Dasymetric Mapping of Building Stocks within HAZUS-FL

by

Brian Patrick McDonald

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List of Abbreviations

CB	Census Block
CBG	Census Block Group
D&B	Dun and Bradstreet
DDF	Depth Damage Function
DEM	Digital Elevation Model
$DCBG_H$	Dasymetric Census Block Group from HAZUS derived NLCD
$DCBG_N$	Dasymetric Census Block Group from NDGC derived NLCD
FIRM	Flood Insurance Rate Map
FIT	Flood Information Tool
FEMA	Federal Emergency Management Agency
HAZUS	Hazards-US [Multi Hazard]
FL	HAZUS Flood Module
GBS	General Building Stock
LULC	Land Use/ Land Cover
MFD	Mean Flood Depth
MOTF	FEMA Modeling Task Force
ND	North Dakota
NDGC	North Dakota GIS Clearinghouse
NFIP	National Flood Insurance Program
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
SA	Study Area

TIGER/Line	Topologically Integrated Geographic Encoding and Referencing
UDDG	User Defined Depth Grid
UDF	User Defined Facilities
US	United States
USGS	US Geological Survey

Abstract

Flooding in the U.S. annually accounts for almost $8 billion of property damages and social impact, prompting the need for insurance, aid, mitigation and other programs which rely on predictive flood damage modeling. The Federal Emergency Management Agency (FEMA) developed the HAZUS FL (FL) model to support these programs. FL creates estimates based on descriptions of people and property, known as the general building stock (GBS), which detail the number and types of buildings within each census block group (CBG). The accuracy of flood damage models is dependent on the relationship between the locations of the GBS and floodwaters. To ensure that FL remains relevant to a wide audience, techniques are needed to enhance the accuracy of these factors in the FL model which do not require additional detailed building datasets or alter the existing FL software code. Improving the GBS representation by applying dasymetry to the GBS would improve the accuracy of the FL model estimates. This thesis demonstrates the viability of dasymetric GBS by applying land use/land cover data to align the GBS with developed land to improve the accuracy of FL models. These effects are most pronounced in areas with partial flooding and/or low density development. CBGs experiencing severe flooding or high density development displayed limited damage differences compared to the current FL building format.

Chapter 1 Introduction

Floods are costly and predictable natural hazards. Flooding in the U.S. inflicts estimated property damages and social impacts tallying nearly $8 billion in damage annually (NOAA, 2014). Societal impacts in affected communities likely double this figure. Increasingly erratic and intense weather patterns aggravate the impact of flood events (Smith and Katz, 2013), and ongoing urbanization increases the financial losses due to floods (USGS, 2006).

Flooding can be defined as "a general and temporary condition of partial or complete inundation of two or more acres of normally dry land area [resulting] from: overflow of inland or tidal waters; unusual and rapid accumulation or runoff of surface waters [or mud]; or collapse or subsidence of land along the shore of a lake or similar body of water" (FEMA, 2014). Two major categories of floods are riverine and coastal. Riverine floods occur when water overtops a channel. Coastal flooding involves water driven onshore by winds and waves.

Flood event modeling involves consideration of historic records, fluvial deposits, and weather patterns. Riverine floods, in particular, are quite predictable with small floods occurring more frequently than large floods. The size of a flood event is characterized by its recurrence interval: the “100-year flood” is an event expected to happen only once in a hundred years, i.e. with a 1% probability in any year, and will be significantly smaller than say the “500-year flood” (Ritter et al., 2002).

The Federal Emergency Management Agency (FEMA) has a broad responsibility to identify, mitigate, and respond to natural hazards across the US. FEMA estimates that each dollar spent on mitigation avoids $4 in emergency response and recovery from disasters of all types, including floods (MMC, 2005). Flood damage mitigation is feasible and sensible given the high frequency and costs associated with flood events: for example, constructing levees to protect areas from flooding or avoiding repeated flood damages by acquiring and razing at-risk structures within frequently inundated areas. An established part of flood mitigation is the use of flood models to complete a cost-benefit analysis of the proposed mitigation effort for given flood recurrence intervals (Tate et al., 2014). Flood maps are static and display the areal extent of floods with specific flood recurrence intervals, such as 10-, 25-, 100- and 500-years. Flood maps cannot be used to estimate flood impacts without the aid of other datasets.

The National Flood Insurance Program (NFIP) is a major FEMA initiative focused on mitigating flood hazards. U.S. Congress established the program in an effort to reduce flood losses nationwide by creating a federal flood insurance program and supporting the development of local building and zoning ordinances (NFIP, 2015). NFIP is particularly focused on addressing flood events that have an interval reoccurrence of 100-years or more.

1.1 HAZUS-MH

The development of the HAZUS flood methodology began in 1997 with the creation of a standardized national hazard damage estimations software package. It covers both physical damages and societal impacts (Scawthorn et al., 2006a, b). HAZUS utilizes selected components of Esri's ArcGIS software platform to perform spatial calculations and mapping. Initially, HAZUS was only comprised of an earthquake hazard model. Since then it has grown to include riverine and coastal flood hazards, along with hurricanes in recent years. HAZUS software is distributed free-of-charge by FEMA through DVD media or via Internet download.

The HAZUS-FL flood model (FL) estimates property damages primarily based on floodwater depth and the characteristics of the buildings in the flooded area. FL also estimates societal impacts, including lost production, temporary shelter requirements, and (in extreme events) loss of life (FEMA, 2012).

The HAZUS flood methodology provides states, counties, and municipalities with a ready-to-use tool to estimate building damages and societal impacts of predictable flood events. Understanding these consequences is essential for evaluating flood mitigation options (Plate, 2002). Accurate, complete, and current data produces the best damage estimates. However, the national data supplied with HAZUS is generalized in terms of its spatial and attribute specificity and often out-of-date. HAZUS users therefore spend substantial time improving the quality of their data before using it to estimate flood damages.

HAZUS makes extensive use of U.S. Census Bureau data. The fundamental unit of analysis in HAZUS is the census block group (CBG). HAZUS assumes a uniform distribution of the population and buildings within a CBG. This assumption is not always accurate in terms of the types and locations of development.

Census block groups survey similar sized populations. A CBG's area depends on population density. The CBGs in dense urban areas CBGs are usually smaller than those in suburban areas and much smaller than those in rural areas. Given that FL damage estimates are a function of geographic inundation and building stock, the assumption of uniformity is probably more tenable for dense urban areas and less so in areas with lower population densities. Figure 1A illustrates this situation. It demonstrates a prototypical mixed-use suburban CBG where buildings of all types are confined to the top-half of the CBG. In this situation, a flood inundating approximately one-third of the CBG will cause different damages and impacts depending on its location. HAZUS, with its assumed uniform building distribution, produces the same damage estimate for each situations as if all the CBGs looked like those represented in Figure 1B-D).

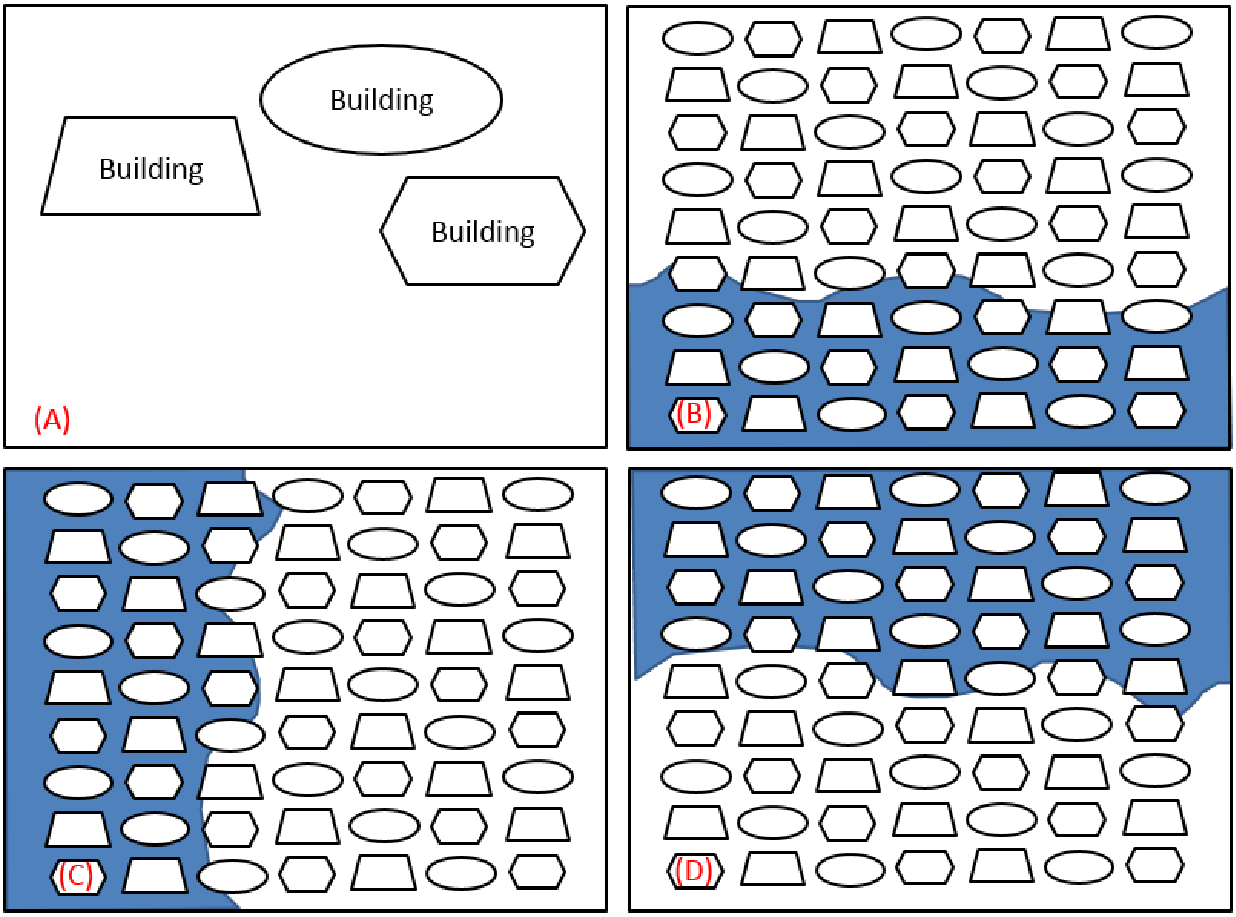

Figure 1 Standard HAZUS Building Stock Distribution

It is possible to improve the accuracy of the data used in HAZUS. A more accurate distribution of buildings within CBGs can be inferred from the National Land Cover Database (NLCD). This dataset classifies land use/land cover (LULC) into 20 categories, at a 30 x 30 m resolution from Landsat TM imagery (Wickham et al., 2013). Four of these categories apply to different levels of urban development and two apply to rural development. Areas with these particular NLCD codes identify the location of GBS within each CBG as represented by the green rectangular areas of dasymetric coverage in Figure 2A. It demonstrates a prototypical mixed-use suburban CBG where buildings of all types are confined to the top-half of the CBG.

In this situation, a flood inundating approximately one-third of the CBG will cause different damages and impacts depending on the flood’s location.

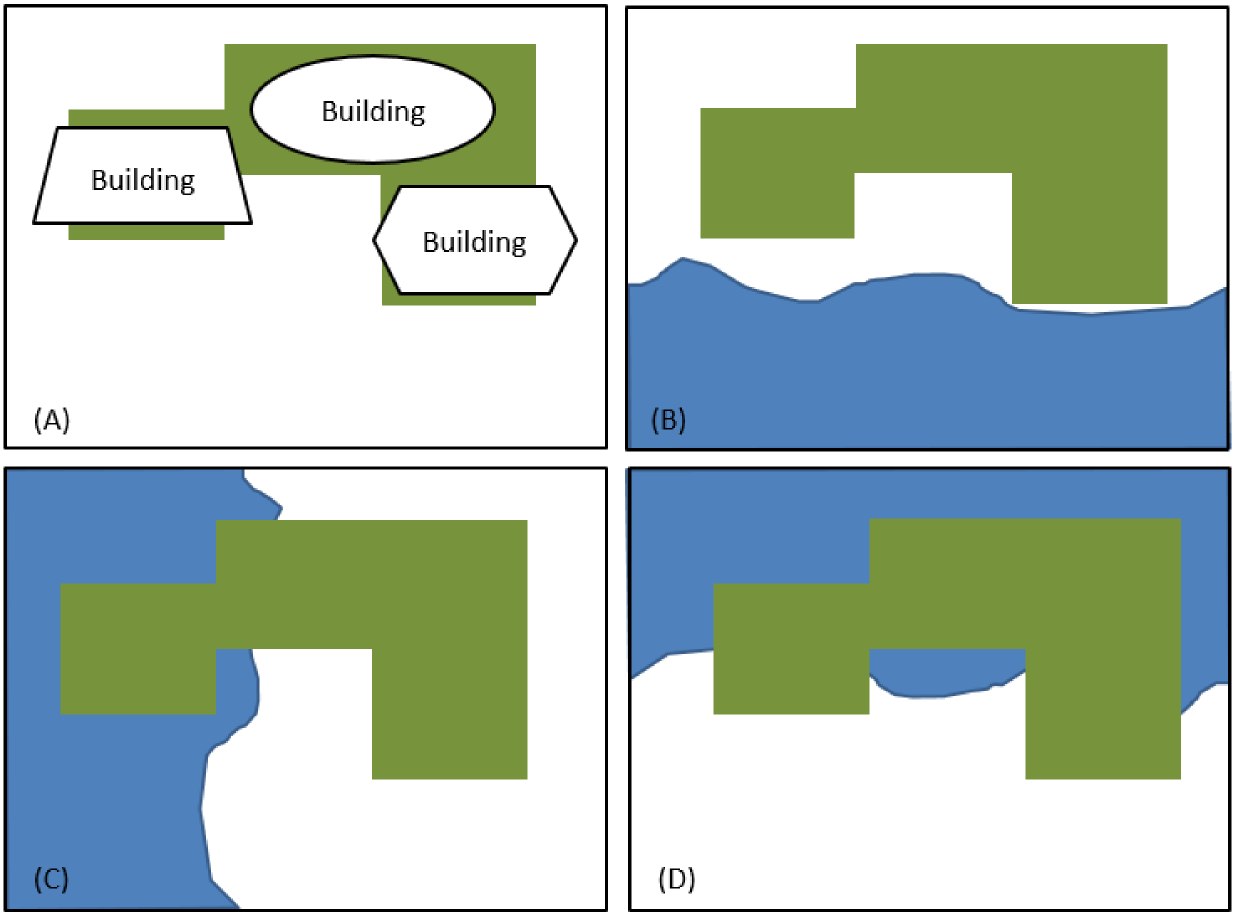

Figure 2 Four idealized dasymetric flood inundation examples

NLCD data can improve on the accuracy of the FL model by distributing the aggregate counts of buildings by CBG using the ancillary, finer-scale LULC data. Dasymetry is a mapping format that distributes a parent dataset’s attributes to a larger scale by using an auxiliary dataset in order to produce a child dataset. This thesis evaluated dasymetry as a method to improve the location representation of the GBS coverage within CBG by allowing buildings to be more realistically located according to the position of related LULC codes to make HAZUS' flood models more realistic.

1.2 North Dakota Study Areas

This thesis examined a process for dasymetric redistribution of GBS within CBG to improve the accuracy of FL estimates against the existing HAZUS methodology and data. This thesis establishes a dasymetric conversion process within the existing FL Level 1 model with minimal alteration and without changing the existing flood loss methodology. The thesis applied dasymetric redistribution and model comparisons in two areas (Figure 3): Cass County, ND for the flood event of 2009 (Figure 4); and Ward County, ND for the flood event of 2011 (Figure 6).

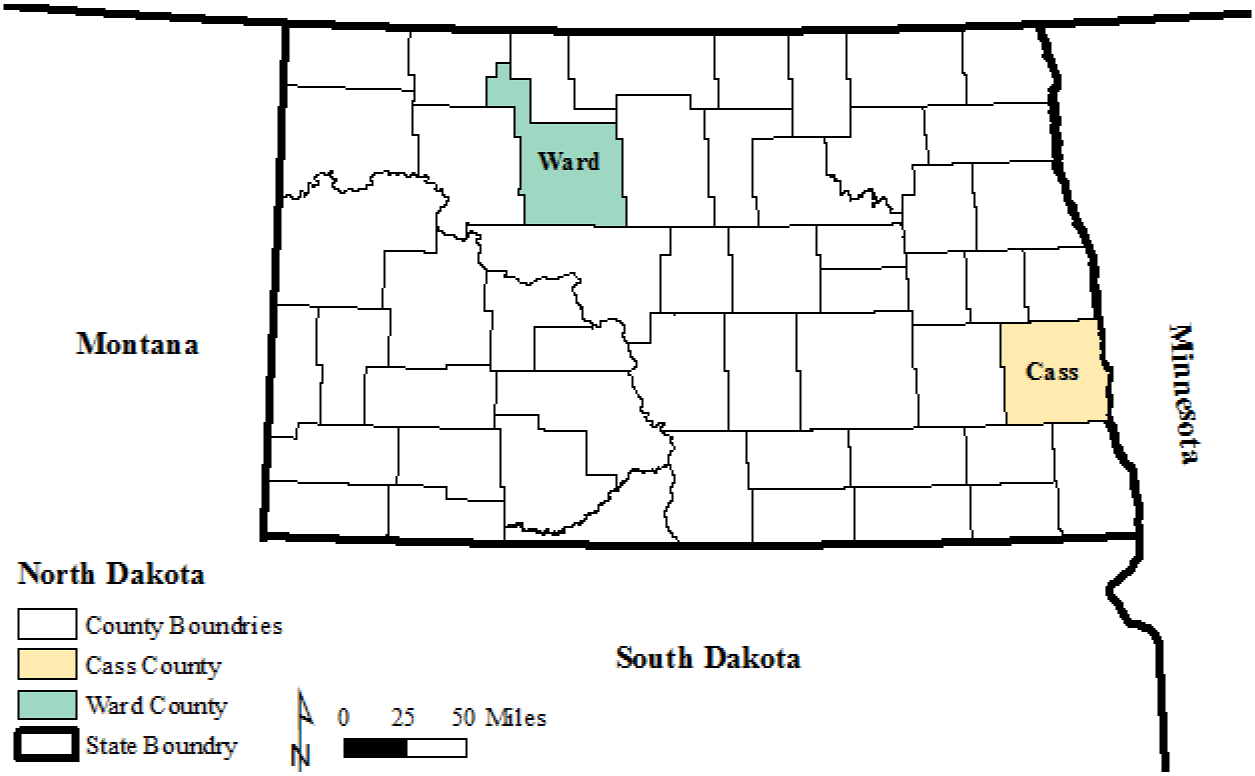

Figure 3 Location of Cass and Ward Counties within North Dakota

The two flood events that were selected for this thesis because each flood occurred near the 2010 Census providing population counts for this thesis. These floods represent large magnitude flood events, a one-in-a-100 year flood for Cass County and a one-in-a-500 year for Ward County. The FEMA Modeling Task Force (MOTF) produced detailed floodwater depth grids for each event by observing high water levels to map the flood's greatest extent and depth. These depth grids make it possible to evaluate the effect of using dasymetry against observed flood magnitude, instead of those estimated using simulated models.

