NASA DEVELOP National Program
2024 Spring Project Proposal

North Carolina – NCEI
Kentucky Disasters
Multi-Hazard Approach to Mapping Flood Susceptibility and Vulnerability in Kentucky

Project Overview

Project Synopsis: Floods are the most frequent natural disaster in Kentucky, and in late July of 2022, 14–16 inches of rain fell over eastern Kentucky in a "1-in-1000-year" event that caused historic flooding. One year later on July 18–19, 2023, another historic flood event occurred in western Kentucky as storms released 6–12 inches of rain in a 10-hour window. In partnership with the Kentucky Climate Center and NOAA National Weather Service Jackson and Paducah Forecast Offices, this project will map soil moisture conditions prior to both flood events. The NASA DEVELOP team will also integrate environmental flood susceptibility data with factors contributing to flood vulnerability for a combined flood risk map for Kentucky. Maps of flood risk will support efforts by the KCC and NWS Forecasting Offices to promote resilience to floods across Kentucky.

Study Location: KY
Study Period: January 2022 – August 2023

Advisors: Brian Nelson (NOAA National Centers for Environmental Information) brian.nelson@noaa.gov, Olivier Pratt (North Carolina Institute for Climate Studies) olivier.prat@noaa.gov, Molly Woloszyn (NOAA National Integrated Drought Information System) molly.woloszyn@noaa.gov

Partner Overview

Partner Organization:

Organization	Contact (Name, Position/Title)	Partner Type	Sector
Kentucky Climate Center	Dr. Jerald "Jerry" Brotzge, Director	End User	State Government
NOAA, National Weather Service, Jackson, KY Forecast Office	Jane Marie Wix, Warning Coordination Meteorologist; Peter "Pete" Gregorian, Service Hydrologist	End User	Federal Government
NOAA, National Weather Service Paducah, KY Forecast Office	Mary Lamm, Service Hydrologist	End User	Federal Government

End User Overview

End User's Current Decision-Making Process & Capacity to Use Earth Observations: The Kentucky Climate Center, the official state climate office of Kentucky, collects, disseminates, and studies weather and climate information through research, education, and outreach conducted in partnership with various stakeholders including federal, state, and local governments, private firms, academic institutions, and non-profit organizations. The Kentucky Mesonet, a network of 81 stations that collect real-time, soil, and atmospheric data in 71 counties across the state, is maintained by the KCC. Additionally, the KCC conducts applied research in areas including emergency management and hydrology to mitigate the impacts of high-impact weather and climate phenomena. Although the KCC collects detailed surface observations through the Kentucky Mesonet at stations across the state, presently they do not interpolate weather information

across these stations. The KCC is interested in assessing the utility of Earth observations to collect weather and climate information and improve spatial coverage of weather information across Kentucky.

Earth Observations Overview

Earth Observations:

Platform & Sensor	Parameter	Use
SMAP L-band Radiometer	Soil moisture	Observations collected by SMAP L-band Radiometer will be used to calculate antecedent soil moisture conditions before flood events.

Ancillary Datasets:

- Kentucky Geological Survey Karst Resources – A 1:500,000-scale karst potential map—showing the tendency (intense, prone, or nonkarst) for geologic units to develop or have karst features such as sinkholes, springs, caves, or other solution features—will be incorporated into the static flood susceptibility map as a flood susceptibility parameter.
- Kentucky NRCS SSURGO Soils Map Service – Soil drainage will be assessed across six classes—excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, very poorly drained—as a flood susceptibility parameter. Additionally, soil hydrology will be assessed across seven classes—from A (very little runoff) to D (take water very slowly and yield large amounts of runoff) as well as A/D, B/D, and C/D—to determine the amount of runoff to be expected when soils are saturated.
- KyFromAbove Kentucky Digital Elevation Model – Kentucky's 5-foot DEM Image Service (5K tiling grid) will be used to map aspect, elevation, slope, and topographic wetness index as indicators of flood susceptibility.
- KyGovMaps Open Data Portal Permitted Mine Boundaries – Proximity to permitted mine boundaries will be incorporated into the flood susceptibility map because partners at the NWS Jackson Office assess potential breakage of slough ponds associated with mining operations as a flood susceptibility factor during extreme precipitation events.
- KyGovMaps Open Data Portal Ky Rivers and Ky 24K NHD Blueline Streams – Calculate distance to streams and rivers across the study area as an indicator of flood susceptibility.
- Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Dataset (NLCD) – Map land cover type—including impervious surfaces and forest type—across the study area as an indicator of flood susceptibility.

