DEVELOPMENT OF DECISION-SUPPORT TOOLS FOR TRANSPORTATION INFRASTRUCTURE ADAPTATION IN RESPONSE TO CLIMATE-INDUCED FLOOD RISK

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Dissertation Research

Overview

- Climate Change
- Precipitation and Flooding
- Infrastructure and Transportation
- Making the Right Choice
- Review and Selection of Flood Damage Assessment Tools
- HAZUS-MH
- Research to Date
- The HAZUS-MH Flood Model
- Current Research Target
- Additional Research Need

Climate Change: A Problem of Growing Concern

- Intergovernmental Panel on Climate Change modeled several emission scenarios:
  - A1 – Work population peaks mid-century then declines; rapid introduction of more efficient technologies
    - A1F – Sub-scenario with energy from fossil fuels
    - A1T – Sub-scenario with energy from non-fossil sources
    - A1B – Sub-scenario with blend of fossil/non-fossil energy
  - A2 – Increasing population growth; slower economic and technological change
  - B1 – Similar to A1 but shift to less resource-dependent information and service economy
  - B2 – Focuses on local solutions to economic, social and environmental issues

Precipitation and Flooding

- Between 1975 and 1994, flooding accounted for the most deaths, damage to property, and damage to agriculture when compared to other natural disasters (Mileti 1999)
- IPCC notes:

  "…the most vulnerable industries, settlements, and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources, and those in areas prone to extreme weather events, especially where rapid urbanization is occurring."

Infrastructure in America

- 2009 American Society of Civil Engineers gave an overall grade of "D" to US infrastructure
- ASCE recommends an investment of $2.2 trillion between 2009 and 2014 to bring to passing grade
- Report did not address any additional stressors associated with climate change except on levees
- Hunt and Watkiss (2011) found that most activity focuses on minimizing infrastructure contribution to GHG emissions and not on its vulnerability to climate-changed induced events
- Transportation systems are of particular interest since:
  - They are mobility and lifeline of a community
  - Impacts are broad and varied
  - Most transportation infrastructure is at end of its design life
  - Impacts can be very disruptive and result in increased wear and tear to system, inability to respond to emergencies, delays in goods/service delivery

Making the Right Choices

- What we know
  - Climate change is occurring
  - Already ailing transportation infrastructure is vulnerable
  - Impacts are both direct and indirect
  - Impacts and adaptation strategies must be evaluated
- Adaptation planning must occur in conjunction with competing priorities and with varied stakeholders
- A tool to assess climate change impacts on transportation infrastructure and evaluate the cost-effectiveness of candidate adaptation strategies is needed

Review and Selection of Flood Damage Assessment Models

- Eleven models for flooding were identified for review
- Predominant problem with most of them was lack of damage estimation associated with flood inundation
- Only four models were identified as having native damage assessment capability
  - MIKE Flood
  - waterRIDE
  - HEC-FIA
  - HAZUS-MH

Model Evaluation Based on Selection Criteria

	Large Extent and Resolution	2D Analysis	Native Damage Assessment	Spatial Data Viewing	Cost <$10,000	Average Technical Skills	Readily Available Training	Technical Support	Commonly Available Hardware
FLO-2D	●	●		●	●	●	●	●	●
TUFLOW	●	●			●	●	●	●	●
SMS	●	●		●	●	●	●	●	●
XP-SWMM	●	●		●	●	●	●	●	●
MIKE Flood	●	●	●	●		●	●	●	●
waterRIDE	●	●	●	●		●	●	●	●
ISIS	●	●		●	●	●		●	●
HEC-RAS	●				●	●	●	●	●
HEC-FIA	●	●	●	●	●		●		●
ArcGIS	●	●		●	●	●	●	●	●
HAZUS-MH	●	●	●	●	●	●	●	●	●

HAZUS-MH

- Originally developed by FEMA as an earthquake prediction tool then expanded to flood and hurricane
- Performs two-dimensional estimate of flood
- Native damage estimation using USACE-derived depth-damage curves
- Comes pre-loaded with US Census data on housing, population and economic factors
- Program is free but requires ArcGIS spatial analysis software ($2,500)

