

A framework for using GIS and stakeholder input to assess vulnerability to coastal-inundation hazards: A case study from Sarasota County, Florida

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Abstract. Continued development in coastal communities results in an increase in the number of people and assets exposed to the type of catastrophic hazards recently displayed by Hurricane Katrina. Traditionally, the vulnerability of coastal communities has been measured either on a micro (community) or a macro (regional) scale. We present research that suggests vulnerability assessments need to be conducted on both micro and a macro scales to more fully address many of the components that contribute to localized community vulnerability. Research presented in this chapter utilizes a GIS methodologically heavy case study of Sarasota County, Florida, in conjunction with an extended version of a vulnerability framework developed by Füssel (2007) to consider traditional components of vulnerability at both the micro and macro scales. This is accomplished through the theoretical concept of geospatially dependent vulnerability where it is demonstrated that local community vulnerability is multi-scalar and thus must be measured at multiple geographic scales to provide a vulnerability analysis sufficiently robust to adequately aid communities in hazard mitigation and resilience enhancement.

Keywords. climate change, GIS, hazards, hurricanes, resilience, vulnerability

1. Introduction

The storm surge and subsequent catastrophic damage from Hurricane Katrina along parts of the Gulf of Mexico coastline [1,2] demonstrated that coastal communities are not prepared for geophysical events of such magnitude. Two worldwide trends—one biophysical and one societal—suggest an increasing potential for a repeat of the Katrina catastrophe. A significant biophysical trend is sea level rise (SLR) associated with global climate change [3,4,5,6,7]. In addition to accelerated coastal erosion, ecosystem degradation, and saline intrusion, SLR will likely increase the inland penetration of hurricane storm surge [8,9]. A significant societal trend is the continuing development of low-lying coastal land that increases the amount of community assets

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in hazard-prone areas [8,9,10]. These two trends, as well as other biophysical and socioeconomic changes, will take place simultaneously, thus placing multiple, often synergistic stresses on coastal communities [11].

The increase in future storm-surge zones due to SLR and continuing development of these zones suggest coastal communities, both in the Gulf Coast and elsewhere, will become increasingly vulnerable to hurricane storm surge. Therefore, comprehensive vulnerability assessments are needed in hurricane-prone communities to facilitate planning aimed at reducing potential losses from contemporary and climate-change-enhanced hazards. To support risk-reduction planning effectively, these vulnerability assessments must successfully integrate geospatial analysis and stakeholder involvement.

This chapter summarizes a case study in west-central Florida (USA) to demonstrate how vulnerability assessments that integrate geospatial analysis and stakeholder input are used to understand and communicate current and future SLR-related vulnerability in hurricane storm-surge zones. To structure this case study, we first discuss vulnerability as a conceptual framework, vulnerability assessments as they apply to hurricane storm-surge and SLR hazards, and stakeholder interaction.

2. Vulnerability as a Conceptual Framework

Vulnerability is a term that crosses many academic disciplines without consensus on its definition [12,13,14,15,16]. It is most simply defined as the potential for loss [12]; however, various definitions are applied depending on the disciplinary area of study and epistemological orientation [17]. The existing literature has illustrated these differences carefully [e.g., 12,14,15,18,19,20], and for this reason and space limitations, we do not spend additional time reviewing disciplinary differences concerning the definition of vulnerability. However, the broad range of definitions, conceptualizations, terminologies, and theoretical frameworks for vulnerability become problematic when applied in an interdisciplinary setting, such as climate change research [20,21]. We chose to employ the categorization of vulnerability as a function of exposure, sensitivity, and adaptive capacity [13,14,15,22,23,24,25]. Exposure refers to hazard proximity of an object, sensitivity refers to differential degrees of potential loss among objects due to this exposure, and adaptive capacity refers to the ability of an object or system to adjust to hazards and impacts. This categorization of vulnerability is most evident in the natural hazards and global change literatures and, therefore, fits the present research well.

The foundations for hazard-related vulnerability research can be traced to Barrows [26] and its focus on society's adjustment to environmental stressors and to Gilbert White and colleagues at the University of Chicago whose research reshaped United States flood management policy [27,28,29,30,31]. Prior to this work, hazard studies emphasized physical aspects of extreme events and engineering solutions with little to no discussion of human exposure and adaptation. Work by White and others focused on human exposure to hazards and discussed how exposure was a complex issue involving human contestation with the physical environment for space. Research also focused on why this contestation existed (e.g., why people chose to live in flood hazard zones), offering the notion that modifying human action and implementing engineering options could both be viable solutions to limiting exposure to hazards [30].

Building on these foundations, subsequent research has explored the premise that behavior modification by some portions of society may not be possible due to lack of resources or coping abilities [e.g., 12,32,33,34,35,36]. These differences in resource access create variations in hazard exposure and sensitivity where segments of a society are disproportionately affected by disasters [37,38]. The “hazards of place” model contends that place vulnerability is the integration of biophysical indicators of geographic context and socioeconomic indicators of social fabric [31,39]. Füssel [20] adds to this framework by stating that vulnerability results from exposure to external biophysical and socioeconomic stressors (e.g., an extreme physical event, national policies) and from internal characteristics of a system (e.g., local environmental conditions, household incomes, social networks) that influence the extent of the stressors’ impacts on the system.

