Appendix A.
Modeling Guidelines

The conceptual model design started with the definition of the desired model functions and features, that is, the general functional and operational requirements. These requirements included:

- **Parsimony.** While all disasters are large complex systems of systems, keeping the initial model as simple as possible was paramount to evaluate the model's various operations and the interactions of the subcomponents and to effectively interpret the results.
- **Limit the data needs.** For many key variables, data are hard to quantify or even obtain.
- **Define appropriate modeling approaches.** The multi-method or hybrid modeling approach offers the benefit of optimizing the model based on integrating various modeling approaches.
- **Model outputs.** Outputs should indicate healthcare system performance.
- **Data visualization.** Complex systems models can be hard to interpret without a method to visualize the resultant model output from a variety of perspectives.

Appendix B.
Supporting Data for Model Development

Data Elements Based on Databases and Data Extraction

The National Oceanic and Atmospheric Administration (NOAA) Storm Events database (https://www.ncdc.noaa.gov/stormevents/) characterizes events by mortality, injury, property damage, and crop damage. This data informed the model of the expected values for a given event. It was also used to determine whether our selected communities had experienced events previously and may be better equipped to respond to an emergency. We included only flood or flash flood events.

A study from McGuire and Silvia (2010) produced a regression analysis to predict intergovernmental collaboration in uncertain environments such as a natural hazard, using evidence from local emergency management individuals. We used the coefficients from their regression results to inform our simulation model, specifically the expected change in disaster response based on intergovernmental agencies' ability to effectively collaborate in a disaster event. The study was based on past experiences, training, and certifications, whether an agency was stand-alone, nongovernmental collaboration, distance to the state capital, Social Vulnerability Index, and the percentage of the population that was urban.

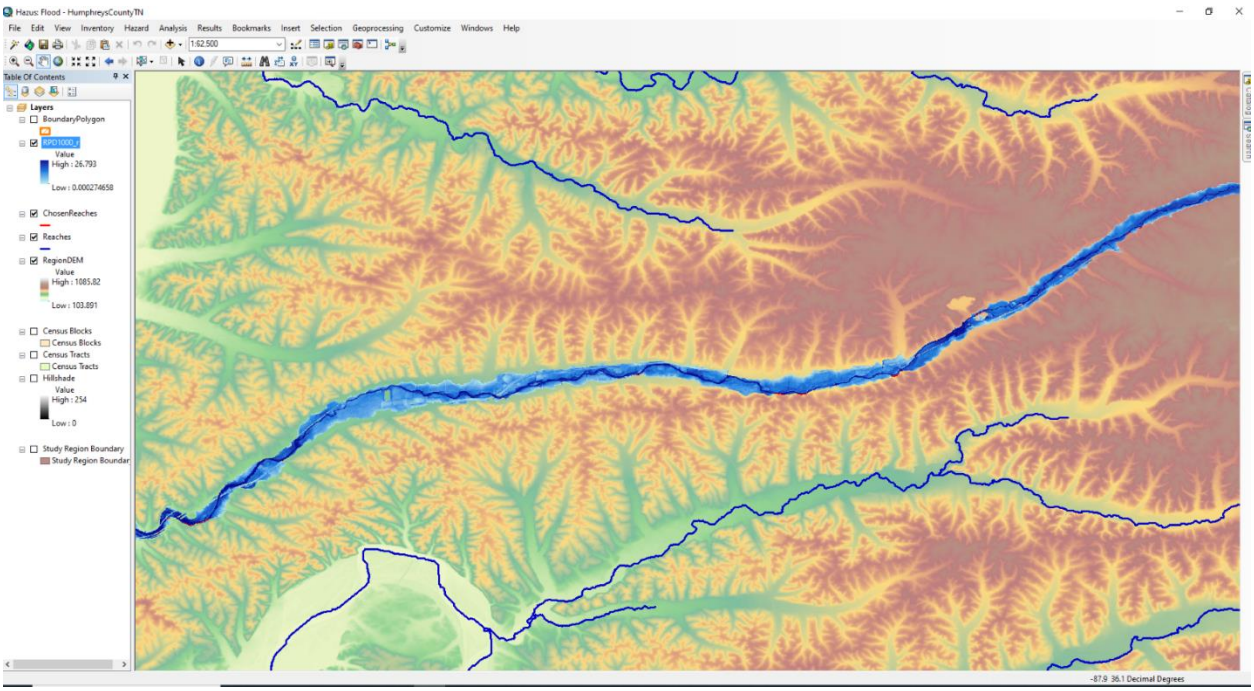
Data Elements Based on Literature References

