A Framework for Measuring Coastal Hazard Resilience in New Jersey Communities

White Paper for the Urban Coast Institute

By

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Achieving loss reduction and community resilience in the face of disasters requires the engagement of academia, practitioners, the private sector, and the policy community. While there is considerable research and federal activity in the area of disaster resilience, most notably the efforts of the Subcommittee on Disaster Reduction (SDR 2005), there is no common framework or understanding on how to measure and monitor community hazard resilience. This paper provides an approach for establishing a hazard resilience measurement baseline that can serve as a benchmark for monitoring progress towards disaster reduction for New Jersey.

New Jersey's Pattern of Disaster Losses

New Jersey has its share of natural disasters and the losses from these events are increasing, a pattern similar to the nation as a whole. The majority of the state's losses from natural hazards are related to coastal and river flooding, coastal erosion, and hurricane/tropical storms (Figure 1). For the period 1960-2005, natural hazards caused more than 1,200 injuries, 262 fatalities, and more than $2 billion in direct property and crop losses within the state (SHELDUS 2008).

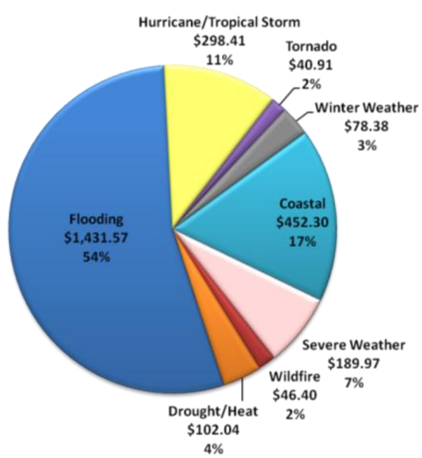

Figure 1 Distribution of New Jersey hazards losses by event type

The distribution of these losses is concentrated in central and southern New Jersey, especially in the coastal counties (Figure 2). The notable exceptions are Sussex and Somerset counties that had severe flooding in 1999 due to Hurricane Floyd's intense rainfall. The map of losses includes only direct losses to property and crops, not indirect losses such as lost income or employment, figures that would make totals significantly larger. Thus, the map of losses is based on a very conservative estimate or the minimum loss level during the time period. These losses reflect both large and small events, some worthy of federal disaster aid, and others less so. New Jersey has received 36 Presidential Disaster Declarations, the most recent one in May 2007 for the Warren Grove wildfire (FEMA 2008). Other notable events for which New Jersey received federal assistance included Tropical Storm Ivan (2004), September 11th terrorist attack (2001), Hurricane Floyd (1999), and the Blizzards of 1993 and 1996. This geographic pattern of losses is a good indicator of a community's vulnerability to natural hazards and its capacity to recover from them, but it is not the only indicator of vulnerability and resilience.

