U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

FINAL REPORT

Rural by Nature
Flood Scenario Impact Assessment:
Counties of Dyer, Lake, Lauderdale, Tipton & Madison

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1. INTRODUCTION

Flooding events can be large and far-reaching, affecting a sizable area and having direct and indirect impacts on human health, economic livelihood and the environment, as well as creating community and social disruption. Having a good understanding of the consequences of various flooding scenarios that could be expected in a particular area enables local/state/regional officials and other stakeholders to identify locations that are most vulnerable to these scenarios and to develop cost-effective strategies to mitigate associated risks, leading to increased resilience.

The objective of this project was to provide an assessment of the impacts of future flood scenarios that could occur in the Rural by Nature target area, comprised of Dyer, Lake, Lauderdale, Tipton and Madison counties. These locations are susceptible to flooding under heavy precipitation scenarios and upstream flooding conditions that are expected to be more frequent in the future. Consequently, the area is under constant threat from flooding hazard, making communities located within the target area highly vulnerable to this type of extreme weather shock/stress.

This flood scenario assessment can help the affected communities facilitate policy changes and activities to proactively build resilience in the most vulnerable areas of their jurisdictions. Moreover, the assessment approach developed and utilized for the target area, is transferable such that it can be applied to other areas of Tennessee and the Southeast region.

The report is structured as follows. Sections 2 and 3 provide background information and characteristics associated with the study region. Section 4 describes the methodology utilized in performing the flood scenario impact assessments. Sections 5-9 describe assessment results for Dyer, Lake, Lauderdale, Tipton and Madison counties, respectively. Each of these sections are written in a form that they can be excerpted from the report and used by county officials. Study conclusions are provided in Section 10, followed by a list of references that comprises Section 11.

2. BACKGROUND

Floods have devastated these five counties on several occasions over the past century, particularly the four that directly border the Mississippi River (Lake, Dyer, Lauderdale, and Tipton). The floods of 1927 occurred between January and May, when the Mississippi River floodplain spanned 80 miles wide in some places. Referred to as the Great Flood of 1927, it was one of the costliest natural disasters in U.S. history, prompting significant re-evaluation of flood mitigation and response that ultimately led to passage of the Flood Control Act of 1928 (NWS & NOAA, retrieved 2019). A decade later, the Mississippi River experienced another major flood, due to the saturated state of the ground from a particularly wet winter, followed by significant rain in late January (Coggins, 2018). January 24th, 1937 became known as “Black Sunday,” as multiple large river systems reached critical levels. Roughly 75,000 homes were impacted, 250 people lost their lives, and 900 others were seriously injured.

More recently, in the Spring of 2011, the Ohio River, Mississippi River and many surrounding tributaries experienced severe flooding. Over one hundred counties and parishes were impacted, affecting over 43,000 people, more than 21,000 structures, and 1.2 million acres of agricultural land, with resulting damages of close to $2.8 billion (USACE, 2013). The volume of water flowing down the middle and lower parts of the Mississippi River was greater than that of the 1937 flood. The flood was a result of snow melt from an extraordinarily wet winter, combined with a two-week period of rainfall in which some tributary basins received 700% to 1,000% above normal values (U.S. Department of Commerce, NOAA, NWS, 2012).

When considering future flood risk for these five counties, it is important to not only account for these historical floods, but also to acknowledge the potential for these events to increase in frequency and magnitude due to the effects of climatic shifts in this region. Individual extreme precipitation events are projected to increase in severity based on several studies (EPA, 2016; Camp et al., 2016; Nelson et al., 2019; Gillespie-Marthaler et al., 2019a). In fact, precipitation during heavy rainstorms over roughly the last seventy years has increased by 27% in the southeast region of the U.S. Moreover, research conducted in this region suggests that our previous notion of a 100-year flood event[1] is no longer a sufficient benchmark to use when preparing for future scenarios (Nelson et al., 2019). These observations indicate an important need for more stringent flood prevention and emergency preparedness measures.

3. STUDY REGION CHARACTERISTICS

The Rural by Nature study area consists of five counties: Dyer, Lake, Lauderdale, Madison and Tipton (see Figure 3-1). Four of the five counties (Lake, Dyer, Lauderdale, and Tipton) border the Mississippi River.

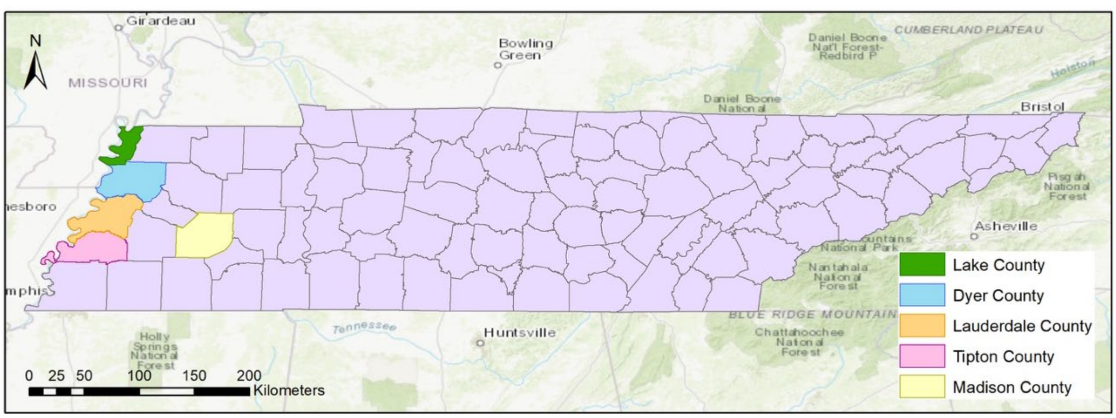


Figure 3-1. Tennessee county map (five counties of interest highlighted)

[1]A 100-year flood event is a flood with a magnitude that has a 1 in 100 (or 1%) annual chance of occurring. This is an average recurrence interval and does *not* mean that a flood of this magnitude could only occur once in 100 years (USGS, retrieved 2019). This terminology is used throughout the rest of the paper when referring to a 100-year flood (1% annual recurrence interval), 500-year flood (0.2% annual recurrence interval), and 1,000-year flood (0.1% annual recurrence interval).

3.1. Lake County

In 2018, Lake County had an estimated population of 7,411, which is a 5.4% decrease since the 2010 Census estimates. Approximately 14% of the population is below age 18, and 16% is over age 65. For those under age 65, roughly 21% have a disability and 12% do not have health insurance. The median household income is $31,993, and 40% of the population is considered below the poverty line (U.S. Census Bureau, retrieved 2019d).

3.2. Dyer County

In 2018, Dyer County had an estimated population of 37,320, which is a 3% decrease since the 2010 Census estimates. Almost one-half of the population lives in the county seat and largest city in Dyer – the city of Dyersburg (population 16,389) – with the remainder of the county population widely dispersed. Approximately 24% of the population is below age 18, and 18% is over age 65. For those under age 65, roughly 15% have a disability and 10% do not have health insurance. The median household income is $44,386, and 17% of the population is considered below the poverty line (U.S. Census Bureau, retrieved 2019b).

3.3. Lauderdale County

In 2018, Lauderdale County had an estimated population of 25,825, which is a 7% decrease since the 2010 Census estimates. Ripley, the county seat and largest city, has a population of 7,879. Approximately 23% of the population is below age 18, and 16% is over age 65. For those under age 65, roughly 17% have a disability and 12% do not have health insurance. The median household income is $35,551, and 21% of the population is considered below the poverty line (U.S. Census Bureau, retrieved 2019e).

3.4. Tipton County

In 2018, Tipton County had an estimated population of 61,581, which is a 0.9% increase since the 2010 Census estimates. The county seat and largest city in the county, the city of Covington, has a population of 8,780. Approximately 24.6% of the population is below age 18, and 14.5% is over age 65. For those under age 65, roughly 12.1% have a disability and 9.1% do not have health insurance. The median household income is $57,212, and 14.0% of the population is considered below the poverty line (U.S. Census Bureau, retrieved 2019a).

3.5. Madison County

In 2018, Madison County had an estimated population of 97,605, which is a 0.7% decrease since the 2010 Census estimates. The county seat and largest city in the county, the city of Jackson, has a population of 66,903. Approximately 22.4% of the population is below age 18, and 17.0% is over age 65. For those under age 65, roughly 11.2% have a disability and 9.6% do not have health insurance. The median household income is $44,946, and 17.5% of the population is considered below the poverty line (U.S. Census Bureau, retrieved 2019c).

4. METHODOLOGICAL APPROACH

The following methodology was applied to each of the five counties that comprised this study. In the event that specific data was unavailable for a particular county, the adjustment to the methodology is noted in the footnotes.

The nationally recommended tool for developing flood hazard mitigation plans in the U.S., in the absence of resources to do a full engineering evaluation of the area's hydrology, is Hazus, a software tool developed by the U.S. Federal Emergency Management Agency (FEMA). The flood application within Hazus is defined as "an integrated system for identifying and quantifying flood risks [that] is intended to support communities in making informed decisions regarding land use and other issues in flood prone areas" (Scawthorn et al., 2006). With such reliance on Hazus to inform flood hazard mitigation planning, it is important to have confidence in the efficacy of the tool by benchmarking Hazus results with other information sources, with a willingness to adapt the methodology to enhance functionality where Hazus does not perform well.

The study methodology comprises three parts: 1) an initial flood loss assessment performed using Hazus for each flood scenario; 2) a comparison of: a) Hazus flood extent results with FEMA-generated Flood Insurance Rate Maps (FIRMs), used by the National Flood Insurance Program to determine insurance rates for buildings within different flood zones (FEMA, retrieved 2019 a,b), as well as historical floods when possible; b) Hazus building damage estimates with Microsoft building footprint analysis; and c) Hazus essential facility inventory with Homeland Infrastructure Foundation-Level Data (HIFLD) data provided by the U.S. Department of Homeland Security; and 3) an assessment of the impacts of flood scenarios for each county, augmenting Hazus data and functionality, including development of social vulnerability indicators, evaluation of road network disruption, and essential facility service area analyses. Much of this research was conducted within the ArcGIS 10.5.1 platform (Esri, 2017), using the projected coordinate system: NAD 1983 2011 State Plane Tennessee FIPS 4100 Ft US.

4.1. Initial Flood Loss Assessment Using Hazus

In order to evaluate a range of potential flooding events, three flood scenarios, 100-, 500- and 1,000-year flood events, were selected based on potential future flood risk. Hazus Version 4.2 SP1 was used to produce respective flood depth grids, and associated loss and damage estimates for each county, utilizing steps outlined in the Hazus User Manual[2] (Department of Homeland Security & FEMA, 2013). The study region was defined as extending slightly beyond the county boundary to preserve river continuity. Topography was defined by importing 1 arc second USGS-produced Digital Elevation Models (DEMs) retrieved from the National Elevation Dataset (USGS, retrieved 2018). A stream network was generated, and a five square mile drainage area was chosen (i.e., rivers that have a drainage area of five square miles or larger

[2]A user manual for Hazus 4.2 was released in August 2018. However, the Hazus portion of this research had already been completed using the previous user manual, which was the 2013 Hazus 2.1 User Manual.

were included), because the selection of a larger drainage area provided less detailed stream networks and a smaller drainage area was not continuous due to discrepancies between the scale of the analysis and the resolution of the DEMs.

Initially, a 100-year flood scenario was defined, and the Hazus hydrologic analysis was run, resulting in delineation of the respective floodplain. Summary impact reports were exported as Excel files, and the geographic data was exported as shapefiles. This process was repeated for the 500- and 1,000-year flood scenarios.

4.2. Comparison of Hazus Flood Results

The accuracy of Hazus flood extent boundaries was assessed through comparison with FIRMs, using both visual comparisons within ArcGIS, as well as quantitative comparisons of the estimated flood inundation area. When possible, Hazus flood extent boundaries were compared to the May 2011 flood via data from U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA)[3]. The analysis results showed that the 500-year FIRM flood extent[4] was in close alignment with what was experienced in May 2011 and was therefore selected as the most reasonable flood extent to use for future flood mitigation planning.

Hazus building damage estimates – the number of damaged buildings predicted for seven general occupancy categories: government, commercial, residential, religious, educational, agricultural, and industrial – were then compared to and augmented through the use of Microsoft Building Footprints (Microsoft, 2018). RStudio was used to isolate the building footprint data for each county and export as a shapefile to use in ArcGIS (RStudio Team, 2015). To estimate the number of buildings affected by flooding, the building footprint polygons that intersected the flood extent polygon for each Hazus scenario (100-, 500-, and 1,000-year) as well as FIRM boundary (100- and 500-year extents) were selected and exported as shapefiles. To eliminate buildings that could represent less costly damages (such as sheds or garages) that would have likely been included in the Microsoft building footprint data, a threshold of 88.3 square meters (950 square feet) — the average size of a single-wide mobile home — was established (US Mobile Home Pros, retrieved 2019). Only buildings above this threshold that intersected the flood boundary were considered impacted. To compare these results with the damaged building results produced by Hazus, centroids were generated and displayed as dots for each of the polygons within the impacted Microsoft building footprints (Esri, retrieved 2019). These centroids could then be visually compared to a dot density map of Hazus' estimated damaged buildings, so that each map displayed one dot per damaged building.

[3]USGS preliminary maps of the flood were available for Lake and Dyer counties – for Dyer, this map was imported into ArcGIS, georeferenced using the outline of Dyer County, and a shapefile was drawn manually to make the comparison easier; NASA Landsat 5 images were available for Lake, Dyer, Lauderdale, and Tipton, but not for Madison.

[4]Lake County does not have a 500-year FIRM, and thus for the rest of the analysis the 100-year FIRM and 100-year Hazus flood extents were compared for Lake County rather than the 500-year FIRM and Hazus flood extent as was used in the rest of the counties.

Essential facilities (i.e., fire stations, police stations, hospitals)[5] are vital in the assessment of emergency response capability to flood hazards, so it was critical to use the most comprehensive dataset available. Hazus' essential facility inventory was compared to HIFLD (U.S. Department of Homeland Security, retrieved 2018). Three datasets representing the most up to date opensource data available for fire stations, police stations, and hospitals were evaluated (International Association of Fire Chiefs, 2019; Technigraphics Inc., 2009; Oak Ridge National Laboratory, 2018a).

4.3. Flood Impact Assessment

Among the key demographic factors that could impact response and recovery are vulnerable populations who may have difficulty due to limited means or mobility. According to Cutter et al (2000), these factors include: 1) population distribution, 2) both sides of the age spectrum – the elderly and young, and 3) those who are considered economically disadvantaged. For the purpose of this study, these indicators were measured using data available at the census block level from the 2010 Census, as follows: 1) total population, 2) population over age 65 and under age 16, and 3) households earning less than $40,000 per year —slightly less than the average ($42,818) of the most recent estimates of the median income for the five counties (U.S. Census Bureau, retrieved 2019). The locations of mobile home parks were also examined[6], as these communities face heightened flood risk due to structural vulnerabilities (ORNL, 2018b; TNECD, 2010). Areas of high vulnerability were identified via spatial analysis by visualizing the proximity of vulnerable populations to flood damage and emergency facilities.

To further assess the impact of flood inundation on transportation, two additional factors were examined: 1) road network disruption, and 2) accessibility to and from essential facilities. Using the road network downloaded from TIGER/Line products (U.S. Census Bureau, 2012), the road network was clipped to the 500-year FIRM polygon[7], producing a shapefile consisting of all road segments that directly overlapped the flood impact area.

To assess essential facility accessibility, a portion of the methodology developed by Kermanshah and Derrible (2017) was adopted and modified. Specifically, ArcGIS Network Analyst was used to compute baseline service areas, defined as the area that can be reached within 16.1 km (10 miles) of an essential facility. The flood extent[8] was then taken into account to determine which portions of the network could potentially be cut off, with the percent reduction in service area used as a quantitative measure of loss.

[5]This definition of essential facilities can be modified to include other facilities of interest (e.g., shelters).

[6]According to the HIFLD data used, there are no mobile home parks in Lake County and thus this step was skipped for this county.

[7]100-FIRM for Lake, see footnote above regarding Lake FIRM availability.

[8]100-FIRM for Lake, see footnote above regarding Lake FIRM availability.

5. RESULTS & FINDINGS FOR DYER COUNTY

5.1. Comparison of Hazus and FIRM Flood Extents

Figure 5-1 displays the estimated flood extents for 100-, 500- and 1,000-year events as produced by Hazus. Note that there are only subtle differences in these inundation areas, and the Mississippi River along the western border does not appear to be significantly flooded.

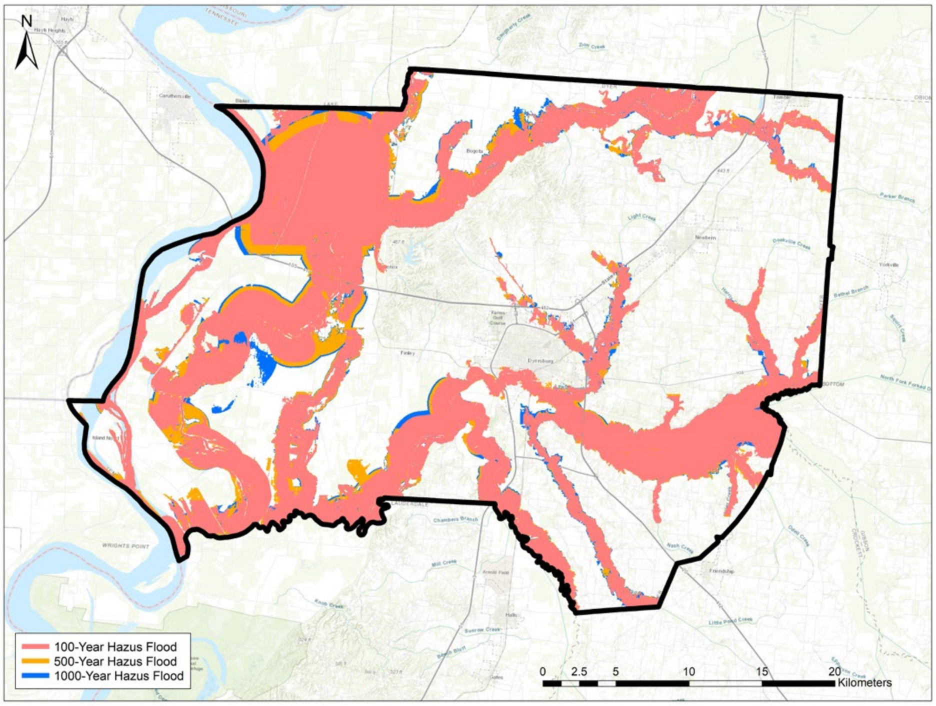


Figure 5-1. Comparison of 100-, 500-, and 1,000-year Hazus flood extents (Dyer)

Figure 5-2 displays the 100- and 500-year FIRM flood extents. These maps also have relatively similar boundaries, with the 500-year FIRM containing only 1.6% more area than the 100-year FIRM.

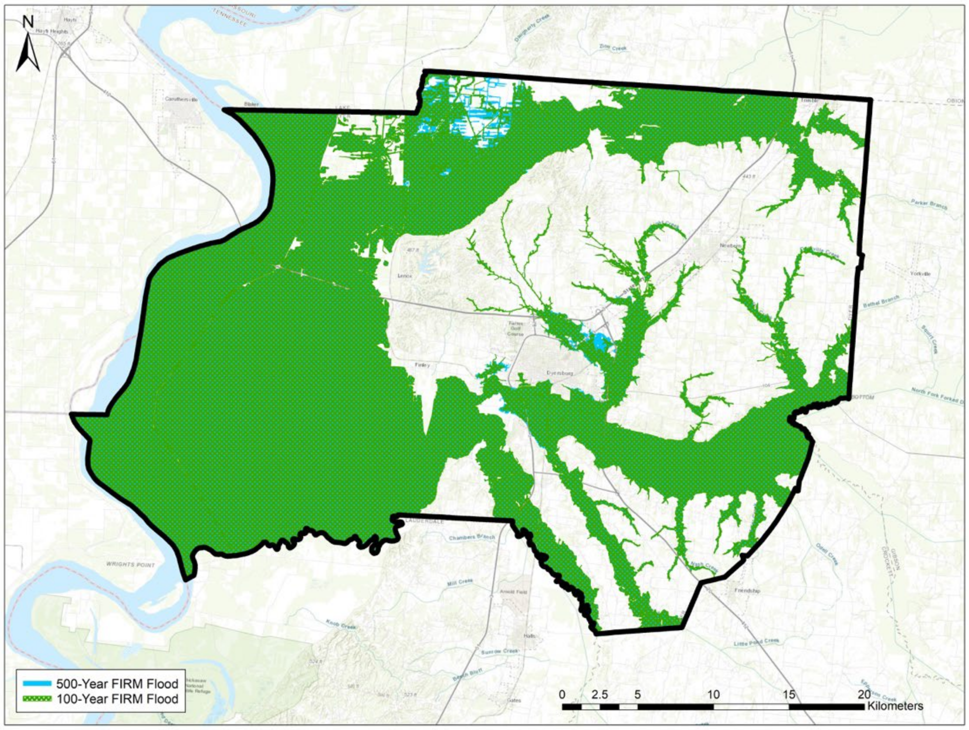


Figure 5-2. Comparison of 100-year and 500-year FIRM flood boundaries (Dyer)

The small discrepancies across the three Hazus flood extents, and between the 100- and 500-year FIRMs (which are generated using detailed local surveys, engineering analysis, and robust hydrologic modeling), respectively, suggest there may not be a sizeable difference in inundation area among the event scenarios. This could be due to the elevation of the region being such that increasing the amount of precipitation results in a flood with greater depth but not necessarily a larger area. This is also likely a function of the small increase in precipitation difference between a 100-year and 500-year recurrence interval on Intensity-Duration-Frequency (IDF) curves[9].

Unlike the comparisons shown in Figures 5-1 and 5-2, respectively, there are large discrepancies, as seen in Figure 5-3, when the flood extents from the two different sources are compared. The 100-year FIRM covers roughly 3.5 times more area than the 100-year Hazus extent (Figure 5-3a), and the 500-year FIRM covers close to 3.6 times more area than the 500-year Hazus extent (Figure 5-3b). One of the most notable differences is along the Mississippi River, the western border of Dyer County. For both Hazus flood extents, the Mississippi River flows mainly within its normal banks. However, the FIRM 100- and 500-year floods show the vast majority of the western portion of the county flooded. Additionally, most tributaries appear more flooded in the FIRM extents.

[9]An IDF curve is a function that relates rainfall intensity with its duration and frequency of occurrence.

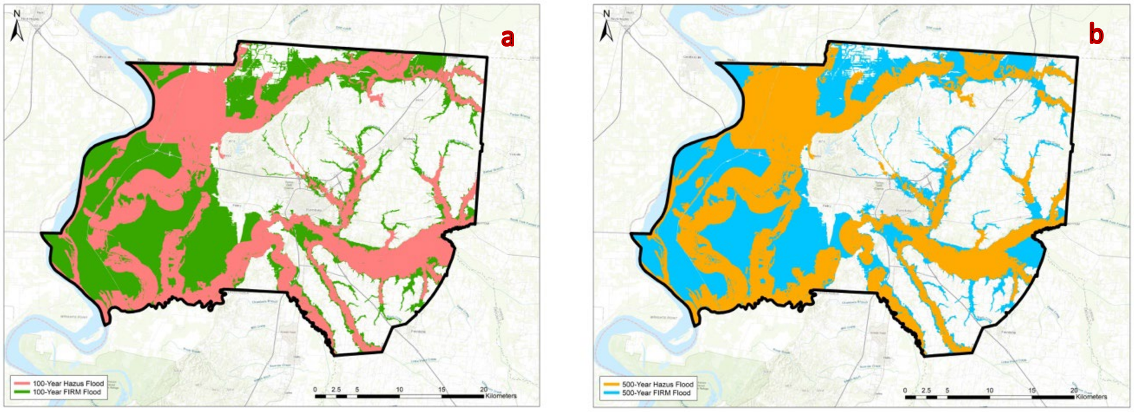


Figure 5-3. Comparison of Hazus and FIRM 100- and 500-year flood maps (Dyer)

To determine whether Hazus or FIRM flood extents would be more appropriate for additional analyses, the boundaries were compared to the historical flood that occurred in Dyer County in May 2011 based on a preliminary map created by USGS (Figure 5-4) and Landsat 5 images from NASA data (Figure 5-5) (USGS, 2011a; NASA, 2011). The NASA satellite images shown in Figure 5-5 display Dyer County in a non-flooded state on April 21, 2010 (Figure 5-5a) and a flooded state on May 10, 2011 (Figure 5-5b). It is evident from both of these data sources that the 2011 flood extent aligns more closely with the 500-year FIRM extent than to the 500-year Hazus extent (Figures 5-4b and 5-5b).

