# SENSITIVITY OF HAZUS-MH FLOOD LOSS ESTIMATES TO SELECTION OF BUILDING PARAMETERS: TWO ILLINOIS CASE STUDIES

By

Samir Shrestha
B.S., Kathmandu University, 2008

A Thesis
Submitted in Partial Fulfillment of the Requirements for the
Master of Science

Department of Geography and Environmental Resources
in the Graduate School
Southern Illinois University Carbondale
December 2014

THESIS APPROVAL

# SENSITIVITY OF HAZUS-MH FLOOD LOSS ESTIMATES TO SELECTION OF BUILDING PARAMETERS: TWO ILLINOIS CASE STUDIES

By
Samir Shrestha

A Thesis Submitted in Partial

Fulfillment of the Requirements

for the Degree of

Master of Science

in the field of

Geography and Environmental Resources

Approved by:

Dr. Jonathan W.F. Remo, Chair

Dr. Guangxing Wang

Dr. Justin T. Schoof

Graduate School
Southern Illinois University Carbondale
October 22, 2014

AN ABSTRACT OF THE THESIS OF

SAMIR SHRESTHA, for the Master of Science degree in Geography and Environmental Resources, presented on October 22, 2014, at Southern Illinois University Carbondale

TITLE: SENSITIVITY OF HAZUS-MH FLOOD LOSS ESTIMATES TO SELECTION OF BUILDING PARAMETERS: TWO ILLINOIS CASE STUDIES

MAJOR PROFESSOR: Dr. Jonathan W.F. Remo

## ABSTRACT

In this study, Hazus-MH (v 2.1 SP 2) flood-loss estimation tools were assessed for their sensitivity to an array of different building and model parameters. The purpose of this study is to help guide users of the Hazus-MH flood-loss modeling tool in the selection of most appropriate model parameters. Six model parameters (square footage of the building, building age, construction types, foundation types, first floor heights, and the number of stories in the building) were assessed for their impacts on flood losses using the Hazus-MH user defined and aggregate flood-loss models. Building stock databases for these analyses were developed using county assessor records from two Illinois counties. A validation assessment was also performed using observed flood-damage survey data collected after the 2011 Mississippi River Flood which inundated the Olive Branch Area in Alexander County, Illinois. This analysis was performed to assess the accuracy of the detailed Hazus-MH User Defined Facility (UDF) flood-loss modeling tool.

The foundation types and its associated first floor heights and number of stories in the building were found to substantially impact flood-loss estimates using the Hazus-MH flood-loss modeling tool. The model building parameters square footage, building age and construction type had little or no effect on the flood-loss estimates. The validation assessment reveled

Hazus-MH UDF flood-loss modeling tool is capable of providing a reasonable estimate of actual flood losses. The validation assessment showed the modeled results to be within 23% of actual losses. The validation study results attained in this study using the detailed UDF flood-loss modeling tool where more realistic (within 23% of actual losses versus > 50% of actual losses) than previous Hazus-MH flood-loss validation assessments. The flood-loss estimates could be further improved by modifying or choosing a more region specific depth-damage curve, using higher resolution DEM and improving the flood-depth grid by incorporating more detailed flood elevation data or estimates using detailed hydraulic models that better reflects the local inundation conditions.

## ACKNOWLEDGEMENTS

This thesis would be incomplete without acknowledging my adviser, Dr. Jonathan Remo for his all supervision, guidance and providing critiques and comments throughout my work and being such an inspiring adviser. I am very thankful to my thesis committee members; Dr. Guangxing Wang and Dr. Justin Schoof. I would like to take this opportunity and thank whole heartedly to the Department of Geography and Environmental Resources specially Jennie Asber, Oilse Mandat, and Dr. Matthew Therrell. This journey would have been incomplete without support of my family and friends.

# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

## LIST OF ACRONYMS

| ACRONYM | DEFINATION |
|---|---|
| AGR1 | Agriculture |
| ASFPM | Association of State Floodplain Managers |
| BI | Building Inventory |
| BLDG AGE | Building Age |
| BLDG TYP | Building Type |
| CDMS | Comprehensive Data Management System |
| COM | Commercial |
| COM1 | Retail Trade |
| COM3 | Personal and Repair Services |
| COM4 | Business/Professional/Technical Services |
| COM5 | Depository Institutions |
| COM6 | Hospital |
| COM8 | Entertainment & Recreation |
| COM9 | Theaters |
| COM10 | Parking |
| DEM | Digital Elevation Model |
| DMA | Disaster Mitigation Act |
| DFIRM | Digital Flood Insurance Rate Map |
| EDU1 | Schools/Libraries |
| EDU2 | Colleges/Universities |
| EQL | Enhanced Quick Look |
| FEMA | Federal Emergency Management Agency |

| | |
|---|---|
| FIRM | Flood Insurance Rate Map |
| FIT | Flood Information Tool |
| FMV | Fair Market Value |
| FND TYP | Foundation Type |
| GBS | General Building Stock |
| GOV1 | General Services |
| GOV2 | Emergency Response |
| HAZUS-MH | Hazards United States Multi-Hazard |
| H&H | Hydrology and Hydraulic (H&H) modeling |
| IND | Industrial |
| IND1 | Heavy |
| IND2 | Light |
| IND3 | Food/Drugs/Chemicals |
| IND4 | Metals/Minerals Processing |
| IND5 | High Technology |
| IND6 | Construction |
| LiDAR | Light Detection and Ranging |
| M.S. | Microsoft |
| NIBS | National Institute of Building Sciences |
| NUM of Stories | Number of Stories |
| NWS | National Weather Service |
| OCCP | Occupancy |
| RES | Residential |
| RES1 | Single Family Dwelling |

| | |
|---|---|
| RES2 | Mobile Home |
| RES3 | Multi Family Dwelling |
| RES3E | Multi Family Dwelling – 20-49 Units |
| RES4 | Temporary Lodging |
| RES5 | Institutional Dormitory |
| RES6 | Nursing Home |
| Sq. Ft. | Square Footage |
| UDF | User Defined Facility |
| USGS | United States Geological Survey |

# CHAPTER 1

## 1.0 Introduction

**HAZ**ards **U**nited **S**tates **M**ulti-**H**azard (Hazus-MH) is Geographic Information System (GIS) enabled planning tool used to estimate damages and losses from earthquakes, hurricanes and flooding. Hazus-MH was developed in early 1990s by National Institute of Building Sciences (NIBS) as earthquake-loss-estimation tool for Federal Emergency Management Agency (FEMA) developed as an extension to, Environmental System Research Institute (ESRI) ArcGIS software. In later version of the Hazus-MH model, hurricane winds and flood-loss estimation tools were added (Schnider and Schauer 2006). While Hazus-MH is available free of cost from FEMA it is a priority software program whose code is not available to the public.

Hazus-MH was born out of need for relatively easy to use natural-hazard-loss -modeling tools to support the Pre-disaster mitigation planning and risk analysis required for compliance with the Disaster Mitigation Act (DMA) of 2000. At the time, existing loss-estimation tools were often too complicated to be used by local planners who were anticipated to be preparing the pre-disaster mitigation plans and associated risk assessments required under DMA 2000 (Meyer 2004).

Hazus-MH is nationally applicable methodology that is indented to addresses the need for a national standardized methodology for assessing potential casualties, damages, and economic losses related to these natural hazards. Hazus-MH locates hazards areas and estimates the potential physical, social and economic costs based on engineering knowledge of the damage- and hazards- loss estimates (FEMA 2012a). The intent of the modeling results is to provide information needed to inform for hazard preparation, mitigation and disaster response, (Qiu, et al. 2010). Using the Hazus-MH damage and loss results managers, planners, and decision makers are able to better prioritize mitigation measures to reduce disaster losses and improve disaster response.

In this study, sensitivity analyses were performed to assess the Hazus-MH flood-loss model's sensitivity to building parameters and a validation study was performed to help better understand the limitations of Hazus-MH flood-loss predicative capabilities. The sensitivity of Hazus-MH flood-loss estimates were assessed for Alexander and St. Clair Counties in Illinois. Flood damage data collected after the 2011 Mississippi River Flood in the Olive Branch area of Alexander County were used for the validation of the Hazus-MH flood-loss estimates. Findings from this sensitivity analyses and validation assessment are intended to help Hazus-MH users to select the appropriate building parameters when using either the site-specific or aggregated building stock datasets in the Hazus-MH flood-loss model and provide an assessment of the uncertainty associated with these parameters.

## 1.1. Hazus-MH Flood-Loss Model

Hazus-MH flood-loss modeling consists of following list of procedure for flood analysis and explanation of detailed analysis that could be done.

### 1.1.1. Flood Hazard Analysis

In a Hazus-MH flood-hazard analysis, the first step is to create the study region (i.e. area of interest). Study regions can be defined by existing geographic boundary such as a state, county, census tract, census block or watershed and physical landscape using Digital Elevation

Model (DEM) overlaying on it. The second step is to delineate a flood hazard scenario (i.e., the flood depth and extent by combining the flood elevation and the land elevation for specified returned period). Third step is to overlay the inventory (i.e., the number and types of buildings, populations and other facilities in the region) with the flood hazard scenario. The fourth step is to estimate the damage by determining the depth of water at building or facility referring to a depth-damage curve and determine the percentage damage. The fifth and final step is to determine the losses by multiplying the percentage damage by the cost of buildings (Scawthorn, Blais, et al. 2006; Scawthorn, Flores, et al. 2006; Muthukumar 2005).

A flood hazard scenario can be delineated either using Hazus-MH modeled scenario or a user defined scenario. If Hazus-MH is employed to define the flood hazard scenario two steps must be under taken (1) delineating stream network; and (2) performing hydrologic & hydraulic analysis. Delineating the stream network is performed by Hazus-MH using ArcGIS's Arc-Hydro tools to generate a synthetic flow direction and a flow accumulation grid from DEM. The stream delineation process in Hazus-MH undertakes the following processes: 1) in filling sinks (errors) in the DEM flow direction of streams and rivers; 2) estimation of flow accumulation; 3) determine stream thresholds; and 4) the construction of a synthetic stream network using the stream to feature tool in ArcGIS (raster to vector). They are called synthetic stream networks because they are derived entirely from the DEM. However, the stream network generated by Hazus-MH may not be the actual location of stream features because low order streams are not well define in DEM of a resolution greater than or equal to 1/3-Arc Second ( ≤10m; ) (Qiu, et al. 2010).

For a user-defined-flood hazard, three Hazus-MH tools can be employed. One of these tools is quick look. Since the downloaded DEM for the study region are generally multiple raster flies that extend beyond the study region, the quick look tool clips the DEM to the area of interest and generates a flood depth grid using a flood depth of interest. Enhanced quick look tool uses a polygon vector layer to delineate a floodplain boundary and using this boundary it determines the maximum flood elevation and the corresponding flood depths for the land contain within it. The third tool is the Flood Information Tool (FIT). FIT can also be used independently as an extension to ArcGIS or within Hazus-MH. FIT is also used to calculate the flood depth grid when supplied with information from locally developed flood studies such as river cross-sections, and ground elevation data (ABS Consulting 2002).

The hydrologic analysis is performed for the Hazus-MH generated flood scenario and for user defined flood scenarios using the FIT tool. The hydrologic analysis performed during the use of these tools involves the use of a stream discharge estimate made at each stream's upstream and downstream nodes for the specified flood return period (Qiu, et al. 2010). If the stream or river is gaged, discharges for the desired flood-return period are interpolated between USGS gaging stations.  If the stream or river is not gaged, discharges for the desired flood frequency are estimated using USGS discharge regression equations developed for un-gagged streams. Hazus-MH's hydraulic analysis then computes the flood water-surface elevation using the flood discharge and hydraulic calculations using the stream's or river's cross-section geometry extracted from the DEM. The collection of cells where the flood elevation equals the ground elevation a floodplain boundary line is generated and cells where the flood-water surface elevation exceeds the ground elevation a flood-depth grid in created.

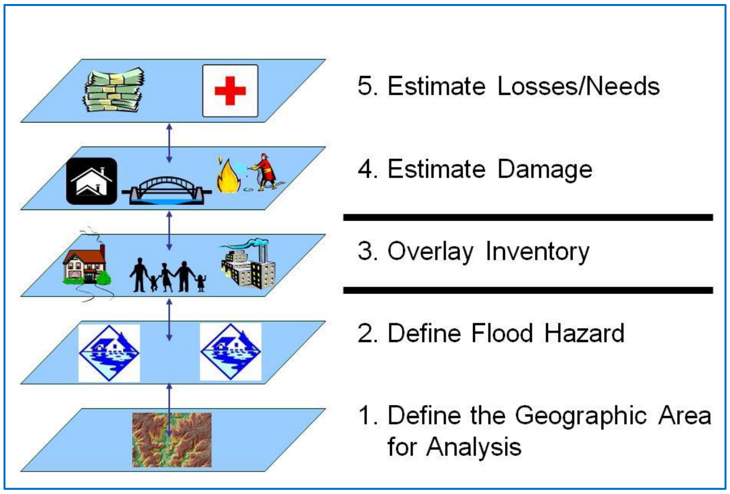


Figure 1.1 – Hazus-MH flood-loss estimation methodology (After Texas Hazard Mitigation Package 2013)

### 1.1.2. Levels of Hazus-MH Analysis

Hazus-MH, allows three level of analysis depending on the user expertise (Figure 1.2). Users can improve the accuracy of Hazus-MH loss estimates by supplying more detailed data from the community, or engineering expertise on the building inventory. Level 1, Level 2 and Level 3 with subsequent level of analyses requiring users to supply more detail data and with the in-depth knowledge of hazard since later analyses are expected to improve the results. Level 1 analysis can be run through using default statewide database requiring minimum effort and knowledge. Level 1 produces a coarse estimate based on statewide database commonly referred as "default" loss estimates. For a level 2 analysis, local information/data is used in the loss assessment. For example, communities might have detailed data on the built environment from the local tax assessor records. More realistic loss estimates are produced using these data than using the default statewide inventories. Level 3 analyses employs data, information or models from detailed engineering and economic studies using models more sophisticated than the ones contained within Hazus-MH (Ding et al. 2008). Such studies require extensive time, effort and financial resources to develop. An example of level 3 effort includes developing region specific depth-damage curves. The higher the level of effort for a flood-loss study the more realistic the flood damages will likely be (Scawthorn, Blais, et al. 2006).

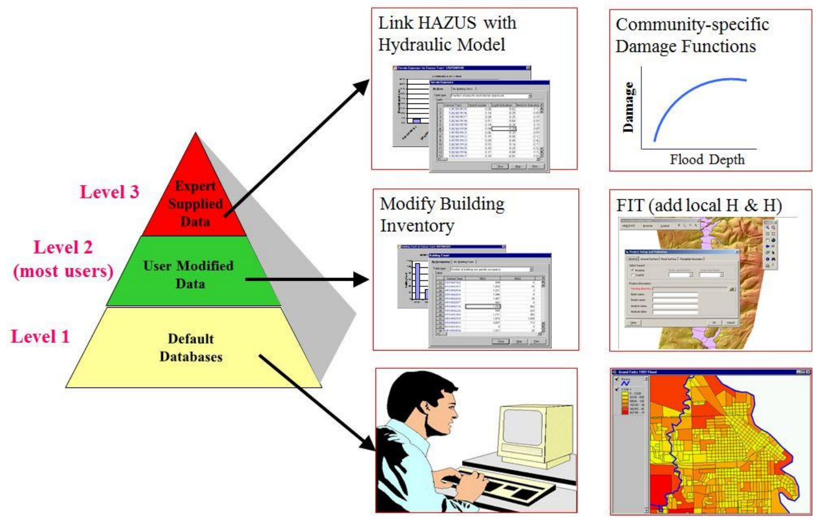


Figure 1.2 – Hazus-MH Level of Analysis and required user sophistication for higher level analysis (After Texas Hazard Mitigation Package 2013)

### 1.1.3. Hazus-MH Inventory

In Hazus-MH, the inventories provided with the software are from national-level databases which have been aggraded by state. This inventory contains a building data model, essential facility, and critical facility geodatabases (Muthukumar 2005). The internal data of the geodatabases is organized to utilize Structured Query Language (SQL) server technology. These inventories are pulled up automatically to the new study region. Inventories are categorized into aggregated and site-specific inventory. Hazus-MH comes with an application Comprehensive Data Management System (CDMS) which is a non-hazard complaint integrating tool. CDMS can be used for querying, exporting Hazus-MH inventories and can be used to upload more detailed information or update existing information to improve the inventory or demographic data for a given region.  These updates are stored within statewide database in which the region is located. CDMS validates the user data type format to insure it is Hazus-MH and consequently SQL complaint. Aggregate inventory includes the information about the buildings as general building stock (GBS) and population as demographic characteristics. This information compiled at the census block or census tract level. Site-specific inventory examples include are but not limited to hospitals, schools, fire stations, utility system, transportations, etc. Site-specific inventory are spatial and represented as points or lines in GIS ( FEMA 2012a, FEMA 2012b).

Hazus-MH default data come from wide variety of sources such as the US census, Department of Energy Housing Characteristics and Energy Consumptions Reports, Dun and Bradstreet (D&B) data report. The census data provides population statistics and residential structure data, and the non-residential structure data are derived from D&B report (FEMA 2012a, FEMA 2012b). The inventories data are classified and grouped into following categories:

i. General Building Stock (GBS)
ii. Population
iii. High potential loss facilities
iv. Transportation systems
v. Lifeline utility system
vi. Agriculture
vii. Vehicles
viii. Hazardous materials facilities

In GBS the community's buildings inventory are categorized into building types, occupancy, square footage, cost of the building and content cost. Population gives the demographic characteristics of community's population with gender, age groups, race and others. The Hazus-MH software has been made flexible enough to allow users to import the locally developed inventories and other data into Hazus-MH that accurately reflect the region.

### 1.1.4. Hazus-MH Flood Depth-damage Curves

The Flood depth-damage curves are applied to estimate flood-loss in Hazus-MH flood model. Physical damages to the buildings and its contents from flooding are estimated directly from the depth of flooding throughout the study region using the depth-damage curve from the Hazus-MH library of more than 900 curves that are specific to building occupancy classes (i.e. residential, commercial, industrial, agriculture, religious, government and educational) and its building configuration (i.e. foundation type, first floor elevation, and construction material). The depth-damage curves were developed based on, damage claims of more than 400,000 during the period from 1978 – 1998 based on occupancy class.  These damage curves were compiled by US Army Corps of Engineers (USACE), Federal Insurance and Mitigation Administration (FIMA), and other federal agencies (FEMA 2012a, FEMA 2012b). The damage to the buildings is calculated as percentage damages to the buildings at certain flood depth. Percentage damage is multiplied by the full or depreciated replacement cost of occupancy class to produce full or depreciated replacement cost expressed in thousands of dollars using valuation method (FEMA 2012a; FEMA 2012b). The full replacement value is the full cost to rebuild the damaged portion of the structure. Depreciated replacement value is the value of the building prior inundation. This value reflects the fair market value of property.