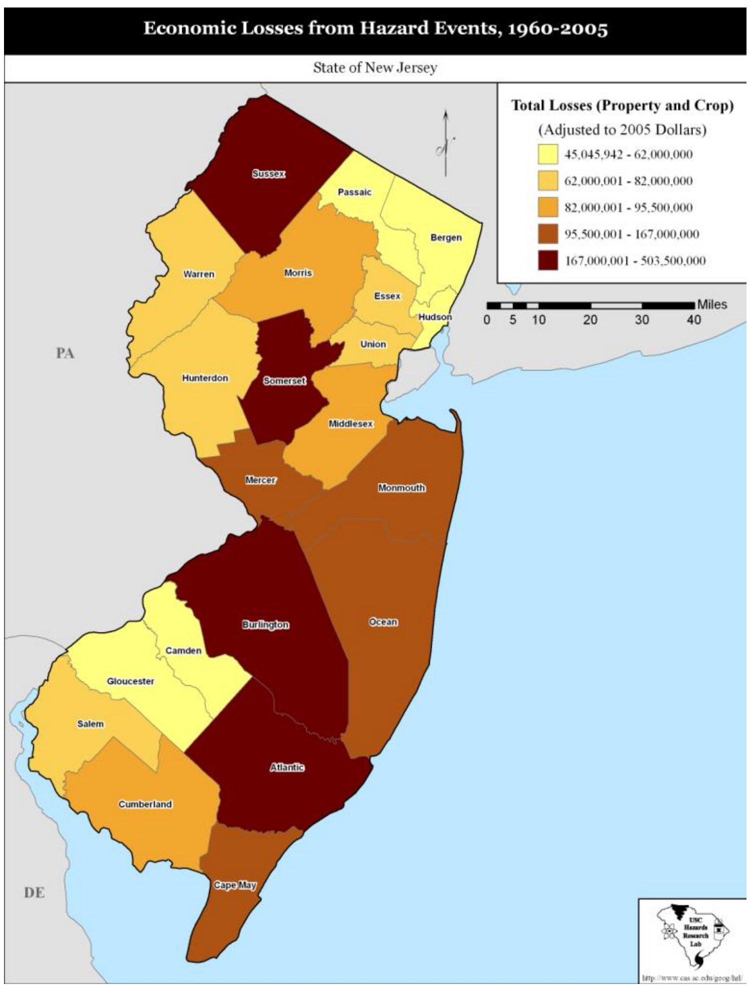

Figure 2 Hazard losses 1960-2005 in ($2005) dollars
Source: SHELDUS 5.1 (http://www.sheldus.org)

Vulnerability and Resilience

The terms vulnerability and resilience are applied to many systems—social, natural, economic, engineering—and at many different units of analysis such as the individual, household, county, or state. Vulnerability and resilience are dynamic characteristics of such systems, changing over time and across space. For the purposes of this discussion, we use the following definitions of vulnerability and resilience that are consistent with the hazards and disasters literature.

Vulnerability is the pre-event characteristic of systems that create the potential for harm or the differential ability to recover following an event. Vulnerability is a function of the exposure (who or what is at risk) and the sensitivity of the system (the degree to which people and places can be harmed) (Cutter et al. 2008). **Resilience** is the ability of a system to respond and recover from disasters. It includes those inherent conditions that allow the system to absorb impacts and cope with an event, as well as those post-event adaptations that help the system to change and learn and thus achieve an acceptable level of functioning.

Factors Contributing to Vulnerability

For more than a half century, social science research has examined communities and residents in the aftermath of disasters. This field-based case study literature suggests a common set of indicators that contribute to vulnerability, which helps explain why some communities or residents are more affected than others, and why they are often slower to recover from the disaster. The most obvious factor contributing to vulnerability is location or proximity to hazard-prone areas such as coastlines or floodplains. This is also termed physical vulnerability or exposure. The density of the built environment is another source of vulnerability since a high density of structures equates to more community assets in harm's way (Heinz Center 2002a). This includes commercial and industrial development and the type of residential housing stock. For example manufactured housing is more vulnerable to high wind conditions than wood-frame or brick construction. Public infrastructure and lifelines such as roads, water, bridges, or power is another source of vulnerability as the loss of this infrastructure could place a large financial burden on smaller communities that lack the resources to rebuild (Chang and Shinozuka 2004). Equally important is the economic health of a community, which in turn is tied to the commercial and industrial development and its vitality. Communities that rely on a single economic sector for their livelihoods, such as tourism or recreation, are more vulnerable than those communities with a diversified economic base. If a hurricane wipes out the beaches and the oceanfront hotels—the mainstay of the local economy—the community may lack the municipal or private resources to recover quickly, further contributing to its economic decline.

Demographic and the social characteristics of residents make some communities more vulnerable than others. The most widely accepted and most often used are age, gender, race, socioeconomic status, special needs populations, non-English speaking immigrants, and seasonal tourists (Laska and Morrow 2007; Enarson and Morrow 1998; Tierney 2006; Tierney et al. 2001; Heinz Center 2002a). Social vulnerability, derived from the factors mentioned above, is one of the foremost explanations for the differential preparedness, impact, and response to disasters (Enarson 2007; Cutter et al. 2006).

