Vulnerability of What? Vulnerability of Whom? Evaluating and communicating vulnerability to extreme floods in Houston, TX using a novel web-based platform

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ABSTRACT

The global climate is changing and these changes will continue to have adverse effects on cities and their residents. Coastal cities in particular, which contain the majority of the global urban population, are becoming increasingly sensitive to changing climactic conditions. The particularly devastating extreme storm season experienced in 2017-18 on the east coast of the United States (including storms Harvey, Irma, Maria, and four nor'easters on the mid-Atlantic coast) has intensified discussion regarding the preparation for, response to, and communication of risk and vulnerabilities related to extreme weather events. Risk is a function of the probability of experiencing a hazard event and the vulnerability of the system in question. Vulnerability to extreme weather events is the susceptibility of a system to internal or external stressors, exposure to those stressors, and the capacity of that system to adapt or respond to that extreme event. These concepts are understood in terms of social, economic, environmental, infrastructural, institutional, and built environment systems, and the focus of policymakers and stakeholders is often split between these domains. Furthermore, responses to vulnerability of any one categorical domain is potentially incongruous with responses to other domains. The modes by which this information is presented to decision-makers often either preferences single domains of interest or obscures the degree to which individual categories influence overall measures of vulnerability. Similarly, this information is often spatialized and presented in a planimetric view which is at times at odds with the conditions experienced on the ground before, during, and after an extreme event. This project begins with a review of relevant literature exploring definitions and measures of vulnerability to extreme flood events, identifying gaps in existing categorical domain combinations and opportunities for the application of a novel method of synthesis for Houston, Texas, a city hit by three 500-year storms in as many years and in the process of updating building codes, flood zone designations, and precipitation estimates. This method is then applied using established statistical tools to create vulnerability scores for social and built environment systems. The result of this analysis is presented in a novel way using web-based technologies that transcend the strictly-planimetric view of the city. This method blends traditional cartographic techniques with perspective, elevation, and diagrammatic representation methods, as well as collected images, to contextualize estimated vulnerability. The resultant web tool is available online at houstonbetweenthelines.com.

Thesis Supervisor: Alan Berger
Title: Norman B. and Muriel Leventhal Professor of Advanced Urbanism

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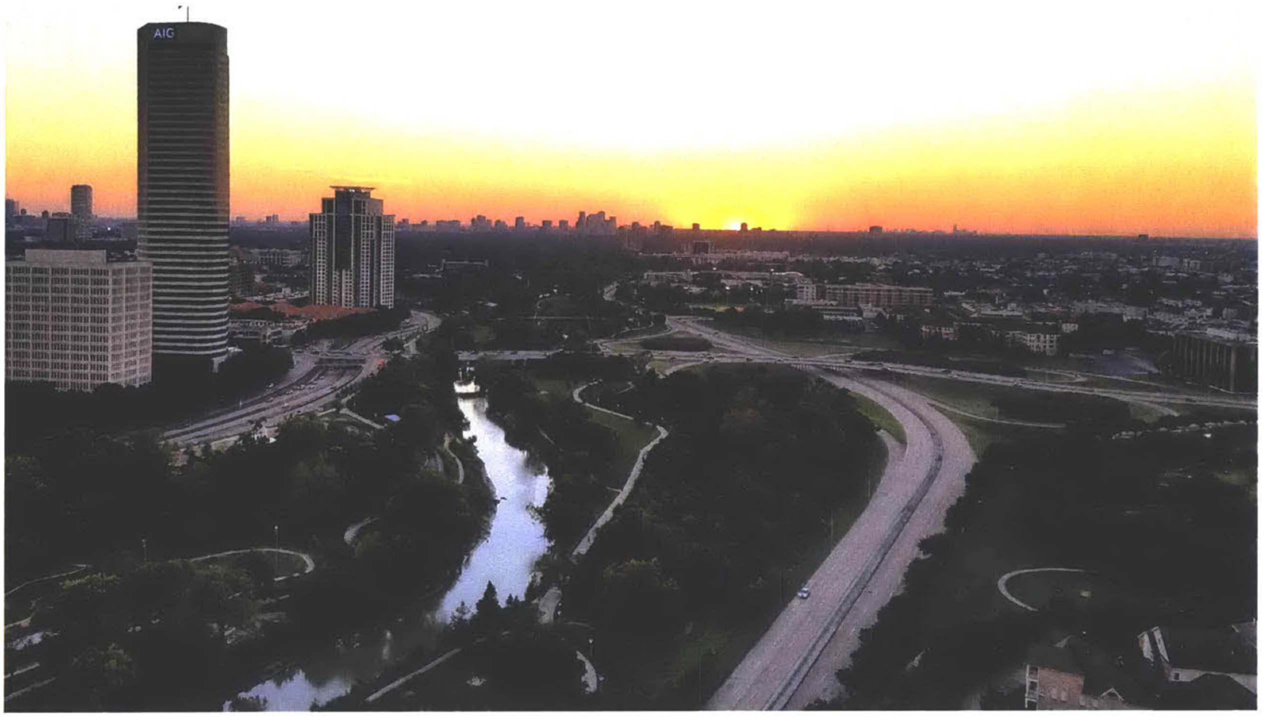
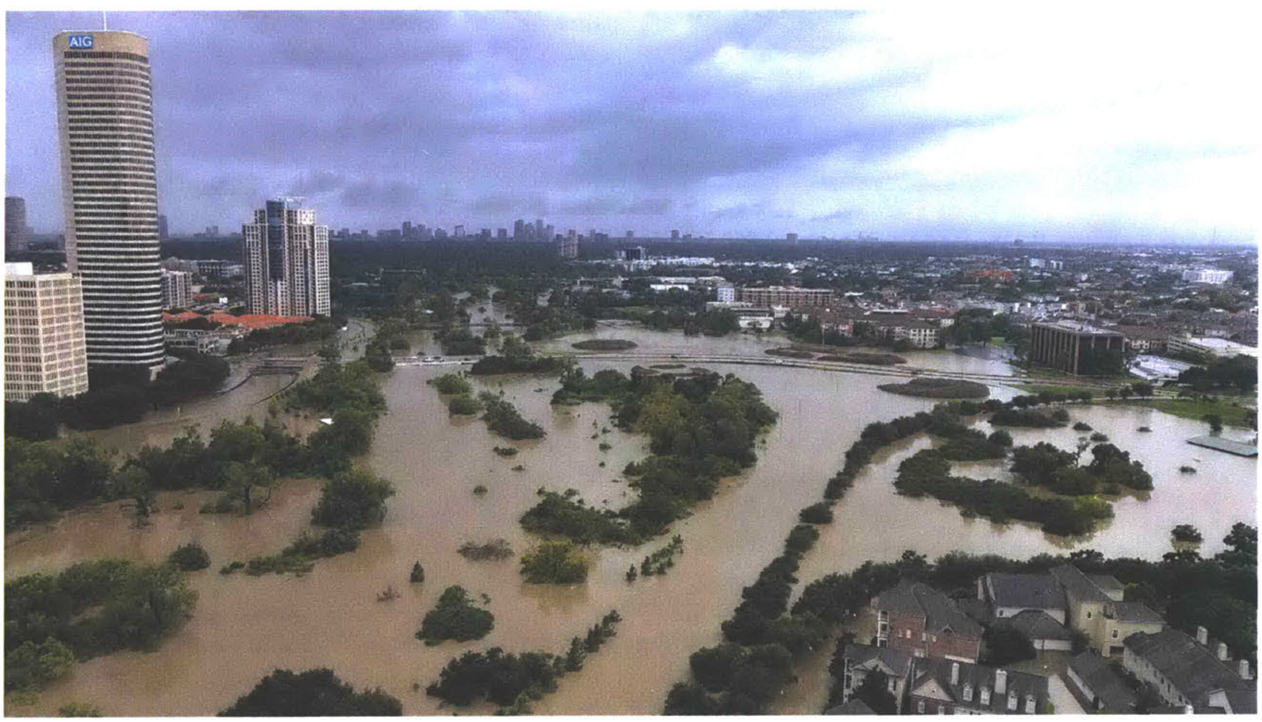
1. Introduction

Coastal cities are increasingly at risk from the consequences of climate change-related events. This includes increased risk from gradual processes, such as sea level change, subsidence, and rising temperatures, as well as the results of stochastic extreme weather events such as hurricanes, floods, mudslides, earthquakes, and tsunamis. The global population is increasingly urban, and coastal cities situated in river deltas are regional capitals of economic activity, cultural production, population density, and administrative power across the globe. This holds true in the United States, where the majority of major metropolitan areas are located on the coast in river deltas, including Boston, New York, Philadelphia, Washington, D.C., Miami, New Orleans, Houston, San Francisco, and Seattle. As human life and economic assets continue to agglomerate in coastal urban areas, and science and recent events suggest that climate-related consequences will become more pronounced and will be experienced at shorter intervals, increased attention should be paid to the understanding of and planning for this new reality.

Vulnerability to climate change can be considered as the susceptibility of a system to sustaining damage from exposure to hazard in relation to its adaptive capacity to respond to internal and external stressors (Schneider and Sarukhan, 2001; Adger, 2006). Risk from climate-related events can be understood as a function of the probability a hazard will occur in a specific place at a specific time multiplied by vulnerability (Flanagan et al., 2011). Hazard events are disastrous when they are experienced in populated areas or at the site of critical infrastructure or assets. Exposure is understood as the proximity of an area of interest to potential hazards, or the degree to which an area is potentially in contact with stressors (Balica et al., 2012). For instance, a seaside community has greater exposure to coastal flooding than a town further inland. Not only is the inland town further away from the water, it also has a buffer in the form of the seaside town. Both distance and the presence of buffers limits exposure. Susceptibility is described as the degree to which the area of interest can experience damage or hardship as a result of hazard (Balica et al., 2012). A seaside town is exposed based on its location; it is susceptible if, for instance, its critical infrastructure is in low-lying areas or is not waterproof. A system's resilience refers to the ability of that system to experience stress and to subsequently resume full operational capacity, either in the same structure as before the event or in an alternate, equally-functional configuration (Gunderson, 2000). Adaptive capacity refers to a system's ability to experience stress and transform to more efficiently or effectively address stressors in the future (Smit & Wandel, 2006). Resilience is the ability to regenerate; adaptive capacity is the ability to evolve. A system's resilience and adaptive capacity serve to balance exposure and susceptibility to an extreme event. For the purpose of this project, which examines vulnerability to stochastic flood events, resilience (as opposed to adaptation) will be considered as a component of vulnerability, although a body of literature supports including adaptive capacity instead of resilience when investigating vulnerability to broader climate change-related phenomena. Taken together, exposure, susceptibility, and resilience define an area's vulnerability. This discussion of risk and vulnerability is meant to illustrate why it is fundamental to develop greater understanding of each input—exposure, susceptibility, and resilience—as we plan for the gradual and stochastic effects of climate change. The increasing probability of extreme events is not the topic of this project; however, the cumulative impact that extreme events can have on a place—the vulnerability—is. The changing climate is the product of global, intergenerational practices and cyclical environmental changes, and will continue to negatively affect coastal regions around the world even if mitigation efforts are earnestly pursued. However, mitigation alone will not protect coastal cities. Susceptibility, exposure, and resilience can be influenced at the national and urban scale and can set the agenda for adaptation planning in coastal cities in the future.



Houston on a normal day (Image credit: Aaron Cohen in Mallonee [2017])



Houston in the aftermath of Hurricane Harvey (Image credit: Aaron Cohen in Mallonee [2017])

2. The Case for Houston

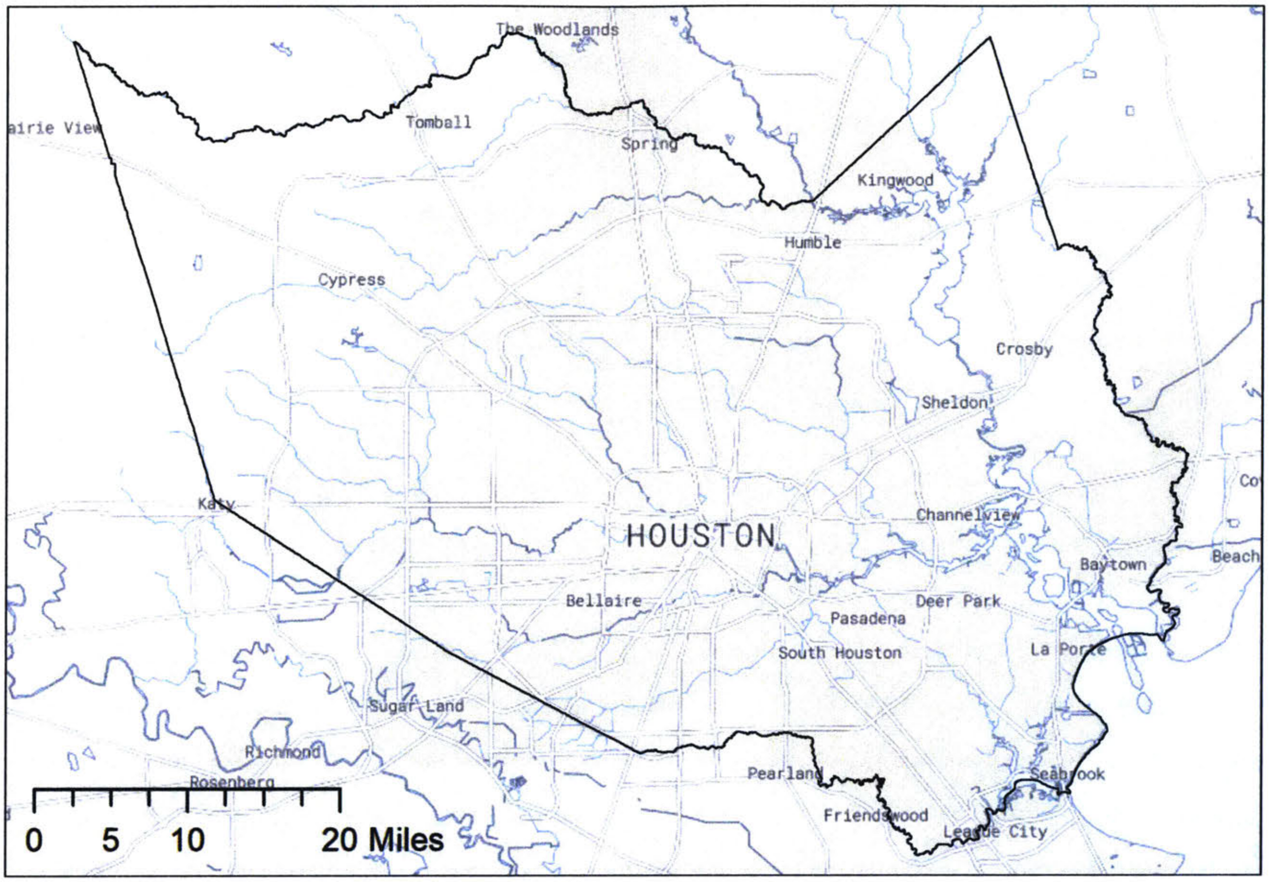


Figure 2.1 Study area (Harris County Boundary)

This research focuses on the Houston, Texas metropolitan region as a case study for exploring vulnerability and methods to communicate vulnerability to policymakers and the public. Harris County includes Houston and nearby suburban towns, as well as unincorporated lands that have been developing over the past ten years (Fig. 2.1). It is the area of interest for this project. Houston is a major urban area located in the Gulf Coast region of the United States and is home to a population of over 4.6 million people (U.S. Census Bureau, 2017). It is a delta region containing 22 distinct watersheds that drain into 22 bayous that wind through the city (Harris County Flood Control District, 2018b). Galveston Bay, where Harris County's watersheds drain, includes the Port of Houston, the largest container port on the Gulf Coast (Port of Houston, 2016). This research is particularly salient in Houston given the recent history of extreme events that have affected the area. Extreme floods including Tropical Storm Allison in 2001, the Memorial Day Floods in 2015, and the Tax Day Floods in 2016, as well as the historic rain and damaging storm surge inflicted during Hurricane Harvey have resulted in multiple deaths and have caused billions of dollars of damage (Table 2.1).

Storm Name	Year	Number of Claims	Average Claim Amount	Total Money Paid
Tropical Storm Allison	2001	30,671	$36,028	$1,105,003,344
Memorial Day Floods	2015	6,761	$68,904	$465,861,960
Tax Day Floods	2016	7,422	$63,111	$468,412,988
Hurricane Harvey*	2017			$378,000,000*

Table 2.1 Damage estimates from four major storms. Adapted from FEMA (2018), except for Harvey estimates, which come from Moravec (2017) and reflect numbers as of September 5, 2017. The total cost of damage from Harvey is predicted to be significantly higher than what has been reported to date.

Hurricane Harvey prompted a National Oceanic and Atmospheric Administration (NOAA) review of the volume of rain that constitutes a 100-year storm, and preliminary results[1] suggest that actual precipitation amounts are actually 3-5 inches higher than the last published rainfall estimates from 1961 (Zaveri, 2017; Office of Water Prediction, 2018). This information, coupled with the occurrence of three 500-year storms in three years, has prompted renewed interest in both the definitions of storm events and mitigation and adaptation measures to meet these changing definitions. In December 2017, Harris County approved updated building code requirements demanding that new buildings constructed in unincorporated Harris County within the 100-year flood plain be built two feet above the 500-year flood plain level (Shelton, 2017). While this regulatory change does not affect construction within Houston or other cities within Harris County, it signals a shift in thinking that could have widespread effects on new construction and patterns of urbanization in the region in the coming years.

Motions to update policy that guides construction, mitigation, and adaptation measures will have an impact on the degree to which current and future structures are affected by changing climactic conditions. The information required to make such policy decisions is derived by a number of different scientific and academic organizations and is mobilized by different stakeholders following different imperatives. The complexity of this information genesis, as well as the differing assumptions and baselines represented in each (i.e. using historic data to understand more recent conditions) leads to a confusing and incongruous understanding of the risks that are faced in Houston. Several stakeholders

[1] Final results will be published in September 2018.

have developed communication tools to convey climate-related information and vulnerability to policy makers, and others have created citizen participation tools to identify vulnerabilities and consequences of extreme events on the ground. This project situates itself as a way to interrogate different factors that contribute to vulnerability while being able to trace the results shown on a map to the original data sources. The following section contains an overview of past efforts to define characteristics of vulnerability and current web-based tools that exist to communicate vulnerability and climate change-related risk to policy makers, researchers, and the public in order to contextualize this project.

3. Literature Review

3.1 Vulnerability

To be able to respond to vulnerability at the urban or individual scale, policy makers and persons alike must be able to understand it. This depends on assumptions and agreement on the context in which vulnerability is applied. Recent literature related to flood vulnerability discusses vulnerability of built systems (e.g. Aroca-Jimenez et al. 2017; Chang and Huang, 2015; Cutter, 2008; Sadeghi-Pouya et al., 2017; Van, 2016), economic systems (e.g. Akukwe et al., 2015; Borden et al., 2007; Cutter, 2008; UNESCO; Van, 2016), environmental systems (e.g. Balica et al., 2012; Chang and Huang, 2015; Rao, 2005; Silva et al. 2016; UNESCO; Zanetti et al., 2016), infrastructural systems (e.g. Aroca-Jimenez et al., 2017; Borden et al., 2007; Cutter, 2008; Silva et al., 2016; UNESCO; Van, 2016), institutional systems (e.g. Aroca-Jimenez et al., 2017, Balica et al., 2012; Cutter, 2008; Sadeghi-Pouya, 2017; Silva et al., 2016; UNESCO), and social systems (e.g. Akukwe et al., 2015; Aroca-Jimenez et al. 2017; Balica et al., 2012; Bathi and Das, 2016; Cançado et al., 2008; Fernandez et al., 2016; Garbutt et al., 2015). Thinking of vulnerability in terms of each of these domains can help decision makers better plan for and respond to extreme flood events.

The discussion of vulnerability as a quantifiable phenomenon has become the topic of research over the past 40 years in the United States. Hundreds of composite indices of multi-hazard vulnerability, resiliency, and risk have emerged globally (Beccari, 2016 Table 3.1), and many others still focused specifically on flood hazards. Flood-specific vulnerability indices were identified in the literature using Google Scholar and through cross-referencing bibliographies of known flood indices. A sample of 40 recently-created flood indices were identified and are included in Appendix I. These flood vulnerability models were classified in terms of the domains of focus (i.e. social, environmental, institutional, economic, infrastructural, and built environment), input indicators, combinatory methods, spatial scale, and area of interest (illustrated in Appendix II). Following the definition of vulnerability proposed above, each indicator was further classified in terms of its relation to exposure, susceptibility, and resilience. This classification exercise provides a cross-study summary of the components of vulnerability to floods and provides a basis for critiquing and creating a composite index.

Index Name	Author
UNESCO FVI	UNESCO (n.d.)
Coastal City FVI	Balica, Wright, van der Meulen (2012)
Cluster Analysis	Fernandez et al. (2016)
Emergy Approach	Chang & Huang (2015)
Delta FVI	Rao (2005)
CVI	Bolter (2013)
ISVI	Aroca-Jimenez et al. (2017)
SIFH-VI	Valchev et al. (2016)
Floodplain-VI	Roder & Sofia (2017)
Integrated-VI	Coninx & Bachus (n.d.)
ICHARM	Shrestha et al. (2013)
UF-VI	Villordon & Gourbesville (2014)
HVI	Van et al. (2016)
VI	Akukwe & Ogdobo (2015)
Hydrological Infrastructure FVI	Ogie et al. (2016)
VI	Cançado et al. (2008)
VI	Silva et al. (2016)
OS-VI	Garbutt et al. (2015)
SSD-VI	Bathi & Das (2016)
PVI	Borden (2007)
Resilience-NH	Burton (2015)
MAZANDARAN	Sadeghi-Pouya et al. (2017)
SEVICA	Zanetti et al (2016)
NFVI	Sayers (2017)
SoVI	Cutter et al. (2008)
SVI	U.S. CDC (2011)

Table 3.1 Flood vulnerability indices analyzed (full list of identified flood vulnerability indices available in Appendix I)

Figure 3.1 displays the breakdown of indicators per flood vulnerability index per domain. Indicators related to social vulnerability prevail and make up at least 20% of overall indicators in all but four studies. Flanagan et al. (2011) suggest that the relatively recent disciplinary focus on social vulnerability came as a reaction to traditional disaster management focus on the vulnerability of large infrastructural systems (p. 1). Across recent literature and in policy, social vulnerability is of paramount importance. Cutter et al. (2003) posit that vulnerability is a social condition, evoking the guiding questions of resiliency planning: "Resilience to what? And resilience for whom?" The assumption that vulnerable populations stand to lose the most in extreme events makes sense, considering other factors equal. The U.S. Center for Disease Control's Social Vulnerability Index (SVI) was developed as a tool to identify the most vulnerable populations in the event of a catastrophe to better direct aid and services before and after a disaster (Flanagan et al., 2011). Table 3.2 displays the various indicators and categories that comprise the SVI, which represents the federal government's definition of social vulnerability. Social vulnerability measures should be used to direct disaster response efforts; however, as planners and policymakers become increasingly aware of the intersections between extreme events and social outcomes, measures of vulnerability, social and otherwise, can be used for preemptive intervention to prevent serious future damage, as well as inform policy directives after the initial disaster response period. From this perspective, other categorical domains of vulnerability—economic, environmental, institutional, infrastructural, built environment—should be included in policymaking analyses to be able to address root causes of social vulnerability before an extreme event takes place, as well as focusing on the effects afterward. This comprehensive perspective allows planners to consider elements of social vulnerability in tandem with related, sometimes competing, non-social objectives.

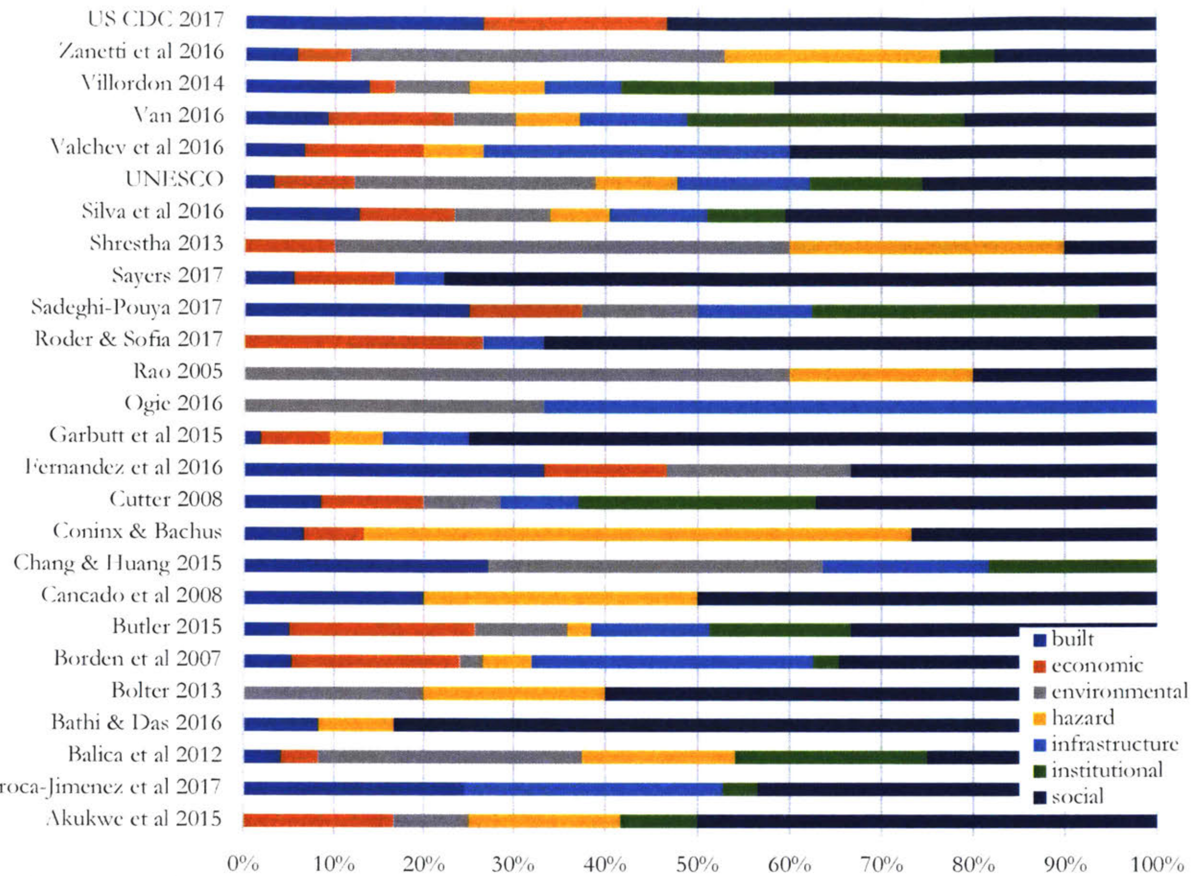


Figure 3.1 Classified indicators by domain as a percentage of total indicators.

Category	Indicator
Socioeconomic status	Below poverty
	Unemployed
	Income
	No high school diploma
Household composition and disability	Aged 65 or older
	Aged 17 or younger
	Civilian with a disability
	Single-parent households
Minority status and language	Minority
	Speak English "less than well"
Housing and transportation	Multi-unit structures
	Mobile homes
	crowding
	No vehicle
	Group quarters

Table 3.2 Components of CDC's Social Vulnerability Index (adapted from Agency for Toxic Substances & Disease Registry, 2017 p. 2)

3.2 Communication of Vulnerability

The scale and complexity of information related to a place's vulnerability to flooding is difficult to comprehend and even more difficult to communicate effectively. Web-based portals provide information geared toward the research and policy community, and to a lesser extent the general public.[2] Government agencies and academic institutions have developed websites to display information relevant to the social and environmental conditions of Houston (Table 3.3). These measures of overall vulnerability, and the factors that contribute to it, should be seen as having a separate purpose than the event-specific tools created by agencies and institutions that represent risk as it is occurring, although in an ideal scenario vulnerability-related tools and datasets should serve as the basis for disaster scenario decision-making tools. The Agency for Toxic Substances & Disease Registry, a division of the U.S. Center for Disease Control and Prevention (CDC) has created a web portal hosting the SVI dataset described above for the entire country at the census tract level. As the name implies, this index consists of primarily social indicators distributed across four categories: socioeconomic status; household composition and disability; minority status and language; and housing and transportation (Agency for Toxic Substances & Disease Registry, 2017). It is the standard against which other vulnerability index datasets can be measured, as it is based on publicly-available census data and represents the federal definition of social vulnerability. The other social vulnerability datasets described herein are mostly derivatives of this dataset, either in terms of input variables or weighting mechanisms. The measure of social vulnerability proposed herein uses several of the same datasets as the CDC version, as well as other indicators proposed in the literature. As of April 2018, the SVI web portal contains social vulnerability estimates using 2014 data.

Rice University's Kinder Institute for Urban Research has published a number of spatial data tools focused on the Houston metropolitan region. The Houston Community Data Connections (HCDC) Dashboard similarly combines canonical measures of social vulnerability (as defined by the CDC), relying primarily on U.S. Census data to describe demographic characteristics and primary survey documents generated by the Kinder Center to describe economic outcomes and public opinion on social issues. In this way, the HCDC Dashboard serves as a repository of descriptive information on Houston's neighborhoods. The public opinion data provides some sense of overall sentiment related to social issues and social vulnerability but makes no claims as to definitions of vulnerability or the

[2] It is assumed that television and the radio provide the general public with event-based vulnerability and hazard-related information before and after storms.

implications that these datasets, if combined, could suggest. The tool does contain an estimate of the total number of homes flooded during Hurricane Harvey and allows for overlays with other layers, but does not offer a synthesis of these layers, nor does it express how intersections between different datasets might be meaningful for policy makers. This tool offers a useful glimpse into the state of social vulnerability in Houston, but not a comprehensive picture.

Tool name	Author	# of Layers	Layer Categories
Social Vulnerability Index Mapping Dashboard	U.S. Center for Disease Control	5	Overall vulnerability, socioeconomic theme, household composition/disability theme, minority status/language theme, housing/transportation theme
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Norman B. Leventhal Center for Advanced Urbanism	18	Neighborhood analysis, poverty and demographics, housing characteristics, urban heat risk, toxic waste sites, natural environment and public space, water quality, flooding risk, administrative boundaries
Texas Coastal Atlas	Center for Texas Beaches and Shores (Texas A&M University)	155	Administrative boundaries, social and built environment, cultural characteristics, landscape features, hydrology, green space, gulf features, environmentally sensitive features, coastal development, parcels, hazards, flood damage, risk, flood vulnerability, land cover, land cover change, future land change, existing inundation, existing losses, post-Ike Dike inundation, post-Ike Dike losses
Buyer Be-Where	Center for Texas Beaches and Shores (Texas A&M University)	12	"Risk"
Coastal Resilience	The Nature Conservancy	125	Regional planning, community planning, future habitat, economics of coastal adaptation, risk explorer, flood & sea level rise
FloodPlain Map	City of Houston-Public Works and Engineering	20	Floodplain data, reference data
HCDC Dashboard	Rice Kinder Center	60	Demographics, economic vitality, education, public opinion, land use, housing, crime
Hurricane Harvey	Rice Kinder Center	7	Provides a narrative explanation of damage incurred during Hurricane Harvey

Table 3.3 Spatial web tools related to flooding and flood vulnerability in Houston (full layer description available in Appendix IV)

The Center for Texas Beaches and Shores at Texas A&M University - Galveston has also produced a number of web-based tools to communicate bio-geophysical and social characteristics of the Houston area. The *Texas Coastal Atlas* represents exhaustive data for Texas coastal communities (152 layers of data) over a range of categories described in Table 3.3. Beyond the range of descriptive datasets, the tool provides social vulnerability data layers for each 2009, 2000, 1990, and 1980. No in-depth description of the layers or the methodology is provided, however it is assumed that the methodology is in-line with the CDC Social Vulnerability Index (detailed above). The tool also provides raw data for a number of other landscape and social characteristics but does not present them in the context of vulnerability, risk, mitigation, or adaptation—they are just there. Two separate, contradictory overlays titled "Galveston Flood Vulnerability" are present, with opposite color scales and contradictory information (Figure 3.2). Beyond the descriptive information, the *Texas Coastal Atlas* contains information on a number of scenarios including estimated future land cover change (based on linear Euclidean growth: creating a buffer around existing settlements), as well as modeled storm surge scenarios with and without the "Ike Dike" coastal storm surge barrier proposed by faculty at Texas A&M Galveston.

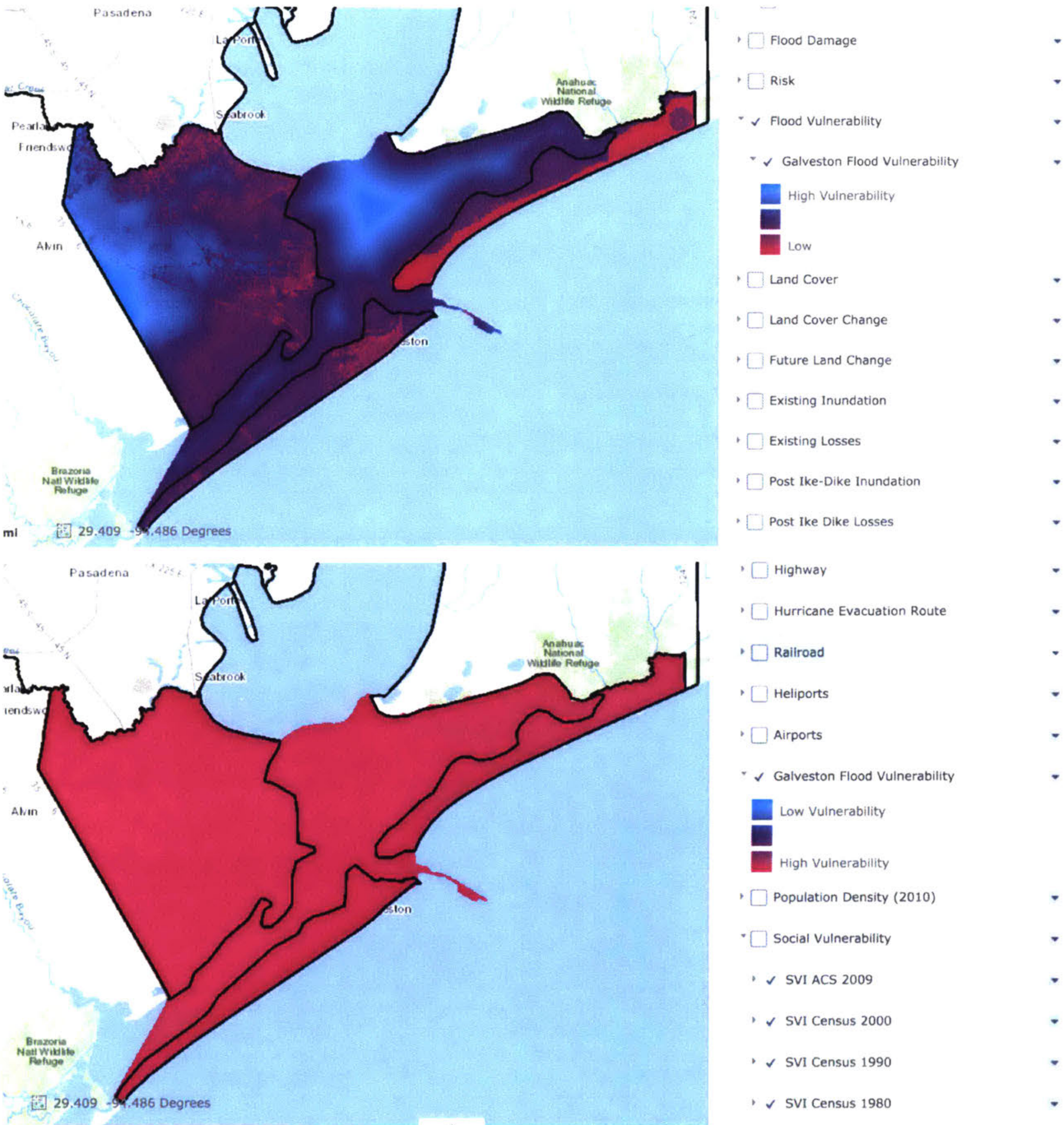


Figure 3.2 Contradictory measures of vulnerability in reversed color scales shown on the *Texas Coastal Atlas*

Buyers Be-Where, another project of Texas A&M University – Galveston, takes a different approach and offers parcel-level information related to the characteristics of buildings. This includes the number of rooms, bathrooms, overall square footage, and an estimated property value from the real estate analytics company Zillow. The interface also provides an image of each parcel using Google's Street View service (https://www.google.com/streetview/), which transcends the planimetric view often offered by map applications and offers a more human perspective. This information is supplemented by a multi-criteria hazard score relating to hurricanes, floods, wildfire, earthquakes, and subsidence, as well as exposure to toxic materials. This site gives a useful overview of hazard risk for each parcel but does not indicate vulnerability of a given area to the described hazards; it seems primarily targeted toward the real estate market as opposed to a policy maker audience.

MIT's Norman B. Leventhal Center for Advanced Urbanism (LCAU) developed *Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment* in 2015 as a tool to explore various characteristics of Houston. The website describes the tool as "a spatial exploration of metropolitan-scale health risks in the greater Houston region, examining health and resiliency factors as they relate to the natural and built environments." (LCAU, 2015). The tool presents a number of overlay layers and allows the user to toggle layers on and off to compare spatial distributions of indicators (see Appendix IV). This tool provides a survey of relevant layers related to high-level environmental risks and cites relevant literature for several included categories. The susceptibility indicators include multi-dimensional social vulnerability, poverty, race, population density, home ownership, and vacancy rates. These indicators correspond with the social vulnerability literature generated by Cutter et al. (2008) and promulgated by the U.S. Center for Disease Control; they represent the canonical national definition of social vulnerability. The second dominant category presented in this tool relates to various kinds of risk and hazard: heat, air pollution, toxic waste, and flooding. This tool offers spatial representations of the inputs to risk calculation (hazard and vulnerability) and allows the user to explore these different elements. However, there is no way to compare the data or to generate any synthesis between the layers beyond toggling layers on and off. This is a common exploratory method but does not allow for second order investigation, requiring uses interested in deeper levels of analysis to obtain and manipulate the data themselves. While it does provide a robust, concise collection of externalities that are relevant for resiliency in Houston, the lack of integration and narrative synthesis of each input prevents it from serving as an effective policy research tool.

3.3 Synthesis vs. Overlay of information

Overlaying disparate layers of spatial information together can reveal patterns in a landscape. This technique revolutionized planning and understanding of large urban areas in the mid-20th century (i.e. in Ian McHarg's seminal 1970 work *Design with Nature*) and served as the basis for geographic information systems as they are known today. This practice led to higher-order spatial analysis techniques, transitioning away from mapping to divine objective facts to synthesizing data in order to not only "expose selected facts embodied in a set of data [but] also to express the meaning a user might attribute to those facts" (Tomlin, 2012, p. 141). Despite the loss of detail that can follow synthesis (discussed below), the ultimate goal of the process of data synthesis and synthetic representation is the revelation of the complex (Tufte, 2001 p.191). Creating composite layers of information formalizes the relationships between disparate data sets and allows the user to more readily interpret patterns that otherwise lie dormant in the data.

3.4 Hazard-Specific Tools

There are a number of other web tools that specifically deal with communicating risk to particular storm events. They are emergency alert and management systems as opposed to vulnerability analysis tools. The administrations of the Houston metro region offer two emergency alert systems: *AlertHouston*, an email, text message, or phone call-based system that sends emergency information based on an address or stated area of interest (Everbridge Inc., 2018). The *Greater Harris County 9-1-1 Emergency Network* sends alerts via email, text message, or phone regarding local area emergencies such as chemical spills, evacuations, or life-threatening weather events (Greater Harris County Emergency Network, 2017). Both of these services require residents to opt in and may have lower participation rates than possible based on whether or not residents know the services exist. The City of Houston also partners with the National Weather Service to issue Wireless Emergency Alerts for extreme storm warnings and Child Abduction Emergencies. The City of Houston's Emergency Operations Center notes that phones in Houston are likely opted in to this system automatically (City of Houston Emergency Operations Center, 2018). Having three emergency alert systems likely ensures that a wide audience receives the messages, although it is unclear to what extent information would be duplicate or contradictory depending on the original source of the information. This could lead to delays in information transmission, general confusion, or information overload during an extreme event. For non-emergency events, Houston provides a 311 Service Helpline (launched in 2001) and mobile application (launched ca. 2013) allowing residents to lodge complaints to relevant city agencies. This service allows citizens to report issues and for responsible agencies to acknowledge these grievances, respond appropriately, and confirm the settlement of these issues to the public. Nationally, this has been an effective means for minimizing the psychological distance between constituents and city agencies and generating a sense of empowerment for concerned citizens. Over 76,000 311 complaints were made between 8/23 – 9/1 (the period of concern and impact for Hurricane Harvey), roughly

21% of the 363,000 complaints made in 2017 (City of Houston 311, 2018). Of these, over 30,000 were explicitly related to flooding. This surge of use of the mobile application suggests that this mode of communication is a viable avenue for engagement in documenting and responding to extreme events.

Similarly, a number of agencies, activist groups, and media outlets created data portals directly before, during, and after Hurricane Harvey in order to guide preparation and response efforts, as well as document the damage from the event. While these tools are outside of the scope of this project (as they are event-specific), they represent a valuable body of information and historical record of the event itself and the information that was mobilized during the event.

3.5 Emergent Technologies

Parallel advancements in virtual and augmented reality technologies, and the decreasing cost associated with these technologies, are leading to new opportunities for wide adaptation of these tools for planners. Mirauda et al. (2018) have prototyped a framework to use web-hosted databases to send live data to an augmented reality platform in the form of points of interest. The framework was developed to allow emergency responders to remotely monitor hydraulic measurement station in the field, providing the ability to visualize data feeds from a range of sensors relative to their positions in the Basento River basin in Italy. Gorton (2014) proposed using video game technology to create immersive augmented reality experiences for visualizing flood risk but found that limited accuracy and availability of FEMA flood maps, accurate geolocation of users in space, and registration of data on the real world were barriers for the widespread application of this technology. Haynes et al. (2015) developed a framework to detect control points within a smart phone's field of view and subsequently overlaying information in the form of diagrammatic planes within the scene. This approach, prototyped in Sheffield, UK, requires users to first pan around the area of interest with their phone to create a control image, which is then processed using computer vision techniques to affectively position data in space. The authors note that the primary drawback with this method is the requirement to properly register control points within the scene, with room for user error. Nevertheless, the researchers developed a successful pilot of this software for a limited area, suggesting that the technology is maturing to the point of being applicable for broader implementation. Recent advances in video game development and geospatial technology suggest that data collection, synthesis, and visualization are approaching a state in which these issues may be overcome. Once data sources are identified, computer programs can automatically identify, download, and process updated risk and resiliency-related information, ensuring the most recent datasets are made available to users. The Mapbox Software Development Kit (SDK) (Tripathi and Berg, 2018), available for the Unity video game development platform, allows for the inclusion of 3D objects informed by these datasets, as opposed to points of interest. Together, I argue that these advancements when paired with robust server-side technologies can minimize the errors caused by user error in geo-locating scenes and registering data over real-world objects to create a model for easy participant immersion in complex, place-specific data using augmented reality technology. This project concludes with a look forward to the potential utility of these tools for policymakers and the public in understanding and contributing to a broader conception of localized vulnerability to extreme flooding.

4. Methods

While much of the existing literature focuses on socio-ecological, socio-economic, infrastructural, or institutional vulnerability, characteristics of the vulnerability of the built environment and particularly residential housing stock are underdeveloped yet are essential for understanding the degree to which hazards may affect people and social systems. Citing the tsunami that struck Asia in 2004 as an example, Adger (2006) posits that stochastic weather events illustrate underlying vulnerability in a place. While susceptibility to damage from hazards centers around social systems or infrastructural systems (see discussion above), characteristics of the built environment (such as building materials, vintage, condition, location, and typology) affect the extent of damage from extreme events and are both sources and manifestations of vulnerability.

Based on a review of the literature and recent and ongoing changes to building code regulations in Harris County, I have opted to focus on social and built vulnerability for the purpose of this project. Social vulnerability is an established concept and is a topic of institutional and academic concern for Houston and coastal areas more broadly. I elected to include built characteristics as a domain of interest due to fact that much of the damage experienced through Hurricane Harvey was suffered by households outside of FEMA's designated flood zones, suggesting that the presence of flood insurance based on existing FIRM maps alone is an insufficient marker of a property's preparedness and ability to cope with flood events. Recent flood events, the rate of urbanization in the area, and the ongoing discussion revolving around revising the building code and flood insurance requirements in Houston signal that the time is ripe to consider vulnerability of structures in the larger discussion about vulnerability, resilience, and adaptation.

The goal of this project is to explore social and built vulnerability to flood events across Houston. By applying statistical techniques, my project will provide a synthesis of vulnerability factors across domains. Existing web tools either rely on the Center for Disease Control's conception of social vulnerability as a measure of vulnerability or present the user with a range of vulnerability-related datasets for exploration. This project extends beyond producing overlays by combining disparate input layers into a synthetic measure of social and built vulnerability while simultaneously calling attention to the explanatory input factors. This tool provides a baseline for multi-domain vulnerability for Houston that can inform policy discussions, guide adaptation initiatives and resource distribution (Smit and Wandel, 2006), and influence data collection and measurement in the future.

There is a body of resilience and vulnerability self-assessment tools that allow communities to develop measures of vulnerability based on surveys, focus groups, and interviews to develop a shared definition of vulnerability and the ways in which that community might develop adaptations to changing conditions (Smit and Wandel, 2006). This qualitative process is instrumental in developing realistic and context-specific adaptations in an ever-changing world and relies wholly on individual input to guide the broader process. The current project relies upon publicly-available data from a number of sources to develop a relative measure of the spatial distribution of vulnerability across the region. Several limitations present themselves in this method, notably the availability of data at a useful scale, the assumption that vulnerability can be quantified at all, and that the data that is available is current enough to form a faithful representation of vulnerability for use in policy making. Despite these limitations, I attempt to arrive at relative measures of vulnerability for Houston in hopes that the effort can inform policymaking or at least discussions about what we mean when we say "vulnerability" in Houston.

