A Predictive Design Approach to Resiliency

Resiliency for Stormwater Professionals

April 26, 2019

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Practice Leader – Stormwater and Floodplain Management
Metro Nashville Water Services

Resiliency Defined

- The Capacity to Recover Quickly
- The Ability to Bounce Back
- On a continuing basis, the CRS Program will lead your city to a state of increased resilience, and reduce your vulnerability to floods

May 2010, Nashville

Photo: The Tennessean

Photo: WKRN

May 2010, Nashville

I-24

May 2010, Nashville

Downtown

Photo: Larry McCormack, The Tennessean

May 2010, Nashville

Opryland Hotel and Opry Mills Mall

Photo: Samuel M. Simpkins, The Tennessean

May 2010, Nashville

Opryland Hotel

May 2010, Nashville

Titans Stadium

As a City Considers Resilience and Readiness…..

We must assume that the next big event
is right around the corner….

Extreme Events – Occurring with unsettling regularity

- Rain Bombs
- Atmospheric Rivers
- Snow or Bomb Cyclones
  - Winter Storm Ulmer….set records for low pressure and extreme winds
  - Led to extreme snowfall, followed by warm weather, rapid snowmelt, and extreme flooding in the plains

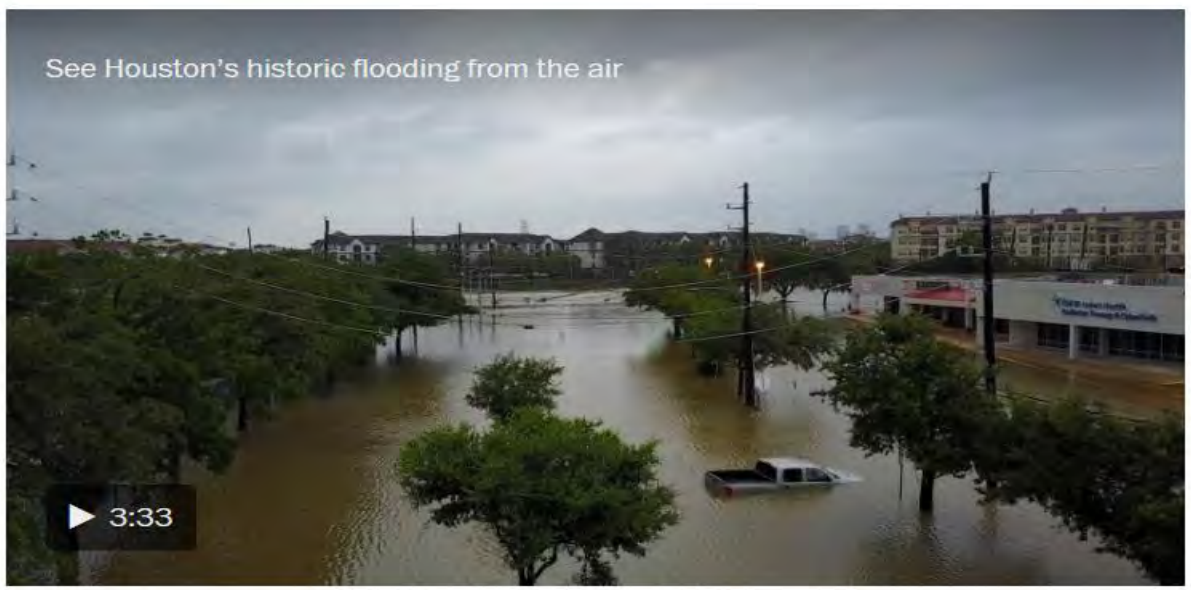
A Rain Bomb….over Phoenix

The Washington Post
Democracy Dies in Darkness

Wonkblog • Analysis

Houston is experiencing its third '500-year' flood in 3 years. How is that possible?

By Christopher Ingraham August 29, 2017 Email the author



This drone video taken Aug. 27 shows the historic flooding in Houston caused by Hurricane Harvey.
(ahmed.gul/Instagram)

THE WALL STREET JOURNAL.

U.S.

Historic Maryland Town Hit by a Second Devastating Flood Since 2016

National Guardsman reported missing in Ellicott City; some businesses not sure they can recover again

The second flash flood in two years hit Ellicott City, Md., on Sunday, sweeping away cars and covering streets in mud. Photo: Getty

The Washington Post
Democracy Dies in Darkness

Capital Weather Gang

Cedar Rapids, Iowa, braces for second biggest river flood on record

By Jason Samenow September 26, 2016 Email the author

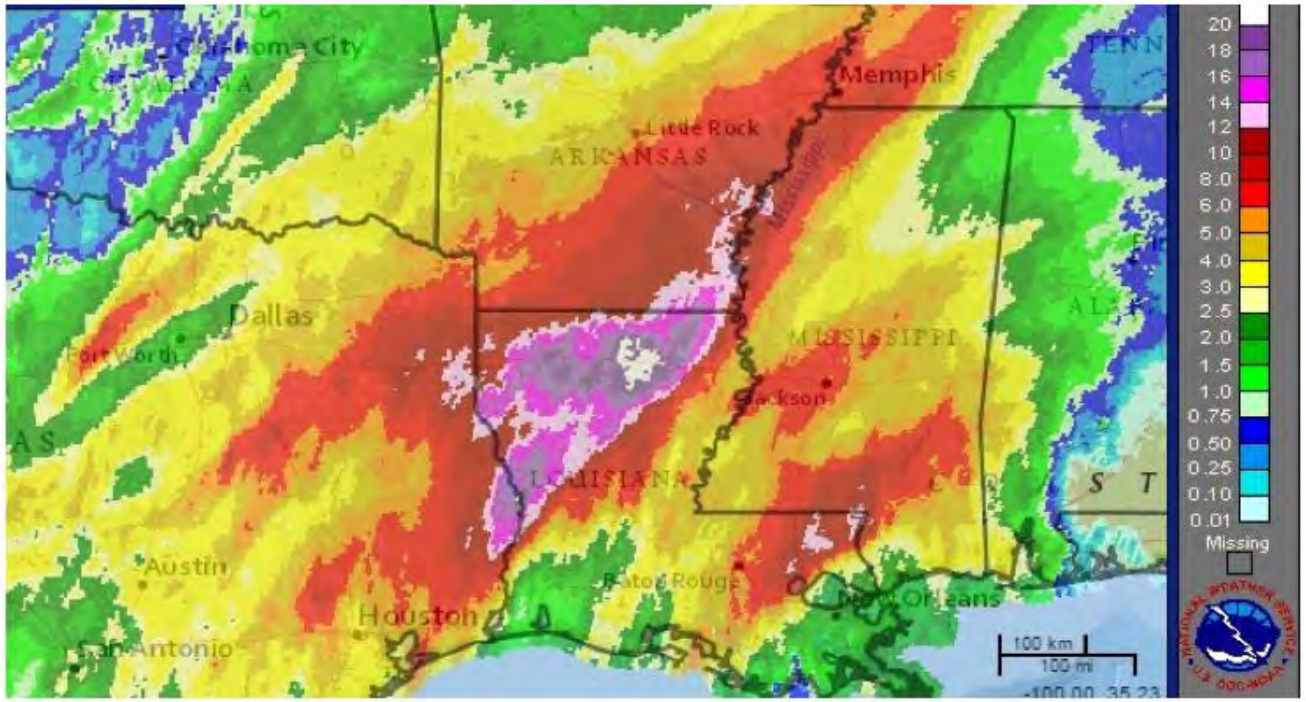
Jason Mann, of Cedar Rapids, Iowa, loads sandbags onto a truck in the New Bohemia District, on Sept. 23. (David Scrivner /Iowa City Press-Citizen via AP)

The Washington Post
Democracy Dies in Darkness

Capital Weather Gang

State of emergency in Louisiana, as atmospheric river unloads disastrous rains

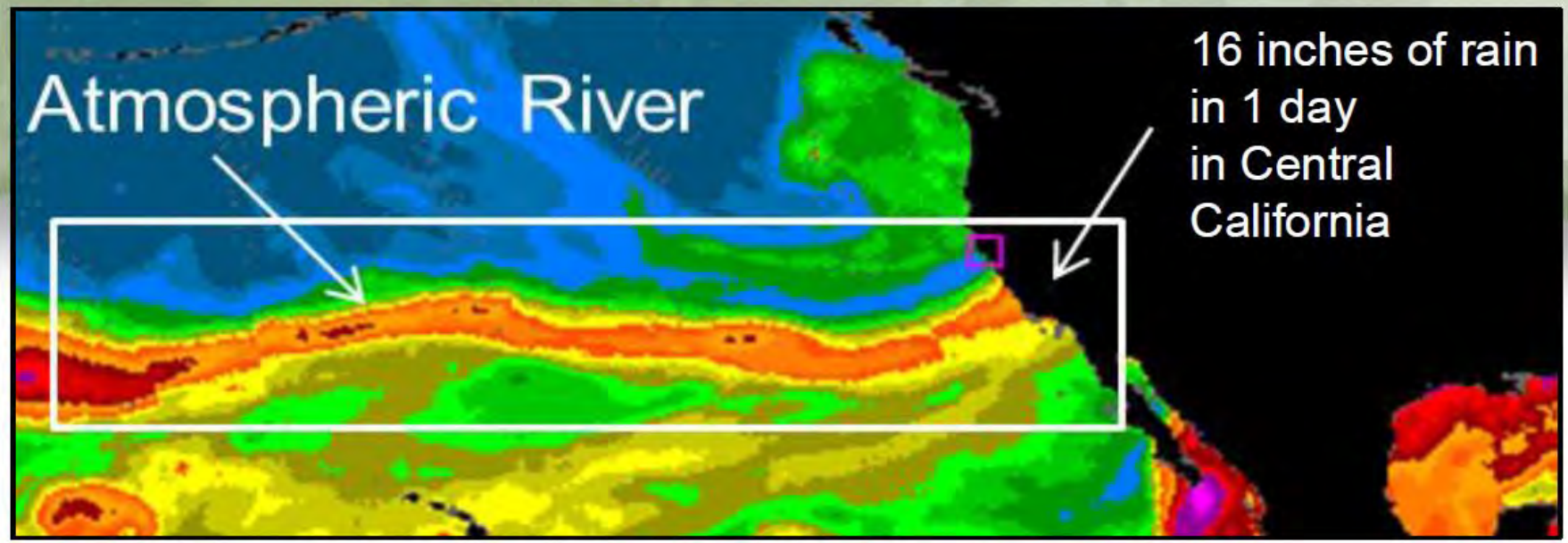
By Jason Samenow March 11, 2016 Email the author



Doppler estimated rainfall over the last four days in South Central U.S. (NWS)

Up to two feet of rain have fallen in Louisiana and three people have died, as historic flood event swamps parts of the South and Gulf Coast states.

Atmospheric Rivers

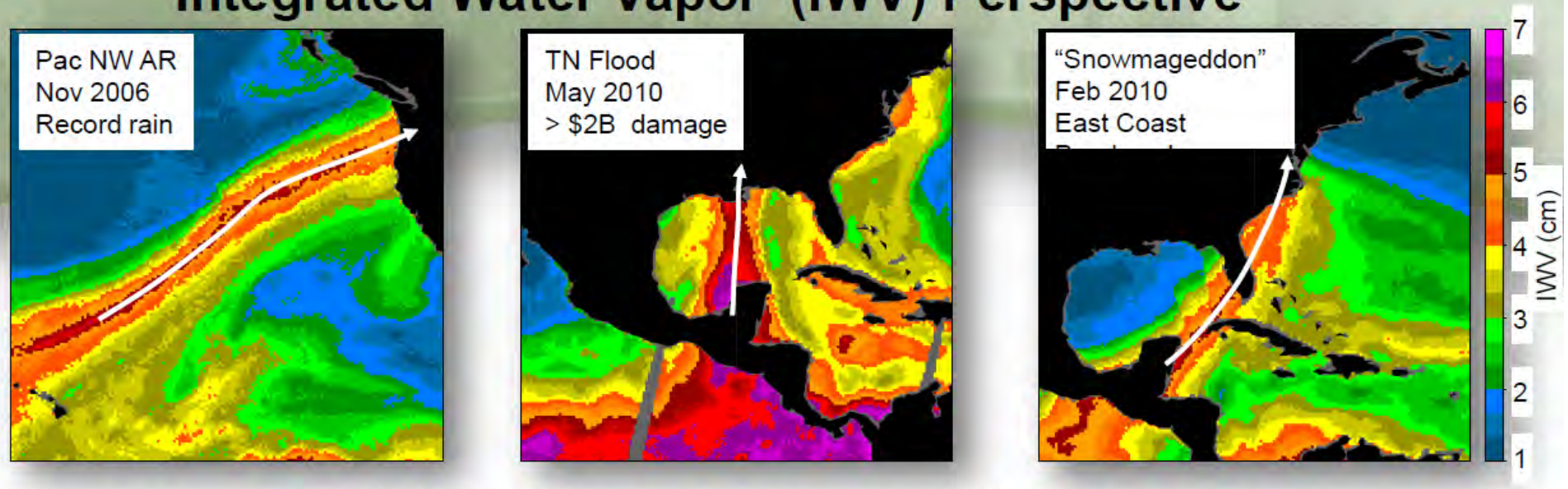


- A narrow "conveyor belt" of water vapor extending from thousands of miles out at sea, carrying, on average, ~10 Mississippi Rivers
- Generally provide 35-50% of annual rainfall across California

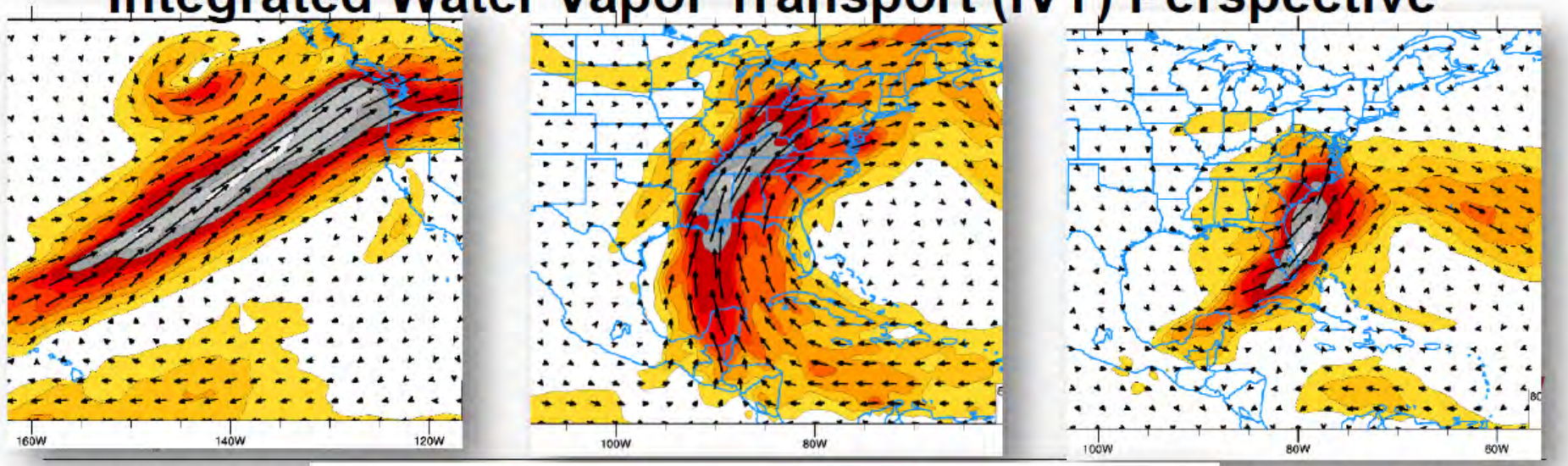
*Dettinger et al., Atmospheric Rivers, "Floods and the Water Resources of California," **Water**, 2011*