Factors Influencing Community Resilience

The increasing pressures on the coasts for development and recreation will inevitably lead to increasing vulnerability (Cutter et al. 2007). In many ways, coastal New Jersey is the poster child for the increasing vulnerability of the nation's coasts with its ever changing shoreline and increasing demand for living and recreational space. However, some of the vulnerability can be mediated by improving community resilience. We should not make the assumption that just because a community is vulnerable, it lacks resilience. But what makes a community resilient? Not surprisingly, most of the scientific literature points to the resilience of natural systems (keeping wetlands and sand dunes intact, maintaining open space, controlling development) as mechanisms for hazard mitigation. In fact, many argue the need to balance environmental and development issues while promoting safe and livable communities is the key to fostering resilience and this can only be done through hazard mitigation planning and managing local land use (Burby et al. 1999). From the perspective of the built environment, improvement in construction practices, building codes, retrofitting homes, elevating homes, are all measures that enhance resilience as does the building of redundancy in some of the critical infrastructure. Social resilience can be enhanced through wealth, insurance, access to other financial resources, social networks, community engagement and participation, local understanding of the risk.

The development of coastal resilience indicators is in its infancy and at present there is no standard methodology or framework for conducting baseline assessments of resilience. There are however, standard methods for conducting vulnerability assessments that are required under the federal Disaster Mitigation Act of 2000 (see for example, South Carolina's hazards assessment (State of South Carolina, 2005)). The systematic development of such locally-based vulnerability assessments provides the basic understanding of the risk and its likely impacts and is the starting point. Once we know where and how communities are vulnerable, strategies for improving their resilience can be targeted more effectively.

Framework for Monmouth County Resilience Assessment

There are four key sets of metrics that are necessary to build a profile or baseline of community resilience (Figure 3). The development of a set of core indicators that measure

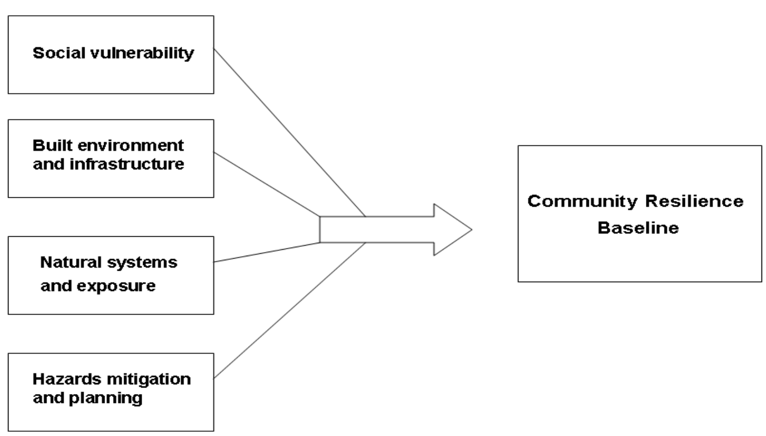

Figure 3 Data Required for Baseline Assessment of Community Resilience

vulnerability is the key to the improved resilience and sustainability of the state's coastal communities. The four components will be described briefly, followed by a listing of candidate variables required for measurement.

Social Vulnerability

Social vulnerability influences individual and community abilities to prepare for, respond to, and recover from disasters. It describes those characteristics of the population that create differential social burdens of hazards and helps explain why the same natural event produces dramatically different impacts within the same geographical area. The Social Vulnerability Index (SoVI), first developed in 2003 (Cutter et al. 2003), uses a common set of broad indicators to explore differences in social vulnerability among places (counties, census tracts, or census block groups). SoVI graphically illustrates the uneven capacity for preparedness and response and provides a useful benchmark for allocating resources to compensate for the different levels of vulnerability. SoVI has been used to asses interstate and intra-state variation in social vulnerability in 2000 (see http://www.cas.sc.edu/geog/hrl/sovi.html) (Figure 4). It has also been downscaled to characterize sub-county levels of social vulnerability at the census tract and census block group level for Charleston, SC; New Orleans, LA; Tampa-St. Petersburg metropolitan area, FL; and the San Francisco Bay Area among others.