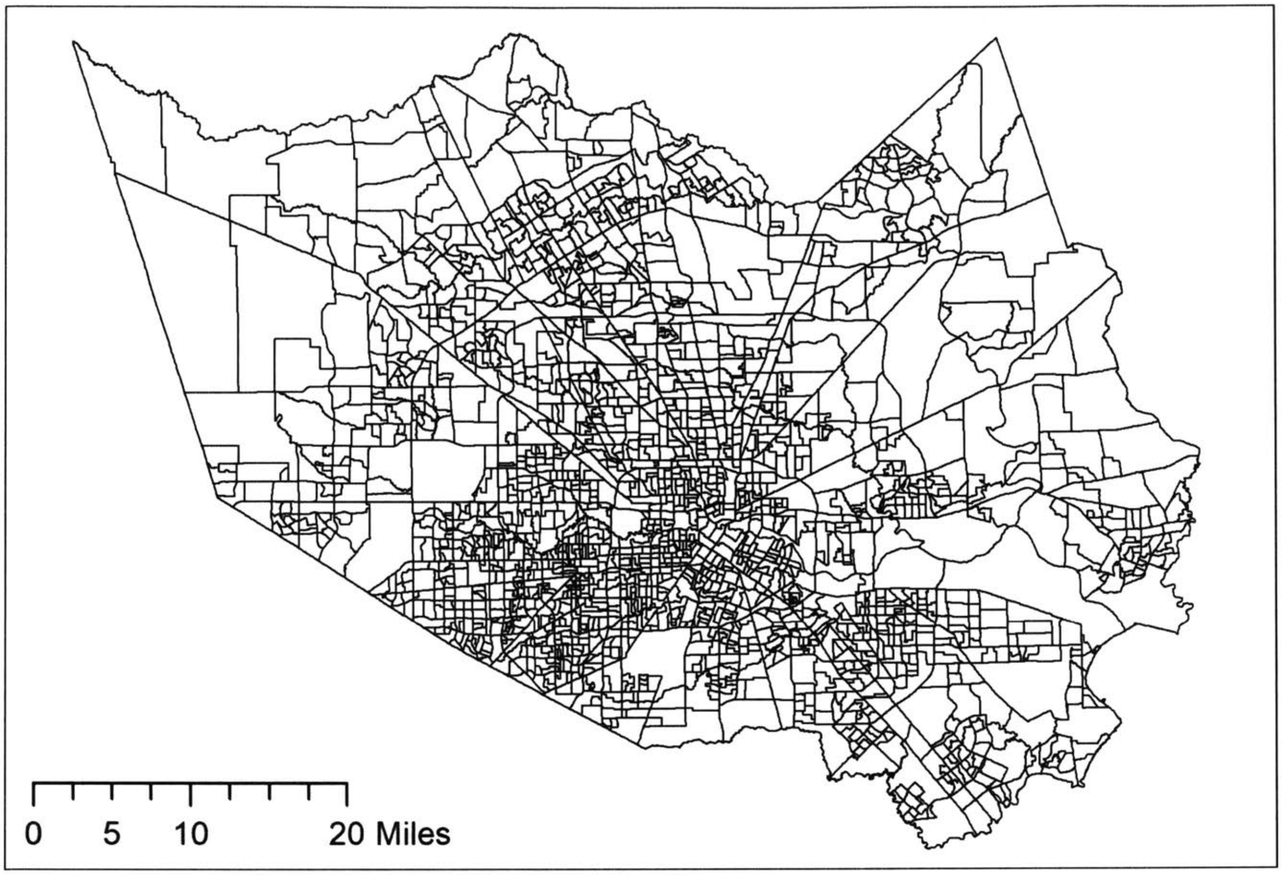


Figure 4.1 Census block group boundaries (units of analysis)

With these limitations in mind and with an understanding of quantifiable elements of vulnerability drawn from the literature, I began collecting data from a number of sources. The U.S. Census provides a rolling statistical characterization of the nation's populace at a variety of spatial scales, with certain data not available at higher resolutions. While many vulnerability measures interested in conveying levels of vulnerability across regions or nations use entire city boundaries as units of analysis, such an approach neglects extreme levels of variation that exist across distinct areas of a city (Committee on Increasing National Resilience to Hazards and Disasters, 2012, p. 94). This phenomenon is referred to as the "Modifiable Areal Unit Problem" in geography and is understood as the revelation or obfuscation of patterns in data depending on the unit of analysis (Jelinski and Wu, 1996), either due to the spatial scale of the unit of analysis or the particular boundaries imposed on the information being measured. Choosing too large a unit can mask patterns in an area, and too small a unit can result in the misinterpretation of noise in the data—a product of data availability and sampling methods—for patterns. The Census Block Group (Fig. 4.1) was chosen as the spatial unit for this project as it is the smallest unit for which the Census publishes data derived from samples (Economics and Statistics

Administration, 1994) but is large enough to provide a summary of information as opposed to information about specific households. Furthermore, the U.S. Census notes that "most block groups were delineated by local participants in the Census Bureau's Participant Statistical Areas Program," suggesting a level of similarity or affinity between the blocks and households included in each block group (U.S. Census Bureau, 2012).

4.1 Social Domain

The susceptibility of a population to extreme flood events can be inferred from a mix of socio-demographic characteristics that indicate the relative ability of a population to experience damage from extreme events, as well as the ability to respond to events to minimize negative impacts from flooding. Table 4.1 contains an overview of the indicators of social vulnerability observed in the literature. This project draws on the existing literature to propose a set of indicators that relate to vulnerability to extreme floods using publicly-available datasets. Socio-demographic data was downloaded from the U.S. Census through the American FactFinder portal (http://www.factfinder.census.gov) as comma-separated values (CSV) data tables. These tables contain a column with the block group unique identification number, which was later used to join the socio-demographic attributes to census block group geometry to make the data spatial. Table 4.2 lists the Census attributes that were downloaded, collated, and made spatial for this project.

Indicator	% of Studies Containing Indicator	Indicator	% of Studies Containing Indicator
Age	57.7	dependency rate	11.5
child mortality	3.9	% that work within neighborhood	3.8
crime rate	7.7	total population	15.4
education	61.5	cultural heritage	7.7
employment	15.4	receipt of social security benefit	11.5
gender	23.1	% renter occupied	19.2
household composition	34.6	% urban population	3.8
household density	11.5	% voting for leading presidential party	3.8
household income	7.7	birth rate	3.8
language barriers	19.2	retirement home density	3.8
local knowledge	3.8	% female labor force participation	3.8
marital status	3.8	education availability	3.8
nationality	19.2	health status	23.1

Indicator	% of Studies Containing Indicator	Indicator	% of Studies Containing Indicator
past experience with flood events	15.4	quality of life	3.8
per capita income	15.4	class	3.8
persons with disabilities	15.4	occupation	7.7
population change	19.2	social embeddedness	3.8
population density	30.8	social networks	11.5
poverty rate	23.1	% population living in assisted living	3.8
preparedness	3.8	information use	3.8
proximity to water	3.8	wealth	3.8
Race	23.1	length of tenure	7.7
risk perception	19.2	awareness	3.8
unemployment	7.7	trust in institutions	3.8
membership in a group	3.8	community support	3.8
medical professional density	3.8	waste disposal	3.8
% of population living in block housing	11.5	attachment to place	3.8
population in flood zone	7.7	health practices	3.8
mobility	23.1	household living standards	3.8
ownership of communication device	7.7	minority	3.8

Table 4.1 Indicators of Social Vulnerability identified in the literature review of vulnerability studies

Census Table ID	Census Table Name
B01001	Age
B01003	Total Population
C24030	Sex By Industry For The Civilian Employed Population 16 Years And Over
B99051	Allocation Of Citizenship Status
B27010	Types Of Health Insurance Coverage By Age
B25070	Gross Rent As A Percentage Of Household Income In The Past 12 Months
B23025	Employment Status For The Population 16 Years And Over
B22010	Receipt Of Food Stamp / SNAP In The Past 12 Months By Disability Status For Householders
B19013	Median Household Income In The Past 12 Months (In 2016 Inflation-Adjusted Dollars)
B15003	Educational Attainment For The Population 25 Years And Over
B11016	Household Type By Household Size
B09019	Household Type (Including Living Alone) By Relationship
B08134	Means Of Transportation To Work By Travel Time To Work
B07201	Geographical Mobility In The Past Year For Current Residence- Metropolitan Statistical Area Level In The United States

Table 4.2 U.S. Census American Community Survey Block Group-level tables included in this project.

After downloading the tables, I imported the data into Access, a popular consumer database management program (https://products.office.com/en-us/access). This software allowed me to organize the data and calculate proportions from the absolute values provided in the raw data for comparison across block groups. Datasets were joined to the Census block group polygons using the Block Group ID as the primary key.

4.1.1 Age

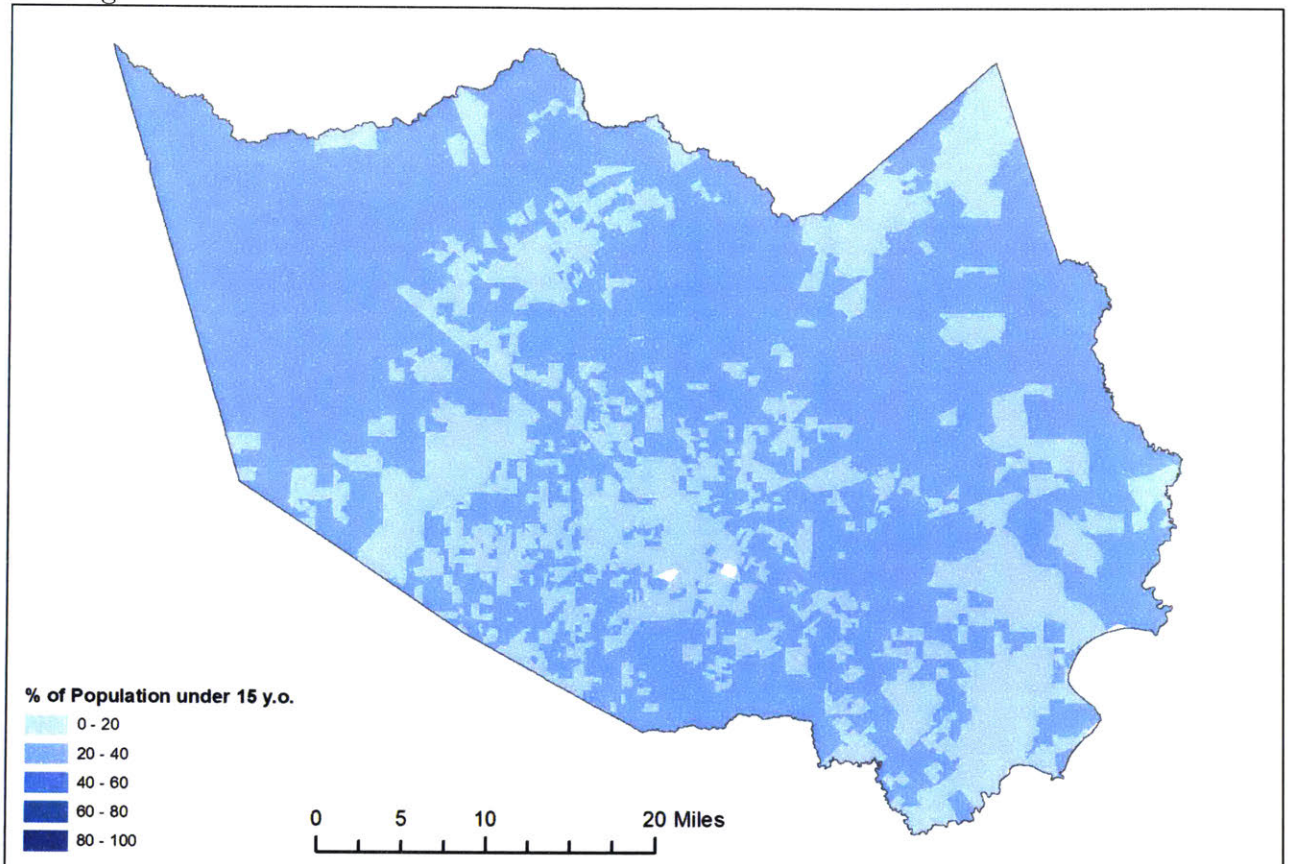


Figure 4.1.1.1 Percent of population under 15 years old

Members of a population that are very young or elderly are less able to respond to extreme events without assistance from others. Elderly persons living in assisted-living institutions or hospitals rely upon caretaker staff in extreme event scenarios, and even in good health are less likely to heed evacuation orders than younger populations (Morrow, 2008). These factors, when coupled with the exacting circumstances often experienced during extreme events, leads to disproportionate mortality rates for elderly populations compared with younger populations. For example, 71% of those that died in Louisiana after Hurricane Katrina were above 60 years old, and 47% were over age 75 (Gibson, 2006). This suggests that the elderly make up a particularly susceptible sub-population which is echoed in the pervasive inclusion of age as a factor of vulnerability in the broader literature (see Table 4.1). Similarly, young persons are particularly susceptible to extreme events and are often similarly dependent on caretakers for provision of food and shelter. This has a negative effect on the overall susceptibility of a household, as parents expend energy caring for dependents (both old and young) when preparing for and responding to extreme events (Cutter et al., 2003). The proportion of census block group residents under 15 years old and over 64 years old were isolated per spatial unit and expressed as a proportion of the total population to determine relative concentrations of the very young and the elderly for this analysis.

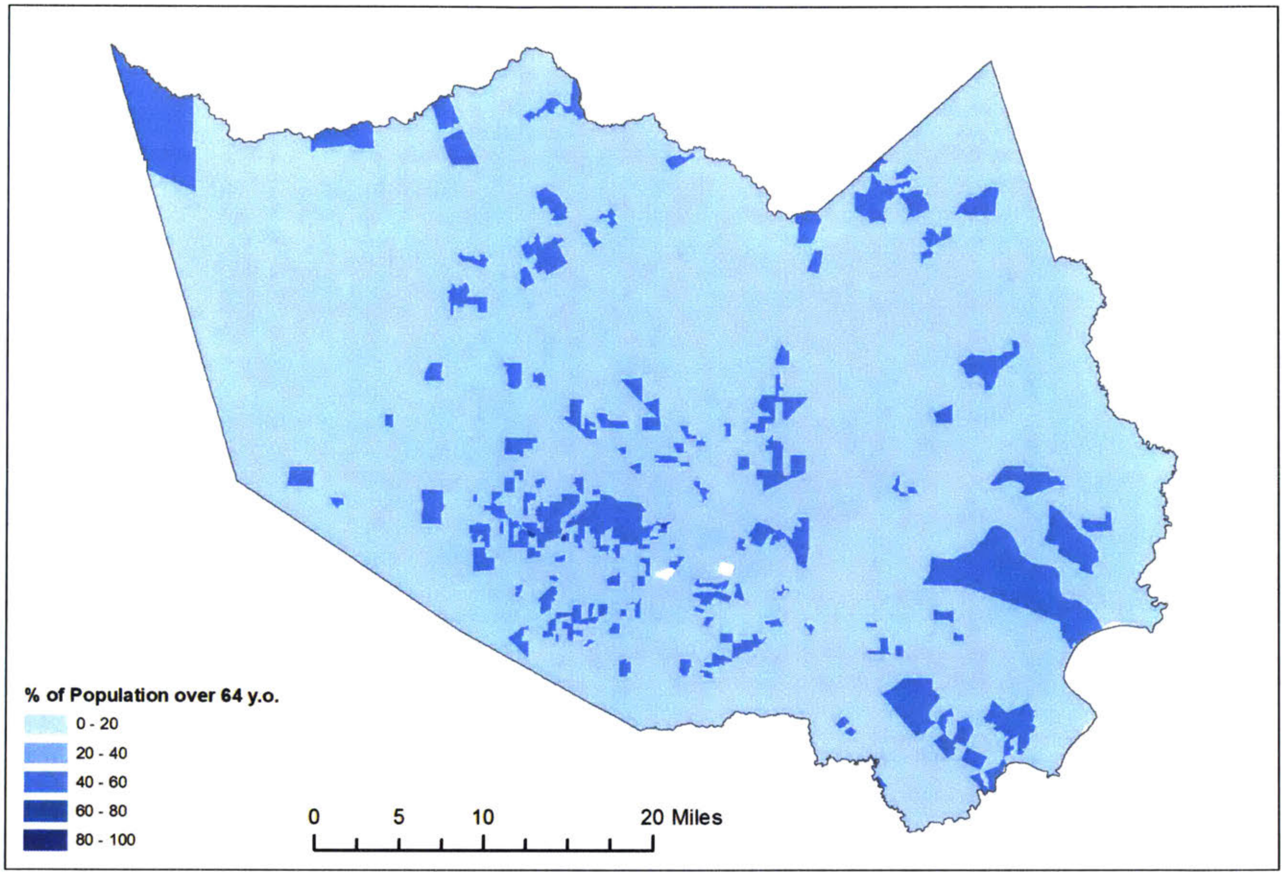


Figure 4.1.1.2 Percent of population over 64 years old

4.1.2 Population / Population Density

Measures of social vulnerability are fundamentally concerned with the degree to which populations are exposed and susceptible to extreme events. Population density was included here as a measure because greater quantities of people exposed to extreme events increases the overall vulnerability of an area, *ceteris paribus*. From a resource management perspective, funding should be allocated to places where there is greatest concentration of at-risk people: high-density urban areas with high levels of vulnerability should receive proportionately greater funding support than sparsely populated rural areas with high levels of vulnerability, *ceteris paribus*. Total population for each census block group was divided by the total area of the census block group to represent the population density for each spatial unit.

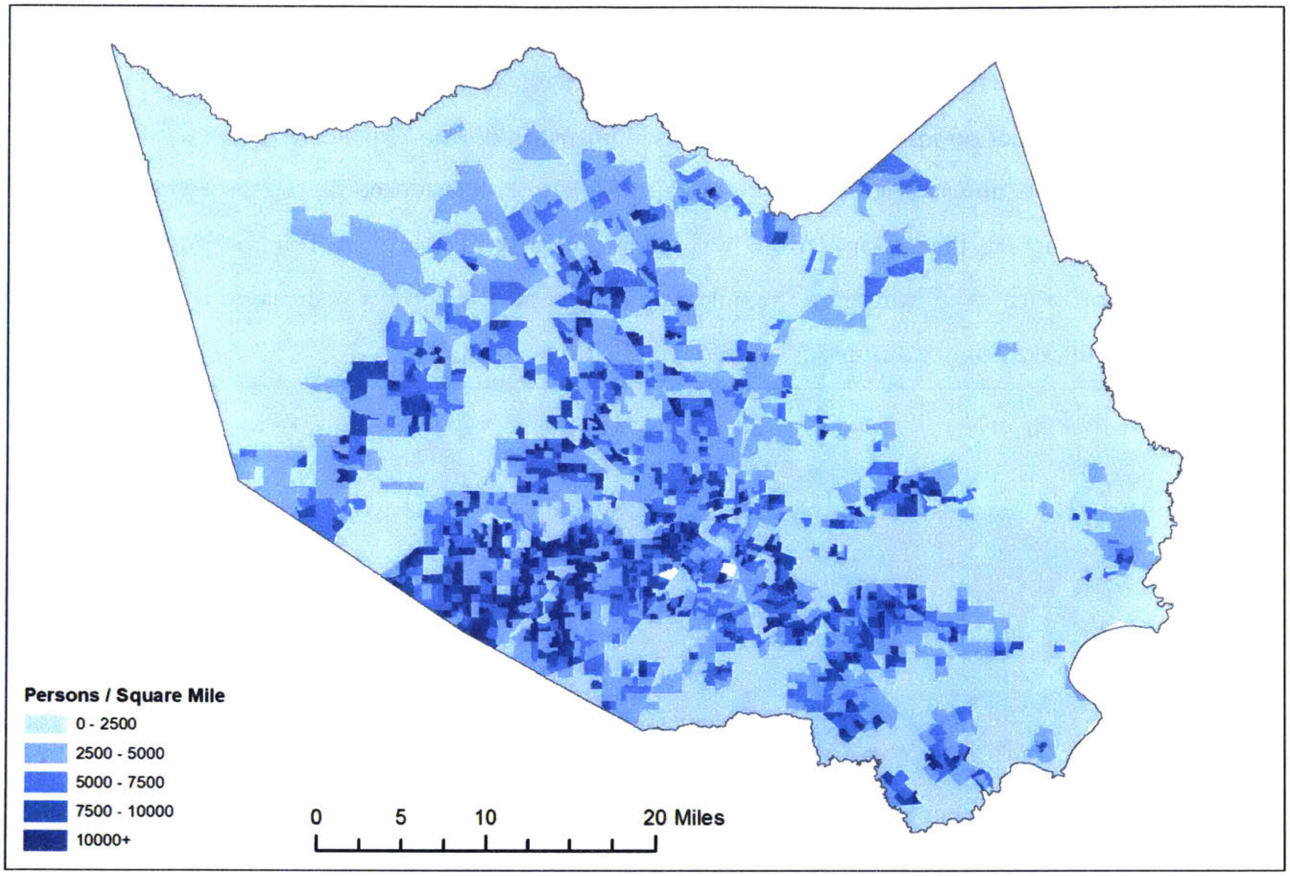


Figure 4.1.2.1 Population Density (persons per square mile per block group)

4.1.3 Citizenship

The citizenship status of a population becomes particularly important in a disaster scenario given the polarized context of immigration policy in the United States today. Non-citizen persons have different access to resources to prepare for extreme events (such as insurance and employment opportunities), as well as resources to respond to and recover from extreme events (such as federal recovery funding). Fear of deportation became an issue of concern during Hurricane Harvey, with vague language published by the U.S. Border Patrol regarding whether or not citizenship checks were occurring at aid distribution shelters and checkpoints drawing admonishment from the American Civil Liberties Union of Texas (Aguilar, 2017) and subsequent clarifications by U.S. Immigration and Customs Enforcement, U.S. Customs and Border Protection, and FEMA that no non-criminal immigrations enforcements would take place at aid locations during or directly after the event (Wilmingham, 2017; ICE, 2017; FEMA, 2017). The confusion around the issues of enforcement of immigration policy during Harvey possibly led to delayed preparation for the event, prevented households from relocating during the storm, and possibly a mistrust of relief services after the event. This led immigrant populations that did not seek shelter to have higher levels of exposure to the storm in the first place, as well as higher levels of susceptibility and lower levels of resilience than non-immigrant populations. It remains to be seen whether the impact of policy in general, and distrust of information in particular, had a deleterious effect on immigrant populations in Houston during Hurricane Harvey. Furthermore, the degree to which undocumented immigrants are likely undercounted in census estimates means that the true impact on these populations will likely never be fully known. For the purposes of this research, the proportion of immigrant population to total population was estimated by dividing total immigrant population by total population per census block group.

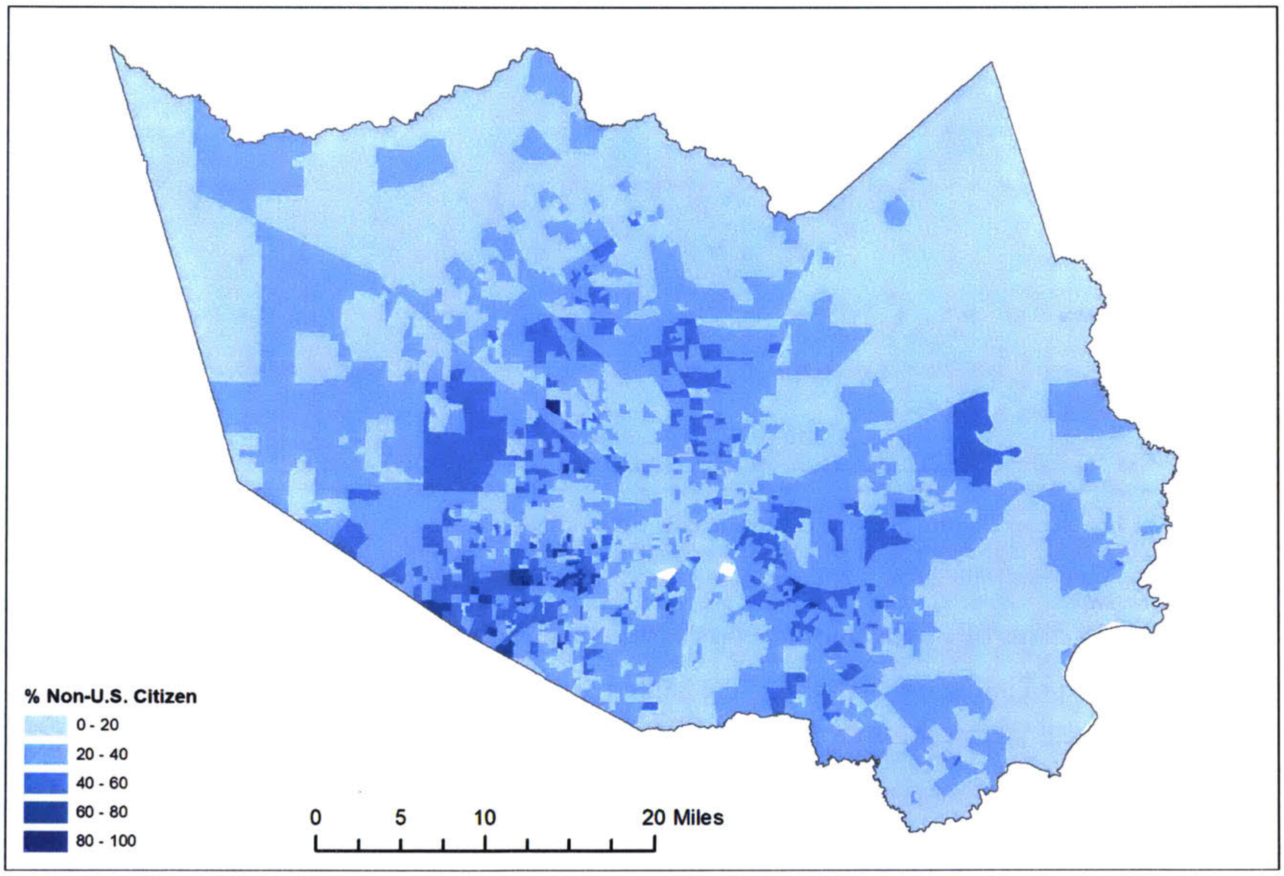


Figure 4.1.3.1 Percent of residents that are non-U.S. citizens

4.1.4 Health Insurance Coverage

Whether or not members of a population have health insurance coverage determines the ease with which populations are able to access critical care after an extreme event. Low-income populations without health insurance coverage are less able to pay for treatment after an extreme event, especially considering other costs associated with a flood event such as evacuation, relocation, replacement of damaged goods, and the opportunity costs of lost wages. This results in higher susceptibility to extreme flooding and can lead to poorer health outcomes over time. The number of people without health insurance coverage were divided by the total population per block group to obtain a proportion of residents without health insurance coverage per block group for this analysis.

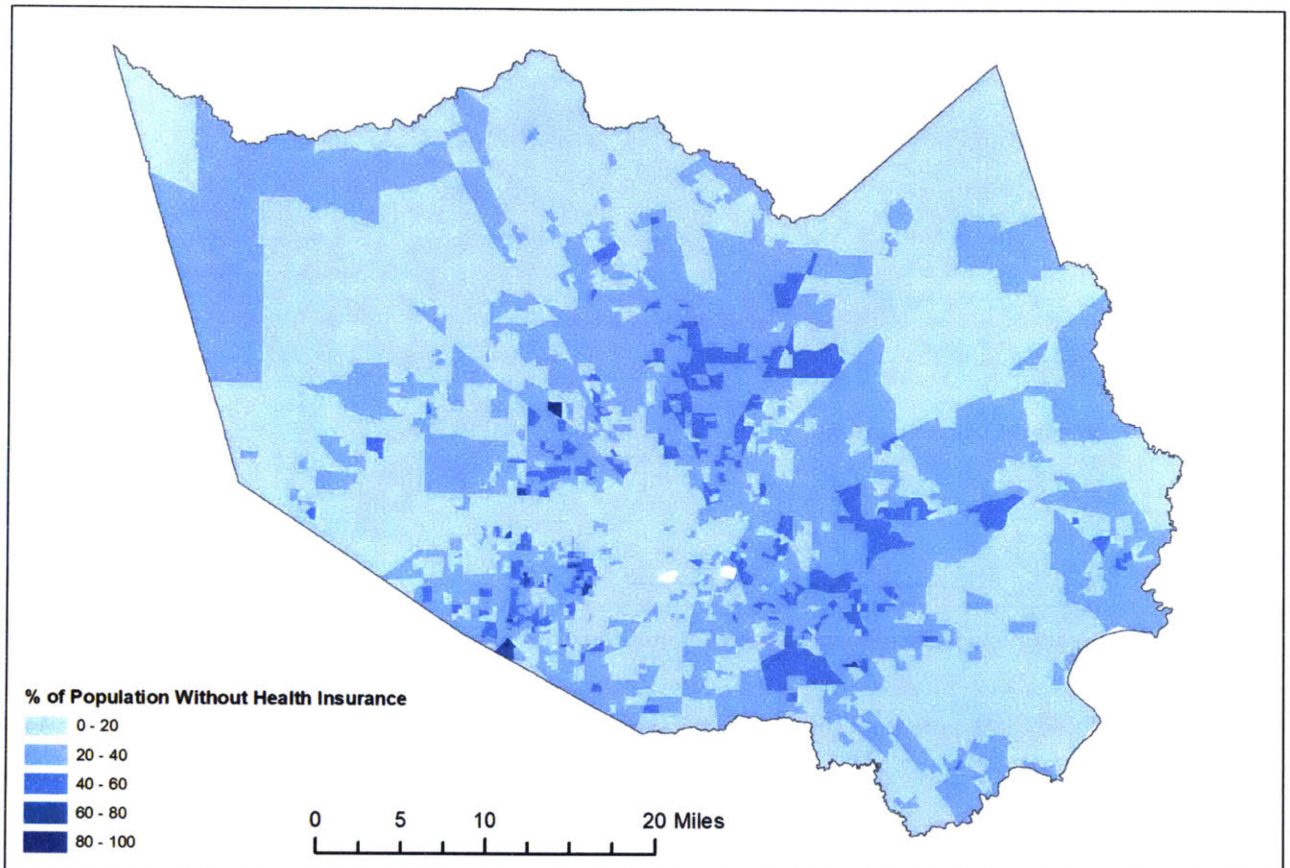


Figure 4.1.4.1 Percent of population without health insurance coverage

4.1.5 Rent as a Proportion of Income

Rising real estate values in cities across the country has led to greater housing cost-related burden over time. Monthly rent as it relates to overall household income indicates the degree to which total household income is expended upon non-assets. The higher the rent to income ratio, the less capital that households have to pay for preparation and recovery costs. Furthermore, a higher ratio also suggests higher financial insecurity in general, and inability to pay for both rental insurance and flood insurance. Texas Property Code Chapter 8 Section 92.054 (Landlord and Tenant, Residential Tenancies, General Provisions) states that if a property becomes "totally unusable" due to an extreme

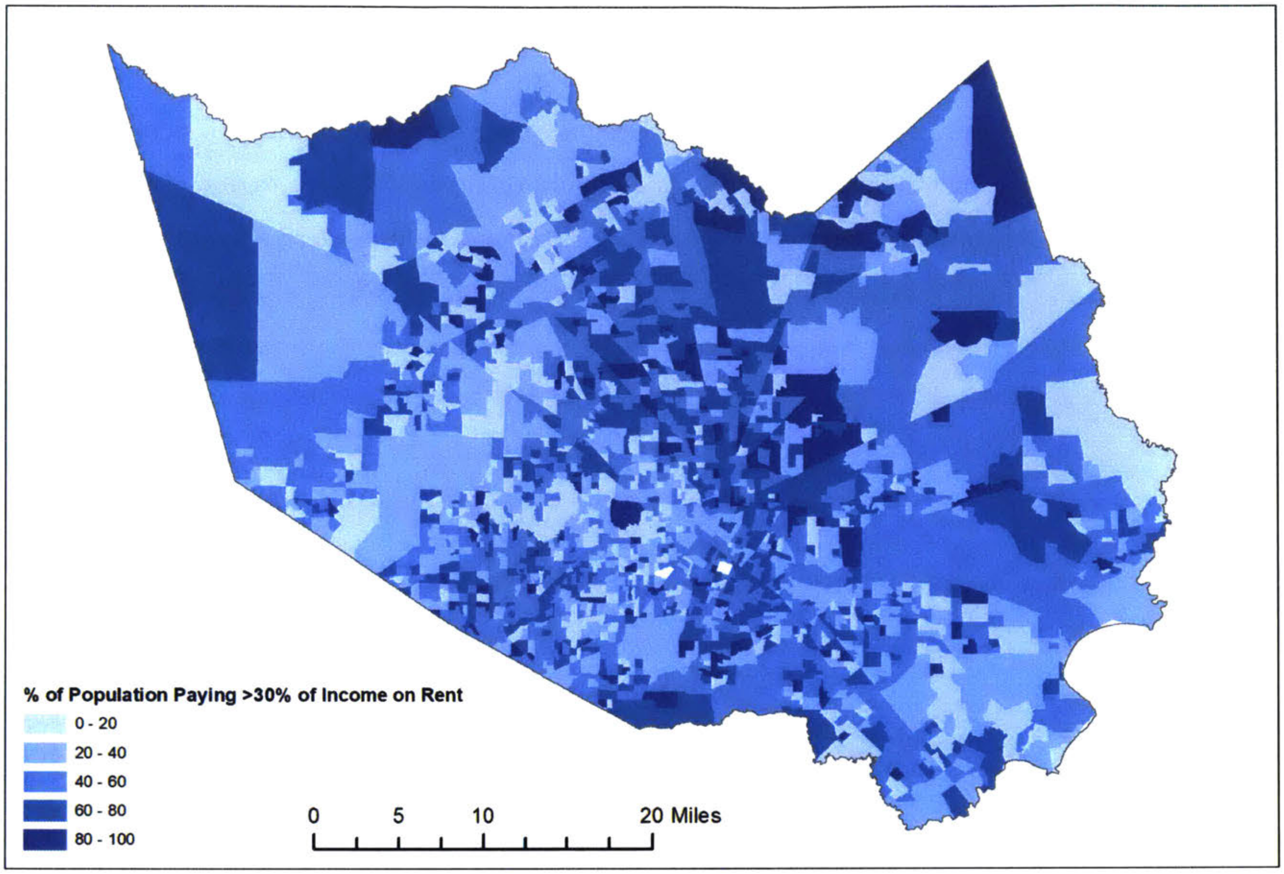


Figure 4.1.5.1 Percent of population paying over 30% of household income on rent

event, the landlord or tenant may terminate a lease. However, the terms of the lease remain in effect if the unit is considered only somewhat unusable. Practically, this resulted in tenants in homes that were damaged and temporarily uninhabitable (including homes with standing water or stripped to the studs) being asked for rent (McKulley, 2017; Milman, 2017), which was particularly burdensome for households with high rent relative to income. This indicator is related to the measure of the proportion of households that are owner-occupied vs. renter-occupied, which has broader implications for the economic conditions of an area and the likelihood that households have flood insurance policies. The proportion of households paying over 30% of income on rent was derived from each census block group and used for further analysis.

4.1.6 Employment Status

The proportion of residents in a spatial unit that is unemployed indicates both the ease with which a population will be able to financially prepare for an extreme event, as well as how well they will be able to cope with the effects of an extreme flood. The greater the proportion of unemployed people, the more susceptible that block group is to a flood event. This value was expressed as a proportion of total population per block group for each spatial unit.

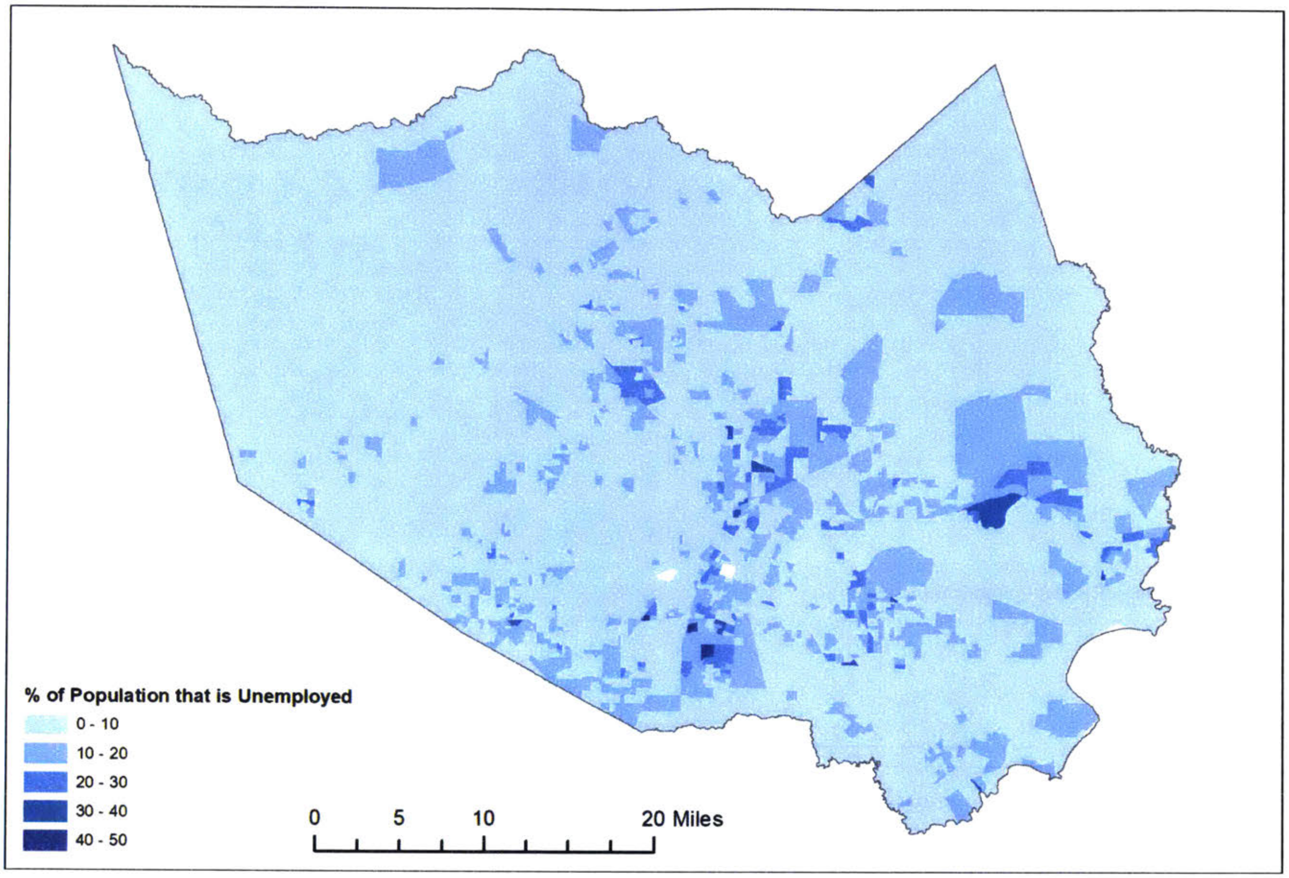


Figure 4.1.6.1 Percent of population that is unemployed

4.1.7 Receipt of Social Benefits

As with the measure of rent as a proportion of income, the proportion of persons who receive social benefits indicates the extent to which persons within an area will have added difficulty in financing preparation for and recovery from extreme events. Persons qualifying for social benefits fall below a certain income threshold or have a disability condition, which also suggests the need for a caretaker in general and in extreme circumstances. As noted above in the discussion of elderly and very young residents, members of this group could be at increased risk during extreme events due to limited mobility. This value is expressed as a proportion of people receiving benefits over the total population for the block group.

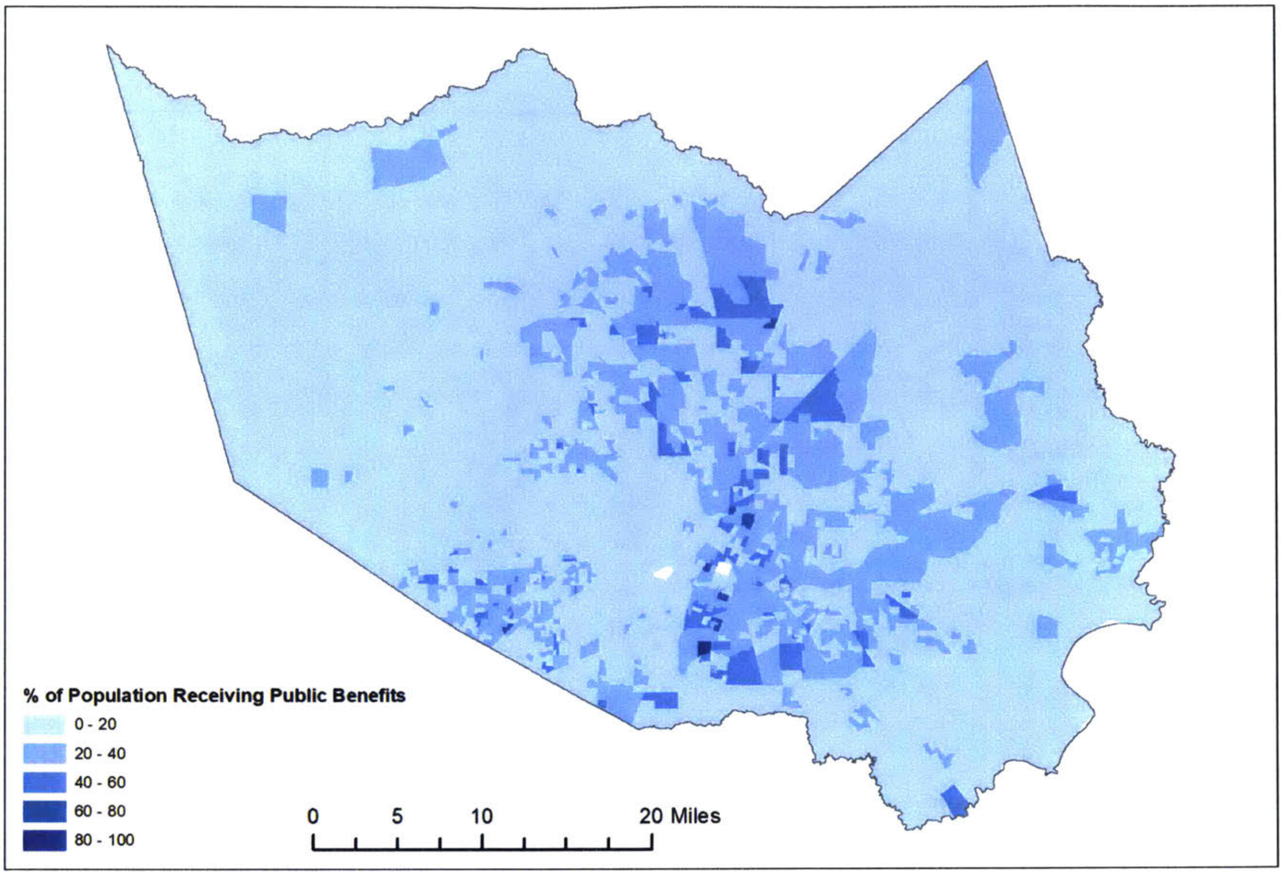


Figure 4.1.7.1 Percent of households receiving public benefits

4.1.8 Median Household Income

The median household income is a measure of the relative ability of households in each census block group to prepare for and respond to extreme flood events. Households with higher incomes generally enjoy greater mobility and are more able to pay for insurance and recovery costs compared to lower income households. Higher income households are less susceptible to the effects of extreme events, but due to development patterns may actually be more exposed to hazard than lower income households (see discussion below).

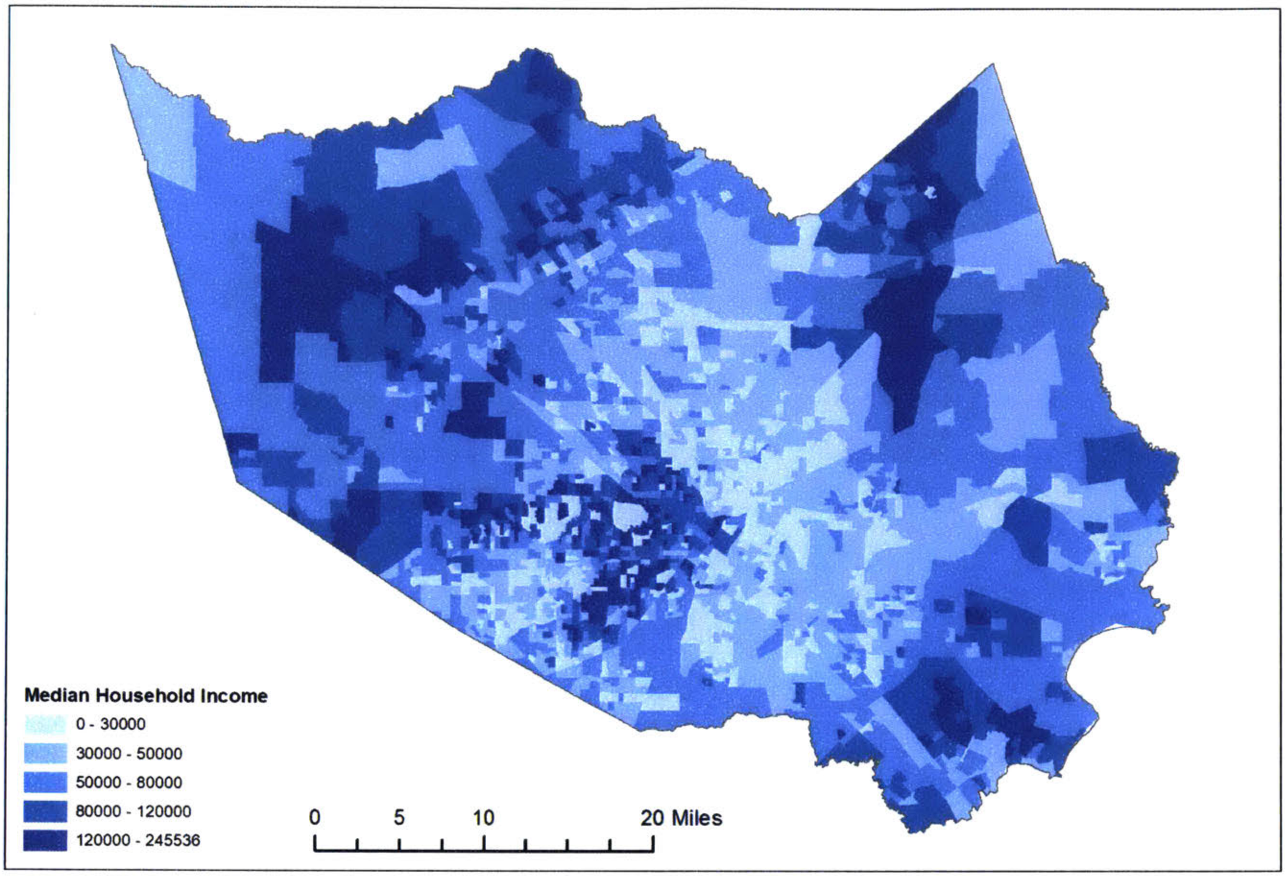


Figure 4.1.8.1 Average Median Household Income per Census Block Group

4.1.9 Educational Attainment

Greater education attainment is often linked with greater economic outcomes, as well as the industry in which a person is employed. Even though 58% (n=15) of reviewed flood vulnerability indices included a measure of educational attainment as an input in the construction of their index, there is disagreement as to the applicability of the measure across different contexts. Silva et al. (2016) position educational attainment as an indicator of public responsiveness to extreme events, implying that literacy can dictate the degree to which a population can respond to information regarding impending risks. Cutter et al. (2003) go a step further and argue that lifetime earnings relate to education attainment, implying that susceptibility as well as resilience are affected by education attainment. Garbutt et al. (2015) claim that measures of education attainment are inappropriate for inclusion in vulnerability studies in developed countries (p. 5), although they ultimately include professional qualification as an input in their model for part of England. I categorized persons in block groups as having obtained a high school diploma or equivalent (or greater), and those who did not. It is possible that this will present itself as a confounding variable and track closely with other socio-economic measures such as household income or rent burden, however this is accounted for in the Principal Component Analysis (see below).