Examples of depth-damage curves for single family residential housing are presented in Figure 1.3. The curves legend 1 Fl, No base stands for single story house without basement, flowingly two stories with no basement, two stories with basement, two stories split level with no basement, two stories split level with basement and last MH Manufactured House with no basement. On the y-axis of the graph is water depth and x-axis is damage percentage based on water depth. The MH is completely destroyed at depth of 7 – 8 ft. of water while at same depth other house may get substantially damaged up to 50%. As shown in Figure 1.3, some of the damage curves are discontinuous. The discontinuous nature of the depth-damage curve attribute to the absence of data for certain depth classes. The damages are calculated in Hazus-MH using these from the discontinued curves by curvilinear interpolation (FEMA 2012a, FEMA 2012b).

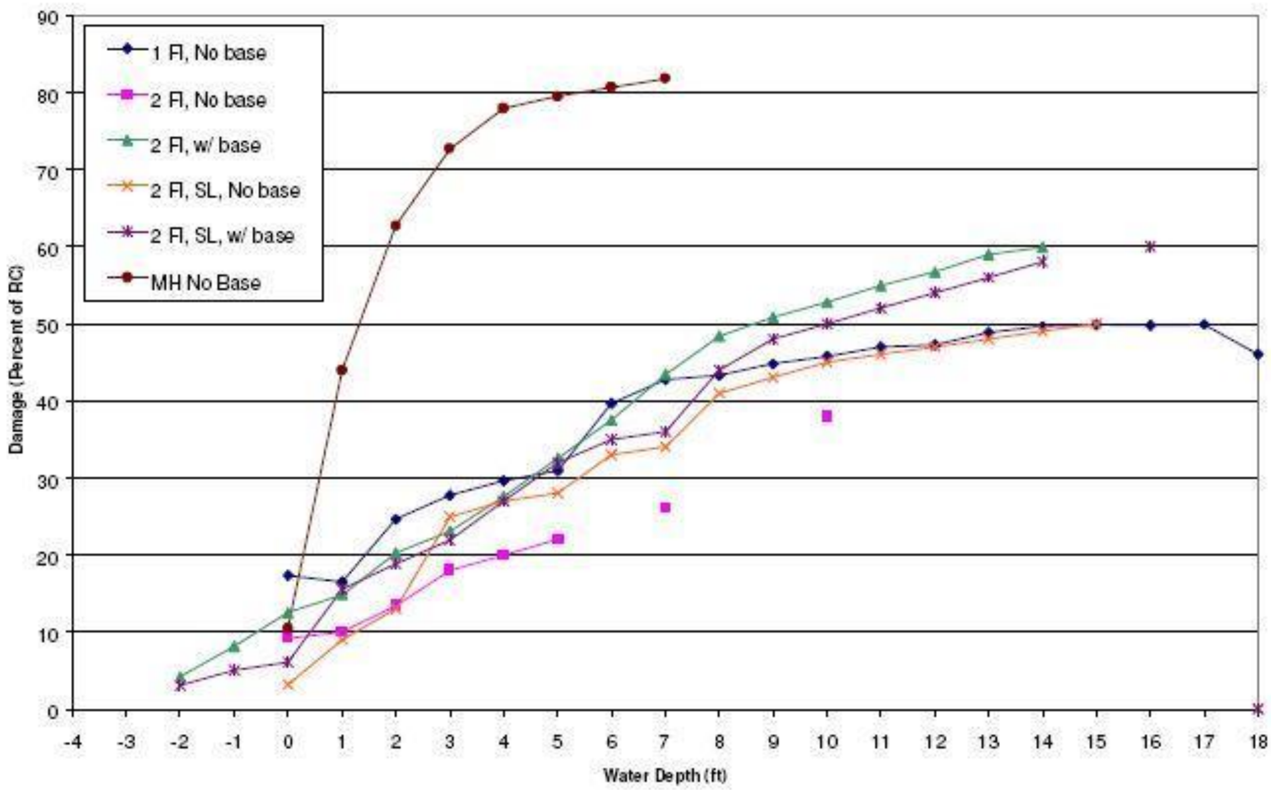


Figure 1.3 – This graph shows the weighted Building Depth-Damage Curves as of 1998 for single family housing (FEMA 2012a, FEMA 2012b). On this graph the x-axis is water depth in feet and the y-axis is the percent of the structured damaged by the flooding. In the legend, FL stands for number of floors, MH represents mobile home, base is an abbreviation for basement, and SL is split level b)

### Building Age

Age of the buildings can be important flood-loss parameter because The National Flood Insurance Act of 1968, which enacted the National Flood Insurance Program (NFIP), requires new construction standards for new buildings constructed within the regulatory floodplain. Buildings constructed prior to 1968 often do not meet the construction standards required for buildings within the regulatory floodplain. As such, these building may be more severely damage than floodplain structures constructed after implementation of the NFIP. Building construct prior to the enactment of the NFIP is commonly referred to as Pre-FIRM structures and building constructed after the enactment are referred to as Post-FIRM structures (FEMA, 2012a).

### Foundation Type and First Floor Elevation

Foundations are the base in which a building is constructed. Foundation types and first floor height are very important parameters in both the aggregate and User Defined Facility (UDF) flood models because they determine the elevation at which flood damage begins. Foundation types vary with geographic location because elevation, soil and groundwater conditions. In addition, foundations often vary with building occupancies. Table 1.1 shows the foundation types and associated first floor height and Table 1.2 gives mapping occupancy of foundation types of single and multi-family residence, temporary lodging, commercial, industrial, agricultural, religious, government, and educational for the FEMA Region V (Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin). The users can modify the distribution of foundations type in flood-specific-occupancy mapping scheme for the aggregate flood-loss model or in data table for the UDF (point) analysis (FEMA, 2012a).

Table 1.1– Definitions of the foundation types with Hazus-MH ID and first floor height (FEMA 2012a, FEMA 2012b)

| Hazus-MH ID | Foundation Types | First floor Height | Definitions |
|---|---|---|---|
| 1 | Pile | 7 ft. | Open foundation, composed of tall and slender members, embedded deeply into the ground. A pile is a single element, not built-up on site like a pier. For our purposes, cast in place columns supported by a deep foundation (pile cap, or mat or raft below the anticipated scour depth). |
| 2 | Pier | 5 ft. | Open foundation (no load-bearing perimeter walls), usually built of masonry units and supported by shallow footings. Piers usually range from approximately 2 ft. to 8 ft. in height. |
| 3 | Solid wall | 7 ft. | Load-bearing perimeter walls greater than 4 ft. in height, usually supported by shallow footings. Floor beams or joists usually rest atop the walls, and may or may not be supported by interior piers or columns. |
| 4 | Basement | 4 ft. | Any level or story, which has its floor subgrade on all sides. Usually load bearing, masonry or concrete walls around the perimeter of the building, supported on shallow footings. Floor beams or joists rest atop the walls. Shallow basements with windows slightly above grade are defined as a garden level basement. |
| 5 | Crawlspace | 3 ft. | Usually short (less than 4 ft. high), load bearing, masonry or concrete walls around the perimeter of the building footprint, supported on shallow footings. Floor beams or joists rest atop the walls and may also rest on interior piers. |
| 6 | Fill | 2 ft. | Soil built up above the natural ground elevation and used to support a slab or shallow footings. |
| 7 | Slab on grade | 1 ft. | Concrete slab resting on the ground. It may have its edges thickened or turned down, but does not rely on other walls or footings for support. |

Table 1.2– Percentage of the default occupancy mapping scheme of foundation types for single and multi-family residences (FEMA 2012a, FEMA 2012b)

| FEMA Region V | Percentage distribution of Foundation Types | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | Pile | Pier | Solid wall | Basement | Crawl | Fill | Slab on grade | |
| RES1 - RES3 | 0 | 0 | 0 | 68 | 21 | 0 | 11 | 100 |
| RES4 – RES6, COM,IND, AGR, REL, GOV, EDU | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 |

### Construction Types

The building types refer to the materials used in its construction. The building types include wood, steel, concrete, masonry and manufactured housing. General construction type mapping scheme gives the percentage distribution of construction materials for specific occupancies and this percentage distribution varies by each state and likely by region. For example, from the Table 1.3 below shows the construction type mapping scheme distribution for RES1, COM1 IND1, and AGR1. However, construction type within the Hazus-MH flood-loss models is not as important of a parameter as they are for the earthquake and hurricane loss models (FEMA, 2012a).

Table 1.3 – Percentage of the building construction type mapping scheme distribution in Hazus-MH

| Occupancy | Wood | Masonry | Concrete | Steel | Manufactured Housing | Total |
|---|---|---|---|---|---|---|
| RES1 | 77 | 22 | 1 | 0 | 0 | 100 |
| COM1 | 30 | 30 | 10 | 30 | 0 | 100 |
| IND1 | 0 | 5 | 25 | 70 | 0 | 100 |
| AGR1 | 10 | 30 | 30 | 30 | 0 | 100 |

### 1.1.5. Flood-Loss Estimates

Loss estimation within the Hazus-MH flood-loss model is undertaken in two preliminary steps: (1) assessment of building inventory and (2) the selection the appropriate flood-damage curve. For the first step, Hazus-MH identifies what portion of the building inventory might be flooded during a given flood scenario. This includes assessment of the building inventory, critical facilities, essential facilities, and the potential population impacted. This information is extracted from the Hazus-MH's building, critical, essential and demographic inventories automatically during the creation of the study region.

The second step in the Hazus-MH flood-loss estimation methodology is estimating the economic damages that may take place using flood depth-damage curve. These damage curves are different for each specific occupancy within general occupancy class such as residential, agricultural, industrial, commercial, religious, educational, and government. For example, within residential single family housing (RES1), the damage curves are different for house with one floor and no basement, ([R11N] represented as single family one story house with no basement), house with one floor with basement (R11B), house with two floors and no basement (R12N) and others shown in Figure 1.3. Damages are estimated as a percent and for an aggregate flood loss analysis is weighted by the area of the inundation at a given depth for a given census block or tract, with consideration for the specific occupancy classifications, building types, and income (Muthukumar 2005). However, in UDF analysis the damage curves are applied to individual buildings and losses are estimated for each building rather than aggregating loss-estimate to a block by area weighted analysis. The UDF flood-loss analysis is widely considered to provide a more realistic loss-estimate for inundated buildings than the aggregate model (Remo et al. 2011).

## 1.2. Sources of uncertainty in the Hazus-MH Flood-Loss Model

Uncertainty is the inherent property of any model limited by computation capacity. Flood-loss modeling is an abstraction or simplification of reality, and can best represent the real world scenario when supplied with the most complete and accurate information. Flood-loss model may allow in predicting and simulating the flood both in space and time. Currently, the Hazus-MH aggregate flood methodology assumes the uniform distribution of building exposure, contents and population over a census block. This is conservative approach of area-weighting the general building stock losses equally throughout the each inundated census block (Rozelle et al. 2011). The assumption of uniform distribution of building stock across the entire census block uses an area weighted flood depth to represent flood depths across the entire census block. This assumptions coupled with the depth-damage function limitation can lead to substantial uncertainty in flood-loss estimates within small study regions which employ the aggregate flood-flood loss methodology. If 50% of the block is flooded, Hazus-MH assumes 50% of the buildings are in flood zone(ASFPM 2009). Generally, the built area of a census block would be concentrated outside the floodplain. This conservative distribution may limit the Hazus-MH flood model loss estimates (URS Group 2007). The aggregate flood-loss methodology is more reliable for large study regions (FEMA 2012a).

For areas with detailed building inventories or such inventories can be constructed form assessors (tax) records, Hazus-MH's UDF flood loss modeling tool, which models individual buildings in their actual geographic location, can be used in place of the aggregate analysis. Using the spatially explicit UDF loss modeling tool can eliminate or minimize the modeling assumption of a uniform building distribution across the entire census block improving the flood-loss estimates, damages are calculated only to the buildings intersecting the flood zone based on building's latitude and longitude. Hazus-MH uses the DEM to calculate the flood depth and flood extent over the defined region and these results could vary with DEM resolution used for its calculation. Lower resolution DEM may not capture the region specific topography, such as the contour, relief and drainage which could add uncertainty to the flood-loss estimate (ASFPM 2009). Hazus-MH comes with inbuilt depth damage curves that are specific to occupancies. However these default damage curves may not always reflect the local condition as these curves are generalized which could add uncertainty in the loss estimation. In addition to the depth-damage curves and aggregate flood-loss model spatial assumptions about the distribution of general building stock, other buildings or model parameters may play an important role in both the aggregate and User Defined Facility (UDF) they include building age, foundation type, first floor height, and construction types.

### 1.3. Review of past sensitivity or validations assessments

Since the release of Hazus-MH, numerous studies have been undertaken for the estimation of losses from floods, earthquakes, and hurricanes. However, there have been few sensitivity or validations studies performed. Review of both the academic and grey literature revealed only five studies performed rigorous sensitivity or validation assessments of the Hazus-MH flood-loss modeling tool. These studies were undertaken by URS Group (2007), Ding et al. 2008, the Association of State Floodplain Managers (ASFPM; 2009, 2010a, 2010b). However, neither of these studies looked assessed building parameter impacts on flood losses.

The URS Group (2007) performed a validation study for a riverine flood event that occurred in St. George, Utah in January 2005. The Hazus-MH flood-loss estimates were generated using Hazus-MH default hydrology and hydraulic tools, using measured discharge values from National Weather Service; 1/3-Arc Second DEM and Hazus-MH's aggregated generalized building stock. Hazus-MH flood-loss estimates where 30% greater than the observed damage. The discrepancy between the Hazus-MH and actual flood losses were attributed to the DEM resolution not being sufficient to fully capture the river channel and floodplain topography (URS Group, 2007).

Ding et al. 2008 performed the validation of Hazus-MH at level 1 and level 2 analysis (see Section 1.1.2 for explanation of Level 1 and Level 2 analysis) for White Oak Bayou watershed region in Harris County Texas for 100-year return period. The level 1 analysis was performed using Hazus-MH default datasets and 1-Arc second DEM. The level 2 analyses were performed with LiDAR DEM of 5 m and FIT generated floodplains and depth grids. The level 2 analysis produced 50% larger floodplain compared to level 1 and matches closely with 211 Federal Flood Control Project, General Re-evaluation Report. The level 1 estimated the residential building loss of $ 330, and level 2 $ 179 million which largely co-related with Re-evaluation Report $ 153 million.

The ASFPM (2009) evaluated the precision of Hazus-MH hydrologic and hydraulic modeling tools for the delineation of the 100-year floodplain. The purpose of this evaluation was to assess Hazus-MH's performance at mapping the 100-year floodplain for regulator use in areas where detailed hydrologic and hydraulic modeling had not been previously performed. This study assessed Hazus-MH ability to create a realistic representation of the 100-year floodplain using different resolutions of DEMs (1-Arc Second, 1/3-Arc Second, and ≤ 1/9-Arc Second LiDAR derived DEMs) within varying physiographic and hydrologic settings. The study was performed for two study regions one within Texas and the other in North Carolina. The Harris County, Texas study region was a low relief area region and analysis was performed along two streams, Roan Gully (4.3 sq. mile watershed) and Willow Creek (40 sq. mile watershed). The North Carolina Study Reach was located in Mecklenburg County which is a region with moderate relief. Again the two study reaches were investigated, Doby Creek (5.7 sq. mile watershed) and Mallard Creek (38.5 sq. mile watershed). In this study it was found that increasing the resolution the DEM resolution alone did not substantially improve in the delineation of the floodplain or flood depth. Higher resolution DEMs (≤1/9-Arc Second) when coupled with discharges and water surface elevations for the Flood Insurance Study (FIS) resulted in improved flood-depth grid resolution. For the flood-depth grid constructed using the FIS data and high resolution DEMS averages depth uncertainty was less than 1 ft for Roan Gully (a small drainage, low relief) 1.8 ft. for Willow Creek (moderate drainage, low relief) 3.3 ft. for Doby Creek (a small drainage, moderate relief) and 4 ft. for Mallard Creek (moderate drainage, moderate relief). In terms of floodplain delineation, the Willow Creek study reach had relatively largest average floodplain boundary error (up to 1100 ft.) and Roan Gully about 200 ft. However for the Doby Creek and Mallard Creek the error which much lower (< 65 ft.). The lower error in the floodplain delineation for Doby and Mallard Creeks were attributed to at availability of higher resolution topographic data (ASFPM 2009).

In 2010, ASFPM performed a validation study were they compared the Hazus-MH flood loss estimates and National Flood Insurance Program claims from June 2008 flooding in Dane County, Wisconsin. Here they performed a UDF flood-loss analysis and compared the results to actual damages in Dane County. This study found the Hazus-MH damage estimates to be about 51% of the NFIP claim (an under prediction of 49%; ASFPM 2010a). These underestimations have been attributed to values used for structure assessment of replacement cost, the depth damage curves in estimating percent damages.

Also in 2010, the ASFPM performed a follow up study to their 2009 assessment of Hazus-MH ability to delineate the 100-year floodplain. In this sensitivity study, the ASFPM compared flood-depth grids created using Hazus-MH default Hydrology and Hydraulic (H&H) modeling, Enhanced Quick Look (EQL) and combination of EQL and Flood Information Tool (FIT). They also evaluated the difference in flood losses when using building inventories of varying level of detail (i.e., Hazus-MH default General Building Stock (GBS), updated aggregated data and UDF database). In this study, ASFPM only evaluated losses for residential, governmental, and not for profit buildings. The flood-depth grid prepared using default H&H modeling estimated damages to buildings in areas where building did not exist. The study found highest damage estimates using Hazus-MH default GBS, followed by updated GBS and then UDF database for all models using depth grid generated from Hazus-MH default Hydrology and Hydraulic modeling, EQL and combination of EQL and FIT (ASFPM 2010b). The flood-loss estimated \$700,000, \$520,000 and \$30,000 for default GBS, updated aggregated data and UDF database respectively using default H&H generated depth grid. Similarly, \$3,610,000, \$2,180,000 and \$1,140,000 from EQL generated depth grid and \$950,000, \$700,000 and \$510,000 from combination of EQL and FIT.

### 1.4. Problem Statement

Review of the past assessment have only assessed the flood-loss estimates varied with change in increasing DEM resolutions and updated building inventory databases, however past research have not address the questions regarding the important building parameter such as construction types, building age, foundation types, first floor elevation, square footage and number of stories that plays crucial role in withstanding the against flood-loss. This research drives with fundamental question how sensitive are these building parameter in Hazus-MH flood-loss estimates. In this study the local tax assessor data will be updated and parameterized with the above building parameters to assess the sensitivity of these parameters in estimating flood-loss.

# CHAPTER 2

## 2.0 Materials and Methodology

This investigation was performed to assess the sensitivity of the Hazus-MH (v 2.1 SP 2) riverine flood-loss models to building parameter selection in order to guide the selection of these parameters for realistic flood-losses estimates. To assess building parameter selection on Hazus-MH flood-loss estimates, the sensitivity of several parameters were evaluated using building inventory data from Alexander and St. Clair Counties in Illinois. Here difference in loss estimates between a building explicit datasets compiled from local tax-assessor records and Hazus-MH GBS data model was assessed. Additional sensitivity analyses were also undertaken for building related parameters such as area, construction type, foundation types, first floor height, and building age for default Hazus-MH GBS data model, Hazus-MH GBS data models updated with local tax assessors data and spatially explicit UDF datasets compiled from assessors records. A validation assessment was also performed using 2011 Mississippi River Flood damage data from the Olive Branch Area of Alexander County to directly assess the uncertainty in flood-loss estimates using Hazus-MH UDF modeling tool.

