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RISK ANALYSIS OF CENTRAL MASSACHUSETTS

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Jamie Lee Mohr

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Professor Jeanine D. Plummer, Advisor

1. Vulnerability
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Abstract

This case study was prepared for the Human-Environmental Regional Observatory (HERO) with the objectives of 1) executing the existing protocol for assessing the vulnerability of central Massachusetts and its people to socio-economic, technological, and natural hazards for the following analysis, 2) assessing the protocol prescribed by HERO, and 3) altering the existing standard to be reevaluated. The challenge of the last two goals was to create a plan of action to aid successfully HERO in its national cross-site vulnerability comparison.

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Introduction

HERO and Vulnerability

The Human-Environment Research Observatory (HERO) project is a multi-university research effort that seeks to understand the interactions between humans and their environment. There are four of these observatories across the United States: SRB-HERO, based at Pennsylvania State University and is studying the Susquehanna River Basin (SRB); HPO-HERO, based at Kansas State University and is studying the High Plains-Ogallala (HPO) region; SOMBRHERO, based at the University of Arizona and is studying the Southwest and Mexico Border Region (SOMBR); and finally HERO-CM, based at Clark University of Worcester, Massachusetts and is studying central Massachusetts (CM).

This year, the four HERO sites are each compiling a vulnerability assessment using a specially designed HERO Vulnerability Protocol. From the HERO perspective, vulnerability is defined as "the potential (susceptibility) for loss or the capacity to suffer harm from a hazardous event" (Wu, 2002). The vulnerability assessments specifically evaluate the risk posed by natural and technological hazards and the ability of the population to cope with those hazards.

Central Massachusetts

The Central Massachusetts study area of the HERO project (HERO-CM) is comprised of ten towns: Auburn, Boylston, Grafton, Holden, Leicester, Millbury, Paxton, Shrewsbury, West Boylston, and Worcester (Figure 1 and 2). Worcester is a large city; with a population of over 170,000, it just recently dropped from the second to the third largest city in New England. It is also highly developed, but economically depressed. Currently, the city suffers from crime, poverty, and pollution. More importantly, Worcester suffers economically because of the minimal amounts of new development that can take place. In 2000 and 2001 the Commonwealth of Massachusetts made a large investment in compiling a series of Build Out Projects. The Build Outs take all land that is developable within a town (developable being defined as not currently developed and not under some form of permanent protection), and develops it based upon zoning and conservation restrictions, so that there will be a picture of what the landscape will look like when all land is developed. According to these Build Outs, Worcester is already completely developed, meaning that there is no land available for new development. The large numbers of urban vacancy and abandonment, combined with the prevalence of brownfields (meaning "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant" (EPA, 2002)) makes redevelopment extremely difficult.

The nine towns surrounding Worcester are in a much different situation both economically and developmentally. Suburbanization has led to increased development over recent years, however each of these towns has a considerable amount of land remaining for development. On top of this, from an economics perspective, many of the surrounding towns have a substantially higher median income and median house value than that of Worcester, indicating an overall better economic situation for those towns.

Existing HERO Protocol: The Objectives

The HERO Vulnerability Protocol provides the framework for completing the analysis necessary to perform a vulnerability assessment of Central Massachusetts. Similar vulnerability assessments have been completed for coastal regions and this protocol has been adapted to work for inland regions. The Protocol is comprised of four steps. The first step is to "identify and map the natural hazards of a place." The Protocol provides for a minimum list of hazards to be studied as well as a mathematical means of evaluating them. The second step is to "identify and map the technological hazards of a place." The Protocol lays out a series of potential pollution sources and describes a method of buffering and weighting them. The third step is to "evaluate and map coping ability of the population." The protocol provides a minimum list of United States Census variables to be collected and analyzed, as well as a mathematical means of evaluating them. The final step is to "synthesize natural and technological hazards with social coping abilities." This final step results in a single map that displays the total vulnerability of the region (Wu, 2002).

Additional technological hazards were added to enhance the value of the hazards analysis more locally applicable. Brownfields and transportation facilities were of key importance in this. For the socio-economic vulnerability and coping ability assessment, a new Vulnerability Index was devised to further assess the vulnerabilities of the people within the study area. The results of the assessment revealed that Worcester is overall the most vulnerable area—especially due to the high prevalence of technological hazards—when compared to HERO's other three study sites, including Pennsylvania, Kansas, and Arizona. All locations shared a similar vulnerability to natural hazards. In addition to completing the vulnerability assessment, this case study also served as a means of evaluating the HERO Vulnerability Protocol. The conclusion reached is that the Protocol is greatly in need of refinement, although it does provide an adequate framework for completing a vulnerability assessment. The biggest concerns are with how well thought out some of the Protocol's steps are how repeatable the entire process truly is.

The Protocol

The following is a breakdown of the protocol into its component parts (Natural Hazards, Technological Hazards, and Socioeconomic Vulnerability and Coping Ability) and an analysis of the results of each section.

Natural Hazards

The National Climatic Data Center (NCDC) has records for ten types of natural hazards since January 1, 1950 that have affected the HERO-CM study area. This list includes cold (record cold temperatures), floods, hail, heat (record heat temperatures), lightning, rain, snow, thunderstorms, tornadoes, and wind. The four HERO sites collaborated to create a list of hazards that can be used across sites (this list includes all of the above-mentioned hazards with the exception of lightning). In another list, all of Massachusetts' natural hazards are evaluated. This directory includes the events that HERO as a whole considers ("HERO Events") and includes lightning, making up the "MA Events." The objective of this section is to assess the vulnerability of people to natural hazards in the Central Massachusetts' region.

Methods

To fulfill the requirements of the existing protocol, it is necessary to list the hazards that have occurred in a given study site per the National Climatic Data Center (NCDC) and compile data on the frequency, the magnitude, and the area affected with spatial references. The next step is to complete the National Oceanic and Atmospheric Administration's (NOAA) relative priority matrix, and finally, to map the areas affected for each of the hazards. Detailed information on the ten naturally occurring hazards have been collected through the NCDC's online storm query and formatted into a fifteen-page dataset for Worcester County, Massachusetts (Table 1). The four HERO sites agreed to create a list of hazards that occur at all sites to prevent any of the states from becoming considered more or less vulnerable because of an index that inaccurately reads zero-value instead of "not applicable." In another list, all of Massachusetts' natural hazards are evaluated.

The members investigating the patterns of natural hazards found that in the best interest of quality research, it would be wisest to disregard the relative priority matrix for ranking the effects of natural hazards as suggested by NOAA for individual sites. To complete the matrix, frequency and area of impact would have to be determined to properly calculate the total impact of each storm. This process was not deemed possible, though, because of the lack of complete information for all four sites. The existing protocol also calls for HERO to examine magnitude of damage, but Massachusetts has not experienced any crop damage in the past 50 years that has totaled the thousand dollars necessary to even be considered by the NCDC. Similar problems exist at other sites as well. Thus, changes have been made to the existing protocol, and the relative priority matrix was discarded.

The next step in the existing protocol is to map the areas affected by each of the natural hazards discussed. It was again determined that the objective of carrying out the given protocol is not to report storm events of the past as long as they can still strike at most any time in the future and at any location. Any maps that could be produced from the dataset would be biased based on the tallied results of the storms under their respective cities they occurred in (and multiple cities where applicable, Table 2) It was then concluded it would only be reliable and of value if those events that are dependent on land cover were mapped. After reviewing the events, a floodplains map (Figure 3) for evaluating floods was generated.

Results

Derived from a complete version of Table 1, Table 3 displays the tallied totals of natural storm events under the "HERO Events" and "MA Events" lists. The third and fourth columns calculate the percentage in which each individual hazard happens compared to the others as a whole. This information was compiled from the NCDC database of hazards that occurred since 1950 in the HERO-CM study area, and it is what will be used to compare the four study sites to one another (Table 5 and 6). Table 4 was used to compare to Table 7 in order to weigh against the frequency of intense storms of the United States to those of Massachusetts. This pie chart shows that a ratio of tornadoes described as Weak: Strong: Violent exists of 61: 36: 3, whereas the national ratio of tornadoes is 74: 25: 1.

Discussion

Massachusetts claims to have periodic droughts, however none of them are recorded in the "MA Events" database. This is because the National Palmer Drought Index says Massachusetts has an average reading of -1.9 to 1.9 or 0 for dryness/wetness, which means that Central Massachusetts is not considered to be an area inundated with droughts. According to the NCDC, the source of the storm records, thunderstorms occur more frequently than rain and wind combined (Table 5 and 6). The data collected from the NCDC stresses the great need to understand the NCDC's practices, including the what, where, when, and why of their methods for recording the storms they do under their online Storm Query. According to the NCDC, who uses FEMA's storm event records, there have been 61 hailstorms since 1950, averaging one to two storms a year. Figure 4 was created from the same database NCDC is greatly founded on, but this map has only two records of hailstorms before 1970, neglecting the 59 other hailstorms in the database. Table 6 illustrates that there are almost three times as many thunderstorms (41%) as there are rain and wind (16%) combined. It is also of interest to note that in Massachusetts, a land described at moderately hilly in a temperature climate in the path of the major wind stream from northern Canada, has twice as many tornados (10%) than snow storms (5%).

Technological Hazards

The central portion of Massachusetts has been subjected to nearly every land cover change possible. It began as a rural, agricultural based society, but with the Industrial Revolution, it blossomed into a hub of technology and heavy industry concentrated in Worcester. In recent times, many of the industries have failed or moved on to more promising markets, while residential expansion continues to occur. This makes for interesting research, especially with respect to technological hazards. One of HERO's goals is to map the technological hazards and assess the population's vulnerability to them in Central Massachusetts. Due to the boom of industry at one point in the history of the study area, technological hazards are abundant. Assessing these hazards is imperative to the future growth and land cover change of the Worcester area. Determining vulnerability to these areas will help serve as a land-use planning tool for development.

Methods

In order to assess the impact of technological hazards, they first had to be mapped. Most of the data the HERO Vulnerability Protocol required was easily obtained through different EPA databases. The main technological hazards the protocol stated were Superfund (CERCLA) sites, both active and archived, Resource Conservation and Recovery Act (RCRA) sites, Toxic Release Inventory (TRI) sites, Permit Compliance System (PCS) sites, National Emission Trends (NET) sites, and National Toxic Inventory (NTI) sites. All of these databases were searched using the

Envirofacts database, which houses all of the above-stated databases (http://www.epa.gov/enviro). Using this database, the most current, 1999 EPA reports, and accurate results were obtained.

In order to understand the vulnerability of an area to technological hazards, it is necessary to know exactly how potentially dangerous each site is. Superfund sites are higher prioritized listings of toxic chemical sites in an area. They receive either federal or state monies to clean a spill, leak, or some other chemical emergency that has taken place. A high-risk superfund site is put on the National Priority List (NPL) as a priority for clean-up. Although there were 15 active superfund sites listed for our study area, none of them were on the NPL. Most of the clean-up that was occurring at these sites was state-led clean-up.

The Resource Conservation and Recovery Act (RCRA), an amended version of the Solid Waste Disposal Act passed by Congress in 1976, establishes a framework for national programs to achieve environmentally sound management of both hazardous and non-hazardous wastes. This act grants authority to the EPA for regulation of certain sites. In the city of Worcester, there are about 500 RCRA facilities, and a total of about 800 exist in the entire study area. They include heavy industry, disposal plants, recycling centers, gas stations, supermarkets, and car dealerships. Due to the variety of the sites and the varying levels of toxicity, these are not as dangerous as Superfund sites. However, in the future, if these businesses cease to operate and the property is abandoned, it could cause more problems, such as seepage from an underground storage tank at a gas station, than when it was in full use.

Information on the monitoring of the chemical releases of certain industries and facilities is compiled in the Toxic Release Inventory (TRI). This database catalogs toxic chemical releases, how much of a certain chemical is released, and if it is transferred to another site. With this information, it is possible to consider the potential threat due to the types of chemicals in question and how much of them exist.