We therefore concluded that the 500-year FIRM boundary is more representative of extreme flood events in this area. Moreover, in solely relying on Hazus outputs, one may be significantly underestimating the 100-year and 500-year flood extents, respectively. A likely explanation can be found in the way Hazus determines flood extent boundaries, particularly the fact that Hazus only accounts for precipitation that occurs *within* the defined study region. Since it is not possible to include the entire, or even a significant portion of, the Mississippi River watershed in the initial study region, Hazus is unable to account for precipitation occurring on the Mississippi River upstream of the study region.

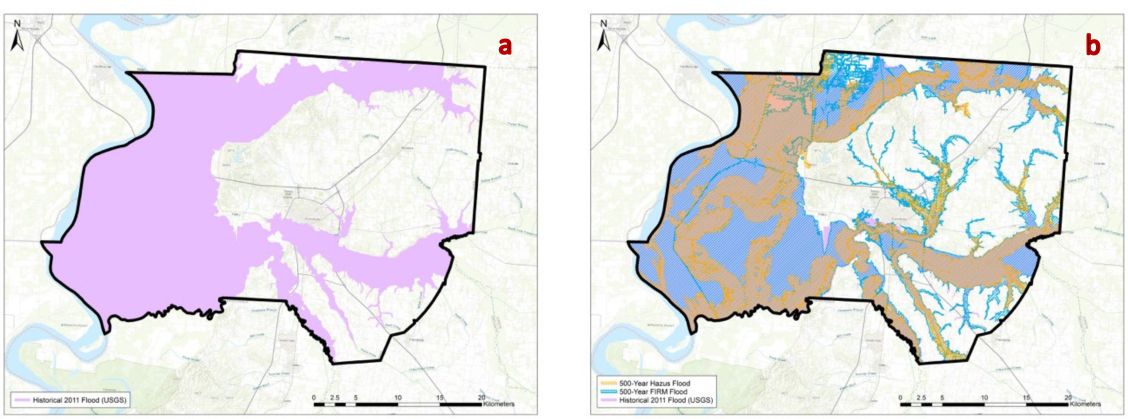


Figure 5-4. Comparison of 500-year FIRM & Hazus flood extents with 2011 flood (Dyer)

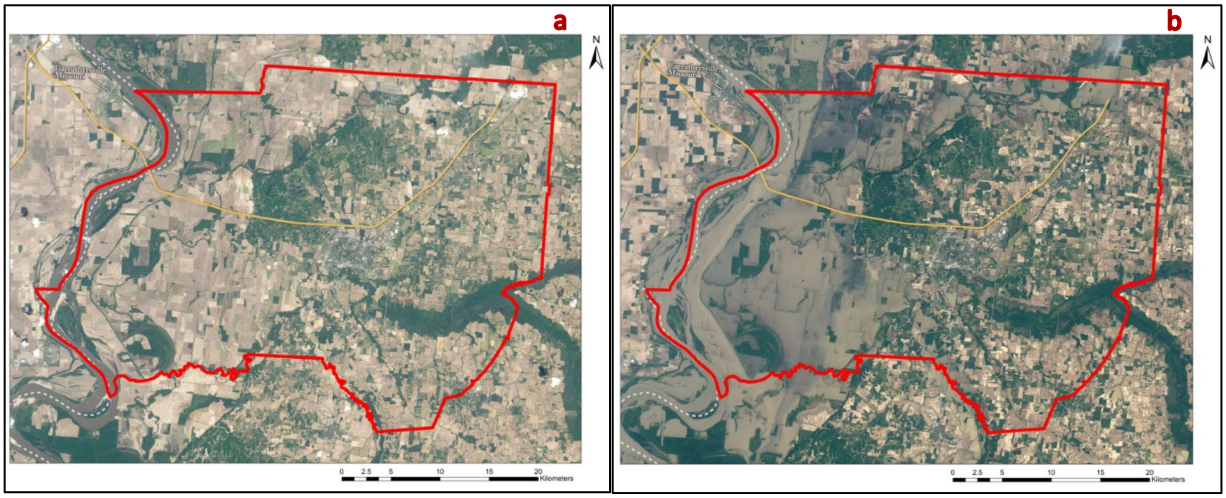


Figure 5-5. NASA Landsat 5 satellite imagery of 2011 Mississippi River flooding (Dyer County)

5.2. Comparison of Hazus Results and Microsoft Building Footprints

One key benefit to using Hazus is the built-in loss and damage functions for each building class and sub-class (e.g., a residential building with one floor and no basement), which account for the flood depth as it is calculated by Hazus using the DEMs. By contrast, FIRMs do not provide impact assessments. Consequently, even though the 500-year FIRM scenario is more representative of the inundation area, utilizing the Hazus impact assessment is a necessary starting point for performing a 500-year impact assessment based on the FIRM flood extents.

Hazus estimates building damage based on assumptions made at the census block level (i.e., if 25% of a census block is inundated, 25% of the buildings of a certain type are considered damaged). The downside to using census-block level estimations is losing the accuracy of the actual building locations (i.e., it is possible that 25% of a census block could be inundated and no buildings coinciding with the inundation area, or vice-versa). In order to explore this potential bias, Microsoft building footprints were obtained for Dyer County and intersected with the flood inundation area.

The results of this process are displayed in Figure 5-6 and Table 5-1. Damaged building estimates from the 500-year flood is shown according to: Hazus model output – which identified 75 damaged residential buildings and zero damage government, commercial, residential, religious, educational, agricultural, or industrial buildings (column A); Microsoft building footprint analysis using Hazus 500-year flood boundary (column B); and Microsoft building footprint analysis using 500-year FIRM flood boundary (column C).

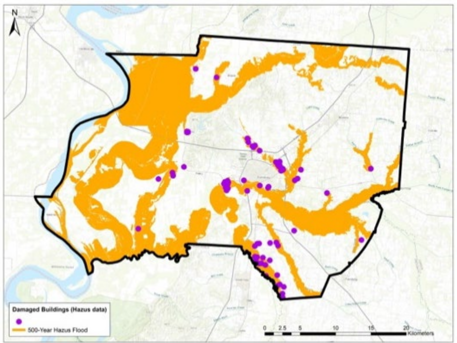
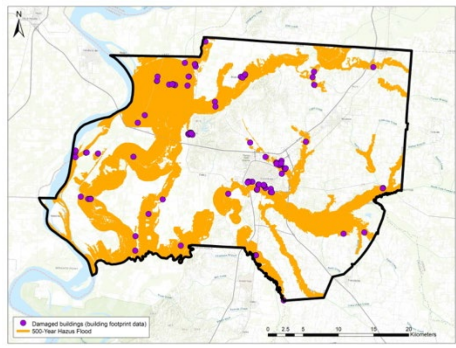
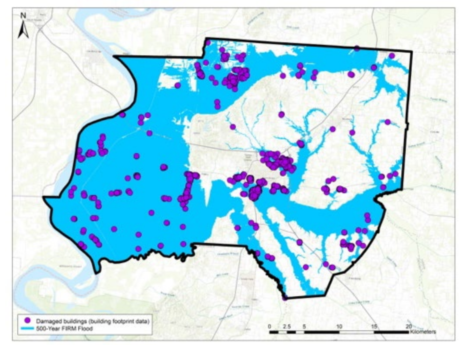
A: Hazus extent (Hazus building data)	*B: Hazus extent (Building footprint data)*	*C: FIRM extent (Building footprint data)*
		

Figure 5-6. Comparative Building Damage Estimates (Dyer)

Table 5-1. Affected Building Counts (Dyer)

Hazus 500-year flood boundary		**FIRM 500-year flood boundary**
Hazus results (# affected buildings)	Microsoft building footprint analysis results (# affected buildings)	Microsoft building footprint analysis results (# affected buildings)
75	128	1,194

There are visible differences in the number of affected buildings based on which flood model and building data are being used. The Microsoft building footprint results indicate a greater number of impacted buildings when compared to Hazus. For example, inspecting the damaged building estimates for just the 500-year Hazus flood extent, the Microsoft building footprint analysis results in the identification of roughly 70% more buildings impacted than initially estimated via Hazus for the same area of inundation.

Another difference is the extent to which the location of damaged buildings differs between the two analyses. The Hazus methodology (Figure 5-6, column A) shows the majority of the damaged buildings as clustered along a corridor in the south-southeast corner of the county, and in the center of the county. In comparison, the Microsoft building footprint analysis (Figure 5-6, column B) agrees that there is a cluster of damaged buildings in the center of the county; however, there is not a significant cluster in the south-southeast portion of the county, and rather the damaged buildings are more widely dispersed across the county.

Due to their flood extent differences, as expected the FIRM boundaries (Figure 5-6, column C) encompass significantly more buildings than do the Hazus flood extents. As shown in Table 1, the 500-year FIRM flood extent with the Microsoft building footprint analysis produces over nine times more damaged buildings than the 500-year Hazus extent with the Microsoft building footprint analysis (Figure 5-6, column B), and almost 16 times more damaged buildings than the 500-year Hazus extent with Hazus' damaged building estimates (Figure 5-6, column A).

One caveat to consider when interpreting the Microsoft building footprint analysis is that the footprints were initially created using Microsoft's artificial intelligence methodology. As mentioned previously, it is not possible to identify a building's function from the footprint, and as a result it is not possible to assess the damage a specific building would sustain if flooded. Despite an attempt to exclude less critical buildings from the Microsoft footprints (only buildings with areas greater than the average size of a single-wide mobile home were included), there may still be many buildings that this threshold does not eliminate which could result in less serious damages (e.g., garages, sheds, or barns that do not house valuable assets). It is likely, however, that excluding dozens of additional building footprints from the figures shown in Figure 5-6, column C would still result in several times more impacted buildings identified than estimated from Hazus' calculations.

These findings suggest that in addition to potentially underestimating the flood extent, Hazus may also be incorrectly estimating the number and location of damaged buildings within a given boundary. This could have significant implications for hazard mitigation planning. If counties are preparing hazard mitigation plans based primarily from Hazus results, not only would resources potentially be incorrectly allocated geographically, but there would likely be significantly more damage in an event than estimated and thus more aid required. For this reason, supplementing Hazus results with the Microsoft building footprint analysis is highly recommended.

5.3. Hazus and HIFLD Essential Facilities Comparison
One key aspect of flood hazard resilience is the ability of emergency responders to reach affected populations, and for affected populations to seek help. In order to assess these considerations, it is important to use the most inclusive set of essential facility data available. In the following discussion, the Hazus essential facility dataset is compared with similar information contained in the HIFLD data.

The two maps in Figure 5-7 show Hazus and HIFLD essential facilities, respectively. Note the discrepancies in both the locations of police and fire stations. For police stations, the differences exist within the Dyersburg city limits, where the Hazus data displays five police facilities and the HIFLD dataset only two. However, on the City of Dyersburg's official website, only two police stations are reported – the two that are included in both datasets (DyersburgTN.gov, retrieved 2019).

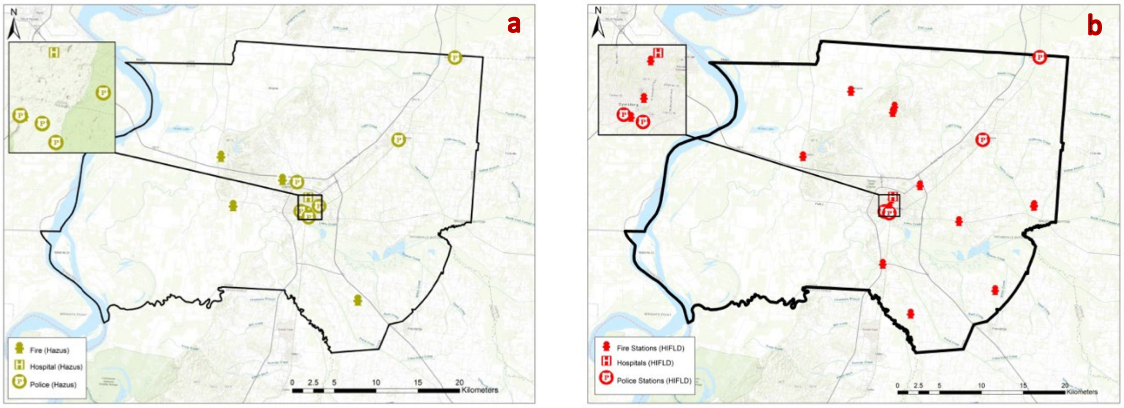


Figure 5-7. Comparison of Hazus and HIFLD essential facility data (Dyer)

A more significant concern is the discrepancy when examining the location of fire stations; Hazus and HIFLD depict 6 and 16 fire stations, respectively. The difference lies in the fact that the HIFLD dataset has recognized the existence of several volunteer fire departments located in Dyer County (Bruceville, Tigrett, East Dyer County, Millsfield, Bogota, Trimble, Fowlkes, and Yorkville), dispersed around the county such that response capability is substantially improved. As a result, it is recommended that the HIFLD dataset be used in analyzing resilience indicators associated with essential facilities.

5.4. Economic Impact

Though many limitations to Hazus have been raised, a beneficial output the software produces are flood depth grids, unlike FIRMs which are boundary polygons without associated depth measurements. These depth grids are subsequently used to estimate loss and damage based on the inundation depth of impacted structures. As this evaluation would be extremely tedious to conduct manually, Hazus provides the means by which base level damage and losses can be estimated, from which extrapolations could be possible to account for Hazus underestimates of the flood boundary and affected infrastructure.

Tables 5-2 through 5-4 provide conservative estimates of the loss and damage that may be expected in Dyer County for a flood event matching the Hazus 500-year flood boundary: 1) roughly $107 million in direct economic losses for buildings, 2) over $13 billion in direct economic losses for agriculture, and 3) around $10 million in direct economic losses for vehicles. Hazus also includes a methodology to estimate displaced people and those needing shelter, as shown in Table 5-5 for the 500-year Hazus flood extent.

Table 5-2. Hazus estimated direct economic building loss for a 500-year flood (Dyer)

Direct Economic Losses for Buildings (thousands of US dollars)								
Capital Stock Losses				Income Losses				
Building Loss	Contents Loss	Inventory Loss	Building Loss Ratio %	Relocation Loss	Capital Related Loss	Wage Losses	Rental Income Loss	**Total Loss**
$17,496	$24,684	$749	2.9	$7,688	$8,985	$44,777	$2,540	**$106,919**

Table 5-3. Hazus estimated direct economic agricultural loss for a 500-year flood (Dyer)

Direct Economic Loss for Agriculture Products (thousands of dollars)					
Crop	Crop Loss Day 0	Crop Loss Day 3	Crop Loss Day 7	Crop Loss Day 14	Max Total Loss
Corn	$0	$3,523,207	$4,697,609	$4,697,609	$4,697,609
Corn Silage	$0	$3,951,068	$5,268,090	$5,268,090	$5,268,090
Soybeans	$0	$220,472	$293,962	$293,962	$293,962
Wheat	$0	$2,656,415	$3,541,887	$3,541,887	$3,541,887
Total	$0	$10,351,161	$13,801,549	$13,801,549	**$13,801,549**

Table 5-4. Hazus estimated direct economic vehicle loss for a 500-year flood (Dyer)

Direct Economic Losses for Vehicles (dollars)			
Car	Light Truck	Heavy Truck	Total Loss
$6,223,842	$3,280,057	$576,224	$10,080,123

Table 5-5. Hazus displaced population & short-term shelter need estimates for a 500-year flood (Dyer)

# of Displaced People	# of People Needing Short-Term Shelter
1,066	20

As noted earlier, Hazus likely underestimates the flood extent and number of damaged buildings for a 500-year flood in Dyer County. As such, these loss and damage results should be considered modest estimates, with the expectation that a flood with an extent similar to the 500-year FIRM boundary would have a more significant economic impact. Further research is recommended to develop a methodology in which these damage and loss estimates could be scaled using some factor, for example based on the difference between the number of damaged buildings calculated by Hazus for a 500-year flood and the number of buildings calculated through the Microsoft building footprint analysis for the 500-year FIRM.

5.5. Social Vulnerability Analysis

Figure 5-8 displays four maps, each depicting an indicator at the census block level of social vulnerability in Dyer County relative to a 500-year FIRM flood extent: a) total population, b) households earning less than $40,000 per year, c) population over age 65, and d) population under age 16. The locations of essential facilities also appear on each map. Figure 5-9 displays the location of mobile home parks in relation to a 500-year FIRM.

All of the respective indicators reveal similar pockets of potentially vulnerable populations in flood inundated areas, most notably situated in the southeastern and central-western portions of the county. As expected, given that one-half of the population of Dyer County lives in Dyersburg, clusters of vulnerable populations are located there. Although Dyersburg is not included in the flood boundary in most places, it is surrounded by inundation, which could impact evacuation routes as well as transportation to and from essential facilities, most notably

Dyer's one hospital. Additionally, all of the four mobile home parks are located within a kilometer of the 500-year FIRM flood boundary – one of which actually lies within the boundary – and those in the south central portion of the county in particular may have difficulty evacuating or reaching the hospital in Dyersburg. Examining these potentially vulnerable areas is a critical component of emergency preparedness, as it allows for advance planning regarding how to best access and provide aid to the most at-risk county residents.

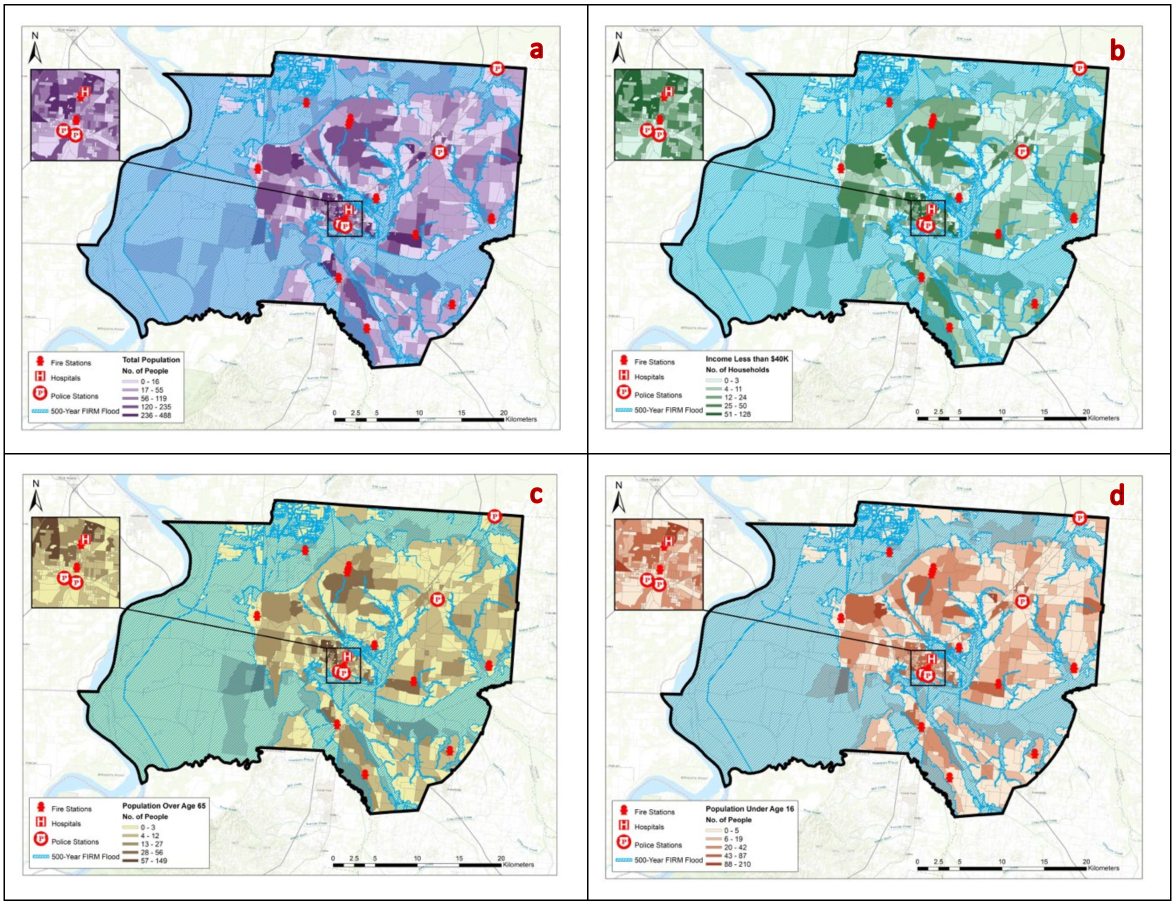


Figure 5-8. Social vulnerability - 500-year FIRM flood extent & HIFLD essential facilities (Dyer)

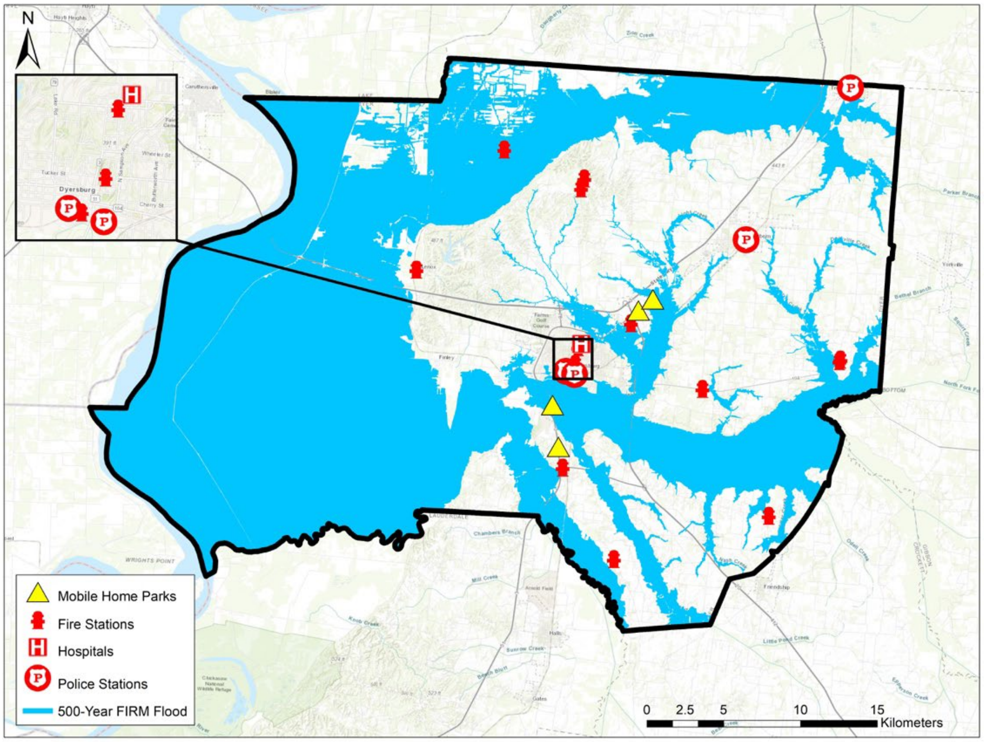


Figure 5-9. 500-year FIRM flood extent and mobile home park locations (Dyer)

5.6. Transportation Mobility Analysis

Figure 5-10 shows the 22% of the road network that is directly inundated by the 500-year FIRM flood extent. This is supported by the results displayed in Table 5-6, which shows the length and percent affected for various road types in the county. Such disruption to the transportation system would dramatically affect local travel, and likely regional travel as well, impacting personal mobility and causing supply chain interruptions. This also underscores the aforementioned concerns regarding access to emergency response and evacuation routes.