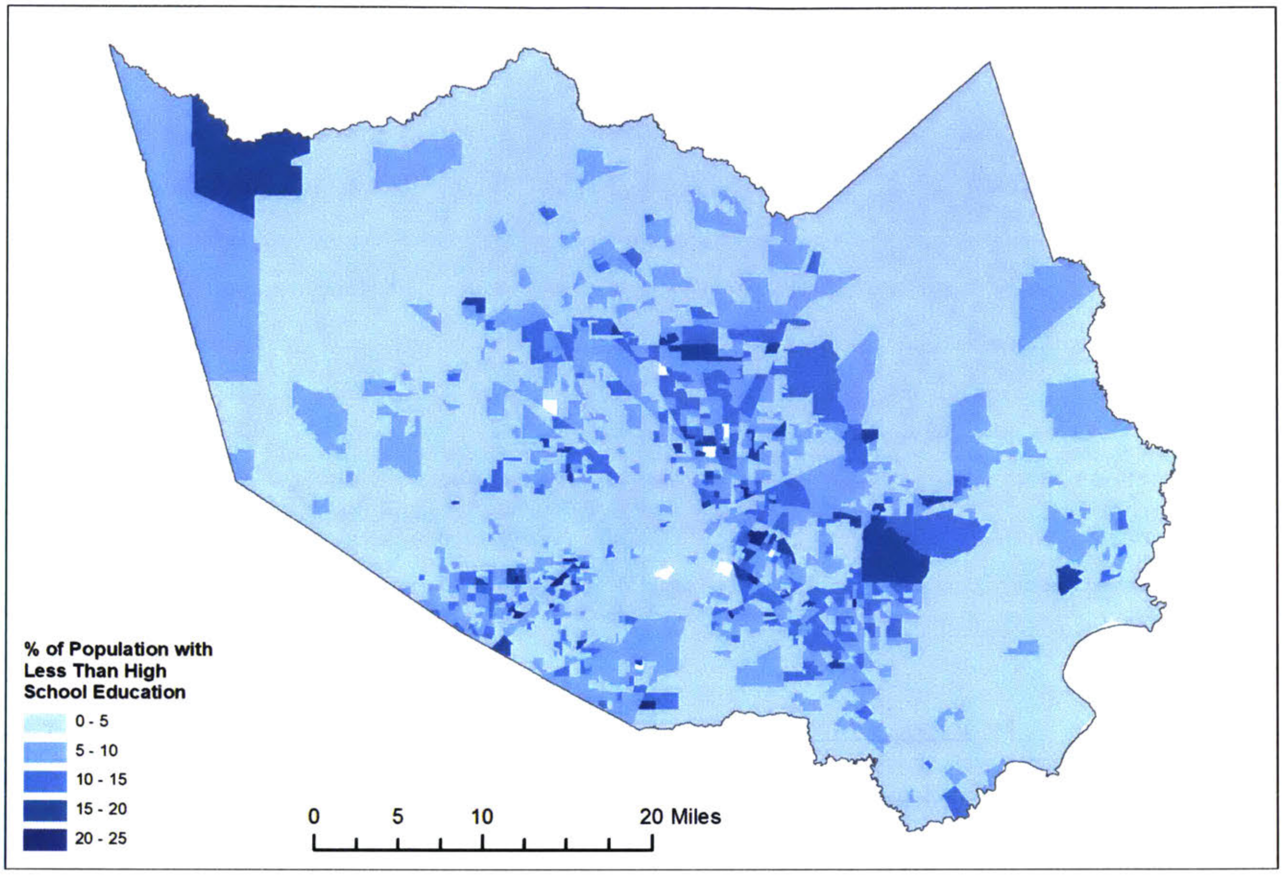


Figure 4.1.9.1 Percent of population with high school or equivalent education or greater

4.1.10 Household Composition / Household Size

Households with only one head of household, as well as larger households, experience greater strain in preparing for and recovering from extreme events (Garbutt et al., 2015; Roder et al., 2017; Borden et al., 2007). In particular, the literature focuses on variations of female-headed households as being particularly vulnerable. Using census data, I was able to categorize households by their size and their head of household characteristics on a census block group level for further analysis. Ultimately, I included household size as a measure of susceptibility, and included the proportion of households with over six members as an input variable.

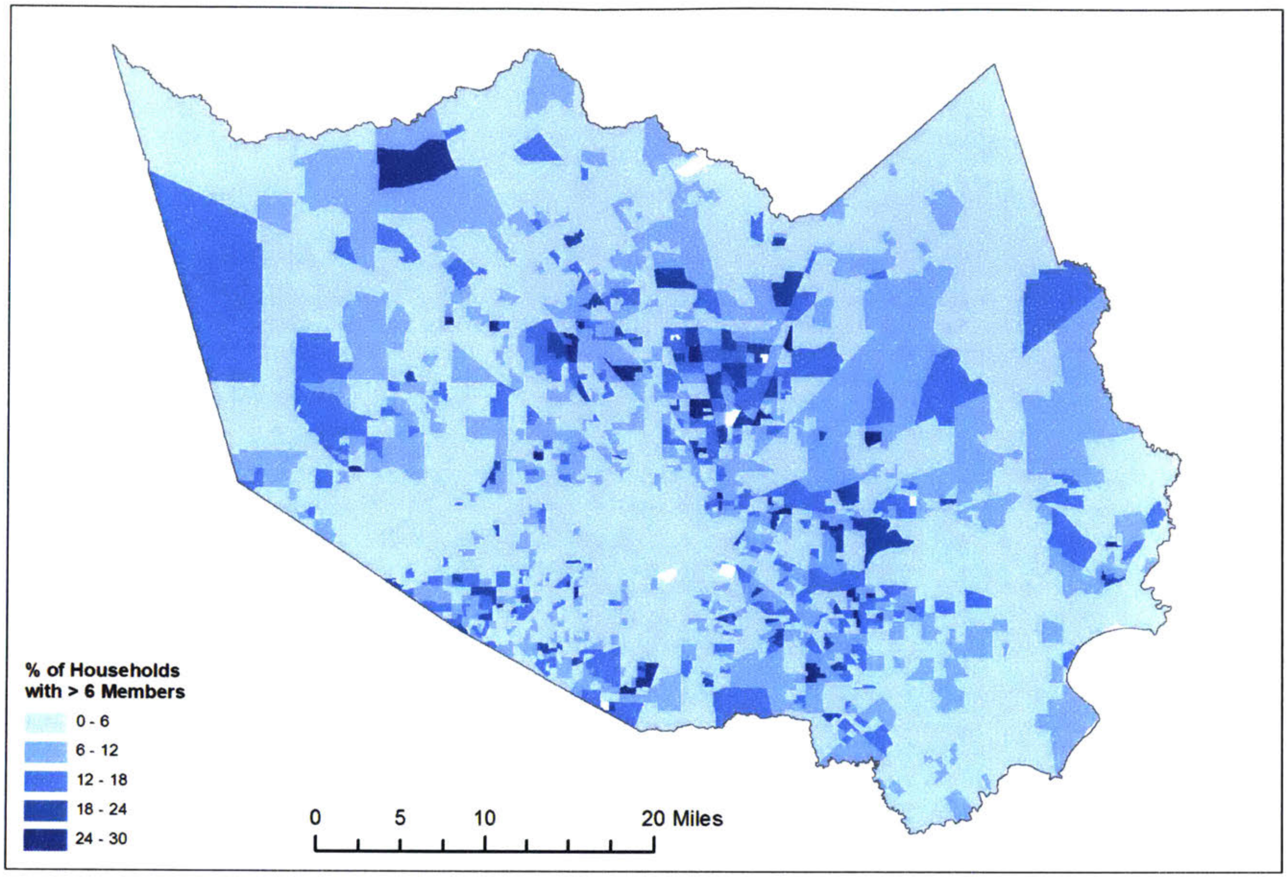


Figure 4.1.10.1 Percent of households with six or more members

4.1.11 Means of Transportation

Access to viable transportation is important in any city, but particularly so in a low-density city such as Houston with a large suburban periphery. Reliance on public transportation can leave populations with greater levels of exposure to extreme events, as well as limited options in disaster events and therefore greater levels of susceptibility (Bathi and Das, 2016). Others such as Valchev et al. (2016) position the presence of transport networks not as an equity or access issue, per se, but as infrastructure that is vulnerable to extreme events based on the level of exposure as well as the local, regional, and national importance of the infrastructure. For the purposes of this study, means of transportation focuses on the degree to which a household has access to a personal motor vehicle (as opposed to public transportation) for use in responding to extreme events.

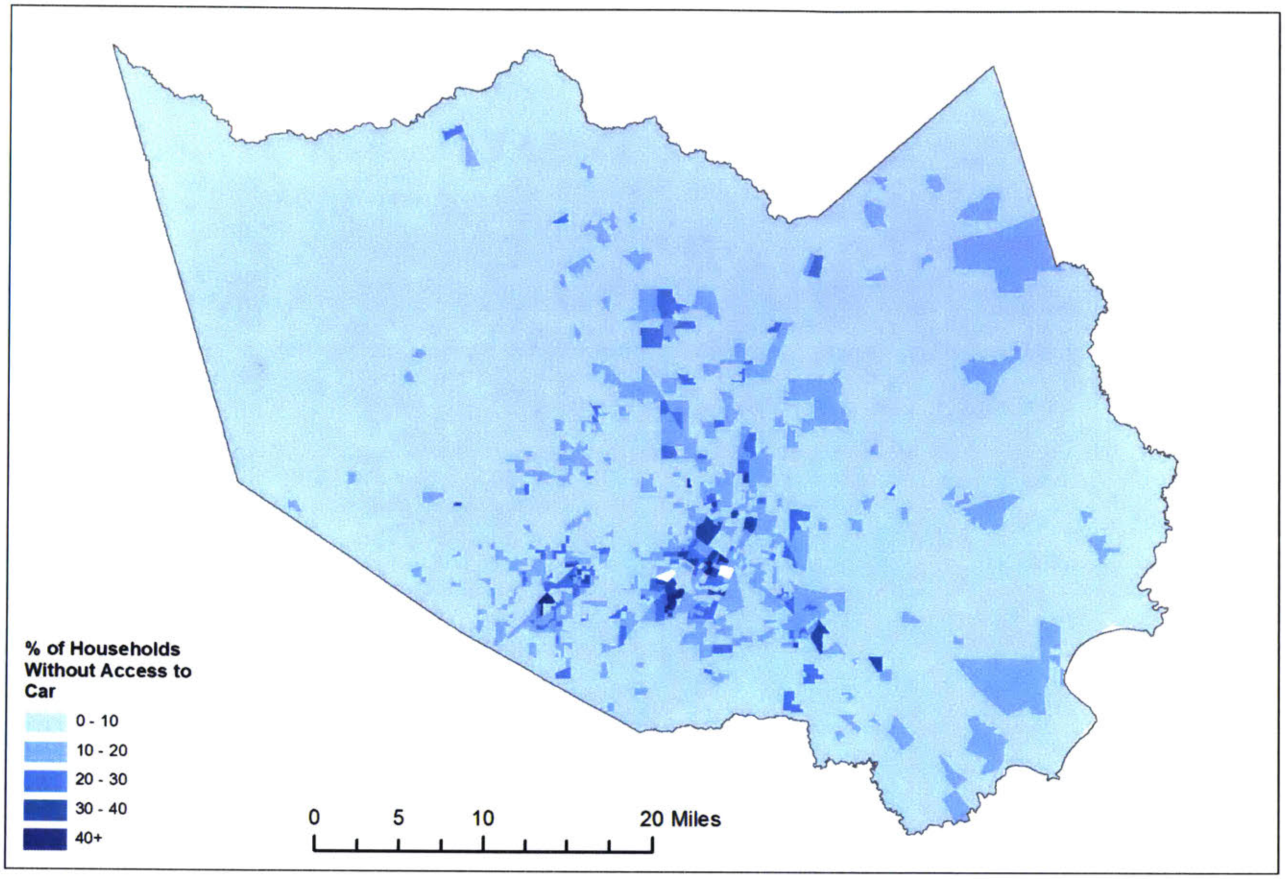


Figure 4.1.11.1 Percent of households without access to personal motor vehicle

4.1.12 Geographical Mobility / Length of Tenure

This indicator serves to measure the degree to which a household has had the opportunity to develop a sense of local social embeddedness based on the length of tenure in their current location. By incorporating Census data related to the length of tenure in the current location, I am able to speculate on the level of connection that a household has to place, as well as the potential for having formed local bonds that could be called upon in disaster scenarios (Cutter et al., 2008). Length of tenure, and location of previous residence (i.e. within the same metropolitan region, in a different metropolitan region, or abroad) can also indicate the level of familiarity a household has with the risk of flooding and the available resources to prepare for and respond to flood events. I classified the block group data into households that lived in the same place over the past year vs. households that lived in a different area in the past year for further analysis.

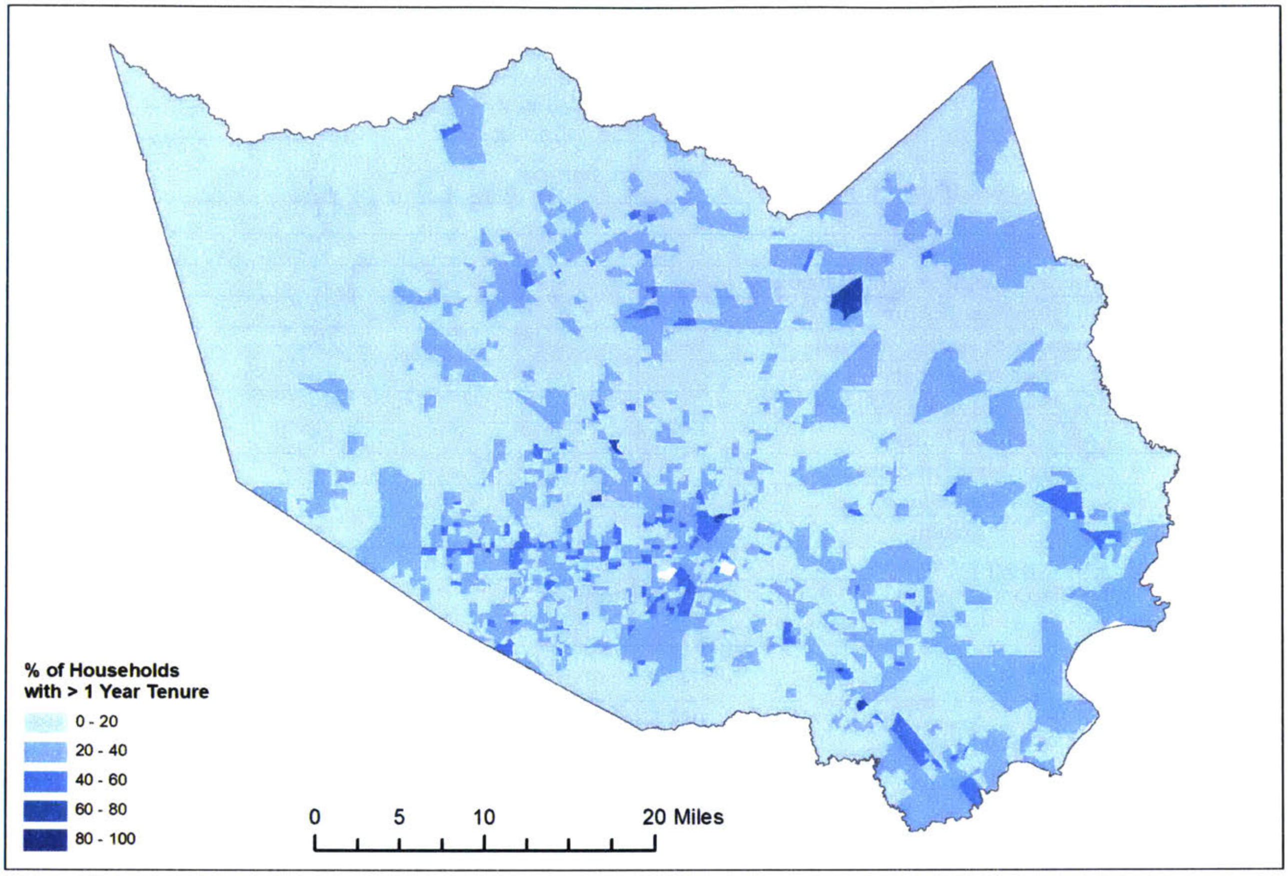


Figure 4.1.12.1 Percent of households that moved into current residence in the past year

4.2 Built Domain

Unlike the Social domain, the sources for the Built domain were drawn from a number of sources and required more spatial processing. Unless otherwise noted, all spatial analysis in this section was performed using ArcGIS 10.5.1 (https://www.esri.com/en-us/arcgis/products/index) in the Universal Transverse Mercator (UTM) Zone 15N projection system. Table 4.2.1 contains a summary of the built environment indicators that were observed in the literature review, and Table 4.2.2 lists the data layers that were created through this process. Following is a description of the data synthesis process for each layer.

Indicator	% of Studies Containing Indicator
% impervious surfaces	7.7
building age	23.1
building condition	11.5
building density	15.4
building type	42.3
household density	7.7
land use	19.2
% built up area	7.7

Indicator	% of Studies Containing Indicator
vacant households	3.8
household net area	3.8
non-accessible households	3.8
underground built up area	3.8
uncontrolled planning zone	3.8
exposure of housing units	3.8
urban growth rate	7.7
% households without central heating	3.8
residents per house	3.8
number of people affected	3.8
building elevation	3.8
number of houses affected	3.8
"urban planning"	3.8
multi-unit structures	3.8
mobile homes	3.8
crowding	3.8
group quarters	3.8

Table 4.2.1 Built environment indicators observed in the literature

Data Layer	Input Data
Proportion Impervious Surface	Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Database 2011 (2014 edition); NASA/USGS LANDSAT-8 Top of Atmosphere Analysis-Ready Imagery (2017)
Proportion Vacant Land	Harris County Appraisal District Parcel Database
Building Age	Harris County Appraisal District Parcel Database
Building Condition	Harris County Appraisal District Parcel Database
Proportion Poor Drainage	Houston-Galveston Area Council / USGS 10-meter resolution Digital Elevation Model
Proximity to Water	Texas Commission on Environmental Quality Stream Segments
Building Density	Harris County Appraisal District Parcel Database
Proportion in Flood Zone	FEMA Harris County Coastal Areas Flood Zone Designation Database

Table 4.2.2 Data layers and data sources for Built Environment domain model.

4.2.1 Proportion of Impervious Surface

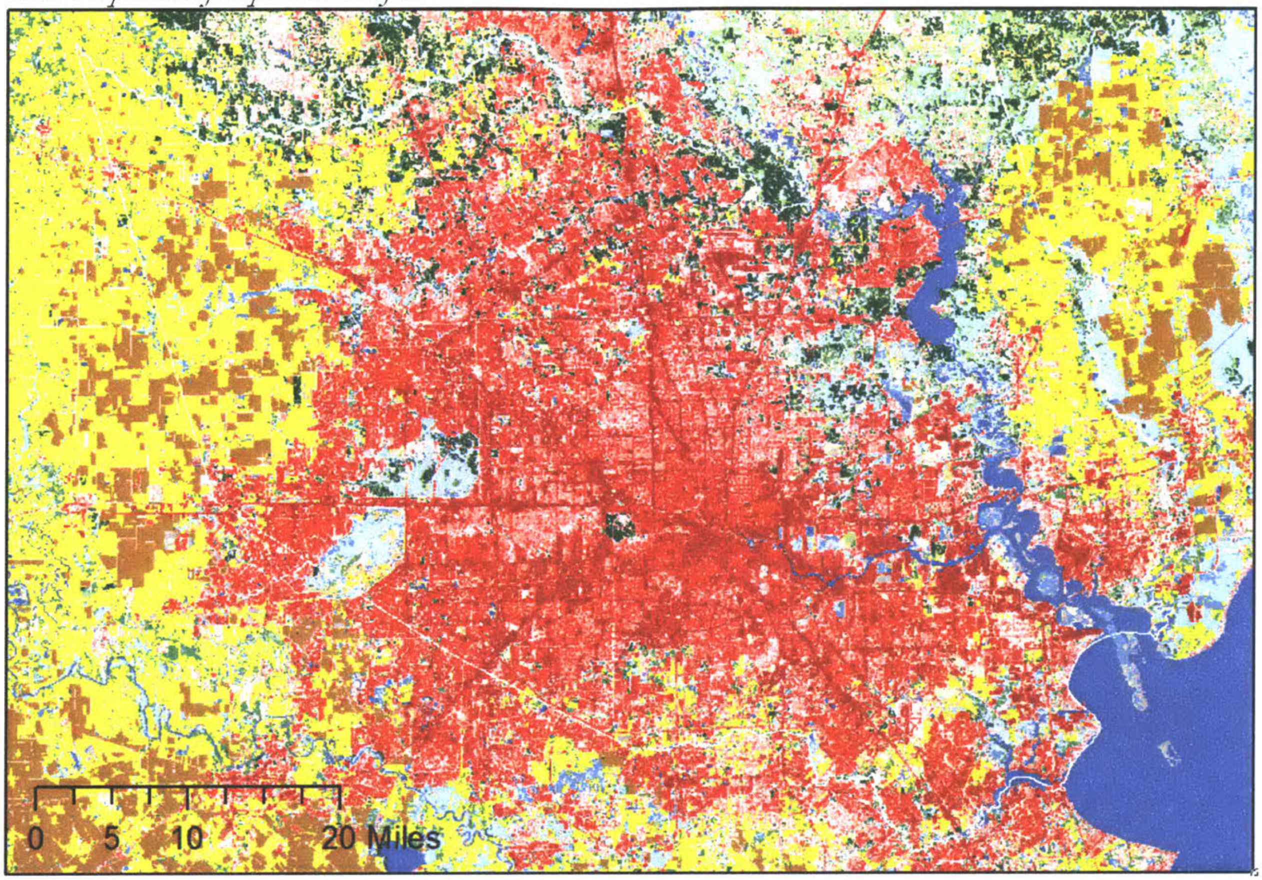


Figure 4.2.1.1 2014 NLCD Land cover classification for study area

Extreme flood events are caused by both coastal storm surge and extreme rain. During Hurricane Harvey, Houston experienced historic levels of rainfall which overwhelmed the sewage system's capacity for rainwater management. Green infrastructure, or pervious surfaces more broadly, offset some of the burden of runoff management from traditional hard infrastructure through absorbing or slowing water before it enters the sewer system. As such, the proportion of impervious surface in an area can signal the degree to which the area is reliant on sewer infrastructure to manage storm water. To calculate the proportion of impervious surface per block group, I downloaded the Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Database (NLCD). The NLCD dataset is a national 30-meter resolution categorical representation of the land cover of the United States derived from satellite data by MRLC, a division of the United States Geological Survey (USGS). The NLDC dataset is a canonical, continuous land cover dataset for the United States and Wickham et al. (2017) observed an 82% accuracy rate for the 2011 version of the dataset, with the source of error largely stemming from the ambiguity of urban density definitions. For each of the urban classifications, a range estimate of proportion of impervious surface is included: *Developed, Open Space*: < 20%; *Developed, Low Intensity*: between 20-49%; *Developed, Medium Intensity*: between 50-79%; *Developed, High Intensity*: between 80-100% (MRLC, 2018). The NLCD dataset was clipped to the Harris County boundary for inclusion in processing.

A clear limitation of the NLCD dataset is the infrequency with which it is updated. Of the ~943,000 parcels registered in the Harris County Appraisal District parcel database that have information on date of construction, ~16,000 (2%) were constructed after 2011, translating to construction on 50 square miles of parcels (Houston County Appraisal District, 2018). Not accounting for decreased area of pervious surfaces on regional water management could lead to increased flooding in new and existing neighborhoods. To update the measure of impervious surface, I downloaded Landsat-8 satellite imagery collected by NASA and distributed by USGS. The Landsat-8 satellite circles the earth once every 16 days and provides 30-meter resolution imagery of most of the planet (U.S. Geological Survey, 2018). I selected four image tiles representing the Houston area in May 2017 (the most recent available data where the area is not occluded by cloud cover) and ran the Composite Band tool to merge the red, green, and blue wavelength image files into a single multi-band true-color image (Figure 4.2.1.2). I then used the Image Analysis package in ArcGIS to identify urban and non-urban areas on the image, ground-truthing the classification using Google Maps (http://www.maps.google.com) and Google Street View. I then used the Interactive Supervised Classification tool to generate a classification of impervious and pervious surfaces in Houston (Figure 4.2.1.3). Using algebraic functions, I combined the NLCD dataset with the derived land cover classification such that clusters of post-2014 development replaced non-urban pixels in the NLCD dataset while maintaining the nuance of the NLCD classes elsewhere.

Figure 4.2.1.2 2017 LANDSAT-8 composite satellite imagery for study area

This composite dataset was converted to polygon features, and a new field was calculated estimating the area of impervious surface based on the midpoint estimate given by MRLC (2018). For pixels that were classified as highways in the supervised classification, I used the *Developed, High Intensity* midpoint proportion of pervious surface (0.1); for other urbanized areas identified in the classification, I used the value for *Developed, Medium Intensity* (0.35). These estimated areas were then summed on a per-block group basis and expressed as a proportion of surface area that is impervious for each block group.

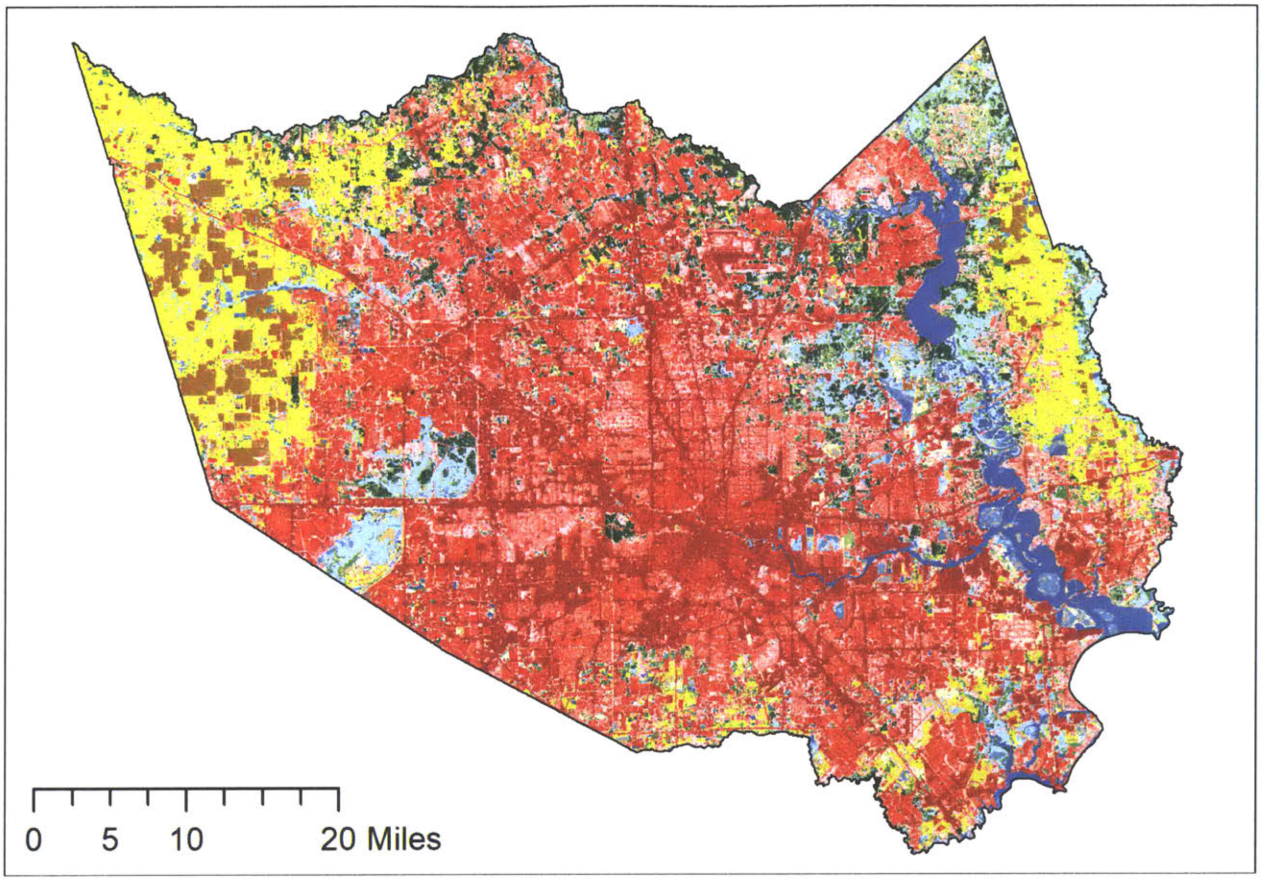


Figure 4.2.1.3 Composite land cover data derived from NLCD and LANDSAT-8 data

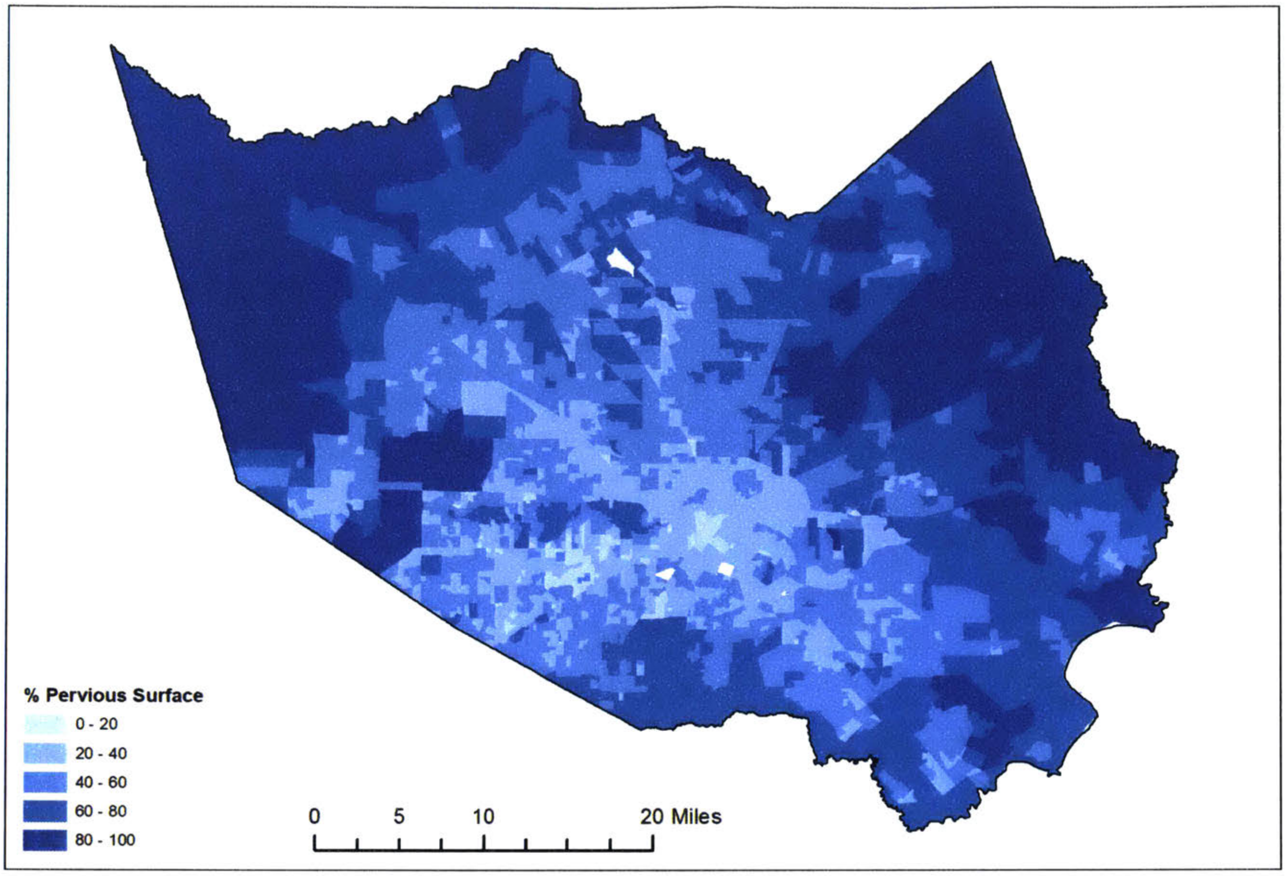


Figure 4.2.1.4 Proportion of land surface that is permeable

4.2.2 Average Building Age

The age of the structures in an area can serve as an indication of the building codes under which the structure was constructed: older houses were likely built without consideration for the frequency and level of severity of flood events as experienced today (for example, not building with regard for changing flood hazard zones as defined by FEMA). Conversely, older houses were likely built on higher ground in areas less likely to be flooded in the first place. However, new housing developments increase the level of impervious surface in an area which can increase the likelihood that nearby pre-existing structures would flood as a result of new construction. These cascading effects of development patterns are outside the scope of this project, but the building vintage was included as an indicator as another proxy for building preparedness for extreme events.

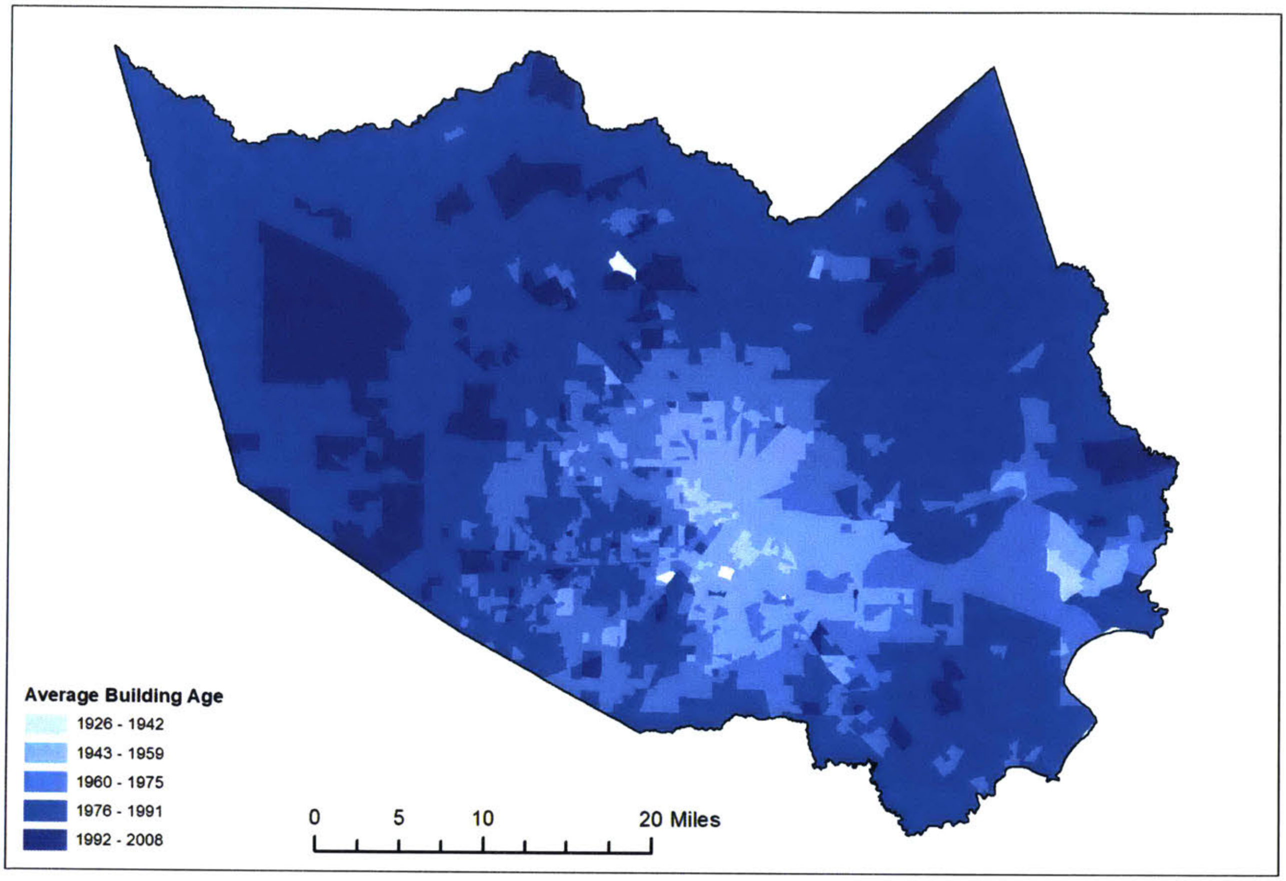


Figure 4.2.2.1 Average building age

Parcel-level information for Harris County was obtained from the Harris County Appraisal District (HCAD) online data portal. CSVs containing a range of information were downloaded and made spatial by joining the attributes to parcel geometries. For each block group, the mean construction age of all parcels within that block group was calculated and assigned to that block group. While outliers may have affected the derived means, it is assumed that development happens in phases and that houses within block groups were constructed around the same time. The resultant dataset was then added to the database.

4.2.3 Building Condition

The Harris County Appraisal District database also includes appraised structure condition, including *Low*, *Average*, *Good*, *Excellent*, and *Superior*. I assume that a structure's condition indicates the degree to which the structure is susceptible to damage from extreme flooding events (i.e. buildings in good condition are less susceptible to damage from storms than buildings in already poor condition, *ceteris paribus*). With that in mind, I used the SciPy Python library to calculate the central tendency (mode) for building condition for each census block group. The resultant dataset was then added to the Access database. In the future iterations of this project it would be worthwhile to also calculate the skew for building qualities for each block group to show whether buildings in that area tend to be in better or worse condition as well as calculating the central tendency.

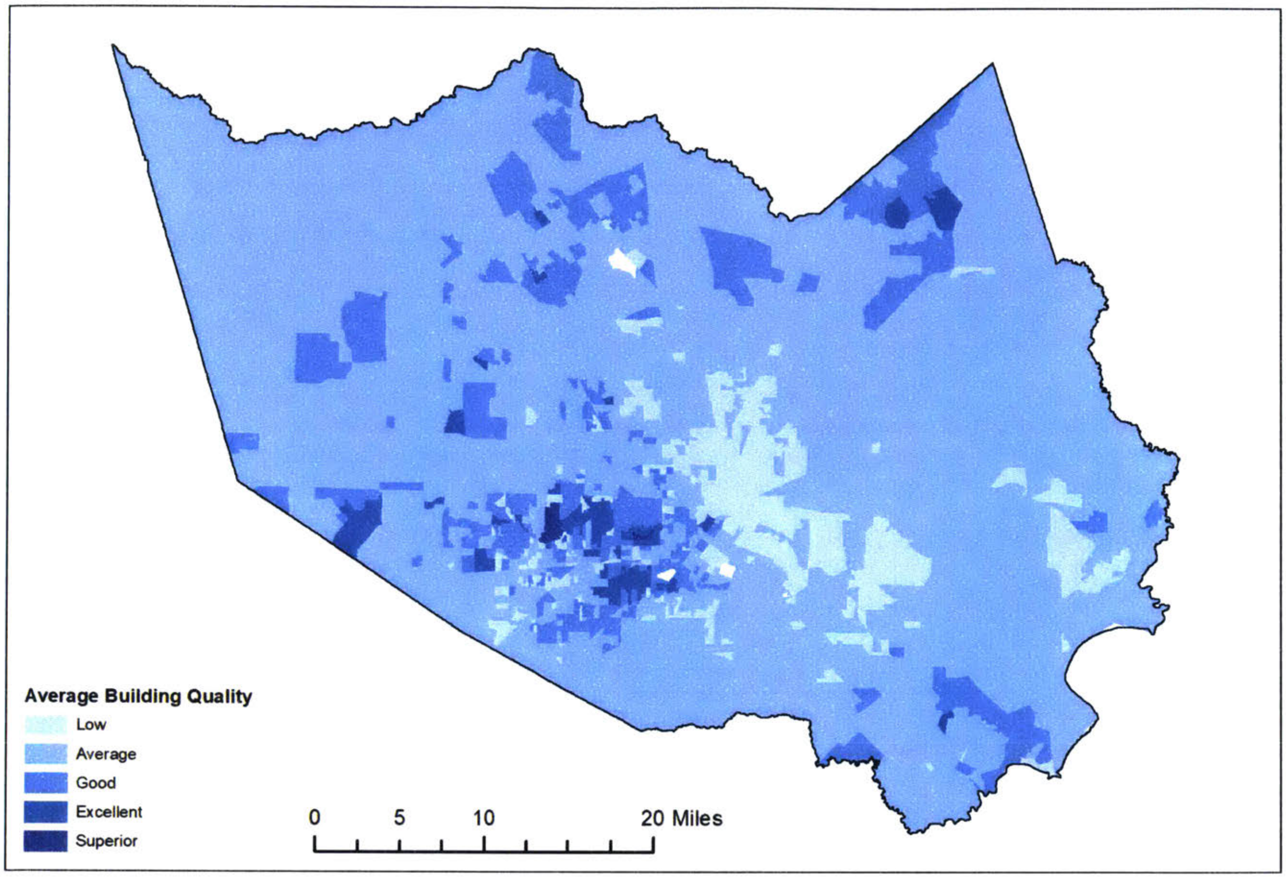


Figure 4.2.3.1 Average building quality per block group

4.2.4 Proximity to Water

Beyond knowing whether or not a building is in a designated flood zone, I found it important to determine how far away from water each census block was. Houston is interspersed with 22 bayous, or streams, which contributes to overall risk of flooding in extreme events. I converted each census block group polygon to a point that represents its centroid (the geometric center of the polygon) to be able to calculate the distance to the nearest water feature. Using the Texas Commission on Environmental Quality's Stream Segment dataset (Texas Commission on Environmental Quality, 2018) and the shoreline as the input water features, I ran the Near analysis tool in ArcGIS to compute planar distance in feet between each centroid and the nearest water feature. The resultant dataset was then added to the Access database.

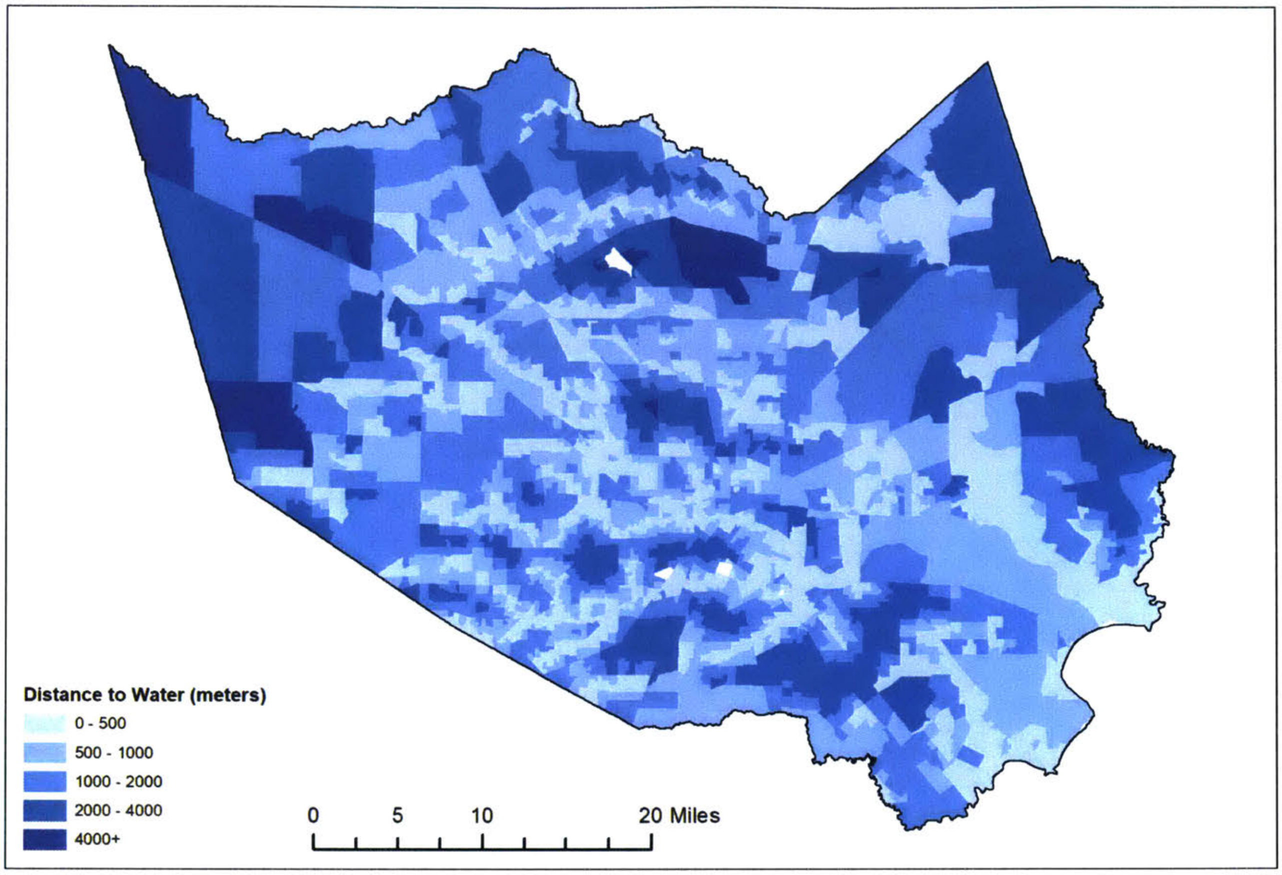


Figure 4.2.4.1 Distance from Census block group centroid to water body

4.2.5 Proportion of Internally-Draining Land

As mentioned previously, proper drainage is an important consideration for water management in general and flood events in particular. I assume that buildings in low-lying areas are more likely to flood than buildings at higher elevations or that drain toward water features. Thus, buildings in "sinks" or internally-draining areas were deemed to be more vulnerable than non-sink areas. To identify sinks, I downloaded the USGS 10-meter resolution Digital Elevation Model (DEM). The DEM is an image that contains elevation values in each pixel. I computed the Flow Direction of the DEM surface, which determines the direction that a liquid would flow for every cell given the relative elevation of all neighboring cells. This process identified broad hydro-geologic flowsheds that correspond with the bayou-bay system present in Houston. This flow direction surface was then used to identify sinks with the Sink spatial analysis tool, which identifies pixels that do not drain into other adjacent cells. These cells were converted to polygons, and the area of all sink cells were summed and expressed as a proportion of the total area of each census block, producing the proportion of each census block that is an internally-draining sink. This dataset was then added to the database for inclusion in the model.

