Association of State Floodplain Managers, Inc.

Social Vulnerability and Urban Flood Risk

Toward Comprehensive Flood Risk Assessments

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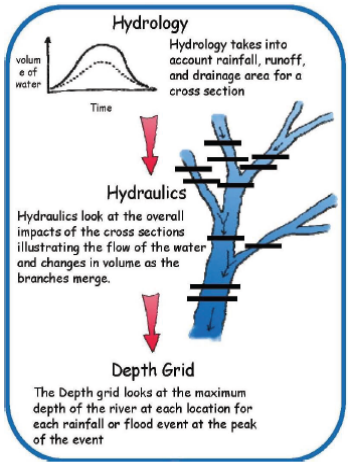
Introduction

Because flooding is one of the most expensive and most common extreme weather events, a single flood can significantly impact middle-income families and push a low-income family below the poverty line or more. Low-income households have fewer resources to prepare for and recover from flood disasters. Impacts to the built and natural environment include expenses related to property damage, clean up and debris removal, water quality and contamination, business and wage interruption while also impacting individual and public health as it relates to morbidity and mortality (Ross, 2013). Low-income is a significant factor, but not the only factor in understanding social vulnerability.

Through funding by the Argosy Foundation, the ASFPM Flood Science Center (FSC) recently completed a project aimed at gaining understanding of the current state of social vulnerability research in relation to urban flood hazards and comprehensive risk assessments, especially in the context and likelihood of increased flooding due to land-use and climate change. The research provided here is meant to give a high-level overview of FSC's socioeconomic and social vulnerability research and linkages with capital improvement planning in a coastal resilience context.

Goals and Objectives

One of the main goals of the Argosy funded research was to understand how socioeconomic conditions and social vulnerability could be included in local flood risk management and planning in urban areas. ASFPM, through its No Adverse Impact initiative, advocates for comprehensive flood risk planning and management, which includes quantifying or understanding the costs related to "direct losses" (i.e. property losses to buildings and their contents) and "indirect losses" (i.e. job losses, business closures, social impacts and public health). The latter includes socioeconomic components and social vulnerability.



Flood Mapping Model

A secondary goal of this research was to move beyond conceptual models to test the integration of actual technical software models in order to understand data flows (i.e. inputs and outputs) between models, describe the process, generate results and identify subsequent issues, gaps and recommendations for next steps. The research proposed to integrate and test the following conceptual models – climate models (future rainfall), flood hazard models (flood mapping and depth), flood damage models (economic loss) and social vulnerability models (human impacts).

The purpose of this report is to provide to NOAA's Office for Coastal Management a more detailed description of the research conducted through the Argosy Foundation funded project titled "Socio-Economic Assessment Scenarios of Natural Infrastructure Strategies for Flood Mitigation." The report will provide insight into why this research was needed, layout the original research proposal including goals and objectives, present key elements of background research, briefly walk through the research methodology, data and result, and finally provide a discussion and recommendations for moving forward. The discussion and recommendations will focus on how this research may be integrated into or used with the "Coastal Resilience through Capital Improvements Planning" project, funded through the NOAA Regional Coastal Resilience Grant Program (Grant # NA16NOS4730010).

This report will also be forthright in describing the challenges and shortfalls realized during the research process. There are always successes and failures, both of which can provide lessons to be shared and provide opportunities to repeat or avoid as appropriate.

Prior Socioeconomic Research – Focus and Gaps

Through prior Great Lakes Restoration Initiative (GLRI) funded projects, ASFPM's Flood Science Center worked with NOAA's Office for Coastal Management (OCM) to provide technical assistance related to community resilience, green infrastructure and flood hazard planning in Toledo OH, Duluth MN and Rochester NY. For each community the work explored the economic and/or community benefits of green infrastructure and provided information on a suite of stormwater management practices that can enable communities to reduce flooding by capturing, storing, or absorbing more water from these precipitation events.

The results of the work in these Great Lakes communities allowed them to: 1) consider and estimate projected changes in future precipitation; 2) assess how increased precipitation will likely impact community flooding; 3) consider a range of available green infrastructure and land use policy options to reduce flooding, and; 4) identify the economic benefits that can be realized by implementing green infrastructure.

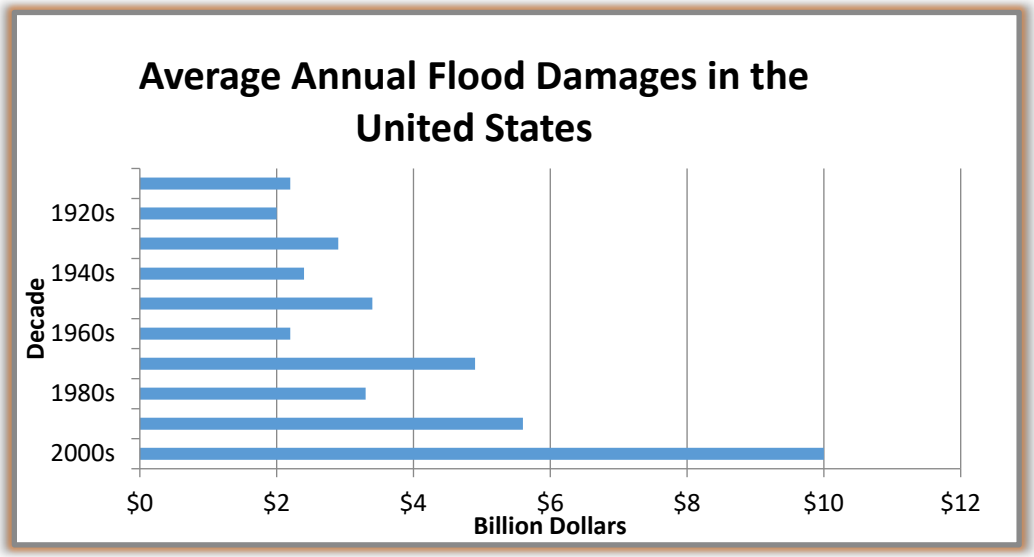
For Toledo and Duluth a full report titled "Economic Assessment of Green Infrastructure Strategies for Climate Change Adaptation: Pilot Studies in the Great Lakes Region" can be found on NOAA's website. For Rochester, a publication titled "City of Rochester & Monroe County – Green Infrastructure Retrofit Manual" is available and provides current best practices for integrating green infrastructure into redevelopment projects.

One of the gaps recognized with the work in Toledo, Duluth and Rochester was our limited understanding of the social vulnerability associated with urban flooding. Thus, one of the main goals as previously described, was to close our knowledge gap that resulted from the limited understanding of social vulnerability related to flooding in an urban environment, especially with the likelihood of increased flooding due to land-use and climate change.

Background

Flooding – Direct and Indirect Costs

Floods are the leading cause of natural disaster losses in the United States, having cost approximately $50 billion in property damage in the 1990s and accounting for more than two-thirds of federally declared natural disasters (National Research Council, 2009). Direct average annual flood damages have jumped from approximately $5.6 billion per year in the 1990s to nearly $10 billion per year in the 2000s, with some years far beyond that, and with these costs increasing more in the current decade because of events like hurricanes Harvey, Irma and Maria.



However, the costs of flooding go far beyond these direct losses. The impacts of a flooding event on individuals occurs in a variety of ways including lost wages, lack of mobility due lost transportation, expenses for evacuating, and significant health and mental health issues before, during and after flooding (Lowe, Ebi, & Forsberg, 2013). For businesses, the effect is quite pronounced as almost “40-60 percent of small businesses never reopen their doors following a disaster” (FEMA, 2015) and another 25 percent fail within one year according to FEMA. Similar statistics from the United States Small Business Administration indicate that over 90 percent of businesses fail within two years after being struck by a disaster. Businesses also experience lost revenues from being closed which, in turn, means lost taxes, jobs and wages throughout the community. Businesses can be affected by employees being unable to get to work due to transportation system failures or their own homes being devastated. Additionally, employee’s mobility and supply lines can be disrupted as a result of closed or limited transportation and utility networks.

Communities overall suffer as well. Loss of income taxes from closed businesses, and diversion of local funds earmarked for other uses, must instead go to flood repair and recovery, physical and mental health, and the use of community resources (staff, equipment, and infrastructure) for response and rescue. Community infrastructure can be severely impacted, including the costliest elements such as water and wastewater treatment facilities. Debris collection and environmental cleanup can be significant. Local taxes (income, property, etc.) are reduced, both in the short and long term.

Flooding – Future Costs and Climate Change

Given the brief period of history in which flood losses have been tracked in the United States, it is fair to say we have not seen the probable maximum flood for most areas. While Hurricanes Katrina and Sandy have caused over $200 billion in losses, either event could have been worse. Trends indicate that the Federal taxpayer is paying a greater share of disaster costs than any time in history. A recent analysis shows that from 1989 to 2004, Federal aid as a percentage of all economic costs from major hurricane events averaged 26%. Since 2005 the Federal aid proportion jumped dramatically to 69% (Cummings, Suher, & Zanjani, 2010).

The United States currently has a population of about 320 million, which is expected to be about 380 million by 2030 and 460 million by 2050. This population explosion combined with our desire to live near water will lead to significantly increased pressure to develop in flood risk areas. Climate change is resulting in sea level rise on the coasts, and more intense storms everywhere. Recent reports from the Government Accountability Office (GAO), and the National Climate Assessment and Development Advisory Committee indicate that there will be significant risk exposure to families, communities, infrastructure, and federal assets due to climate change and sea level rise.

