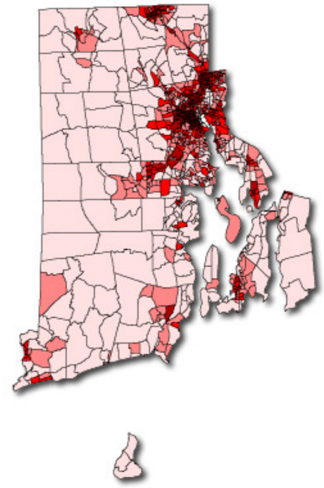
Odeh Engineers, 2001

Combined Relative Exposure Maps

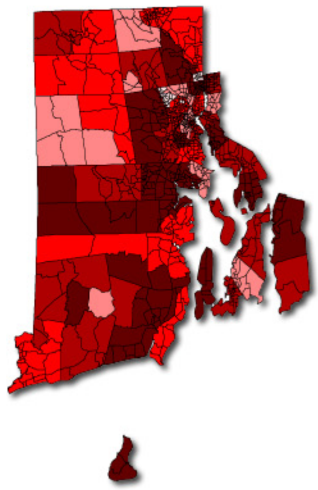
Including Critical Facilities, Social, Economic, Environmental, and Combined Exposure Maps



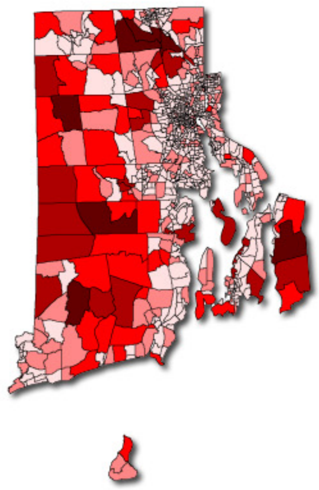
Critical Facilities Scores



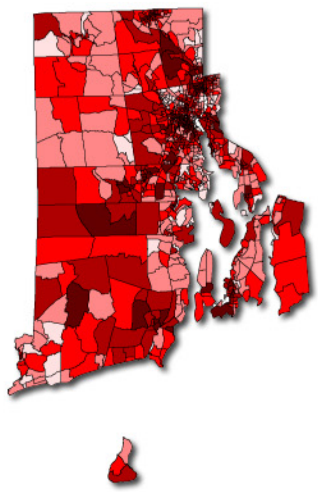
Social Exposure Scores



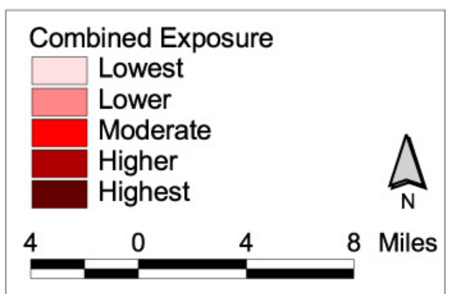
Economic Exposure Scores



Environmental Exposure Scores



Combined Exposure Scores

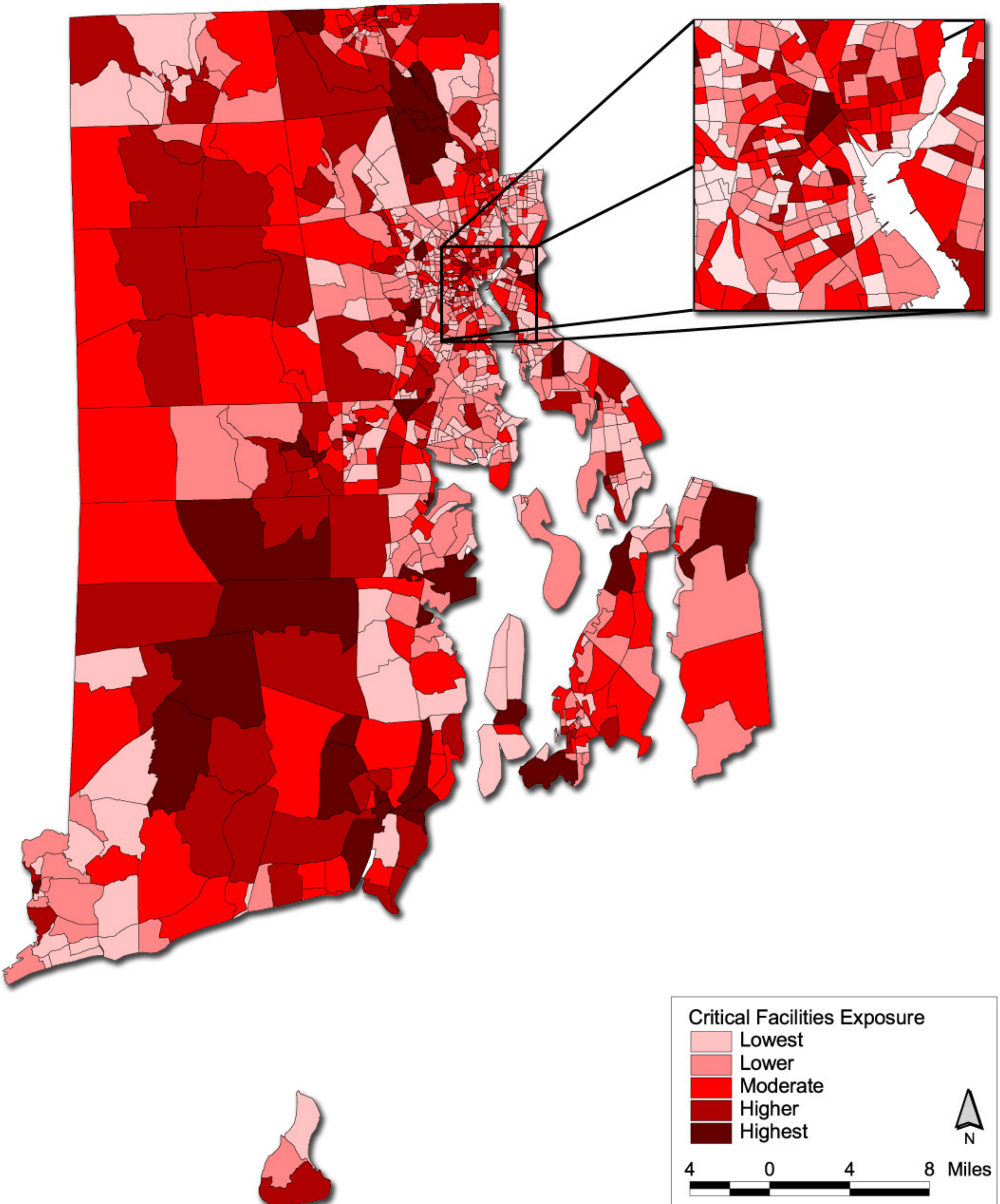


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Relative Critical Facilities Exposure Map

Including marinas, fire & rescue stations, police stations, water treatment facilities, railroad & airport depots, and government facilities.

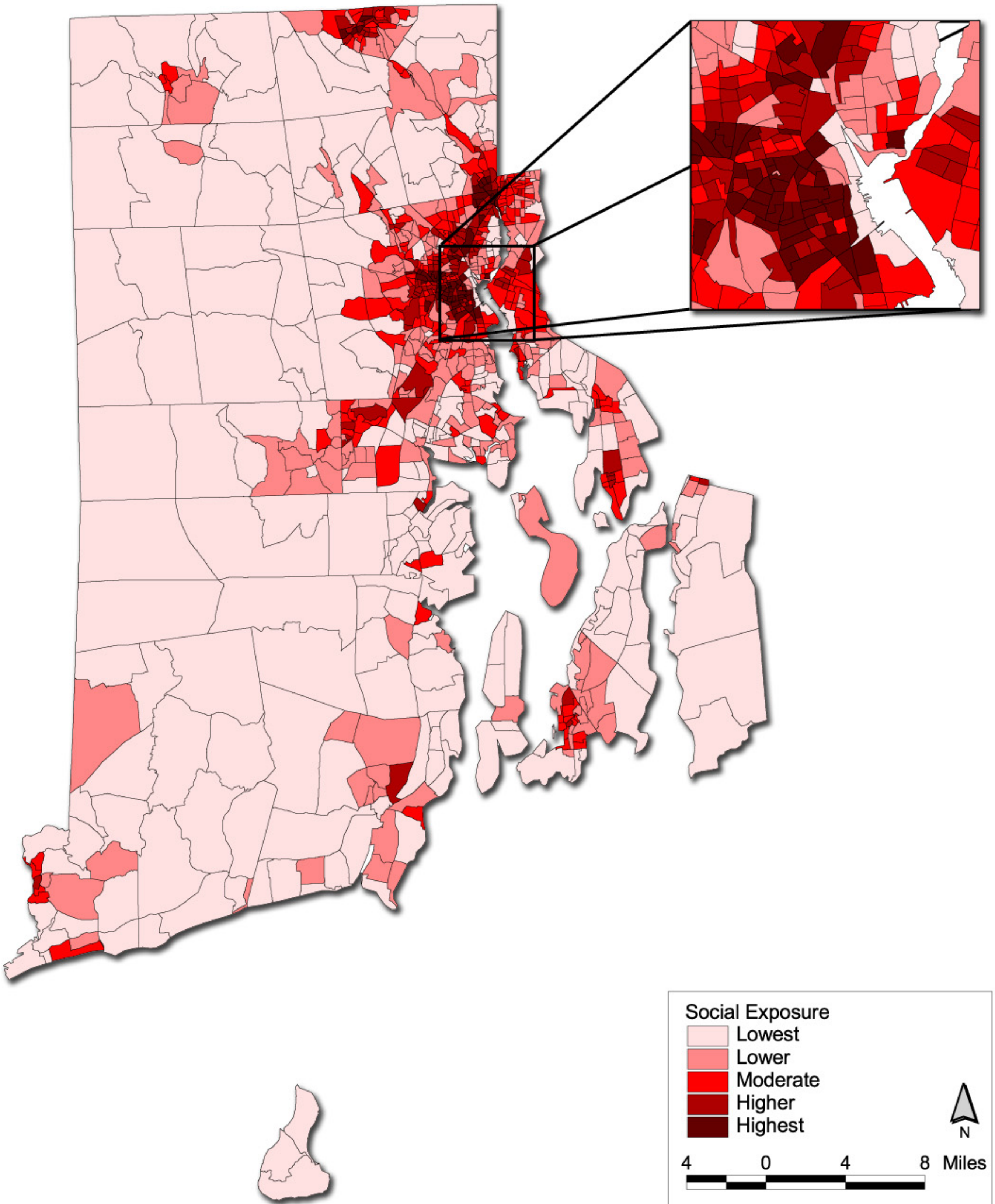


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Relative Social Exposure Map

Including population density, elderly, no high school education, public assistance, those without vehicles, renters, disabled, and non-english speaking populations.