HAZUS-MH and the Assessment Criteria

- Extent and Resolution
  - Capable of modeling almost all major metropolitan areas
- Native Damage Assessment
  - Comes pre-loaded with basic information on all census areas of US as well as damage algorithms
- Spatial Viewing, Technical Ability, Cost and Hardware
  - Integrates with ArcGIS
  - Training is available from ESRI online for less than $200 that will allow basic use
  - Runs on commonly available hardware

How HAZUS-MH Works

- HAZUS-MH performs 3 levels of analysis
  - Level 1 – Utilizes pre-loaded data for all information
  - Level 2 – Utilizes some pre-loaded and some user supplied
  - Level 3 – Complete user customization for flood data and inventory

HAZUS-MH in Detail

- Flood loss in HAZUS-MH focuses on 5 elements
  - Inventory data
    - Built environment
  - Flood hazard data
    - Depth/Extent
  - Direct physical damage
    - Depth-Damage relationship to built inventory
  - Induced physical damage
    - Damage from flood disturbing hazardous material, entrained scour material, etc.
  - Economic and social impact
    - Modified input-output model with and without depreciation

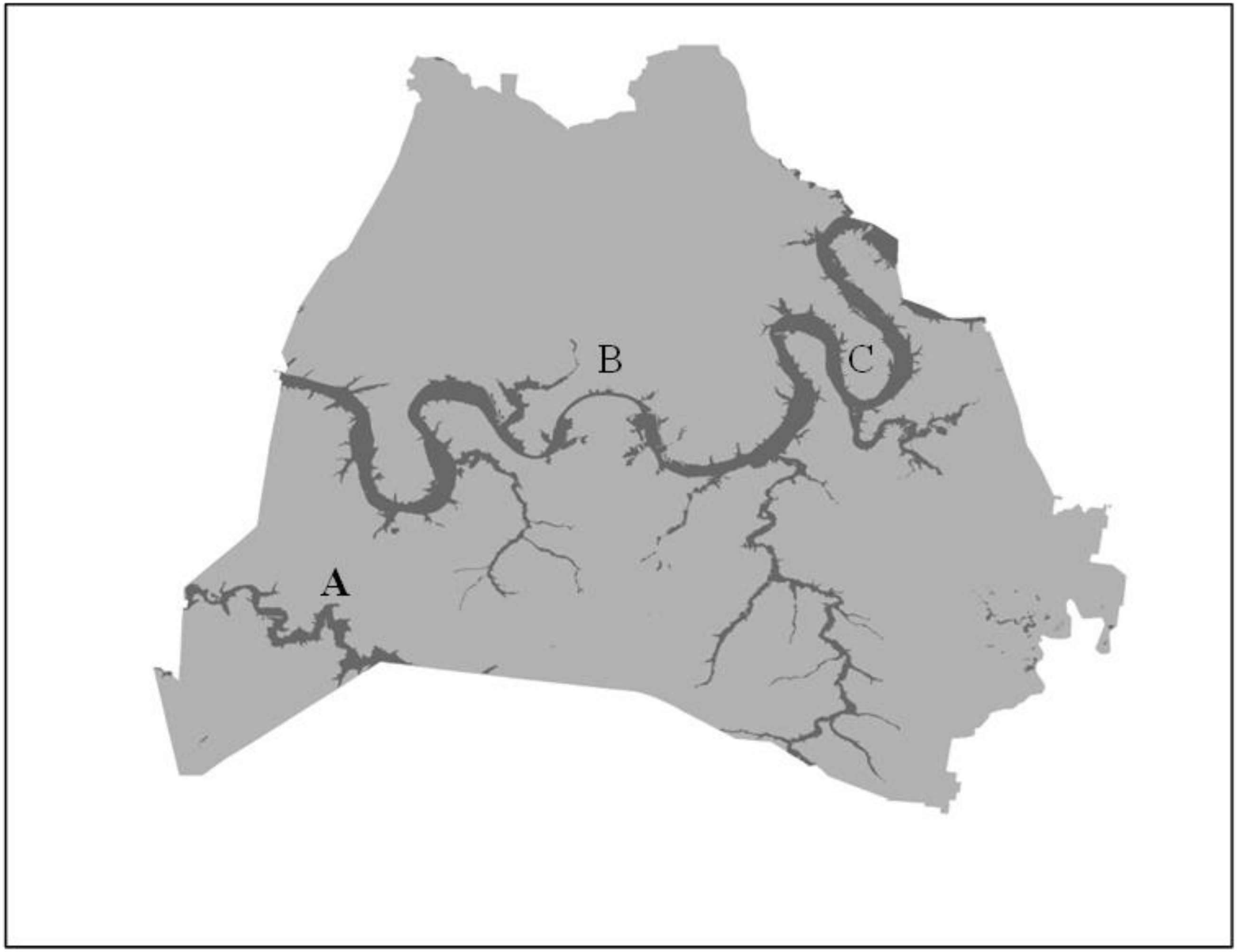
Research to Date

- Compared Hazus models to calibrated flood extent and damage surveys from the 2010 flood that impacted Davidson County, Tennessee (Nashville)
- Results of comparisons of flood models and 2010 data indicate:
  - Hazus can identify areas of impact at county resolution but not at sub-county resolution
  - At sub-county, Hazus fails to predict flood or damage with any certainty
  - Hazus underestimates flood surface areas even when extreme events are modeled

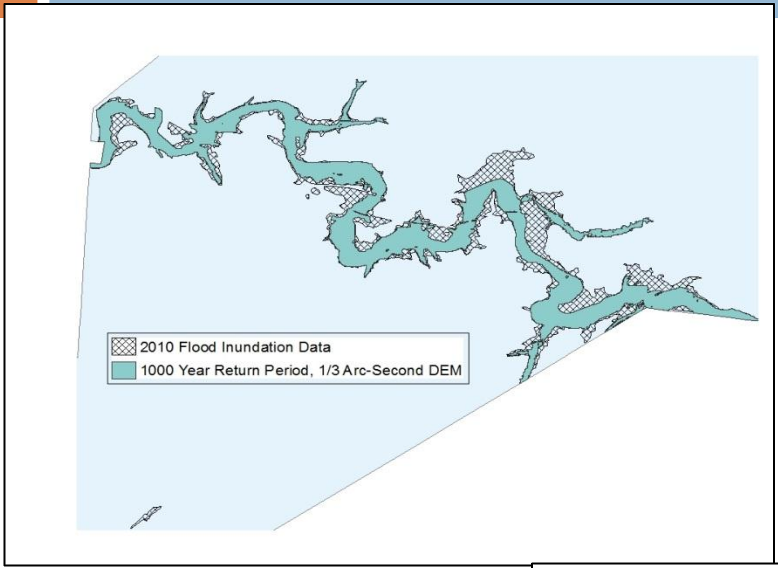
Hazus and USACE Data Compared

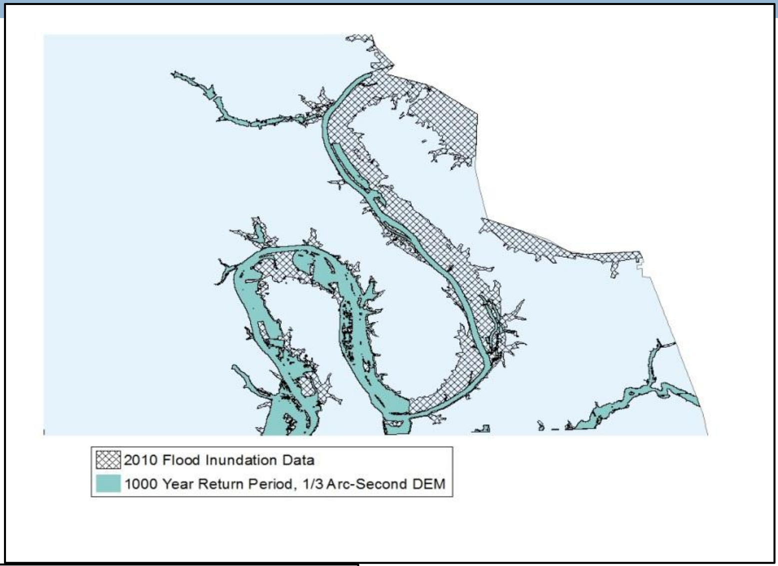
Flood Return Period (Years)	Estimated Flood Surface Area (square miles) 1 Arc-second DEM	As % of Observed Surface Area (46.08 mi^2)	Estimated Flood Surface Area (square miles) 1/3 Arc-second DEM	As % of Observed Surface Area (46.08 mi^2)
100	34.76	75%	33.53	73%
500	37.28	81%	40.16	87%
1000	37.78	81%	40.17	87%

