Population Evacuation: Assessing Spatial Variability in Geophysical Risk and Social Vulnerability to Natural Hazards

Jayajit Chakraborty[1]; Graham A. Tobin[2]; and Burrell E. Montz[3]

Abstract: Developing an effective evacuation strategy for hurricane zones presents challenges to emergency planners because of spatial differences in geophysical risk and social vulnerability. This study examines spatial variability in evacuation assistance needs as related to the hurricane hazard. Two quantitative indicators are developed: a geophysical risk index, based on National Hurricane Center and National Flood Insurance Program data, and a social vulnerability index, based on census information. These indices are combined to determine spatial patterns of evacuation assistance needs in Hillsborough County, Florida. Four evacuation dimensions are analyzed: population traits and building structures, differential access to resources, special evacuation needs, and a combination of variables. Results indicate that geophysical risk and social vulnerability can produce different spatial patterns that complicate emergency management. Different measures of social vulnerability also confound evacuation strategies and can result in ineffective practices. It is argued that careful consideration be given to the characteristics of local populations.

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Introduction

Hazards researchers from a number of disciplines have turned their attention to issues associated with risk and vulnerability (Blaikie et al. 1994; Bernstein 1998; Kunreuther 1998; Mileti 1999; Cutter et al. 2000; Slovic 2000; Jaeger et al. 2001). Although the approaches differ and definitions vary, there has been increasing emphasis on the importance of the intersection of geophysical conditions and social systems (Liverman 1990; Dow 1992; Montz and Tobin 2003). Geophysical conditions are generally considered to define levels of risk, and the social systems are considered to define variations in vulnerability. Various definitions of such terms exist; but for these purposes, hazard is used to denote the overall problem; and a disaster (i.e., an event that has occurred) is defined as some function of geophysical risk and socioeconomic vulnerability (Tobin and Montz 1997). Research to date has focused on enhancing understanding of each separately and as they may work together to define varying degrees of hazardousness. Although the academic discussion surrounding geophysical risk, socioeconomic vulnerability, and overall hazardousness is important, so too is the application of this knowledge to particular hazard assessment and management problems. It makes a difference whether risk and vulnerability are being evaluated with respect to land use policies and practices, a medium- to long-term process, or to evacuation planning, usually a short-term need. This research is directed to evacuation planning.

The estimation of geophysical risk and vulnerability is problematic, due in part because of a lack of accurate data and because of the way in which available data are used (The Heinz Center 2000). This estimation is particularly challenging in coastal areas where rapid population growth and increasing development complicate evacuation planning by necessitating continued revisiting of factors that influence risk and vulnerability. The research presented here approaches these issues by evaluating spatial variations in both geophysical risk and social vulnerability at a specific coastal area and then combining them to assess the overall evacuation assistance needs of that location. In doing so, this project is aimed at answering three questions:

1. How does the spatial distribution of socially vulnerable people and structures compare with the spatial distribution of geophysical risk?
2. To what extent does changing the variables that are included alter the overall patterns of social vulnerability and thus of evacuation assistance need?
3. How might the responses to these questions affect emergency management and evacuation planning approaches?

The goal of this research, therefore, is to facilitate effective emergency planning for the evacuation of populations in urbanized coastal areas. Using a geographical information systems (GIS) framework, various geophysical patterns and social vulnerability indicators are combined to determine the spatial distribution of evacuation assistance needs and explore the answers to these questions, on the basis of a case study conducted in a coastal county: Hillsborough County, Florida.

[1]Assistant Professor, Dept. of Geography, Univ. of South Florida, 4202 E. Fowler Ave., SOC 107, Tampa, FL 33620.

[2]Professor, Dept. of Geography, Univ. of South Florida, 4202 E. Fowler Ave., SOC 107, Tampa, FL 33620.

[3]Professor, Dept. of Geography, P.O. Box 600, Binghamton Univ., Binghamton, NY 13902-6000.

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Vulnerability Analysis

Recent hazard research has focused on vulnerability and the role that it can play in exacerbating or ameliorating the effects of disasters. The combination of geophysical risk and vulnerability reflects the degree to which societies or individuals are threatened by, or alternatively, protected from, the effects, of natural hazards (UNISDR 2001). Vulnerability, therefore, is a human-induced situation that results from public policy and resource availability/distribution, and it is the root cause of many disaster impacts. Indeed, research demonstrates that marginalized groups invariably suffer most in disasters. Higher levels of vulnerability are correlated with higher levels of poverty, with the politically disenfranchised, and with those excluded from the mainstream of society.

The hazards literature has identified many of the components that comprise vulnerability (e.g., Susman et al. 1983; Blaikie et al. 1994; Monte 1994; Kasperson et al. 1995; Cutter 1996a; Hewitt 1997; Tobin and Montz 1997; Mustaafa 1998) but few clear measures of vulnerability have been established. An index of vulnerability would help to account for the dynamic characteristics of the human system. A more recent challenge has been to address the interaction of vulnerability components in the context of multiple hazards and risk. So far, however, no predictive, scientifically based model that correlates measures of vulnerability with the degree of hazard impact has been developed. Progress has been made; notably through the work of Cutter (1996a,b), Cutter et al. (1997, 1999), and Emrich (2000), which have attempted to place models on a quantitative footing, but these need considerable refining before they can be successfully employed within a policy-making framework.

Much of the research undertaken in recent years into assessing community vulnerability has centered on the hazardousness of place, expanding on the early ideas of Hewitt and Burton (1971). Some of these studies incorporate a multitude of geophysical threats to an area (Cutter et al. 2000; Flax et al. 2002), encompassing measures of geophysical risk probabilities and recurrence intervals (Montz 1994), whereas others explore the spatial extent of areas at risk for different events (Montz and Tobin 1998; Odeh 2002). In addition, the vulnerability of populations has also been included, with attention focused specifically on demographic traits of those at risk, as well as issues of exposure and marginalization. For instance, Montz and Tobin (1998) look at the location of critical facilities with regard to risk from riverine flooding and tropical storm surge, whereas Cutter et al. (2000) develops quantitative indicators to represent social vulnerability and incorporates them into maps that depict areas at risk for multiple hazards. Frequently, the objective has been to produce indices of social vulnerability and geophysical risk and ultimately provide a model of community vulnerability. At this time, however, no single index fits all situations.

