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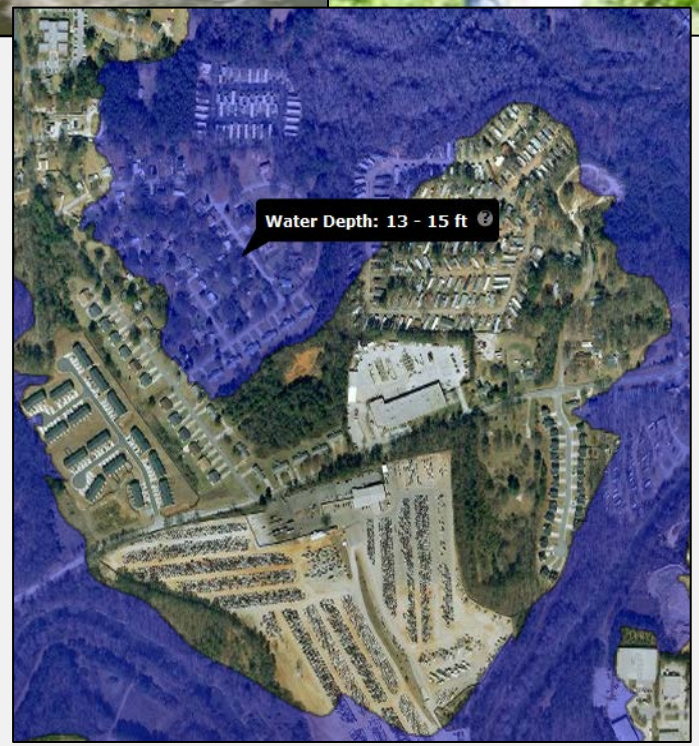
USGS Flood Inundation Mapping Science

Marie Peppler Flood Inundation Mapping Coordinator

U.S. Department of the Interior
U.S. Geological Survey



USGS and NWS Data Networks

Over 8,100 USGS Gages reporting current stream conditions in NWIS

Over 4,000 NWS Flood Forecast/Warning locations in AHPS

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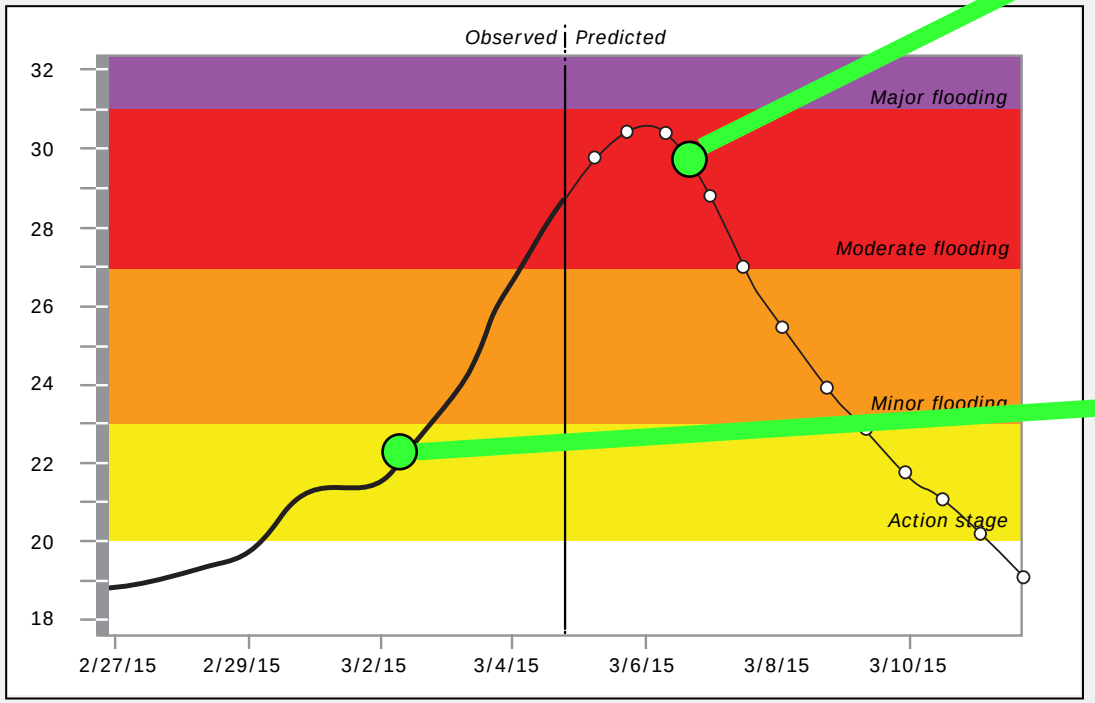
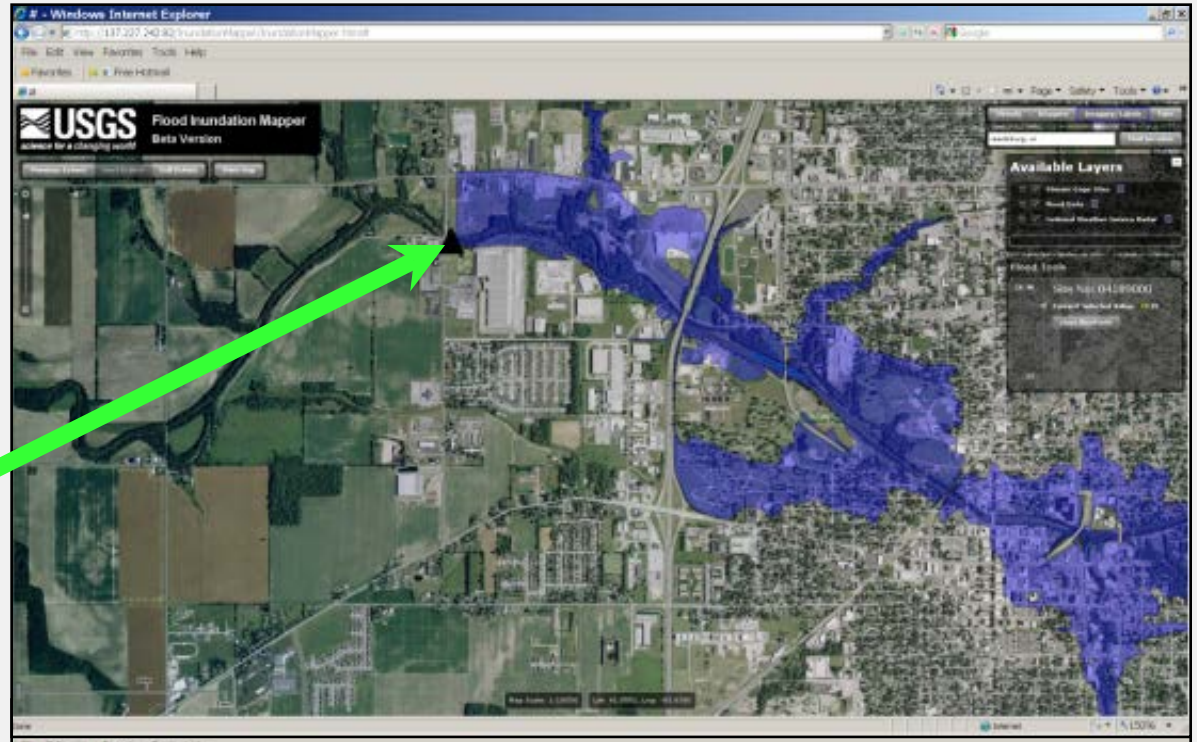
Flood Inundation Maps can translate a hydrograph into operational maps that communicate risk and consequences





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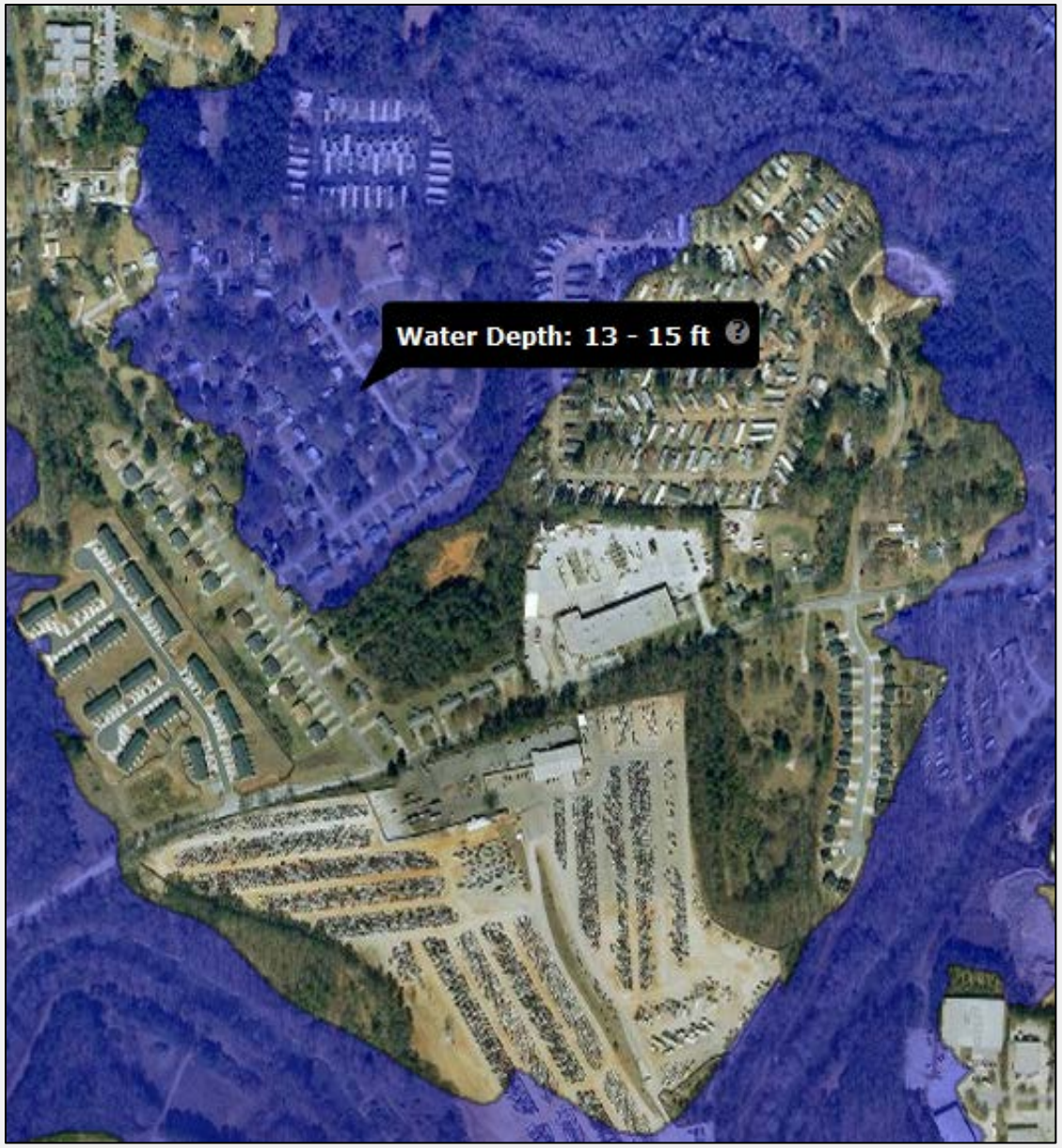
A Flood Inundation Map is:

- a map with a line where one side is wet and the other is dry <u>under one defined situation</u>.
  - Modeled,
  - Measured,
  - Or Both!



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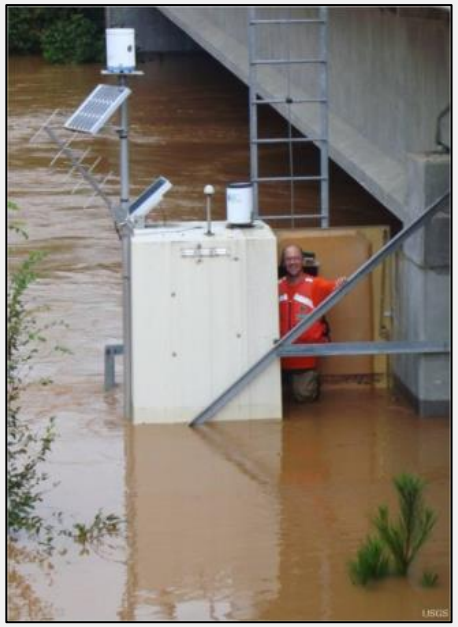
FIM becomes a tool for flood…



- Preparedness
  - “What-if” scenarios
- Response
  - Tied to gage & forecast data
- Recovery
  - Damage assessment
- Mitigation & planning
  - Flood risk analyses
- Environmental & ecological assessments

Environmental Assessments and Support

- Ecological studies of floodplains
  - Such as frequency of inundation
- Riparian habitat
  - 7-day inundation areas
- Hazardous substance spills
  - Kalamazoo River Oil Spill

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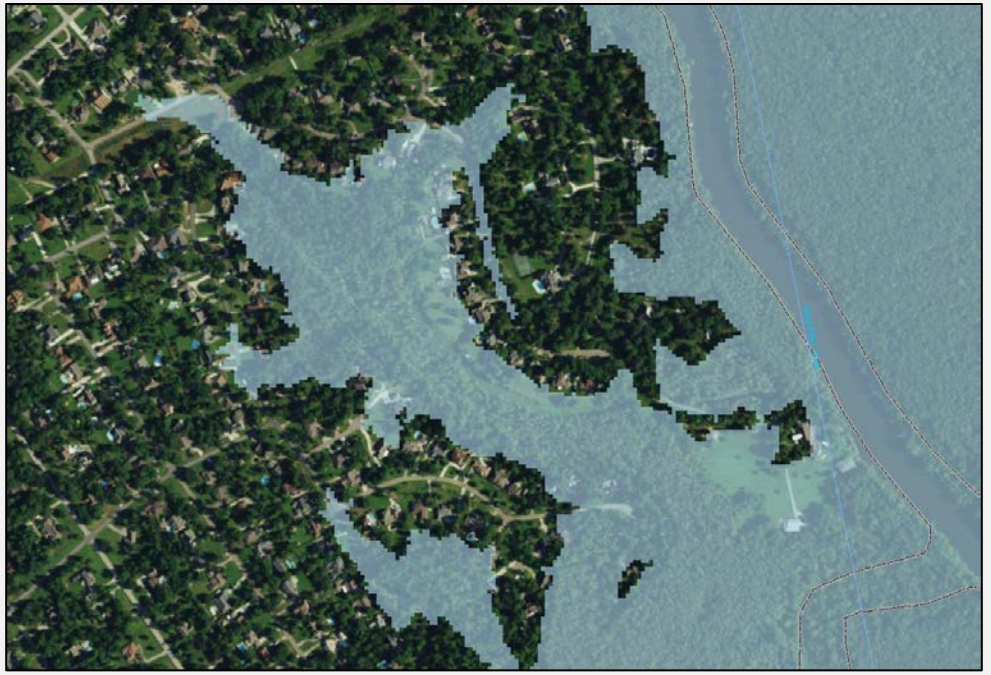
Types of Flood Inundation Maps

- **Modeled Flood Inundation Map Libraries**
  - **Probabilistic Flows (i.e. 1% chance flood)**
  - **Deterministic Flows**
    - **Stage Intervals (i.e. every 2 feet in stage)**
    - **Critical stages (i.e. Moderate and Major flood stages)**
- **Flood Documentation Studies**
  - **Measured**
  - **Interpolated from measurements**
  - **Remotely Sensed**
    - **Satellite**
    - **Aerial (manned or unmanned)**