Atmospheric Rivers: Not just a West Coast Issue

Integrated Water Vapor (IWV) Perspective



Integrated Water Vapor Transport (IVT) Perspective

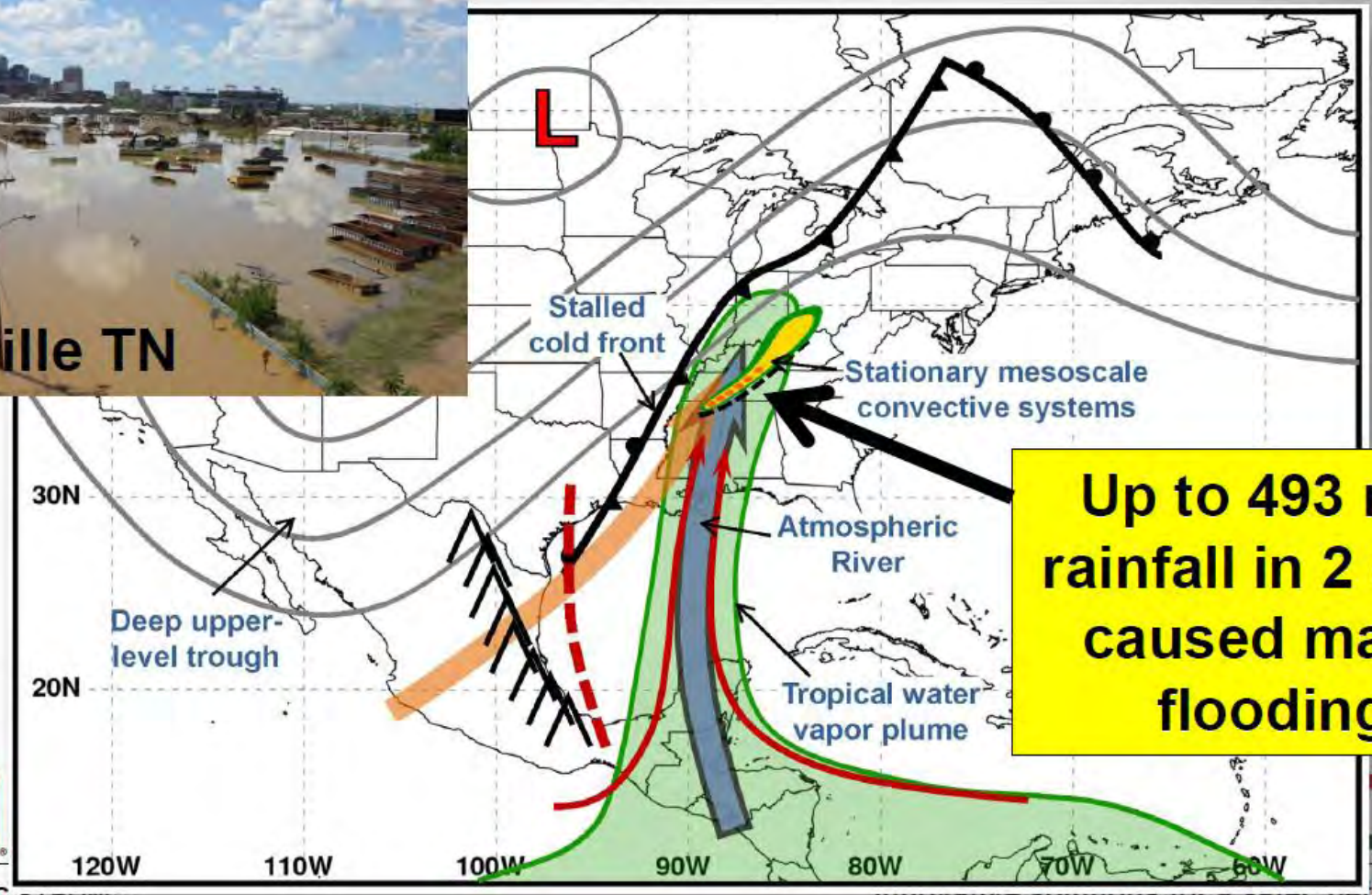


Slide courtesy Marty Ralph

Physical Processes Associated with Heavy Flooding Rainfall in Nashville, Tennessee, and Vicinity during 1–2 May 2010: The Role of an Atmospheric River and Mesoscale Convective Systems

Ben Moore, Paul Neiman, Marty Ralph, Faye Barthold

Monthly Weather Review (2012)



Up to 493 mm rainfall in 2 days caused major flooding

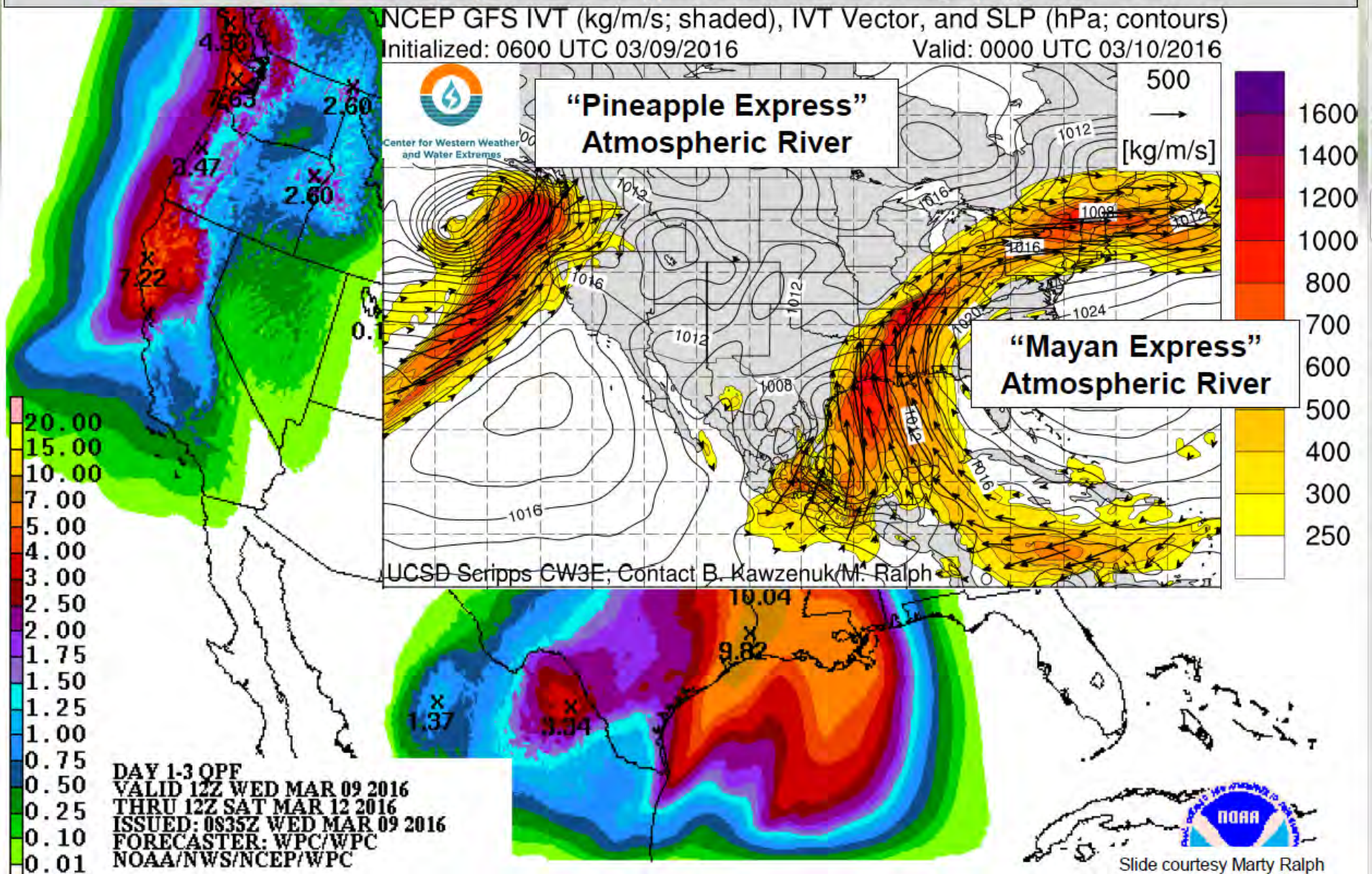
BUILDING STRONG®

Innovative solutions for a safer, better world

Slide courtesy Marty Ralph

Atmospheric rivers and current extreme precipitation events in the Southeast & West Coast

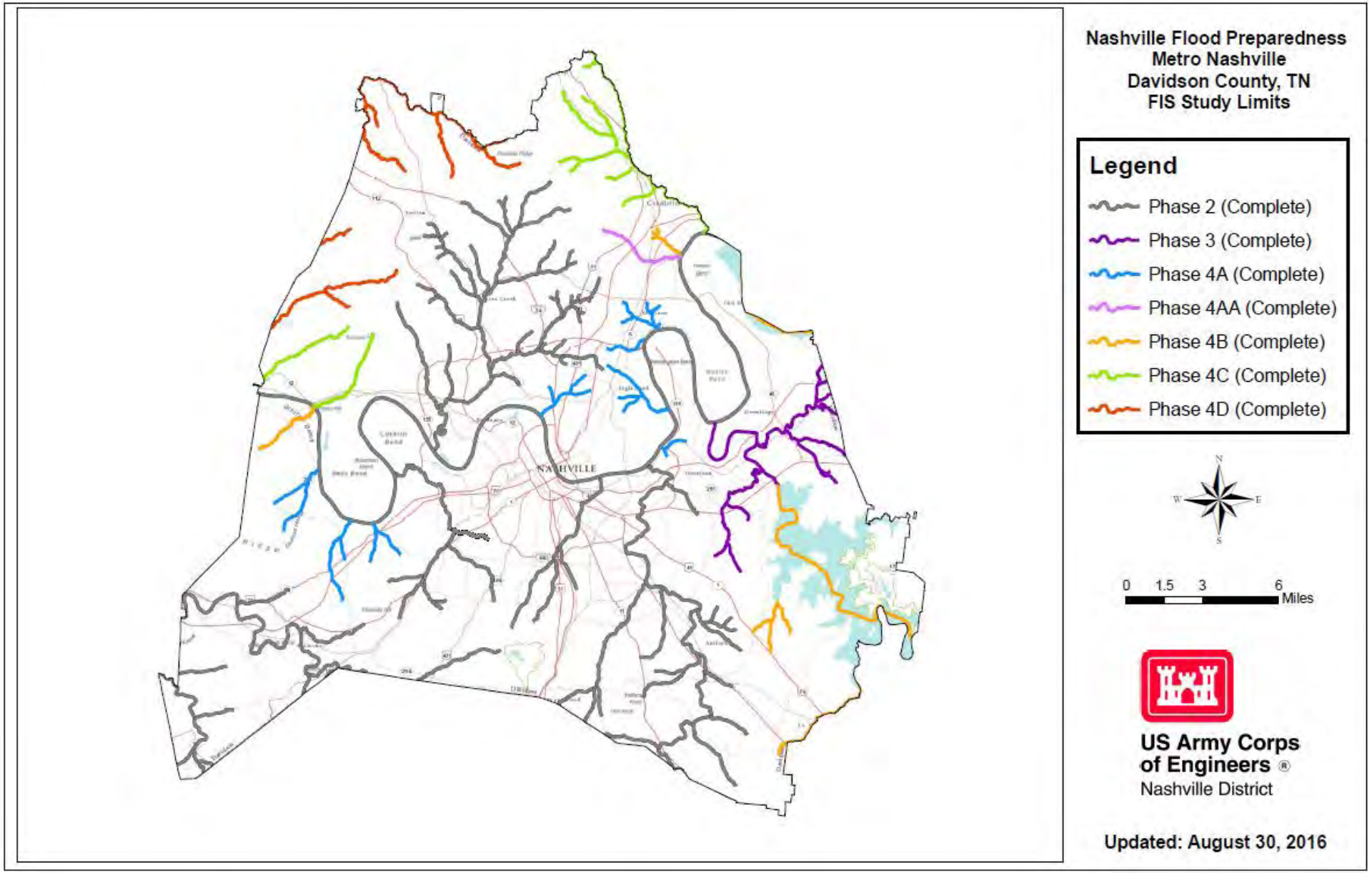
F. M. Ralph (CW3E at Scripps Institution of Oceanography)



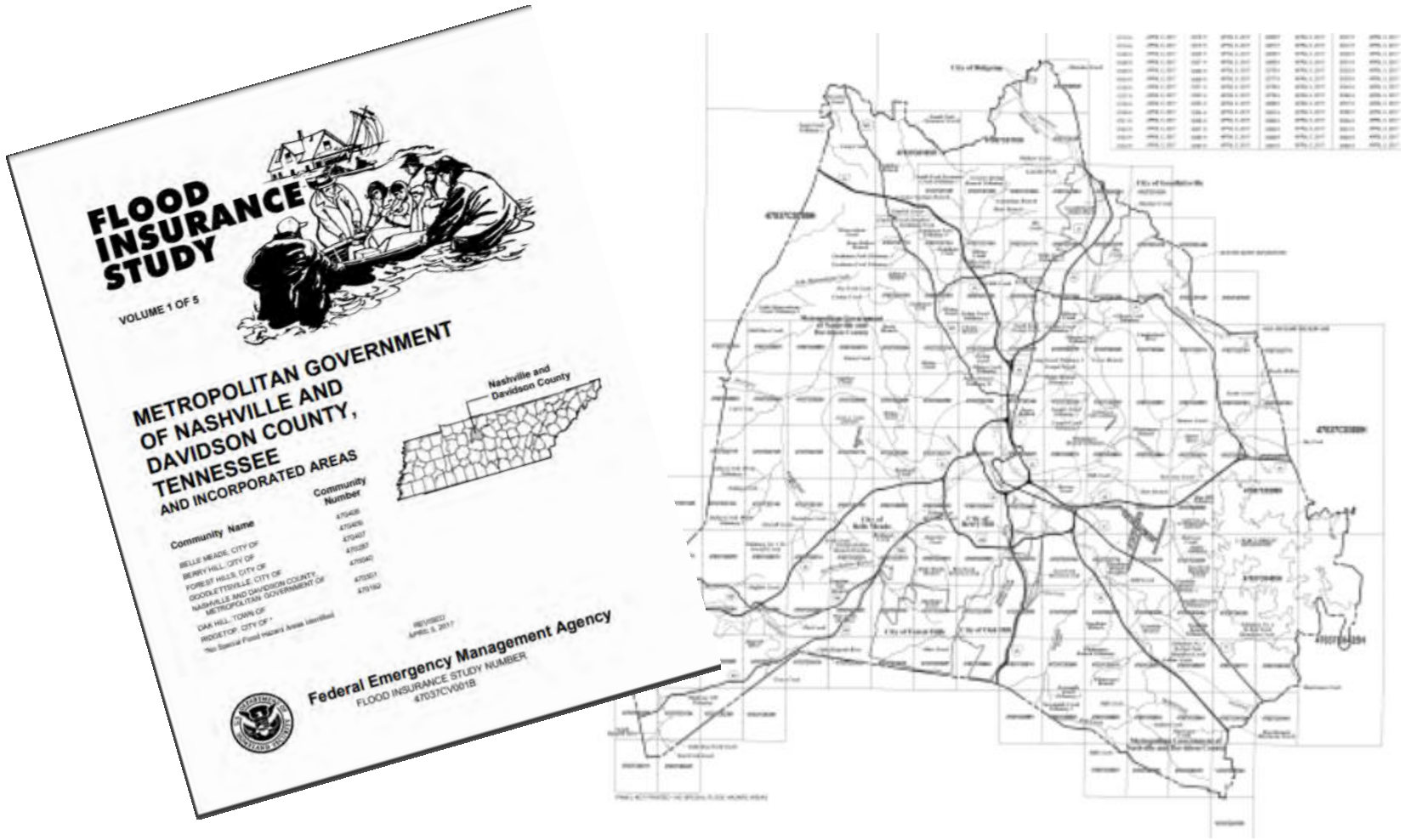
Slide courtesy Marty Ralph

Building Resilience……after the Flood

- Post-Disaster Response
  - Public Infrastructure
  - Private Property
- Buyouts – 370 homes that will never flood again
  - Continuing to purchase homes with HMGP, USACE and Metro Money
  - We will buy hundreds more as money becomes available
- Elevating Substantially Damages homes
- Significant private mitigation – Opryland Hotel and Schermerhorn
- Nashville SAFE, NERVE and HEC-RTS
- New Flood Insurance Rate Maps



All New H&H….county-wide!! Led to….