Flood Mapping – Identifying the Hazards

Flooding is a natural phenomenon. Maps will not prevent floods from occurring, but they are an essential tool in avoiding or minimizing the damage to property and loss of life caused by floods, and for communicating flood risk. Without accurate flood maps, local officials face serious difficulties in guiding development away from the most hazardous areas or in ensuring that development is properly built and protected. ***Floodplain mapping is a cost-effective taxpayer investment.*** In 1997, FEMA conducted a benefit-cost analysis of its proposed flood mapping program. Based on that analysis, floodplain mapping showed a benefit to the taxpayer of over $2 for every $1 invested in flood mapping. Later, the State of North Carolina used the same methodology as FEMA and calculated a benefit-cost ratio of 2.3 to 1.

Flood Mapping - Limitations

National standards for mapping flood hazards depict existing flood conditions while rarely depicting future conditions related to land-use or climate change. Not only are these maps used for establishing flood insurance rates for buildings in the floodplain but in order to participate in the National Flood Insurance Program communities are required to use these mapping for siting new development. This failure to implement adaptation measures that reflect future conditions associated with the impact of climate change and urban development that increases impervious areas is problematic. An assessment report on weather extremes issued by the U.S. Climate Change Science Program states, “One of the clearest trends in the U.S. observational record is an increasing frequency and intensity of heavy precipitation events” (Karl, Melillo, & Peterson, 2009). In addition, flooding may increase significantly in areas experiencing urban growth due to increased impervious areas in the watershed.

For urban areas, the limitations related to incomplete flood hazard mapping are more pronounced. Urban flooding as defined in the *Report for the Urban Flooding Awareness Act* (Illinois Department of Natural Resources, 2015) is “The inundation of property in a built environment, particularly in more densely populated areas, caused by rainfall overwhelming the capacity of drainage systems, such as storm sewers. ‘Urban flooding’ does not include flooding in undeveloped or agricultural areas.” From the same report, it states, “Over 90% of urban flooding damage claims from 2007 to 2014 were outside

the mapped floodplain, which is roughly proportional to the developed floodplains within Illinois urban areas."

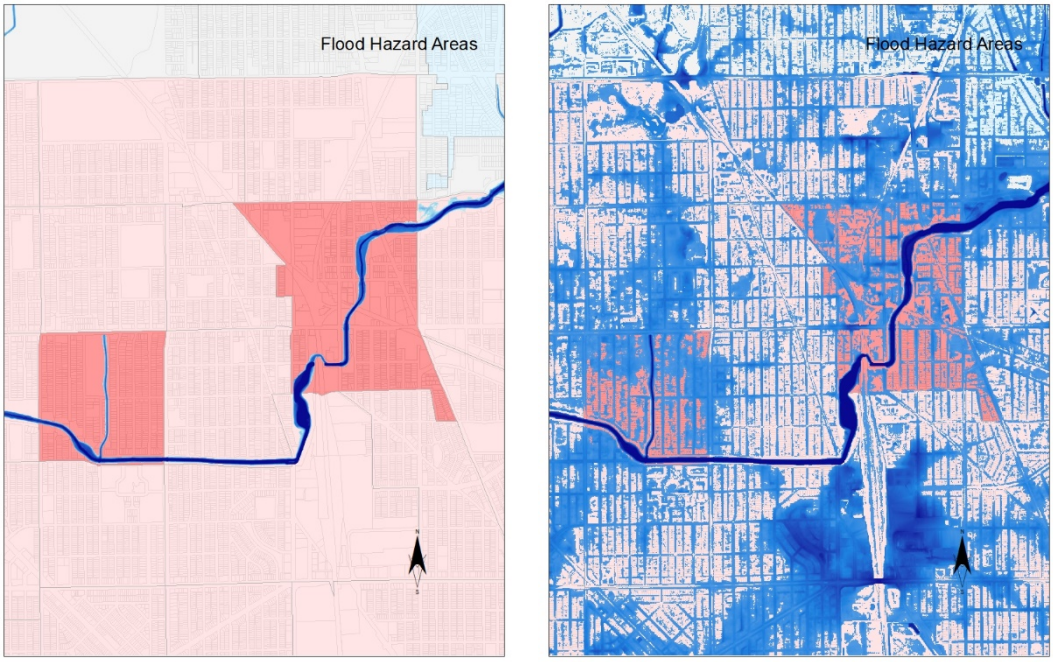


Figure 1 - Riverine-only flood hazard mapping (HEC-RAS 1D) vs. urban flood hazard mapping (HEC-RAS 2D) for 1% Annual Chance (100-yr) flood in Milwaukee, Wisconsin.

Literature and Research Review – Social Vulnerability and Flooding

Social Vulnerability research continues to grow and along with it, a growing list of publications from academia and government agencies. Our literature review, initially revealed an academic body of work largely focused on overall community vulnerability to all natural disasters (vs. specific disasters like flooding) and were generally associated with large scale disasters across broad regions – states or countries (vs. smaller communities or watersheds). Further review helped identify publications that included more specific population characteristics associated with vulnerability and flood disaster in particular. This early literature review process helped us understand the broader issues and potential flaws of using a general social vulnerability index that encompassed all natural disaster for large areas to analyze flood vulnerability in more localized scenarios. Following is a brief literature review focusing on social vulnerability and flooding.

Social vulnerability describes those characteristics of the population that lead to differential impacts of natural hazards (Cutter, 2010). Cutter further states that "social vulnerability helps to explain why some communities experience a hazard differently, even though they are affected by the same magnitude or severity of flooding or storm surge inundation". Dr. Susan Cutter et al. (Cutter, Boruff, & Shirley, 2003) originally developed the Social Vulnerability Index (SoVI) to provide general community vulnerability to all disasters. SoVI (HVRI, 2014) and other indices, such as the U.S. Centers for Disease Control's Social Vulnerability Index (CDC, 2016), are publically available.

Caution and understanding is required when using an existing index like SoVI, as it may not be appropriate for use to analyze flood vulnerability at the community scale, such as small watersheds in Milwaukee County. In fact, this data may have the opposite result than intended by masking the

problem. This is due to the multi-variate statistical methods used, which will rank the population characteristics that are included in the analysis making the results dependent on the geographic area included.

Moving beyond vulnerability to all natural disasters to focus more specifically on flooding and considering smaller regions, several notable articles provide additional direction and integration with community planning exercises. The first article titled *"Evaluation of Networks of Plans and Vulnerability to Hazards and Climate Change - A Resilience Scorecard"* (Berke, et al., 2015) reviews "the potential role of different types of local plans (e.g., the comprehensive plan as well as plans for hazard mitigation, infrastructure and parks and recreation) in reducing the destructive effects of hazards". Their research goes on to develop a resilience scorecard that "evaluates both physical and social vulnerability to flooding and sea-level rise hazards" and is actually tested in the city of Washington, North Carolina. Berke et al., go on to describe specific population attributes and statistical methods and issues that are informative for this research, especially the results from the pilot community.

Berke et al. measure social vulnerability by using variables from the Social Vulnerability Index (SVI) for Disaster Management, an index developed by the U.S. Centers for Disease Control (CDC) using data from the 2010 U.S. Census at the census tract and block group levels. They rank 12 social indicators to develop their SVI and utilize LandScan, a national population distribution model developed at Oak Ridge National Laboratory, to weight the indicators using population density, providing a more accurate representation for the pilot community.

In February 2017, Cutter et al. made public an article titled "Integrating social vulnerability into federal flood risk management planning" (Cutter & Emrich, 2013). Originally published in 2013, the paper proposes a methodology for incorporating the Social Vulnerability Index (SoVI), into U.S. Army Corps of Engineers civil works planning, aimed at understanding how to incorporate social characteristics into the measures currently utilized in flood control project evaluation and consideration. According to the authors, the "Results indicate that while it is possible to create simplified, yet robust, versions of SoVI for individual places, such 'lite' metrics tend to fall short in areas of scalability and transferability in relation to the original SoVI Formulation". The article is valuable in helping explore ways to integrate social vulnerability into flood risk management while also confirming the limitations one-size-fits-all approaches to vulnerability indices.

Engagement with vulnerable populations, the people who will bear the most risk, has been increasing within the Corps of Engineers as part of their water resources studies and planning process. In 2016, COE released a primer titled *"Identification and Engagement of Socially Vulnerable Populations in the USACE Decision Making Process"* (Baker, Cohen, Coulson, Durden, & Rossman, 2016). In the forward, Hal Cardwell with USACE writes, "The primer presents the basics on how to identify and engage socially vulnerable populations during USACE water resources studies and processes and gives a rationale for the need to focus on these populations at risk." The primer provides key characteristics of vulnerable populations, supplies questions for use during public engagement and lays out how social vulnerability will be included in the Corps of Engineers 6-step planning process. For example, in Step 1, the study team can gain a better understanding of the potential social impacts by using Census information and local demographic reports to identify socioeconomic characteristics of the study area population." (Baker, Cohen, Coulson, Durden, & Rossman, 2016, p. 7) The primer continues describing how the project team would refine and add more data to the community's social vulnerability profile including future conditions and provides other resources available, like SoVI.

The prior publications described here have focused on the population characteristics such as income, age and education, but other potential factors related to public health, such as physical and mental illness, like post-traumatic stress (PTS), might help build a more complete profile of flood vulnerability, especially for long-term recovery (Lowe, Ebi, & Forsberg, 2013). For example, individuals that lack the resources to insure or repair properties and problems with the insurer have increased risk factors related to long-term PTS. Another potential attribute to consider adding to a social vulnerability index would be the percent of population with/without flood insurance.

Moving toward a more specific integration of social vulnerability with flood risk, Dr. Jonathan Remo et al. published their paper titled "*Assessing Illinois's flood vulnerability using Hazus-MH*" (Remo, Pinter, & Mahgoub, 2016). This paper provided a peer-reviewed process for developing a Flood Vulnerability Index, expressed mathematically as:

Flood Vulnerability = Exposure + Susceptibility + Social Vulnerability

Exposure is defined as the estimated value of the buildings that are present in the areas potentially threatened by flooding. *Susceptibility* is defined as the probability of the human population affected and associated building stock damaged within the floodplain during a flood of a particular magnitude. The authors developed their "flood vulnerability index to help planners screen the relative flood vulnerability across the entire state of Illinois at the county, jurisdictional, and census block scales". They utilized FEMA's Hazus-MH multi-hazard loss estimate software to provide flood damage estimates along with supplying the underlying US Census population attributes used in the social vulnerability analysis.