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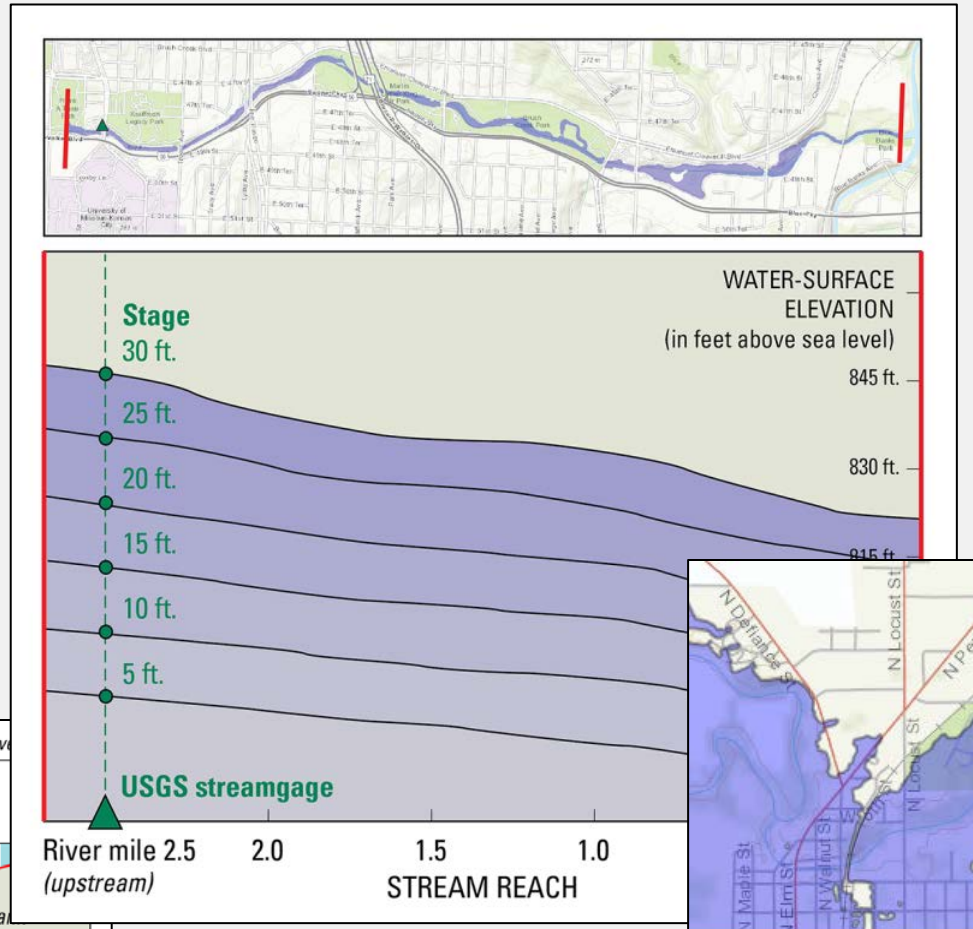
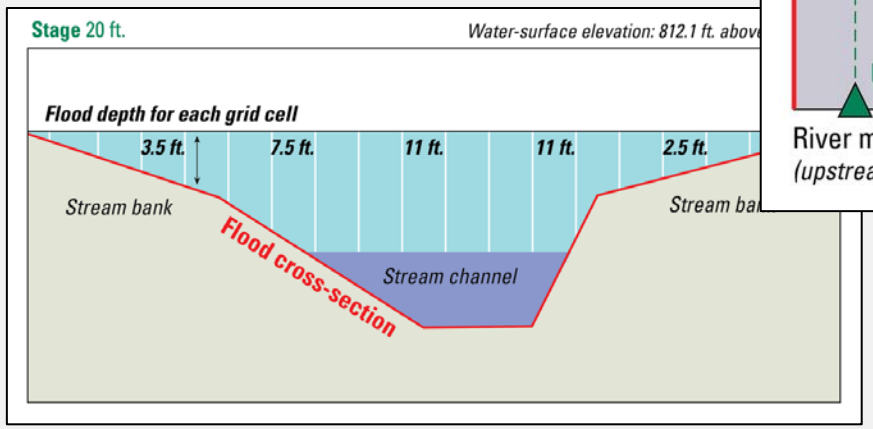
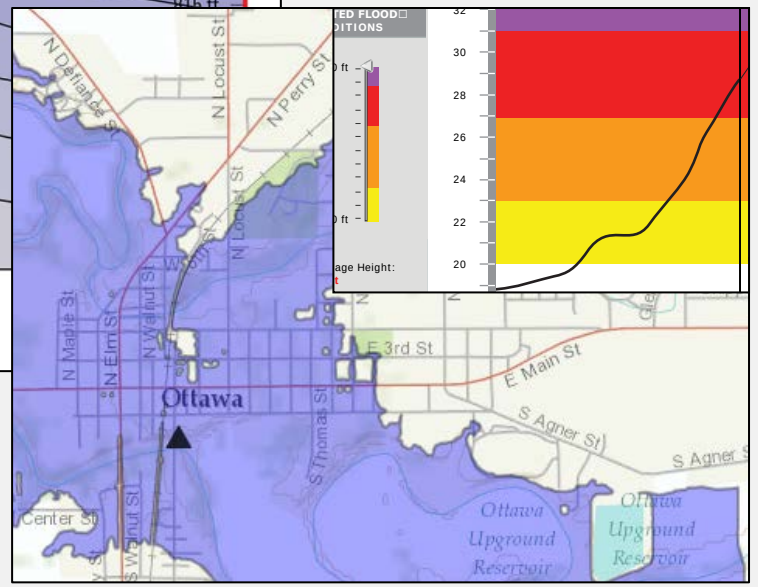
Hydraulic Modeled Flood Inundation Map Libraries

1. Stream Selection
2. Model Flood Heights
3. Delineate Flood Extents
4. Compute Flood Depths
5. Process Map Library







Probabilistic Flood Inundation Map Libraries

- Most common example are FEMA's Flood Insurance Rate Maps (FIRM)
- Typically several are created
  - 20%, 10%, 5%, 1%, 02% Exceedance Probability Flows

- Same modeling method
- Different inputs and purpose

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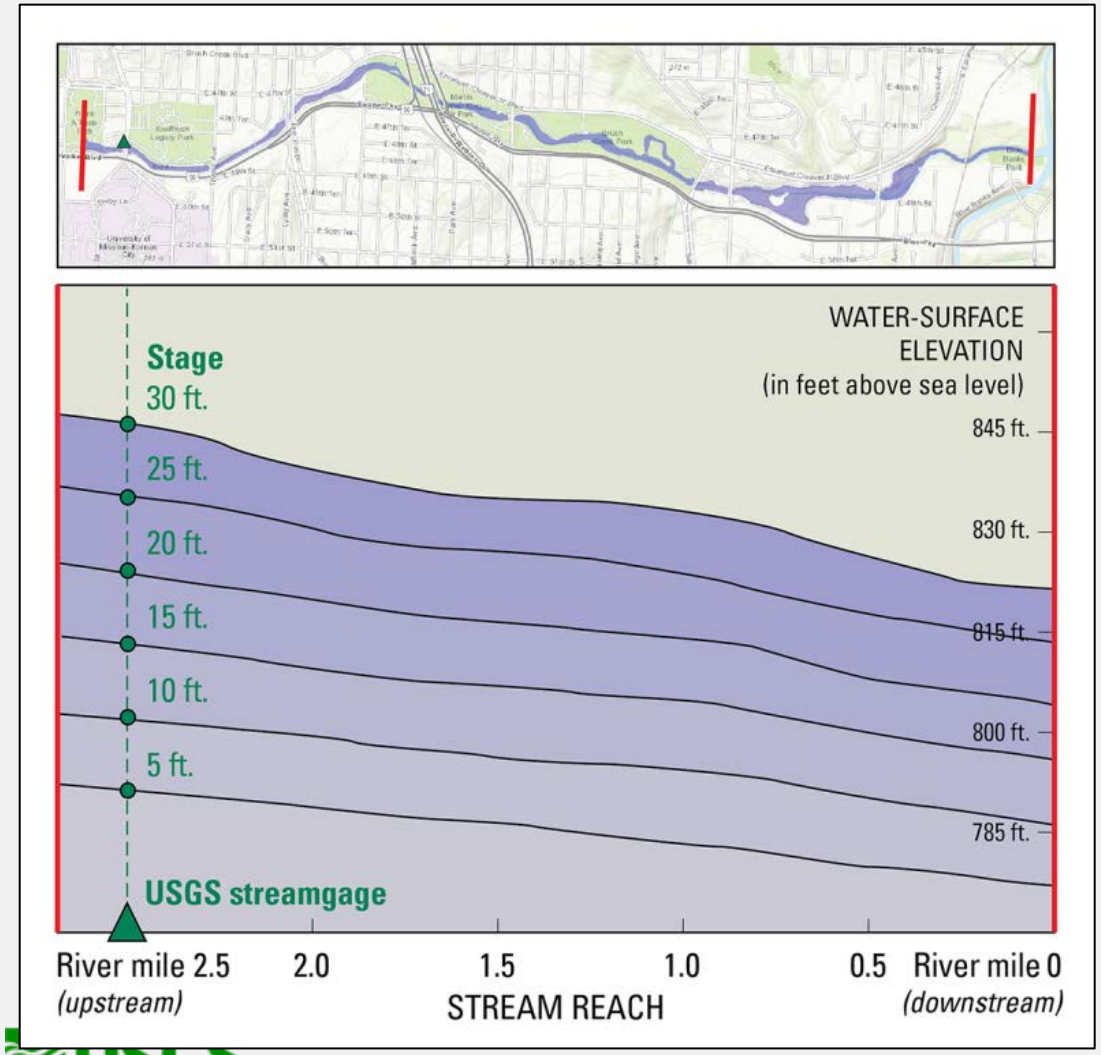
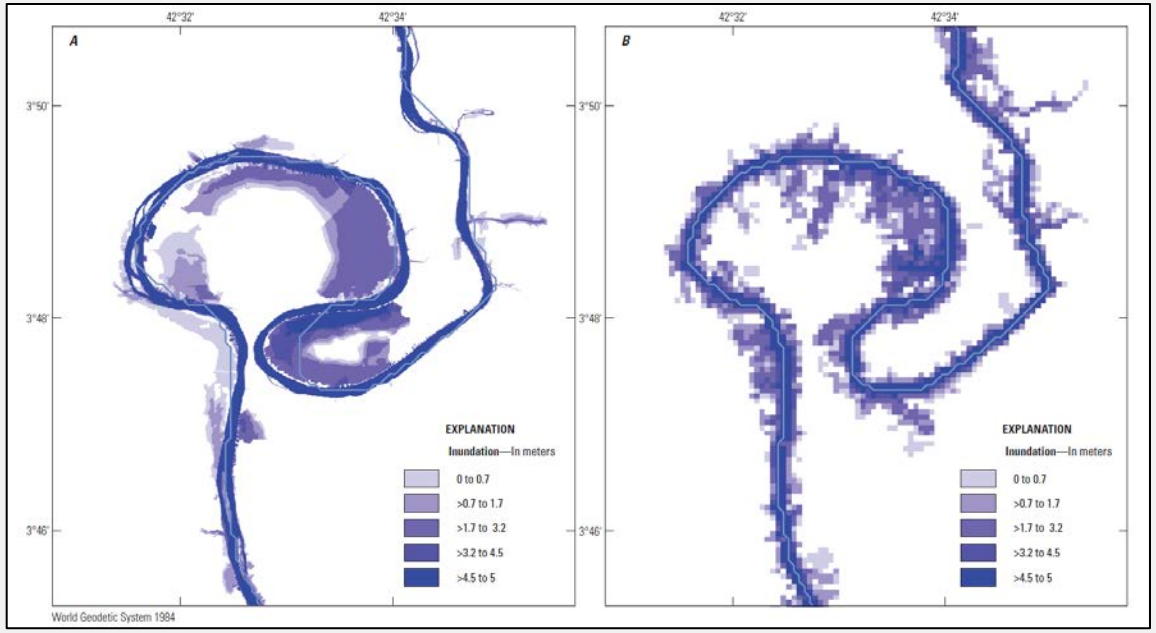
Deterministic Flood Inundation Map Libraries



- Based on even “slices” of stage or flow
- Any hydraulic model (calibrated to a USGS gage rating curve)
- Presents a full range of maps
  - Usually ~15 maps
  - From bankfull to peak of record
- Robust as long as base conditions don’t change

GIS Modeled Flood Inundation Map Libraries



10-meter 90-meter

USGS GIS Flood Tool Sample Output

- Numerous methods are GIS only or have a loose hydrologic modeling component
- GISFlood Tool, HAND, Bathtub, etc.
- Can be flow, stage, or connectivity based
- Scale is critical for interpretation

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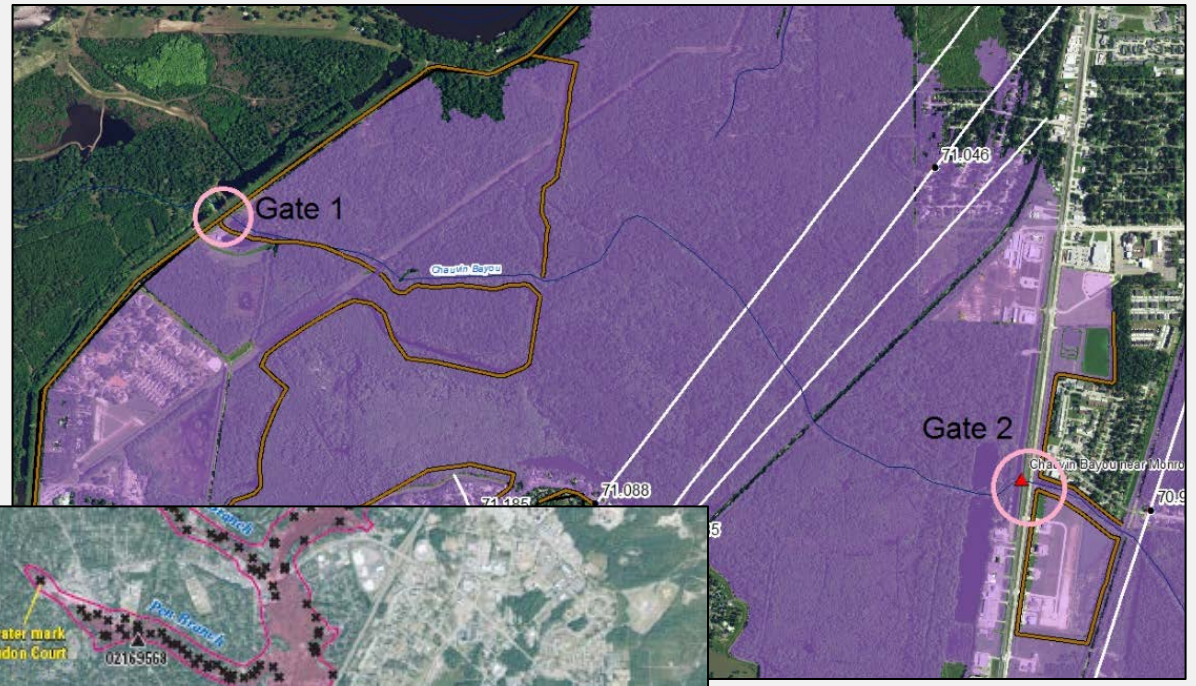
Creation of Flood Documentation Maps

1. Measure some aspect of the water level
    1. Streamgages or other sensors
    2. High-water marks
    3. Remote sensing
2. Connect the dots
    1. GIS model with elevation data
    2. Literally connect the dots
3. Delineate Flood Extents
4. Compute Flood Depths

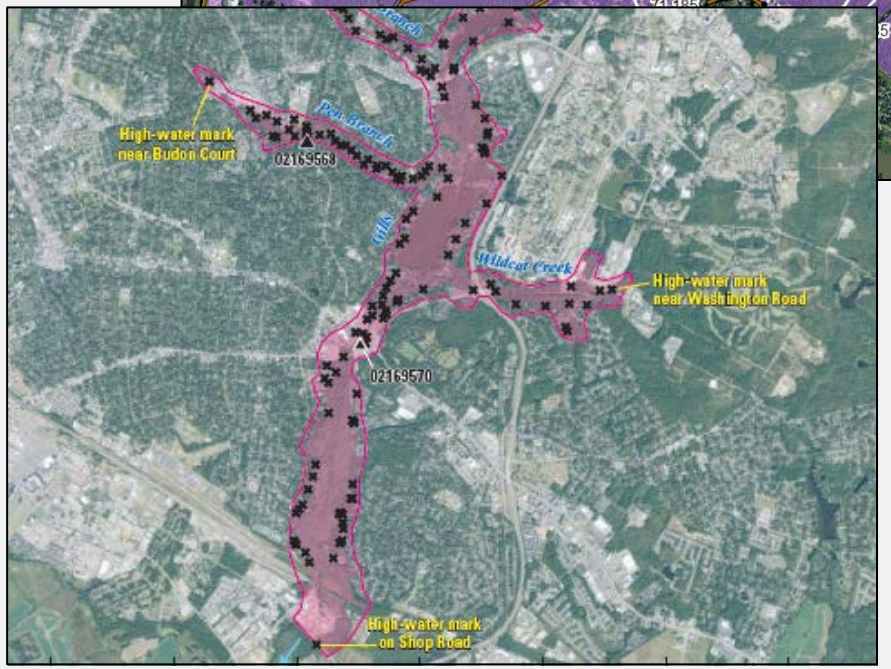
Cedar River, IA

High-Water-Mark Derived Flood Documentation Map

- Use the High-Water Mark information with the DEM to extend the marks out on the landscape
- Can be used for riverine or coastal flooded areas with some modifications