The International Labour Organization (2022) suggests that an effective early warning system can reduce loss of life and damage by 30%. The model determines the readiness level of response based on the advance warning of the given event. In a study of institutional trust in emergency management, Krogh and Lo (2023) suggest that trust between responders is a vital component in robust emergency management that swiftly adapts multi-actor response to changing conditions during crises. It corresponds with the observation that robust governance systems are inherently trust-based since mutual trust eases communication, facilitates collaboration, and enhances the collective capacity to adjust the course of action in response to new, unexpected developments (Ansell et al., 2023).

Geographic Information Systems Data

We generate and use a flood depth grid that identifies depths of riverine flooding, provided by the Federal Emergency Management Association's (FEMA) Hazus Flood Model (https://www.fema.gov/flood-maps/products-tools/hazus). The Waverly, TN, example is provided in Figure B1, which runs within ESRI's ArcGIS Desktop platform (i.e., ArcGIS 10.8.2; https://www.esri.com/en-us/arcgis/products/arcgis-desktop/resources). We adopted the Hazus Flood Loss Estimation Methodology developed by FEMA (https://www.fema.gov/sites/default/files/2020-09/fema_hazus_flood-model_technical-manual_2.1.pdf)—which enables users to anticipate the consequences of floods and develop plans and strategies for reducing risk.