There is a growing body of articles, publications and research related to socioeconomics and social vulnerability and flooding. As written earlier, household income is a key population characteristic that keeps rising to the top as one of the major factors associated with post-flood recovery. While other socioeconomic and social vulnerability factors play a key role in response and short-term recovery such as age or race, it may be more efficient from a flood risk and long-term recovery stand-point to focus on income as a primary driver that further affords the ability to purchase flood insurance, access community health services or avoid unsustainable debt.

Process and Methods

The Flood Vulnerability Index (FVI) approach utilized by Dr. Remo et al., described in the previous section, was chosen as the approach for our analysis. The FVI approach incorporates building damage loss estimates into the index, which adds an economic component to the overall FVI. Additionally, the FVI approach uses nationally available data provided within FEMA's Hazus-MH software and data package, which is seen as a benefit since Hazus-MH software and data is publically and freely available, except that Hazus is an extension that needs to be run with Esri's ArcGIS software. Our familiarly with Hazus and its underlying data and software were key in using this approach. The Principal Component Analysis required for the FVI approach would be undertaken by an external consultant since we did not have that expertise in-house.

Study Area



Milwaukee County, Wisconsin was selected as the study area. The county includes 10 cities and 9 villages that range from smaller, more affluent areas like River Hills to larger, more diverse communities like the City of Milwaukee. As of the 2010 census, there were 947,735 people, 383,591 households, and 221,019 families residing in the county. The racial makeup of the county was 60.6% White, 26.8% Black or African American, 0.7% Native American, 3.4% Asian, 0.003% Pacific Islander, 5.4% from other races, and 3.0% from two or more races. 13.3% of the population were Hispanic or Latino of any race. Based on the American Community Survey (ACS) 2016 1- and 5-year estimates, Per capita income is $27,524, which is 90% of Wisconsin and U.S. average. Median household income is $47,607, which is 80% of Wisconsin and U.S. average. 19.6% of people are below the poverty line, which is 1.5 times the rate in Wisconsin (11.8%) and 1.4 times the rate in the U.S. (14.1%) (U.S. Census Bureau, 2016).

It is the most populous county in Wisconsin and the 45th most populous in the United States. Its county seat is Milwaukee, which is also the most populous city in the state. According to the U.S. Census Bureau, the county has a total area of 1,190 square miles and is the third-smallest county in Wisconsin by land area. It is watered by the Milwaukee, Menomonee, Kinnickinnic, and Root Rivers (Wikipedia).

Modeling Overview

The modeling process is made up of the following 4 conceptual models:

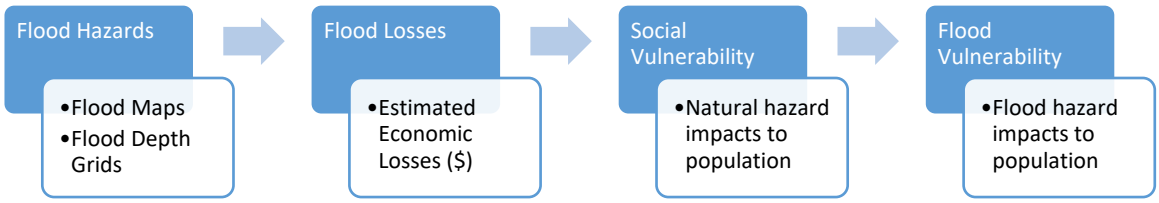


Figure 2 - Flood Vulnerability Conceptual Model Process

Modeling Scenarios

Using the conceptual modeling process above (Figure 2), the following modeling scenarios were completed across different combinations of the following datasets in order to construct the vulnerability indices:

- **Flood Hazard Data** – flood boundaries and depth grids
  - 100-yr annual chance flood – HEC RAS 1D engineering model
  - 100-yr annual chance flood – HEC 2D engineering model
  - 2010 flood event – HEC 2D engineering model
- **Demographic Data** – population characteristics
  - Hazus-based 2010 attributes
  - APL-based* 2010 attributes (full)**
  - APL-based* 2010 attributes (reduced)**
  - APL-based* 2030 attributes (reduced)**

** The University of Wisconsin – Madison, Applied Population Lab (APL) ran the Principal Component Analysis (PCA) for the project. After running the initial PCA based on Hazus demographic attributes, APL recommended using different demographic attributes for the PCA.*

***For the "reduced" verse "full" designation, the full index includes income measures, like median household (HH) income that cannot be forecasted properly. Anytime there's a median value it becomes problematic to march that value forward. The reduced index only included those values that can appropriately be forecasted into the future, hence requiring a reduction in the number of values possible to construct the index.*

The following sections, describe each of the four steps of the conceptual model process, provide basic process descriptions, data inputs and outputs, and finally any caveats or issues related to that model.

Flood Hazards – Hydrologic & Hydraulic Modeling

Description

Hydrologic and Hydraulic (H&H) models work together to convey how water moves below the earth's surface, on the earth's surface, and through engineered conveyance mechanisms. Hydrology refers to the flow of water through and on natural terrain. Hydraulics refers to the flow of water through natural or engineered channels and structures. There is overlap between H&H, which is why H&H are often modeled in tandem. There are many different models that can be used to assess H&H (e.g., Hydrologic Engineering Center Hydrologic Modeling System [HEC-HMS], HEC-RAS 1D, HEC-RAS 2D, MIKE11, WinTR-55, etc.).

Flood hazard maps and flood depth grids were generated for the 1% annual chance flood (100-yr flood) and the 0.2% annual chance flood (500-yr flood) using HEC HMS (hydrology) and HEC RAS (hydraulic) modeling software.

All major watersheds in Milwaukee County were included except the Root River watershed in the southwest part of the county. The map below (Map 1) provides a county-wide overview of the 100-yr flood depth grids, major watershed boundaries along with the major cities and villages.

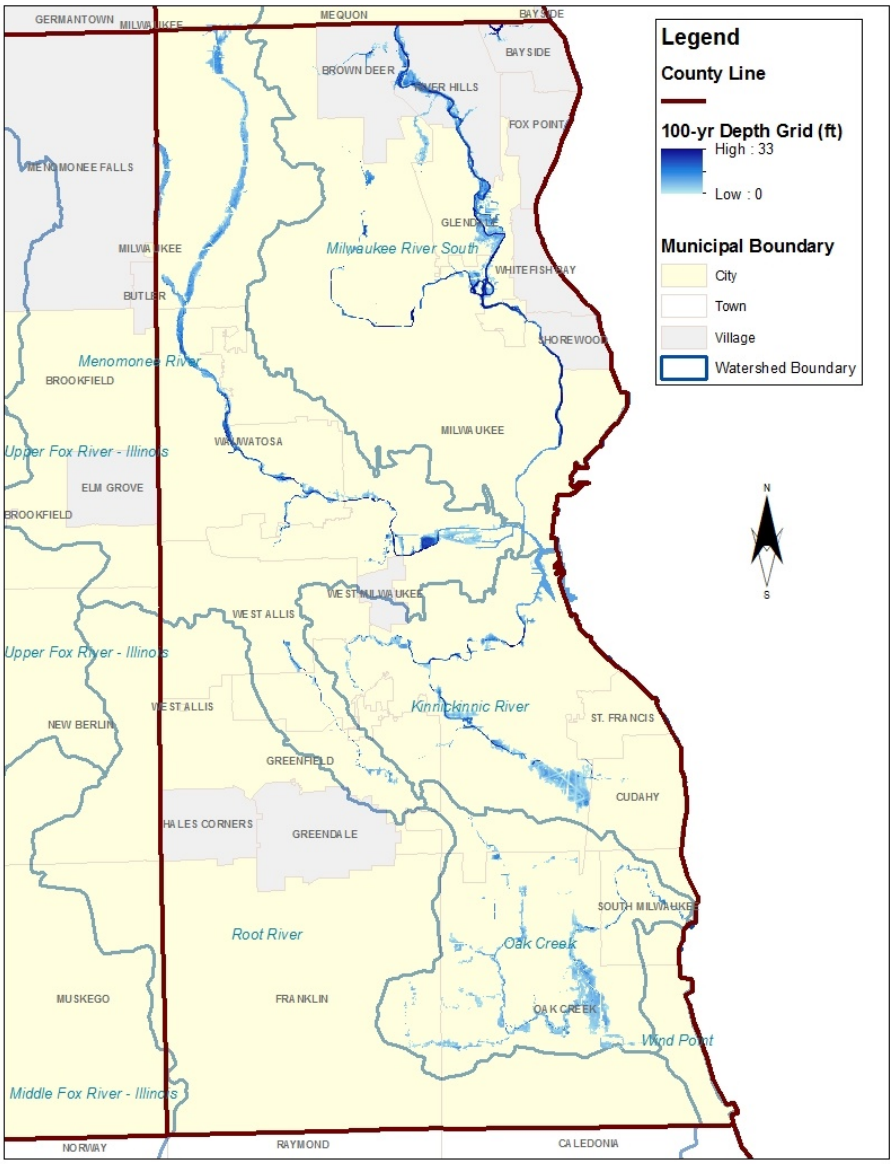
The HEC-RAS 2D engineering model was run for the 1% annual chance flood for the same rivers/watersheds and for the 2010 flood event. The 2010 flood in Milwaukee occurred on July 22 with rainfall amounts between 5 to 9 inches in a 24-hour period.