Working map view
Ouachita River Complex, LA



Published map view
Columbia, SC

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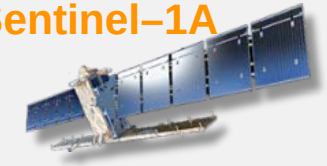
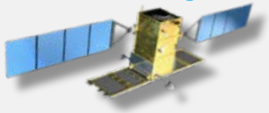
Remote-Sensing Derived Flood Documentation Map

ALOS–2

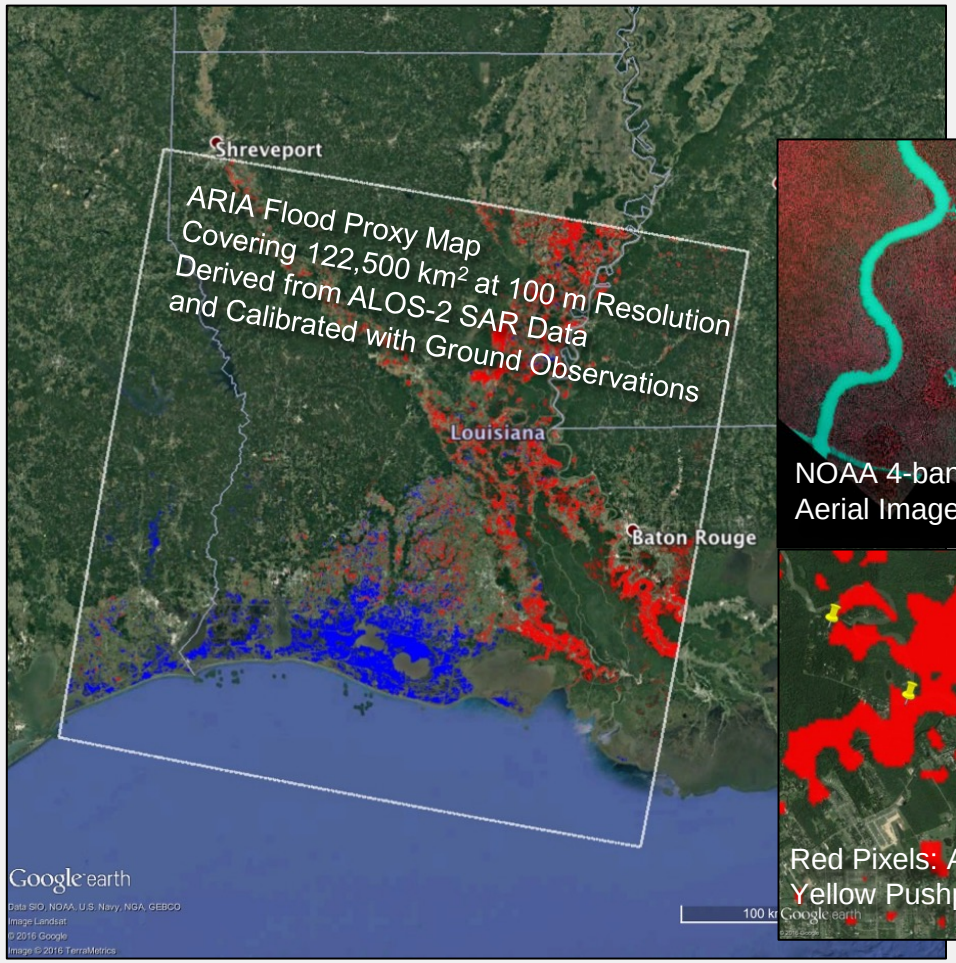
Sentinel–1A

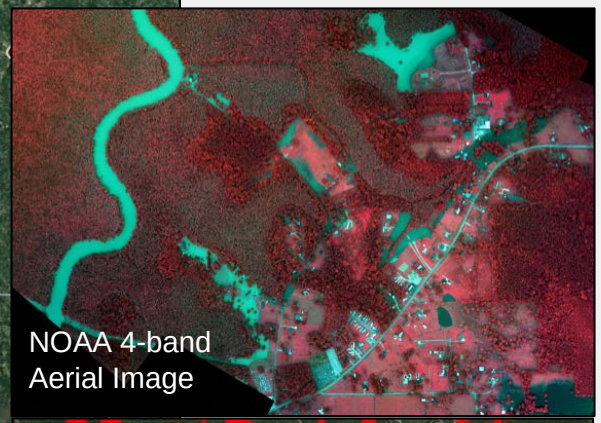


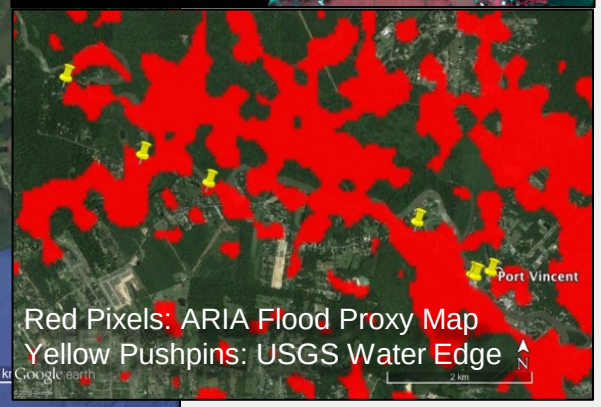
COSMO-SkyMed



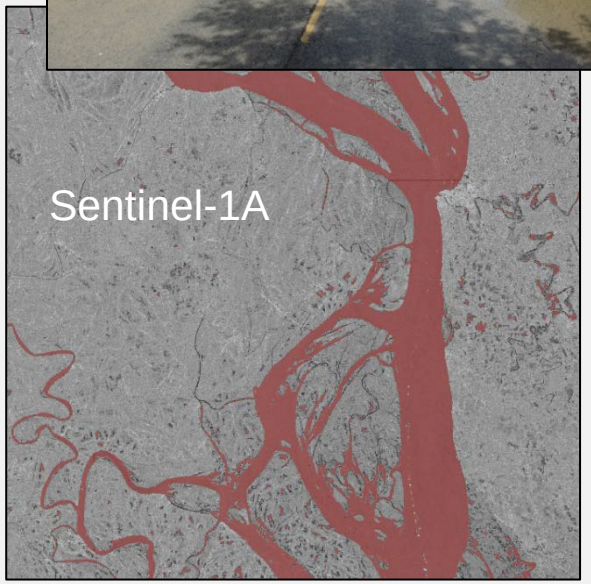
RADARSAT–2







Landsat



USGS FIM Research

- FIM Library Lifecycle
  - When should maps be reexamined?
  - Under what conditions should they be removed?
- Expand RapidFIM testing
  - Develop standards for comparing FIM methods
    - Possibly F-Score (working with NWS LMRFC on this)
- Communicating more varied quality of FIM libraries (uncertainty computations and display)

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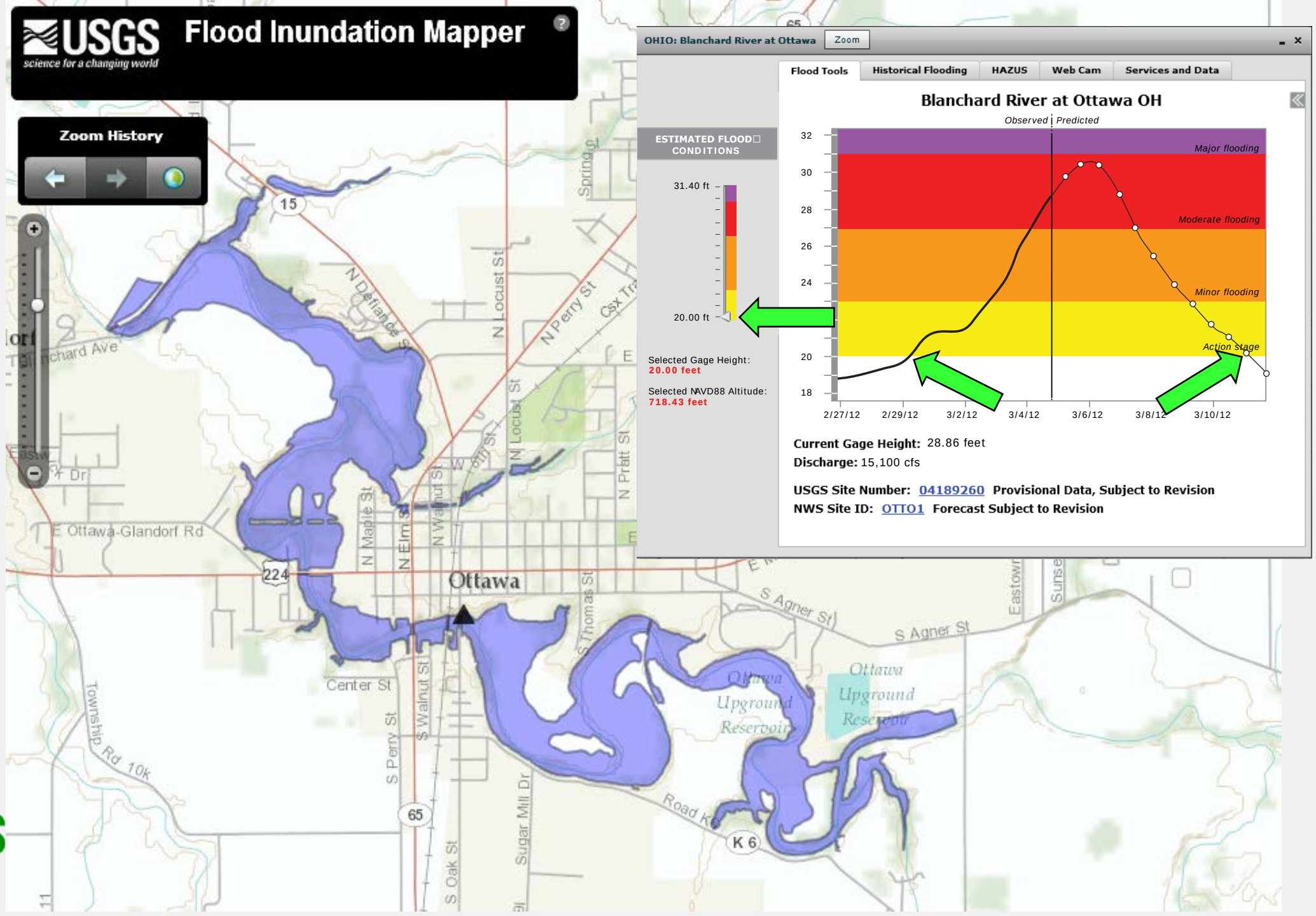
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Flood Inundation Mapper
Zoom History
OHIO: Blanchard River at Ottawa
Zoom
Flood Tools
Historical Flooding
HAZUS
Web Cam
Services and Data
Blanchard River at Ottawa OH
Observed | Predicted
ESTIMATED FLOOD CONDITIONS
31.40 ft
20.00 ft
Major flooding
Moderate flooding
Minor flooding
Action stage
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Selected NAVD88 Altitude:
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NWS Site ID: OTTO1 Forecast Subject to Revision
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Ottawa Upground Reservoir
Township Rd 10K
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N Pratt St
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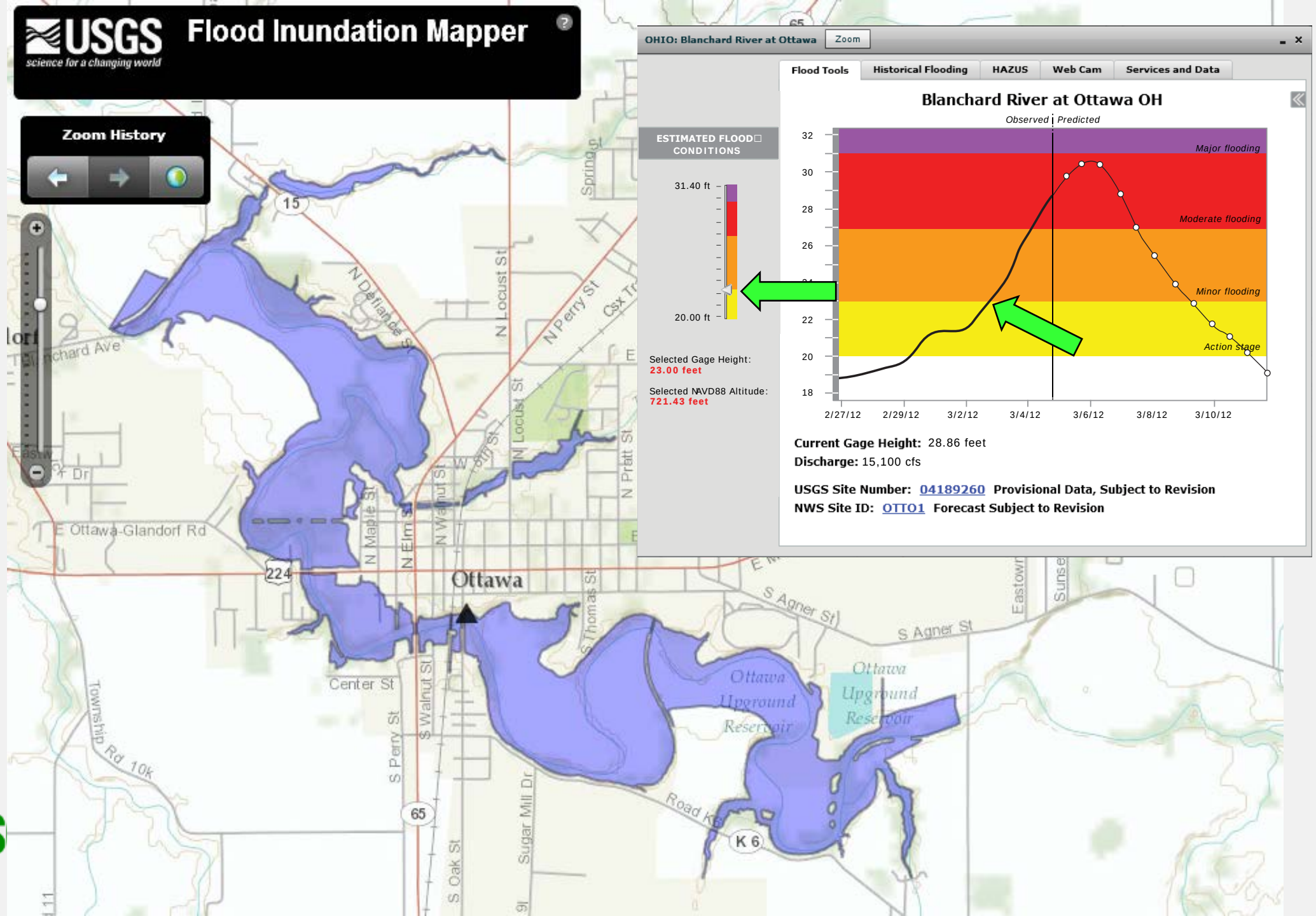
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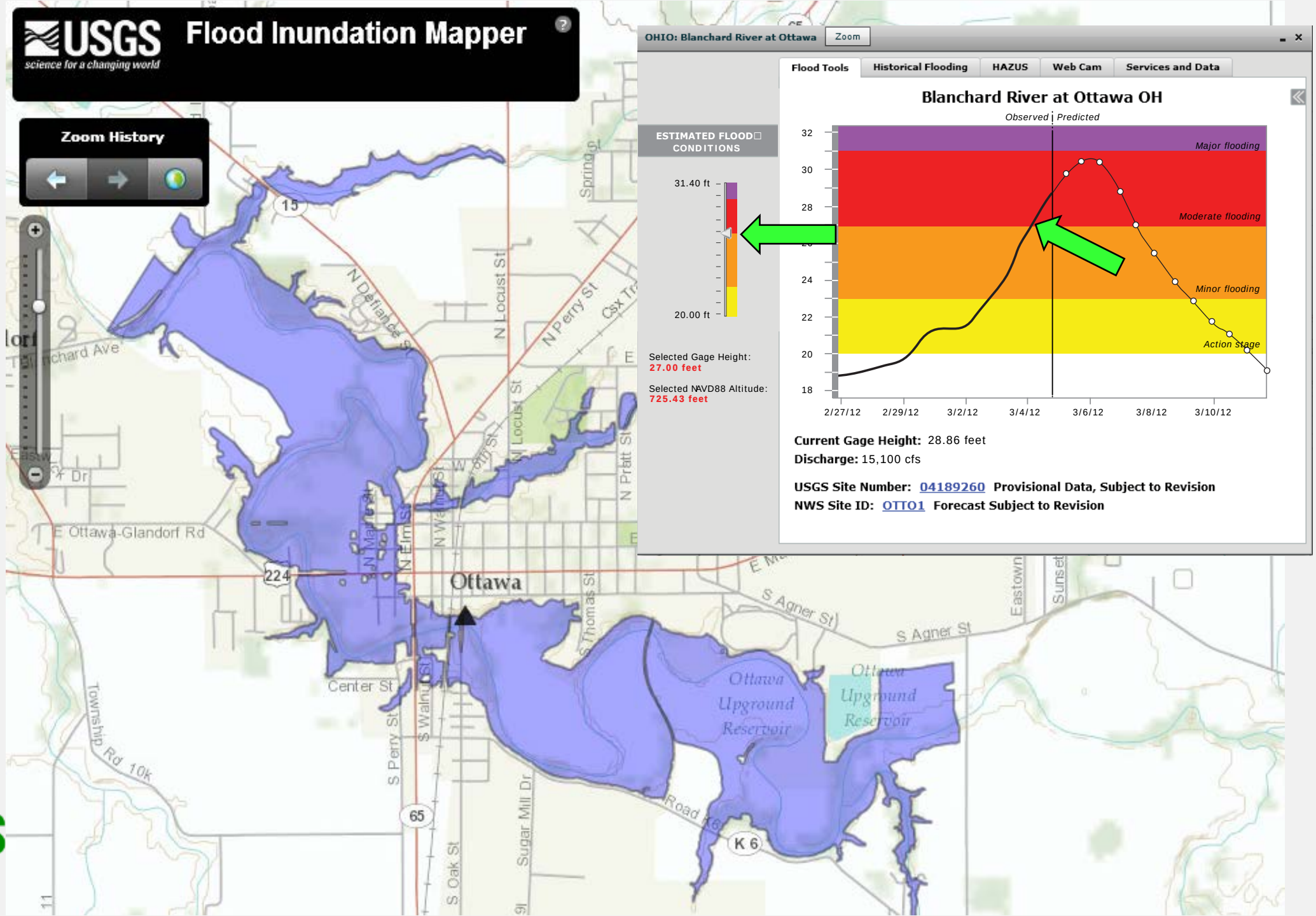
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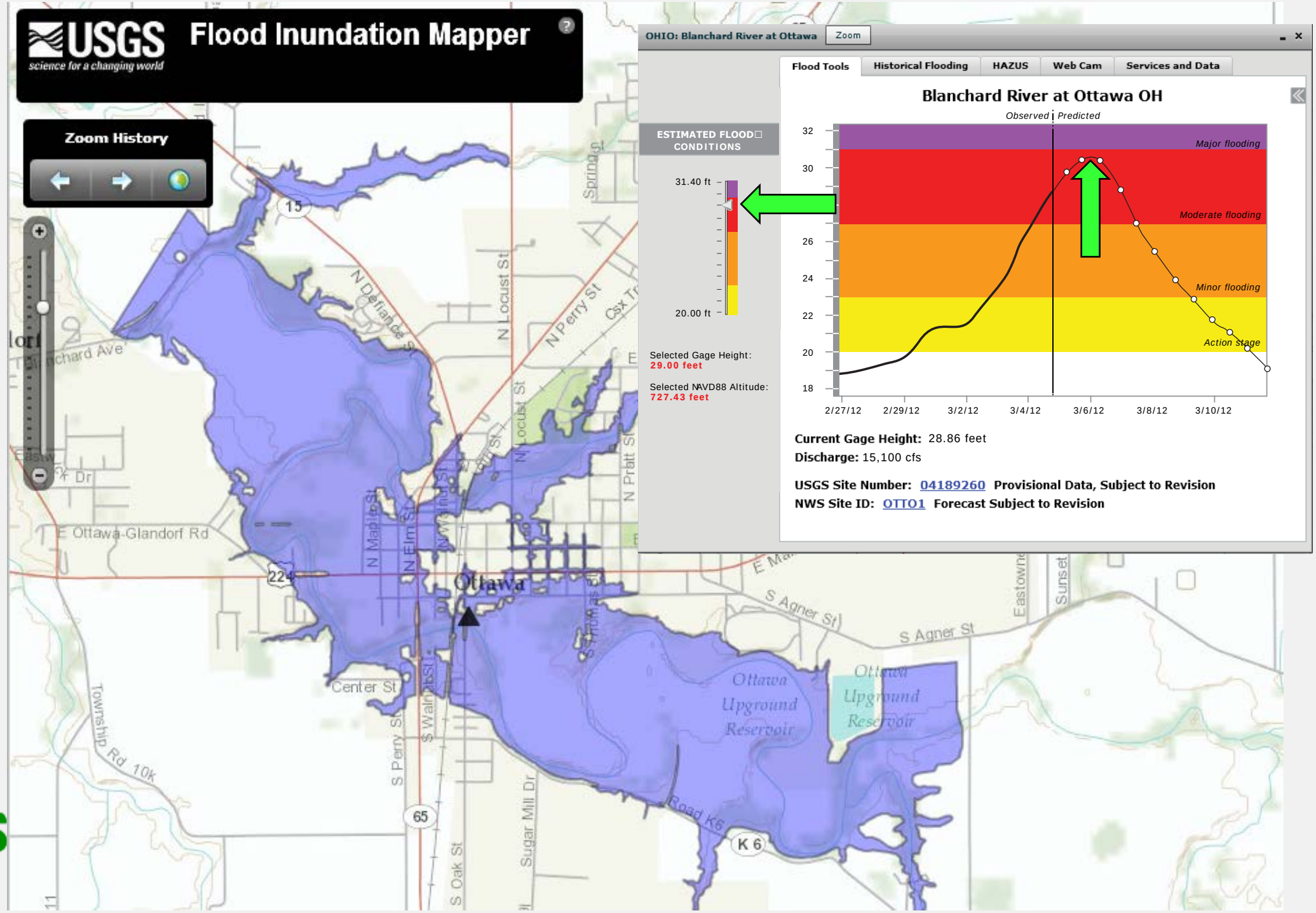
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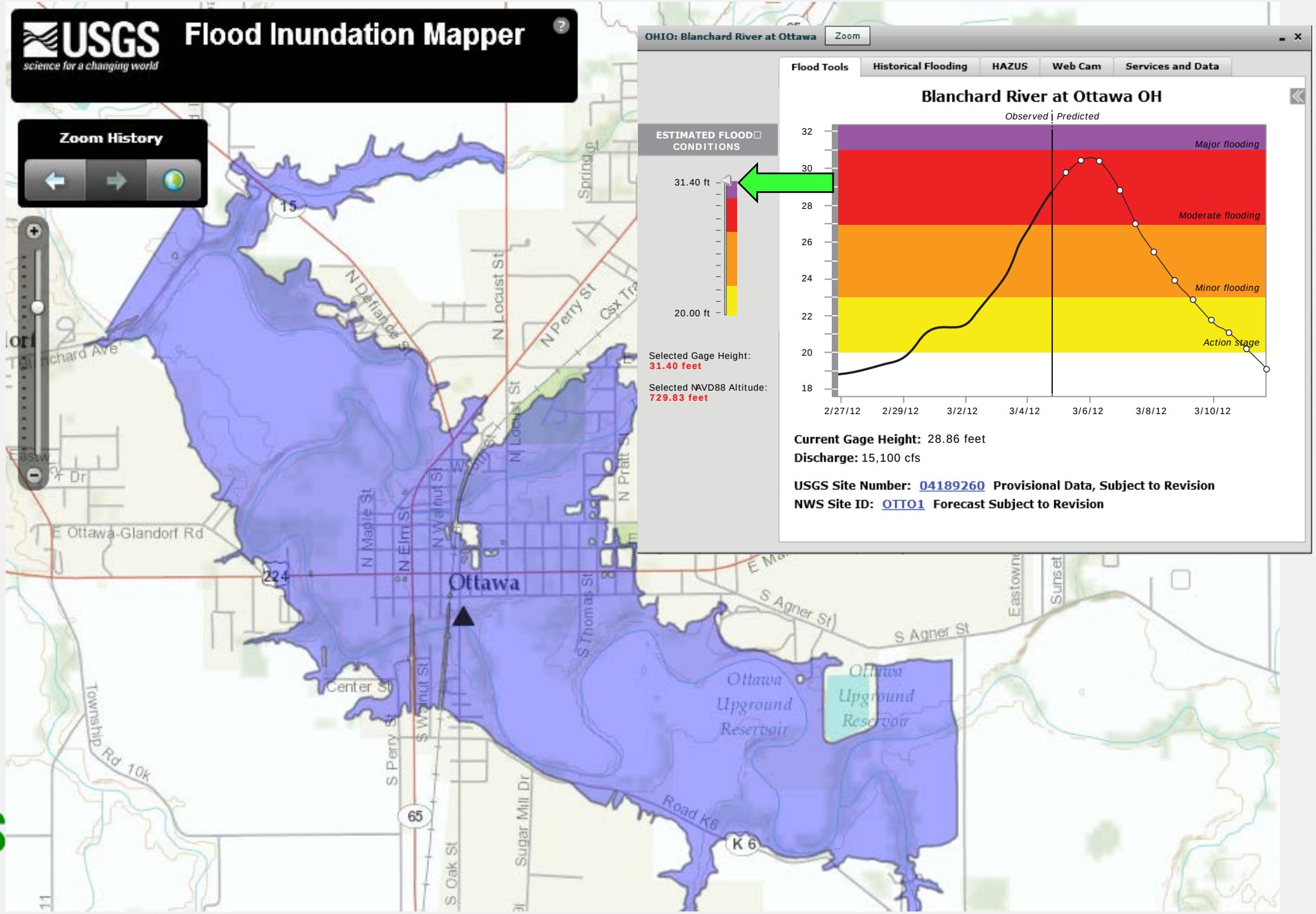
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Contact Information