### 2.1. Study Regions

For this study, Alexander and St. Clair Counties were selected to perform the sensitivity assessment because of data availability and their respective flood risk. In addition, comparing the difference in rural and urban setting of Alexander versus St. Clair Counties, respectively allowed for the additional assessment of community scale impacts on Hazus-MH modeled flood-loss estimates.

Alexander County is located at the southern tip of Illinois with an area of 611 sq. km. Alexander County is flanked by the Mississippi River on the west and the Ohio River on the east. The Mississippi and Ohio rivers converge at the southern tip of Alexander County (Figure 2.1). The population of Alexander County is estimated population to be approximately 7,700 people (U.S. Census Bureau 2014a). Figure 2.2 displays the flood-depth grid map for a flood with a 100-year return period and the census blocks within Alexander County. As can be seen on Figure 2.2, almost half of the county area lies within the 100-year floodplain.

St. Clair County is located in southwest Illinois near the City of St. Louis, MO (Figure 2.1). This county is considered a part of the St Louis metropolitan region and has an estimated population of approximately 269,000 people with an area of 1,720 sq. km (U.S. Census Bureau 2014b). Geographically, the western one-third of the county is located within the Mississippi River floodplain while the western two-thirds are mostly located on uplands and out of floodplains (Woolpert 2011).

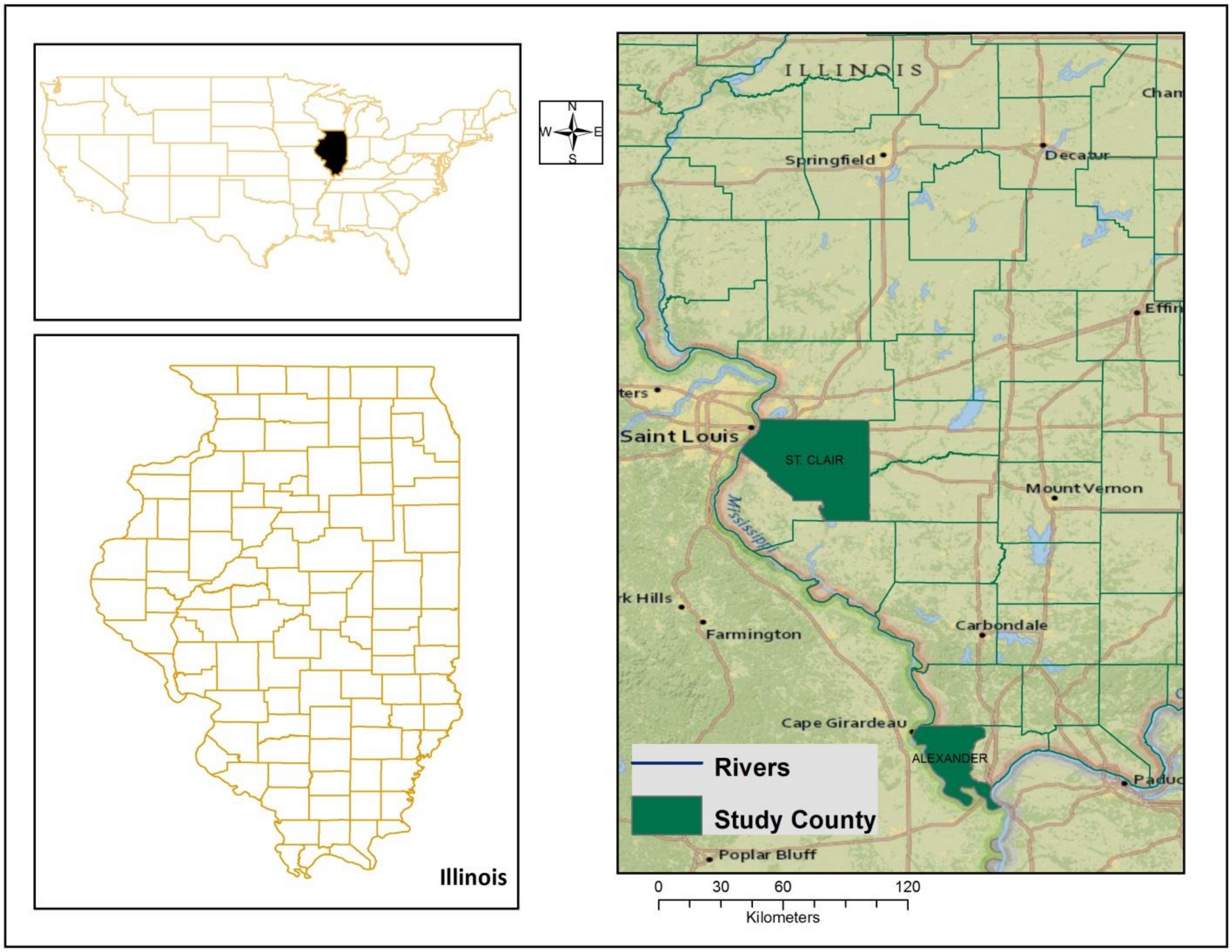


Figure 2.1 – Location Illinois within the United State and the location of Alexander and St. Clair Counties within the State of Illinois

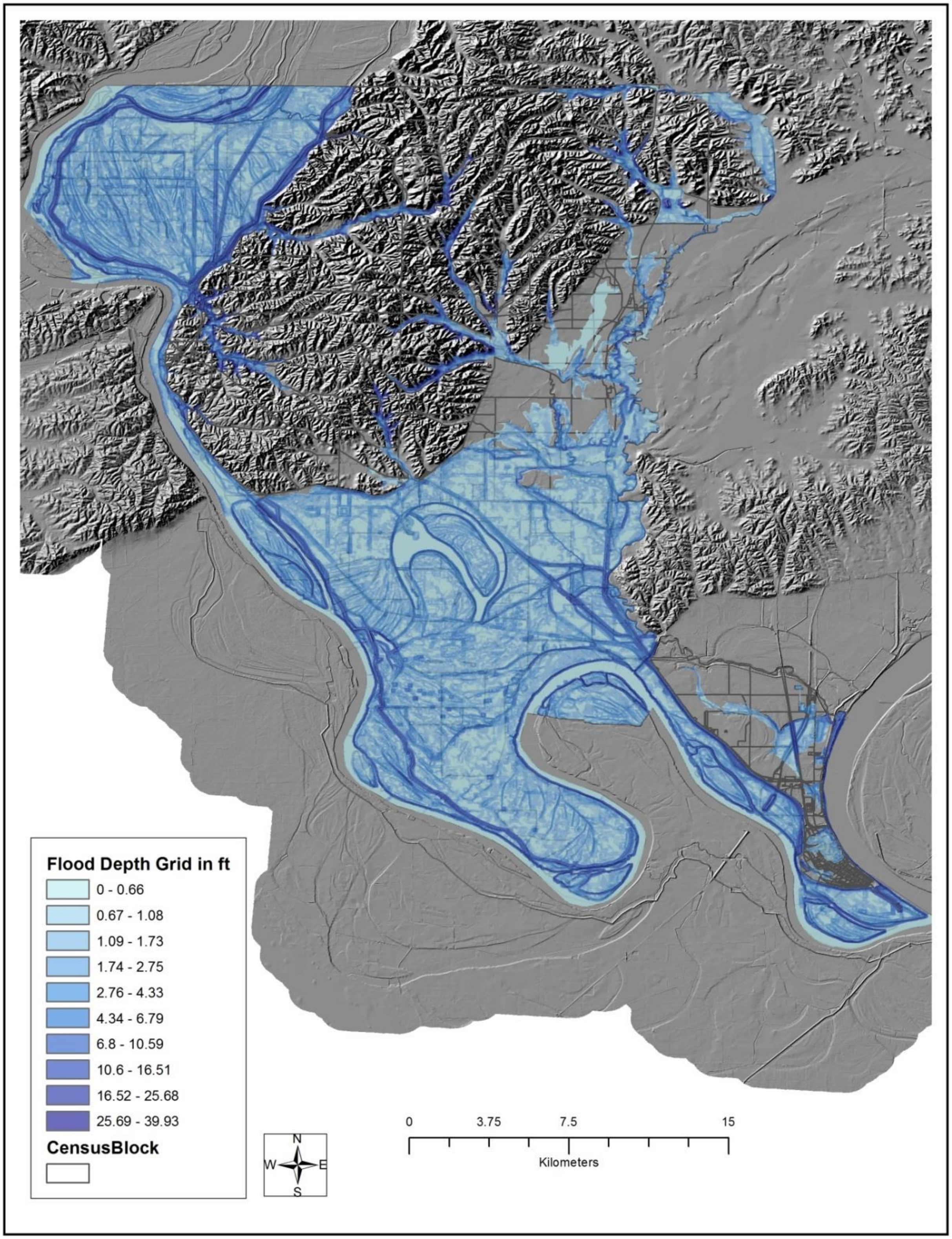


Figure 2.2 – Alexander County with its census blocks and a flood-depth grid representing the 100-year floodplain

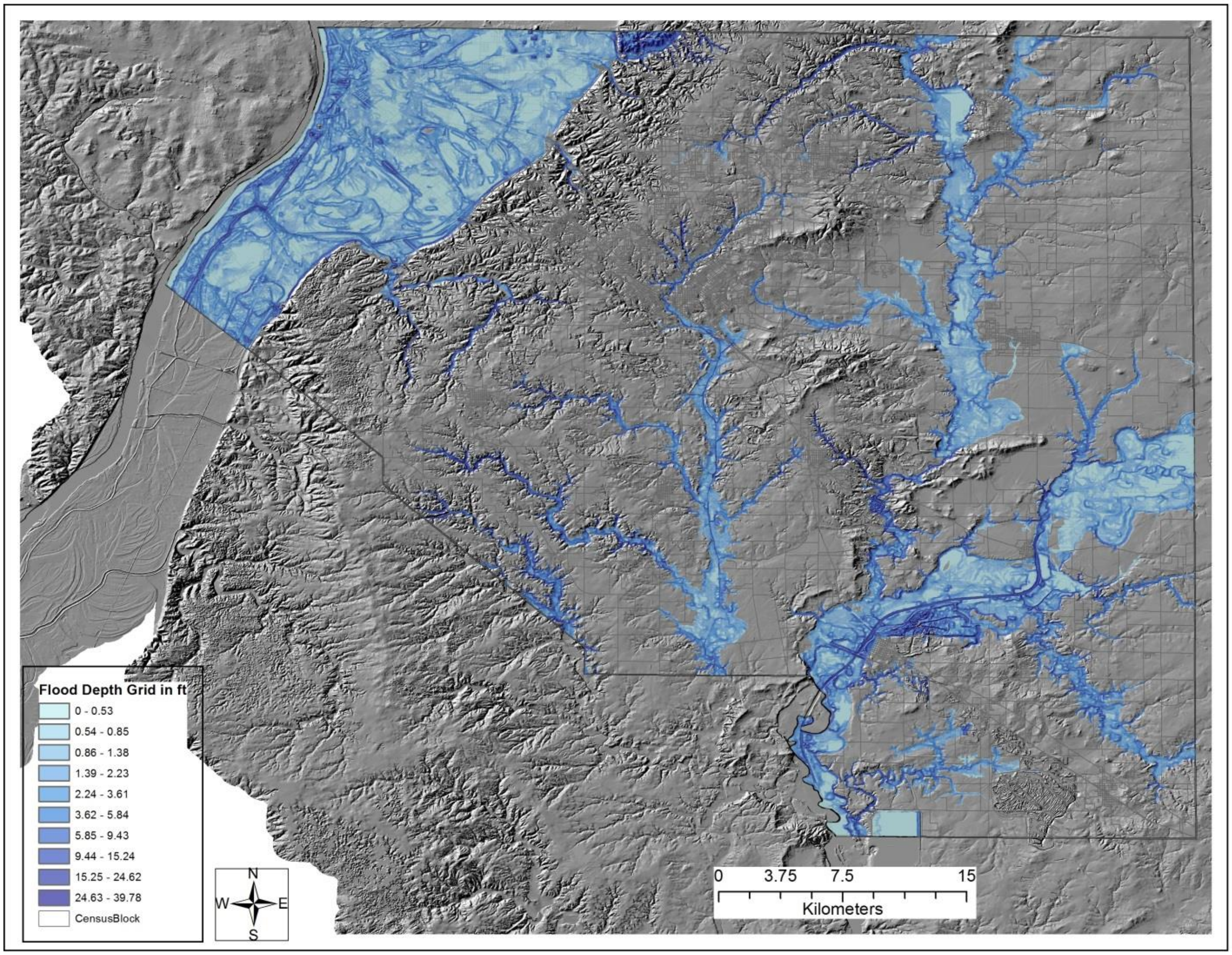


Figure 2.3 – St. Clair County with its census blocks and a flood-depth grid representing the 100-year floodplain

## 2.2. Data Sources

### 2.2.1. Floodplain Maps

Floodplain maps are prepared for a community to show the flood extent for the 100-year regulatory flood. FEMA oversees the National Flood Hazard Mapping Program across the country and is responsible for producing the national Flood Insurance Rate Maps (FIRM's). These maps are prepared from a detailed Flood Insurance Study. In addition to the 100-year floodplain boundary, these maps show insurance risk zones and where detailed hydrologic and hydraulic models have been constructed base-flood elevations (BFEs). As part of implementing FIRM, a community is required to adopt a floodplain management ordinance. This ordinance establishes land-use rules and building codes designed to reduce the flood losses. Insurance rates are charged based on what flood zone a building is located in and how flood prone its lowest floor is (H2O Partners 2013). DFIRMs stand for Digital Flood Insurance Rate Maps and they are the newest generation flood rate insurance map. Unlike the FIRMs, the DFIRMs are GIS based maps which are compiled using the best available hydrologic and hydraulic modeling and topographic data. The DFIRMs are created on a county-wide basis incorporating all the communities within a given county, under one map rather than having separate maps for each community. The overlay of aerial photography on the maps makes it easier to visualize the extent of the floodplain over the region. While both FIRMs and DFIRMs map the 100-year floodplain boundary, the key difference is the quality of the elevation data in the mapping of the regulatory floodplain boundary (Patterson and Doyle 2009).

### 2.2.2. Digital Elevation Model (DEM)

A DEM is an array of uniformly spaced elevation data. A DEM is point based, and the elevations are converted to a raster by placing the elevation point at the center of a cell (Chang 2010). DEMs produced by the United States Geological Survey (USGS) are available at the following resolutions: 1-Arc Second (30 m), 1/3-Arc Second (10 m) and 1/9-Arc Second (3 m) at free of cost from USGS National Elevation Dataset (NED) server. The 1/3-Arc Second DEM resolution (~10 m) DEMs has often been used in Hazus-MH flood-loss simulations because it provides a sufficient resolution for realistic flood-loss model results and requires less computation time than higher resolution DEMs (URS Group 2007).

### 2.2.3. General Building Stock

In Hazus-MH, two infrastructure databases can be employed, the aggregated general building stock (GBS) data model or a user define facilities database (inventory; see below). The GBS is an engineering based model of structures by occupancy type. The GBS inventory in the Hazus-MH flood model is compiled at the census block which then can be aggregated to the census tract level, state level or user defined region, which allows for faster computations of the hazards that are modeled over large geographic extents. The GBS inventory is modeled in part using US census demographic and residential building inventory data. The residential building inventory is reported by occupancy type, construction type (e.g., construction material), square footage, building counts and dollar exposure to the buildings and its contents. The aggregated general building stock uses building valuations from Dunn and Bradstreet's 2006 R.S. Means Values. Consequently, the flood-loss and flood-exposure estimations presented in this thesis are evaluations estimated during year 2006 in thousands of dollar. Hazus-MH flood model assumes the uniform distribution of GBS over a census block. In addition, the GBS are not hazard specific and serves only as proxy for loss estimation. Often the evenly distributed building assumption has been found to cause an overestimation of flood-loss within the study region (Rozelle et al. 2011). For more realistic flood-loss estimates, the GBS should be replaced with local tax assessor data that are more detailed in characterizing a region's building inventory (FEMA 2012a).

### 2.2.4. User Defined Facility

User defined facilities (UDF) are those structures which the user may wish to analyze on a site-specific basis. Compared to GBS, the UDF provides the actual location of buildings and facilities at risk to flood damage. UDF records the basic characteristics of the individual buildings and this information can be updated by building specific data that are hazard specific. Specific building information is useful for analyzing individual structures. UDF allows pinpointing the location of individual buildings in the study region and analyses for loss estimates with more hazard specific building information. Generally, the UDF modeling is more realistic particularly for smaller study regions (i.e., less than a county). This is because of the spatially explicit nature and specific building characteristics captured in the UDF structure database; as GBS data is aggregated to census block or census tract. UDF are uploaded into the study region, UDF analysis requires the built environment: structure location (latitude & longitude), specific occupancy, building cost, content cost, foundation type and first floor height for loss estimates (FEMA 2012a).

In this study, UDF analyses were performed to model-flood losses in Alexander and St. Clair Counties using local tax assessor data. The Alexander and St. Clair Counties local tax assessor data were attributed with land-use codes which needed to be reclassified into Hazus-MH specific occupancy classes as shown in Table 2.1. Both counties local tax assessor data contained assessed building values which were used to calculate the fair market value (FMV) of each individual building (i.e., the building cost). The content costs were estimated as per specific occupancy. Additionally, building specific data such as square footage, foundation type, first floor height and others parameters were required and how they were estimated or obtained is explained in the following section.

Table 2.1 – Local tax assessor land-use code reclassified into the followings:

| Local Assessor Land-use codes | Hazus-MH Occupancy Codes |
|---|---|
| 0010 | AGR1 |
| 0060 | COM1 |
| 0066 | COM3 |
| 0064 | COM4 |
| 9001 | COM6 |
| 0070 | COM8 |
| 0080 | IND1 |
| 5000 | IND2 |
| 0040 | RES1 |
| 0051 | RES3E |

### 2.2.5. Hazus-MH Geodatabase development

The local tax assessor data from both counties were compiled into Hazus-MH compliant datasets. The local tax assessor's parcel data were shape-files in the North American Datum 1983 State Plane Illinois West Coordinate System. Datum transformations were made to parcel layer converting them to Geographic Coordinate System North American 1983. Next the parcel features were converted to parcel points using the feature-to-point tool in ArcGIS. Then the latitude and longitude of the parcel points were calculated in ArcGIS. These points were then spatially joined to census block and census tract layer files. The points outside of the census block were deleted. The local tax assessor parcel-point layer were exported to a text file and then imported into Microsoft (M.S.) Excel 2010 for additional editing. In M.S. Excel, the parcel points without buildings (i.e., unimproved [vacant] parcels or right-of-ways, etc.) were removed from the dataset because locations (points) without structure do not influence the flood loss modeling results. The following first figure shows the original parcel point's buildings from local tax-assessor and second figure shows parcels with buildings only that has assess value.