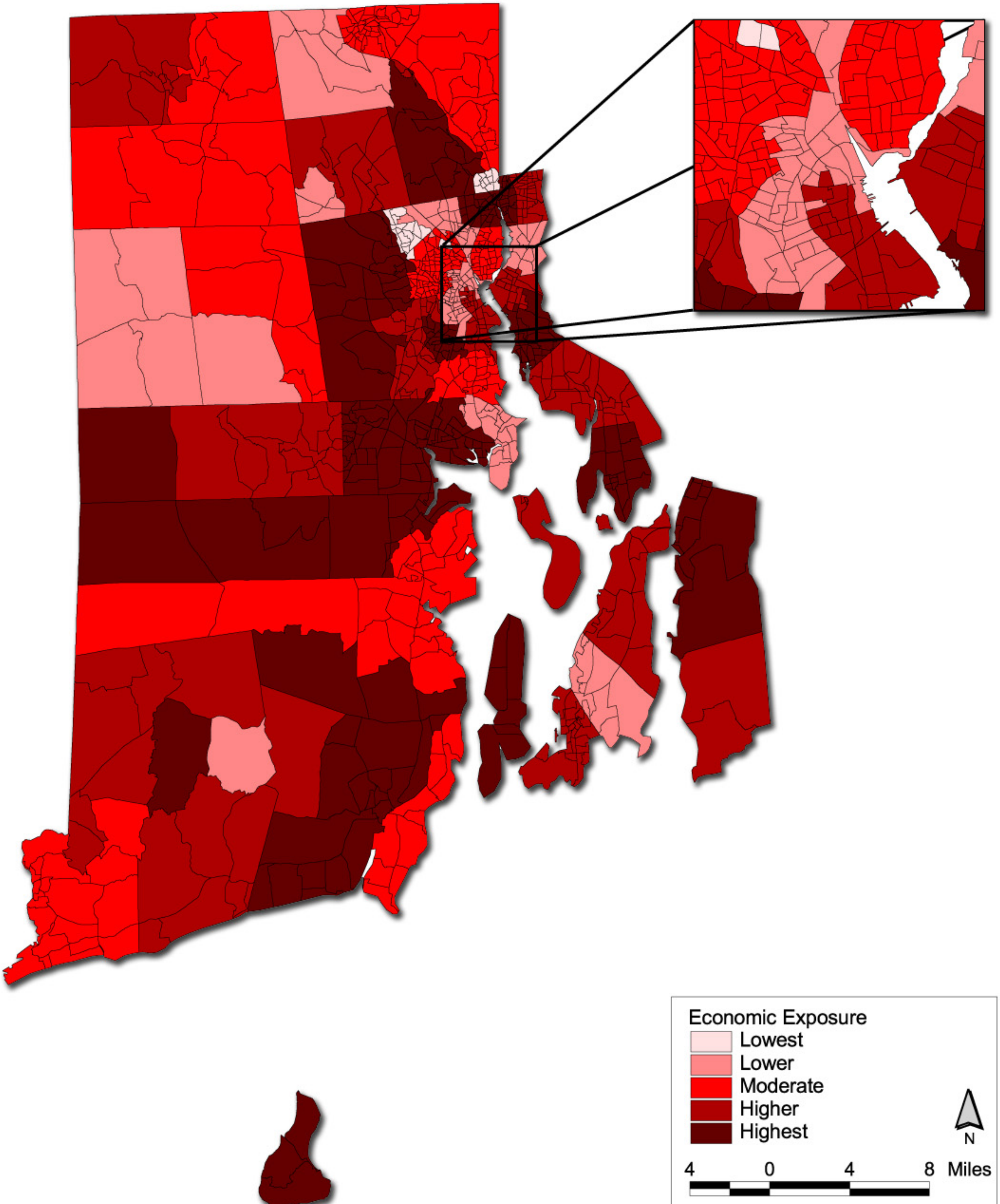


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Relative Economic Exposure Map

Including construction, light manufacturing, wholesale, hotels/motels, agriculture, professional/technical services, retail, financial, and domestic property values.

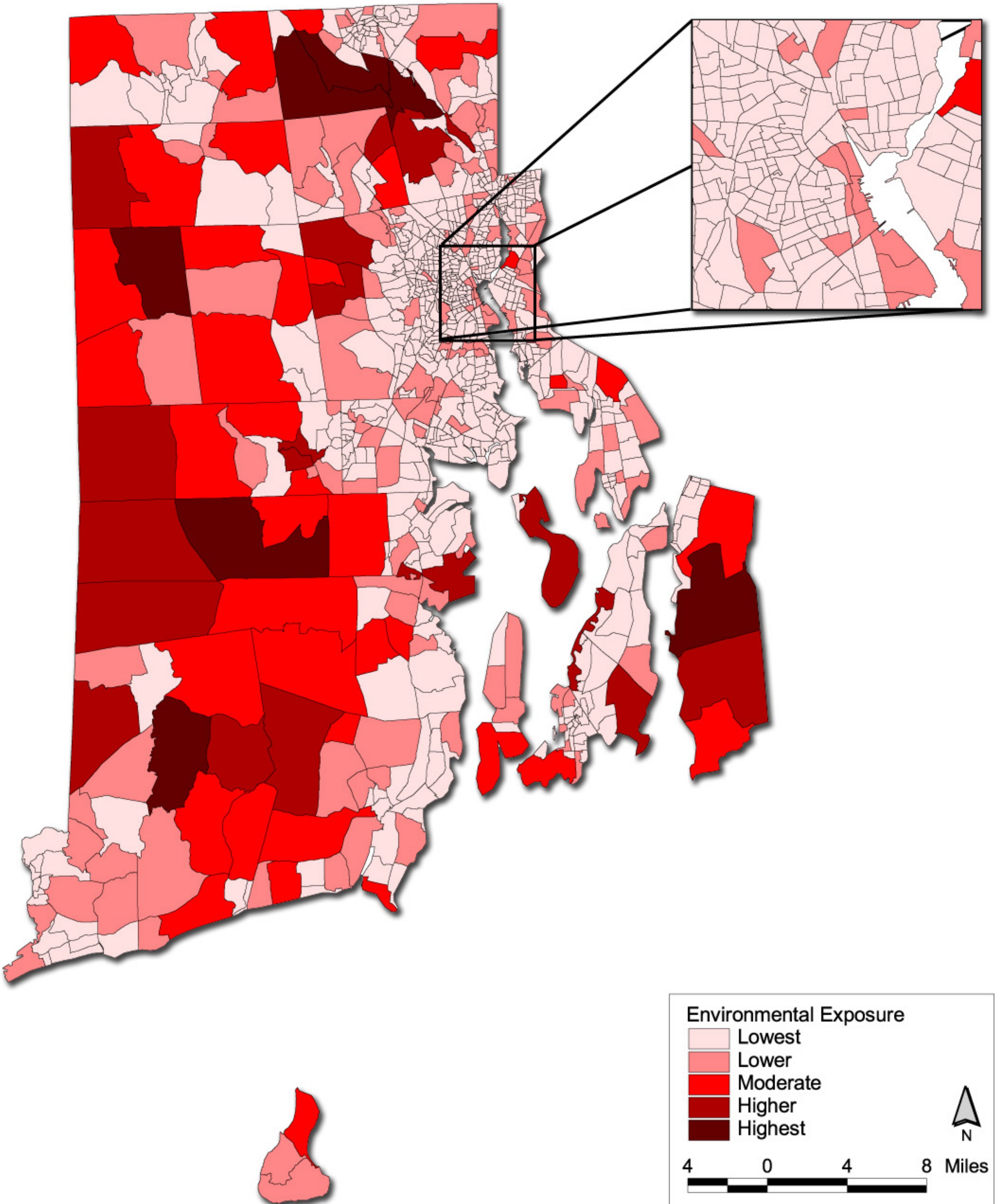


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Relative Environmental Exposure Map

Including CIRCLIS sites, areas of scenic beauty, and rare species habitats

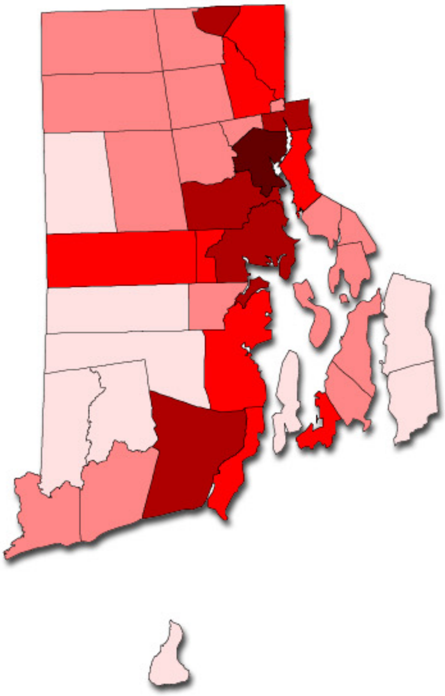


Source: Rhode Island Natural Hazard & Exposure Database

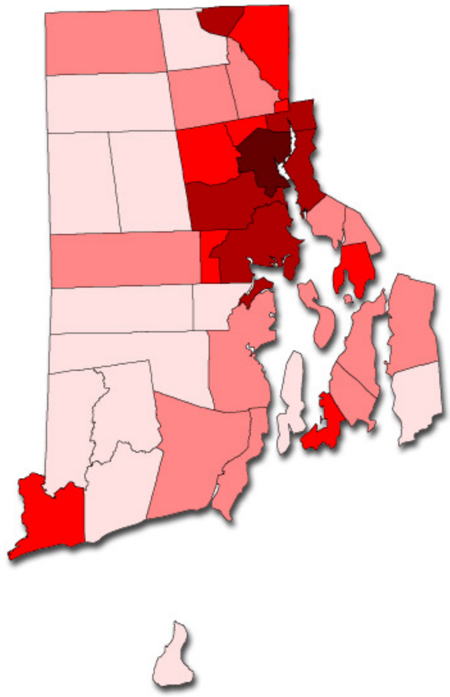
Odeh Engineers, 2001

Combined Community Exposure Maps

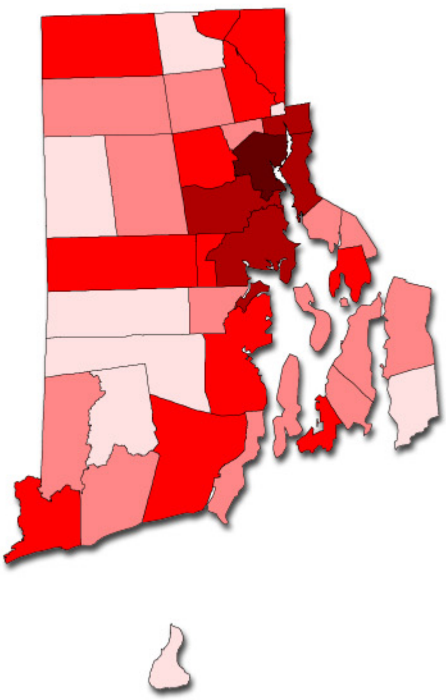
Including Critical Facilities, Social, Economic, Environmental, and Combined Exposure Maps



