REAL-TIME FLOOD FORECASTING IN NASHVILLE, TN USING HEC-RTS

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Silver Jackets Webinar
17 July 2018
May 2010 Flood Impacts

- New regulated flood of record for middle and lower Cumberland River
- In Franklin, TN, 17.87 inches of rain fell over May 1st and 2nd exceeding the NOAA Atlas 14 1000-yr storm event by more than 5 inches
- Widespread flooding on the Cumberland and Duck Rivers and especially on tributaries within Metro-Nashville
- May 2010 event resulted in significant impacts
  - Economic Damages - over $2B in damages
  - Fatalities - 26 fatalities overall; 11 in Nashville alone (all in tributaries to the Cumberland River)
May 1-2 Rainfall in Nashville

Incremental Rainfall
May 1\textsuperscript{st} ~ 8.25”
May 2\textsuperscript{nd} ~ 8”

Cumulative Rainfall
Consecutive 500-yr to 1000-yr storm events
May Flood Rainfall versus Cumberland River Reservoirs

Cumberland River Flood 1 and 2 May 2010 Radar Rainfall Project Operations

Storage at Peak Elevation
Available → Peak
Pie area scaled to Storage capacity.

Cumberland River Project Watersheds
Delineation
- Flood Control
- Uncontrolled Drainage

2Day Total Observed Precipitation (in)
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- 13 - 14+
Post May 2010 Flood Efforts

- May 2010 flood resulted in a major shift in focus
  - Dissect what happened during the flood
  - Local, state, and federal agencies were trying to determine:
    - What happened
    - What could we do differently
    - How can we better prepared in the future

- From USACE perspective
  - Began re-evaluating our relationships and communication strategies with other agencies
  - Developed a Post Flood Documentation Report
  - Used computers models to test our actions during the event
Post May 2010 Flood Efforts

- Immediately started working with Nashville and other federal agencies
  - Building models and developed mapping products to better understand flood risk
Inundation Products
Cumberland River WS Profiles Referenced to the Nashville Gauge

Cumberland River Profiles
May 2010 Flood Event Unsteady Flow Model Simulation

Note: River stages and elevations referenced from the Nashville gage (Datum 367.76 ft NAVD). Profiles generated using HEC-RAS unsteady flow model simulation. River Miles shown below were generated from hydraulic model and may not match published USGS river miles.

- 52ft_el420_MAX
- 50ft_el415_May02 2200
- 48ft_el416_May02 1900
- 45ft_el413_May02 1600
- 42ft_el410_May02 1300
- 40ft_el408_May02 1100
- 37ft_el405_May02 0800
- 35ft_el403_May02 0100
- 32ft_el400_May01 2200
- 30ft_el396_May01 2000
- 25ft_el393_May01 1700
- 15ft_el387_may01 0600
- Cheatham Normal Pool

US Army Corps of Engineers
Nashville District
Cumberland River May 2010 Flood Inundation

Downtown Nashville

Opryland Area Upstream

Nashville Gage Reading

- River Miles
  - 52ft_El. 420 ft
  - 50ft_El. 418 ft
  - 48ft_El. 416 ft
  - 45ft_El. 413 ft
  - 42ft_El. 410 ft
  - 40ft_El. 408 ft
  - 37ft_El. 405 ft
  - 35ft_El. 403 ft
  - 32ft_El. 400 ft
  - 30ft_El. 398 ft
  - 25ft_El. 393 ft
Post May 2010 Flood Efforts

- 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**
Post May 2010 Flood Efforts

- 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
Nashville SAFE Guide Books

Metropolitan Nashville Watershed Advisory Guides

April 2011
Nashville SAFE Action Levels

### Watershed Action Level Summary

<table>
<thead>
<tr>
<th>River Mile</th>
<th>Datum Elevation</th>
<th>NAVD 88 Elevation</th>
<th>Action Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.32</td>
<td>433.40</td>
<td>457.72</td>
<td>K</td>
</tr>
<tr>
<td>45027</td>
<td>454.33</td>
<td>20.93</td>
<td>H</td>
</tr>
<tr>
<td>20572</td>
<td>453.16</td>
<td>19.78</td>
<td>G</td>
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<tr>
<td>21890</td>
<td>451.7</td>
<td>18.3</td>
<td>F</td>
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<tr>
<td>17224</td>
<td>450.57</td>
<td>17.17</td>
<td>E</td>
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<tr>
<td>14642</td>
<td>449.22</td>
<td>15.82</td>
<td>D</td>
</tr>
<tr>
<td>11364</td>
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<td>7519</td>
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<tr>
<td>3665</td>
<td>442.48</td>
<td>9.08</td>
<td>A</td>
</tr>
</tbody>
</table>