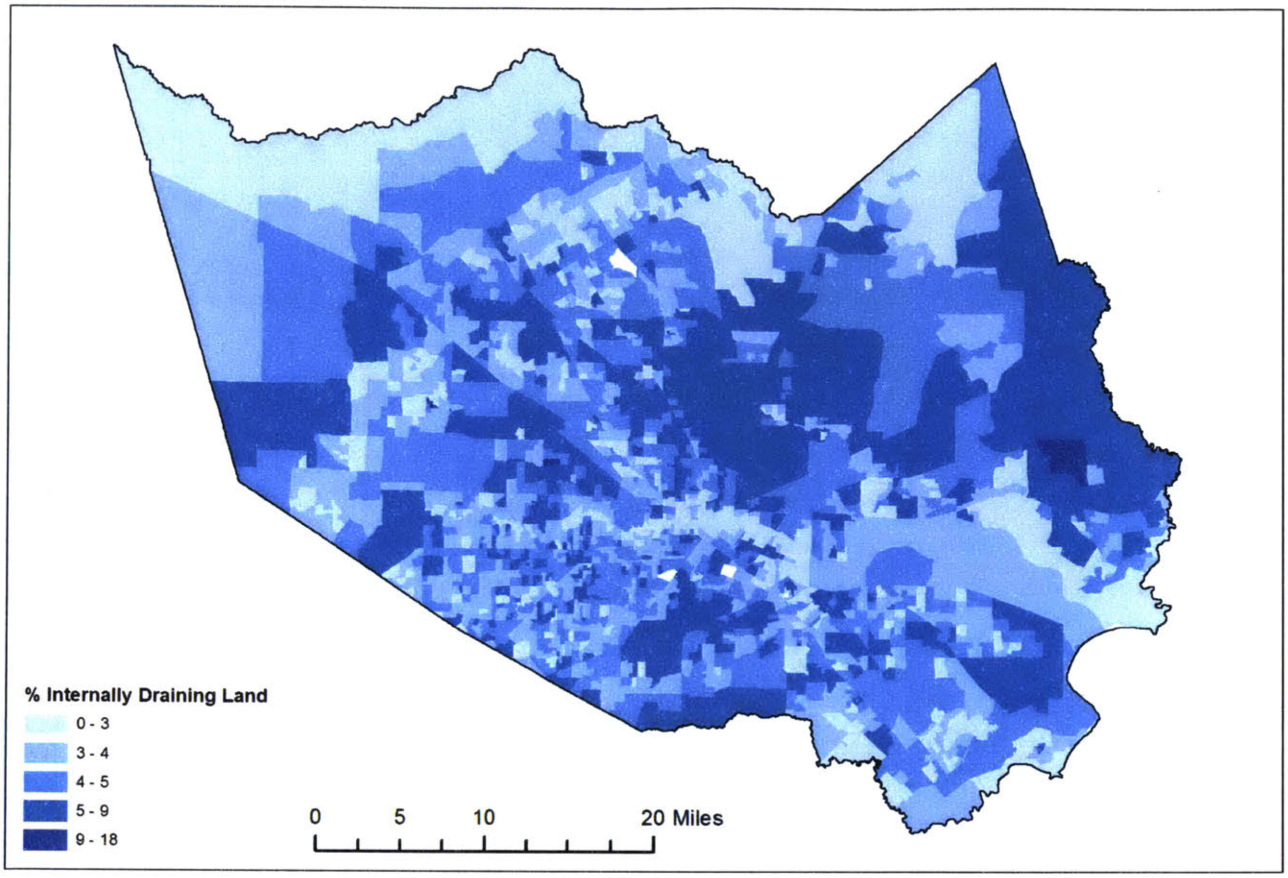


Figure 4.2.5.1 Proportion of internally-draining land

4.2.6 Building Density

High density areas provide a number of benefits in terms of agglomeration of services and resources. However, in extreme event scenarios, higher levels of density can provide issues for risk reduction, namely for retreat of vulnerable populations, the concentration of critical infrastructure (and higher possible levels of damage per unit area than less dense areas), and impeding search and rescue efforts due to high density areas (Cutter et al., 2003). Net building area was aggregated for each block group polygon and expressed as a ratio to total surface area for each census polygon. This density ratio is higher in the city center where buildings have high floor area relative to building footprints compared to outlying areas where the floor to area ratio is much lower. The output from this analysis was stored in the Access database for inclusion in further modeling.

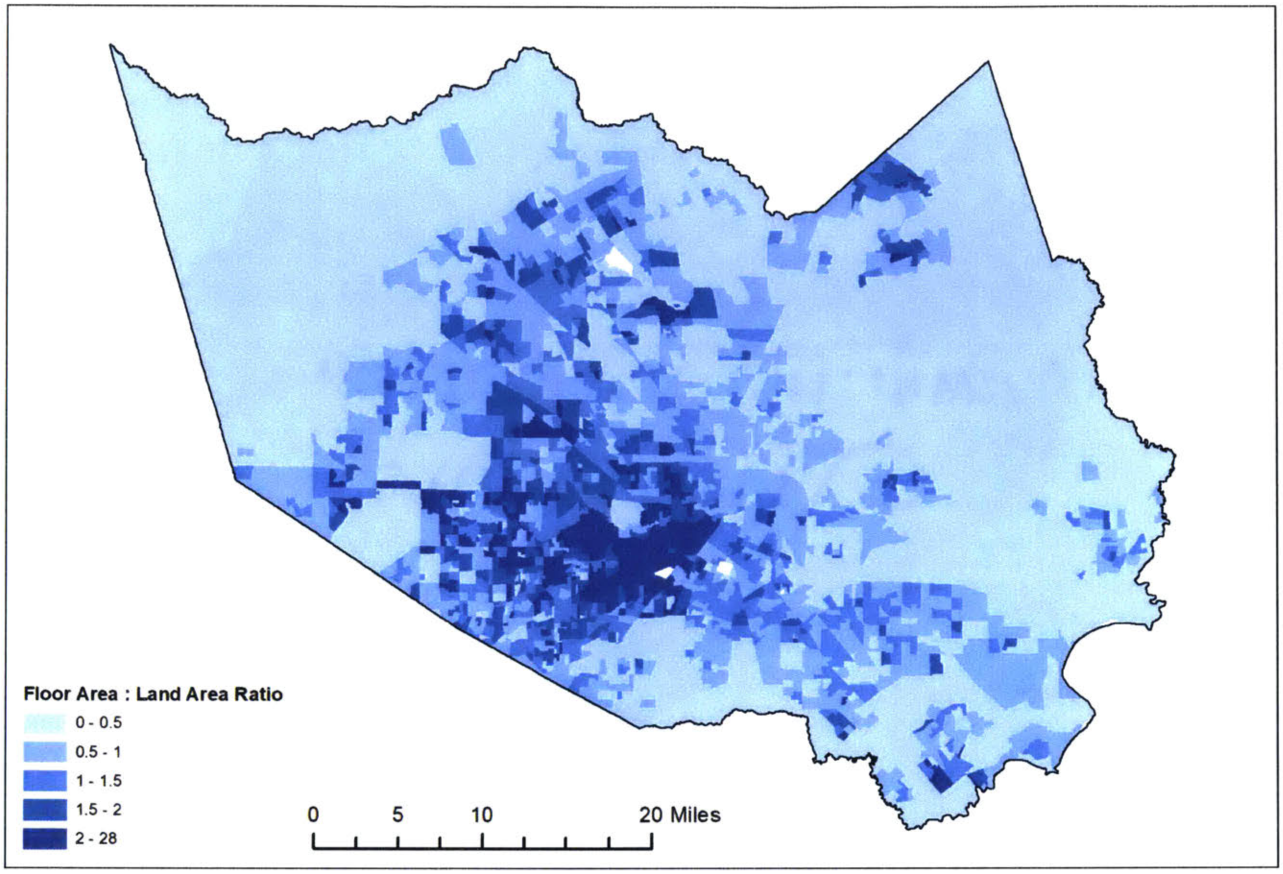


Figure 4.2.6.1 Building Density (Floor area / census block group area)

4.2.7 Proportion of land in the flood zone

Although the flood zone designations published by FEMA are out of date and the subject of much criticism, an important measure of exposure to flooding, as well as resilience (in terms of the probability that a house has flood insurance), is whether or not an area is within the flood zone. Flood insurance is required by FEMA if a structure is constructed or financed (in whole or in part) through assistance from the federal government in the 100-year flood zone (Harris County Flood Control District, 2018a; FEMA, 2014). The current FEMA flood zone designations were downloaded from the FEMA web site (FEMA, 2018) and combined using the Union spatial analysis tool with the census block group polygons. Dissolving polygons based on the census block group unique identifier allowed me to calculate the proportion of census block group in the 100-year and 500-year flood zones, as well as the total proportion of area within either flood zone. This dataset was also exported to the database for processing in Python.

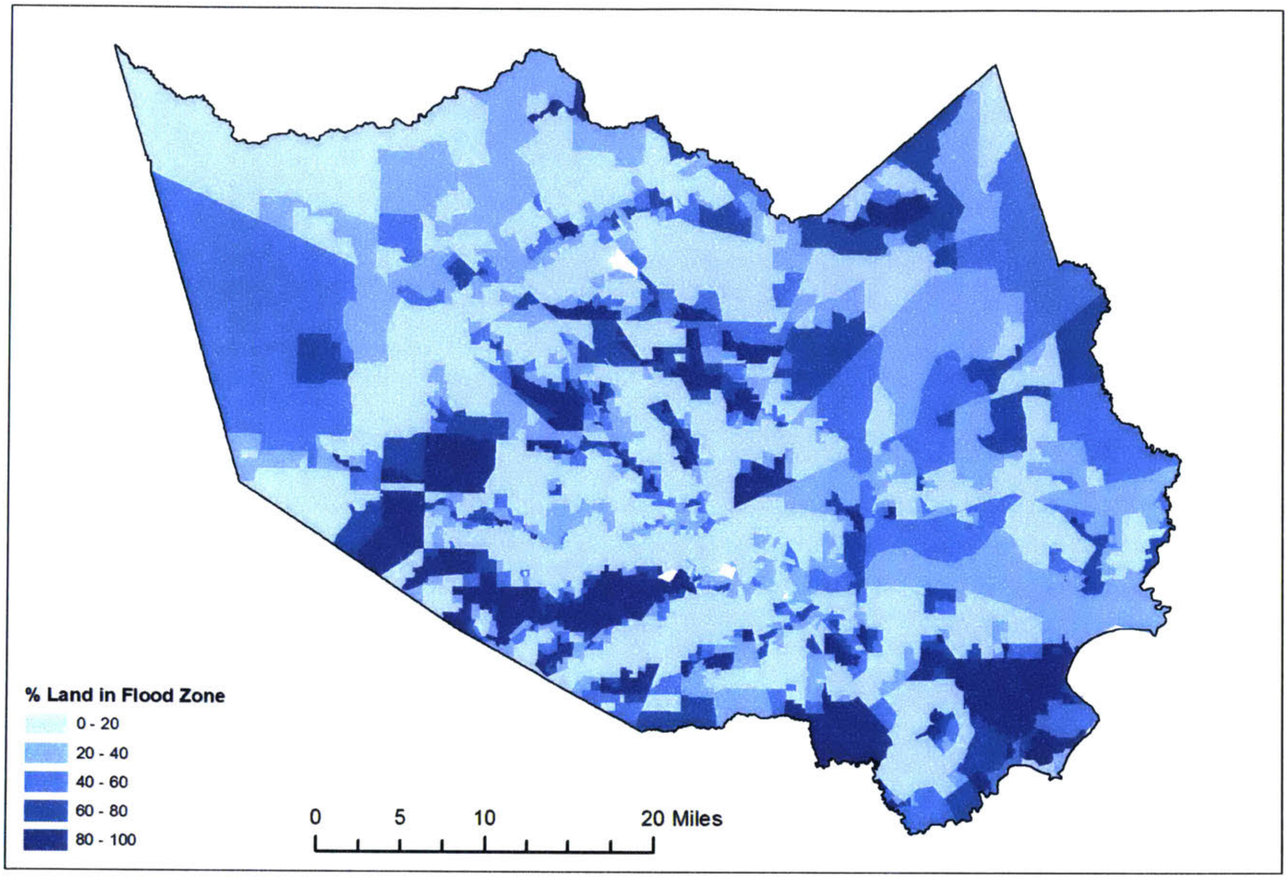


Figure 4.2.7.1 Proportion of census block in flood zone

4.2.8 Building Type

It should be noted that despite the prevalence of the building type indicator in the literature, it was not included in this study. This is due to the fluidity of its definition in the source material: Aroca-Jimenez et al. (2017), Fernandez et al. (2016), and Sadeghi-Pouya (2017) employ the concept in relation to number of stories for buildings, which was not available in the datasets I gathered; Aroca-Jimenez et al. (2017), Bathi & Das (2016), and Butler (2015) use it to distinguish whether a structure is a mobile home (which was also unavailable in the data I gathered); and Silva et al. (2016) use it to distinguish between construction methods, which points to a much needed research direction for which I was not able to gather enough literature to substantiate a ranking system. Considering building type in terms of land use falls into the domain of economics (in terms of basing vulnerability on potential for loss) and could be included in further iterations of the project.

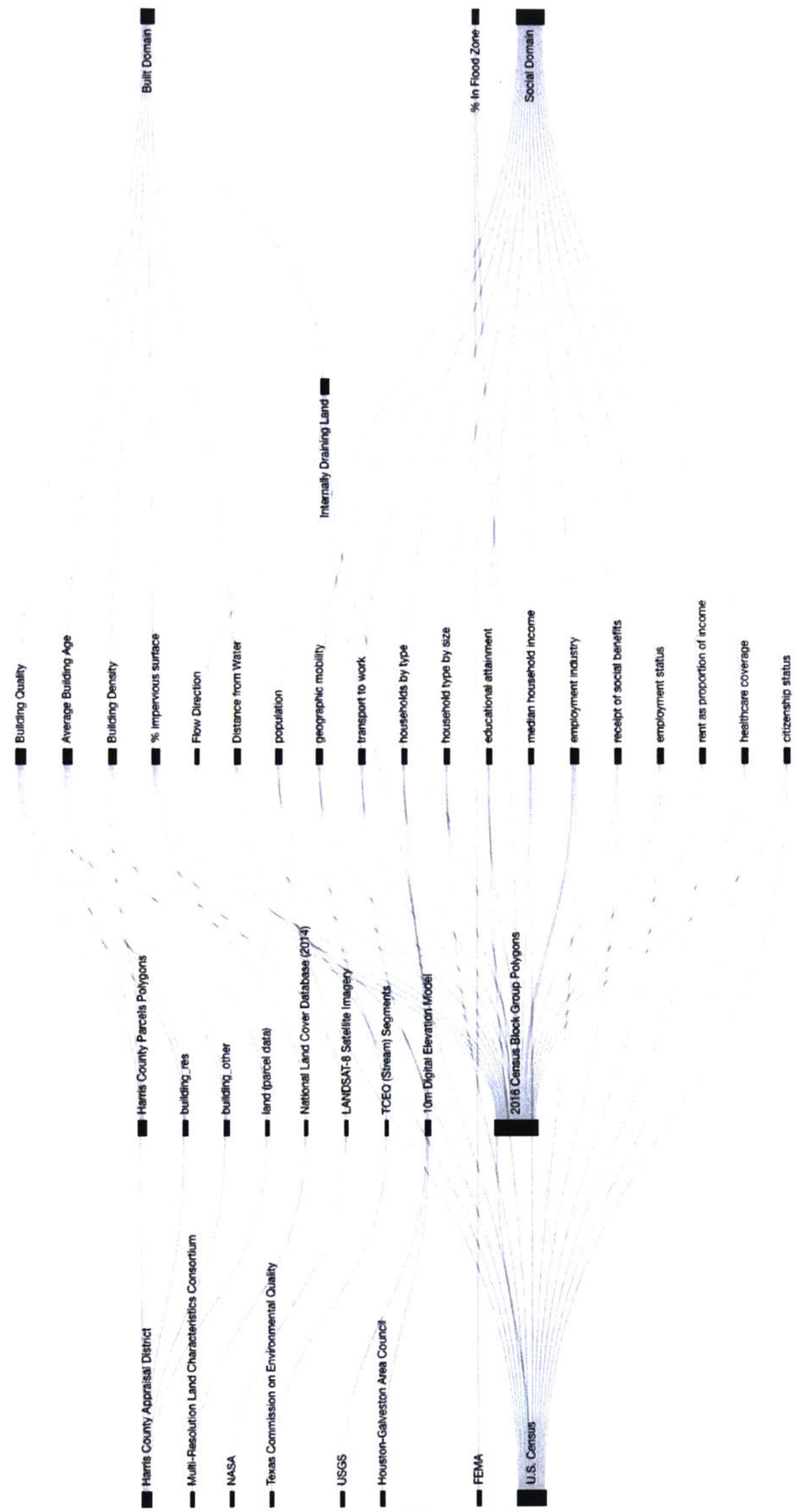


Figure 4.3 Combined Model Schema

4.3 Principal Component Analysis

After compiling all of the input datasets in the Microsoft Access database, I was able to begin combining the data to form the measures of vulnerability. Unless otherwise noted, all following analysis steps were conducted using Python v. 2.7 (www.python.org) and the following libraries: Pandas (https://pandas.pydata.org/), NumPy (http://www.numpy.org/), Matplotlib (https://matplotlib.org/), SciPy (https://www.scipy.org/), and Sci-kit(http://scikit-image.org/). The input data attributes were read in as CSVs and standardized to represent scores for each indicator relative to the median score for that indicator. This practice is a common step in data processing. After some exploratory analysis, I performed a Principal Component Analysis (PCA). PCA is a common statistical technique in which multiple descriptive dimensions of a dataset are simplified based on underlying inter-correlated relationships between different elements of that data (Abdi and Williams, 2010). This allows for meaningful relationships in the data to become apparent while removing extraneous or colinear attributes of a dataset (VanderPlas, 2016). For example, if a condition *A* can be described by high concentrations of characteristics *x* and *y*, Principal Component Analysis will measure the degree to which the relationship between *x* and *y* can be explained by a third, composite attribute *z*. In this way data scientists are able to distill complex, potentially-explanatory datasets with many variables to core characteristics (expressed with fewer variables).

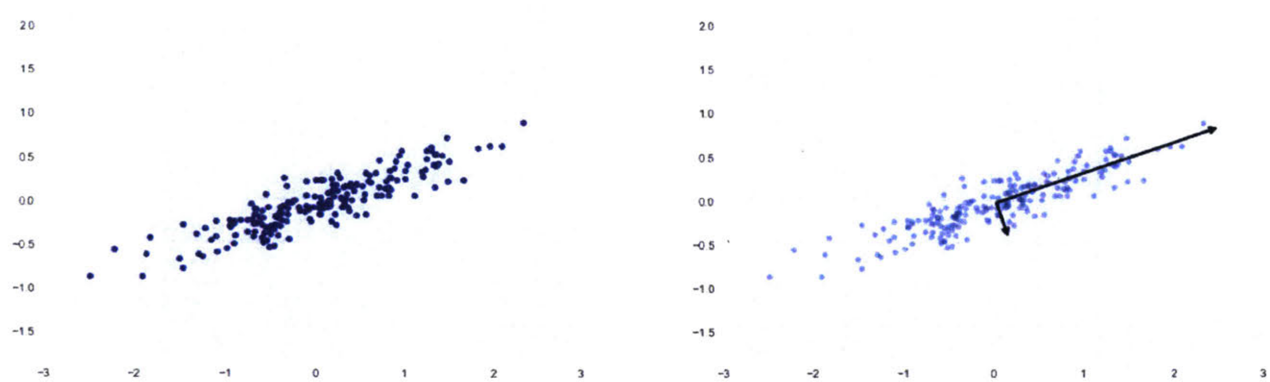


Figure 4.4 Condition *A* expressed in terms of *x* and *y* axes (left), and Condition *A* expressed in terms of true relationship of the data *z* derived from PCA (black axes in right image). Courtesy of VanderPlas (2016).

This mode of analysis is commonly used in the creation of vulnerability indices as a way to identify key descriptors of vulnerability (e.g. Roder and Sofia, 2017; Akukwe and Ogdobo, 2015; Garbutt et al., 2015; Cutter et al., 2008).

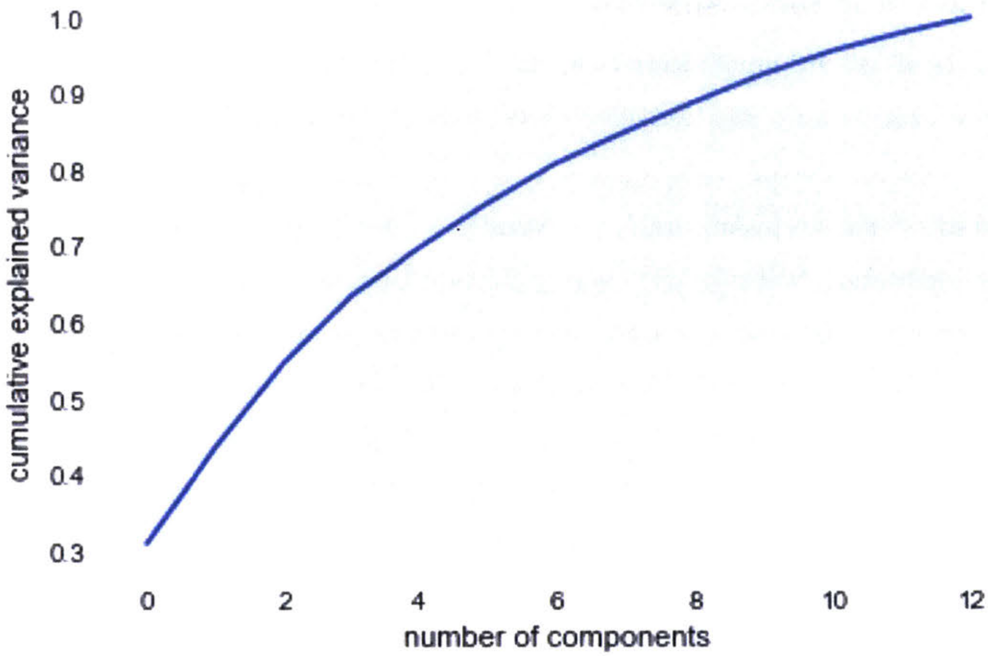


Figure 4.5 Explained variance across components in the Social domain

# of Components	Contribution of variable to score (proportion)
1	0.31
2	0.437
3	0.546
4	0.635
5	0.697
6	0.756
7	0.809
8	0.85
9	0.89
10	0.926
11	0.957
12	0.98
13	1

Table 4.3.1 Contribution of variance score for Social domain

The input elements described in detail above were transformed through the PCA process with the intention to normalize the values between 0-1 for each indicator and calculate an average of all transformed indicator values for each census block group polygon. Figures 4.5 and 4.6 illustrate the observed contribution of various input characteristics as a product of the Principal Component

Analysis. The low explained variance per component (shown in Tables 4.3.1 and 4.3.2) suggests that a very heterogenous pattern exists across Houston: there is no one input variable that serves as an indicator of overall social vulnerability. This could be explained by the relatively few input variables, chosen from the most frequently occurring indicators across the literature, compared to other indices—for instance, the UNESCO index has 90 variables. However, due to the high degree of independence shown in Tables 4.3.1 and 4.3.2 (i.e. the low explanatory overlap between input variables), the standardized indicator values (not the transformed values from the PCA) were normalized and averaged together to form the ultimate vulnerability scores. This process corresponds with the method used to calculate the CDC's Social Vulnerability Index described in Flanagan et al. (2011). The resultant composite vulnerability patterns are shown on the following pages.

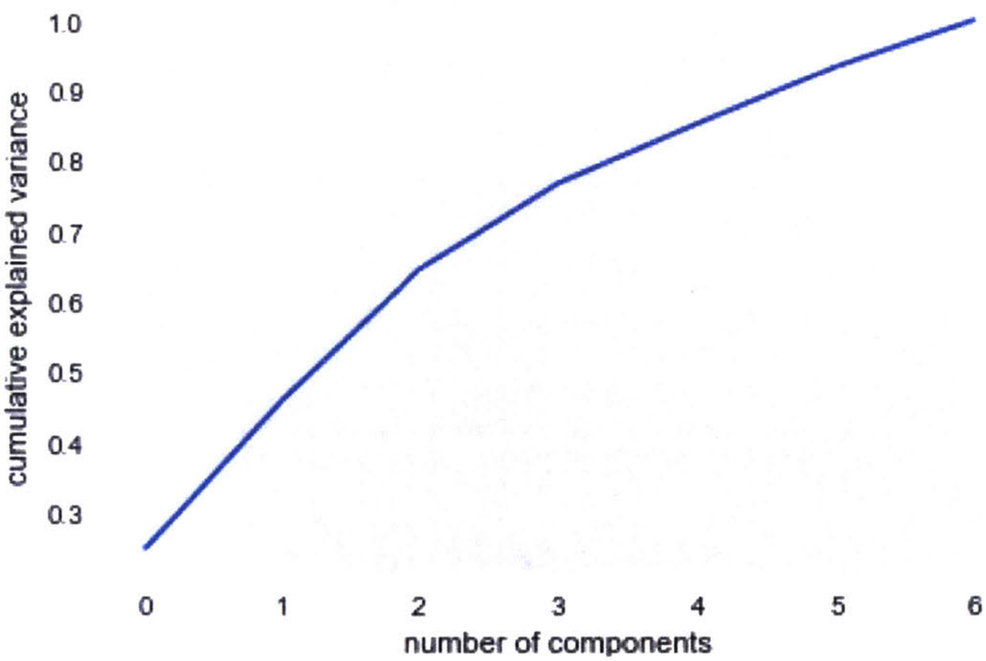


Figure 4.6 Explained variance across components in the Built domain

# of Components	Contribution of variable to score (proportion)
1	0.249
2	0.461
3	0.646
4	0.768
5	0.852
6	0.933
7	1

Table 4.3.2 Contribution of variance score for Built domain

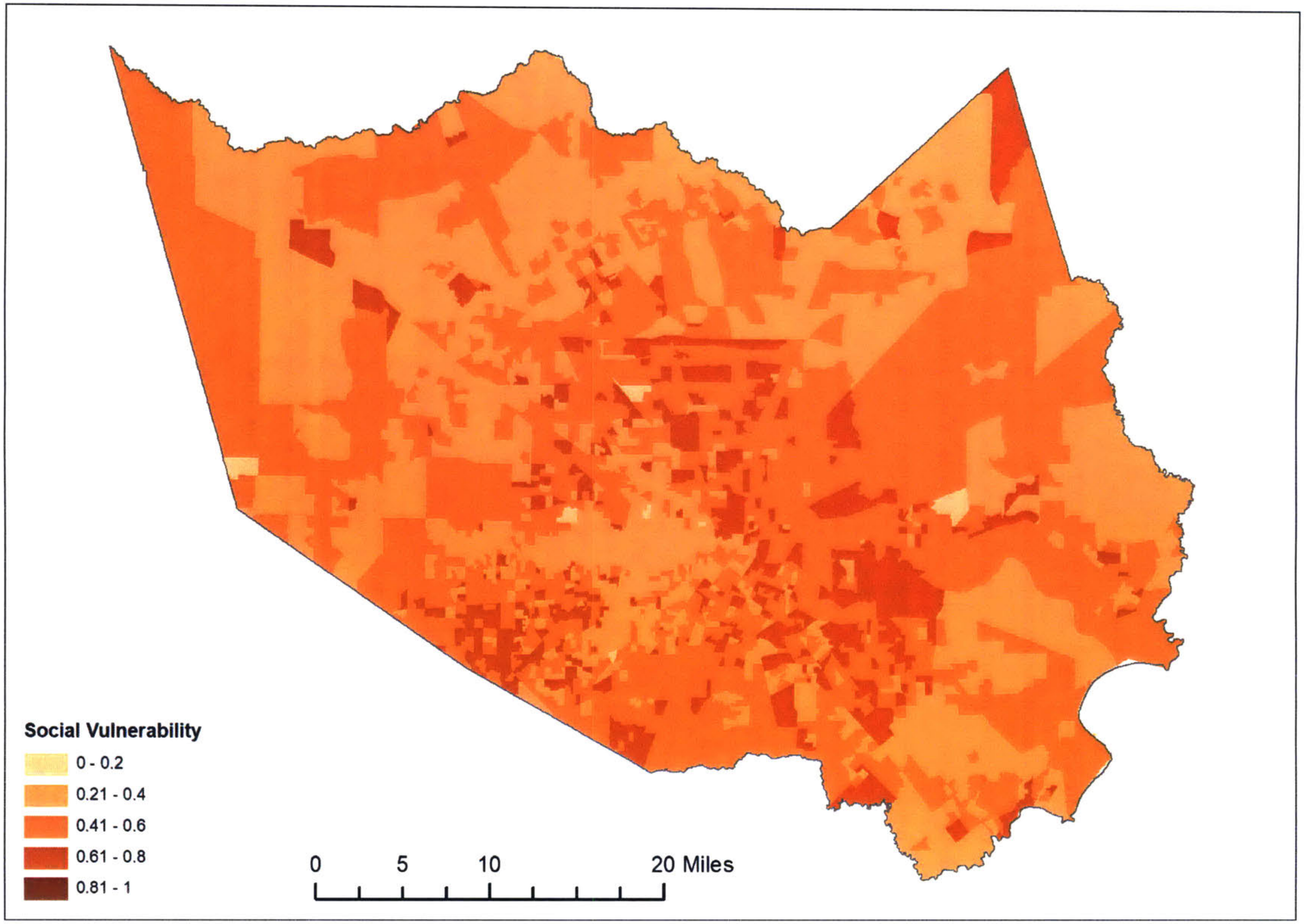


Fig. 5.2.1 Social Vulnerability by Census Block Group

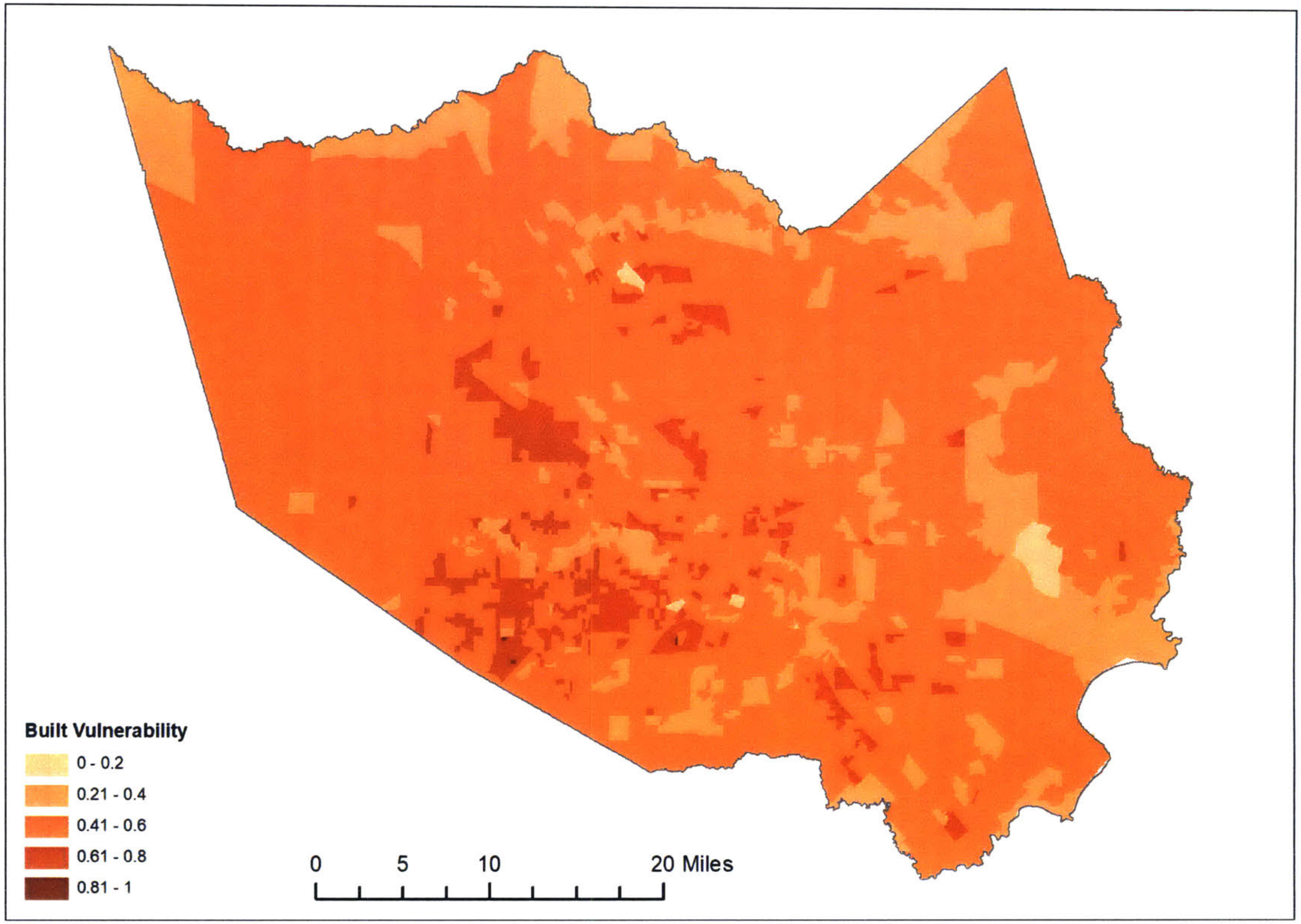


Fig. 5.2.1 Built Vulnerability by Census Block Group

5. Results

The maps on the preceding pages show the overall computed vulnerability scores for both the social and built environment domains. While they are the product of extensive data collection, processing, and modeling, it is difficult to discern significant patterns simply by looking at the data, despite certain clusters of darker or lighter colors scattered across the map. A Hot Spot Analysis (Getis-Ord Gi*) was conducted using an inverse distance weighting algorithm to determine areas of statistically-significant clusters of high and low vulnerability. Clusters were defined in cases where areas of statistically-significant high and low levels of vulnerability share a border with other significantly-vulnerable census block groups. It reveals that statistically-significant clusters of social vulnerability are present in the Near Northside and Greater Fifth Ward neighborhoods north of downtown Houston, as well as in the Central Southwest neighborhood in the south of the city (Fig. 5.3). Conversely, statistically significant clusters of low vulnerability areas are present in the Tomball and Northpointe neighborhoods in the northwest reaches of Harris County, as well as Taylor Lake Shores in the southeast and Kingwood in the northeast.

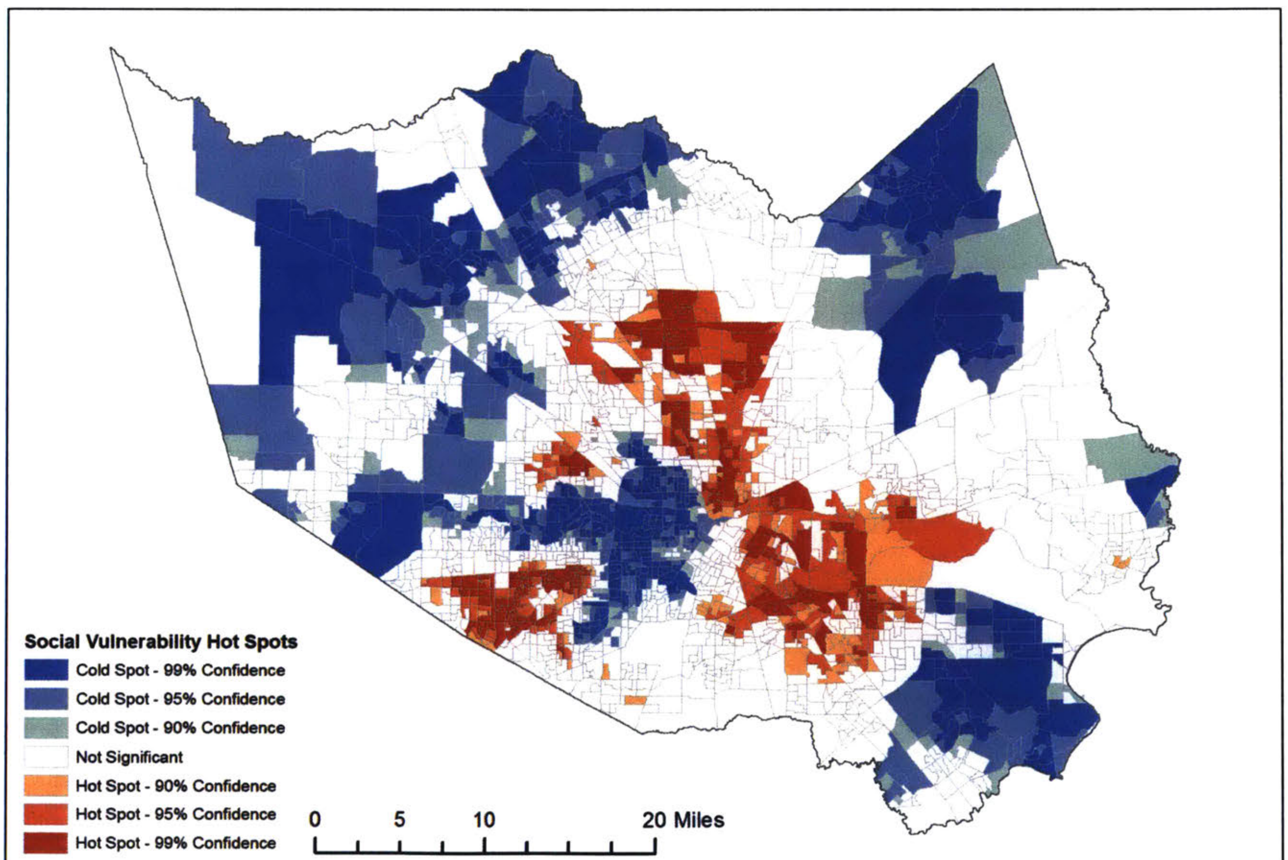


Figure 5.3 Statistically significant clusters of high and low levels of social vulnerability

The Hot Spot Analysis was conducted for the Built domain as well, and similarly reveals patterns of statistically-significant clustering of built vulnerability in certain parts of the city (Fig. 5.4). The Woodland Heights neighborhood north of the city center, as well as Jersey Village to the northwest, and Westchase and Bellaire to the southwest exhibit statistically significant clustering of built vulnerability.

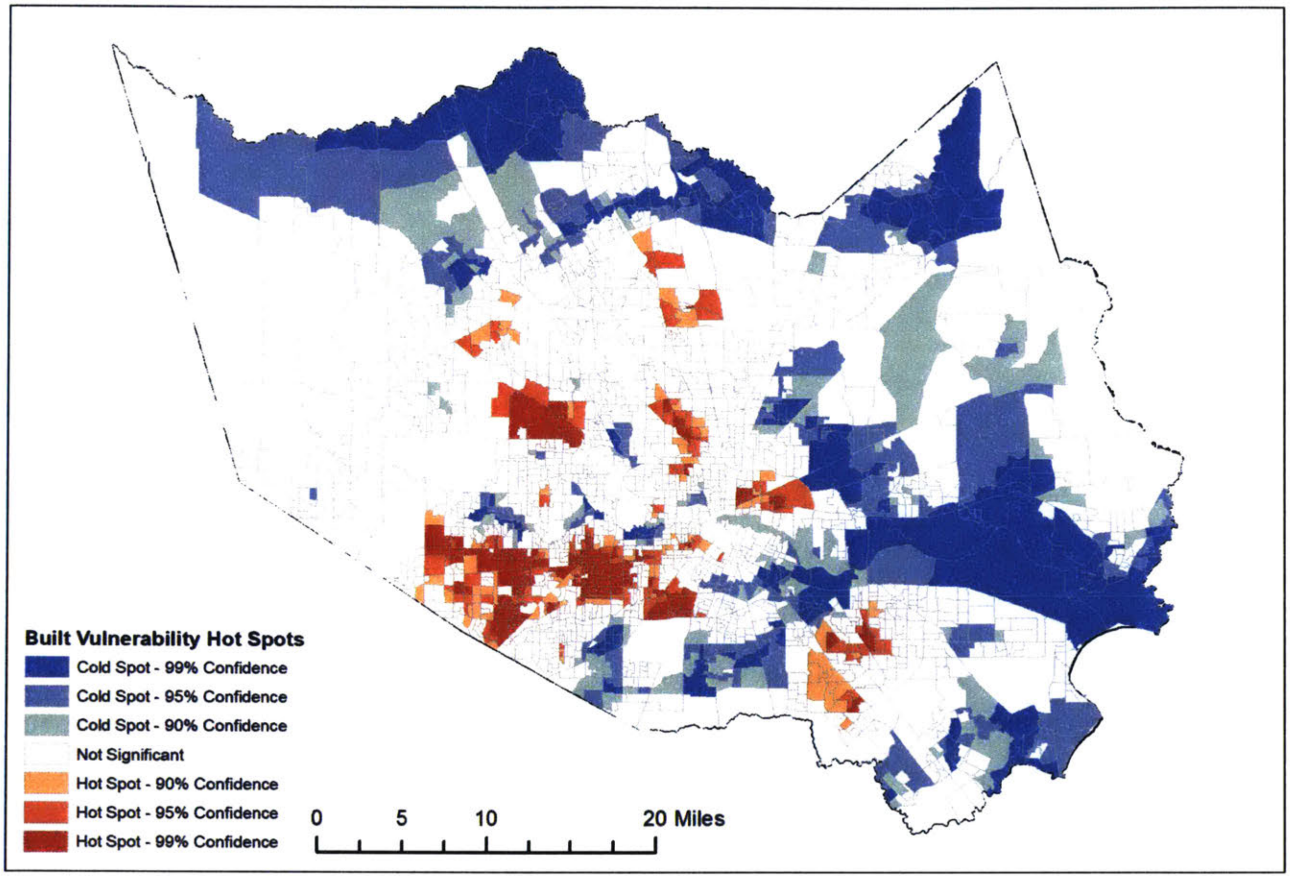


Figure 5.4 Statistically significant clusters of built vulnerability

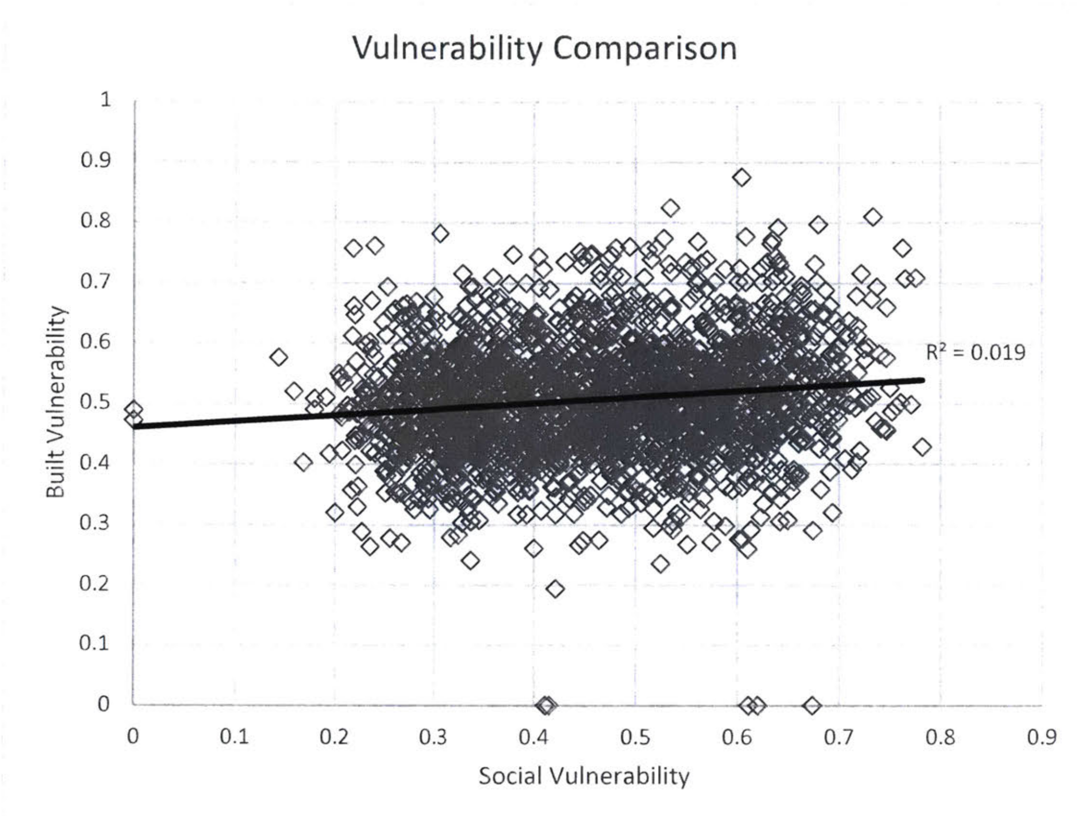


Figure 5.5 Relationship between Social and Built vulnerability per census block group

Figure 5.5 illustrates the relationship between Social and Built vulnerability for each census block group in the study area. The low R^2 value (0.019) suggests there is a positive yet weak relationship between built vulnerability and social vulnerability. This result seems to further confirm the previously reported observation that vulnerability in Houston is actually quite heterogenous and does not conform to an overarching single measure of vulnerability. The decision was made to not combine the domains into an overarching vulnerability score in efforts to avoid an obfuscation of domain-specific vulnerability. Furthermore, from a policy perspective, different kinds of vulnerability require various kinds of interventions. More stringent building and land use codes (following a review of flood zone and flood intensity designations), along with more strict requirements for flood insurance, could serve to minimize built vulnerability for new construction, and targeted retrofit, storm water infrastructure improvements, and more widely available flood insurance policy (or more stringent enforcement of existing policy) could both minimize susceptibility before an extreme event and increase the ability of households to recover from events.

High levels of social vulnerability should be addressed in general, as many of the factors that influence vulnerability to extreme flooding also apply to other stochastic events (both natural and man-made, such as economic shock), as well as gradual stressors such as variable housing prices, exposure to pollution, heat island effect, and inequity more broadly. These vulnerability scores can be used in the context of extreme flooding to provide targeted preparation resources, as well as direct evacuation and emergency services after an extreme event. When coupled with broader analysis of presence of infrastructure such as location of emergency services, distance to health care centers, and social institutions that could serve as resource distribution centers and loci of community capacity building, social vulnerability measures can provide policy makers with the information they need to effectively prepare for and respond to extreme events. Individual input variables—such as rent to income ratio, presence of persons needing assistance (both persons with disabilities and in extreme age groups), and income—can be used to predict the rate at which different communities will be able to recover or adapt to changing environmental conditions as well as extreme events. Examining clusters of vulnerability in terms of built and social characteristics can serve as a powerful tool for policymakers to focus efforts on specific areas, potentially by using special zone overlays, localized funding mechanisms, or other capacity-building interventions.

6. Communicating the results

6.1 Web Interface

After generating the vulnerability index data, I turned to creating a data visualization for a wider audience to be able to access the model results. All of the other tools reviewed above rely on traditional planimetric display of spatial data overlays (Figure 6.1). While this is method has defined the spatial data landscape up until now, recent advances in technology allow for novel interaction with data in 2.5D[3] or through immersive experiences. Mapbox (www.mapbox.com) is one of several companies that offers 2.5D rendering of spatial data in the browser and was chosen as the visualization engine for this project (Fig. 6.3). Data was initially loaded in a PostgreSQL database on an Amazon Elastic Cloud Computing (EC2) Linux instance to generate and serve features to the web application but was retired in favor of Mapbox's proprietary hosting service. The results of the vulnerability index creation process are available for viewing, along with the input datasets, at www.houstonbetweenthelines.com. The layers included in the map view are shown in Table 6.1.

[3] 2.5D refers to three-dimensional data displayed on a flat screen.