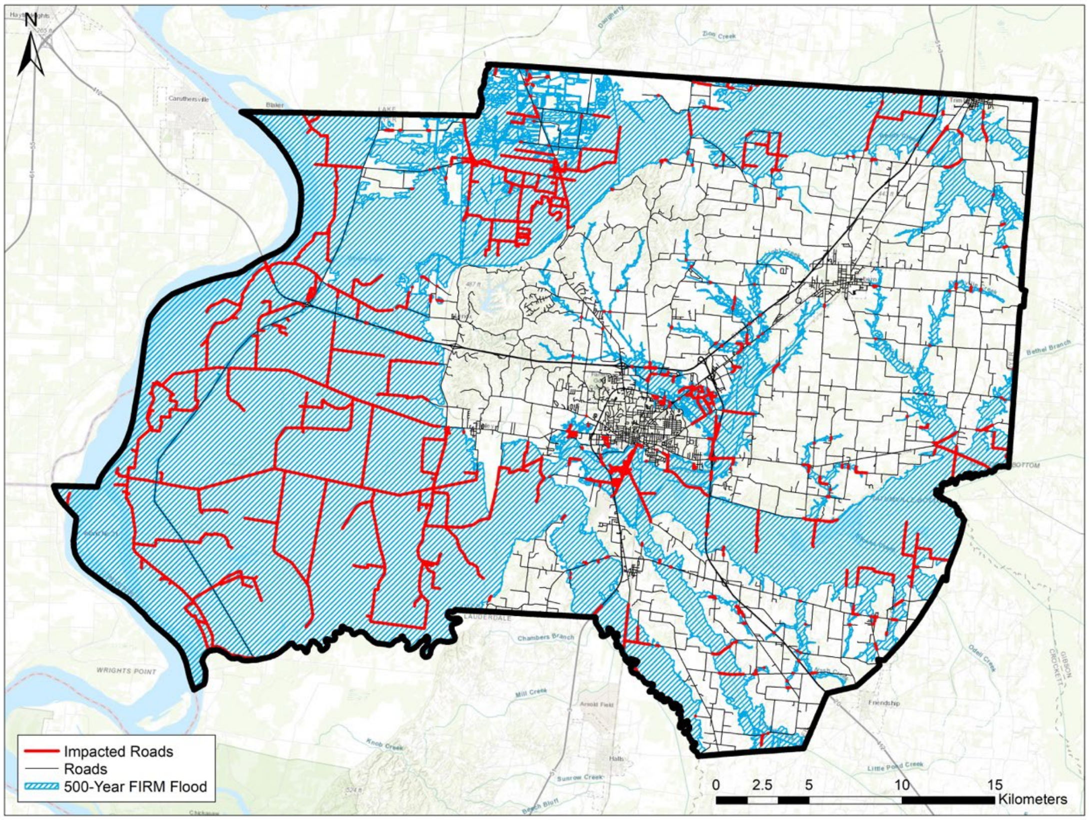


Figure 5-10. Road network affected by a 500-year FIRM extent flood (Dyer County)

Table 5-6. Inundation by road type for 500-year FIRM flood (Dyer County)

Road Type	Length (miles)	% Affected
County	4.8	10%
Interstate	3.3	11%
Common Name	196.4	23%
State Recognized	29.9	15%
U.S.	9.9	8%
Not Categorized	71.7	38%

Another perspective in assessing the impact of a 500-year FIRM on the transportation system is the extent to which the service area of the county is affected. Recall that this is defined as the area that can be reached within 16.1 km (10 miles) of an essential facility. As shown in Figure 5-11, when compared with the initial baseline service area (Figure 5-11a), the 500-year FIRM event results in a service area reduction of roughly 49% less (Figure 5-11b). Additionally, note that some essential facilities are located within the inundated area and many are surrounded by inundation, diminishing their ability to provide assistance and potentially requiring help themselves. This has dramatic implications in terms of human health and safety.

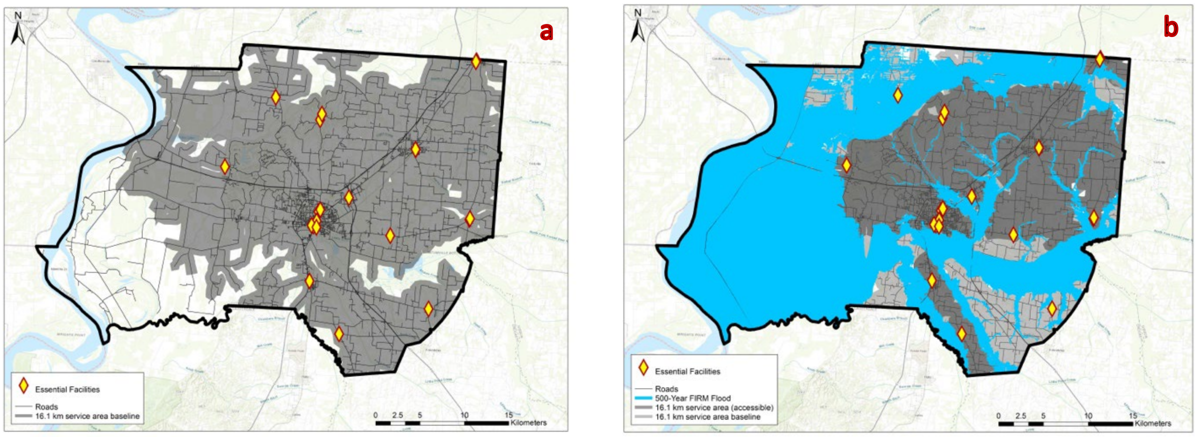


Figure 5-11. Baseline and 500-year FIRM service area analysis results (Dyer County)

6. RESULTS & FINDINGS FOR LAKE COUNTY

6.1. Comparison of Hazus and FIRM Flood Extents

Figure 6-1 displays the estimated flood extents for 100-, 500- and 1,000-year events as produced by Hazus. Note that there are only subtle differences in these inundation areas, and the Mississippi River along the western border does not appear to be significantly flooded.

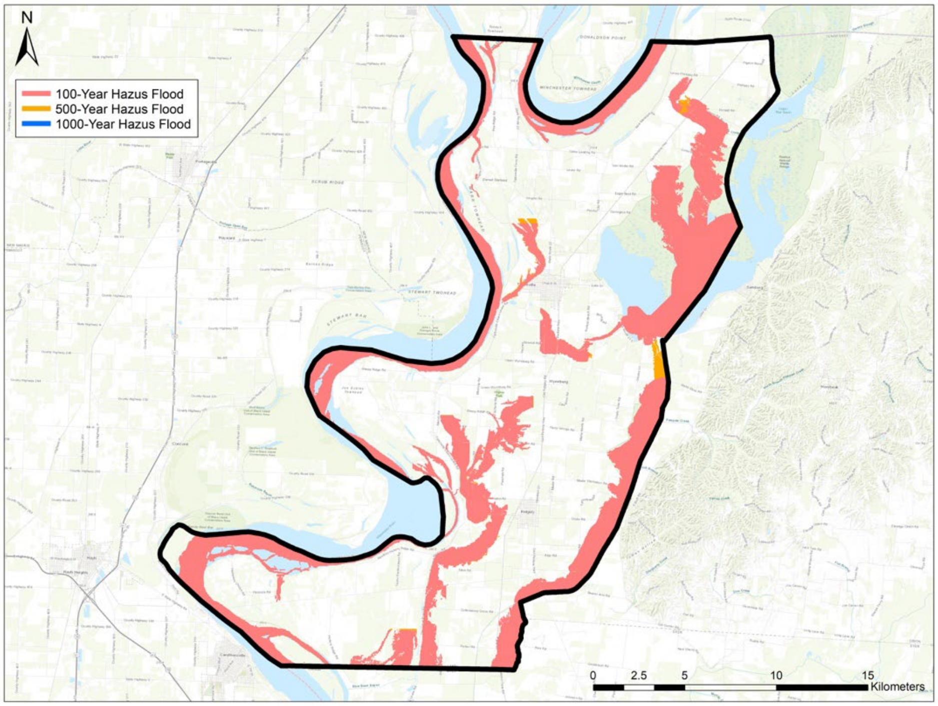


Figure 6-1. Comparison of 100-, 500-, and 1,000-year Hazus flood extents (Lake)

The small discrepancies across the three Hazus flood extents suggest there may not be a sizeable difference in inundation area among the event scenarios. This could be due to the elevation of the region being such that increasing the amount of precipitation results in a flood with greater depth but not necessarily a larger area. This is also likely a function of the small increase in precipitation difference between a 100-year and 500-year recurrence interval on Intensity-Duration-Frequency (IDF) curves[10].

According to the FIRM data for Lake County (which is generated using detailed local surveys, engineering analysis, and robust hydrologic modeling), a 100-year flood boundary has been determined, but there are no additional areas recognized as a 500-year flood extent. Thus, the Lake County flood scenario assessment will examine the available data for evaluating the 100-year FIRM map in comparison to the 100-year Hazus boundary.

As seen in Figure 6-2, there are large discrepancies when these two flood extents are compared. The 100-year FIRM covers roughly 4.6 times more area than the 100-year Hazus extent. One of the most notable differences is along the Mississippi River, the western border of Lake County. According to the 100-year Hazus flood extent, the Mississippi River flows mainly within its normal banks. However, the FIRM 100-year flood shows the vast majority of the western portion of the county as flooded.

[10]An IDF curve is a function that relates rainfall intensity with its duration and frequency of occurrence.

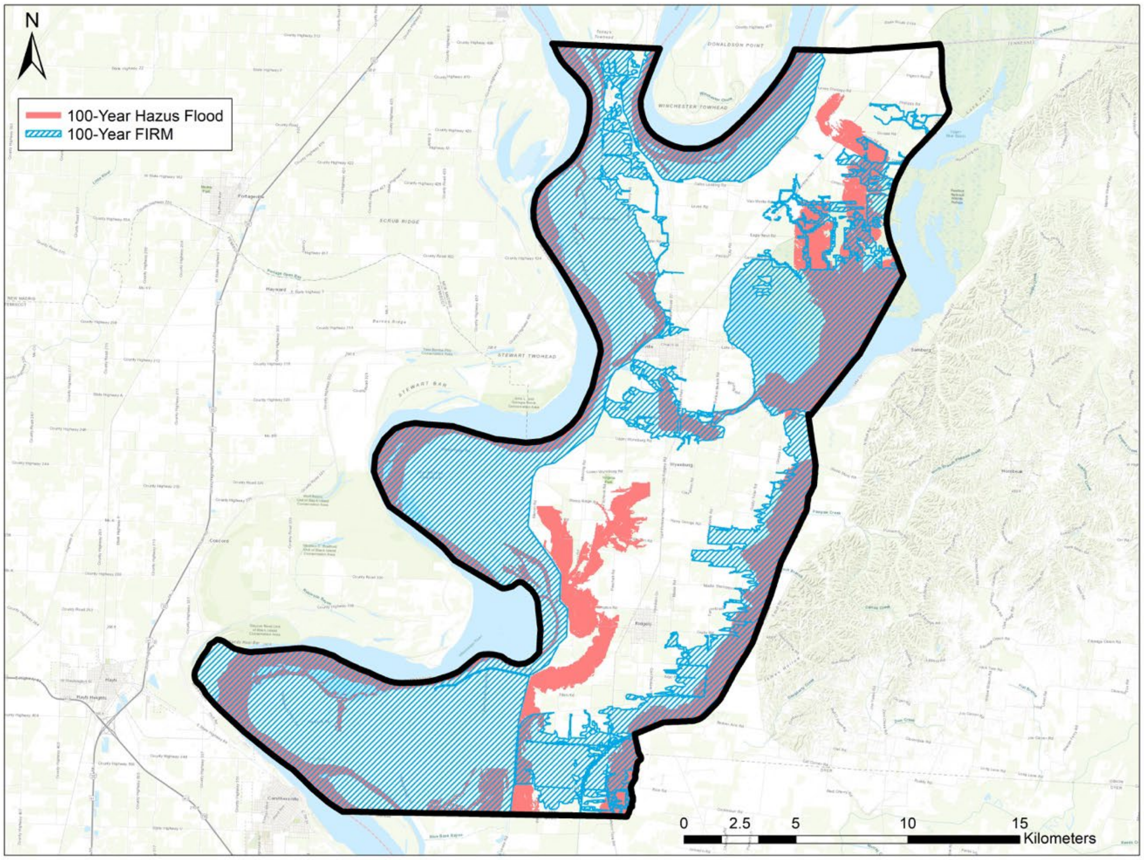


Figure 6-2. Comparison of Hazus and FIRM 100-year flood maps (Lake)

In order to determine whether Hazus or FIRM flood extents would be more appropriate for additional analyses, the boundaries were compared to the historical flood that occurred in Lake County in May 2011, based on a preliminary map created by USGS (see Figure 6-3) and Landsat 5 images from NASA data (Figure 6-4) (USGS, 2011b; NASA, 2011). The NASA satellite images shown in Figure 15 display Lake County in a non-flooded state on April 21, 2010 (Figure 6-4a) and a flooded state on May 10, 2011 (Figure 6-4b). It is evident from both of these data sources that the 2011 flood extent aligns more closely with the 100-year FIRM boundary than to the 100-year Hazus extent[11]. It was therefore concluded that the 100-year FIRM boundary is more representative of extreme flood events in this area.

[11]The discrepancy may be due to the way Hazus predicts flood extent boundaries, particularly the fact that Hazus only accounts for precipitation that occurs within the defined study region. Since it is not possible to include the entire, or even a significant portion of, the Mississippi River watershed in the initial study region, Hazus is unable to account for precipitation occurring on the Mississippi River upstream of the study region.

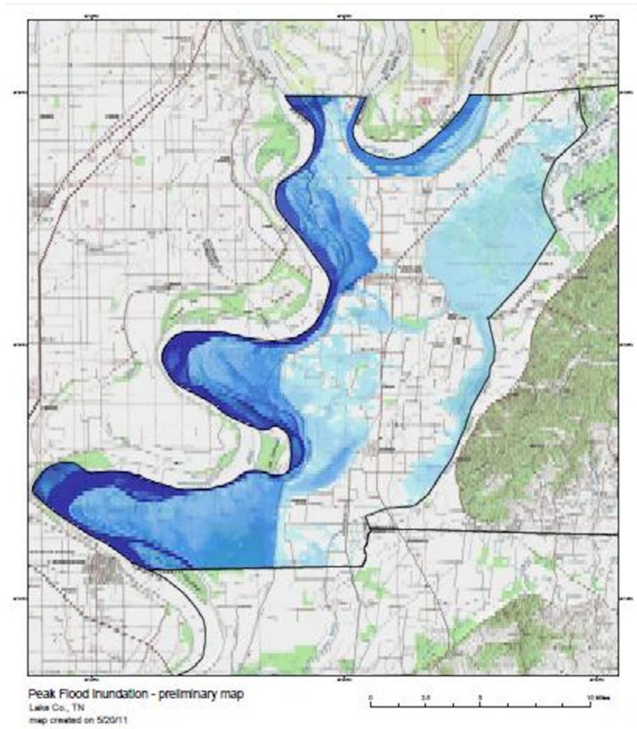


Figure 6-3. USGS preliminary map of Lake County 2011 flood (Lake)

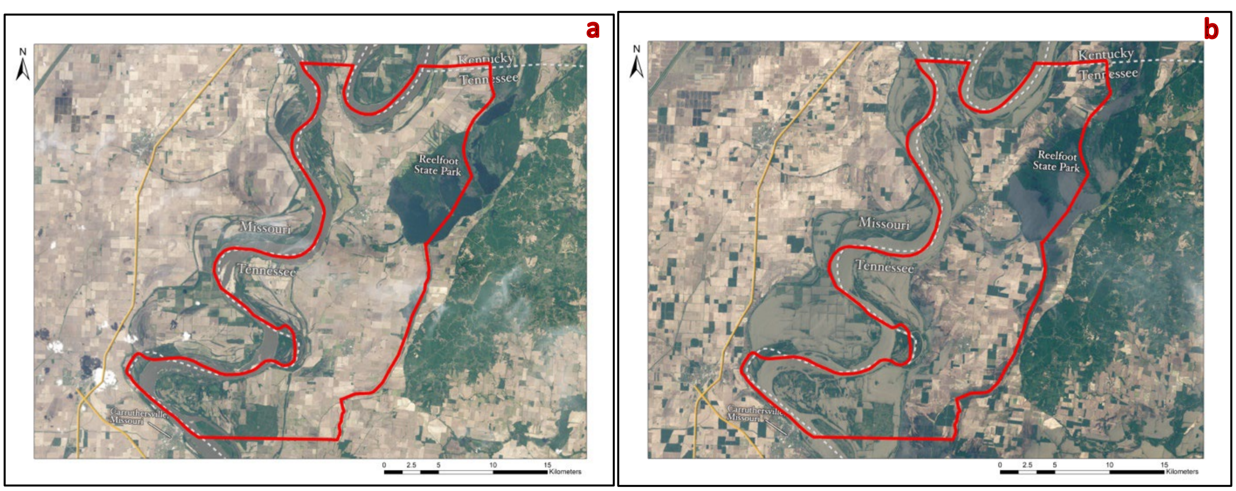


Figure 6-4. NASA Landsat 5 satellite imagery of 2011 Mississippi River flooding (Lake)

6.2. Comparison of Hazus Results and Microsoft Building Footprints

One key benefit to using Hazus is the built-in loss and damage functions for each building class and sub-class (e.g., a residential building with one floor and no basement), which account for the flood depth as it is calculated by Hazus using the DEMs. By contrast, FIRMs do not provide impact assessments. Consequently, even though the 100-year FIRM scenario is more representative of the inundation area, utilizing the Hazus impact assessment is a necessary starting point for performing a 100-year FIRM impact assessment based on the FIRM flood extents.

Hazus estimates building damage based on assumptions made at the census block level (i.e., if 25% of a census block is inundated, 25% of the buildings of a certain type are considered damaged). The downside to using census-block level estimations is losing the accuracy of the actual building locations (i.e., it is possible that 25% of a census block could be inundated and no buildings coinciding with the inundation area, or vice-versa). In order to explore this potential bias, Microsoft building footprints were obtained for Lake County and intersected with the flood inundation area.

The results of this process are displayed in Figure 6-5 and Table 6-1. Damaged building estimates from the 100-year flood is shown according to Hazus model output (column A), Microsoft building footprint analysis using Hazus 100-year flood boundary (column B), and Microsoft building footprint analysis using 100-year FIRM flood boundary (column C).

A: Hazus extent (Hazus building data)	*B: Hazus extent (Building footprint data)*	*C: FIRM extent (Building footprint data)*

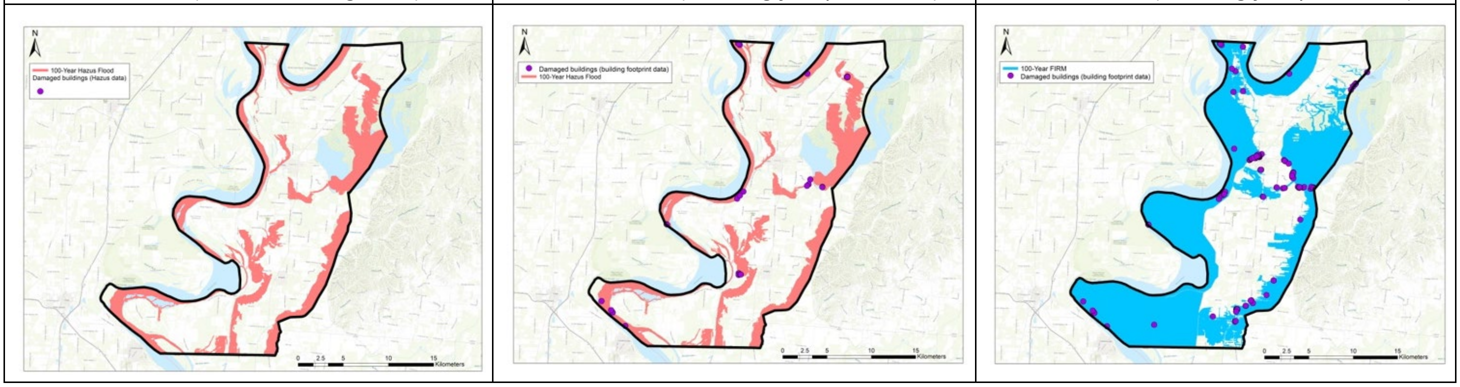


Figure 6-5. Comparative Building Damage Estimates (Lake)

Table 6-1. Affected Building Counts (Lake)

Hazus flood boundary		**FIRM flood boundary**
Hazus results (# affected buildings)	Microsoft building footprint analysis results (# affected buildings)	Microsoft building footprint analysis results (# affected buildings)
0	28	131

There are notable differences in the number of affected buildings based on which flood model and building data are being used. Hazus' analysis determined that no buildings were damaged in the 100-year flood (Figure 6-5, column A). In contrast, for the same Hazus 100-year flood boundary, the Microsoft building footprint analysis resulted in 28 impacted buildings.

Due to their flood extent differences, as expected the FIRM boundary (Figure 6-5, column C) encompasses significantly more buildings than the Hazus flood extent. As shown in Table 6-1, the 100-year FIRM flood extent with the Microsoft building footprint analysis produces roughly

4.7 times more damaged buildings than the 100-year Hazus extent with the Microsoft building footprint analysis (Figure 6-5, column B).

One caveat to consider when interpreting the Microsoft building footprint analysis is that the footprints were initially created using Microsoft's artificial intelligence methodology. As mentioned previously, it is not possible to identify a building's function from the footprint, and as a result it is not possible to assess the damage a specific building would sustain if flooded. Despite an attempt to exclude less critical buildings from the Microsoft footprints (only buildings with areas greater than the average size of a single-wide mobile home were included), there may still be many buildings that this threshold does not eliminate which could result in less serious damages (e.g., garages, sheds, or barns that do not house valuable assets). It is likely, however, that excluding dozens of additional building footprints from the figures shown in Figure 6-5, column C would still indicate significant damage during an extreme flood whereas Hazus calculated no damaged buildings.

These findings suggest that in addition to potentially underestimating the flood extent, Hazus may also be incorrectly estimating the number and location of damaged buildings within a given boundary. This could have significant implications for hazard mitigation planning. If counties are preparing hazard mitigation plans based primarily from Hazus results, not only would resources potentially be incorrectly allocated geographically, but there would likely be significantly more damage than estimated and thus more aid required. For this reason, supplementing Hazus results with the Microsoft building footprint analysis is highly recommended.

6.3. Hazus and HIFLD Essential Facilities Comparison

One key aspect of flood hazard resilience is the ability of emergency responders to reach affected populations, and for affected populations to seek help. In order to assess these considerations, it is important to use the most inclusive set of essential facility data available. In the following discussion, the Hazus essential facility dataset is compared with similar information contained in the HIFLD data.