Several tools have been used in such research. For example, Bender (2002), in a valuable collection of papers, discusses the importance of vulnerability assessment techniques in supply-and-demand terms; the supply of knowledge through the academic environment and the demand for such information by users combine to help planning goals. Some of this work has focused on structural vulnerability to natural hazards including threats to rural road systems (Keller 2002); to other infrastructure, such as port facilities (Wood et al. 2002); and to cities (Kuroiwa 2002). These useful studies have important lessons for planners, but they do not address social vulnerability for emergency management.

Various problems emerge when considering how to measure hazardousness; indeed, combining geophysical risks presents methodological difficulties. For example, Odeh (2002) combines various geophysical risk factors into a hazard score as a multiplicative function of event frequency, scope (area), and intensity. Although the interpretation of each of these variables is open to debate, the goal was to produce a common measure of such risk. Others have summed the geophysical risk as a function of recurrence intervals (Montz and Tobin 1998; Cutter et al. 2000). The problems are further exacerbated when one tries to account for human factors of vulnerability. Odeh (2002) used measures of exposure (assets, population, and resources) within a given region to determine social vulnerability; again, one might argue with the selection of variables and actual measurements, but the attempt is laudable. Many different variables have been identified as possibly affecting vulnerability (Blaikie et al. 1994), but determining which of them are most significant under different conditions has proved elusive. Clark et al. (1998) used factor analysis, whereas others have advocated the use of "expert opinion."

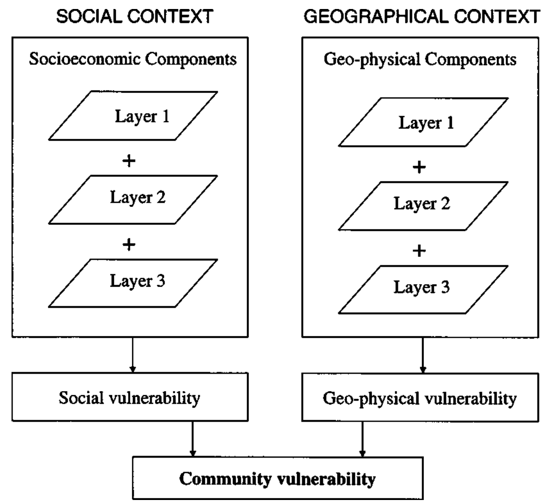

Fig. 1. GIS-based vulnerability analysis

Integrating geophysical risk and social vulnerability compounds the methodological problems. Odeh (2002) combines the two scores (hazard and exposure) by multiplying the two indices, as does Cutter et al. (2000), whereas Montz and Evans (2001) summed the two indices. Further testing is needed to determine the appropriateness of these approaches. Flax et al. (2002) took a broader perspective in looking at community vulnerability and used a vulnerability assessment tool developed by NOAA's Coastal Services Center. In outlining the model under different conditions, and moving the discussion along, they strongly advocate proactive action to address emergency response mitigation. Both Odeh (2002) and Flax et al. (2002) go a long way in furthering our understanding of the vulnerability issue.

In undertaking such research, extensive use has been made of GIS. This technology is particularly well suited for such research because it allows for (1) the integration of multiple data sources, including hazardous locations and vulnerable populations; (2) the geographic representation of complex data in map form; and (3) the application of spatial analytic techniques, including buffering and overlay (Chakraborty et al. 1999; Sheppard et al. 1999). Fig. 1—based on the work of Lowry et al. (1995), Cutter (1996a), and Montz and Evans (2001)—summarizes the most common approach to modeling community vulnerability by using GIS and reflects the contributions of social and geographic contexts to understanding vulnerability and risk (Clark et al. 1998; Cutter et

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al. 2000; Montz and Evans 2001). To analyze social context, variables that represent various socioeconomic characteristics are combined, either as absolute numbers, relative numbers, or quantitative indicators of vulnerability. Similarly, data layers that represent various aspects of the geophysical environment, including hydrologic and topographic factors, are combined. The integration of these two sets in a GIS environment provides a composite view of community vulnerability to hazards.

Fig. 1 does not adequately represent the dynamic nature of the components that contribute to community vulnerability. It is recognized that knowledge of the geophysical event is critical because people are not vulnerable, at least not directly, if they are not at some risk from the physical environment. Although considerable research has focused on physical, hydrological, and meteorological processes that represent the geophysical risk of an area, more work is required to understand and evaluate social vulnerability. With regard to evacuation, the location of particular populations is of concern because of their special needs. Existing models of social vulnerability typically emphasize the ability to cope with or recover from hazards. Although several researchers have also used GIS technology and simulation methods for regional evacuation modeling (e.g., Cova and Church 1997; Cova and Johnson 2002), this work has evolved primarily along a temporal line of inquiry. Research has focused on estimating or reducing the time needed to evacuate a specified zone, and vulnerability has been measured on the basis of transportation difficulties faced by different neighborhoods.

Missing from much of this work is an examination of the other dimensions of social vulnerability and the evacuation assistance needs of local residents in emergency situations, especially in coastal regions. More research is necessary, therefore, to develop methods and models to assist hazard managers and emergency responders in evacuating people with economic difficulties, mobility restrictions, and special needs. Our paper addresses this research gap by focusing on a coastal county in the state of Florida.

The Study Area

Hillsborough County, Florida, serves as the study area for this project. It was chosen because it incorporates a range of hazard probabilities, including areas subject to storm surge, coastal flooding, and other hazards associated with hurricanes, as well as areas with relatively less risk. This county occupies approximately 2,779 km^2 on Florida's west central coast; the county seat and the largest city is the city of Tampa. According to the 2000 U.S. Census, the population of the county was 998,948, with Tampa accounting for 303,447 people, or about 30% of the county's total (Binghamton Univ. 2002).

The county is hazard-prone, facing hurricanes, floods, lightning, tornadoes, and droughts, among other hazards. A comprehensive review of the susceptibility of Tampa to multiple hazards can be found in Montz (2000). The region has been directly threatened numerous times by hurricanes and tropical storms, although few have made landfall in Tampa Bay. Since the beginning of the twentieth century, approximately 60 such storms have come within 75 mi of Egmont Key, at the entrance to Tampa Bay (Neumann 1987). The most recent events include hurricanes Elena (1985), Georges (1998), Gabrielle (2001), Eduoard (2002) and Henri (2003).

