ASSESSING THE VULNERABILITY OF COASTAL COMMUNITIES TO EXTREME STORMS: THE CASE OF REVERE, MA., USA

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Abstract. Climate change may affect the frequency, intensity, and geographic distribution of severe coastal storms. Concurrent sea-level rise would raise the baseline of flooding during such events. Meanwhile, social vulnerability factors such as poverty and disability hinder the ability to cope with storms and storm damage. While physical changes are likely to remain scientifically uncertain into the foreseeable future, the ability to mitigate potential impacts from coastal flooding may be fostered by better understanding the interplay of social and physical factors that produce human vulnerability. This study does so by integrating the classic causal model of hazards with social, environmental, and spatial dynamics that lead to the differential ability of people to cope with hazards. It uses Census data, factor analysis, data envelopment analysis, and floodplain maps to understand the compound social and physical vulnerability of coastal residents in the city of Revere, MA, USA.

Background

The impacts of hazardous events are usually unevenly distributed among and within nations, regions, communities, and groups of individuals. Vulnerable groups are those who are likely to suffer a disproportionate share of the effects of hazardous events. For the purposes of this study, we draw on a growing literature of vulnerability studies (reviewed by Dow, 1992, 1993) to define ‘vulnerability’ to hazards as *people’s differential incapacity to deal with hazards, based on the position of groups and individuals within both the physical and social worlds.* Building on this literature, we see vulnerability as a function of two attributes: 1) exposure (the risk of experiencing a hazardous event); and 2) coping ability, subdivided into resistance (the ability to absorb impacts and continue functioning), and resilience (the ability to recover from losses after an impact). In this paper, we use coping ability as an antonym of social vulnerability.

Exposure (the risk of experiencing a hazardous event) as a concept is well-explicated in the ‘technical’ risk literature (see for example Renn, 1992, pp. 58–

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TABLE I.
Sources of vulnerability themes

Age	Bolin, 1982
	Bolin and Klenow, 1983
	Drabek and Key, 1984
	Quarantelli, 1991
	Rossi et al., 1983
Disabilities	Parr, 1987
Family structure and social networks	Bolin and Bolton, 1986
	Drabek and Key, 1991
Housing and the built environment	Bolin and Bolton, 1986
	Bolin and Stanford, 1991
	Godschalk, Brower and Beatley, 1989
	NRC, 1984
	White and Haas, 1975
Income and material resources	Bolin and Bolton, 1986
	Bolin and Stanford, 1991
	Drabek and Key, 1984
	Perry and Lindell, 1991
	Quarantelli, 1991
	Rossi et al., 1983
Lifelines	NRC, 1984; Platt, 1991
Occupation	Bolin, 1982
Race and ethnicity	Bolin and Bolton, 1986
	Drabek and Key, 1991
	Perry, Green and Mushkatel, 1983
	Perry and Lindell, 1991
	Rossi et al., 1983
	Trainer and Bolin, 1976

61) and is in general the most widely cross-disciplinarily understood dimension of vulnerability. For this reason, we do not comment further on exposure except to say that it, too, is partly socially constructed, in that existing land use and daily commuting patterns, to name but two exposure variables, are social and temporal phenomena. We use a simplified measure of exposure – a floodplain map – in order to focus on the more explicitly social variables that together determine coping ability. Coping ability, the ability to either absorb impacts (e.g., by exiting the scene or dealing with the hazard in-place) or to recover from them (e.g., though insurance, cash reserves, or other means), is influenced by a large list of variables identified by

sociologists, geographers, political scientists, and other investigators. See Table I and below under 'Methods'.

This paper does not pretend to be a review of the vulnerability literature or a catalog of all the past and future definitions and approaches to vulnerability. However, There are several authors who should be mentioned for those who wish to explore the terminology in depth. Timmerman (1981) provided an early look at the concept and origins of the term 'vulnerability' and sparked a need to explore and clarify the term as well as our understanding of the phenomenon. Liverman (1990) focused the debate by providing a catalog of the 'conditions and variables . . . important in determining vulnerability to global environmental change.' Wisner (1992) looked at vulnerability in the developing world, examining the concept of marginality and the role of the state in vulnerability. Blaikie et al. (1994) also focused on the developing world, analyzing the forces that combine to cause a crisis. Chen (1994) examined vulnerability on a relatively large scale in light of global environmental change. Dow and Downing (1995) commented on the state of vulnerability research in the wake of the Social Science Research Council-sponsored First Open Meeting of the Human Dimensions of Global Environmental Change Community, at Duke University in June, 1995. Cutter (1996) broadly reviews the definitions of vulnerability and the types of studies carried out since 1980. Hewitt (1997) reviews the vulnerability literature with an emphasis on vulnerability as a form of powerlessness that is socially reproduced.

Exposure and coping ability as co-determinants of people's vulnerability to hazards are of particular interest to hazard managers inclined to address behavioral, managerial, institutional and other human activity-related issues that change the likelihood of severe impacts from hazards. Short of affecting the environmental hazard itself, hazard managers seek points of intervention in the causal chain between an hazardous event and the downstream human consequences. In the hazards literature of the past two decades, this search has been supported through causal modeling (inspired by the classic work of Hohenemser, Kasperson, and Kates, 1985), which has since then also found entry into the global change literature (e.g., Clark, Jager, and van Eijndhoven, forth-coming; Moser, 1997). Hohenemser, Kasperson, and Kates (1985) illustrate that this view of hazards as processes 'strongly implies three possible strategies for hazard control: (1) prevention of hazard events; (2) prevention of hazard consequences once events have taken place; and (3) mitigation of consequences once these have occurred'.

The parallels to the search for possible responses to global climate change are obvious in spite of the varigated terminology: (1) prevention of further increases in the atmospheric concentration of greenhouse gases, (2) mitigation of impacts (bounding of first order environmental changes), and (3) adaptation to the impacts (higher order responses to impacts) (Bruce, Lee, and Haites, 1996; Houghton *et al.*, 1996; Watson et al., 1996). Understanding the causal linkages among the social and physical processes that interact to produce a hazard on the one hand, and illuminating the causal linkages across scales from the global to the local on the other, are parallel challenges that need to be addressed in order to adequately prepare for the management of climate change-related environmental hazards (e.g., Cash, 1997; Global Environmental Assessment Project, 1997; Kotlyakov et al., 1988; Turner et al., 1990).