The Permit Compliance System (PCS) provides information on companies that have been issued permits to discharge wastewater into rivers. This database allows the user to see which companies are in compliance and which ones are not. It also provides which chemicals have been found after testing the water as well as the sources of those chemicals.

Estimates of annual emissions of criteria air pollutants from point, area, and mobile sources are found in the National Emission Trends (NET) and National Toxics Inventory (NTI) databases. When these databases were searched, they were limited to Particulate<10um (PM10) and Volatile Organic Compounds (VOC), which are the most hazardous emissions.

Other interesting EPA databases are the National Drinking Water Contaminant Occurrence Database (NCOD) which provides a list of safe drinking water and water systems, the Sites Awaiting National Priority List Decision by State (SAND) which lists ongoing NPL decisions, and the Short Term/Removal (SHORT) which lists short term clean-up endeavors. The SAND and SHORT sites may be something to look into for future projects as they may be as hazardous as other listed sites and thus, affect vulnerability.

Once all of these sites were identified and their information obtained from the appropriate EPA databases, they were mapped using a combination of geocoding (which is using addresses to map a location) and coordinate mapping, depending on whether the site had an address or coordinates.

Besides mapping toxic chemical sites, other technological hazards were considered as well. A map of state highways was obtained from the Massachusetts Office of Geographic and

Environmental Information (MassGIS - http://www.state.ma.us/mgis/). Included in this map of highways were interstate highways, US federal highways, state highways, and major road connectors. Airports, runways, Amtrak stations, and railroads were also considered technological hazards and were all mapped. These datalayers were found online at the Bureau of Transportation Statistics (http://www.bts.gov/gis/ntatlas/networks.html).

With the data fully collected and mapped, the next step was to buffer each of the layers. The original protocol suggested a half-mile buffer distance for all technological hazards. However, a half-mile buffer distance seemed too large for some of the features noted as technological hazards. For example, the major highways were to be buffered at a half-mile like all of the other hazards. For a roadway spill or accident, it does not seem plausible that an area a half-mile on either side of the road would regularly be affected. Thus, a new buffer distance of a quarter-mile was decided on for the roads. Superfund (CERCLA), RCRA, TRI, NET, NTI, and PCS sites were all buffered at a half-mile, however archived superfund sites were buffered at a quarter-mile. This is due to the fact that these sites have been determined by the EPA to be clean, thus there would be a smaller area of hazardousness compared to the active sites. After they were in place, each buffer was assigned a value of one.

The next step was to overlay all of the maps to obtain a total technological hazards map. When all the maps are overlaid, the buffer weights are added for overlapping areas to get a total hazard score (a site where three buffers overlap will have a total hazard score of three).

Results

The final maps of the total technological hazards are the main results of this portion of the protocol. Figure 5 represents the end result of implementing the technological hazard section of the protocol. As mentioned in the previous section, each of the hazards were buffered and overlaid, so that the buffer scores were added together to get the total hazard map. The features that were utilized to create this map were as follows: superfund (CERCLA) sites, archived superfund sites, RCRA sites, TRI sites, NET sites, NTI sites, PCS sites, and main highways. As can be seen from the figure, the darker the color, the more technologically hazardous the area. These dark colors result from the overlapping of multiple hazard sites. The hazard scores range from 1-9 on this map. It can be readily seen that the darker colors are concentrated in the middle of the map, which is where Worcester is located. Thus, the map is a logical representation of the known landscape, with the most industrial areas being the darkest.

Figure 6 is another version of the total technological hazards, however some other factors are taken into consideration besides those listed in the protocol. Due to the heavy industrialization of the HERO-CM study area, there are other sites that should be considered as technological hazards that may not affect more rural areas. The first thing that was added to the map was brownfields. As defined by the EPA, a brownfield is an abandoned site with actual or perceived contamination. This can be industrial factories, abandoned office buildings, or service stations. EPA region 1, the New England area, has the highest number of brownfield sites, and within New England, Massachusetts has the highest number. In the HERO-CM small study area, there are approximately 350 brownfields, most of them being contained within Worcester's borders. Because they are so prominent in the area, brownfields need to be considered. On deciding what the appropriate buffer would be, the possible hazardousness of the sites was considered.

Looking at the definition, a site may be classified as a brownfield even if the contamination is only perceived, thus, a quarter-mile buffer was chosen instead of the half-mile buffer used for protocol sites.

The railroads and Amtrak stations were buffered at a quarter-mile due to the lower hazardousness. This is based primarily on the fact that the main highways were only buffered at a quarter-mile and thus, it seemed logical that railways and Amtrak stations would be as hazardous if there were an accident or spill. Airports were considered more hazardous and were buffered at a half-mile. Because our small study area has a history with runoff from the Worcester airport, it seemed that a bigger buffer would be more logical for this hazard. Reservoirs and ponds downstream of the airport have not frozen due to the runoff of de-icing fluid used on planes in the winter. Thus, it appears that airport runoff is a bigger hazard than possible accidents on major highways or railroads.

With the four features added, a new map was constructed with the total technological hazard scores (Figure 6). As before, technological hazards are more prevalent in the darker areas then in the lighter colored areas. Once again they are concentrated in the center of the map where the industrial heart of the study area is located. Instead of having a range of 1-9 as Figure 5 had, it has a range of 1-11, meaning that some areas are exposed to up to 11 different technological hazards.

Discussion

As was explained in the previous section, the protocol was modified to better suit the study area. These changes are probably not applicable to all HERO sites, but for a postindustrial area, it is logical, for example, to map brownfields. Also, with these particular changes, the protocol standards were adapted, especially when buffering the new technological hazards. The buffers chosen seemed logical, however they could also be refuted and changed. It is important to note that the protocol should be rigid enough such that it can allow comparison between sites, while at the same time providing enough flexibility to allow for some adaptations with respect to a specific study area.

One important barrier to assessing technological hazards is the way in which a buffer is placed and how it is determined. The classification of the site does not appear to be a good representation of the potential danger of the site. Thus, a new way of classifying the sites other than the EPA distinctions should be pursued.

Socio-economic Vulnerability and Coping Ability

Methods

The HERO Vulnerability Protocol calls for ten variables to be analyzed in order to assess the social vulnerability and coping ability. These ten variables are all a part of the decennial United States Census. They are:

- Total Population
- Total Housing Units
- Number of Females
- Number of Minorities
- Number of People under 18
- Number of People over 65
- Number of Single Mother Households
- Number of Renter-Occupied Housing Units
- Median House Value
- Median Household Income

These variables can be broken down into two groups: demographic variables and economic variables (where demographic variables are defined as the eight social variables, or everything but the two economic variables). All of the demographic variables are collected as part of the Census Short Form (100% data), which is available for download from the Census website (www.census.gov) in Summary File 1. The economic variables are collected as sample data in the Census Long Form, which is in Summary File 3. All data is currently available for 1990, however only Summary File 1 is available for 2000. For these reasons, the vulnerability assessment was put together using the complete data set for 1990. The determination was made at the HERO-CM site that trying to combine data from two different time periods (such as using demographic data from 2000 and economic data from 1990) would paint an extremely inaccurate and misleading picture of the CM region, as well as provide many logistical problems. The data is collected at the block group level for the ten towns in the study area. For 1990, there are 314 block groups, while for 2000 there are less than 280. Given the initial misgivings about combining data sets in addition to the difficulties that doing so would create, the decision was made that the most intact assessment could be compiled using a complete and accurate data set, namely that of 1990.

The block group map for 1990 was compiled by downloading the block group boundaries from the Geography Network for the entirety of Worcester County, and then clipping that map so that it only included the 10 towns within the HERO-CM study area. The ten variables prescribed in the HERO Vulnerability Protocol were then collected from the 1990 census data and attached to the map of block groups. Vulnerability was then calculated using the HERO vulnerability index. "The vulnerability index for each social [demographic] variable *i* is defined as the ratio of that variable in each census block group (V_i) to the maximum value (V_{max}) for variable in the [study area]." (Wu, 2002) Represented mathematically:

$$I_i = V_i / V_{max}$$

The economic variables are calculated by subtracting the ratio of the block group value to the maximum value for the study area from 1 so as to inverse the calculated value. Represented mathematically:

$$I_i = 1 - V_i / V_{max}$$

The composite "vulnerability index for each census block group is defined as the arithmetic mean of the vulnerability indices of all variables." (Wu, 2002)

The individual vulnerability indices as well as the composite vulnerability index were also appended to the map of block groups. This map of block groups could then be used to display not only the spatial distribution of the block groups across the landscape, but also to display the raw census data, individual vulnerability indices for each variable, and the composite vulnerability index.

To compensate for problems with the vulnerability index provided in the HERO Vulnerability Protocol (see Discussion), a new vulnerability index was devised. This new index uses densities to assess vulnerability rather than raw numbers. For example, if a town was comprised of two block groups, one that had a total population of 1000 people with 500 minorities, and one that had a total population of 400 people but all 400 of them were minorities, which one would be more vulnerable? The block group with population 1000 would have 50% used in the vulnerability index calculation rather than 500, and the population 400 block group would have

100% used. Using percentages enables much better comparative analysis by building in a certain level of understanding about the relative nature of each block group. The new index also solves the problem that the original index had in terms of sensitivity to population fluctuations. If the variation in block group size was an outgrowth of design rather than chance, then it would be necessary to account for size differentials, but since the size of the block group and/or the total population of that block group has no significance other than distinguishing groups by population size, then it is acceptable to minimize the impact that this has.

The other significant aspect of the new index is the fact that it normalizes all vulnerability calculations such that they are truly scaled from 0 to 1. The new vulnerability calculations are as follows (for demographic variables):

$$I_i = (V_i - V_{min}) / (V_{max} - V_{min})$$

For economic variables:

$$I_i = 1 - (V_i - V_{min}) / (V_{max} - V_{min})$$

V_{max} continues to represent the largest value for any block group, but it is now the largest percentage rather than the largest raw number. V_{min} is the smallest value for any block group. What this effectively does is cause the block group with the smallest vulnerability to have an index of 0, the largest block group to have an index of 1, and all other block groups to be scaled in between based upon the distribution of the percentages (meaning that regardless of whether or not there is a close or wide distribution, the indices will still be scaled). The great benefit of this is that it means that a vulnerability index of 0.75 will mean the same thing for all block groups and for all variables. This index also allows for a weighting scheme to be applied to the dataset. If the determination was made that the economic variables should be give an increased weight over the demographic variables, then that weight could be added and the impacts would be clear and understandable. This new index sheds much more light on the highly relative vulnerability of the people in the Central Massachusetts' study area.

Results

The socioeconomic data for central Massachusetts tells a very interesting story about the region – it is one of stark contrasts. Worcester is a highly vulnerable city compared to the relatively small towns surrounding it (Table 8). When the vulnerability index was calculated based on town-level data (this town-level data being the same census data for the block groups, just aggregated into towns), Worcester had an index of 0.88 (where 1.00 represents the highest possible vulnerability and 0.00 represents the lowest), while the next highest towns (Auburn and Shrewsbury) had vulnerability indices of 0.11. One main reason for the extreme dichotomy in vulnerability at the town wide scale is the fact that Worcester's population in 1990 was 169,738, while the next largest town, Shrewsbury, only had a population of 24,167. When analysis is performed at the block group level, though, a completely different picture is painted of the study area (Table 9). Worcester's vulnerability index drops from 0.88 to 0.24. Worcester also goes from being the most vulnerable town to being the second most vulnerable, with Grafton becoming the most vulnerable with an index of 0.26 (it is important to note that a town-wide index of 0.26 simply means that the average of all vulnerability indices for that town is equal to 0.26). One significant reason that Worcester's vulnerability index drops so significantly from the town index to the block group index is the fact that Worcester is comprised of over a 160 block groups, while every other town only has somewhere between 4 and 30. Many of Worcester's block groups have total populations of less than 1000 people, many of them being less than 500 people. The way the vulnerability index is calculated, using raw values for comparison and normalization, all of these relatively small block groups have a relatively low vulnerability index, thus when they are averaged together, the result is a very low index.