The vulnerability of people or groups in an area is typically described by a series of indicators [40] that depend on the researcher’s conceptualization of vulnerability [20]. These indicators include infrastructure, social capital, economic well being, access to resources, and physical location to name a few [24,33,40,41]. The study of vulnerability continues to evolve with research attention shifting from simply understanding the concept vulnerability to developing analytical methods for assessing vulnerability [17,29,31,39,42,43]. Many contend that vulnerability indicators and their assessment have meaning only in reference to a particular place or situation [20,43,44]. In contrast, others argue that efforts to quantify place vulnerability should be abandoned in favor of a focus on select variables or components and specific stressors [20,45]. We support the focus on place in vulnerability assessments [24,25,31,46,47], but see a need for specific indicators unique to hazard type and geographic location to replace traditional vulnerability indicators that are too general to form a comprehensive assessment. An assessment based on a contextual framework that fails to consider all internal and external components that contribute to a place’s vulnerability would be incomplete and could thus fall short in guiding SLR-related hazard mitigation and adaptation strategies. Therefore, we adopt the vulnerability assessment framework reviewed in Füssel [20] to consider social, biophysical, internal, and external indicators in our research.

The framework presented by Füssel [20] categorizes vulnerability into four broad dimensions—the *system* (e.g., economic sector), the *attribute of concern* (e.g., human lives), the *hazard*, and the *temporal reference*. We extend this framework by assessing vulnerability as specific not only to particular hazards and places, but also to the multi-scalar aspects (e.g., internal vs. external) inherent in Füssel’s *system* dimension. We respond to calls for greater integration of internal and external factors in climate-change-related vulnerability research [20,43,48] by examining the theoretical concept of inter- and intra-community *geospatially dependent vulnerability*, defined here as vulnerability that is diminished or intensified depending on the spatial proximity of traditional vulnerability indicators. For example, the vulnerability of a community with no health care facility is linked to the vulnerability of the nearest community with a health care facility thereby creating a dependent connection for the first community. We propose that these multi-scalar indicators (e.g., electrical power grid, water systems, natural gas distribution networks, roads and bridges, etc.) have a great influence on geospatially dependent vulnerability and should be integral to comprehensive vulnerability assessments related to climate-change hazards [20,49].

We assess multi-scalar aspects of vulnerability by coupling geospatial analysis with multi-criteria collaborative decision-support methods. In our work, geospatial

analysis involves the use of geographic-information-system (GIS) tools to integrate modeled physical data delineating potential contemporary and SLR-enhanced storm surge inundation zones with socioeconomic data characterizing coastal development. Multi-criteria collaborative decision-support methods involve the use of focus groups to validate and expand GIS-based results with local expert knowledge [50,51,52,53,54] and to include value-based human dynamics of geospatially dependent vulnerability, population growth, and development. Our integrated approach ensures a comprehensive vulnerability assessment by providing a method for integrating traditional and non-traditional infrastructure components that are internal and external to the system. This approach supports the development and advancement of system-level mitigation strategies that increase community and regional resilience.

3. Use of GIS to Assess Vulnerability to SLR-enhanced Storm Surge

Assessing vulnerability to SLR-related hazard impacts requires knowledge of local physical factors (e.g., bathymetry, topography) and socioeconomic factors (e.g., population demographics, economic well being). To date, however, assessments have measured impacts at broad regional scales [55,56,57,58,59,60,61] that are too general for practical use in local hazard mitigation efforts [62,63]. To support local planning efforts, there is a need to model SLR and potential hurricane storm surge on much smaller regional or, if possible, local scales in conjunction with community vulnerability assessments.

From the hurricane-hazard perspective, the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model output provided by the United States National Oceanic and Atmospheric Administration (NOAA) has grid-spacing at a relatively fine regional scale (approximately 3.2 km) that can be useful for local vulnerability assessments [9,64,65,66]. An early example of an effective use of NOAA's SLOSH model for vulnerability assessments was a flood insurance study completed by Mercado [64] to determine the 100- and 500-year return period for stillwater elevation in Puerto Rico and the United States Virgin Islands. The use of NOAA's SLOSH model for local vulnerability assessments, however, has limitations (traditionally plus or minus 20 percent error) because several of its empirical coefficients (including wind drag, eddy viscosity, and bottom slip) are universally set as best fits constraints derived from historical storm events and do not take into account the specific geography of the modeled area. In spite of these limitations to the SLOSH model, the exactness of its output is still more than adequate for our study given our primary research goals. Other storm surge models exist, such as The Arbiter of Storms (TAOS) [67] and the NOAA Advanced 3D Circulation Model (ADCIRC) [68] however, the outputs of these models are not uniformly available for most United States coastal locations.