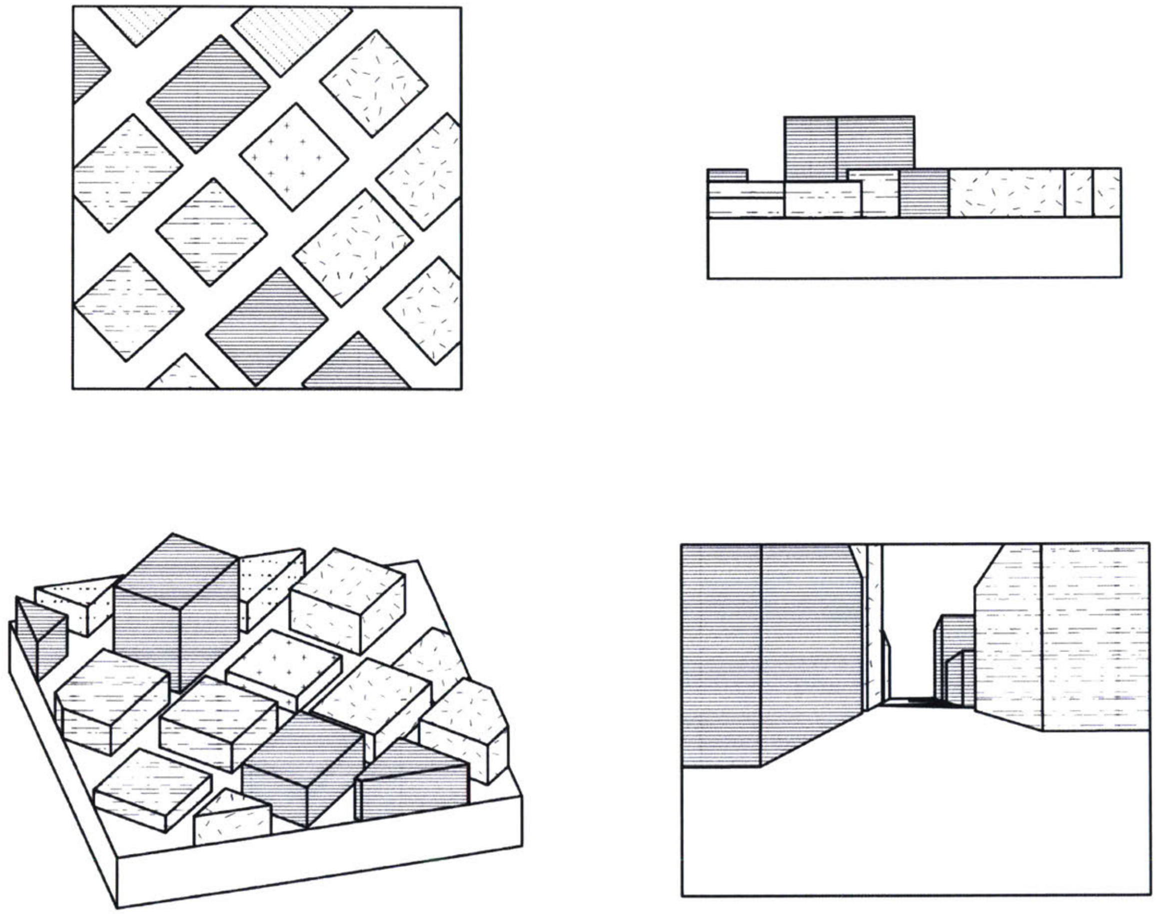


Figure 6.1 Traditional plan view (top left), elevation (top right), perspective view (bottom left), and first-person perspective (bottom right) allow for different engagement with information and different levels of understanding.

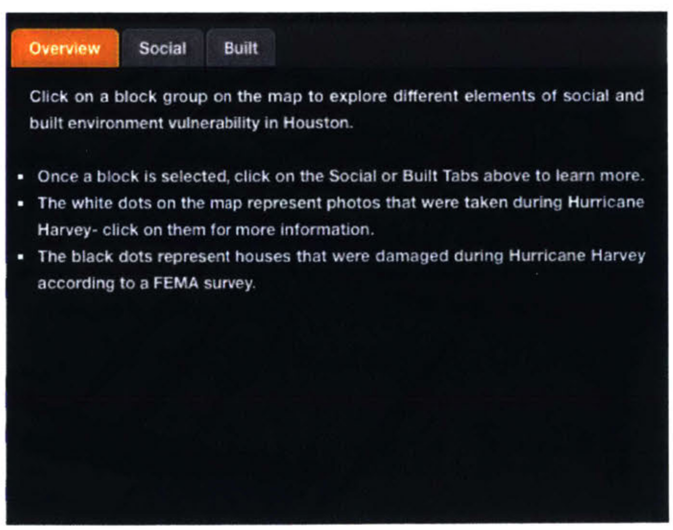


Figure 6.2 Overview tab provides introductory information to user

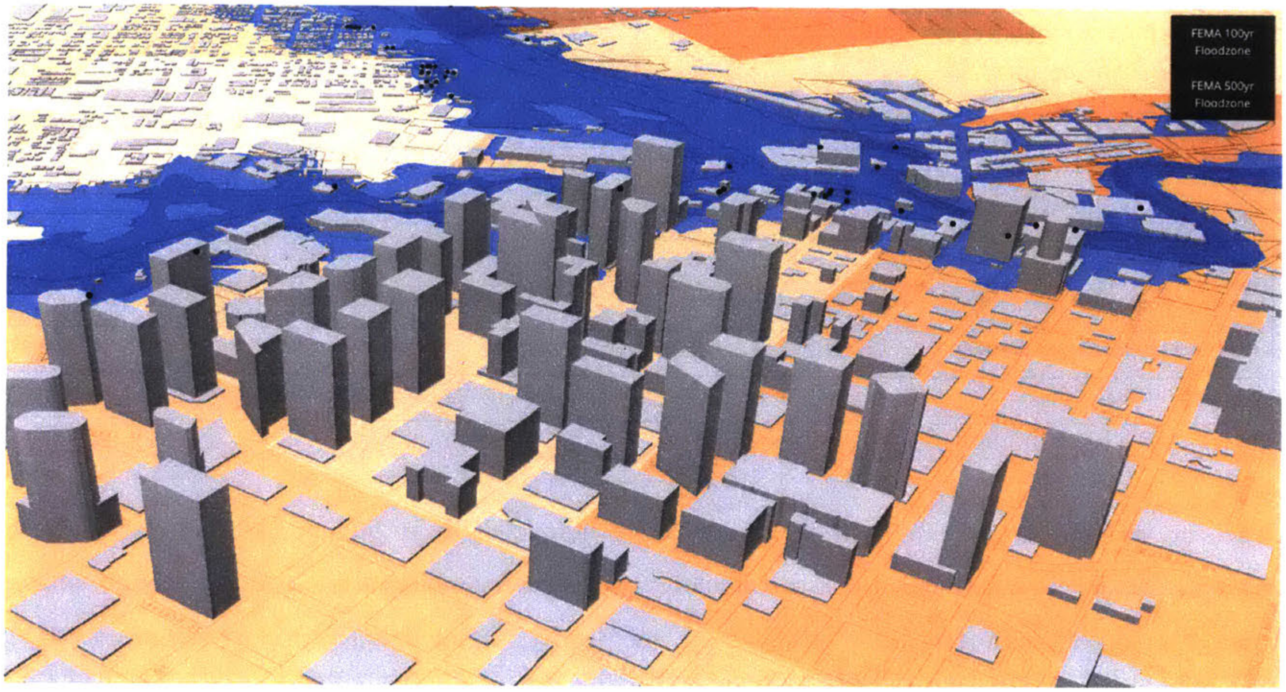


Figure 6.3 Screenshot from project website (houstonbetweenthelines.com) showing in-browser 3D rendering capabilities

Layer Name	Data Source
Social Vulnerability	Composite of all other social indicators
Population	U.S. Census American Community Survey 2016
Population Density	U.S. Census American Community Survey 2016
Median Household Income	U.S. Census American Community Survey 2016
Percent of residents without high school diploma or equivalent	U.S. Census American Community Survey 2016
Percent of population under 15 years old	U.S. Census American Community Survey 2016
Percent of population over 64 years old	U.S. Census American Community Survey 2016
Built Vulnerability	Composite of all other built environment indicators
Building Density	Harris County Appraisal District Parcel Database
Average Building Condition	Harris County Appraisal District Parcel Database
Proportion of Area in Flood Zone	FEMA Harris County Coastal Areas Flood Zone Designation Database
Proportion of Internally Draining Land	Houston-Galveston Area Council / USGS 10-meter resolution Digital Elevation Model
Proportion Pervious Surface	Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Database 2011 (2014 edition); NASA/USGS LANDSAT-8 Top of Atmosphere Analysis-Ready Imagery (2017)

Proportion of Land that is Vacant	Harris County Appraisal District Parcel Database
Average Distance to Water	Texas Commission on Environmental Quality Stream Segments
FEMA 100-year Flood Zone	FEMA Harris County Coastal Areas Flood Zone Designation Database (2018b)
FEMA 500-year Flood Zone	FEMA Harris County Coastal Areas Flood Zone Designation Database (2018b)
Hurricane Harvey Images	ArcGIS Image API
Damaged Buildings	FEMA Damage Assessment

Table 6.1 Data layers included in beta web application

Users are able to compare the bird's-eye perspective view available in the map canvas simultaneously with a street-level view (Fig. 6.4). This will allow for an understanding of the context beyond what is offered in either planimetric view or bird's eye perspective . Being able to contrast imagery from an "average day" as captured by Google Street View allows users to interact more deeply with

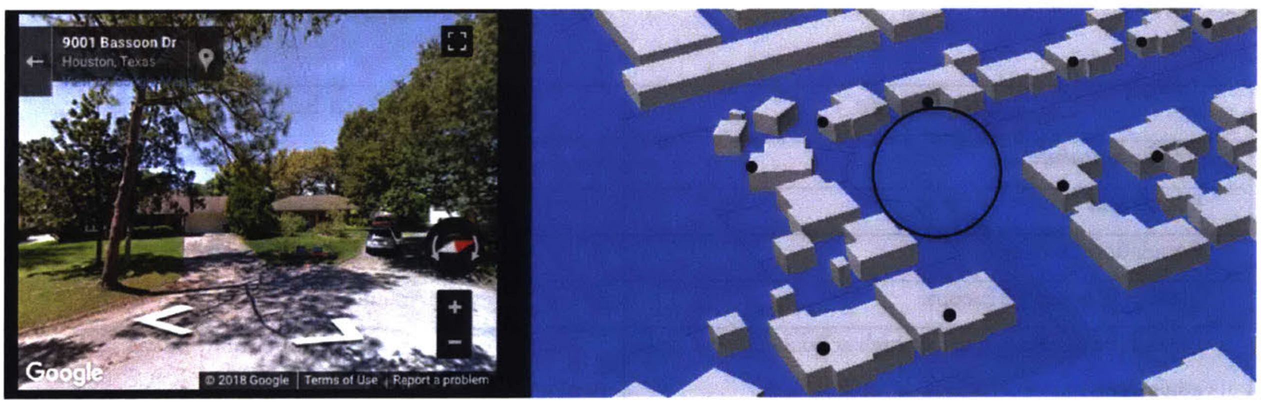


Figure 6.4 Screenshot displaying the paired perspectival and street-level view offered in the web interface.

the available information than what is available through one way of viewing alone. This comparative process is made richer when paired with social media data gathered from the internet, displaying crowd-sourced imagery for key points throughout the city during Hurricane Harvey (Fig. 6.5). Combining and comparing datasets gathered by a number of agencies, as well as private companies like Google, with information collected by individuals, further complicates any individual image of the city.

Figure 6.5 Social media images retrieved from the internet allow a user to compared Street View imagery with imagery from Hurricane Harvey

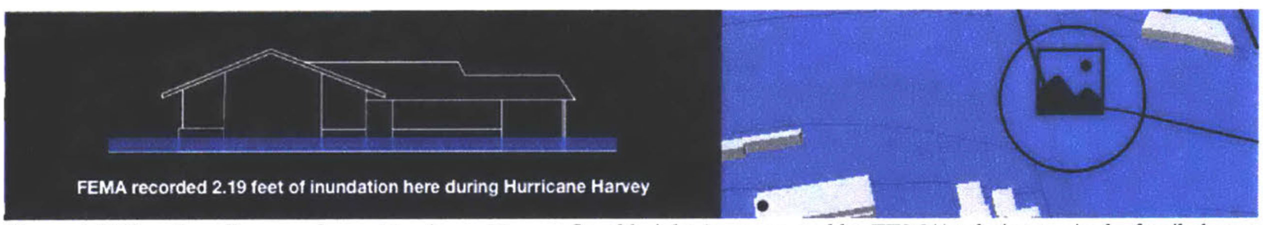


Figure 6.6 Elevation diagram shows Hurricane Harvey flood height (as measured by FEMA) relative to single-family home for any point in Houston

A responsive elevation diagram in the left-hand panel displays Hurricane Harvey flood height data relative to a single-family home. As the user clicks through Houston, either on the larger map or by moving through the Street View module, this diagram updates to represent flood height data gathered by FEMA during and directly after Hurricane Harvey. As flood water has both a horizontal (i.e. surface area) and vertical (i.e. flood depth) relationship with the city, the elevation diagram is instrumental in communicating flood water's relationship with the city during extreme events.

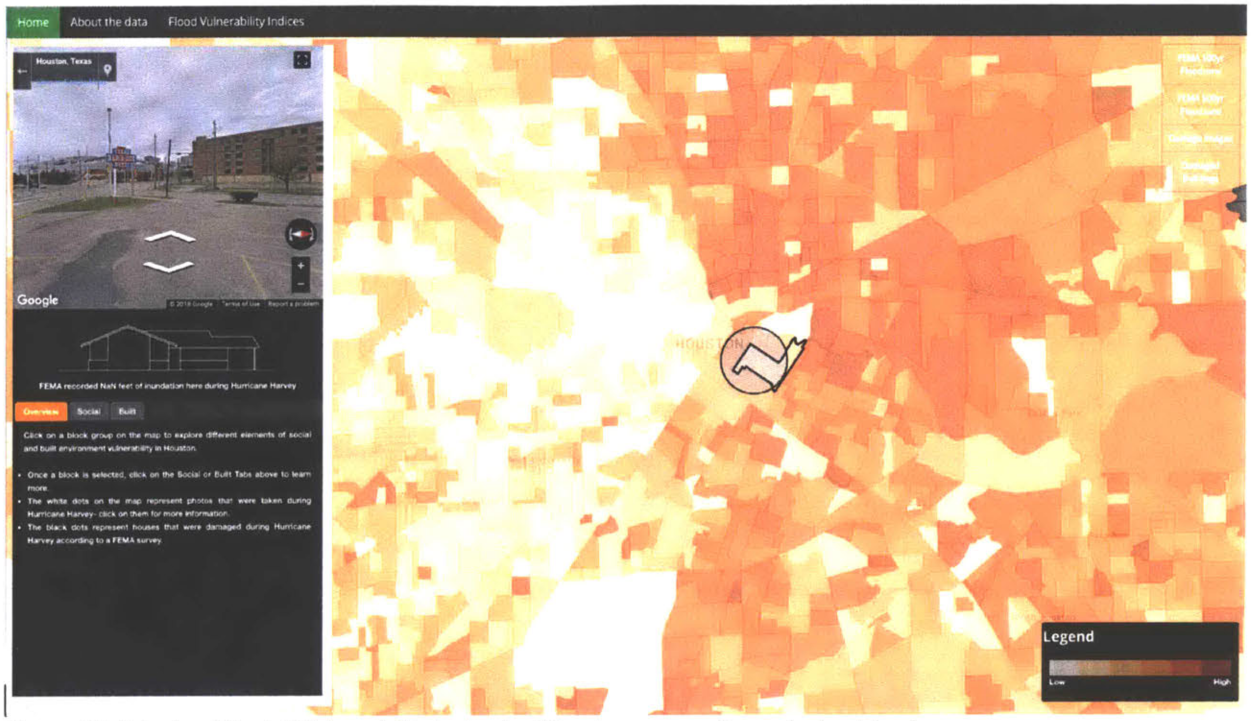


Figure 6.7 Calculated Social Vulnerability index for Houston as seen from planimetric view

The patterns that emerge from the social and built environment composite index creation process are more readily visible to the user upon zooming out and turning of some of the complementary layers. It is at this point that the web tool resembles existing web portals detailing the presence of vulnerability in Houston (see discussion above or Appendix III and IV). The social vulnerability layer is on by default when the user enters the site (Fig. 6.7) and shows a distribution of vulnerability that corresponds generally with that produced by the CDC's Social Vulnerability Index. Upon clicking the "Built" button in the left-hand panel, the map changes and loads the built environment vulnerability layer, as shown in Figure 6.8. The simplicity of the design—clearly separating elements of social and built environment vulnerability—allows the user to focus on the topic of interest without being overloaded with information and options from the start.

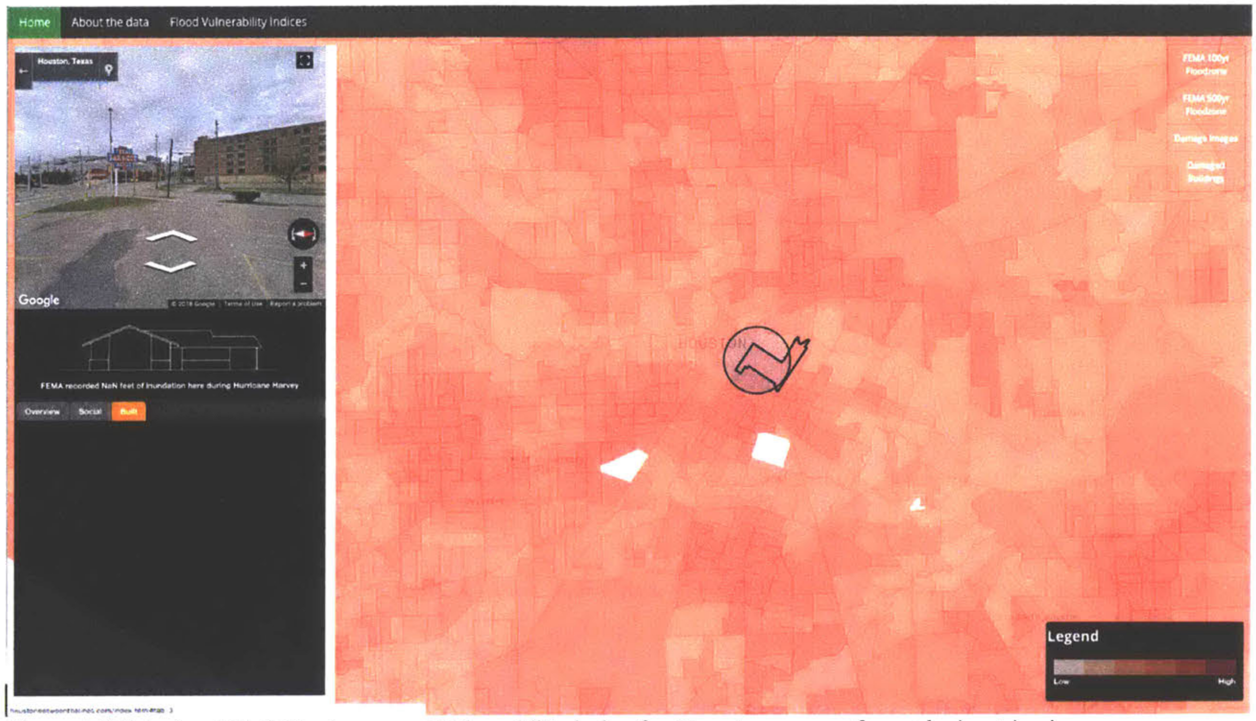


Figure 6.8 Calculated Built Environment Vulnerability index for Houston as seen from planimetric view

However, all of the input data for each vulnerability domain is available to the user in tabular format, as well as in the form of a map layer. When a user clicks on a census block group within Houston, the left panel updates to show statistics that relate to each input variable for the given spatial unit (Fig. 6.9). This provides another way for the user to investigate the meaning of the unitless vulnerability index score beyond observing a pattern on a map. Including clear labels of the input data closes the gap between input data and output results and allows the user to gain a more wholistic understanding of what the patterns represent. Each input variable is accompanied by a button that reads "Show layer" which loads the layer in question, showing the distribution of each input variable on the map. In this way, users are able to move seamlessly between composite scores and input variables.

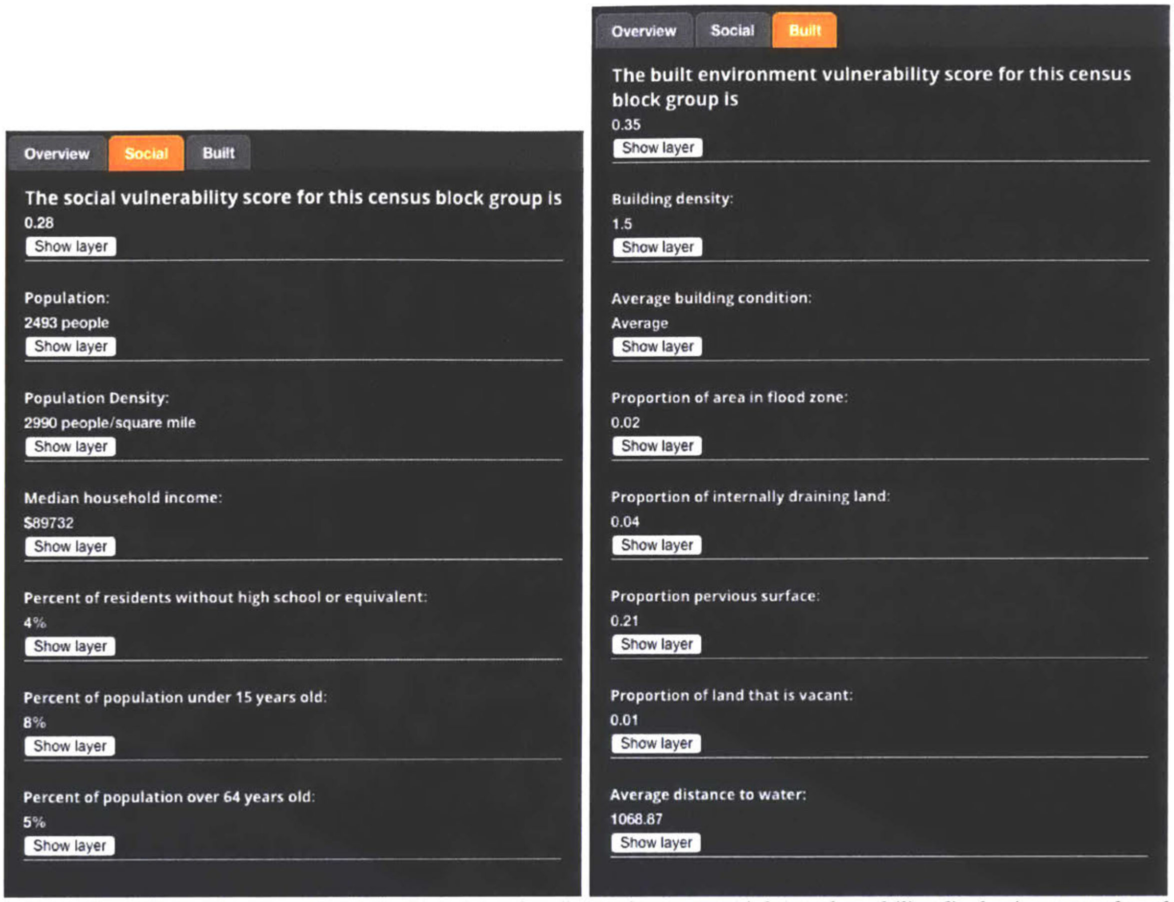
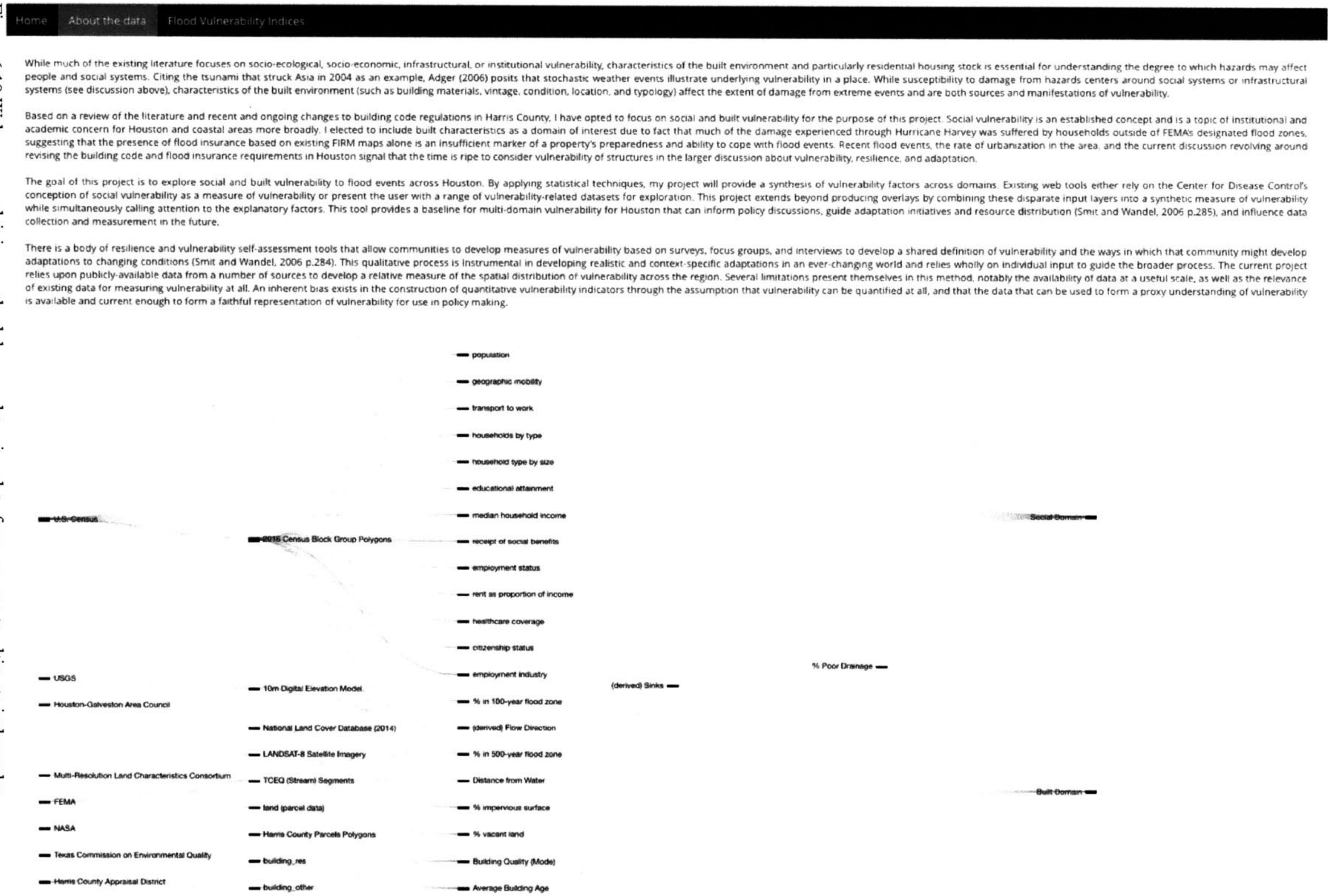


Figure 6.9 Indicators table for each Social (left) and Built Environment (right) Vulnerability display inputs and explanations for cumulative index values

One of the goals of the web portal is to minimize the distance between the metadata for each data layer shown on the map and the map itself. Clicking "About the data" in the top menu bar loads a linked web page that contains a preamble about the variable collection and creation process (included previously in this text), displayed in Fig. 6.10. An interactive version of Fig. 4.3 showing the combined model schema, from data creation agency to final composite layers, is provided on the page, allowing users to trace the data shown on the map, through intermediate stages, back to the original provider of the data. This graphic representation provides a greater level of transparency than what is available through textual description alone and displays the influence and responsibility that certain agencies hold relative to the understanding and calculation of indicators related to demographics and the built environment. Fig. 6.11 displays the third web page available in the tool, which provides a brief summary of the landscape of flood vulnerability index creation from the literature. It also contains a summary graphic showing the prevalence of various indicators across categories from each of the flood index creation efforts surveyed in this project (and provided in more detail in Appendix II).



Home | About the data | Flood Vulnerability Indices

While much of the existing literature focuses on socio-ecological, socio-economic, infrastructural, or institutional vulnerability, characteristics of the built environment and particularly residential housing stock is essential for understanding the degree to which hazards may affect people and social systems. Citing the tsunami that struck Asia in 2004 as an example, Adger (2006) posits that stochastic weather events illustrate underlying vulnerability in a place. While susceptibility to damage from hazards centers around social systems or infrastructural systems (see discussion above), characteristics of the built environment (such as building materials, vintage, condition, location, and typology) affect the extent of damage from extreme events and are both sources and manifestations of vulnerability.

Based on a review of the literature and recent and ongoing changes to building code regulations in Harris County, I have opted to focus on social and built vulnerability for the purpose of this project. Social vulnerability is an established concept and is a topic of institutional and academic concern for Houston and coastal areas more broadly. I elected to include built characteristics as a domain of interest due to fact that much of the damage experienced through Hurricane Harvey was suffered by households outside of FEMA's designated flood zones, suggesting that the presence of flood insurance based on existing FIRM maps alone is an insufficient marker of a property's preparedness and ability to cope with flood events. Recent flood events, the rate of urbanization in the area, and the current discussion revolving around revising the building code and flood insurance requirements in Houston signal that the time is ripe to consider vulnerability of structures in the larger discussion about vulnerability, resilience, and adaptation.

The goal of this project is to explore social and built vulnerability to flood events across Houston. By applying statistical techniques, my project will provide a synthesis of vulnerability factors across domains. Existing web tools either rely on the Center for Disease Control's conception of social vulnerability as a measure of vulnerability or present the user with a range of vulnerability-related datasets for exploration. This project extends beyond producing overlays by combining these disparate input layers into a synthetic measure of vulnerability while simultaneously calling attention to the explanatory factors. This tool provides a baseline for multi-domain vulnerability for Houston that can inform policy discussions, guide adaptation initiatives and resource distribution (Smit and Wandel, 2006 p.285), and influence data collection and measurement in the future.

There is a body of resilience and vulnerability self-assessment tools that allow communities to develop measures of vulnerability based on surveys, focus groups, and interviews to develop a shared definition of vulnerability and the ways in which that community might develop adaptations to changing conditions (Smit and Wandel, 2006 p.284). This qualitative process is instrumental in developing realistic and context-specific adaptations in an ever-changing world and relies wholly on individual input to guide the broader process. The current project relies upon publicly-available data from a number of sources to develop a relative measure of the spatial distribution of vulnerability across the region. Several limitations present themselves in this method, notably the availability of data at a useful scale, as well as the relevance of existing data for measuring vulnerability at all. An inherent bias exists in the construction of quantitative vulnerability indicators through the assumption that vulnerability can be quantified at all, and that the data that can be used to form a proxy understanding of vulnerability is available and current enough to form a faithful representation of vulnerability for use in policy making.

Figure 6.10 Web page explaining methodology and tracing data from source to ultimate index value

Figure 6.11 Web page discussing vulnerability indices and illustrating indicator prevalence across the literature

6.2 Augmented Reality Application

Fig. 6.12 Screenshot of sample AR application

The web tool described above falls into Smit and Wandel's (2006) third category of vulnerability research, in which characteristics of vulnerability are selected, measured, and used to calculate a relative vulnerability for a system based on the assumption that there is inherent vulnerability to measure (p. 285). This precondition stems from an understanding of the body of research and policy which describes coastal flood vulnerability in terms of input indicators and categorical domains. This mode of research seeks to inform policymaking decisions but does not interrogate the causal forces behind inequalities in vulnerability, nor does it address the power structures through which vulnerability is minimized or adaptive capacity is operationalized. The augmented reality application component of this project falls into the fourth category of vulnerability studies outlined by Smit in Wandel (2006 p. 285), in that it invites and depends upon personal community insight to document and inform the ways in which vulnerability is experienced on the ground, similar to the Street View-level exploration detailed in the description above. In this way, the assumptions and inputs to the web-based model are reckoned with based on the observations and a feedback loop is formed between top-down data synthesis and bottom-up observation and data collection. While it does presume that inputs will relate to specific categories, it will offer latitude in terms of specific factors that relate to *in situ* vulnerability. Although considerable effort was put in to developing the augmented application, it remains unfinished. Fig. 6.12 shows a screenshot from the application pulling FEMA flood layers and buildings and overlaying them at reduced scale in the user's smart phone screen.

7. Conclusions

By the time it dissipated in early September last year, Hurricane Harvey was the third 500-year storm to strike the Houston area in as many years. The storm affected over 150,000 properties in the region and the property damage is still being totaled, with estimates for direct payment made by FEMA approaching $400 million. As coastal flooding becomes more frequent and more destructive, planners and policymakers must develop new tools and ways of approaching preparation for and response to extreme events to minimize future damage and create more resilient cities. In his seminal piece *Vulnerability*, Adger (2006) argues that "the challenges for vulnerability research are to develop robust and credible measures, to incorporate diverse methods that include perceptions of risk and vulnerability, and to incorporate governance research on the mechanisms that mediate vulnerability and promote adaptive action and resilience" (p. 1). Through the course of this project, I proposed a novel tool for understanding and communicating vulnerability to extreme events in Houston. Drawing from a body of literature focused on understanding and measuring vulnerability in coastal cities, as well as existing efforts to use web-based technologies to communicate relevant information to stakeholders, this project departs in several key ways. First, I draw explicit linkages between the sources of vulnerability and resiliency-related data and outline the ways in which specific agencies and data sources define the body of knowledge with which decision makers operate. This level of transparency regarding the data itself and the methods with which it is synthesized closes the gap between the raw information and the final product. Second, I proposed a system for approaching both social and built environment vulnerability in a way that allows different stakeholder groups to isolate elements of vulnerability and see broader trends simultaneously. This way of seeing moves beyond simple overlays in terms of richness and provides a sense of depth not available in existing modes of synthesis. Finally, I presented these various datasets not with a flat view of the world offered by planimetric mapping, but with three-dimensional perspectives, elevations, and photographs. This variety of ways of seeing Houston, presented together and operating as a system, add a degree of richness to the understanding of place not available through any single method, or through data alone. Together, these efforts form a critique of the dominant means for exploring and interpreting spatial data and vulnerability data in particular, as well as a powerful tool with which planners, policymakers, and the public can understand vulnerability of place and work toward a more resilient future. While it deals with questions of vulnerability, risk, and destruction caused by extreme events, my intention is not to promote a sense of fear, but rather to inform the discourse with which knowledge is produced and decisions are made in a dynamic urban environment such as Houston. Understanding a problem is a key step in solving it; reckoning with the sources of vulnerability can allow decision makers to see opportunities for positive future development.

To that end, this project offers several contributions to the overarching goal of preparing for and responding to a changing climate in coastal cities. The survey of the existing flood vulnerability literature is a unique effort to catalogue and understand broadly the ways in which professionals from around the world define vulnerability to extreme flooding. This benchmark confirms that social vulnerability has become a disciplinary focus for planners and policymakers around the world, across geographic focus and scale of involvement. Similarly, it identifies opportunities for expanding efforts to understand the particular vulnerabilities of the built environment to extreme flooding, as well as proposing a baseline set of criteria with which to measure vulnerability of building stock in a coastal city such as Houston. In identifying each of the domains of focus of vulnerability studies across the literature, and the language with which it is discussed, this research provides perhaps the first systematic review of efforts to quantify vulnerability specifically to floods in coastal cities (web searches yielded literature reviews of multi-hazard vulnerability studies; comparisons of earthquake and flood vulnerabilities; and reviews of flood vulnerability assessment methodologies, but no reviews of efforts to quantify flood vulnerability as such). This comparison, however incomplete, distills the current state of flood vulnerability calculation and measurement today.

Beyond establishing how vulnerability is discussed in the academic literature, my project also catalogues all of the web-based efforts to communicate flood vulnerability to researchers, policymakers, and the public in Houston. This collection allows the reader to examine how various government bodies and academic institutions approach the task of conveying complex urban, social, and environment-related data for a city that has recently found itself the subject of repeated, devastating hazard events. While this effort was initially undertaken as a way to organize and compare the themes and data layers that are operationalized to communicate risk and vulnerability, it has also become a survey of the capabilities of recent web-based mapping and communication methods. By comparing disparate efforts to convey similar information, I provide the material required to create a best practice guide for the communication of vulnerability-related information for researchers and decision-makers. The rate at which information—related to climate, vulnerability, resilience, or otherwise—is produced, consumed, and employed by a wide range of actors with different intentions has increased exponentially over the past several years, as have the capabilities of web-based data visualization frameworks. Given this proliferation and the examples presented here, I suggest that a focused study of web-based spatial information communication platforms be completed so as to formalize best practices, establish baselines, and promote clearer, more useful data communication in the future. While identifying these best practices exists outside the scope of this project, I hope to have internalized some of these observations in the tool that I created.

The tool hosted at houstonbetweenthelines.com attempts to marry the best parts of existing frameworks, libraries, and tools to create a useful lens through which interested parties can explore concepts of vulnerability in Houston. While there will never be a better way to fully understand a place than in the field, *in the place*, my hope is that the various perspectives that I offer through the tool move beyond the traditional, planimetric-based vantage point offered in most mapping efforts. Instead of offering a view from the sky, devoid of the detail, complexity, and contradictions uncovered through experience, my tool offers the ability to observe a place from perspective (showing three-dimensional context), elevation (showing the relationship between water and the city), first-person perspective (eliciting a sense of being-in-place without being in a place), and photographs (which expose the sometimes extreme, sometimes beautiful idiosyncrasies experienced by real people *who were there*), which allows the user to investigate, question, explore, compare, and draw conclusions from complimentary (if sometimes contradictory) modes of seeing. I argue that offering these different options together encourages the user to engage more deeply than through any one mode alone. Although there is room for improved design in the interface itself, the high density of information displayed moves toward allowing the viewer "to select, to narrate, to recast and personalize data for their own thinking. Thus, control of information is given over to viewers," (Tufte, 161) even if it was curated and editorialized by the author.

The data and model results that were included were chosen based on an extensive review of existing efforts to calculate and communicate vulnerability by specialist practitioners. While the domains of information that were included were limited by time, the domains that were chosen—social factors and built environment factors—were included based on earnest judgement of pressing and (in the case of the built environment) underdeveloped themes. Furthermore, the various processing scripts that were developed through the research project offer the opportunity to automate parts of this process, facilitating easier updates to the model results as new or updated data becomes available. These scripts could be extended to automatically query online databases to check whether new data has been published, greatly streamlining the entire process.

While the social vulnerability index has much in common with that operationalized by the Center for Disease Control's national Social Vulnerability Index, it deviates in several important ways. Firstly, the CDC operates at the census tract level. This facilitates a nation-wide comparison at an easily identifiable spatial unit, for which the majority of demographic information collected by the census is available. My choice to instead choose the census block level required considerable effort to download, process, and collate data, but I feel that the effort to compare information at the census block group scale—roughly the scale of a neighborhood—is an important step toward understanding how vulnerability is experienced in different ways by different groups without being distracted by the "noise" in the data at the block or parcel scale. I also deviated from the CDC's social vulnerability index in terms of the indicators I included. Firstly, I declined to include minority status as a variable because I reject the idea that race or minority status as such determines an inherent condition of social vulnerability. The systemic and pervasive prejudices inflicted on minority groups in the United States does contribute to vulnerability and is a product of institutional shortcomings and decisions and will be treated as a component of institutional vulnerability in future work. Instead, citizenship status was employed as a variable because of the current political climate, immigration enforcement policies, and the culture of fear that bred during Hurricane Harvey (see above). Furthermore, I added rent as a proportion of income as a variable instead of proportion of the population living below the poverty line in effort to express the relationship between people and capital assets. Conditions in which renters pay inordinate proportions of their income on housing become doubly damaging during extreme floods, where housing units can become uninhabitable and residents lack the resources to adjust or adapt. Median income is included to measure relative poverty across Houston. Although I encountered 70 unique measures of social vulnerability across the literature review, I chose twelve that I thought were particularly relevant for Houston. The principal component analysis above confirms that these indicators are independent and contribute each to the overall picture of vulnerability. However, future iterations, field validation, and adaptation initiatives could reveal the importance of other factors, meaning this list should be considered a work in progress.

The effort to quantify the vulnerability of the built environment domain presents itself as another important contribution of the thesis. While a number of other researchers have investigated the vulnerability of the built environment, the specific focus is often on infrastructural systems as opposed to building stock. My approach attempts to isolate the built form as such (i.e. structural vulnerability), an area of inquiry that is typical in vulnerability studies for earthquakes but less so for floods. While de Ruiter et al. (2017) trace both structural and occupancy indicators through the literature regarding the vulnerability of the built environment in their review of earthquake and flood vulnerability, my survey of flood-specific vulnerability measures uncovered a dearth of indicators and relatively few studies that included structural indicators at all. In a place like metropolitan Houston, which continues to expand rapidly and which is considering updates to building codes across the board, the characteristics of the new structures being built—and their relationship with people and other built structures—should assume a role of primary importance for researchers, policymakers, and designers alike. Thankfully, research has emerged recently that suggests that the study and optimization of buildings in response to vulnerability thinking is emerging, and points to a rich future for this field of study (Keenan, 2014).

8. Future work

This project represents an effort to create a unified methodology for determining and representing components of social and built environment vulnerability in Houston. However, it should be viewed as the introduction to a larger project. Future efforts will extend the model to include measures of vulnerability for economic, institutional, infrastructural, and environmental systems, which were largely excluded from the scope of this work. Each represents an important facet of vulnerability for a dynamic urban area such as Houston. Furthermore, future efforts will be made to validate the results of these models to ensure that they represent conditions in Houston in practice. Figure 9.1 Shows a first effort at comparing the estimated vulnerability scores observed through this project compared with the degree of damage observed during Hurricane Harvey as recorded by FEMA in the aftermath of the event. This sort of effort can provide context and suggests application for the vulnerability index beyond an academic exercise.

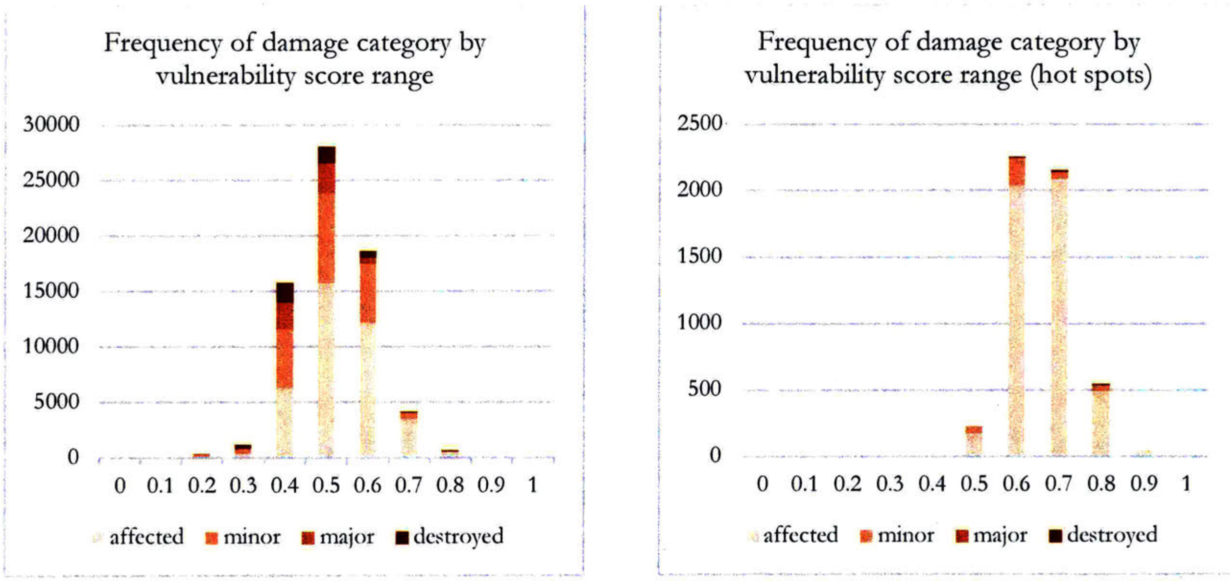


Figure 8.1 Built environment vulnerability scores by property damage for all buildings (left) and buildings in vulnerability clusters (right)

Flanagan et al. (2011) observed patterns of direct mailings to determine how long homes remained vacant after Hurricane Katrina in New Orleans. By observing which households were receiving mail before and after the extreme event at different intervals, they proposed a way to determine whether their assumptions about vulnerability could be confirmed through this measure. This suggests that other measures of flows of information (such as social media) could be used to determine the rate at which different affected areas recover after extreme events.

Beyond further developing the model, I intend to extend the visual and interactive components of the project. Further advances could be made to the web-based user interface to enhance the bi-lateral communication of information: instead of investigating pre-loaded available information, users could add their own anecdotes and data points to create a richer overall body of knowledge. This sentiment extends to the further development of the augmented reality application, which today shows relevant data in 3D but does not allow for user input. Furthermore, I am continuing to develop the application outside the scope of this project to allow for a first-person interaction with the information, as opposed to a third person perspective shown in Fig. 6.12 above. Emergent technology is making this possible and will continue to mature over the coming years. Fig. 8.1 below illustrates an early demonstration of this technology and its application in wayfinding.