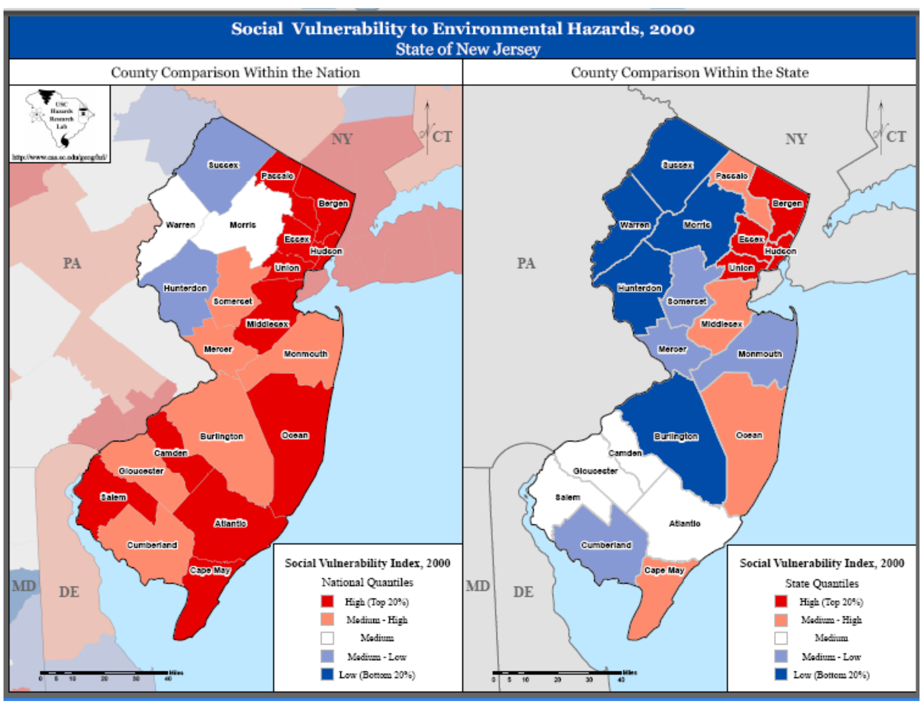

Figure 4 Social Vulnerability Index (SoVI), 2000 for New Jersey mapped for national comparisons (left) and re-mapped for county comparisons only within the state (right)
Source: http://www.cas.sc.edu/geog/hrl/sovi.html

Data. A total of 42 variables are used in the construction of the county-level SoVI. However, not all of these variables are available at the sub-county level, so in applications focused on census tracts or census block groups, a consistent set of 30 variables are used. These are listed below and represent the data needs for constructing the social vulnerability metric for communities.

Table 1 Data Requirements for Social Vulnerability Analyses using SoVI methodology

Census Variable Description (from the 2000 Census)	
% black population	Median gross rent ($) for renters
% Native American population	Number physicians per 100,000 population
% Asian or Pacific Islanders population	% rural farm population
% Hispanic persons	% female headed households, no spouse there
% population under 5 years old	% housing units that are mobile homes
% population 65 or older	% population over 25 with less than High School education
Median age	% civilian labor force participation
% female	% females in civilian labor force
% of the civilian labor force unemployed	% employed in fishing, farming, forestry
Per capita income	% employed in transportation, communications, and other public utilities
Average number of people per household	% employed in service occupations
% families earning more than $100,000	Nursing home residents per capita
% families living in poverty	% Social Security recipients
Median dollar value of owner occupied housing	% migrate to US from abroad in last 5 years
% renter occupied housing units	% population living in urban areas

Procedures. The SoVI is produced through a statistical procedure called a principal components analysis which reduces the 30 variables to a series of 6-8 components that are then summed to produce an overall social vulnerability score. The exact methodology can be found in Cutter et al. (2003) and on the web (http://www.cas.sc.edu/geog/hrl/sovi.html). Once the scores are generated for each census tract or census block group, they can be mapped to provide a visual representation of the variability in social vulnerability for the county (Monmouth), all coastal counties within the state, or for the entire state. The mapped scores also become a data layer within a GIS to analyze social vulnerability in relation to other metrics (Figure 5).