In this paper we focus on the former challenge largely because the likely magnitude of local consequences from global climatic changes are far from predictable and the causal mechanisms that would link global processes to local impacts are still inadequately understood. In the absence of such greater ability to predict local consequences of global climate change, it is still possible and, as a no-regrets strategy, advisable to address human vulnerability to environmental perturbations. We thus adapt the hazards causal model here by introducing vulnerability via its two dimensions, exposure and coping ability.

Some attempts have already been made to link vulnerability and the causal structure of hazards. Watts and Bohle (1993) use a tripartate model of property relations, political power, and economic power. While this model is useful in exploring the political economic dimensions of the problem, it addresses neither the spatial aspects nor the physical environment. Cutter (1996) posits a synthetic 'hazards of place' model which recognizes both the physical and the social in relation to the causal processes of hazards. (Although Cutter cites Hewitt and Burton (1971) as the inspiration for her term 'hazards of place', it should be noted that Hewitt and Burton use the term 'hazardousness of a place' differently, not to introduce 'vulnerability' or to emphasize causal modelling, but simply to mean the inclusion of multiple hazard types in the analysis of hazards at a given location.) While Cutter integrates the physical and social into a model of hazard processes, our incorporation of vulnerability into the hazards causal model of Hohenemser, Kasperson, and Kates (1985) accomplishes this integrative step while at the same time emphasizing the spatial distribution of vulnerability and, through the notion of hazard as process, allowing the identification of points of action in order to combat the effects of the hazard.

The crux of vulnerability to global environmental change is as follows: people stand to experience impacts from hazards of global change of varying degrees that fall along a spectrum from positive to negative, based on their position in the social and physical worlds. The problem, then, is twofold. (1) How do we begin to analyze and understand the differential potential for harm in a local context? (2) How do we incorporate vulnerability into our understanding of hazards as a type of interplay between social and physical phenomena, in order to have a way of discussing vulnerability's implications and of adjudicating between different policy and management options?

In order to answer the first question, we need to explore the social and spatial distribution of vulnerability to global change hazards. In order to answer the second question, we examine the implications of this research for causal modelling of hazards and for storm preparation and response. We do so in the context of a small U.S. coastal city, Revere, MA (see below) as an example of the type of

Figure 1. An MBTA (metropolitan Boston) bus driver works to keep his windshield clear during the January, 1996 'northeaster' in Revere, MA. Access to private automobiles and dependence on public transportation are among the variables that determine the ability to cope with severe storms.

coastal communities and the types of management challenges faced by coastal zone and hazard managers in developed countries. Clearly, we make no claim for general representativeness, especially not in an international comparison. We do believe, however, that Revere is far from singular with regard to the problems of on-the-ground storm hazard and sea-level rise management faced along developed shorelines. Comparative studies of coastal communities in other countries are invited. Our analysis offers one approach to address vulnerability not at the large scale at which economists and other workers often assess problems, but at the scale at which hazards managers commonly need to implement hazard reduction strategies.

Setting

Revere, Massachusetts (1990 population 42 786), located just north of Boston, is exposed to flooding and wave damage on three sides, from the Atlantic Ocean to the east and from tidal rivers to the north and south. We chose this city for our study because of (1) the availability of extensive detailed economic and topographic baseline data (Hunt, 1990); (2) the large portion of floodprone residential area in the city; and (3) the range of economic circumstances, from working-class to affluent (despite Revere's local reputation as a blighted community [Vigue, 1997]), in the floodplain and community as a whole.

The threat of accelerated global sea-level rise, which is projected to be between 13 cm and 94 cm by 2100 (Warrick et al., 1996), portends increased flood and wave damage. Massachusetts also has a recent historical 2 millimeters of annual relative sea-level rise due to subsidence (Giese, Aubrey, and Zeeb, 1987), which if extrapolated over the Warrick et al. study span could amount to an additional 20 cm by 2100. Wind, snow, and ice damage may also increase, depending on the highly uncertain effects of global climate change on storm frequency and intensity.

Recent experience underlines the significance of the storm hazard to Massachusetts coastal communities whether climate change and accelerated sea-level rise occur or not. The area weathered four especially severe coastal storms in the nineteen-month period between August 1991 and March 1993: Hurricane Bob in 1991 and three severe extratropical storms, regionally known as 'northeasters': the 'Halloween Northeaster' or 'No-name Storm' of 1991, the 'Blizzard of December '92', and the 'Blizzard of March '93', which affected the entire eastern seaboard of the United States. Most recently, the area endured a major snowstorm in January 1996 that left two feet of new snow on eastern Massachusetts, set records for total snow depth in the area, and put the region on the way to a new record for seasonal snowfall (Nealon, and Brelis, 1996; see Figures 1, and 2). The damage from each of these storms pales in comparison to the flood damage from the Blizzard of 1978, when federal assistance for coastal Massachusetts totalled \$38 million, and Red Cross spending in Revere alone totalled \$400 000 (Corps of Engineers, 1979; Hunt, 1990). Each event also caused serious disruption beyond its monetary toll.

TABLE II.