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703.648.5314

http://water.usgs.gov/osw/flood_inundation/

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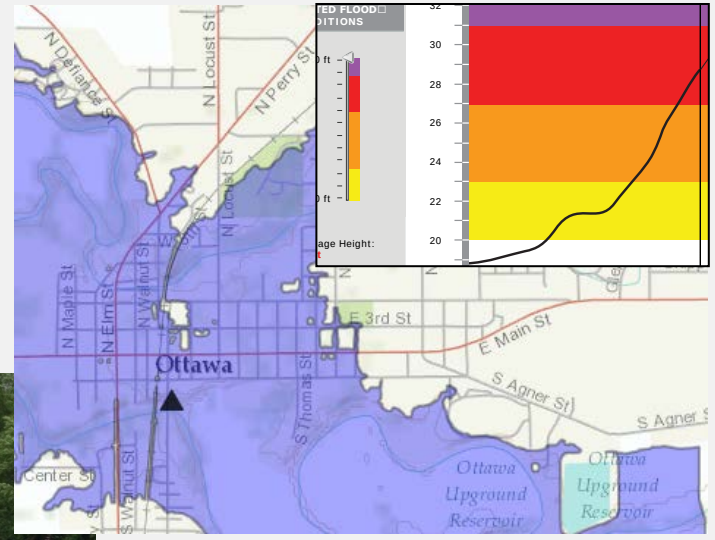
General Steps for Creation of a Modeled Flood Inundation Map Library using a Hydraulic Model

1. Stream Selection
2. Model Flood Heights
3. Delineate Flood Extents
4. Compute Flood Depths
5. Process Map Library



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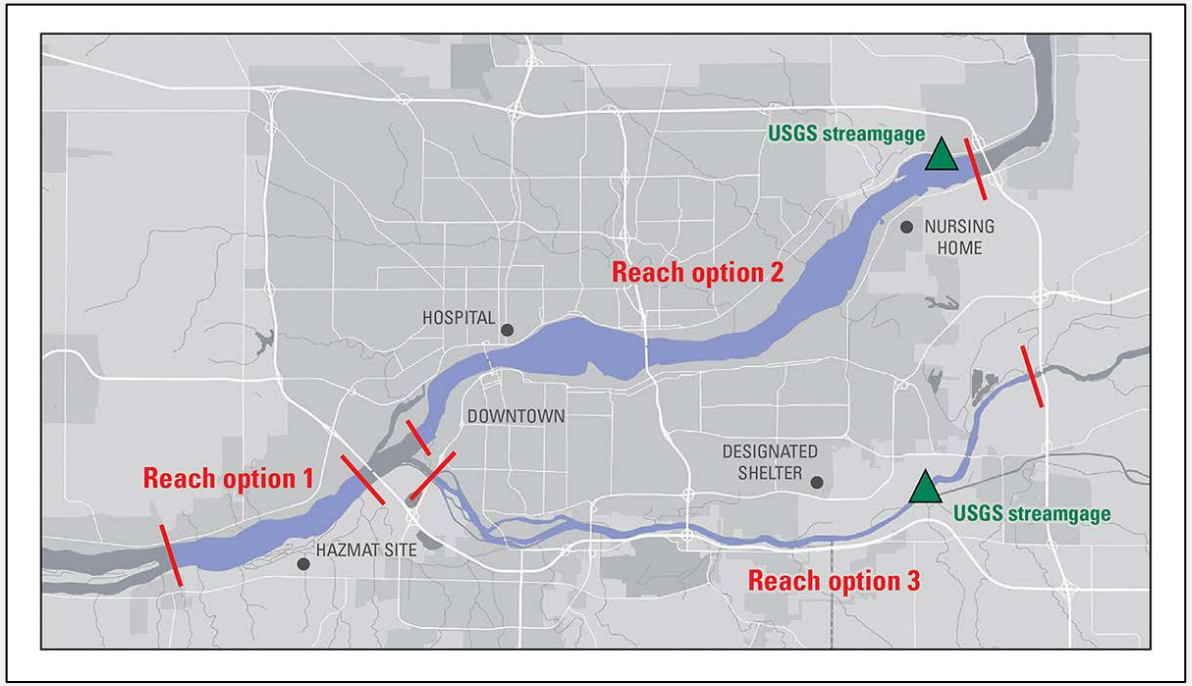
1. Stream Selection

- Streamflow information
- Flood Forecast information
- Elevation data availability
  - Topography
  - Bathymetry
  - Structural surveys

- Flood Impact Locations
  - Critical infrastructure
  - Routes of egress
  - Populations



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Gather Data

- Real-time streamflow information from a gage within the selected reach
  - Historical flood levels at that gage
  - Current and historical rating curves at that gage
- Short-term probabilistic forecasts at that gage
- High-resolution elevation data (dictates the quality of the maps more than any other factor)
- Existing hydraulic models (if available and recent)