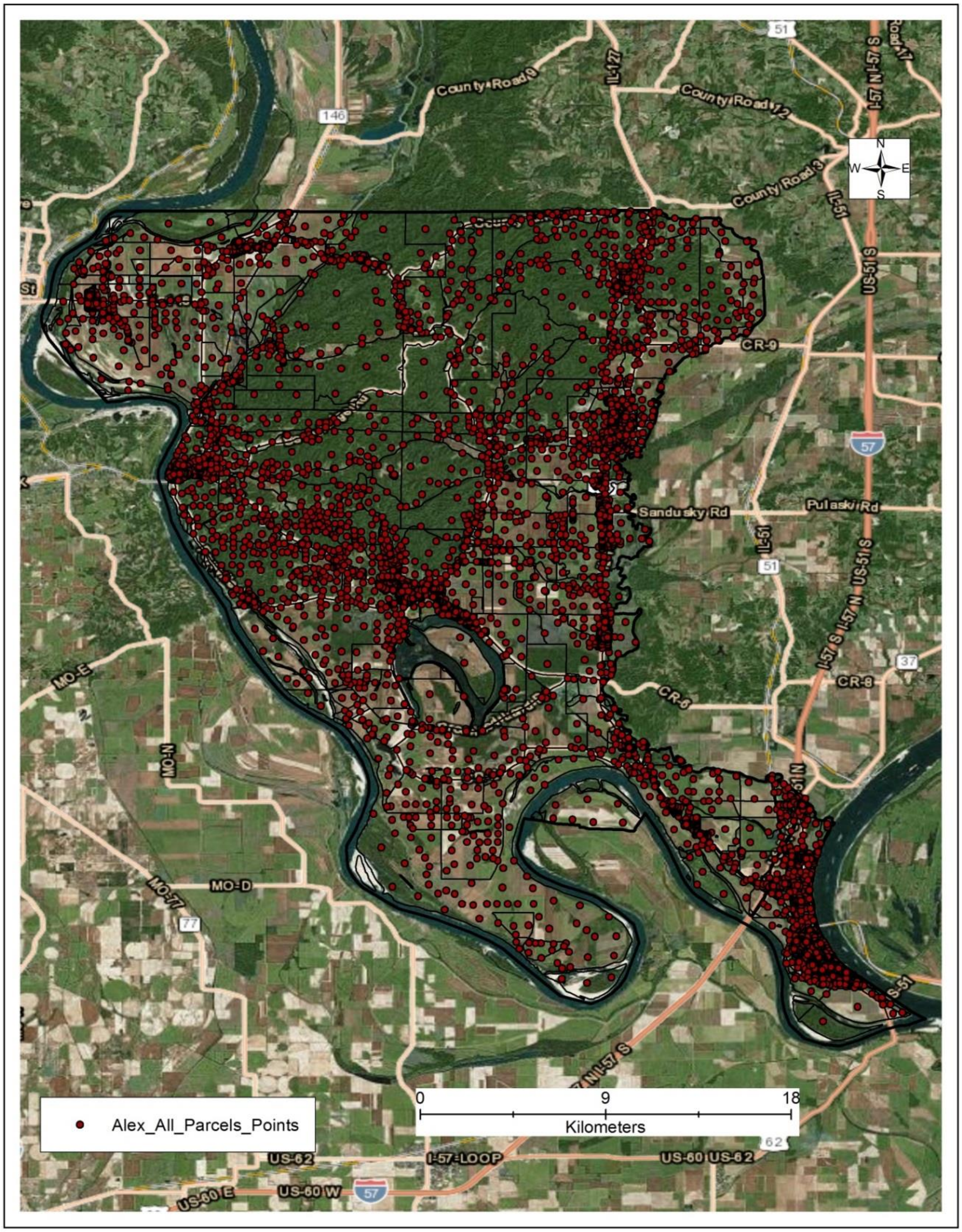


Figure 2.4 – Alexander County map with all parcels points

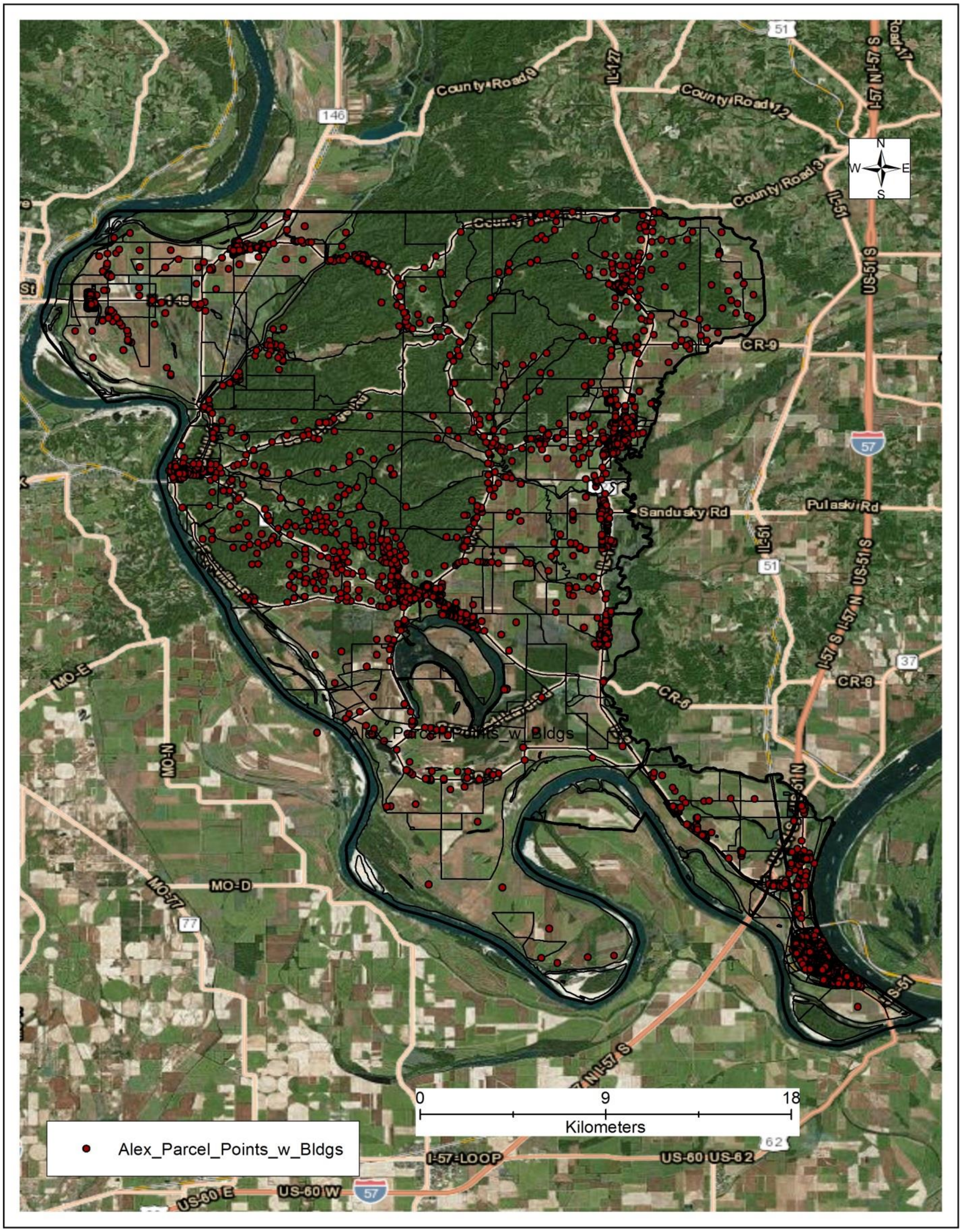


Figure 2.5 – Alexander County parcel points map showing only the parcels with buildings and assessed values

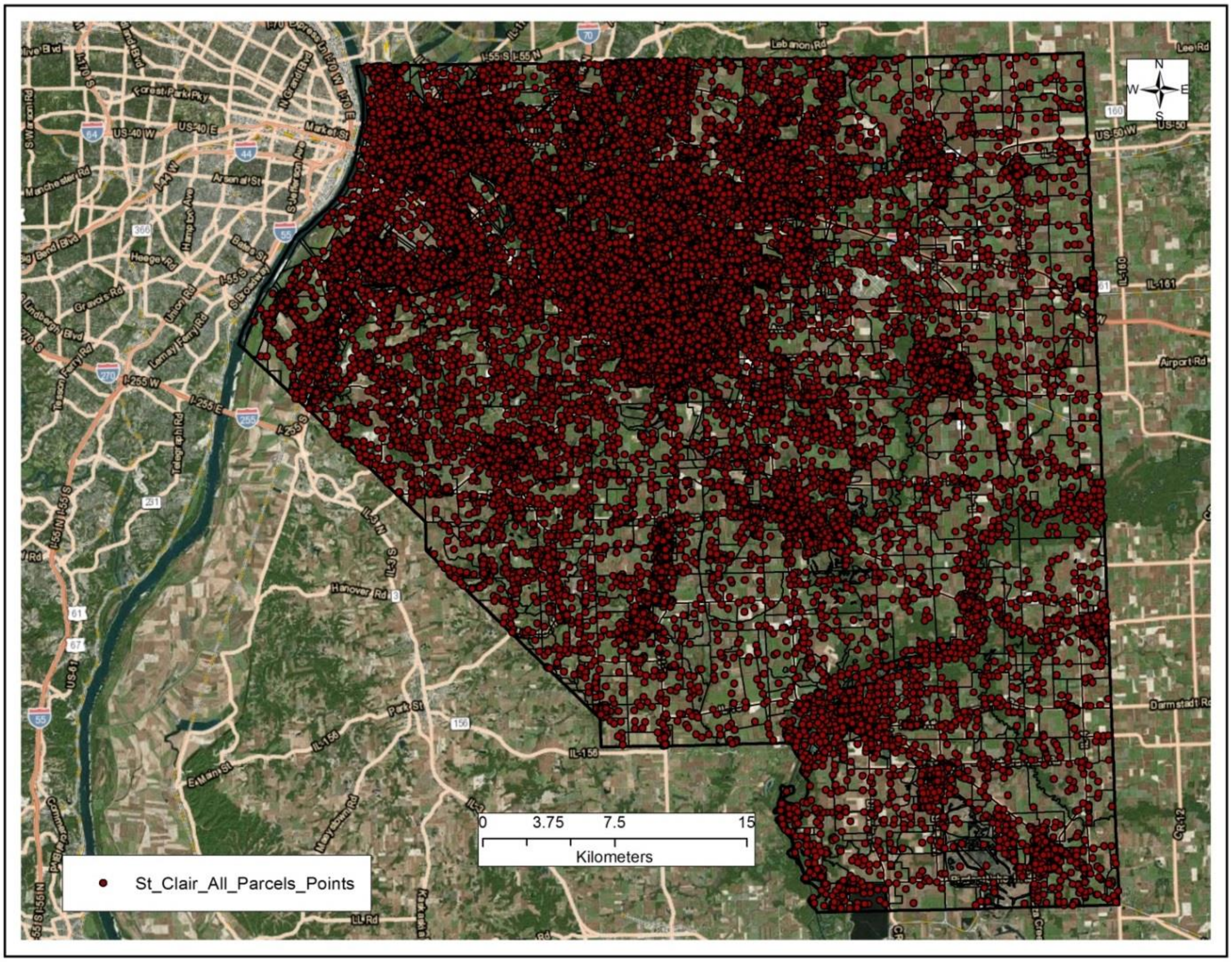


Figure 2.6 – St. Clair County map with all parcels points mapped

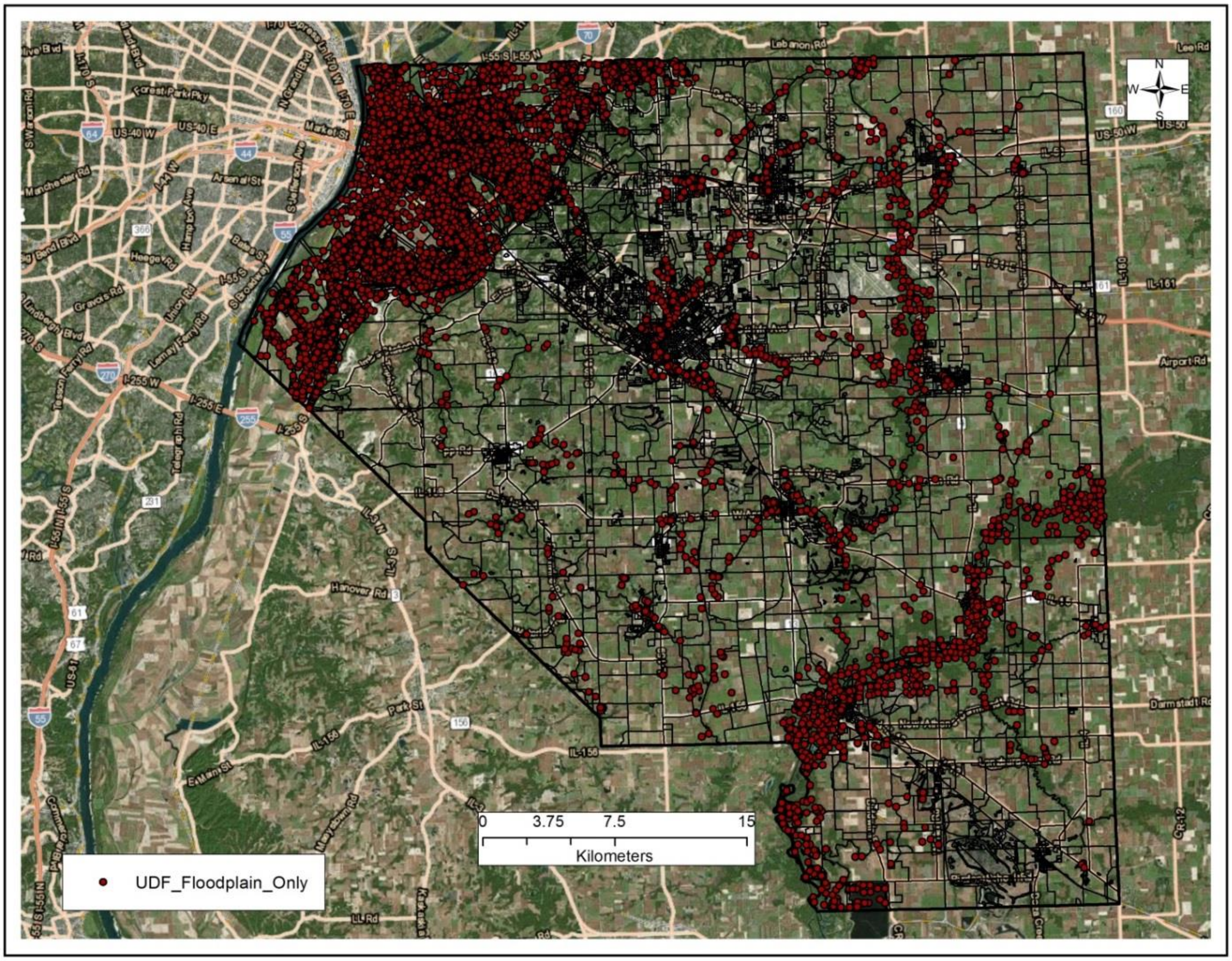


Figure 2.7 – St. Clair County map with parcels which contain buildings within the 100-year floodplain

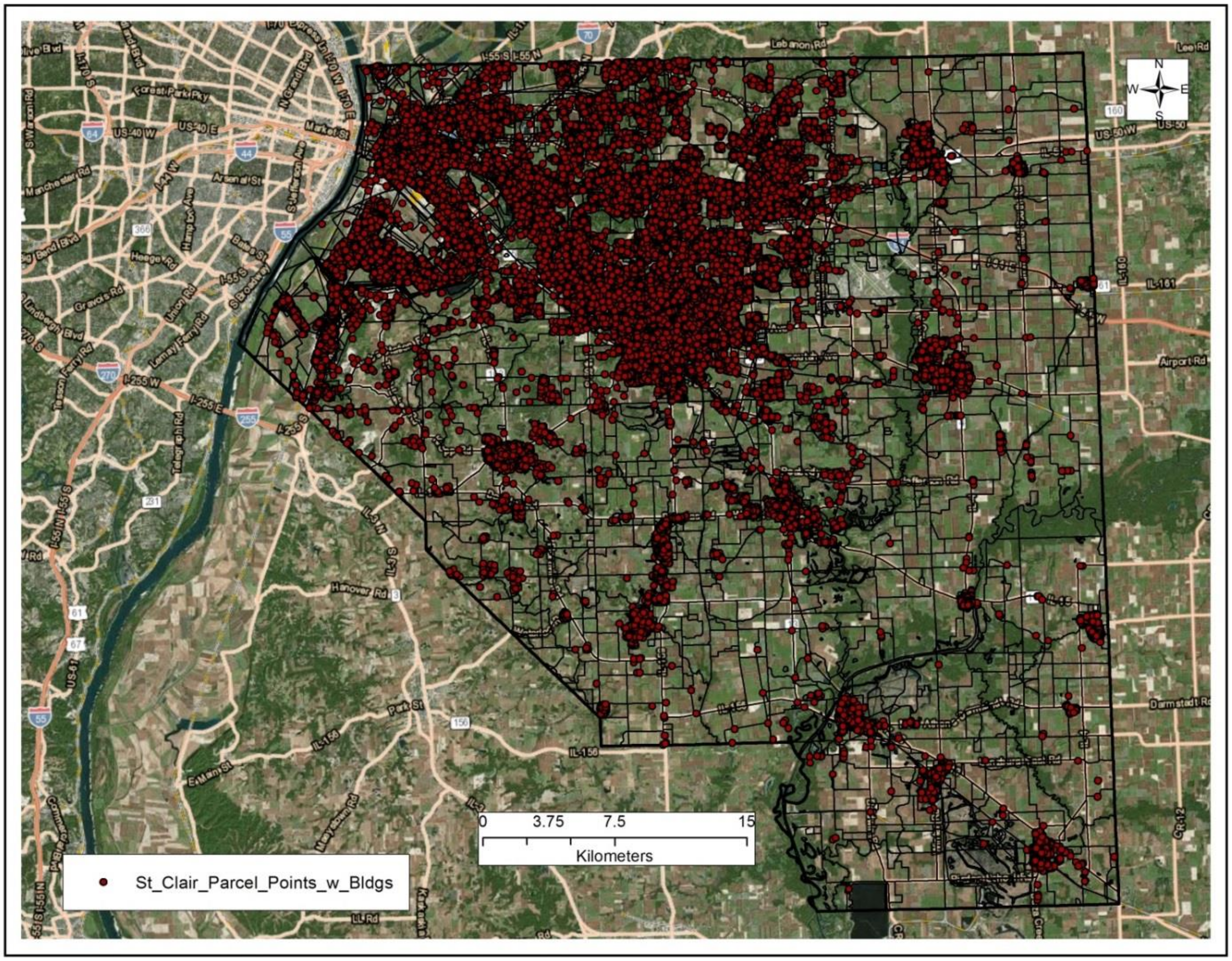


Figure 2.8 – St. Clair County parcel point map showing only the parcels with buildings

In M.S. Excel building parameters field names and the associated values were added to the dataset. The parameters added included: square footage, building type, building age, and number of stories, foundation type and its associated first floor heights. The local tax assessor land-use codes were matched with the corresponding Hazus-MH occupancy classes. The local tax assessor data contained the assessed value for each structure. To convert the assessed value for a given structure to fair market value the assessed value was multiplied by three. This calculation was under taken because the assessed value of a property in Illinois is approximately 1/3 the Fair Market Value (FMV) (Illinois Dept of Revenue 2010). The content costs were estimated based on specific occupancy and building cost. Table 2.2 shows the content costs factors developed by FEMA for each general occupancy class (FEMA 2012a, FEMA 2012b). For example RES1 is single family housing; its content cost is calculated multiplying the FMV building cost by 0.5 i.e. the content cost factor. Similarly the COM is Commercial buildings, IND is Industrial buildings, ARG is Agriculture buildings, GOV is Government buildings, COM is Commercial building, and EDU is Educational buildings. The content cost and buildings fair market values were added together to determine the total value of each building.