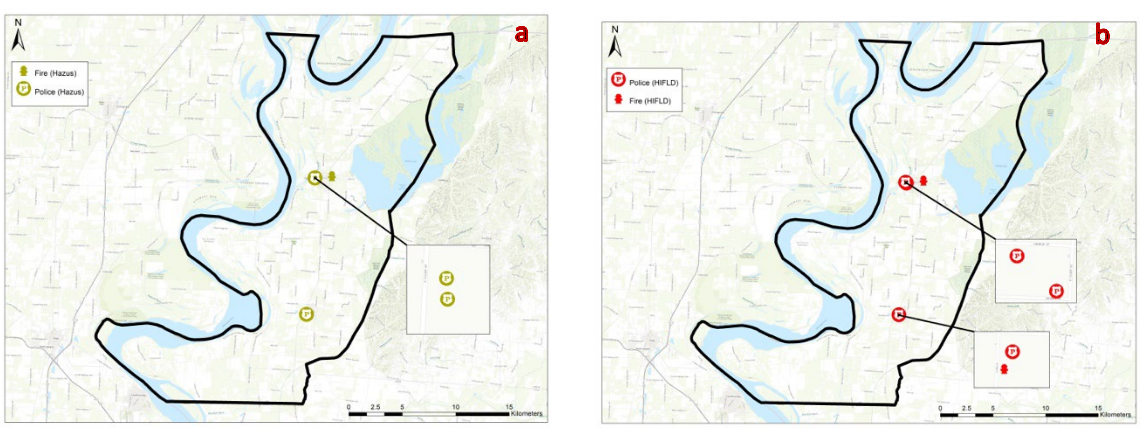


Figure 6-6. Comparison of Hazus and HIFLD essential facility data (Lake)

The two maps in Figure 6-6 show Hazus and HIFLD essential facilities, respectively. According to both the Hazus and HIFLD data sets, there are no hospitals in Lake County. Additionally, both data sets contain information for three police stations within the county. For fire stations however, the HIFLD data set contains one more fire station than the Hazus data set. Since the HIFLD datasets are more comprehensive, it is recommended that these datasets be used in analyzing resilience indicators associated with essential facilities.

6.4. Economic Impact

Though many limitations to Hazus have been raised, a beneficial output the software produces are flood depth grids, unlike FIRMs which are boundary polygons without associated depth measurements. These depth grids are subsequently used to estimate loss and damage based on the inundation depth of impacted structures. As this evaluation would be extremely tedious to conduct manually, Hazus provides the means by which base level damage and losses can be estimated, from which extrapolations could be possible to account for Hazus underestimates of the flood boundary and affected infrastructure.

Tables 6-2 through 6-4 provide conservative estimates of the loss and damage that may be expected in Lake County for a flood event matching the Hazus 100-year flood boundary: 1) roughly $1 million in direct economic losses for buildings, 2) close to $3 billion in direct economic losses for agriculture, and 3) a little over $165,000 in direct economic losses for vehicles. Hazus also includes a methodology to estimate displaced people and those needing shelter, as shown in Table 6-5 for the 500-year Hazus flood extent.

Table 6-2. Hazus estimated direct economic building loss for a 100-year flood (Lake)

Direct Economic Losses for Buildings (thousands of US dollars)								
Capital Stock Losses				Income Losses				
Building Loss	Contents Loss	Inventory Loss	Building Loss Ratio %	Relocation Loss	Capital Related Loss	Wage Losses	Rental Income Loss	**Total Loss**
$396	$240	$2	1.5	$166	$146	$59	$57	**$1,066**

Table 6-3. Hazus estimated direct economic agricultural loss for a 100-year flood (Lake)

Direct Economic Loss for Agriculture Products (thousands of dollars)					
Crop	Crop Loss Day 0	Crop Loss Day 3	Crop Loss Day 7	Crop Loss Day 14	Max Total Loss
CORN	$0	$605,099	$806,799	$806,799	$806,799
SOYBEANS	$0	$29,424	$39,233	$39,233	$39,233
WHEAT	$0	$430,426	$573,902	$573,902	$573,902
WHEAT, WINTER	$0	$961,355	$1,281,806	$1,281,806	$1,281,806
Total	$0	$2,026,305	$2,701,740	$2,701,740	**$2,701,740**

Table 6-4. Hazus estimated direct economic vehicle loss for a 100-year flood (Lake)

Direct Economic Losses for Vehicles (dollars)			
Car	Light Truck	Heavy Truck	Total Loss
$118,030	$46,274	$1,174	$165,478

Table 6-5. Hazus displaced population & short-term shelter need estimates for a 100-year flood (Lake)

# of Displaced People	# of People Needing Short-Term Shelter
58	0

As noted earlier, Hazus likely underestimates the flood extent and number of damaged buildings for a 100-year flood in Lake County. As such, these loss and damage results should be considered modest estimates, with the expectation that a flood with an extent similar to the 100-year FIRM boundary would have a more significant economic impact. Further research is recommended to develop a methodology in which these damage and loss estimates could be scaled using some factor, for example based on the difference between the number of damaged buildings calculated by Hazus for a 100-year flood and the number of buildings calculated through the Microsoft building footprint analysis for the 100-year FIRM.

6.5. Social Vulnerability Analysis

Figure 6-7 displays four maps, each depicting an indicator at the census block level of social vulnerability in Lake County relative to a 100-year FIRM flood extent: a) total population, b) households earning less than $40,000 per year, c) population over age 65, and d) population under age 16. The locations of essential facilities also appear on each map.

All of the respective indicators reveal similar pockets of potentially vulnerable populations in flood inundated areas, most notably situated in isolated clusters in the southern and central portions of the county where the Town of Ridgely and the City of Tiptonville, respectively, are located. Examining these potentially vulnerable areas is a critical component of emergency preparedness, as it allows for advance planning regarding how to best access and provide aid to the most at-risk county residents.

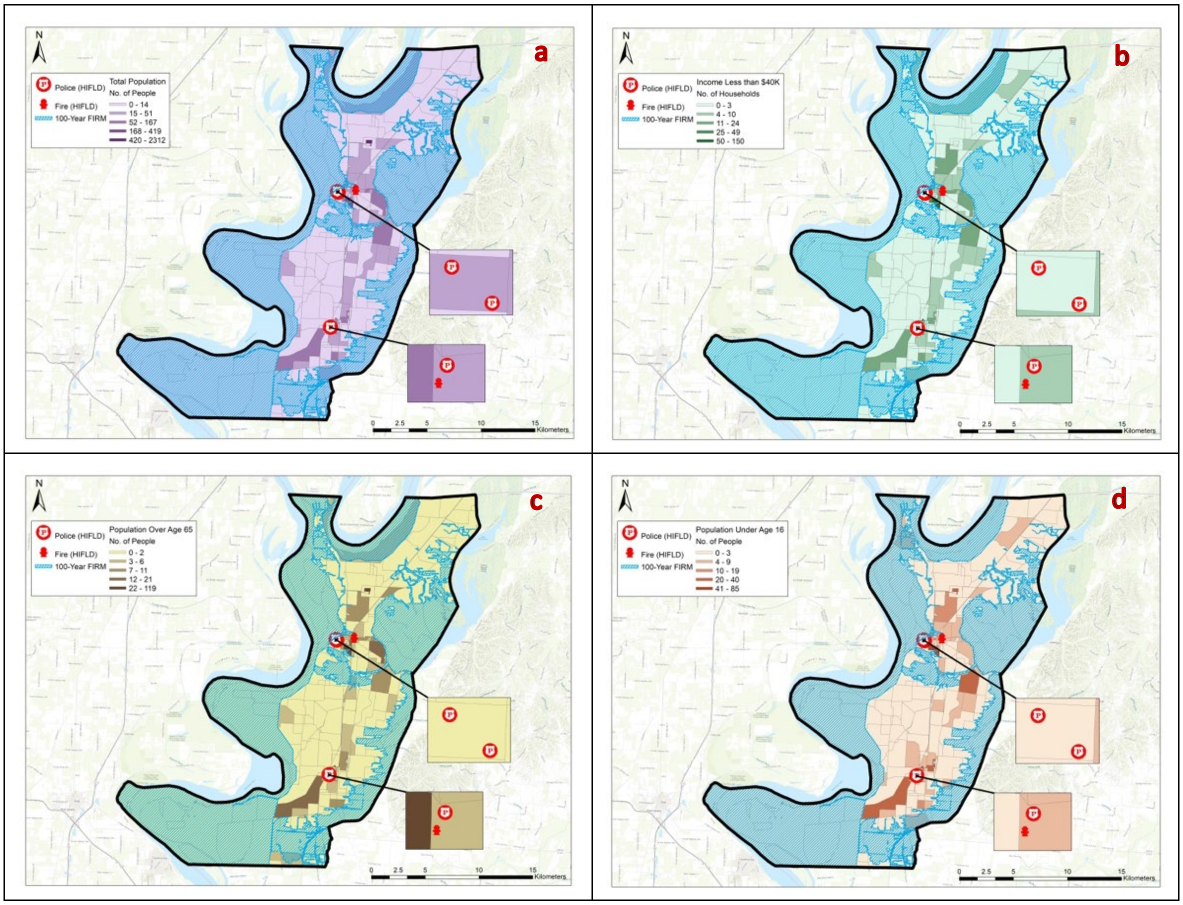


Figure 6-7. Social vulnerability - 100-year FIRM flood extent and HIFLD essential facilities (Lake)

6.6. Transportation Mobility Analysis

Figure 6-8 shows the 22% of the road network that is directly inundated by the 100-year FIRM flood extent. This is supported by the results displayed in Table 6-6, which shows the length and percent affected for various road types in the county. Such disruption to the transportation system could impact local travel, and regional travel as well, potentially affecting personal mobility and causing supply chain interruptions.

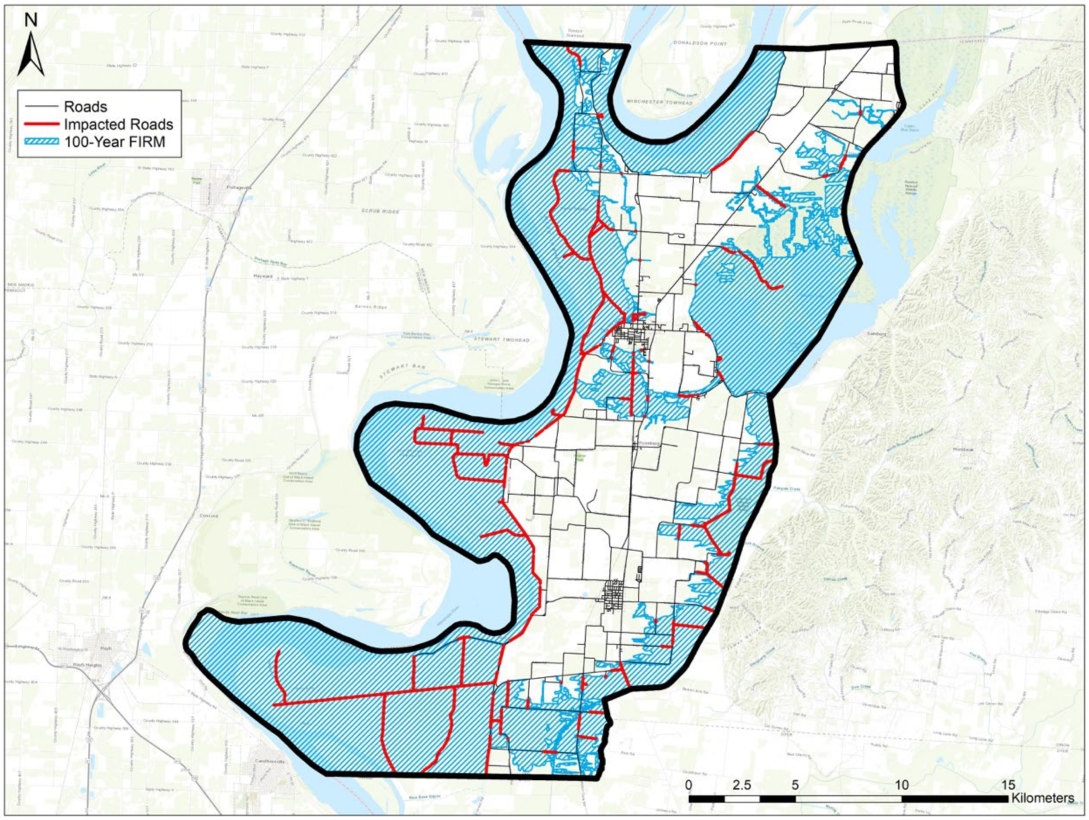


Figure 6-8. Road network affected by a 100-year FIRM extent flood (Lake)

Table 6-6. Inundation by road type for 100-year FIRM flood (Lake)

Road Type	Length (miles)	% Affected
Common Name	51.2	22%
State Recognized	12.3	14%
Not Categorized	15.8	46%

Another perspective in assessing the impact of a 100-year FIRM on the transportation system is the extent to which the service area of the county is affected. Recall that this is defined as the area that can be reached within 16.1 km (10 miles) of an essential facility. As shown in Figure 6-9, when compared with the initial baseline service area (Figure 6-9a), the 100-year FIRM event results in a service area reduction of roughly 39% less (Figure 6-9b). Additionally, note that some essential facilities are located in close proximity to the inundated area, diminishing their ability to provide assistance and potentially requiring help themselves. This could have serious implications in terms of human health and safety.

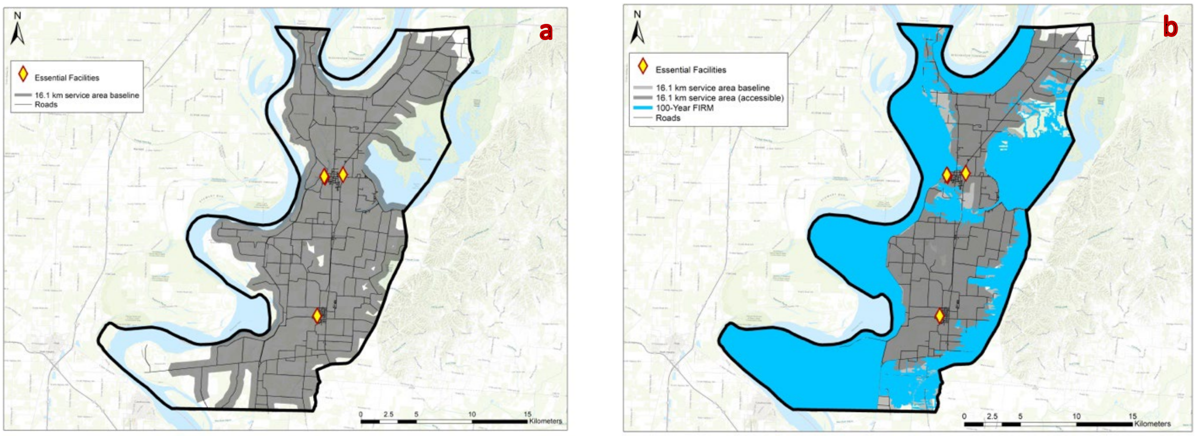


Figure 6-9. Baseline and 100-year FIRM service area analysis results (Lake)

7. RESULTS & FINDINGS FOR LAUDERDALE COUNTY

7.1. Comparison of Hazus and FIRM Flood Extents

Figure 7-1 displays the estimated flood extents for 100-, 500- and 1,000-year events as produced by Hazus. Note that there are only subtle differences in these inundation areas, and the Mississippi River along the western border does not appear to be significantly flooded.

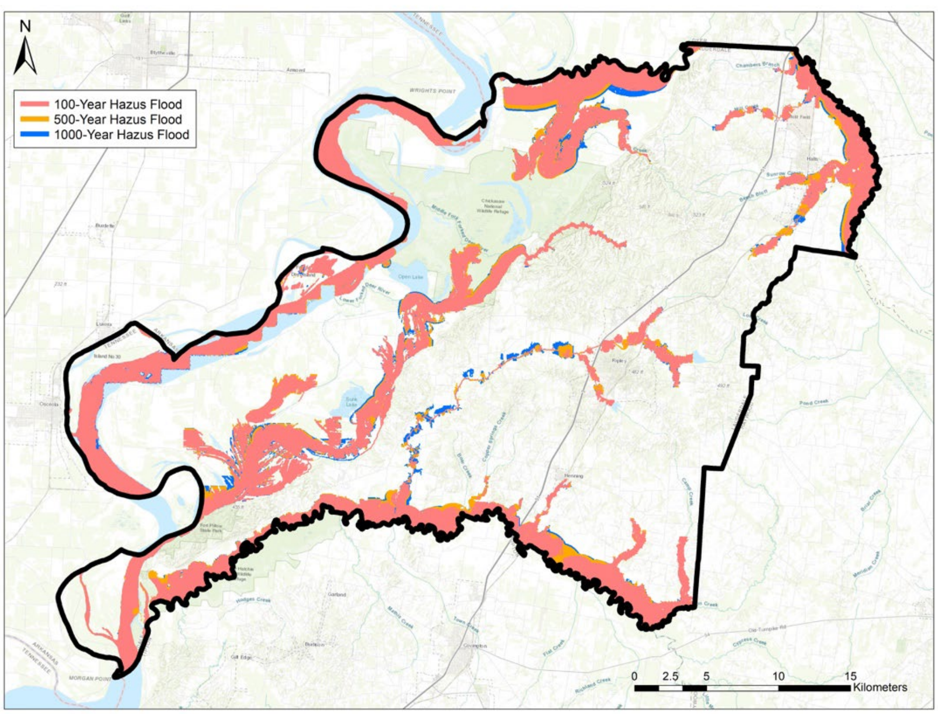


Figure 7-1. Comparison of 100-, 500-, and 1,000-year Hazus flood extents (Lauderdale)

Figure 7-2 displays the 100- and 500-year FIRM flood extents. These maps also have relatively similar boundaries, with the 500-year FIRM containing only 1% more area than the 100-year FIRM.

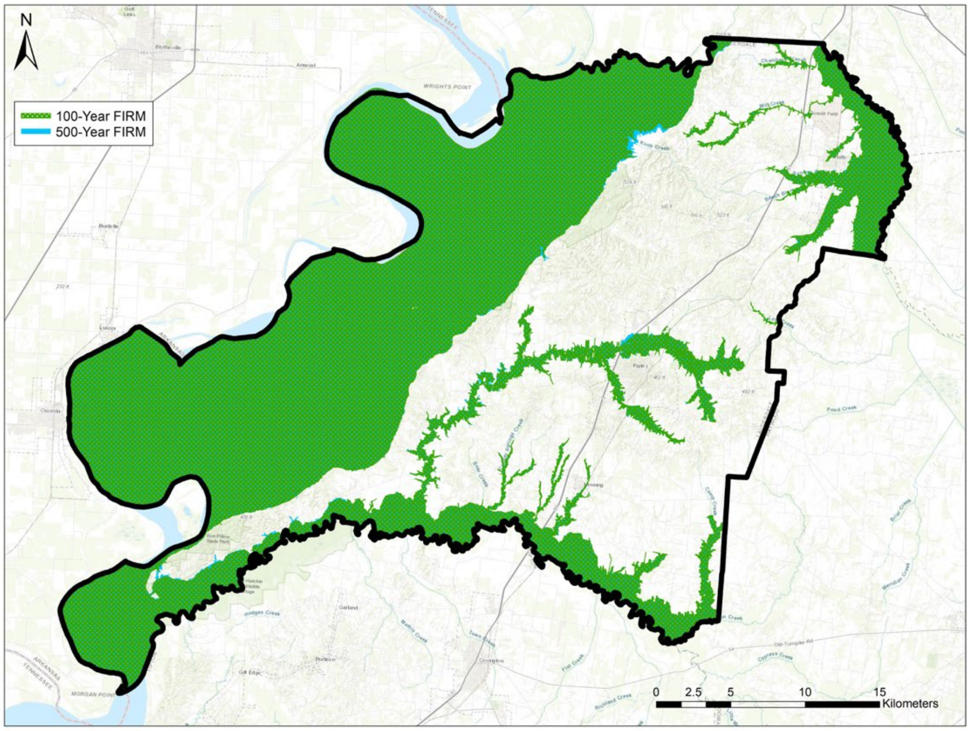


Figure 7-2. Comparison of 100-year and 500-year FIRM flood boundaries (Lauderdale)

The small discrepancies across the three Hazus flood extents, and between the 100- and 500-year FIRMs (which are generated using detailed local surveys, engineering analysis, and robust hydrologic modeling), respectively, suggest there may not be a sizeable difference in inundation area among the event scenarios. This could be due to the elevation of the region being such that increasing the amount of precipitation results in a flood with greater depth but not necessarily a larger area. This is also likely a function of the small increase in precipitation difference between a 100-year and 500-year recurrence interval on Intensity-Duration-Frequency (IDF) curves[12].

Unlike the comparisons shown in Figures 7-1 and 7-2, there are large discrepancies, as seen in Figure 7-3, when the flood extents from the two different sources are compared. The 100-year FIRM covers roughly 5.5 times more area than the 100-year Hazus extent (Figure 7-3a), and the 500-year FIRM covers approximately 5.7 times more area than the 500-year Hazus extent (Figure 7-3b). One of the most notable differences is along the Mississippi River, the western border of Lauderdale County. For both Hazus flood extents, the Mississippi River flows mainly

[12]An IDF curve is a function that relates rainfall intensity with its duration and frequency of occurrence.

within its normal banks. However, the FIRM 100- and 500-year floods show the vast majority of the western portion of the county flooded. Additionally, most tributaries appear more flooded in the FIRM extents.

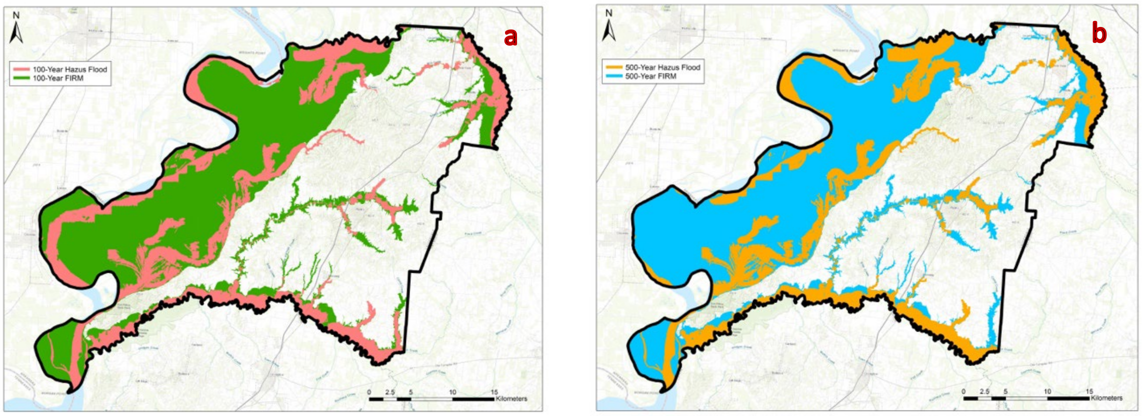


Figure 7-3. Comparison of Hazus and FIRM 100- and 500-year flood maps (Lauderdale)

A comparison can be made between the flood boundaries shown above and the NASA satellite images shown in Figure 7-4, displaying Lauderdale County in a non-flooded state on April 21, 2010 (Figure 7-4a) and a flooded state on May 10, 2011 (Figure 7-4b) (NASA, 2011). The historical 2011 flood extent (Figure 7-4b) aligns more closely with the 500-year FIRM extent than the 500-year Hazus extent. It was therefore concluded that the FIRM-500 boundary is more representative of extreme flood events in this area. Moreover, in solely relying on Hazus outputs, one may be significantly underestimating the 100-year and 500-year flood extents, respectively. A likely explanation can be found in the way Hazus determines flood extent boundaries, particularly the fact that Hazus only accounts for precipitation that occurs within the defined study region. Since it is not possible to include the entire, or even a significant portion of, the Mississippi River watershed in the initial study region, Hazus is unable to account for precipitation occurring on the Mississippi River upstream of the study region.