Limitations, Issues and Recommendations

Future precipitation or rainfall as a result of climate change was not included in the flood hazard modeling at this time for several reasons. First, the initial H&H modeling used was limited to riverine-based flooding and did not take into account stormwater system or urban flooding, which is a significant contributor of flood damages in the study area, especially for events like the 2010 flooding. Thus the flood models do not reflect the entirety of flooding and even with future rainfall forecasts, the flood hazard models would not provide a comprehensive view of the future social or economic risks. In most cases the 500-yr flood event, which was modeled, can serve as a proxy for future riverine flood conditions.

Urban flooding would be more accurately reflected within a 2D modeling scheme in most cases as it would account for lateral in/outflows from the channel. Also, in most cases the flood depths will vary away from the main stem which cannot be reflected in a 1D model (i.e. HEC-RAS used in this study). See Figure 1 above comparing coverage in an urban area between 1D flood depth grids and 2D flood depth grids.

For the main goals of this research, use of 1D flood hazard models allowed for the successful integration and development of the Flood Vulnerability Index. The 2D depth grids which were generated were not successfully imported into Hazus and used to develop a comparable Flood Vulnerability Index for Milwaukee County.



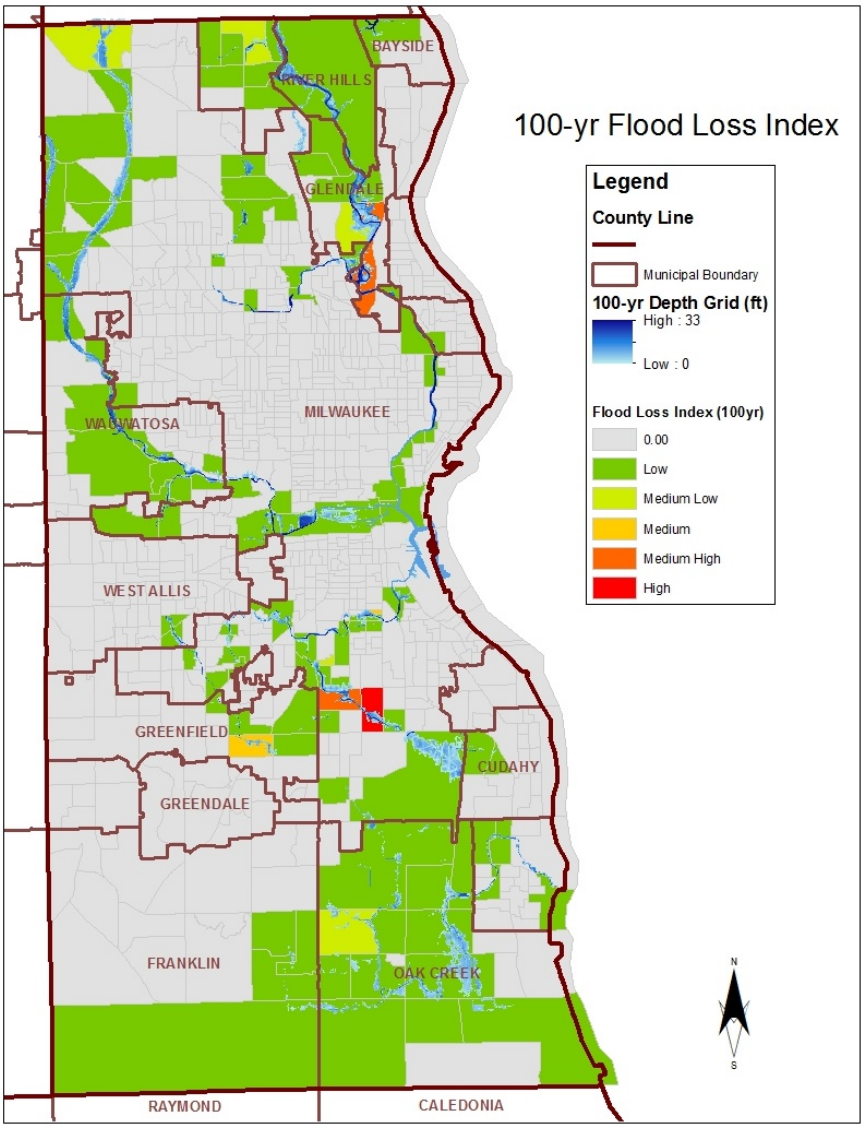
Map 1 - HEC HMS & HEC RAS Flood Hazard Maps and Depth Grids

Flood Losses – Hazus-MH Modeling

Description

FEMA's Hazus-MH Version 3.2 software was used to run a Level 2 analysis for Milwaukee County by utilizing 1) the General Building Stock inventory available within Hazus at the census block and block group level and 2) importing flood depth grids generated by the HEC-RAS 1D models previously described.

Flood loss estimates were generated for the 1% annual chance flood (100-yr flood) and the 0.2% annual chance flood (500-yr flood). Flood loss estimates were generated for every census block that intersects with the flood hazard depth grids for the appropriate flood event (i.e. the 100-yr or 500-yr). The flood loss estimates were normalized using a standard indexing method to generate a Flood Loss Index – below (Map 2) is Flood Loss Index for the 100-yr flood in Milwaukee County. Areas with high estimated flood losses are shown in red and low estimated flood losses shown in green.



Map 2 - Hazus-MH Flood Loss Index

Hazus flood damage estimates were run based on all occupancy types (residential, commercial, industrial, retail, etc.) and for residential only occupancy types. When considering where vulnerable or low-income populations actually live, it makes sense to consider flood damage estimates for only residential structures.

Hazus flood losses for this project are for building-related losses only. Building-related losses include building damages, building inventory damages, and commercial inventory damages. These building-related flood loss estimates do not include damage to infrastructure (i.e., roads, bridges, and utilities),

agricultural losses, or indirect economic losses (i.e., loss of business or industrial production). In addition, these flood loss and exposure estimates are based on full replacement cost (i.e., the estimated cost to replace the damaged portion of a building). Hence, the resulting flood loss estimates may be significantly higher than insured losses or loss estimates calculated using property assessment data. Insured losses and loss estimates using assessor data commonly use fair market values, which include depreciation of building values after initial construction.

Limitations, Issues and Recommendations

As part of a Level 2 analysis, Hazus does allow building/structure points to be imported as User-Defined Facilities (UDF) and used for flood loss estimates. The UDF analysis provides estimated flood damage for each building point (based on parcel centroids) as the main output. Parcel-level data linked with the community's tax assessor database would be the preferred level of detail for conducting flood loss calculations. However, two main issues existed that prohibited use of parcel data to generate building points or UDF for all of Milwaukee County. First, the county is made up of multiple jurisdictions, which required contacting each community to acquire their assessor data, requesting the data and then formatting the data for use within Hazus. The parcel level data with links to the actual assessor attributes was not available for every community. Second, there is considerable cleanup and formatting needed and a large number of assumptions that need to be applied, since most assessor data is incomplete.

We did acquire the parcel and assessor data for the City of Milwaukee, which covers a majority of the land area in Milwaukee County, and started processing this data since it was the largest dataset within the county. To format and improve the flood loss results, we started moving the parcel centroid to the actual location of the building within the parcel for areas within the 500-yr floodplain. We also started adding attribute values required by Hazus – listed below are the required attributes with highest importance for determining flood loss estimates utilizing Hazus' User-Defined Facilities (UDFs). Each of these attributes must be populated with a valid value in order to run the analysis.

- Occupancy Type – residential, commercial, retail
- Structure Cost – assessed, market, replacement
- First Floor Elevation – height of first floor above the ground
- Square Footage of the building footprint – area of first floor
- Foundation Type – basement, slab-on-grade, crawlspace
- Stories – 1, 2 or more
- Year Built

If values don't exist for these attributes, there are often assumptions that can be made, for example the first floor elevation for most homes with a basement would be 1-foot above the ground. But the city's assessor data was incomplete or contained values that were not usable. For example, the assessor data had total square footage of the building, but there was no way to determine how many stories were in the building in order to determine the square footage of the main floor. Additionally, assumptions for first floor elevation values were difficult to determine due to incomplete values for the foundation type. Due to the issues with developing a reasonably accurate UDF database for all of Milwaukee County it was decided that the Hazus General Building Stock inventory would be used to generate flood loss estimates.

It should be noted that Hazus-estimated damages included in this research are likely to be lower than the damages that the community might currently experience. Hazus estimates damages based on flood depth grids associated with modeled riverine flood inundation and does not account for water in the basement as a result of urban flooding, stormwater backup, flash flooding or antecedent conditions (saturated ground). Flood losses would be improved by using 2D models, which would allow better planning opportunities, but damage estimates would still only be estimates.

Another minor challenge avoided by using the Hazus GBS inventory relates to the mismatch between geographic scales that would have occurred between the parcel level data for flood loss estimates and the census block group data that's used for running a social vulnerability index. Some population characteristics included in the U.S. Census data is only available at the block group level. Block groups are statistical divisions of census tracts, are generally defined to contain between 600 and 3,000 people, and consists of clusters of blocks (highest or most detailed level) within the same census tract. The parcel level data would have needed to be aggregated to the block group level. This would be very possible and would have resulted in a more accurate flood loss estimate, except for the previous reasons provided as they relate to incomplete assessor data values.

Social Vulnerability – Principal Component Analysis (PCA)

Description

Overall, we follow the approach used by Dr. Jonathan Remo et al. (Remo, Pinter, & Mahgoub, 2016) in their paper titled "Assessing Illinois's flood vulnerability using Hazus-MH". This paper provided a peer-reviewed process for developing a Flood Vulnerability Index, which they express mathematically as:

Flood Vulnerability = Exposure + Susceptibility + Social Vulnerability

In this definition, exposure is defined as the estimated value of the buildings that are present in the areas potentially threatened by flooding. Susceptibility is defined as the probability of the human population affected and associated building stock damaged within the floodplain during a flood of a particular magnitude (Remo, Pinter, & Mahgoub, 2016). They utilized Hazus to provide flood damage estimates along with supplying the underlying US Census population attributes used in the social vulnerability analysis.