Key themes and possible exposure/resistance/resilience scenarios

Age. Young children entail an extra burden of child care, which may be disrupted during storm events (exposure). Parents may lose work time if their daycare is closed down. The same may apply to adults in elder care. Both young and old populations also may be unable to resist storms or respond on their own, although the vulnerability of elders is decreased by their wealth of experience.
Disabilities. Disabilities can hinder taking action in any of the phases of vulnerability.
Family structure and social networks. Large families may be harder to care for or keep track of in a storm and its aftermath (exposure, resistance, resilience). Yet if enough are working, large families could be a benefit in sharing of recovery costs. Social networks play a role in disaster warning, perception, and behavior (exposure, resistance). Strong social networks may help bear the cost of rebuilding as well (resilience).
Housing and the built environment. The spatial distribution of the built environment is highly inertial, establishing patterns of peoples' location, use, and travel (exposure). Likewise the quality of construction can determine the ability of individuals or groups to successfully ride out a storm (resistance).
Income and material resources. Income allows spending on prevention items such as retrofitting the house or relocating furnaces to higher floors in a flood. Money or vehicles may also enable a fast exit from a hazardous environment. (exposure, resistance) Of course, money also allows rebuilding to proceed (resilience). On the other hand, those with a lot of wealth have a lot to lose (exposure).
Lifelines (which includes transportation, communication, utilities, emergency response, and hospitals). Telephones and the media provide advance warning of storms. Transportation can provide a way out of the hazard for evacuation or a way in if caught in rush hour (exposure). Utilities of all sorts are necessary for resistance and resilience. Hospitals and emergency response of course provide resistance to the storm, and help to those who have already fallen victim (resilience). Emergency response crews can also lessen exposure by helping people evacuate.
Occupation. Some occupations, such as fishing, tend to be located in harm's way (exposure). Once equipment is ruined, it may be months and a whole fishing season away before insurance or relief payments begin, so opportunity is lost. Self-employed people often have poor documentation of business receipts and therefore may have difficulty establishing the record necessary to receive recovery aid (resilience).
Race and ethnicity. Minorities may encounter discrimination when seeking post-storm aid (resilience) which may change the ability to prepare for the next storm (resistance). They may be confined by real estate discrimination to certain hazard-prone neighborhoods (exposure).

Figure 2. Temporary pipes snake across a street in the low-lying neighborhood of Roughan’s Point in Revere, during the January ‘Blizzard of ’96’. City workers pumped the storm drains in order to prevent damage due to tidal flooding in this physically vulnerable neighborhood.

The problem

Such impacts and the potential for worse ones with climate change indicate the value of a better understanding of how hazardous events and human populations interact. Aggregate estimates of damage of the sort just cited, though useful, do not address the point emphasized in vulnerability analysis: that the impacts of hazardous events are unevenly distributed among and within the exposed populations.

Methods

The literature on vulnerability identifies many elements contributing to differential ability to cope with hazards. Ones frequently mentioned are age, disabilities, family structure and social networks, housing and the built environment, income and material resources, lifelines (including transportation, communication, utilities, and other services), occupation, and race and ethnicity. Studies addressing each of these themes are listed in Table I. Less explicitly dealt with in the vulnerability literature were transience, immigration, and education levels, but the significance of all three can be inferred from discussions of the importance of hazard perception and experience (e.g. Mitchell, 1984). Table II illustrates how various attributes may influence the ability to deal with and recover from storms.

We chose Census data to represent these attributes because they are widely available and familiar to local managers. Data from the 1990 Census on 34 variables reflecting themes from the literature were assembled at the block group level (Table III). The block group is a Census unit containing approximately 1000 people; this unit is chosen for analysis because it is the smallest for which relatively complete socioeconomic data is available. We acknowledge that vulnerability varies on small scales and even at the household level.* Nevertheless, the block group is a practical unit in advising local officials on the allocation of resources.

We used factor analysis as an objective way to simplify our multivariate data set. Factor analysis allows researchers to identify and cluster variables that measure essentially the same underlying theme. Factorial ecology in the 1960’s and 1970’s, for example, showed that many descriptive attributes of urban populations could be grouped into a few factors, but that these factors were not further reducible. These factors displayed differing and characteristic spatial patterns such that city form was not simply a matter of overall ring or sector patterns of all phenomena, but a mosaic resulting from the superimposition of socioeconomic status, family status, and ethnicity. A factor analysis of coping abilities shows how far, and in what combinations, the many variables suggested by the literature measure separate or similar characteristics in the chosen block groups.

We identified five most important factors from the analysis (Table IV) and gave each an appropriate name. The factor that accounted for the largest amount

* Revere has 44 block groups; we extracted and analyzed the data for a larger area consisting of Revere and the adjoining municipalities of Malden, Lynn, and Saugus, with 225 block groups in all. The larger scope allows us to have robustness of analysis as well as a sense of how Revere (with the most floodprone residential area) compares to other towns in the watershed. At the same time, our focus on Revere allows us to keep the focus on social variation within one community rather than institutional differences between neighboring jurisdictions.

TABLE III.
Census variables analyzed

WRKPRNT	Children 17 and under whose resident parents or guardians all work, expressed as a percentage of the population.
AMERINPC	Percent of people who are American Indian, Eskimo, or Aleutian.
ASIAPIPC	Percent of people who are Asian or Pacific Islander.
BIGFAM	Households with 7 people per occupied housing unit.
BLACKPC	Percent of population which is Black.
BLD.39PB	Percent of housing units which were built prior to 1939.
BLIZIMIG	Percent of the population which was foreign-born and came to the U.S. between 1980 and 1990 (approximation of post-Blizzard of '78).
CARPLPC	Percent of people who carpool to work.
CARSPCAP	Cars per person.
CHILD5PC	Percent of people age 5 and under.
COMMUTE	Average travel time to work (minutes) not including those who work at home nor those who do not work.
DISABLPC	Work-disabled people per capita.
FEMALEPC	Percent of population which is female.
FISHERPC	Percent of population employed in fishing, agriculture, or forestry.
HISPNCPC	Percent of the population which is Hispanic.
HOMELESS	Percent of population counted in shelters or on the street.
HOMEVALU	Median value (dollars) of owner-occupied homes.
IMMOBLPC	Percent of the population which is physically immobile.
LANGISOL	Percent of the population which lives in a household without at least one English-speaking adult or older child.
LOCAREPC	Percent of the population which has a low capacity for self-care.
MTG35.PH	Percent of owner-occupied households with mortgages 35 percent or more of household income.
NEWCMRPC	Percent of the population which moved in from 1989 to 1990.
NEWIMMIG	Percent of the population which is foreign-born and entered the U.S. between 1987 and 1990.
NODIPL18	Adults with educational levels less than a high school diploma.
NURSHMPC	Percent of people who live in nursing homes.
NWCMSTRM	Percent of the population which moved in between 1980 and 1990 (approximation of post-Blizzard of '78).
OLD65.UP	Percent of people age 65 and up.
PCINCOME	Per capita income in 1989.
PHONEPH	Percent of occupied housing units with no telephone.
POVRTYPC	Percent of people with incomes below the federally-defined poverty line.
PUBTRANS	Percent of the population that travels to work on public transportation.
RACEOTPC	Percent of race not White, Black, Native American, Asian, or Hispanic.
RENTINC	Median gross rent as a percent of median household income.
SLFMPLPC	Percent of people who are self-employed.