1.2.1 Cass County

Cass County is located in southeast North Dakota (Figure 3). Fargo is the largest city within the county and the county seat. Fargo had 105,549 residents spread across 46,791 households in 2010 (U.S. Census Bureau, 2010a). The city has a high concentration of buildings within the city center, surrounded by agriculture fields and pasture areas (Figure 4). As of 2015, there were over 1 million acres of cropland within the county producing soybeans, corn, and wheat (NDSU, 2015). The Red River is the county's primary natural feature and the largest river within the region. The river forms the county's eastern boundary and the state boundary between North Dakota and Minnesota.

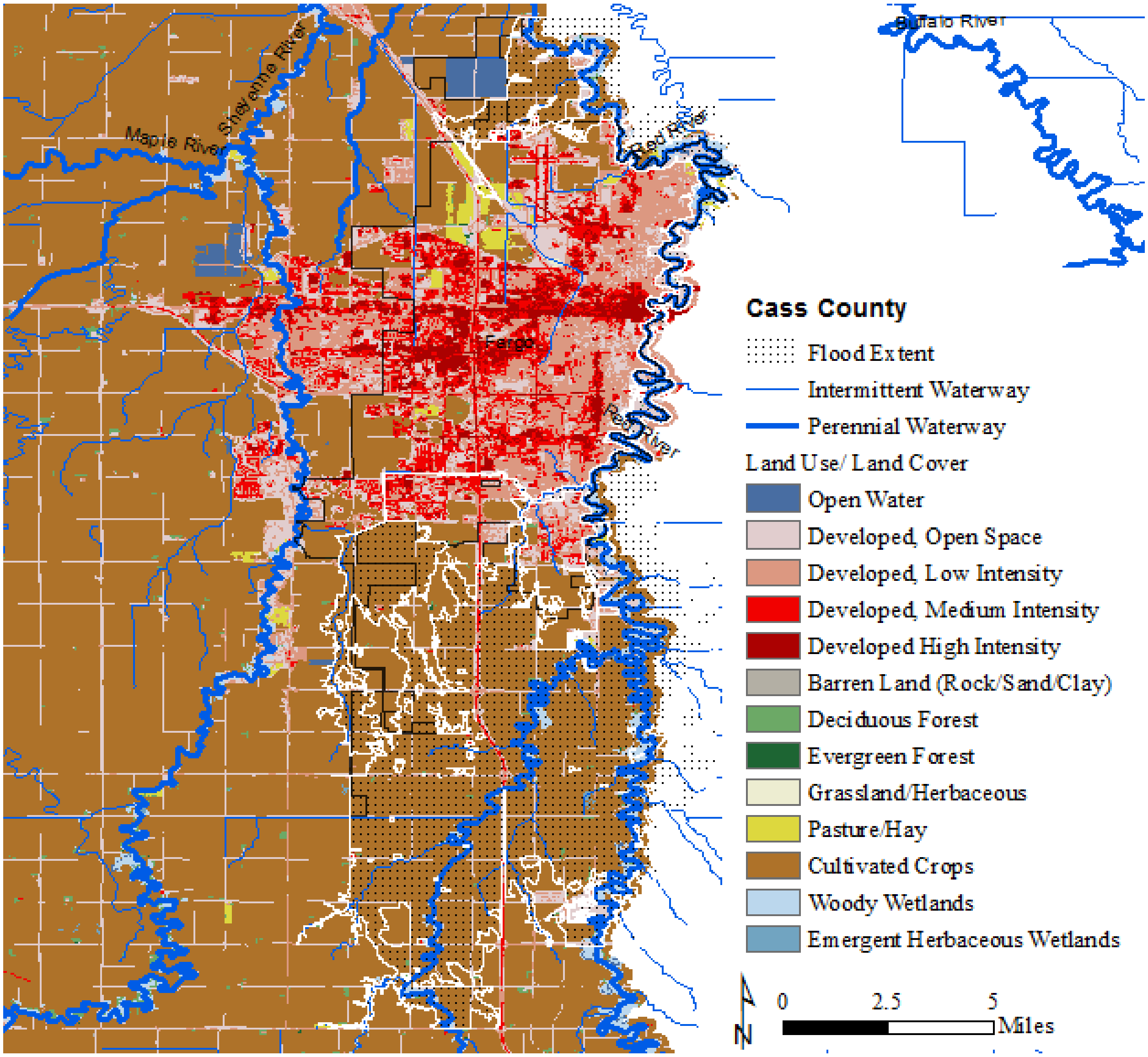

Figure 4 Cass County land use/land cover map

The Red River drainage basin covers parts of eastern North Dakota and western Minnesota flowing north into Canada. The river encounters erodible clay-rich soils, high riverbank relief, and a narrower channel near Fargo (Figure 5). The river bed has a gentle gradient which during major flooding causes the river's discharge to fill the channel and surrounding floodplain quickly and to then inundate additional land to form expansive, shallow floods given the relief of the valley (Schwert, 2015).

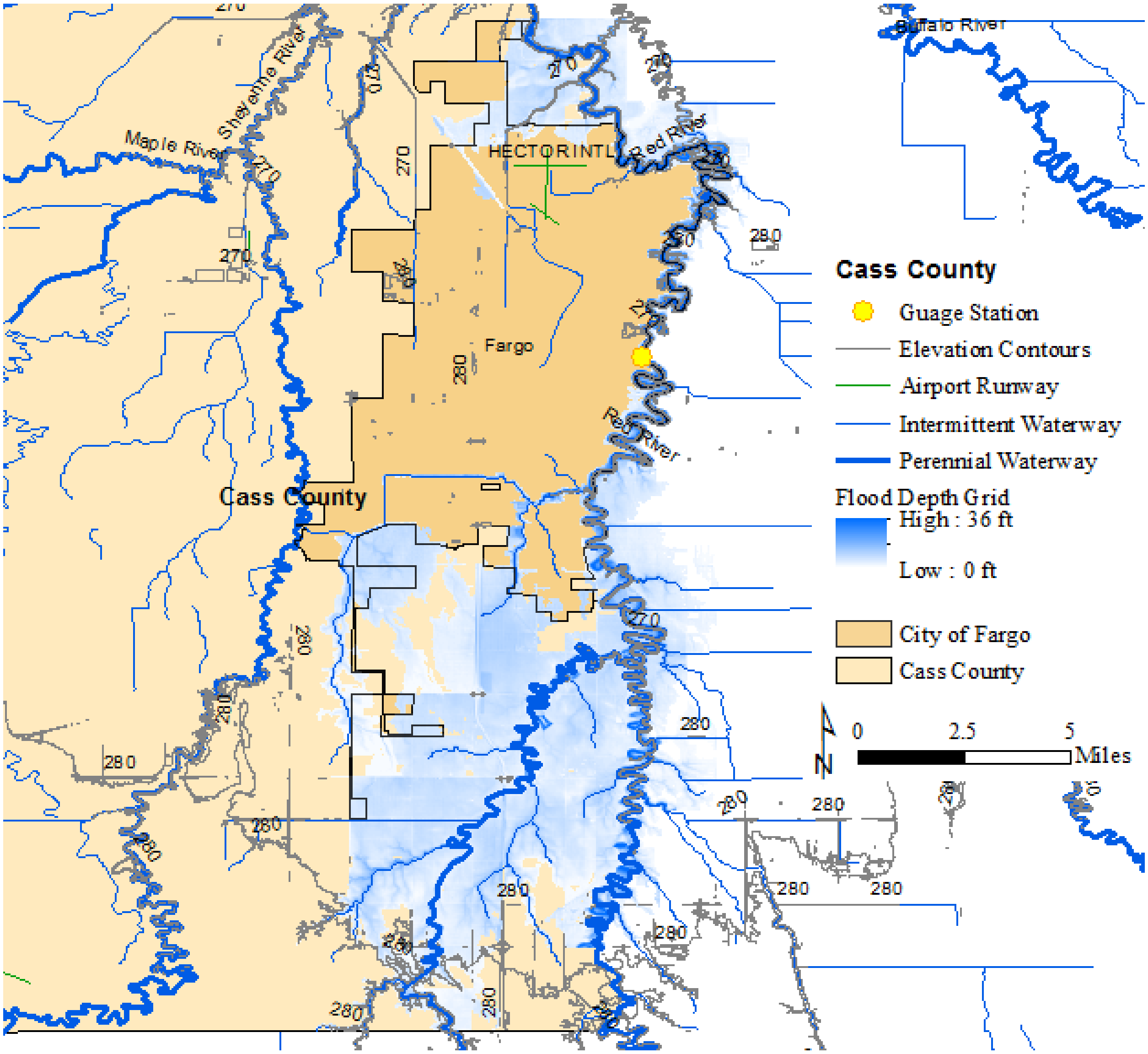

Figure 5 Cass County hydrography and topography map

The flood event used within this thesis was caused by an excessive influx of seasonal meltwater in March 2009. The initial flooding occurred south of the city as the water backed up and spread out (Figure 5). This meltwater originated from rapid snow melt caused by the combination of above-freezing temperatures and heavy rains (Starr, 2009). This additional water caused the Red River to swell and surpass the typical amount of water commonly present during that time of the year. It is typical for this area to experience high water flow during the spring snow melt. The high water mark for this flood reached in excess of 43 feet at the river gauging station, which exceeded the previous high water mark and the maximum height of the city's dikes. The flood caused widespread evacuation of residents in low-lying homes near levees and the hospital to ensure the public’s safety.

FEMA mapped a portion of the 2009 flood event focusing on Fargo to provide an observed historical flood to compare against various HAZUS flooding event scenarios. The survey’s extent encompasses the area where the majority of building damages occurred, but the Red River also produced flooding in the surrounding areas outside of Fargo and Cass County. This was a destructive flood given that the area received $80 million in Federal, State and local aid coordinated under Presidential Disaster Declarations (Rozelle, 2011) for the 2009 and 2010 floods. Since the 2009 flood, Cass County enacted a series of flood mitigation efforts to reduce the flooding damages. The city of Fargo has spent $100 million on flood protection acquiring and condemning hundreds of homes in low-lying areas and constructing a large levee system (Peters, 2013). A levee is a flood control mechanism consisting of earthen embankments to locally raise the river bank’s elevation relative to the potential height of the floodwaters. A levee seeks to limit the effect of the floodwater inundation by channeling the floodwaters downstream as opposed to inundating the floodplain.

1.2.2 Ward County

Ward County is located in north central North Dakota (Figure 3). Minot is the largest city and the county seat. There is a U.S. Air Force base and a commercial airport located to the north of the city. In 2010, 40,888 people lived within 17,863 households across the city of Minot (U.S. Census Bureau, 2010b). The majority of building development within the city is concentrated on the high ground near the river (Figure 6). The remaining portion of the county is primarily agricultural.

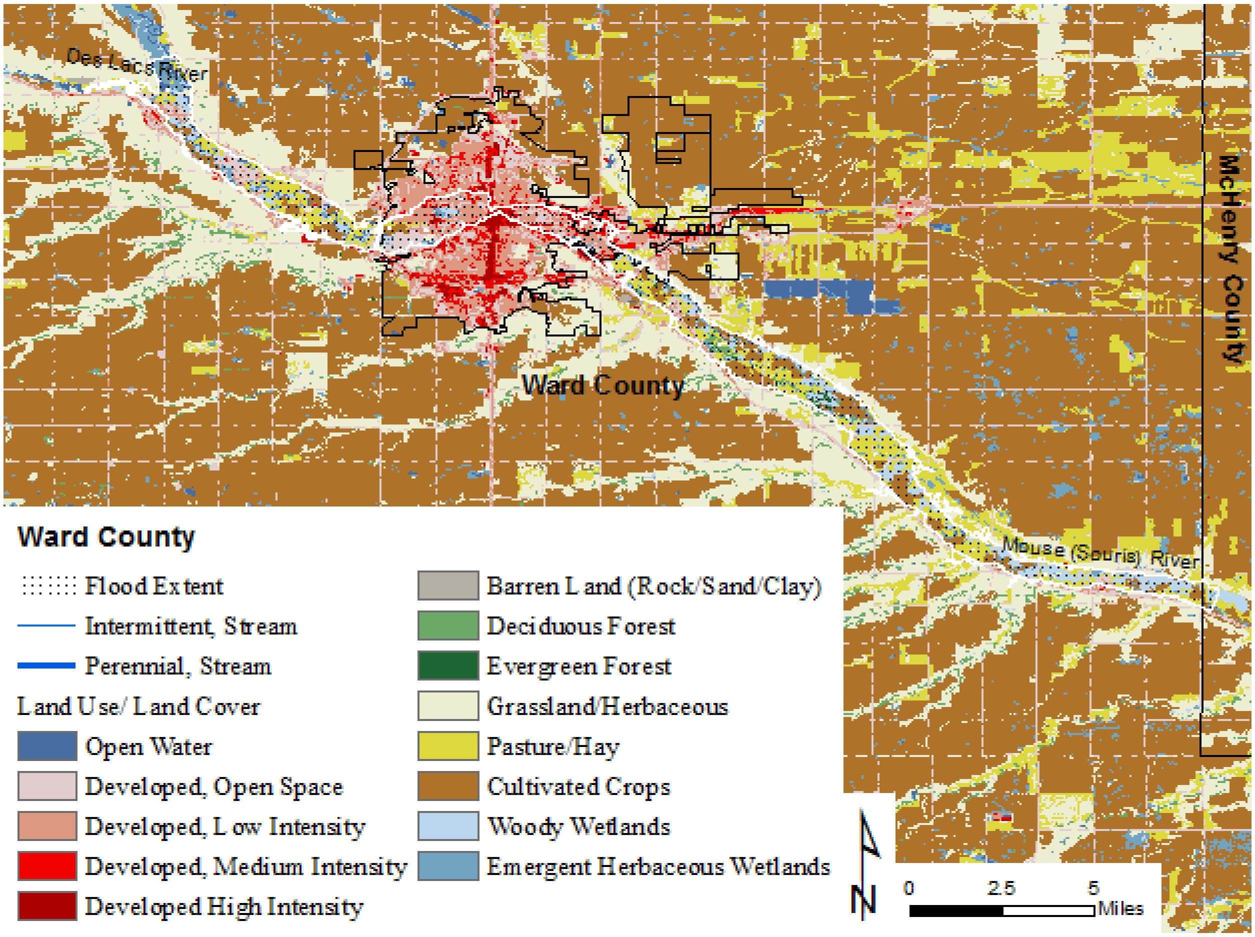

Figure 6 Ward County land use/land cover map

The Souris ("Mouse") River bisects both the city and the county. The river has a well-defined channel and limited floodplain due to the high relief (Figure 7). The river flows south through Minot before turning north into Canada. Minot experienced major flooding in 1969 prompting the construction of levees around the city designed to resist 100-year floods. The Souris River has a series of dams to control the spring melt water floods (up to 2,000 cfs) and a 100 year floodplain which could contain a river discharge of 5,000 cfs (Rozelle, 2012). On June 24, 2011, the Souris River reached its peak discharge of 24,000 cfs, roughly three times higher than the river experienced in 1969 and 12 times greater than the typical seasonal flow. From May to July 2011, the Souris River overwhelmed the dam and levee systems, flooding 4,100 structures and displacing between 10,000 and 12,000 people (Wirtz, 2011). The 2011 flood was categorized as a one-in-a-500 year event (Wirtz, 2011).