Figure B1. Hazus Simulated 1,000-Year Flood in Waverly, TN

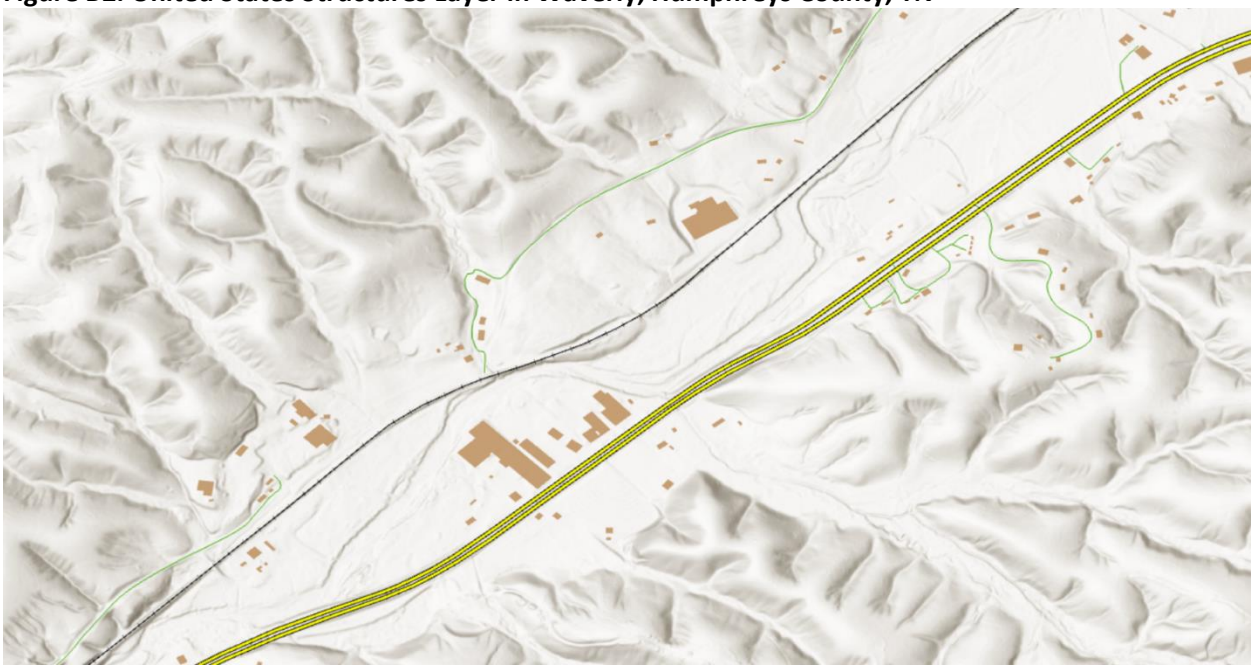


Note. Inundated areas of the August 21, 2021, Waverly, Tennessee flood. Source: Hazus (https://www.fema.gov/flood-maps/products-tools/hazus). Image from Liem Tran.

We used the following additional data sources for flood loss estimation:

- State-level Disasters Public Files, available at https://disasters-geoplatform.hub.arcgis.com/ for Tennessee and Nebraska;
- U.S.A. structure data—a GIS feature layer, utilizing FEMA data to display footprints for all structures (buildings) greater than 450 square feet in the United States and its territories, available at https://gis-fema.hub.arcgis.com/pages/usa-structures. The Waverly, TN, example is provided in Figure B2;

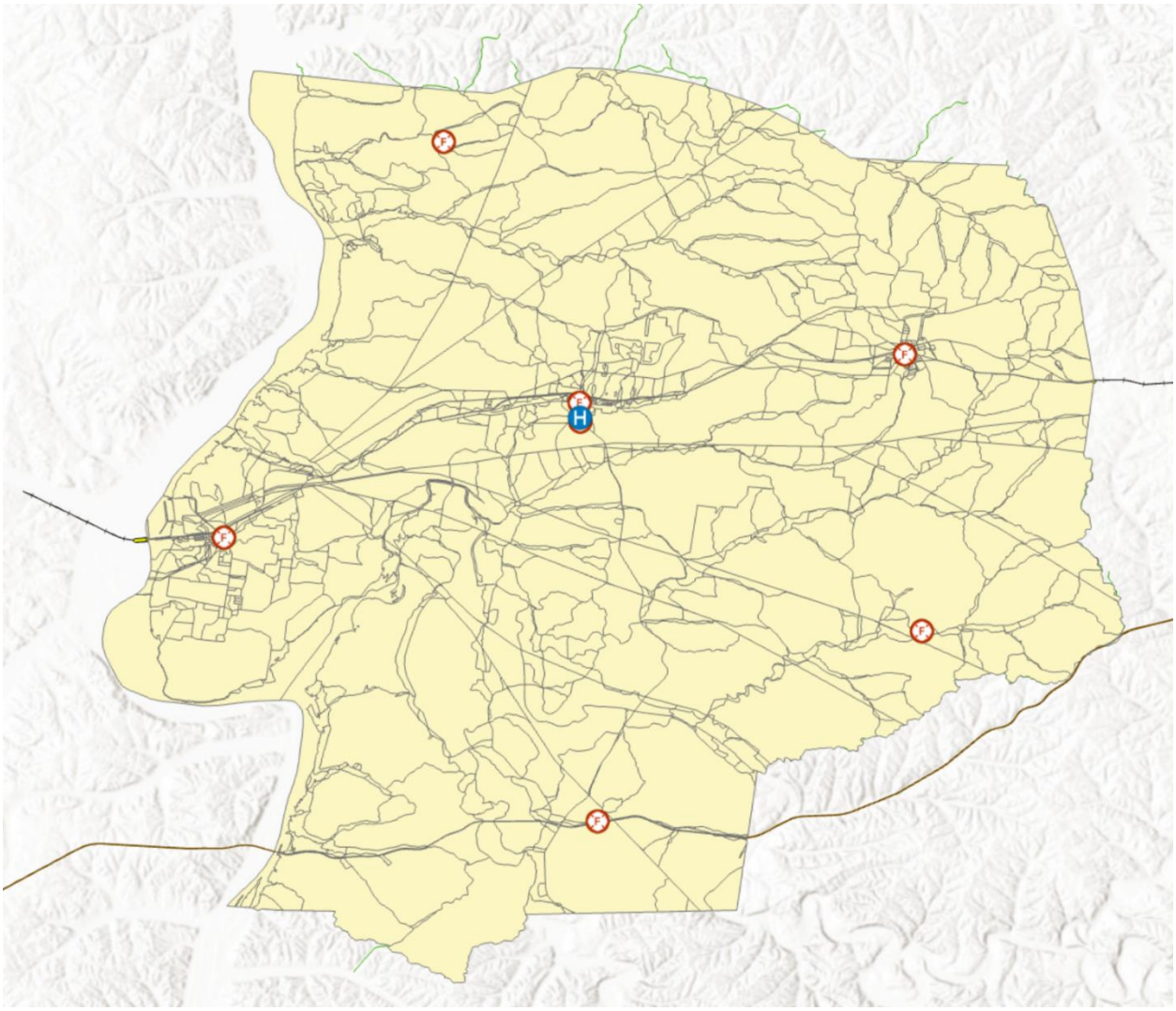
Figure B2. United States Structures Layer in Waverly, Humphreys County, TN