TABLE IV.
Groupings of vulnerability factors

Literature Themes	Census Variables	Factor Name
Factor Grouping 1		
Income/Resources	Low Income	‘Poverty’
	High Fed. Poverty	*Variance explained: 25%*
Race/Ethnicity	Hispanic	
	‘Other’ Race	
	Black	
Education	Few H.S. Diplomas	
Lifelines	Fewer Cars	
Factor Grouping 2		
Transience	Newcomer Since ’80	‘Transience’
	Recent Newcomers	*Cumulative variance explained: 24%*
Built environment housing	Few High Mortgages	
Factor Grouping 3		
Disabilities	Immobile	‘Disabilities’
	Low Self-Care	*Cumulative variance explained: 42%*
	Disabled	
Factor Grouping 4		
Race/Ethnicity	Asian & Pacific	‘Immigrants’
		Cumulative variance explained: 49%
Lifelines	Public Transport	
Immigrants	Immigrants Since ’80	
	Recent Immigrants	
Factor Grouping 5		
Age	Few Elders	‘Young Families’
		Cumulative variance explained: 55%
Family Structure	Many Children < 5	
	Working Parents	

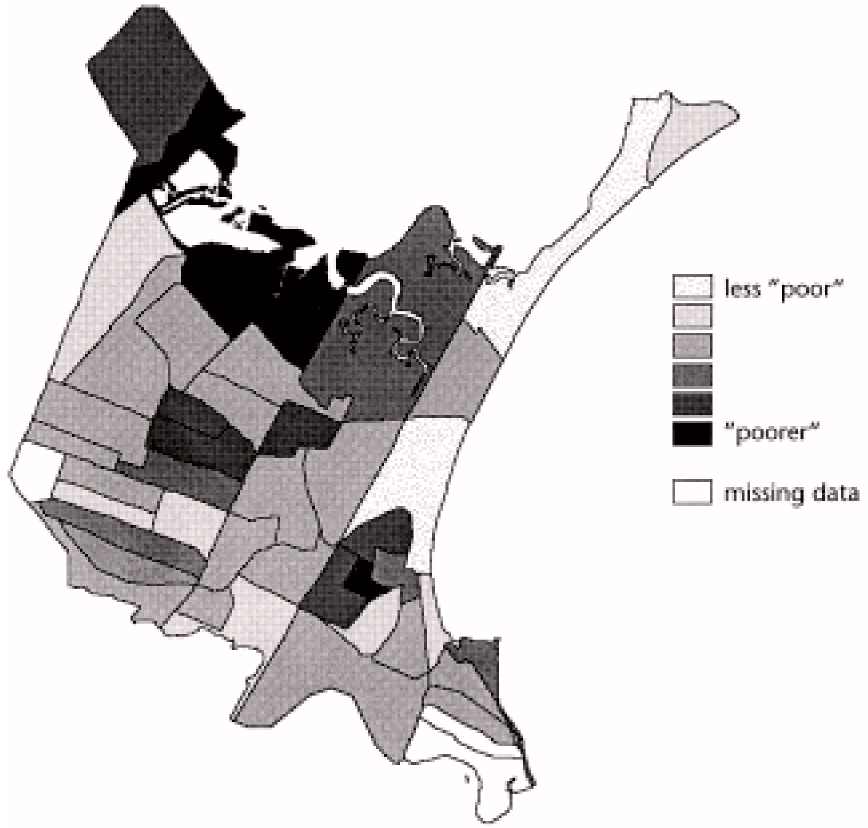

Figure 3. Factor scores on the 'poverty' factor, Revere, MA. The coastline is to the east, with tidal rivers to the north and south. Boston lies directly south along the coast. In this and following maps, north is at the top of the page.

of variance included issues of income and material resources, race and ethnicity, education, and lifelines (transportation, utilities, and emergency response–see Platt, 1991). For want of a more inclusive term, and because per capita income had the strongest association of all the variables, we named this factor '*poverty*'.

The remaining factors, in order of variance explained, were '*transience*', associated most with the people new to the area since a record-setting blizzard in 1978; '*disabilities*', which included measures of immobility, ability to care for oneself, and work disability; '*immigrants*', which reflected the concentration of recent Asian immigrants in certain parts of the study area; and '*young families*', which represented families with young children without a parent at home, high numbers of young children, and a low proportion of elderly residents.

Four more factors, which showed lesser significance, but had eigenvalues of greater than one, included the following groups of census variables: few homeless and high percentage of women; fishing occupations, nursing homes, self employment, and Native Americans; few telephones; and rent as a high percentage of income. For lack of a compelling reason to exclude them, they were incorporated in the composite vulnerability indices described below.

The factor analysis thus underlines the complex and multidimensional character of hazard vulnerability. Low coping ability (high social vulnerability) cannot be reduced to a single variable such as income or unfamiliarity with the area and its hazards. At the same time, the results of the factor analysis suggest that the multidimensional complexity of coping ability may be represented by far fewer factors than the original list of thirty-four variables.

Results

We mapped the factor scores for each individual factor onto a base map of block groups for the town of Revere. Figure 3 is a map of factor loadings for the ‘poverty’ factor. Remember that ‘poverty’ as used here includes a complex of several Census variables. Similar maps were created for each factor.

Mapping each of the factors independently provides valuable information; however, it is also useful to combine the multidimensional factors into a single scalar measure of social vulnerability to provide an overall assessment. We use two methods for obtaining the scalar index of coping ability, (1) averaging, which provides an absolute index, and (2) data envelopment analysis (DEA), which produces a relative measure. The method which practitioners would choose to use in a study depends on a number of circumstances, including confidence in weighting of factors and the end use of the index.