The National Hurricane Center (NHC) in conjunction with NOAA has divided the United States coasts into 38 elliptical basins for SLOSH modeling each consisting of hundreds of grid cells. NHC SLOSH simulations consisting of hundreds of hypothetical hurricanes of various Saffir-Simpson categories were performed to determine at-risk areas for storm surge for the United States coasts. These hypothetical hurricane simulations consisted of a broad range of forward speeds, landfall directions, and landfall locations for each of the 38 elliptical basins and were used to generate envelopes of water reflecting the maximum surge height obtained in each grid cell for

each model run. After all model runs were completed, a composite of MEOWs or Maximum Envelopes of Water were formed for each grid cell. Maximum surge heights for each gridded cell correlated with various hurricane storm intensities and tracks are contained within each MEOW. The Maximum of MEOWs (MOM) is also calculated by SLOSH and represents the maximum surge height for each cell for any hurricane regardless of storm track, land-falling direction, or Saffir-Simpson category [69,70]. We employ the output from the SLOSH model that consists of five gridded layers corresponding to storm-surge levels for category 1-5 intensity hurricanes on the Saffir-Simpson scale for our analysis.

The use of GIS in understanding societal vulnerability to hurricane storm surge varies and has included heuristic tools to support local mitigation planning [71], critical facility and evacuation impacts [72], and population demographic analysis [31,73]. Cutter et al. [31] used GIS to integrate social and biophysical indicators of vulnerability in spatial terms and demonstrated that biophysical vulnerability does not always intersect with social vulnerability, thereby showing the importance of place in vulnerability assessments. With regards to the influence of sea level rise on altering future hurricane hazards, Wu et al. [8] and Kleinosky et al. [9] used GIS to produce contemporary and future vulnerability analyses for coastal communities (Cape May, New Jersey and Hampton Roads, Virginia, respectively) and echoed the Cutter et al. [31] findings of the importance of social and biophysical components in place vulnerability. In addition to static assessments of contemporary hazards, these studies included *dynamic* aspects (as phrased by Füssel, [20]) of vulnerability by modeling SLR. Wu et al. [8] was one of the first efforts to use GIS tools to estimate the impacts of SLR-enhanced storm surge on coastal communities by adding 30, 60, and 90 cm of SLR to SLOSH model outputs. Rygel et al. [17] and Kleinosky et al. [9] extend this work by considering the affect of 30, 60, and 90 cm of SLR on vulnerability in the 16-county Hampton Roads metropolitan area. Rygel et al. [17] specifically investigates social components of Hampton Roads' vulnerability using a principal components analysis and a novel Pareto ranking scheme.

Our research extends and adapts the work by Wu et al. [8], Rygel et al. [17], and Kleinosky et al. [9] in several ways. First, we incorporate recently modified projections that suggest sea level will rise by 0.8 to 2.0 m by 2100 [58,60,74,75]. Second, we include a GIS-based method from Wood et al. [46] to determine which societal components are located within the various risk zones. Finally, we incorporate information gathered via stakeholder interaction to complete a comprehensive vulnerability assessment.

4. Stakeholder Interaction

4.1. Collaborative Decision-making

Every day, individuals and organizations face spatial decisions. Individuals make spatial decisions—e.g., which route to take to work, where to shop—typically without formal analysis because the consequences of incorrect choices are usually not dire. Organizations, however, are responsible for making spatial decisions that affect larger groups of individuals—e.g., where to site new water treatment facilities, proposed residential and commercial development, or road and street infrastructure—and thus

have a need for formal analysis in their decision-making process. Collaborative spatial decision-making (CSDM) involves discussions and negotiations among a group of stakeholders, decision makers, and technical specialists to address spatially relevant issues [76,77].

The role of stakeholder interaction in long-range comprehensive planning is well documented and increasing [50,54,76,77,78,79,80,81]. The desire to increase stakeholder involvement has grown out of the realization that those affected by public decisions should have more input in the CSDM process [76,77]. Stakeholder involvement in research that has profound societal impact (e.g., climate change) also provides local participants the opportunity to improve their understanding of this scientific research, which serves to validate and confirm the science in the minds of nonscientists [50,51,52,54,82].

When community issues and plans have a high degree of complexity, uncertainty, and conflicting values, community members often respond with a stance of “not in my backyard” to a potential solution. This situation can be avoided if a more diverse group of stakeholders are brought into a CSDM process to reflect the varied domain expertise, political agendas, and social interests inherent in any community [76,79,80,83,84]. Increased collaboration and stakeholder involvement in group decision-making, however, is not problem-free and can lead to overly social or emotional attachments to issues, to judgments made before adequately defining the problem, and to pressure felt by subordinates that often serve to inhibit creativity [76,77,85,86]. Potential organizational issues include meetings that are disorganized, inconclusive, and contain redundant or digressive conversation [76,77,78,80,85,86].

To minimize the conceptual and organizational issues related to CSDM, Jankowski and Nyerges [76] developed the *Adaptive Structuration Theory* and the subsequent *Enhanced Adaptive Structuration Theory* (EAST2) as ways to explain how decisions on the micro stage (e.g., local) influence and are influenced by decisions on the macro stage (e.g., global). These theories focus on describing group stability versus group change and the human-computer-human interaction that incorporates advanced technology for group interaction. A primary goal is to reduce the complexity of the decision problem in order to lighten the cognitive workload of participants [76]. The micro-macro framework (much like Füssel’s internal and external indicators) can serve as the basis for a participatory decision strategy (Table 1) [76,77].