Figure 7 represents this phenomenon quite well. Block groups of varying vulnerability are randomly strewn about the landscape and there is no real rhyme or reason to the distribution of vulnerability throughout the study area. When local knowledge of the region is brought to bear on this map, one even finds that the original index predicts that many of the most affluent locations are the most vulnerable, which is not a logical conclusion to reach.

When the new index is used to calculate the vulnerability of the central Massachusetts region, a different but more consistent picture is painted. At the town-wide level of analysis, Worcester continues to have the greatest vulnerability with an index of 0.85, however all other towns have indices ranging from 0.18 to 0.49 (Table 10). At the block group level, Worcester's average vulnerability drops to 0.46 while the other towns range from 0.32 to 0.40 (Table 11). Worcester's index still suffers from the impacts of averaging a great number of block groups together, however because of the way that the new index is calculated, Worcester remains as the most vulnerable location in the study area.

Figure 8 shows a much more uniform vulnerability across the study area, signifying a relatively homogeneous population across the region. In Worcester, the vulnerability increases sharply in some areas, but local knowledge suggests that these areas are the most logical places for vulnerability to be at its highest.

Discussion

The original HERO vulnerability index does not incorporate any sense of comparative understanding into its calculations. The idea of comparative understanding is that there is more to learn about a block group than just the raw numbers. Using the example given in the Methods section, according to the current index, the block group with 500 minorities would be more vulnerable from the minority perspective then the block group with total population of 400, simply because it has more minorities. The converse to this would be that while it has 500 minorities, it also has 500 people who do not fall into a vulnerability category, and thus would be much better suited to coping with any environmental hazards that may strike. The block group with 400 minorities comprising the entire population, while having fewer minorities, also has 0 people who do not fall into a vulnerability category. When assessing the vulnerability of a region, understanding the ability of the total population to cope is vital, thus understanding that the smaller block group would have a much more difficult time coping (based upon the criteria outlined by the HERO Vulnerability Protocol) is a key piece of understanding.

Another problem of great significance with the vulnerability index provided for in the HERO Vulnerability Protocol deals with the method of calculation. The method of calculating the index for each variable results in a different type of result and thus an inadvertent weighting scheme on the total index. The best example of this is the manner in which the economic variables are calculated. The demographic variables are all calculated in the same manner. Using the number of females as an example, the block group with the largest number of females is used to normalize the index for all other block groups, but when the female vulnerability is calculated for that specific block group, the result is an index of 1.00. The block group with the smallest number of females will then have an index somewhere between 0 and 1, however the only way a value of 0 would ever be achieved is if there were 0 females within a block group. Since this is not likely to ever happen, the result is that the indices are skewed upwards based on the size of the population in question. Homogeneous populations then tend to have a greater vulnerability because the distribution of values is so small (so when the index is calculated they all have values approaching 1.00). When calculating the index for the economic variables, the maximum is still used, but the maximum is actually the least vulnerable, hence the fact that the result is subtracted from 1. The impact that this has though is that rather than the most vulnerable being assigned a value of 1.00, the least vulnerable block group is assigned a value of 0.00, with all other values range from 0 to 1. The only way a value of 1 would ever be assigned is if a median house value or a median income was ever equal to $0.00. The effect of this is that while a maximum vulnerability for demographic variables is always 1.00, the maximum value of economic variables almost never actually reaches 1 and is usually less than 0.7. By the very nature of the composite vulnerability index, this means that the economic variables have been given a reduced weight when compared to the demographic variables. This is clearly demonstrated in Table 8, where Worcester has the highest vulnerability in all ten Census categories, yet the total index only adds up to 0.88 because of the method of calculation of the economic variables.

Results: The Data Merge

An overlay of the natural hazards and technological hazards was done to depict a total hazard score for the Central Massachusetts study area (Figure 9). This total hazard map was then overlaid with the map of vulnerability indices. One of the most striking features of this map is that the city of Worcester, in the center of the map, is nearly completely covered in at least one technological hazard.

When the technological hazards are looked at in light of the 100-year floodplains, it is questionable whether or not the floodplains contribute to more risk. Most floodplains are made up of wetlands, which act as natural sponges, trapping and slowly releasing surface water, rain, snowmelt, groundwater, and flood waters. Wetlands within and downstream of urban areas are particularly valuable, counteracting the greatly increased volume of surface water runoff from pavement and buildings. This system naturally dilutes the wastes produced from the examined technological hazards, but more concern is raised because of the urbanization that surrounds the polluted waters, including the groundwater.

Whereas a majority of Worcester's floodplains are built up, meaning that there are fewer natural buffers and filters, there is more concern regarding whether the pollutants are being broken up before entering the aquifers in amounts of higher concentration. The two-fold effect of this is that while the chemicals being introduced into the environment will not poison wetland areas, more of the toxins will make their way directly into the groundwater.

It is not possible to present a single story of both the natural and technological hazards when combined with the socioeconomic vulnerability and coping ability. The only natural hazard that can be logically mapped are the floodplains, but these have a varying risk associated with them, and only mapping this one hazard ignore 8 other hazards that have an even distribution of risk across the study area. Humans are roughly equally at risk to other storm events throughout the area, so the future risk of any individual human in the region is roughly equal, although humans on floodplains to face a somewhat higher risk. This fact is mitigated by the minimal amount of residential development that will take place in a floodplain though.

Rather than predicting future risk for technological hazards, this protocol can only assess the current vulnerability that any given person may have to existing hazards. Knowing where they currently exist provides a basis for understanding where the most dangerous areas currently are and what the worst areas to have new hazards strike would be. Because of the sheer mass of technological hazards, though, just about all of Worcester faces at least some risk of exposure. While risk in other towns is diminished, it is definitely still present.

Figure 12 represents the final step in the protocol. The natural hazards and technological hazards maps were overlaid with the map of the coping score (which is derived from the vulnerability index – Figure 11). Areas of white are areas that have a total vulnerability score of 0. The higher up on the color scale that any particular location goes, the greater the vulnerability is to environmental hazards. The problem with this map is that there should realistically be no area that has a total vulnerability of 0. Every location on the map is evenly at risk for non-spatially explicit storm events (such as snow storms or temperature extremes). Rather than having values of 0, these areas should have a value of 8 (because there are 8 non-spatially explicit storm events in the HERO protocol; in addition, since the relative priority matrix was ultimately not used, and data obtained from the NCDC was so questionable, the only logical way to assess these events was to give them an equal value), and all other locations should be scaled upwards from there. A new natural hazards map was created that represents both the spatial (floodplains) and non-spatial natural hazards. This map was then overlaid with the technological hazards map to create a new map of total hazards (Figure 10), and this was then overlaid with the map of coping score to create the final map of true total vulnerability (Figure 13).

Analysis of the Existing HERO Protocol

To best evaluate the HERO Vulnerability Protocol, it makes sense to break the evaluation down in the same manner that the analysis was broken down. Each section of the Protocol had its own benefits and its own problems. Since a large part of the goal of this project was to evaluate the Protocol, it is important to touch upon all of the issues at hand.

Natural Hazards

The National Oceanic and Atmospheric Administration's (NOAA) relative priority matrix for ranking the effects of natural hazards focuses on frequencies, magnitudes of damages, and areas of impact within one study area. The HERO protocol and its inability to use NOAA's relative priority matrix limited the possibility and accuracy of cross-site comparison and so adjustments were made. It was proposed that the most valid and reliable information with the objective of eventual collaboration would be extracted by tallying the frequency (Table 3) of the "HERO Events" and then calculating the percentage in which each storm strikes (Table 5 and 6). This avoids the obstacle of the great difference in area that the individual sites have selected, as well as being obtainable for all sites.

The magnitude of the storm itself was not the best means for calculating the impact of the storms though because the Massachusetts dataset, for example, notes almost half of the thunderstorms to have whirled through the area at zero (0) knots if it was not recorded as having a magnitude that was "not applicable" for recording. The remaining thunderstorms produced winds of at least 50 knots. This approach of assessing the magnitude by the individual characteristics of the storm assumes that a strong tornado in Kansas' wastelands will result in more destruction than a smaller funnel cloud will through Phoenix, Arizona. Finally, there are not enough deaths or injuries caused by storms in Massachusetts to even be able to compare the intensity of the storms to one another.

Technological Hazards

Being able to determine the actual hazardousness of a site is a key step to making a good vulnerability map of technological hazards. Having every site with the same buffer and the same weight does not really reflect the different levels of toxicity of each specific chemical that is at each particular site. There are also problems in being so specific, especially when you have 800 RCRA sites, for example, which the Central Massachusetts study area does. However, a system that ranks the buffer and the weight of the buffer based on the chemicals present would be more representative of the actual threat a site poses to the population. This would require much research and expertise on the potency of all the chemicals and then much patience in mapping all the points with specific buffers and weights.

Socio-economic Vulnerability and Coping Ability

The HERO Vulnerability Protocol represents a decent starting point for the vulnerability assessments that were compiled, however, there is still a long way to go to improve it. Beyond the problems with the vulnerability index, there were also several points relating to the socioeconomic aspect of the protocol that are important to consider. Perhaps the most significant is how applicable this protocol is to international sites. Beyond the geographic and data availability issues that would be encountered (not every country is going to have a census or an equivalent to the block group), there is also an important question of which variables should be included. If this study was being done in Mexico, does the number of non-whites matter? Would not the white population be much more vulnerable? From this perspective, the other problem with the vulnerability index that is included within the protocol is that it is not comparable to other sites. The entire index is arbitrary and locally relevant. The new index would be able to solve some of these problems. A cross-site index would simply have maximum percentages be 100 and minimums be 0 such that all indices would then be scaled between 0 and 1, and would be easily compared and understood.

In addition to these features of the protocol, there is also an issue of methodology. The e-conferences, e-mails, and outside discussions that were had by the entire HERO REU team revealed that each HERO site went about collecting, compiling, and analyzing their data in different ways. The problem that this poses is that, while on the surface the data and results may be comparable, a true understanding of how each site did its work might reveal that the data is not actually consistent or comparable across sites. An example of this is one proposed way of collecting socioeconomic data for the year 2000. While Census data for demographic variables was easily compiled, economic data was not yet available. The suggestion that equivalent data be collected from available sources is well intentioned, but it could possibly lead to an inability to truly compare site economic data. Inconsistencies, data quality issues, or even data availability limit the value of such an effort. Much more specific direction in terms of methodology for carrying out the protocol would lead to a much more coherent product and a much better one as well.

Conclusions

Overall, the protocol was too unrefined to draw any conclusions for certain. From the technological hazards perspective, the crude way in which the buffering and overlaying system was defined made it difficult to assess the vulnerability to technological hazards as buffers may exist where there is no real threat, or no buffers exist where there is actual threat. Elevation maps and groundwater flow could possibly provide another avenue to the analysis of the buffering system, as it would appear that those variables would have great affect as to where the chemicals from the site could travel. From the Natural hazards perspective, the potential results from the existing protocol would be either unattainable or useless, providing their objective is to be compared against the other study sites' outcomes. From the socioeconomic perspective, questions about the validity of the vulnerability index spell great uncertainty about the legitimacy of the entire analysis. Even the final steps of the protocol where the maps of natural and technological hazards are combined is questionable because there is no comparison done to determine if weather events are more dangerous than any of the technological hazards; the weighting scheme for each hazard was seeming developed independently of each other, so again the project would suffer from a lack of comparative understanding.

Recommendations

Stemming from the problems that were found with the protocol, changes could be enacted to improve the overall quality of the final product. The new proposed protocol for natural hazards can determine which hazards are most likely to occur in a given year. This holds true as long as it can be determined that the existing data under the NCDC is reliable, considering the concerns that have been raised. Although comparing the frequency of storms by the percentage in which they occur as a whole is possible, this information cannot be used to determine what storms cost the most in property or crop damage or in injuries or lives. Future research may also be directed in different areas stemming from technological hazard analysis. For example, the governing bodies that take care of these technological hazards could be analyzed. If there are divided regions of jurisdiction, an analysis of the border regions might prove to be beneficial as those sites may not really be claimed by either party. Township lines may also have similar effects. Finally, closer examination of the vulnerability index will lead to a more coherent story across sites.