The small urban watersheds, characteristic of Hillsborough County, are frequently flooded by both localized summer thunderstorms and frontal systems. Hillsborough County has been in the regular phase of the National Flood Insurance Program since 1980, with an update of some floodplain maps accomplished in 1992. There were just over 1,900 flood insurance claims in the county between September 1978 and December 2002, although a number of these were likely attributable to coastal flooding, as well.

Table 1. Return Periods and Probabilities of Occurrence

Category	Wind speed (knots)	Return period (years)	Probability of occurrence
Tropical storm	<64	14	0.070
1	64–83	19	0.050
2	84–96	65	0.020
3	97–113	160	0.006
4	114–135	400	0.003
5	>135	500	0.002

Methods

Measuring Geophysical Risk

Hurricanes and floods are included in this analysis of geophysical risk because their probability of occurrence varies significantly across the county. In contrast, the probability of other events, such as lightning or tornadoes, does not vary spatially and hence does not provide sufficient differentiation to address the questions examined in this study. Technological hazards that exist in the study area are not included because of the difficulty in estimating probabilities of occurrence and the linkages of such events with other events, such as hurricanes.

Geophysical risk zones for hurricanes and tropical storms were defined using the National Hurricane Center Risk Analysis Program (HURISK) (Neumann 1987), from which probabilities of occurrence at Egmont Key could be calculated (Table 1). Probabilities of flooding were derived from the flood insurance maps that provide the means of determining the spatial extent of the flood hazard based on the 100-year flood area (0.01 probability) and the 100–500 year floodplain (0.002 probability). Coastal flooding areas are considered in Table 1 in the hurricane data. A geophysical risk index (GPRI), representing total probability, was derived by summing the two individual probabilities.

Measuring Social Vulnerability for Evacuation Assistance

The literature on assessment of social vulnerability has identified several characteristics that contribute to differential ability for coping with, and recovering from, natural hazards. Frequently mentioned traits include age, physical and mental disabilities, family structure and social networks, income and material resources, housing and built environment, and infrastructure and lifelines (Clark et al. 1998). Some of these attributes can also be used to understand and measure the mobility and evacuation assistance needs of a community. Following the literature on vulnerability analysis, this study focuses on three specific characteristics of the population that are important from an evacuation perspective:

- General population and structural attributes,
- Access to resources, and

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Table 2. Variables Used to Determine Social Vulnerability for Evacuation Assistance Need

Characteristic	Variable
Population and structure	Total population
	Number of housing units
	Number of mobile homes
Differential access to resources	Population below poverty level
	Occupied housing units with no telephones
	Occupied housing units with no vehicles
Population with special evacuation needs	Institutionalized population in group quarters
	Population age 5 years or under
	Population age over 85 years
	Population (age over 5 years) with disabilities

- Special evacuation needs because of physical disability or age.

Census data are used to represent these characteristics because they are publicly available and familiar to local emergency managers. The block group is the analytical unit chosen for this study because it is the smallest census unit for which detailed demographic and socioeconomic data are published. Although hazardousness and vulnerability vary at smaller geographic scales and even at the household level (Clark et al. 1998), the block group is a useful and practical unit for advising local officials on the allocation of resources. Thus, data on ten variables from the 2000 U.S. Census of Population and Housing that reflect the three characteristics were collected for the 795 block groups in Hillsborough County (Table 2). Certainly, additional and different variables could be used to measure the evacuation assistance needs of a community. However, these variables were selected because they include a range of practical considerations and provide an initial metric to operationalize and illustrate the concept of evacuation assistance need.

Several methods have been suggested to compute composite vulnerability measures on the basis of multiple variables. Some incorporate weighting systems; (Lowry et al. 1995; Montz and Evans 2001) that reflect the relative contributions of the variables under study, while others are based on indices with differing elements that contribute to them (Cutter et al. 2000; Montz 2000). We modified the procedure developed by Cutter et al. (2000) to formulate an index to measure the social vulnerability of the population for evacuation assessment needs at the block group level, based on the variables listed in Table 2. The methodology used to compute this social vulnerability for evacuation assistance index (SVEAI) for each block group in the study area can be summarized as follows:

1. Step 1. For each variable i, determine the ratio of the variable in the block group to the total number of that variable in the county (R_i).
2. Step 2. Compute a standardized social vulnerability for evacuation index (SVEAI_i) for variable i using the maximum ratio value ($R_{\max}$) observed in the county.

$$\mathrm{SVEAI}_i = \frac{R_i}{R_{\max}}$$

3. Step 3. To combine multiple variables in the assessment of social vulnerability, calculate the arithmetic mean of the vul-