Our research incorporates Jankowski and Nyerges’ macro-micro framework with Füssel’s internal and external conceptual framework for vulnerability to create a macro-micro vulnerability assessment. The Florida case study detailed later in this chapter utilizes a hybrid method of focus groups and participatory mapping to complete phases A and B of Jankowski and Nyerges’ Macro-Micro, Participatory Decision Strategy. Ideally a CSDM session would be completed prior to the implementation of any mitigation strategies. It was, however, not the intention of this research to complete a CSDM session but only to determine if climate modeling could be used by local stakeholders to arrive at spatial decisions that could be incorporated into long range comprehensive plans. Subsequent research by this team will complete the CSDM for our study site.

Table 1. Jankowski and Nyerges' Macro-Micro, Participatory Decision Strategy

Micro-Activities in a Decision Strategy	Macro-Phases in a Decision Strategy		
	Intelligence about values, objectives, & criteria	Design of a set of feasible options	Choice about recommendations
Gather	issues to develop & refine value trees as a basis for objectives	primary criteria as a basis for option generation	values, criteria, & option list scenarios for evaluation
Organize	objectives as a basis for criteria & constraints	& apply approach(es) for option generation	approaches to priority & sensitivity analyses
Select	criteria to be used in analysis as a basis for generating options	the feasible option list	recommendation as a prioritized list of options
Review	criteria, resources, constraints, & standards	option set(s) in line with resources, constraints & standards	recommendation(s) in line with original value(s), goal(s) & objectives

4.2. Focus Groups and Participatory Mapping

Successful application of vulnerability assessments requires local knowledge gained through stakeholder interaction [50,51,52,53,54,87,88,89]. To involve stakeholders in our case study, we use focus groups and a participatory mapping exercise. The use of focus groups for stakeholder interaction began as a market research technique first cited by Bogardus in 1926, and later refined by Merton and his research team in the 1940s to study participant reactions to wartime propaganda [90]. Focus groups themselves are effective for developing a deeper, more nuanced, and more contextualized understanding of the kinds of value-based human dynamics involved in decision-making than the knowledge one gains from quantitative models alone [91, 92,93,94]. Decision-making policy concerning climate change often relies heavily on information collected through focus group research [95].

Participatory mapping relies on stakeholder familiarity with a place to elicit intimate knowledge of local surroundings in a spatial context [89,96,97,98,99]. Local knowledge that is provided by stakeholders who are intimately familiar with their communities that is captured on workshop maps can be coupled with expert information that is supplied by scientific research teams to produce a comprehensive understanding of community issues. In participatory mapping sessions, stakeholders provide information by collaboratively drawing on study-area maps and, in doing so, they validate scientific research through personal familiarity with their community [100].

Our case study follows a *sequential explanatory mixed-methods* strategy of inquiry as the research model. This model involves a sequential data collection process that starts with quantitative data (e.g., GIS-based analysis) and follows with qualitative data collected in hybrid session of focus groups, and participatory mapping complemented by semi-structured interviews. Research emphasis can be placed on either the quantitative or qualitative data or both. Most often with this model, and as evidenced in our research, the qualitative data are used to explain or strengthen the quantitative data. Quantitative data or analysis can guide the project, while qualitative procedures obtain broader, more-diverse perspectives that inform the narrower results of the quantitative analysis [101].

5. Case Study

This case study is part of a larger body of research that has an overall goal of increasing community resilience to future hurricane storm surge through developing a collaborative decision support system. For this chapter, we provide an overview of the study area, a geospatial approach for delineating hazards and assessing variations in community exposure, and methods for involving stakeholders in a participatory mapping exercise.

5.1. Study Area

This study focuses on Sarasota County, located on the west-central coast of Florida, and on the 27 incorporated cities within the county that have land prone to hurricane storm-surge inundation (Figure 1). Due to its desirable coastal location and subtropical climate, the county has experienced significant growth in recent years, with a population increase of 17% from 1990 to 2000 [102]. According to Sarasota County's historic preservation plan [103], public officials face challenges of how to balance increasing population growth and development with the need to lower community vulnerability to natural hazards. Faced with the continual storm-surge threats posed by hurricanes and the potential for significant changes in the current physical landscape given future sea-level-rise scenarios, Sarasota County is a prototypical place where growth and development will likely intersect with SLR to increase vulnerability to hurricane storm surge.