To complete accurately the project, research that is more specific is needed. Only once this is done will it be possible to create a true vulnerability assessment for Central Massachusetts.

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Table 2. Tally of weather events in the HERO-CM study area since 1950. This table shows how many storms have been totaled for each city and raises questions regarding the biases of the data collected for Worcester in comparison to the other cities. This information was compiled from the NCDC database of hazards.

City	Cold	Flood	Hail	Heat	Lightning	Rain	Snow	Tstorms	Tornado	Wind
Auburn	-	1	-	-	-	-	-	1	-	-
Boylston	-	-	-	-	-	-	-	-	-	-
Grafton	-	-	-	-	-	-	-	1	-	-
Holden	-	-	-	-	-	-	-	1	-	-
Leicester	-	-	1	-	-	-	-	-	-	-
Millbury	-	-	-	-	-	-	-	1	-	-
Paxton	-	-	-	-	-	-	-	-	-	-
Shrewsbury	-	1	-	-	1	-	-	2	-	-
W. Boylston	-	-	-	-	-	-	-	-	-	-
Worcester	1	4	2	2	-	8	-	7	-	-
All cities	2	8	58	-	16	8	19	132	36	41

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HAZARDS	FREQUENCY	% of HERO EVENTS	% of MA EVENTS
Cold	3	0.89%	0.85%
Flood	13	3.87%	3.68%
Hail	61	18.15%	17.28%
Heat	2	0.60%	0.57%
Lightning	17	N/A	4.82%
Rain	16	4.76%	4.53%
Snow	19	5.65%	5.38%
Thunderstorm	145	43.15%	41.08%
Tornado	36	10.71%	10.20%
Wind	41	12.20%	11.61%

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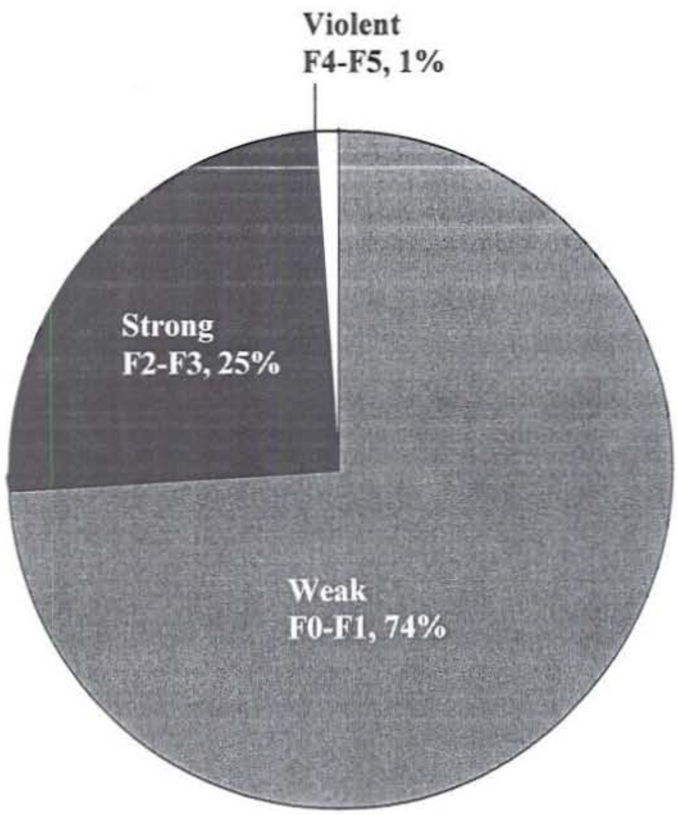

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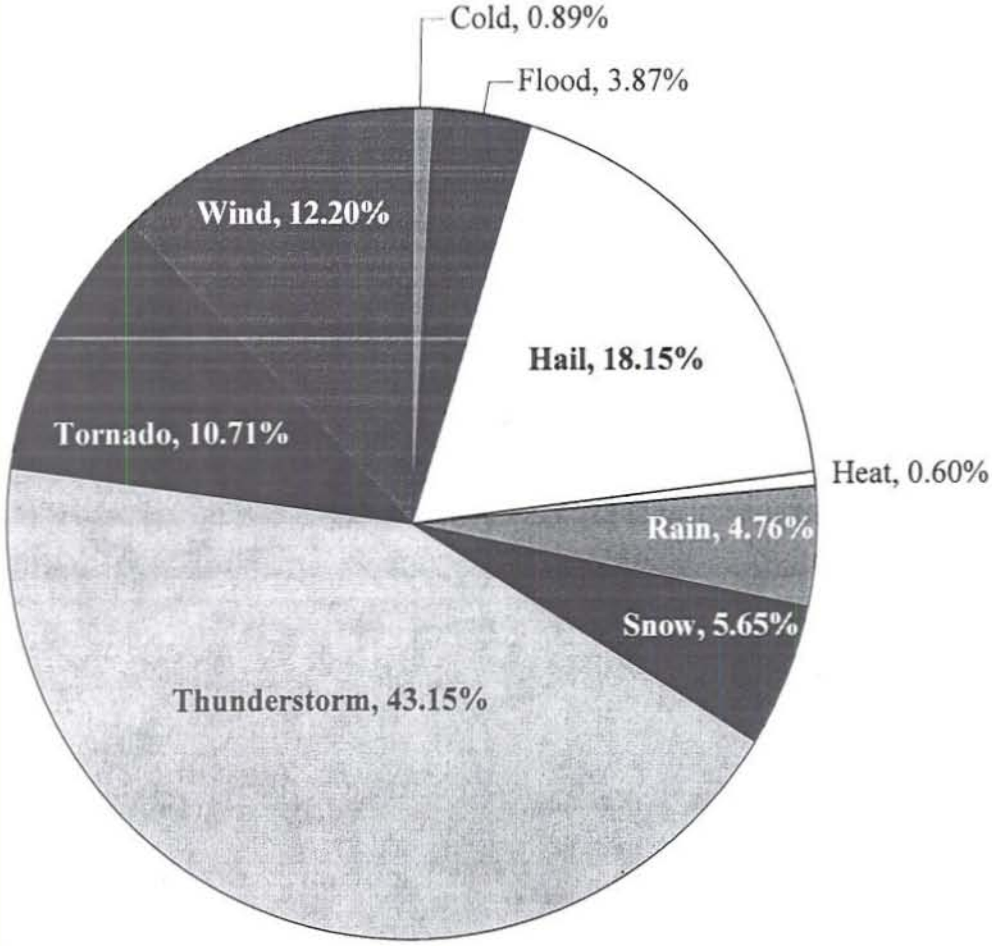

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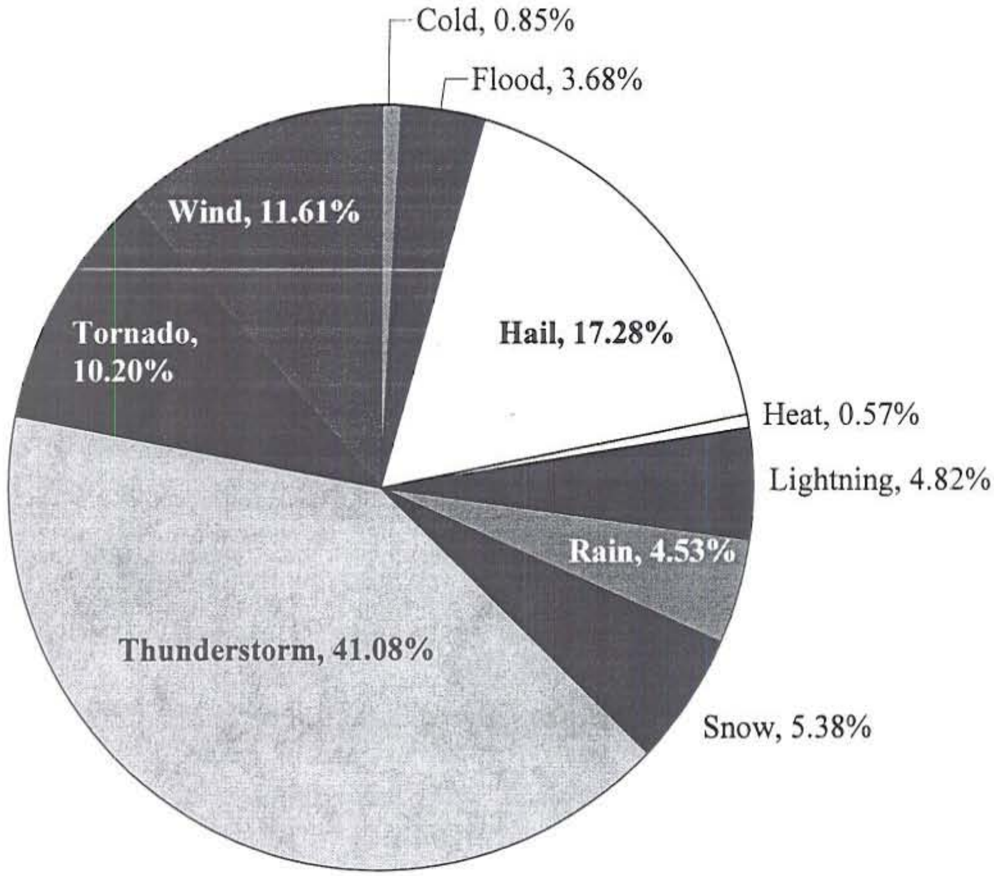

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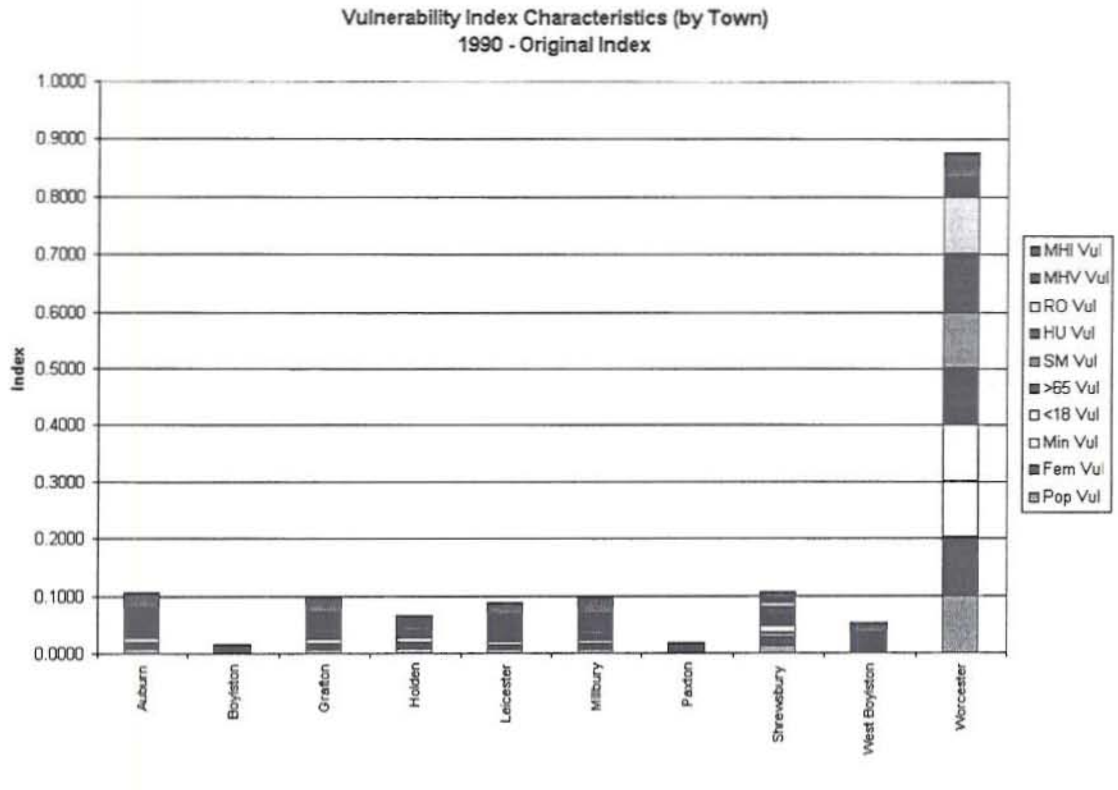