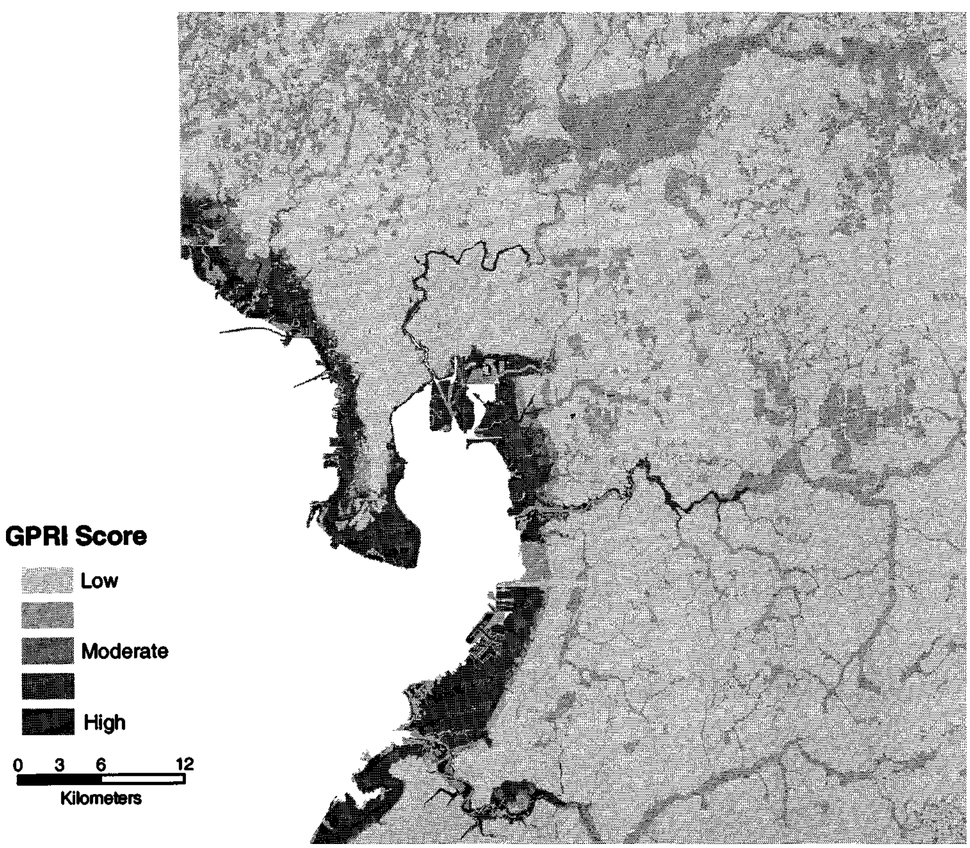

Fig. 2. Spatial distribution of geophysical risk, Hillsborough County, Florida

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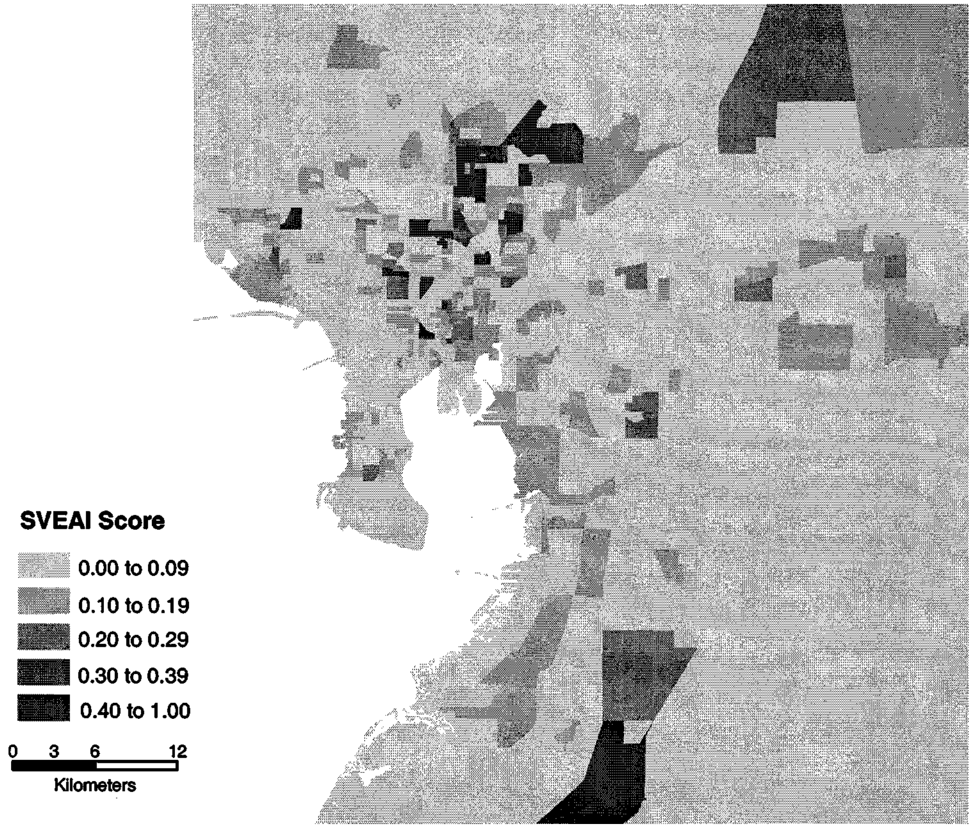

Fig. 3. Social vulnerability by census block group based on differential access to resources (Approach 2)

nerability indices by dividing the sum of index values of all variables by the number of variables (n) considered.

$$\mathrm{SVEAI} = \frac{\sum \mathrm{SVEAI}_i}{n}$$

When standardized in this manner, the values of SVEAI range from 0 to 1 and are not influenced by the number of variables included in the computation. Higher scores for this index indicate greater vulnerability or evacuation assistance need for the block group in question. Although each socioeconomic variable can be examined independently, the average of all measures provides a general overview of social vulnerability for any region within the county and is more useful for the emergency management community than individual factors are.

We present four alternative approaches for grouping the variables to calculate social vulnerability for evacuation and for examining the spatial distribution of each approach within the study area. Each grouping approach represents a combination of variables from Table 2. These characteristics are listed below, along with the number of variables associated with each approach:

- Approach 1: Population and structure (three variables),
- Approach 2: Differential access to resources (three variables),
- Approach 3: Special evacuation needs (four variables), and
- Approach 4: All three characteristics (10 variables).

Each approach addresses a specific dimension of evacuation assistance need that can be examined and visualized independently, a process that recognizes the different issues that local emergency managers face in developing evacuation plans. The intent is not to suggest that one approach is necessarily better than another, but rather to evaluate the differences that might exist if different variables are used to develop plans. Approach 4, for instance, combines multidimensional factors into a single standardized measure of social vulnerability to provide an overall assessment.

Determining Evacuation Assistance Need

For the purposes of this research, the overall evacuation assistance need is defined as the product of the geophysical risk index (GPRI) and the social vulnerability for evacuation index (SVEAI), computed at the block group level. This approach, used by Cutter et al. (2000) and Montz and Tobin (2003), gives equal weight to both components and all variables associated with each. Other scholars have argued for the use of weights, with the argument being that some variables contribute more to a population's vulnerability than do others (Lowry et al. 1995; Montz and Evans 2001), but there is little agreement on the relative contributions of variables considered. In addition, the emphasis of this work is on the types of variables mapped and the differences they might make in evacuation planning. As a result, weighting is not appropriate here.