5.2. Hazard Assessment

We based hurricane storm-surge hazards on SLOSH model outputs for hurricanes Category 1 through Category 5. The maximum surge height for hurricanes of a particular Saffir-Simpson category was calculated for each grid cell using high-tide model runs and then compared to elevation values. After matching the vertical datum (National Geodetic Vertical Datum or NGVD) of the SLOSH model to a Digital Elevation Model (DEM), we mapped those areas where storm-surge heights were greater than elevation values for each hurricane category. Because high-elevation barriers can prevent the propagation of floodwaters, we excluded any low-lying area appearing to be at risk of flooding but surrounded by higher, non-flooded land in the at-risk zone. Because the available SLOSH output is based on an older sea-level datum, contemporary maximum surge height estimates could be lower than they would be with an up-to-date datum. We present conservative estimates of maximum surge heights because we did not account for the effect of wind-driven waves, which can magnify the effective height of a storm surge [104].

To delineate the hurricane storm-surge hazards enhanced by SLR, we raised the base level of the Category 1 through Category 4-5 storm surges by 30, 60, 90, and 120 cm using techniques described in Wu et al. [8] and Kleinosky et al. [9]. We projected these values onto the DEM, thereby estimating the spatial coverage of the storm surges given higher sea levels. The scenarios range from the lower to upper bounds of IPCC estimates of SLR by 2100 [74,75,105].

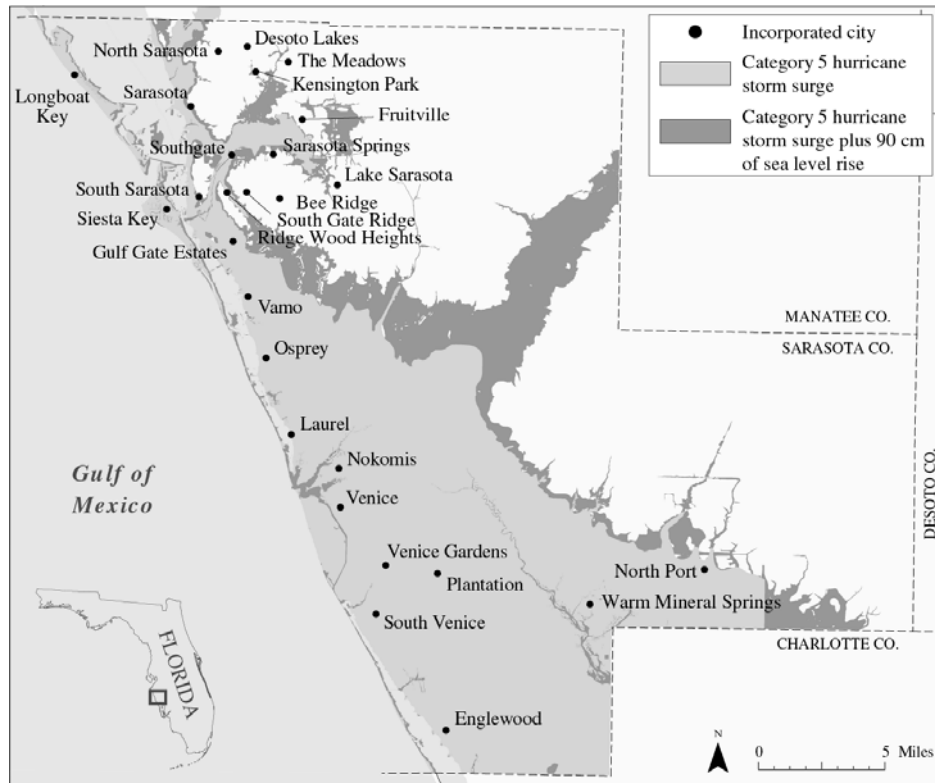


Figure 1. Sarasota County Category 4-5 hurricane surge zones with 90cm of SLR

5.3. Vulnerability Assessment

To assess variations in community exposure to current and future storm-surge inundation from hurricanes, we applied GIS-based methods described in Wood et al. [46] to integrate data characterizing coastal hazards, populations, land cover, businesses (including critical and essential facilities), and tax-parcel values. The number and demographic characteristics (e.g., ethnicity, age, gender, tenancy) of residents in the various hazard zones were determined using demographic data from census blocks of the 2000 United States Census [102]. Land-cover data from NOAA's Coastal Change Analysis Program [106] was used to determine the kinds of land-use and land-cover types are found in the various hazard zones, with specific attention given to developed classes (e.g., greater than 25 percent impervious cover). County tax-parcel data were acquired to determine the amount and percentage of a municipality's tax base that is located within the various hazard zones.

To assess potential impacts on economic vitality and overall community resilience [15,107,108], we extracted georeferenced business data from the 2006 infoUSA Employer Database, which includes information of total employees, total sales volume, and the North American Industry Classification System (NAICS) code for each business. These data allowed researchers to determine the type of and number of businesses in the risk zones as well as the sales volume and number of employees for each business. Previous work by Wood et al. [46] concerning exposure to tsunami

hazards highlighted the number of employees working in the risk zones to assist in evacuation planning, and to determine potential income disruption should a tsunami occur. The current case study primarily used employee information to determine potential income disruption that has been shown to be important for short- and long-term recovery [108]. Facilities considered critical for short-term response (e.g., national security facilities, fire and police stations, water and sewer treatment facilities, gas and electric companies, hospitals, nursing homes, daycares, etc.) or essential for long-term recovery (e.g., banks, gas stations, grocery stores, government offices, etc.) were also extracted from the employer database.