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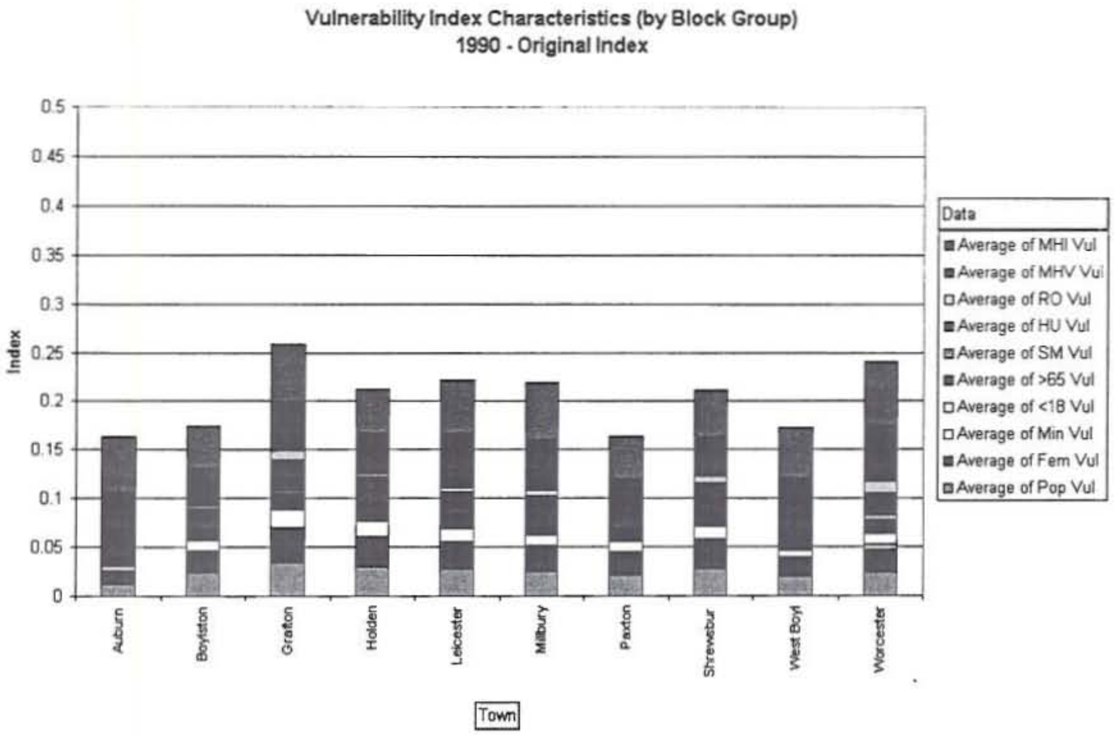

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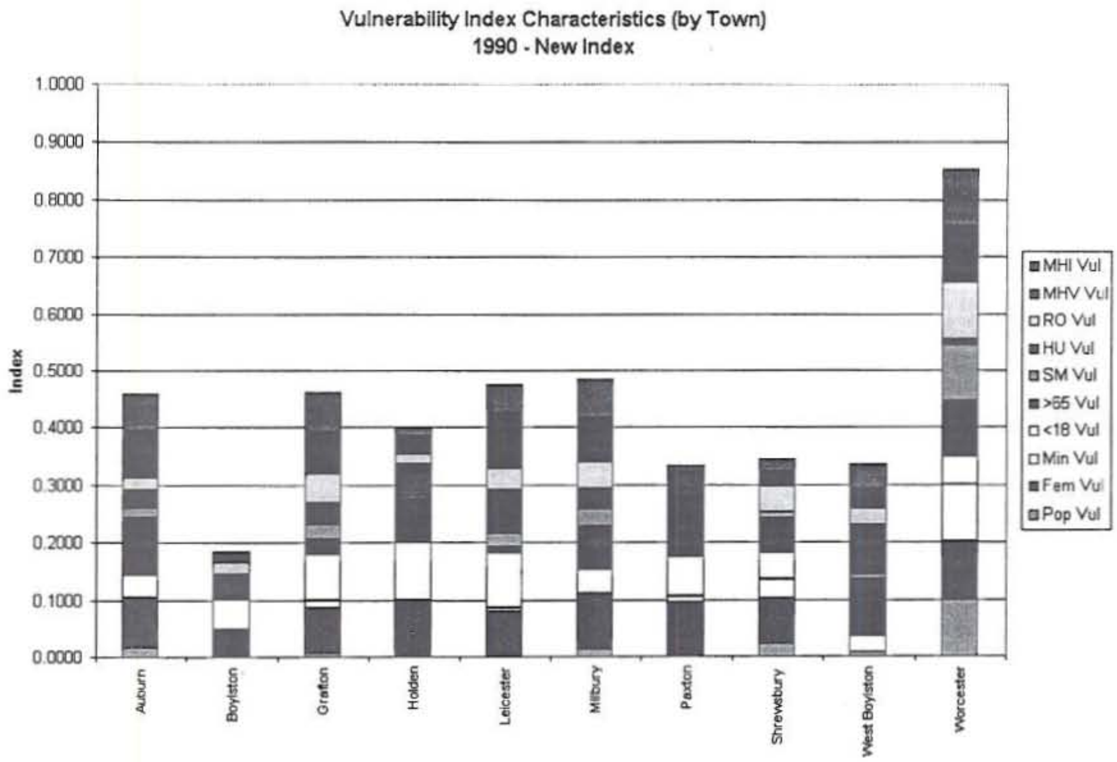

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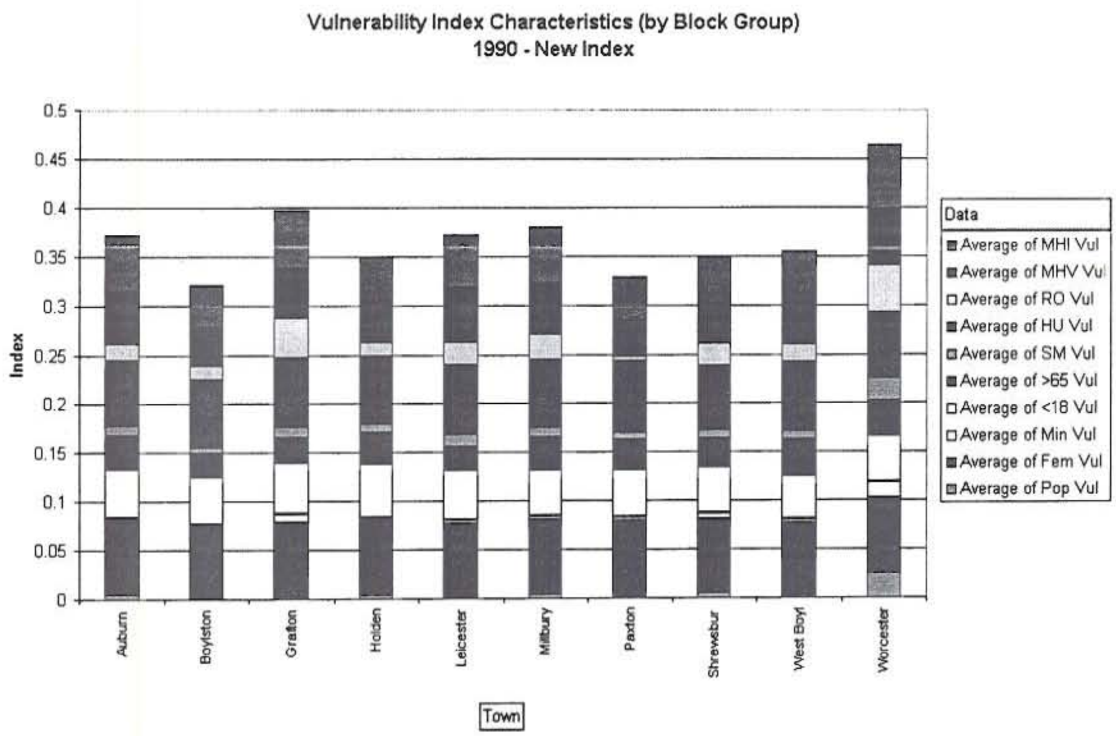

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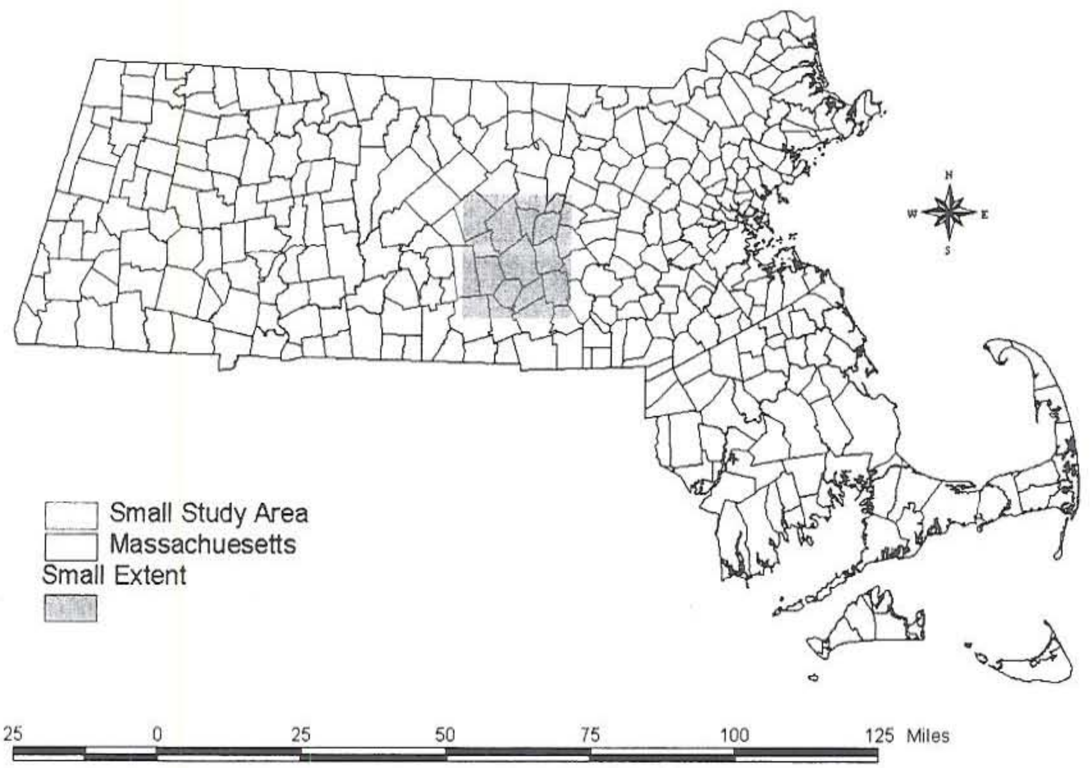