Results

Spatial Distribution of Geophysical Risk

The map shown in Fig. 2 represents the spatial distribution of geophysical risk (GPRI and scores) and is based on combining the probabilities of storm surge and flood probabilities. Not surprisingly, the high-risk zones are mostly along the coast, because tropical storms and hurricanes of low intensity have relatively

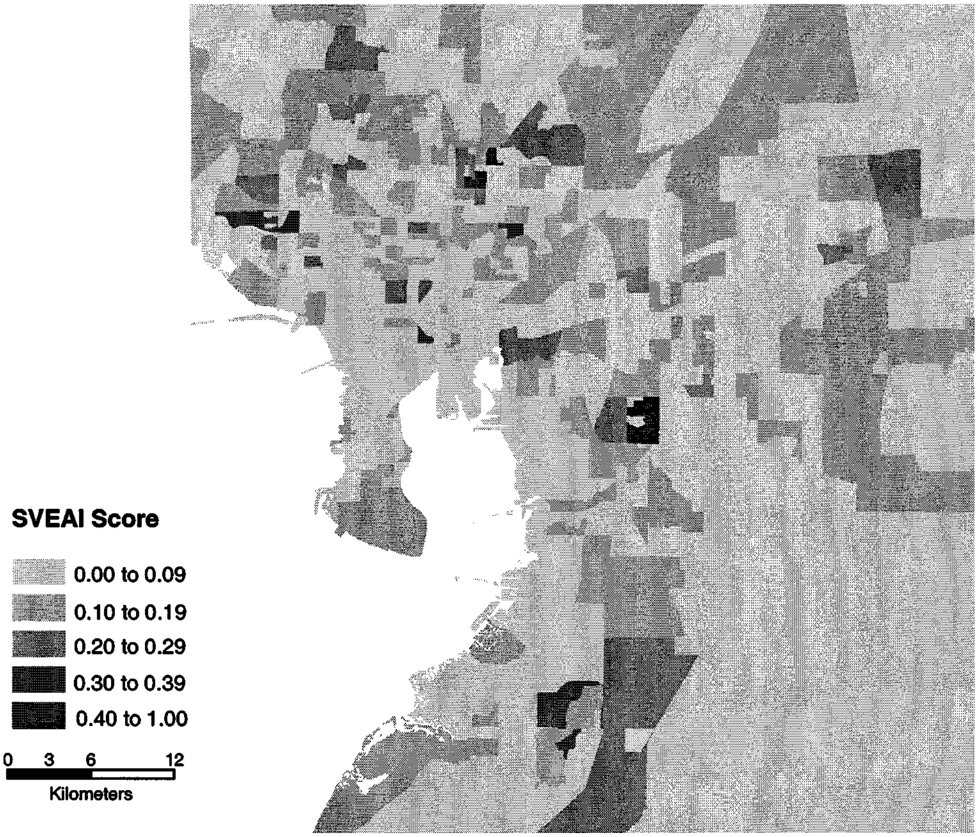

Fig. 4. Social vulnerability by census block group based on populations with special evacuation needs (Approach 3)

high probabilities of occurrence. However, there are also inland areas with relatively high levels of risk associated with flood problems.

From this map alone, the message for evacuation planners is that priority should be given to coastal areas. Clearly, the areas at greatest risk are those that should be evacuated first. However, occurrence of an event is one consideration in evacuation planning. The ability of the population to evacuate is another key issue and must be addressed in conjunction with geophysical risk.

Spatial Distribution of Social Vulnerabilty

For this research, social vulnerability for evacuation purposes was measured using four different approaches, as detailed previously. Only two of them are presented here (Figs. 3 and 4) because they illustrate the differences that result. The patterns in the maps show the substantial spatial variability that exists in characteristics used to define social vulnerability, even over relatively small areas. In Fig. 3, the SVEAI score is based on differential access to resources. Most of the county is characterized by relatively low scores, and coastal areas appear to be least in need. Several areas in the county, notably in the north-central and south-central regions, are characterized by populations with a relative lack of access to resources. Fig. 4 presents a rather different picture using populations with special needs as the definition of social vulnerability. Although many block groups are above the lowest SVEAI category, very few are highly vulnerable on the basis of this measure. In comparison to the patterns in Fig. 3, the special needs populations are distributed widely throughout the county, with very few areas of concentration.

These two maps strongly support the argument that how social vulnerability is measured makes a difference. Evacuation plans made on the basis of these maps are likely to result in wide variations in response, both in timing and in locational priorities. Fig. 3 might suggest deploying resources throughout the county, whereas Fig. 4 would result in concentrating personnel and other resources in specific regions to address the greatest needs. These maps reflect the complexity of defining vulnerability and evacuation assistance need, even without considering the geophysical environment. When variations in risk are added, the complexity increases even more, as described in the next section.

Patterns of Overall Evacuation Assistance Need

The product of our geophysical risk and social vulnerability indices (GPRI × SVEAI) was classified into five categories that were based on the magnitude of evacuation assistance need (lowest to highest) and mapped using GIS software. Figs. 5–8 present the four combinations of social vulnerability and geophysical risk for census block groups in Hillsborough County. These maps suggest that the inclusion of geophysical risk makes a significant difference to the spatial distribution of evacuation assistance need. In all four maps, inland areas, particularly in the northeastern part of the county, are at much less risk. The southwestern portions of Hillsborough County exhibit the greatest risk, and consequently, the highest overall evacuation assistance need, regardless of the variables used to calculate the SVEAI. Still, the differences among the maps are important.

Fig. 5 illustrates areas with relatively large population and housing densities and with a relatively high proportion of mobile homes. In addition to the high-risk coastal areas, which are to be expected, given the high probability of occurrence of an event,