5.4. Stakeholder involvement

Stakeholder involvement for this case study consisted of a focus-group workshop where participants considered the implications of various hazard overlay scenarios on a map showing planned land use and land cover (LULC) for Sarasota County in the year 2050. For the purpose of our research, a scenario is a sequence of plausible, hypothetical future events developed in conjunction with stakeholders to inform decision-making. In much of the literature, the terms *scenario* and *alternative futures* are used interchangeably, but, methodologically speaking, there are distinct differences between the two terms. Alternative futures refer to a possible end state, whereas scenario is a means of reaching that state [109]. Scenarios in this research are used to examine the uncertainties of future events based on collaborative assumptions and expert opinions rather than facts.

To elicit expert opinions from local stakeholders, we conducted a one-day focus group session with 33 local participants from varied domain expertise traditionally critical to community preparedness and mitigation efforts. The focus group began with an initial morning plenary session to discuss the research project and to present the GIS-based, storm-surge modeling results. The participants were divided into five breakout subgroups based on the following domain expertise:

- Planning, including city, county, and regional planning officials;
- Government, including city managers, mayors, county commissioners, and sustainability officers;
- Business, including representatives from local chambers of commerce, insurance companies, restaurants, tourist accommodations, and retail trade;
- Environmental sector, including estuary program coordinators and marine researchers; and
- Emergency management and infrastructure, including public works managers, county health officials, recovery planners, and county emergency managers.

The decision to divide the groups by domain expertise resulted in each group approaching the scenario from their particular expertise. We believed that five groups with mixed domain expertise would result in five similar responses to the scenario. Dividing the groups by domain expertise ensured that the perspective of each knowledge domain was captured. Each group was instructed to review a map showing SLOSH-modeled storm surge inundation and 2050 LULC for Sarasota County and to determine if and how they would reallocate land use based on the contemporary storm surge modeling results [110]. Group members were asked to document on their maps

any concerns, changes, or suggestions related to future land use. A transparent overlay grid was provided to allow participants to be more numerically precise in proposing changes.

After the breakout sessions and before the ensuing plenary sessions, the maps from each group were collected and posted to provide the opportunity for everyone to view all subgroup maps. A spokesperson from each group presented the group's map and discussed their land use decisions. The plenary mapping session allowed for integration of information along various knowledge domains. In the afternoon, the procedure for both the breakout and plenary mapping sessions were repeated in a further round of exercises with an alternative scenario map showing the SLOSH storm surge output of a category 3 hurricane enhanced with 30, 60, 90, and 120 cm of SLR.

5.5 Results

The research presented in this case study is ongoing with full project results not yet realized. A preliminary map of potential storm-surge zones enhanced by SLR projections for a category 4-5 hurricane (Figure 2) nonetheless indicate that SLR could significantly increase hazard zones, thereby putting larger numbers of population and development at risk.

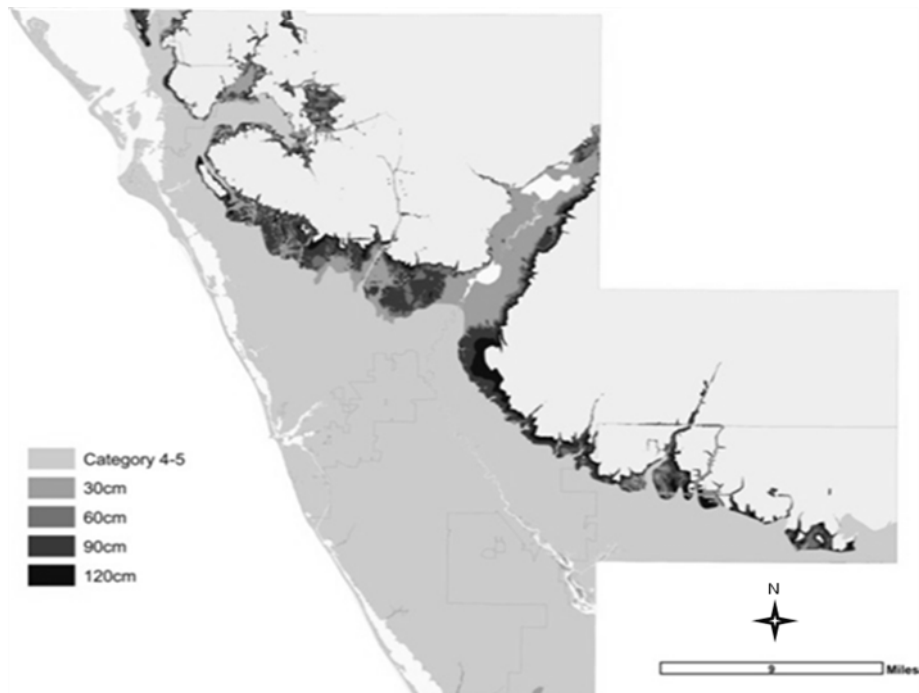


Figure 2. Contemporary and SLR Enhanced SLOSH Storm Surge Hazards Zones for a Category 4-5 Hurricane: Sarasota County, FL