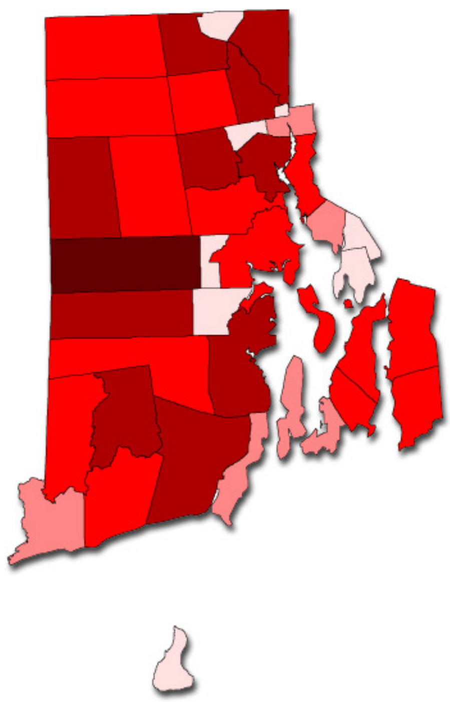
Critical Facilities



Social Exposure



Economic Exposure



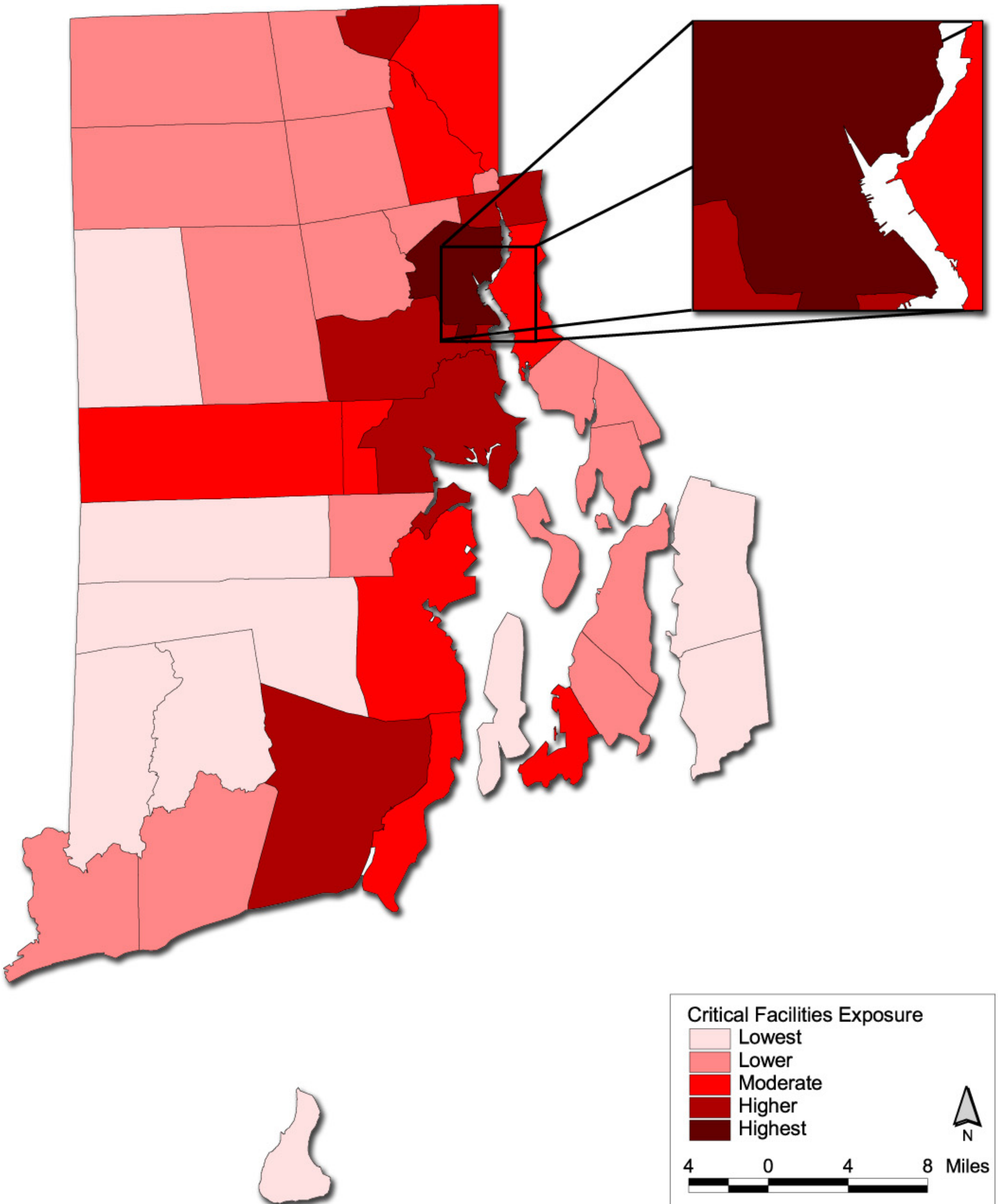
Environmental Exposure

Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Community Critical Facilities Exposure Map

Including marinas, fire & rescue stations, police stations, water treatment facilities, railroad and airport depots, and government facilities.

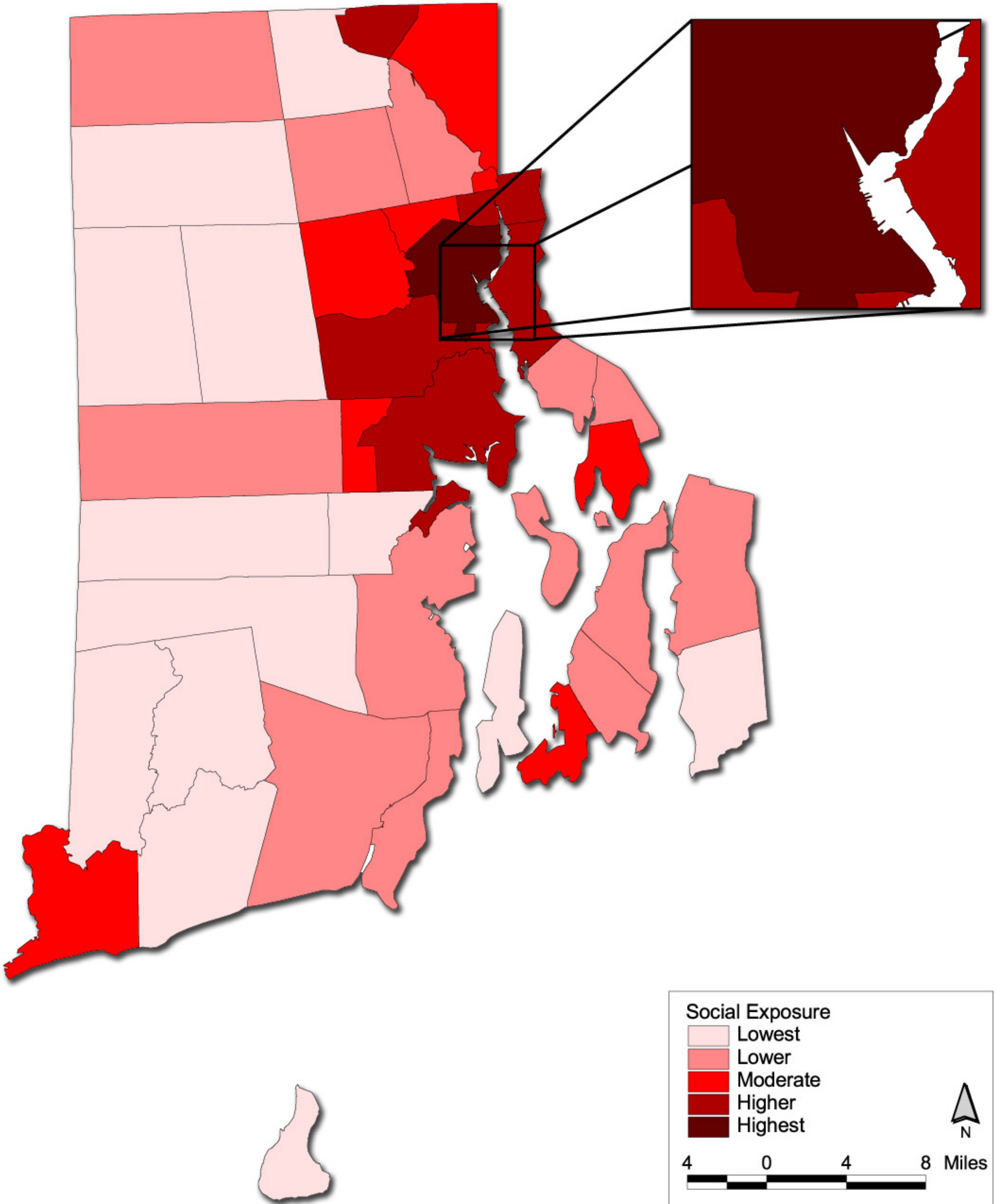


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Community Social Exposure Map

Including population density, elderly, no high school education, public assistance, those without vehicles, renters, disabled, and non-english speaking populations.

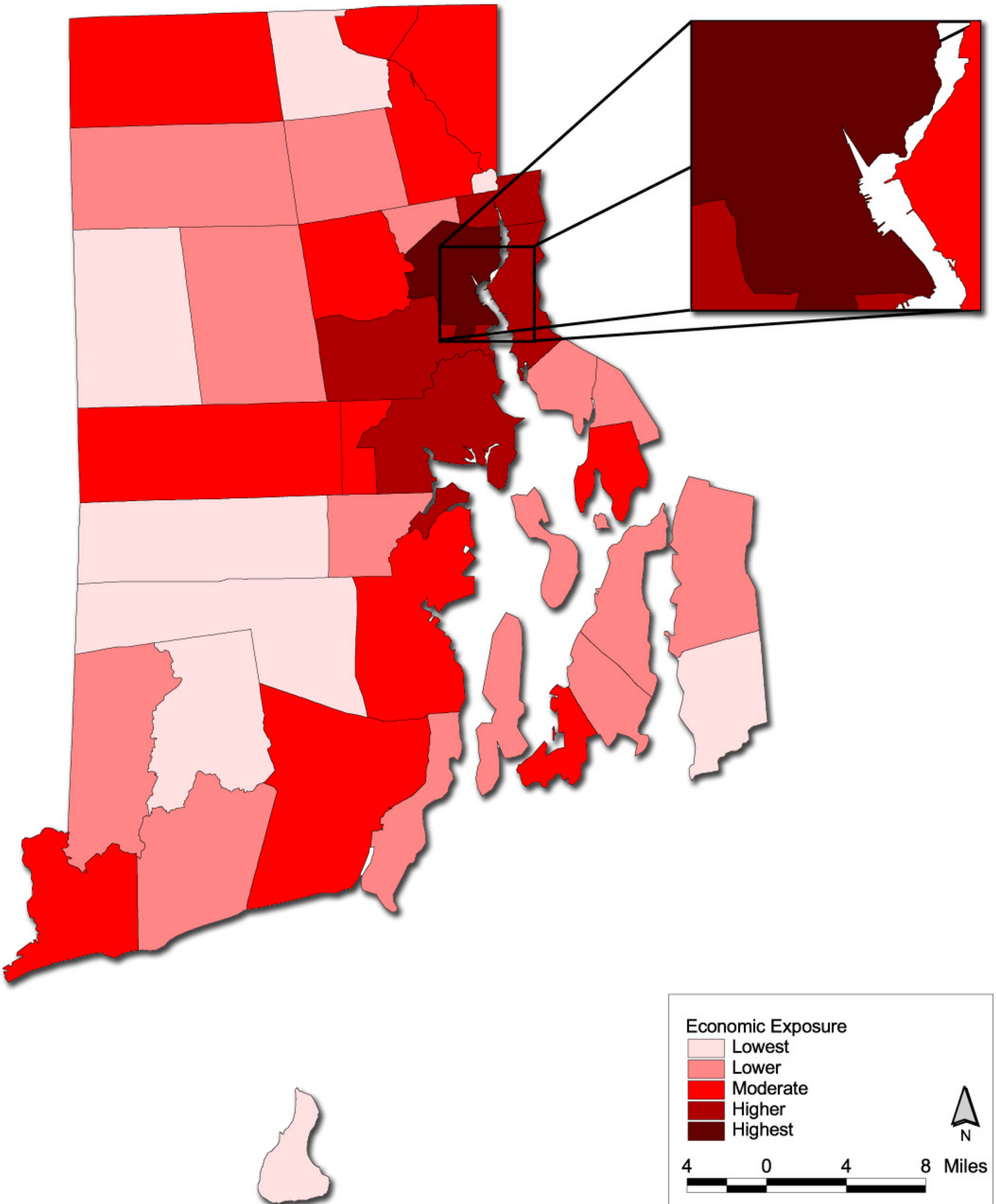


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Community Economic Exposure Map

Including construction, light manufacturing, wholesale, hotels/motels, agriculture, professional/technical services, retail, financial, and domestic property values.