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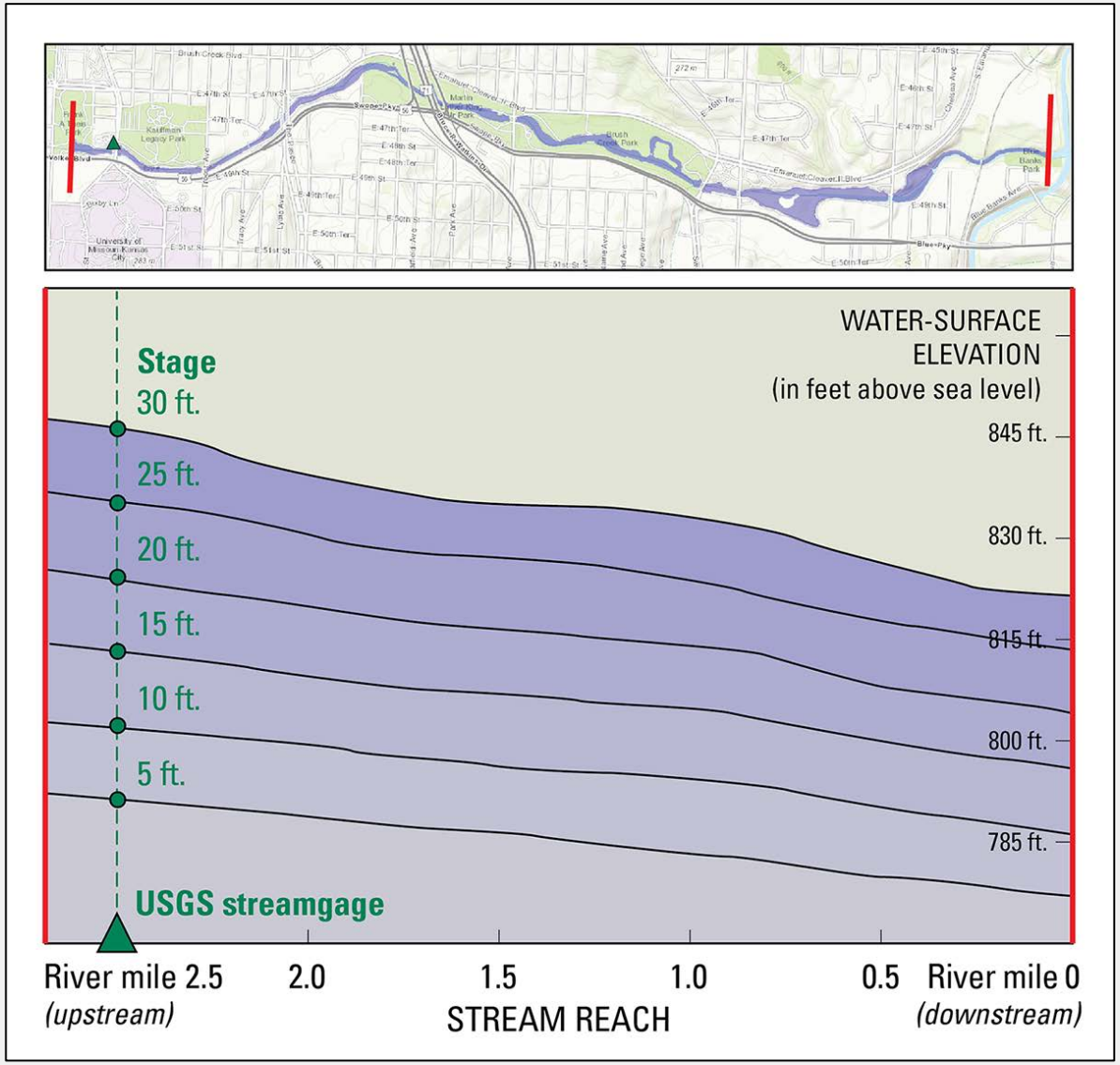
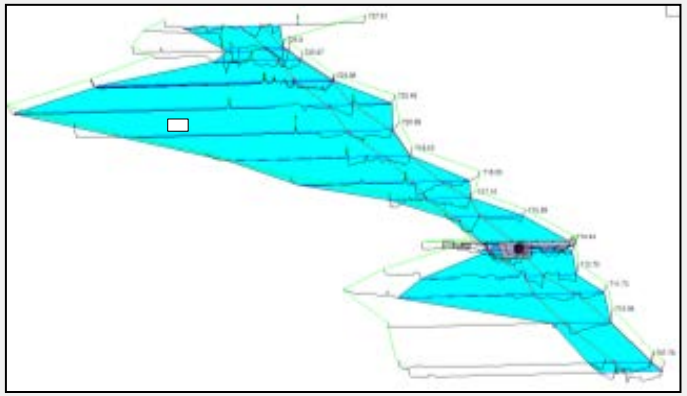
2. Model Flood Heights

- Hydraulic model calibrated to a USGS gage rating curve
- Rating curve extensions possible
- Can be any generally accepted appropriate model



Hydraulic Modeling details



2. Hydraulic Modeling

- Calibrate model to streamgage record and current land cover
  - Well developed rating curves are crucial
- Any appropriate model is accepted
  - USACE HEC-RAS is common
  - Model must be peer-reviewed and documented

- Modeled flood scenarios are chosen to reflect local conditions (bridge conditions, levees, temporary structures, etc.)
- In highly complex flow situations, a 2D model might be warranted

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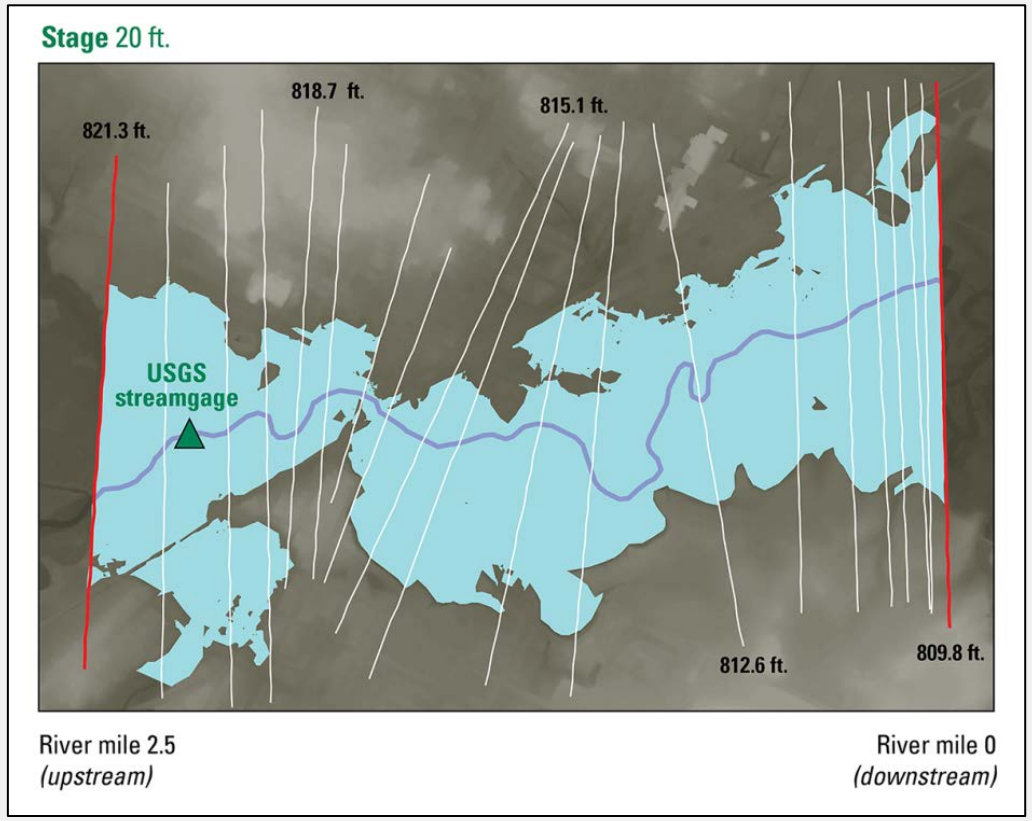
3. Delineate Flood Extents

Geospatial Processing

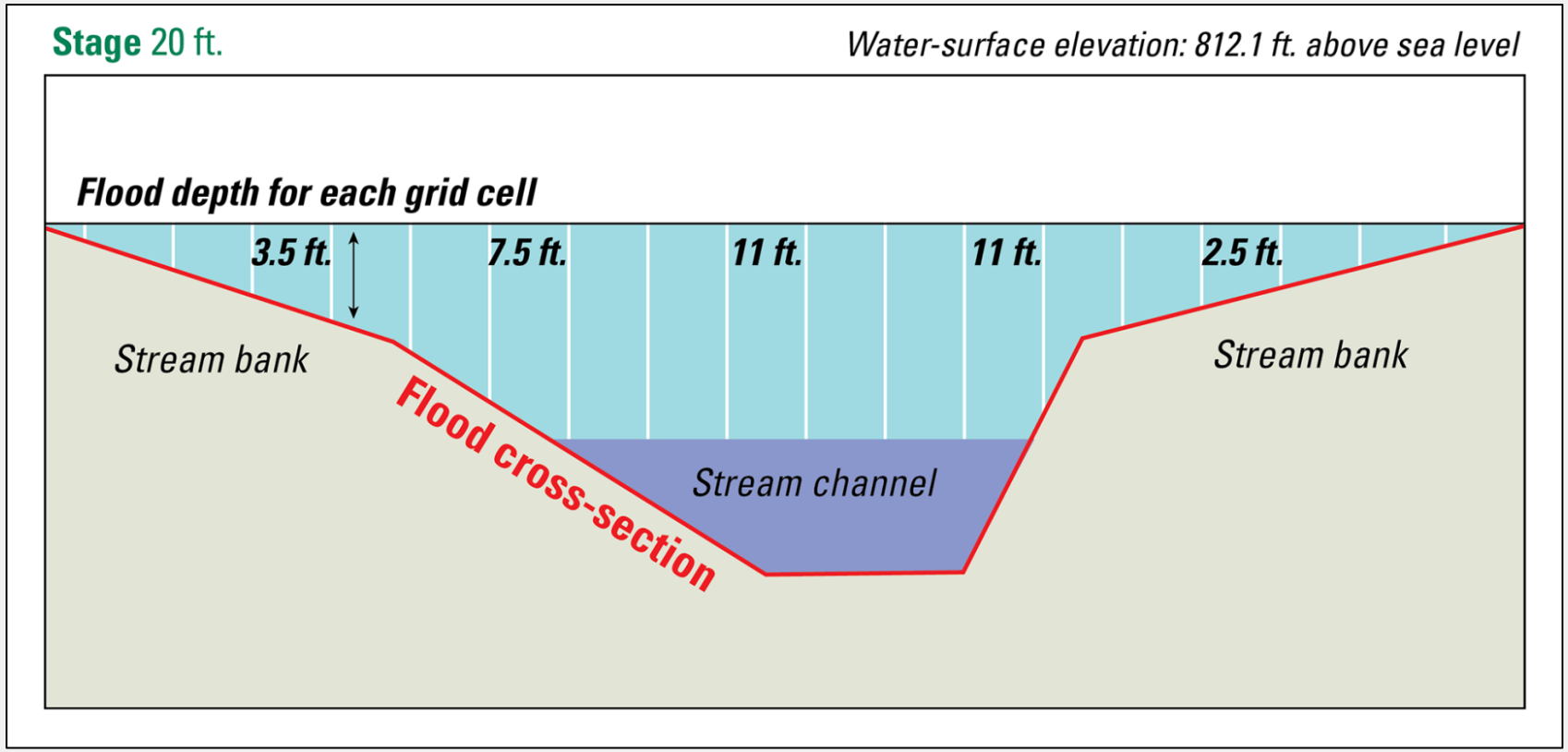
- Create TIN models using cross sections and the modeled water surface profile
- Intersect the TIN with the DEM to generate predicted inundated areas depth grids
- Clean up and QA data

- Repeat for all modeled water surface profiles to generate a library of maps



4. Compute Flood Depths

- **Flood extents are processed with the topographic data to produce estimated depths across the floodplain**



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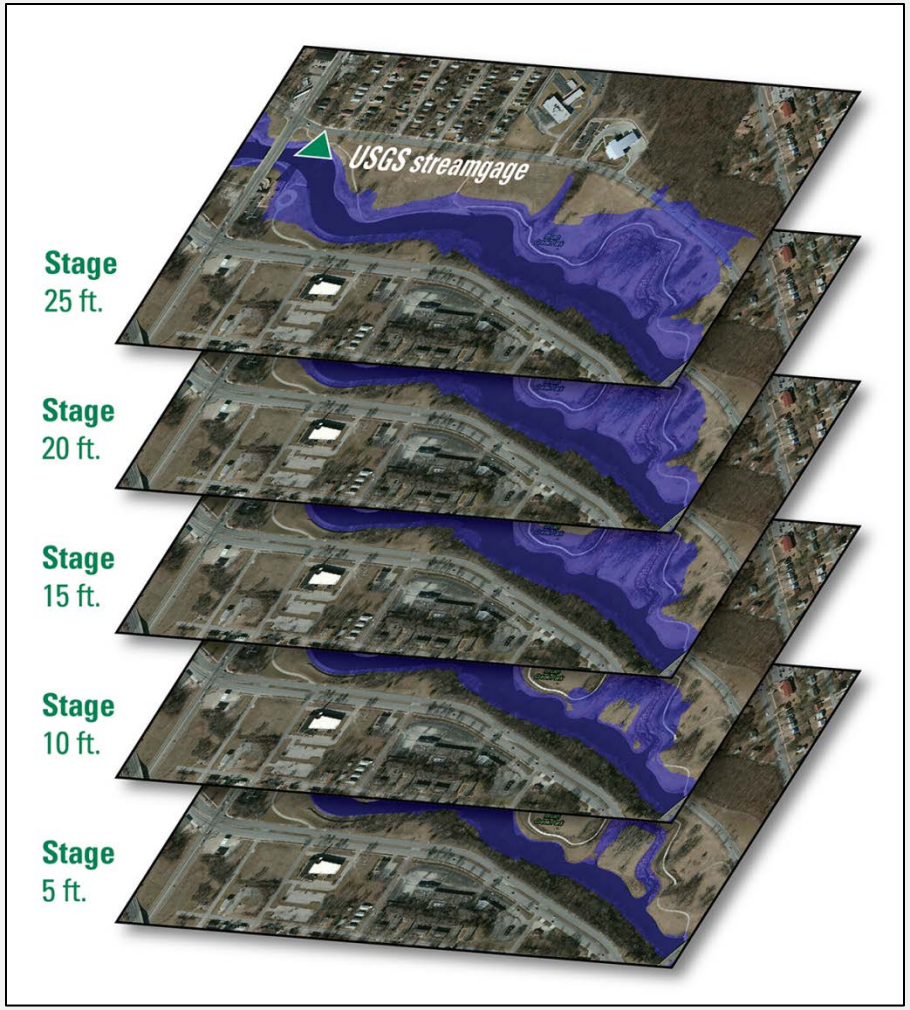
5. Process Map Library

- The hydraulic model, flood extents and flood depths are peer reviewed and documented
- Maps are overlaid onto city maps to aid in planning and response



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Peer-Reviewed Documentation

- **Required:**
  - **Uncertainty and Use Limitations**
  - **Study area and scope**
  - **Hydrologic data**
  - **Hydraulic model calibration and performance**
  - **Accuracy assessment**
  - **Metadata**
- **Recommended:**
  - **Technical Summary Notebook of the hydraulic model**
  - **Project QA/QC checklist completed by the project team**
- **Published to a public website**

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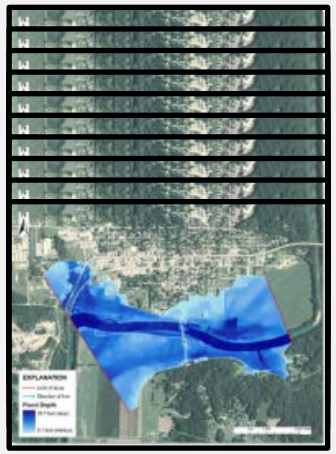
http://water.usgs.gov/osw/flood_inundation/toolbox/librarytools.html

FIM Mapper – more than just maps

Turns the modeled map data into an operational tool by combining data together with tools that enhance the utility and don't require any Modeling or GIS software or skills



Flood Library

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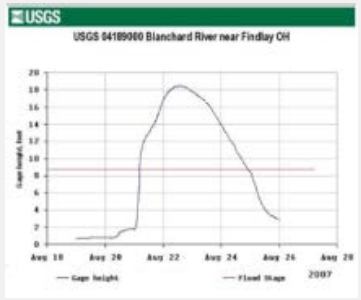