Table 2.2– Content cost factor for specific occupancies (please see acronym list for description of table abbreviations within the table below)

| Occupancy Class | Content Cost Factor |
|---|---|
| RES 1 to RES 6 and COM 10 | 0.5 |
| COM 1 to COM 5, COM8, COM 9, IND6, ARG1, GOV1, EDU 1 | 1.0 |
| COM 6 and 7, IND 1 to 5, GOV2 and EDU2 | 1.5 |

The assessor's data for Alexander and St. Clair Counties did not contain any data pertaining to buildings, construction type or foundation types. In this study, it was assumed the constructions of all buildings were a single story building of constructed of wood with a concrete slab foundation. For the sensitivity analysis performed, in this study the first floor height was based on foundation type. The Hazus-MH complaint dataset are imported into M.S. Assess 2003 to edit the building parameter data types. For each parameters/field following specific data-type and its size described in Table 2.3 were entered in-order to prepare Hazus-MH and SQL data compliant. For UDF analysis, the final geodatabase is imported into the Hazus-MH study region.  In the case of the aggregate analysis, the geodatabase was imported using CDMS replacing the default GBS in the statewide inventory database of each respective county.

Table 2.3 – Building parameter data types with its field size

| Field | Description | Type | Field Size |
|---|---|---|---|
| Name | | Text | 40 |
| Address | | Text | 40 |
| City | | Text | 40 |
| State | | Text | 2 |
| Zipcode | | Text | 10 |
| Contact | | Text | 40 |
| PhoneNumber | | Text | 14 |
| Building Age | Building Age | Number | Integer |
| Cost | Replacement cost | Currency | 8 |
| NumStories | Number of Stories | Number | Byte |
| Area | Square footage | Number | Single |
| ContentCost | | Currency | 8 |
| Latitude | X | Number | Double |
| Longitude | Y | Number | Double |
| Bldgtype | Construction Type | Text | 15 |
| DesignLevel | Design Level | Text | 1 |
| FoundationType | | Text | 1 |
| FirstFloorHeight | First floor elevation | Number | Double |
| Occupancy | Type of occupancy | Text | 5 |
| Block | Census Block | Text | 15 |
| Tract | Census Tract | Text | 11 |

### 2.2.6. Damage Survey

During the 2011 Mississippi River Flood, large portions of Alexander County were inundated. After the flood, a damage survey was performed in the Olive Brach Area of the county. This survey was performed by the local floodplain manager with assistance from Southern Illinois University, Carbondale and the Illinois Department of Natural Resources Office of Water Resources. Flood damage data was collected for 82 buildings within the Olive Branch area. The data collected included the location, the assessed value, percent damage, and other attributes for each of the damaged buildings. This damage survey data was used in this study for a validation analysis.

### 2.3. Sensitivity Analyses

In this study six building parameters were analyzed using the Olive branch area UDF database (Table 2.4) to test their sensitivity for Hazus-MH flood-loss. We used the result from these sensitivity analyses to guide which parameters we would test using the larger UDF, default GBS and updated GBS datasets for Alexander and St. Clair Counties. The parameters test which did not affect flood-loss estimates were not assessed using the larger datasets. However one parameter, square footage, was tested using all the datasets because the Hazus-MH Flood Manual indicated it was a key flood-loss modeling parameter (FEMA 2012a). The section below discusses in detail the sensitivity analysis scenarios.

For these sensitivity scenarios, the same flood scenario was employed in each model run. The flood scenario modeled was the inundation of the 100-year floodplain in both Alexander and St. Clair Counties. While this is not a realistic flood scenario because it is highly unlikely that all streams and river is these counties would flood to exactly the 100-year event at the same time, it provides a useful scenario from which to compare flood-loss estimates. Each county's DFIRM was used to delineate the 100-year floodplain boundary and the enhanced quick look tool and the USGS's 1/3-Arc Second DEM were used to generate the flood-depth grid. The protection the levees would provide to, many of these floodplain structures in these counties were not take into consideration in this study.

### 2.3.1. Building Inventory Data Models

In Hazus-MH flood loss analysis, aggregate model assumes the uniform distribution of building inventory in the census block and uses an area weighted method for assessing flood losses. This method of loss estimation may be ambiguous in comparison to actual loss because this methods takes into account of the uniform inventories in all census block, which is not correct in reality and the distribution of inventories are generally less dense along the floodplains (ASFPM 2010a). Hazus-MH loss estimates using a UDF database are modeled as individual building as opposed to the weighted area approach in the Hazus-MH aggregate data model. Hazus-MH flood-loss estimates using aggregate data model can be improved if the national level data is replaced with local data. In some instances the aggregate data model may be preferred approach if the study region is very large (e.g., multiple counties or statewide), only relative flood losses assessment is needed, or if other Hazus-MH flood-loss estimates, such as indirect losses, are need for a particular flood-loss study.

Here the difference in Hazus-MH flood-loss estimates was assessed using three different building inventories: 1) the Hazus-MH default aggregate GBS inventory, 2) updated aggregate inventory, and 3) UDF inventory. The local tax assessor data was used to replace the default (statewide) data in the aggregate model by importing them into the statewide inventory geodatabase through CDMS. New study regions were created with the local data and modeled as aggregate analysis. The Hazus-MH formatted tax-assessor datasets from both counties were imported into new study region every time as a UDF database containing individual buildings these three analyses also allowed for comparison of the flood-loss estimates for the same region and how the results varied at the county level.

### 2.3.2. Aggregate Building Parameters

Based on the flood-loss modeling results from Olive Branch Area, sensitivity analyses were performed on the following parameters: foundation type and associated first floor heights, number of stories and square-footage. For the aggregate analysis the number of stories were adjusted in the updates GBS. The square footage and foundation types and associated first floor heights for the aggregate analysis were adjusted both in the aggregate database and the Hazus-MH Flood Specific Occupancy Mapping window. The numbers of stories were adjusted from single to two story buildings and the national average square footage was reduced by 25% for all occupancies in these sensitivity analyses. Local assessor data were aggregated with these building parameters and ran flood-loss model as UDF and Aggregate analysis for the Alexander and St. Clair County, to check if those parameters support or counter previous results.

### 2.3.3. Scenario development for sensitivity analysis

For the sensitivity analysis performed in this study, four scenarios, five sub-scenarios and 28 models were performed. The following Figure 2.4 shows the progression of the sensitivity analysis scenarios. The sub- scenarios and model are described in their respective sections below.

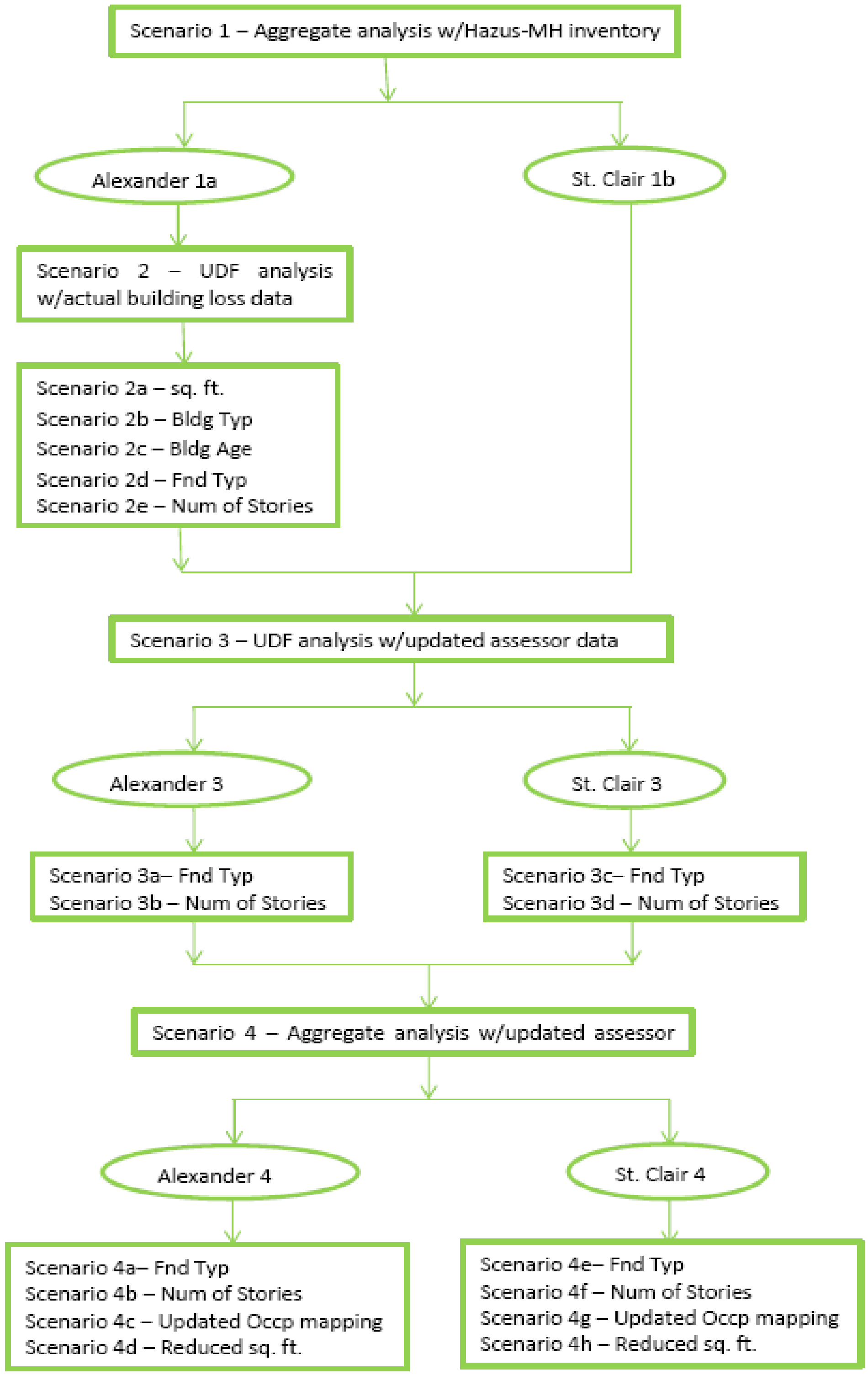


Figure 2.9 – Flow chart showing the sensitivity assessment scenario development for the level 1 and 2 aggregate and UDF models with their associated datasets. Please see abbreviation list for unspecified abbreviations in this figure

**Sensitivity Scenario 1** (Level 1)

In Scenario 1 Hazus-MH default GBS inventory was used to estimate flood-losses in the 100-year floodplain. This analysis provides loss-estimates based on default inventory and the total building exposure within the 100-year floodplain for each county.

**Sensitivity Scenario 2** (Level 2)

The second scenario was undertaken using flood-damaged buildings datasets from Olive Branch Area of Alexander County. The sub-scenarios and model runs for the sensitivity analyses performed are listed in Table 2.4. This analysis allowed us to select the sensitive building parameters which affected Hazus-MH flood loss estimates for further assessment and at the county level scale.

Table 2.4 – Building parameter sub-scenarios with sub-models

| Sub-scenarios | Building Parameters | Model Parameter Tested |
|---|---|---|
| Scenario 2a | Square Footage | National Average |
| | | Building Footprints |
| Scenario 2b | Construction type | Wood |
| | | Manufactured House |
| Scenario 2c | Build Age | 1950 |
| | | 1995 |
| Scenario 2d | Foundation Type | Solid wall |
| | | Basement |
| | | Crawl space |
| | | Slab on grade |
| Scenario 2e | Number of stories | 1 |
| | | 2 |
| Scenario 2f | First Floor heights | 7ft. |
| | | 4ft. |
| | | 3ft. |
| | | 1ft. |

**Sensitivity Scenario 3** (Level 2)

The third scenario was a UDF analysis using a spatially explicit database constructed using local tax assessor datasets. The UDF analysis was performed for the 100-year floodplain in both Alexander and St. Clair Counties.

**Sensitivity Scenario 4** (Level 2)

The fourth scenario were aggregate analyses which employed updated building inventory databases using local tax assessor records for both Alexander and St. Clair counties. These analysis total loss results will allow us to compare each counties total loss at level 1 and level 2 and differentiate the total loss-estimates with each model.

### 2.4. Validation Assessment

Hazus-MH flood losses estimates were compared to flood losses for the 2011 Mississippi River Flood in the Olive branch area of Alexander County. The intent of this validation assessment was to determine how realistic flood losses estimates are for a small rural jurisdiction. The validation assessment was performed as UDF analysis for 82 damaged building with building parameters collected from site and compared to percentage damage to the buildings. The map below shows the point location of actual damaged buildings in Olive Branch Area, Alexander County. The user supplied flood-depth grid for this scenario were developed using actual observed peak flood elevations and USGS 1/3-Arc Second DEM.


Figure 2.10 – Point locations of actual damaged buildings in Alexander County

# CHAPTER 3

## 3.0 Results

### 3.1. Sensitivity analysis

#### 3.1.1. Scenario 1 (Aggregate - Level 1)

**Alexander County (Scenario 1a)**

Alexander County has 1106 census blocks which the default GBS inventory estimates a building count of nearly 5,200 buildings. Within the 100-year floodplain Hazus-MH estimates $ 351 million building value and $ 213 million contents is exposed to potential inundation. The Hazus-MH flood-loss model using the GBS inventory database (level-1 analysis) estimates there will be approximately $ 20 million in total losses with nearly $ 9 million in buildings losses and $ 11 million in content losses. The estimated loss ratio (losses/exposure) for this scenario was 0.035 (Table 3.1).

**St. Clair County (Scenario 1b)**

St. Clair County has 8645 census blocks which the default GBS inventory estimates a building count of nearly 110,000 buildings. Within the 100-year floodplain Hazus-MH estimates $ 7.5 billion building value and $ 4.6 billion contents is exposed to potential inundation. The Hazus-MH flood loss model using the GBS inventory database (level-1 analysis) estimates there will be approximately $ 493 million in total losses with approximately $ 225 million in buildings losses and $ 268 million in content losses. The estimated loss ratio for this scenario was 0.040 (Table 3.2). It is important to point out this scenario does do not account for the levees which protect much of the Metro-East St. Louis communities located within the Mississippi River Floodplain.

Table 3.1– Results for Alexander County sensitivity analyses showing the exposures and loss-estimates values. All values are in thousands of dollars. *Scenarios with equivalent losses

| **Aggregate-Level 1** | **Scenario 1** | | **Building Value** | **Content Value** | **Total Losses** |
|---|---|---|---|---|---|
| Exposure | | | $ 350,565 | $ 213,462 | $ 564,027 |
| Losses | 1a | Hazus Default | $ 8,894 | $ 10,946 | $ 19,840 |
| Loss ratio | | | 0.025 | 0.051 | 0.035 |
| | | | | | |
| **UDF-Level 2** | **Scenario 2** | | **Building Value** | **Content Value** | **Total Losses** |
| Exposure | | | $ 5,321 | $ 2,660 | $ 7,981 |
| Losses | 2a | National Average* | $ 1,024 | $ 480 | $ 1,505 |
| | | Building Footprints* | $ 1,024 | $ 480 | $ 1,505 |
| | 2b | Wood* | $ 1,024 | $ 480 | $ 1,505 |
| | | Manufactured House* | $ 1,024 | $ 480 | $ 1,505 |
| | 2c | Building Age 1950* | $ 1,024 | $ 480 | $ 1,505 |
| | | Building Age 1995* | $ 1,024 | $ 480 | $ 1,505 |
| Loss ratio | | | 0.192 | 0.180 | 0.188 |
| Losses | 2d | Solid wall | $ 16 | $ 7 | $ 23 |
| Loss ratio | | | 0.003 | 0.002 | 0.002 |
| Losses | | Basement | $ 405 | $ 143 | $ 548 |
| Loss ratio | | | 0.076 | 0.053 | 0.068 |
| Losses | | Crawl space | $ 229 | $ 104 | $ 333 |
| Loss ratio | | | 0.043 | 0.039 | 0.041 |
| Losses | | Slab on grade | $ 1,024 | $ 480 | $ 1,505 |
| Loss ratio | | | 0.192 | 0.180 | 0.188 |
| Losses | 2e | Num of stories 2 | $ 692 | $ 310 | $ 1,002 |
| Loss ratio | | | 0.130 | 0.116 | 0.125 |
| | | | | | |
| **UDF-Level 2** | **Scenario 3** | | **Building Value** | **Content Value** | **Total Losses** |
| Exposure | | | $ 97,339 | $ 76,763 | $ 174,102 |
| Losses | 3a | Solid wall | $ 1,158 | $ 2,379 | $ 3,537 |
| Loss ratio | | | 0.012 | 0.030 | 0.020 |
| Losses | | Basement | $ 4,057 | $ 3,861 | $ 7,918 |
| Loss ratio | | | 0.042 | 0.050 | 0.045 |
| Losses | | Crawl space | $ 2,855 | $ 3,711 | $ 6,565 |
| Loss ratio | | | 0.029 | 0.048 | 0.038 |
| Losses | | Slab on grade | $ 7,787 | $ 7,318 | $ 15,105 |
| Loss ratio | | | 0.080 | 0.095 | 0.087 |
| Losses | 3b | Num of stories 2 | $ 5,499 | $ 6,108 | $ 11,607 |
| Loss ratio | | | 0.056 | 0.08 | 0.067 |

| Aggregate-Level 2 | Scenario 4 | | Building Value | Content Value | Total Losses |
|---|---|---|---|---|---|
| Exposure | | | $ 97,339 | $ 76,763 | $ 174,102 |
| | 4a | Solid wall* | $ 2,913 | $ 5,010 | $ 7,923 |
| | | Basement* | $ 2,913 | $ 5,010 | $ 7,923 |
| | | Crawl space* | $ 2,913 | $ 5,010 | $ 7,923 |
| | | Slab on grade* | $ 2,913 | $ 5,010 | $ 7,923 |
| | 4b | Num of stories* | $ 2,913 | $ 5,010 | $ 7,923 |
| | 4c | Updated BI -Default Occupancy Mapping* | $ 2,913 | $ 5,010 | $ 7,923 |
| | 4d | Reduced sq. ft.* | $ 2,913 | $ 5,010 | $ 7,923 |
| Loss ratio | | | 0.03 | 0.065 | 0.046 |

Table 3.2 – Results for St. Clair County sensitivity analyses with the exposures, loss-estimates values. All values are in thousands of dollars. *Scenarios with equivalent losses

| Aggregate-Level 1 | Scenario 1 | | Building Value | Content Value | Total Losses |
|---|---|---|---|---|---|
| Exposure | | | $ 7,511,279 | $ 4,684,486 | $ 12,195,765 |
| Losses | 1b | Hazus Default | $ 224,824 | $ 268,234 | $ 493,058 |
| Loss ratio | | | 0.030 | 0.057 | 0.040 |
| | | | | | |
| **UDF-Level 2** | **Scenario 3** | | **Building Value** | **Content Value** | **Total Losses** |
| Exposure | | | $ 1,120,034 | $ 804,352 | $ 1,924,385 |
| Losses | 3c | Solid wall | $ 39,938 | $ 37,749 | $ 77,687 |
| Loss ratio | | | 0.036 | 0.047 | 0.040 |
| Losses | | Basement | $ 125,270 | $ 80,594 | $ 205,863 |
| Loss ratio | | | 0.112 | 0.100 | 0.107 |
| Losses | | Crawl space | $ 87,887 | $ 90,189 | $ 178,077 |
| Loss ratio | | | 0.078 | 0.112 | 0.093 |
| Losses | | Slab on grade | $ 195,147 | $ 171,843 | $ 366,990 |
| Loss ratio | | | 0.174 | 0.214 | 0.190 |
| Losses | 3d | Num of stories | $ 140,273 | $ 145,744 | $ 286,017 |
| Loss ratio | | | 0.125 | 0.181 | 0.149 |
| | | | | | |
| **Aggregate-Level 2** | **Scenario 4** | | **Building Value** | **Content Value** | **Total Losses** |
| Exposure | | | $ 6,815,972 | $ 4,451,275 | $ 11,267,247 |
| | 4e | Solid wall* | $ 97,779 | $ 90,462 | $ 188,241 |
| | | Basement* | $ 97,779 | $ 90,462 | $ 188,241 |
| | | Crawl space* | $ 97,779 | $ 90,462 | $ 188,241 |
| | | Slab on grade* | $ 97,779 | $ 90,462 | $ 188,241 |
| | 4f | Num of stories* | $ 97,779 | $ 90,462 | $ 188,241 |
| | 4g | Updated BI -Default Occupancy Mapping* | $ 97,779 | $ 90,462 | $ 188,241 |
| | 4h | Reduced sq. ft.* | $ 97,779 | $ 90,462 | $ 188,241 |
| Loss ratio | | | 0.014 | 0.020 | 0.017 |

#### 3.1.2. Scenario 2 (UDF - Level 2)

Scenario 2 modeled 82 buildings which were damaged in the 2011 Mississippi River within Alexander County. The occupancy classes for these building were all residential (specifically single family homes [RES1], manufactured housing [RES2], and apartments [RES4]. The sensitivity analysis performed here were to assess the effects of different damage parameters (Square Footage, Construction Types, Building Age, Foundation Types, and Number of Stories) on Hazus-MH UDF flood-loss estimates. The building parameters that were found to substantially affect the flood-loss results were then assessed at the county level to provide insight into the impact these parameters have on larger spatial scale of flood-loss modeling (See scenario 3 and 4).