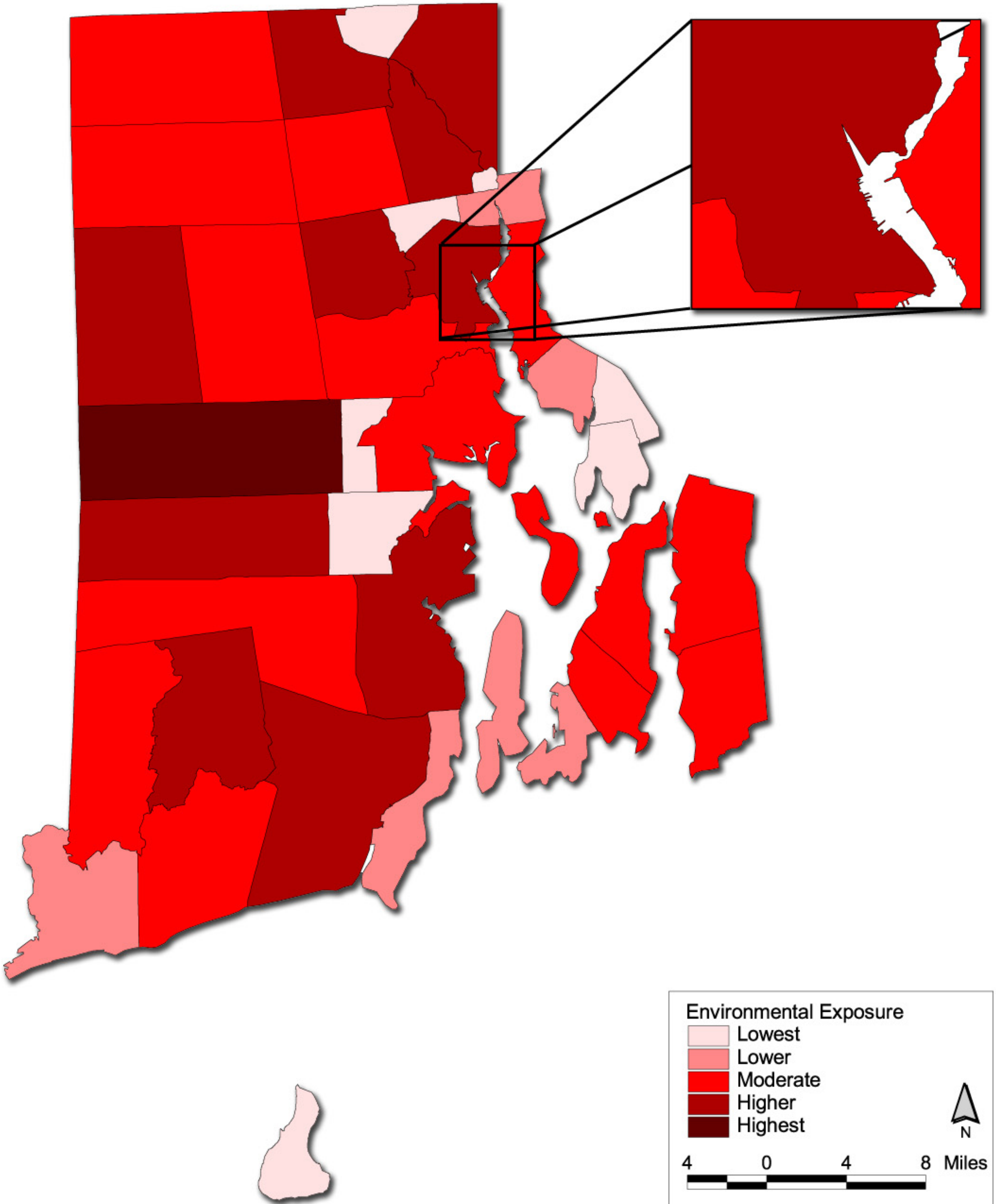


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Community Environmental Exposure Map

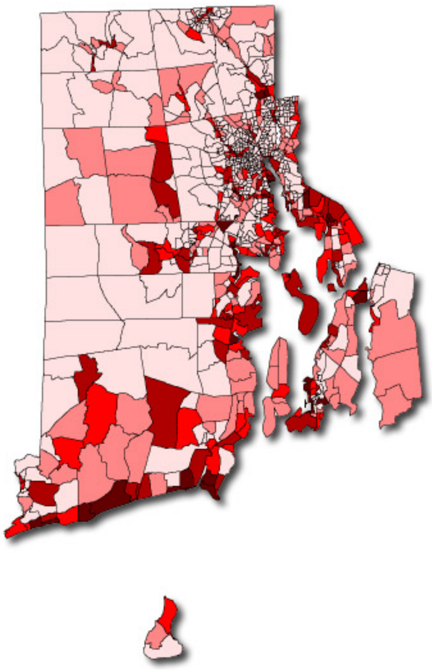
Including CIRCLIS sites, areas of scenic beauty, and rare species habitats



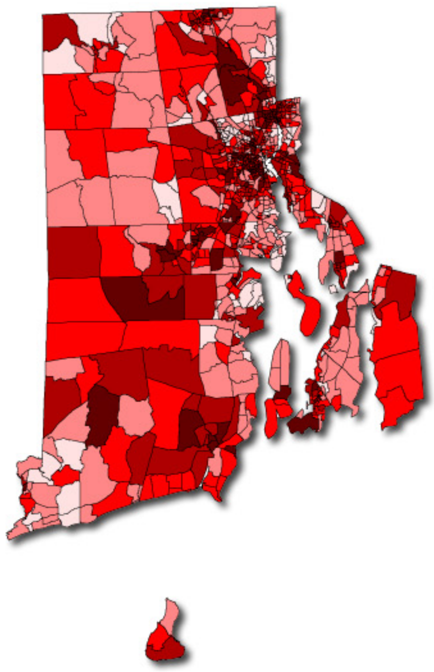
Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

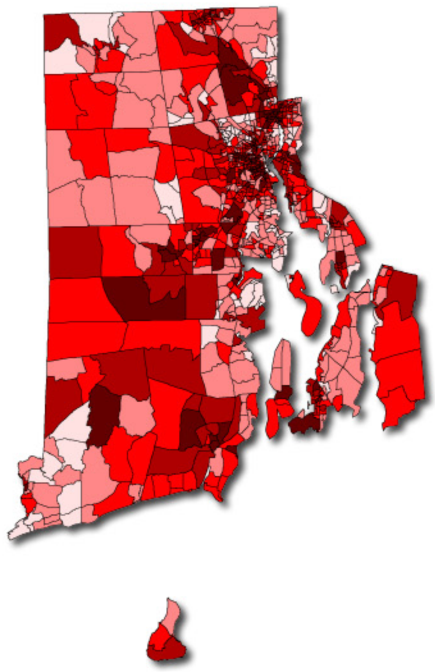
Hazard Scores Multiplied by Combined Exposure Scores