Built Environment and Infrastructure

Measures of the built environment and infrastructure provide an overall assessment of the amount of public and private property that could be damaged by disasters, and the likely economic losses. It also provides an indicator of the community response capacity (e.g. public safety structures, shelters, health care facilities), as well as the identification of critical infrastructure such as pipelines, roads and bridges, water treatment and storage, communications, and power transmission. For example, coastal communities accessible only by a two-lane bridge over the inter-coastal waterway may be more vulnerable than those with a number of different access routes. Should that bridge get destroyed in a hurricane, for example, the community would remain isolated and dependent on airlifts or boatlifts for vital supplies until such time as alternative access routes could be constructed. If the transportation route in question is a main arterial, such as Interstate 10 along the Gulf Coast, or the Garden State Parkway in New Jersey, closure of such vital roadways results in interruptions in the movement of goods, people, and relief supplies to the affected area, and increases recovery time. There is no standard index for built environment vulnerability, like there is for social vulnerability, but there is some initial work being done (Borden et al. 2007).

Data. A list of candidate variables for determining built environment vulnerability is listed in Table 2. The most appropriate scale for these variables is at the census tract or census block group. Not all of these may be available, but the goal is to obtain as many as possible within each broader category. It is important, however, to have data representation within each category. Italicized variables are easily obtainable from US Census and other readily available sources such as FEMA's HAZUS-MH software.

Table 2 Candidate Variables for Built Environment and Infrastructure Assessment

Category	**Variable**
Residential	*Median age of housing units, Housing units built before 1960, Density of housing units, Density of mobile homes,* Number of building permits for new housing units, Daily water usage, Value of all residential property
Commercial & Industrial Development	*# commercial establishments, # manufacturing establishments, Value of sales for all businesses ($), value of all sales for all farms,* Industrial earnings ($), *Banking offices*, Private non-farm business establishments, *Hazardous materials facilities,* # Small businesses, # marinas
Lifelines	*Hospitals, Schools, Electric power facilities, Potable water facilities, Wastewater facilities, Dams, Police stations, Fire stations, Oil and natural gas facilities, Nuclear facilities, Emergency centers, Number of hospital beds, Communications towers/antennae*
Transportation Infrastructure	*Airports*, *Bus terminals*, Ferry facilities, *Interstate miles*, *Other principal arterial miles,* Fixed transit and ferry network miles, *Rail miles, Highway and rail* bridges, Ports
Monuments and Icons	*Churches, Landmark and Historic registry buildings, parks*

Procedures. Following the statistical procedure for social vulnerability, the built environment variables can also be reduced to multi-variable components. The resulting components are then summed for each enumeration unit (e.g. census tract or block group) to produce an overall score on building vulnerability. These scores can then be mapped using GIS to illustrate differences within a county (Figure 5).

Natural Systems and Exposure

There is more research on natural systems indicators of sustainability and resilience than on any other component. In coastal areas, for example, wetlands and dunes offer a buffer against impending storm surges, while biodiversity enables the system to recover more quickly after a disturbance. Species at risk from over-harvesting, pollution, or habitat degradation influence the economic vitality of communities dependent upon them for their livelihoods and thus incur an economic loss when nature's services are diminished. The best place to begin with assessments of natural systems is the Heinz Center's report, *The State of the Nation's Ecosystems* (Heinz Center 2002b). In addition to national indicators, the report lists candidate indicators for coastal ecosystems. The majority of these are focused on the natural ecosystem, not the human use of it.