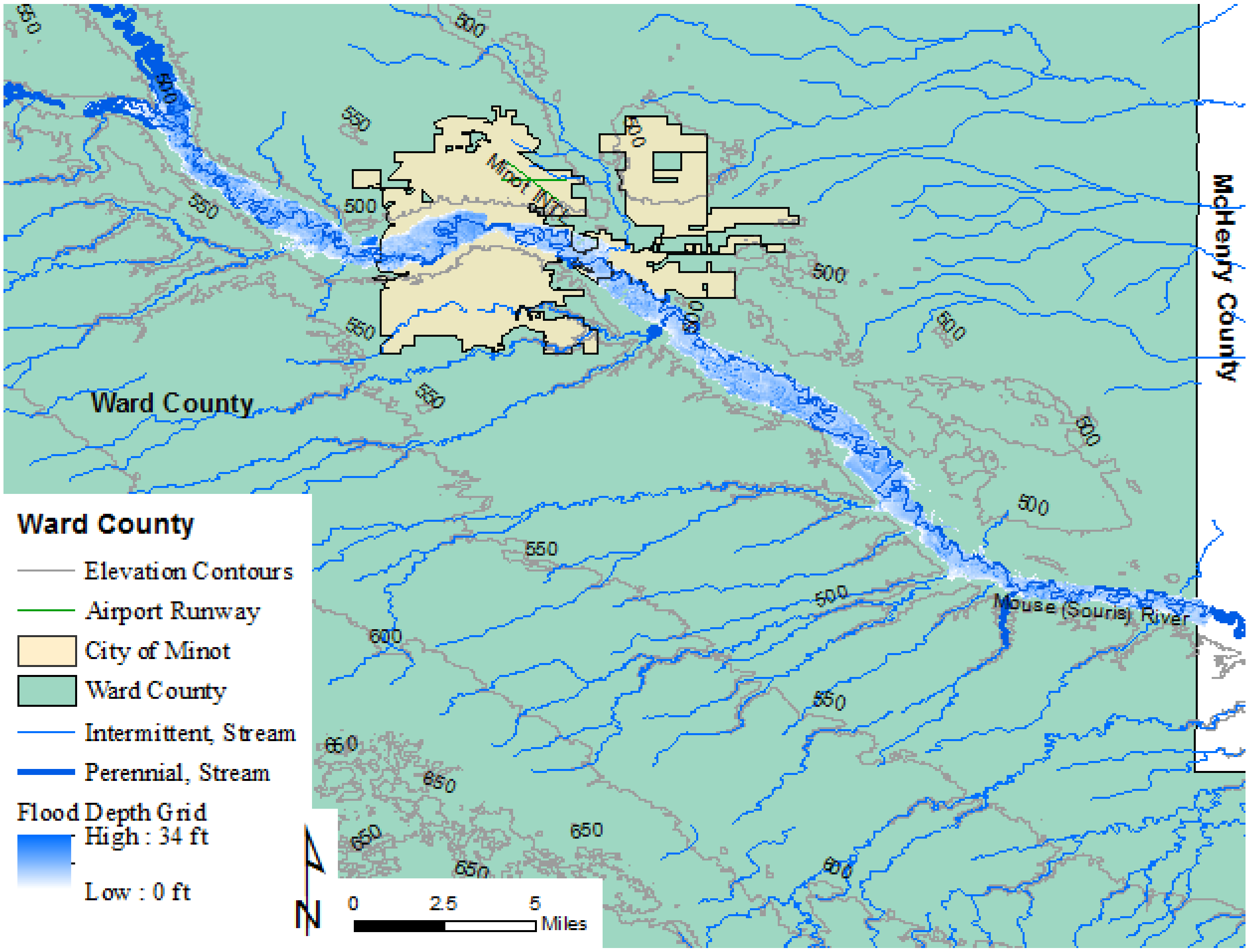

Figure 7 Ward County hydrography and topography map

The flood survey was conducted by FEMA as a Rapid Turnaround Damage Assessment quantifying the initial building damage. The flood event used within this thesis was caused by an excessive influx of seasonal spring snowmelt caused by above-freezing temperatures and heavy rains which caused the river to swell and surpass the typical amount of water commonly present during that time of the year.

FEMA uses the HAZUS hazard mitigation software to evaluate flood hazards. This thesis focuses on implementing dasymetry within Cass and Ward Counties. The use of dasymetry will produce an uneven distribution of buildings within each CBG. The location of these buildings is important to improve the model's estimation capacity, aiding damage estimation and land development planning efforts. These dasymetric datasets will be used to create HAZUS damage estimates to compare against the existing HAZUS's hazard model. Comparing the results of the dasymetric and current HAZUS models will determine the impact and appropriate uses of dasymetric building distribution while using observed flood events to constrain the results.

1.3 Progression

This thesis describes the processes of creating a dasymetric building distribution and generating HAZUS estimated flood damages. The effect of using dasymetric building distributions was examined by comparing the uniform and dasymetric distributed CBGs for each county. The models were analyzed by examining each CBG's acreage, flood depth, and estimated building damages. These comparisons describe how dasymetry altered the estimated building damage estimates and are used to gauge the ideal scenarios for implementing dasymetry within HAZUS.

Chapter 2 Background

Floods are the most common and costly natural disaster in the U.S. (NFIP, 2015). Floods are generally classified into two broad categories based on the origin of the floodwaters. Coastal floods occur when water is driven onto a coastline. Riverine floods occur when water overflows existing drainage networks. Occasionally, floods may also be caused by earthquake activity that affects lakes and reservoirs.

This thesis was exclusively concerned with riverine floods, which are devastating, recurring natural disasters, although they are not precisely predictable. The statistical risk of riverine flooding is expressed using the concept of a recurrence interval: the average period of time between floods of a particular magnitude. Thus, the "100-year" flood (1% chance of occurring in any year) is statistically four times less likely to occur than the "25-year" flood (4% chance), but five times more likely than a "500-year" flood (0.2% chance) – two other common recurrence intervals.

2.1 National Flood Insurance Program

The National Flood Insurance Program (NFIP) is a federal program focused on underwriting affordable flood insurance for property owners, in conjunction with floodplain management by state and local governments to mitigate future flood damages. The NFIP was established through the National Flood Insurance Act of 1968 (P.L. 90-448) and has been continually updated. FEMA has been responsible for administering the NFIP since the agency’s inception in 1979.

The NFIP is particularly focused on the 100-year flood boundary, characterized by the extent of a flood event that has a 1% chance of occurring in any given year. The Special Flood Hazard Area (SFHA) is the area within the 100-year flood boundary and federal law mandates that structures within this area obtain private or federal flood insurance. The NFIP developed

Flood Insurance Rate Maps (FIRMs) to depict the boundary of the SFHA (among other flood concerns) on topographic maps. The flood related data has been subsequently digitized to create DFIRMs as GIS became more prevalent in the 1990s. FIRMs and DFIRMs are periodically updated when there are changes noted about an area's hydrology or floodplain behavior. These updates undergo a formal administrative process as they impact mandated insurance policies. While these maps display the flood boundaries, they require their readers to infer which properties and populations would be impacted in a flood event.

2.2 HAZUS

HAZUS is a GIS-based software package developed by FEMA for estimating the physical losses and societal impacts caused by selected natural hazards: earthquakes, floods, and hurricane winds (FEMA, 2012). HAZUS provides a nationally applicable hazard mitigation, preparation, and response tool (Scawthorn et al., 2006a, b). HAZUS focuses on the exposure of buildings and an area's population to a hazard, in contrast to the previous FIRM approach, which only displayed flood prone areas. Buildings are prominently featured in the HAZUS loss-estimation methodology because they are expensive, immobile assets, and a proxy for the population's location.

HAZUS was first released in 1997 as earthquake modeling software. Each HAZUS release requires a specified ArcGIS version due to code library dependencies. In 2004, HAZUS was extended to model riverine floods, coastal floods, and wind-related hurricane events in addition to existing earthquake hazards. HAZUS was renamed to HAZUS-MH (for multi-hazard) to represent the release of the new models. In 2011, a coastal-surge model was added to HAZUS to model the effects of coastal flooding and hurricane winds because coastal flooding is largely driven by hurricanes. In 2012, the name of the software was updated to HAZUS 2.0, to reflect the major code updates so the model would function with ArcGIS 10.0. The most current HAZUS at the time of writing was HAZUS 2.2, released in 2015, which is certified to run with ArcGIS 10.2.2. Possible future HAZUS versions may include tsunami and wildfire natural hazards.

The HAZUS flood model (FL) estimates loses to life and property from a flood event in a specific study area. The general FL methodology is depicted in Figure 8. FL requires a landscape elevation model as shown at the lowest tranche (Figure 8). By default, the landscape is approximated by using the 30 m digital elevation model (DEM) that is part of the National Elevation Dataset (NED) (USGS, 2015b), but more detailed landscape datasets are supported (FEMA, 2012).

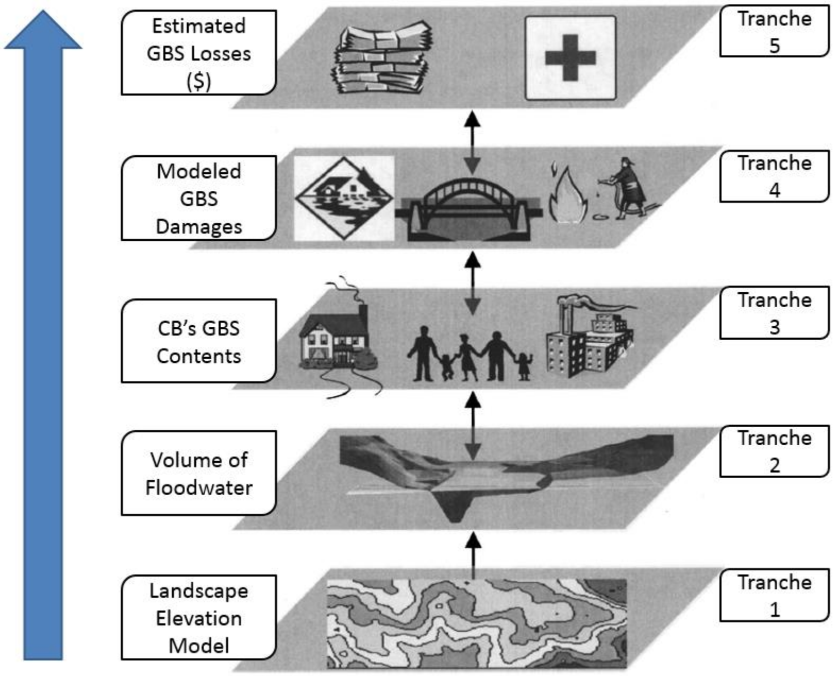

Figure 8 Basic HAZUS flood loss estimation methodology, modified from (Scawthorn et al., 2006a)

From the FIRMs, the boundary of a statistical flood may be obtained; this intersects the landscape at a more-or-less uniform elevation. Subtracting landscape elevation from the flood elevation gives the depth of floodwater within the flooded area, as shown in the second tranche of Figure 8. Flood elevations for inland areas are correlated with nearby river stages, i.e. the depth and rate of discharge upstream of the study area. HAZUS calculates a floodwater depth grid to represent the depth and location of the floodwater. HAZUS also accepts a user defined depth grid (UDDG) that are generated from empirical measurements or other flood simulations. UDDGs are used in place of the HAZUS generated depth grid.

HAZUS maintains an inventory of buildings, known as the General Building Stock (GBS). The GBS is an essential component of HAZUS. This dataset contains the age and construction type of various real estate categories, e.g. single-family homes, apartment complexes, office buildings, etc., at both the Census tract (CT, coarser) and Census Block Group (CBG, finer) scales. At both scales, the residential real estate categories of the GBS are inferred from the decennial federal Census, while the real estate components are derived from Dun and Bradstreet (D&B), a commercial data provider. GBS is only an approximation of the built environment, due to its spatial resolution, slow update frequency, and automatic census block group realignment and generalization from the original base data. Critically, HAZUS presumes the GBS is uniformly distributed across CBGs and CTs, which is frequently not true: only small and/or densely developed CBGs and CTs have a uniform distribution of buildings and hence people. Users typically opt for using the CBG scale because these contain fewer people and generally cover smaller areas than CTs.

The GBS can be augmented or supplanted by using User Defined Facilities (UDF) in HAZUS. UDFs represent the location of individual buildings as point features, in contrast to the assumed uniform GBS distribution. Regions with low-density and/or mixed development benefit particularly from using UDFs, because these tend to violate the uniform assumptions of the GBS.

FL models using UDFs by providing more specific data, at the added cost of establishing and subsequently maintaining the UDF data.

The FL model predicts the amount of potential flood damages to buildings by using depth damage functions (DDF), which represent algorithms estimating the percent of total physical damage as a function of the water depth. DDF were developed from previous building damage observations and models from the Federal Insurance Administration and the U.S. Army Corps of Engineers (Scawthorn et al., 2006b), empirically documenting the relationship between floodwater depth and building damages and various type of building construction. There are more than 900 DDFs in HAZUS (Scawthorn et al., 2006b; FEMA, 2013a).

The fourth tranche in Figure 8 represents the building damage calculations based on the depth grid. The FL model determines the flooded area of each CBG and the GBS damages using DDF. DDF are damage curves which express the expected amount of damage based on the depth of the floodwaters and type of building (FEMA, 2012).

These values are summed up for each combination of flood depth interval and building types for each CBG. HAZUS assumes a uniform GBS distribution for each CBG (FEMA, 2012). This thesis concentrates on the physical damages, which can be readily assessed and quantified.

The fifth and final tranche in Figure 8 represents the loss from the flooding to the people and the community that extends past the qualified property damages in the fourth tranche. The values in the fifth tranche quantify how the residents would be impacted beyond the initial inundation of the flood.

FL identifies three levels of analysis. Level 1 analyses are available “out-of-the-box” and can be run with little configuration, additional data, or subject-matter expertise. Level 1 analyses are typically used to determine the magnitude of a projected flood event and are the focus of this thesis. Level 2 and 3 analyses require progressively more detailed data about the floodwater or affected buildings to provide more precise and reliable results (FEMA, 2013a). The FL Level 1 results are often questioned by the end users (Nastev and Todorov, 2013). By default, the flood depth grid for riverine floods in Level 1 can be obtained by interpolating historical discharge curves for rivers affecting the SA, at known recurrence intervals (stages). These interpolated depth grids are approximations of the flood. By contrast, this thesis used measured flood depth grids, UDDGs, which recorded the observed flood depths for both study areas (SA).

2.3 Dasymetry

Dasymetry is a cartographic process of areal interpolation, where coarse attribute data from a parent dataset is disaggregated and redistributed according to an auxiliary dataset with higher spatial resolution based on an obvious, if latent relationship between the two datasets (Eicher and Brewer, 2001; Goodchild and Lam, 1980). Dasymetry has been commonly used to represent the locations of populations, for example, crude national population data can be disaggregated to population centers, based on remote sensing of nighttime illumination, which correlate with the distribution of people (Zandbergen and Ignizio, 2010). This *redistribution* of the original dataset into smaller enumeration units allows the dataset to be more accurately represented. Dasymetry can be constrained to maintain the total of the original attributes, described as pycnophylactic interpolation, to smooth changes between enumeration units, particularly those at the edges (Tobler, 1979).

The use of dasymetry has grown with the availability of satellite imagery: over 75% of the dasymetric mapping references have been published after 2000 (Petrov, 2012). The auxiliary dataset does not need to be remotely sensed. It can be inferred from mapping of impervious surfaces, road networks, building developments, nighttime lights, etc. (Zandbergen and Ignizio, 2010). Dasymetric refinement of the Census data is a recent development and has been used in a variety of population and natural science applications (Sleeter and Gould, 2007).

This thesis utilized remotely sensed LULC data to refine the distribution of buildings within CBGs, i.e. the GBS, without the need to develop expensive UDF data. The fundamental idea is that buildings generally will be located in those portions of CBGs covered under the LULC categories recognized as developed (commercial and/or residential) or actively used for agriculture with the other portions assumed largely free of buildings, and hence people. Thus, the aggregate GBS *exposure* in each CBG can be redistributed to just those CBG portions with LULC *coverage* to provide greater accuracy of each CBG's GBS. In HAZUS, this redistribution is achieved by omitting the uncovered portions the CBGs themselves.

LULC was initially derived from remote sensing onto topographic maps spanning the U.S. (Anderson et al., 1976). LULC is now routinely produced from Landsat imagery by the Multi-Resolution Land Characteristic Consortium (Fry et al., 2011). MRLC produces the NLCD (National Land Cover Dataset) on 5-year intervals, most recently in 2011. The 2001 and 2006 NLCD rasters conform to the same format as the 2011 version, to facilitate LULC comparison detection. The standard NLCD product is a 30 x 30 m resolution raster distributed through the MRLC web site. The 2006 NLCD raster is the most recent dataset version which exists for both the NLCD and HAZUS-formatted datasets near the Cass and Ward floods.

In March 2011, the HAZUS Flood Steering Committee oversaw the development of FL, first proposed using a dasymetric approach to improve the accuracy of Level 1 damage assessments (Todorov, 2012). The committee noted that the HAZUS user community had been moving away from the Level 1 model because of perceived damage *over*-estimation and general ignorance of building distribution. To counter this trend, the user community has been increasingly using UDF datasets (Nastev and Todorov, 2013), which are difficult to develop and expensive to maintain, limiting some of the value of HAZUS.

In 2012, the Hazards Flood Steering Committee established a proof of concept for dasymetry in HAZUS, utilizing estuary riverine flooding damage estimates in Bristol County, Rhode Island based on the NLCD 2006 dataset. The use of dasymetry allowed the GBS to be distributed according to developed areas observed within the NLCD. The proof-of-concept was developed as an Esri ArcGIS toolkit to allow further development of dasymetric GBS representations.

In 2013, a second study compared five different damage models for Charleston County, South Carolina based on: (1) a uniform GBS distribution; (2) a binary dasymetric GBS redistribution; (3) a weighted dasymetric GBS redistribution by LULC codes; (4) UDFs representing building centroids; and (5) UDFs representing parcel centroids (Todorov et al., 2013). The binary dasymetric GBS distribution method parsed the GBS based on the presence or absence of developed LULC coverage. The weighted dasymetric GBS distribution method assigns increasing importance to developed areas based on their particular LULC codes. Overall, this thesis confirmed reduced damages, as expected, but also suggested some higher damages where aggressive land development occurred within flood zones. In 2014, the FEMA HAZUS application team started to create a dasymetric GBS layer for the U.S. as an alternative dataset to the existing uniform GBS distribution for Level 1 Analysis (Bausch, 2014).

This thesis builds upon the prior studies involving the use of dasymetric approaches and the previous dasymetric methods detailed by FEMA. This thesis is unique as it is the first FL study to examine the use of dasymetry GBS distribution within large magnitude flood events.

The next chapter outlines the methods and datasets used to complete a FL damage estimate. These methods include a process to create the dasymetric Census Block Groups that is unique to this thesis.

Chapter 3 Methods and Data

FL relies on two spatially extensive datasets in calculating damage: landscape elevation and Census Block Groups (CBG). In FL, landscape elevation could be provided as a digital elevation model (DEM) or as a user defined depth grid (UDDG). The CBGs and CTs provide the spatial context for the GBS. This thesis required land-use/land-code data from the NLCD to perform dasymetry.

3.1 Flood Depths

This thesis utilized UDDGs to represent the extent and depth of floodwaters in a raster format and do not require a DEM. UDDGs were derived from onsite measurements produced by FEMA employees who surveyed the study areas after flood events (Rozelle et al., 2011). The availability of relevant UDDGs allowed this thesis to use the observed flood impacts. This thesis did not use FL generated depth grids because they introduce potential error as they are models of where flooding might occur.