Ancillary Datasets:

- Esri ArcGIS Pro 3.0.1 – Generate flood susceptibility map by reclassifying flood risk parameters to a common scale and combine using the raster calculator tool based on weights assigned by flood experts through the analytical hierarchy process (prior to project start)
- Google Earth Engine API – Acquire and process SPL4SMGP SMAP L4 Global 3-hourly 9-km Surface and Root Zone Soil Moisture data

Decision Support Tool & End Product Overview

End Products:

End Product	Partner Use	Datasets & Analyses
Flood Susceptibility Map	The flood susceptibility map will be created using environmental parameters that indicate susceptibility to flooding. These maps can be used by the Kentucky Climate Center and NWS Forecast	Flood susceptibility parameters will be reclassified in ArcGIS based on the weighting schemes generated during the analytical hierarchy process. These datasets will be combined on a common scale in

	Office to identify areas at risk of flooding during high precipitation events.	ArcGIS using the raster calculator tool to generate a flood susceptibility map for the state of Kentucky.
Flood Vulnerability Map	The flood vulnerability map can be used by the Kentucky Climate Center and NWS Forecast Office to identify vulnerabilities to flood events across Kentucky and support efforts by project partners to promote resilience to flood events.	Flood vulnerability information (demographic data and/or infrastructure vulnerability) will be gathered for Kentucky. These data will be combined into a flood vulnerability map in ArcGIS.
Flood Risk Map	A flood risk map for the state of Kentucky combining susceptibility and vulnerability to flood events will inform emergency management efforts by the Kentucky Climate Center and NWS Forecast Office in response to flood events.	The NASA DEVELOP team will integrate flood susceptibility and flood vulnerability maps into a combined flood risk map for Kentucky.
Antecedent Soil Moisture Maps	Maps of antecedent conditions in July 2022 and 2023 will depict soil moisture conditions prior to recent flood events. These maps will serve as a proof of concept for integrating satellite observations into flood management efforts in Kentucky.	Soil moisture conditions preceding the July 2022 and July 2023 flood events will be mapped using SMAP soil moisture observations.

Project Timeline & Previous Related Work

Project Timeline: 1 Term: 2024 Spring

Similar Past DEVELOP Projects:

- 2020 Spring LaRC Toa Baja Disasters (Internal DEVELOPedia link)
- 2020 Spring NC Ohio River Basin Water Resources (Internal DEVELOPedia link)
- 2021 Spring LaRC Fairfax Water Resources (Internal DEVELOPedia link)
- 2021 Spring ARC Northern Great Plains Disasters (Internal DEVELOPedia link)
- 2021 Spring MSFC Cheat Water Resources (Internal DEVELOPedia link)
- 2021 Summer MA Cincinnati & Covington Urban Development II (Internal DEVELOPedia link)
- 2021 Summer NC & MSFC Illinois Disasters (Internal DEVELOPedia link)

Notes & References:

Notes: Several counties in Kentucky are at or near the top of the list of counties with the most federally declared disasters since 1990. Here is a link to a news story about US counties with the most federally declared disasters (link to data summaries), including an interactive map of the number of declared disasters by county. Contacts from Jane Marie Wix related to this project: Andrea (Andrea Schoettmer - NOAA Federal) is the Senior Service Hydrologist at NWS Louisville, KY and also serves as the State Hydrologist; Link to information about Matt Crawford and Landslide studies.

References:

Drum, R. G., J. Noel, J. Kovatch, L. Yeghiazarian, H. Stone, J. Stark, P. Kirshen, E. Best, E. Emery, J. Trimboli, J. Arnold, & D. Raff. (2017). *Ohio River Basin–Formulating Climate Change*

Mitigation/Adaptation Strategies Through Regional Collaboration with the ORB Alliance. Civil Works Technical Report, CWTS 2017-01, U.S. Army Corps of Engineers, Institute for Water Resources: Alexandria, VA. https://www.lrh.usace.army.mil/Portals/38/docs/orba/USACE%20Ohio%20River%20Basin%20CC%20Report_MAY%202017.pdf