The most common way to combine factors would be to create an index based upon a weighted average, where the weights reflect the importance of each of the factors to the activities or decisions that need to be made. One difficulty in implementing this method centers on the way in which the weights are obtained, which often requires subjective assessments of importance. Another characteristic of this technique is that averaging may obscure high values on one of the factors when it is combined with other factors whose scores are low. For some end uses of an index, e.g., emergency response, this may not be desirable since extreme values may indicate where resources are needed most.

Creating a scalar index using DEA (See Haynes et al., 1993; and Charnes, Cooper, and Rhodes, 1979) has the same mathematical structure as the weighted average except that the weights are obtained for each block group objectively through the use of an optimization model. In this method, no subjective *a priori* evaluations need to be made about the weights. In addition, when DEA is used, block groups that have high values on only one factor may still be identified as vulnerable. The DEA index technique provides a relative measure of vulnerability, ranking block groups on the basis of their comparative degrees of social vulnerability. Note that the DEA measure can change significantly if new block groups are

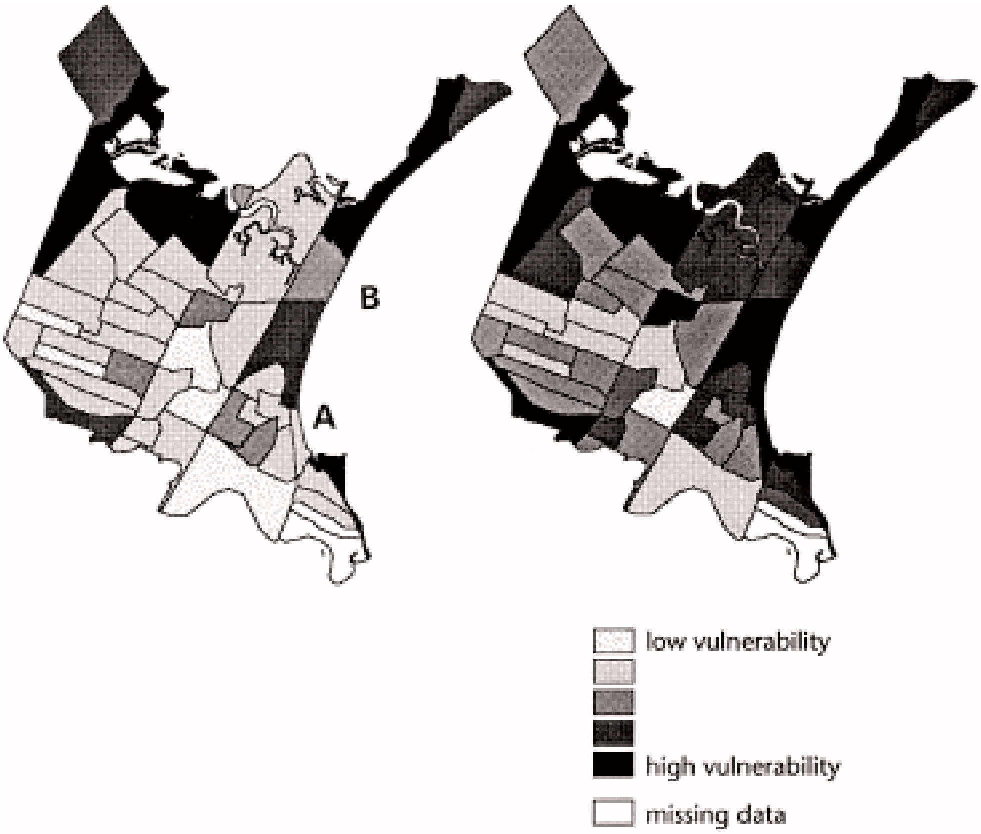

Figure 4. Average vs. DEA overall social vulnerability, Revere, MA. Composite social vulnerability using the average method is on the left, and using the Data Envelopment Analysis (DEA) method is on the right. The block group on the coast at 'A' appears more vulnerable using the DEA method because its inhabitants are highly transient. The block group on the coast at 'B' appears more vulnerable using the DEA method because it contains a large number of disabled inhabitants.

added to the analysis, making this technique sensitive to the set of block groups chosen.

Figure 4 shows the average social vulnerability for Revere on the left (in the absence of other information all factors were equally weighted) and the DEA social vulnerability index on the right. Darker areas are calculated to have a higher degree of social vulnerability. As expected, there are several block groups that appear more vulnerable in the DEA map due to the dampening of high values in the weighted average. For example, one block group (A) is flagged because of a high factor score on transience and appears more vulnerable in the DEA map. Block group (B) has a high factor score for disabilities, and so it also is more vulnerable in the DEA map. For the remainder of the paper, we focus on the DEA map, using a three-category (or low, medium, and high vulnerability) version of the DEA map when discussing overall social vulnerability.