*Source: ArcGIS U.S.A. Structures Data (*https://gis-fema.hub.arcgis.com/pages/usa-structures*). Image from Liem Tran.*

- Medical emergency response structures—a GIS feature layer utilizing National Geospatial Data Asset (NGDA) data from the U.S. Geological Survey (https://hub.arcgis.com/maps/2c36dbb008844081b017da6fd3d0d28b/about), displays hospital medical centers, ambulance services, Fire Stations, and EMS Stations in the United States. The Waverly, TN, example is provided in Figure B3;

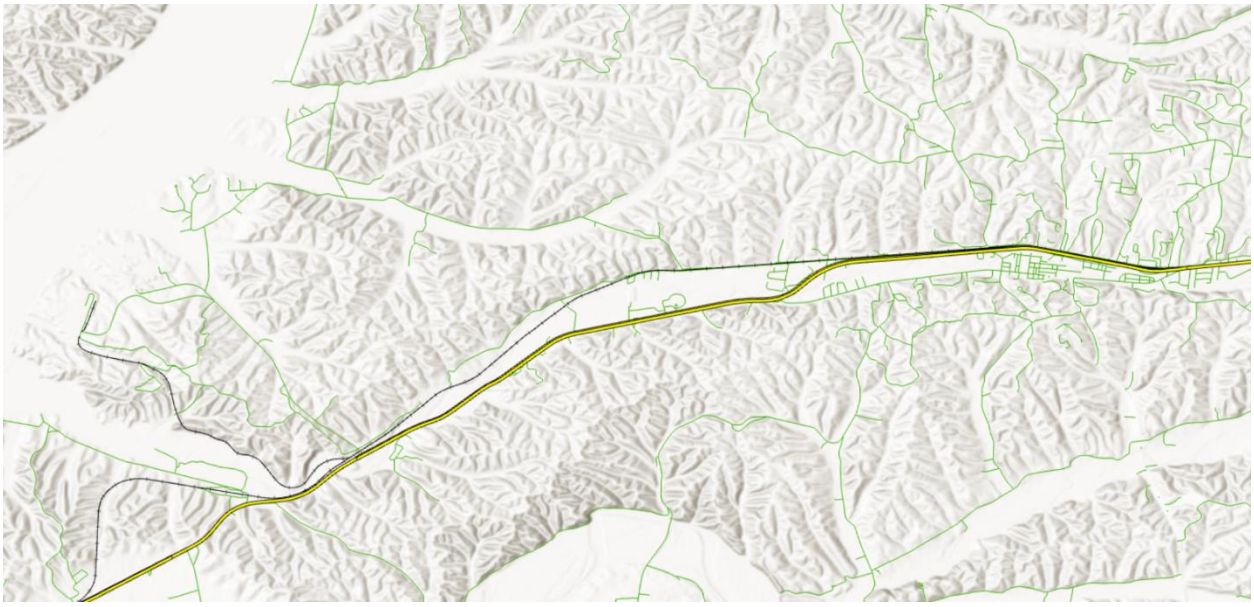
Figure B3. Medical Emergency Response Structures Layer in Waverly, Humphreys County, TN