Remo et al. developed a Social Vulnerability Index (SVI) "using a mainly inductive modeling approach, employing socioeconomic data derived from the 2000 US Census and included within Hazus-MH (v 2.1) …., they identified 27 vulnerability-relevant demographic parameters available within Hazus-MH from which to develop a SVI". See "Table 1" below from Remo et al., 2015, p.275)

Table 1 The 27 socioeconomic vulnerability-relevant parameters from Hazus-MH's demographic database which were evaluated for use in the formulation of the SVI

Normalized parameter description	Consolidated parameters
Percentage of male population <16 years of age	Percent of population under 16 and greater than 65 years of age
Percentage of female population <16 years of age	
Percentage of male population >65 years of age	
Percentage of female population >65 years of age older	
Percentage of the population white	Percent white
Percentage of the population black	
Percentage of the population Asian	Percent nonwhite
Percentage of the population Hispanic	
Percentage of the population Pacific Islander	
Percentage of the population Native American	
Percentage of the population other race	
Percentage of the households with income of $0–$10K	Percentage of households earning $0–$20K
Percentage of the households with income of $10–$20K	
Percentage of the households with income of $20–$30K	Percentage of households earning $20–$40K
Percentage of the households with income of $30–$40K	
Percentage of the households with income of $40–$50K	Percentage of households earning $40–$60K
Percentage of the households with income of $50–$60K	
Percentage of the households with income of $60–$75K	Percentage of households earning $60–$100K
Percentage of the households with income of $75–$100K	
Percentage of the households with income over $100K	Percentage of households earning >$100K
Percentage of owner-occupied units	
Percentage of renter-occupied units	
Percentage of vacant homes	
Percentage of the population working in commercial industry	
Percentage of the population working in industrial industry	
Percentage of homes owned	
Percentage of vacant houses	
Percentage of homes rented	

The age, race, and occupation parameter classes were normalized to total population within a census block (number of persons/total number of persons in a census block), and the income and housing status parameters were normalized to the total number of households within an census block (number of households/total number of households within a census block)

Dr. Bill Buckingham, from the Applied Population Lab (APL) at the University of Wisconsin – Madison was brought onto our project to create the social vulnerability index for Milwaukee County. While working with Dr. Buckingham there were several discussions about the modifying the demographic variables that Dr. Remo used for their social vulnerability assessment and additionally to look at population projections for a future point in time. Following this discussion, it was decided that we would generate four different Social Vulnerability Indexes (SVI) as follows:

1. **Hazus-MH demographic parameters** – use the same demographic parameters as Remo et al., (2015) to develop the SVI. The resulting Hazus-based SVI uses all the same demographic parameters and analysis steps developed by Dr. Remo.

2. **APL demographic parameters (full*)** – use new demographic parameters (described below) with revised Principal Component Analysis (PCA). Final index is the same as Dr. Remo.
3. **APL demographic parameters (reduced*)** – use new demographic parameters (described below) with revised Principal Component Analysis (PCA). Final index is the same as Dr. Remo.
4. **APL demographic parameters 2030 (reduced*)** – use new "projected" demographic parameters for the year 2030 using a revised PCA. Final index is the same as Dr. Remo.

> **For the "reduced" verse "full" designation, the full index includes income measures, like median household (HH) income that cannot be forecasted properly. Anytime we have a median value it becomes problematic to march that value forward. The reduced index only included those values that can appropriately forecasted ahead, hence requiring a reduction in the number of values possible to construct the index.*

New demographic parameters

The new APL-based indices are created using principal components analysis (PCA) technique. For each index a suite of factors is created from the US Census American Community Survey 2006-2010 Estimates at the Census Block Group geographic level. In the R statistical environment, the PCA is constructed to determine the factor loadings for each component. In each case, two principal components, one domain of income and poverty and one of housing, were constructed. The PCA loadings for each domain were obtained and then applied against the individual block group based factors. Once summed, the resulting score was standardized against the mean score and normalized to produce the output vulnerability index score. The technique used is modeled after the work of Singh (2003) for construction of the indices. The attributes for each index are listed below:

- Income Disparity
- Education Disparity
- Poverty Disparity
- Crowded Housing Disparity
- Rent ($) Disparity
- Home Value Disparity
- Occupation Disparity
- Single Parent Household (HH) Disparity

Disparity measures were constructed for each unit of geography. Negative results indicated a high disparity in favor of protective factors and positive results indicated high disparity with negative outcomes. Each disparity value was log transformed to produce the resulting value used in the weighted index from the PCA values.

Additionally, while working with Dr. Buckingham we also discussed the value of developing a SVI for a future point in time. If we're looking at future climate conditions, should we also be looking at future population projections? We felt this "future population projection" would benefit the research and chose the year 2030, then based on Dr. Buckingham's recommendations we also created a new index for the year 2030 based on the following demographic parameters:

- Projected Unemployment
- Projected Population with no access to a Car
- Projected Poverty
- Projected Single Female Households with Children
- Projected Income Disparity
- Projected Population Living with greater than 1 person per room in a housing unit
- Projected Home Ownership

The projected 2030 values were obtained using trends from existing American Community Survey (ACS) 2006-2010 and Census data at the 2010 Block Group geography and then projected forward using the ETS projection methodology.

There were four social vulnerability indices created

Limitations, Issues and Recommendations

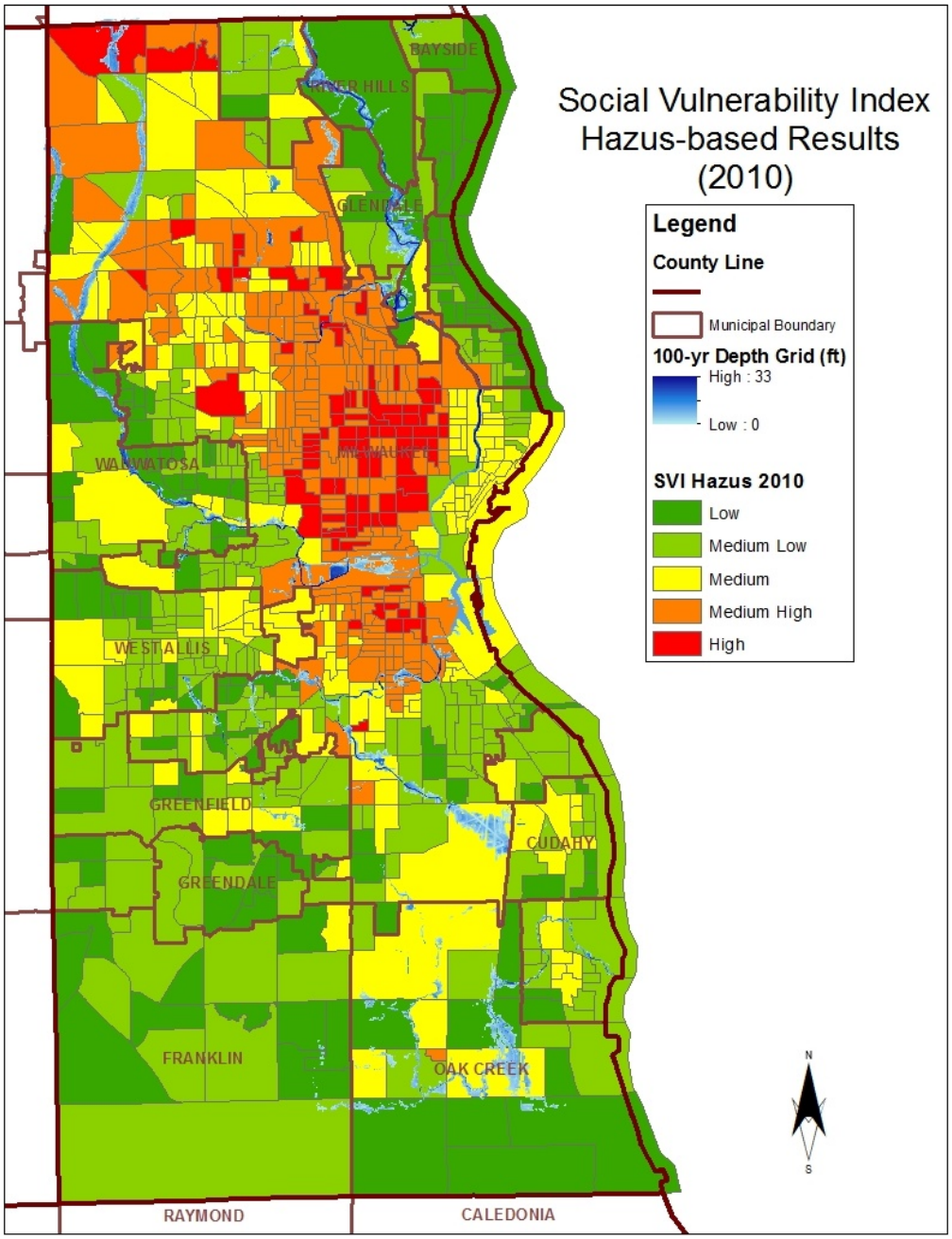
As described earlier, new research is continually emerging in the area of social vulnerability especially related to hazard specific vulnerability such as flooding. The choice of demographic parameters (e.g. income, race, age, etc.) to include or even which statistical approach (e.g. PCA) to use to build a social vulnerability index is not settled and perhaps never will or should be due to different geography or hazards. It would be recommended here then, that we stay informed of the status of social vulnerability research and look for valid approaches that could support community level planning and be transferrable to different communities consisting of diverse and different populations and of different sizes.