3.2 Census Block Groups and Tracts

The U.S. Census Bureau has used Census Tracts and Census Block Groups as the primary geographic units to collect and tabulate census results since 1940 (U.S. Census Bureau, 2000). The Bureau's smallest enumeration unit is the census block (CB). Like the larger CBG and CT units, population distribution rather than geographic boundaries form CBs. CBs represent a small number of households living in residential structures. The Census Bureau attempts to contact each household to ascertain the number of people living in the area. CBGs are considered the most accurate data from the Census Bureau where there is 100% data coverage (as opposed to, for example, the data sampling approach now used for the American Community Survey for CBs).

Populations change over time influences the number and shape of CBs, CBGs, and CTs. Change with each census alters the geography of CBG boundaries which are often constrained within county and state boundaries and omit water bodies. The Census Bureau produces the spatial representations of the CBG and CT census enumeration units as part of the broader TIGER/Line (Topologically Integrated Geographic Encoding and Referencing/Line) dataset, which contains additional small-scale geometry. The compilation of TIGER/Line data is publicly available and distributed free-of-charge. HAZUS-MH utilizes the U.S. Census data extensively to obtain population and demographics data and to delineate reporting units.

3.3 General Building Stock

The General Building Stock (GBS) characterizes the buildings within each CBG. GBS data describes the building's occupancy class, foundation type, assumed first floor elevation, square footage, building counts, valuation parameters, dollar exposure, and if the building conforms to the Flood Insurance Rate Map modernization program (FEMA, 2012). These building characteristics affect the building's flood resistance. GBS is used as inputs for the FL's DDF. The GBS is downloaded as an additional dataset from FEMA for each state or territory and can subsequently be manually updated.

The residential building stock provided a way to infer the number of people within a CBG. The non-residential data was compiled from Dun & Bradstreet in 2002 as a commercial dataset. HAZUS GBS attributes are linked to the CBGs, hzCensusBlock, by joining on the layers according to their CBG ID.

FL presumes that GBS is evenly distributed across a CBG. This assumption simplifies the data but it creates a fallacy because not every type of building occurs across a CBG. Common building zoning observations indicate that building types are not evenly distributed across a CBG. This thesis seeks to address this observation by incorporating National Land Cover data (NLCD) to specify the locations of various types of buildings within individual CBGs using dasymetry.

3.4 Land-Use/Land-Cover

The term land-use/land-cover (LULC) refers to the predominant type of land occupancy and/or land cover visible on the Earth’s surface. The earliest iteration was the Anderson LULC system, developed by the USGS in the early 1970s. It comprised nine major and 37 sub-classifications of land occupancy (Anderson et al., 1976). The Anderson dataset was created using photogrammetry, by which aerial photographs were used to manually outline the area of each land classification. The results were transposed onto 1:100,000-scale USGS topographic maps. The smallest features resolved were ~4 ha for man-made objects and ~16 ha for natural land cover features.

Satellite remote sensing, particularly Landsat Thematic Mapper (TM), has improved the efficiency and quality of generating LULC datasets. The National Land Cover Database (NLCD) is the TM-based successor to Anderson’s 1976 LULC database. Unlike the LULC, the NLCD is a raster dataset comprised 30 x 30 m cells, each representing the type of land classification present at that location from one of the 20 categories listed in Table 1 (Wickham et al., 2013). The Multi-Resolution Land Characteristics Consortium (MRLC), a partnership between multiple Federal agencies, is responsible for producing the NLCD. The MRLC has produced NLCD coverages from data collected in 1992, 2001, 2006, and 2011. A small adjustment in 2011 to the

LULC classification scheme improved change detection by MRLC, requiring the NLCD 2006 data to be reprocessed. Nearly 80% of the LULC categorized in the NLCD 2006 were confirmed accurate following ground truth and aerial imagery analysis (Wickham et al., 2013).

Table 1 NLCD Land Classification Codes

NLCD Code	Land Classification	Focus of Study
11	Open Water	---
12	Perennial Ice / Snow	---
21	Developed, Open Space	Yes
22	Developed, Low Intensity	Yes
23	Developed, Medium Intensity	Yes
24	Developed, High Intensity	Yes
31	Barren Land	---
41	Deciduous Forest	---
42	Evergreen Forest	---
43	Mixed Forest	---
51	Dwarf Scrub	---
52	Scrub / Scrub	---
71	Grassland / Herbaceous	---
72	Sedge / Herbaceous	---
73	Lichens	---
74	Moss	---
81	Pasture / Hay	Yes
82	Cultivated Crops	Yes
90	Woody Wetlands	---
95	Emergent Herbaceous Wetlands	---

This thesis uses the NLCD in the dasymetric mapping conversion process to specify the location of buildings in the GBS in the CBGs. NLCD 2006 was selected for this thesis because the dataset is the most accurate available and the closest in time to the HAZUS-MH 2.2 demographic data prior to the Fargo (2009) and Minot (2011) flood events. The NLCD 2006 data is available with a 30 x 30 m cell size. The HAZUS-supplied NLCD cells were created by generalizing the original NLCD 2006 cell size from 30 x 30 m to 180 x 270 m, as shown in

Figure 9, thereby reducing the storage requirement by a factor of nearly 50 (Fry et al., 2011). The "coarser" data coverage of the HAZUS-modified NLCD represents the most frequently occurring NLCD 2006 LULC code within its boundary.

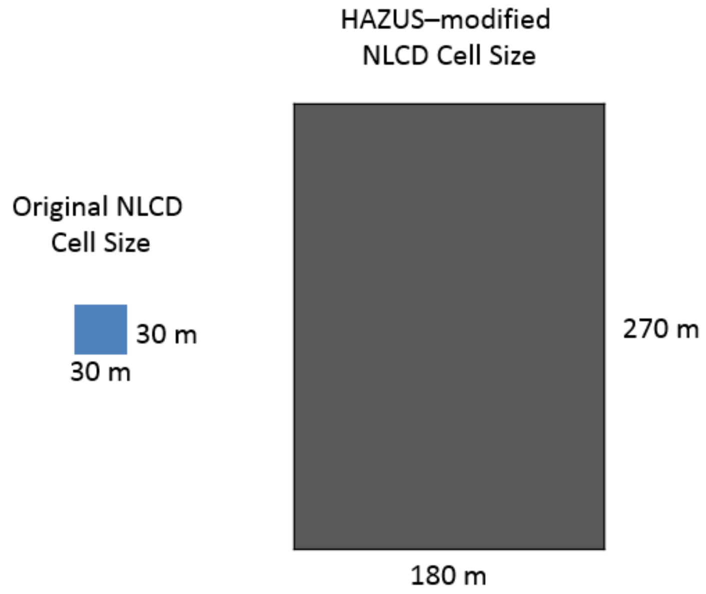

Figure 9 Original NLCD & HAZUS-modified NLCD Cell Size Comparison

3.5 NLCD Extraction and Conversion Processes

The NLCD extraction and conversion processes detail how areas with developed surfaces were identified within the HAZUS-modified and North Dakota GIS Clearinghouse (NDGC)-supplied NLCD to form the respective dasymetric CBGs, $DCBG_H$ and $DCBG_N$. The process of extracting the relevant LULC data from HAZUS and NDGC was unique to each dataset due to their different data formats.

3.5.1 HAZUS-modified NLCD Data Conversion

The HAZUS-modified NLCD raster was used to produce a final raster containing developed land within the North Dakota state boundaries as displayed in Figure 3. The initial step involved extracting the data within the North Dakota state boundary from the HAZUS-modified NLCD raster (ArcGIS "Clip Raster" tool). A new raster was produced by extracting selected LULC codes (ArcGIS "Extract by Attributes" tool) to represent the developed land areas within North Dakota. This thesis used the following LULC codes from the HAZUS-modified NLCD raster to identify the areas of developed LULC: 21 Developed, Open Space; 22 Developed, Low Intensity; 23 Developed, Medium Intensity; 24 Developed, High Intensity; 81 Pasture/ Hay, and 82 Cultivated Crops (Todorov, 2012). The raster cells without one of the preceding codes, have a code of zero indicating an undeveloped area. This process produced a raster which only contained the developed land areas within North Dakota from the initial HAZUS-modified NLCD raster, as shown in Figure 10.

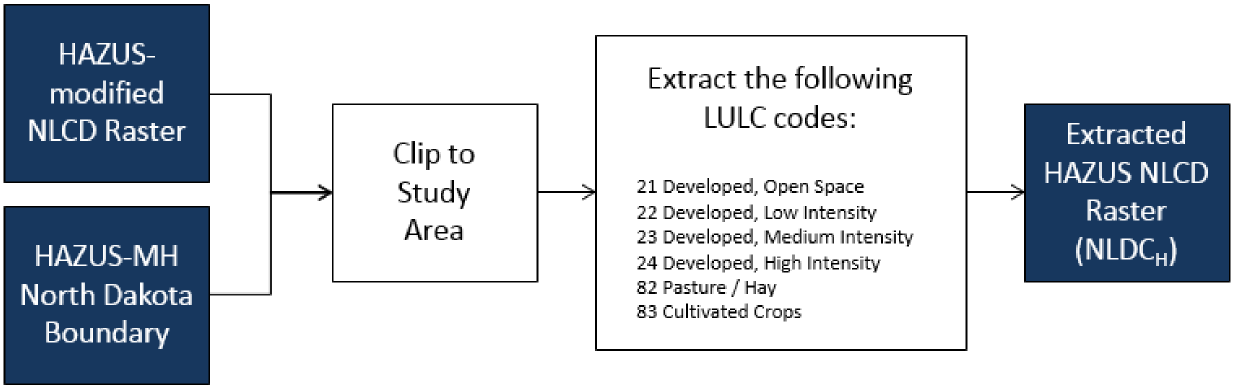

Figure 10 HAZUS NLCD Extraction Process

3.5.2 NDGC-supplied NLCD Data Conversion

The NDGC-supplied NLCD raster contains data within the North Dakota state boundary and has a different set of symbolic LULC codes than the HAZUS-supplied NLCD raster. A raster was produced by extracting selected LULC codes (ArcGIS "Extract by Attributes" tool) from the NDGC-supplied NLCD raster to identify the areas of developed LULC: 2 Developed, Open Space; 3 Developed, Low Intensity; 4 Developed, Medium Intensity; 5 Developed, High

Intensity; 12 Pasture/ Hay; and 13 Cultivated Crops. The raster cells without one of the preceding codes, were assigned a code of zero to indicate undeveloped area. This process produced a raster containing the extracted developed land areas within North Dakota, as shown in Figure 11.

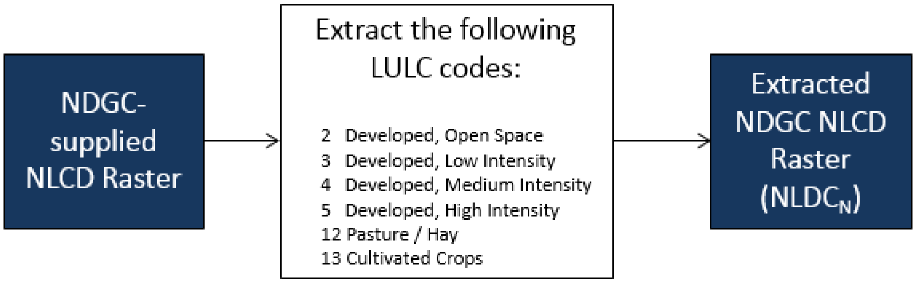

Figure 11 NDGC NLCD Extraction Process

3.5.3 Final NLCD Data Conversion

The final portion of the data conversion converted the previously standardized extracted NLCD rasters into a format compatible with the FL software. This conversion must be done separately for the NLCD$_H$ and NLCD$_N$ rasters as shown in Figure 12 and Figure 13. The products of each raster extraction process were converted into binary values to classify the presence or absence of developed land within the state. Cells containing non-zero values had their values set to 1 and the remaining cells containing values of zero were left unchanged. Each binary raster was converted to a polygon format (ArcGIS “Raster to Polygon” tool, with No_Simplify option enabled to preserve the raster cells’ perimeters). Finally, these separate vector polygons had their internal boundaries dissolved to create a single multi-part polygon (ArcGIS “Dissolve” tool). This polygon forms the NLCD coverage details where GBS exposure exists and consequently could produce building damages if inundated by flood waters.

The NLDC coverages were intersected with CBGs (ArcGIS "Intersect" tool) to produce the representative set of dasymetric CBGs containing developed areas within in each CBG. Generally, the $DCBG_H$ and $DCBG_N$ contained a portion of the original CBG's area given that the majority of census blocks contain undeveloped areas. FL requires that the dasymetric coverage exists with the same attribute column formats as the existing CBG in order to allow the dataset to be interchangeable.

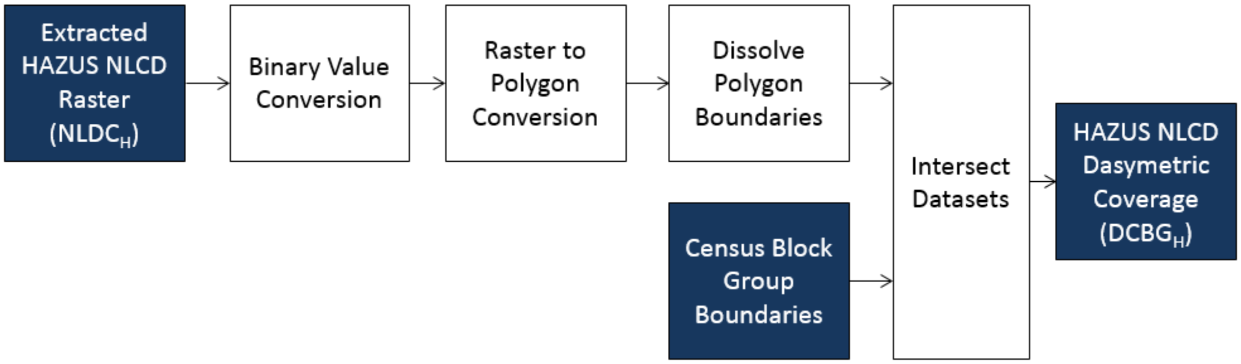

Figure 12 HAZUS NLCD Dasymetric Coverage Production

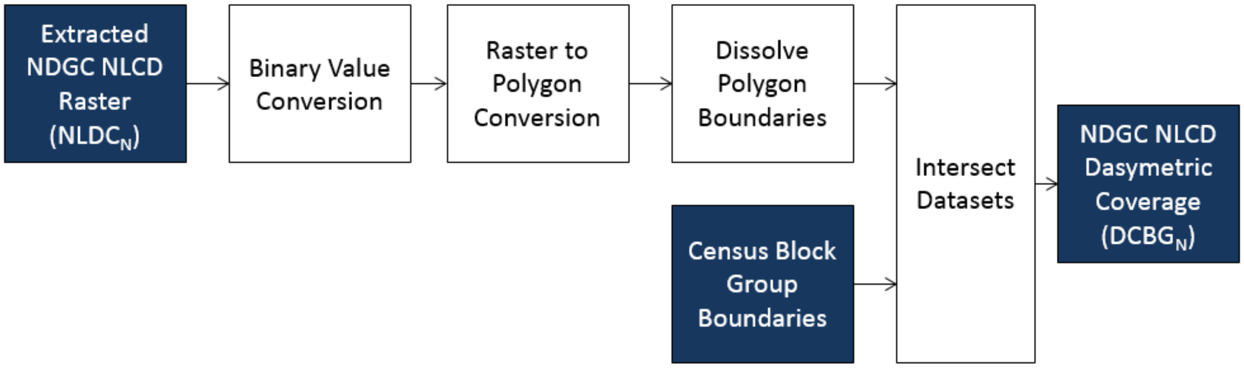

Figure 13 NDGC NLCD Dasymetric Coverage Production

3.6 Evaluating the GBS Coverage Creation

Once the $DCBG_H$ and $DCBG_N$ were created, each DCBG dataset was validated to ensure that each CBG containing GBS exposure persisted through the NLCD Extraction and Conversion process. The validation process consisted of determining if a census block contained GBS exposure and if the CBG intersected with the NLCD coverage. This validation ensured a commensurate comparison between the FL Level 1 models because all of the GBS exposure was consistently maintained.

Categories were defined to characterize the CBG types within Cass County and Ward based on the presence or absence of GBS exposure and NLCD coverage. The CBGs with both exposure and coverage contain the GBS needed to yield a damage estimate if the DCBGs is inundated. They are the most important for the FL model. However, areas with exposure and without apparent coverage and potentially omit GBS from the estimated damage total, which can artificially lower the damage total. These CBGs were manually examined and processed separately.

The CBGs with exposure but lacking coverage were manually reviewed using aerial imagery to identify developed areas. Developed areas were manually digitized from aerial imagery into polygons at a scale of approximately 1:1,000 for each CBG. These digitized developed areas were merged into the previously-dissolved NLCD coverage (ArcGIS “Merge” tool). The DCBG intersection was rerun to generate a final DCBG layer, which contained the full inferred GBS exposure, as shown in Figure 14.

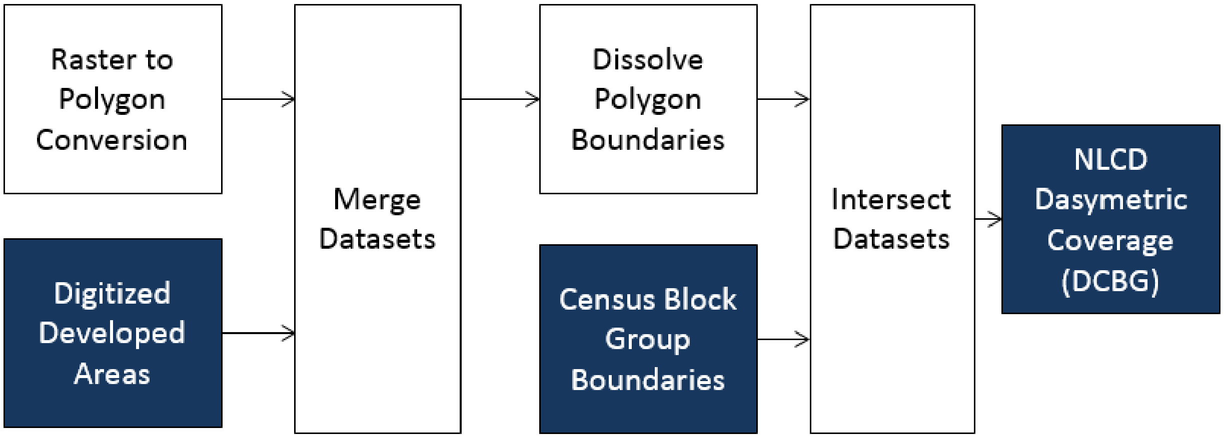

Figure 14 Process of Incorporating Additional Digitized Coverage

Some 95% (i.e., 343 of the 361 of the CBGs with exposure and lacking NLCD coverage) were successfully reclaimed after being digitized across the state but only a few were located within either Cass or Ward County. The remaining 18 CBGs were checked again before being omitted from the $DCBG_H$ and $DCBG_N$ datasets.