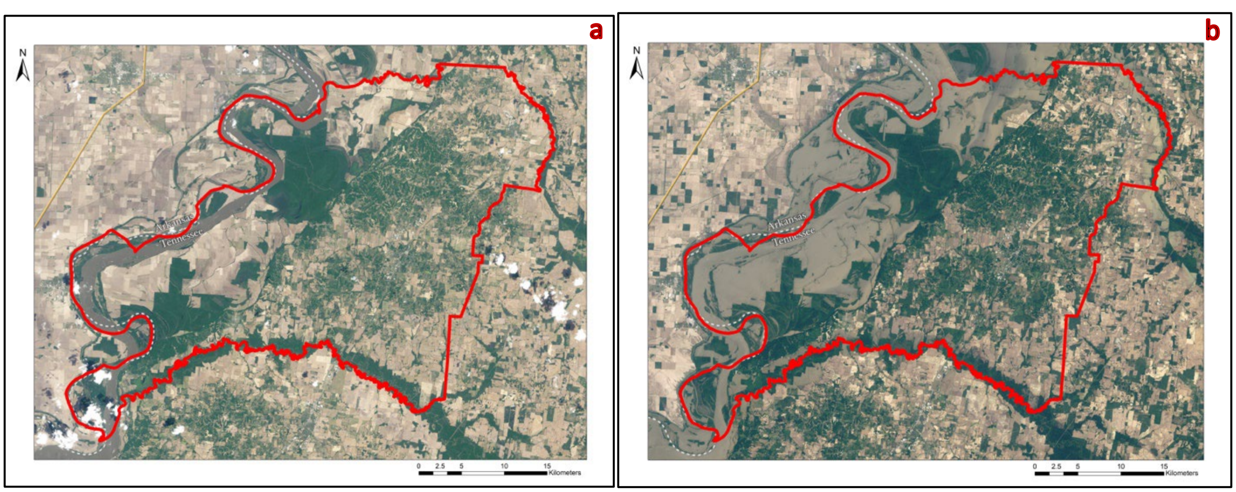


Figure 7-4. NASA Landsat 5 satellite imagery of 2011 Mississippi River flooding (Lauderdale)

7.2. Comparison of Hazus Results and Microsoft Building Footprints

One key benefit to using Hazus is the built-in loss and damage functions for each building class and sub-class (e.g., a residential building with one floor and no basement), which account for the flood depth as it is calculated by Hazus using the DEMs. By contrast, FIRMs do not provide impact assessments. Consequently, even though the 500-year FIRM scenario is more representative of the inundation area, utilizing the Hazus impact assessment is a necessary starting point for performing a 500-year impact assessment based on the FIRM flood extents.

Hazus estimates building damage based on assumptions made at the census block level (i.e., if 25% of a census block is inundated, 25% of the buildings of a certain type are considered damaged). The downside to using census-block level estimations is losing the accuracy of the actual building locations (i.e., it is possible that 25% of a census block could be inundated and no buildings coinciding with the inundation area, or vice-versa). In order to explore this potential bias, Microsoft building footprints were obtained for Lauderdale County and intersected with the flood inundation area.

The results of this process are displayed in Figure 7-5 and Table 7-1. Damaged building estimates from the 500-year flood are shown according to Hazus model output (column A), Microsoft building footprint analysis using Hazus 500-year flood boundary (column B), and Microsoft building footprint analysis using 500-year FIRM flood boundary (column C).

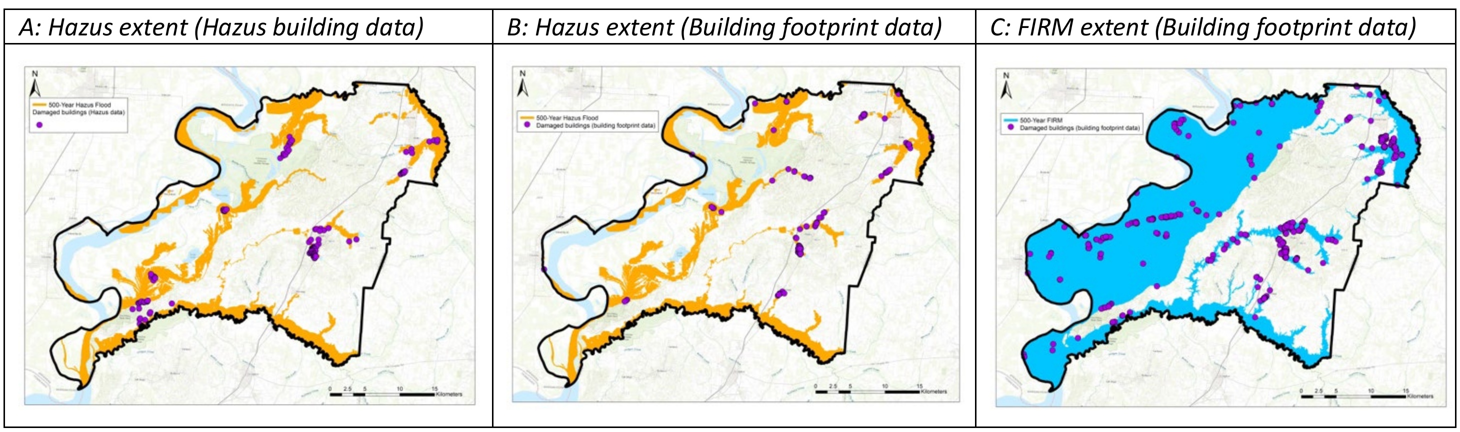


Figure 7-5. Comparative building damage estimates (Lauderdale)

Table 7-1. Affected building counts (Lauderdale)

Hazus flood boundaries		**FIRM flood boundaries**
Hazus results (# affected buildings)	Microsoft building footprint analysis results (# affected buildings)	Microsoft building footprint analysis results (# affected buildings)
138	180	626

There are visible differences in the number of affected buildings based on which flood model and building data are being used. The Microsoft building footprint results indicate a greater number of impacted buildings when compared to Hazus. For example, inspecting the damaged building estimates for just the 500-year Hazus flood extent, the Microsoft building footprint analysis results in the identification of roughly 30% more buildings impacted than initially estimated via Hazus for the same area of inundation.

Another difference is the extent to which the location of damaged buildings differs between the two analyses. The Hazus methodology (Figure 7-5, column A) shows clusters of damaged buildings in the southwestern, northern and central sections of the county. In comparison, the Microsoft building footprint analysis (Figure 7-5, column B) identifies a similar cluster in the central portion of the county, but has the remaining clusters in the northern central portion of the county and northeastern corner, and fewer in the southwestern and northern portions of the county.

Due to their flood extent differences, as expected the FIRM boundaries (Figure 7-5, column C) encompass significantly more buildings than do the Hazus flood extents. As shown in Table 7-1, the 500-year FIRM flood extent with the Microsoft building footprint analysis produces roughly 3.5 times more damaged buildings than the 500-year Hazus extent with the Microsoft building footprint analysis (Figure 7-5, column B), and over 4.5 times more damaged buildings than the 500-year Hazus extent with Hazus' damaged building estimates (Figure 7-5, column A).

One caveat to consider when interpreting the Microsoft building footprint analysis is that the footprints were initially created using Microsoft's artificial intelligence methodology. As mentioned previously, it is not possible to identify a building's function from the footprint, and as a result it is not possible to assess the damage a specific building would sustain if flooded. Despite an attempt to exclude less critical buildings from the Microsoft footprints (only buildings with areas greater than the average size of a single-wide mobile home were included), there may still be many buildings that this threshold does not eliminate which could result in less serious damages (e.g., garages, sheds, or barns that do not house valuable assets). It is likely, however, that excluding dozens of additional building footprints from the figures shown in Figure 7-5, column C would still result in a significantly greater number of impacted buildings identified than estimated from Hazus' calculations.

These findings suggest that in addition to potentially underestimating the flood extent, Hazus may also be incorrectly estimating the number and location of damaged buildings within a given boundary. This could have significant implications for hazard mitigation planning. If counties are preparing hazard mitigation plans based primarily from Hazus results, not only would resources potentially be incorrectly allocated geographically, but there would likely be significantly more damage than estimated and thus more aid required. For this reason, supplementing Hazus results with the Microsoft building footprint analysis is highly recommended.

7.3. Hazus and HIFLD Essential Facilities Comparison

One key aspect of flood hazard resilience is the ability of emergency responders to reach affected populations, and for affected populations to seek help. In order to assess these considerations, it is important to use the most inclusive set of essential facility data available. In the following discussion, the Hazus essential facility dataset is compared with similar information contained in the HIFLD data.

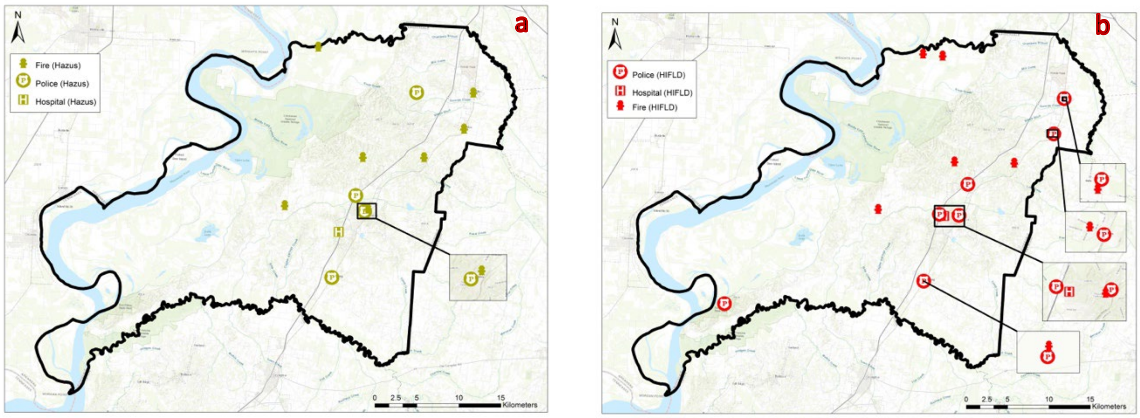


Figure 7-6. Comparison of Hazus and HIFLD essential facility data (Lauderdale)

The two maps in Figure 7-6 show Hazus and HIFLD essential facilities, respectively. Both data sources recognize one hospital within the county. However, there are several differences in both the police and fire station datasets. The Hazus dataset displays four police stations and the HIFLD dataset identifies seven. The HIFLD data includes two additional volunteer fire stations that were not included in the Hazus data – the Frog and Henning volunteer stations. As the HIFLD data appears to be more comprehensive, it is recommended that the HIFLD data be used in analyzing resilience indicators associated with essential facilities.

7.4. Economic Impact

Though many limitations to Hazus have been raised, a beneficial output the software produces are flood depth grids, unlike FIRMs which are boundary polygons without associated depth measurements. These depth grids are subsequently used to estimate loss and damage based on the inundation depth of impacted structures. As this evaluation would be extremely tedious to conduct manually, Hazus provides the means by which base level damage and losses can be estimated, from which extrapolations could be possible to account for Hazus underestimates of the flood boundary and affected infrastructure.

Tables 7-2 through 7-4 provide conservative estimates of the loss and damage that may be expected in Lauderdale County for a flood event matching the Hazus 500-year flood boundary: 1) roughly $97 million in direct economic losses for buildings, 2) over $2 billion in direct economic losses for agriculture, and 3) over $6 million in direct economic losses for vehicles. Hazus also includes a methodology to estimate displaced people and those needing shelter, as shown in Table 7-5 for the 500-year Hazus flood extent.

Table 7-2. Hazus estimated direct economic building loss for a 500-year flood (Lauderdale)

Direct Economic Losses for Buildings (thousands of US dollars)								
Capital Stock Losses				Income Losses				
Building Loss	Contents Loss	Inventory Loss	Building Loss Ratio %	Relocation Loss	Capital Related Loss	Wage Losses	Rental Income Loss	**Total Loss**
$14,805	$17,611	$298	2.4	$7,058	$7,309	$46,662	$3,267	**$97,010**

Table 7-3. Hazus estimated direct economic agricultural loss for a 500-year flood (Lauderdale)

Direct Economic Loss for Agriculture Products (thousands of dollars)					
Crop	Crop Loss Day 0	Crop Loss Day 3	Crop Loss Day 7	Crop Loss Day 14	Max Total Loss
CORN	$0	$1,620,544	$2,160,726	$2,160,726	$2,160,726
SOYBEANS	$0	$83,413	$111,218	$111,218	$111,218
WHEAT	$0	$375,892	$501,189	$501,189	$501,189
Total	$0	$2,079,850	$2,773,133	$2,773,133	**$2,773,133**

Table 7-4. Hazus estimated direct economic vehicle loss for a 500-year flood (Lauderdale)

Direct Economic Losses for Vehicles (dollars)			
Car	Light Truck	Heavy Truck	Total Loss
$4,445,344	$2,169,002	$266,156	**$6,880,502**

Table 7-5. Hazus displaced population & short-term shelter need estimates for a 500-year flood (Lauderdale)

# of Displaced People	# of People Needing Short-Term Shelter
1060	44

As noted earlier, Hazus likely underestimates the flood extent and number of damaged buildings for a 500-year flood in Lauderdale County. As such, these loss and damage results should be considered modest estimates, with the expectation that a flood with an extent similar to the 500-year FIRM boundary would have a more significant economic impact. Further research is recommended to develop a methodology in which these damage and loss estimates could be scaled using some factor, for example based on the difference between the number of damaged buildings calculated by Hazus for a 500-year flood and the number of buildings calculated through the Microsoft building footprint analysis for the 500-year FIRM.

7.5. Social Vulnerability Analysis

Figure 7-7 displays four maps, each depicting an indicator at the census block level of social vulnerability in Lauderdale County relative to a 500-year FIRM flood extent: a) total population, b) households earning less than $40,000 per year, c) population over age 65, and d) population under age 16. The locations of essential facilities also appear on each map. Figure 7-8 displays the location of mobile home parks in relation to a 500-year FIRM.

All of the respective indicators reveal similar pockets of potentially vulnerable populations in flood inundated areas, most notably situated around the City of Ripley in the central portion of the county. The inundated area surrounds the center of Ripley, including the one hospital in the county, which could impact evacuation routes as well as transportation to and from essential facilities. Additionally, one of the three mobile home parks lies within the 500-year FIRM flood boundary. Examining these potentially vulnerable areas is a critical component of emergency preparedness, as it allows for advance planning regarding how to best access and provide aid to the most at-risk county residents.

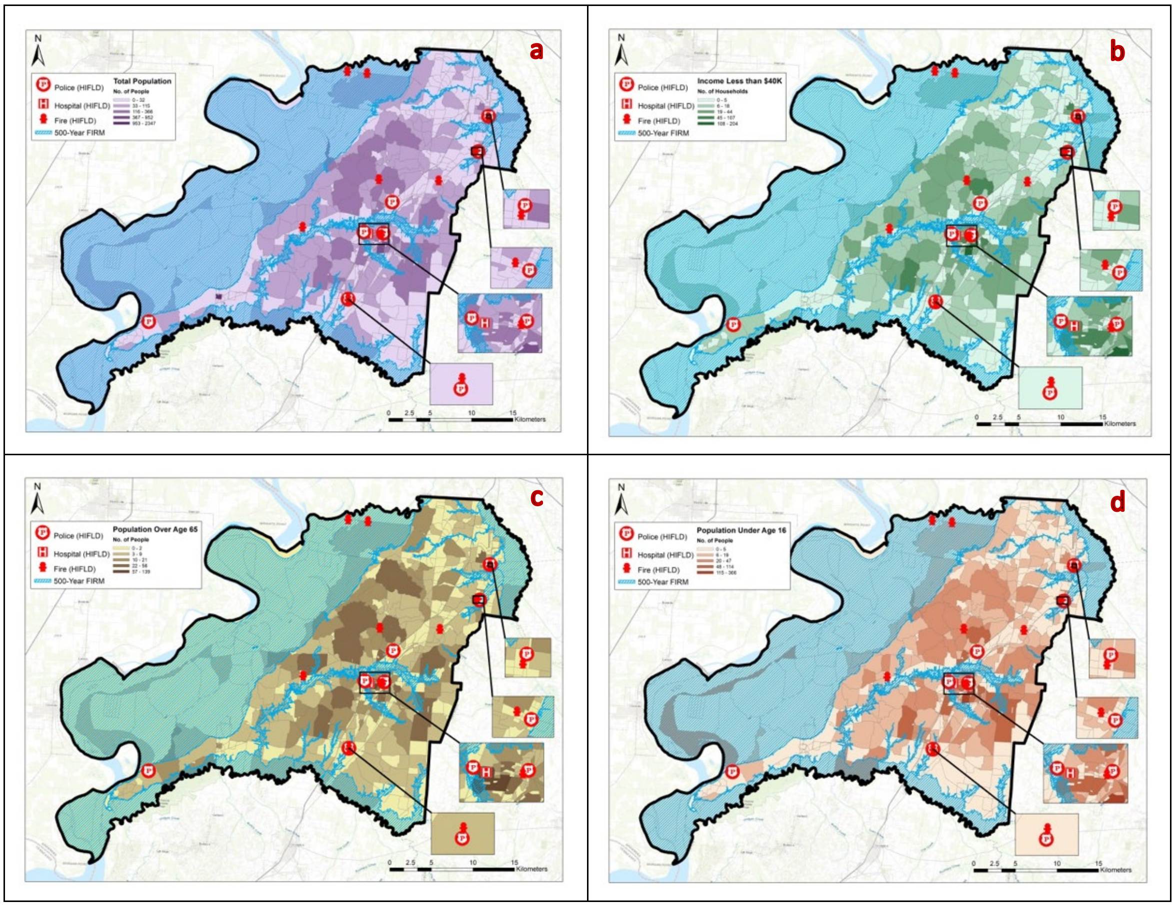


Figure 7-7. Social vulnerability - 500-year FIRM flood extent and HIFLD essential facilities (Lauderdale)

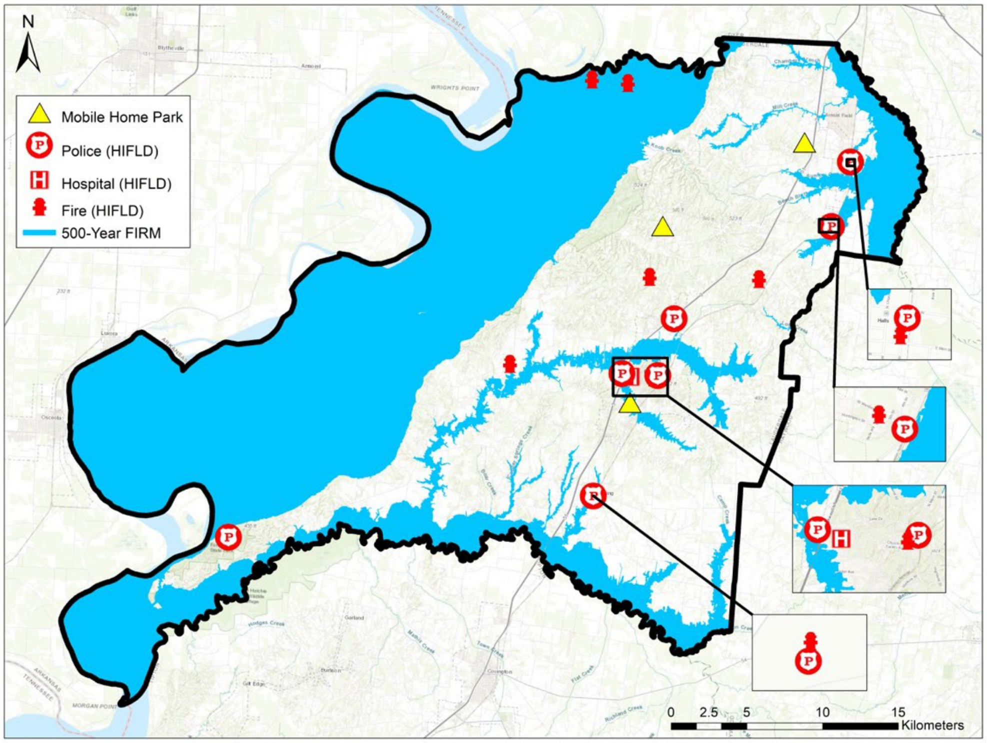


Figure 7-8. 500-year FIRM flood extent and mobile home park locations (Lauderdale)

7.6. Transportation Mobility Analysis

Figure 7-9 shows the 22% of the road network that is directly inundated by the 500-year FIRM flood extent. This is supported by the results displayed in Table 7-6, which shows the length and percent affected for various road types in the county. Such disruption to the transportation system could impact local travel, and potentially regional travel as well, affecting personal mobility and causing supply chain interruptions. This also underscores the aforementioned concerns regarding access to emergency response and evacuation routes.

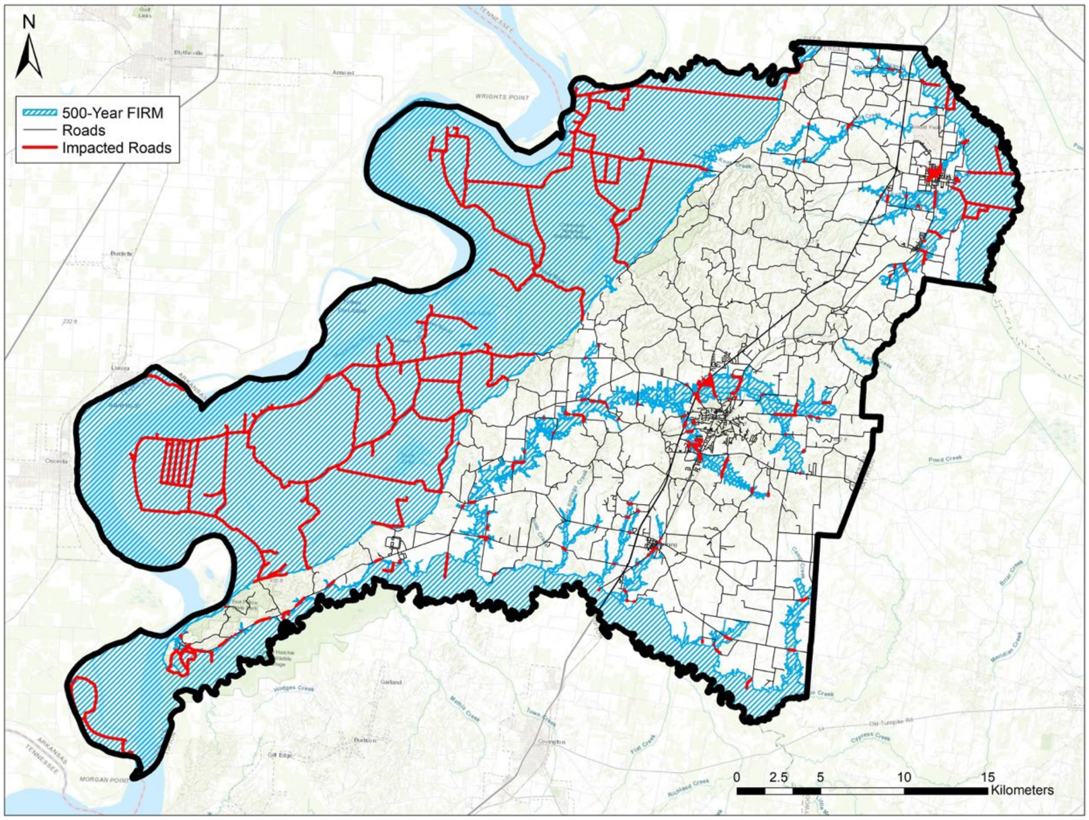


Figure 7-9. Road network affected by a 500-year FIRM extent flood (Lauderdale)

Table 7-6. Inundation by road type for 500-year FIRM flood (Lauderdale)

Road Type	Length (miles)	% Affected
Common Name	168.2	20%
State Recognized	33.3	20%
U.S.	1.4	3%
Not Categorized	42.3	49%

Another perspective in assessing the impact of a 500-year FIRM on the transportation system is the extent to which the service area of the county is affected. Recall that this is defined as the area that can be reached within 16.1 km (10 miles) of an essential facility. As shown in Figure 30, when compared with the initial baseline service area (Figure 7-10a), the 500-year FIRM event results in a service area reduction of roughly 35% less (Figure 7-10b). Additionally, note that some essential facilities are located either within the inundated area or surrounded by inundation, diminishing their ability to provide assistance and potentially requiring help themselves. This has dramatic implications in terms of human health and safety.