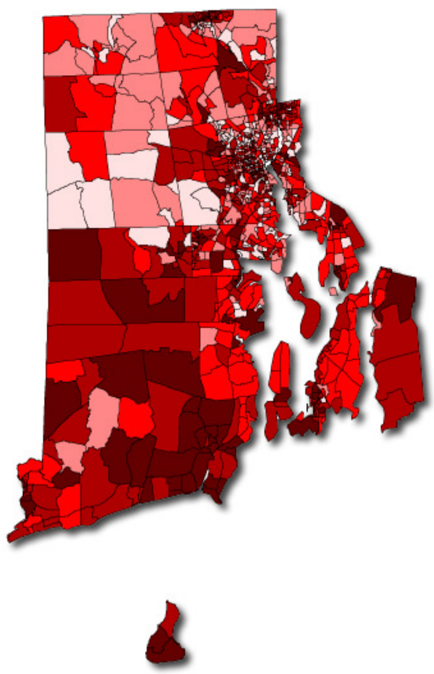
Flood Exposure Scores



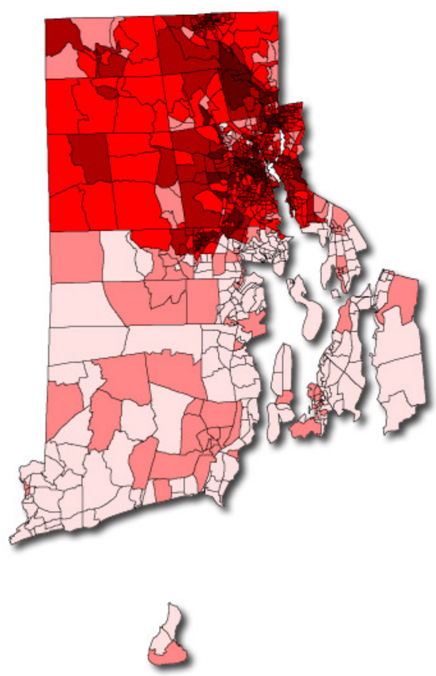
Earthquake Exposure Scores



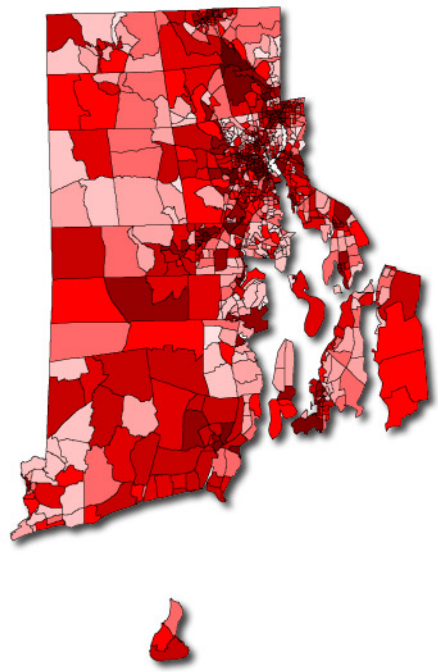
Hail Exposure Scores



Hurricane Exposure Scores



Snow Exposure Scores

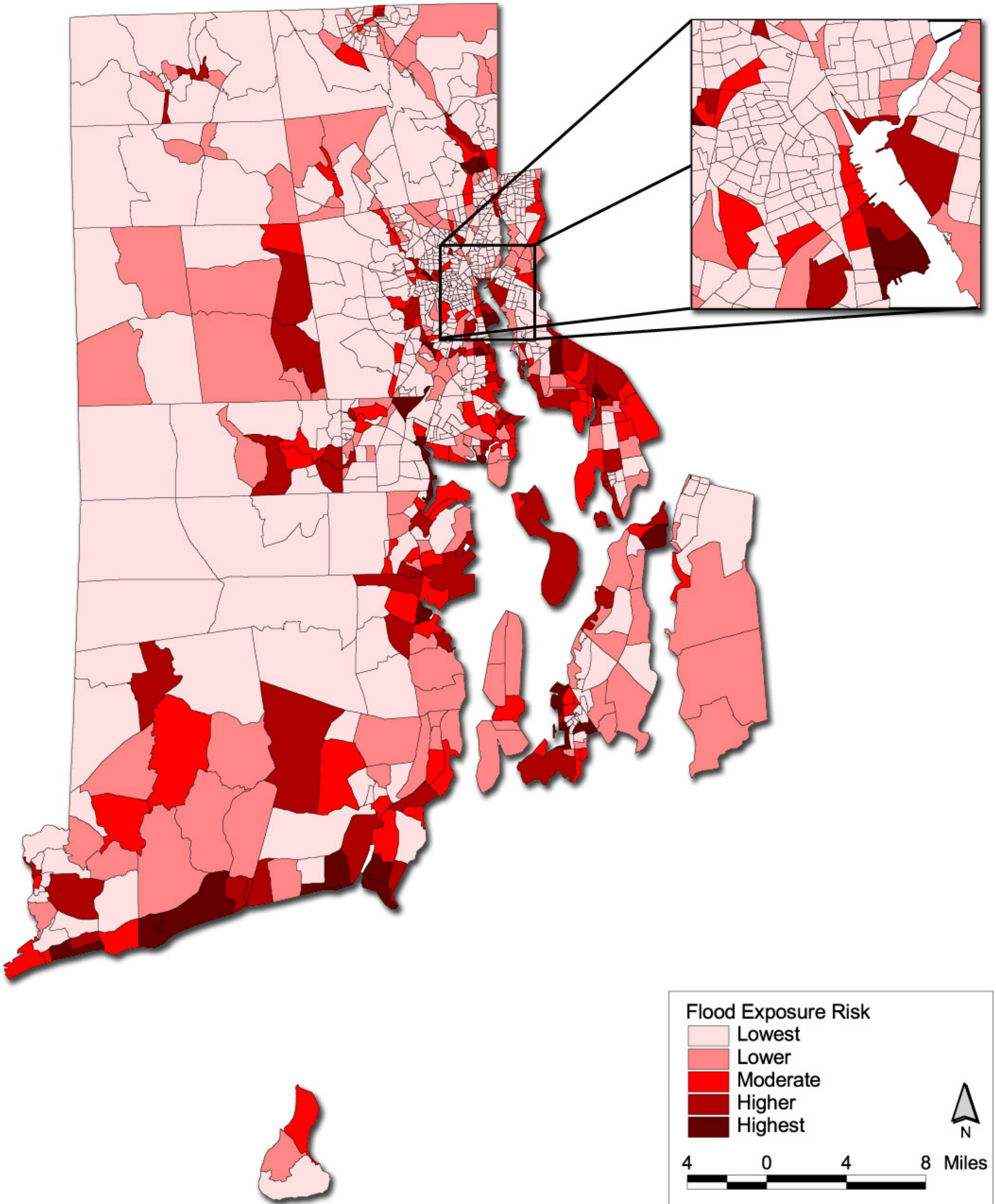


Combined Hazard Times Combined Exposure

Source: Rhode Island Natural Hazard & Exposure Database   Odeh Engineers, 2001

Flood Exposure Map

Derived by multiplying flood hazard scores with combined exposure scores

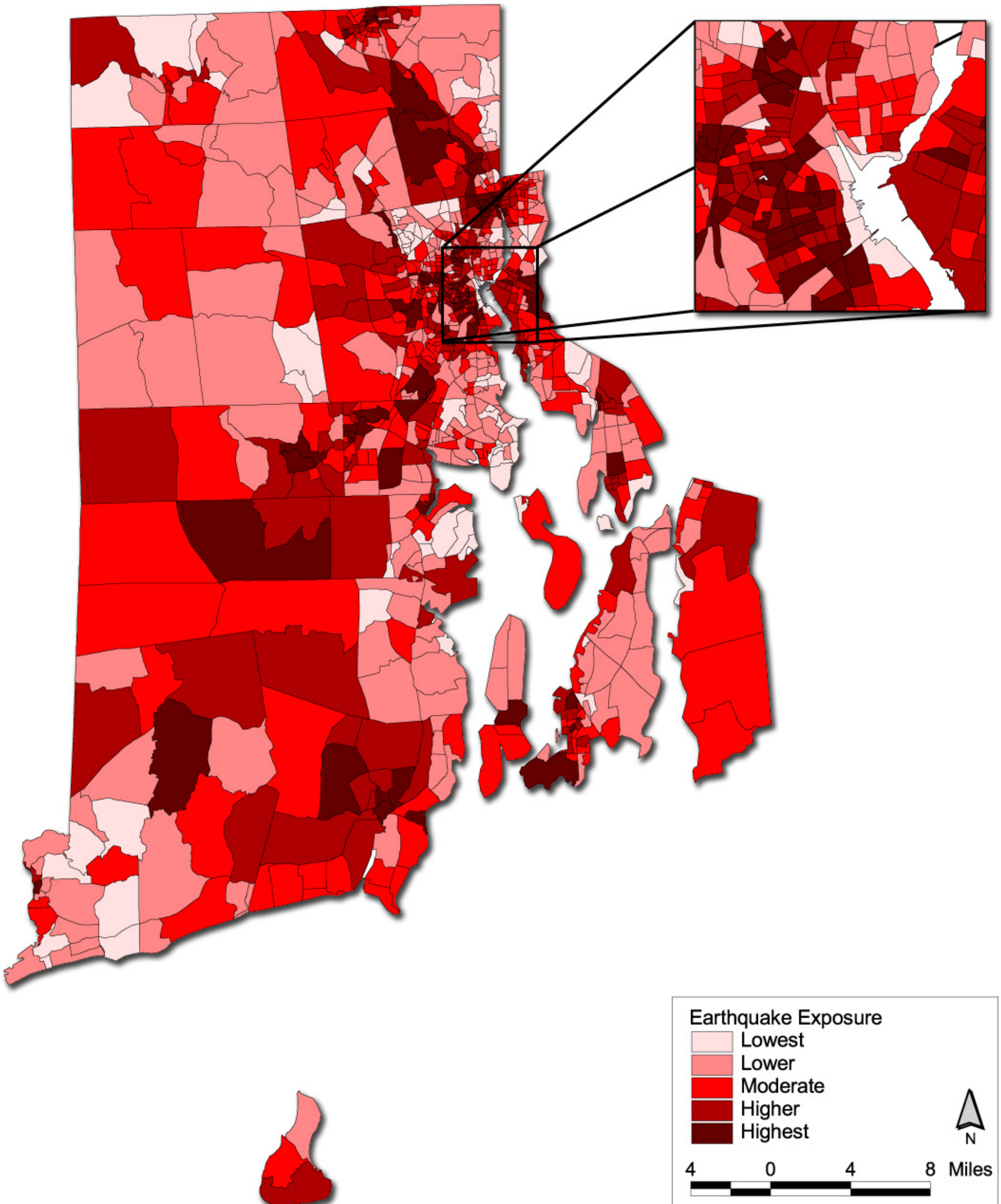


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Earthquake Exposure Map

Derived by multiplying earthquake hazard scores with combined exposure scores.