The CBGs without exposure do not impact the FL Level 1 estimated damages because they did not contain buildings so they do not have GBS values. The CBGs without exposure and with coverage can occur due to a modifiable areal unit problem (MAUP). MAUP can be an issue because the boundaries of the datasets being used do not align. The greater difference between the source and target dataset, the greater the risk of introducing error because of the assumption that the values of the source dataset are uniformly distributed (Zandbergen and Ignizio, 2010). The MAUP in this thesis exists because the NLCD raster cell sizes do not conform to the HCBG polygon boundaries. Figure 15 displays an example were a NLCD raster cell spans the border between CBG_A and CBG_B. If this raster cell corresponded to any of the eligible codes listed in Table 1 then both CBGs would have coverage.

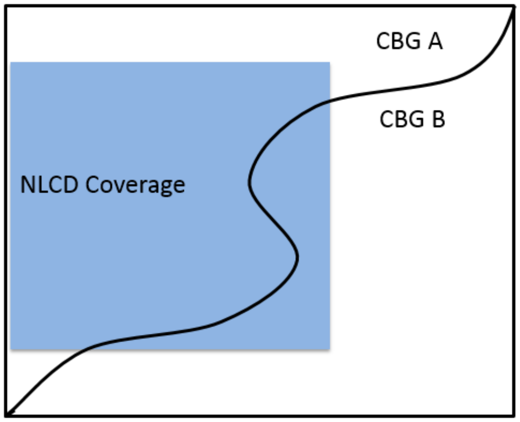

Figure 15 Example of Overlapping NLCD Coverage

The CBGs without exposure and with coverage could also exist if development occurred in the intervening time between the creation of the GBS in 2002 and the NLCD coverage dataset in 2006. CBG's without coverage and without exposure are common in North Dakota because the state has extensive natural and agricultural land outside city centers.

3.7 Execution of FL Level 1 Analysis

FL Level 1 damage estimates where generated for three GBS distributions for the 2009 flood in Cass County and the 2011 flood in Ward County. The three distributions were: (1) the uniform case by which the GBS was spread evenly across the appropriate CBG (HCBG); (2) the dasymetric case derived from $DCBG_H$; and (3) the dasymetric case derived from the $DCBG_N$. These six damage analyses allowed a comparison between the default uniform GBS and dasymetric GBS distributions.

Any properly formatted CBG representation can be used to generate a FL damage model. This thesis used the substitution of CBG representations to serve as different GBS distributions without altering the HAZUS application code. The CBG polygon must contain all of the FL required attributes for the CBG representation in order to stand in for the original polygon layer, entitled the hzCensusBlock layer. For the modified CBG representation file to be used, it must be located within the following file directory (C:\HazusData\Inventory\<StateAbbreviation>\syBoundary.mdb), before creating a study region.

Using the background processes outlined in this chapter, the next chapter compares and contrasts the damage estimates generated using these three GBS portrayals within Cass and Ward Counties. This comparison will examine the underlying factors between each GBS portrayal within a single county to understand how the allocation of GBS affects the damage estimate. The GBS portrayals between Cass and Ward counties are compared to determine if there is a correlation between the magnitude of the floodwater's extent and damage magnitude.

This thesis examined the FL Level 1 estimated damages and the values represent the "Economic Loss by Full Replacement Cost" category for Capital Stock Losses. This value represents the estimated damages to both Pre-FIRM & Post-FIRM (flood insurance rate map timing) structures, contents, and inventory losses. These losses reflect the building's deflation and contents. These field types are consistent with the previous HAZUS dasymetric evaluations (Todorov, 2012).

Chapter 4 Damage Estimate Results

This chapter presents the results of the flood damage estimates using the previously created dasymetric CBG formats. These estimated damages and their meaning are a function of the data describing GBS's location, acreage, and flood depth for each CBG. Damage estimates were compared with the affected CBGs and acreage for each county and GBS format to evaluate the impact to the other datasets. FL Level 1 building damage estimates were produced using three GBS exposures: HCBG, $DCBG_H$, and $DCBG_N$ using the Cass County 2009 flood extent and Ward County 2011 flood extent (Figure 5 and Figure 7).

Flood damage results were recorded by reporting the factors that comprise the damage estimation functions. The Total Acreage represents the county's total area that could be subjected to flooding. The Inundated Acreage represents the flooded area within the county. The Mean Flood Depth (MFD) comparison highlights the average floodwater depth between GBS formats. The Normalized Damage Estimates provide a standardized comparison between the GBS formats.

4.1 Estimated Flood Damages

Cass County displayed significant differences in the estimated building damages between the HCBG, $DCBG_H$, and $DCBG_N$ representations (Table 2).

Table 2 Cass County Flood Damage Estimates

GBS Representation	**Total CBG**	**Total Acreage (ac)**	**Inundated CBG**	**Inundated Acreage (ac)**	**Building Damages**
HCBG	240	51,909	162	28,547	$253,163,000
DCBG$_H$	236	48,161	156	25,572	$198,970,000 (21.4% below HCBG)
DCBG$_N$	239	48,288	162	25,691	$207,301,000 (18.1% below HCBG)

Ward County displayed similar estimated flood damages between the HCBG, DCBG$_H$, and DCBG$_N$ representations, but significant differences between the total and inundated acreages, but not in the building damages (Table 3). Notice that many CBGs were fully inundated or completely developed and, therefore, there would not be any difference between the HCBG and DCBG representations.

Table 3 Ward County Flood Damage Estimates

GBS Representation	**Total CBG**	**Total Acreage (ac)**	**Inundated CBG**	**Inundated Acreage (ac)**	**Building Damages**
HCBG	577	43,565	415	11,290	$520,527,000
DCBG$_H$	567	26,689	418	8,408	$518,474,000 (0.4% below HCBG)
DCBG$_N$	572	26,117	413	7,994	$517,489,000 (0.6% below HCBG)

4.2 Acreage Comparisons

The overall acreage of each CBG is a primary factor in FL Level 1 damage estimates. Total Acreage represents the total area of each CBG representation (Esri ArcGIS Calculate Geometry). Inundated Acreage represents the flooded area within each CBG representation (Esri ArcGIS

Calculate Geometry intersection between Flood Extent and CBG). FL uses the ratio between inundated acreage and total acreage to represent the percentage of GBS applied to the DDF. Comparing the HCBG and DCBG acreages for a county highlights how the GBS was subjected to damage.

While all three GBS representations describe the same physical CBG acreage, each represents that acreage differently. Since the damage estimation model is concerned with the damage to physical property and the way each representation accounts for physical property (GBS) is different – they produce different Total Acreage values.

HCBG assumes a uniform distribution of GBS and, therefore, accounts for the greatest acreage across the original CBG representation. $DCBG_H$ and $DCBG_N$ represented the use of the dasymetric processing to focus on isolating the areas containing LULC codes consistent with containing GBS. The differences between these representations can be compared to illustrate the various damage estimates. The Acreage Metric Equation represents the acreage metric used to compare percent change in the original acreage. An acreage metric of 0 represents where the HCBG and DCBG representations have the same acreage. An acreage metric of nearly 1 represents where the HCBG is substantially larger than the DCBG representation.

$$Acreage\ Metric = \frac{(Uniform\ Acreage - Dasymetic\ GBS\ Acreage)}{(Uniform\ Acreage)} \qquad (1)$$

Figure 16 displays the different acreages for a single CBG. The HCBG Total Acreage is the total area outlined by the thick black line. It encompasses both the $DCBG_N$ area and the HCBG area. The $DCBG_N$ only contains the areas where GBS is present according to LULC data. The underlying flood depth gird represents the inundation extent within the CBG. These factors illustrate how the Total and Inundated Acreages are related and how the damages can be different between CBG representations (Figure 17).

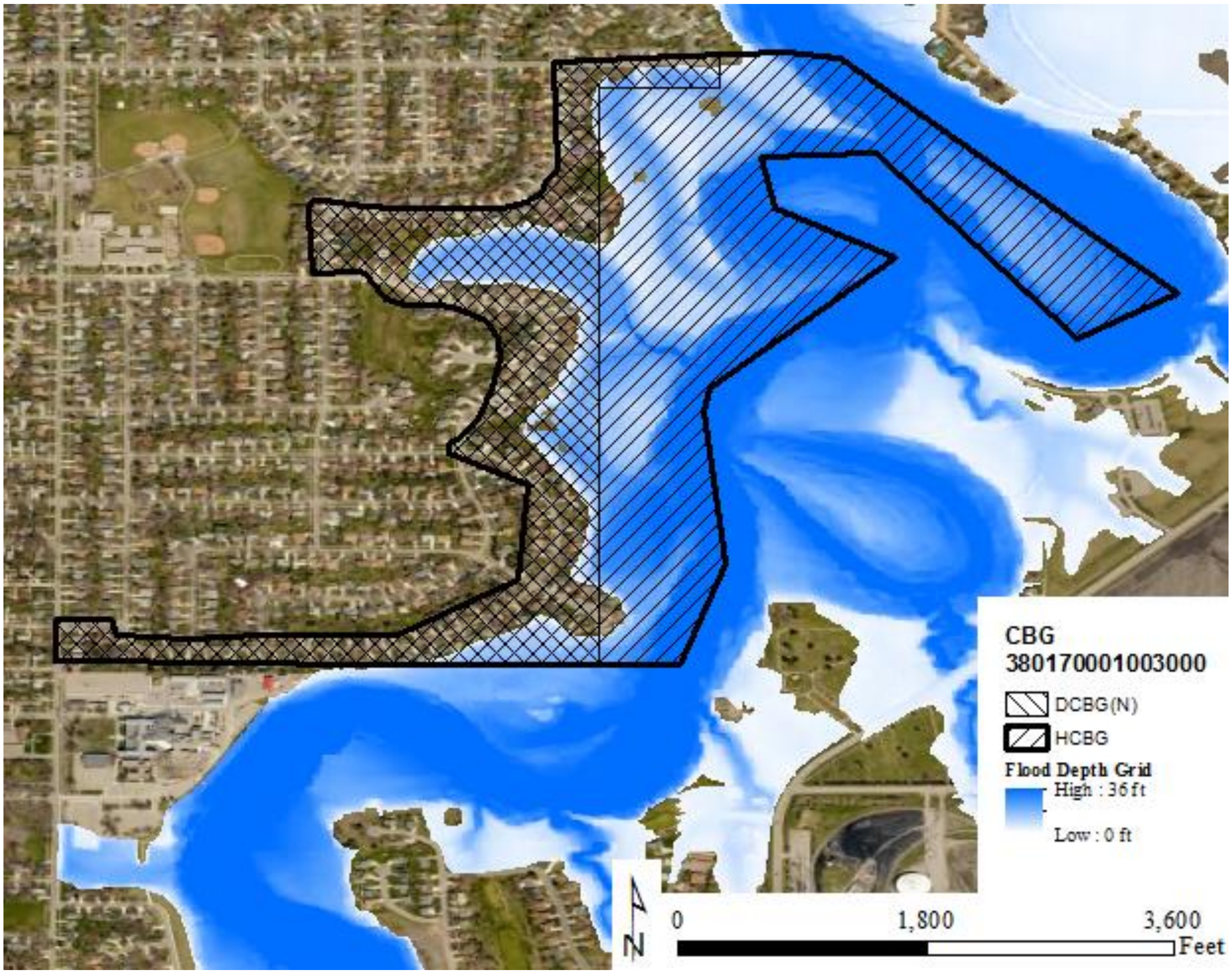

Figure 16 Total and Inundated Acreage Comparisons

Cass County had a range of total acreage metric values because of the number of CBGs with limited indicated LULC development (Figure 18). This change in total acreage also affected the inundated acreage comparison as the area subjected to flooding is different.

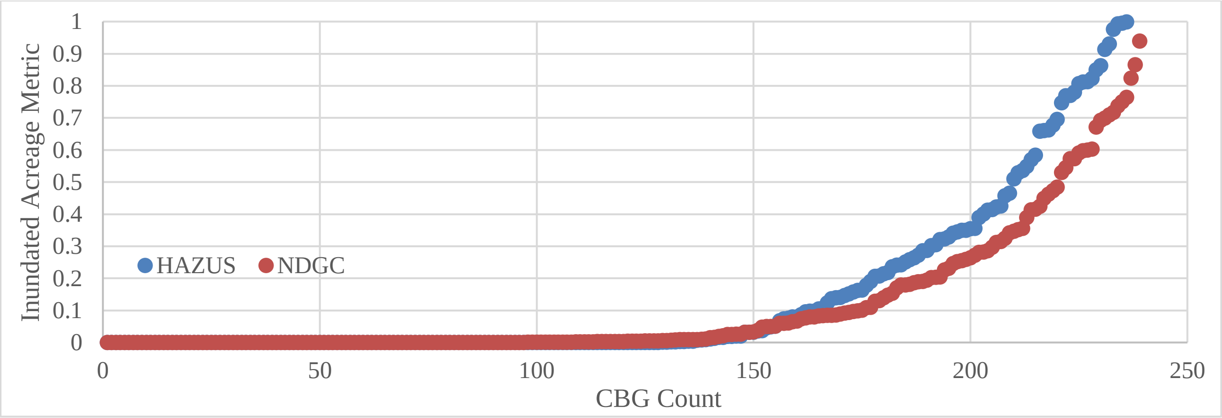

Figure 17 Cass County Inundated Acreage Metric

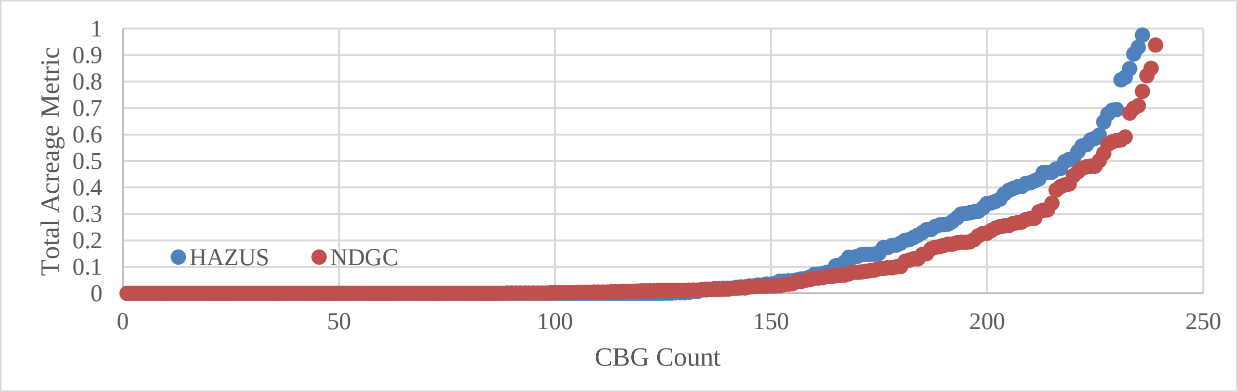

Figure 18 Cass County Total Acreage Metric

Ward County displayed similar Inundated Acreage values between the DCBG representations (Figure 19). The Total Acreage Metric values are different between the CBGs representations because the CBGs were small and more developed than Cass County (Figure 20), which were affected by the NLCD cell size producing the DCBGs.

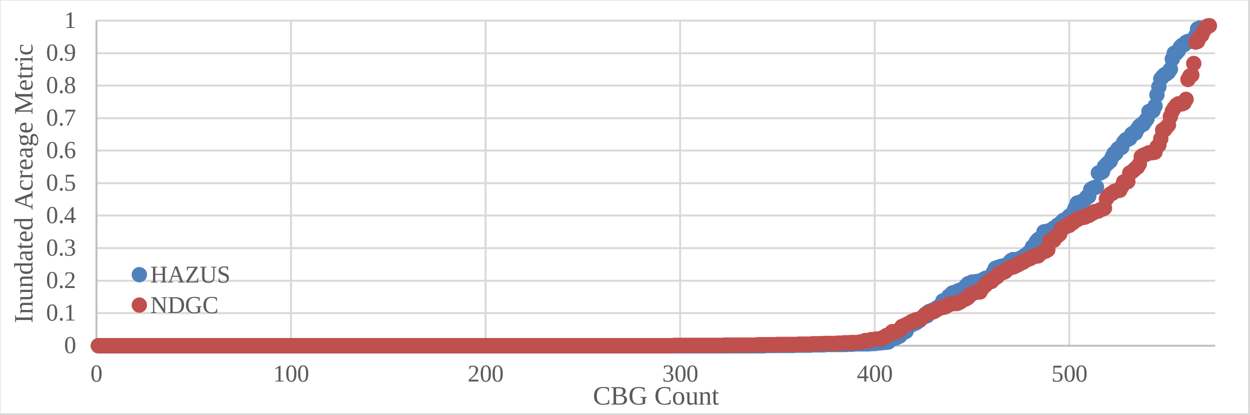

Figure 19 Ward County Inundated Acreage Metric

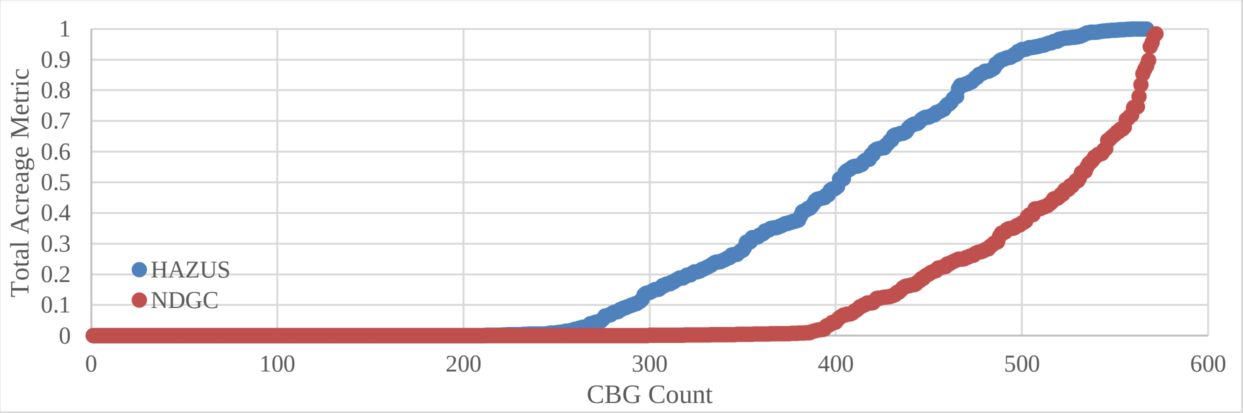

Figure 20 Ward County Total Acreage Metric

4.3 Mean Flood Depth

The Mean Flood Depth (MFD) represents the average floodwater depth within a CBG. The floodwater's depth is a primary factor in the FL Level 1 damage estimates. A change in MFD can affect how DDF are applied. Figure 21 displays a DDF to show the correlation between flood depth and estimated building damage expressed as a percent of the building's replacement cost.