We offer examples of how SLR affects population number (Figure 3a) and population percentage (Figure 3b) in the SLOSH hazard zone of a category 4-5 hurricane enhanced by 90 cm of SLR. The category 4-5 surge zone in Sarasota County contains 184,148 residents or approximately 56 percent of the county's total population. When the surge zone for a category 4-5 storm is increased by 90 cm of SLR, these numbers increase to 221,511 residents or approximately 68 percent of county totals. The addition of SLR to this surge zone translates to six municipalities (Englewood, Laurel, Longboat Key, Nokomis, Osprey, Siesta Key, Vamo, and Warm Mineral Springs) joining Plantation and Venice Gardens as municipalities with 100% of their residents in the hazard zone. We expect subsequent research results to indicate that the number of Sarasota County residents located within the hazard zone will continue to increase with higher levels of SLR.

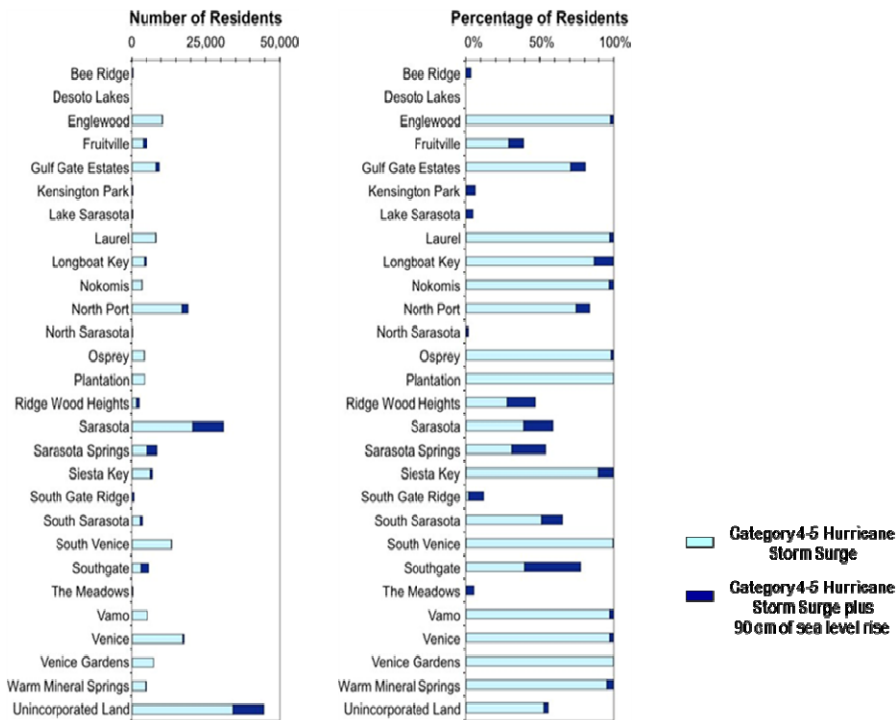


Figure 3. (a) Number and (b) percentage of residents in Category 4-5 hazard zones and hazard zones enhanced by 90 cm of potential sea level rise

Preliminary research results indicate that SLR will likely have a significant impact on the municipal tax bases in Sarasota County (Figure 4). Total land parcel values in city of Sarasota storm-surge zones increased from \$7 billion to \$11 billion with the addition of 90 cm of SLR, while total parcel values doubled for the municipalities of Sarasota Springs, Fruitville, Ridge Wood Heights, and Southgate (Figure 4a). The amount of tax parcel value exposure for unincorporated county land also significantly increased in this example from \$11 billion to \$14 billion. The percentage of a community's total tax base also increased significantly for several jurisdictions with the

addition of 90 cm of SLR (Figure 4b). Several communities (e.g., Lake Sarasota, Kensington Park, Bee Ridge, South Gate Ridge, and the Meadows) have zero percent of their tax base in storm-surge zones under current conditions but could have varying levels of exposure once the effects of SLR are included. The inclusion of SLR effects on storm-surge hazards would result in several communities (e.g., Englewood, Laurel, Longboat Key, Nokomis, Osprey, Siesta Key, South Sarasota, South Venice, Vamo, Venice, and Warm Mineral Springs) having 100 percent of their tax base in hazard zones.