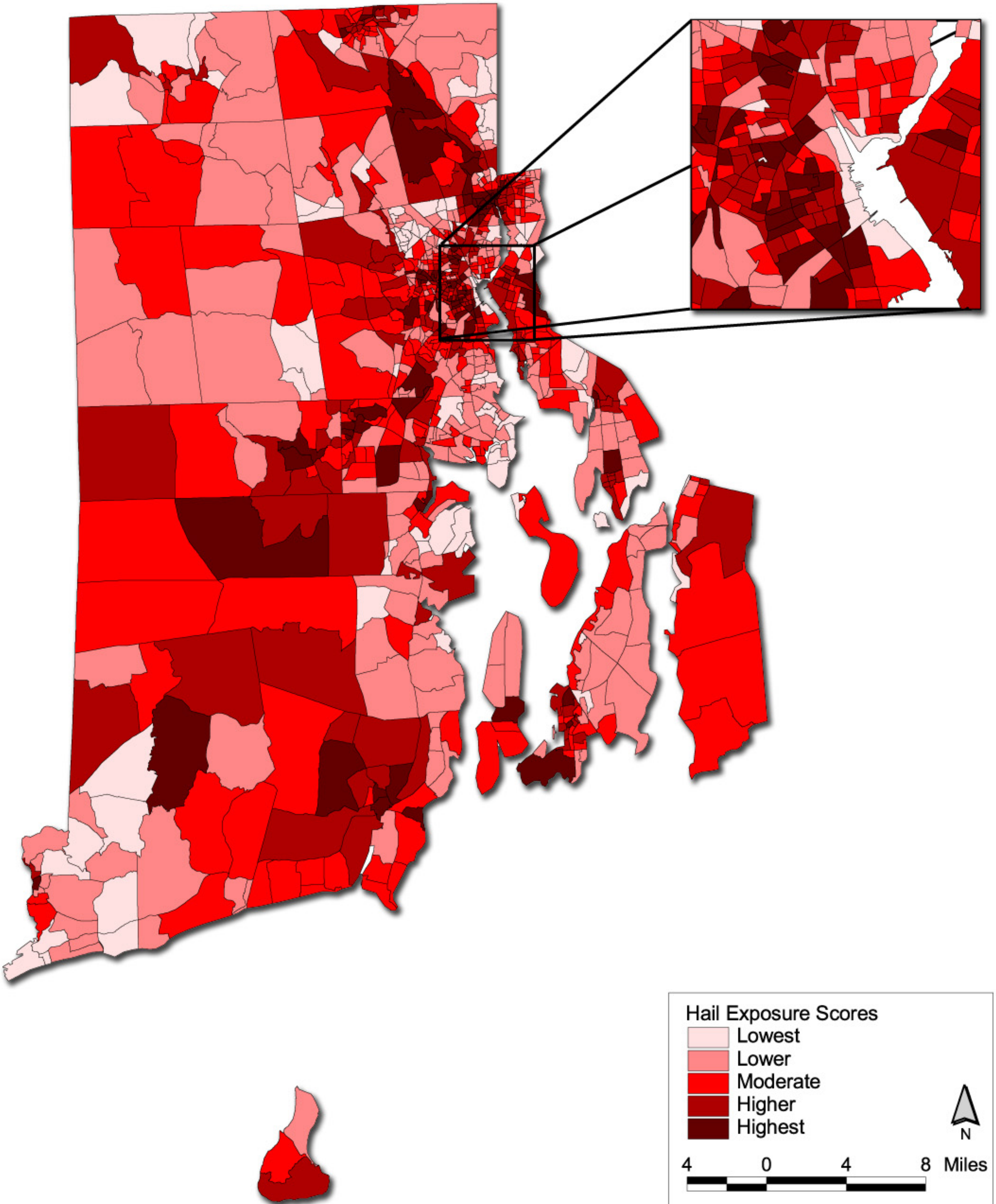


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Hail Exposure Map

Derived by multiplying hail hazard scores with combined exposure scores

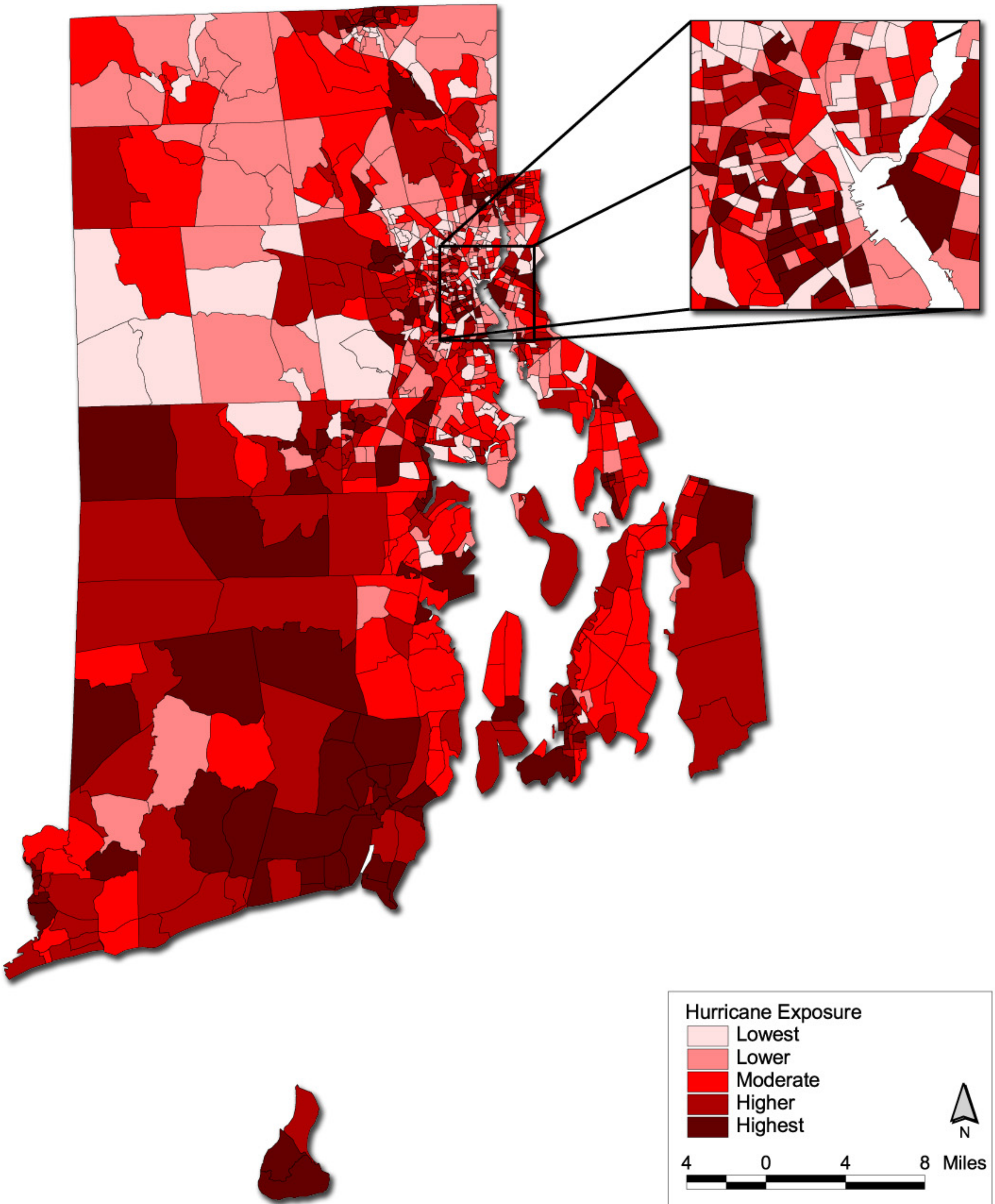


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Hurricane Exposure Map

Derived by multiplying hurricane hazard scores with combined exposure scores

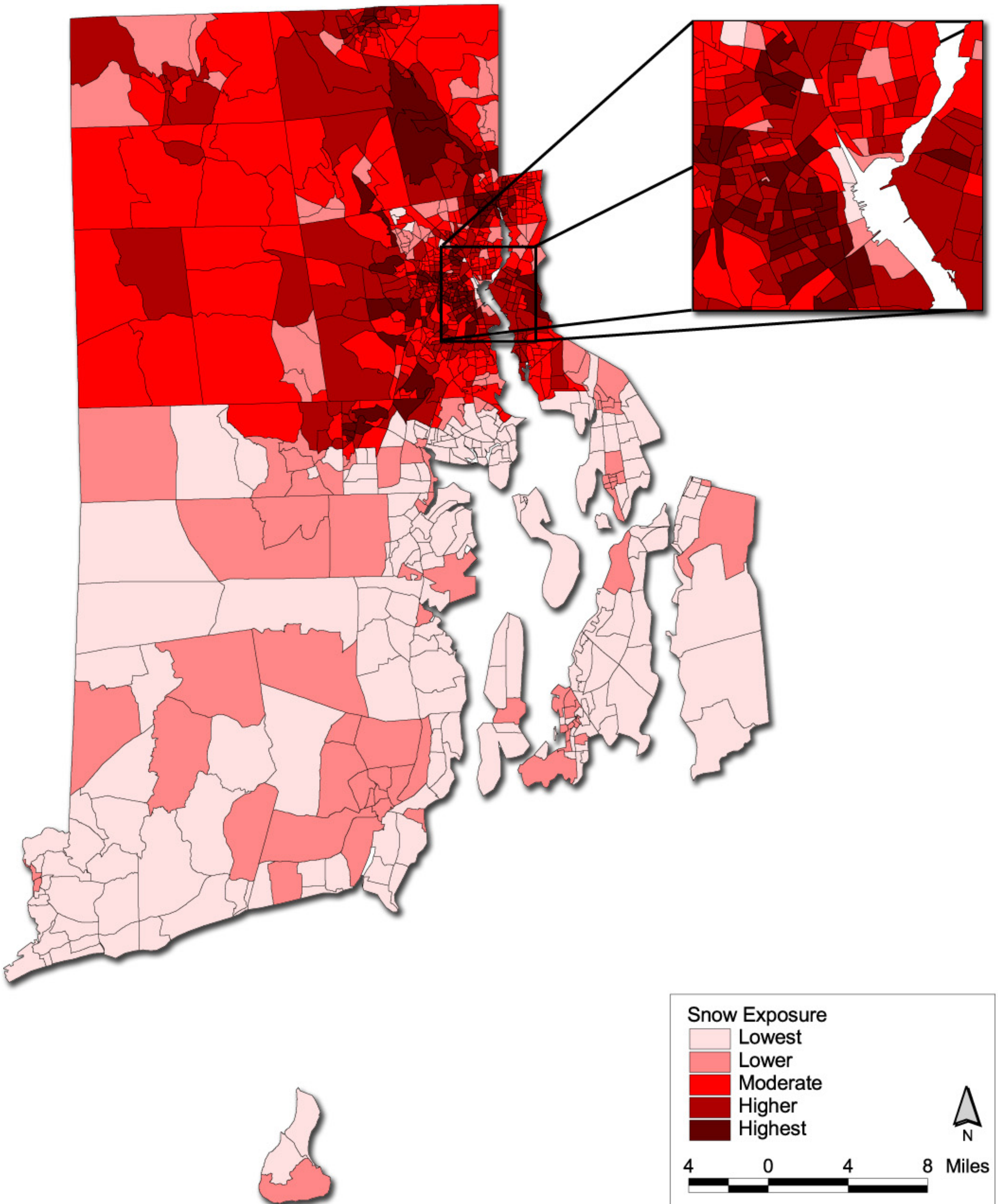


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Snow Exposure Map

Derived by multiplying snow hazard scores with combined exposure scores

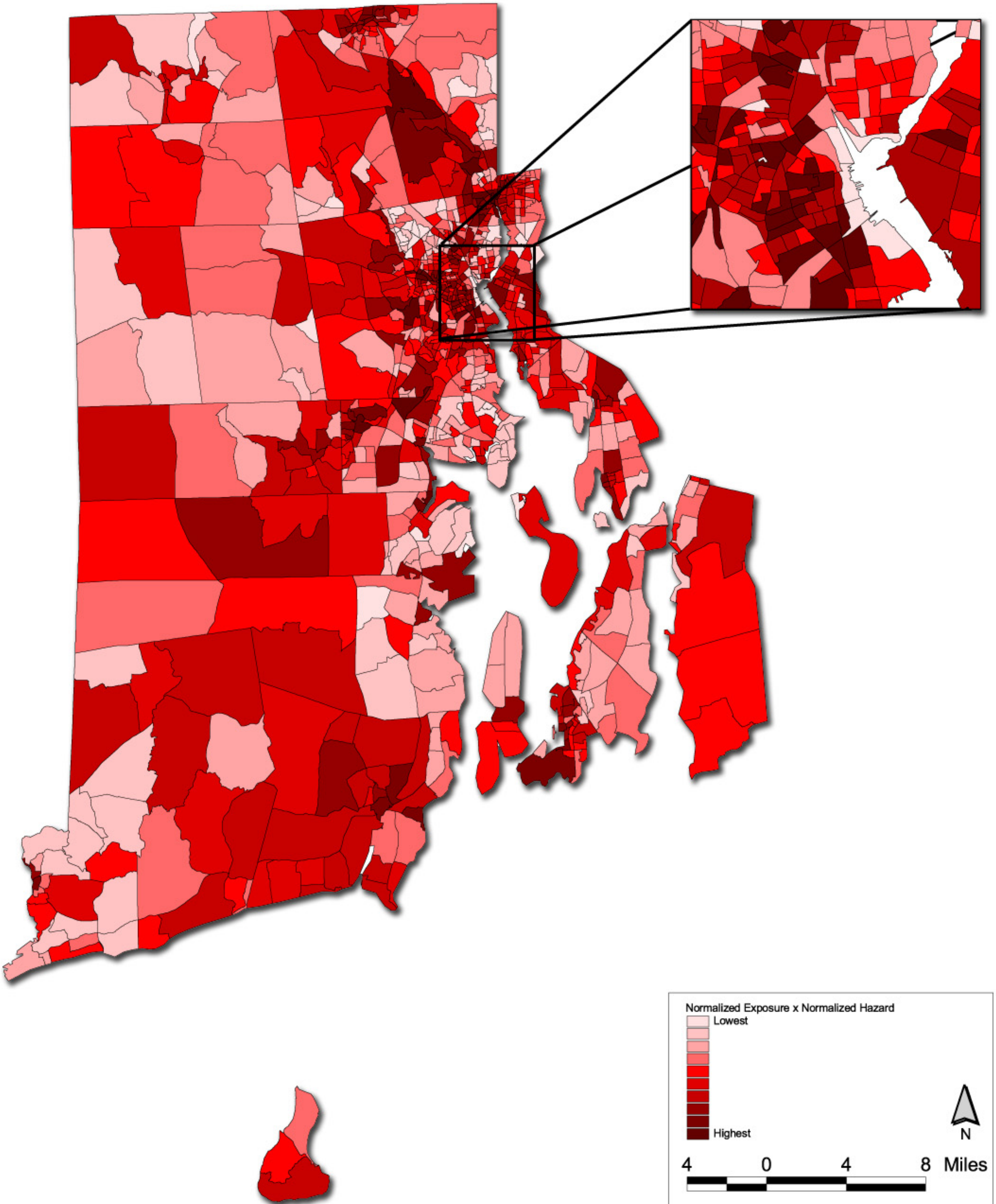


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Hazard Times Exposure

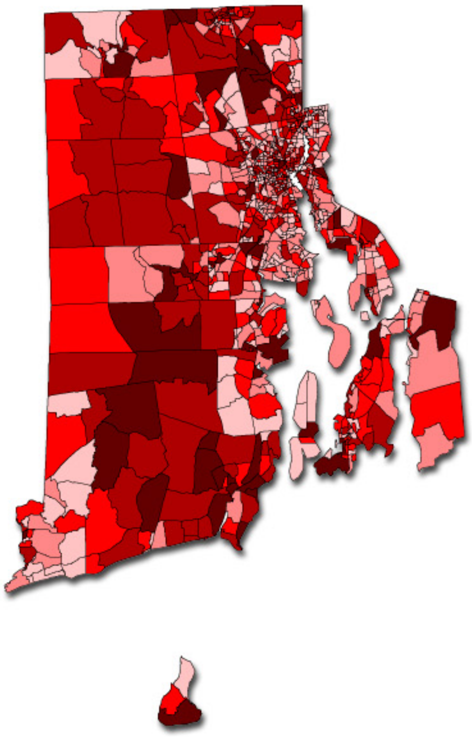
Derived by multiplying combined hazard scores with combined exposure scores



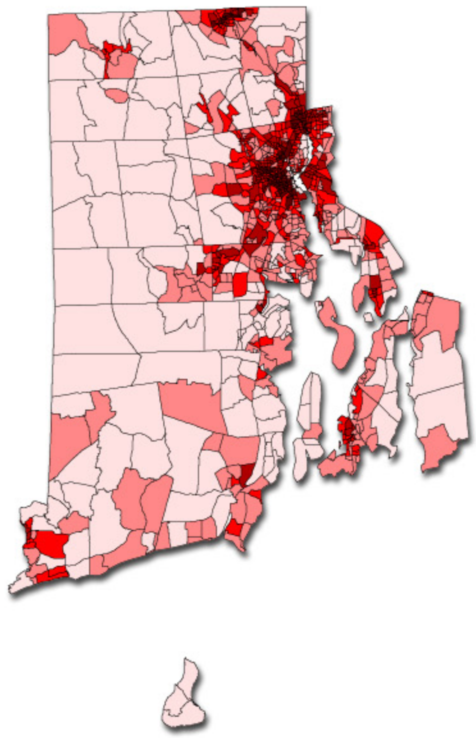
Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Exposure Categories Multiplied by Combined Hazard Categories