Kentucky Emergency Management. (2018). 2018 Kentucky Hazard Mitigation Plan: Kentucky Flood Risk Assessment. https://kyem.ky.gov/recovery/Documents/CK-EHMP%202018,%20S3-S6,%20Risk%20Assessment,%20Hazard%20Identification,%202,%20Flooding,%20Original%20Submittal.pdf

Mahmood, R., M. Schargorodski, S. Foster, & A. Quilligan. (2019). A technical overview of the Kentucky Mesonet. *Journal of Atmospheric and Oceanic Technology*, *36*, 1753–1771. https://doi.org/10.1175/JTECH-D-18-0198.1.

2024 Spring Project Work Plan

Objectives and Priorities

1. **Flood susceptibility map**: Combine the 10 flood susceptibility parameters into a flood susceptibility map in ArcGIS based on the weighting scheme provided by flood subject matter experts (SMEs) using the analytical hierarchy process.

2. **Flood vulnerability maps**: Map information indicating vulnerability to flood events in Kentucky.
    - Partners are interested in maps depicting the vulnerability of infrastructure to flood events. Additionally, partners hope to identify communities that are disproportionally impacted by flood events in Kentucky to support outreach to frontline communities.

3. **Flood risk map**: Overlay flood susceptibility information with flood vulnerability data.
    - See the 2021 Spring MSFC Cheat Water Resources (Internal DEVELOPedia link) project (Figure 2) for examples of maps of infrastructure vulnerability in relation to flood risk
    - See the 2020 Spring LaRC Toa Baja Disasters (Internal DEVELOPedia link) project (Figurea 3–5) for bivariate choropleth risks maps indicating flood susceptibility and vulnerability

4. **Antecedent condition maps**: Map soil moisture preceding flood events using SMAP soil moisture data.

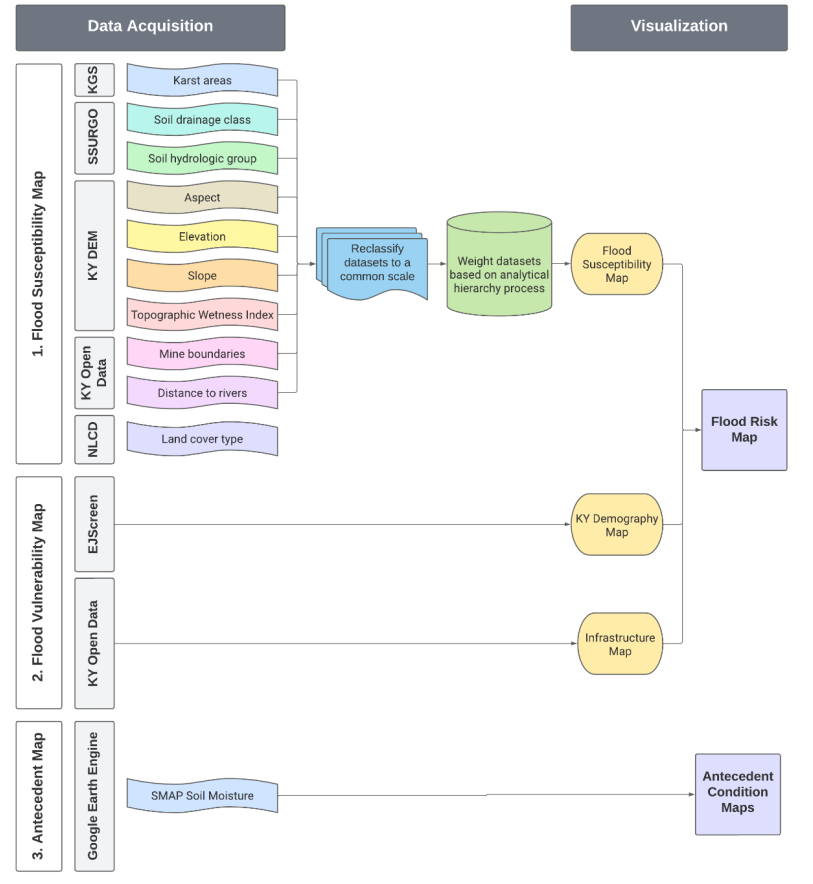


Figure 1. Editable flowchart for project methodology (requires a free account). Source: Lucidchart.