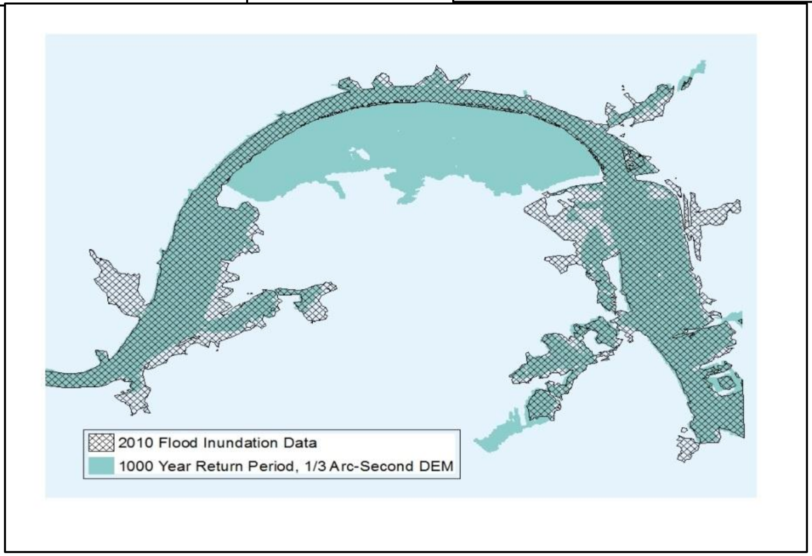
Selected Areas of Comparison



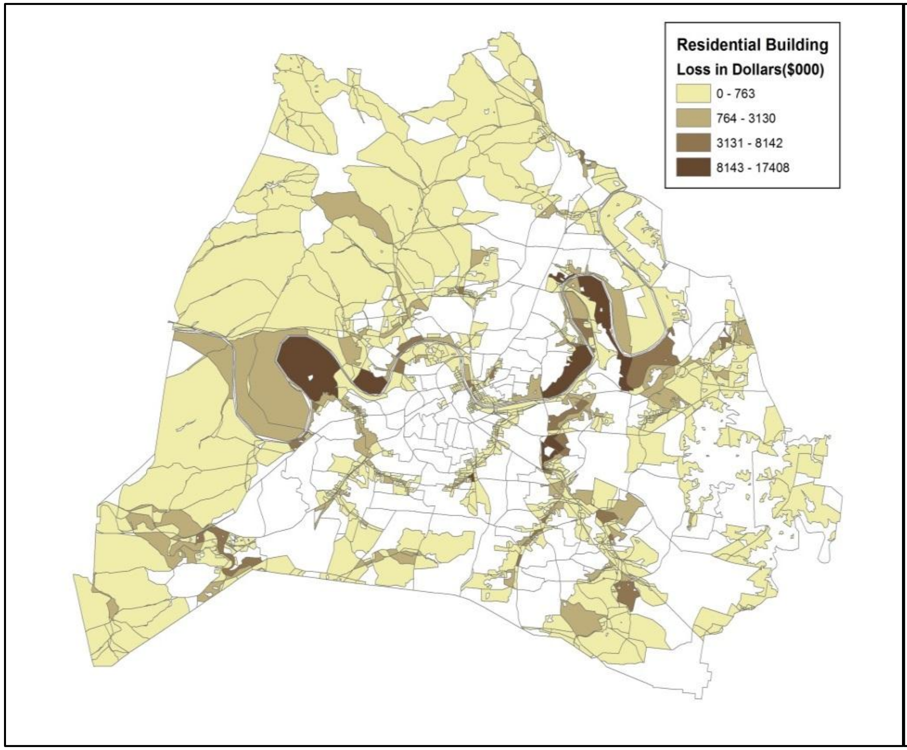
Areas A, B and C



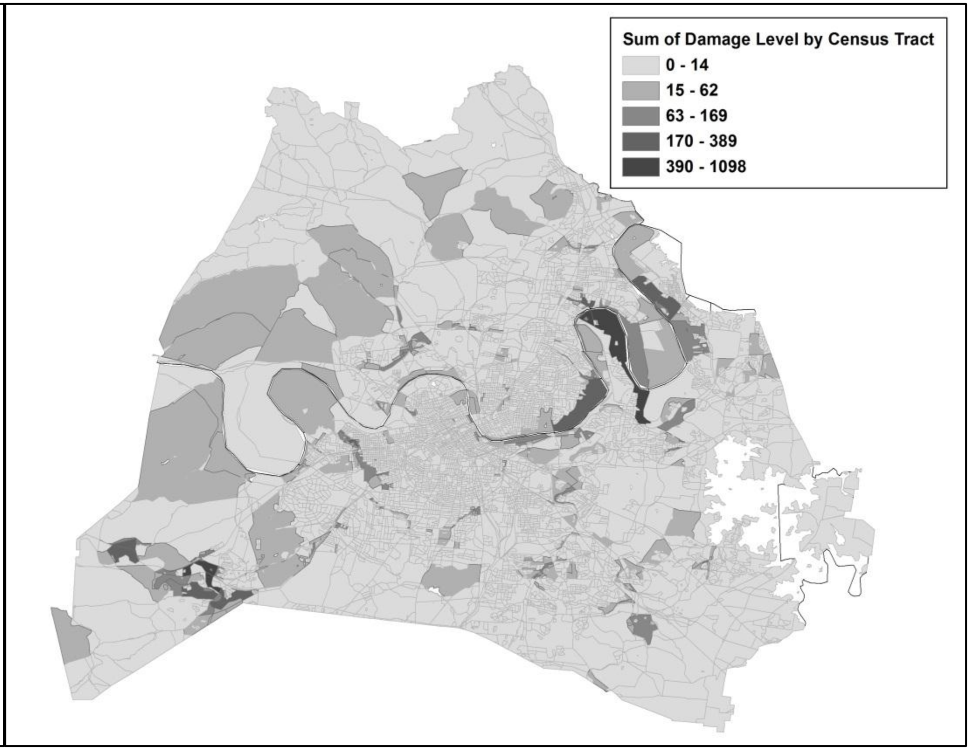




Predicted and Observed Damage



Hazus Predicted Damage



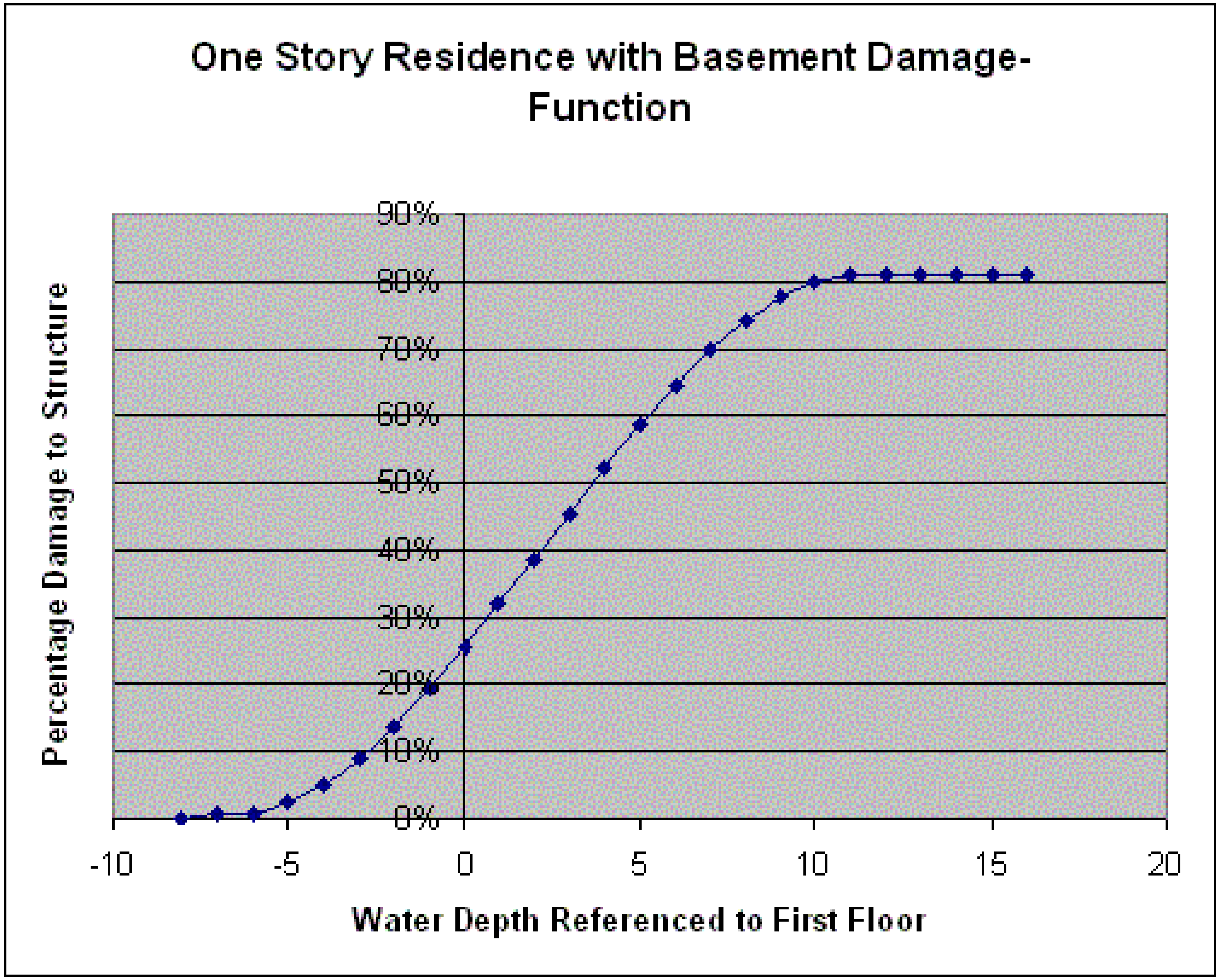
Actual Damage

Pearson's $r = 0.45$
($n=114$, $p=0.005$)

The Hazus Flood Model

- Floods flows are predicted using a log-Pearson Type III regression equation
- These equations are derived for the various states/regions across the US and published by the US Army Corps of Engineers
- These USACE equations are present in Hazus and used to develop stream flows/volumes
- Once flow is predicted, channel topography and a surrounding buffer are used to predict flood extent
- Parameters used to estimate flood damage are depth, elevation and flow velocity, but mostly depth
- Flood model has the ability to be refined using HEC-RAS data

USACE Depth-Damage Curve



Current Research Target: Bridge Scour

- Intent of research is for an easy to use tool for bridge damage assessment