Source: U.S. Geological Survey Emergency Response Structures (https://hub.arcgis.com/maps/2c36dbb008844081b017da6fd3d0d28b/about). Image from Liem Tran.

- Transportation data—a GIS feature layer, utilizing NGDA data from the U.S. Census Bureau (https://ngda-transportation-dev-geoplatform.hub.arcgis.com/), which displays primary roads, secondary roads, local roads, and railroads in the United States. These include all primary, secondary, local neighborhood, and rural roads, city streets, vehicular trails, ramps, service drives, alleys, parking lot roads, private roads for service vehicles (logging, oil fields, ranches, etc.), bike paths or trails, bridle/horse paths, and walkways/pedestrian trails. The Waverly, TN, example is provided in Figure B4]; and
- Population data—population data at the Census block level joined with GIS Census Blocks layer.

Figure B4. Transportation Layer in Waverly, Humphreys County, TN



*Source: U.S. Census Bureau Transportation Data (*https://ngda-transportation-dev-geoplatform.hub.arcgis.com/*). Image from Liem Tran.*

Appendix C.
Model Variable Descriptions by Main Model Components

The following tables provide further detail on the variables, including type and description, included in each component of the simulation.

Table C1. Model Variable Descriptions for the Healthcare System

Variable	Type	Description
HealthCareResources	Stock	Any type of resource used in caring for patients, including people and supplies
Replenish	Flow	Rate at which HealthCareResources are replenished on a normal basis
OutsideResources	Stock	Available external resources that can replenish HealthCareResources in an emergency
flow1	Flow	Rate at which HealthCareResources are replenished in an emergency
external_HC_resources	Stock	Rate at which Outside_resources can be replenished
response_efffectiveness	Flow	Rate HealthCareResources are consumed
ServicingPop	Stock	Patients in need of HealthCareResources
Flow	Flow	Rate patients are served by HealthCareResources

Table C2. Model Variable Descriptions for Emergency Management

Variable	Type	Description
EMA Response	Stock	EMA availability to respond to an event
response effectiveness	Flow	Rate to replenish the EMA Response
EMA depletion	Flow	Rate EMA Response is depleted
EMA capability	Stock	Core capabilities established by the EMA
EMA Input	Flow	Rate EMA builds EMA capability
EMA Resources Stock	Stock	Resources the EMA has accumulated to respond to an event
resource utilization	Flow	Rate at which EMA Resources are consumed
External Resources	Stock	Resources accumulated from outside the local EMA that are available to replenish resources
ext resource flow	Flow	Rate that EMA Resources can be replenished by external resources
external resource flow	Flow	Rate at which external resources can accumulate and replenish
advanced warning	Var	How much notice the EMA has that an event is going to occur
event intensity	Var	Severity of the event
event impact	Var	Rate the EMA's ability to respond erodes

Table C3. Model Variable Descriptions for Emergency Response

Variable	Type	Description
RescueWorkers	Stock	People available to assist in rescue efforts
RescueEffort	Flow	Rate that RescueWorkers can respond to someone in need of rescue
RescueWorkersOut	Stock	Number of RescueWorkers currently responding
RescueBreak	Flow	Rate that RescueWorkers will require a break
replenish1	Flow	Rate that RescueWorkers become available to assist in rescue efforts
external_ER_resources	Flow	Rate that external emergency response workers can be available to assist if needed
stock	Stock	Number of external RescueWorkers available to assist if needed
external_ER_resources1	Flow	Rate external RescueWorkers can be made available to assist rescue efforts