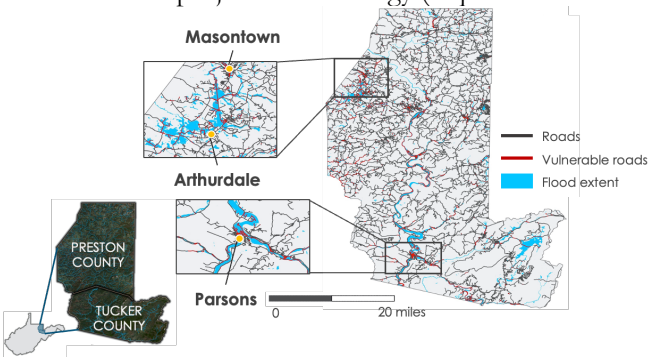
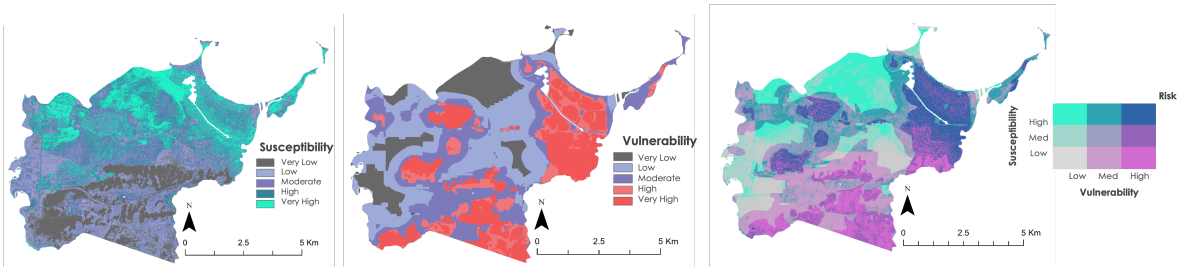


Figure 2. Example maps depicting roads vulnerable to flooding in Preston and Tucker Counties based on flood extent and FEMA floodplain maps. Source: NASA DEVELOP Cheat Water Resources team.



Figures 3–5. Example maps from left to right: a) flood susceptibility map based on nine flood risk parameters (elevation, topographic wetness index, storm surge, distance to water, slope, NDVI, height above nearest drainage, land cover type, and saturated hydraulic conductivity); b) social vulnerability map based on three parameters (building density, population density, and informal settlements); and c) flood risk map highlighting the intersection of social vulnerability and flooding susceptibility in Toa Baja, Puerto Rico. Source: NASA DEVELOP Toa Baja Disasters team.

Flood Susceptibility Mapping

Flood Susceptibility Methodology:

- The methodology for developing the Kentucky flood susceptibility map will be based on the methodology developed in the NASA DEVELOP 2020 Spring Toa Baja Disasters project.
- Flood susceptibility parameters for Kentucky (Figure 6; Table 1) will be reclassified to a common scale in ArcGIS (Figure 7) and combined using the raster calculator tool based on weights assigned by flood experts during the analytical hierarchy process prior to project start.
- Here is a video tutorial that outlines a similar methodology to the methods for this project: Flood Susceptibility Mapping using GIS-AHP Multi-criteria Analysis

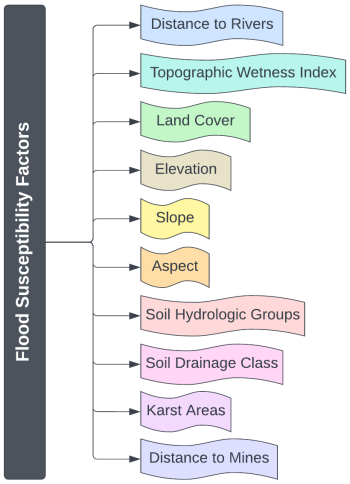


Figure 6. List of flood susceptibility parameters for NASA DEVELOP Kentucky flood project. Source: Lucidchart.