USGS Real-time streamgage

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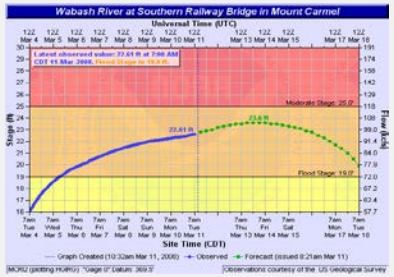
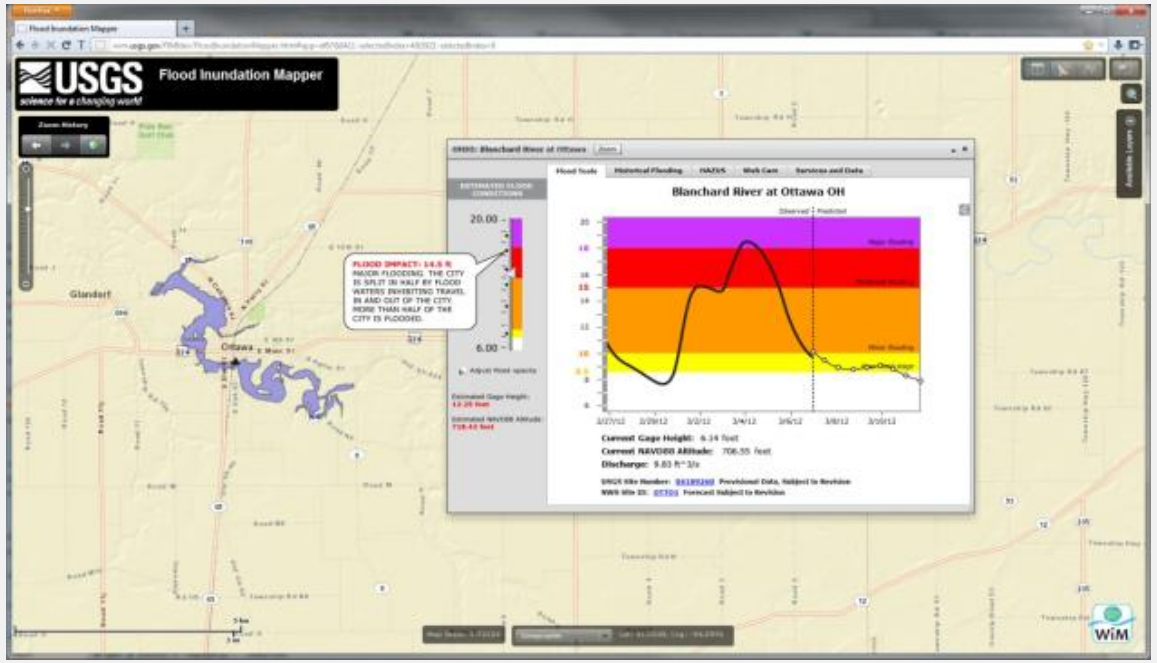
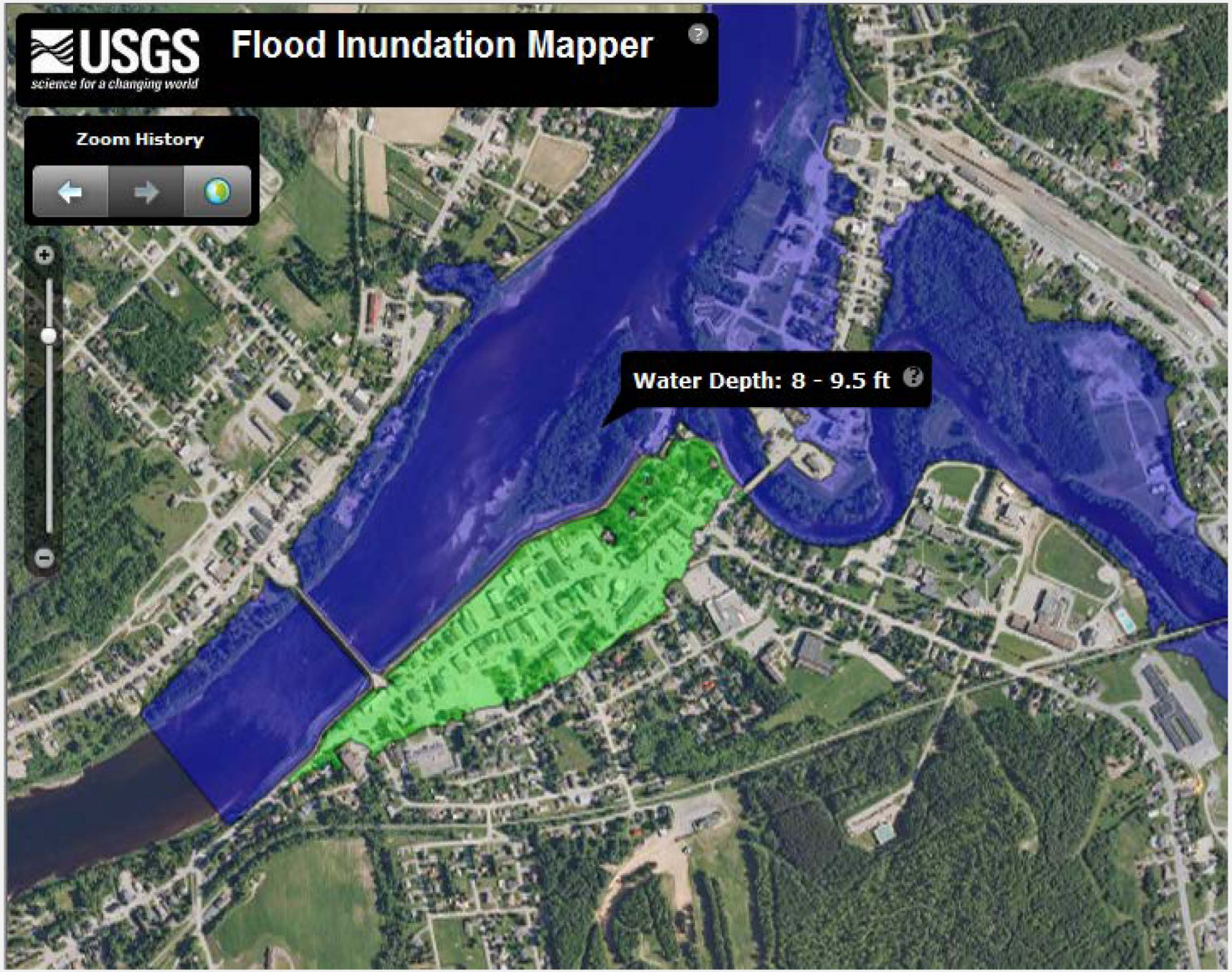
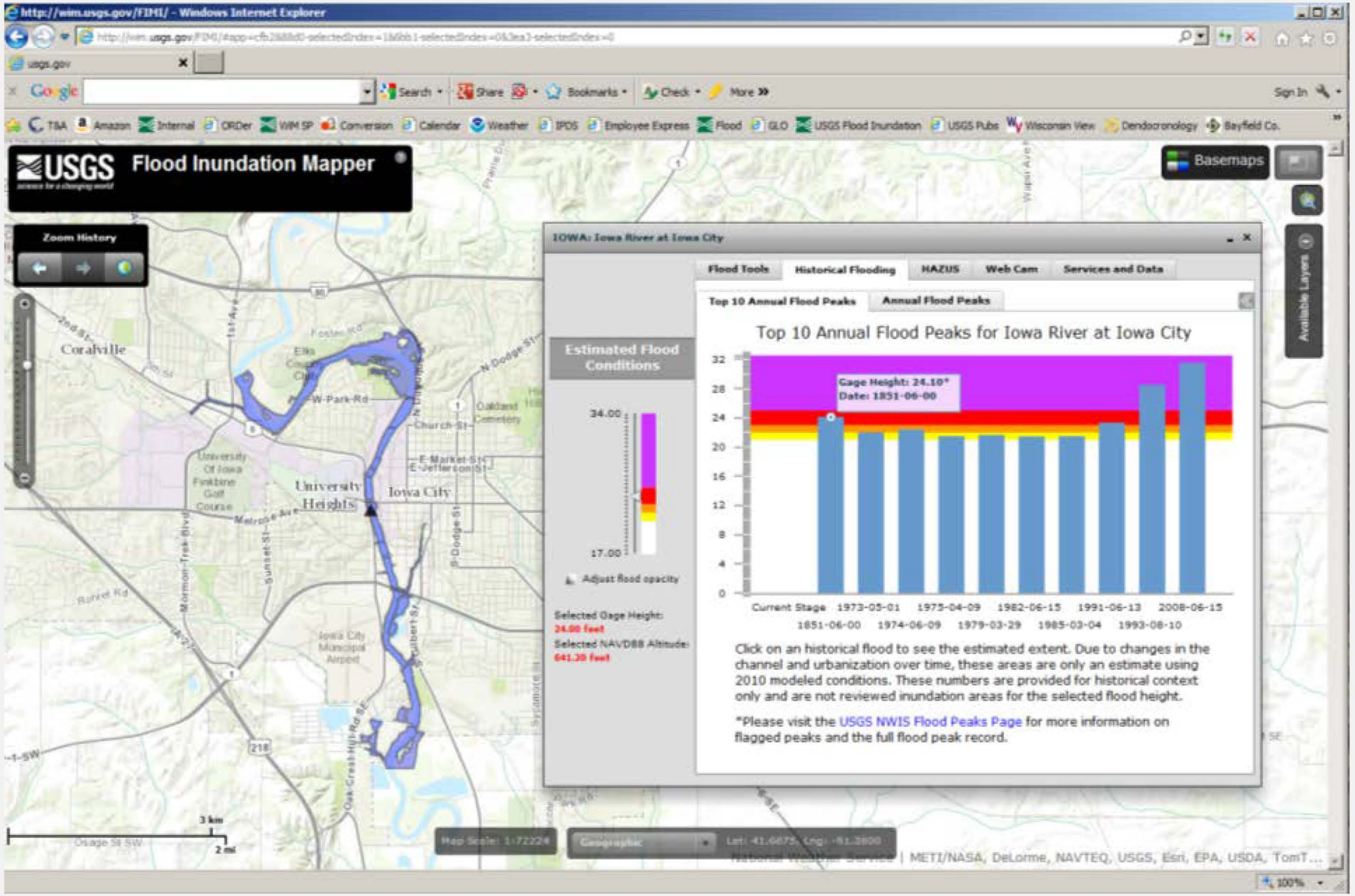


NWS Flood Forecast

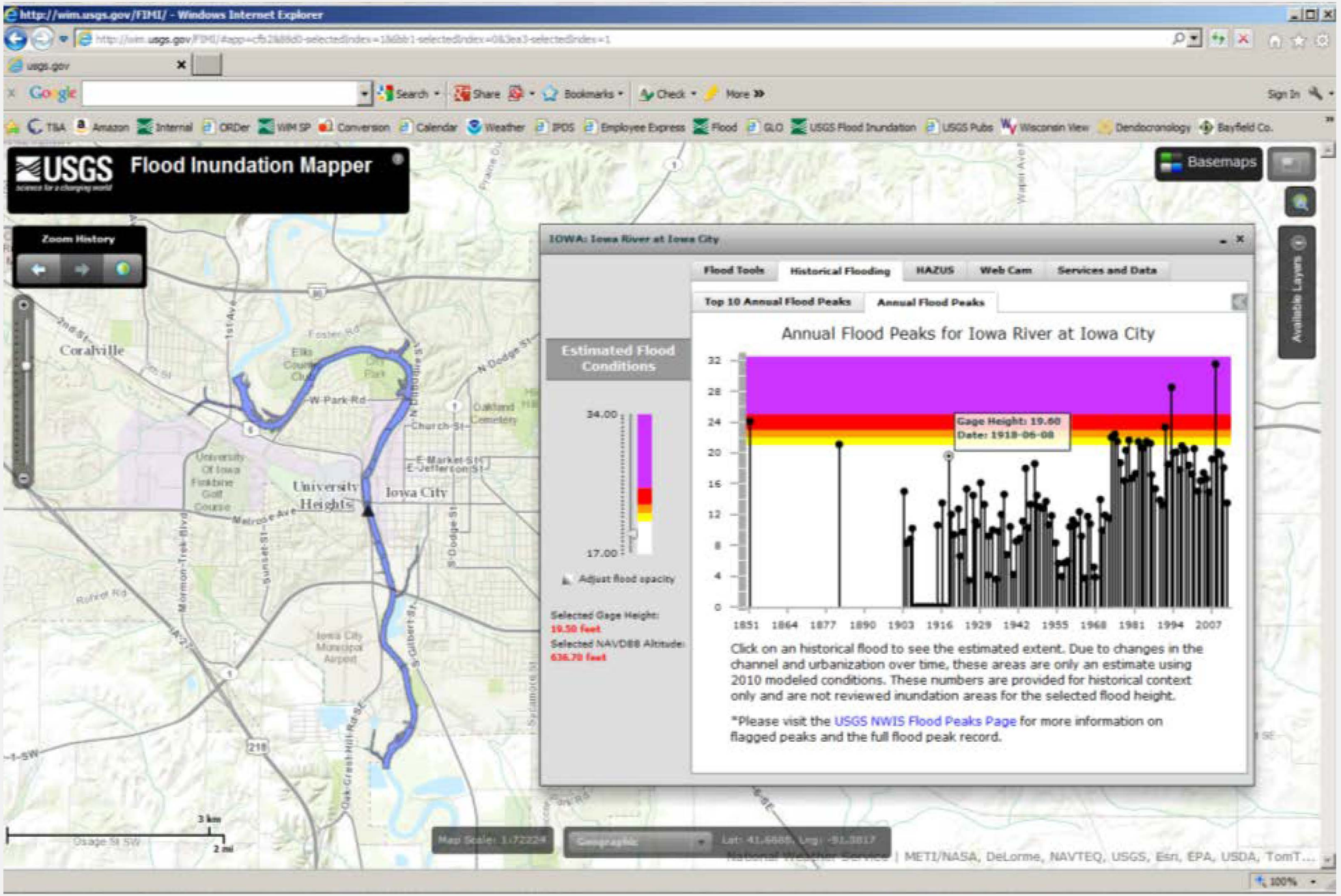



USGS
science for a changing world
Flood Inundation Mapper
Zoom History
Water Depth: 8 - 9.5 ft