- DOT Hydraulic Engineering Circular 18, "Evaluating Scour at Bridges"
  - Contains equations necessary to calculate scour potential for bridges and their components
- A review of Hazus and the underlying data tables suggest that the data necessary to solve these equations is available through Hazus or the functions available in ArcGIS
- Current phase of research is in developing an interface to identify data in Hazus, link it to a "solver tool" and present results as a portfolio for a given area's bridges

Live Bed Contraction Scour Calculation

$$y_s = y_2 - y_0$$

$$y_2 = y_1\left[\left(\frac{Q_2}{Q_1}\right)^{6/7}\left(\frac{W_1}{W_2}\right)^{k_1}\right]$$

Where:

y_s = average contraction scour depth
y_0 = average existing depth in contracted section
y_1 = average depth upstream
y_2 = average equilibrium depth in contraction after scour
Q_2 = Flow in contraction (estimated using velocity from Manning and cross section of stream)
Q_1 = Flow in upstream (estimated using velocity from Manning and cross section of stream)
W_1 = Bottom width of main channel
W_2 = Bottom width at contraction

k_1 is a constant depending on ration of shear velocity to fall velocity (HEC-18, pg 6.10)

Additional Research Potential

- Although predicted flood surface areas are only 13% less than observed, Hazus models do not coincide with the flood extents seen in the 2010 Davidson County flood event
- Preliminary research into the methodology employed by Hazus suggests that
  - The data used in the regression equations may need to be limited to recent history (e.g., 20 years)
  - The regional regression equations used to develop flow may need to be reassessed to determine if they are still appropriate

DISCUSSION

Publications to Date

- Banks, J., Camp, J., & Abkowitz, M. (2014). Adaptation planning for floods: a review of available tools. *Natural Hazards, 70*(2), 1327-1337.
- Submitted to *Natural Hazards Review*
  - Banks, J., Camp, J., & Abkowitz, M.

    Scale and Resolution Considerations in the Application of HAZUS-MH to Flood Risk Assessments