150 New FIRM Panels

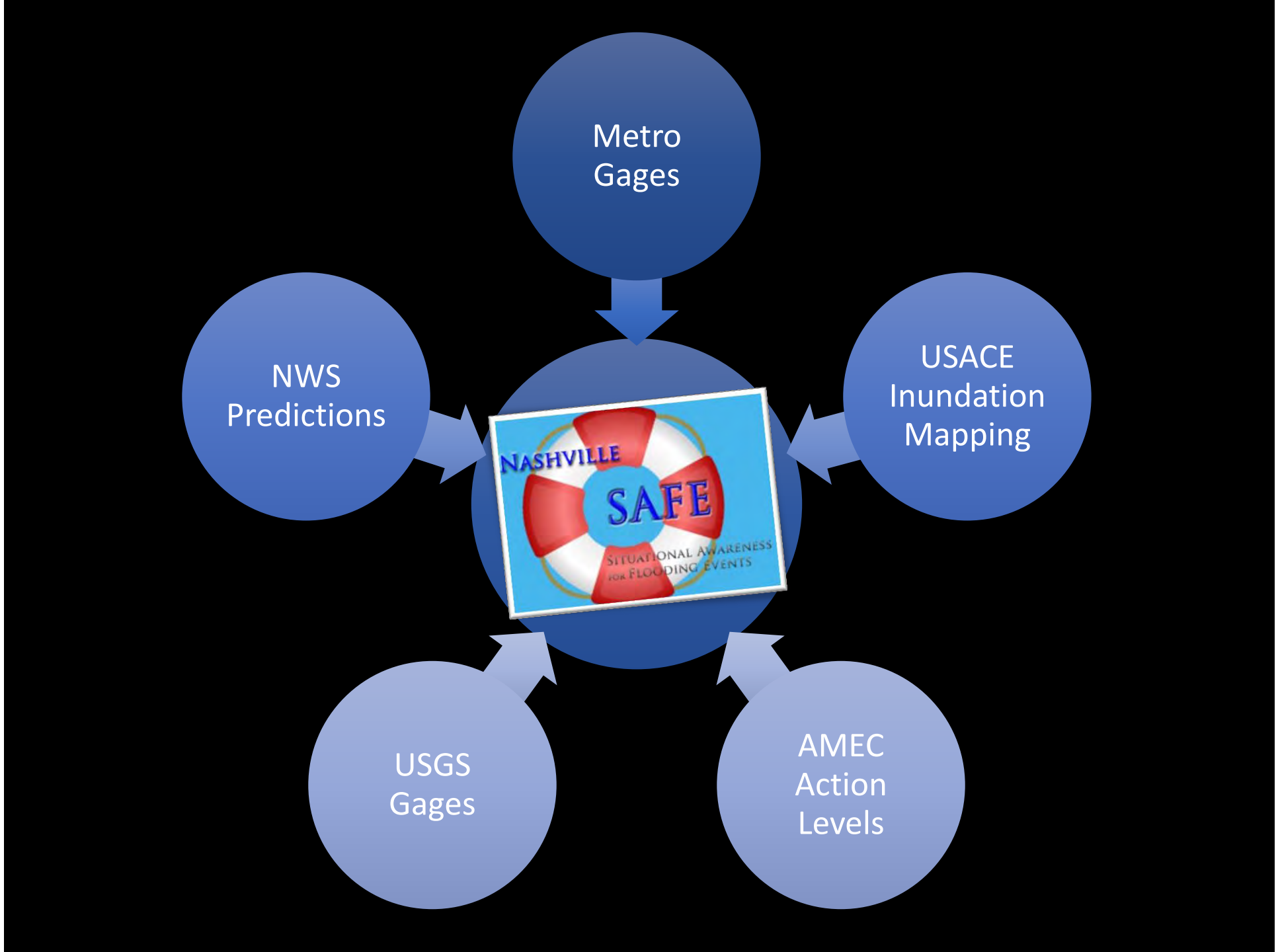
Nashville SAFE & NERVE

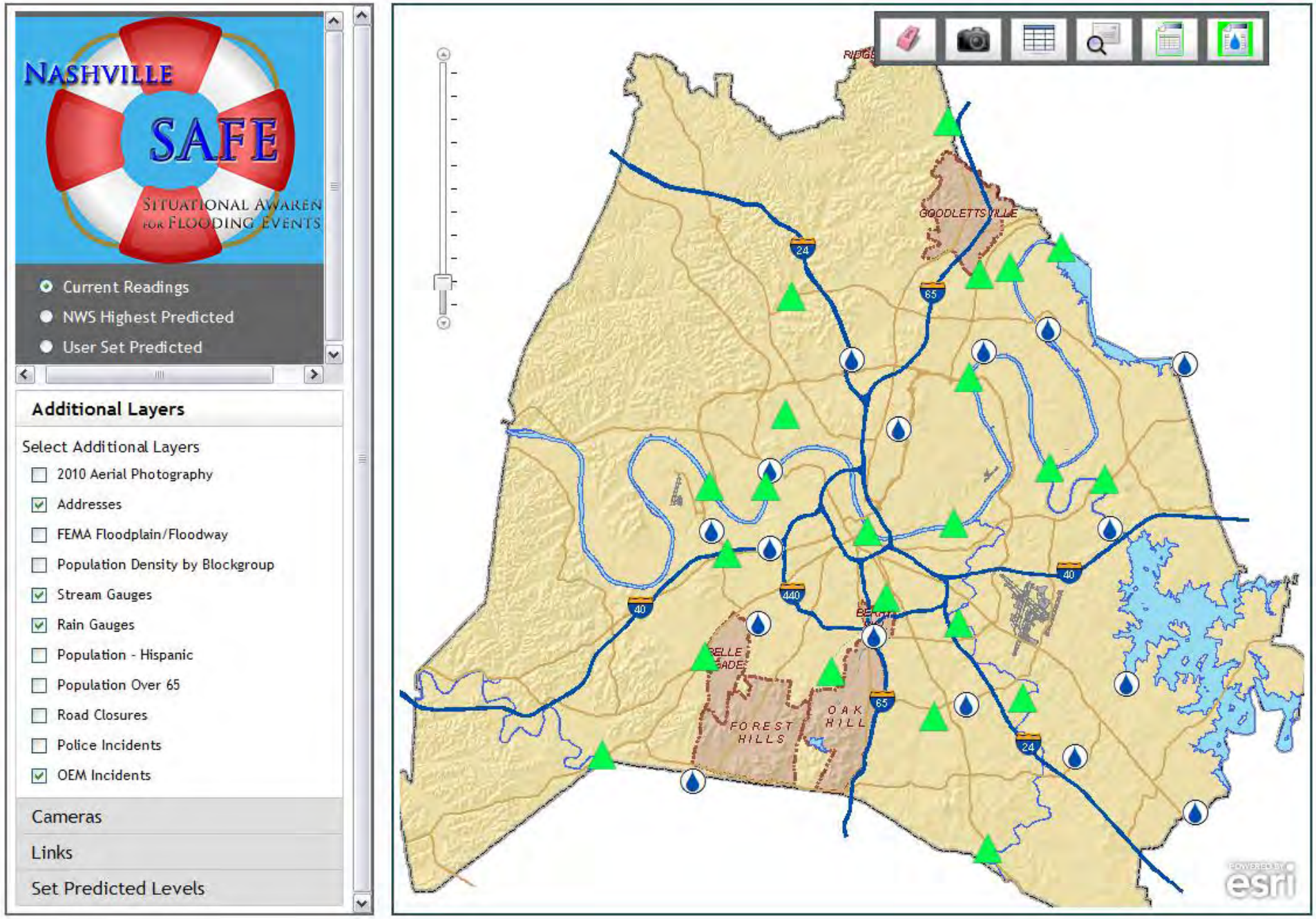
Initial efforts began during the months after the 2010 Flood

- Nashville SAFE – a flood forecasting and response tool

- Nashville NERVE – a Public Information Tool

Service Assessment Recommendations


Metro Gages
NWS Predictions
USACE Inundation Mapping
NASHVILLE
SAFE
SITUATIONAL AWARENESS FOR FLOODING EVENTS
USGS Gages
AMEC Action Levels


NASHVILLE
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2010 Aerial Photography
Addresses
FEMA Floodplain/Floodway
Population Density by Blockgroup
Stream Gauges
Rain Gauges
Population - Hispanic
Population Over 65
Road Closures
Police Incidents
OEM Incidents
Cameras
Links
Set Predicted Levels
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FOREST HILLS
OAK HILL
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65
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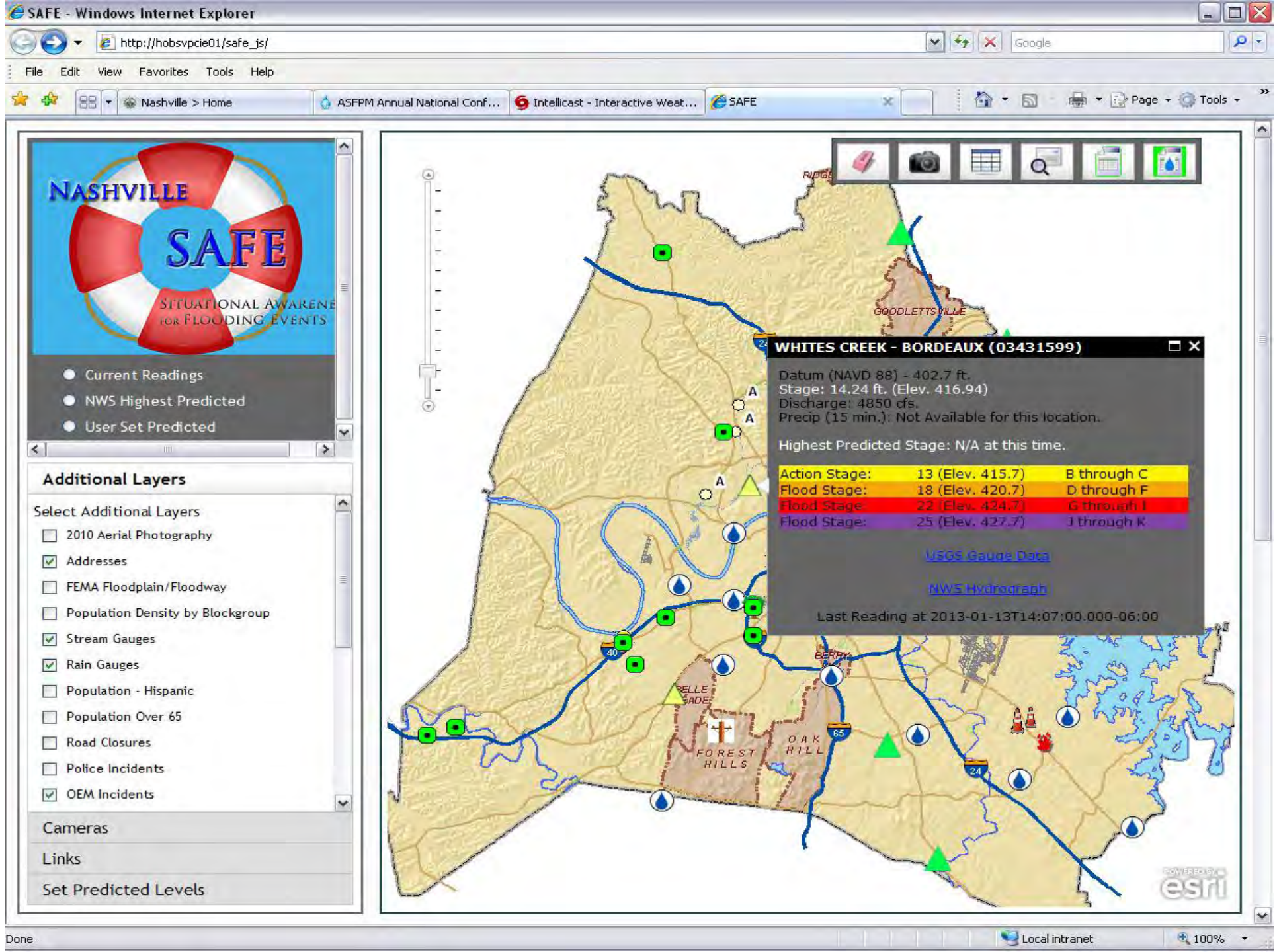
SAFE - Windows Internet Explorer
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Intellicast - Interactive Weat...
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Road Closures
Police Incidents
OEM Incidents
Cameras
Links
Set Predicted Levels
WHITES CREEK - BORDEAUX (03431599)
Datum (NAVD 88) - 402.7 ft.
Stage: 14.24 ft. (Elev. 416.94)
Discharge: 4850 cfs.
Precip (15 min.): Not Available for this location.
Highest Predicted Stage: N/A at this time.
Action Stage: 13 (Elev. 415.7) B through C
Flood Stage: 18 (Elev. 420.7) D through F
Flood Stage: 22 (Elev. 424.7) G through I
Flood Stage: 25 (Elev. 427.7) J through K
USGS Gauge Data
NWS Hydrograph
Last Reading at 2013-01-13T14:07:00.000-06:00
GOODLETTSVILLE
BERRY
FOREST HILLS
OAK HILL
esri
Done
Local intranet
100%

WHITES CREEK - BORDEAUX (03431599)

Datum (NAVD 88) - 402.7 ft.
Stage: 5.96 ft. (Elev. 408.66)
Discharge: 180 cfs.
Precip (15 min.): Not Available for this location.

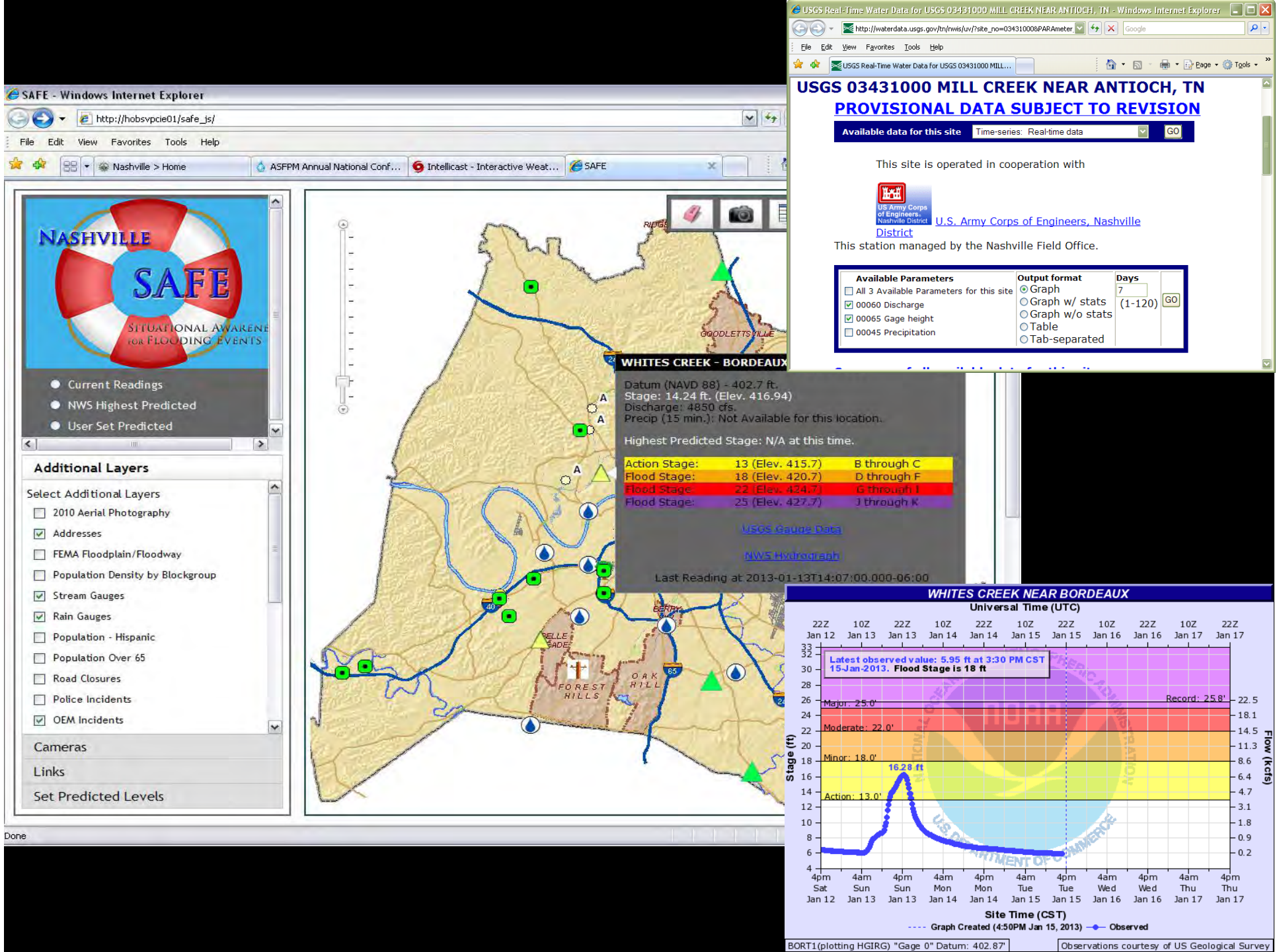
Highest Predicted Stage: N/A at this time.