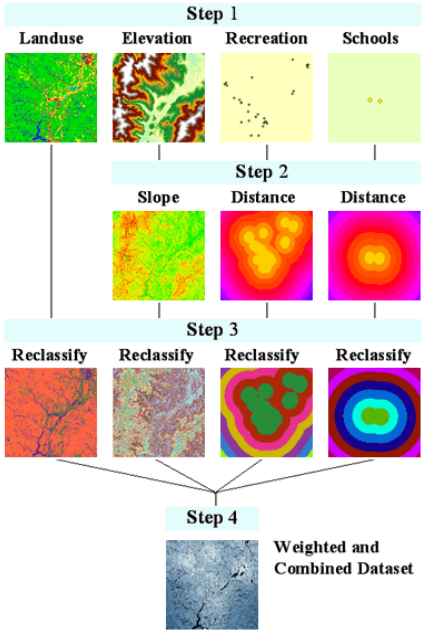


Figure 7. Example of using reclassification in a Weighted Overlay workflow. Source: Esri "Understanding Reclassification."

Table 1. Datasets used to map flood susceptibility in Kentucky.

Source	Parameter / Product	Use
Kentucky Geological Survey Karst Resources	Karst areas	A 1:500,000-scale karst potential map—showing the tendency (intense, prone, or nonkarst) for geologic units to develop or have karst features such as sinkholes, springs, caves, or other solution features—will be incorporated into the static flood susceptibility map as a flood susceptibility parameter

Kentucky NRCS SSURGO Soils Map Service	Soil drainage	Soil drainage will be assessed across six classes—excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, very poorly drained—as a flood susceptibility parameter
Kentucky NRCS SSURGO Soils Map Service	Soil hydrology	Soil hydrology will be assessed across seven classes—from A (very little runoff because they are rapidly or very rapidly permeable and take in water at equal or faster rates than most rains fall in the area) to D (take water very slowly and yield large amounts of runoff. Poorly drained soils generally are in Group D because the high water table prevents movement of water in the soil) as well as A/D, B/D, and C/D—to determine the amount of runoff to be expected from the soil when saturated
KyFromAbove Kentucky Digital Elevation Model	Aspect	Kentucky's 5-foot DEM Image Service (5K tiling grid) will be used to map aspect
KyFromAbove Kentucky Digital Elevation Model	Elevation	Kentucky's 5-foot DEM Image Service (5K tiling grid) will be used to map elevation
KyFromAbove Kentucky Digital Elevation Model	Slope	Kentucky's 5-foot DEM Image Service (5K tiling grid) will be used to map slope
KyFromAbove Kentucky Digital Elevation Model	Topographic Wetness Index	Kentucky's 5-foot DEM Image Service (5K tiling grid) will be used to map topographic wetness index
KyGovMaps Open Data Portal Permitted Mine Boundaries	Mine boundaries	Partners at the NWS Jackson, KY Office assess potential breakage of slough ponds associated with mining operations as a flood susceptibility factor during extreme precipitation
KyGovMaps Open Data Portal Ky Rivers and Ky 24K NHD Blueline Streams	Hydrogeography	Calculate distance to streams and rivers across the study area
Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Dataset (NLCD)	Land cover type	Map land cover type—including impervious surfaces and forest type—across the study area

Flood Risk Data Notes:

- Landing page for information about Kentucky.gov geospatial data
- Information about the 1:500,000-scale karst potential map classification is through the Karst Potential Classification webpage link
- Kentucky's digital elevation model (DEM) data is available through Amazon Web Service (AWS)
    - KyFromAbove on AWS link
    - GitHub documentation link
- Karst areas: The KyGovMaps Open Data Portal's 24K Karst Potential includes 1:500,000 karst potential data link
- Topography: The elevation data used in the Kentucky Flood Hazard Portal may be found in this ElevationServices folder, which is listed under "resources"
- Flood risk: See the FEMA Flood Map Service Center's (MSC) "Flood Hazard Products Direct Download" fact sheet for information about downloading FEMA flood information
- MRLC NLCD Class Legend and Description located here

Analytical Hierarchy Process

Three flood researchers (hereon "subject matter expert" or SME) each used the analytical hierarchy process to determine the relative weight of each parameter that will contribute to the flood susceptibility map. The analytical hierarchy process was carried out using a pairwise comparison matrix (Table 2) to compare each

flood susceptibility parameter against each other parameter. More information about the methodology the SMEs utilized in the analytical hierarchy process can be found in this folder.

Table 2. Pairwise comparison matrix of flood susceptibility parameters for analytical hierarchy process.