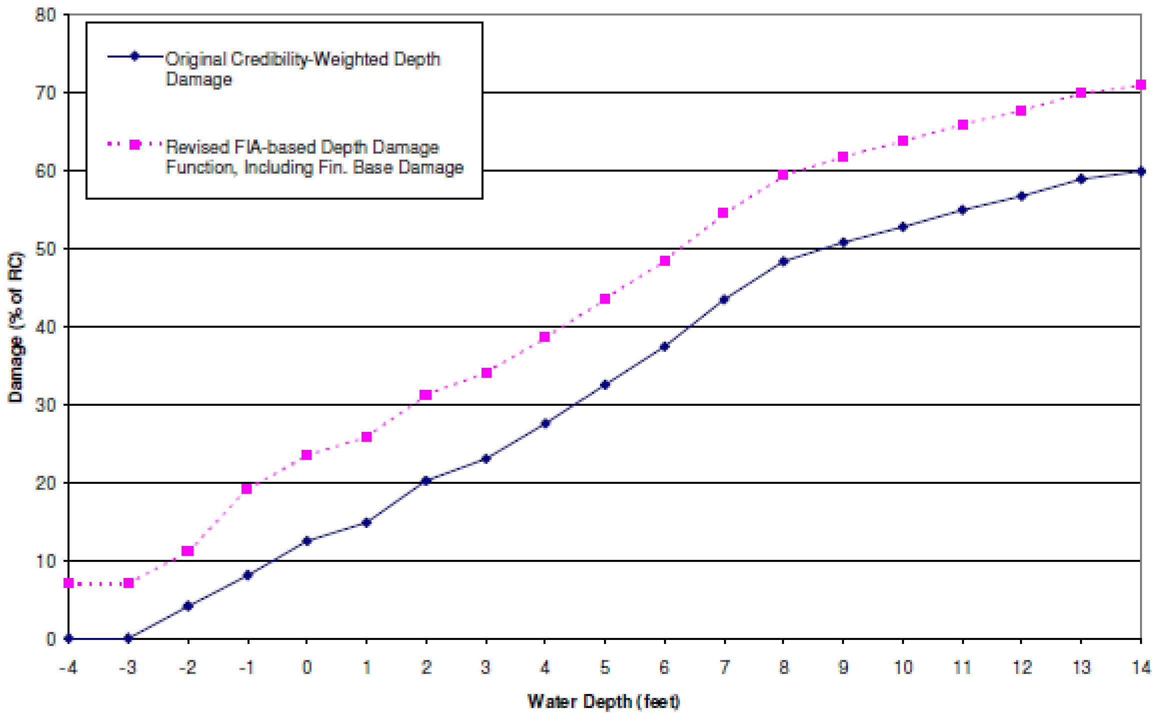

Figure 21 Sample Depth Damage Curve (FEMA, 2012)

FL Level 1 applies DDFs to each CBG to estimate building damages. These estimates are affected by the GBS's location relative to the flood. Expressing MFD's for a county is less representative as the value is an average of the depth averages. This thesis compared the MFD from the $DCBG_H$ against HCBG and $DCBG_N$ against HCBG to demonstrate how the floodwater's depth changed within each CBG for each GBS representation. Figure 22 focuses on an inset of Figure 16 to compare the Total Acreage of the CBG against the flood depth to illustrate the relationship between the flood depth and damages. Different GBS representations can lead to different MFD values within the same CBG. This CBG example shows the deepest flood depths occur in the HCBG format, and not in the $DCBG_N$ inundated acreage.

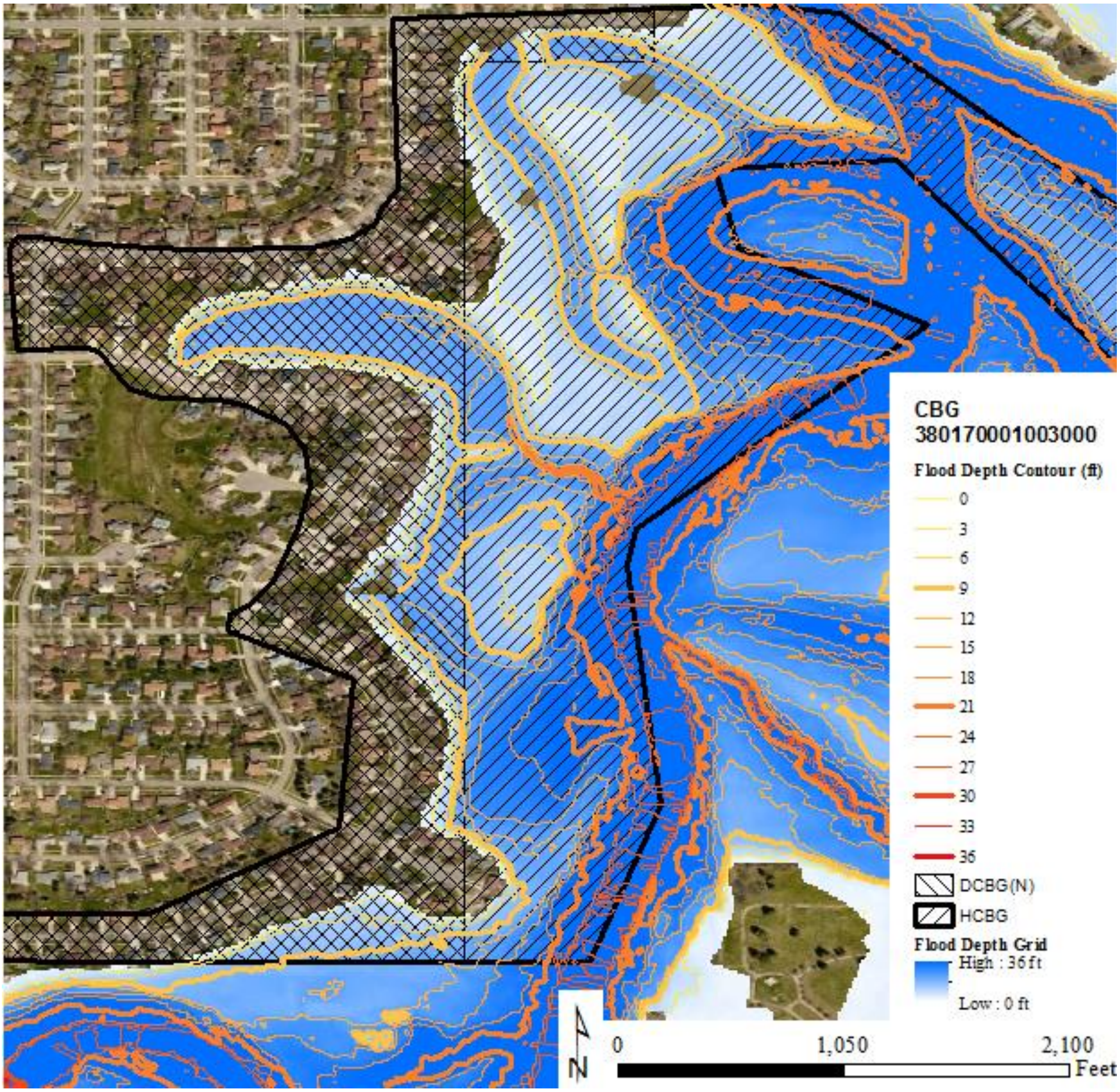

Figure 22 Mean Flood Depth Comparison

Equation (2) was created to compare the MFD between HCBG and DCBGs to compare the effect of dasymetry on the floodwater's depth. Each CBG comparison was plotted on a histogram to compare the MFD between HCBG and DCBG GBS representations in Cass and Ward Counties (Figure 23 and Figure 26).

$$Mean\ Flood\ Depth\ Metric = Mean\ HCBG\ Flood\ Depth\ - Mean\ DCBG\ Flood\ Depth \quad (2)$$

Positive values indicate that the HCBG had a higher MFD than the DCBG; which would increase the damage predicted by DDF. HCBGs and DCBGs have MFD values of 0 when the MFDs are equal. This means, on average, if HCBG and DCBG had the same Total Acreage inundated that the DCBG would produce less damage because of the shallower depths used in the DDF.

In Cass County, HCBGs typically had greater than or equal to MFD values than the DCBG (Figure 23). The MFDs were 26% shallower for $DCBG_H$ and 30% shallower for $DCBG_N$ than the HCBG MFD. These values represent less estimated damages within either DCBG representation than for HCBG given the same considered areas. HCBGs displayed much deeper MFDs along the Red River within the expected river channel. The DCBGs typically omitted the lowest lying floodplains as they do not contain GBS and led to lower MFDs. CBGs removed from the main river channel typically experienced identical MFD values for both HCBG and DCBGs representations (Figure 24 and Figure 25).

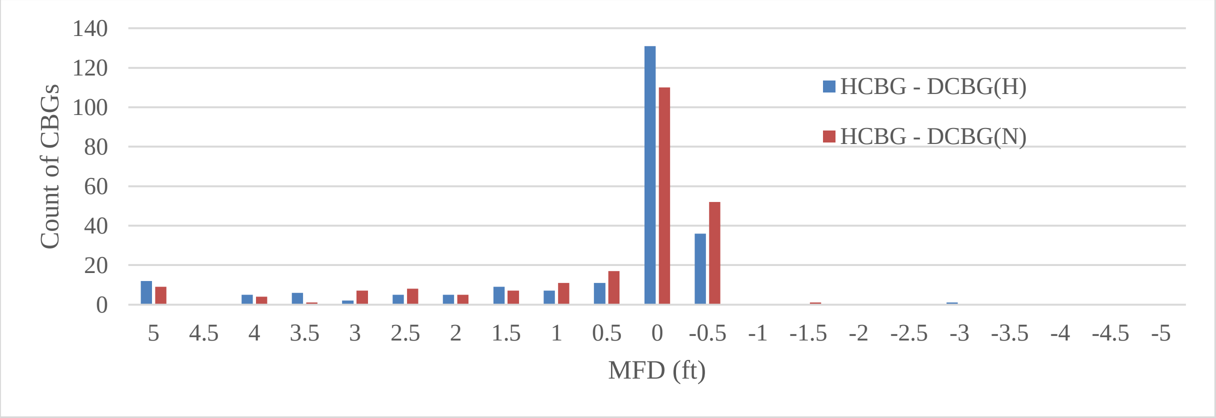

Figure 23 Cass County Mean Flood Depth Comparison

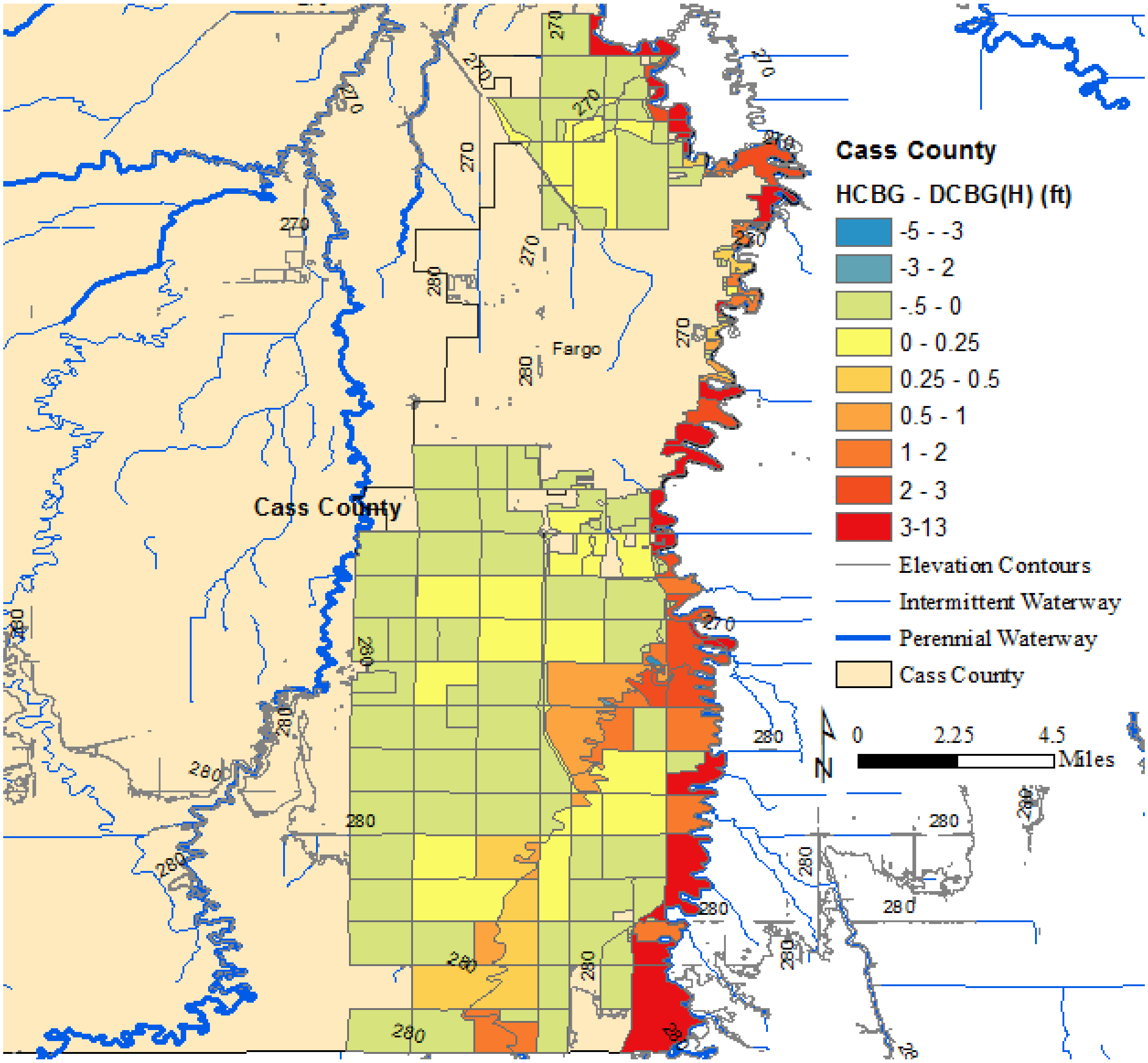

Figure 24 Cass County Mean Flood Depth Comparison (HCBG - NCBG$_H$)

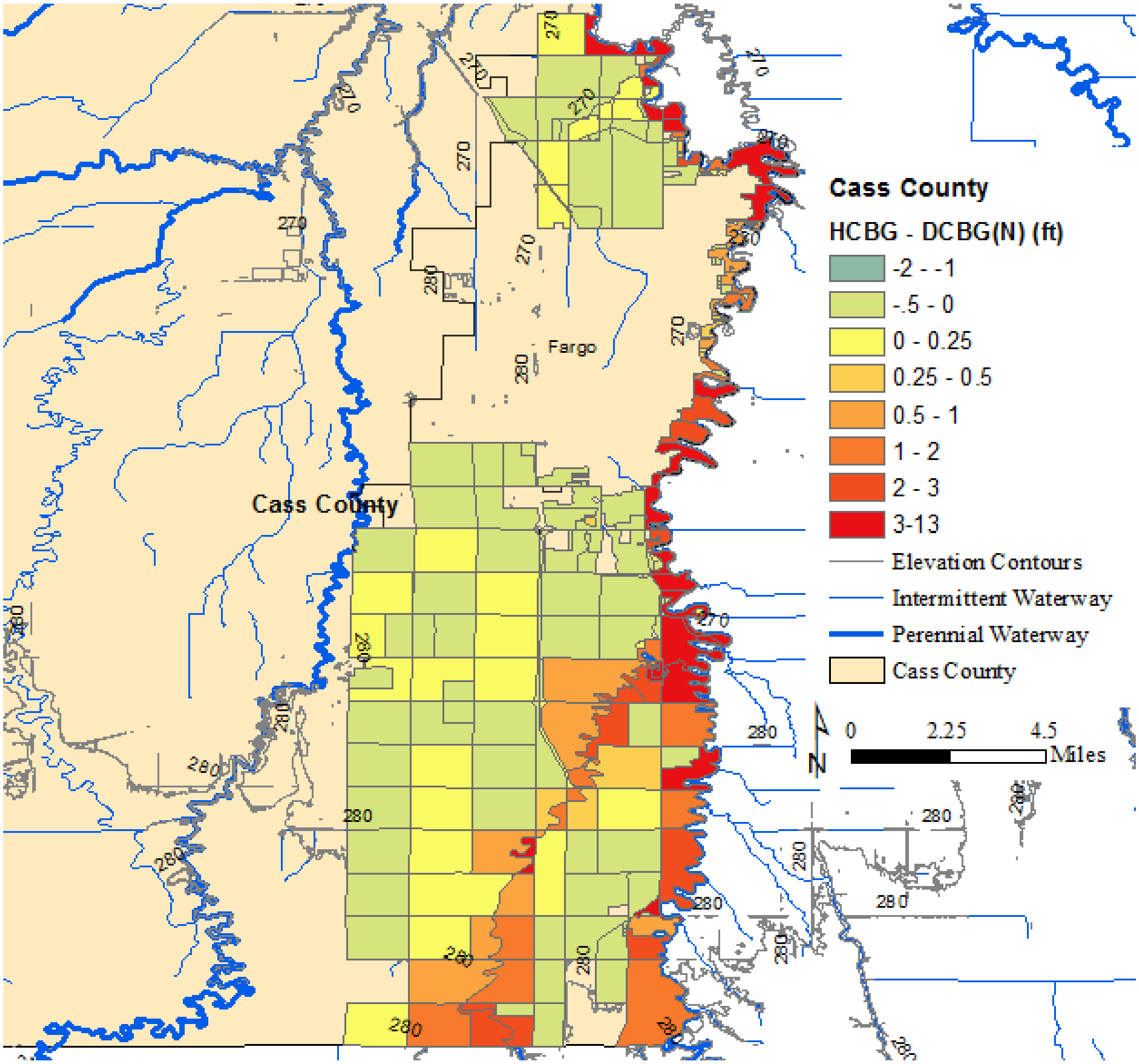

Figure 25 Cass County Mean Flood Depth Comparison (HCBG - NCBG$_N$)

In Ward County, DCBG and HCBG displayed similar MFD values (Figure 26). Ward County had a high number of highly developed and inundated DCBGs which had the same area as the HCBG representation. Many of these CBGs within Minot were completely inundated because of the large magnitude of the flood, which lead to similar MFD values across all GBS representations (Figure 27 and Figure 28).