Action Stage:	13 (Elev. 415.7)	B through C
Flood Stage:	18 (Elev. 420.7)	D through F
Flood Stage:	22 (Elev. 424.7)	G through I
Flood Stage:	25 (Elev. 427.7)	J through K

USGS Gauge Data

NWS Hydrograph

Last Reading at 2013-01-15T16:30:00.000-06:00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Set Predicted Levels
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Discharge: 4850 cfs.
Precip (15 min.): Not Available for this location.
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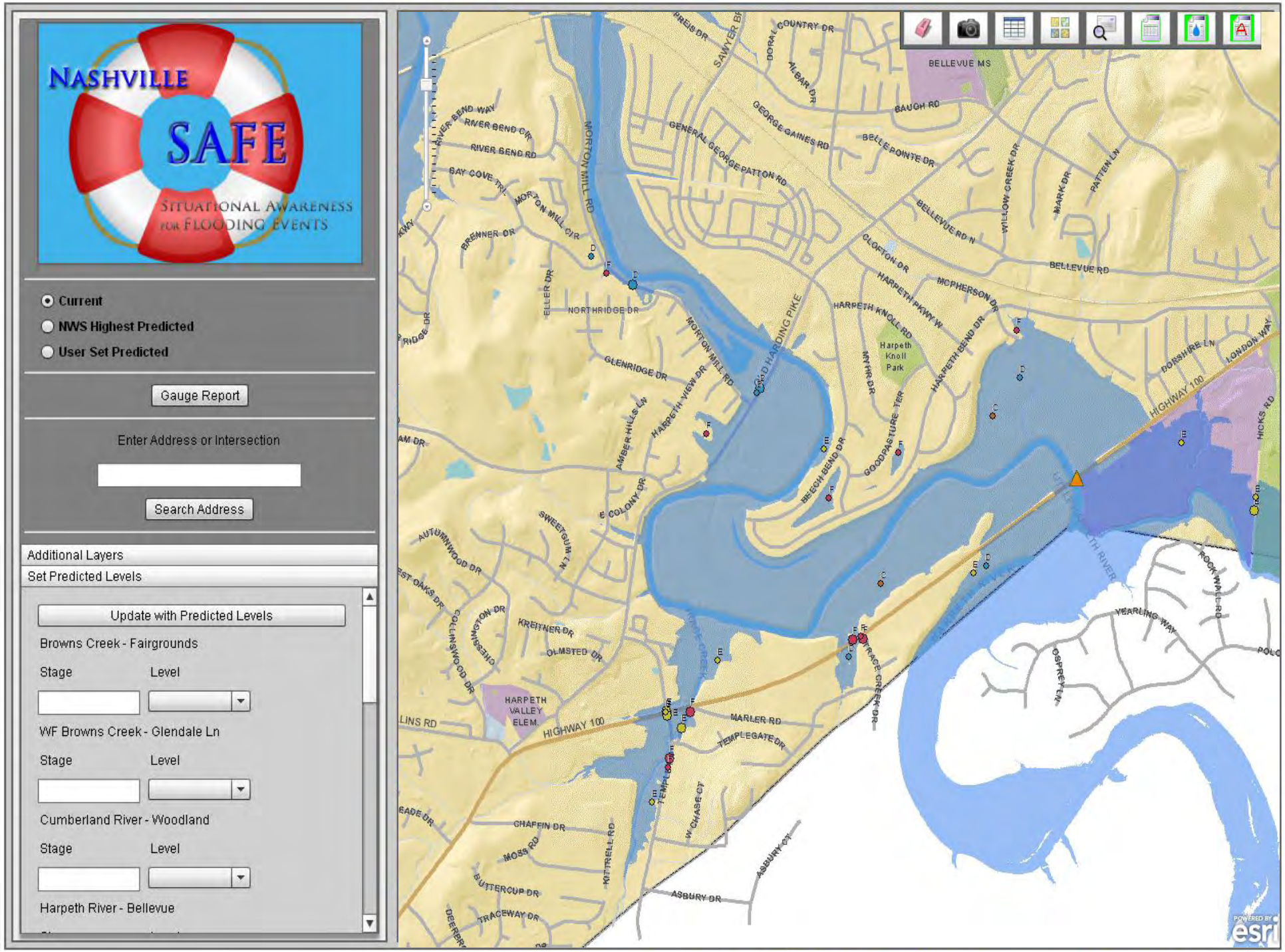
Flood Stage: 18 (Elev. 420.7) D through F
Flood Stage: 22 (Elev. 424.7) G through I
Flood Stage: 25 (Elev. 427.7) J through K
USGS Gauge Data
NWS Hydrograph
Last Reading at 2013-01-13T14:07:00.000-06:00
GOODLETTSVILLE
BERRY HILL
FOREST HILLS
OAK HILL
Done
USGS Real-Time Water Data for USGS 03431000 MILL CREEK NEAR ANTIOCH, TN - Windows Internet Explorer
http://waterdata.usgs.gov/tn/nwis/uv/?site_no=03431000&PARAmeter...
USGS 03431000 MILL CREEK NEAR ANTIOCH, TN
PROVISIONAL DATA SUBJECT TO REVISION
Available data for this site
Time-series: Real-time data
GO
This site is operated in cooperation with
US Army Corps of Engineers, Nashville District
U.S. Army Corps of Engineers, Nashville District
This station managed by the Nashville Field Office.
Available Parameters
All 3 Available Parameters for this site
00060 Discharge
00065 Gage height
00045 Precipitation
Output format
Graph
Graph w/ stats
Graph w/o stats
Table
Tab-separated
Days
7
(1-120)
GO
WHITES CREEK NEAR BORDEAUX
Universal Time (UTC)
Latest observed value: 5.95 ft at 3:30 PM CST 15-Jan-2013. Flood Stage is 18 ft
Record: 25.8'
Major: 25.0'
Moderate: 22.0'
Minor: 18.0'
Action: 13.0'
16.28 ft
Stage (ft)
Flow (kcfs)
Site Time (CST)
Graph Created (4:50PM Jan 15, 2013)
Observed
BORT1(plotting HGIRG) "Gage 0" Datum: 402.87'
Observations courtesy of US Geological Survey


NASHVILLE
SAFE
SITUATIONAL AWARENESS FOR FLOODING EVENTS
Current
NWS Highest Predicted
User Set Predicted
Gauge Report
Enter Address or Intersection
Search Address
Additional Layers
Set Predicted Levels
Update with Predicted Levels
Browns Creek - Fairgrounds
Stage
Level
WF Browns Creek - Glendale Ln
Stage
Level
Cumberland River - Woodland
Stage
Level
Harpeth River - Bellevue
BELLEVUE MS
BAUGH RD
GENERAL GEORGE PATTON RD
BELLE POINTE DR
BELLEVUE RD N
BELLEVUE RD
MORTON MILL RD
NORTHRIDGE DR
GLENRIDGE DR
HARPETH VIEW DR
OLD HARDING PIKE
HARPETH KNOLL RD
HARPETH PKWY W
MCPHERSON DR
Harpeth Knoll Park
HARPETH BEND DR
BEECH BEND DR
GOODPASTURE TER
HIGHWAY 100
DORSHIRE LN
LONDON WAY
HICKS RD
E COLONY DR
SWEETGUM LN
AUTUMNWOOD DR
KREITNER DR
OLMSTED DR
HARPETH VALLEY ELEM.
MARLER RD
TEMPLEGATE DR
TRACE CREEK DR
YEARLING WAY
ROCK WALL RD
OSPREY LN
CHAPPIN DR
MOSS RD
BUTTERCUP DR
TRACEWAY DR
ASBURY DR
ASBURY CT
W CHASE CT
KITTRELL RD
POWERED BY esri

NWS – Quantitative Precipitation Forecasts

National Weather Service
Weather Prediction Center
weather.gov

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DOC NOAA NWS | NCEP Centers: AWC CPC EMC NCO NHC OPC SPC SWPC WPC

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City, St Go

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- National High & Low
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- Days ½-2½ CONUS
- Days 3-7 CONUS
- Days 4-8 Alaska
- QPF
- PQPF
- Excessive Rainfall
- Mesoscale Precip Discussion
- Flood Outlook
- Winter Weather
- Storm Summaries
- Heat Index
- Tropical Products
- Daily Weather Map
- GIS Products

Current Watches/ Warnings

Quantitative Precipitation Forecasts

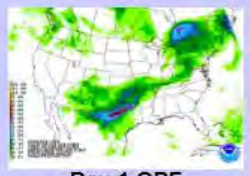
Day 1	Days 1-2	5- and 7-day Totals
Day 2	Days 1-3	
Day 3	Days 4-5 and Days 6-7	

Loop of All 6-hourly or 24-hourly Forecasts for Days 1-3
View 12-Hour QPFs for Days 1-3

WPC QPF Archive

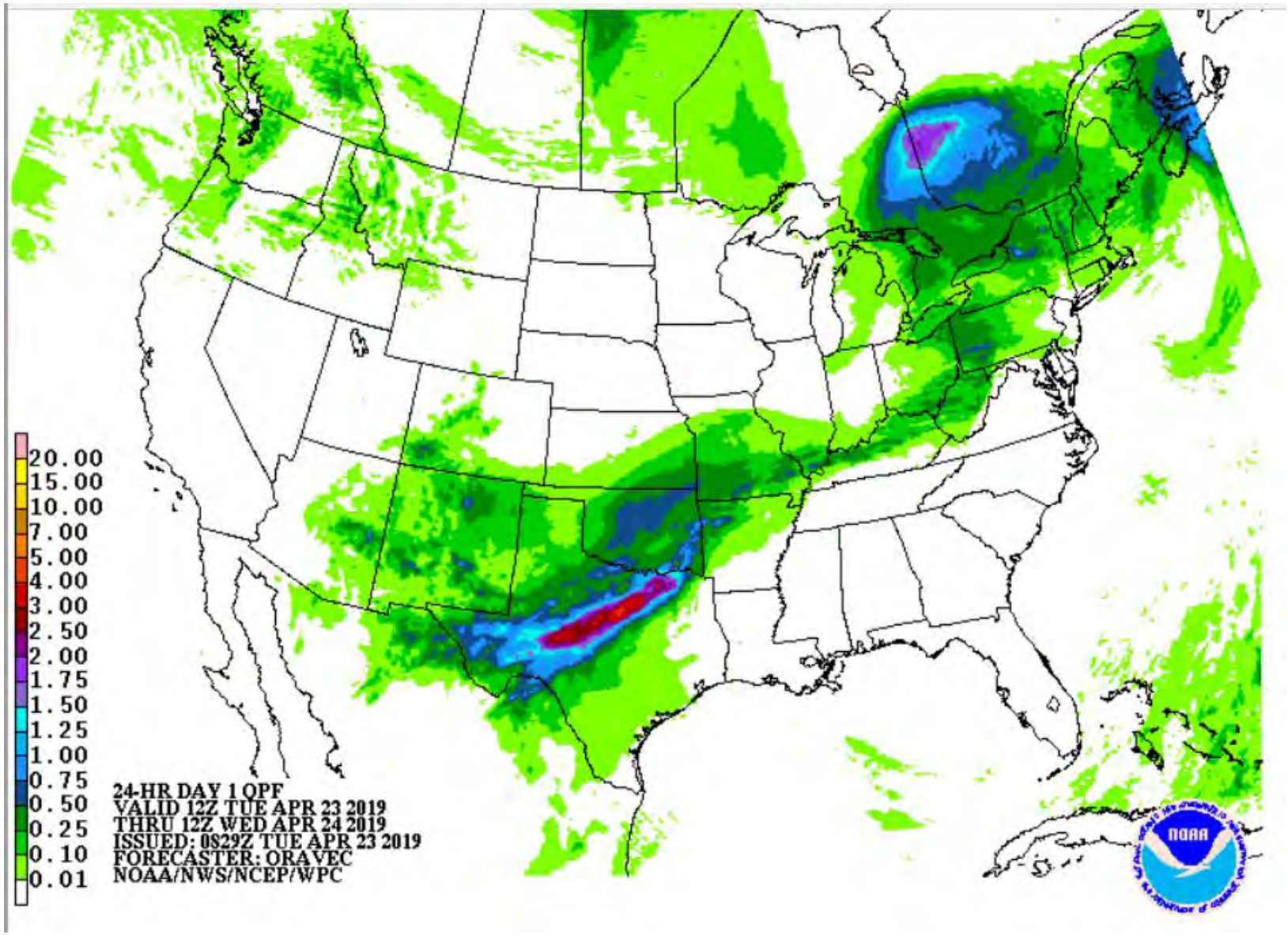
Experimental Extreme Precipitation Monitor

24 Hour Precipitation Total - Day 1

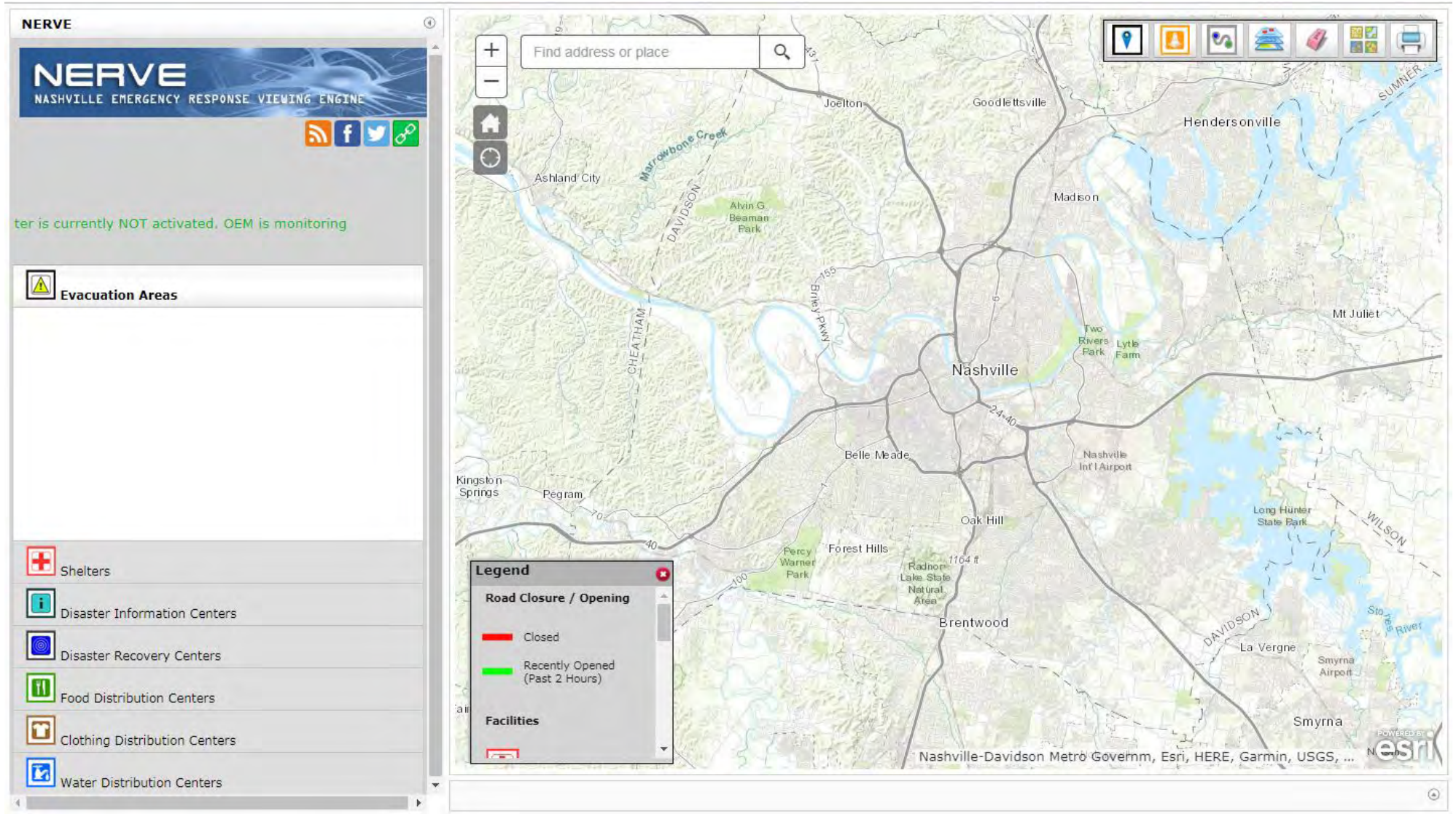


Day 1 QPF
[contours only]

NWS – Quantitative Precipitation Forecasts



Nashville NERVE



Transitioning to Real Time Simulation became the logical next step….

Post May 2010 Flood Efforts - USACE

- Immediately started working with Nashville and other federal agencies
  - Building models and developed mapping products to better understand flood risk
  - USGS added stream gauges further up in watersheds
  - Created the Nashville SAFE program to better understand NWS forecasts
  - Performed hundreds of miles of updates to flood insurance rate maps in coordination with FEMA
- **Work culminated in the development of HEC-RTS modeling**

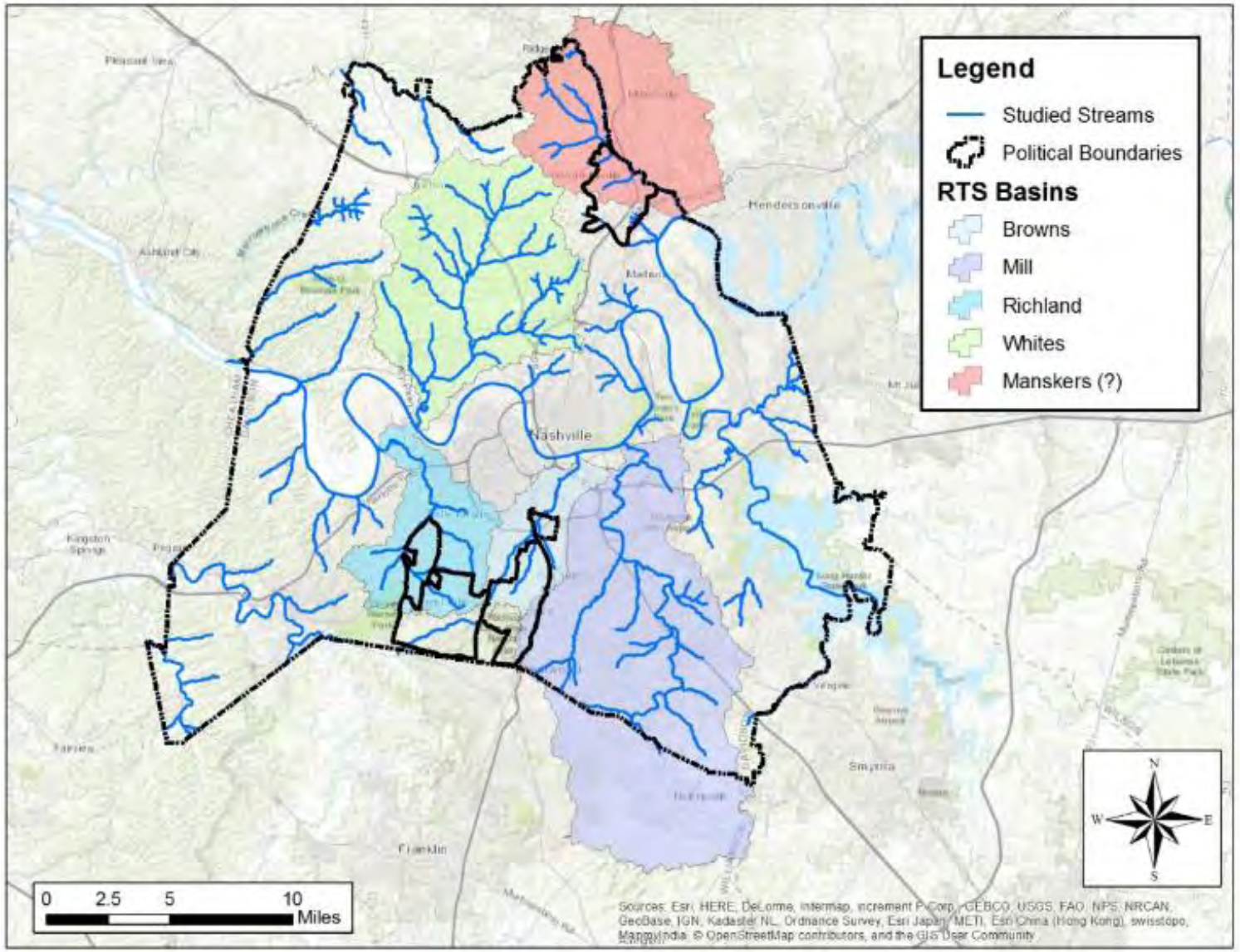
Real Time Simulation (HEC-RTS)