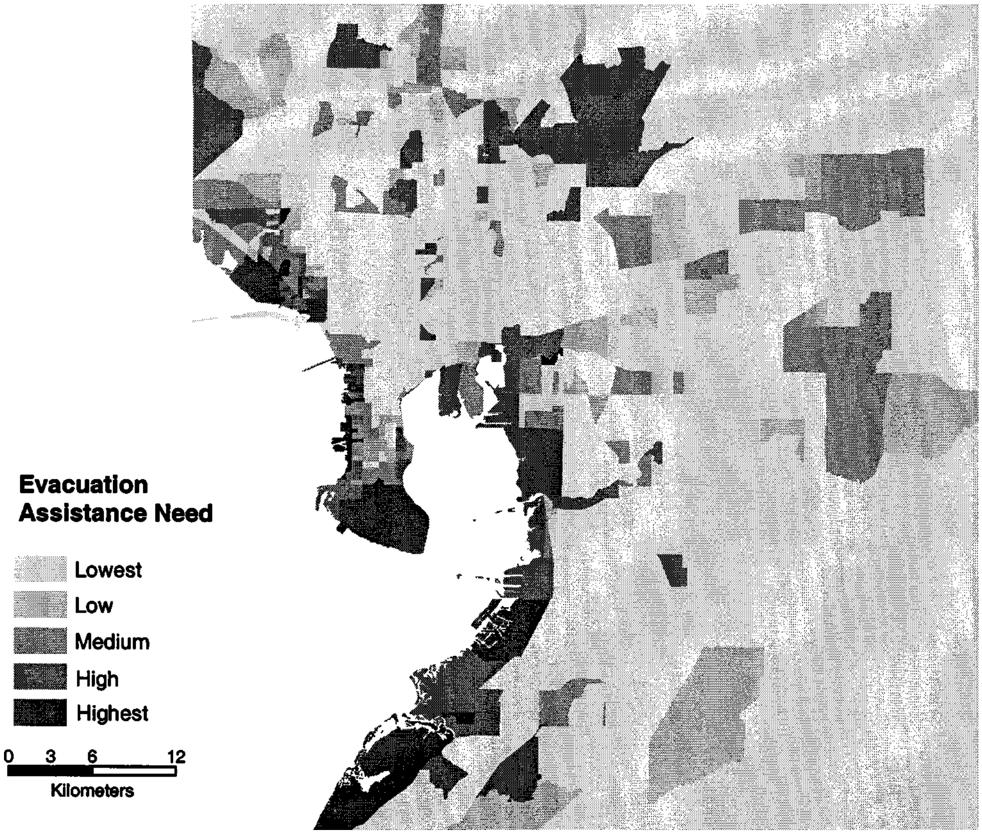

Fig. 5. Spatial distribution of overall evacuation assistance need based on geophysical risk and general population/structural characteristics (Approach 1)

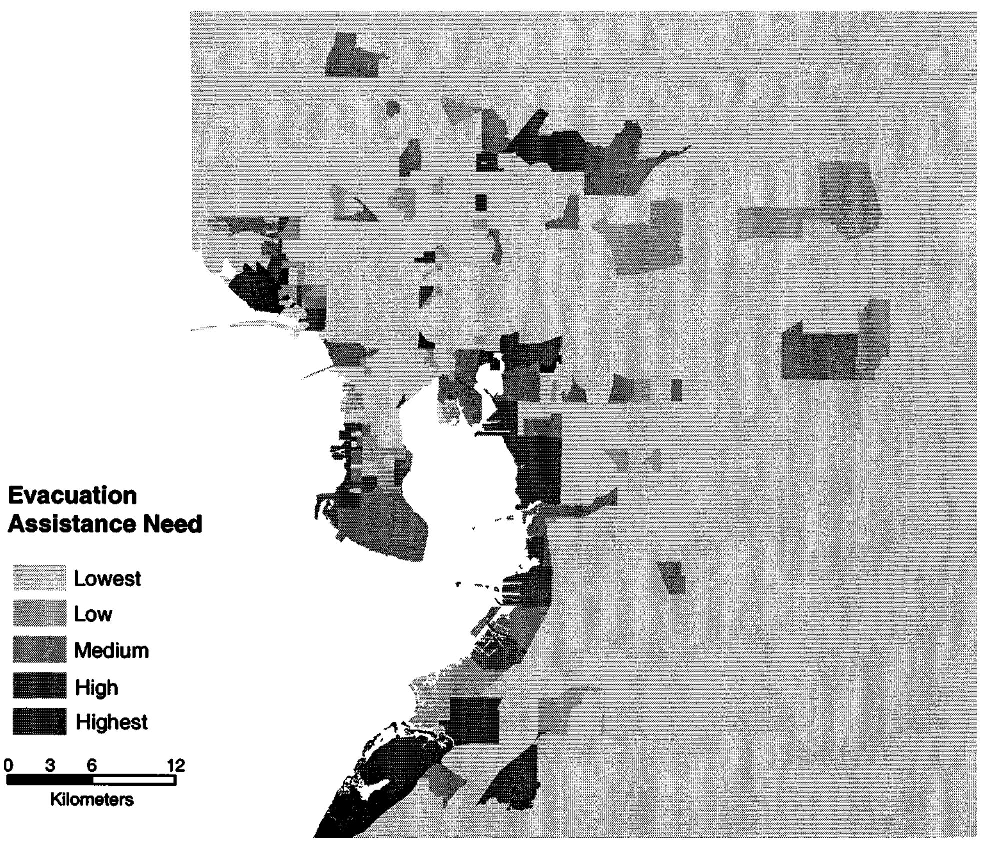

Fig. 6. Spatial distribution of overall evacuation assistance need based on geophysical risk and differential access to resources (Approach 2)

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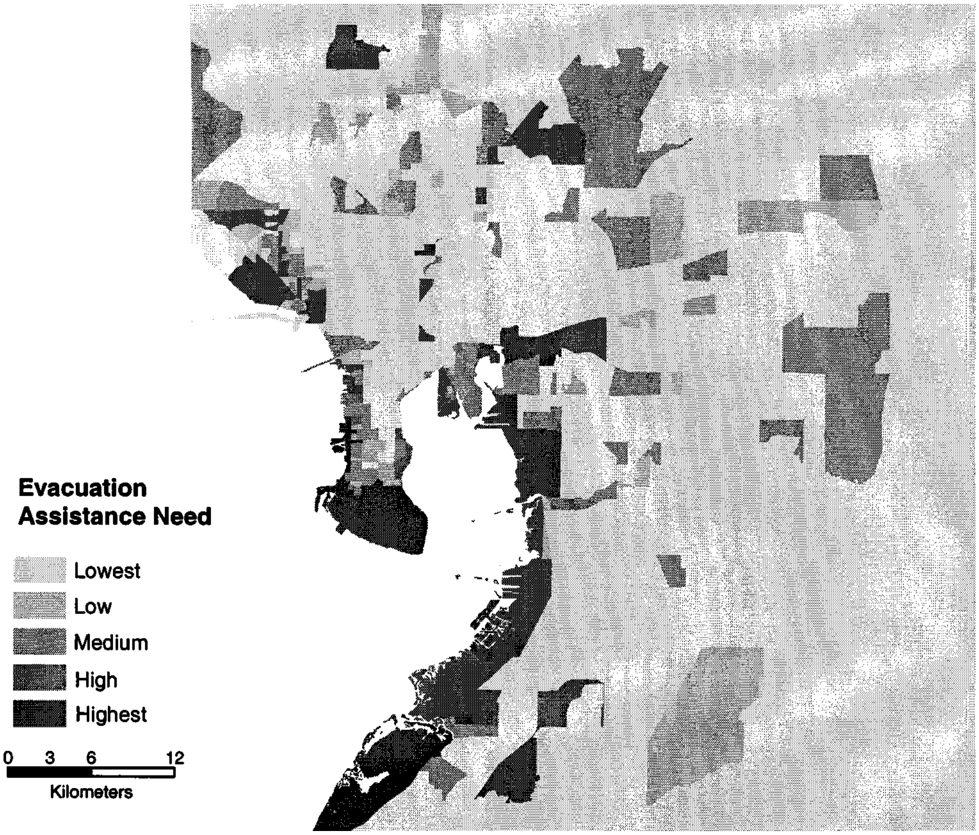