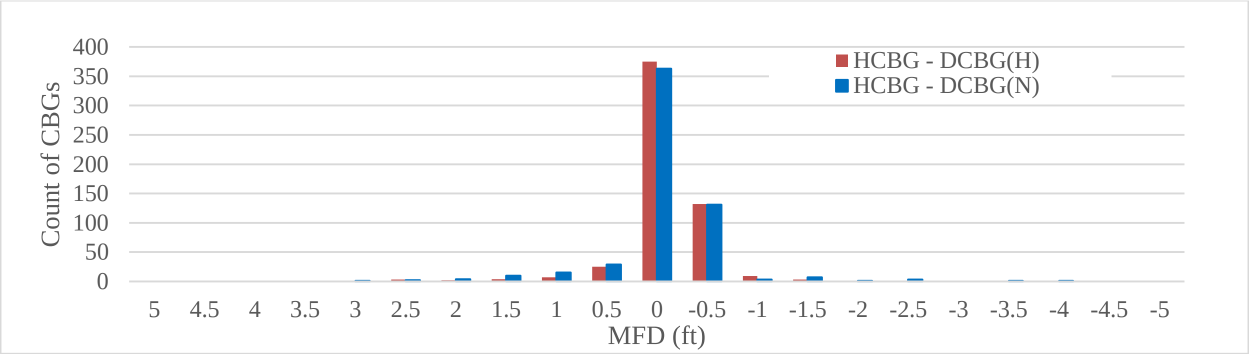

Figure 26 Ward Country Mean Flood Depth Comparison

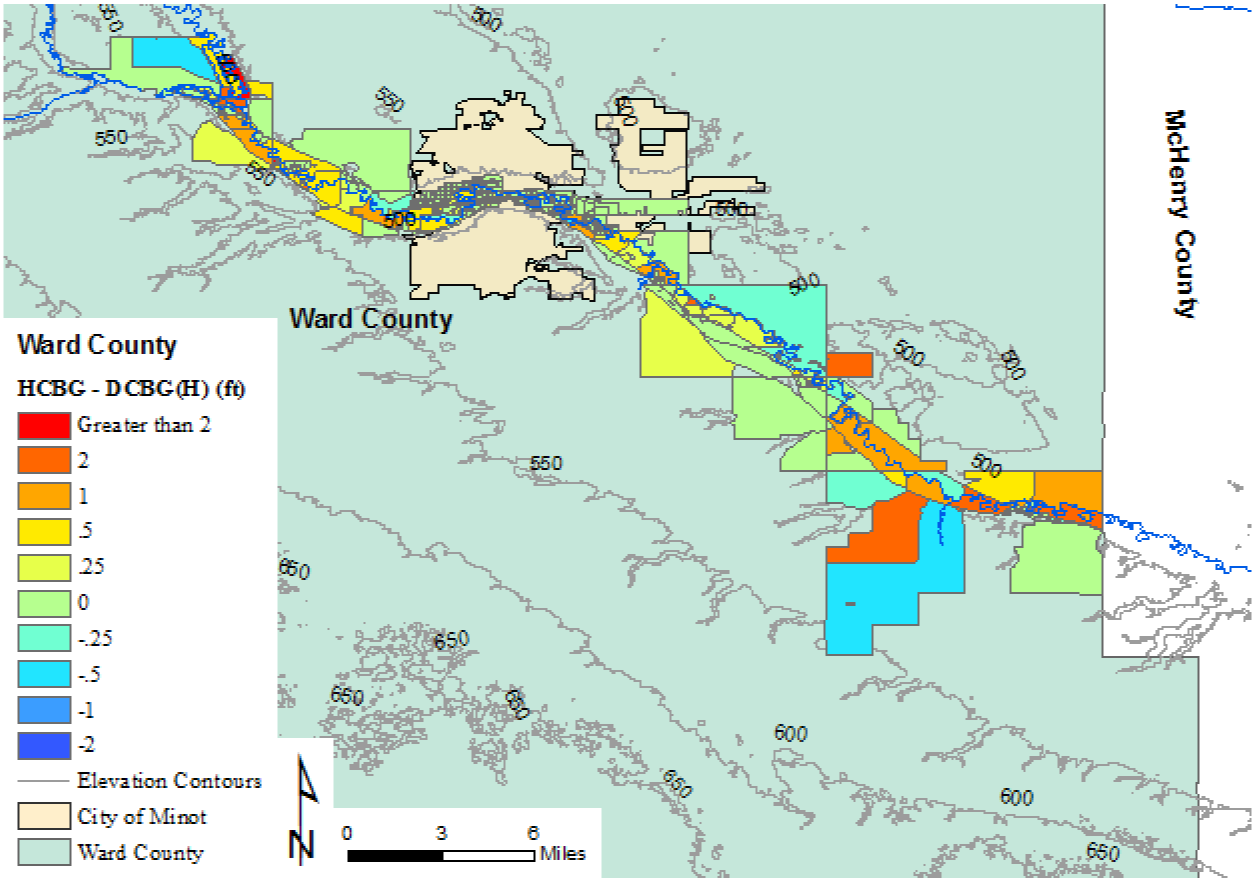

Figure 27 Ward County Mean Flood Depth Comparison (HCBG - NCBG$_H$)

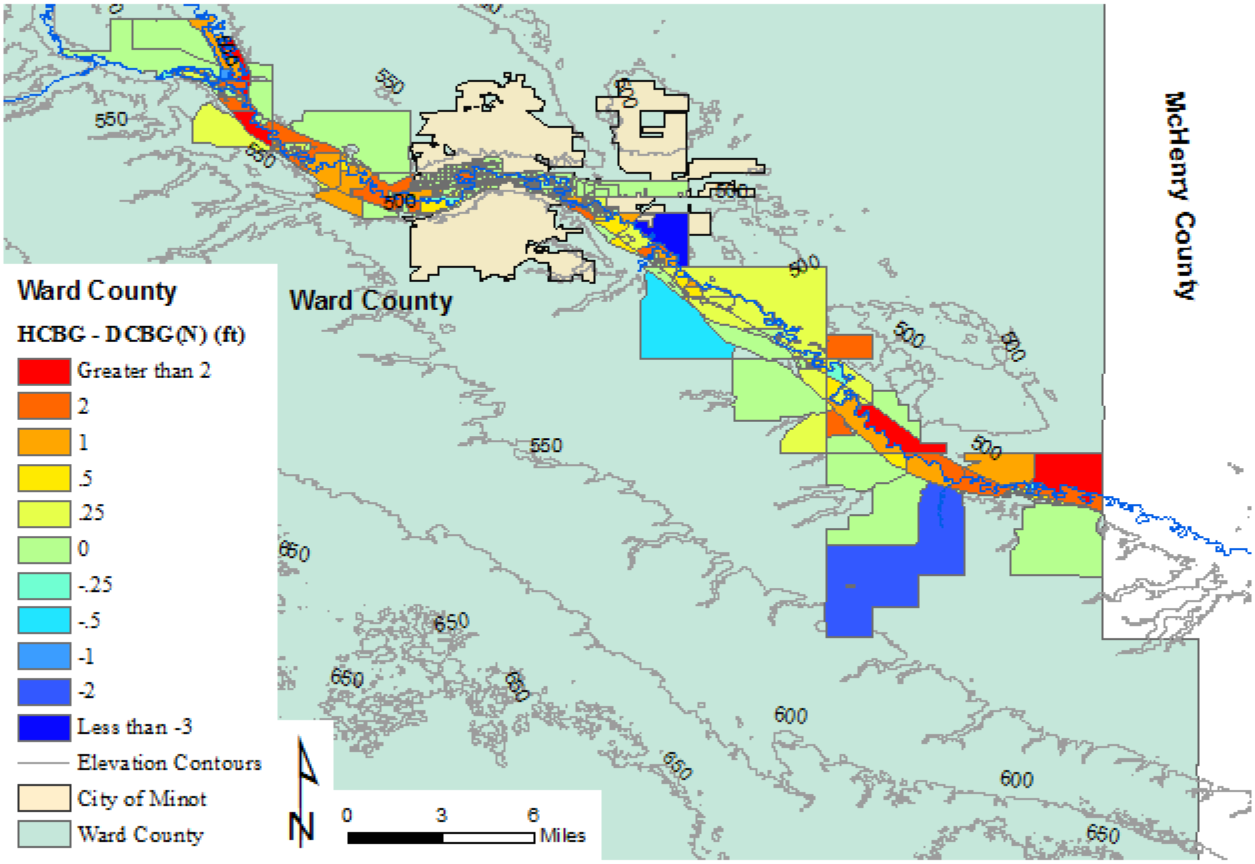

Figure 28 Ward County Mean Flood Depth Comparison (HCBG - NCBG$_N$)

4.4 Normalized Damage Estimates

The dasymetric damages were normalized to demonstrate how the DCBG$_H$ and DCBG$_N$ estimated damages were different than the HCBG estimated damage. The normalization process yielded the difference between HCBG and DCBG, expressed as a metric in Equation (3), and showing the relative degree of under/over estimation between them in Figure 29.

$$Damage\ Metric = \frac{(Uniform\ GBS\ Damages - Dasymetic\ GBS\ Damages)}{(Uniform\ GBS\ Damages)} \quad (3)$$

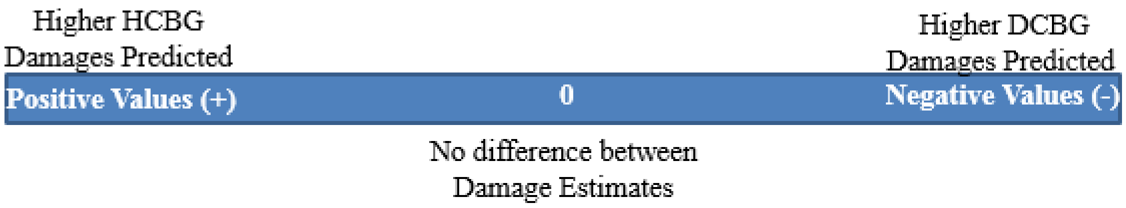

Figure 29 Damage Metric Explanation

Positive values represent greater modeled HCBG than DCBG damages. A value of +1 indicates that a CBG had no predicted DCBG damages. Conversely, a negative value indicates a DCBG has a higher predicted GBS damages than under the uniform GBS. A value of -1 indicates a CBG with dasymetric damages twice as large as HCBG damages. While there are lower limits for the normalized values, values less than -10 were not seen in this thesis. A value of 0 indicates that either a CBG did not have any predicted damages or the HCBG and DCBG predictions agree. The CBG predictions agree if the same area and locations are inundated to the same depth (Figure 30).

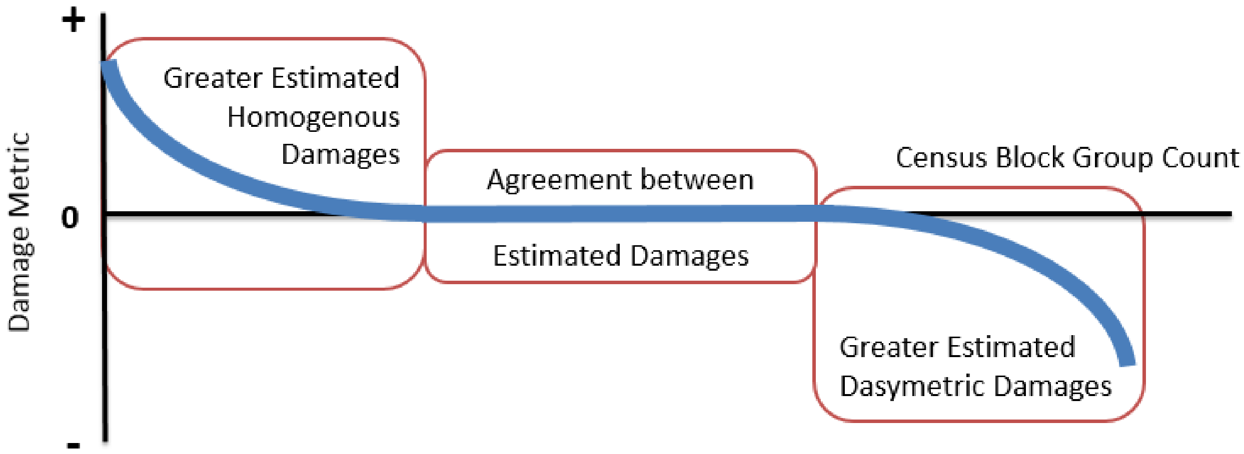

Figure 30 Damage Metric Sigmoid

Cass County displayed significant differences in damages between dasymetric GBS representations (Table 2 and Figure 31 - Figure 33).