Table C4. Model Variable Descriptions for Public Health

Variable	Type	Description
Public Health Preparedness	Stock	How well the local public health agency is prepared for a disaster or emergency of any type
Communications	Flow	How well public health can communicate before and during an event, both internally and with external partners (e.g., healthcare system, emergency management, etc.)
Risk communication system	Var	Main components available and used in the local risk communication system
Pre-Event Electronic Data Systems	Var	Standard electronic data systems that are available and used by the local public health system
Event Electronic Data Systems	Var	Standard disaster or emergency focused electronic data systems that are available and used by the local public health system
Policies & Procedures	Flow	Availability, current updates, and breadth of the disaster-related policies and procedures available at the local public health agency
All-Hazards Plan	Var	Whether the local all-hazards plan is both flexible, detailed, and current
Data Sharing Agreements	Var	Data sharing agreements in place between public health and external agencies
Recovery Operations Plan	Var	Whether such a plan exists at the local level
Resources	Flow	Local and regional resources available to the local public health agency that affect both the day-to-day function, as well as the response to a disaster
Specialized Staff	Var	Availability of both local and regional staff with specialized capabilities or functions
Public Health Laboratory	Var	Efficiency of the public health laboratory capabilities available to local public health
Stockpiles	Var	Amount and availability of stockpiles at the local or regional level
Disaster-Related Tools or Resources	Var	Whether one or more local or regional staff members are trained on disaster-related data collection tools and resources (e.g., ACE, CASPER, shelter surveillance)
Training & Exercises	Flow	Number of staff who have specific training or experience in emergency response
Disaster Response	Flow	Extent of the disaster to determine who quickly local public health preparedness is affected and reduced

Table C5. Model Variable Descriptions for the Population

Variable	Type	Description
PreEventState	State	Person's pre-event attributes get established such as age, gender, race, and whether they have a chronic health condition
InAreaAffected	State	Person is in an area affected by the event
Recovered_Nonaffected	State	Person is not in the event or is no longer in need of help
Sheltered	State	Person was affected and is currently in a shelter
Stranded	State	Person is affected and currently stranded
StrandedAccute	State	Person is affected and currently stranded with an acute injury
StrandedChronic	State	Person is affected and currently stranded and has a chronic health condition
ShelteredChronic	State	Person is affected and is currently in a shelter and has a chronic health condition
Treatment	State	Person is currently receiving treatment
HealthCareCenter	State	Person is currently at a healthcare facility of some kind
Death	State	Person is deceased
Afflicted	State	Person is in need of some form of health care
OutsideHealthCareCenter	State	Person traveled to a healthcare facility outside of the event area
medMaxWait	Param	Maximum time the person needs to acquire a medication before succumbing to affliction
StrandedmaxWait	Param	Maximum time the person can wait to be rescued before succumbing to affliction
treatmentRate	Param	Rate at which the person can be treated
AcuteInjuryLevel	Param	Severity of the persons injury
CountyBlock	Param	Where the person lives within the county
number_stranded	Var	Number of people currently stranded
number_strandedInj	Var	Number of people currently stranded and injured
number_strandedMed	Var	Number of people currently stranded and need medication
number_sheltered	Var	Number of people currently sheltered
number_shelteredInj	Var	Number of people currently stranded and injured
DeathsAtHCC	Output	Number of deaths at a health care center
DeathsAtHCCoutside	Output	Number of deaths at an outside health care center
DeathsAtHCCshelter	Output	Number of deaths at a shelter
StrandedInjuryDeaths	Output	Number of people stranded that died from injuries that could not be treated in time to save them
StrandedChronicDeaths	Output	Number of people stranded that died from a chronic health condition

Table C6. Model Variable Descriptions for the Key Factors

Variable	Type	Description
experience	Var	Responders have experience with a disaster event
inter-communication	Var	Communication level between the agencies responding to an event
preparation	Var	Level of pre-event preparation the agencies had in place i.e., MOUs in place
relationships	Var	Level of relationships that exist between the agencies pre-event
resilience	Var	Resilience of the community
trust	Var	Level of trust between the members of the various agencies