Data. While ecosystem services are one aspect of natural systems that are important for coastal communities, there are others (McFadden et al. 2007). The following candidate variables provide a more comprehensive view of coastal vulnerability and resilience to disasters, those only based on ecosystem services.

Table 3 Candidate Variables for Natural Systems and Exposure

Variables
Area of dunes
Average dune height
Average beach width
Erosion rates
Acreage of wetlands
Wetland/habitat loss (% change from previous decade)
Acreage of undisturbed habitat
Coastal subsidence (rate per year)
Sediment supply (estimated berms and offshore bars)
and location of coastal defenses (groins, jetties, seawalls, revetments)
and size of storm water detention basins
Water contamination (surface and ground)
100-year and 500-year flood zones delineations
Storm surge inundation zones
Land cover classification
Amount of impervious surfaces
Projected Sea Level rise from IPCC

Procedures. This element in the framework is not statistically-derived, but utilizes common spatial analysis techniques such as overlays. Each of the indicators is represented as a separate "data layer" within a GIS and covers the entire county (e.g. Monmouth) or study area (Figure 5). For example, one layer illustrates the 100-year flood zone as defined by FEMA's Q3 data. Another layer represents the storm surge inundation zones as modeled by the National Hurricane Center's SLOSH model. Once all the layers are constructed, they can be overlain within the GIS to identify areas of overlap or intersection. The higher the number of hazardous zones or sensitive areas that intersect within a unit of analysis, the higher the exposure level and vice versa. The GIS-based analysis also enables the determination of the causes of high or low exposure or sensitivity. For example high exposure areas along the coast might include the intersection of data layers representing wetlands, dunes, flood zones, storm surge inundation, coastal defenses, while an equally high exposure areas inland might be a function of impervious surfaces, land cover, and flood zones.

Hazards Mitigation and Planning for Resilience

There is considerable evidence in the literature that risk reduction and hazards mitigation planning offer the best path towards enhancing community resilience (Burby et al. 1999). There are many examples of resilient cities, rebounding after both natural disasters and human-induced destruction such as warfare (Vale and Campanella 2005). Using a slightly different perspective the SDR (2006, p. 1) suggests that the characteristics of resilient communities include the following:

- Relevant hazards are recognized and understood.
- Communities at risk know when a hazard event is imminent.
- Individuals at risk are safe from hazards in their homes and places of work.
- Disaster-resilient communities experience minimum disruption to life and economy after a hazard event has passed.

As communities consist of physical infrastructure, emotional ties, and cultural institutions, it is difficult to adequately measure many of these less tangible components that foster resilience. These include elements such as local leadership, social capital and networks, the role of faith-based institutions within the community, non-governmental organizations, and most importantly, the values, ethics, and collective responsibility toward disaster reduction within the community.

<u>Data.</u> Table 4 lists those variables that lend themselves to measurement at the community level and thus provide a baseline for measuring progress toward resilience.

Table 4 Candidate Variables for Hazards Mitigation and Planning for Resilience

Variables
Disasters/emergency response plans
Building standards, codes and enforcement
Hazard mitigation plans and hazard vulnerability assessments (required by DMA 2000)
Comprehensive plans (Land use and growth management)
Zoning ordinances prohibiting development of high hazard areas
Continuity of operations plans for local governments
Interoperable communications among police, fire, and emergency responders
Disaster recovery plans
Participation in NFIP
Coastal setbacks for development
Dune management districts
Transfer of development rights to discourage development in sensitive areas
Fiscal policies to shift public infrastructure costs (water, sewer, roads) to developers
Provision of risk/hazard information to the public
Tabletop and mock-exercises and drills for disaster response

Procedures. This element in the framework must be conducted at the local community (or municipal) level within a county. If comparing a number of different counties and their communities (e.g. all of New Jersey's Atlantic coastal counties) then data on the above is required for each county as well. Rather than providing a detailed analysis of each plan, a simple checklist can be developed that illustrates the presence or absence of each of the elements. Communities can be scored based on the number of elements out of the total (e.g. 5/15 or a score of 0.33). These scores can then become another baseline data layer within the GIS, where higher scores represent more resilience (Figure 5).