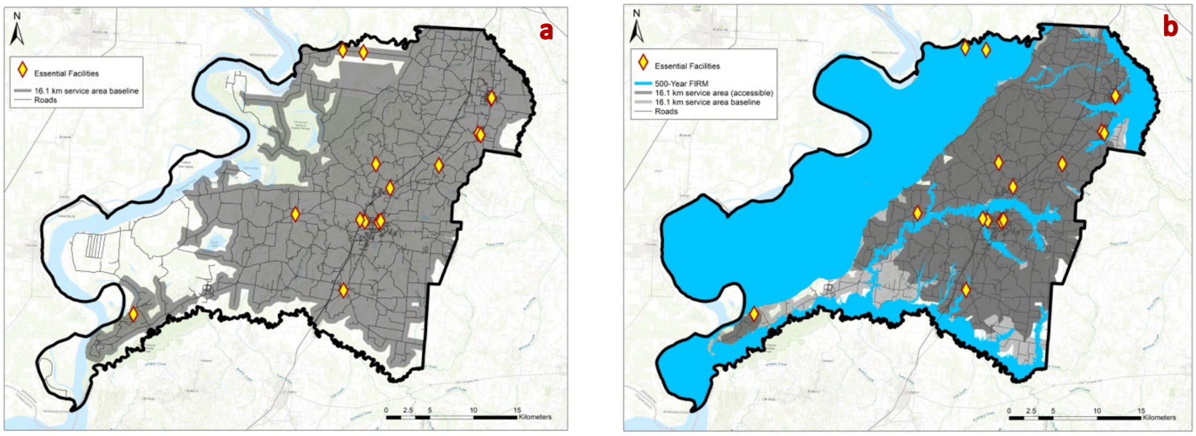


Figure 7-10. Baseline and 500-year FIRM service area analysis results (Lauderdale)

8. RESULTS & FINDINGS FOR TIPTON COUNTY

8.1 Comparison of Hazus and FIRM Flood Extents

Figure 8-1 displays the estimated flood extents for 100-, 500- and 1,000-year events as produced by Hazus. Note that there are only subtle differences in these inundation areas, and the Mississippi River along the western border does not appear to be significantly flooded.

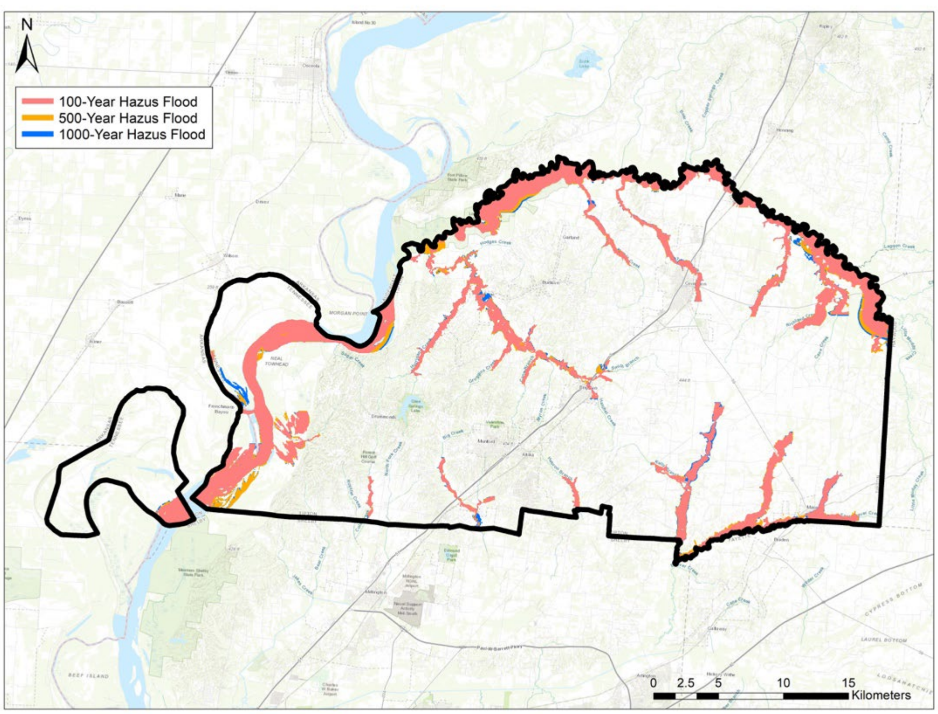


Figure 8-1. Comparison of 100-, 500-, and 1,000-year Hazus flood extents (Tipton)

Figure 8-2 displays the 100- and 500-year FIRM flood extents. These maps also have relatively similar boundaries, with the 500-year FIRM containing less than 1 % more area than the 100-year FIRM.

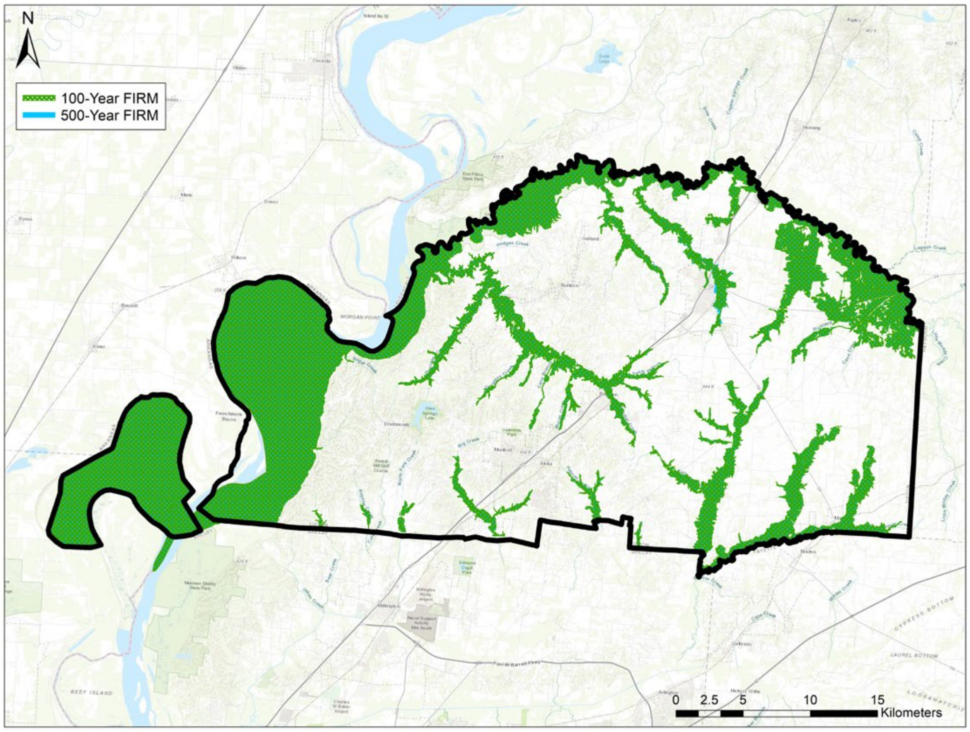


Figure 8-2. Comparison of 100-year and 500-year FIRM flood boundaries (Tipton)

The small discrepancies across the three Hazus flood extents, and between the 100- and 500-year FIRMs (which are generated using detailed local surveys, engineering analysis, and robust hydrologic modeling), respectively, suggest there may not be a sizeable difference in inundation area among the event scenarios. This could be due to the elevation of the region being such that increasing the amount of precipitation results in a flood with greater depth but not necessarily a larger area. This is also likely a function of the small increase in precipitation difference between a 100-year and 500-year recurrence interval on Intensity-Duration-Frequency (IDF) curves[13].

Unlike the comparisons shown in Figures 8-1 and 8-2, there are large discrepancies, as seen in Figure 8-3, when the flood extents from the two different sources are compared. The 100-year FIRM covers close to 5.8 times more area than the 100-year Hazus extent (Figure 8-3a), and the 500-year FIRM covers roughly 5.5 times more area than the 500-year Hazus extent (Figure 8-3b). One of the most notable differences is along the Mississippi River, the western border of

[13]An IDF curve is a function that relates rainfall intensity with its duration and frequency of occurrence.

Dyer County. For both Hazus flood extents, the Mississippi River flows mainly within its normal banks. However, the FIRM 100- and 500-year floods show more dramatic flooding in the western portion of the county. Additionally, most tributaries appear more flooded in the FIRM extents.

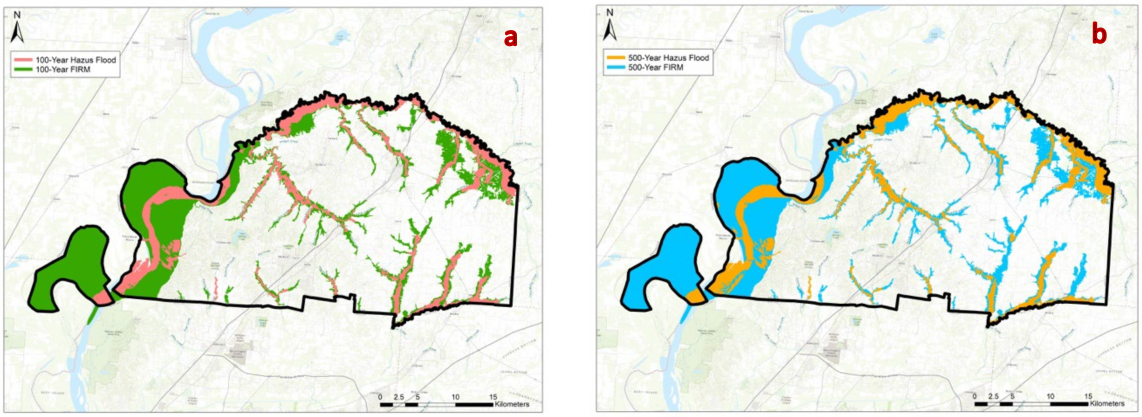


Figure 8-3. Comparison of Hazus and FIRM 100- and 500-year flood maps (Tipton)

A comparison can be made between the flood boundaries shown above and the NASA satellite images shown in Figure 8-4 below, displaying Tipton County in a non-flooded state on April 21, 2010 (Figure 8-4a) and a flooded state on May 10, 2011 (Figure 8-4b) (NASA, 2011). The historical 2011 flood extent (Figure 8-4b) aligns more closely with the 500-year FIRM extent than the 500-year Hazus extent. It was therefore concluded that the 500-year FIRM boundary is more representative of extreme flood events in this area.

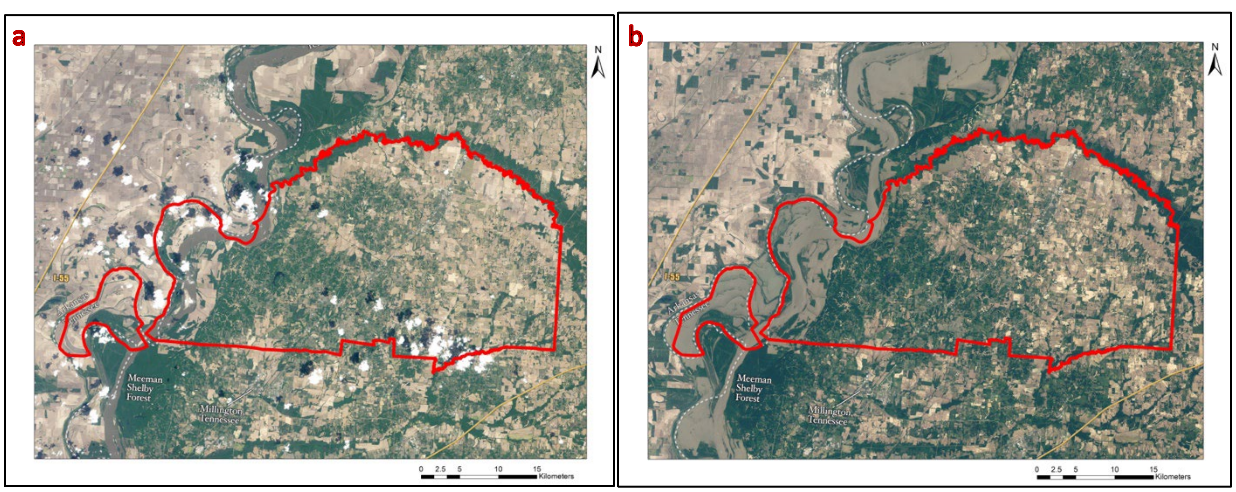


Figure 8-4. NASA Landsat 5 satellite imagery of 2011 Mississippi River flooding (Tipton)

Moreover, in solely relying on Hazus outputs, one may be significantly underestimating the 100-year and 500-year flood extents, respectively. A likely explanation can be found in the way Hazus predicts flood extent boundaries, particularly the fact that Hazus only accounts for precipitation that occurs within the defined study region. Since it is not possible to include the entire, or even a significant portion of, the Mississippi River watershed in the initial study region, Hazus is unable to account for precipitation occurring on the Mississippi River upstream of the study region.

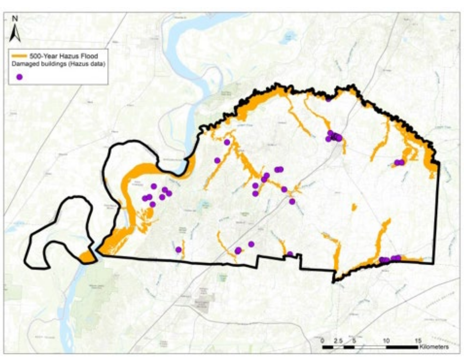
8.2 Comparison of Hazus Results and Microsoft Building Footprints

One key benefit to using Hazus is the built-in loss and damage functions for each building class and sub-class (e.g., a residential building with one floor and no basement), which account for the flood depth as it is calculated by Hazus using the DEMs. By contrast, FIRMs do not provide impact assessments. Consequently, even though the 500-year FIRM scenario is more representative of the inundation area, utilizing the Hazus impact assessment is a necessary starting point for performing a 500-year FIRM impact assessment based on FIRM flood extents.

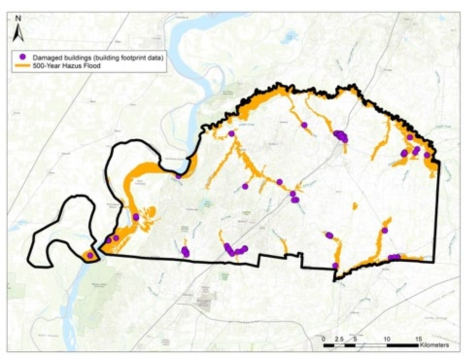
Hazus estimates building damage based on assumptions made at the census block level (i.e., if 25% of a census block is inundated, 25% of the buildings of a certain type are considered damaged). The downside to using census-block level estimations is losing the accuracy of the actual building locations (i.e., it is possible that 25% of a census block could be inundated and no buildings coinciding with the inundation area, or vice-versa). In order to explore this potential bias, Microsoft building footprints were obtained for Dyer County and intersected with the flood inundation area.

The results of this process are displayed in Figure 8-5 and Table 8-1. Damaged building estimates from the 500-year flood are shown according to Hazus model output (column A), Microsoft building footprint analysis using Hazus 500-year flood boundary (column B), and Microsoft building footprint analysis using 500-year FIRM flood boundary (column C).

A: Hazus extent (Hazus building data)



B: Hazus extent (Building footprint data)



C: FIRM extent (Building footprint data)

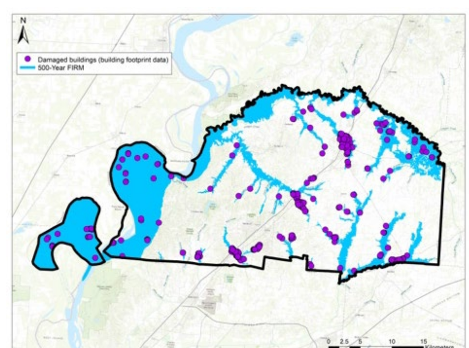


Figure 8-5. Comparative Building Damage Estimates (Tipton)

Table 8-1. Affected Building Counts (Tipton)

Hazus flood boundaries		**FIRM flood boundaries**
Hazus results (# affected buildings)	Microsoft building footprint analysis results (# affected buildings)	Microsoft building footprint analysis results (# affected buildings)
60	82	517

There are visible differences in the number of affected buildings based on which flood model and building data are being used. The Microsoft building footprint results indicate a greater number of impacted buildings when compared to Hazus. For example, inspecting the damaged building estimates for just the 500-year Hazus flood extent, the Microsoft building footprint analysis results in the identification of roughly 37% more buildings impacted than initially estimated via Hazus for the same area of inundation.

Another difference is the extent to which the location of damaged buildings differs between the two analyses. When examining the respective results for the same Hazus 500-year flood boundary in Figures 8-5a and 8-5b, both identify damaged buildings in the central and northern portion of the county. However, the Hazus damaged building results (Figure 8-5a) highlight a cluster of damaged buildings in the western portion of the county whereas the Microsoft building results (Figure 8-5b) feature significant clusters in the southern and northwestern portion of the county.

Due to their flood extent differences, as expected the FIRM boundaries (Figure 8-5c) encompass significantly more buildings than do the Hazus flood extents. As shown in Table 8-1, the 500-year FIRM flood extent with the Microsoft building footprint analysis produces approximately 6.3 times more damaged buildings than the 500-year Hazus extent with the Microsoft building footprint analysis (Figure 8-5a), and roughly 8.6 times more damaged buildings than the 500-year Hazus extent with Hazus' damaged building estimates (Figure 8-5a).

One caveat to consider when interpreting the Microsoft building footprint analysis is that the footprints were initially created using Microsoft's artificial intelligence methodology. As mentioned previously, it is not possible to identify a building's function from the footprint, and as a result it is not possible to assess the damage a specific building would sustain if flooded. Despite an attempt to exclude less critical buildings from the Microsoft footprints (only buildings with areas greater than the average size of a single-wide mobile home were included), there may still be many buildings that this threshold does not eliminate which could result in less serious damages (e.g., garages, sheds, or barns that do not house valuable assets). It is likely, however, that excluding dozens of additional building footprints from the figures shown in Figure 8-5c would still result in several times more impacted buildings identified than estimated from Hazus' calculations.

8.3. Hazus and HIFLD Essential Facilities Comparison

One key aspect of flood hazard resilience is the ability of emergency responders to reach affected populations, and for affected populations to seek help. In order to assess these considerations, it is important to use the most inclusive set of essential facility data available. In the following discussion, the Hazus essential facility dataset is compared with similar information contained in the HIFLD data.

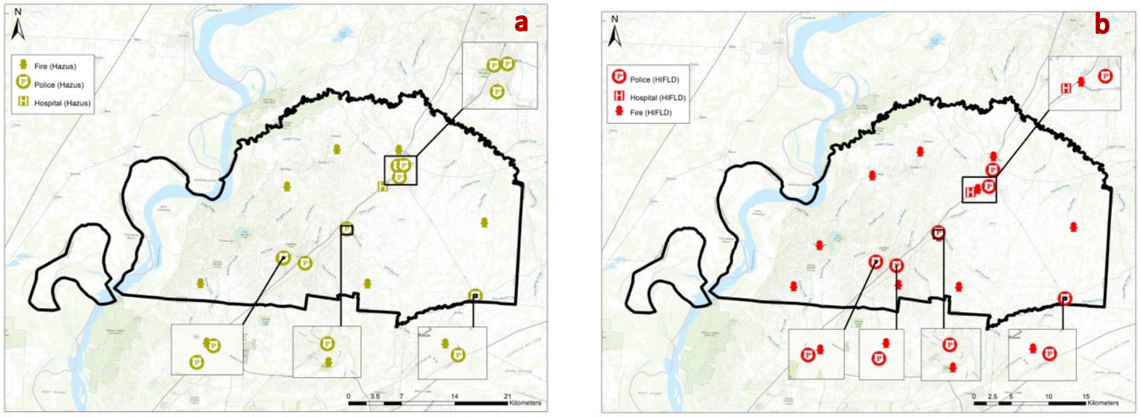


Figure 8-6. Comparison of Hazus and HIFLD essential facility data (Tipton)

The two maps in Figure 8-6 show Hazus and HIFLD essential facilities, respectively. Both data sources recognize one hospital within the county. However, there are several differences in both the police and fire station datasets. The Hazus data identifies nine police stations while the HIFLD dataset identifies only six. The three additional police stations in the Hazus data set are likely errors in data collection and categorization rather than important additional facilities – there are two Munford Police Stations listed that are located less than 80 meters apart; there are two Tipton County Sheriff Departments listed with addresses 1.5 km apart, only one of which matches the address given on Tipton County's official website (TiptonCo.com, retrieved 2019); and there is a "Crimestoppers of Tipton County" listed at the same address as the correct Sheriff department, not likely representing an additional unique essential facility location to be considered.

In terms of fire stations, the Hazus data contains nine stations, whereas the HIFLD data set contains thirteen. The four additional locations in the HIFLD data include two other Munford and Atoka fire stations, an additional Quito volunteer fire station, and an additional Covington fire station. Each of these thirteen locations represents have a unique address and are at least two kilometers from the nearest adjacent fire station; thus it is likely that each of these thirteen sites should be considered valid essential facility locations. The additional fire stations found in the HIFLD data set improve the accuracy of the response capability of the county, and thus it is recommended that the HIFLD dataset be used in analyzing resilience indicators associated with essential facilities.

8.4. Economic Impact

Though many limitations to Hazus have been raised, a beneficial output the software produces are flood depth grids, unlike FIRMs which are boundary polygons without associated depth measurements. These depth grids are subsequently used to estimate loss and damage based on the inundation depth of impacted structures. As this evaluation would be extremely tedious to conduct manually, Hazus provides the means by which base level damage and losses can be estimated, from which extrapolations could be possible to account for Hazus underestimates of the flood boundary and affected infrastructure.

Tables 8-2 through 8-4 provide conservative estimates of the loss and damage that may be expected in Tipton County for a flood event matching the Hazus 500-year flood boundary: 1) roughly $49 million in direct economic losses for buildings, 2) over $1 billion in direct economic losses for agriculture, and 3) close to $6 million in direct economic losses for vehicles. Hazus also includes a methodology to estimate displaced people and those needing shelter, as shown in Table 8-5 for the 500-year Hazus flood extent.

Table 8-2. Hazus estimated direct economic building loss for a 500-year flood (Tipton)

Direct Economic Losses for Buildings (thousands of US dollars)								
Capital Stock Losses				Income Losses				
Building Loss	Contents Loss	Inventory Loss	Building Loss Ratio %	Relocation Loss	Capital Related Loss	Wage Losses	Rental Income Loss	**Total Loss**
$12,323	$15,652	$920	1.4	$5,248	$4,900	$7,718	$2,319	**$49,080**

Table 8-3. Hazus estimated direct economic agricultural loss for a 500-year flood (Tipton)

Direct Economic Loss for Agriculture Products (thousands of dollars)					
Crop	Crop Loss Day 0	Crop Loss Day 3	Crop Loss Day 7	Crop Loss Day 14	Max Total Loss
CORN	$0	$470,722	$627,630	$627,630	$627,630
SOYBEANS	$0	$36,012	$48,016	$48,016	$48,016
WHEAT	$0	$300,619	$400,825	$400,825	$400,825
Total	$0	$807,353	$1,076,470	$1,076,470	**$1,076,470**

Table 8-4. Hazus estimated direct economic vehicle loss for a 500-year flood (Tipton)

Direct Economic Losses for Vehicles (dollars)			
Car	Light Truck	Heavy Truck	Total Loss
$3,762,124	$1,853,790	$372,747	**$5,988,661**

Table 8-5. Hazus displaced population & short-term shelter need estimates for a 500-year flood (Tipton)

# of Displaced People	# of People Needing Short-Term Shelter
1,221	47

As noted earlier, Hazus likely underestimates the flood extent and number of damaged buildings for a 500-year flood in Tipton County. As such, these loss and damage results should be considered modest estimates, with the expectation that a flood with an extent similar to the 500-year FIRM boundary would have a more significant economic impact. Further research is recommended to develop a methodology in which these damage and loss estimates could be scaled using some factor, for example based on the difference between the number of damaged buildings calculated by Hazus for a 500-year flood and the number of buildings calculated through the Microsoft building footprint analysis for the 500-year FIRM.