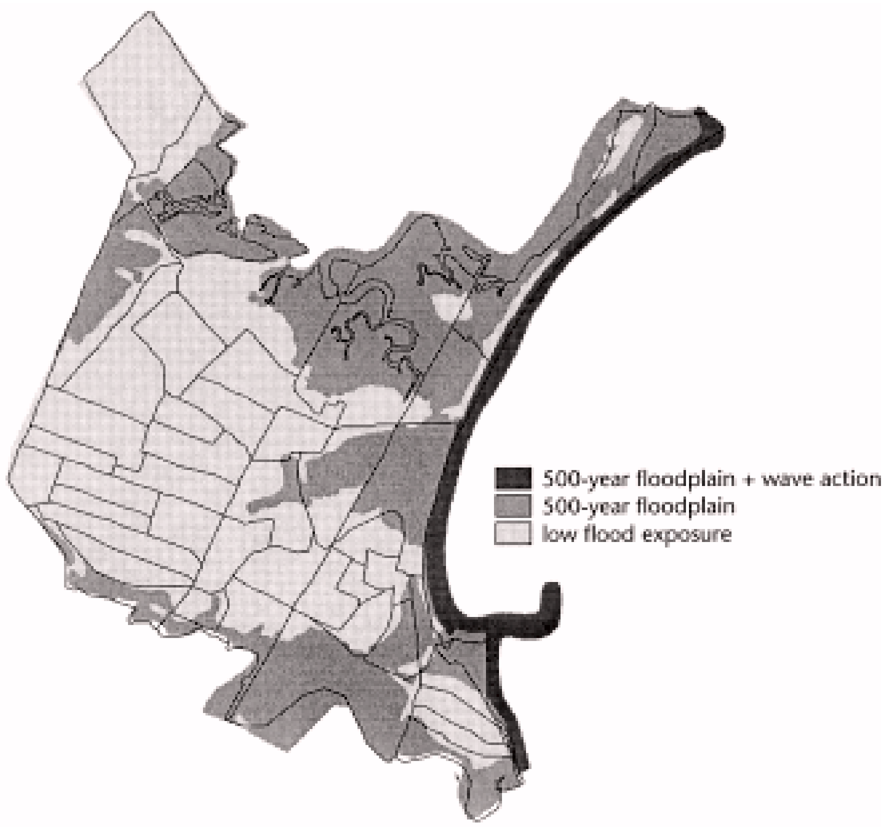

Figure 5. Physical flood exposure, Revere, MA.

In order to understand how social vulnerability interacts with physical exposure to the hazard, we adapted a FEMA Insurance Rate Map of flood zones for Revere (Figure 5). This adapted map has three different risk zones: one of no risk (light gray), one 500 y flood risk zone (medium gray), and one zone subject to both 500-year flood risk and wave action (dark gray). (In our study area, the 100- and 500 y floodplains are coincident for all practical purposes. Either term could be used.)

It is important to note that, though a smaller risk is assumed for people who do not live in the floodplain, they may also suffer the effects of severe storms. They may be affected by wind, rain, snow, and ice damage, and their routes of travel, day care centers, other lifelines, and places of business may also be affected by flooding.

Analysis

Finding all those areas that are both physically high-risk *and* socioeconomically in less of a position to cope with the hazard allows us to display the interaction of

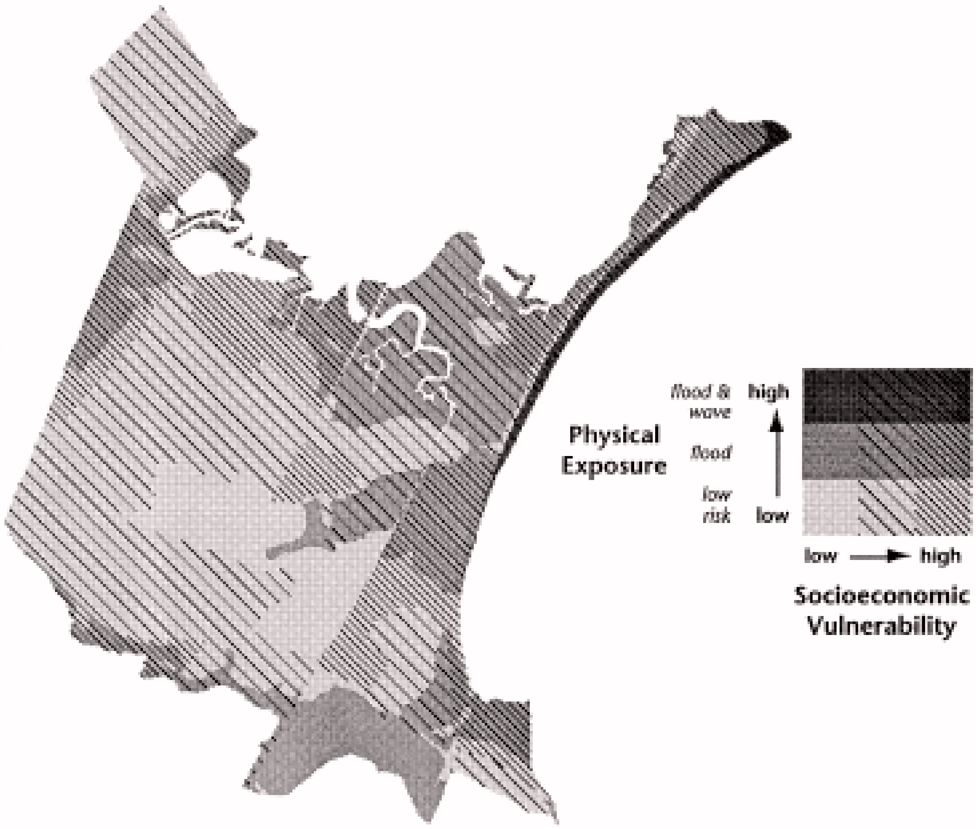

Figure 6. Overall social (DEA) and physical vulnerability, Revere, MA. Note that the upper left legend category, the combination of highest physical exposure and lowest DEA socioeconomic vulnerability, does not occur in Revere.

physical risk with socioeconomic dimensions of resistance and resilience. Analysis of how each block group of Revere scores on the physical and socioeconomic scales lets us create a new, overall vulnerability map of Revere (Figure 6). The legend shows increasing physical vulnerability in darker shades of gray on the Y-axis and increasing social vulnerability in denser crosshatching on the X-axis.

The immediate conclusion that can be drawn from these maps that show how vulnerability varies spatially is that the threat of physical vulnerability is differentially compounded by social vulnerability. Maps at this level of generality are quite useful in pointing out areas that need more in-depth attention. For example, coastal zone and emergency managers have to focus their finite time, personnel, and fiscal resources when deciding on hazard mitigation projects. This choice may be guided by physical vulnerability only (e.g., 100 y flood zones on FEMA maps) or they may be guided, as suggested here, by a combination of physical and social vulnerability (e.g., choosing all combinations of medium to high physical and medium to high