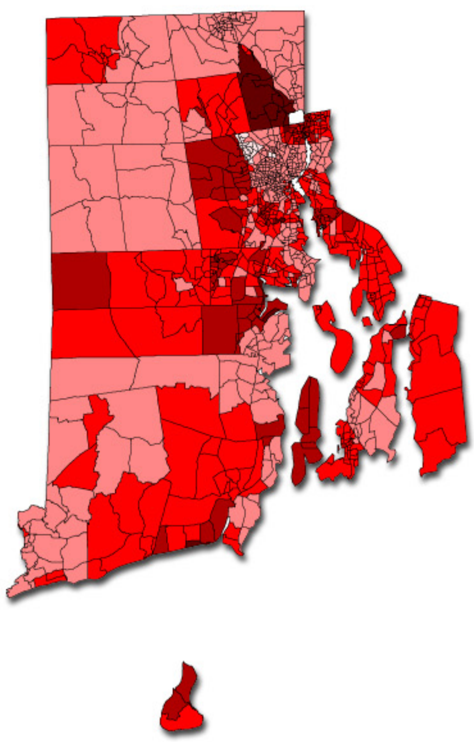


Critical Facilities Hazard Scores

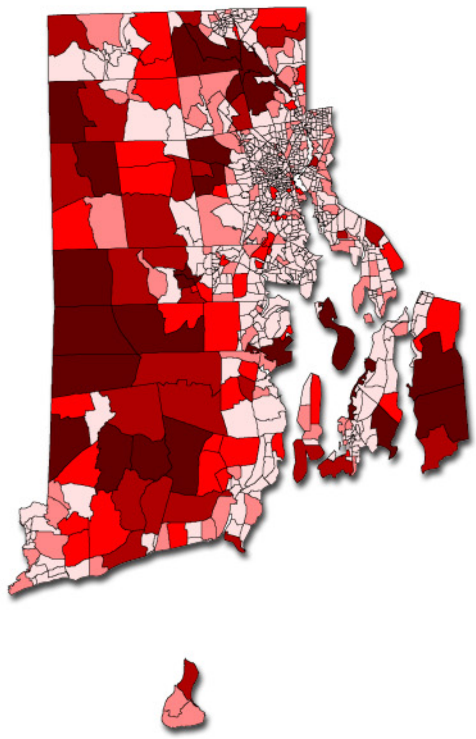


Social Hazard Scores

Economic Hazard Scores



Environmental Hazard Scores

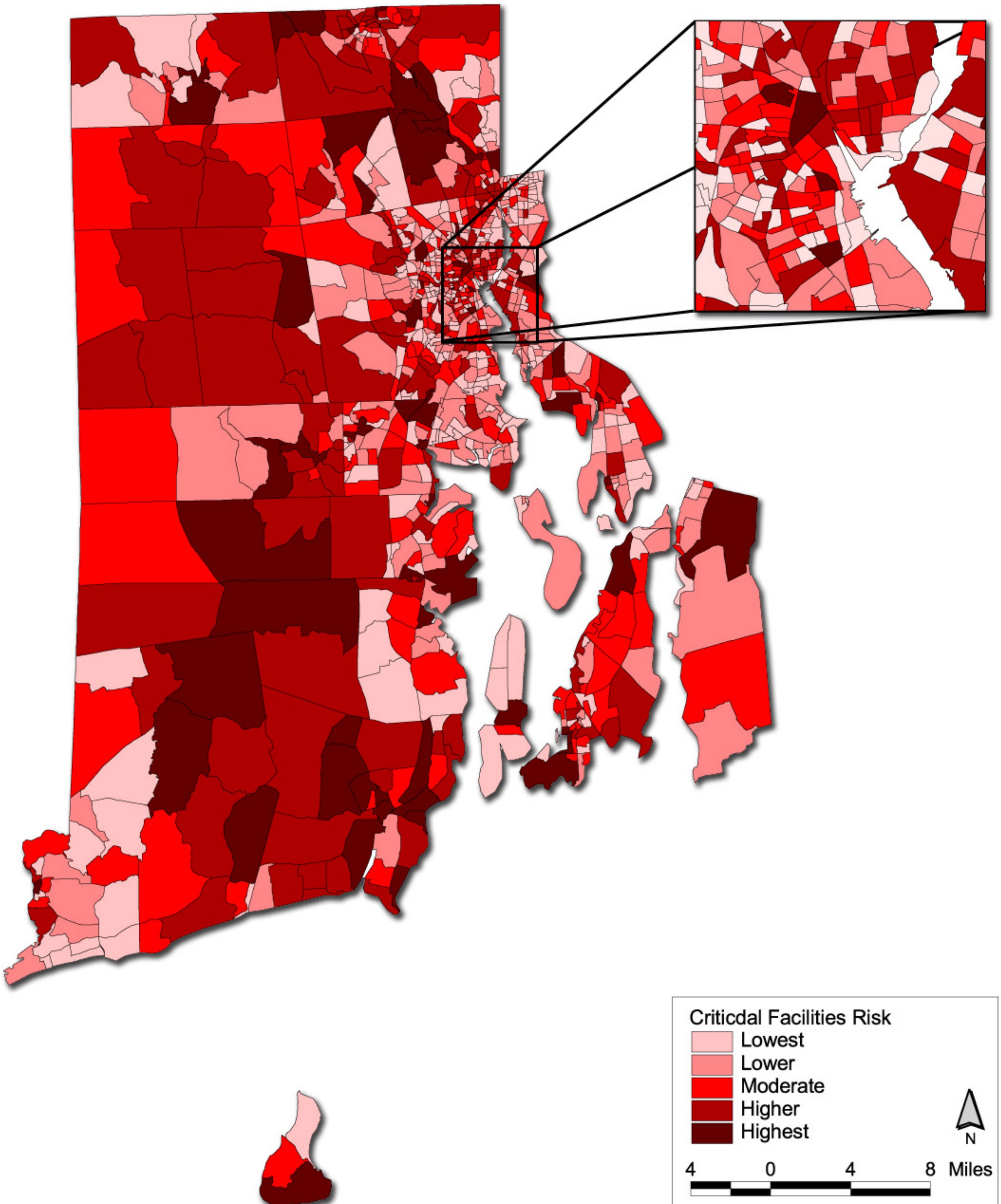


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Combined Hazard to Critical Facilititities

Derived by multiplying critical facilities exposure scores by combined hazard score.