**Square footage (Scenario 2a)**

In scenario 2a, building square footage was evaluated here to assess the uncertainty in applying national averages for a particular occupancy to buildings in which square footage was unknown. This assessment was accomplished by comparing flood-loss estimates for the 82 building Alexander county flood-damage dataset using average national square footage based on their respective occupancy class and square footage determine from building footprints. Using the national averages to estimate total square footage estimate for these 82 buildings in the flood damage dataset was 1,599,050 sq. ft. Using building footprints to estimate building square footage suggested these buildings encompasses an area of only 112,025 sq. ft. which ~14 times less than the square footage estimated using national averages. The large discrepancy in square footage between the using the national average and the building foot print was largely drive by the RES4 occupancy classes. The estimates for RES4 occupancy class differed by -5354%, where the estimates for RES1 and RES2 occupancies differed by 24% and 71% respectively Table 3.3. Despite the substantial differences in square footage, the flood-loss results were identical for both estimates of square footage, total loss of $ 1.5 million with approximately $ 1 million in building related losses and $ 0.5 million in content related losses. The flood-loss ratios for both sensitivity analyses were estimated to be 0.189 Table 3.1. These results suggest square footage is not an important parameter for determining flood losses in Hazus-MH using the UDF flood-loss modeling model.

Table 3.3 – Comparison of National Average Square (sq.) Footage (ft.) vs. Building Footprint Estimated Square Footage in Alexander County

| Occupancy | No of Buildings | Total Sq. Ft | National Average Sq. Ft. | Building Footprints Sq. Ft. | Average Sq. Ft. in Alexander County | Percent Difference |
|---|---|---|---|---|---|---|
| **RES1** | 53 | 84,800 | 1,600 | 110,890 | 2,092 | 24% |
| **RES2** | 18 | 29,250 | 1,625 | 101,377 | 5,632 | 71% |
| **RES4** | 11 | 1,485,000 | 135,000 | 27,226 | 2,475 | -5,354% |
| **Total** | 82 | 1,599,050 | | 239,493 | | |

### Construction Types (Scenario 2b)

In scenario 2b, building construction types, such as wood frame, masonry, or manufactured housing were assessed for their influence on Hazus-MH UDF flood-loss estimates. For this scenario, only two construction types were assessed wood framed and manufactured housing. Despite the differences in these construction types, the flood-loss results were identical for these construction types. Total flood losses were estimated to be $ 1.5 million with approximately $ 1 million in building related losses and $ 0.5 million in content related losses for both scenarios. The flood-loss ratios for both sensitivity analyses were estimated to be 0.189 (Table 3.1). These results suggest building construction type is not an important parameter for determining flood losses in Hazus-MH using the UDF flood-loss modeling model.

### Building Age (Scenario 2c)

In scenario 2c, building age was assessed for its impact on Hazus-MH flood-losses. Building age is a model parameter because it can be assumed buildings constructed after the passage of the Flood Insurance Act (FIA) of 1968 were more likely constructed to better withstand the impacts of the 100-year flood. Here the years of 1950 (prior to the implementation of building requirement in the FIA for flood prone buildings) and 1995 (after the implementation of building requirement in the FIA for flood prone buildings) were assessed for their impact on Hazus-MH UDF estimated flood-losses. Like the previously sensitivity analysis, the age of the building did not impact flood losses. The total flood losses for the assessed scenarios were both estimated to be $ 1.5 million with approximately $ 1 million in building related losses and $ 0.5 million in content related losses. The flood-loss ratios for both sensitivity analyses were estimated to be 0.189 (Table 3.1). These results suggest building age is not an important parameter for determining flood losses using Hazus-MH's UDF flood-loss modeling model.

### Foundation Types (Scenario 2d)

In scenario 2d, foundation types (i.e., solid wall, basement, crawl space, and slab on grade) were assessed for their effect on Hazus-MH flood-loss estimates. This analysis found buildings with solid wall and crawl space foundation types had less damage, and consequently lower flood losses, compared to structures with basements or slab on grade foundation type.

The assessment for solid wall foundation was found to have the lowest flood losses with $ 23,000. The assessment for crawl space and basements was found to have losses between $ 0.3 and $ 0.5 million. The total flood-loss estimate for all structures with slab on grade foundation was the highest at $ 1.5 million (Table 3.1).

#### Number of stories (Scenario 2e)

In scenario 2e, the number of stories was assessed for its influence on the flood-loss estimates. Here 1- and 2- story structures were assessed for occupancy classes RES 1 and RES3. RES2 are manufactured housing which is assumed to be single story structures (FEMA 2012a, FEMA 2012b). Total flood losses for all RES1 and RES3 structures of two-story construction were estimated to be ~ $ 1 million with approximately $ 0.7 million in building-related losses and $ 0.3 million in content related losses. The flood-loss ratios for both sensitivity analyses were estimated to be 0.125 (Table 3.1). The results differ from all structures assumed to be 1-story suggesting the number of stories in an important flood-loss modeling parameter for the Hazus-MH UDF analysis (see Scenario 2a).

### 3.1.3. Scenario 3 (Countywide UDF Flood-Loss Analysis - Level 2)

The sensitivity analysis performed in section 3.1.2 found the Hazus-MH UDF flood-loss model to be sensitive to foundation type and number of stories. To better understand the uncertainty in the selection of foundation type and number of stories (scenarios 2d and 2e) flood-loss parameters on Hazus-MH flood-loss estimates at the county-level scale, two additional sensitivity analyses were performed. These assessments utilized local tax-assessor data from Alexander and St. Clair Counties.

**Alexander County [Scenario 3- Foundation Types (a) and Number of stories (b))**

Alexander County's local tax assessor data contained 8196 land parcel (Figure 5.1). Of these parcels, 3584 contained structures (Figure 5.2) located with the regulatory (100-year) floodplain mapped by FEMA for the NFIP. The estimated fair market values of these building (flood exposure) was $ 174 million. Pattern of losses observed in the sensitivity analyses for scenarios 2d and 2e were also observed in the Alexander County- wide assessments. For foundation type parameters, solid wall foundation had the smallest total flood-loss estimate of $ 3.5 million, followed by $ 6.5 million in total flood losses for crawl space, $ 8 million for basement foundations and $ 15 million in total losses for slab on grade foundations. Increasing the number of stories from 1 to 2 stories decreased in the total estimated flood losses by 23% ($11.6 million; [Table 3.1]).

**St. Clair County [Scenario 3- Foundation Types (c) and Number of stories (d)]**

St. Clair County's local tax assessor data contained 25,157 land parcels (Figure 5.3). Of these parcels, 17,960 contained structures located with the 100-year floodplain. It is important to note the structures in this estimates of flood vulnerable structures includes >15,000 building protected by levees which exceed the 100-year flood-protection level. These buildings were included in this analysis to assess the impact of Hazus-MH flood-loss model parameterization on a large population of at risk buildings. The total exposure of these 17,960 buildings is estimated to be approximately $ 2 billion. The sensitivity analysis performed here agreed with the trends observed in scenarios 2d, 2e, and 3a. The solid wall foundation had the smallest total flood-loss estimate of $ 78 million, followed by $ 178 million for crawl space, $ 205 million in flood losses for basement foundations and $ 366 million in flood losses for slab on grade foundations. Increasing the number of stories from 1 to 2 stories decreased in the total estimated flood losses by 22% less ($286 million) than compared to all structures being 1 story (Table3.2).

### 3.1.4. Scenario 4 (Countywide Aggregate Flood-Loss Analysis - Level 2)

For sensitivity analysis performed in Scenario 4, the default Hazus-MH general building stock was updated using local tax assessor data  for the both Alexander and St. Clair Counties. Then individual sensitivity analyses were performed for the foundation types and number of stories by changing the flood occupancy mapping scheme within Hazus-MH.

#### Alexander County (Scenario 4)

The sensitivity of flood-loss modeling results to the selection of foundation type and number of stories using an update GBS were also assessed. The pattern of changes in flood losses observed in the previous foundation type sensitivity analyses were not observed in the Alexander County sensitivity analyses. The flood-loss estimates for all foundation types and number of stories were the same as Scenario 4 (Updated GBS Inventory with default Hazus-MH occupancy mapping scheme [Table 3.2]). The sensitivity analysis for the Hazus-MH flood loss-modeling tool using the updated BGS inventory suggests foundation type and number of stories are not important when using this flood-loss aggregate model.

#### St. Clair County (Scenario 4)

The sensitivity of flood-loss modeling results to the selection of foundation type and number of stories using an update GBS were also assessed. Like the Alexander County updated GBS sensitivity analysis flood losses did not change when modifications to foundation and first-floor height were made. The flood-loss estimates for all foundation types and number of stories were the same as Scenario 4 (Updated GBS Inventory with default Hazus-MH occupancy mapping scheme; [Table 3.3]). The sensitivity analysis for the Hazus-MH flood loss-modeling tool using the updated GBS inventory suggests foundation type and number of stories are not important when using this flood-loss model.

### 3.2. Validation Assessment

To assess the ability of Hazus-MH to realistically model flood losses, comparisons between the Hazus-MH flood-loss estimates to flood-damage assessments performed after 2011 Mississippi River flood damage survey in Olive Branch area within Alexander County. The field flood-damage data were collected for 82 buildings which were comprised of residential occupancies [RES1, RES2, and RES4] Hazus-MH UDF flood-loss model estimated $ 3.2 million total loss with $ 2.1 million in direct building related losses and $ 1.1 million in content losses. The total loss ratio was 0.405. The 2011 observed damage survey estimated $ 4.2 million total loss with the loss ratio of 0.53 (Table 3.4). The Hazus-MH loss model estimated the total damage of about 77% of the observed damage. Hazus-MH estimated the average building loss of $ 25,000 and the observed average building loss of $ 34,000.

Table 3.4 – Results for validation assessment of Alexander County with exposures, loss-estimates values. All values are in thousands of dollars

| Validation Assessment | | Building Value | Content Value | Total Value |
|---|---|---|---|---|
| Exposure | | $ 5,321 | $ 2,660 | $ 7,981 |
| Losses | Hazus-MH Damage | $ 2,086 | $ 1,147 | $ 3,233 |
| Loss ratio | | 0.392 | 0.431 | 0.405 |
| Losses | Observed Damage | $ 2,786 | $ 1,393 | $ 4,178 |
| Loss ratio | | 0.523 | 0.523 | 0.523 |

**CHAPTER 4**

# 4.0 Discussions

## 4.1. Comparison of Building Inventories

Comparing rural Alexander County's exposure estimates derived from the local tax assessor records to the total exposure estimate using the Hazus-MH default GBS database revealed the Hazus-MH based default total exposure ($ 564 million) is greater by factor of 3 than exposure estimates based on local tax assessor records ($ 174 million). Similarly, comparing the more urban St. Clair County's exposure estimates derived from the local tax assessor records to the total exposure estimate using the Hazus-MH default GBS database revealed the Hazus-MH based default total exposure ($ 12 billion) is greater by factor of 1.08 than exposure estimates based on local tax assessor records ($ 11 billion). This limited comparison suggests the default GBS within Hazus-MH may more realistically model urban jurisdictions than rural ones.   It also provides an assessment of scale of uncertainty in flood-loss estimates which may be attributed to using the default HAZUS-MH aggregate data model, in place of an aggregate- or UDF- data model constructed from local tax assessor's data. This finding is consistent with the guidance provided in the Hazus-MH user manual (FEMA 2012a, FEMA 2012b).

## 4.2. Sensitivity Analysis

### 4.2.1. UDF Flood-Loss Sensitivity Analysis

From the sensitivity analyses performed in Alexander and St. Clair Counties (Scenario 2 and 3) it was found that the foundation types and number of stories were sensitive building parameters in the Hazus-MH UDF flood-loss model. Foundations are structures on which buildings stand, hence it plays a crucial role to resist flood damages. Each foundation type has its associated first floor height above grade. Foundations are characterized by the type of materials as base of structure to withstand the load of building. Slab on grade foundations have an associated first floor height of 1 ft. above grade, which means during the flooding, flood water may reach higher to the exterior wall of building compared to crawlspace, basement, and solid wall foundation types whose first floor heights are higher (3,4, and 7 feet, respectively). Hence, the sensitivity analysis scenario with all structures being slab on grade produces the largest flood losses. The sensitivity analysis scenario with all structures having basement had the second largest flood losses. This is despite having a higher first floor elevation that structures constructed with a crawlspace foundation type. The depth-damage curves applied to structure with a basement takes into account the damage caused by the basement being flooded before the water level reaches the first floor of the building. This damage can be more substantial because many basements contain the heating, cooling, and hot water mechanical systems in many homes in the U.S. (FEMA, 2012a). Comparison of the slab on grade, basement, crawlspace and solid wall foundation sensitivity analysis scenarios revealed difference as large as a factor of 65 between slab on grade and solid wall foundation types. Even comparison of common foundation types of crawlspace and basement showed substantial difference (factor of 2) in loss estimates (Table 3.1). These large differences underscore the importance of having the correct foundation type for realistic flood-loss estimation.

The sensitivity analysis performed on the Hazus-MH UDF flood-loss model revealed the flood-loss estimates were also sensitive to the number of stories. The reason why one story building are likely to receive more damage than two story buildings is more of the structure and its contents are subject to inundation than in a two or more story home where more of the house would be above the flood level (FEMA 2012a, FEMA 2012b).

While the Hazus-MH user manual (FEMA 2012a, FEMA 2012b) informs the modeler all the parameters tested here (square footage, building types, building age, foundation types, first floor heights and number of stories) are utilized by the software to estimate flood losses. However, it appears from the sensitivity assessment performed in this study the version of Hazus-MH tested here are not utilizing square footage, building types and building age in the Hazus-MH UDF flood loss model. In contrast, foundation types, first floor heights and number of stories were found to be important parameters in Hazus-MH UDF flood-loss model. These sensitivity assessments suggest that molders should focus on acquiring the most accurate information about foundation types, first floor heights and number of stories in order to improve their UDF flood-loss assessments.

#### 4.2.2. Aggregate Flood-Loss Sensitivity Analysis

For the Hazus-MH aggregate flood-loss model, sensitivity analysis were performed on the foundation type, square footage, and number of stories parameters. Foundation type and number of stories were assessed because they were the parameters found to influence the flood-loss estimates during the UDF flood-loss model sensitivity analyses. Square footage was tested again in the Hazus-MH aggregate flood-loss model because, unlike the UDF flood-loss model, square footage is used to estimate the number of structures impacted by a particular flood scenario. Due to the fact that the Hazus-MH aggregate and UDF flood-loss models use the same damage-curves employing the same model parameters, the building parameters found to have no impact of flood-loss estimates (building types and building age) were not reassessed in the aggregate flood-loss model sensitivity analyses.

The aggregate flood-loss model sensitivity results revealed the flood-loss estimates were not sensitive to any of the model parameters tested. The tested parameters were updated in both the building inventory and the in occupancy mapping parameters. While it is not clear from the Hazus-MH user manual, it appears certain parameters such as foundation types and first floor height can be only adjusted using the occupancy mapping tools within Hazus-MH. This is because no matching destination fields were availed for these parameters in the CDMS import tool (see Figure 4.1). Since both updating the building inventory using CDMS and updated the tested building parameters using the occupancy mapping tool were tried, it unclear why there was no change in the flood-loss estimates when the building parameter were change. Based on these results here, there appears to be technical issues with updating the building parameters in the Hazus-MH aggregate flood-loss model.