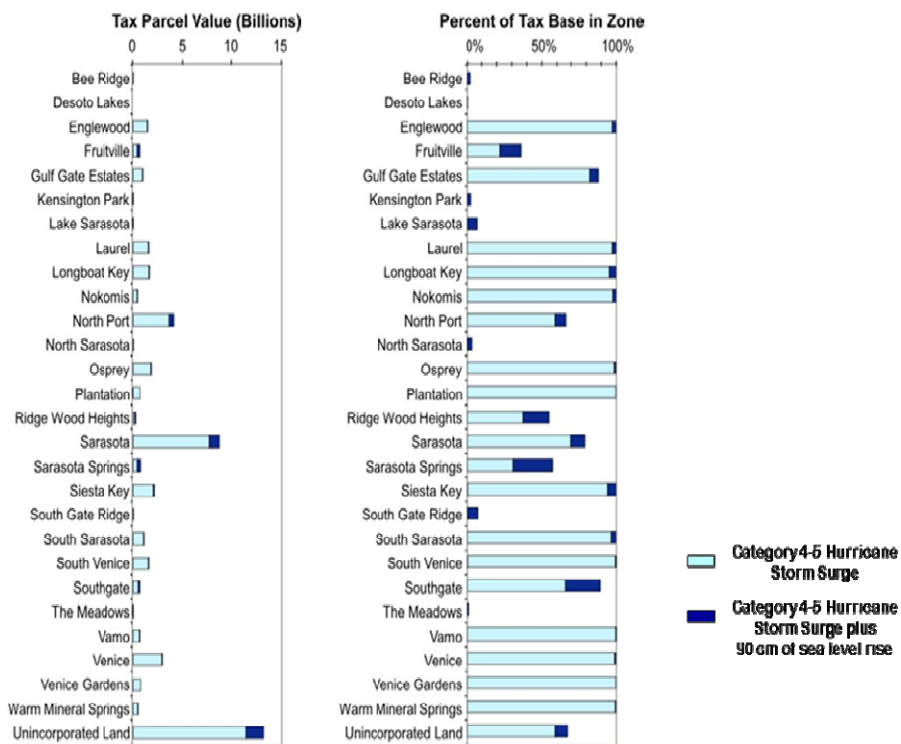


Figure 4. The (a) amount and (b) percent of total parcel value in Category 4-5 hazard zones and hazard zones enhanced by 90 cm of potential sea level rise.

When these and other storm-surge modeling results were presented to focus groups in Sarasota County, participants from each knowledge domain saw the need to revise the county’s 2050 land-use plan and documented potential adaptation strategies on workshop maps (Figure 5). Examples of proposed revisions include increasing housing density in areas not exposed to storm surge, revising proposed plans to widen Interstate 75 (and instead, using the money to build an alternative road outside the risk zone), and altering the county’s urban growth boundary that currently (and unintentionally) restricts growth to within the risk zones.

Stakeholders also saw the need to move from focusing on events at a municipal or county level to working as a region to solve problems associated with SLR and storm surge. Focus group participants indicated regional vulnerability assessments are needed

that take into account internal and external vulnerability components to provide a more accurate assessment of community vulnerability. For example, several multi-scalar indicators drew considerable attention such as the location of critical and essential facilities, the affect of transportation network problems on regional evacuation, and the need to address the lack of connectivity among the county's various water systems. County response and redevelopment officials noted that the city of Sarasota should deliver potable water to southern portions of the county if SLR hurricane scenarios were realized because a significant portion of the city's wells are located outside the risk zones. County response and recovery officials were concerned, however, because City of Sarasota waterlines are not compatible with those used in municipalities in southern portions of the county. This incompatibility of waterlines demonstrates a geospatially-dependent vulnerability for portions of southern Sarasota County. Sarasota city and county officials discussed the need to remedy this lack of connectivity by suggesting the need to work at city, county, and regional levels to develop a more unified regional infrastructure package. Participants thus acknowledged the need for a macro/micro multi-criteria collaborative spatial decision support system to integrate this and other infrastructure components.



Figure 5. Example of a participatory map used in the Sarasota focus groups to capture adaptation strategies for dealing with SLR-enhanced storm-surge hazard zones.

6. Conclusions

The GIS modeling completed for this research allowed the research team to identify the level of exposure of various Sarasota County demographic groups, land uses and land covers, critical and essential facilities, and economic activities. The GIS and spatial dependency network analysis when completed should allow the research team to

identify critical nodes of infrastructure located within contemporary and future risk zones. These findings should allow the research team to assess vulnerability more accurately and provide local stakeholders with valuable information that they can use for hazard mitigation and SLR adaptation planning.

The ability of local stakeholders to participate in the vulnerability assessment contributed extensively to the findings of this case study. The examples provided by this case study illustrate that GIS-based SLR modeling can be coupled with stakeholder interaction and incorporated into long-range comprehensive plans for coastal communities. The need to address these issues and other issues is apparent, and the framework we have introduced show promise for increasing risk awareness and affecting adaptive change in local communities. Our efforts to incorporate biophysical, socioeconomic, and internal and external vulnerability indicators into a framework that also considers geospatially dependent vulnerability appears to be an effective methodology for a more comprehensive localized vulnerability assessment. Research is ongoing that seeks to determine the effectiveness of this framework. Future research will complete a comprehensive content analysis concerning the focus group session conducted for this case study to gain a more complete understanding of the types of decisions promoted by focus group participants. Follow-up interviews with focus group participants will also be conducted in order to gain an understanding of the effectiveness of the methodology presented in this chapter.

7. Acknowledgements

This study is being supported by the National Oceanic and Atmospheric Administration's Sectoral Applications Research Program, the U.S. Geological Survey Geographic Analysis and Monitoring Program, and the National Science Foundation's SBE Doctoral Dissertation Research Improvement Grant Program.

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