- What is HEC-RTS?
  - Real-time decision support system developed by the USACE - Hydrologic Engineering Center
  - Relies on suite of HEC software (HEC-HMS, HEC-RAS, etc.)
  - Provides a real-time flood forecasting environment integrating HEC software
  - Utilizes python scripts to import real-time data from the internet
  - Utilizes python scripts to publish and disseminate results to necessary stakeholders

Real Time Simulation (HEC-RTS)

- Why is it important?
  - LIFE SAFETY
  - Time matters – Most basins in Nashville have a very short reaction time
- Who is the suite of Nashville HEC-RTS models intended for?
  - Modelers
    - National Weather Service (NWS)
    - Metro-Nashville Staff/Contractors
  - Beneficiaries
    - Metro emergency services
    - NWS forecasters
    - Public

Nashville HEC-RTS Watersheds

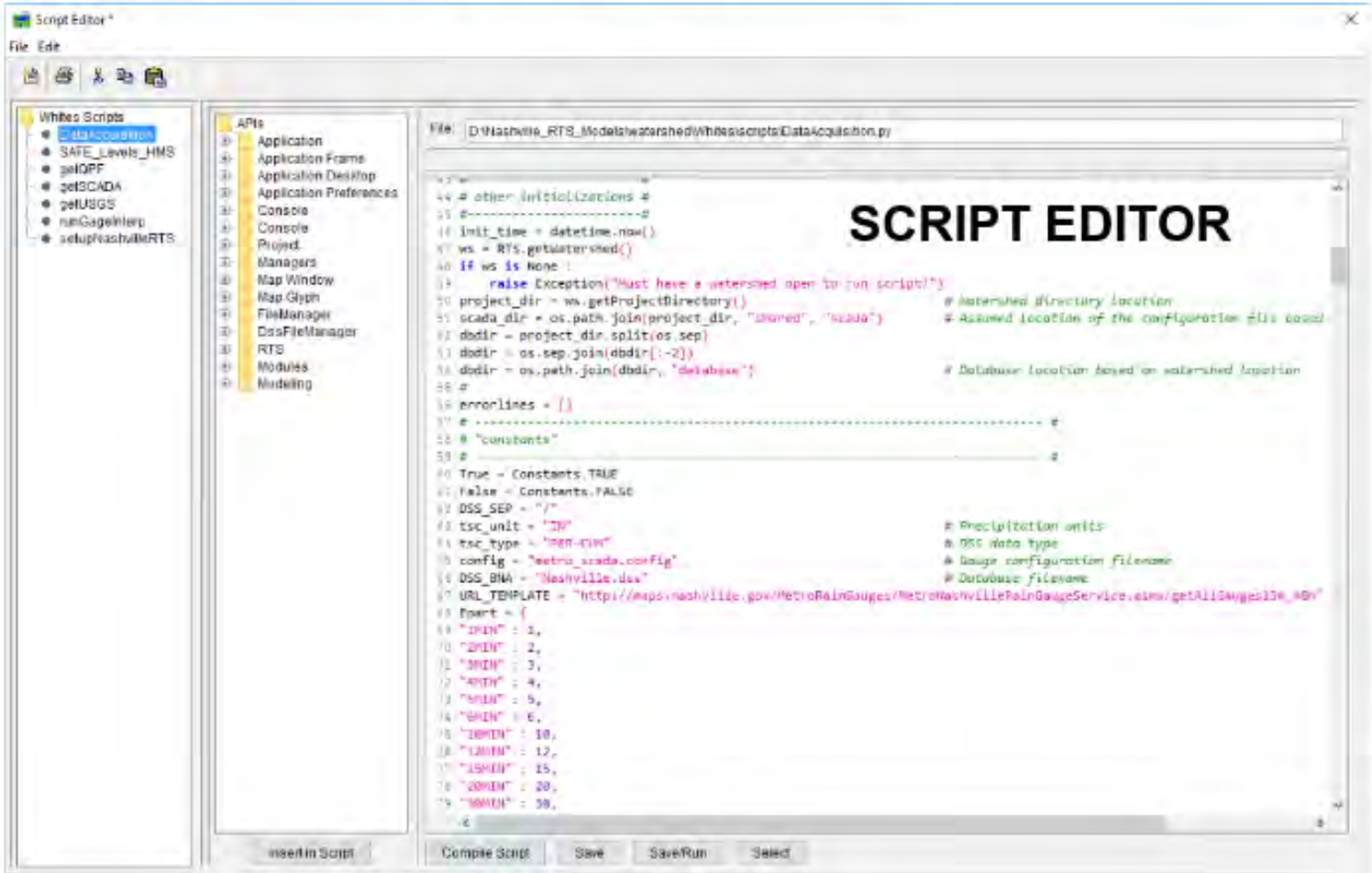


Input Data to the Model

- Data is very important to the model performance
- All data derived from publicly available web sources
- HEC-RTS model relies on several sources of data
  - Stage/Flow Time Series Data – USGS
  - Gridded Precipitation
    - Lookback – GageInterp-derived (15-min); NWS QPE (1-hr)
    - Forecasted – NWS/NOAA QPF (6-hr); NWS NOAA HRRR (1-hr)

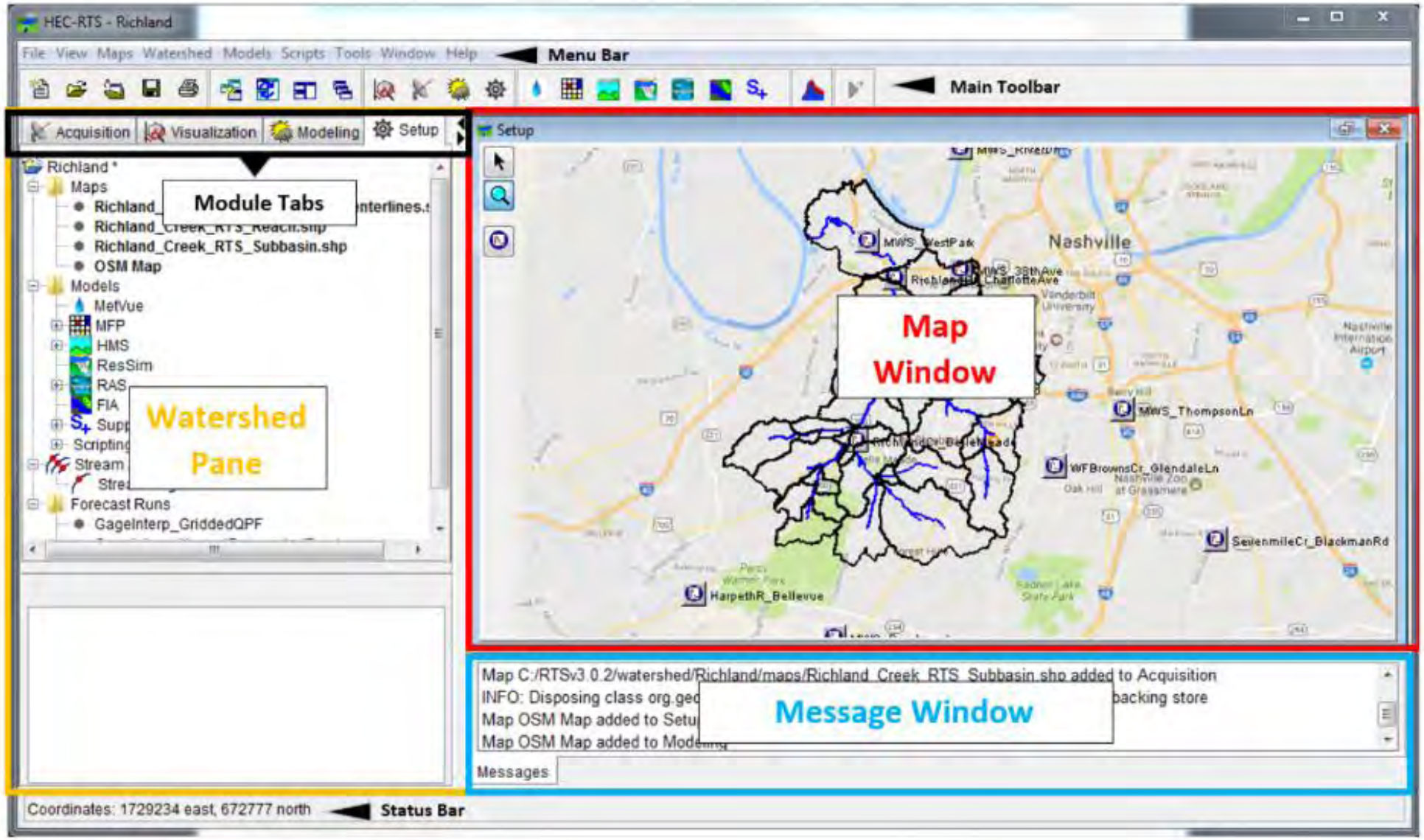
Input Data to the Model

- Python scripting is used to download and format input data into



- Scripts
  - USGS Data
  - Nashville SCADA Precip Gauges
  - GageInterp
  - NOAA QPE
  - NOAA QPF
  - NOAA HRRR
  - Action Level Tool
- Scripts can be run on a schedule

HEC-RTS Tour


HEC-RTS - Richland
File View Maps Watershed Models Scripts Tools Window Help
Menu Bar
Main Toolbar
Acquisition
Visualization
Modeling
Setup
Module Tabs
Richland *
Maps
Richland_Creek_RTS_Subbasin.shp
OSM Map
Models
MetVue
MFP
HMS
ResSim
RAS
FIA
Scripting
Stream
Forecast Runs
GageInterp_GriddedQPF
Watershed Pane
Setup
Nashville
Map Window
MWS_ThompsonLn
WFBrownsCr_GlendaleLn
SevenmileCr_BlackmanRd
HarpethR_Bellevue
Map C:/RTSv3 0.2/watershed/Richland/maps/Richland_Creek_RTS_Subbasin.shp added to Acquisition
INFO: Disposing class org.ged
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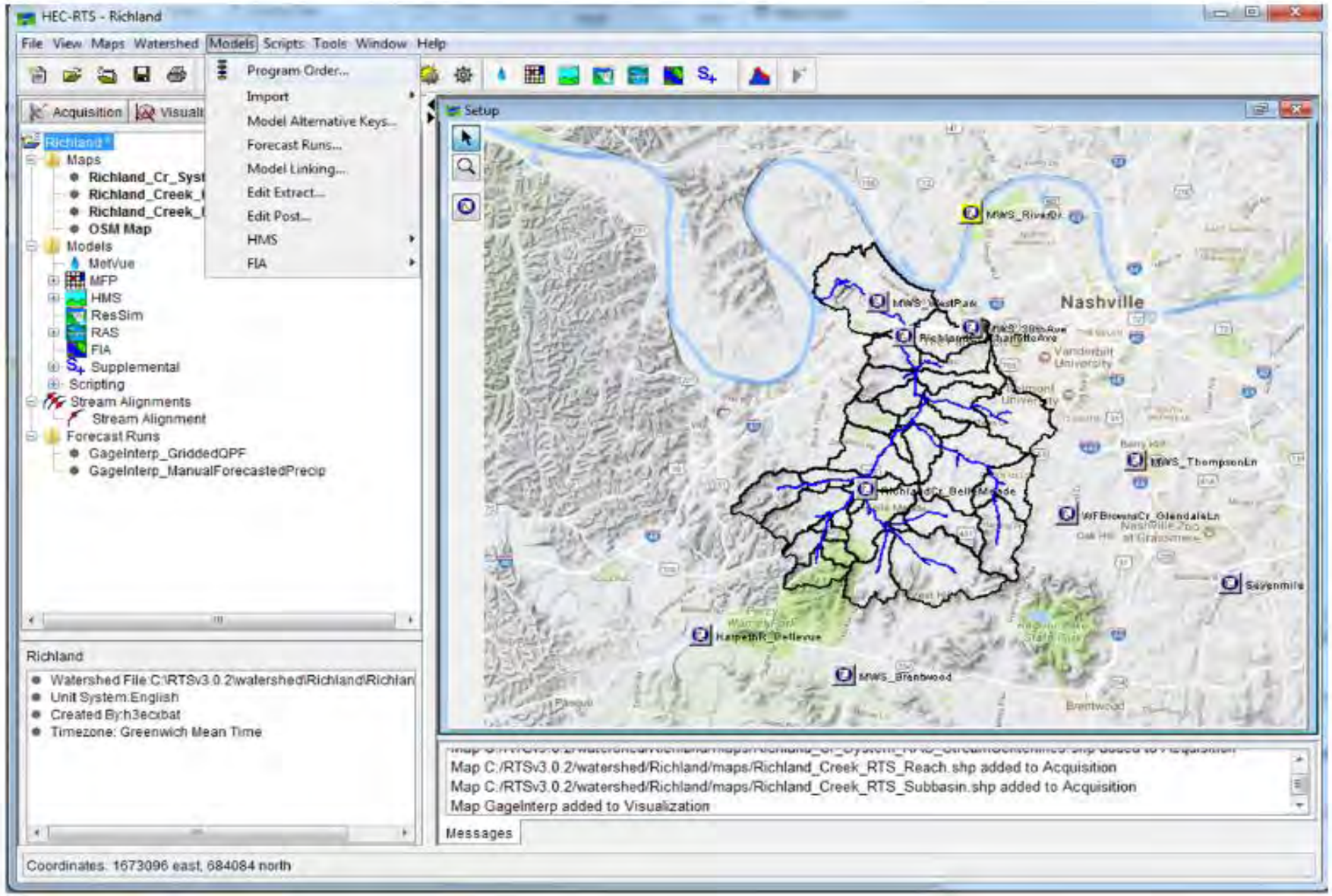
Map OSM Map added to Mode
Message Window
Messages
Coordinates: 1729234 east, 672777 north
Status Bar

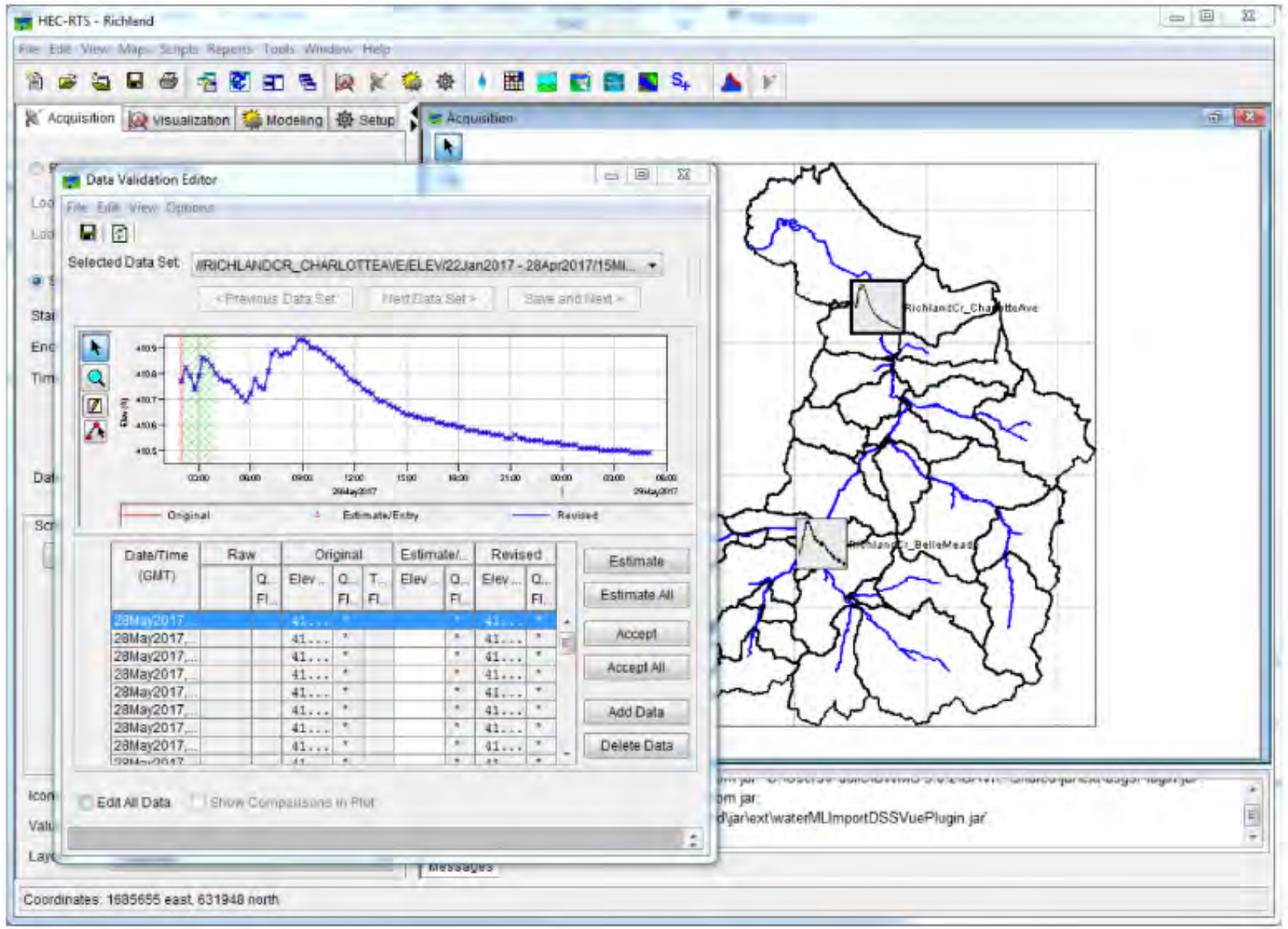
HEC-RTS Modules

- Setup
  - Models imported
  - Program order (MFP ► HMS ► RAS)
  - Data Setup
- Acquisition
  - Data Acquisition
  - Data QC
- Visualization
  - Visualize data and make initial forecasting decisions
- Modeling
  - Where all the magic happens
  - Create forecasts and execute individual modeling components