### National Weather Service Flood Categories

<table>
<thead>
<tr>
<th>Elevation Stage</th>
<th>NAVD88 (Ft)</th>
<th>Flood Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>454.4</td>
<td>Major Flood Stage</td>
</tr>
<tr>
<td>17</td>
<td>450.4</td>
<td>Moderate Flood Stage</td>
</tr>
<tr>
<td>14</td>
<td>447.4</td>
<td>Flood Stage</td>
</tr>
<tr>
<td>12</td>
<td>445.4</td>
<td>Action Stage</td>
</tr>
</tbody>
</table>

### Historical Crests

<table>
<thead>
<tr>
<th>Historical Crest</th>
<th>Date (YYYY-MM-DD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>454.8</td>
</tr>
<tr>
<td>20.6</td>
<td>454.0</td>
</tr>
<tr>
<td>16.9</td>
<td>450.3</td>
</tr>
<tr>
<td>16.2</td>
<td>449.6</td>
</tr>
<tr>
<td>15.8</td>
<td>448.2</td>
</tr>
</tbody>
</table>

### Action Level A
- N/A - no flooding

### Action Level B
- Backyards of houses along Drummond Drive are flooded

### Action Level C
- Houses in the East Glenncliff neighborhood begin to flood
- Homes on Curry Rd begin to flood
- 2nd Dairy King property floods
- Homes on Wimpole Drive near Thomson Lane begin to flood
- Mobile Home Park off Murfreesboro Road and Philfire drive begins to flood

### Action Level D
- Commercial buildings on Space Park Drive begin to flood
- Flooding becomes more extensive on Wimpole Drive in the Glenncliff Estates neighborhood
- Flooding becomes extensive at the mobile home park off Murfreesboro Road and Philfire drive

### Action Level E
- Commercial buildings on Withagen Rd begin to flood
- Commercial building on the corner of Elm Hill Pike and Massman Drive begins to flood

### Action Level F
- 1-24 just south of sevenmile creek begins to flood
- Commercial buildings near Mill Creek at the intersection of Thompson Ln and Murfreesboro Rd begin to flood
- Commercial buildings South East of Philfire Ct near Murfreesboro Road begin to flood
- Roads in Millwood Commercial Park off of Murfreesboro Road begin to flood
- Commercial buildings at the intersection of Mill Creek and Elm Hill Pike as well as on Massman Drive begin to flood

### Action Level G
- Extensive flooding in the East Glenncliff neighborhood
- Flooding begins at Cartyle Place Neighborhood off of Briley Pkwy Murfreesboro Road overtops at Mill Creek Crossing
- Elm Hill Pike begins to flood
- Homes on Bemis Race (North of Elm Hill Pike) begin to flood
- East Haven Townhomes and adjacent neighborhood begins to flood

### Action Level H
- Buildings in Millwood Commercial Park off of Murfreesboro Road begin to flood
- Flooding becomes more extensive on Belle Acre neighborhood off of Lebanon Pike

### Action Level I
- Flooding becomes extensive in the Glenncliff Estates neighborhood

### Action Level J
- I-40 near Frontage Road begins to flood
- Extensive flooding on Elissa Drive near Massman Lane

### Action Level K
- Briley Parkway Just north of I-40 begins to flood
- Lebanon Pike begins to flood near Donelson Hills Drive
Nashville SAFE Inundation Mapping
Post May 2010 Flood Efforts

- 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
Metro FIS Modeling Updates

Nashville Flood Preparedness
Metro Nashville
Davidson County, TN
FIS Study Limits

Legend
- Phase 2 (Complete)
- Phase 3 (Complete)
- Phase 4A (Complete)
- Phase 4AA (Complete)
- Phase 4B (Complete)
- Phase 4C (Complete)
- Phase 4D (Complete)

US Army Corps of Engineers
Nashville District

Updated: August 30, 2016
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- 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
    - USACE
  - 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

**SCRIPT EDITOR**

- 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

Module Tabs

Watershed Pane

Map Window

Message Window

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
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 of 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

- **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

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

![Graph showing precipitation and flow over time with a 2-hour response time.]
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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