For the 4 Social Vulnerability Indices run (see above), the APL-based (full) SVI (#2) was generated to allow comparison with the Hazus-based SVI (#1) – both indices represent the current population characteristics for the county. The APL-based (reduced) (#3) and the APL-based 2030 (reduced) (#4) indices allow comparison of the same population characteristics between 2 different time periods. Comparison between the indices (#1 to #2; #3 to #4) was limited to visual comparison due to project scope limitations at this time. All four Social Vulnerability Indices created are provided below (Map 3 – 6) for visual comparison.

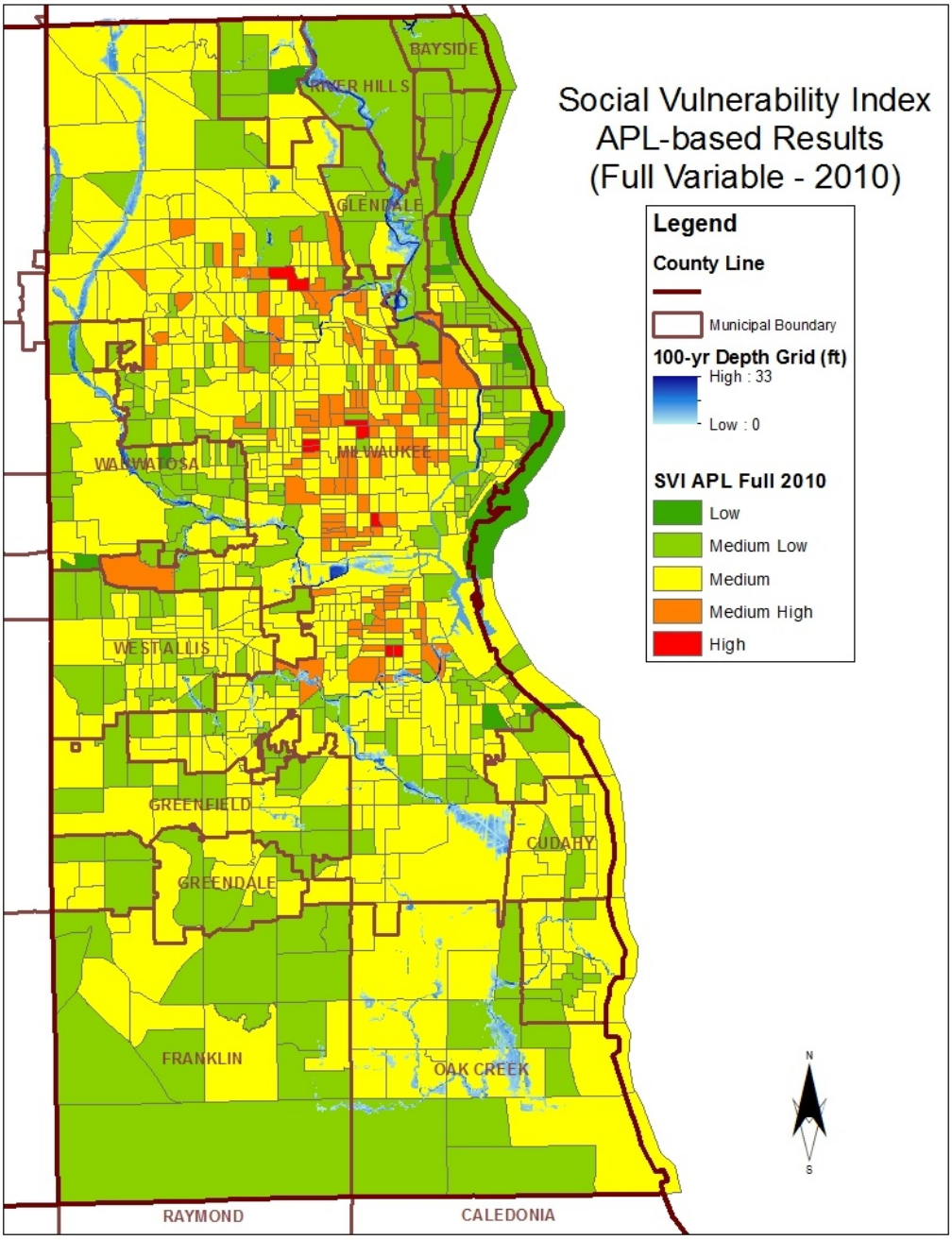
It might be helpful to run analytical comparisons between indices generated for this project and even run comparisons with other indices such as SoVI (Cutter, Boruff, & Shirley, 2003) or CDC's index (CDC, 2016), but it should be noted that Remo et. al. (Remo, Pinter, & Mahgoub, 2016) did compare their Hazus-based SVI with SOVI, finding that "*SoVI and SVI scores were generally in agreement (~80 %) in their relative vulnerability classification [i.e., high (top 25 %), medium (middle 50 %), and low (bottom 25 %)] for Illinois counties.*" At this point, further comparison would not add much to this discussion.

However, a field-based validation should be carried out comparing the SVI results with actual conditions on the ground. Community stakeholders that have a strong understanding of local and neighborhood characteristics would be an initial approach, followed by more detailed field surveys as needed.

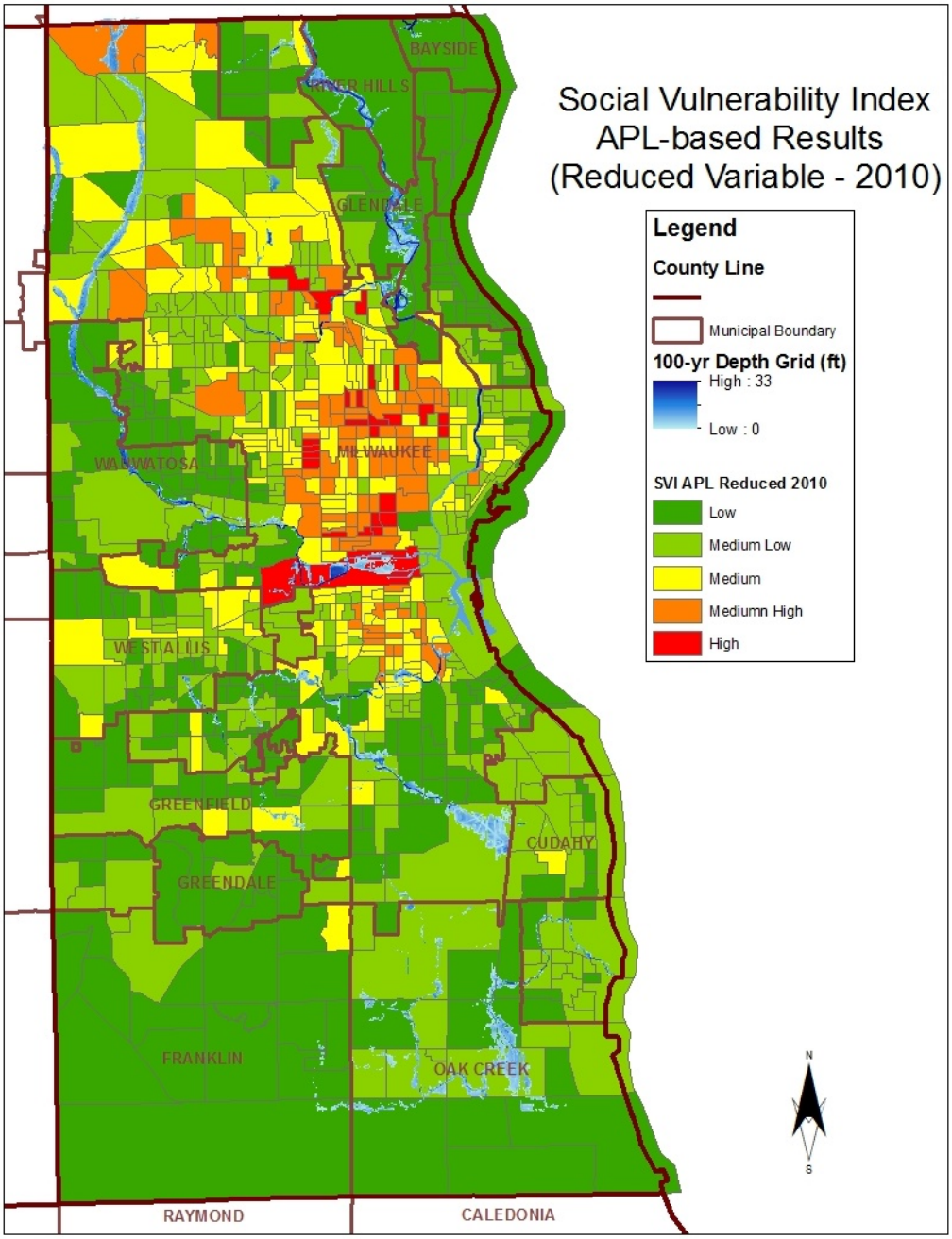
A key consideration to help transferability and use by a community would be to keep the approach, data and methods as simple as possible. The large number of variables included in social vulnerability indices and the complex statistical analysis, such as Principal Component Analysis, are onerous and require expertise and skills outside the capabilities and capacity of most community staff. The ability for communities to acquire and analyze the data can be made more possible, by reducing population or socioeconomic attributes to values such as "household income" and a few others that focus on factors associated with long-term flood recovery.