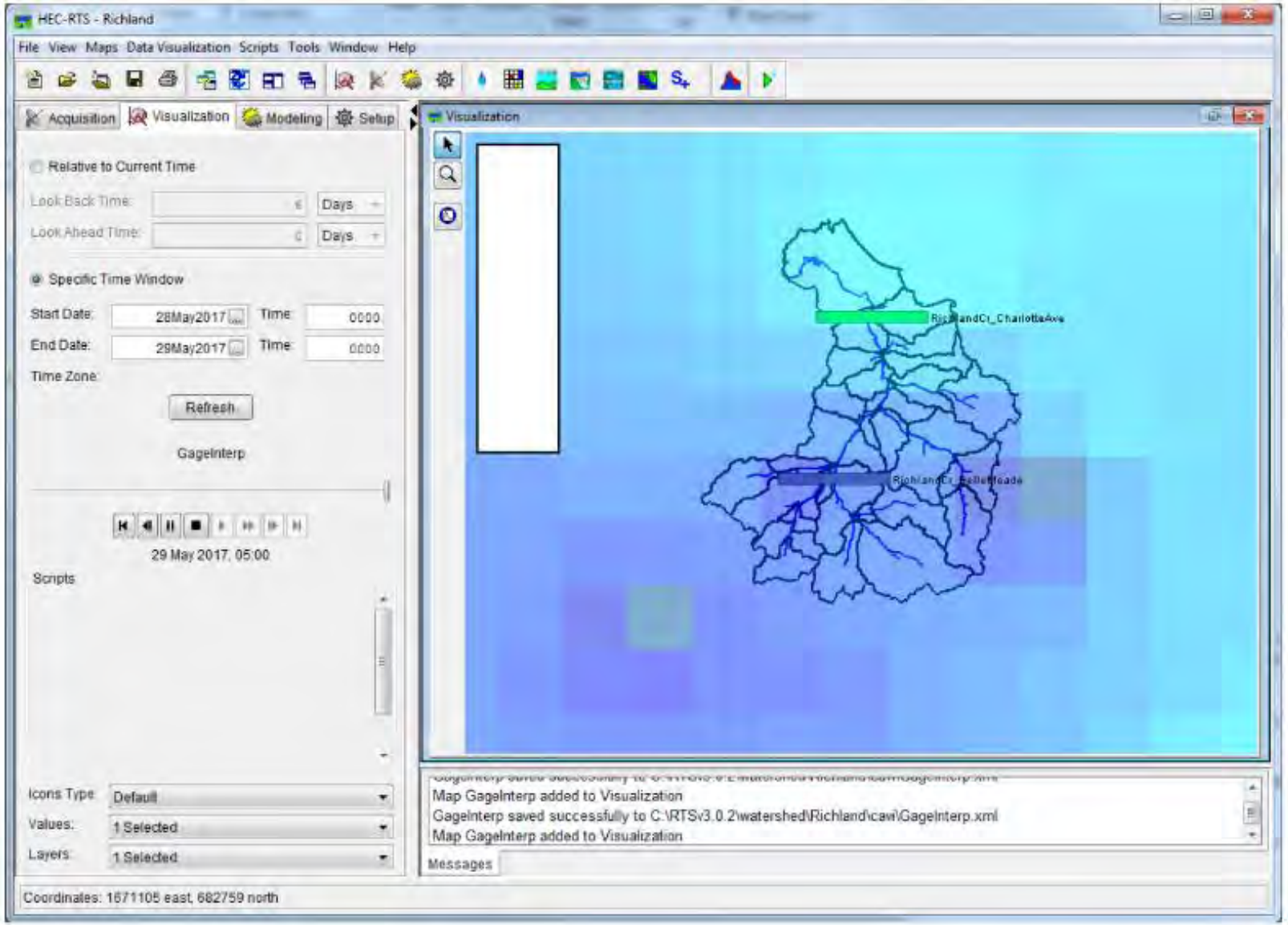
Setup Module



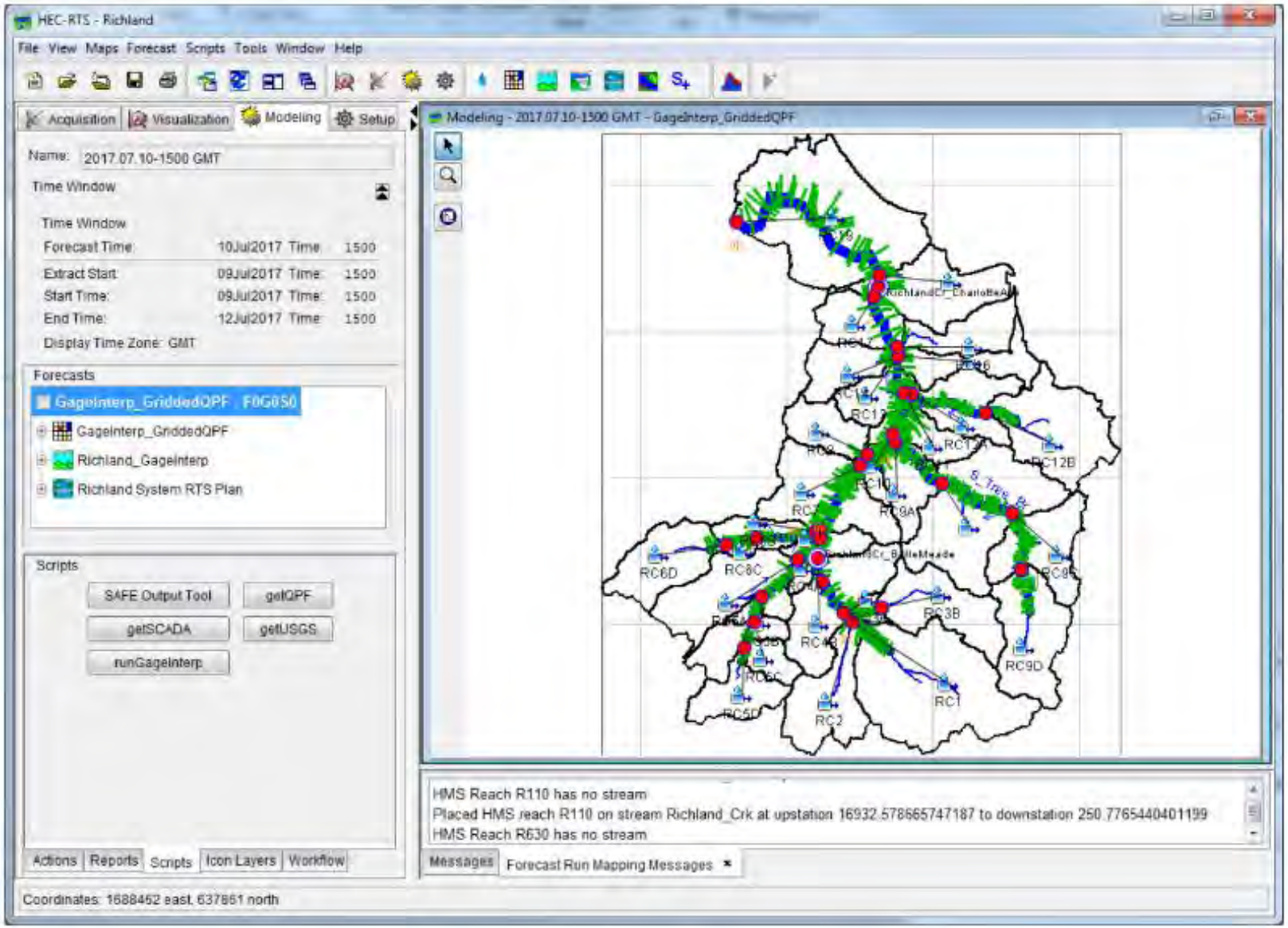
Data Acquisition Module



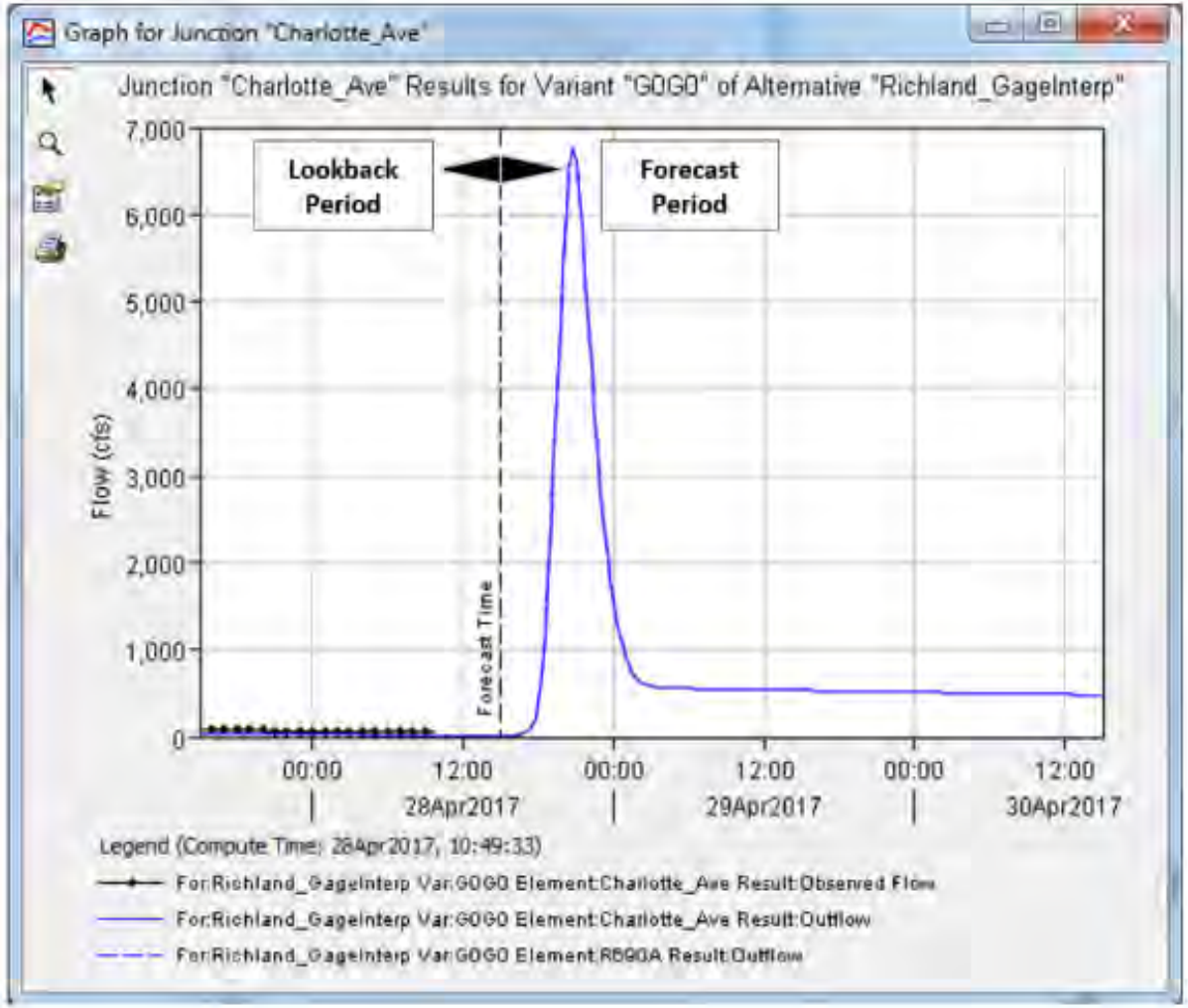
Data Visualization Module



Modeling Module

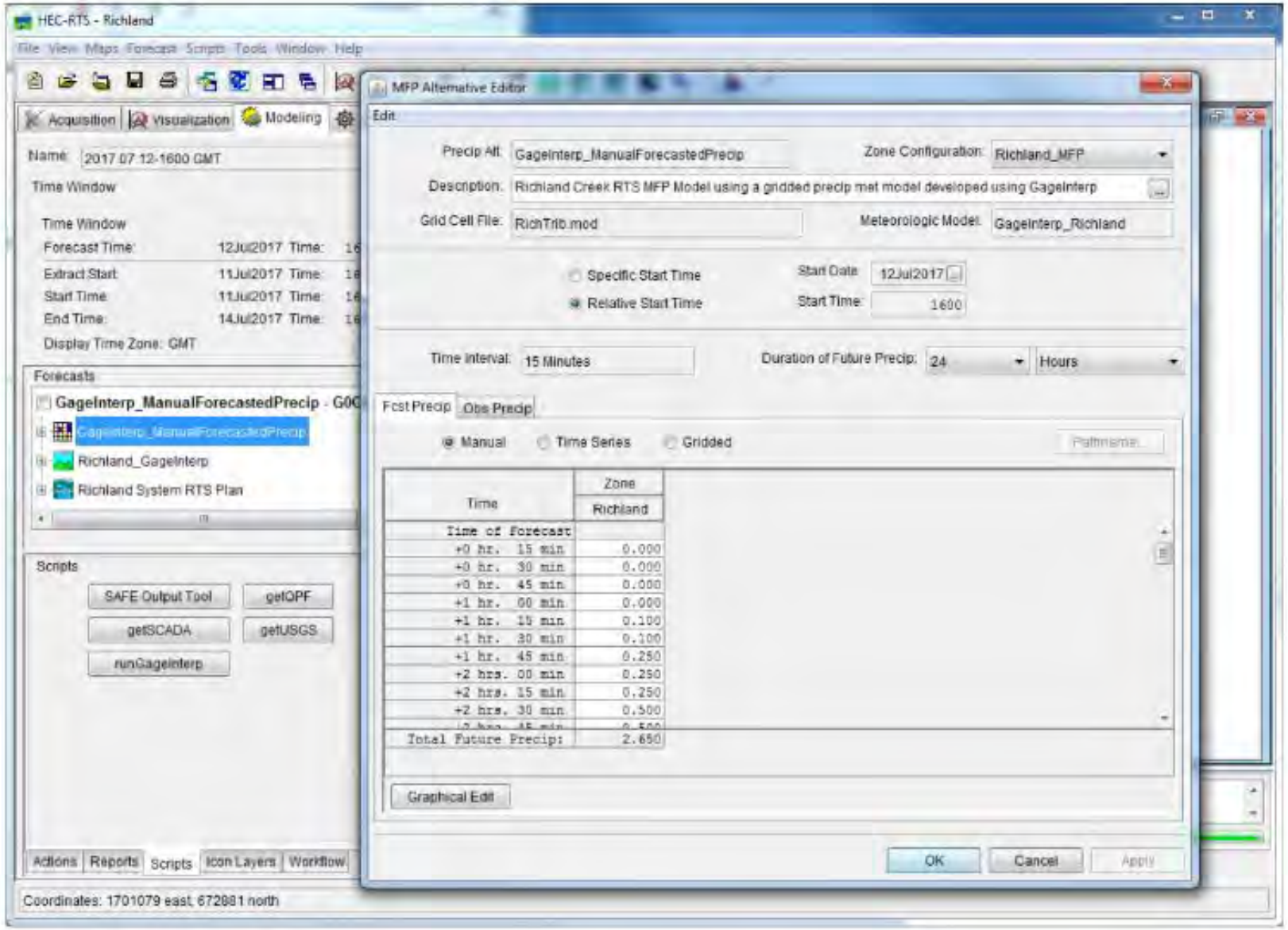


Modeling

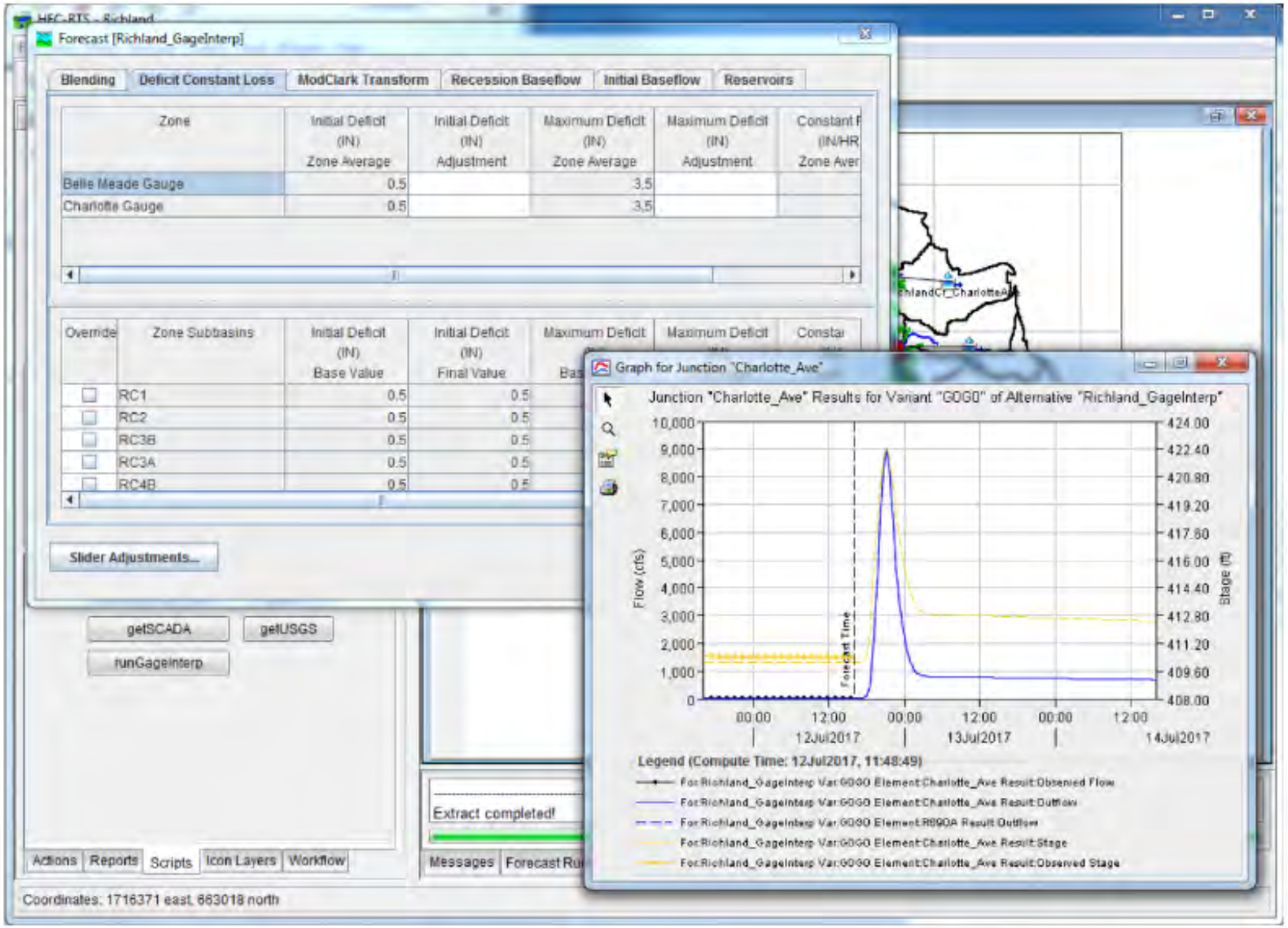


- Setting up a forecast
- Set a forecast time, lookback period, and forecast period
- Choose a forecast run from a pre-defined list of model alternatives
- Model Alternatives
  - MFP – sources for observed and forecasted precip
  - HMS – dry, normal, wet antecedence conditions
  - RAS – seasonally varied roughness
- Scheduled Forecasts

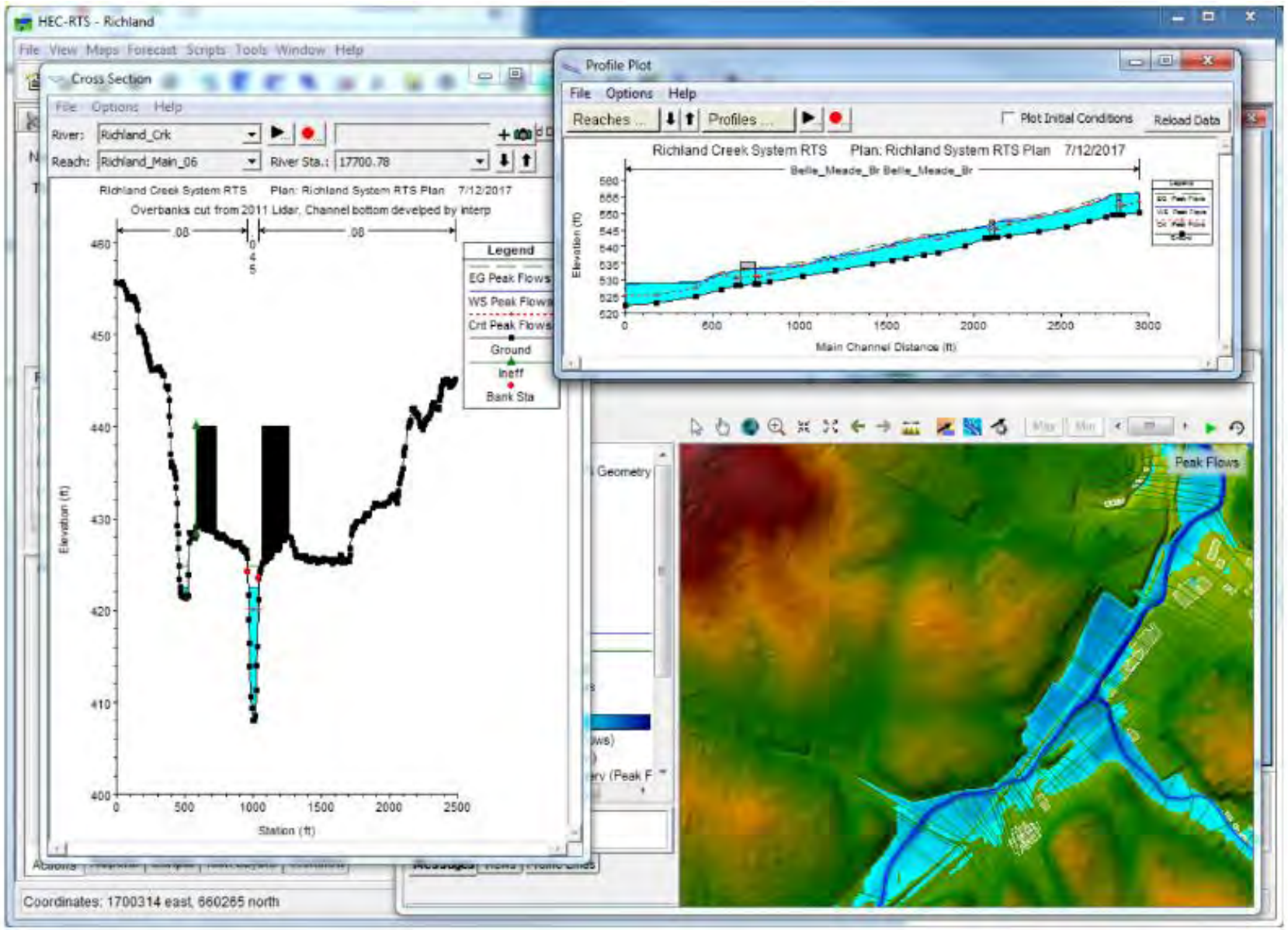
Modeling - Precipitation



Modeling - Hydrology



Modeling - Hydraulics



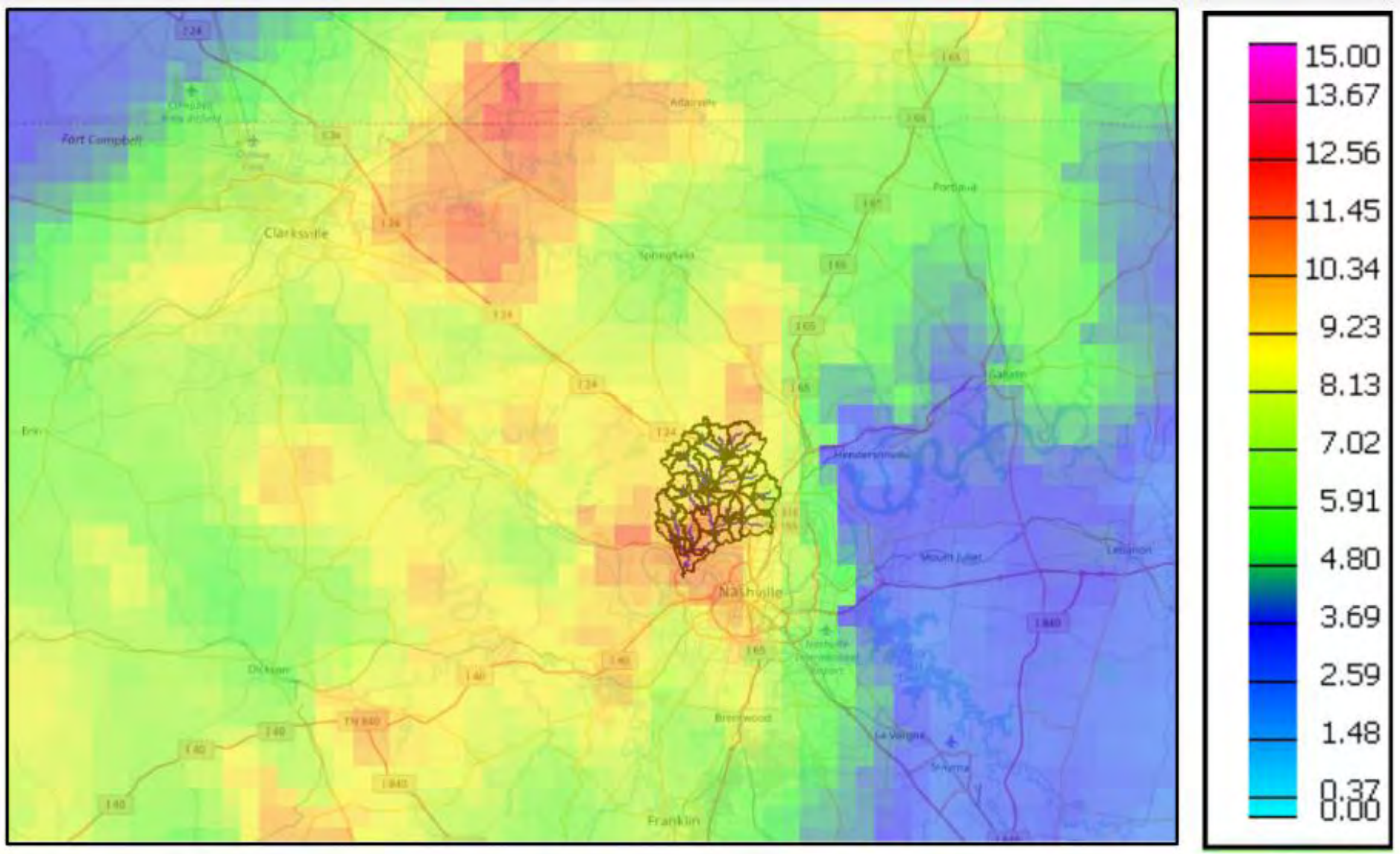
Data Dissemination

- Models are great…