8.5 Social Vulnerability Analysis

Figure 8-7 displays four maps, each depicting an indicator at the census block level of social vulnerability in Tipton County relative to a 500-year FIRM flood extent: a) total population, b) households earning less than $40,000 per year, c) population over age 65, and d) population under age 16. The locations of essential facilities also appear on each map. Figure 8-8 displays the location of mobile home parks in relation to a 500-year FIRM.

All of the respective indicators reveal similar pockets of potentially vulnerable populations in flood inundated areas, most notably situated in the southwestern and central northern portions of the county near the Town of Atoka and City of Covington, respectively. Additionally, all four of the mobile home parks are located within 2.5 kilometers of the 500-year FIRM boundary, with the western-most park is on the edge of the flood boundary. Examining these potentially vulnerable areas is a critical component of emergency preparedness, as it allows for advance planning regarding how to best access and provide aid to the most at-risk county residents.

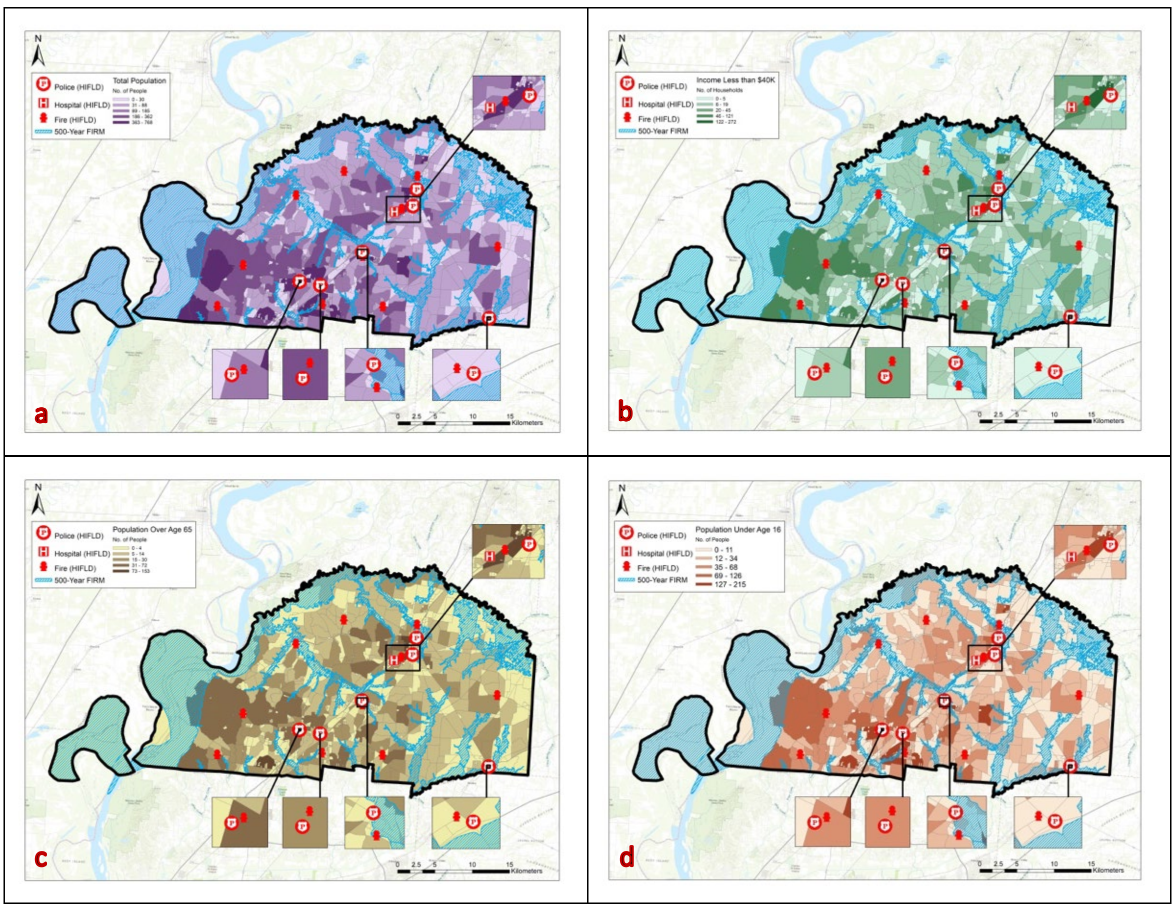


Figure 8-7. Social vulnerability - 500-year FIRM flood extent and HIFLD essential facilities (Tipton)

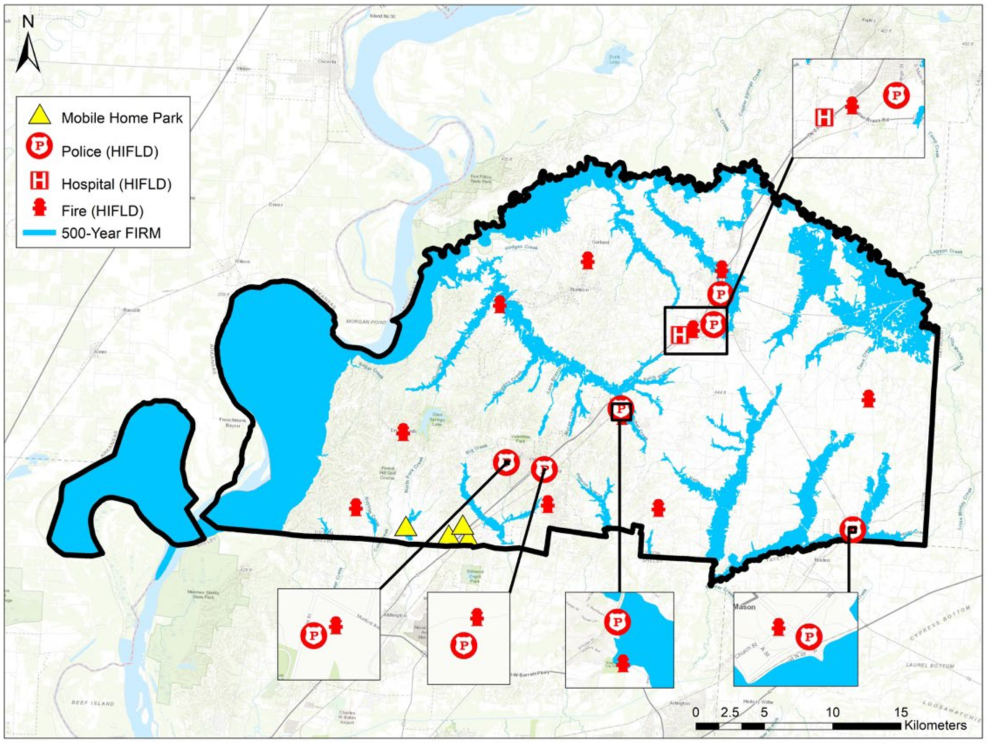


Figure 8-8. 500-year FIRM flood extent and mobile home park locations (Tipton)

8.6 Transportation Mobility Analysis

Figure 8-9 shows the 10.8% of the road network that is directly inundated by the 500-year FIRM flood extent. This is supported by the results displayed in Table 8-6, which shows the length and percent affected for various road types in the county. Such disruption to the transportation system could impact local travel, and likely regional travel as well, impacting personal mobility and causing supply chain interruptions. This also underscores the aforementioned concerns regarding access to emergency response and evacuation routes.

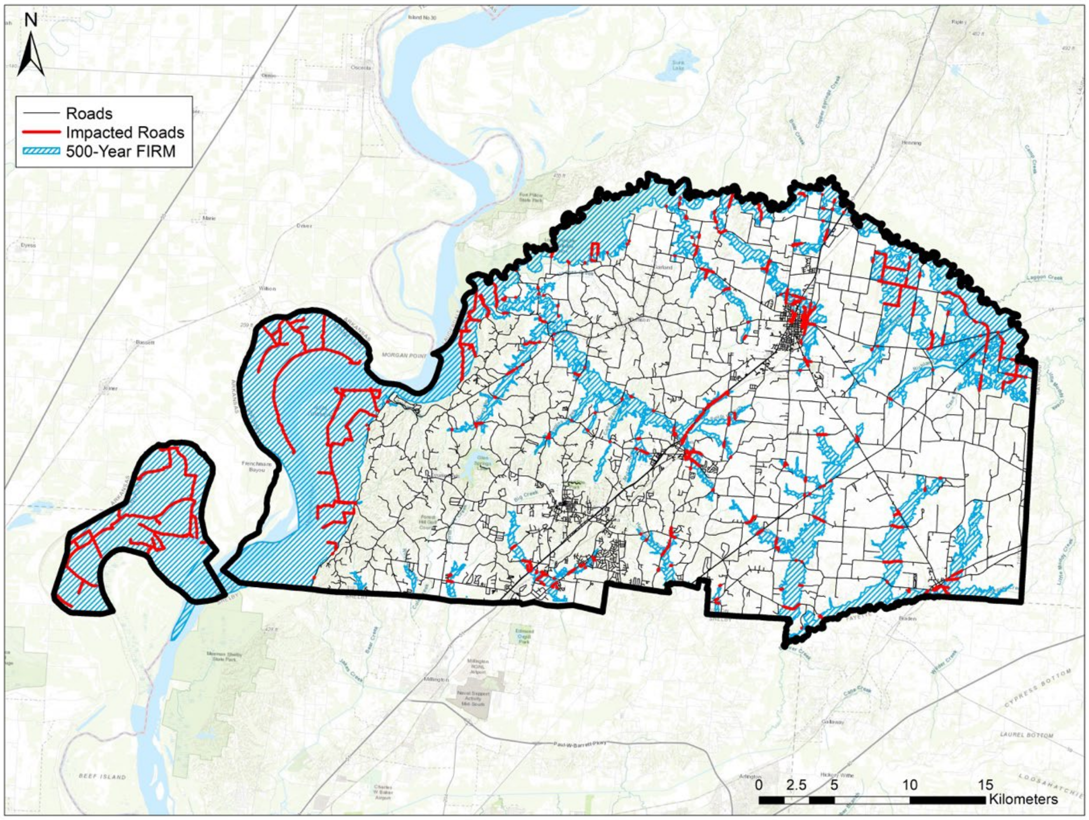


Figure 8-9. Road network affected by a 500-year FIRM extent flood (Tipton)

Table 8-6. Inundation by road type for 500-year FIRM flood (Tipton)

Road Type	Length (miles)	% Affected
Common Name	105.0	10%
State Recognized	9.9	6%
U.S.	5.3	12%
Not Categorized	30.5	27%

Another perspective in assessing the impact of a 500-year FIRM on the transportation system is the extent to which the service area of the county is affected. Recall that this is defined as the area that can be reached within 16.1 km (10 miles) of an essential facility. As shown in Figure 8-10, when compared with the initial baseline service area (Figure 8-10a), the 500-year FIRM event results in a service area reduction of roughly 28% less (Figure 8-10b). Additionally, note that some essential facilities are located within or in close proximity to the inundated area, diminishing their ability to provide assistance and potentially requiring help themselves. This has serious implications in terms of human health and safety.

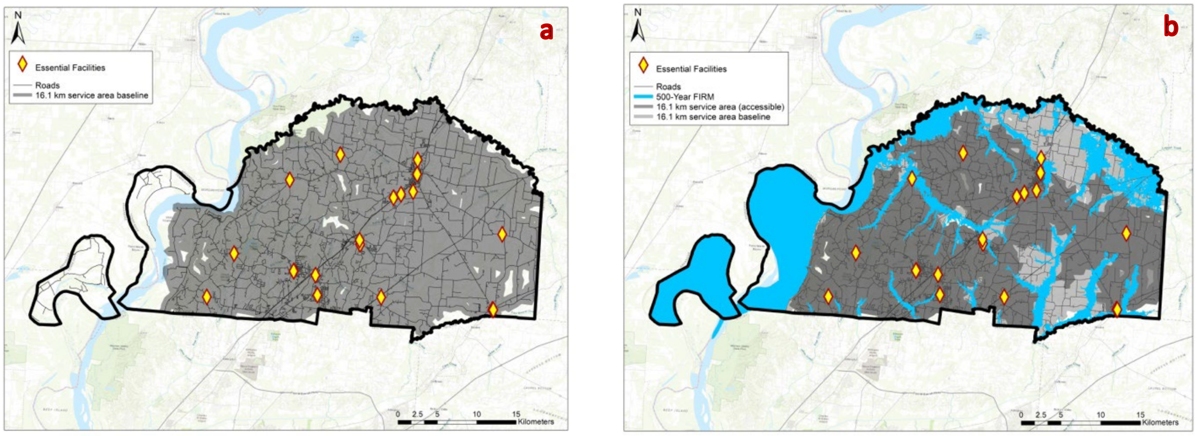


Figure 8-10. Baseline and 500-year FIRM service area analysis results (Tipton)

9. RESULTS & FINDINGS FOR MADISON COUNTY

9.1 Comparison of Hazus and FIRM Flood Extents

Figure 9-1 displays the estimated flood extents for 100-, 500- and 1,000-year events as produced by Hazus. Note that there are only subtle differences in these inundation areas.

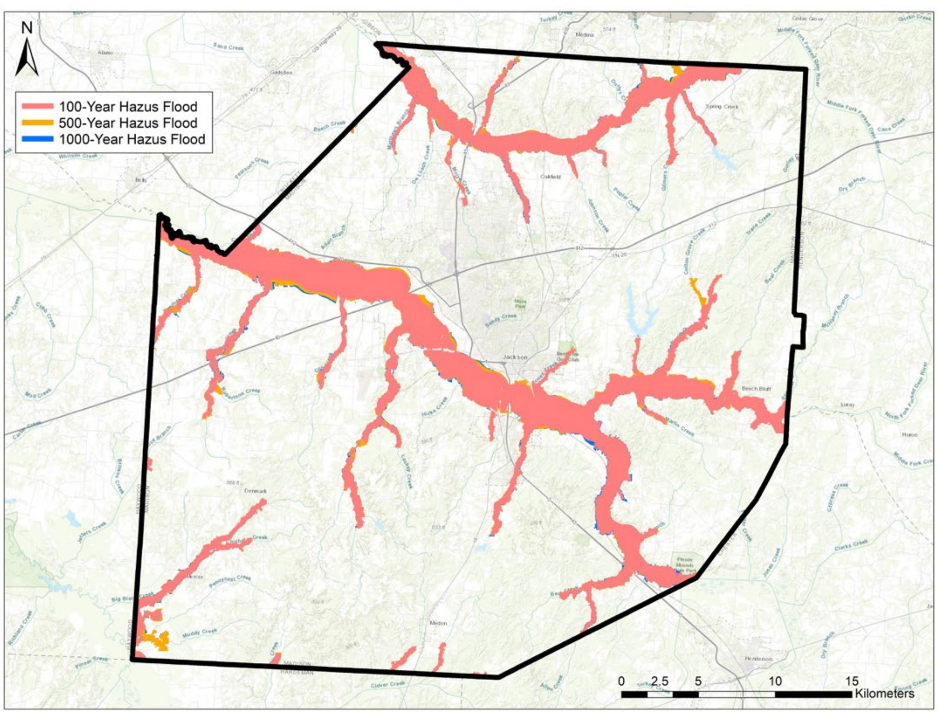


Figure 9-1. Comparison of 100-, 500-, and 1,000-year Hazus flood extents (Madison)

Figure 9-2 displays the 100- and 500-year FIRM flood extents. These maps also have relatively similar boundaries, with the 500-year FIRM containing only 2.9% more area than the 100-year FIRM.

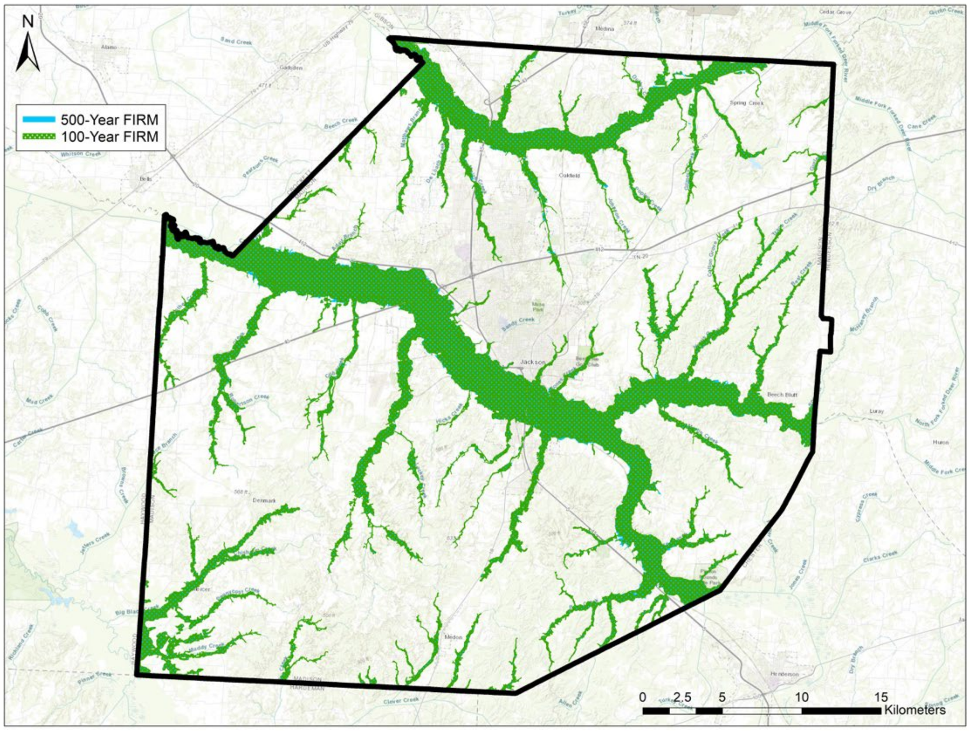


Figure 9-2. Comparison of 100-year and 500-year FIRM flood boundaries (Madison)

The small discrepancies across the three Hazus flood extents, and between the 100- and 500-year FIRMs (which are generated using detailed local surveys, engineering analysis, and robust hydrologic modeling), respectively, suggest there may not be a sizeable difference in inundation area among the event scenarios. This could be due to the elevation of the region being such that increasing the amount of precipitation results in a flood with greater depth but not necessarily a larger area. This is also likely a function of the small increase in precipitation difference between a 100-year and 500-year recurrence interval on Intensity-Duration-Frequency (IDF) curves[14].

Unlike the comparisons shown in Figures 9-1 and 9-2, there are more significant discrepancies, as seen in Figure 9-3, when the flood extents from the two different sources are compared. The 100-year FIRM covers roughly 2.6 times more area than the 100-year Hazus extent (Figure 9-3a), and the 500-year FIRM covers close to 2.9 times more area than the 500-year Hazus extent (Figure 9-3b). In both the 100- and 500-year comparisons, the majority of the tributaries appear more flooded in the FIRM extents compared to the Hazus flood boundaries.

[14]An IDF curve is a function that relates rainfall intensity with its duration and frequency of occurrence.

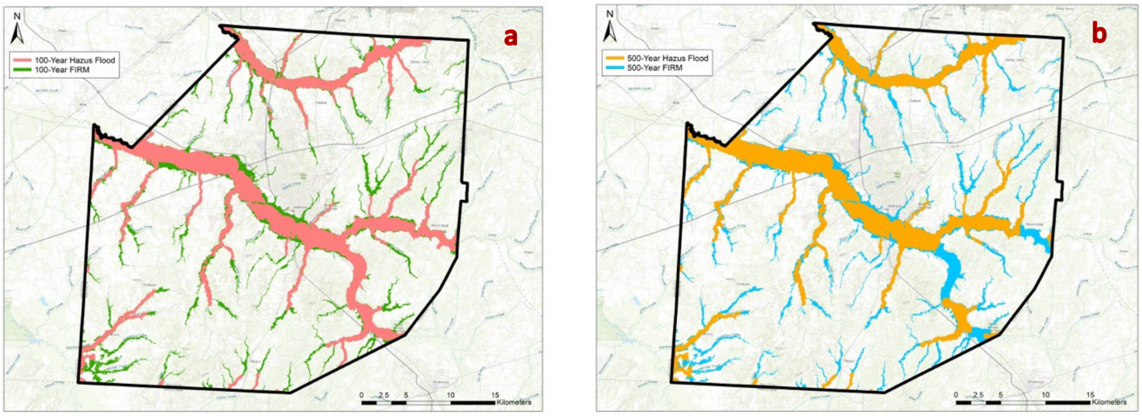


Figure 9-3. Comparison of Hazus and FIRM 100- and 500-year flood maps (Madison)

Since the data sources used for the other counties to evaluate the 2011 historical flood (USGS preliminary map and NASA Landsat 5 images) were unavailable for Madison County, the assumption was made that the results from the other four comparisons would likely be true for Madison – that the 500-year FIRM is the more accurate boundary for an extreme flood event in this area.

9.2 Comparison of Hazus Results and Microsoft Building Footprints

One key benefit to using Hazus is the built-in loss and damage functions for each building class and sub-class (e.g., a residential building with one floor and no basement), which account for the flood depth as it is calculated by Hazus using the DEMs. By contrast, FIRMs do not provide impact assessments. Consequently, even though the 500-year FIRM scenario is more representative of the inundation area, utilizing the Hazus impact assessment is a necessary starting point for performing a 500-year FIRM impact assessment based on FIRM flood extents.

Hazus estimates building damage based on assumptions made at the census block level (i.e., if 25% of a census block is inundated, 25% of the buildings of a certain type are considered damaged). The downside to using census-block level estimations is losing the accuracy of the actual building locations (i.e., it is possible that 25% of a census block could be inundated and no buildings coinciding with the inundation area, or vice-versa). In order to explore this potential bias, Microsoft building footprints were obtained for Madison County and intersected with the flood inundation area.

The results of this process are displayed in Figure 9-4 and Table 9-1. Damaged building estimates from the 500-year flood is shown according to Hazus model output (column A), Microsoft building footprint analysis using Hazus 500-year flood boundary (column B), and Microsoft building footprint analysis using 500-year FIRM flood boundary (column C).

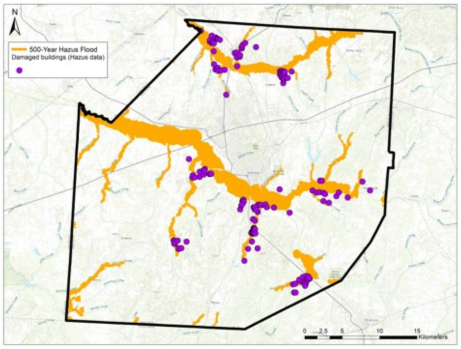
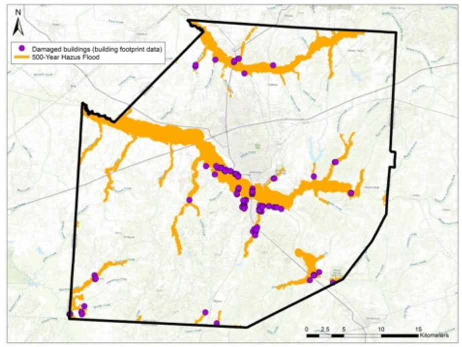
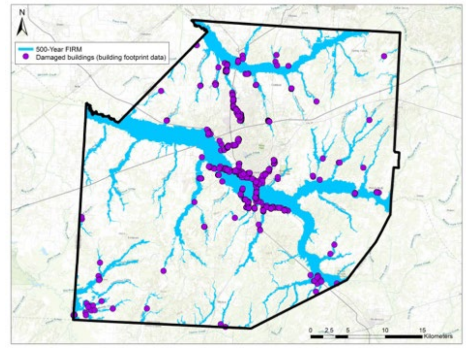
A: Hazus extent (Hazus building data)	*B: Hazus extent (Building footprint data)*	*C: FIRM extent (Building footprint data)*
		

Figure 9-4. Comparative Building Damage Estimates (Madison)

Table 9-1. Affected Building Counts (Madison)

Hazus flood boundaries		**FIRM flood boundaries**
Hazus results (# affected buildings)	Microsoft building footprint analysis results (# affected buildings)	Microsoft building footprint analysis results (# affected buildings)
159	139	620

There are visible differences in the number of affected buildings based on which flood model and building data are being used. Interestingly, unlike the trend seen in the other four counties analyzed in this project (Lake, Dyer, Lauderdale, Tipton), the Microsoft building footprint results for Madison indicate that for the same 500-year Hazus flood boundary, 12.6% less buildings are expected to be damaged compared to the initial Hazus results. Importantly, there is also a difference in location of these damaged buildings when Figure 9-4a and Figure 9-4b are compared; both identify a significant number of damaged buildings in the central portion of the county, however, the Microsoft building results (Figure 9-4b) identify possible damage in the southern and southwestern portions of the county that are not identified in the Hazus results, as well as less buildings damaged in the southeastern and northern portions of the county.