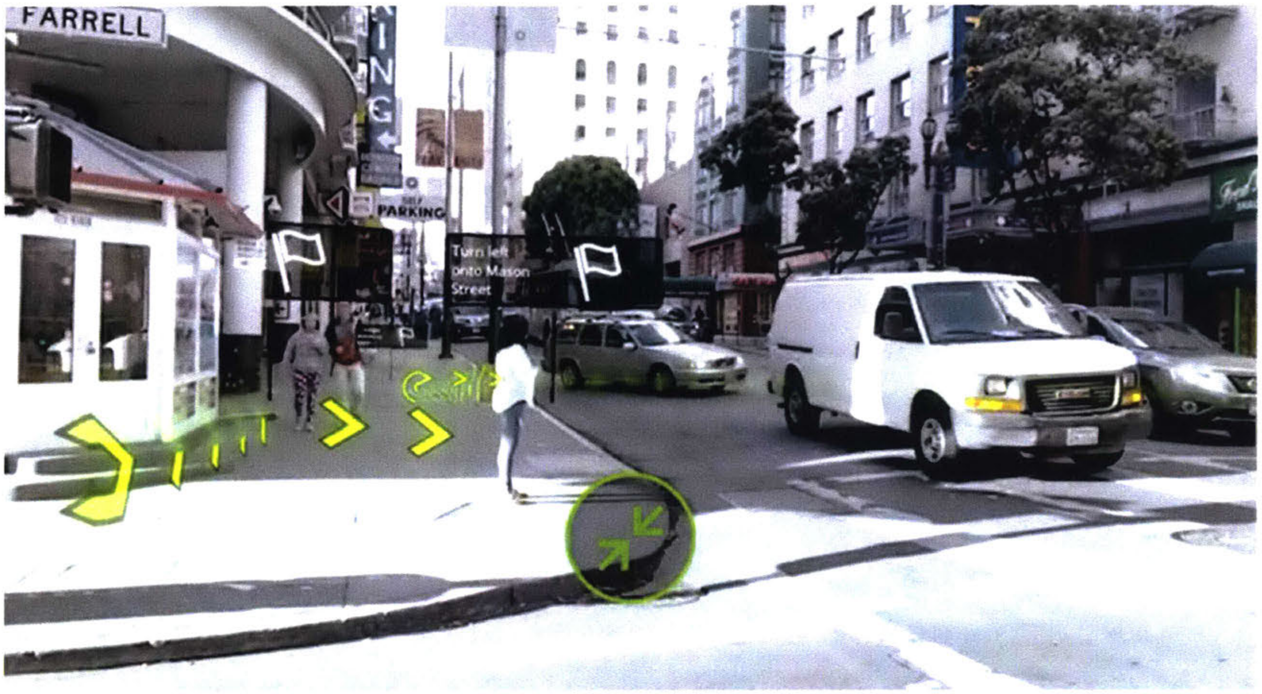


Figure 8.1 Demonstration of first-person augmented reality application for wayfinding in an urban context (image credit: Mapbox)

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Appendix I: Full list of flood-specific vulnerability indices

Index Name	Author	Included
UNESCO FVI	UNESCO (n.d.)	*
Coastal City FVI	Balica, Wright, van der Meulen (2012)	*
Cluster Analysis	Fernandez et al. (2016)	*
Emergy Approach	Chang & Huang (2015)	*
Delta FVI	Rao (2005)	*
CVI	Bolter (2013)	*
ISVI	Aroca-Jimenez et al. (2017)	*
SIFH-VI	Valchev et al. (2016)	*
Floodplain-VI	Roder & Sofia (2017)	*
Integrated-VI	Coninx & Bachus (n.d.)	*
ICHARM	Shrestha et al. (2013)	*
UF-VI	Villordon & Gourbesville (2014)	*
HVI	Van et al. (2016)	*
VI	Akukwe & Ogdobo (2015)	*
Hydrological Infrastructure FVI	Ogie et al. (2016)	*
VI	Cançado et al. (2008)	*
VI	Silva et al. (2016)	*
OS-VI	Garbutt et al. (2015)	*
SSD-VI	Bathi & Das (2016)	*
PVI	Borden (2007)	*
Resilience-NH	Burton (2015)	*
MAZANDARAN	Sadeghi-Pouya et al. (2017)	*
SEVICA	Zanetti et al (2016)	*

NFVI	Sayers (2017)	*
SoVI	Cutter et al. (2008)	*
SVI	U.S. CDC (first appearance?)	*
Localized VI	Khan (2017)	
Flood Risk Assessment	Balica (2012)	
Feweas	Red Cross (2018)	
ResilUS	Miles & Chang (2011)	
Yazoo	Zachos et al. (2016)	
CVI Mapping	NJ Department of Environmental Protection (2014)	
Justice VI	Lindley et al (2011)	
Unequal VI	Oulahen (2014)	
PFVI	de Brito et al. (2018)	
Flood Delta City Index	Verschuur et al (2017)	
FDI	Kazmierczak et al (2015)	
VI	Cheng (2013)	
VI	Zhang (2013)	

Appendix II: Full list of observed indicators from literature review

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Akukwe et al 2015	socioeconomic	wealth	membership in a group	economic	membership in a group
Akukwe et al 2015	socioeconomic	wealth	monthly income	economic	monthly income
Akukwe et al 2015	biophysical	proximity to water body	distance of dwelling units to river/creek/stream	environmental	proximity to water
Akukwe et al 2015	biophysical	flood characteristics	frequency of flood	hazard	hazard frequency
Akukwe et al 2015	biophysical	depth/height of flood	height of flood	hazard	storm surge
Akukwe et al 2015	socioeconomic	wealth	receipt of assistance/relief	institutional	receipt of assistance/relief
Akukwe et al 2015	biophysical	quality of building structure	% of population living in block housing	social	% of population living in block housing
Akukwe et al 2015	socioeconomic	literacy rate	educational qualification	social	education
Akukwe et al 2015	biophysical	flood characteristics	severity of flood	social	flood severity
Akukwe et al 2015	socioeconomic	technology	% ownership of radio/tv/phone	social	ownership of communication device

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Akukwe et al 2015	biophysical	flood experiences	past flood experiences	social	past experience with flood events
Akukwe et al 2015	biophysical	flood perception	awareness of flood	social	risk perception
Aroca-Jimenez et al 2017	buildings		above-ground built up area	built	% built up area
Aroca-Jimenez et al 2017	buildings		built-up area without buildings	built	% impervious surfaces
Aroca-Jimenez et al 2017	buildings		mean age of household construction	built	building age
Aroca-Jimenez et al 2017	buildings		households in good condition	built	building condition
Aroca-Jimenez et al 2017	buildings		households in poor condition	built	building condition
Aroca-Jimenez et al 2017	buildings		households with 2+ stories above ground	built	building type
Aroca-Jimenez et al 2017	buildings		permanent households	built	building type
Aroca-Jimenez et al 2017	buildings		single story households and/or houses with a basement	built	building type
Aroca-Jimenez et al 2017	buildings		household mean useful area	built	household net area
Aroca-Jimenez et al 2017	development and infrastructures		tourist accommodation	built	land use
Aroca-Jimenez et al 2017	buildings		non-accessible households	built	non-accessible households
Aroca-Jimenez et al 2017	buildings		underground built-up area	built	underground built up area
Aroca-Jimenez et al 2017	buildings		vacant households	built	vacant households
Aroca-Jimenez et al 2017	collective vulnerability		areas suited to population evacuation	infrastructure	access to evacuation routes
Aroca-Jimenez et al 2017	collective vulnerability		potential intersections between evacuation routes and rivers	infrastructure	access to evacuation routes
Aroca-Jimenez et al 2017	healthcare services		distance to nearest health center	infrastructure	access to health center

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Aroca-Jimenez et al 2017	healthcare services		health centers	infrastructure	access to health center
Aroca-Jimenez et al 2017	healthcare services		travel time to nearest health center	infrastructure	access to health center
Aroca-Jimenez et al 2017	healthcare services		distance to the nearest hospital	infrastructure	access to hospital
Aroca-Jimenez et al 2017	healthcare services		travel time to nearest hospital	infrastructure	access to hospital
Aroca-Jimenez et al 2017	development and infrastructures		campsites	infrastructure	campsites
Aroca-Jimenez et al 2017	healthcare services		hospital beds	infrastructure	hospital bed availability
Aroca-Jimenez et al 2017	healthcare services		medical staff	infrastructure	medical professional density
Aroca-Jimenez et al 2017	development and infrastructures		retirement homes	infrastructure	retirement homes
Aroca-Jimenez et al 2017	development and infrastructures		elementary schools	infrastructure	schools
Aroca-Jimenez et al 2017	development and infrastructures		kindergartens	infrastructure	schools
Aroca-Jimenez et al 2017	development and infrastructures		secondary schools	infrastructure	schools
Aroca-Jimenez et al 2017	healthcare services		type of healthcare (community)	infrastructure	type of healthcare
Aroca-Jimenez et al 2017	development and infrastructures		municipal available budget per capita	institutional	municipal budget per capita
Aroca-Jimenez et al 2017	development and infrastructures		municipal dept per inhabitant	institutional	municipal debt per capita
Aroca-Jimenez et al 2017	employment situation		people that work within urban area of residence	social	% that work within neighborhood
Aroca-Jimenez et al 2017	dependency		households where people 65+ live	social	age
Aroca-Jimenez et al 2017	population		age 0-4	social	age
Aroca-Jimenez et al 2017	population		age 15-64	social	age

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Aroca-Jimenez et al 2017	population		age 5-14	social	age
Aroca-Jimenez et al 2017	population		age 65+	social	age
Aroca-Jimenez et al 2017	dependency		dependency rates: females	social	dependency rate
Aroca-Jimenez et al 2017	dependency		dependency rates: males	social	dependency rate
Aroca-Jimenez et al 2017	education		illiterate people	social	education
Aroca-Jimenez et al 2017	education		literate people	social	education
Aroca-Jimenez et al 2017	employment situation		households where any employed people live	social	employment
Aroca-Jimenez et al 2017	population		foreigners	social	nationality
Aroca-Jimenez et al 2017	population		new residents	social	new residents
Aroca-Jimenez et al 2017	dependency		disabled people	social	persons with disabilities
Aroca-Jimenez et al 2017	population		pop projection 0-4 for 2025	social	population change
Aroca-Jimenez et al 2017	population		pop projection 15-64 for 2025	social	population change
Aroca-Jimenez et al 2017	population		pop projection 5-14 for 2025	social	population change
Aroca-Jimenez et al 2017	population		pop projection 65+ for 2025	social	population change
Aroca-Jimenez et al 2017	buildings		population per settlement area	social	population density
Aroca-Jimenez et al 2017	population		total population	social	total population
Aroca-Jimenez et al 2017	employment situation		households where any unemployed people live	social	unemployment
Aroca-Jimenez et al 2017	employment situation		long-term unemployed people	social	unemployment

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Aroca-Jimenez et al 2017	employment situation		unemployment rates	social	unemployment
Balica et al 2012	politico-administrative	exposure	uncontrolled planning zone	built	uncontrolled planning zone
Balica et al 2012	future economic	exposure	growing coastal population	economic	population change
Balica et al 2012	hydro-geological	exposure	coastline	environmental	coastline
Balica et al 2012	socio-economic	resilience	km of drainage	environmental	drainage
Balica et al 2012	hydro-geological	exposure	river discharge	environmental	river discharge
Balica et al 2012	hydro-geological	exposure	sea-level rise	environmental	sea-level rise
Balica et al 2012	hydro-geological	exposure	foreshore slope	environmental	slope
Balica et al 2012	hydro-geological	exposure	soil subsidence	environmental	soil subsidence
Balica et al 2012	future hydro-geological	exposure	soil subsidence	environmental	soil subsidence
Balica et al 2012	future hydro-geological	exposure	number of cyclones	hazard	hazard frequency
Balica et al 2012	hydro-geological	exposure	number of cyclones	hazard	hazard frequency
Balica et al 2012	future hydro-geological	exposure	sea-level rise	hazard	sea-level rise
Balica et al 2012	hydro-geological	exposure	storm surge	hazard	storm surge
Balica et al 2012	politico-administrative	resilience	flood protection	institutional	% population covered by flood insurance program
Balica et al 2012	politico-administrative	susceptibility	flood hazard maps	institutional	flood hazard maps
Balica et al 2012	politico-administrative	resilience	institutional organizations	institutional	institutional capacity
Balica et al 2012	socio-economic	resilience	recovery time	institutional	recovery time
Balica et al 2012	socio-economic	resilience	shelters	institutional	shelters
Balica et al 2012	socio-economic	exposure	cultural heritage	social	cultural heritage
Balica et al 2012	socio-economic	susceptibility	% of disabled persons (<14 and >65)	social	persons with disabilities
Balica et al 2012	socio-economic	exposure	growing coastal population	social	population change
Balica et al 2012	future hydro-geological	exposure	population close to coastline	social	population in flood zone
Balica et al 2012	socio-economic	exposure	population close to coastline	social	population in flood zone
Balica et al 2012	socio-economic	resilience	awareness and preparedness	social	risk perception

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Bathi & Das 2016	flood vulnerability		extent the tract is flooded during a disaster	hazard	% area flooded
Bathi & Das 2016	socio-economic		people in group quarters	social	% of population living in block housing
Bathi & Das 2016	socio-economic		population over 65 years or disabled	social	age
Bathi & Das 2016	socio-economic		population under 18 years	social	age
Bathi & Das 2016	socio-economic		housing units in mobile homes	built	building type
Bathi & Das 2016	socio-economic		population 18 years and over with no diploma	social	education
Bathi & Das 2016	socio-economic		number of female-headed households	social	household composition
Bathi & Das 2016	socio-economic		no one age 14 and over speaks English only or speaks English "very well"	social	language barriers
Bathi & Das 2016	socio-economic		people below poverty in past 12 months	social	poverty rate
Bathi & Das 2016	socio-economic		non-white population	social	race
Bathi & Das 2016	socio-economic		households with no vehicle	social	reliance on public transportation
Bathi & Das 2016	socio-economic		total population	social	total population
Bolter 2013	physical		elevation	environmental	elevation model
Bolter 2013	physical		storm surge zone	hazard	inundation zone
Bolter 2013	social		percent of population over 60	social	age
Bolter 2013	social		median income	social	per capita income
Bolter 2013	social		population density	social	population density
Borden et al 2007	built environment	residential property	housing units built before 1960	built	building age
Borden et al 2007	built environment	residential property	median age of housing units	built	building age
Borden et al 2007	built environment	residential property	density of housing units	built	building density
Borden et al 2007	built environment	residential property	density of mobile homes	built	building density
Borden et al 2007	socio-economics	employment and occupation	% of civilian labor force employed in farming, fishing, or forestry occupations	economic	% of civilian labor force employed in farming, fishing, or forestry occupations
Borden et al 2007	socio-economics	employment and occupation	% of civilian labor force employed in the service industry	economic	% of civilian labor force employed in the service industry

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Borden et al 2007	socio-economics	employment and occupation	% of civilian labor force employed in transportation, communications, or other public utilities	economic	% of civilian labor force employed in transportation, communications, or other public utilities
Borden et al 2007	socio-economics	employment and occupation	% of female participation on civilian labor force	economic	% of female participation on civilian labor force
Borden et al 2007	built environment	commercial and industrial development	commercial establishments	economic	commercial density
Borden et al 2007	hazard exposure / experience	magnitude and intensity	crop losses	economic	crop losses
Borden et al 2007	built environment	commercial and industrial development	industrial earnings	economic	industrial revenue
Borden et al 2007	built environment	commercial and industrial development	manufacturing establishments	economic	manufacturing density
Borden et al 2007	socio-economics	socio-economic status	median house value	economic	median house value
Borden et al 2007	socio-economics	socio-economic status	median rent	economic	median rent
Borden et al 2007	socio-economics	socio-economic status	per capita income	economic	per capita income
Borden et al 2007	hazard exposure / experience	magnitude and intensity	property loss impact	economic	property loss impact
Borden et al 2007	socio-economics	employment and occupation	% unemployed in civilian labor force	economic	unemployment
Borden et al 2007	built environment	commercial and industrial development	value of all non-residential property and fam products sold	economic	value of non-residential property and farm products sold
Borden et al 2007	built environment	monuments and icons	parks	environmental	open space
Borden et al 2007	built environment	residential property	daily water usage	environmental	water consumption rate
Borden et al 2007	hazard exposure / experience	magnitude and intensity	# deaths	hazard	# deaths
Borden et al 2007	hazard exposure / experience	magnitude and intensity	# injuries	hazard	# injuries
Borden et al 2007	hazard exposure / experience	complexity of mitigation	hazard diversity (# different hazards/18 the total number of different	hazard	hazard diversity

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
			hazard types in the database)		
Borden et al 2007	hazard exposure / experience	temporal spacing	hazard occurrence interval (#events/period of record)	hazard	hazard frequency
Borden et al 2007	built environment	transportation infrastructure	airports	infrastructure	airports
Borden et al 2007	built environment	lifelines	antennae structures	infrastructure	antennae structures
Borden et al 2007	built environment	transportation infrastructure	bus facilities	infrastructure	bus facilities
Borden et al 2007	built environment	lifelines	dams	infrastructure	dams and storage capacity
Borden et al 2007	built environment	lifelines	electric power facilities	infrastructure	electric power facilities
Borden et al 2007	built environment	lifelines	emergency centers	infrastructure	emergency centers
Borden et al 2007	built environment	transportation infrastructure	ferry facilities	infrastructure	ferry facilities
Borden et al 2007	built environment	lifelines	fire stations	infrastructure	fire stations
Borden et al 2007	built environment	transportation infrastructure	highway bridges	infrastructure	highway bridges
Borden et al 2007	built environment	lifelines	hospitals	infrastructure	hospital bed availability
Borden et al 2007	built environment	lifelines	number of hospital beds	infrastructure	hospital bed availability
Borden et al 2007	built environment	transportation infrastructure	interstate miles	infrastructure	miles of highway
Borden et al 2007	built environment	transportation infrastructure	other principle arterial miles	infrastructure	miles of principle arterials
Borden et al 2007	built environment	transportation infrastructure	fixed guide way transit and ferry network miles	infrastructure	miles of transit networks
Borden et al 2007	built environment	transportation infrastructure	rail miles	infrastructure	miles of transit networks
Borden et al 2007	built environment	lifelines	natural gas facilities	infrastructure	natural gas facilities
Borden et al 2007	built environment	lifelines	oil facilities	infrastructure	oil facilities
Borden et al 2007	built environment	lifelines	police stations	infrastructure	police stations
Borden et al 2007	built environment	transportation infrastructure	ports	infrastructure	ports
Borden et al 2007	built environment	lifelines	potable water facilities	infrastructure	potable water facilities
Borden et al 2007	built environment	transportation infrastructure	rail bridges	infrastructure	rail bridges
Borden et al 2007	built environment	lifelines	schools	infrastructure	schools
Borden et al 2007	built environment	lifelines	wastewater facilities	infrastructure	wastewater facilities
Borden et al 2007	built environment	residential property	building permits for housing units	institutional	building permits

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Borden et al 2007	socio-economics	socio-economic status	local government debt to revenue ratio	institutional	municipal debt per capita
Borden et al 2007	socio-economics	migration and housing tenure	% renter occupied housing units	social	% renter occupied
Borden et al 2007	socio-economics	migration and housing tenure	% urban population	social	% urban population
Borden et al 2007	socio-economics	political power	% voting for leading presidential party	social	% voting for leading presidential party
Borden et al 2007	socio-economics	age	% greater than 65 years of age	social	age
Borden et al 2007	socio-economics	age	% less than 5 years of age	social	age
Borden et al 2007	socio-economics	age	median age of population	social	age
Borden et al 2007	socio-economics	age	birth rate	social	birth rate
Borden et al 2007	built environment	monuments and icons	churches	social	churches
Borden et al 2007	socio-economics	education	% of population greater than 25 years of age without a high school diploma	social	education
Borden et al 2007	socio-economics	employment and occupation	% of population participation in civilian labor force	social	employment
Borden et al 2007	socio-economics	gender, race, and ethnicity	% female population	social	gender
Borden et al 2007	built environment	lifelines	nuclear families	social	household composition
Borden et al 2007	socio-economics	gender, race, and ethnicity	% female headed households	social	household composition
Borden et al 2007	socio-economics	migration and housing tenure	average people per housing unit	social	household density
Borden et al 2007	built environment	monuments and icons	landmark buildings	social	landmark buildings
Borden et al 2007	socio-economics	employment and occupation	persons per 100,000 employed as health care practitioners	social	medical professional density
Borden et al 2007	socio-economics	migration and housing tenure	% immigrants 1990-2000 of total immigrant population	social	nationality
Borden et al 2007	socio-economics	socio-economic status	% household earning greater than $100,000/year	social	per capita income
Borden et al 2007	socio-economics	migration and housing tenure	% population change 1990-2000	social	population change
Borden et al 2007	socio-economics	socio-economic status	% of population below poverty level	social	poverty rate
Borden et al 2007	socio-economics	gender, race, and ethnicity	% African American	social	race
Borden et al 2007	socio-economics	gender, race, and ethnicity	% Asian	social	race

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Borden et al 2007	socio-economics	gender, race, and ethnicity	% Hispanic	social	race
Borden et al 2007	socio-economics	gender, race, and ethnicity	% native American	social	race
Borden et al 2007	socio-economics	socio-economic status	% of population collecting social security benefits	social	receipt of social security benefit
Borden et al 2007	socio-economics	age	per capita people in nursing homes	social	retirement home density
Butler 2015	Infrastructural Resilience	infrastructure exposure	density of single-family detached homes	built	building density
Butler 2015	Infrastructural Resilience	housing type	% housing that is not a mobile home	built	building type
Butler 2015	Economic Resilience	economic diversity	% population not employed in primary industries	economic	% employed in secondary industries
Butler 2015	Economic Resilience	economic diversity	commercial establishments per 1,000 population	economic	commercial density
Butler 2015	Community Capital	creative class	professional, scientific, and technical services per 1,000 population	economic	commercial sectors
Butler 2015	Economic Resilience	economic/livelihood stability	% working age population that is employed	economic	employment
Butler 2015	Economic Resilience	economic/livelihood stability	mean sales volume of businesses	economic	mean sales volume
Butler 2015	Economic Resilience	resource equity	doctors and medical professionals per 1,000 population	economic	medical professional density
Butler 2015	Economic Resilience	economic/livelihood stability	per capita household income	economic	per capita income
Butler 2015	Economic Resilience	economic diversity	ratio of large to small businesses	economic	ratio of large to small businesses
Butler 2015	environmental systems resilience	protective resources	% land area that is a wetland, swamp, marsh, mangrove, sand dune, or natural barrier	environmental	land use
Butler 2015	environmental systems resilience	sustainability	% land area that is non-developed forest	environmental	land use
Butler 2015	environmental systems resilience	sustainability	% land area with no wetland decline	environmental	land use change
Butler 2015	environmental systems resilience	risk and exposure	number of river miles	environmental	number of river miles
Butler 2015	environmental systems resilience	hazard event frequency	frequency of loss-causing weather events (hail, wind, tornado, hurricane)	hazard	hazard frequency
Butler 2015	Infrastructural Resilience	response and recovery	% fire, police, emergency relief services, and temporary shelters outside of hazard zones	infrastructure	% fire, police, emergency relief services, and temporary

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
					shelters outside of hazard zones
Butler 2015	Infrastructural Resilience	response and recovery	fire, police, emergency relief services, and temporary shelters per 1,000 population	infrastructure	emergency services density
Butler 2015	Social Resilience	community health/well-being	health services per 1,000 population	infrastructure	health services density
Butler 2015	Infrastructural Resilience	access and evacuation	principal arterial miles	infrastructure	miles of principle arterials
Butler 2015	Infrastructural Resilience	response and recovery	school density	infrastructure	schools
Butler 2015	Institutional Resilience	hazard mitigation/planning	% households covered by National Flood Insurance Program policies	institutional	% population covered by flood insurance program
Butler 2015	Institutional Resilience	hazard mitigation/planning	% population covered by a recent hazard mitigation plan	institutional	% population covered by flood insurance program
Butler 2015	Institutional Resilience	hazard mitigation/planning	% population participating in Community Rating System (CRS) for flood	institutional	% population covered by flood insurance program
Butler 2015	Institutional Resilience	preparedness	% population with Citizen Corps program participation	institutional	% population covered by flood insurance program
Butler 2015	Social Resilience	community health/well-being	community services (recreational facilities, parks, historic sites, libraries, museums) per 1,000 population	institutional	community services density
Butler 2015	Economic Resilience	resource equity	lending institutions per 1,000 population	institutional	lending institution density
Butler 2015	Economic Resilience	economic/livelihood stability	% female labor force participation	social	% female labor force participation
Butler 2015	Social Resilience	Social Capacity	% population without a disability	social	% population disabled
Butler 2015	Economic Resilience	economic/livelihood stability	% homeownership	social	% renter occupied
Butler 2015	Community Capital	social capital	religious organizations per 1,000 population	social	churches
Butler 2015	Community Capital	social capital	arts, entertainment, and recreation centers per 1,000 population	social	community services density
Butler 2015	Social Resilience	equity	ratio % college degree to % no high school diploma	social	education

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Butler 2015	Social Resilience	community health/well-being	adult education and training programs per 1,000 population	social	education availability
Butler 2015	Social Resilience	Social Capacity	% population that doesn't speak English as a second language	social	language barriers
Butler 2015	Social Resilience	Social Capacity	% population with telephone access	social	ownership of communication device
Butler 2015	Social Resilience	Social Capacity	% population that is not a minority	social	race
Butler 2015	Social Resilience	community health/well-being	social assistance programs per 1,000 population	social	receipt of social security benefit
Butler 2015	Social Resilience	Social Capacity	% population with vehicle access	social	reliance on public transportation
Butler 2015	Community Capital	social capital	social advocacy organizations per 1,000 population	social	social advocacy organization density
Cançado et al 2008	impact		home density	built	building density
Cançado et al 2008	impact		relative vulnerability of buildings	built	exposure of housing units
Cançado et al 2008	flood hazard		flood probability	hazard	flood probability
Cançado et al 2008	flood hazard		water depth	hazard	inundation depth
Cançado et al 2008	flood hazard		water velocity	hazard	inundation velocity
Cançado et al 2008	impact		age vulnerability	social	age
Cançado et al 2008	socioeconomic		illiteracy rate	social	education
Cançado et al 2008	socioeconomic		index of relative education of the householders	social	education
Cançado et al 2008	socioeconomic		householders income monthly average	social	household income
Cançado et al 2008	impact		poverty index	social	poverty rate
Chang & Huang 2015	sensitivity	emergy storage of land use	empower density per land cover type	built	building type
Chang & Huang 2015	exposure	emergy of accumulated runoff	land cover	built	land use
Chang & Huang 2015	sensitivity	emergy storage of land use	area of land cover type	built	land use
Chang & Huang 2015	exposure	emergy of accumulated runoff	soil type (pervious storage capacity)	environmental	pervious storage capacity
Chang & Huang 2015	exposure	emergy of accumulated runoff	rainoff	environmental	rainoff

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Chang & Huang 2015	exposure	emergy of accumulated runoff	runoff	environmental	runoff
Chang & Huang 2015	exposure	emergy of accumulated runoff	runoff curve number	environmental	runoff
Chang & Huang 2015	adaptive capacity	man-made	total emergy content of physical flood barriers	infrastructure	dams and storage capacity
Chang & Huang 2015	adaptive capacity	man-made	total construction and maintenance cost of physical flood barriers and pumps	infrastructure	dams and storage capacity cost
Chang & Huang 2015	adaptive capacity	socioeconomic capacity	total annual budget for flood control	institutional	annual budget for flood control
Chang & Huang 2015	adaptive capacity	socioeconomic capacity	government employees' salaries for representing the extent of human resources of different cities to flood control or management	institutional	salaries for gov't employed working in flood control management
Coninx & Bachus	social vulnerability		property type	built	building type
Coninx & Bachus	social vulnerability		income	economic	per capita income
Coninx & Bachus	flood characteristics		debris	hazard	debris
Coninx & Bachus	flood characteristics		duration of flood	hazard	flood duration
Coninx & Bachus	flood characteristics		frequency of flood	hazard	hazard frequency
Coninx & Bachus	flood characteristics		inundation depth	hazard	inundation depth
Coninx & Bachus	flood characteristics		inundation velocity	hazard	inundation velocity
Coninx & Bachus	biophysical vulnerability		whether someone lives in flood risk area	hazard	population in flood zone
Coninx & Bachus	flood characteristics		speed of water rise	hazard	rate of water rise
Coninx & Bachus	flood characteristics		time of flooding	hazard	time of flooding
Coninx & Bachus	flood characteristics		water pollution	hazard	water pollution
Coninx & Bachus	social vulnerability		age	social	age
Coninx & Bachus	social vulnerability		health status	social	health status
Coninx & Bachus	social vulnerability		family structure	social	household composition
Coninx & Bachus	social vulnerability		nationality	social	nationality
Cutter 2008	ecological		% impervious surfaces	built	% impervious surfaces
Cutter 2008	infrastructure		residential housing age	built	building age
Cutter 2008	infrastructure		residential housing stock	built	building type

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Cutter 2008	infrastructure		commercial and manufacturing establishments	economic	commercial density
Cutter 2008	economic		employment	economic	employment
Cutter 2008	economic		value of property	economic	property value
Cutter 2008	economic		wealth generation	economic	wealth generation
Cutter 2008	ecological		biodiversity	environmental	biodiversity
Cutter 2008	ecological		erosion rates	environmental	erosion rates
Cutter 2008	ecological		wetlands acreage and loss	environmental	land use change
Cutter 2008	ecological		# coastal defense structures	infrastructure	# coastal defense structures
Cutter 2008	infrastructure		lifelines and critical infrastructure	infrastructure	critical infrastructure
Cutter 2008	infrastructure		transportation network	infrastructure	transportation network
Cutter 2008	institutional		participation in hazard reduction programs (NFIP, Storm Ready)	institutional	% population covered by flood insurance program
Cutter 2008	community competence		counseling services	institutional	counseling services
Cutter 2008	institutional		emergency response plans	institutional	emergency response plans
Cutter 2008	institutional		emergency services	institutional	emergency services density
Cutter 2008	institutional		continuity of operations plans	institutional	institutional capacity
Cutter 2008	institutional		interoperable communications	institutional	interoperable communications
Cutter 2008	economic		municipal finance / revenues	institutional	municipal budget per capita
Cutter 2008	institutional		hazard mitigation plans	institutional	presence of mitigation plans
Cutter 2008	institutional		zoning and building standards	institutional	zoning and building standards
Cutter 2008	social		age	social	age
Cutter 2008	social		faith-based organizations	social	churches
Cutter 2008	social		class	social	class
Cutter 2008	social		gender	social	gender
Cutter 2008	community competence		absence of psychopathologies (alcohol, drug, spousal abuse)	social	health status
Cutter 2008	community competence		health and wellness (low rates mental illness, stress-related outcomes)	social	health status
Cutter 2008	social		community values - cohesion	social	membership in a group
Cutter 2008	social		occupation	social	occupation

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Cutter 2008	community competence		quality of life (high satisfaction)	social	quality of life
Cutter 2008	social		race	social	race
Cutter 2008	community competence		local understanding of risk	social	risk perception
Cutter 2008	social		social embeddedness	social	social embeddedness
Cutter 2008	social		social networks	social	social networks
Fernandez et al 2016	physical		construction period	built	building age
Fernandez et al 2016	physical		building density	built	building density
Fernandez et al 2016	physical		building structure	built	building type
Fernandez et al 2016	physical		number of floors	built	building type
Fernandez et al 2016	environmental		urban growth	built	urban growth rate
Fernandez et al 2016	economic		economic activity sector	economic	commercial sectors
Fernandez et al 2016	economic		unemployment	economic	unemployment
Fernandez et al 2016	environmental		agricultural land use	environmental	land use
Fernandez et al 2016	environmental		forest land use	environmental	land use
Fernandez et al 2016	environmental		land use	environmental	land use
Fernandez et al 2016	social		age	social	age
Fernandez et al 2016	social		education level	social	education
Fernandez et al 2016	social		gender	social	gender
Fernandez et al 2016	social		household composition	social	household composition
Fernandez et al 2016	social		housing occupancy	social	household composition
Garbutt et al 2015	economic wealth and material well-being	housing	% households with no central heating	built	% households without central heating
Garbutt et al 2015	economic wealth and material well-being	employment and income	% retired	economic	% retired
Garbutt et al 2015	Hazards & Deprivation	strength of local economy	areas with house repossessions rate above national average	economic	areas with house repossessions rate above national average
Garbutt et al 2015	Hazards & Deprivation	strength of local economy	areas with landlord repossession rate above national average	economic	areas with landlord repossession rate

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
					above national average
Garbutt et al 2015	Hazards & Deprivation	strength of local economy	zones with bankruptcy rate >= 50% of 5-year national average	economic	bankruptcy rate
Garbutt et al 2015	Hazards & Deprivation	presence of flood hazard	>50% area in flood zone	hazard	% area within flood zone
Garbutt et al 2015	Hazards & Deprivation	presence of flood hazard	centroid within flood zone?	hazard	% area within flood zone
Garbutt et al 2015	accessibility	access to health care	area centroid unable to reach closest hospital due to being cut off by flood zone	hazard	access to hospital
Garbutt et al 2015	accessibility	access to infrastructure	areas with car drive time to food store above national average	infrastructure	access to food
Garbutt et al 2015	accessibility	access to health care	car drive time to a general practitioner above national average	infrastructure	access to health center
Garbutt et al 2015	accessibility	access to health care	areas with car drive time to hospital above national average	infrastructure	access to hospital
Garbutt et al 2015	accessibility	access to infrastructure	areas with hospital beds/1000 people below national average	infrastructure	access to hospital
Garbutt et al 2015	economic wealth and material well-being	housing	% households whose only accommodation is a caravan	infrastructure	reliance on public transportation
Garbutt et al 2015	economic wealth and material well-being	housing	% residents permanently living in communal residences	social	% of population living in block housing
Garbutt et al 2015	health, self, and support	age	% residents 65+	social	age
Garbutt et al 2015	health, self, and support	age	% residents above median age	social	age
Garbutt et al 2015	health, self, and support	age	% residents under 16	social	age
Garbutt et al 2015	health, self, and support	careers	% residents providing care between 20-49 hrs./week	social	caretaker status
Garbutt et al 2015	health, self, and support	careers	% residents providing care in excess of 50 hrs./week	social	caretaker status
Garbutt et al 2015	Hazards & Deprivation	crime rate	crime rate above national average	social	crime rate
Garbutt et al 2015	health, self, and support	dependent children	% households with 3+ dependent children	social	dependency rate
Garbutt et al 2015	health, self, and support	dependent children	% households with dependent children where head of household is unemployed	social	dependency rate

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Garbutt et al 2015	health, self, and support	dependent children	% households with dependent children where one person has long-term health problems/disability	social	dependency rate
Garbutt et al 2015	health, self, and support	education	% residents with less than "five GCSEs awards)	social	education
Garbutt et al 2015	health, self, and support	education	% residents with no qualifications	social	education
Garbutt et al 2015	economic wealth and material well-being	employment and income	% of residents working 49+ hours work week	social	employment
Garbutt et al 2015	health, self, and support	gender	% residents female	social	gender
Garbutt et al 2015	health, self, and support	health and special needs	% of children classed as unhealthy (i.e. underweight/overweight)	social	health status
Garbutt et al 2015	health, self, and support	health and special needs	% residents reporting bad and very bad health	social	health status
Garbutt et al 2015	health, self, and support	health and special needs	% residents reporting limited actions due to long-term health problems/disability	social	health status
Garbutt et al 2015	health, self, and support	health and special needs	adults accessing mental health service above average	social	health status
Garbutt et al 2015	economic wealth and material well-being	housing	% one-person +65yr household	social	household composition
Garbutt et al 2015	economic wealth and material well-being	housing	% one-person households	social	household composition
Garbutt et al 2015	health, self, and support	lone parents	% LPH where parent is female and has full-time employment	social	household composition
Garbutt et al 2015	health, self, and support	lone parents	% LPH with dependent children	social	household composition
Garbutt et al 2015	health, self, and support	lone parents	% of households classed as lone-parent households	social	household composition
Garbutt et al 2015	health, self, and support	lone parents	% of LPH where parent is employed	social	household composition
Garbutt et al 2015	health, self, and support	lone parents	% of LPH where parent is female and unemployed	social	household composition
Garbutt et al 2015	health, self, and support	health and special needs	% of one-person households whose occupant reports long-term health problem/disability	social	household composition

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Garbutt et al 2015	economic wealth and material well-being	housing	% households with > 1.5 persons/bedroom	social	household density
Garbutt et al 2015	health, self, and support	language	% residents who cannot speak English well or at all	social	language barriers
Garbutt et al 2015	economic wealth and material well-being	employment and income	% households with below average median household income	social	per capita income
Garbutt et al 2015	Hazards & Deprivation	deprivation dimensions	% of households with two or more deprivation dimensions	social	poverty rate
Garbutt et al 2015	Hazards & Deprivation	strength of local economy	% residents unemployed with individual insolvency rate above national avg.	social	poverty rate
Garbutt et al 2015	Hazards & Deprivation	deprivation dimensions	households >= 50% of local deprivation score	social	poverty rate
Garbutt et al 2015	Hazards & Deprivation	deprivation dimensions	households >= 50% of national deprivation score	social	poverty rate
Garbutt et al 2015	health, self, and support	ethnicity/race	% non-white residents	social	race
Garbutt et al 2015	economic wealth and material well-being	employment and income	% working age claiming benefits	social	receipt of social security benefit
Garbutt et al 2015	health, self, and support	health and special needs	% residents of working age claiming incapacity benefit	social	receipt of social security benefit
Garbutt et al 2015	accessibility	access to car	% of households with no access to car	social	reliance on public transportation
Garbutt et al 2015	economic wealth and material well-being	employment and income	% of residents who have never worked	social	unemployment
Garbutt et al 2015	economic wealth and material well-being	employment and income	% working age unemployed	social	unemployment
Ogie 2016	infrastructure	exposure	length of all waterways that flow from upstream toward floodgate	environmental	length of waterways
Ogie 2016	infrastructure	resilience	structural resilience + (sum of (capacity / length * number of channels for each floodgate) for each floodgate)	infrastructure	dams and storage capacity
Ogie 2016	infrastructure	susceptibility	capacity of floodgate	infrastructure	dams and storage capacity

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Rao 2005	social		land use	environmental	land use
Rao 2005	physical		distance from the coast	environmental	proximity to water
Rao 2005	physical		ground slope	environmental	slope
Rao 2005	physical		location with respect to cyclone track	hazard	location w/r/t cyclone track
Rao 2005	social		population density	social	population density
Roder & Sofia 2017	employment		% of people employed in agricultural sector	economic	% of civilian labor force employed in farming, fishing, or forestry occupations
Roder & Sofia 2017	employment		% retired	economic	% retired
Roder & Sofia 2017	income		mean annual income per capita	economic	per capita income
Roder & Sofia 2017	employment		% of unemployed	economic	unemployment
Roder & Sofia 2017	socio-economic status		% of households without basic sanitation	infrastructure	access to basic sanitation
Roder & Sofia 2017	special needs people		% population living in assistance institute	social	% population living in assisted living
Roder & Sofia 2017	socio-economic status		% of rent houses	social	% renter occupied
Roder & Sofia 2017	age		% of dependent people (<4 and >85)	social	dependency rate
Roder & Sofia 2017	education		% illiterate	social	education
Roder & Sofia 2017	education		% with less than 8 years education	social	education
Roder & Sofia 2017	gender		% female	social	gender
Roder & Sofia 2017	family structure		% families with >6 members	social	household composition
Roder & Sofia 2017	family structure		% single parent households	social	household composition
Roder & Sofia 2017	ethnicity		% non-native people	social	nationality
Roder & Sofia 2017	population consistency		population growth index	social	population change
Sadeghi-Pouya 2017	technical	building conditions	age	built	building age
Sadeghi-Pouya 2017	technical	building conditions	quality	built	building condition
Sadeghi-Pouya 2017	technical	river	wall condition	built	building condition
Sadeghi-Pouya 2017	socio-economic		height distribution	built	building type

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Sadeghi-Pouya 2017	socio-economic		training of citizens	economic	citizen preparedness
Sadeghi-Pouya 2017	socio-economic		tourism	economic	tourism
Sadeghi-Pouya 2017	population-environmental		environmental sensitivity	environmental	environmental sensitivity
Sadeghi-Pouya 2017	socio-economic		land use	environmental	land use
Sadeghi-Pouya 2017	technical	river	fall barrier	infrastructure	dams and storage capacity
Sadeghi-Pouya 2017	technical	studies	classification	infrastructure	scientific monitoring
Sadeghi-Pouya 2017	socio-economic		evacuation of the riverside	institutional	evacuation efficacy
Sadeghi-Pouya 2017	technical	monitoring	hydrometry	institutional	scientific monitoring
Sadeghi-Pouya 2017	technical	monitoring	meteorology	institutional	scientific monitoring
Sadeghi-Pouya 2017	technical	river	surveillance	institutional	scientific monitoring
Sadeghi-Pouya 2017	technical	studies	urban detailed plan	institutional	urban planning
Sadeghi-Pouya 2017	population-environmental		population density	social	population density
Sayers 2017	community support		housing characteristics	built	building type
Sayers 2017	ability to prepare		income	economic	per capita income
Sayers 2017	ability to respond		income	economic	per capita income
Sayers 2017	community support		service availability	infrastructure	access to basic services
Sayers 2017	ability to prepare		property tenure	social	% renter occupied
Sayers 2017	Susceptibility		age	social	age
Sayers 2017	ability to respond		crime	social	crime rate
Sayers 2017	Susceptibility		health	social	health status
Sayers 2017	ability to recover		information use	social	information use
Sayers 2017	ability to prepare		information use	social	information use
Sayers 2017	ability to respond		information use	social	information use
Sayers 2017	ability to prepare		local knowledge	social	local knowledge
Sayers 2017	ability to respond		local knowledge	social	local knowledge
Sayers 2017	ability to respond		physical mobility	social	local knowledge
Sayers 2017	ability to recover		physical mobility	social	mobility

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Sayers 2017	community support		direct flood experience	social	past experience with flood events
Sayers 2017	ability to recover		income	social	per capita income
Sayers 2017	community support		social networks	social	social networks
Shrestha 2013	Economic		avg. house value	economic	property value
Shrestha 2013	Environmental	agriculture	elevation model	environmental	elevation model
Shrestha 2013	Built (loss estimation)	house	land use	environmental	land use
Shrestha 2013	Environmental	agriculture	land use	environmental	land use
Shrestha 2013	Environmental		rainfall	environmental	rainfall
Shrestha 2013	Environmental	agriculture	river water level	environmental	water level
Shrestha 2013	Built (loss estimation)	house	house damage curve	hazard	building damage
Shrestha 2013	Economic (loss estimation)	agriculture	crop damage curve	hazard	crop damage
Shrestha 2013	Hazard		water depth	hazard	inundation depth
Shrestha 2013	Social	house	population density	social	population density
Silva et al 2016	social / social vulnerability index		property construction average age	built	building age
Silva et al 2016	economic / SEcVI	vulnerable elements	housing type	built	building type
Silva et al 2016	environmental / Socio-environmental vulnerability index	physical exposure	construction type	built	building type
Silva et al 2016	environmental / Socio-environmental vulnerability index	physical exposure	home characteristics	built	building type
Silva et al 2016	structural / flood risk index	consequences	household density	built	household density
Silva et al 2016	environmental / Socio-environmental vulnerability index	population responsiveness	number of residents per house	built	residents per house
Silva et al 2016	environmental / Socio-environmental vulnerability index	population responsiveness	job market situation	economic	employment prospects

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Silva et al 2016	environmental / Socio-environmental vulnerability index	population responsiveness	income	economic	per capita income
Silva et al 2016	social / social vulnerability index		income	economic	per capita income
Silva et al 2016	social / social vulnerability index		monthly average income	economic	per capita income
Silva et al 2016	structural / flood risk index	consequences	income	economic	per capita income
Silva et al 2016	environmental / Socio-environmental vulnerability index	physical exposure	water supply	environmental	access to potable water
Silva et al 2016	environmental / Socio-environmental vulnerability index	physical exposure	garbage collection	environmental	garbage collection
Silva et al 2016	environmental / Socio-environmental vulnerability index	physical exposure	home ownership	environmental	home tenure
Silva et al 2016	environmental / Socio-environmental vulnerability index	physical exposure	public lighting	environmental	public lighting
Silva et al 2016	environmental / Socio-environmental vulnerability index	physical exposure	sewage	environmental	sewage
Silva et al 2016	structural / flood risk index	flood specificity	permanence factor	hazard	flood duration
Silva et al 2016	structural / flood risk index	flood specificity	speed factor	hazard	inundation velocity
Silva et al 2016	structural / flood risk index	flood specificity	overflow blade	hazard	overflow blade
Silva et al 2016	structural / flood risk index	consequences	inadequate sanitation	infrastructure	access to basic sanitation
Silva et al 2016	economic / SEcVI	vulnerable elements	critical infrastructure	infrastructure	critical infrastructure
Silva et al 2016	economic / SEcVI	preparation and response	severity on regulation control	infrastructure	flood zone regulation
Silva et al 2016	economic / SEcVI	recovery	quality of medical services	infrastructure	quality of medical services
Silva et al 2016	structural / flood risk index	consequences	traffic	infrastructure	traffic

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Silva et al 2016	economic / SEcVI	recovery	existence of disaster funds	institutional	disaster funds
Silva et al 2016	economic / SEcVI	preparation and response	emergency response	institutional	emergency response plans
Silva et al 2016	economic / SEcVI	preparation and response	extent of emergency protocol	institutional	emergency response plans
Silva et al 2016	economic / SEcVI	preparation and response	capacity to quickly alert "the society"	institutional	interoperable communications
Silva et al 2016	economic / SEcVI	vulnerable elements	younger than 5 or older than 65	social	age
Silva et al 2016	environmental / Socio-environmental vulnerability index	population responsiveness	age	social	age
Silva et al 2016	social / social vulnerability index		number of children under 14	social	age
Silva et al 2016	social / social vulnerability index		people older than 65	social	age
Silva et al 2016	economic / SEcVI	vulnerable elements	people without post-secondary education	social	education
Silva et al 2016	environmental / Socio-environmental vulnerability index	population responsiveness	education	social	education
Silva et al 2016	economic / SEcVI	vulnerable elements	people responsible for household income	social	employment
Silva et al 2016	social / social vulnerability index		number of single-parent households	social	household composition
Silva et al 2016	social / social vulnerability index		total number of families	social	household density
Silva et al 2016	economic / SEcVI	vulnerable elements	household income	social	household income
Silva et al 2016	economic / SEcVI	vulnerable elements	people with language and cultural barriers	social	language barriers
Silva et al 2016	environmental / Socio-environmental vulnerability index	population responsiveness	time in house	social	length of tenure
Silva et al 2016	environmental / Socio-environmental vulnerability index	population responsiveness	marital status	social	marital status
Silva et al 2016	social / social vulnerability index		non-European migrants	social	nationality

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Silva et al 2016	economic / SEcVI	vulnerable elements	population density	social	population density
Silva et al 2016	environmental / Socio-environmental vulnerability index	population responsiveness	race	social	race
Silva et al 2016	economic / SEcVI	preparation and response	population risk perception	social	risk perception
Silva et al 2016	social / social vulnerability index		total population	social	total population
Silva et al 2016	economic / SEcVI	recovery	personal wealth	social	wealth
UNESCO	Social	exposure	% of urbanized area	built	% built up area
UNESCO	Economic	susceptibility	urban growth	built	urban growth rate
UNESCO	Environmental	susceptibility	urban growth	built	urban growth rate
UNESCO	Economic	susceptibility	regional GDP per capita	economic	GDP per capita
UNESCO	Economic	susceptibility	inequality	economic	inequality
UNESCO	Economic	exposure	land use	economic	land use
UNESCO	Economic	susceptibility	income	economic	per capita income
UNESCO	Economic	exposure	*cadastre survey*	economic	presence of land use map
UNESCO	Economic	exposure	closeness to inundation area	economic	proximity to inundation area
UNESCO	Economic	exposure	proximity to river	economic	proximity to water
UNESCO	Economic	susceptibility	unemployment	economic	unemployment
UNESCO	Environmental	exposure	% of urbanized area	environmental	% built up area
UNESCO	Physical	exposure	*coast line*	environmental	coastline
UNESCO	Economic	resilience	dams and storage capacity	environmental	dams and storage capacity
UNESCO	Economic	resilience	dikes/levees	environmental	dams and storage capacity
UNESCO	Environmental	exposure	degraded area	environmental	degraded area
UNESCO	Environmental	exposure	overused area	environmental	degraded area
UNESCO	Physical	exposure	coastal bathymetry	environmental	elevation model
UNESCO	Environmental	resilience	*environmental concern*	environmental	environmental concern
UNESCO	Physical	exposure	evaporation rate	environmental	evaporation rate
UNESCO	Physical	exposure	*geography*	environmental	geography
UNESCO	Environmental	exposure	land use	environmental	land use
UNESCO	Environmental	exposure	types of vegetation	environmental	land use
UNESCO	Environmental	exposure	unpopulated land area	environmental	land use
UNESCO	Environmental	exposure	forest change rate	environmental	land use change
UNESCO	Environmental	susceptibility	nature reservations	environmental	nature reservations
UNESCO	Physical	exposure	geology	environmental	pervious storage capacity