- But if the results can't be communicated to the necessary people at the critical time; they're WORTHLESS!
-  Still under construction 
- Currently looking at two sources of dissemination:
  - Metro – Linkages to the Nashville SAFE program
  - NWS – Leave the forecasting to the experts. Already have the dissemination tools in place
- Action Level Tool

Real World Application – Remnants of Harvey Event

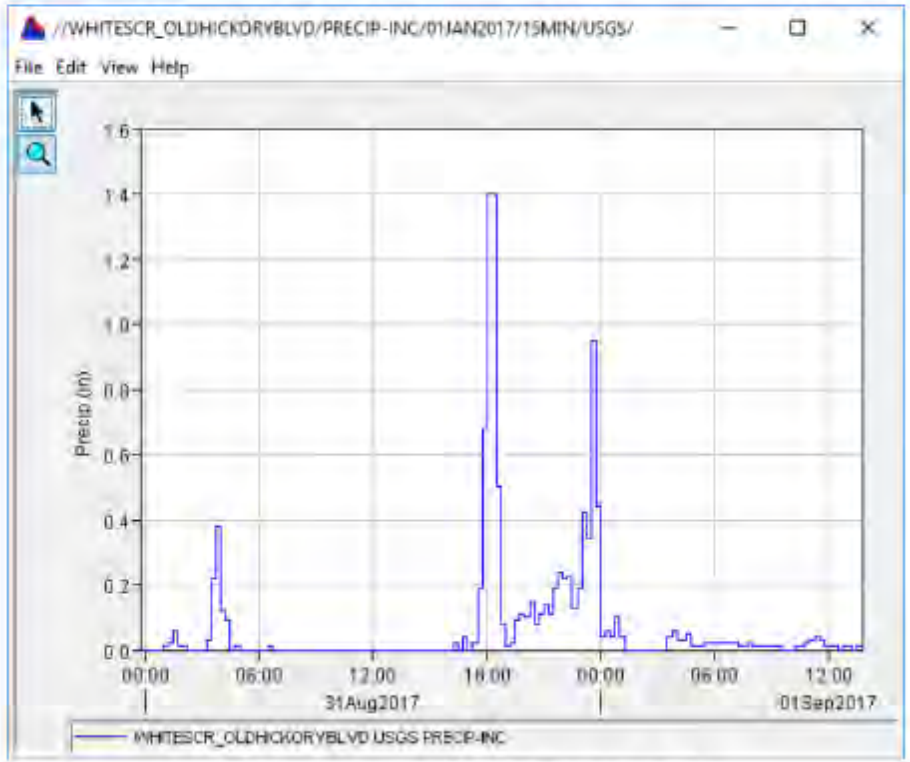
- Hurricane Harvey devastated the Texas coast from 25-29 August 2017
- Harvey system eventually worked its way to middle Tennessee a couple days later
- The system stalled over Nashville on the evening 31 August
- The event resulted in flooding throughout Nashville
- About 30 water rescues were performed mostly in the Whites Creek Basin (a trib to the Cumberland River
- Event also produced several tornadoes in the Middle Tennessee area including Davidson Co.