Fig. 7. Spatial distribution of overall evacuation assistance need based on geophysical risk and populations with special evacuation needs (Approach 3)

evacuation assistance needs are scattered throughout the county. Still, the patterns in this map are different from those in Fig. 3 because a number of block groups have moved from scoring high on the SVEAI to being rather low in evacuation assistance need when risk is considered. A large number of block groups have medium to high evacuation assistance need, and they are generally found in the northern half of the county. The results shown in Fig. 5 contrast with those shown in Fig. 6, which illustrates differential access to resources. When Fig. 6 is compared with Fig. 4, very different patterns emerge. Notably, the interior areas of the county become much less important and the coastal areas increase in need. However, the number of block groups at risk is relatively small, especially when compared with the other maps.

The location patterns of special needs populations influence the spatial distribution of evacuation assistance need in Fig. 7. Again, coastal areas dominate as areas of high need, but some inland block groups also stand out, particularly in northern Hillsborough County. Emphasis, however, remains on the coastal areas. The patterns in Fig. 8 are quite similar to those in Fig. 7. For the most part, block groups indicating high need when considering special needs populations also have high needs when all variables are considered. However, this outcome does not suggest that emergency evacuation planning strategies would be similar. Although the existence of socially and physically vulnerable populations in areas with high geophysical risk is a major concern, consideration must also be given to the specific needs or evacuation issues associated with these populations in such high-risk areas.

Quantitative Comparison of Results

Although the four maps in Figs. 5–8 provide a visual assessment of evacuation assistance need patterns within the study area, the analytical capabilities of GIS software can be used to estimate the total population in each evacuation assistance need zone, as well as their socioeconomic and structural characteristics. These numerical estimates also allow us to examine the variability of results obtained from the four different approaches to measuring social vulnerability in conjunction with geophysical risk. We compare the four approaches quantitatively by focusing on two specific aspects that are important for risk management and evacuation planning: (1) the number of people living in each evacuation assistance need zone; and (2) the characteristics of the population and structures in areas with the highest evacuation assistance need.

The present of the population of Hillsborough County population residing in each evacuation assistance need zone is provided in Table 3. Regardless of the approach adopted, the percentage of the population appears to decline with an increase in the magnitude of evacuation assistance need (from lowest to highest). Approach 1 indicates that almost 15% of the county population (146,495 people) can be found in areas where evacuation assistance need is high or highest; this estimate drops to about 8% (76,540 people) for Approach 2 and to about 4% for Approach 3 (39,768 people) and Approach 4 (41,950 people). The numerical differences among the estimates obtained from the four approaches are reasonably consistent with the variation in patterns observed in our visual assessment of the four maps. The popula-

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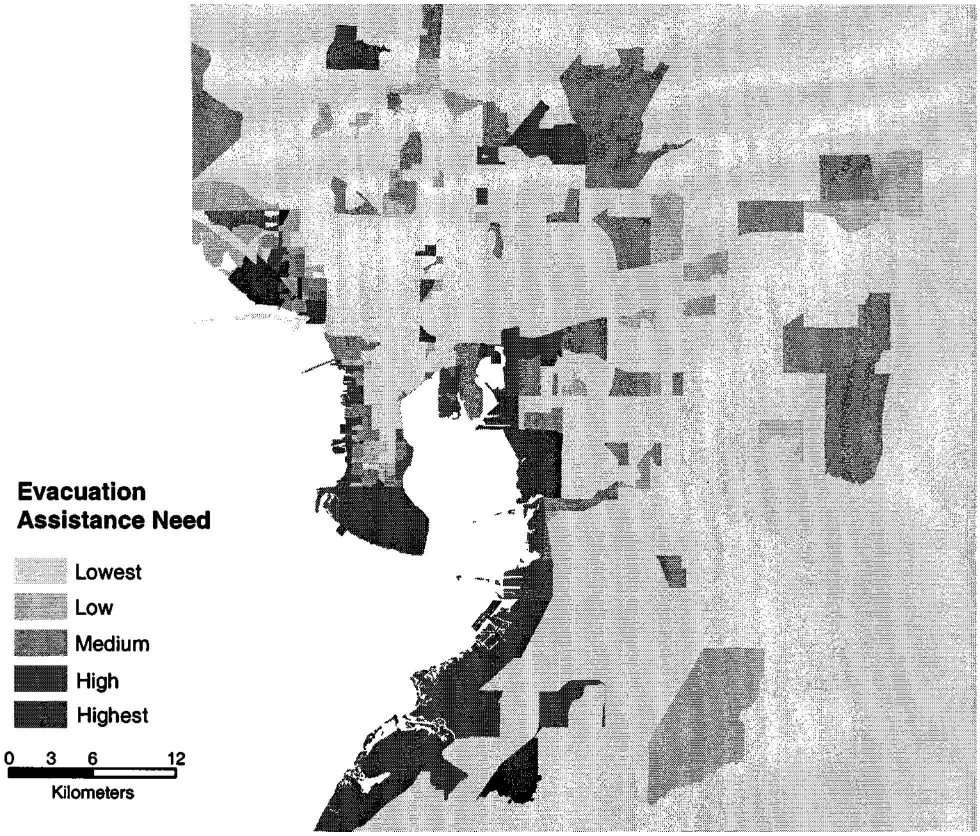

Fig. 8. Spatial distribution of overall evacuation assistance need based on geophysical risk and social vulnerability (Approach 4)

Table 3. Percent of County Population within Evacuation Assistance Need Zones

Evacuation need	Approach 1 (%)	Approach 2 (%)	Approach 3 (%)	Approach 4 (%)
Lowest	70.77	78.57	73.82	73.31
Low	5.88	6.79	5.87	6.02
Medium	8.68	6.98	16.33	16.47
High	10.23	5.17	2.74	2.73
Highest	4.44	2.49	1.24	1.46
Total percent	100	100	100	100

tion estimates from Approach 3, for example, are similar to those provided by Approach 4. The greatest fluctuation of population estimates can be observed for the medium evacuation assistance need zone. In contrast, the percentage of the population in the highest need zone remains relatively constant across all four approaches. This finding could have important implications, since population estimates for the zones with the highest evacuation assistance need are usually more crucial for evacuation planning and related needs than estimates for the other zones.