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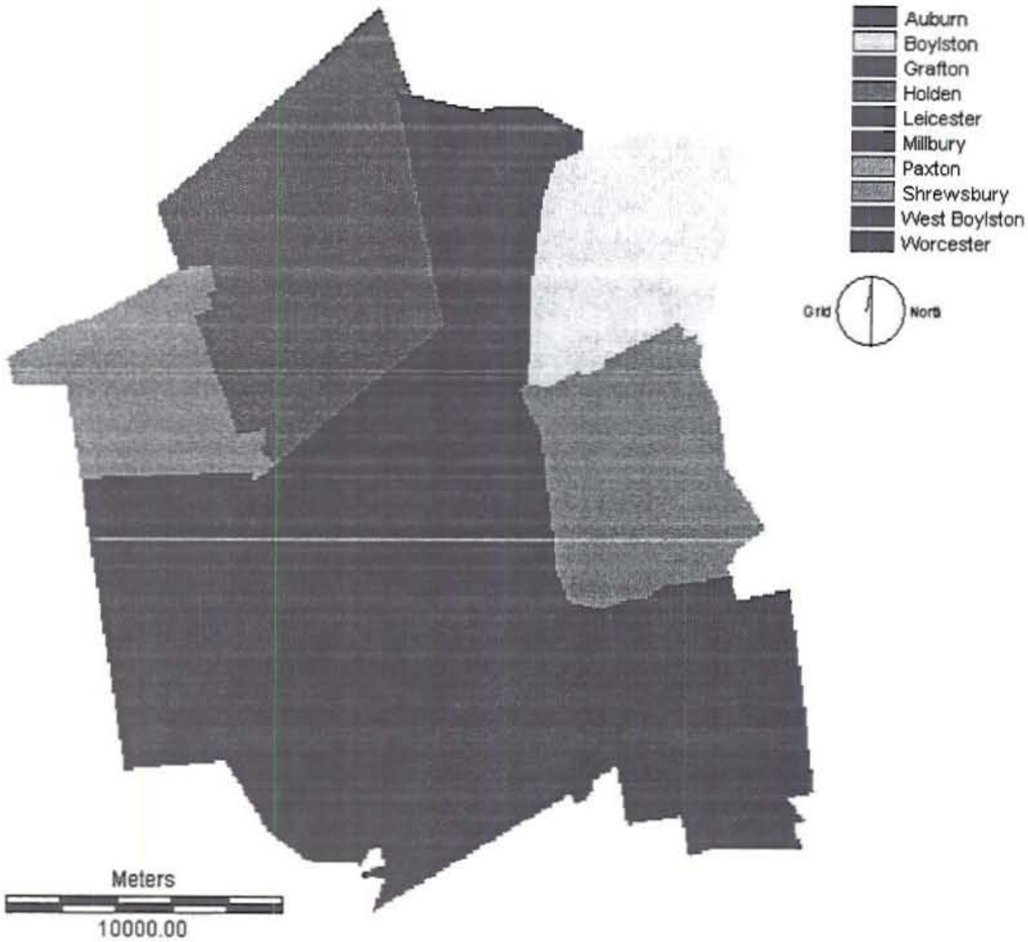

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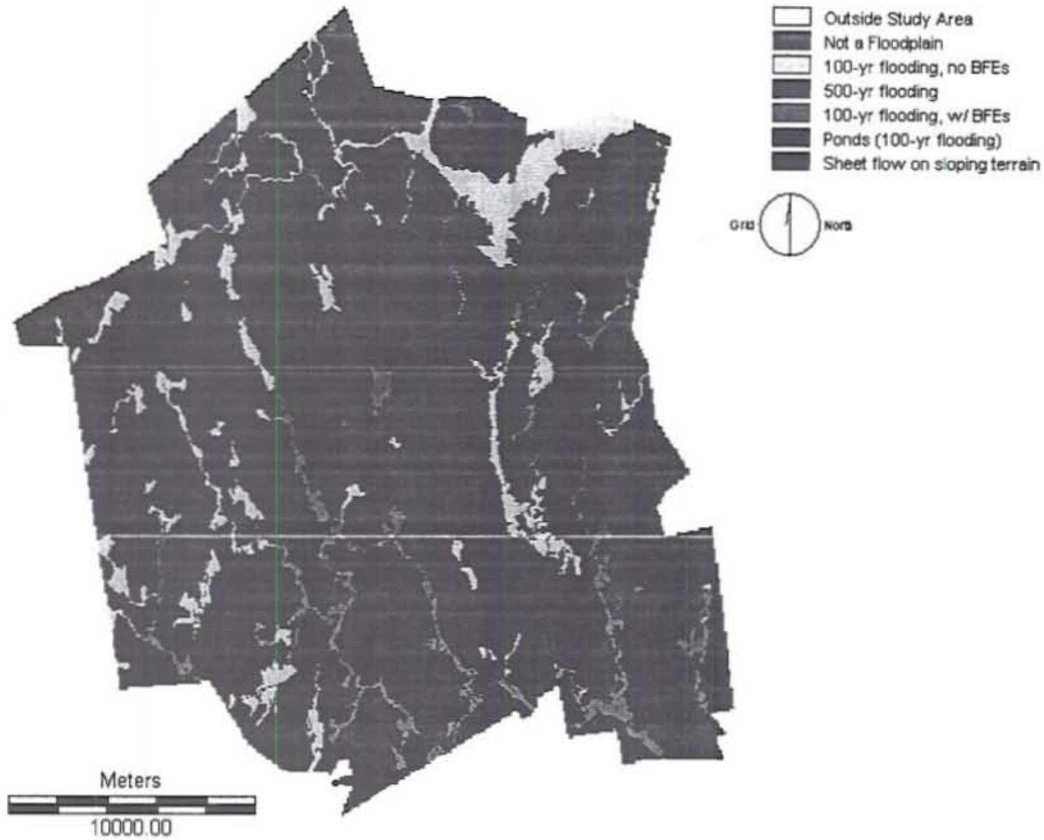

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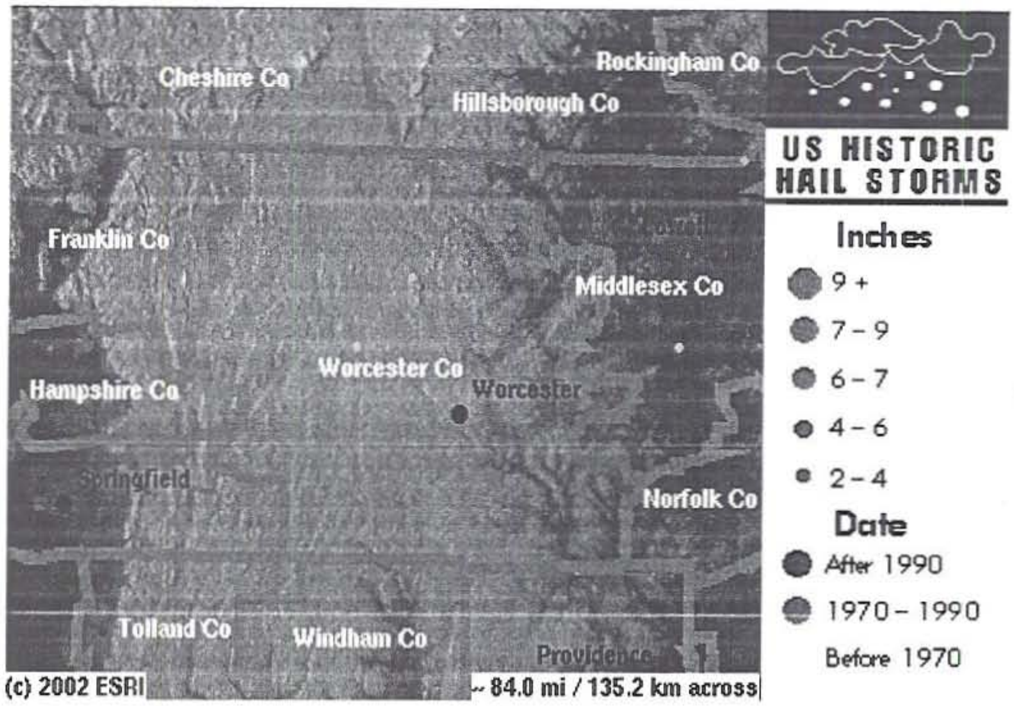

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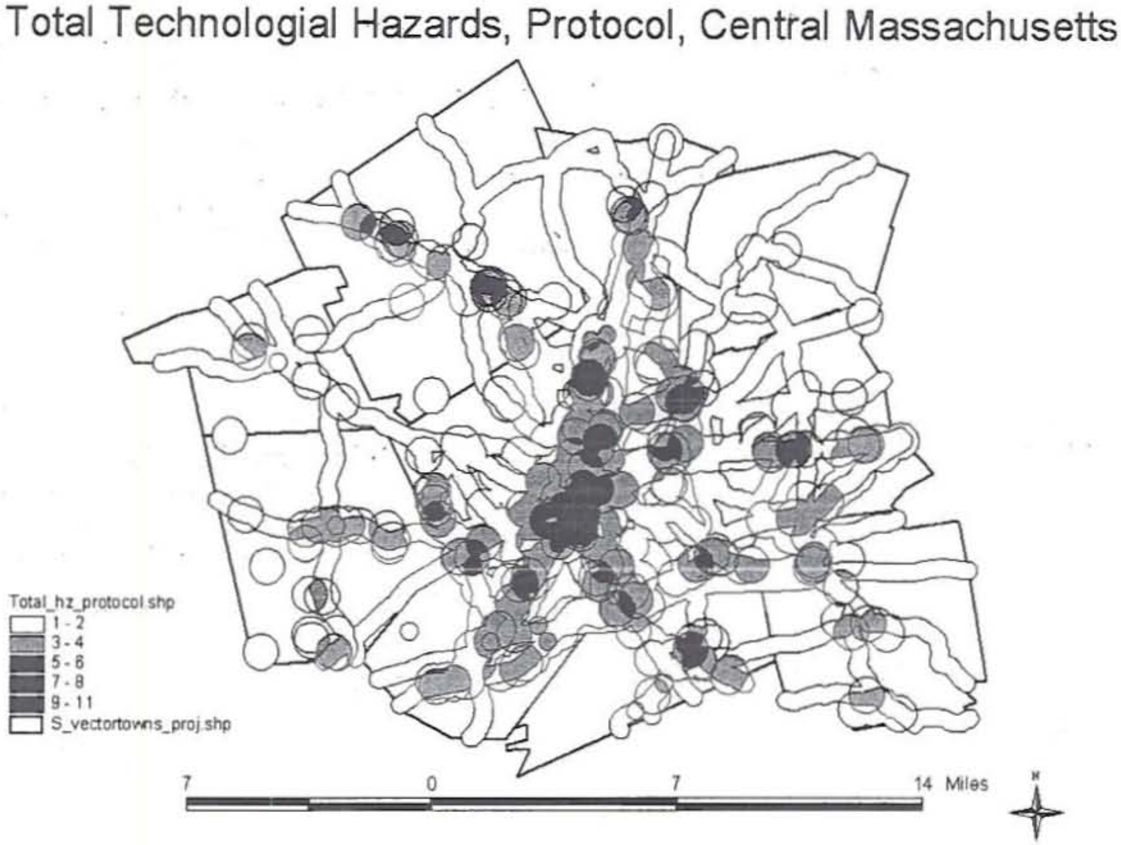

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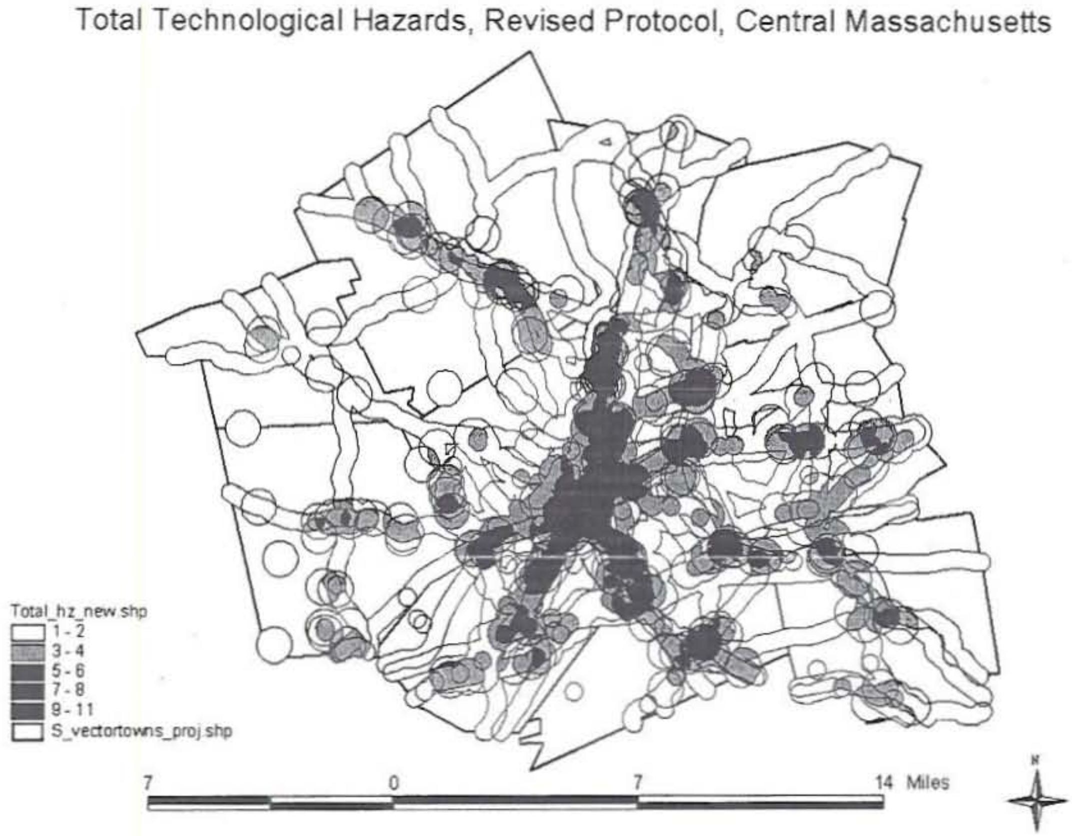