Harvey Event Cumulative Rainfall

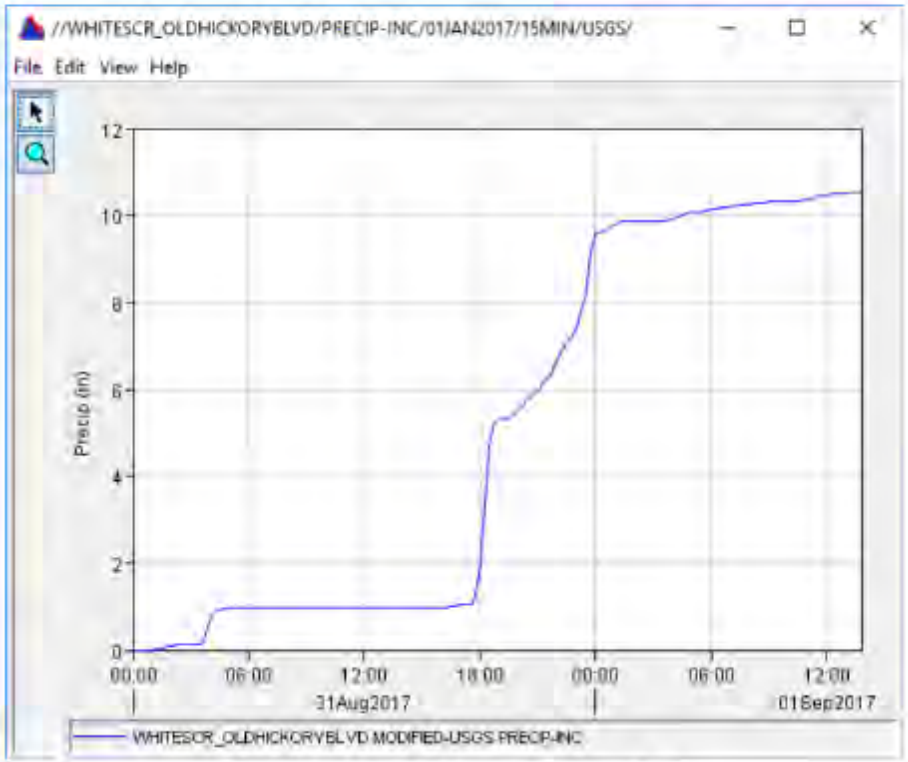


Harvey Event Precipitation Totals

- About an inch of rain occurred early in the morning of 31 August
- Around 4 pm on 31 Aug, an intense rain event began
- From 4 – 7 pm, the initial event dropped about 5.5 inches of rain
- From 7 – 11 pm, it continued to rain steadily totaling ~3” of rain
- From 11 pm to midnight, another relatively intense 2” event occurred

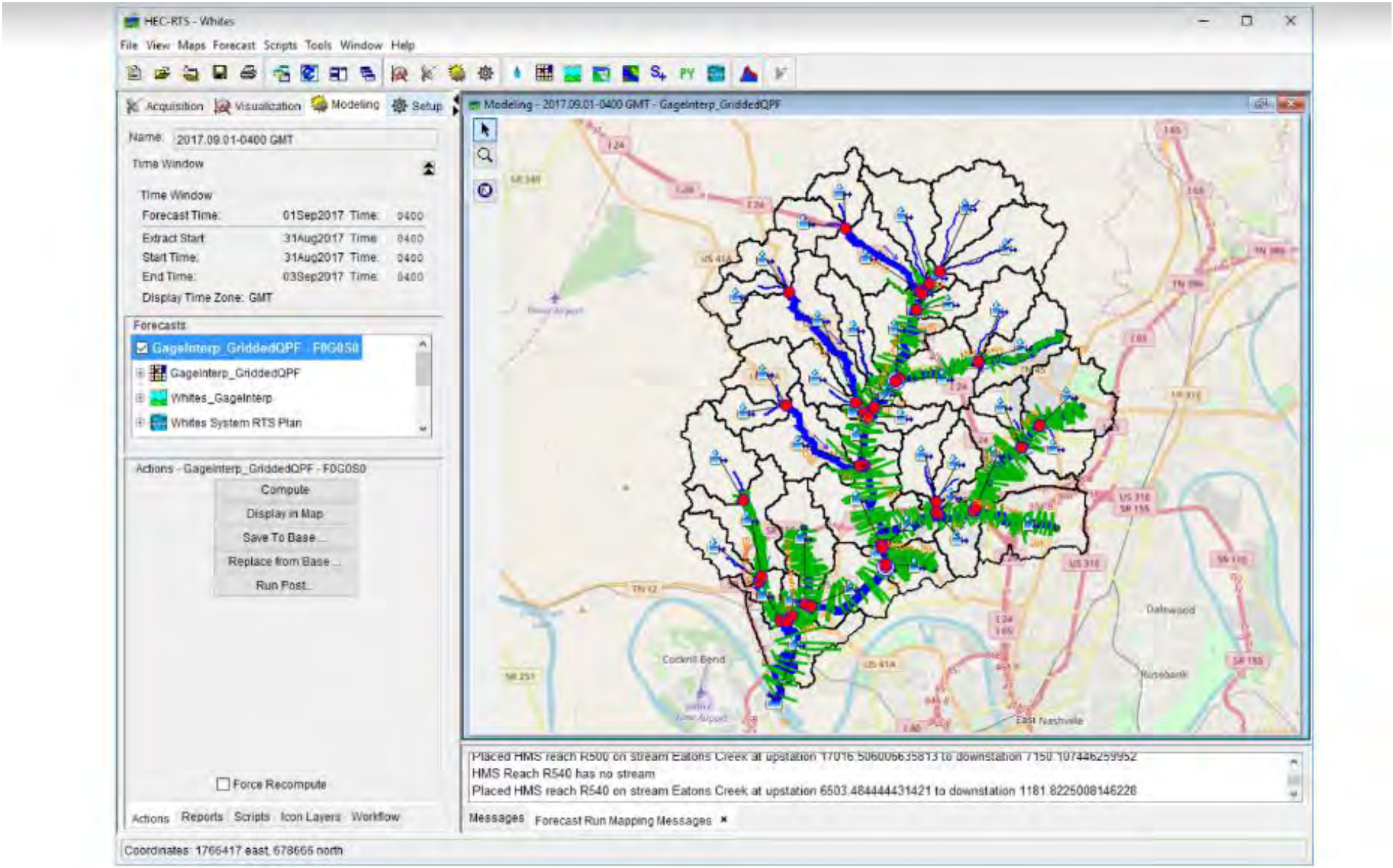


Incremental Rainfall

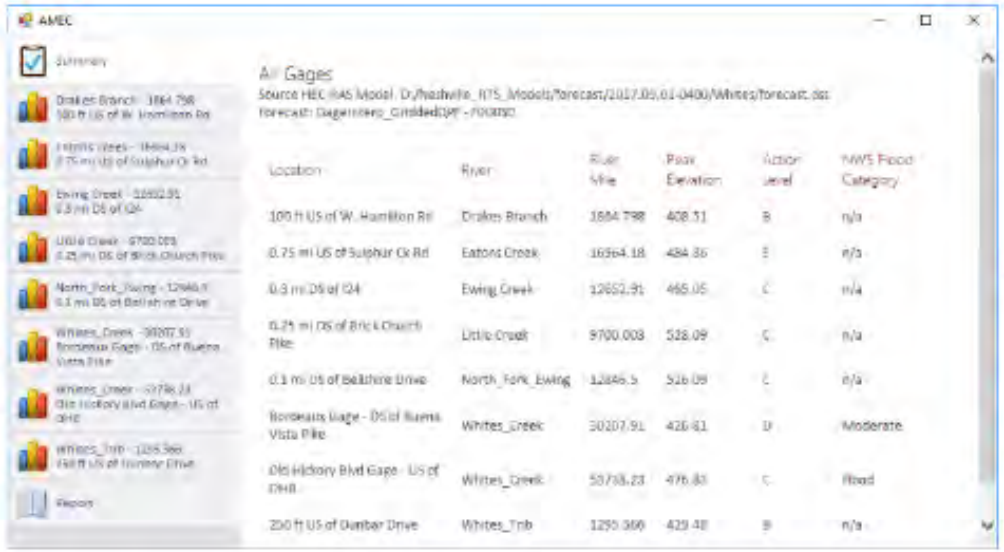


Cumulative Rainfall

Whites Creek Watershed HEC-RTS Model



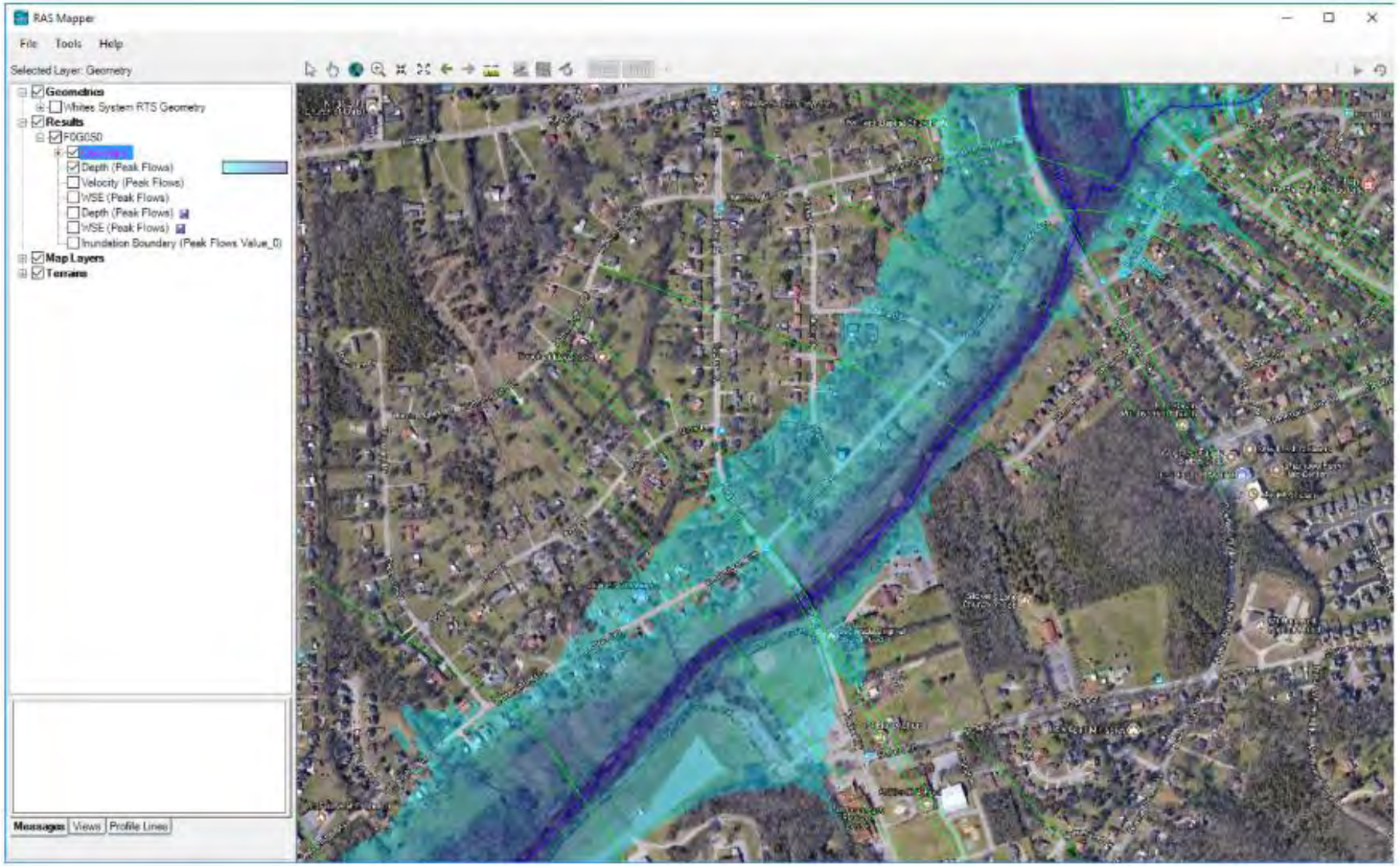
Action Level Tool



- Provides action level information for forecast points throughout the watershed
- Nashville SAFE and NWS Action Levels

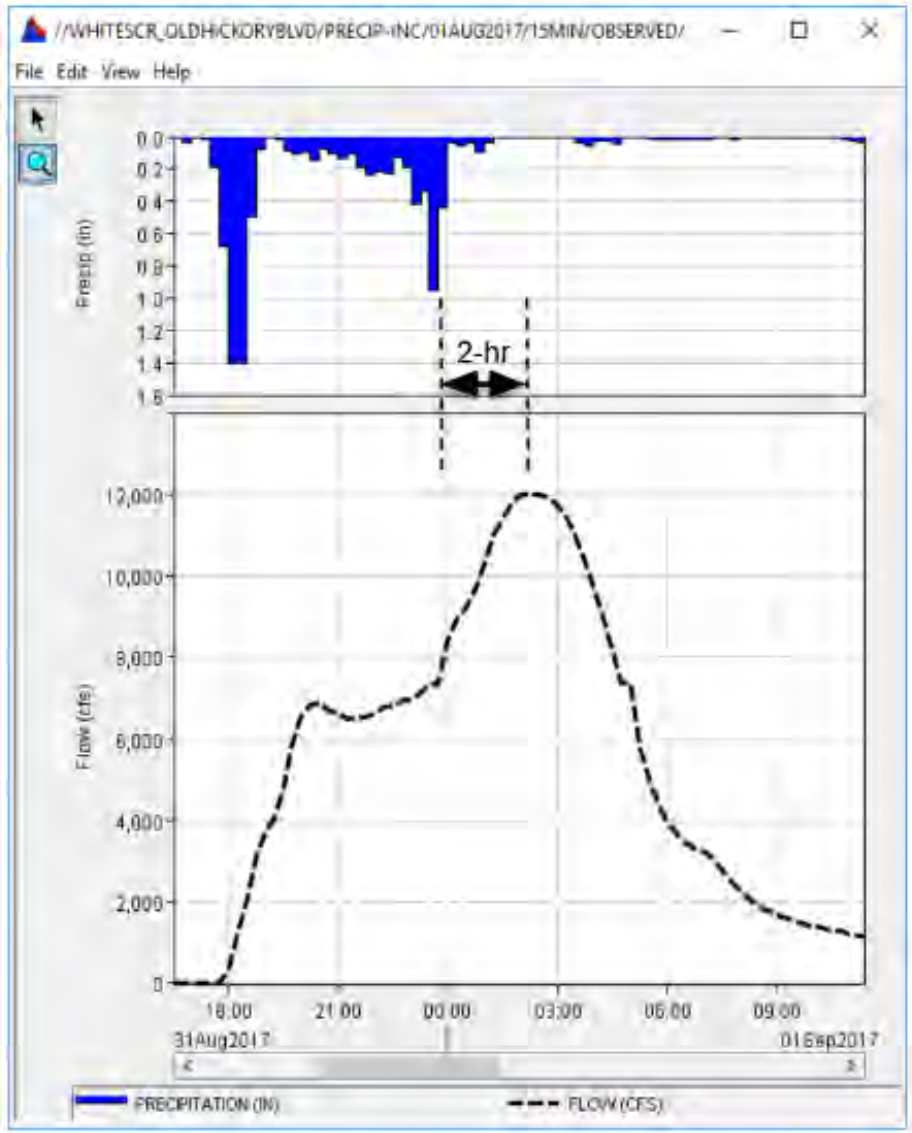
- Summary Table (above)
  - Summarizes action levels throughout the basin
- Forecast Point Information (right)
  - Accessed through left portion of the tool
  - Peak elevation and timing
  - Action Level
  - Stage Hydrograph

Inundation Mapping



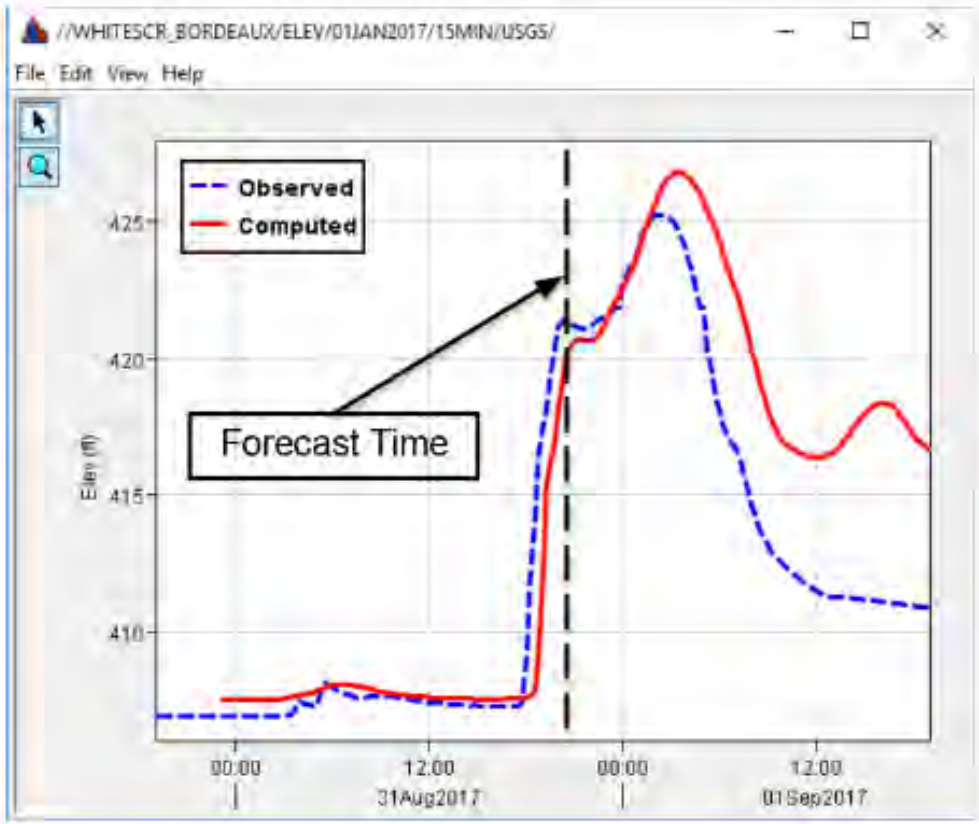
Characteristics of the Event

- Observed data from event
- Double event
- First event saturated the basin
- About 2 hour response time
- HEC-RTS can be run continuously through event



Post-Flood Evaluation

- Information aided Metro staff with warnings and evacuations
- Forecasted flood stages and timing aligned relatively well
- Forecasted inundation represented the observed flooding
- Based on temporally distributed 6-hr QPF



Next Steps

- Develop processes and outputs that will provide the most useful information to the necessary decision makers and emergency personnel in the Nashville Government
- A flood exercise will be held in August to better understand the needs of emergency managers
- Expand HEC-RTS model development to the remaining major watersheds in Metro
- Build a comprehensive HEC-RTS model for the entire Metro region as opposed to individual basin models
- Incorporate HEC-FIA to provide real-time structure by structure damages and population at risk

Conclusions

- HEC-RTS provides an integrated environment to conduct flood forecasting using detailed H&H modeling software developed by HEC
- Interface is relatively user-friendly and provides direct access to commonly used H&H software packages
- Ability to create output products useful to emergency person is only limited by our imagination
- The speed at which information and warnings can be distributed can save lives and property
- Supports collaborative relationships between local, state, and federal agencies
- Once completed and implemented, the Nashville HEC-RTS system will be one of the most advanced systems nationally

Questions??

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