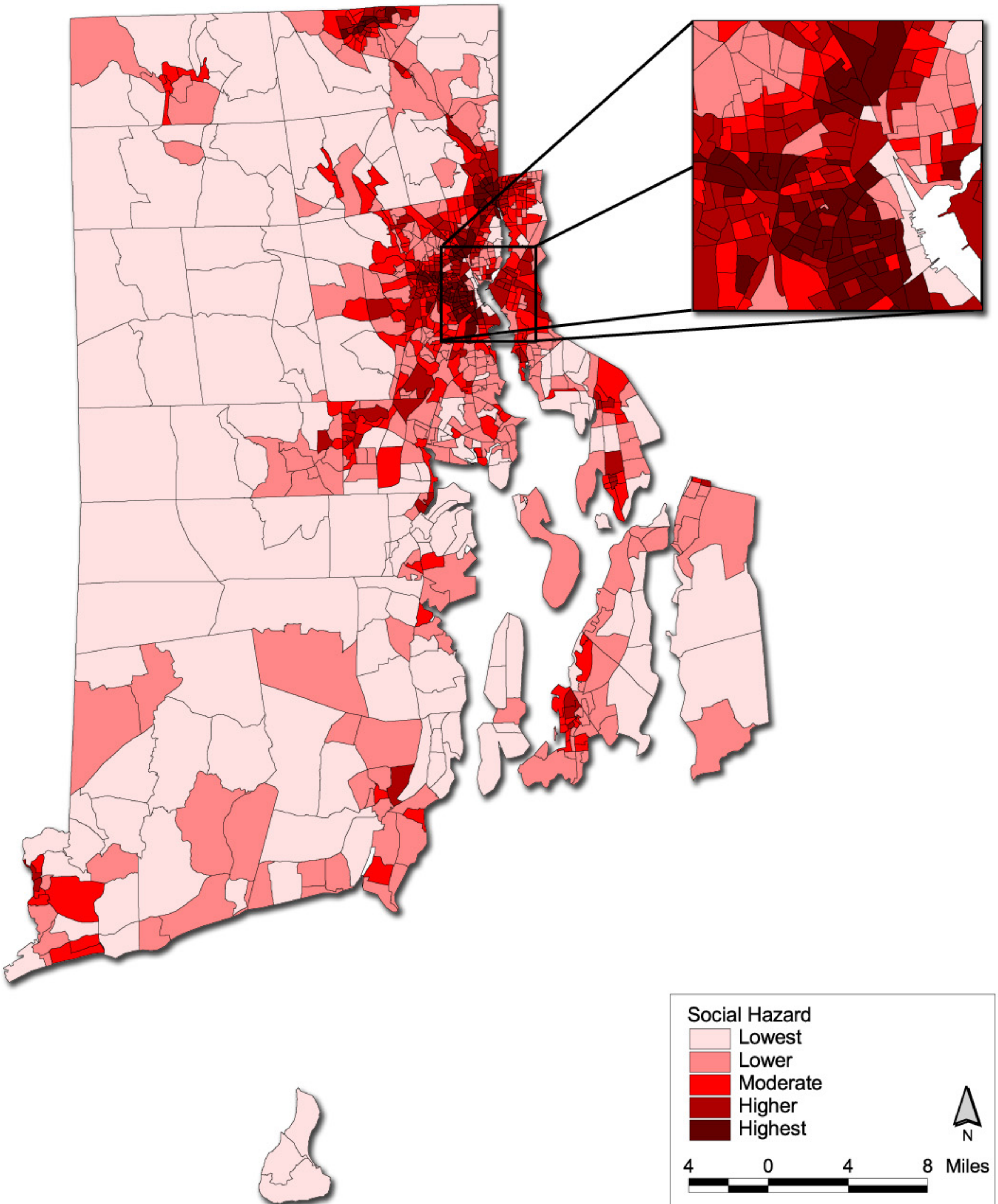


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Social Hazard Map

Derived by multiplying social exposure scores with combined hazard scores

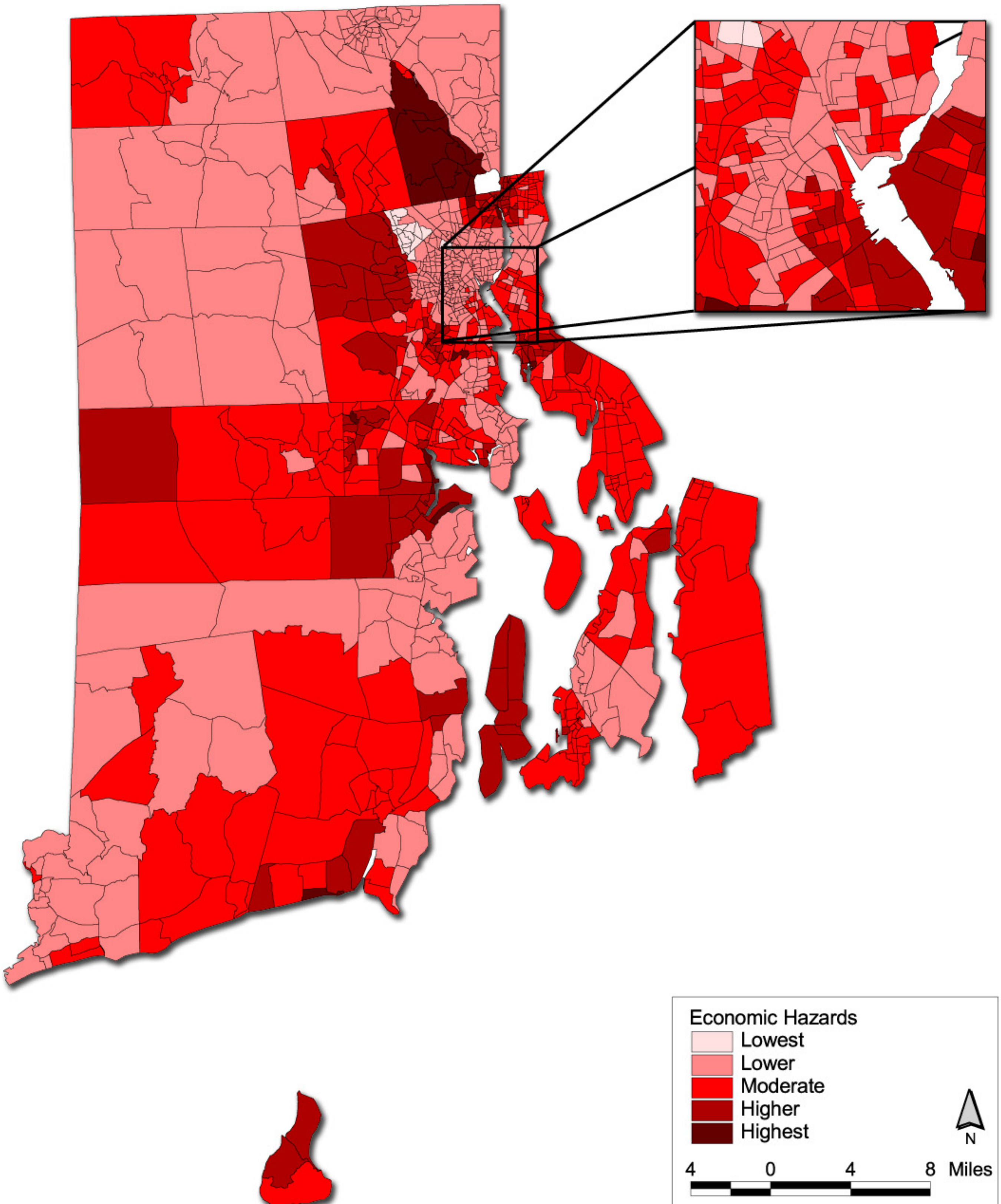


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Economic Hazard Map

Derived by multiplying economic exposure scores with combined hazard scores

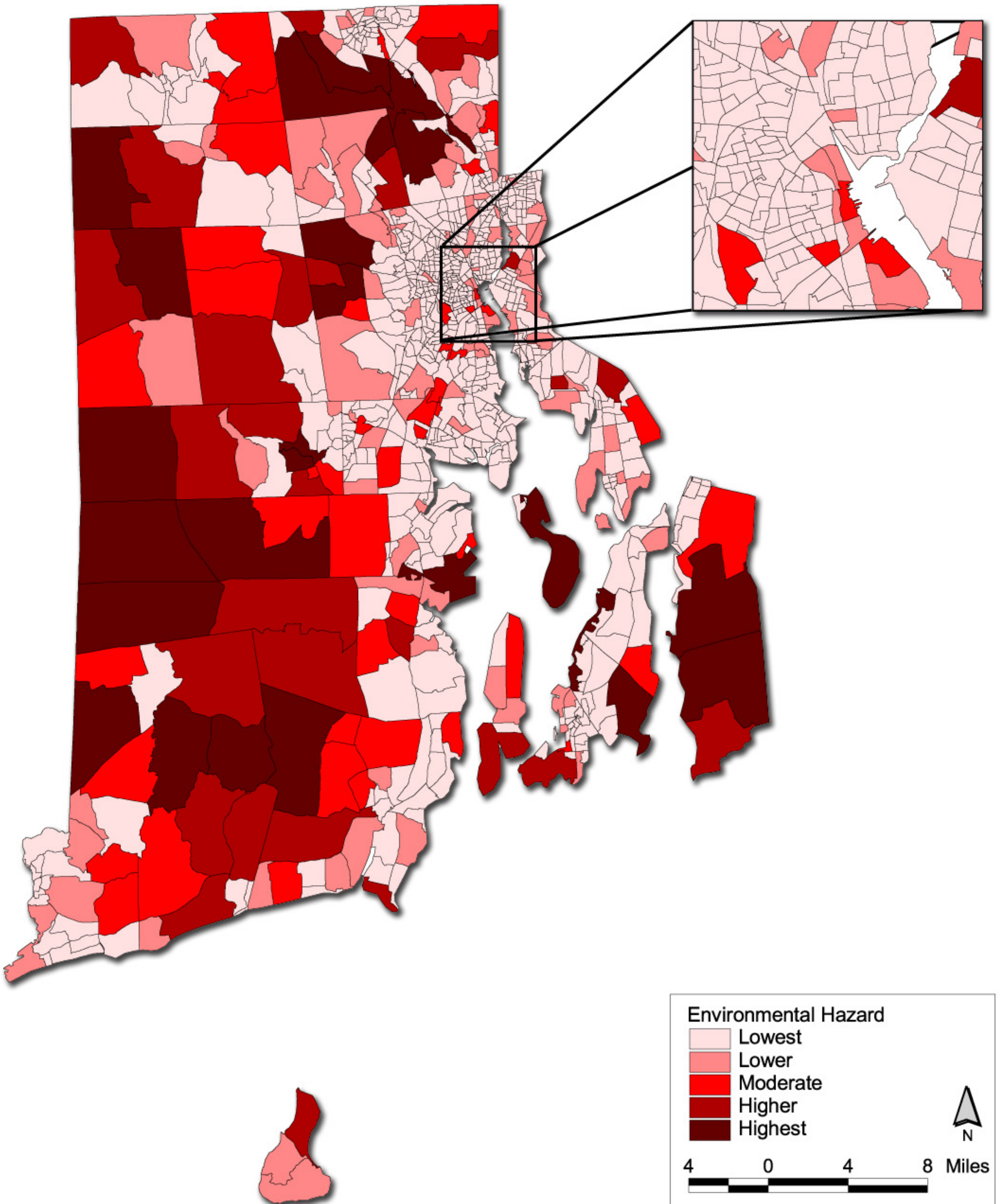


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Environmental Hazard Map

Derived by multiplying environmental exposure scores with combined hazard scores

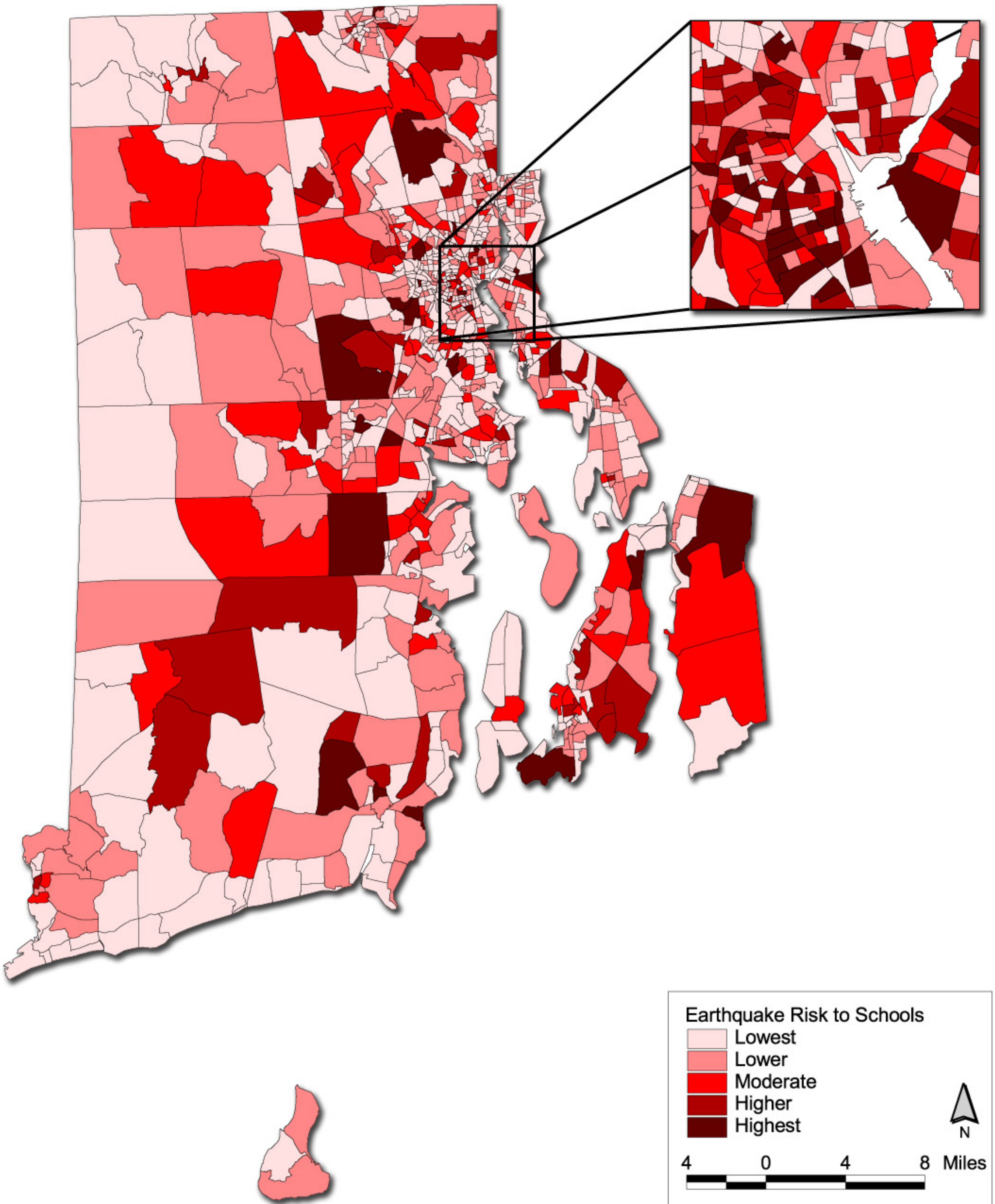


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Schools at Earthquake Risk

Derived by multiplying critical facilities school exposure scores by combined hazard scores

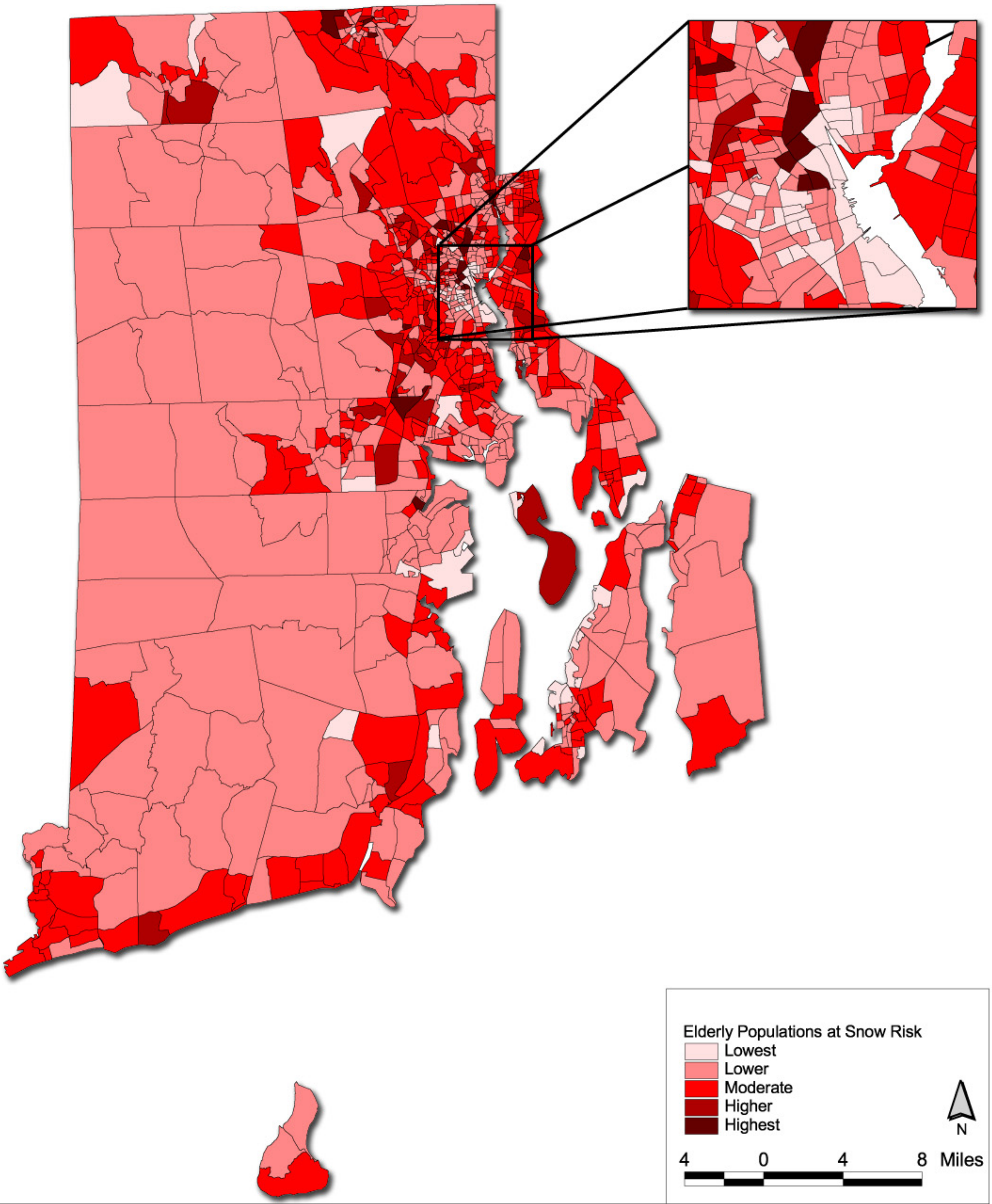


Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001

Elderly Populations at Snow Risk

Derived by multiplying elderly population exposure scores with snow hazard scores



Source: Rhode Island Natural Hazard & Exposure Database

Odeh Engineers, 2001