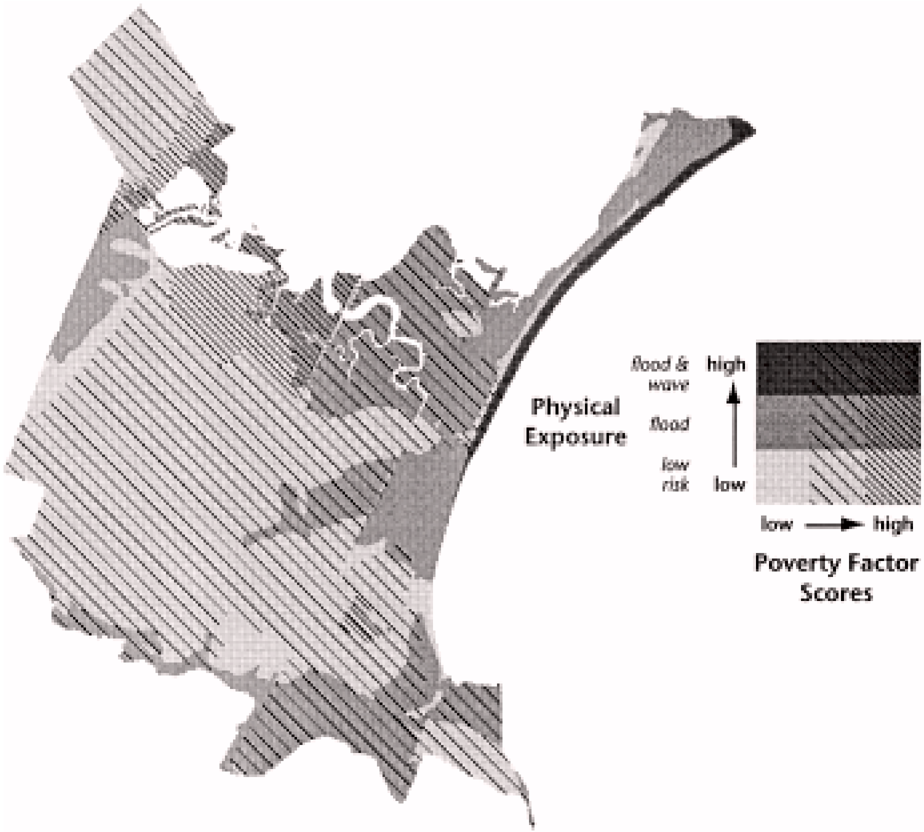

Figure 7. Poverty factor scores and physical vulnerability, Revere, MA. Note that the upper right legend category, the combination of highest poverty factor scores and highest physical exposure, does not occur in Revere.

social vulnerability; or choosing only the areas of greatest physical AND social vulnerability, and so on).

In order to then find out *what* makes an area socially vulnerable, we have to go back to the factor level, and perhaps ultimately even the variable level. The underlying social situation that makes a particular area vulnerable can then inform the strategy and choice of mitigation effort. For example, if an area scores high on the 'disability' factor, emergency evacuation plans could be adjusted to assure earlier warning and evacuation, and the availability of transportation for the physically less able or mobile. In other words, the type and degree of intervention can be adjusted to the special needs in specified floodprone coastal areas. It should be apparent that the scale of analysis is important in determining the use of a map, and that a gradation of scales can be used as a sifting tool, informing where to invest time and resources as more focused studies and actions are planned.

In our study, we go one step back down the scale to the factor level. Figure 7 is a simplified (three-category) version of poverty factor map crosstabulated with

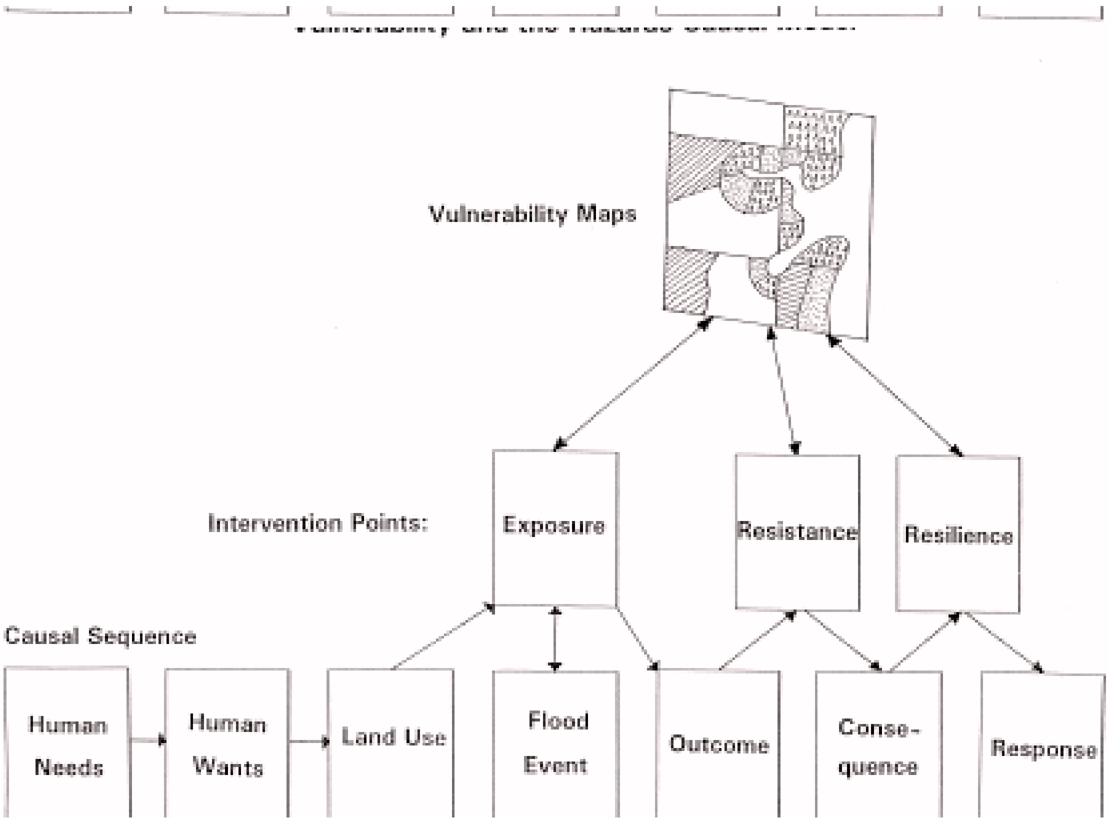

Figure 8. Vulnerability and the hazards causal model.

the FEMA flood zone map. Figure 7 shows *why* in a particular area people are so vulnerable and how they intersect with the three levels of physical risk.