Constructing the Community Resilience Baseline

Each of the four components within the framework (social vulnerability, built environment/infrastructure, natural systems and exposure, and hazards mitigation) are represented within a GIS as separate data layers using the hazards of place model of vulnerability (Cutter et al. 2000). Through the analytical procedures within the GIS, these layers can be combined to illustrate the composite pattern for the entire county (Figure 5). For example, the composite maps of social vulnerability and built environment can be mapped where high values illustrate greater levels of vulnerability. A composite of the natural systems and exposure can also be created where high values represent more exposure or greater hazard-proneness (Cutter et al. 2000). When all three layers are combined, they represent the intersection of values for social, built, and natural systems and clearly identify areas that are high on each of them. The final part of the analysis is to incorporate the mitigation component. Here, higher values represent progress towards resilience and vulnerability reduction. Within the GIS, the mitigation values are thus subtracted from the total vulnerability scores because of their role in lessening the impact of disasters.

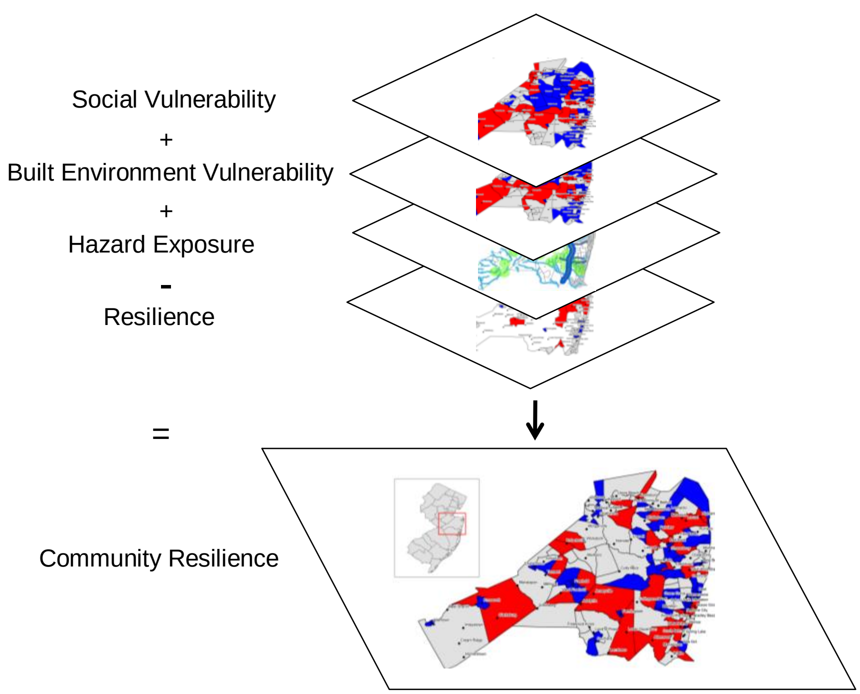

Figure 5 Schematic representation of resilience baseline GIS integration methodology

Summary

As the development increases in coastal areas, more people and more property are at risk every year. Coupled with the inevitability of climate change and its adverse impacts, it is only a matter of time before the next coastal catastrophe is upon us. The time to take action is now, and the best place to start is building disaster resilient communities, especially in our coastal areas. But, we need to know the existing conditions and establish a starting point, so that we can measure progress towards achieving such resilience. This baseline must consider our existing vulnerabilities, those fostered by our social systems, the built environment, and nature itself. To that we must add our abilities (or lack thereof) to plan for and mitigate such threats. This paper provides an initial conceptual framework for accomplishing such a baseline-- one that will require testing and refinement at the local level.

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