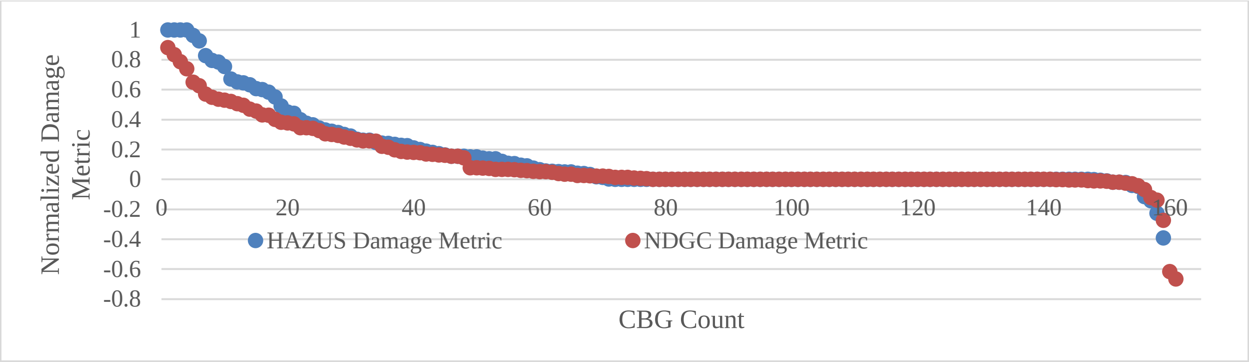

Figure 31 Cass County Normalized Damage Metric

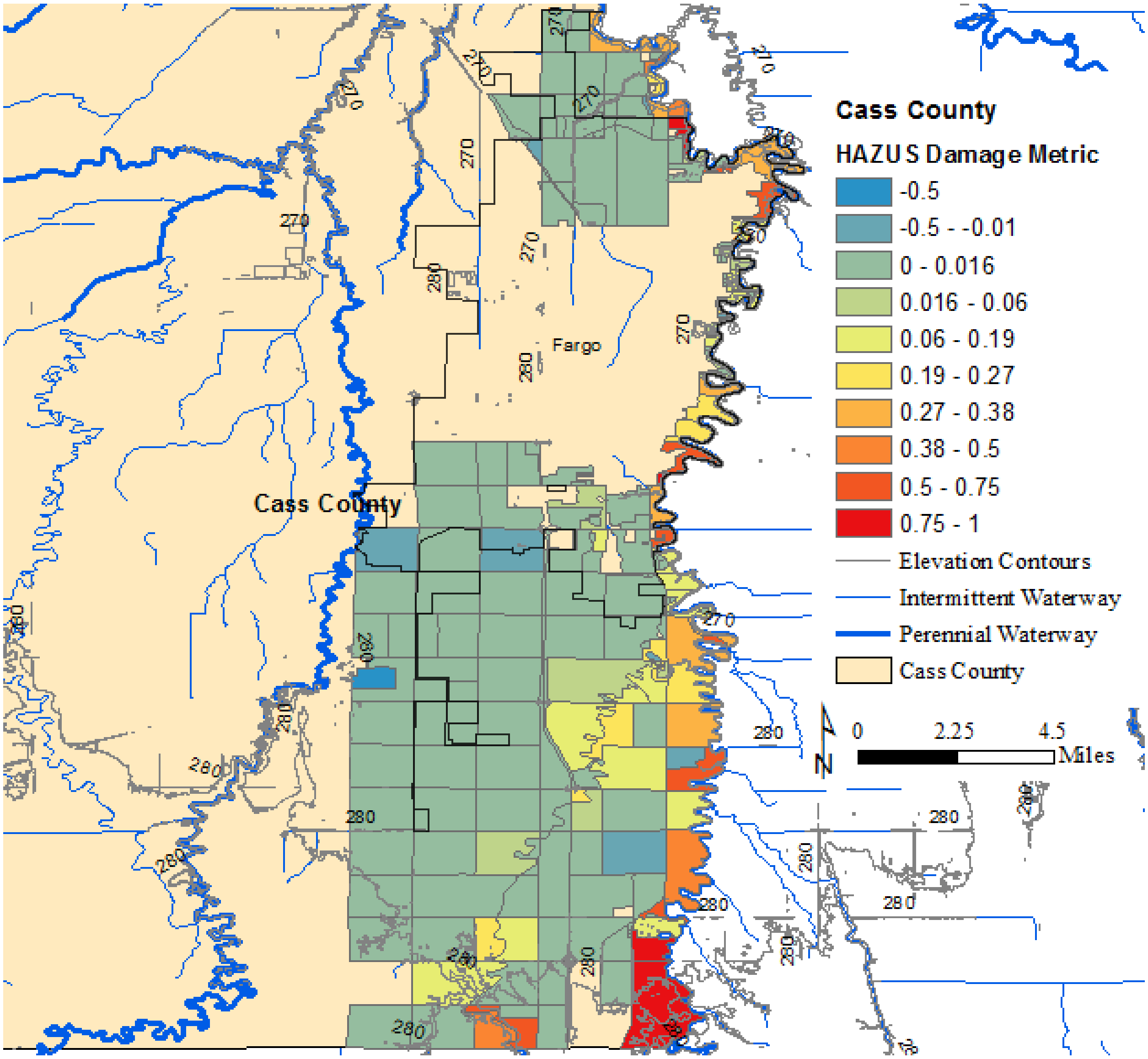

Figure 32 Cass County HAZUS Damage Metric

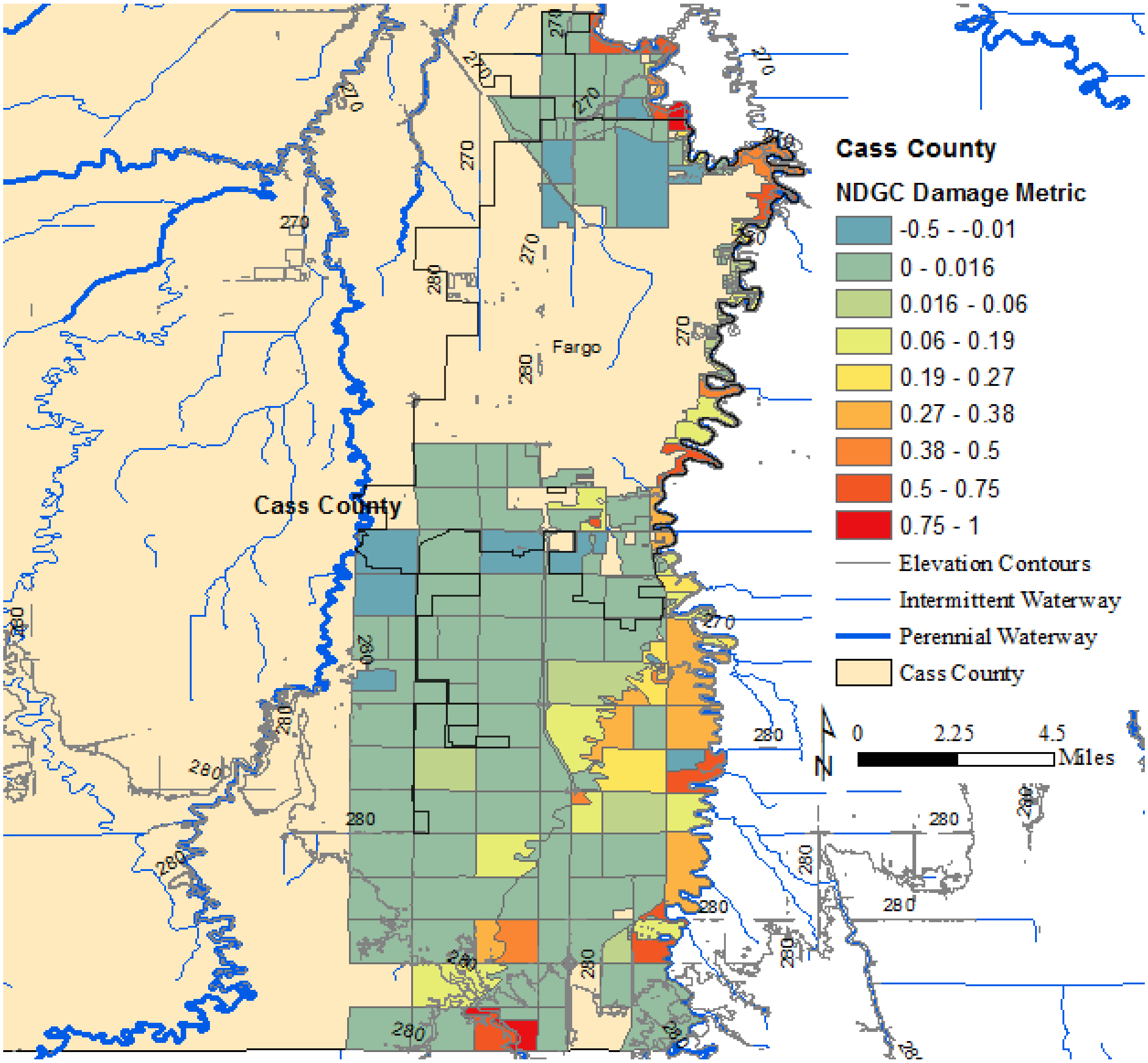

Figure 33 Cass County NDGC Damage Metric

Ward County displayed small differences in damages between dasymetric and uniform GBS representations (Table 3 and Figure 34). In Minot, the majority of the development is concentrated near the river (Figure 6). These CBGs produced similar inundated and total acreages and MFD for each GBS representation. These three factors lead to similar estimated damages within the city (Figure 35 and Figure 36). The normalized damage metric DCBG outliers were located outside of the city and did not contain significant GBS. These damage differences were not great enough to impact the total building damage.

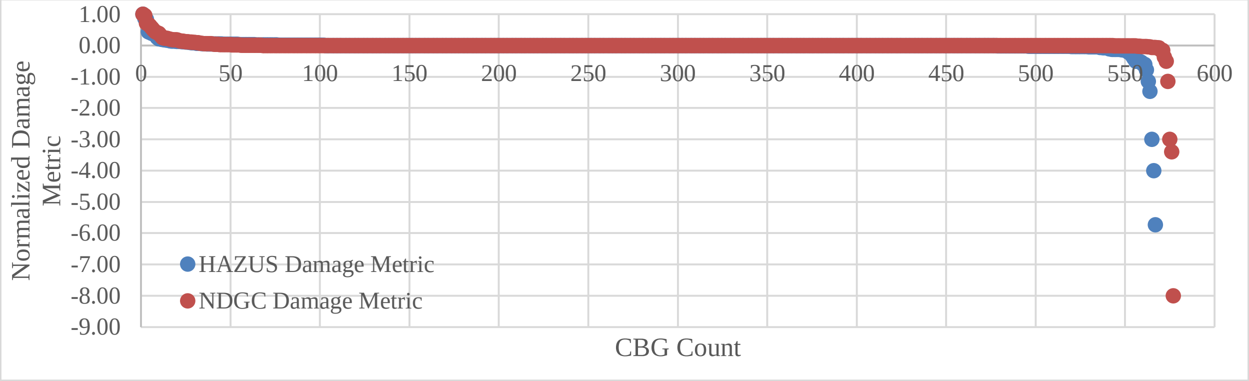

Figure 34 Ward County Normalized Damage Metric

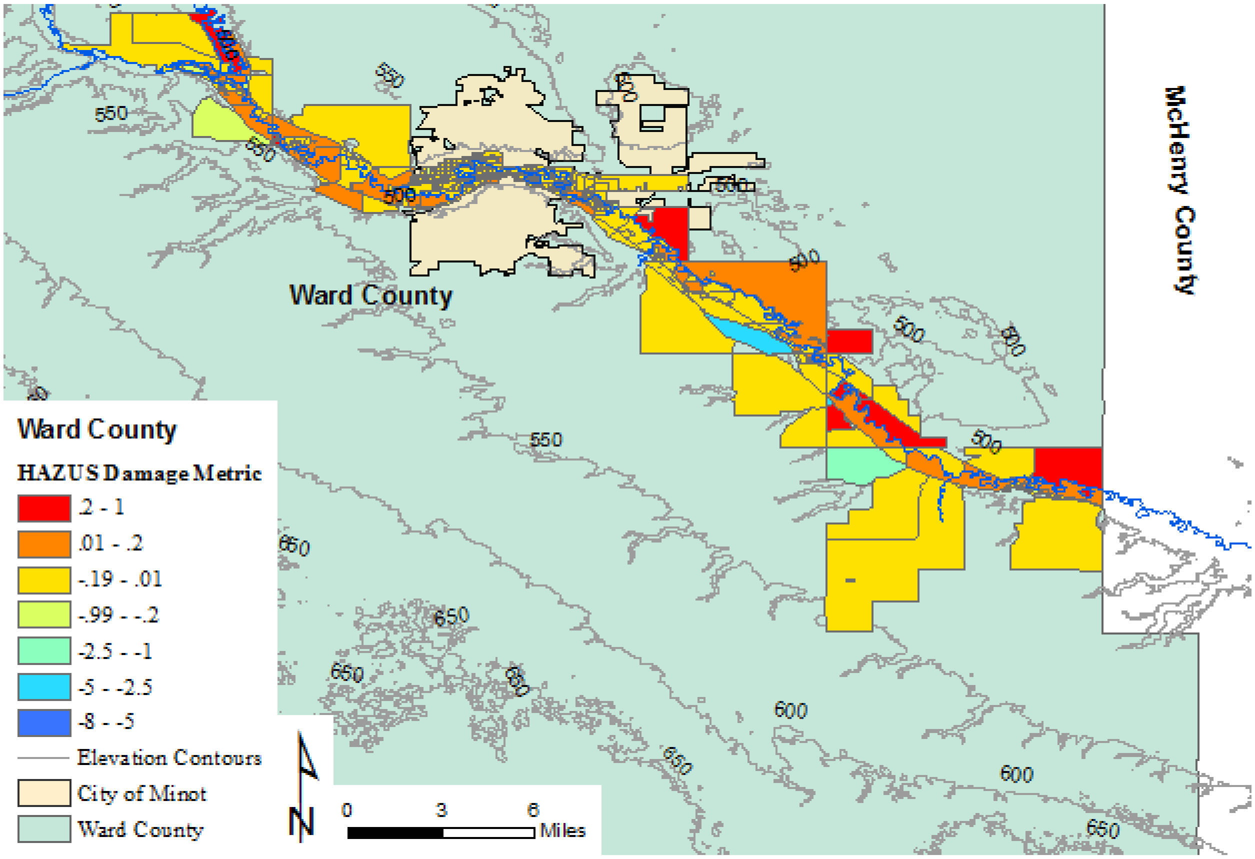

Figure 35 Ward County HAZUS Damage Metric

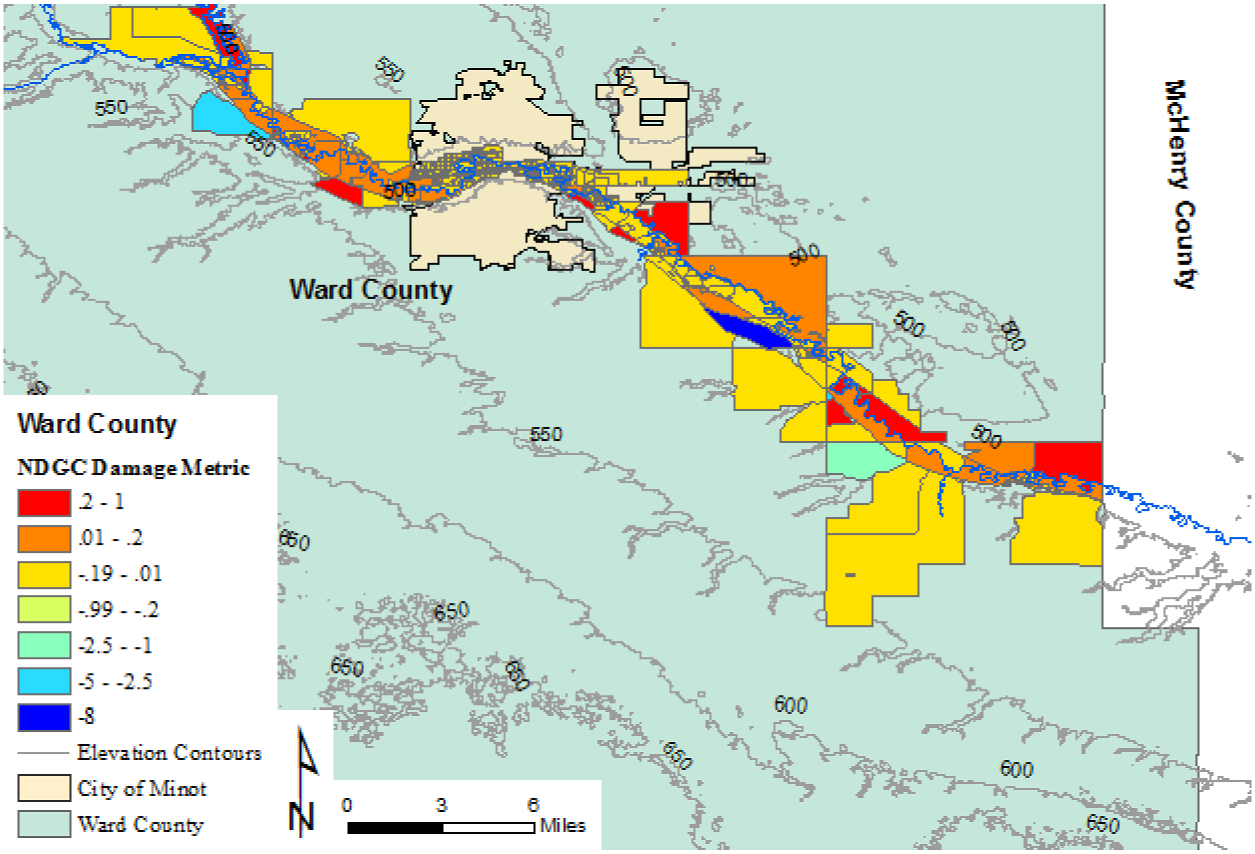

Figure 36 Ward County NDGC Damage Metric

Chapter 5 Discussion

This thesis highlights the accuracy improvement that FEMA could achieve by implementing a dasymetric approach to refine the FL Level 1 Riverine Flood model. This thesis utilized remotely sensed LULC data to refine the distribution of buildings within CBGs and avoided the need to develop expensive UDF data. While the dasymetry, may not produce a significant difference in all cases, this approach does remove some of the estimation inaccuracy introduced by misrepresenting the GBS with a uniform building distribution.

5.1 Future Research Opportunities

Future research is needed to increase the number of sample comparisons between uniform and dasymetric distributed GBS. An increased sample size should include study areas with different terrain and varying flood magnitudes. For example, a high plains river would flood in a different manner than mountain streams or braided channels. It is also important to consider the effect of different flood magnitudes. Lower discharge events would inundate less acreage, showing more CBG estimated damage variability, while high magnitude events would show less estimated damage variation based on the flooding observed in this thesis. These test results could help refine when it is appropriate to justify the use of dasymetric data in estimated flood damages.

Another potential project focuses on implementing a weighted GBS distribution. This distribution would assigned different damage values depending on the type of LULC instead of using the current binary NLCD coverage. For example, a “Developed, High Intensity” LULC cell has greater GBS value than a “Developed, Open Space” LULC cell, given the buildings or contents it could contain.

5.2 FL Assumptions

HAZUS is a proven hazard damage estimation tool enabling a user to identify and understand the risk of flood hazards, despite its complexities and potential flaws (FEMA, 2013a,b). The FL methodology has been reviewed by subject matter experts who compared HAZUS estimates and simulations against historical events with favorable results (FEMA, 2013a).

The damage estimates are determined entirely by: (1) the modeling methodology; and (2) the population and GBS data (Scawthorn et al., 2006a, b). The uncertainty of the FL model, like any another event modeling software, is dependent on the quality of the underlying data and the model's assumptions. FL Level 1 estimates damages using three sets of input data: (1) asset inventories; (2) depth-damage functions; and (3) flood-depth grids. Each set of inputs contributes its own uncertainties into the final model arising from generalizations, assumptions, and omissions (FEMA 2012). Any uncertainty in the input parameters shifts the results from a deterministic process toward a probabilistic one (Tate et al., 2014). FL's highest quality damage estimates come in conjunction with detailed UDF inventories, assuming there is sufficient time and financial support to prepare them (FEMA, 2013a). This thesis focused solely on evaluating the viability of using an alternate CBG representation to represent GBS exposure. None of the default values specified for these other variables were altered.

5.3 Dasymetric Comparison to Observed Damages

This project compared estimated FL damages using uniform and dasymetric GBS representations to determine situations where dasymetry produced more accurate results. The project compared HCBG and DCBG estimated damages, in the absence of observed damage data, to investigate the relationship between flood water inundation and representations of GBS. A future project in this area would involve comparing dasymetric-based estimated damages against observed flood damages to validate the predictive power of the dasymetric model. This comparison would provide a method to also determine the overall accuracy of either $DCBG_H$ or $DCBG_N$ approach.

Comparing estimated FL damages based on dasymetric GBS representations with observed flood damages requires overcoming a number of hurdles. Existing federal damage reimbursements are currently the only publicly available damage data. Actual damages from private insurance and unreported damages would be needed to provide a more complete comparison.

5.4 Conclusions

FL can effectively use a dasymetry GBS representation to estimate GBS damages. Dasymetry allows buildings to be more realistically located within their CBGs using selected LULC codes. These results were analyzed by using the resulting acreage, MFD and normalized damage results from the resulting estimated building damages.

Dasymetry proved to provide better damage estimates for partially flooded or low density development CBGs. High inundation and high development limited changes in either dasymetric model compared to FL’s current uniform distributed GBS. Catastrophic flood events, those with high levels of inundation or involving areas of high development, tend to produce similar damage estimates.

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