Implications for causal modelling of hazards

More succinctly describing the components of vulnerability through factor analysis allows us to add the concept of vulnerability to a model of how hazards happen. The causal model proposed in *Perilous Progress* by Hohenemser, Kasperson, and Kates (1985) outlines the circumstances that must coincide at the intersection of the human and physical systems in order for a hazardous event to take place. Furthermore, their model is constructed in a way that highlights possible points of appropriate and timely intervention in order to avert the consequences–opportunities to expand the 'practical range of choice' (Wescoat, 1987; White, 1961).

Recognizing and incorporating into the causal model the spatial distribution of the physical and social components of vulnerability (in this case the factors of poverty, transience, immigrants, disability, and young families) will help interested parties focus attention on problems of social justice, a major issue in emerging hazards and global environmental change research (Wescoat, 1993).

According to the causal model, hazards emerge through a sequence of choices and occurrences: human needs, human wants, choice of technology, initiating events, outcomes, exposure, and consequences. A reinterpretation of the hazards causal model to incorporate vulnerability based on this research appears in Figure 8.

In our adaptation of the hazards causal model from technical to environmental hazards, we substitute ‘land use’ for ‘choice of technology’. In doing so, we do not intend to imply that land use or social situation is a ‘choice’ for everyone, merely that landscapes are socially adapted phenomena and need to be thought of as such rather than as *tabulae rasae* on which environmental hazards play themselves out.

In our model, exposure, resistance, and resilience each function as a filter or amplifier for the impacts of the hazardous event at different stages. Where these components of vulnerability are seen to worsen the hazard impact, they identify places where progress could be made in hazard management.

Exposure is determined by both existing land use and by the characteristics of the storm event, such as timing, duration, and intensity. At the same time, the storm as a hazardous event implies an interaction with human systems, so the arrow goes both ways between exposure and storm event, producing an intersection, known as an outcome. For example, flood waters rise to a given height, which potentially affects a given number of houses, businesses, cars, people, etc. The consequences (i.e., the damages to life, health, well-being, and property) of an outcome are then determined by peoples’ resistance to the hazard. Finally, the ability to respond (i.e., recover from the event and prepare for the next) is determined by the resilience of the population or individual.

Another aspect of this model is that a map of each factor can be used to inform each stage of vulnerability (exposure, resistance, and resilience). To use the poverty example, poor people may be constrained by the real estate market to a given neighborhood which has poorly maintained drainage or physical protection from the hazard (exposure). In terms of resistance, poor people may lack the money or equipment to buy or make stormproofing adjustments to their homes. For resilience, they may not have been able to purchase insurance to let them rebuild. To continue the filter/amplifier metaphor of the causal model, ‘turning down’ a vulnerability factor such as poverty in a given area makes the outcomes of hazardous events become more favorable.

Structuralist practitioners, such as Hewitt (1997, 1983, and especially chapters 13 and 14 in Hewitt, 1983: Watts, 1983: Susman, O’Keefe, and Wisner, 1983); Blaikie (1985); and Wisner (1992) might argue (somewhat correctly) that the causal model addresses only the proximate causes of vulnerability, as opposed to systemic root causes such as global capitalism, colonialism, racism, and so on. They might further argue that we merely point out poverty rather than question why poverty exists here and elsewhere in the first place.

We agree that these are necessary efforts. However, we would like to emphasize intervention points in the causal chain that can be addressed within the scope of coastal policy-makers, managers, and community organizers. We also argue that we too attempt to promote a somewhat sophisticated view of poverty as including elements of economics, racism, education, and transportation (see Table IV). Further, we encourage the identification and rectification of more upstream causes of vulnerability as local analysis is performed.

Concerted interagency and community efforts to forge better links between emergency management, public works, labor and employment agencies, and private organizations are useful pathways of action at the community level even if they do not fix, for example, the exploitation of labor through global capitalism. By speaking to the scale, areas, and processes over which local leaders have some control, we hope to leave room for action and even optimism on a grassroots level.

Implications for coastal hazard management

Such practical damage reduction programs might include contingency plans for weather-robust public transportation to and from shelters, insurance centers, places of employment, and regional rail networks, since transportation access issues score highly on each of the poverty, disability, and immigrant factors. Interpreters and victim advocates might be used to help those covered by the immigrants and transience factors to communicate with or to be made aware of available community resources. Many potential initiatives can be identified through vulnerability analysis, and the more ‘proactive’ or ‘upstream’ the step taken, the greater the downstream benefit. Reduced exposure through improvement or elevation of housing stock means fewer people needing to resist or overcome effects of storms. Increased resistance means less need for recovery, and so on.

It is no accident that maps of vulnerability feature prominently in this framework. Based on our factor analysis, they represent a succinct understanding of the distribution of a large number of physical and social variables which is crucial to a more complete picture of the hazards process. On a practical basis, vulnerability maps similar to the ones produced in this study have potential benefits for both crisis management and planning for future contingencies, including potential impacts of global climate change. For example, disaster-management resources can be more easily and swiftly directed to the locales of greatest need, and resources can be applied according to the specific factors that render a certain population socially vulnerable. Vulnerability maps thus allow for the focusing of limited resources on areas of highest priority or of potentially greatest improvement.

Likewise these vulnerability maps should be very useful for generating scenarios. One can model a ‘100 y coastal storm’ (or any other hazardous event) and see who is affected in various ways. Thus, vulnerability maps could be used not only as a response tool to intervene in an ongoing event, but also as an impact assessment tool that is more sophisticated than most current global change impact assessment models, and hence as a planning tool that can be employed even in spite of lacking localized information about changing sea level and storm climate.

By focusing attention and action on communities' current ability to deal with coastal hazards on a local scale, this study suggests that there are many opportunities to improve on hazard management that are beneficial in the present and that leave vulnerable areas in a better position for the future if hazards become exacerbated by climate change. Localities using this type of 'no regrets' approach would be enabled to take action against hazards in spite of a high level of uncertainty about the future.

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