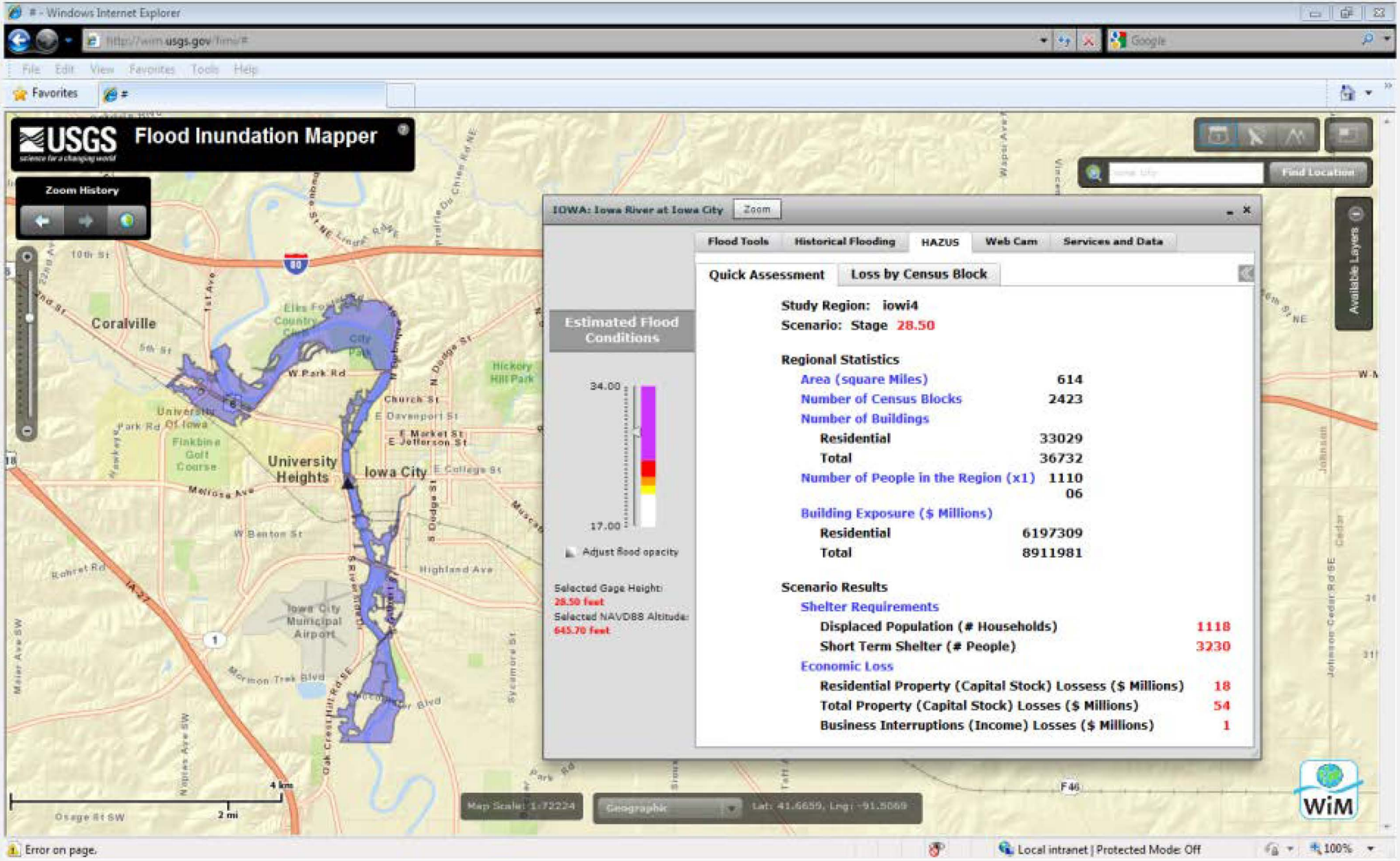
USGS

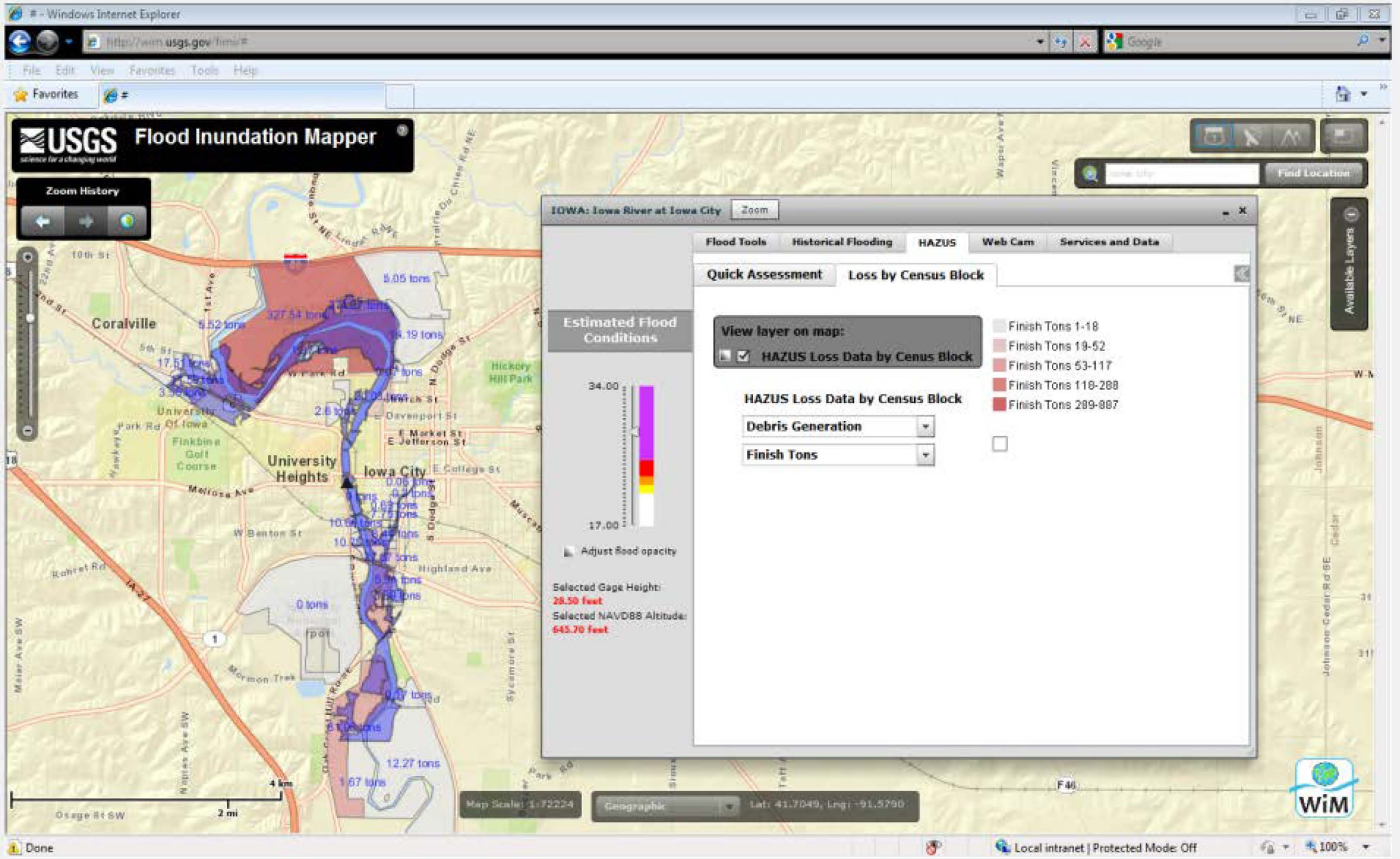

http://wim.usgs.gov/FIMI/ - Windows Internet Explorer
USGS Flood Inundation Mapper
Basemaps
Zoom History
IOWA: Iowa River at Iowa City
Flood Tools
Historical Flooding
HAZUS
Web Cam
Services and Data
Top 10 Annual Flood Peaks
Annual Flood Peaks
Top 10 Annual Flood Peaks for Iowa River at Iowa City
Gage Height: 24.10*
Date: 1851-06-00
Estimated Flood Conditions
34.00
17.00
Adjust flood opacity
Selected Gage Height:
24.00 feet
Selected NAVD88 Altitude:
641.20 feet
Current Stage
1973-05-01
1973-04-09
1982-06-15
1991-06-13
2008-06-15
1851-06-00
1974-06-09
1979-03-29
1985-03-04
1993-08-10
Click on an historical flood to see the estimated extent. Due to changes in the channel and urbanization over time, these areas are only an estimate using 2010 modeled conditions. These numbers are provided for historical context only and are not reviewed inundation areas for the selected flood height.
*Please visit the USGS NWIS Flood Peaks Page for more information on flagged peaks and the full flood peak record.
Coralville
University Heights
Iowa City
3 km
2 mi
METI/NASA, DeLorme, NAVTEQ, USGS, Esri, EPA, USDA, TomT...

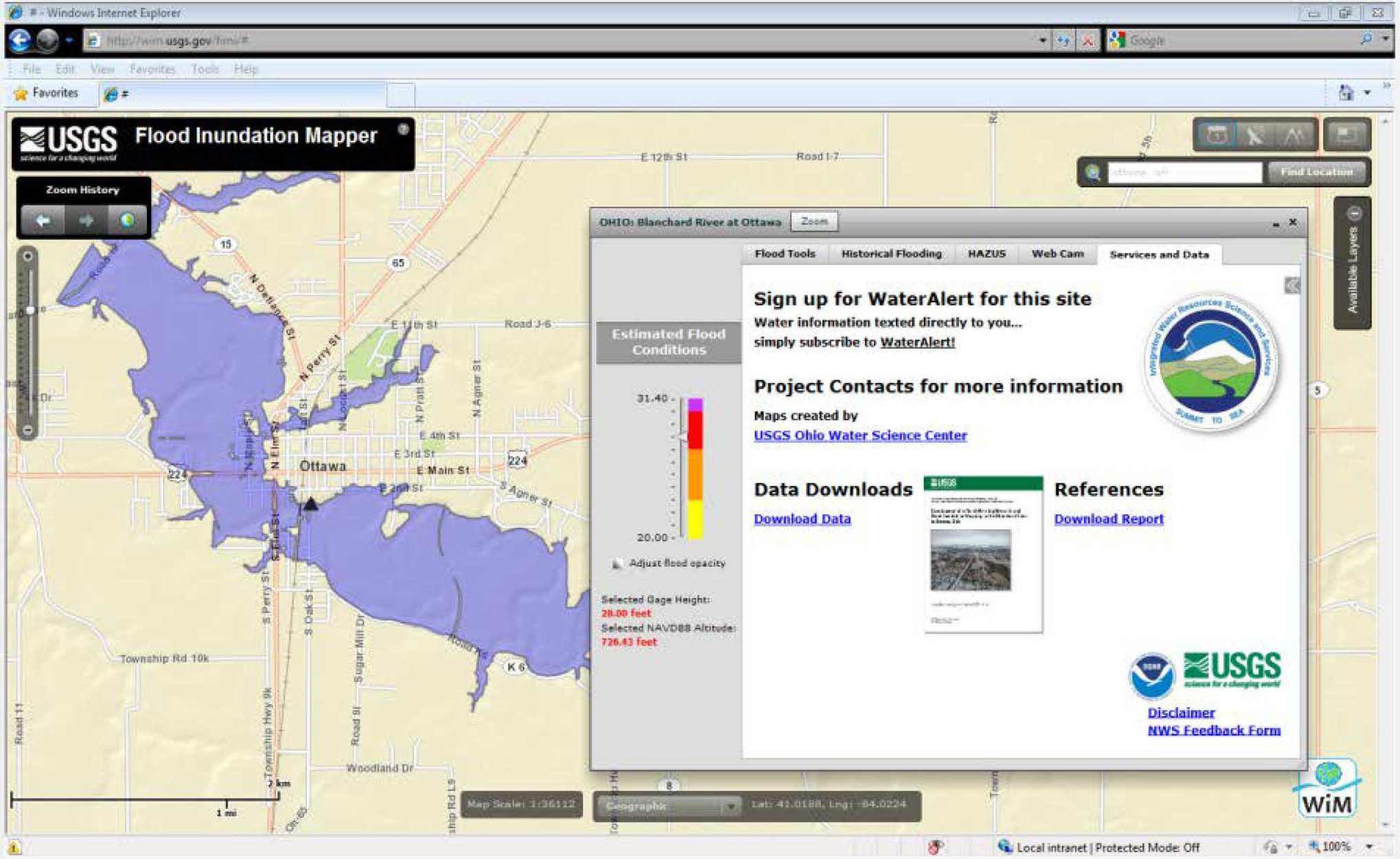
USGS


http://wim.usgs.gov/FIMI/ - Windows Internet Explorer
USGS Flood Inundation Mapper
Basemaps
Zoom History
IOWA: Iowa River at Iowa City
Flood Tools
Historical Flooding
HAZUS
Web Cam
Services and Data
Top 10 Annual Flood Peaks
Annual Flood Peaks
Annual Flood Peaks for Iowa River at Iowa City
Gage Height: 19.60
Date: 1918-06-08
Estimated Flood Conditions
34.00
17.00
Adjust flood opacity
Selected Gage Height:
19.50 feet
Selected NAVD88 Altitude:
636.70 feet
Click on an historical flood to see the estimated extent. Due to changes in the channel and urbanization over time, these areas are only an estimate using 2010 modeled conditions. These numbers are provided for historical context only and are not reviewed inundation areas for the selected flood height.
*Please visit the USGS NWIS Flood Peaks Page for more information on flagged peaks and the full flood peak record.
Available Layers
Coralville
University Heights
Iowa City
Map Scale: 1:72224
METI/NASA, DeLorme, NAVTEQ, USGS, Esri, EPA, USDA, TomT...

USGS

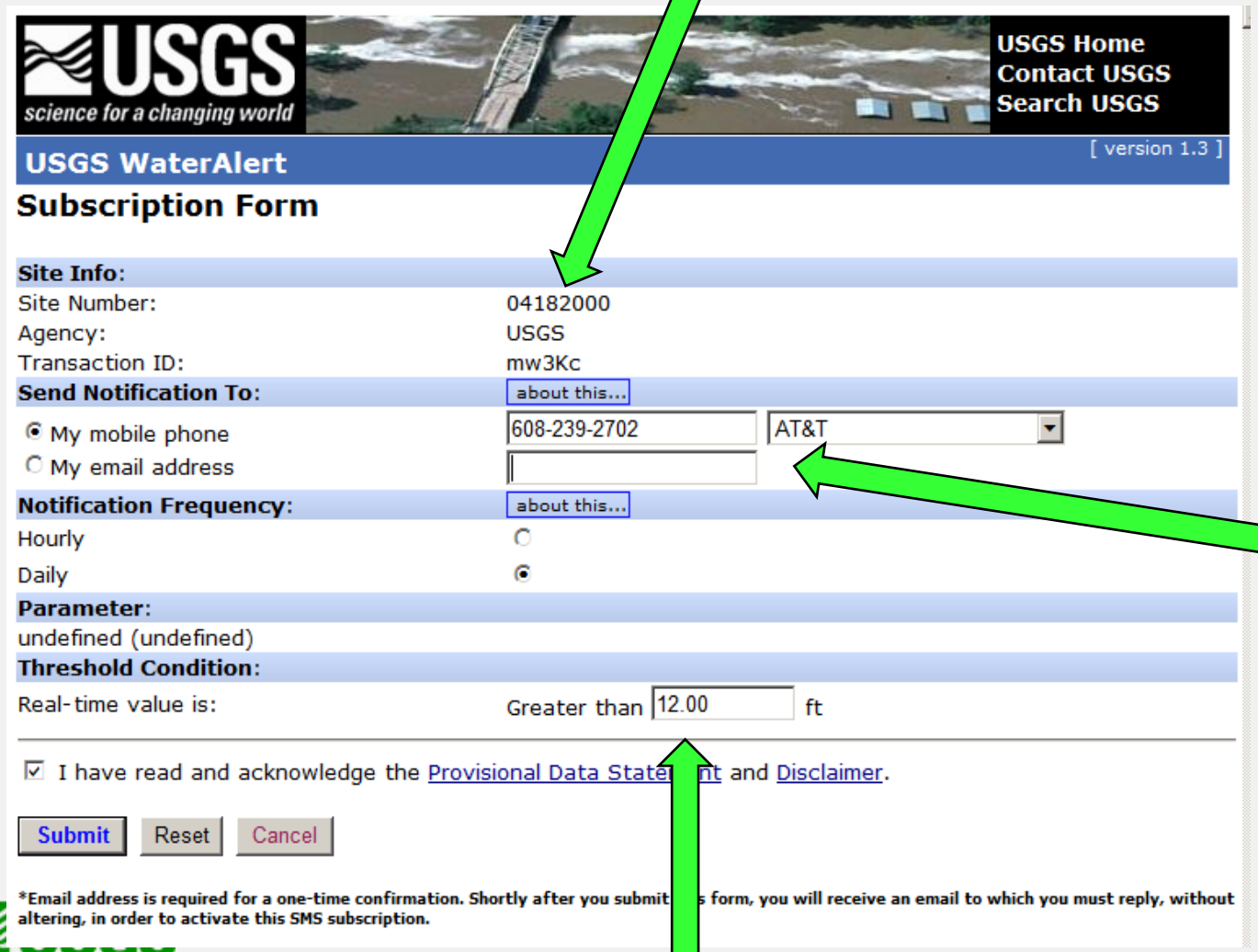

USGS Flood Inundation Mapper
Zoom History
Find Location
Available Layers
IOWA: Iowa River at Iowa City
Zoom
Flood Tools
Historical Flooding
HAZUS
Web Cam
Services and Data
Quick Assessment
Loss by Census Block
Estimated Flood Conditions
34.00
17.00
Adjust flood opacity
Selected Gage Height:
28.50 feet
Selected NAVD88 Altitude:
645.70 feet
Study Region: iowi4
Scenario: Stage 28.50
Regional Statistics
Area (square Miles) 614
Number of Census Blocks 2423
Number of Buildings
Residential 33029
Total 36732
Number of People in the Region (x1) 111006
Building Exposure ($ Millions)
Residential 6197309
Total 8911981
Scenario Results
Shelter Requirements
Displaced Population (# Households) 1118
Short Term Shelter (# People) 3230
Economic Loss
Residential Property (Capital Stock) Lossess ($ Millions) 18
Total Property (Capital Stock) Losses ($ Millions) 54
Business Interruptions (Income) Losses ($ Millions) 1
Coralville
University Heights
Iowa City
Map Scale: 1:72224
Geographic
Lat: 41.6659, Lng: -91.5069
WiM
Error on page.
Local intranet | Protected Mode: Off
100%


USGS Flood Inundation Mapper
Zoom History
Find Location
IOWA: Iowa River at Iowa City
Zoom
Flood Tools
Historical Flooding
HAZUS
Web Cam
Services and Data
Quick Assessment
Loss by Census Block
Estimated Flood Conditions
34.00
17.00
Adjust flood opacity
Selected Gage Height:
28.50 feet
Selected NAVD88 Altitude:
645.70 feet
View layer on map:
HAZUS Loss Data by Census Block
HAZUS Loss Data by Census Block
Debris Generation
Finish Tons
Finish Tons 1-18
Finish Tons 19-52
Finish Tons 53-117
Finish Tons 118-288
Finish Tons 289-887
Available Layers
Coralville
University Heights
Iowa City
Hickory Hill Park
Finkbine Golf Course
Map Scale: 1:72224
Geographic
Lat: 41.7049, Lng: -91.5790
WiM
Done
Local intranet | Protected Mode: Off
100%


Flood Inundation Mapper
Zoom History
Find Location
Available Layers
OHIO: Blanchard River at Ottawa
Zoom
Flood Tools
Historical Flooding
HAZUS
Web Cam
Services and Data
Estimated Flood Conditions
31.40
20.00
Adjust flood opacity
Selected Gage Height:
28.00 feet
Selected NAVD88 Altitude:
726.43 feet
Sign up for WaterAlert for this site
Water information texted directly to you...
simply subscribe to WaterAlert!
Project Contacts for more information
Maps created by
USGS Ohio Water Science Center
Data Downloads
Download Data
References
Download Report
Disclaimer
NWS Feedback Form
Ottawa
E 12th St
Road I-7
E 11th St
Road J-6
E 4th St
E 3rd St
E Main St
E 2nd St
N Perry St
N Agner St
S Agner St
S Perry St
S Oak St
Sugar Mill Dr
Township Rd 10k
Township Hwy 9k
Road 11
Road 51
Woodland Dr
Map Scale: 1:36112
Geographic
Lat: 41.0188, Lng: -84.0224
WiM
Local intranet | Protected Mode: Off
100%

WaterAlert form

Site number, sent by mapper



Personal info

Threshold level, selected by mapper

U.S. Department of the Interior
U.S. Geological Survey

Scientific Investigations Map 3232
Map Notes and Uses

Report accompanies map

Flood-Inundation Map for the Wabash River at Terre Haute, Indiana at the U.S. Geological Survey Streamgage Number 03341500

UNCERTAINTY AND USE LIMITATIONS

Although the flood-inundation maps represent the boundaries of inundated areas with a distinct line, some uncertainty is associated with these maps. The flood boundaries shown were estimated based on gage heights at selected USGS streamgages. Water-surface elevations along the stream reaches were estimated by steady-state hydraulic modeling, assuming unobstructed flow and using discharges and hydrologic conditions anticipated at the USGS streamgage(s). The hydraulic model reflects the land-cover characteristics of any bridge, dam, levee, or other hydraulic structure existing in 2012. Unique meteorological factors (timing and distribution of precipitation) may cause actual discharges along the modeled reach to vary from assumed conditions during a flood and lead to deviations in the water-surface elevations and inundation boundaries shown. Additional areas may be flooded due to unanticipated backwater from major tributaries along the main stem or from localized debris or ice jams.