Parameter	River proximity	TWI	Land cover	Elevation	Slope	Aspect	Hydrology	Drainage	Karst	Mine Proximity	Sum	Rank
River proximity	—											
TWI		—										
Land cover			—									
Elevation				—								
Slope					—							
Aspect						—						
Hydrology							–					
Drainage								–				
Karst									–			
Mine proximity										–		

Flood Vulnerability Mapping

Partners have expressed an interest both in mapping infrastructure vulnerability to floods and mapping population demographic factors indicating vulnerability to floods. If it becomes necessary to prioritize between these tasks due to time constraints, it would be helpful to revisit this topic with the partners to clarify which product they prefer.

Population Demographic Mapping:

See this description from the VEJ Portland Urban Development team on how they arrived at language for describing communities with vulnerability to environmental factors:

> "In conversation with Depave, we decided to use the term "frontline community" to appropriately describe the areas with the highest potential vulnerability to extreme heat in Portland. It was critical for us to be intentional with the language we used to represent these communities, understanding that the label "vulnerability" can have a negative and victimizing connotation. However, we also recognize that "Social Vulnerability Index" is an established tool in urban heat literature. Given this, we continued the use of "vulnerability" as a tool and metric but refrained from using it as a label for these communities."

If the partners are interested in integrating demographic data into the vulnerability map, the partners will be a helpful resource for determining which factors to consider for identifying frontline communities. Past DEVELOP teams have utilized the EPA's Environmental Justice Screening and Mapping Tool (EJScreen) for data on environmental and demographic indicators related to environmental exposures.

Infrastructure Vulnerability Mapping:
See 2021 Spring MSFC Cheat Water Resources (Internal DEVELOPedia link) for related methods.

Table 3. Potential datasets for mapping infrastructure vulnerability in Kentucky.

Source	Parameter / Product	Use
KYGovMaps Open Data Portal	Bridges	Infrastructure—such as bridge locations and water and power lines—will be overlaid with the flood susceptibility map to identify areas vulnerable to floods.
KYGovMaps Open Data Portal	Infrastructure	Infrastructure—such as bridge locations and water and power lines—will be overlaid with the flood susceptibility map to identify areas vulnerable to floods.
KYGovMaps Open Data Portal	Regulated dams	Infrastructure—such as bridge locations and water and power lines—will be overlaid with the flood susceptibility map to identify areas vulnerable to floods.

Antecedent Soil Moisture Mapping

SMAP Soil Moisture:
Tutorial for using SMAP soil moisture products in Google Earth Engine.

Wishlist Items

With 10 weeks to conduct this project, it is important to prioritize tasks and objectives. First, focus on the objectives outlined in this proposal and if there is additional time, the following additional analyses can be pursued. Additionally, any wishlist items that are not completed can be listed as "future work" ideas in your presentation and technical report at the end of the term!

Wishlist item #1:

Flood risk map validation: The weighting scheme of the flood risk variables may be refined by comparing flood risk maps generated under different weight schemes to the flood extent of the 2022 and 2023 flood events based on the methodology developed through the Toa Baja Disasters project.

Wishlist item #2:

Time series trend comparison of antecedent conditions: Assess the feasibility of using SMAP data to supplement ground-based data by comparing SMAP soil moisture data with soil moisture data collected by the Kentucky Mesonet prior to flood events.

End Product	Partner Use	Datasets & Analyses
Time Series Trend Analysis of Antecedent Conditions	Comparisons of *in situ* and remote Earth observations will be used to assess the feasibility of using satellite products to enhance weather monitoring and support	Satellite observations collected by SMAP will be compared with KY Mesonet ground-based measurements in time series that depict environmental trends before both flood events.

	emergency management in Kentucky.	

Wishlist item #3:

GPM IMERG Precipitation: Map precipitation prior to flood events using GPM IMERG data.

Wishlist item #4:

Flood impact scenarios: The Kentucky Climate Center is interested in understanding the potential impact of floods under different precipitation scenarios. For example, if x amount of precipitation falls, what is the anticipated flood depth and flood extent in the affected region? One approach to develop and visualize flood scenarios is using the Esri Flood Impact Analysis Solution solution to map potential flood extent:

- Introductory video on the Flood Impact Analysis Solution
- Link to a StoryMap with an overview of the Flood Impact Analysis Solution
- Video tutorial for using the Flood Impact Analysis Solution