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
UNESCO	Physical	exposure	soil moisture	environmental	pervious storage capacity
UNESCO	Social	exposure	*cadastre survey*	environmental	presence of land use map
UNESCO	Physical	exposure	river discharge	environmental	river discharge
UNESCO	Physical	exposure	sedimentation load	environmental	sedimentation load
UNESCO	Physical	exposure	topography (slope)	environmental	slope
UNESCO	Physical	exposure	temperature (yearly average)	environmental	temperature
UNESCO	Physical	exposure	*tidal*	environmental	tidal characteristics
UNESCO	Environmental	exposure	*Ground WL*	environmental	water level
UNESCO	Economic	exposure	% of urbanized area	hazard	% of urbanized area exposed
UNESCO	Physical	exposure	flood duration	hazard	flood duration
UNESCO	Physical	exposure	frequency of occurrence	hazard	hazard frequency
UNESCO	Physical	exposure	flood water depth	hazard	inundation depth
UNESCO	Physical	exposure	flow velocity	hazard	inundation velocity
UNESCO	Physical	exposure	heavy rainfall	hazard	rainfall
UNESCO	Physical	exposure	return periods	hazard	return periods
UNESCO	Physical	exposure	storm surge	hazard	storm surge
UNESCO	Social	susceptibility	population access to sanitation	infrastructure	access to basic sanitation
UNESCO	Social	susceptibility	rural population without access to water	infrastructure	access to potable water
UNESCO	Physical	resilience	dams and storage capacity	infrastructure	dams and storage capacity
UNESCO	Physical	resilience	dikes/levees	infrastructure	dams and storage capacity
UNESCO	Social	resilience	emergency service	infrastructure	emergency services density
UNESCO	Social	resilience	evacuation routes	infrastructure	evacuation rotes
UNESCO	Social	susceptibility	hospitals	infrastructure	hospital bed availability
UNESCO	Social	susceptibility	quality of energy supply	infrastructure	quality of energy supply
UNESCO	Economic	susceptibility	quality of infrastructure	infrastructure	quality of infrastructure
UNESCO	Environmental	susceptibility	quality of infrastructure	infrastructure	quality of infrastructure
UNESCO	Social	susceptibility	quality of water supply	infrastructure	quality of water supply
UNESCO	Social	resilience	shelters	infrastructure	shelters
UNESCO	Physical	resilience	roads	infrastructure	transportation network
UNESCO	Economic	resilience	flood insurance	institutional	% population covered by flood insurance program

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
UNESCO	Economic	resilience	infrastructure management	institutional	infrastructure management
UNESCO	Social	resilience	institutional capacity	institutional	institutional capacity
UNESCO	Social	resilience	warning system	institutional	interoperable communications
UNESCO	Social	susceptibility	communication penetration rate	institutional	interoperable communications
UNESCO	Economic	resilience	investment in counter measures	institutional	investment in counter measures
UNESCO	Economic	resilience	recovery time	institutional	recovery time
UNESCO	Environmental	resilience	recovery time to floods	institutional	recovery time
UNESCO	Economic	susceptibility	*urban planning*	institutional	urban planning
UNESCO	Social	susceptibility	*urban planning*	institutional	urban planning
UNESCO	Physical	susceptibility	building codes	institutional	zoning and building standards
UNESCO	Social	exposure	% youth and elderly	social	age
UNESCO	Social	susceptibility	*awareness*	social	awareness
UNESCO	Economic	susceptibility	child mortality	social	child mortality
UNESCO	Environmental	susceptibility	child mortality	social	child mortality
UNESCO	Social	exposure	*cultural heritage*	social	cultural heritage
UNESCO	Social	susceptibility	education (literacy rate)	social	education
UNESCO	Economic	susceptibility	*years of sustaining health life*	social	health status
UNESCO	Environmental	susceptibility	human health	social	health status
UNESCO	Environmental	susceptibility	years of sustaining health life	social	health status
UNESCO	Social	susceptibility	human health	social	health status
UNESCO	Economic	resilience	past experience with flood events	social	past experience with flood events
UNESCO	Social	susceptibility	past experience with flood events	social	past experience with flood events
UNESCO	Social	susceptibility	population growth	social	population change
UNESCO	Social	exposure	Population Density	social	population density
UNESCO	Social	exposure	rural population	social	population density
UNESCO	Social	exposure	population close to coast line	social	population in flood zone
UNESCO	Social	exposure	Population in flood area	social	population in flood zone
UNESCO	Social	exposure	population in poverty	social	poverty rate
UNESCO	Social	susceptibility	*preparedness*	social	preparedness
UNESCO	Physical	exposure	proximity to river	social	proximity to water
UNESCO	Social	exposure	closeness to inundation area	social	proximity to water
UNESCO	Social	exposure	slums	social	slums

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
UNESCO	Social	susceptibility	trust in institutions	social	trust in institutions
US CDC 2017		socioeconomic	below poverty	economic	below poverty
US CDC 2017		socioeconomic	unemployed	economic	unemployment
US CDC 2017		socioeconomic	income	economic	income
US CDC 2017		socioeconomic	no high school diploma	social	no high school diploma
US CDC 2017		household composition and disability	aged 65 or older	social	age
US CDC 2017		household composition and disability	aged 17 or younger	social	age
US CDC 2017		household composition and disability	civilian with a disability	social	% population disabled
US CDC 2017		household composition and disability	single-parent households	social	single-parent households
US CDC 2017		minority status and language	minority	social	minority
US CDC 2017		minority status and language	speaks English less than well	social	language barriers
US CDC 2017		housing and transportation	multi-unit structures	built	multi-unit structures
US CDC 2017		housing and transportation	mobile homes	built	mobile homes
US CDC 2017		housing and transportation	crowding	built	crowding
US CDC 2017		housing and transportation	no vehicle	social	reliance on public transportation
US CDC 2017		housing and transportation	group quarters	built	group quarters
Valchev et al 2016	land use		importance value for selected land use	built	land use
Valchev et al 2016	business settings		importance of business activities	economic	commercial sectors
Valchev et al 2016	population	financial deprivation	unemployment	economic	unemployment
Valchev et al 2016	land use		exposed surface	hazard	% area within flood zone
Valchev et al 2016	transport		importance of infrastructure	infrastructure	importance of infrastructure
Valchev et al 2016	utilities		importance of utilities	infrastructure	importance of infrastructure
Valchev et al 2016	transport		presence of roads	infrastructure	miles of principle arterials
Valchev et al 2016	transport		presence of railroads	infrastructure	miles of transit networks

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Valchev et al 2016	transport		capacity of infrastructure	infrastructure	quality of infrastructure
Valchev et al 2016	population	financial deprivation	non-home ownership	social	% renter occupied
Valchev et al 2016	population	age	(elderly 75+)	social	age
Valchev et al 2016	population	education	(has primary education)	social	education
Valchev et al 2016	population	health	long-term sickness	social	education
Valchev et al 2016	population	household structure	single parents	social	household composition
Valchev et al 2016	population	financial deprivation	non-car ownership	social	reliance on public transportation
Van 2016		sensitivity	housing type	built	building type
Van 2016		sensitivity	number of households	built	household density
Van 2016		exposure	land use	built	land use
Van 2016		sensitivity	number of people flooded	built	number of people affected
Van 2016		sensitivity	service industries percentage	economic	% of civilian labor force employed in the service industry
Van 2016		sensitivity	industry percentage	economic	commercial sectors
Van 2016		sensitivity	*main incomes*	economic	commercial sectors
Van 2016		capacity	production recovery	economic	economic recovery rate
Van 2016		sensitivity	occupation	economic	employment prospects
Van 2016		sensitivity	per capita income	economic	per capita income
Van 2016		sensitivity	current forest status	environmental	ecosystem health
Van 2016		sensitivity	quality environmental	environmental	ecosystem health
Van 2016		sensitivity	agriculture percentage	environmental	land use
Van 2016		flood magnitude	flood duration	hazard	flood duration
Van 2016		flood magnitude	flood depth	hazard	inundation depth
Van 2016		flood magnitude	flow velocity	hazard	inundation velocity
Van 2016		capacity	necessities	infrastructure	access to basic services
Van 2016		sensitivity	doctor, nurse ratios	infrastructure	doctor to nurse ratios
Van 2016		capacity	flood control equipment	infrastructure	flood control infrastructure
Van 2016		sensitivity	domestic water sources	infrastructure	quality of water supply
Van 2016		sensitivity	transport system	infrastructure	transportation network

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Van 2016		capacity	property protection	institutional	% population covered by flood insurance program
Van 2016		sensitivity	healthcare services	institutional	access to health center
Van 2016		capacity	flood control ability	institutional	capacity to control flooding
Van 2016		capacity	public constructors	institutional	capacity to control flooding
Van 2016		capacity	training	institutional	citizen preparedness
Van 2016		capacity	government support	institutional	institutional capacity
Van 2016		capacity	the ability to apply solutions to prevent flood	institutional	institutional capacity
Van 2016		capacity	forecast and warning flooding	institutional	interoperable communications
Van 2016		sensitivity	communication systems	institutional	interoperable communications
Van 2016		capacity	flood control contractures	institutional	investment in flood control
Van 2016		capacity	environment recovery	institutional	recovery time
Van 2016		capacity	health recovery	institutional	recovery time
Van 2016		capacity	living recovery	institutional	recovery time
Van 2016		capacity	community support	social	community support
Van 2016		sensitivity	*education attainment*	social	education
Van 2016		sensitivity	gender	social	gender
Van 2016		sensitivity	disease	social	health status
Van 2016		sensitivity	household living standards	social	household living standards
Van 2016		sensitivity	household main occupation	social	occupation
Van 2016		capacity	experience against flood	social	past experience with flood events
Van 2016		sensitivity	poverty rate	social	poverty rate
Van 2016		sensitivity	*population*	social	total population
Villordon 2014	economic components	susceptibility	housing conditions (e.g. semi-concrete, tent light materials, and plastic materials)	built	building condition
Villordon 2014	hydro-geological	exposure	houses not on elevated area	built	building elevation
Villordon 2014	hydro-geological	exposure	houses reached by floods	built	number of houses affected
Villordon 2014	politico-administrative	exposure	land use and management and structural design	built	urban planning
Villordon 2014	hydro-geological	resilience	land use management and structural design	built	urban planning

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Villordon 2014	economic components	resilience	family income	economic	per capita income
Villordon 2014	politico-administrative	exposure	the "River's Natural Resources & Natural Features Management and Program"	environmental	ecosystem management plans
Villordon 2014	economic components	exposure	presence of rats in the vicinity	environmental	presence of pests
Villordon 2014	economic components	exposure	presence of water logged areas in the vicinity	environmental	presence of water logged areas
Villordon 2014	hydro-geological	exposure	frequency of flooding	hazard	hazard frequency
Villordon 2014	hydro-geological	susceptibility	number of typhoons per year (50%)	hazard	hazard frequency
Villordon 2014	hydro-geological	exposure	height of flooding	hazard	inundation depth
Villordon 2014	economic components	exposure	houses with no access to improved sanitation	infrastructure	access to basic sanitation
Villordon 2014	economic components	exposure	houses with no access to an improved water source	infrastructure	access to potable water
Villordon 2014	social components	resilience	water treatment or sterilization practice	infrastructure	access to potable water
Villordon 2014	economic components	resilience	property insurance	institutional	% population covered by flood insurance program
Villordon 2014	politico-administrative	resilience	relocation site project	institutional	availability of developable land
Villordon 2014	politico-administrative	susceptibility	governance (warning and evacuation, emergency response, disaster recovery)	institutional	institutional capacity
Villordon 2014	politico-administrative	resilience	susceptible community livelihood program	institutional	institutional capacity
Villordon 2014	politico-administrative	resilience	post-risk assessment and integration	institutional	post-risk assessment and integration
Villordon 2014	politico-administrative	resilience	health and prevention program of E. coli, leptospirosis and Dengue fever	institutional	presence of preventative health services
Villordon 2014	social components	exposure	unwillingness to vacate and be relocated	social	attachment to place
Villordon 2014	social components	susceptibility	educational attainment	social	education
Villordon 2014	socio-behavioral	exposure	practices of households on dengue fever	social	health practices
Villordon 2014	socio-behavioral	exposure	practices of households on E. coli (e.g. nature of E. coli, mode of transmission, prevention, signs and symptoms, it is	social	health practices

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
			fatal, treatment, financial cost of treatment)		
Villordon 2014	socio-behavioral	exposure	practices of households on flood resilience (e.g. hazards, risks, exposure, preparedness, response, recovery, coordination, adaptation strategies)	social	health practices
Villordon 2014	socio-behavioral	exposure	practices of households on leptospirosis	social	health practices
Villordon 2014	socio-behavioral	resilience	knowledge of households on Dengue Fever	social	risk perception
Villordon 2014	socio-behavioral	resilience	knowledge of households on E. coli	social	risk perception
Villordon 2014	socio-behavioral	resilience	knowledge of households on flood resilience	social	risk perception
Villordon 2014	socio-behavioral	susceptibility	attitude of households on E. coli	social	risk perception
Villordon 2014	socio-behavioral	susceptibility	attitude of households on flood resilience (hazards, risks, exposure, preparedness, response, recovery, coordination, adaptation strategies)	social	risk perception
Villordon 2014	socio-behavioral	susceptibility	attitude of households on leptospirosis	social	risk perception
Villordon 2014	socio-behavioral	susceptibility	attitude of houses on Dengue fever	social	risk perception
Villordon 2014	social components	resilience	social networks	social	social networks
Villordon 2014	social components	exposure	open disposal of animal waste	social	waste disposal
Zanetti et al 2016	socio-economic	land use	land use	built	land use
Zanetti et al 2016	socio-economic	socio-economic status	income	economic	per capita income
Zanetti et al 2016	Geo-physical	coastal erosion	geomorphology	environmental	geomorphology
Zanetti et al 2016	Geo-physical	land slides	geotechnical classification of soil	environmental	pervious storage capacity
Zanetti et al 2016	Geo-physical	wave exposure	sea level rise	environmental	sea-level rise
Zanetti et al 2016	Geo-physical	coastal erosion	sea level rise	environmental	sea-level rise
Zanetti et al 2016	Geo-physical	land slides	slope	environmental	slope
Zanetti et al 2016	Geo-physical	rainfall-induced flood	slope	environmental	slope
Zanetti et al 2016	Geo-physical	coastal erosion	tide height	environmental	tidal characteristics
Zanetti et al 2016	Geo-physical	land slides	number of extreme events in the last 10 years	hazard	hazard frequency

Study	Conceptual Category	Stated Subcategory	Variables	Classified Domain	Classified Indicator
Zanetti et al 2016	Geo-physical	rainfall-induced flood	number of extreme events in the last 10 years	hazard	hazard frequency
Zanetti et al 2016	Geo-physical	wave exposure	distance of the coast	hazard	proximity to water
Zanetti et al 2016	Geo-physical	rainfall-induced flood	water body proximity	hazard	proximity to water
Zanetti et al 2016	Geo-physical	wave exposure	relief	institutional	institutional capacity
Zanetti et al 2016	socio-economic	population density	age	social	age

Appendix III: Houston-related data portals

Author	URL
MIT Center for Advanced Urbanism	http://web.mit.edu/cron/project/E+U/
Center for Texas Beaches and Shores (Texas A&M University- Galveston)	http://www.texascoastalatlas.com/AtlasViewers/bayatlas/viewer.html
Center for Texas Beaches and Shores (Texas A&M University- Galveston)	http://www.texascoastalatlas.com/buyersbewhere/harris3.5.php
The Nature Conservancy	http://maps.coastalresilience.org/gulfmex/
City of Houston- Department of Public Work and Engineering	http://www.gims.houstontx.gov/FloodplainWAB/
Rice University Kinder Institute for Urban Research	http://www.datahouston.org/Map.html
Rice University Kinder Institute for Urban Research	http://arcg.is/2hzS6Qp

Appendix IV: Web Tool Layer Descriptions

Tool Name	Layer Category	Layer Name	Description
Buyers B-Where	Risk Data	Hurricanes	Description: This layer is derived from the Texas A and M / DEM Risk Area maps. Risk area zones (1 - 5) are identified by hurricane categories. Area 1 corresponds to a Category 1 Hurricane.
Buyers B-Where	Risk Data	Floods	Description: Parcels within the 100-year floodplain are scored the highest (5), parcels within 500-year floodplain are considered to be at medium risk (3).

Tool Name	Layer Category	Layer Name	Description
Buyers B-Where	Risk Data	Flood Claim Score	Description: Parcels with a score of 1, are located within a block group without any paid claims since 2000. Scores between 1 and 2 indicate the property is located in an area with a relatively low frequency of flooding. A parcel with a score of 2-3 is located in an area that experiences moderate flooding. A score between 4-5 can be interpreted as being a parcel located within group with high amount of flooding. Any parcel with a score of 5 would be within a block group that experiences a very high amount of flooding. This scale offers insight into the frequency at which parcels within a block group are flooded, regardless of whether they are located within a flood zone.
Buyers B-Where	Risk Data	Wildfire	Description: The map was developed from mapping done by the Rocky Mountain Fire Sciences Lab for the entire United States. Data for Texas was extracted from a raster grid and converted to shapefile format. The end map was an integration of 3 GIS data layers: housing density, potential fire exposure, and extreme weather potential.
Buyers B-Where	Risk Data	Traffic	Description: This measure of traffic proximity is based on average annual daily traffic (AADT) estimates in the Highway Performance Monitoring System (HPMS 2011) dataset in the Department of Transportation (DOT) National Transportation Atlas Database (NTAD). The HPMS highway data is maintained by states and compiled by DOT.
Buyers B-Where	Risk Data	NPL Sites	Description: EPA places sites on the National Priorities List (NPL) (a key subset of all "Superfund" sites) based on a defined set of criteria and a public comment process. Inclusion of a site on the NPL does not impose a financial obligation on EPA, nor does it assign liability to any party. The NPL serves primarily informational purposes, identifying sites that appear to warrant remedial actions, thereby conveying to policymakers and the public the size and nature of the nation's cleanup challenges.

Tool Name	Layer Category	Layer Name	Description
Buyers B-Where	Risk Data	RMP Sites	Description: RMP facilities are those facilities required by the Clean Air Act (CAA) to file risk management plans. The regulations under CAA section 112(r) establishes a List of Regulated Substances—72 substances listed because of their high acute toxicity and 60 because of their flammable or explosive potential—along with threshold quantities (TQs) for each. The listed substances are those that pose the greatest risk of harm from accidental releases. If a facility maintains a quantity of any such chemical above those TQs, it must file an RMP with EPA. More information is available at:
Buyers B-Where	Risk Data	TSDF Sites	Description: The Resource Conservation and Recovery Act (RCRA) was further amended in 1984 with the addition of the Hazardous and Solid Waste Amendments. RCRA Subtitle C establishes a federal program to manage hazardous wastes from "cradle to grave," or from generation to disposal, to ensure that hazardous waste is managed in a manner that protects human health and the environment. EPA has developed Subtitle C regulations governing hazardous waste generation, transportation, and the several hundred active treatment, storage or disposal facilities (TSDFs).
Buyers B-Where	Risk Data	Ozone	Description: Ozone data are estimated by EPA from a combination of monitoring data and Community Multi-scale Air Quality (CMAQ) modeling. The downscaling was done by EPA using fusion model that utilize both air quality monitoring data from NAMS/SLAMS (data collected by EPA, state, local and tribal air pollution control agencies at more than 600 hundred monitors nationwide) and numerical output from the Models-3/CMAQ model. This downscaling approach is designed to provide daily, predictive PM2.5 (daily average) and O3 (daily 8-hour maximum) surfaces for a given year, such as 2011, at specified points.

Tool Name	Layer Category	Layer Name	Description
Buyers B-Where	Risk Data	Particulate Matter	Description: PM2.5 data are estimated by EPA from a combination of monitoring data and Community Multi-scale Air Quality (CMAQ) modeling. The downscaling was done by EPA using fusion model that utilize both air quality monitoring data from NAMS/SLAMS (data collected by EPA, state, local and tribal air pollution control agencies at more than 600 hundred monitors nationwide) and numerical output from the Models-3/CMAQ model. This downscaling approach is designed to provide daily, predictive PM2.5 (daily average) and O3 (daily 8-hour maximum) surfaces for a given year, such as 2011, at specified points.
Buyers B-Where	Risk Data	Earthquake	This layer is derived from the USGS. Ground acceleration is measured as a percent of gravity (distance/time). The dataset utilized showed the peak acceleration (% gravity) with 10 % probability of exceedance in 50 years. The lowest is 0-2%, highest is 32+%.
Buyers B-Where	Risk Data	Subsidence	Description: The dataset was created by Texas Geographic society depicting the occurrence of subsidence along the Texas coastline. The base data utilized to create this indicator shows gradation of subsidence from 1 to 10 feet in 5 groupings
Coastal Resilience	Open Space Project	Study Area Watersheds	
Coastal Resilience	Open Space Project	Watershed- high likelihood of flood damages	
Coastal Resilience	Open Space Project	watersheds- high conservation opportunity	
Coastal Resilience	Open Space Project	multi objective watersheds	
Coastal Resilience	Texas	Restoration Projects	

Tool Name	Layer Category	Layer Name	Description
Coastal Resilience	Texas	Habitats - San Antonio Bay Oyster Reef	
Coastal Resilience	Texas	Galveston Bay Oyster Reef (1995)	
Coastal Resilience	Texas	Historic Oyster Reef (1975 NOAA)	
Coastal Resilience	Texas	Oyster Reef (2001 TNC Ecoregional Assessment)	
Coastal Resilience	Texas	Bathymetry	
Coastal Resilience	Texas	Salinity- High Salinity Season (ppt)	
Coastal Resilience	Texas	Salinity- Low Salinity Season (ppt)	
Coastal Resilience	Texas	Coastal Management - Coastal Lease Area	
Coastal Resilience	Texas	Coastal Management- State Submerged Land	
Coastal Resilience	Texas	Coastal Management- Bay Boundary (TCEQ)	
Coastal Resilience	Texas	Coastal Management- Shellfish Harvesting Area	
Coastal Resilience	Texas	Social and Economic - Social Vulnerability Index	
Coastal Resilience	Texas	Social and Economic- Percent Population under age 5	
Coastal Resilience	Texas	Social and Economic- Percent Population age 65 or older	

Tool Name	Layer Category	Layer Name	Description
Coastal Resilience	Texas	Social and Economic - Persons living in Poverty	
Coastal Resilience	Texas	Social and Economic - Percent employed in agriculture, fishing, forestry	
Coastal Resilience	Texas	Social and Economic- Percent employed in Construction	
Coastal Resilience	Galveston Bay	Coastal Salt Marsh Change- 1 meter of SLR by 2100 scenario	
Coastal Resilience	Galveston Bay	Coastal Wetland Change- Existing Habitat	
Coastal Resilience	Galveston Bay	Coastal Wetland Change- SLR Scenario- IPCC A1B max SLR by 2100	
Coastal Resilience	Galveston Bay	Coastal Wetland Change- SLR Scenario- 1 meter of SLR by 2100	
Coastal Resilience	Galveston Bay	Coastal Wetland Change- SLR Scenario- 1.5 meter of SLR by 2100	
Coastal Resilience	Galveston Bay	Coastal Wetland Change- SLR Scenario- 2 meters of SLR by 2100	
Coastal Resilience	Galveston Bay	Estuarine Water Gains - 1 meter of SLR by 2100 Scenario	

Tool Name	Layer Category	Layer Name	Description
Coastal Resilience	Carbon Sequestration and Emission in Coastal Habitats	Carbon Sequestration/Emission from 2004 to 2050 with 0.17m SLR	Sea-Level Rise Scenario- IPCC A1B mean SLR by 2100
Coastal Resilience	Carbon Sequestration and Emission in Coastal Habitats	Carbon Sequestration/Emission from 2050 to 2100 with 0.39m SLR	Sea-Level Rise Scenario- IPCC A1B mean SLR by 2100
Coastal Resilience	Carbon Sequestration and Emission in Coastal Habitats	Carbon Sequestration/Emission from 2004 to 2100 with 0.39m of SLR	Sea-Level Rise Scenario- IPCC A1B mean SLR by 2100
Coastal Resilience	Carbon Sequestration and Emission in Coastal Habitats	Carbon Sequestration/Emission from 2004 to 2050 with 0.41m SLR	Sea-Level Rise Scenario- 1m of SLR by 2100
Coastal Resilience	Carbon Sequestration and Emission in Coastal Habitats	Carbon Sequestration/Emission from 2050 to 2100 with 1m SLR	Sea-Level Rise Scenario- 1m of SLR by 2100
Coastal Resilience	Carbon Sequestration and Emission in	Carbon Sequestration/Emission from 2004 to 2100 with 1m of SLR	Sea-Level Rise Scenario- 1m of SLR by 2100

Tool Name	Layer Category	Layer Name	Description
	Coastal Habitats		
Coastal Resilience	Carbon Sequestration and Emission in Coastal Habitats	Carbon Sequestration/Emission from 2004 to 2050 with 0.82m SLR	Sea-Level Rise Scenario- 2m of SLR by 2100
Coastal Resilience	Carbon Sequestration and Emission in Coastal Habitats	Carbon Sequestration/Emission from 2050 to 2100 with 2m of SLR	Sea-Level Rise Scenario- 2m of SLR by 2100
Coastal Resilience	Carbon Sequestration and Emission in Coastal Habitats	Carbon Sequestration/Emission from 2004 to 2100 with 2m SLR	Sea-Level Rise Scenario- 2m of SLR by 2100
Coastal Resilience	Carbon Storage in Coastal Habitats	Carbon Sequestration/Emission from 2004 to 2050 with 0.17m SLR	Sea-Level Rise Scenario- IPCC A1B mean SLR by 2100
Coastal Resilience	Carbon Storage in Coastal Habitats	Carbon Sequestration/Emission from 2050 to 2100 with 0.39m SLR	Sea-Level Rise Scenario- IPCC A1B mean SLR by 2100
Coastal Resilience	Carbon Storage in Coastal Habitats	Carbon Sequestration/Emission from 2004 to 2100 with 0.39m of SLR	Sea-Level Rise Scenario- IPCC A1B mean SLR by 2100
Coastal Resilience	Carbon Storage in	Carbon Sequestration/Emissio	Sea-Level Rise Scenario- 1m of SLR by 2100

Tool Name	Layer Category	Layer Name	Description
	Coastal Habitats	n from 2004 to 2050 with 0.41m SLR	
Coastal Resilience	Carbon Storage in Coastal Habitats	Carbon Sequestration/Emission from 2050 to 2100 with 1m SLR	Sea-Level Rise Scenario- 1m of SLR by 2100
Coastal Resilience	Carbon Storage in Coastal Habitats	Carbon Sequestration/Emission from 2004 to 2100 with 1m of SLR	Sea-Level Rise Scenario- 1m of SLR by 2100
Coastal Resilience	Carbon Storage in Coastal Habitats	Carbon Sequestration/Emission from 2004 to 2050 with 0.82m SLR	Sea-Level Rise Scenario- 2m of SLR by 2100
Coastal Resilience	Carbon Storage in Coastal Habitats	Carbon Sequestration/Emission from 2050 to 2100 with 2m of SLR	Sea-Level Rise Scenario- 2m of SLR by 2100
Coastal Resilience	Carbon Storage in Coastal Habitats	Carbon Sequestration/Emission from 2004 to 2100 with 2m SLR	Sea-Level Rise Scenario- 2m of SLR by 2100
Coastal Resilience	Community Risk and Resiliency	Community Resilience in 2100	Conservation and Resiliency Analysis - 1 meter of SLR by 2100 scenario
Coastal Resilience	Community Risk and Resiliency	Sea-level rise exposure in 2100	Conservation and Resiliency Analysis - 1 meter of SLR by 2100 scenario
Coastal Resilience	Community Risk and Resiliency	Storm Surge Exposure to Hurricane Ike like event in 2004	Conservation and Resiliency Analysis - 1 meter of SLR by 2100 scenario
Coastal Resilience	Community Risk and Resiliency	Storm surge exposure to Hurricane Ike like event in 2100	Conservation and Resiliency Analysis - 1 meter of SLR by 2100 scenario

Tool Name	Layer Category	Layer Name	Description
Coastal Resilience	Community Risk and Resiliency	Sea-level rise risk in 2100	Conservation and Resiliency Analysis - 1 meter of SLR by 2100 scenario
Coastal Resilience	Community Risk and Resiliency	Storm surge risk to hurricane Ike like event in 2004	Conservation and Resiliency Analysis - 1 meter of SLR by 2100 scenario
Coastal Resilience	Community Risk and Resiliency	Storm surge risk to hurricane Ike like event in 2100	Conservation and Resiliency Analysis - 1 meter of SLR by 2100 scenario
Coastal Resilience	Fishery Habitat Change	Blue Crab	(has info for each of the three SLR scenarios included)
Coastal Resilience	Fishery Habitat Change	Brown Shrimp	(has info for each of the three SLR scenarios included)
Coastal Resilience	Fishery Habitat Change	Red Drum	(has info for each of the three SLR scenarios included)
Coastal Resilience	Fishery Habitat Change	Southern Flounder	(has info for each of the three SLR scenarios included)
Coastal Resilience	Marsh Conservation	Existing Marsh Management 2004	Marsh Conservation and Management- 1m of SLR by 2100 scenario
Coastal Resilience	Marsh Conservation	Conservation Areas in 2004	Marsh Conservation and Management- 1m of SLR by 2100 scenario
Coastal Resilience	Marsh Conservation	Potential Future Marsh Management Areas in 2100	Marsh Conservation and Management- 1m of SLR by 2100 scenario
Coastal Resilience	Marsh Conservation	Existing Marsh Loss in 2100	Marsh Conservation and Management- 1m of SLR by 2100 scenario

Tool Name	Layer Category	Layer Name	Description
Coastal Resilience	Marsh Conservatio n	Future Marsh Advance in 2100	Marsh Conservation and Management- 1m of SLR by 2100 scenario
Coastal Resilience	Marsh Conservatio n	Marsh Priority Areas for Galveston Bay, Texas in 2100	Marsh Conservation and Management- 1m of SLR by 2100 scenario
Coastal Resilience	Marsh Conservatio n	Marsh Priority Areas for Jefferson County, TX in 2100	Marsh Conservation and Management- 1m of SLR by 2100 scenario
Coastal Resilience	Marsh Conservatio n	Marsh Viability by Census Block Group in 2100	Marsh Conservation and Management- 1m of SLR by 2100 scenario
Coastal Resilience		Developed Land	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Undeveloped Land	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Swamp	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Cypress Swamp	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Inland Freshwater Marsh	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Tidal Freshwater Marsh	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Scrub/Shrub	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Regularly Flooded Marsh	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Estuarine Beach	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Tidal Flat	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Ocean Beach	unclear exactly what they mean by future habitat, no description given

Tool Name	Layer Category	Layer Name	Description
Coastal Resilience		Inland Open Water	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Riverine Tidal	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Estuarine Water Gains - 1 meter of SLR by 2100 Scenario	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Open Ocean	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Irregularly Flooded Marsh	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Inland Shore	unclear exactly what they mean by future habitat, no description given
Coastal Resilience		Tidal Swamp	unclear exactly what they mean by future habitat, no description given
Coastal Resilience	Exposure	Residential Assets (USD) under 10m elevation	
Coastal Resilience	Exposure	Percent total Residential Assets under 10m elevation	
Coastal Resilience	exposure	Commercial Assets (USD) under 10m elevation	
Coastal Resilience	exposure	Percent total Commercial Assets under 10m elevation	
Coastal Resilience	exposure	Industrial Assets (USD) percent under 10m elevation	
Coastal Resilience	exposure	Percent total Industrial Assets under 10m elevation	

Tool Name	Layer Category	Layer Name	Description
Coastal Resilience	exposure	Essential Facilities (USD) under 10m elevation	
Coastal Resilience	exposure	Percent total Essential Facilities under 10m elevation	
Coastal Resilience	risk	flood- storm return period 10 year	considers the type of storm based on models of **past** storms; storms with higher return periods are less frequent and more intense
Coastal Resilience	risk	flood- storm return period 50 year	considers the type of storm based on models of **past** storms; storms with higher return periods are less frequent and more intense
Coastal Resilience	risk	flood- storm return period 100 year	considers the type of storm based on models of **past** storms; storms with higher return periods are less frequent and more intense
Coastal Resilience	risk	flood- storm return period 250 year	considers the type of storm based on models of **past** storms; storms with higher return periods are less frequent and more intense
Coastal Resilience	risk	flood- storm return period 500 year	considers the type of storm based on models of **past** storms; storms with higher return periods are less frequent and more intense
Coastal Resilience	risk	economic scenario- low	1% economic growth and 5% demographic growth
Coastal Resilience	risk	economic scenario- high	2% economic growth and 1% demographic growth
Coastal Resilience	solutions	wetland restoration- risk reduction	salt marsh restoration built along shorelines in 0.5sq mi unites in the 6 counties with highest past asset damages and a loss of >25 sq. mi of marsh
Coastal Resilience	solutions	wetland restoration- conservation	salt marsh restoration built along shorelines in 0.5 sq. mi units in the 5 counties that have lost the most marsh in the last 2 decades
Coastal Resilience	solutions	barrier island restoration	(n/a/ for Texas, only for Alabama and Louisiana)

Tool Name	Layer Category	Layer Name	Description
Coastal Resilience	solutions	oyster reef restoration	artificial restoration of oyster reefs; restoration of 25 miles of oyster reefs in each of the 24 counties with suitable habitat
Coastal Resilience	solutions	beach nourishment	(n/a/ for Texas, for Florida only)
Coastal Resilience	solutions	home elevation	homes elevated by 10 feet.
Coastal Resilience	solutions	sandbags	sandbags used around homes for category 3 hurricanes or above; located in all counties around all houses in low-lying areas (below 10m)
Coastal Resilience	solutions	levee	six-foot levees built to protect houses; all houses in the counties in highest risk areas
Coastal Resilience	Risk	Natural Habitats	
Coastal Resilience	Risk	Geomorphology	
Coastal Resilience	Risk	Relief	
Coastal Resilience	Risk	sea-level change	
Coastal Resilience	Risk	wind exposure	
Coastal Resilience	Risk	wave exposure	
Coastal Resilience	Risk	surge potential	
Coastal Resilience	Vulnerabilit y	total population	
Coastal Resilience	Vulnerabilit y	number of people older than 65	
Coastal Resilience	Vulnerabilit y	number of families with income below the poverty line	

Tool Name	Layer Category	Layer Name	Description
Coastal Resilience	Show Me	priority conservation areas where habitats likely reduce risk now	
Coastal Resilience	Show Me	priority restoration areas where new oyster reefs could reduce risk	
Coastal Resilience	Show Me	median residential property values	
Coastal Resilience		Shallow Coastal Flooding	
Coastal Resilience		Sea Level Rise scenarios	ranges from not mapped to 6ft above MHHW
Coastal Resilience		storm surge scenarios	
Coastal Resilience		storm type	
Coastal Resilience		critical facilities	
FloodPlain Map	Floodplain Data	Historic FIRM (2007)	
FloodPlain Map	Floodplain Data	Historic FIRM (2000)	
FloodPlain Map	Floodplain Data	Effective FIRM (1/6/2017)	
FloodPlain Map	Floodplain Data	Effective (TSARP) Catchment	
FloodPlain Map	Floodplain Data	Effective (TSARP) Watersheds	
FloodPlain Map	Reference Data	Block Number	
FloodPlain Map	Reference Data	Parcel	
FloodPlain Map	Reference Data	Property Tax Info	This is a land use map

Tool Name	Layer Category	Layer Name	Description
FloodPlain Map	Reference Data	Street Centerline	
FloodPlain Map	Reference Data	Street Names	
FloodPlain Map	Reference Data	Easement	
FloodPlain Map	Reference Data	Pavement	
FloodPlain Map	Reference Data	Contours	
FloodPlain Map	Reference Data	Keymap Grid	reference grid
FloodPlain Map	Reference Data	Zip Code	
FloodPlain Map	Reference Data	Super Neighborhood	
FloodPlain Map	Reference Data	Subdivision	
FloodPlain Map	Reference Data	Council District	
FloodPlain Map	Reference Data	ETJ	
FloodPlain Map	Reference Data	City Limit	
HCDC Dashboard	Demograph ics	Population	
HCDC Dashboard	Demograph ics	Population Density	Population Density by Sq. Mi
HCDC Dashboard	Demograph ics	% Population under 5 years	Percent of Total Population Age Under 5
HCDC Dashboard	Demograph ics	% population 5-17 years	Percent of Total Population Age 5-17
HCDC Dashboard	Demograph ics	% population 18-34 years	Percent of Total Population Age 18-34

Tool Name	Layer Category	Layer Name	Description
HCDC Dashboard	Demographics	% population 35-64	Percent of Total Population Age 35-64
HCDC Dashboard	Demographics	% population over 65	Percent of Total Population Age 65 and over
HCDC Dashboard	Demographics	% non-Hispanic white population	Percent of Total Population Identifying as Non-Hispanic White
HCDC Dashboard	Demographics	% non-Hispanic African American Population	Percent of Total Population Identifying as Non-Hispanic African American
HCDC Dashboard	Demographics	% non-Hispanic Asian population	Percent of Total Population Identifying as Non-Hispanic Asian
HCDC Dashboard	Demographics	% Hispanic or Latino	Percent of Total Population Identifying as Hispanic
HCDC Dashboard	Demographics	% foreign born population	Percent of Total Foreign-born population, excluding population born at sea
HCDC Dashboard	Demographics	% limited English speaking household	Percent of Total Population Speaking English less than "very well" in Household
HCDC Dashboard	Demographics	% children living with single parents	Percent of Children Living with Single Parents in a Household
HCDC Dashboard	Demographics	% veteran	Percent of Total Population with Civilian Veteran Status
HCDC Dashboard	Demographics	% population with disability	Percent of Total Civilian Noninstitutionalized Population with a disability
HCDC Dashboard	Demographics	racial diversity	Fractionalization Index. It is computed as one minus the Herfindahl index of ethnic group shares. The index ranges between 0 and 1. The index equals to zero if the CTA is composed of one racial ethnic group and is least diverse. The larger the fractionalization index, the more diverse.
HCDC Dashboard	Demographics	opportunity youth	Percent of youth aged 16 to 19 who are not in school and are unemployed
HCDC Dashboard	economic vitality	% household income less than Houston median household income	Percent of Total Households with Income less than Houston Median Household Income of $46,187 (in 2015 inflation adjusted dollars) * $45,000 was used as the threshold

Tool Name	Layer Category	Layer Name	Description
HCDC Dashboard	economic vitality	% owner occupied units	Percent of Total Owner-Occupied Housing Units
HCDC Dashboard	economic vitality	% rented occupied units	Percent of Total Renter Occupied Housing Units
HCDC Dashboard	economic vitality	% children in poverty	Percent of Children Under 18 years old Living Below the Poverty Level in the past 12 Months
HCDC Dashboard	economic vitality	% persons in poverty	Percent of All People Living Below the Poverty Level in the past 12 Months
HCDC Dashboard	economic vitality	% renters paying more than 30% of income on housing cost	Percent of Occupied Units Paying Rent that Exceeds 30% of their Household Income
HCDC Dashboard	economic vitality	number of jobs	Number of reported jobs
HCDC Dashboard	economic vitality	% low-wage earners	Percent of low-wage earners who earned less than $3,333 per month
HCDC Dashboard	education	% population 25+ without high school diploma	Percent of Total Population 25+ without High School Diploma
HCDC Dashboard	education	% population 25+ with high school diploma or GED	Percent of Total Population 25+ with High School Diploma or GED
HCDC Dashboard	education	% population 25+ with some college	Percent of Total Population 25+ with Some College
HCDC Dashboard	education	% population 25+ with bachelor's degree or higher	Percent of Total Population 25+ with Bachelor's Degree or Higher
HCDC Dashboard	public opinion	% positive ratings on job opportunity	Percent of respondents saying "excellent" or "good" to the question "how would you rate job opportunities, in terms of living in the Houston area? Would you say: excellent, good, fair, or poor?"
HCDC Dashboard	public opinion	% positive ratings on ethnic relations	Percent of respondents saying "excellent" or "good" to the question "how would you rate the relations among racial or ethnic groups in the Houston area? Would you say: excellent, good, fair, or poor?"

Tool Name	Layer Category	Layer Name	Description
HCDC Dashboard	public opinion	% fear of being victim of a crime	Percent of respondents saying "very worried" or "somewhat worried" to the question "how worried are you personally that you or a member of your family will become the victim of a crime? Would you say you are: very worried, somewhat worried, not very worried, or not worried at all?"
HCDC Dashboard	public opinion	% optimistic about personal financial future	Percent of respondents saying "better off" or "about the same" to the question "How's your financial situation 3 or 4 years down the road? Do you think you'll be better off, worse off, or about the same as today?"
HCDC Dashboard	public opinion	% positive rating of personal financial situations over the past few years	Percent of respondents saying "better off" or "about the same" to the question "During the last few years, has your financial situation been getting better, getting worse, or has it stayed about the same?"
HCDC Dashboard	public opinion	% attitudes toward national spending on improving the conditions of the poor (too little)	Percent of respondents saying "too little" to the question "As a national program, do you think we're now spending too little, too much, or about the right amount of money on improving the conditions of the poor?"
HCDC Dashboard	public opinion	% attitudes toward national spending on improving and protecting the environment (too little)	Percent of respondents saying "too little" to the question "As a national program, do you think we're now spending too little, too much, or about the right amount on improving and protecting the environment?"
HCDC Dashboard	public opinion	% participation in volunteering activities	Percent of responds saying "yes" to the question "During the past twelve months, did you personally contribute any of your time to a volunteer activity?"
HCDC Dashboard	public opinion	% support for providing a path to legal citizenship	Percent of respondents saying "support" to the question "What about granting illegal immigrants in the U.S. a path to legal citizenship, if they speak English and have no criminal record?"
HCDC Dashboard	public opinion	% protestant	Percent of Protestant
HCDC Dashboard	public opinion	% catholic	Percent of Catholic

Tool Name	Layer Category	Layer Name	Description
HCDC Dashboard	public opinion	% with no religion	Percent of respondents with no religion
HCDC Dashboard	public opinion	% republican	Percent of respondents declared or closer to the Republican Party
HCDC Dashboard	public opinion	% democrat	Percent of respondents declared or closer to the Democratic Party
HCDC Dashboard	public opinion	% optimistic about the country's future prospects	Percent of respondents saying "better times" to the question. When you look ahead to the next few years, do you tend to believe that the country is headed for better times or more difficult times?
HCDC Dashboard	public opinion	% positive rating of quality of living conditions in Houston over the past few years	Percent of respondents who had been in Houston for more than 3 years and said "getting better" or "about the same" to the question "When thinking about the quality of living conditions in the Houston area over the past 3 or 4 years, do you think conditions have been getting better, getting worse, or having stayed the same?"
HCDC Dashboard	public opinion	% self-reported health (fair or poor)	Percent of respondents saying "fair" or "poor" to the question "In general, would you say that your overall state of health these days is excellent, very good, good, fair, or poor?"
HCDC Dashboard	public opinion	% attendance of religious services	In the past thirty days, did you attend a religious service, other than a wedding or funeral?
HCDC Dashboard	health	% population without health insurance	Percent of Total Population without Health Insurance
HCDC Dashboard	mobility	% worker 16 and over using public transportation	Percent of Total Workers Age 16 and over Who Commute using Public Transportation
HCDC Dashboard	mobility	% households without a car	Percent of Total Occupied Housing Units with no Vehicles Available
HCDC Dashboard	land use / housing	estimated number of Harvey flooded homes	Number of Residential / Manufactured Home Impacted by Hurricane Harvey (FEMA modeled)
HCDC Dashboard	land use / housing	% vacant units	Percent of Total Vacant Housing Units
HCDC Dashboard	land use / housing	% single-family units	Percent of Total 1-unit (attached & detached) Housing Units

Tool Name	Layer Category	Layer Name	Description
HCDC Dashboard	land use / housing	% multi-family units	Percent of Total 2-unit or more Housing Units
HCDC Dashboard	land use / housing	number of parks	Number of parks overlap with the CTA
HCDC Dashboard	land use / housing	total acres of parks	Total park area of parks overlaps with the CTA
HCDC Dashboard	crime	crime rate	Reported Criminal Offenses per 1,000 residents
HCDC Dashboard	crime	% violent crime	Percent of Reported Violent Crime Offenses as defined by Crime Part 1 Classification
HCDC Dashboard	crime	% property crime	Percent of Reported Property Crime Offenses as defined by Crime Part 1 Classification
Hurricane Harvey	Landing Page	Rainfall between 8/25/17-8/30/17	
Hurricane Harvey	Before & After	Voss Road @ Memorial	slider showing satellite imagery before and after flooding
Hurricane Harvey	Before & After	Memorial @ Beltway	slider showing satellite imagery before and after flooding
Hurricane Harvey	Before & After	Kingwood	slider showing satellite imagery before and after flooding
Hurricane Harvey	Before & After	Barker Reservoir	slider showing satellite imagery before and after flooding
Hurricane Harvey	Flooded Area	Number of likely flood-impacted homes	Using the community tabulated areas boundary in Harris County, the Kinder Institute estimated the number of likely flood-impacted homes in each neighborhood, using model data from the Federal Emergency Management Agency (FEMA). The map below shows the 15 neighborhoods expected to have experienced the most flooding.
Hurricane Harvey	Flooded Area	Households damaged by last four floods	Point slider maps showing dots where Tropical Storm Allison (June 2001), Memorial Day Floods (May 2015), Tax Day Floods (April 2016), and Hurricane Harvey (August 2017) - modeled are
Metropolitan Houston: Health,	Neighborhood Analysis	Socially Vulnerable Flood Groups	No description given. Appears to be a mix of: poverty rate; social vulnerability index (although unclear which); percent Hispanic population; African American population percent;

Tool Name	Layer Category	Layer Name	Description
Resiliency, and the Natural & Built Environment			housing vacancy rate; owner occupancy rate; impervious cover; tree canopy cover; urban heat risk index; percent of area in flood zone; number of parks within 0.25 miles; total park area within 0.25 miles; respiratory health risk index
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Neighborhood Analysis	HGAC (Houston-Galveston Area Council) Census Block Groups	No description given. Appears to be a mix of: poverty rate; social vulnerability index (although unclear which); percent Hispanic population; African American population percent; housing vacancy rate; owner occupancy rate; impervious cover; tree canopy cover; urban heat risk index; percent of area in flood zone; number of parks within 0.25 miles; total park area within 0.25 miles; respiratory health risk index
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Poverty and Demographics	African-American Population Density	"These layers show the density of African American and Hispanic populations, where they are higher than Houston's average. This information is layered with the percentage of households below poverty to highlight Houston's poor, minority neighborhoods. Why poverty and demographics? Public health research looking into a variety of health risks (urban heat, air pollution, vector-borne diseases, etc.) repeatedly points to disadvantaged neighborhoods dominated by minorities as the ones most at risk of poor health outcomes."
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Poverty and Demographics	Households Below Poverty (%)	"These layers show the density of African American and Hispanic populations, where they are higher than Houston's average. This information is layered with the percentage of households below poverty to highlight Houston's poor, minority neighborhoods. Why poverty and demographics? Public health research looking into a variety of health risks (urban heat, air pollution, vector-borne diseases, etc.) repeatedly points to disadvantaged neighborhoods

Tool Name	Layer Category	Layer Name	Description
			dominated by minorities as the ones most at risk of poor health outcomes."
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Poverty and Demographics	Hispanic Population Density	"These layers show the density of African American and Hispanic populations, where they are higher than Houston's average. This information is layered with the percentage of households below poverty to highlight Houston's poor, minority neighborhoods. Why poverty and demographics? Public health research looking into a variety of health risks (urban heat, air pollution, vector-borne diseases, etc.) repeatedly points to disadvantaged neighborhoods dominated by minorities as the ones most at risk of poor health outcomes."
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Housing Characteristics	Population Density	"Dense areas with high vacancy rates and renters are linked to poor health outcomes."
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Housing Characteristics	Owner-occupied units (%)	"Dense areas with high vacancy rates and renters are linked to poor health outcomes."
Metropolitan Houston: Health, Resiliency,	Housing Characteristics	Housing Vacancy Rate	"Dense areas with high vacancy rates and renters are linked to poor health outcomes."