STUDY AREA

The city of Terre Haute, Indiana (Ind.), is in central Vigo County and is the county seat of government. The Wabash River forms the western boundary of the corpo¬rate limits of Terre Haute. The drainage area is 12, 263 square miles at the Terre Haute streamgage. The Wabash River had instances of severe flooding in 1913, 1943, 1950, 1958, 1959, and 2005.

PURPOSE AND SCOPE

The purpose of this report is to describe the develop¬ment of a series of estimated flood-inundation maps for a 6.3-mile reach of the Wabash River near Terre Haute, Ind., and to make these maps available to emergency workers and the public by way of the USGS Flood Inundation Mapping Science Web site at http://water.usgs.gov/oswflood_inundation/.

MAP SOURCES

Detailed source data for this map series can be found in "Flood-inundation maps for the Wabash River at Terre Haute, Indiana (2013)" at: http://pubs.usgs.gov/sim/3232/

Suggested citation:
Lombard, P.J., 2013, Flood-inundation maps for the Wabash River at Terre Haute, Indiana: U.S. Geological Survey Scientific Investigations Map 3232, 22 sheets, 7-p. pamphlet

HYDROLOGIC DATA

The study area hydrologic network consists of one streamgage, Wabash River at Terre Haute (station number 03341500) that has been operated by the USGS continuously since 1927, although the actual streamgage location was moved in 1985. Water level (stage) is measured continuously and continuous records of streamflow are computed at this streamgage. Steady-flow data consisted of flow regime, boundary conditions, and peak discharge information, the latter obtained from field measurements and the stage-discharge relation that was developed by the USGS at the Wabash River at Terre Haute streamgage.

HYDRAULIC MODEL

The hydraulic model was calibrated to the most current stage-discharge relation at the Wabash River at Terre Haute streamgage. Model calibration was accomplished by adjusting Manning's n values until the results of the hydraulic computations closely agreed with the known flood discharge and stage values. Differences between measured and simu-lated water levels for specified flows were equal to or less than 0.1 foot (ft).

WATER-SURFACE PROFILES

Profiles were developed for a total of 22 stages at 1-ft intervals between and including 9 ft (action stage) and 30 ft (flood of record) as referenced to the Wabash River at Terre Haute streamgage (station number 03341500). Discharges correspond-ing to the various stages were obtained from the most current stage-discharge relation (rating 55.1) at the streamgage. The streamgage is near the midpoint of the 6-mile reach.

FLOOD-INUNDATION MAPS

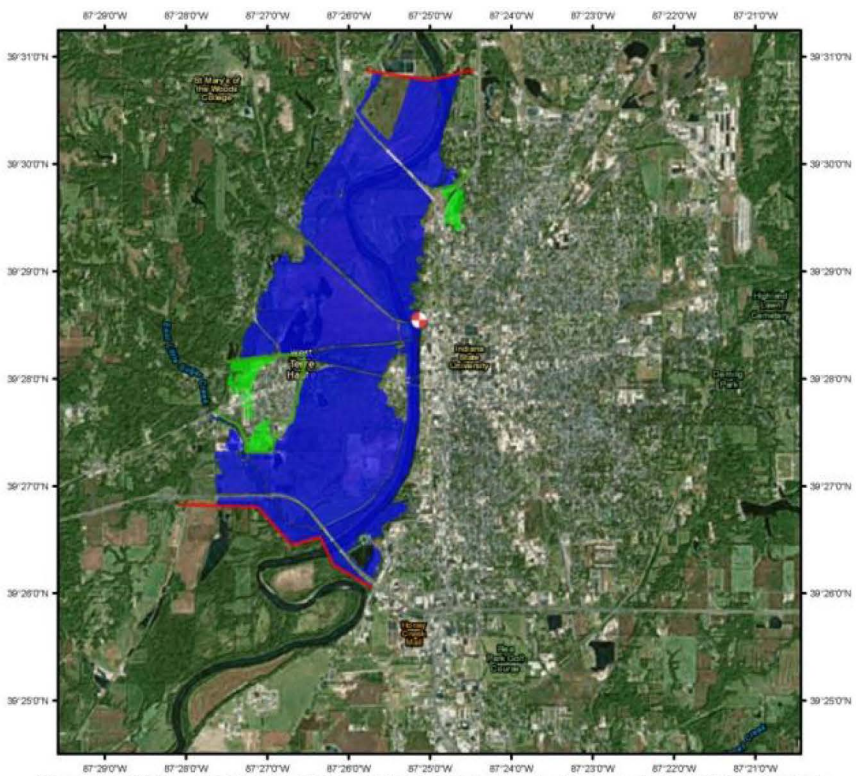
The inundation maps were created in a geographic information system (GIS) by combining the water-surface profiles and digital elevation model (DEM) data. The DEM data were derived from light detection and ranging (LiDAR) data that had a horizontal accuracy of 1.02 ft and a vertical accuracy of 0.37 ft.

DISCLAIMER

The flood maps should not be used for navigation, regulatory, permitting, or other legal purposes. The United States Geological Survey (USGS) provides these maps as a quick reference and emergency planning tool but assumes no legal liability or responsibility for any direct, indirect, incidental, consequential, special, or exemplary damages or lost profit resulting from the use or misuse of this information.

U.S. Department of the Interior
U.S. Geological Survey

Scientific Investigations Map 3232
Report accompanies map



Flood-Inundation Map for the Wabash River at Terre Haute, Indiana at the U.S. Geological Survey Streamgage Number 03341500

Map corresponding to a Gage Height of 23.00 feet and an Elevation of 468.40 feet (NAVD 88)

Projection: Web Mercator (WGS84)
Please visit http://water.usgs.gov/oswflood_inundation/ for full map library.

1.5 0.75 0 1.5 MILES
2 1 0 2 KILOMETERS

NORTH AMERICAN VERTICAL DATUM 1988 (NAVD88)

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
Sources: Esri, DeLorme, USGS, NPS

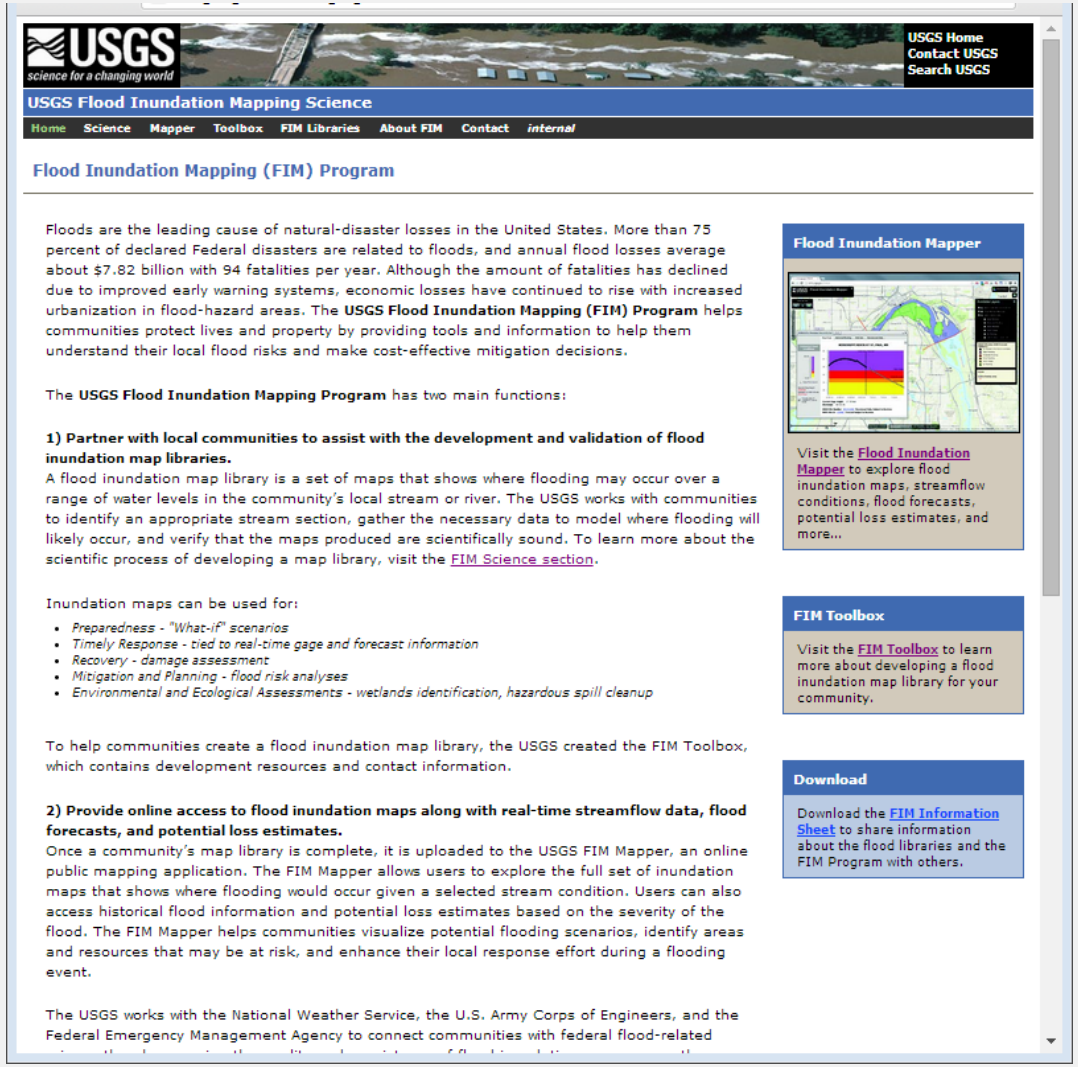
EXPLANATION

- Flood-inundation area
- Area of uncertainty due to levee (where applicable)
- Levee
- Study area boundary
- USGS streamgage and NWS forecast site (if applicable)

LOCATION

Website Resources

- Outline of FIM Science and library development processes
  - Toolbox
- Information Sheet
  - Two page pdf
- Mapper
- Training

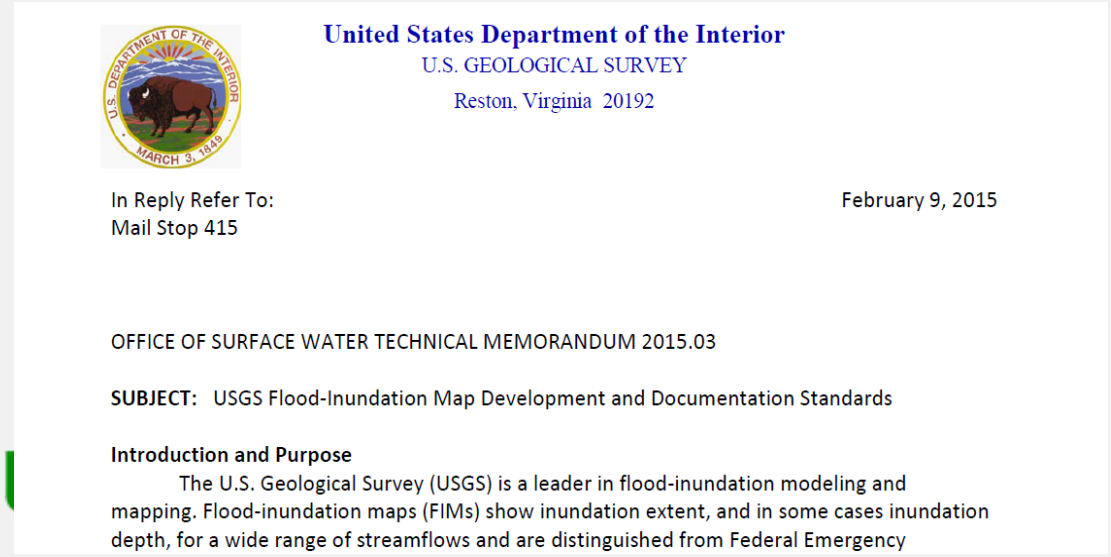


USGS

Surface Water Tech Memorandum 2015.03

USGS Flood-Inundation Map Development and Documentation Standards

- At a USGS gage
- Starts with NWS guidelines but with 10 exceptions/additions
- Documentation
- Peer-review



United States Department of the Interior
U.S. GEOLOGICAL SURVEY
Reston, Virginia 20192

In Reply Refer To:
Mail Stop 415

February 9, 2015

OFFICE OF SURFACE WATER TECHNICAL MEMORANDUM 2015.03

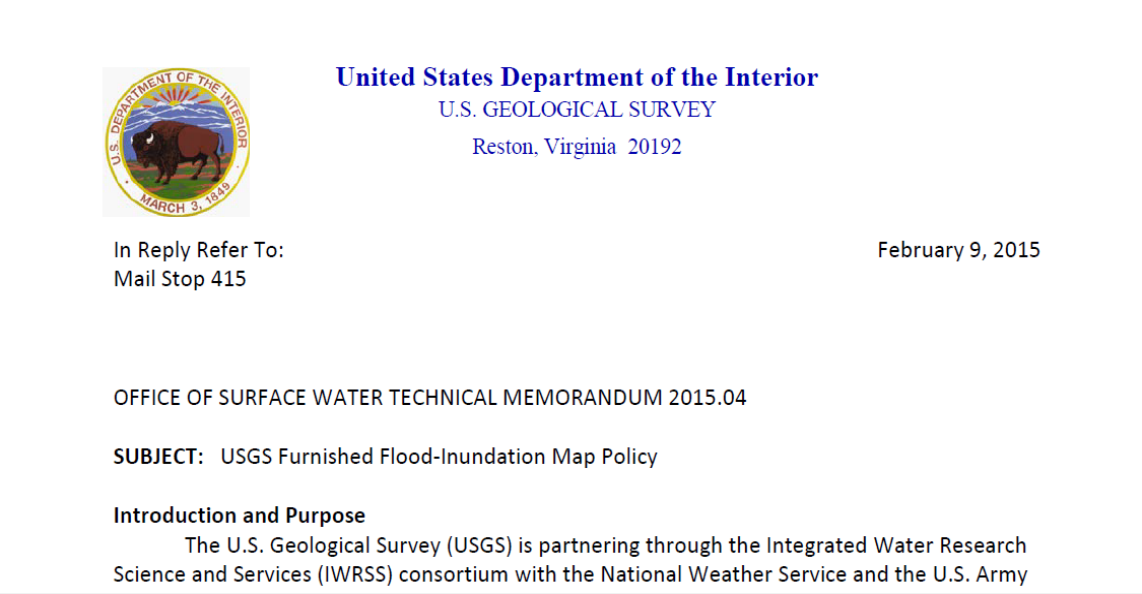
SUBJECT: USGS Flood-Inundation Map Development and Documentation Standards

Introduction and Purpose

The U.S. Geological Survey (USGS) is a leader in flood-inundation modeling and mapping. Flood-inundation maps (FIMs) show inundation extent, and in some cases inundation depth, for a wide range of streamflows and are distinguished from Federal Emergency

Surface Water Tech Memorandum 2015.04

- **<u>USGS Furnished Flood-Inundation Map Policy</u>**
- **First approved in Idaho, Dec, 2015**
- **At a USGS gage**
- **Meets USGS Requirements**
- **Work with local USGS Water Science Center**



United States Department of the Interior
U.S. GEOLOGICAL SURVEY
Reston, Virginia 20192

In Reply Refer To:
Mail Stop 415

February 9, 2015

OFFICE OF SURFACE WATER TECHNICAL MEMORANDUM 2015.04

SUBJECT: USGS Furnished Flood-Inundation Map Policy

Introduction and Purpose

The U.S. Geological Survey (USGS) is partnering through the Integrated Water Research Science and Services (IWRSS) consortium with the National Weather Service and the U.S. Army