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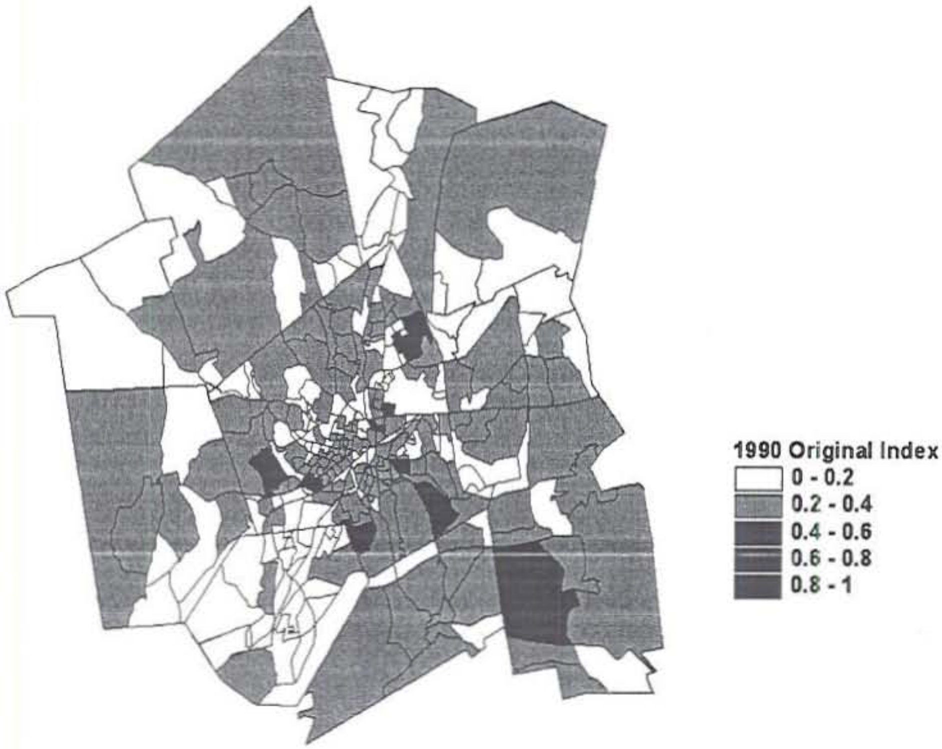

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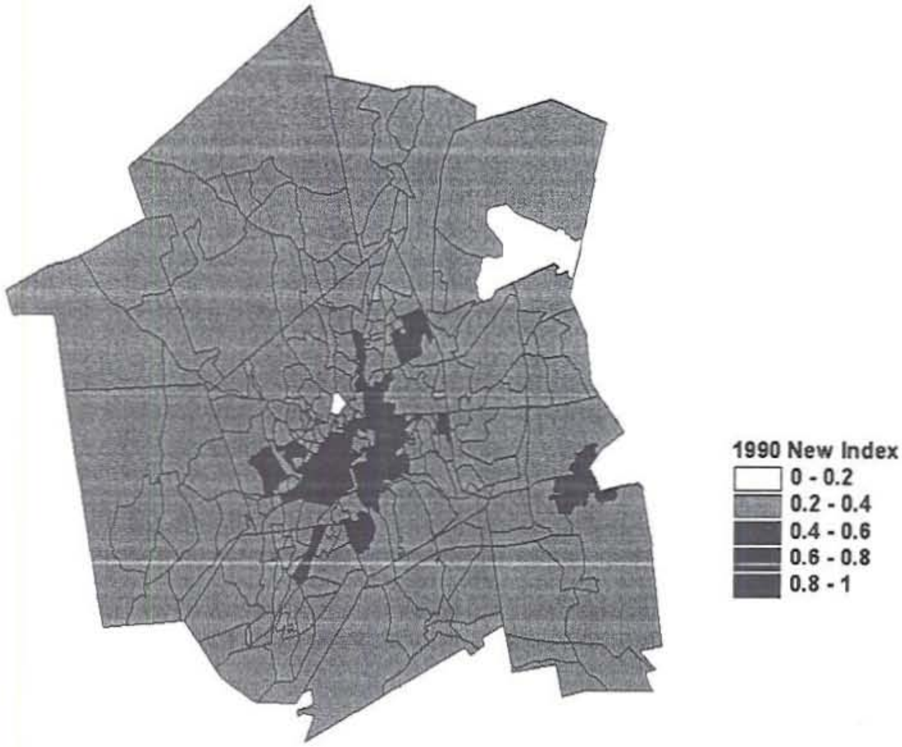

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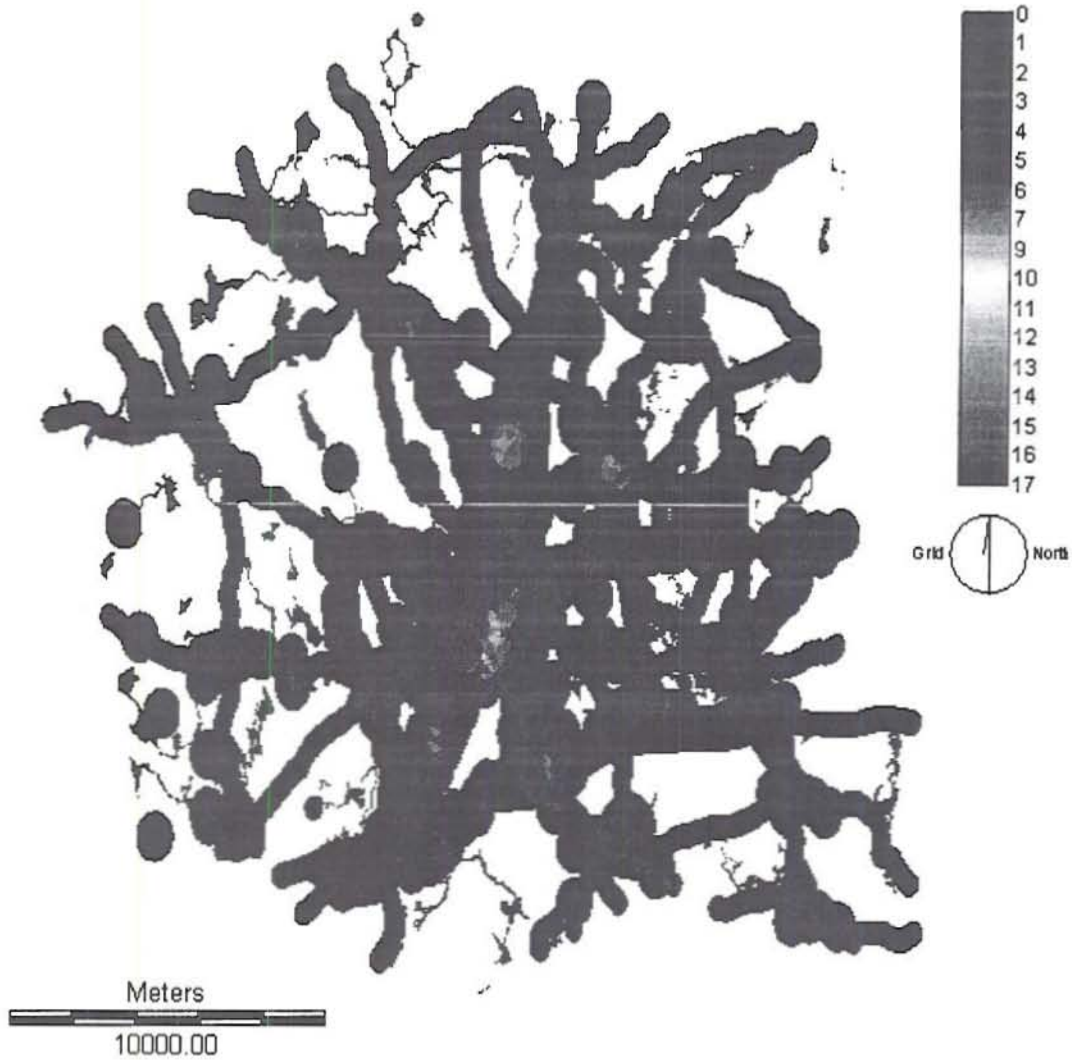

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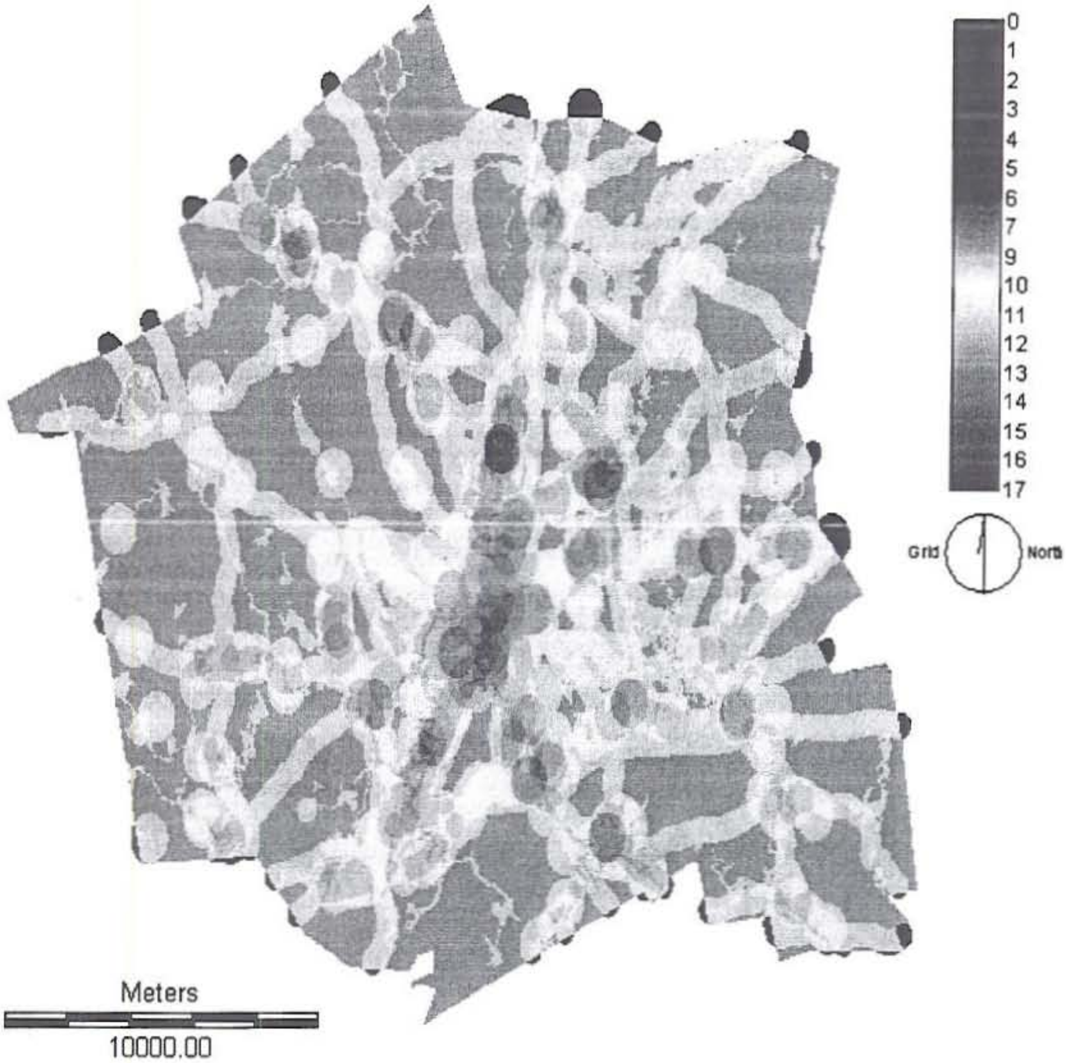