Tool Name	Layer Category	Layer Name	Description
and the Natural & Built Environmen t			
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environmen t	Urban Heat Risk	Cooling Stations	"This map shows a relative risk index for the degree of vulnerability of areas as calculated by a set of climactic and social factors. The higher the index, the more vulnerable the area. Cooling stations are public facilities, such as libraries, that vulnerable populations can use as a refuge to heat."
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environmen t	Urban Heat Risk	Risk Relative to Extreme Heat	"This map shows a relative risk index for the degree of vulnerability of areas as calculated by a set of climactic and social factors. The higher the index, the more vulnerable the area. Cooling stations are public facilities, such as libraries, that vulnerable populations can use as a refuge to heat."
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environmen t	Toxic Waste Sites	Superfund Sites	No description given.
Metropolitan Houston: Health,	Toxic Waste Sites	Radioactive Waste Disposal Facilities	No description given.

Tool Name	Layer Category	Layer Name	Description
Resiliency, and the Natural & Built Environment			
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Toxic Waste Sites	Municipal Solid Waste	No description given.
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Natural Environment and Public Space	Bikeways	No description given.
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Natural Environment and Public Space	Parks	No description given.
Metropolitan Houston:	Water Quality	Wastewater Outfalls	No description given.

Tool Name	Layer Category	Layer Name	Description
Health, Resiliency, and the Natural & Built Environmen t			
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environmen t	Water Quality	Impaired Streams	No description given.
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environmen t	Water Quality	Water Features	No description given.
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environmen t	Flooding Risk	Watersheds	12-digit hydrologic unit

Tool Name	Layer Category	Layer Name	Description
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Flooding Risk	Floodplains	gives 100-year and 500-year floodplains
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Administrative Boundaries	Houston	
Metropolitan Houston: Health, Resiliency, and the Natural & Built Environment	Administrative Boundaries	Houston-Galveston Area Council	
Metropolitan Houston: Health, Resiliency, and the Natural & Built	Administrative Boundaries	Harris County	

Tool Name	Layer Category	Layer Name	Description
Environmen t			
Texas Coastal Atlas	Administrat ive Boundaries	Zip codes	
Texas Coastal Atlas	Administrat ive Boundaries	Community Boundaries	
Texas Coastal Atlas	Administrat ive Boundaries	Counties	SUMMARY: In order for others to use the information in the Census MAF/TIGER database in a geographic information system (GIS) or for other geographic applications, the Census Bureau releases to the public extracts of the database in the form of TIGER/Line Shapefiles. DESCRITPION: The TIGER/Line Files are shapefiles and related database files (.dbf) that are an extract of selected geographic and cartographic information from the U.S. Census Bureau's Master Address File / Topologically Integrated Geographic Encoding and Referencing (MAF/TIGER) Database (MTDB). The MTDB represents a seamless national file with no overlaps or gaps between parts, however, each TIGER/Line File is designed to stand alone as an independent data set, or they can be combined to cover the entire nation. The primary legal divisions of most States are termed counties. In Louisiana, these divisions are known as parishes. In Alaska, which has no counties, the equivalent entities are the organized boroughs, city and boroughs, and municipalities, and for the unorganized area, census areas. The latter are delineated cooperatively for statistical purposes by the State of Alaska and the Census Bureau. In four States (Maryland, Missouri, Nevada, and Virginia), there are one or more incorporated places that are independent of any county organization and thus constitute primary divisions of their States. These incorporated places are known as independent cities and are treated as equivalent entities for

Tool Name	Layer Category	Layer Name	Description
			purposes of data presentation. The District of Columbia and Guam have no primary divisions, and each area is considered an equivalent entity for purposes of data presentation. The Census Bureau treats the following entities as equivalents of counties for purposes of data presentation: Municipios in Puerto Rico, Districts and Islands in American Samoa, Municipalities in the Commonwealth of the Northern Mariana Islands, and Islands in the U.S. Virgin Islands. The entire area of the United States, Puerto Rico, and the Island Areas is covered by counties or equivalent entities. The 2010 Census boundaries for counties and equivalent entities are as of January 1, 2010, primarily as reported through the Census Bureau's Boundary and Annexation Survey (BAS).
Texas Coastal Atlas	Administrative Boundaries	Texas Senate Boundaries	Texas 2013 State Senate Districts from the US Census. Data was obtained from the US Census website and is based on their January 1, 2013 dataset.
Texas Coastal Atlas	Administrative Boundaries	Texas House Boundaries	Texas 2013 State House Districts from the US Census. Data was obtained from the US Census website and is based on their January 1, 2013 dataset.
Texas Coastal Atlas	Social and Built Environment	County Boundary	SUMMARY: In order for others to use the information in the Census MAF/TIGER database in a geographic information system (GIS) or for other geographic applications, the Census Bureau releases to the public extracts of the database in the form of TIGER/Line Shapefiles. DESCRITPION: The TIGER/Line Files are shapefiles and related database files (.dbf) that are an extract of selected geographic and cartographic information from the U.S. Census Bureau's Master Address File / Topologically Integrated Geographic Encoding and Referencing (MAF/TIGER) Database (MTDB). The MTDB represents a seamless national file with no overlaps or gaps between parts, however, each TIGER/Line File is designed to stand alone as an independent data set, or they can be combined to cover the entire nation. The primary

Tool Name	Layer Category	Layer Name	Description
			legal divisions of most States are termed counties. In Louisiana, these divisions are known as parishes. In Alaska, which has no counties, the equivalent entities are the organized boroughs, city and boroughs, and municipalities, and for the unorganized area, census areas. The latter are delineated cooperatively for statistical purposes by the State of Alaska and the Census Bureau. In four States (Maryland, Missouri, Nevada, and Virginia), there are one or more incorporated places that are independent of any county organization and thus constitute primary divisions of their States. These incorporated places are known as independent cities and are treated as equivalent entities for purposes of data presentation. The District of Columbia and Guam have no primary divisions, and each area is considered an equivalent entity for purposes of data presentation. The Census Bureau treats the following entities as equivalents of counties for purposes of data presentation: Municipios in Puerto Rico, Districts and Islands in American Samoa, Municipalities in the Commonwealth of the Northern Mariana Islands, and Islands in the U.S. Virgin Islands. The entire area of the United States, Puerto Rico, and the Island Areas is covered by counties or equivalent entities. The 2010 Census boundaries for counties and equivalent entities are as of January 1, 2010, primarily as reported through the Census Bureau's Boundary and Annexation Survey (BAS).
Texas Coastal Atlas	Social and Built Environme nt	Critical Structures	
Texas Coastal Atlas	Social and Built Environme nt	Interstate	This data set includes interstate highways in the Texas Coastal Atlas. The original dataset is the statewide NHS dataset, maintained by the Transportation Planning and Programming Division of TxDOT in the Data Analysis, Mapping and Reporting Branch per Federal Highway

Tool Name	Layer Category	Layer Name	Description
			Administration requirements, and to serve as a base layer for TxDOT's cartographic products.
Texas Coastal Atlas	Social and Built Environme nt	Highway	This data set includes major highways in the Texas Coastal Atlas. The original dataset is the statewide NHS dataset, maintained by the Transportation Planning and Programming Division of TxDOT in the Data Analysis, Mapping and Reporting Branch per Federal Highway Administration requirements, and to serve as a base layer for TxDOT's cartographic products.
Texas Coastal Atlas	Social and Built Environme nt	Hurricane Evacuation Route	This data set includes the hurricane evacuation routes in the Texas Coastal Atlas. The original dataset, produced by TxDOT, shows routes to be taken away from the Texas coast during an emergency.
Texas Coastal Atlas	Social and Built Environme nt	Railroad	This data was created by the Transportation Planning and Programming Division of TxDOT in the Data Analysis, Mapping and Reporting Branch using aerial imagery. It is maintained to enable the visualization of railroad inventory attributes, update railroad crossing data, and serve as a base layer for cartographic products
Texas Coastal Atlas	Social and Built Environme nt	Heliports	Locations of heliports in Texas coastal counties. Data generated from latitude/longitude coordinates provided by the Texas Dept. of Transportation Aviation Division. Notes that "data are incomplete and some locations may be spatially inaccurate"
Texas Coastal Atlas	Social and Built Environme nt	Airports	This data set includes airports in the Texas Coastal Atlas. The original dataset was created by Aviation Division and modify by the Transportation Planning and Programming Division of TxDOT in the Data Analysis, Mapping and Reporting Branch for planning and asset inventory purposes, as well as for visualization, county map book, and general mapping. This dataset contains information about airport name, ownership, county, district, and the Federal Aviation Administration (FAA) facility numbers.
Texas Coastal Atlas	Social and Built	Galveston Flood Vulnerability	

Tool Name	Layer Category	Layer Name	Description
	Environment		
Texas Coastal Atlas	Social and Built Environment	Population Density (2010)	
Texas Coastal Atlas	Social and Built Environment	Social Vulnerability: SVI ACS 2009	No description given.
Texas Coastal Atlas	Social and Built Environment	Social Vulnerability: SVI Census 2000	No description given.
Texas Coastal Atlas	Social and Built Environment	Social Vulnerability: SVI Census 1990	No description given.
Texas Coastal Atlas	Social and Built Environment	Social Vulnerability: SVI Census 1980	No description given.
Texas Coastal Atlas	Cultural Characteristics	Historic Places (National Register)	No description given.
Texas Coastal Atlas	Cultural Characteristics	Public Schools	2014-2015 Statewide School Districts for Texas. This information was collected from all 253 county central appraisal districts and from the Texas Education Agency. GIS staff of the Texas Legislative Council created the school district boundaries using the 2010 TIGER/Line Shapefile as base geography and made further corrections to match the school district boundary updates and name changes for the 2014-2015 School Year.

Tool Name	Layer Category	Layer Name	Description
Texas Coastal Atlas	Cultural Characteristics	Place Names	The Texas Gazetteer, developed by the TNRIS in cooperation with the U.S. Board on Geographic Names (BGN), contains information about physical and cultural geographic features in the United States and associated areas, both current and historical, but not including roads and highways. The database also contains geographic names in Antarctica. The database holds the Federally recognized name of each feature and defines the location of the feature by state, county, USGS topographic map, and geographic coordinates. Other feature attributes include names or spellings other than the official name, feature designations, feature class, historical and descriptive information, and for some categories of features the geometric boundaries. The database assigns a unique feature identifier, a random number, that is a key for accessing, integrating, or reconciling Texas Gazetteer data with other data sets. The GNIS is our Nation's official repository of domestic geographic feature names information.
Texas Coastal Atlas	Cultural Characteristics	Populated Places	No description given.
Texas Coastal Atlas	Cultural Characteristics	Property Values 2000 (County)	Data was created by combining the values of property contents and building valuations from the HAZUS-MH inventory database. This data was modified by HRRC for the display in Texas Coastal Planning Atlas… All data was developed at the census block level (for the United States in the s in the fifty states, the District of Columbia, and the territories), and then aggregated at census tract level. ABSG developed this data set from the 2000 version of TIGER/Line files and first quarter of 2002 data from D&B. The datasets were generated through the application of proportions of contents to building value over the total building value for each specific occupancy, and by applying

Tool Name	Layer Category	Layer Name	Description
			RS Means replacement values for typical building floor areas and construction for each specific occupancy.
Texas Coastal Atlas	Cultural Characteristics	Property Values 2000 (Tract)	Data was created by combining the values of property contents and building valuations from the HAZUS-MH inventory database. This data was modified by HRRC for the display in Texas Coastal Planning Atlas… All data was developed at the census block level (for the United States in the s in the fifty states, the District of Columbia, and the territories), and then aggregated at census tract level. ABSG developed this data set from the 2000 version of TIGER/Line files and first quarter of 2002 data from D&B. The datasets were generated through the application of proportions of contents to building value over the total building value for each specific occupancy, and by applying RS Means replacement values for typical building floor areas and construction for each specific occupancy.
Texas Coastal Atlas	Cultural Characteristics	Property Values 2000 (Block Group)	Data was created by combining the values of property contents and building valuations from the HAZUS-MH inventory database. This data was modified by HRRC for the display in Texas Coastal Planning Atlas… All data was developed at the census block level (for the United States in the s in the fifty states, the District of Columbia, and the territories), and then aggregated at census tract level. ABSG developed this data set from the 2000 version of TIGER/Line files and first quarter of 2002 data from D&B. The datasets were generated through the application of proportions of contents to building value over the total building value for each specific occupancy, and by applying RS Means replacement values for typical building floor areas and construction for each specific occupancy.
Texas Coastal Atlas	Cultural Characteristics	Location Quotient	No description given.
Texas Coastal Atlas	Landscape Features	Topography Lines	Contours depicting land topography were constructed for the Texas coastal region. The underlying dataset was the U.

Tool Name	Layer Category	Layer Name	Description
			S. Geological Survey National Elevation Dataset (NED), a raster dataset having a one arc-second grid resolution; it was imported into GMT (Generic Mapping Tools), where digital vector contours were derived. The raster data were smoothed and filtered prior to contouring. Editing of contours was carried out in the Adobe Illustrator software package and exported in an image file. The vector contours were imported into Arc-GIS, where a shapefile containing the contours was created. The National Elevation Dataset (NED) is a new raster product assembled by the U.S. Geological Survey (USGS). Data corrections were made in the NED assembly process to minimize artifacts, permit edge matching, and fill sliver areas of missing data. The NED has a resolution of 1 arc-second (approximately 30 meters) for the conterminous United States, Hawaii, and Puerto Rico and a resolution of 2 arc-seconds for Alaska. National Elevation Dataset data sources have a variety of elevation units, horizontal datums, and map projections. For information on NED, refer to http://erg.usgs.gov/isb/pubs/factsheets/fs14899.html For information on GMT, refer to http://gmt.soest.hawaii.edu/ Note: Support of the Texas Parks and Wildlife Department in preparation of these datasets is gratefully acknowledged.
Texas Coastal Atlas	Landscape Features	Rainfall	This CD-ROM contains vector and polygon coverages of average monthly and annual precipitation for the climatological period 1961-90. Parameter-elevation Regressions on Independent Slopes Model (PRISM) derived raster data is the underlying data set from which the polygons and vectors were created. PRISM is an analytical model that uses point data and a digital elevation model (DEM) to generate gridded estimates of annual, monthly and event-based climatic parameters. Detailed descriptions of the PRISM raster data can be found with the accompanying raster data sets. For further information, the

Tool Name	Layer Category	Layer Name	Description
			online PRISM homepage can be found at <URL:http://www.ocs.orst.edu/prism/prism_new.html>.
Texas Coastal Atlas	Landscape Features	Eco-regions	Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. They are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components. By recognizing the spatial differences in the capacities and potentials of ecosystems, ecoregions stratify the environment by its probable response to disturbance (Bryce and others, 1999). These general-purpose regions are critical for structuring and implementing ecosystem management strategies across federal agencies, state agencies, and nongovernment organizations that are responsible for different types of resources within the same geographical areas (Omernik and others, 2000). The approach used to compile this map is based on the premise that ecological regions are hierarchical and can be identified through the analysis of the spatial patterns and the composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Wiken 1986; Omernik 1987, 1995). These phenomena include geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology. The relative importance of each characteristic varies from one ecological region to another regardless of the hierarchical level. A Roman numeral hierarchical scheme has been adopted for different levels of ecological regions. Level I is the coarsest level, dividing North America into 15 ecological regions. Level II divides the continent into 52 regions (Commission for Environmental Cooperation Working Group 1997). At level III, the continental United States contains 104 ecoregions and the conterminous United States has 84 ecoregions (United States Environmental Protection Agency [USEPA] 2003). Level IV is a further subdivision

Tool Name	Layer Category	Layer Name	Description
			of level III ecoregions. Explanations of the methods used to define the USEPA's ecoregions are given in Omernik (1995), Omernik and others (2000), and Gallant and others (1989). Ecological and biological diversity of Texas is enormous. The state contains barrier islands and coastal lowlands, large river floodplain forests, rolling plains and plateaus, forested hills, deserts, and a variety of aquatic habitats. There are 12 level III ecoregions and 56 level IV ecoregions in Texas and most continue into ecologically similar parts of adjacent states in the U.S. or Mexico. The level III and IV ecoregions on this poster were compiled at a scale of 1:250,000 and depict revisions and subdivisions of earlier level III ecoregions that were originally compiled at a smaller scale (USEPA 2003; Omernik 1987). This poster is part of a collaborative project primarily between USEPA Region VI, USEPA National Health and Environmental Effects Research Laboratory (Corvallis, Oregon), Texas Commission on Environmental Quality (TCEQ), and the United States Department of Agriculture-Natural Resources Conservation Service (NRCS). Collaboration and consultation also occurred with the United States Department of the Interior-Geological Survey (USGS)-Earth Resources Observation Systems Data Center, and with other State of Texas agencies and universities.
Texas Coastal Atlas	Landscape Features	vegetation	Vegetation types of Texas - including cropland as delineated from Landsat MSS satellite imagery and ground survey. The data was accessed from the Texas General Land Office and clipped by HRRC for the display in Texas Coastal Planning Atlas.
Texas Coastal Atlas	Landscape Features	wetlands	Wetland areas mapped by the US Fish and Wildlife Service's National Wetlands Inventory based on 1992-93 photography within the areas of certain USGS 1:24,000 quads in coastal counties of Texas. Digital line graph files containing these quad areas were converted to ARC?INFO

Tool Name	Layer Category	Layer Name	Description
			and appended into a single coverage by Texas General Land Office
Texas Coastal Atlas	Landscape Features	seagrass	These data were derived by traditional aerial photo-interpretation and digitization or ground transects. The data generally represent seagrass distributions in the 1990s except for Matagorda Bay (data from 2001 or 2007) and Galveston Bay (data from 2000 or 2005). No suitable data were available for Baffin Bay.
Texas Coastal Atlas	Landscape Features	hydrological units (8)	This shapefile represents the Hydrologic Unit Codes of Texas (River Basins). The data have been modified by HRRC for display in Texas Coastal Planning Atlas
Texas Coastal Atlas	Landscape Features	hydrological units (10)	This shapefile represents the Hydrologic Unit Codes of Texas (River Basins). The data have been modified by HRRC for display in Texas Coastal Planning Atlas
Texas Coastal Atlas	Landscape Features	hydrological units (12)	This shapefile represents the Hydrologic Unit Codes of Texas (River Basins). The data have been modified by HRRC for display in Texas Coastal Planning Atlas
Texas Coastal Atlas	Landscape Features	Dams	The original data layer portrays major dams of the United States, including Puerto Rico and the U.S. Virgin Islands. The map layer was created by extracting dams 50 feet or more in height, or with a normal storage capacity of 5,000 acre-feet or more, or with a maximum storage capacity of 25,000 acre-feet or more, from the 79,777 dams in the U.S. Army Corps of Engineers National Inventory of Dams. This is a replacement for the April 1994 map layer. The data was modified by HRRC for the display in Texas Coastal Planning Atlas.
Texas Coastal Atlas	Hydrology	Lakes	
Texas Coastal Atlas	Hydrology	Streams	
Texas Coastal Atlas	Green Space	Coastal Preserves	
Texas Coastal Atlas	Green Space	Federal Lands	This data set includes federal lands in the Texas Coastal Atlas. The original map layer consists of federally owned or

Tool Name	Layer Category	Layer Name	Description
			administered lands of the United States, Puerto Rico, and the U.S. Virgin Islands. For the most part, only areas of 320 acres or more are included; some smaller areas deemed to be important or significant are also included. There may be private inholdings within the boundaries of Federal lands in this map layer. Some established Federal lands which are larger than 320 acres are not included in this map layer, because their boundaries were not available from the owning or administering agency.
Texas Coastal Atlas	Green Space	Texas State Parks	Statewide polygon boundary data representing lands owned or managed by Texas State Parks Division of Texas Parks & Wildlife Department (TPWD).
Texas Coastal Atlas	Green Space	Wildlife Refuge	National Wildlife Refuges in Texas owned by the U.S. Fish and Wildlife Service (USFWS). Digitized by Texas General Land Office from hardcopy maps provided by the USFWS Realty Division. Areas with REFUGE_SOURCE values of "USFWS" were provided by the USFWS as AutoCAD drawings. This dataset was modified by HRRC for the display in Texas Coastal Planning Atlas.
Texas Coastal Atlas	Green Space	Audubon Sanctuary	Sanctuaries managed by the National Audubon Society or local Audubon Society chapters in Texas coastal bays.
Texas Coastal Atlas	Green Space	County and City Parks	This data set includes parks at the county, city, and unknown level in the Texas Coastal Atlas. The original dataset is part of the state-wide Texas park boundary dataset. It is one component of the Texas Strategic Mapping Program (StratMap). The StratMap program developed seven digital base map, or layers for Texas. StratMap is managed by the Texas Natural Resources Information System (TNRIS), a division of the Texas Water Development Board (TWDB). All data produced through StratMap are available in the public domain. The StratMap boundary dataset produced files corresponding to multi-county councils of government across Texas as well as a statewide dataset. Each boundary file has five themes including state, county, city, parks, and other (i.e. federal

Tool Name	Layer Category	Layer Name	Description
			lands, landmarks, country clubs). The data sources for each council of government coverage vary but could include digital orthophoto quads (DOQs), USGS digital raster graphics (DRGs), Texas Department of Transportation data, and local data from the council of governments or its component governments. The attribute coding scheme is designed to accommodate several basic cartographic data categories such as feature type, feature name, jurisdiction entity, data source used in feature collection, data source date and revision date(s) if applicable
Texas Coastal Atlas	Gulf Features	Beach Access	This data set includes public beach access points in the Texas Coastal Atlas. The original dataset was created by the Texas General Land Office with coastal towns and counties.
Texas Coastal Atlas	Gulf Features	Marinas	Point locations representing marinas in Texas Coastal Counties; complete but revision needed
Texas Coastal Atlas	Gulf Features	Boat Ramps	This data set includes point locations of boat ramps in the Texas Coastal Atlas. The original dataset was created from points collected by TPWD employees locating public access boat ramps in Texas. This feature class is a component of TPWD 'base' data. 'Base' data includes current, statewide geospatial information intended to provided context for mapping purposes.
Texas Coastal Atlas	Gulf Features	Bathymetry Points	Locations of bathymetric values generated by GLO personnel from coordinate data provided by the National Oceanic and Atmospheric Administration (NOAA). Data are not to be used for navigation and may not accurately depict current bathymetric features.
Texas Coastal Atlas	Gulf Features	Detailed Bathymetry Contours	Bathymetry was constructed from xyz hydrographic survey data from the northwest Gulf of Mexico Continental Shelf and inshore areas. The underlying source data are about 3.5 million soundings from 300 historic hydrographic surveys conducted in 1930-2005 by the U. S. Coast Survey, and available from the NOAA National Geophysical Data Center. Vector contours were derived from the source data

Tool Name	Layer Category	Layer Name	Description
			sets using the GMT (Generic Mapping Tools) software package. Editing of source data reconciled: differences in zero datum; land subsidence with time; a diversity of survey methods and depth units; various other errors/ inaccuracies; and changes in nearshore bathymetry with time. The data were gridded, smoothed, and filtered prior to contouring. Editing of contours was carried out in the Adobe Illustrator software package. The vector contours were imported into Arc-GIS, where a shapefile containing the contours was created. For more information on NOAA Coast Survey hydrographic data sets, refer to: <http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html>Note: Bathymetric contours describing navigation channels, the Intracoastal Waterway, riverbeds, and nearshore areas may in certain areas be incomplete or unreliable, and subject to change due to natural or anthropogenic causes. For reliable and up-to-date information on shipping channels and navigation safety, refer to U. S. Coast Survey charts:<http://ocsdata.ncd.noaa.gov/OnLineViewer/GulfCoastViewerTable.html> For more information on GMT, refer to: <http://gmt.soest.hawaii.edu/> Note: Support of the Texas Parks and Wildlife Department in preparation of these datasets is gratefully acknowledged.
Texas Coastal Atlas	Gulf Features	Tidal Influence Zone	This layer depicts the official TCEQ Stream Segments for the State of Texas as listed in Title 30, Chapter 307 of the Texas Administrative Code (TAC), also known as the Surface Water Quality Standards. These are streams and waterbodies that have been individually defined by the TCEQ and assigned unique identification numbers. Intended to have relatively homogeneous chemical, physical, and hydrological characteristics, a segment provides a basic unit for assigning site-specific standards and for applying water quality management programs of the agency. Both "classified" and "unclassified" segments have

Tool Name	Layer Category	Layer Name	Description
			been included in this layer. Classified segments, also referred to as designated segments, refer to water bodies that are protected by site- specific criteria. The classified segments are listed and described in Appendix A and C of Chapter 307.10. The site-specific uses and criteria are described in Appendix A. Classified waters include most rivers and their major tributaries, major reservoirs, and estuaries. Unclassified waters are those smaller water bodies that do not have site-specific water quality standards assigned to them, but instead are protected by general standards that apply to all surface waters in the state. This layer also identifies which segments and water bodies have been listed as impaired or threatened in the final draft of the Texas 2000 Clean Water Act Section 303(d) List (effective December 19, 2002). 303(d) Lists from other years can be accessed from TCEQ's Texas Water Quality Inventory and 303(d) List page. An impaired segment is a water body which does not meet the standards set for its use, or is expected not to meet its use in the near future. The database file associated with this layer contains fields which indicate which segments are impaired and which pollutants are responsible for the failure of those segments to meet water quality standards. For additional information and data related to Texas Surface Water Quality, please refer to the following TCEQ web site: <http://www.tceq.state.tx.us/nav/data/swq_data.html> This layer is not a complete hydrographic layer of Texas. It is only meant to show the classified and unclassified stream segments for the state. Therefore, many stream segments and water bodies will appear to be detached. To fill in the remaining hydrography, this layer should be used with the certified layer entitled "Major Streams".
Texas Coastal Atlas	Gulf Features	Detailed Shoreline	The digital vector shoreline, NOAA Medium Resolution Digital Vector Shoreline, was imported directly into GMT (Generic Mapping Tools), where it was considered to be

Tool Name	Layer Category	Layer Name	Description
			the zero contour for both bathymetry and land topography. It was exported in a postscript file to Adobe Illustrator, where it was edited, and then imbedded in an image file. The Adobe Illustrator image file was imported into Arc-GIS, and separated from the bathymetry and land topography into a stand-alone shapefile. The NOAA Medium Resolution Digital Vector Shoreline is a high-quality, Geographic Information System-ready, general-use digital vector data set originally created by the Strategic Environmental Assessments (SEA) Division of NOAA's Office of Ocean Resources Conservation and Assessment. The Medium Resolution Digital Vector Shoreline is now managed by the NOS Special Projects Office. It was compiled from hundreds of NOAA coast charts, this product comprises over 75,000 nautical miles of coastline (nearly 2.5 million vertices), representing the entire conterminous United States of America. For information on the NOAA digital vector shoreline, refer to: <http://www.ngdc.gov/mgg/shorelines/noaamrdvs.html> For information on GMT, refer to: <http://gmt.soest.hawaii.edu/> Note: Support of the Texas Parks and Wildlife Department in preparation of these datasets is gratefully acknowledged.
Texas Coastal Atlas	Gulf Features	Ship Channel	Ship Channels and Gulf Intracoastal Waterway maintained by the U.S. Army Corps of Engineers. Digitized by Texas General Land Office from engineering drawings of various scales provided with Corps of Engineers dredging plans.
Texas Coastal Atlas	Gulf Features	Ship Fairway	Boundaries of shipping safety fairways in the Gulf of Mexico offshore of Texas. Digitized by Texas General Land Office in AutoCAD 12 from lat/lon coordinates provided by the U.S. Army Corps of Engineers.
Texas Coastal Atlas	Gulf Features	Coast Guard	Locations of U.S. Coast Guard (USCG) stations in Texas coastal counties. Data digitized by Texas General Land Office based on USCG information.

Tool Name	Layer Category	Layer Name	Description
Texas Coastal Atlas	Gulf Features	Coastal Lease Boundaries	Locations of structures and activities permitted by the GLO within state-owned land and waters. Includes areal features such as dredging areas, parks, mitigation projects, and conservation easements.
Texas Coastal Atlas	Gulf Features	Dredged sites	no description given.
Texas Coastal Atlas	Gulf Features	coastal barriers	This Coastal Barrier Resources System (CBRS) data set, produced by the U.S. Fish and Wildlife Service (Service), contains areas designated as undeveloped coastal barriers in accordance with the Coastal Barrier Resources Act (CBRA), 16 U.S.C. 3501 et seq., as amended. The boundaries used to create the polygons herein were compiled between 4/1/2007 and 12/18/2014 from the official John H. Chafee Coastal Barrier Resources System CBRS maps. The majority of the boundaries were digitized from the official paper maps. In cases where the official map was created through digital methods, the digital boundary was used. As maps are revised this data set will be updated with the new boundaries. This data set contains CBRS polygons that have varying levels of horizontal accuracy depending on the methods used for digitization of the boundaries, and the age and quality of the official CBRS map. The different levels of horizontal accuracy are described below in the horizontal accuracy statement. These digital polygons are only representations of the CBRS boundaries shown on the official CBRS maps and are not to be considered authoritative. The Service is not responsible for any misuse or misinterpretation of this digital data set, including use of the data to determine eligibility for federal financial assistance such as federal flood insurance. CBRS maps are either enacted by Congress or adopted administratively by the Secretary of the Interior (Secretary), and are maintained by the Service. Copies of the official CBRS maps are available for viewing at Service's Headquarters office and are also available to view or download at

Tool Name	Layer Category	Layer Name	Description
			http://www.fws.gov/cbra/maps. CBRS boundaries viewed using the CBRS Mapper or the shapefile are subject to misrepresentations beyond the Service's control, including misalignments of the boundaries with third party base layers and misprojections of spatial data. The official CBRS map is the controlling document and should be consulted for all official determinations. Official determinations are recommended for all properties that are in close proximity (within 150 feet of Tier 1 and 20 feet of Tier 2) of a CBRS boundary. For an official determination of whether or not an area or specific property is located within the CBRS, please follow the procedures found at http://www.fws.gov/cbra/determinations.html. For any questions regarding the CBRS, please contact your local Service field office or email CBRA@fws.gov. Contact information for Service field offices can be found at http://www.fws.gov/offices.
Texas Coastal Atlas	Gulf Features	dispersant	Boundaries of pre-approved area for use of dispersant in oil spill response. Boundaries were created by combining the 10-meter offshore bathymetric contour and the three nautical mile line. The boundary follows whichever line is farthest offshore. Data are not to be used for navigation or for mapping at large scales.
Texas Coastal Atlas	Gulf Features	erosion	The Texas General Land Office rules for management of the beach/dune system (31 TAC sections 15.1-15.10) define "eroding areas" as "a portion of the shoreline which is experiencing a historical erosion rate of greater than two (2) feet per year based on published data of the University of Texas at Austin, Bureau of Economic Geology." An eroding area is considered critical when the rate of erosion exceeds two (2) feet per year and poses a threat to: - public infrastructure or areas of national importance, - public beach access and recreation, - traffic safety, - private property, or - fish or wildlife habitat. Nine critical erosion areas were determined from a ranking system and public

Tool Name	Layer Category	Layer Name	Description
			input. For a detailed description of the erosion areas, ranking criteria, potential solutions and funding sources and much more, see the Texas Coastwide Erosion Response Plan or contact the Texas General Land Office, Coastal Division, 1-800-85-BEACH or (512) 463-5385.
Texas Coastal Atlas	Environme ntally Sensitive Features	Ecosystem Criticality Measure	no description given.
Texas Coastal Atlas	Environme ntally Sensitive Features	Environmental Sensitivity Index	Gulf and bay shoreline of Texas classified by shoreline types coded for environmental sensitivity to oil/hazardous material spills and cleanup operations. Shoreline arc features extracted from U.S. Fish and Wildlife Service 1992 National Wetland Inventory digital data files by Texas General Land Office. Environmental Sensitivity Index code values assigned by coastal geologists with the University of Texas Bureau of Economic Geology coastal geologists representing sensitivity to oil spills and ease of cleanup.
Texas Coastal Atlas	Environme ntally Sensitive Features	Species	Coastal distribution of animals, plants and habitats potentially at risk from oil spill damage or response activities. Mapped as part of a joint project involving GLO, TPWD and other entities.
Texas Coastal Atlas	Environme ntally Sensitive Features	Rookery	Polygonal areas representing colonial waterbird (gulls, terns, wading birds) rookeries in Texas coastal counties and bays. Defined and digitized by Texas General Land office personnel in cooperation with representative of Texas Parks and Wildlife Dept., US Fish and Wildlife Service, and the Texas Colonial Waterbird Society
Texas Coastal Atlas	Environme ntally Sensitive Features	Hardreefs	To address the issues of concern, and in response to the requirements of the Coastal Coordination Act, the Coastal Coordination Council has designated Hard Substrate Reefs as coastal natural resource areas requiring special management under the Coastal Management Program and defined as naturally occurring hard substrate formations, such as rock outcrops or serpulid worm reefs (living or

Tool Name	Layer Category	Layer Name	Description
			dead), in intertidal or subtidal areas that are discrete and contiguous.
Texas Coastal Atlas	Environmentally Sensitive Features	Habitat Priority	This data set includes habitat priority areas in the Texas Coastal Atlas. The original dataset displays Polygonal areas adjacent to coastal bays and the Gulf of Mexico in Texas containing sensitive coastal habitats or species to be protected from oil spill contamination or response activities. Defined and digitized by Texas General Land Office personnel based on consultation with representatives of Texas Parks and Wildlife Dept. and other public agencies, academic institutions, and private groups and citizens. More information about polygons is contained in supplementary hardcopy documents or text files at General Land Office.
Texas Coastal Atlas	Coastal Development	Wetland Permits (1991 - 2014)	
Texas Coastal Atlas	Coastal Development	Resource Management Codes	Resource Management Codes (RMCs) are intended to assist potential users of state-owned submerged lands with their project planning efforts. State and federal resource agencies assign two-letter codes to state-owned tracts in Texas bays and estuaries and Gulf of Mexico waters, representing development guidelines for certain activities within the tracts. The codes are designed to assist in and enhance protection of sensitive natural resources by recommendations for minimizing adverse impacts from mineral exploration and development activities. RMCs are based on the recommendations from the U.S. Fish and Wildlife Service, National Marine Fisheries Service, Texas Parks and Wildlife Department, Texas Historical Commission, and U.S. Army Corps of Engineers (Corps). The RMC data layer is based on the State-owned Submerged Tracts layer--survey information for tracts in submerged state-owned bays, estuaries, and the nearshore Gulf of Mexico.

Tool Name	Layer Category	Layer Name	Description
Texas Coastal Atlas	Coastal Development	Oil and Gas Units	Oil and Gas pooling agreements managed by the Texas General Land Office.
Texas Coastal Atlas	Coastal Development	Oil and Gas Leases	This data set includes the oil and gas leases managed by GLO within the Texas Coastal Atlas.
Texas Coastal Atlas	Coastal Development	Oil and Gas Platforms	This data set contains point locations for oil and gas platforms (structures) located in the Gulf of Mexico federal waters. Note: Platforms are being added or modified continuously; obtaining updates of this database are required to know the true distribution of platform data. Because GIS projection and topology functions can change or generalize coordinates, these GIS files are considered to be approximate and are NOT an OFFICIAL record. Contains the platform locations as of December 2014. Used ArcCatalog to create shape files.
Texas Coastal Atlas	Coastal Development	Off-shore Blocks	This data set contains OCS block outlines (clipped) to the GOM Planning Area Boundary in ArcGIS shape file format for the BOEM Gulf of Mexico Region. OCS blocks are used to define small geographic areas within an Official Protraction Diagram (OPD) for leasing and administrative purposes. These blocks have been clipped along the Submerged Lands Act (SLA) boundary and along the Continental Shelf Boundaries. Further information on the SLA and development of this line from baseline points can be found in OCS Report BOEM 99-0006: Boundary Development on the Outer Continental Shelf. https://www.boem.gov/BOEM-Newsroom/Library/Publications/1999/99-0006-pdf.aspx Contains the block polygons clipped on the fedstate (SLA-boundary) as of March 15, 2013. Used ArcCatalog to create shape files.
Texas Coastal Atlas	Coastal Development	Coastal Lease Boundaries	Locations of structures and activities permitted by the GLO within state-owned land and waters. Includes areal

Tool Name	Layer Category	Layer Name	Description
			features such as dredging areas, parks, mitigation projects, and conservation easements.
Texas Coastal Atlas	Parcels	Harris	Contains parcel polygons and HCAD account number of real property in Harris County.
Texas Coastal Atlas	Parcels	Galveston	Parcel polygon is the delineation of the property boundary
Texas Coastal Atlas	Parcels	Chambers	Parcel polygon is the delineation of the property boundary
Texas Coastal Atlas	Hazards	Hurricane Risk Zones	This layer is derived from the Texas A and M / DEM Risk Area maps. Risk area zones (1 - 5) are identified by hurricane categories. Area 1 corresponds to a Category 1 Hurricane. The original data was modified by HRRC for the display in Texas Coastal Planning Atlas.
Texas Coastal Atlas	Hazards	Hurricane Surge Zones	no description given.
Texas Coastal Atlas	Hazards	Wind Risk	This layer is derived from the Texas A and M / DEM Risk Area maps. Risk area zones (1 - 5) are identified by hurricane categories. Area 1 corresponds to a Category 1 Hurricane. The original data was modified by HRRC for the display in Texas Coastal Planning Atlas.
Texas Coastal Atlas	Hazards	Hurricane Tracks	This Historical North Atlantic and East-Central North Pacific Tropical Cyclone Tracks file contains the 6-hourly (0000, 0600, 1200, 1800 UTC) center locations and intensities for all subtropical depressions and storms, extratropical storms, tropical lows, waves, disturbances, depressions and storms, and all hurricanes, from 1851 through 2006. The original data was modified by HRRC for the display in Texas Coastal Planning Atlas.
Texas Coastal Atlas	Hazards	Hazard Events (1960-2005)	no description given.
Texas Coastal Atlas	Hazards	Fire Risk Zones	The map was developed from mapping done by the Rocky Mountain Fire Sciences Lab for the entire United States. Data for Texas was extracted from a raster grid and converted to shapefile format. The end map was an integration of 3 GIS data layers: housing density, potential

Tool Name	Layer Category	Layer Name	Description
			fire exposure, and extreme weather potential. The original data was modified by HRRC for the display in Texas Coastal Planning Atlas.
Texas Coastal Atlas	Hazards	Earthquake Risk Zones	This layer is derived from the USGS. Ground acceleration is measured as a percent of gravity (distance/time). The map shows peak acceleration (% gravity) with 10 % probability of exceedance in 50 years. The lowest is 0-2%, highest is 32+%. The original data was modified by HRRC for the display in Texas Coastal Planning Atlas.
Texas Coastal Atlas	Flood Damage	Flood Damage 1978-2014	doesn't say but my guess is HAZUS
Texas Coastal Atlas	Flood Damage	Tropical Storm Allison Damage	doesn't say but my guess is HAZUS
Texas Coastal Atlas	Flood Damage	Hurricane Ike Damage	doesn't say but my guess is HAZUS
Texas Coastal Atlas	Risk	Flood Plain	FEMA floodplains for HGAC 13-County area. This feature includes DFIRM data for Harris County, Liberty County, and Galveston Island. All other areas are currently covered by Q3 data. These areas will be updated as the DFIRM data becomes available. In its continuing efforts to perform hazards mitigation and to improve customer service by expanding the availability of flood risk data, the Federal Emergency Management Agency (FEMA) has released the Q3 Flood Data product. Designed to support FEMA's Response and Recovery activities and flood insurance policy marketing initiatives, Q3 Flood Data will be used in floodplain management, hazards analysis, and risk assessment activities. The product contains a subset of information derived from paper Flood Insurance Rate Maps (FIRMs). While the digital data were developed to support floodplain management activities, they do not replace the paper FIRMs.
Texas Coastal Atlas	Risk	Soils	http://www.texascoastalatlas.com/AtlasViewers/bayatlas/viewer.html

Tool Name	Layer Category	Layer Name	Description
Texas Coastal Atlas	Risk	Wind Risk	This layer is derived from the Texas A and M / DEM Risk Area maps. Risk area zones (1 - 5) are identified by hurricane categories. Area 1 corresponds to a Category 1 Hurricane. The original data was modified by HRRC for the display in Texas Coastal Planning Atlas.
Texas Coastal Atlas	Risk	Hurricane Surge Zones	no description given.
Texas Coastal Atlas	Risk	Hurricane Tracks	This Historical North Atlantic and East-Central North Pacific Tropical Cyclone Tracks file contains the 6-hourly (0000, 0600, 1200, 1800 UTC) center locations and intensities for all subtropical depressions and storms, extratropical storms, tropical lows, waves, disturbances, depressions and storms, and all hurricanes, from 1851 through 2006. The original data was modified by HRRC for the display in Texas Coastal Planning Atlas.
Texas Coastal Atlas	Risk	Hazard Events (1960-2005)	no description given.
Texas Coastal Atlas	Flood Vulnerabilit y	Galveston Flood Vulnerability	
Texas Coastal Atlas	Land Cover	Land Cover 2010	Abstract: This is a final classification. It is ready for distribution. This data set is the 2010-era classification of U.S. Texas and Louisiana. This data set utilized 14 full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover	Land Cover 2006	This is a final classification. It is ready for distribution pending review by NOAA-CSC staff. This data set is the pre-hurricane Katrina 2006-era classification of the US Gulf Coast, zones 36 and 37. This data set utilized 18 full or partial Landsat 5 Thematic Mapper scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover	Land Cover 2001	This data set contains the 2001-era or classifications of US Gulf Coast, zones 36 and 37 and can be used to analyze

Tool Name	Layer Category	Layer Name	Description
			change. This imagery was collected as part of the Multi-Resolution Land Characteristics program in a multi-agency effort to provide baseline multi-scale environmental characteristics and to monitor environmental change. This data set utilized 67 full or partial Landsat 5 and 7 Thematic Mapper and Enhanced Thematic Mapper scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover	Land Cover 1996	This data set contains the 2006-era or classifications of US Gulf Coast, zones 36 and 37 and can be used to analyze change. This imagery was collected as part of the Multi-Resolution Land Characteristics program in a multi-agency effort to provide baseline multi-scale environmental characteristics and to monitor environmental change. This data set utilized 67 full or partial Landsat 5 and 7 Thematic Mapper and Enhanced Thematic Mapper scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Unconsolidated Shore to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Scrub/Shrub to: (2001 - 2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Pasture Hay to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were

Tool Name	Layer Category	Layer Name	Description
			analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Palustrine Scrub Wetland to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Palustrine Forested Wetland to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Palustrine Emergent Wetland to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Palustrine Aquatic Bed to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Mixed Forest to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Low Intensity Developed to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data

Tool Name	Layer Category	Layer Name	Description
			set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Medium Intensity Developed to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	High Intensity Developed to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Grassland to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Evergreen Forest to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Estuarine Scrub/Shrub Wetland to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.

Tool Name	Layer Category	Layer Name	Description
Texas Coastal Atlas	Land Cover Change	Estuarine Emergent Wetland to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Estuarine Aquatic Bed to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Developed Open Space to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Deciduous Forest to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Cultivated to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Land Cover Change	Bare Land to: (2001-2010)	Abstract: This is a final classification. It is ready for distribution. This data set is the 2001-2010-era change classification of the Texas and Louisiana region. This data set utilized full or partial Landsat scenes which were

Tool Name	Layer Category	Layer Name	Description
			analyzed according to the Coastal Change Analysis Program (C-CAP) protocol to determine land cover.
Texas Coastal Atlas	Future Land Change	HGAC Land Change 2016	
Texas Coastal Atlas	Future Land Change	HGAC Land Change 2025	
Texas Coastal Atlas	Future Land Change	HGAC Land Change 2035	
Texas Coastal Atlas	Future Land Change	HGAC Land Change 2044	
Texas Coastal Atlas	Future Land Change	HGAC Land Change 2054	
Texas Coastal Atlas	Future Land Change	HGAC Land Change 2063	
Texas Coastal Atlas	Future Land Change	HGAC Land Change 2073	
Texas Coastal Atlas	Future Land Change	HGAC Land Change 2082	
Texas Coastal Atlas	Future Land Change	HGAC Land Change 2092	
Texas Coastal Atlas	Future Land Change	HGAC Land Change 2101	
Texas Coastal Atlas	Existing Inundation	Study Boundary	

Tool Name	Layer Category	Layer Name	Description
Texas Coastal Atlas	Existing Inundation	Proxy: 500 Year Storm Existing Infrastructure	
Texas Coastal Atlas	Existing Inundation	Proxy: 100 Year Proxy Storm Existing Infrastructure	
Texas Coastal Atlas	Existing Inundation	Possible Storm A (900 mb)	
Texas Coastal Atlas	Existing Inundation	Possible Storm B (930 mb)	
Texas Coastal Atlas	Existing Inundation	Possible Storm C (960 mb)	
Texas Coastal Atlas	Existing Inundation	Possible Storm D (975 mb)	
Texas Coastal Atlas	Existing Inundation	Hurricane Ike without Ike-Dike	
Texas Coastal Atlas	Existing Losses	500 yr. Proxy storm: 18ft maximum coastal storm surge	
Texas Coastal Atlas	Existing Losses	100 yr. proxy storm: 15ft maximum coastal storm surge	
Texas Coastal Atlas	Existing Losses	possible storm (a): 15ft maximum coastal storm surge	
Texas Coastal Atlas	Existing Losses	possible storm (b): 14ft maximum coastal storm surge	
Texas Coastal Atlas	Existing Losses	possible storm (c): 9ft maximum coastal storm surge	
Texas Coastal Atlas	Existing Losses	possible storm (d): 7ft maximum coastal storm surge	

Tool Name	Layer Category	Layer Name	Description
Texas Coastal Atlas	Post Ike-Dike Inundation	500 yr. proxy storm: 18ft maximum coastal storm surge	
Texas Coastal Atlas	Post Ike-Dike Inundation	100 yr. proxy storm: 15ft maximum coastal storm surge	
Texas Coastal Atlas	Post Ike-Dike Inundation	possible storm (a): 15ft maximum coastal storm surge	
Texas Coastal Atlas	Post Ike-Dike Inundation	possible storm (b): 14ft maximum coastal storm surge	
Texas Coastal Atlas	Post Ike-Dike Inundation	possible storm (c): 9ft maximum coastal storm surge	
Texas Coastal Atlas	Post Ike-Dike Inundation	possible storm (d): 7ft maximum coastal storm surge	
Texas Coastal Atlas	Post Ike-Dike Inundation	Hurricane Ike Inundation with Ike-Dike	
Texas Coastal Atlas	Post Ike Dike Losses	Study Boundary	
Texas Coastal Atlas	Post Ike Dike Losses	Proxy: 500 Year storm Post Ike Dike	
Texas Coastal Atlas	Post Ike Dike Losses	Proxy: 100-year storm post Ike Dike	
Texas Coastal Atlas	Post Ike Dike Losses	Possible Storm A Post Ike Dike (900 mb)	
Texas Coastal Atlas	Post Ike Dike Losses	Possible Storm B Post Ike Dike (930 mb)	
Texas Coastal Atlas	Post Ike Dike Losses	Possible Storm C Post Ike Dike (960 mb)	
Texas Coastal Atlas	Post Ike Dike Losses	Possible Storm D Post Ike Dike (975 mb)	