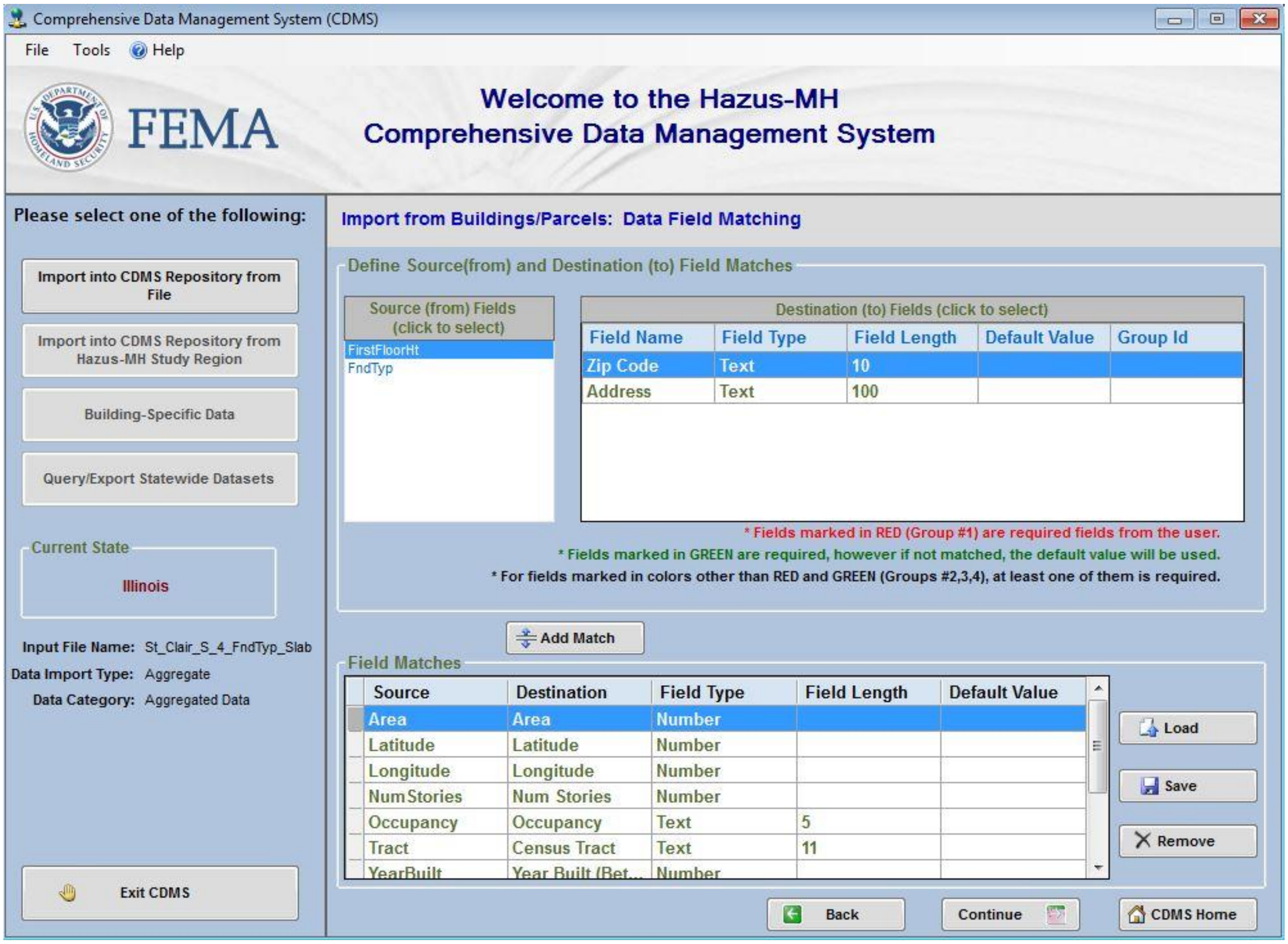


Figure 4.1– CDMS data field matching of the imported local tax assessor data to Hazus-MH data types (CDMA import tool FEMA)

## 4.3. Comparison of Hazus-MH GBS and aggregated building stock compiled from local tax assessor records

### 4.3.1. Alexander County

The exposure estimates for Alexander County differed by a factor of 3 between the Hazus-MH GBS and the building stock estimated using local tax records. Similarly, the flood-loss estimates using the Hazus-MH aggregated GBS were 2.5 times greater than the flood-loss estimate which utilized the building stock aggregated form local tax records (Table 3.1). Alexander County has had a decrease in buildings and population from 2000 through 2010 (US

Census Bureau 2012). The version of Hazus-MH used here employs 2000 census data. The over estimation in exposure and potentially flood losses may be attributed, in part, to the outdated census data used to construct Hazus-MH GBS. For example, U.S. census currently estimates a decrease in population of ~20% in Alexander between 2000 and 2014 (U.S. Census 2014). If the Hazus-MH GBS is employed to estimate flood losses, it might be useful for the modeler to update 2000 with the 2010 census data to improve Hazus-MH GBS inventory to more adequately reflect the study regions building stock.

#### 4.3.2. St. Clair County

The exposure estimates for St. Clair County differed by a factor of 1.1 between the Hazus-MH GBS and the building stock constructed using local tax records. However, the flood-loss estimate using the Hazus-MH aggregated GBS was 2.6 times greater than the flood-loss estimate which utilized the building stock aggregated form local tax records (Table 3.2). While the building exposures for St. Clair County are in more reasonable agreement than in Alexander County, the difference in flood-loss estimates generated using the default GBS and the building inventory constructed from local tax records were still quite large. The large difference is attributed to the difference in distribution of structures within the census blocks of St. Clair County. The building inventory is presumed to have distributed the building inventory more realistically between the census blocks than the Hazus-MH GBS data model. This result shows the importance of realistic distribution of building inventory in Hazus-MH flood-loss model.

## 4.4. Comparison of Aggregate and the UDF flood-loss modelling Results

### 4.4.1. Alexander County

Comparison of the Alexander County flood-loss estimates for the models which employed the Hazus-MH default aggregated GBS inventory, the updated aggregated building inventory, and the UDF building inventory revealed large difference in flood-loss estimates. The Hazus-MH default aggregated GBS inventory had the largest estimated losses, followed by UDF building inventory, and the updated aggregated building inventory. The large difference (factor of 1.3 to 2.5) between the Hazus-MH default aggregated GBS inventory and UDF and the updated aggregated building inventories is largely attributed to the inability of the Hazus-MH GBS inventory to realistically represent the Alexander County's actual building inventory. The more modest differences in flood-loss estimates between the UDF flood-loss model and the aggregated model employing the updated building inventory are attributed to the selected building construction parameters. Depending on the building parameters assumed in the UDF building inventory, flood-loss estimates varied by a factor of +1.9 to 0.47 between the UDF flood-loss model and the aggregate model with updated building inventory (Table 3.1). The maps below shows total losses comparisons for default aggregated, UDF and updated aggregated loss.

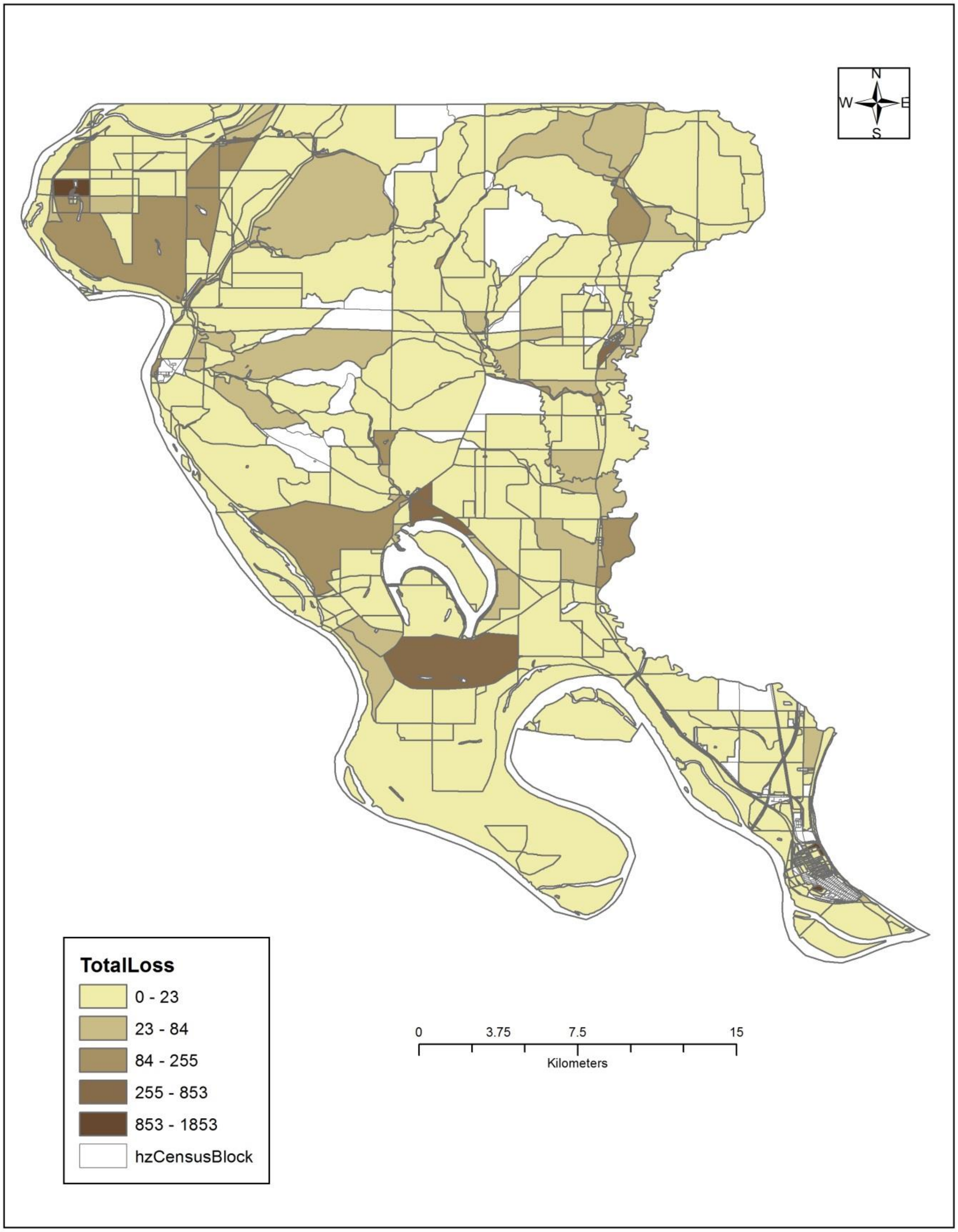


Figure 4.2 – Alexander County total building losses from the Hazus-MH default aggregated flood-loss analysis. These total losses are depreciated replacement costs and are in thousands of dollars

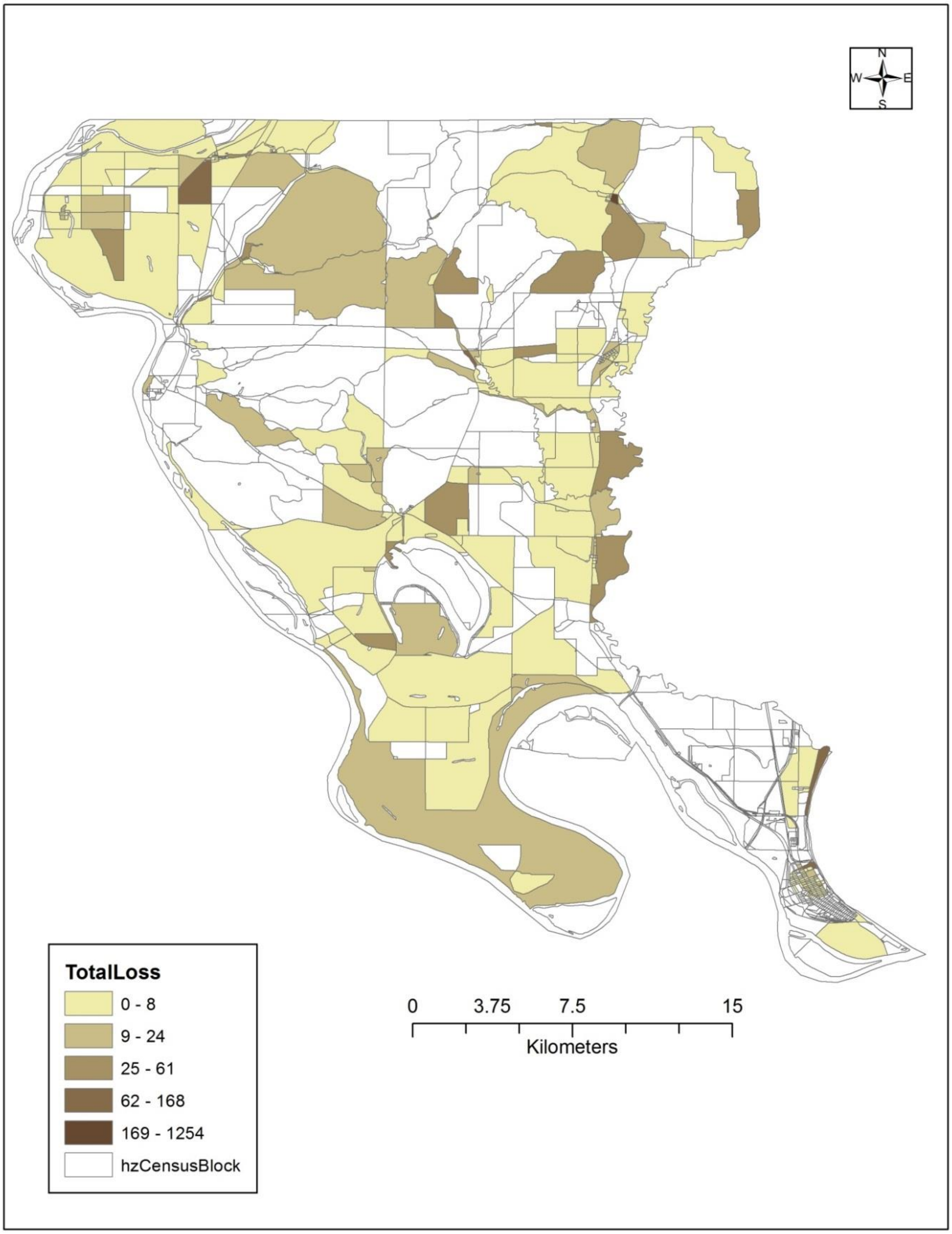


Figure 4.3 – Alexander County total building losses for the Hazus-MH UDF flood-loss analysis. These are total building losses fair market value (similar to depreciated replacement cost) and are in thousands of dollars

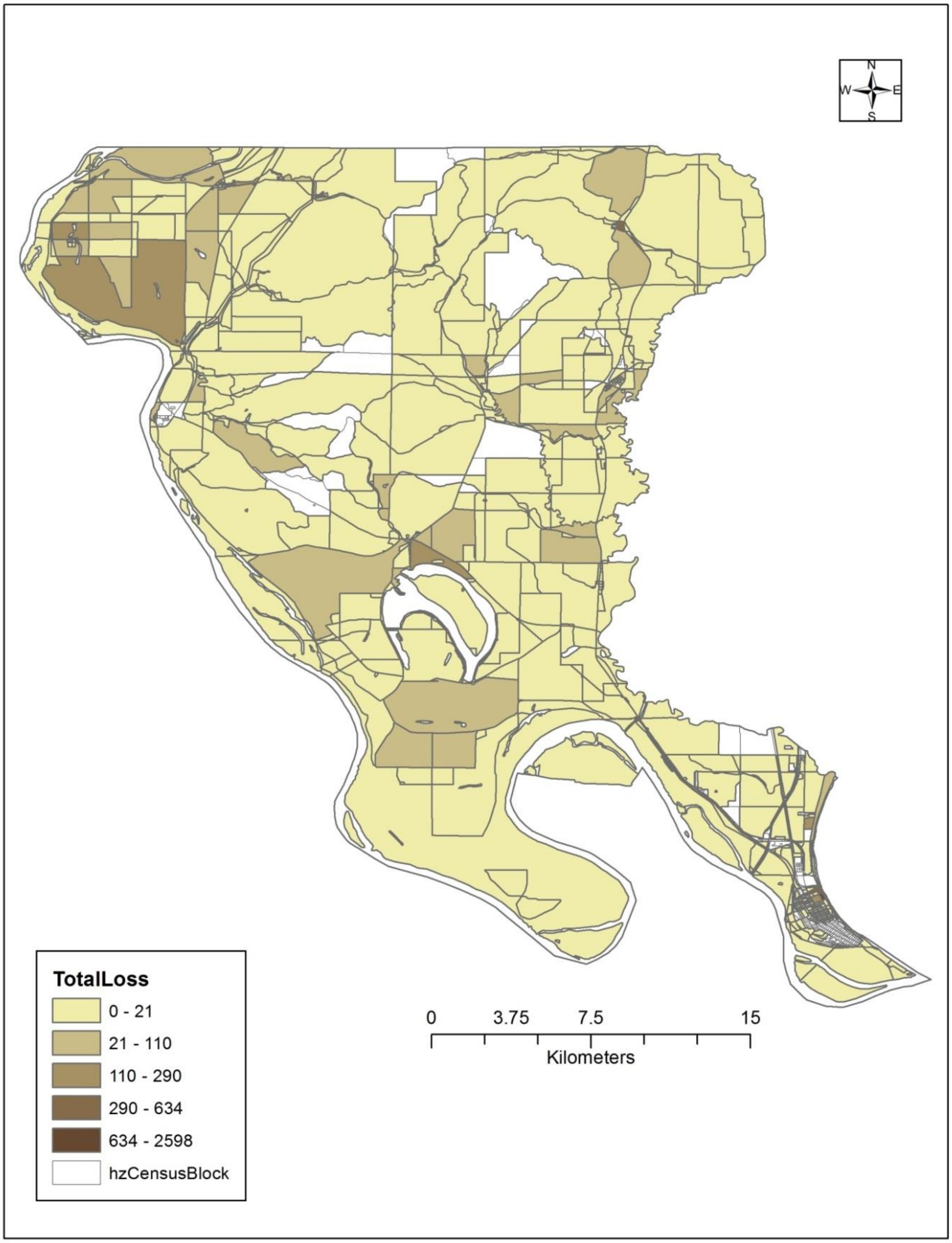


Figure 4.4 – Alexander County total building losses for the Hazus-MH updated aggregated flood-loss analysis. These total losses are depreciated replacement costs and are in thousands of dollars

### 4.4.2. St. Clair County

Comparison of the St. Clair County flood-loss estimates for the models which employed the Hazus-MH default aggregated GBS inventory, the updated aggregated building inventory, and the UDF building inventory also revealed large differences in flood loss estimates. However unlike in Alexander County, the Hazus-MH default aggregated GBS inventory was more realistically representing the building inventory in St. Clair County. Therefore, the majority of the difference (up to a factor of 2.6) between these flood-loss estimates is attributed to Hazus-MH aggregate flood-loss model's assumption of an even distribution of buildings across the census block. In all likelihood, buildings are likely concentrated in areas with lower flood risk (i.e., on higher ground) leading to overestimation of losses when the aggregate model is used (Remo, et al.,2012). Like Alexander County, smaller difference between the UDF flood-loss model and the updated aggregated model are attributed to difference in the building parameters. The maps below shows total losses comparisons for default aggregated, UDF and updated aggregated loss.