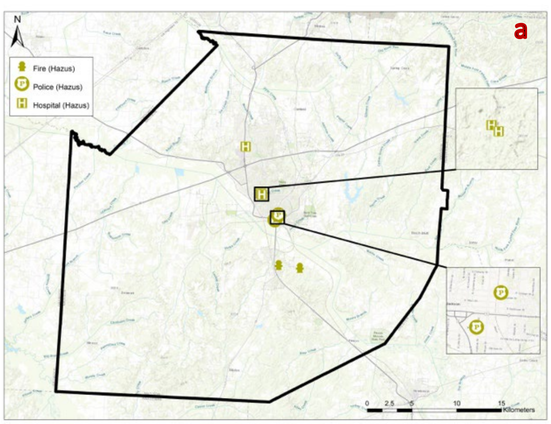
Additionally, there is a dramatic difference in damage expected when the 500-year FIRM boundary is taken into consideration. Due to their flood extent differences, as expected, the FIRM boundaries (Figure 9-4, column C) encompass significantly more buildings than do the Hazus flood extents. As shown in Table 9-1, the 500-year FIRM flood extent with the Microsoft building footprint analysis produces roughly 4.5 times more damaged buildings than the 500-year Hazus extent with the Microsoft building footprint analysis (Figure 9-4, column B), and approximately 3.9 times more damaged buildings than the 500-year Hazus extent with Hazus' damaged building estimates (Figure 9-4, column A).

One caveat to consider when interpreting the Microsoft building footprint analysis is that the footprints were initially created using Microsoft's artificial intelligence methodology. As mentioned previously, it is not possible to identify a building's function from the footprint, and as a result it is not possible to assess the damage a specific building would sustain if flooded. Despite an attempt to exclude less critical buildings from the Microsoft footprints (only buildings with areas greater than the average size of a single-wide mobile home were included), there may still be many buildings that this threshold does not eliminate which could result in less serious damages (e.g., garages, sheds, or barns that do not house valuable assets). It is likely, however, that excluding dozens of additional building footprints from the figures shown in Figure 9-4, column C would still result in several times more impacted buildings identified than estimated from Hazus' calculations.

These findings suggest that in addition to potentially underestimating the flood extent, Hazus may also be incorrectly estimating the number and location of damaged buildings within a given boundary. This could have significant implications for hazard mitigation planning. If counties are preparing hazard mitigation plans based primarily from Hazus results, not only would resources potentially be incorrectly allocated geographically, but there would likely be significantly more damage than estimated and thus more aid required. For this reason, supplementing Hazus results with the Microsoft building footprint analysis is highly recommended.

9.3. Hazus and HIFLD Essential Facilities Comparison

One key aspect of flood hazard resilience is the ability of emergency responders to reach affected populations, and for affected populations to seek help. In order to assess these considerations, it is important to use the most inclusive set of essential facility data available. In the following discussion, the Hazus essential facility dataset is compared with similar information contained in the HIFLD data.



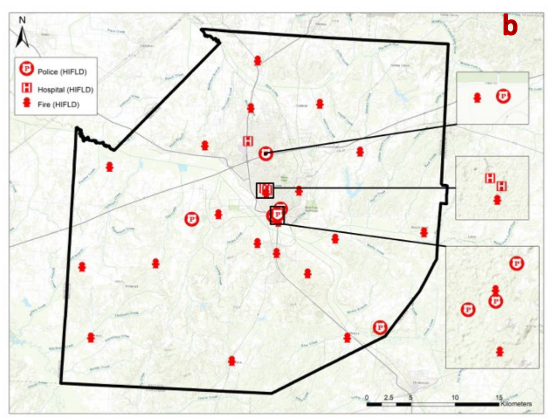


Figure 9-5. Comparison of Hazus and HIFLD essential facility data (Madison)

The two maps in Figure 9-5 show Hazus and HIFLD essential facilities, respectively. Both data sources recognize the same three hospitals within the county. However, there are several differences in both the police and fire station datasets. The Hazus data displays two police stations, whereas the HIFLD data identifies six. More surprising is the difference in fire stations; the Hazus data identifies only two fire stations whereas the HIFLD data shows twenty-two, dispersed around the county such that response capability is substantially improved. As a result, it is recommended that the HIFLD dataset be used in analyzing resilience indicators associated with essential facilities.

9.4. Economic Impact

Though many limitations to Hazus have been raised, a beneficial output the software produces are flood depth grids, unlike FIRMs which are boundary polygons without associated depth measurements. These depth grids are subsequently used to estimate loss and damage based on the inundation depth of impacted structures. As this evaluation would be extremely tedious to conduct manually, Hazus provides the means by which base level damage and losses can be estimated, from which extrapolations could be possible to account for Hazus underestimates of the flood boundary and affected infrastructure.

Tables 9-2 through 9-4 provide conservative estimates of the loss and damage that may be expected in Madison County for a flood event matching the Hazus 500-year flood boundary: 1) roughly $155 million in direct economic losses for buildings, 2) over $2 billion in direct economic losses for agriculture, and 3) around $20 million in direct economic losses for vehicles. Hazus also includes a methodology to estimate displaced people and those needing shelter, as shown in Table 9-5 for the 500-year Hazus flood extent.

Table 9-2. Hazus estimated direct economic building loss for a 500-year flood (Madison)

Direct Economic Losses for Buildings (thousands of US dollars)								
Capital Stock Losses				Income Losses				
Building Loss	Contents Loss	Inventory Loss	Building Loss Ratio %	Relocation Loss	Capital Related Loss	Wage Losses	Rental Income Loss	**Total Loss**
$36,541	$51,586	$4,146	3.6	$14,346	$15,182	$26,012	$6,751	**$154,564**

Table 9-3. Hazus estimated direct economic agricultural loss for a 500-year flood (Madison)

Direct Economic Loss for Agriculture Products (thousands of dollars)					
Crop	Crop Loss Day 0	Crop Loss Day 3	Crop Loss Day 7	Crop Loss Day 14	Max Total Loss
CORN	$0	$1,079,728	$1,439,637	$1,439,637	$1,439,637
SOYBEANS	$0	$57,619	$76,825	$76,825	$76,825
WHEAT	$0	$491,291	$655,055	$655,055	$655,055
Total	$0	$1,628,638	$2,171,517	$2,171,517	**$2,171,517**

Table 9-4. Hazus estimated direct economic vehicle loss for a 500-year flood (Madison)

Direct Economic Losses for Vehicles (dollars)			
Car	Light Truck	Heavy Truck	Total Loss
$11,735,019	$6,266,009	$2,017,985	**$20,019,013**

Table 9-5. Hazus displaced population & short-term shelter need estimates for a 500-year flood (Madison)

# of Displaced People	# of People Needing Short-Term Shelter
1599	28

As noted earlier, Hazus likely underestimates the flood extent and number of damaged buildings for a 500-year flood in Madison County. As such, these loss and damage results should be considered modest estimates, with the expectation that a flood with an extent similar to the 500-year FIRM boundary would have a more significant economic impact. Further research is recommended to develop a methodology in which these damage and loss estimates could potentially be scaled using some factor, for example based on the difference between the number of damaged buildings calculated by Hazus for a 500-year flood and the number of buildings calculated through the Microsoft building footprint analysis for the 500-year FIRM.

9.5. Social Vulnerability Analysis

Figure 9-6 displays four maps, each depicting an indicator at the census block level of social vulnerability in Madison County relative to a 500-year FIRM flood extent: a) total population, b) households earning less than $40,000 per year, c) population over age 65, and d) population under age 16. The locations of essential facilities also appear on each map. Figure 9-7 displays the location of mobile home parks in relation to a 500-year FIRM.

All of the respective indicators reveal similar pockets of potentially vulnerable populations in flood inundated areas, most notably situated around the central northern portions of the county where the City of Jackson is located. Another concern is that flooding occurring in in the center of the county may impact the ability for residents in the southeastern portion to reach one of the three hospitals, which are all located to the northwest of the river running through Madison County. Additionally, all of the seven mobile home parks are within two kilometers of the 500-year FIRM boundary and a few are situated on the boundary edge. Examining these potentially vulnerable areas is a critical component of emergency preparedness, as it allows for advance planning regarding how to best access and provide aid to the most at-risk county residents.

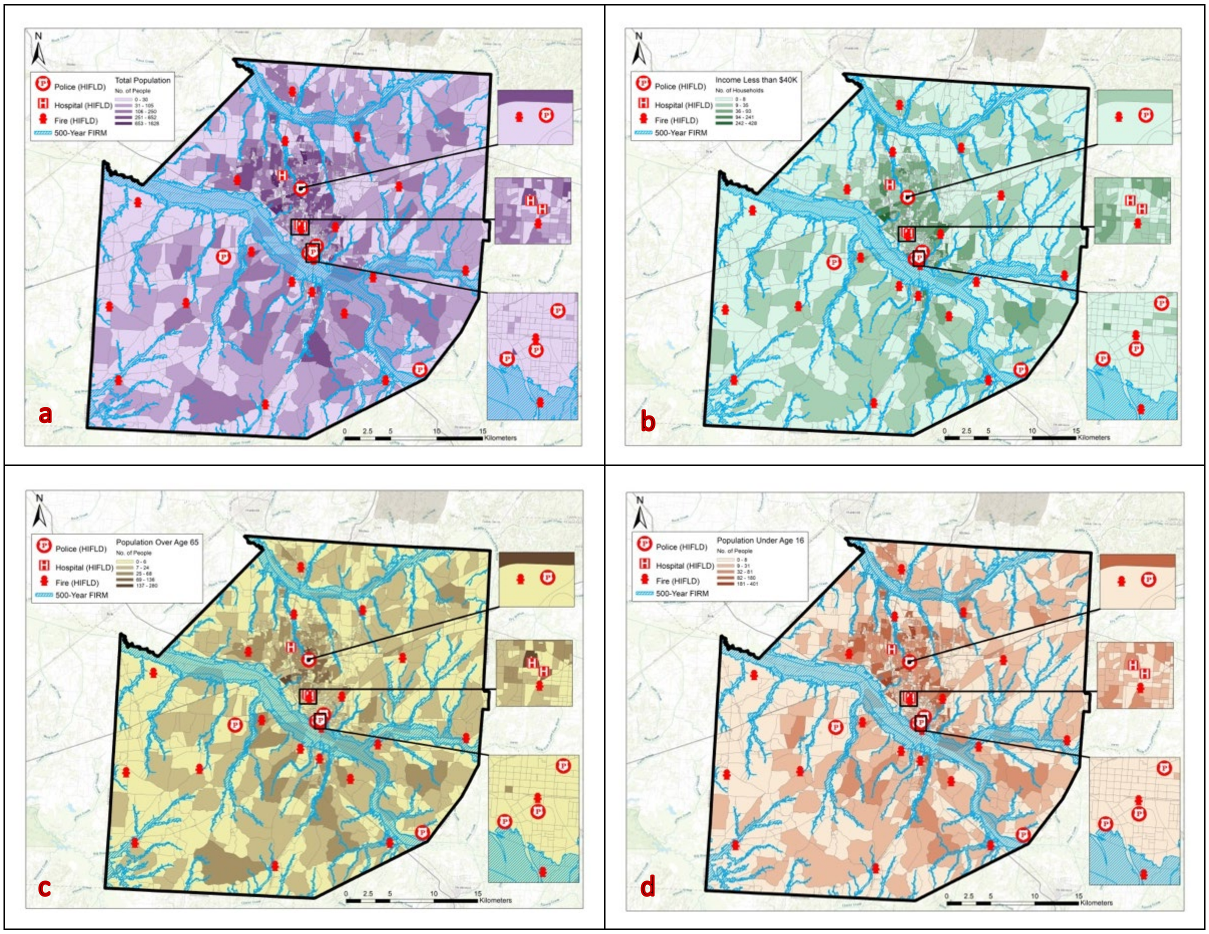


Figure 9-6. Social vulnerability - 500-year FIRM flood extent and HIFLD essential facilities (Madison)

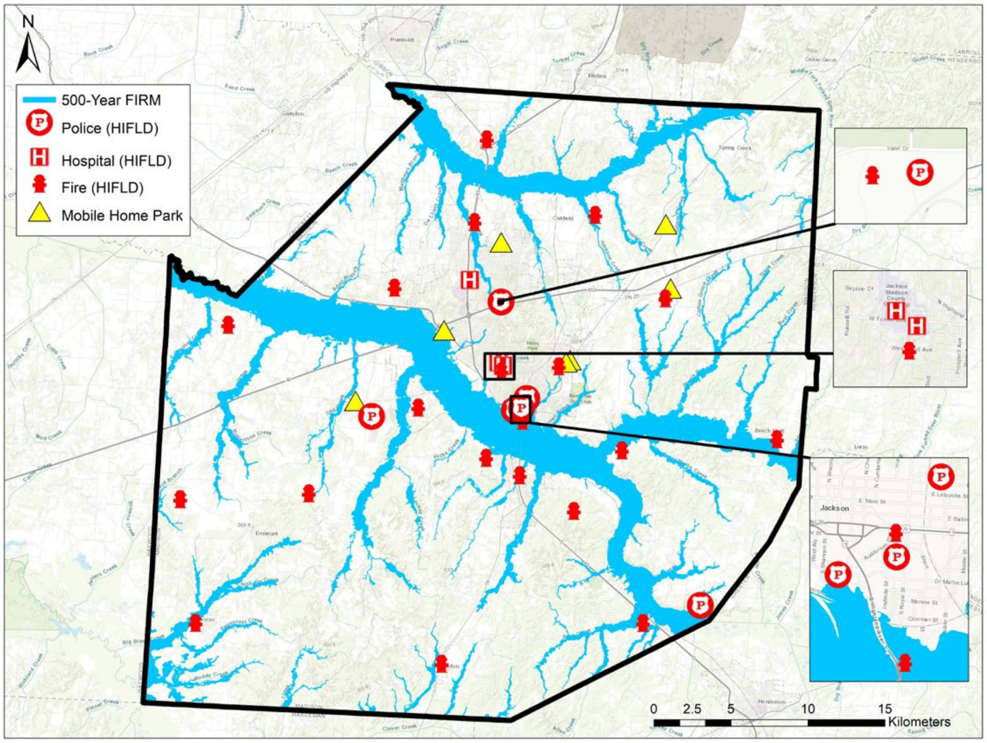


Figure 9-7. 500-year FIRM flood extent and mobile home park locations (Madison)

9.6. Transportation Mobility Analysis

Figure 9-8 shows the 4.4% of the road network that is directly inundated by the 500-year FIRM flood extent. This is supported by the results displayed in Table 9-6, which shows the length and percent affected for various road types in the county. Such disruption to the transportation system could impact local travel, and possibly regional travel as well, affecting personal mobility and causing supply chain interruptions. This also underscores the aforementioned concerns regarding access to emergency response and evacuation routes.

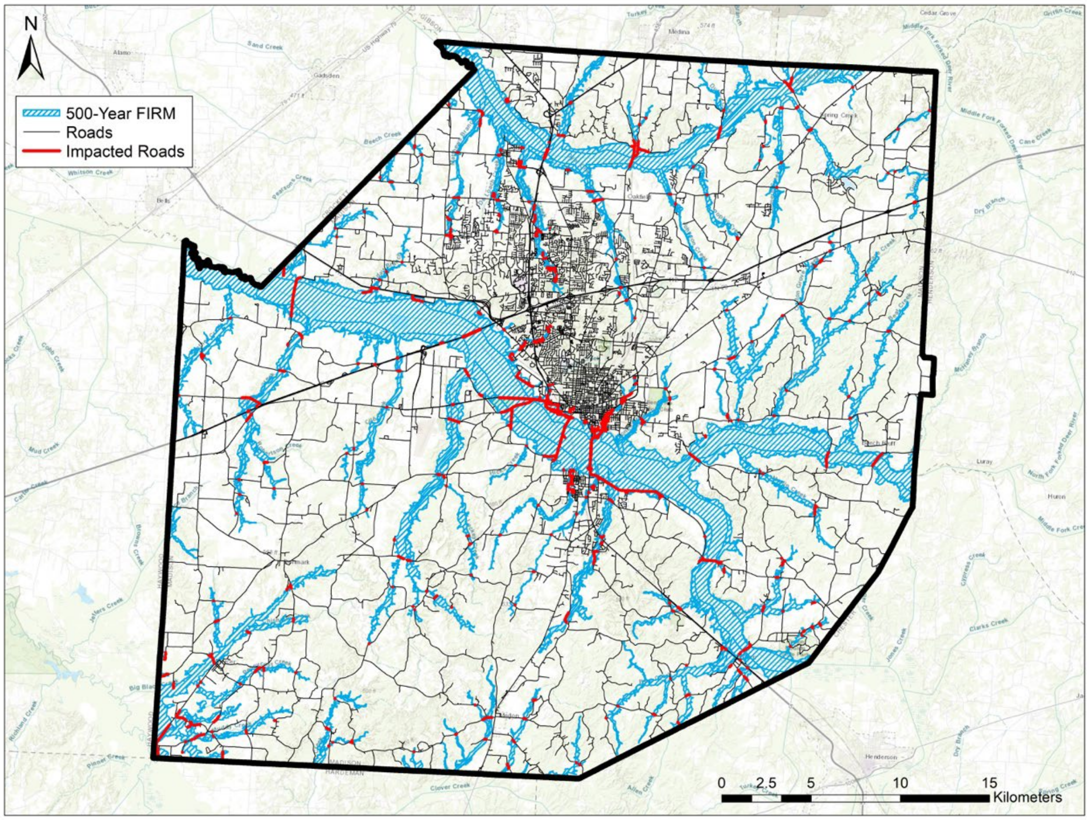


Figure 9-8. Road network affected by a 500-year FIRM extent flood (Madison)

Table 9-6. Inundation by road type for 500-year FIRM flood (Madison)

Road Type	Length (miles)	% Affected
Interstate	1.7	3%
Common Name	49.5	4%
State Recognized	17.6	7%
U.S.	11.9	7%
Not Categorized	9.0	4%

Another perspective in assessing the impact of a 500-year FIRM on the transportation system is the extent to which the service area of the county is affected. Recall that this is defined as the area that can be reached within 16.1 km (10 miles) of an essential facility. As shown in Figure 9-9, when compared with the initial baseline service area (Figure 9-9a), the 500-year FIRM event results in a service area reduction of roughly 34% less (Figure 9-9b). Additionally, note that multiple essential facilities are located either within or in close proximity to the inundated area, diminishing their ability to provide assistance and potentially requiring help themselves. This has serious implications in terms of human health and safety.

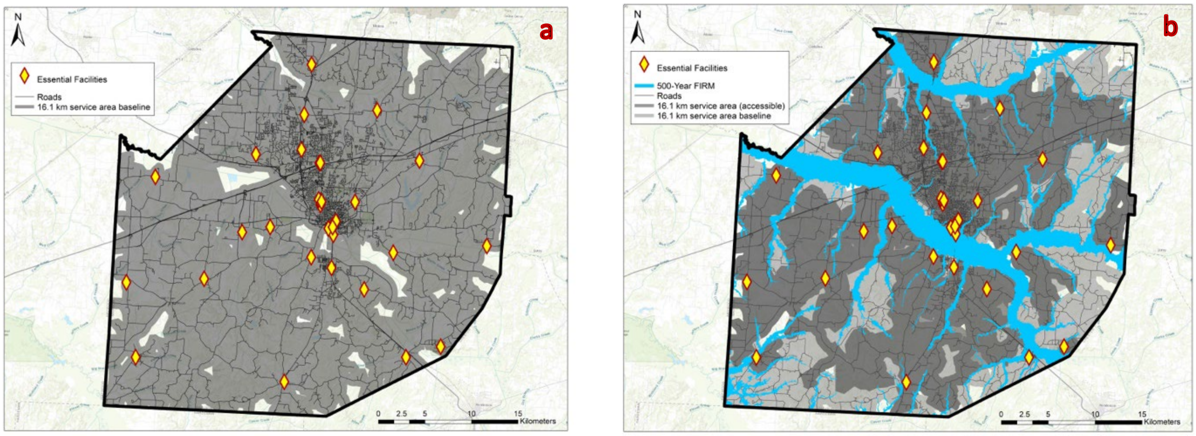


Figure 9-9. Baseline and 500-year FIRM service area analysis results (Madison)

10. CONCLUSION

For each of the five counties, areas were identified where more vulnerable populations may be impacted by flooding. These locations should be the focus of future flood management planning, as well as communication with residents and business about heightened flood risk. Creating this informed dialogue within the community before the next major flood is vital to ensuring that people are aware of such risks and know the best protocols to follow in case of an emergency.

This study also demonstrated the potential for flooding to cause immense disruption of the transportation network for all of the counties, impacting personal mobility, supply chain continuity, and emergency response. Within this context, special emphasis was placed on the mobility needs of at-risk populations (e.g., impoverished, young and elderly age groups). This additional consideration can enable communities to facilitate policy changes and activities to build resilience in the most vulnerable areas of their jurisdictions.

Important methodological considerations were discovered involving the use of Hazus for planning responses to flood events. It was observed that: 1) Hazus likely underestimates the flood extent boundaries for study regions along major rivers such as the Mississippi, and the 500-year FIRM (or 100-year FIRM if the 500-year FIRM is unavailable) is a more realistic boundary to use in preparing for a significant flood event, 2) Hazus may be incorrectly predicting the number and location of damaged buildings, and 3) Hazus essential facility inventory data underrepresents the accessibility and response capabilities of essential facilities for all five of the counties.

These methodological findings have important implications given that Hazus is the nationally recommended tool for flood mitigation planning at the county level. If these western

Tennessee counties were to base their flood emergency response plans on the initial Hazus results (flood extents, damaged buildings, essential facility locations, and resulting loss and damage), they could be woefully underprepared for future flood events of significant magnitude.

There are several ways these concerns could be addressed. The methodology described in this study provides a starting point (i.e., comparing Hazus results with other sources to determine flood extent, affected buildings, and essential facilities; augmenting the assessment with social vulnerability and transportation mobility analyses to understand ability to evacuate or be reached by emergency responders). Nonetheless, the Hazus damage and loss results are helpful in providing an initial perspective on the implications of a flood of the magnitude predicted by a Hazus flood extent and could potentially be scaled to provide a more realistic estimate of the consequential impacts.

There is also a need for further research, including improved tools and data availability. The creation of flood depth grids based on FIRM boundaries that could be used in Hazus would enable more accurate damage and loss estimates. Alternatively, the Hazus software hydrologic models could be improved to account for precipitation that does not occur within the study region, such that flooding in communities bordering large river systems with extensive watersheds can be more realistically portrayed, without compromising the intricacy of the stream network or requiring extensive computing power. Additionally, it is difficult to update the general building stock data within Hazus, as any modifications require detailed information (for example the number of stories and type of basement for each building). Since collecting such data for every building may not be feasible, Hazus damage loss curves could benefit from having more generalized settings which would allow the user to estimate loss and damage on more current building data.

Finally, this work was intended to create a methodology that can be replicated by other counties and regions who wish to evaluate their flood resilience and improve decisions regarding future flood management. Of the data and software described in the methodology, the only element that is not open source was ArcGIS 10.5.1, which requires a license to operate (Esri, 2017). Though the methodology was developed to be conducted in ArcGIS, much of it can be adapted to be performed in QGIS – an open source alternative.

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