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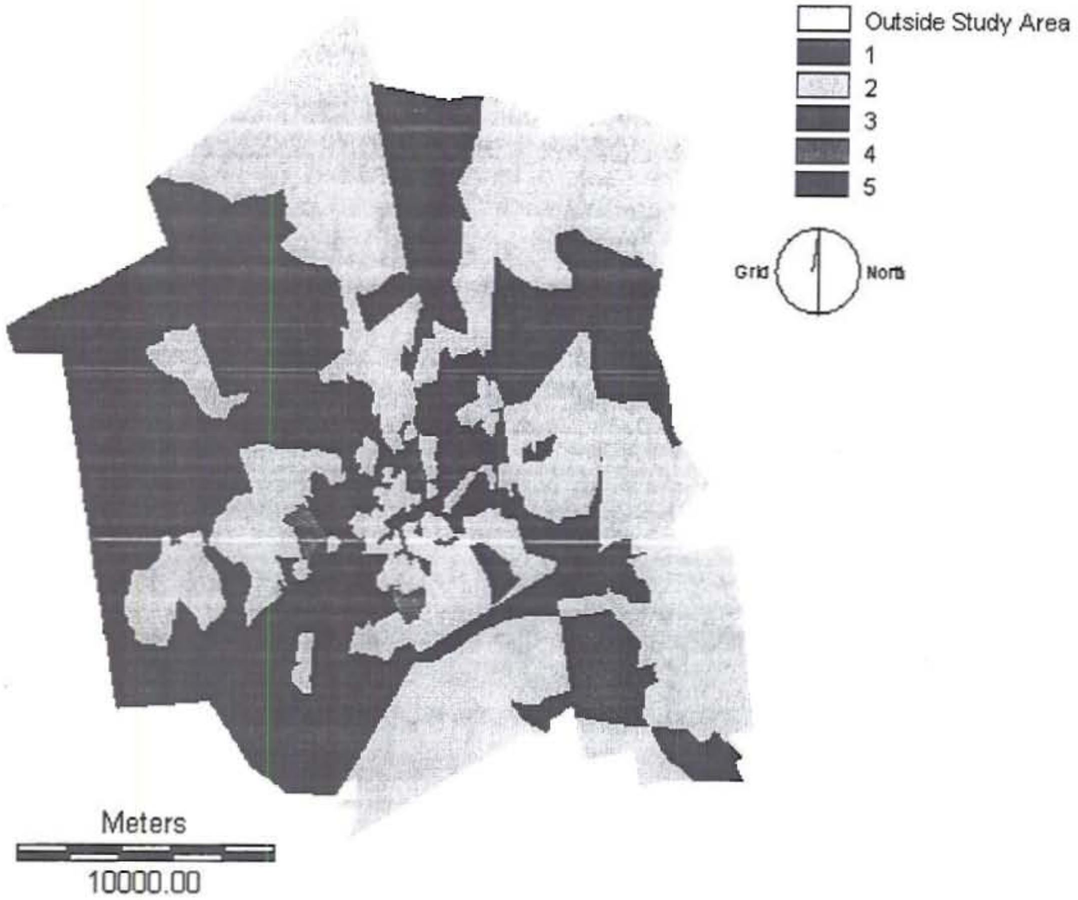

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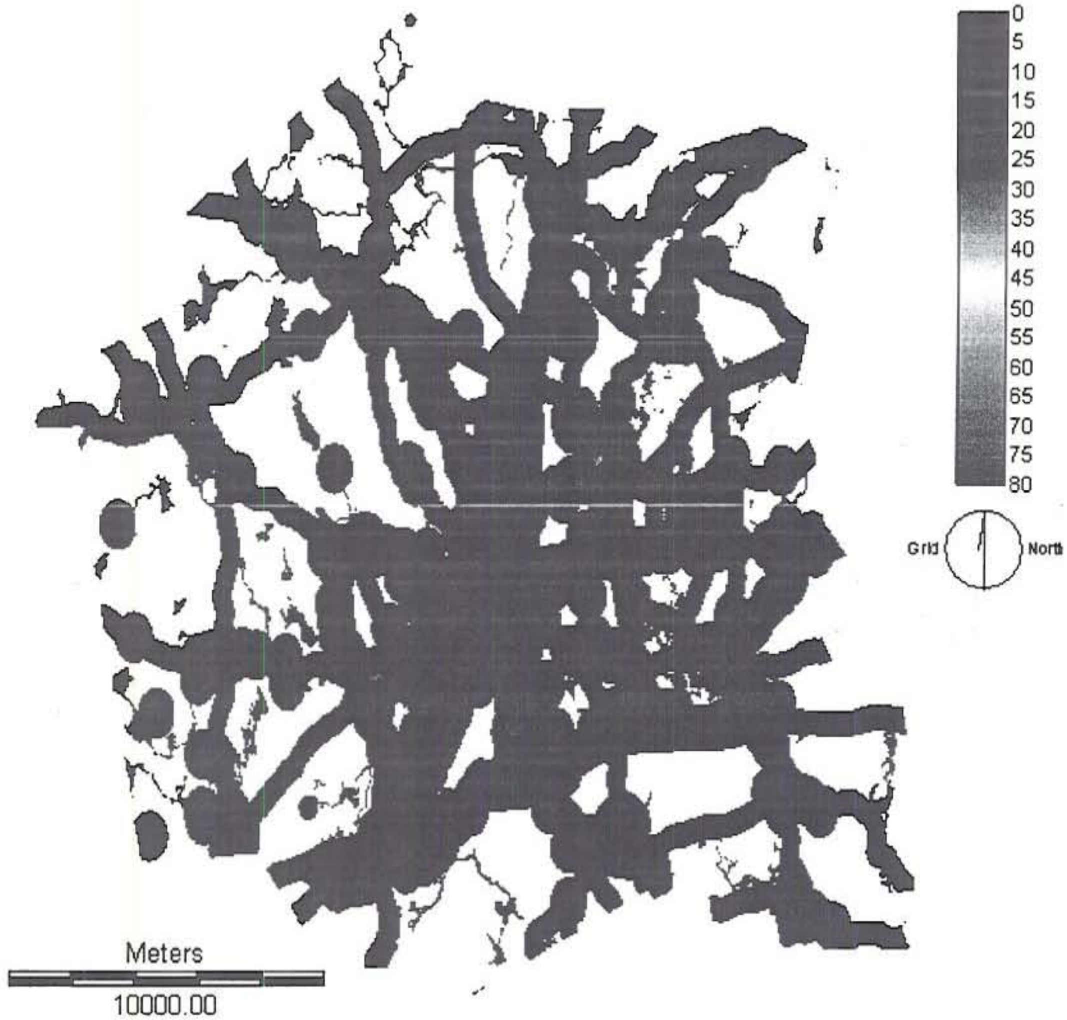

Figure 12. Map of total vulnerability for Central Massachusetts. White areas represent areas that have a total vulnerability score of 0. The higher up on the scale the color goes, the greater the vulnerability score. The center of the map (Worcester) generally has the highest vulnerability score.

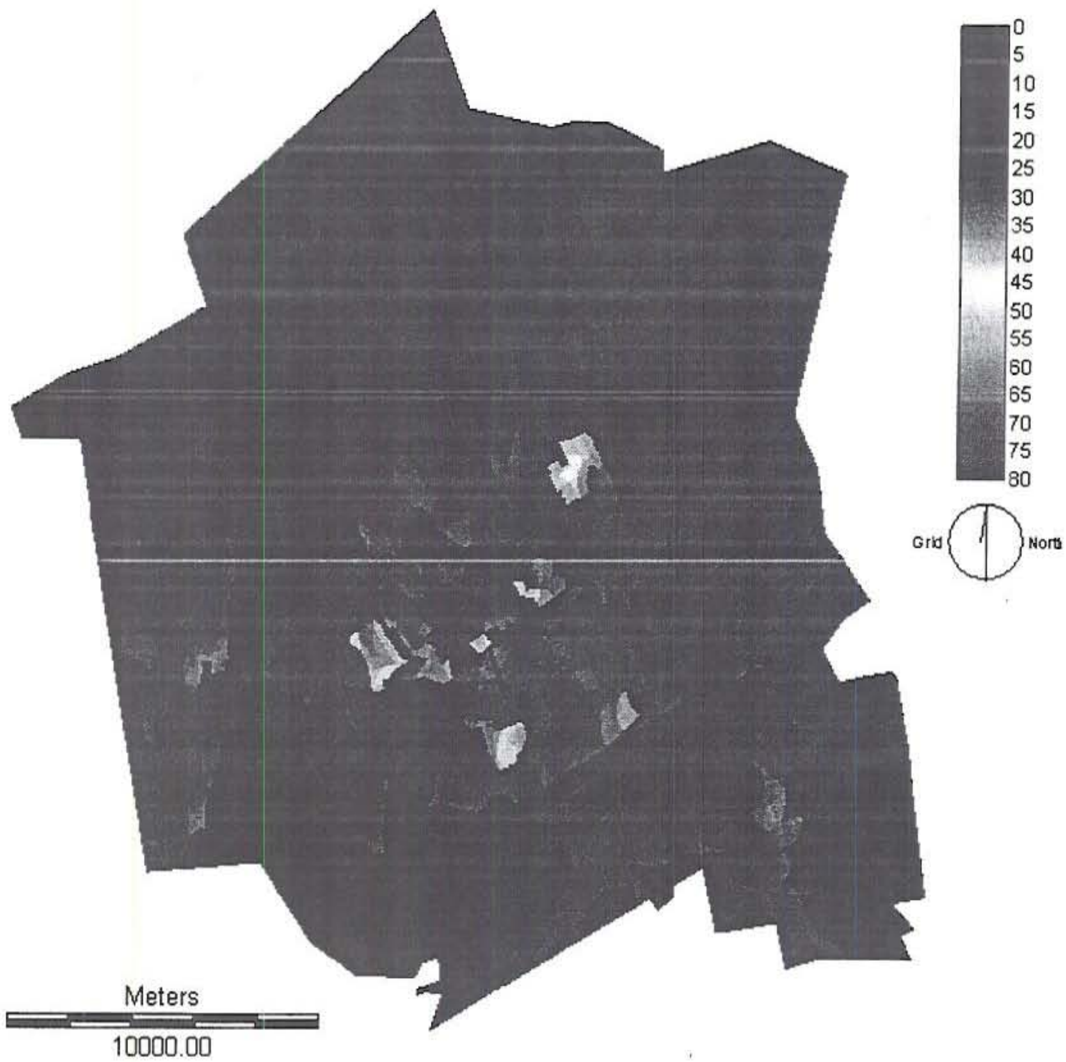

Figure 13. Map of true total vulnerability for Central Massachusetts. Every area has a minimal vulnerability score of 8 because every area is equally as likely to get hit by on of the non-spatially explicit HERO events. The higher up on the scale the color goes, the greater the vulnerability score. The legend on both Total Vulnerability maps has been set the same so that the maps can be easily compared to one another. The central region of the map (Worcester) generally has a greater vulnerability score.