Although estimating the number of people within each evacuation assistance need zone is important, emergency responders and planners often need to focus their time and resources on areas with the highest evacuation assistance need. The structural and socioeconomic characteristics of regions with the highest evacuation assistance need are summarized in Table 4 based on the

Table 4. Social Vulnerability Characteristics of Zone withHighest Evacuation Assistance Need

Evacuation need	Approach 1 (%)	Approach 2 (%)	Approach 3 (%)	Approach 4 (%)
Total population	4.44	2.49	1.24	1.46
Number of housing units (HUs)	5.25	3.36	1.83	2.18
Number of mobile homes	9.97	6.90	4.44	4.46
Population below poverty level	3.53	3.96	0.97	1.29
Occupied HUs with no telephones	3.49	5.06	0.78	1.18
Occupied HUs with no vehicles	2.66	4.17	0.51	0.60
Institutionalized population	3.81	2.35	0.72	0.88
Population age 5 years of under	4.30	2.79	1.64	1.71
Population age over 85 years	1.50	1.50	0.00	0.00
Population (age 5+) with disabilities	4.23	2.59	1.22	1.40

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proportion of the county total for each variable used to measure social vulnerability. The estimates from Approach 1, for example, indicate that the zones with the highest evacuation assistance need contain almost 10% of the mobile homes in Hillsborough County but only about 5% of housing units. The proportion of mobile homes in the highest need areas is greater than the proportion of housing units, regardless of the approach used to measure social vulnerability for evacuation.

Table 4 also reveals several interesting differences in the estimates obtained from the four approaches. With the exception of variables describing access to resources, the largest percentages for all variables are provided by Approach 1. Approaches 3 and 4, in contrast, yield the smallest proportions for all variables and estimates that are again very similar. Our analysis of social vulnerability appears to be biased mainly by the general population and structural characteristics of block groups, followed closely by differential access to resources. The results from Approach 3 suggest that the third dimension (special needs population) has the smallest effect on the assessment of overall evacuation assistance need. The explanation for this result is that individuals with special evacuation needs currently reside in areas with very low levels of geophysical risk (see Fig. 4). Since the product of the two indices for Approach 3 is more influenced by the geophysical component, block groups with high overall evacuation assistance need contain a relatively small percentage of the special needs population.

Conclusion

The maps and quantitative analyses provide an empirical basis upon which the three research questions can be addressed. First, the coastal locations of Hillsborough County present a very hazardous situation, and geophysical risk is highest there. However, social vulnerability, as measured in our study, is not particularly high in these zones. In fact, relatively few block groups are characterized by high evacuation assistance need. Yet, we know that vulnerable populations are at risk and that many live in high-hazard regions even if their actual numbers are relatively small. Thus, in response to the first research question, important differences exist in the spatial distributions of geophysical risk and vulnerability.

Second, our findings indicate the important fact that the variables that are used for vulnerability analysis make a difference. Depending on which the measures that are used, between 4 and 15% of the population of Hillsborough County are in the high and highest evacuation assistance need areas. The proportions are not large; but when absolute numbers are considered, these translate to between 40,000 and 150,000 people. Clearly, this finding will make a difference to emergency managers and to those who are developing evacuation plans.

Finally, the results of this research have important implications for emergency management and especially for evacuation planning. Evacuation planners cannot ignore the high-risk areas, because no matter who lives in these areas, appropriate measures need to be in place before an event. However, other areas are also at risk, because of their population characteristics and not necessarily because of their geophysical risk. Special needs populations are not concentrated but may well require evacuation assistance in the form of early warning, mobility assistance, or both. These results, then, call for a two-pronged approach to evacuation planning, one prong concentrating on high-risk areas and the other on particular needs of populations in particular areas, regardless of the magnitude of geophysical risk. Indeed, geophysical risk is a rather static measure. Once the spatial extent of the high-risk areas has been identified, plans can be developed and appropriate measures implemented. Social vulnerability is not a static measure for at least two reasons. First, people move, so the distribution of those with high evacuation assistance need will change over time. Second, measures of evacuation assistance need change with different types of hazards. It makes a difference whether mobility or communication is of primary importance. If mobility is of primary importance, then those areas with special evacuation assistance needs should take priority. If communication is of primary importance, then one would want to concentrate efforts in areas that lack access to resources or in areas with high population densities.

The results of this research demonstrate the importance of evaluating both risk and vulnerability from several perspectives for emergency management purposes. The emphasis here has been on evacuation, but the results have more widespread implications. Clearly, it makes a difference how the factors of concern are chosen and measured, and recognizing and incorporating the dynamic nature of many of them is important. GIS has greatly facilitated emergency management and evacuation planning, as the case study used here illustrates. Yet, much more needs to be done if we are to develop dynamic, effective, and efficient evacuation plans. For example, the location and capacity of evacuation routes will greatly influence the success (or lack of success) of any evacuation process. Within GIS, data layers representing transportation networks can be included to identify optimal evacuation routes or locations for proposed emergency response facilities. These data layers can also be used to evaluate and model "evacuation vulnerability" of neighborhoods (Cova and Church 1997). Populations with special evacuation needs can be more or less vulnerable depending on their proximity to transportation routes or facilities. In addition, risk and vulnerability of surrounding counties can affect evacuation planning in Hillsborough County, particularly if evacuation routes traverse the county and intersect zones of high geophysical risk or high evacuation assistance need. Although some of these considerations are beyond the scope of the project presented in this paper, they provide an important foundation for future research.

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