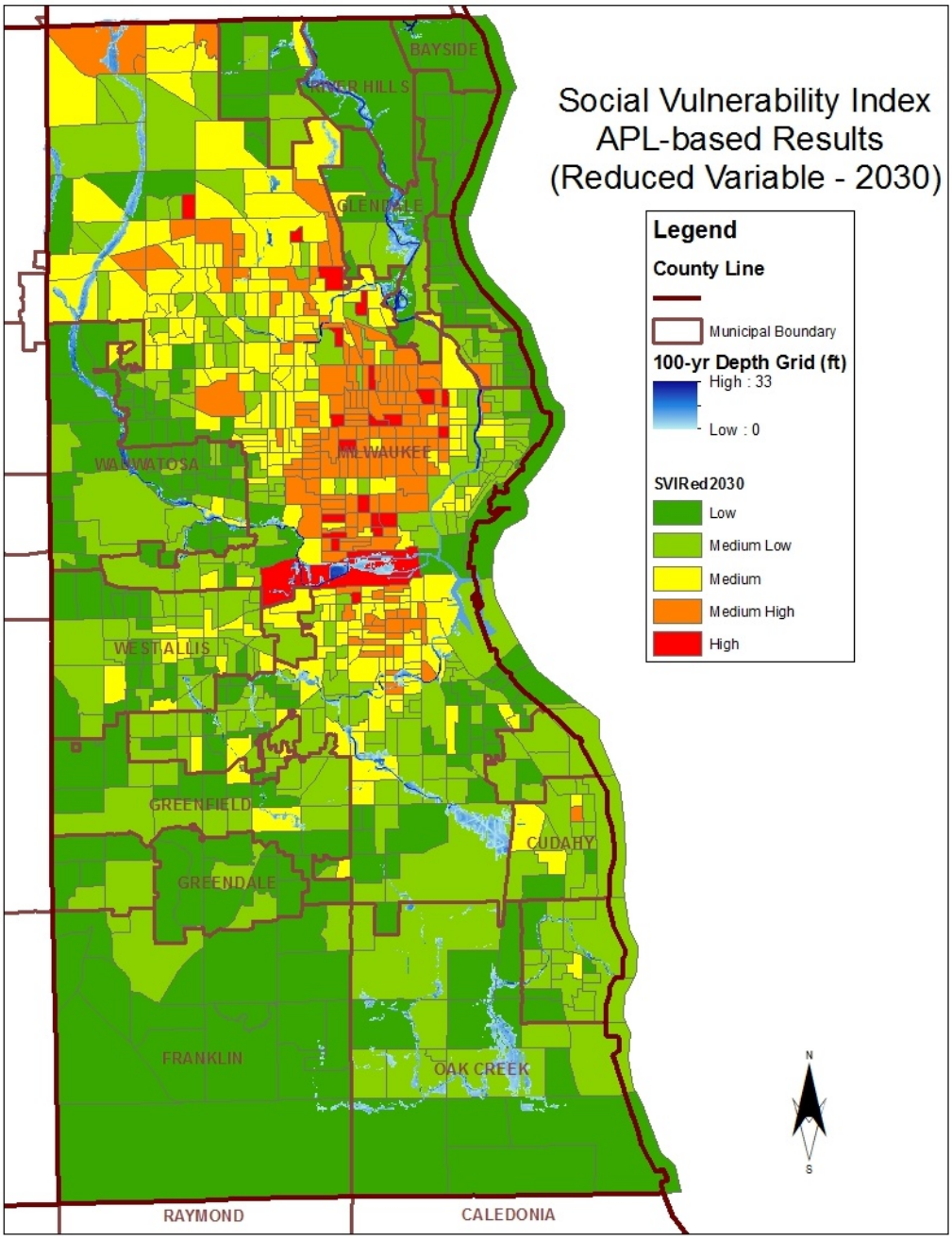
Map 3 - Hazus-based Social Vulnerability Index - 2010



Map 4 - APL-based Social Vulnerability Index - 2010 (full)



Map 5 - APL-based Social Vulnerability Index - 2010 (reduced)



Map 6 - APL-based Social Vulnerability Index - 2030 (reduced)

Flood Vulnerability – Flood Losses + Social Vulnerability

The final step in the process is to actually calculate the Flood Vulnerability Index (FVI) for each census block group for Milwaukee County. There are a total of eight (8) flood vulnerability indices created for this project, based on having 2 flood events and 4 different indices as follows:

We integrate the flood damage estimates for two (2) flood events:

1. 100-yr flood event
2. 500-yr flood event

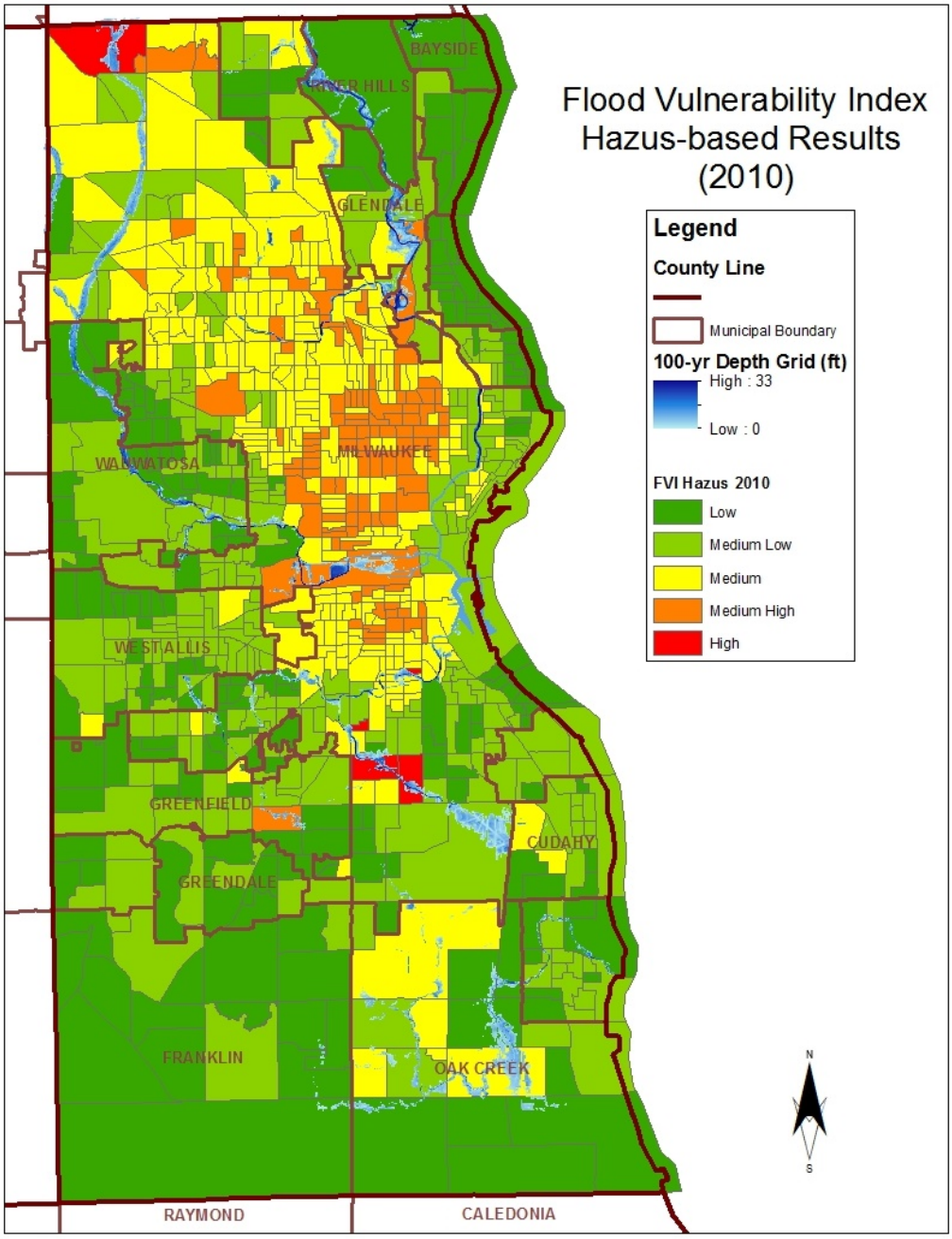
With the 4 different social vulnerability indices developed:

1. Hazus-based 2010 SVI
2. APL-based 2010 SVI (reduced)
3. APL-based 2030 SVI (reduced)
4. APL-based 2010 SVI (full)

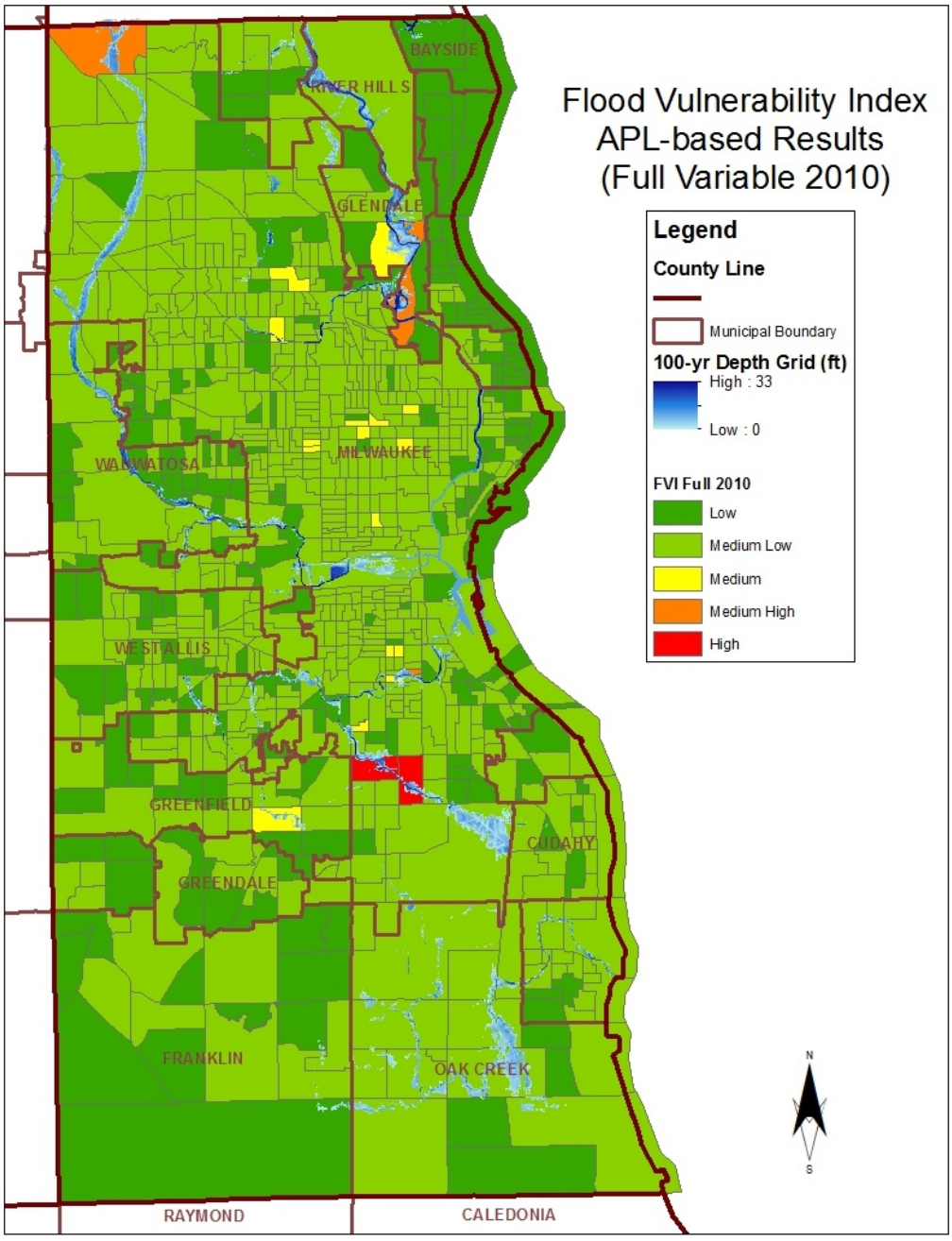
The majority of work required for this section involves joining (table joins) the final results of the Hazus flood loss estimates and total flood exposure values with the final results of the PCA social vulnerability indices. We generate 2 unique datasets, one for each flood recurrence interval – following are the 2 unique GIS datasets:

1. 100-yr filename: BlockGrp_FVI_100yr.shp
2. 500-yr filename: BlockGrp_FVI_500yr.shp

Once the results are compiled within the 2 datasets, the remaining processing is all database field calculations and index standardization methods. For brevity, the following 2 maps show the Hazus-based Flood Vulnerability Index and the APL-based Flood Vulnerability Index for the current (2010) population data.



Map 7 - Hazus-based Flood Vulnerability Index - 2010



Map 8 - APL-based Flood Vulnerability Index (full) - 2010

Discussion

Overall, the research conducted here helps ASFPM's Flood Science Center achieve its primary proposed outcomes for this research. First, we have a much better understanding of social vulnerability and socioeconomic issues related to flood hazards, which has helped us outline the gaps and recommendations provided below. Second, the move from conceptual models to implementing technical models and analysis has provided another level of technical capabilities and capacity to support the pilot projects proposed below.

Various technical and policy gaps and limitations exist in the project to date. The technical gaps include lack of comparative quantitative analysis and lack of a local/community partner to help verify outputs as mentioned above. Additionally, due to the small area of analysis, using census block group or tract level data may not be appropriate or should be used with caution – then as appropriate, more detailed data, such as building footprints with assessor data should be used for estimating flood losses. The work load and time would increase considerably if building level and demographic data were incorporated.

Another gap is the lack of comprehensive urban flood maps and corresponding flood loss estimates. As previously written, a report from the Illinois DNR titled *Report for the Urban Flooding Awareness Act in 2015* (Illinois Department of Natural Resources, 2015), "Over 90% of urban flooding damage claims from 2007 to 2014 were outside the mapped floodplain …" The project was able to fund and develop better urban flood mapping and depth grids utilizing newer 2D flood modeling software, but was unable to run flood loss estimates due to the size and complexity of the urban flood mapping and depth grid datasets.

Technical questions and takeaways include, developing a better understanding of the flood specific vulnerability indicators that should be included in a flood vulnerability index – for example, should the % percent of households without flood insurance be included as an indicator? And, at what scale and/or resolution should the data and models be used? Additionally, since we are focused on socioeconomic and social vulnerability, should we only be considering the location of residential property (owned or rented) for flood losses/damages and household income as a single primary factor impacting long-term recovery and resilience.

There are other questions, caveats and issues associated with using social vulnerability indices, but larger policy questions exist related to the use of vulnerability data in community flood risk planning and management efforts. And, even if this project was able to run flood losses for the 2D urban flood mapping data with building level data, the overall process for developing a flood vulnerability index would be the same and the larger underlying policy questions would still exist.

The larger policy questions would be – are vulnerable populations being included in the prioritization of flood planning and management efforts or as part of mitigation projects? Why and why not? What are the barriers and/or opportunities for including social vulnerability into urban flood risk planning and management? Can social vulnerability be utilized to help prioritize community planning efforts like a capital improvement plan or prioritize project level implementation like a building buyout/acquisition project?

There is an example from a community in Ohio that used population characteristics (e.g. income, age, and ethnicity) related to vulnerability have been used for a mitigation project, but overall it does not appear that vulnerable populations are frequently included. It might be the case that the process is biased based on the use of typical benefit-cost analysis related to community planning and project

prioritization. BCA generally focus on using direct/bottom line dollars and avoided losses, which helps prioritize higher valued properties. Potential opportunities exist to include indirect losses (long-term job loss, vulnerability, public health, etc.) into the BCA, which then could make a community more resilient by keeping the work force intact, decreasing the risk of disease and making people safer.

More recently at the federal government level, two efforts have been identified that include social effects as part of natural hazard mitigation planning and projects. The *Natural Hazards Mitigation Saves: 2017 Interim Report* (Multihazard Mitigation Council, 2017) includes discussion "that new buildings designed to exceed 2015 I-Code requirements and comply with the 2015 IWUIC would avoid deaths, nonfatal injuries and incidents of PTSD that by U.S. government standards would be worth spending $2.0 billion." (Multihazard Mitigation Council, 2017).

From the Corps of Engineers, since social vulnerability is seen as a key social effect, the Corps has developed a primer entitled Identification and Engagement of Socially Vulnerable Populations that addresses vulnerable populations in evaluating potential projects, studies, or regulatory decisions (Baker, Cohen, Coulson, Durden, & Rossman, 2016). The primer is intended to help Corps personnel and its partners understand the importance of identifying and engaging those individuals and groups who are more vulnerable to floods and other environmental hazards.

> *"The social impacts of hazard exposure often fall disproportionately on the most vulnerable people in a society—the poor, minorities, children, the elderly and the disabled. These groups often have the fewest resources to prepare for a flood, live in the highest-risk locations, and occupy substandard housing. They may also lack the social and political connections necessary to access information and resources that would help them to avoid exposure to hazards or to speed their recovery after a disaster." (Baker, Cohen, Coulson, Durden, & Rossman, 2016).*

Recommendations for Capital Infrastructure Planning

The next steps should focus on how socioeconomic and social vulnerability characteristics could be integrated into community planning or project prioritization. The guidelines and information provided by the *Natural Hazards Mitigation Saves: 2017 Interim Report* and the Corps of Engineers primer would be valuable starting points to help move these approaches from the federal level down to state and local authorities. These federal efforts and selected elements of the research described here should be brought into the NOAA CRG project and APA PAS report that is looking at best practices for Capital Improvement Planning (CIP) in Toledo/Lucas County, Ohio and Savannah/Chatham County, Georgia.

Specifically, based on the prior research conducted and cited in this report and beyond, we recommend the following approach (pending costs and budgets) to be piloted for Toledo/Lucas County, Ohio and Savannah/Chatham County, Georgia:

1. Run urban flood models to capture comprehensive flood risks
    a. Use appropriate engineering models (1D, 2D, stormwater, riverine, coastal) to generate flood hazard maps and flood depth grids that would support running flood loss estimates
2. Run custom flood loss estimates at the structure/building scale
    a. Use community parcel dataset and/or building footprint dataset to create the inventory

    b. Link the communities' assessor database to the structures/buildings and populate required values – assessed building value ($), square footage, foundation type, foundation elevation, etc.
3. Run custom socioeconomic/social vulnerability analysis at the structure/building scale
    a. Focus on economic vitality of the impacted people for long-term flood recovery and resilience, which includes – household income, average monthly expenses vs. obligations (debt ratio), flood insurance status (covered or not covered), property equity, and mental health impacts (access and distance to mental health services.
4. Develop a Long-Term Flood Recovery Index based on flood loss estimates and socioeconomic/vulnerability values
    a. Overlay the Long-Term Flood Recover Index with planned CIP projects to help prioritize projects that would benefit socially vulnerable or economically disadvantaged communities.
5. Develop Social Benefits Value that could be used for FEMA or other federal Benefit-Cost Analysis formulas
    a. Research FEMA BCA tools and others to propose potential social benefit values
6. Conduct workshops using the CHARM (Community Health And Resource Management) platform for both communities (see http://www.communitycharm.org/)
    a. CHARM is a new user-friendly mapping tool that enables everyday citizens and local officials to create planning scenarios that are complex and dynamic with results that are instantaneous in terms of a variety of impacts.
    b. Create awareness and understanding of the socioeconomic and social vulnerability issues within a community and link them with planning scenarios with No Adverse Impact approach by including direct and indirect losses into a project prioritization process.

The proposed approach and steps above, provide the following benefits:

- Comprehensive flood risk assessment – moves beyond riverine only flooding by including urban flooding
- Building level analysis – provides a higher level of detail by populating and analyzing flood losses, socioeconomic and social vulnerability at the structure level
- Benefit-cost analysis – moves toward integration of social benefits with federal benefit-cost analysis tools
- Public engagement – introduces the concepts and issues related to socioeconomic factors and social vulnerability

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