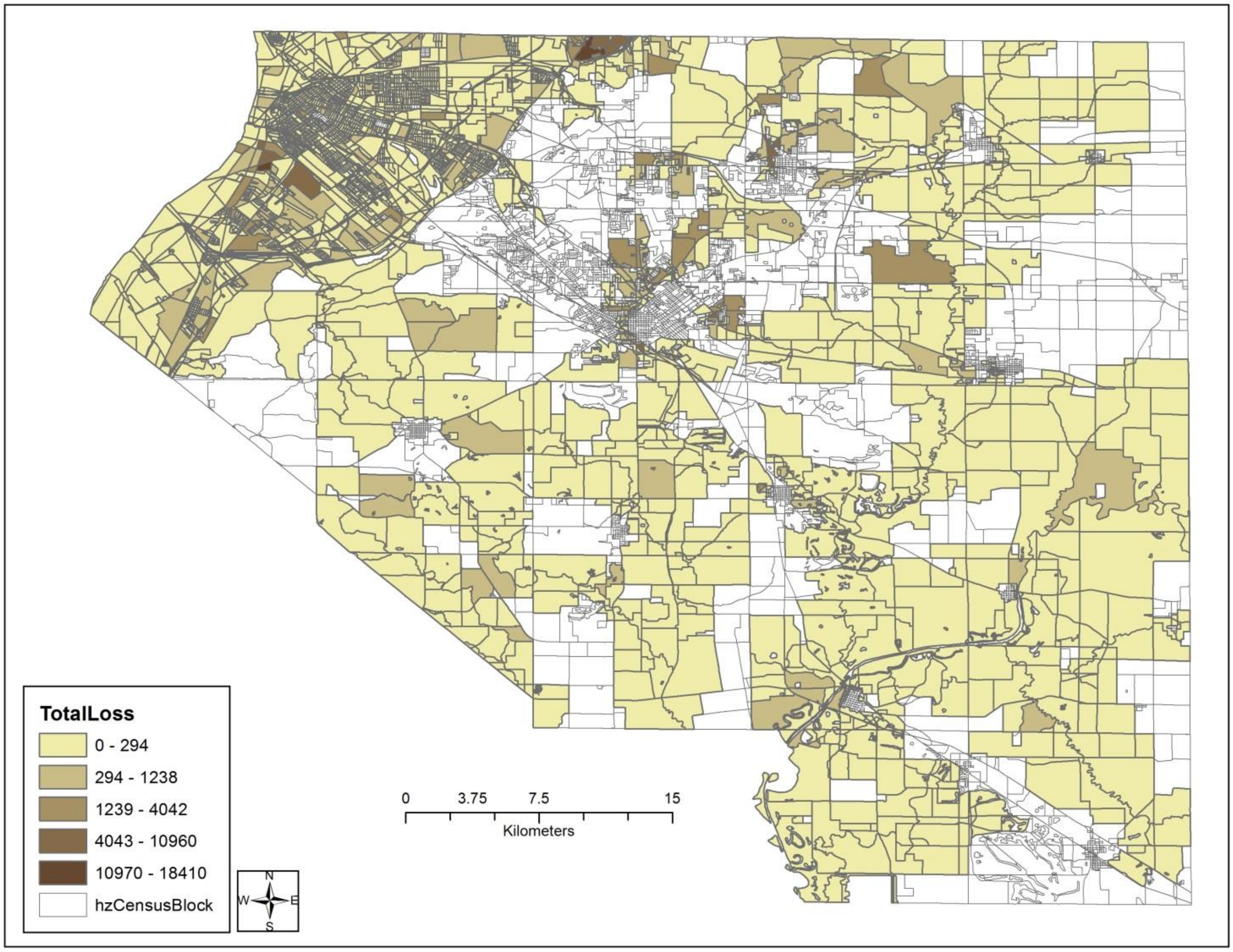


Figure 4.5 – St. Clair County total building losses from the Hazus-MH default aggregated flood-loss analysis. These total losses are depreciated replacement costs and are in thousands of dollars

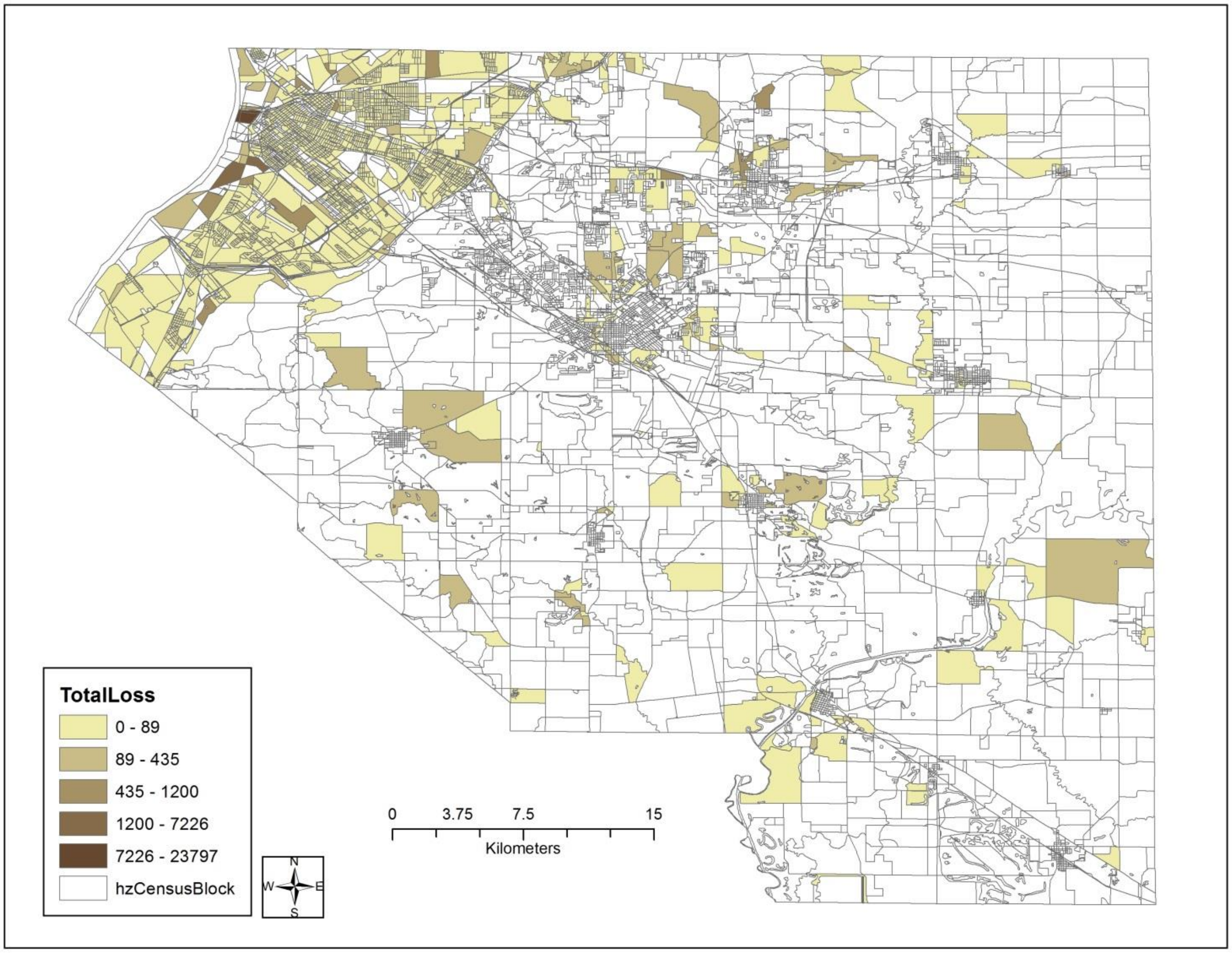


Figure 4.6 – St. Clair County total building losses for the Hazus-MH updated aggregated flood-loss analysis. These total losses are depreciated replacement cost and are in thousands of dollars.

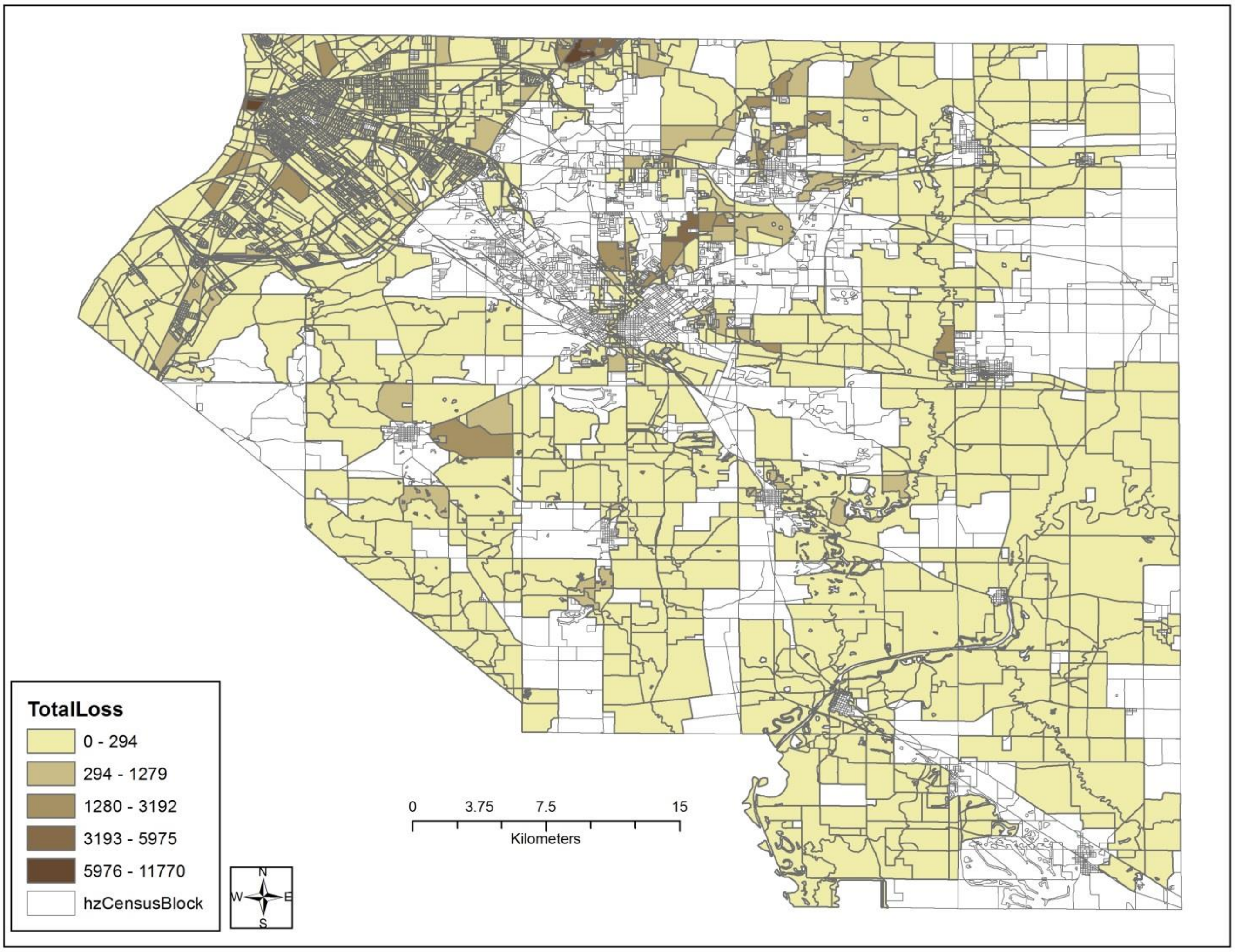


Figure 4.7 – St. Clair County total loss map from updated assessor data as aggregate analysis

### 4.5. Validation Assessment

In order to assess the ability of Hazus-MH to realistically model building damage from a large a comparison between Hazus-MH model flood-loss estimates to actual flood damages documented after 2011 Mississippi River Flood in Alexander County were evaluated. The total flood-loss estimates using Hazus-MH's UDF flood-loss model with detailed water-surface elevations were within 23% of the actual flood losses, which means our validation model underestimated the actual loss by 23%. In a similar validation study by ASFPM 2010 found the

Hazus-MH UDF model had underestimated flood losses by as high as 51%. This assessment showed the best loss-estimates are using actual building inventory data and observed water-surface elevations.

# CHAPTER 5

## 5.0 Conclusions

In this study, square footage of the building, building age, construction type, foundation type associated first floor heights, and the number of stories were assessed for their impacts on flood losses using the Hazus-MH user-defined and aggregate flood-loss models. The foundation types and their associated first-floor heights and number of stories were found to substantially impact flood-loss estimates using the Hazus-MH UDF flood-loss modeling tool. The building parameters square footage, building age and construction type had little or no effect on the flood-loss estimates suggesting these parameters are not important in the estimation for flood losses using Hazus-MH's UDF flood-loss model.

Comparison of estimated/modeled GBS and the actual building stock compiled from tax records in Alexander County showed large differences (up to 3 times) in exposure estimates. The large difference in GBS versus building stock compiled from local tax data is attributed, at least in part, to the now antiquated census data used to construct the Hazus-MH GBS inventory/data model. The large differences in flood-loss estimates for 100-year flood in St. Clair County between aggregate models constructed using GBS and local tax data is the attributed to the uniform distribution of building inventory within the aggregate flood-loss model.

The aggregate flood-loss model sensitivity results showed the flood-loss estimates were not sensitive to any of the model parameters tested. It is unclear why there was no change in the flood-loss estimates when the building parameters were changed. Based on these results, there appears to be technical issues with updating the building parameters in the aggregate flood-loss model within Hazus-MH.

Comparison of the Alexander and St. Clair County updated aggregated and UDF flood-loss modeling results revealed substantial difference in flood-loss estimates. In Alexander County, the difference in flood-loss estimates are largely attributed to the selected building construction parameters. In St. Clair County, the majority of the differences in flood-loss estimates are attributed to the even distribution of buildings across the census block assumption in the Hazus-MH aggregate flood-loss model. The even distribution of building within a census block is not likely realistic because buildings, in reality, are likely concentrated in areas with lower or no flood risk (i.e., on higher ground). Assuming an even distribution thereby leads to overestimation of flood losses when the aggregate model is used (Remo et al., 2012).

The validation assessment performed using observed flood damages revealed Hazus-MH UDF flood-loss modeling tool is capable of providing a reasonable estimate of actual flood losses. This assessment showed the modeled results to be within 23% of actual losses. The validation study results attained in this study using the detailed building data and the UDF flood-loss modeling tool were more realistic (within 23% of actual losses versus > 50% of actual losses) than previous Hazus-MH flood-loss validation assessments performed by ASFPM (2010a). The flood-loss estimates could be further improved by modifying or choosing a more region specific depth-damage curves, more detailed flood water-surface elevation data, or having detailed information on foundation types and first floor elevations.

# REFERENCES


ABS Consulting. 2002. *Flood Information Tool MR3 User Manual*. National Institute of Building Sciences.

ASFPM. 2009. *HAZUS_MH Flood Model Validation*. The National Institute of Building Sciences.

———. 2010a. “Comparing HAZUS Flood Loss Estimates Across Hazard Identification Methods and Building Stock Inventory Data Albion Township Dane County, Wisconsin.”

———. 2010b. “Structure Level Flood Damage Analysis: NFIP & HAZUS Midwest Flooding 2008 Albion Township, Dane County, WI.”

Ding, Aiju, James F. White, Paul W. Ullman, and Adebola O. Fashokun. 2008. “Evaluation of HAZUS-MH Flood Model with Local Data and Other Program.” *Natural Hazards Review* 9 (1): 20–28. http://ascelibrary.org/doi/abs/10.1061/(ASCE)1527-6988(2008)9:1(20).

FEMA. 2012a. “Multi-Hazards Loss Estimation Methodology Flood Model User Manual.” Department of Homeland Security.

———. 2012b. “Muilti-Hazard Loss Estimation Methodology Flood Model Technical Manual.” Department of Homeland Security.

H2O Partners. 2013. “FEMA Mapping Changes.” http://www.h2opartnersusa.com/nfiptraining/mapping_changes.html.

Illinois Dept of Revenue. 2010. “Property Assessment and Equalization.”

Meyer, Jennifer. 2004. “Comparative Analysis between Different Flood Assessment Technologies in HAZUS-MH.” Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the Requirements for the degree of Master of Science in The Department of Environmental Studies by Jennifer Meyer BA, Louisiana State University. http://etd.lsu.edu/docs/available/etd-11082004-112134/.

Muthukumar, Subrahmanyam. 2005. “Riverine Flood Modeling in HAZUS-MH: Overview of the Implementation.” In *Proceedings of the 2005 Georgia Water Resources Conference, April*, 25–27. http://www.gwri.gatech.edu/sites/default/files/files/docs/2005/MuthukumarS-GWRCpaper%20April%2013.pdf.

Patterson, Lauren A., and Martin W. Doyle. 2009. “Assessing Effectiveness of National Flood Policy Through Spatiotemporal Monitoring of Socioeconomic Exposure.” *JAWRA Journal of the American Water Resources Association* 45 (1): 237–52. doi:10.1111/j.1752-1688.2008.00275.x.

Remo, Jonathan W.F. 2011. “Illinois Multi-Hazard Mitigation Plan Project Workflow.” Southern Illinois University Ccarbondale.

Remo, Jonathan W. F., Megan Carlson, and Nicholas Pinter. 2012. “Hydraulic and Flood-Loss Modeling of Levee, Floodplain, and River Management Strategies, Middle Mississippi River, USA.” *Natural Hazards* 61 (2): 551–75. doi:10.1007/s11069-011-9938-x.

Rozelle, Jesse, Doug Bausch, Sean McNabb, and Nicol Robles-Kyle. 2011. “Analyzing Potential Flood Damages to Fargo, North Dakota Using a Detailed HAZUS Level 2 Analysis.” In *ESRI User Conference*, 16.

Scawthorn, Charles, Neil Blais, Hope Seligson, Eric Tate, Edward Mifflin, Will Thomas, James Murphy, and Christopher Jones. 2006. “HAZUS-MH Flood Loss Estimation Methodology. I: Overview and Flood Hazard Characterization.” *Natural Hazards Review* 7 (2): 60–71. http://ascelibrary.org/doi/abs/10.1061/(ASCE)1527-6988(2006)7:2(60).

Scawthorn, Charles, Paul Flores, Neil Blais, Hope Seligson, Eric Tate, Stephanie Chang, Edward Mifflin, Will Thomas, James Murphy, and Christopher Jones. 2006. “HAZUS-MH Flood Loss Estimation Methodology. II. Damage and Loss Assessment.” *Natural Hazards Review* 7 (2): 72–81. http://ascelibrary.org/doi/abs/10.1061/(ASCE)1527-6988(2006)7:2(72).

Schnider, Philip J, and Barbara A Schauer. 2006. “HAZUS - Its Development and Its Future.” *Natural Hazards Review* 7 (May): 40–44.

Texas Hazard Mitigation Package. 2013. “HAZUS Presentation THMP.” Accessed October 11. thmp.info/user_resources/HAZUS%20Presentation.ppt.

URS Group. 2007. *HAZUS-MH Riverine Flood Validation Study*. Washington County, Utha Vicinity.

U.S. Census Bureau. 2014a. “Alexander County QuickFacts from the US Census Bureau.” Accessed September 30. http://quickfacts.census.gov/qfd/states/17/17003.html.

———. 2014b. “St. Clair County QuickFacts from the US Census Bureau.” Accessed September 30. http://quickfacts.census.gov/qfd/states/17/17163.html.

———. 2012. Illinois: 2010 "Population and Housing Unit Counts." Department of Commerce Economic and Statistics Administration. Accessed September 30. http://www.census.gov/prod/cen2010/cph-2-15.pdf

Woolpert. 2011. “St. Clair County Comprehensive Plan.” St. Clair County, Illinois

# VITA

Graduate School

Southern Illinois University

Samir Shrestha

shresthasamir@gmail.com

Kathmandu University

Bachelor of Science, Environmental Science, November 2008

Thesis title:

Sensitivity of Hazus-MH Flood Loss Estimates to Selection of Building Parameters: Two Illinois case studies

Major Professor: Dr. Jonathan W.F. Remo