Effective Use of FLASH in Hydro Operations

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Traditional Flash Flood Warning Methodology

Largely qualitative analysis

How much rain fell vs flash flood guidance

Rainfall rates, antecedent conditions, and local knowledge may add confidence, but largely unknown impacts

Land use often ambiguous and only accounted for anecdotally
WFO Memphis Flash Flood Warnings

NWS Issuance Count of [FFW] Flash Flood Warning
Plot valid between 01 Jan 2010 00:00 UTC and 31 Dec 2019 00:00 UTC, based on unofficial IEM Archives

2010-2019

2nd most FFW in the CONUS

False alarm rate > 60% for 7 of 8 years between 2011-2018
WFO Memphis Flash Flood Warnings By Year

Revamped Methodology 2019
WFO Memphis Flash Flood Warnings

2020-current

12th most FFW in the CONUS
Estimating Precipitation Amounts

Legacy Radar Estimates

- Single Z-R relationship across the domain
- Rainfall rate capped at 4.1”/hr
- May include non-meteorological echoes

Dual-Pol Radar Estimates

- Dynamic Z-R relationship based on hydrometeor classification algorithm
- Rainfall rate capped at 8”/hr
- Able to ignore non-meteorological echoes

Multi-Radar Multisensor Estimation (MRMS)

- Mosaic radar product
- Dual-pol dynamic Z-R relationship
- Rainfall rate capped at 5.9”/hr

Rainfall rate caps are primarily to mitigate hail contamination (excessive rates)
## What is FLASH?

**Flooded Locations and Simulated Hydrographs**

Relies on MRMS Radar Only QPE (Q3) for forcing

<table>
<thead>
<tr>
<th>What it is</th>
<th>What it’s not</th>
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</thead>
<tbody>
<tr>
<td>Ensemble modeling of hydro routing designed to improve forecasters ability to forecast flash flooding</td>
<td>A stand-alone prediction tool for flash flooding</td>
</tr>
<tr>
<td>A means to help quantify flash flooding impacts</td>
<td>An observation of runoff/flooding</td>
</tr>
<tr>
<td></td>
<td>Without limitations</td>
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</tbody>
</table>
FLASH Modeling

Ensemble Framework for Flash Flood Forecasting (EF5)

Suite of water balance models used to simulate surface flow rates:

- Coupled Routing and Excess Storage Model (CREST)
- Sacramento Soil Moisture Accounting Model (SAC-SMA)
- Hydrophobic Model
CREST vs. SAC-SMA vs. Hydrophobic

CREST

Known for its coupling of upstream runoff into downstream cells to more accurately depict saturation in low-lying areas first. Better performance in urban areas and provides a good first guess for areal extent of flooding.

SAC-SMA

Similar to CREST but doesn’t use a percent imperviousness parameter to model urban effects. Known to saturate from the bottom-up and works well in long duration, high-end events. Often lower values than CREST.

Hydrophobic

Just like the SAC-SMA, but doesn’t allow any infiltration into the underlying soil layers. More or less the worst-case scenario where everything is runoff.
CREST vs. SAC-SMA vs. Hydrophobic

CREST

Known for its coupling of upstream runoff into downstream cells, CREST is particularly effective in portraying saturation in low-lying areas. It offers better performance in urban areas and provides a good first guess for the areal extent of flooding.

SAC-SMA

SAC-SMA is similar to CREST but does not use a percent imperviousness parameter to model urban effects. It tends to saturate from the bottom-up and is well-suited for long-duration, high-end events. SAC-SMA often produces lower results compared to CREST.

Hydrophobic

Just like SAC-SMA, Hydrophobic does not allow for any infiltration into the underlying soil layers. It represents a worst-case scenario where everything is runoff.

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As per Gourley et al. (2017), the following table summarizes the performance of the three water balance components supported in EF5:

<table>
<thead>
<tr>
<th>Water Balance Module</th>
<th>No. of Events</th>
<th>Pearson Correlation</th>
<th>Spearman Correlation</th>
<th>POD</th>
<th>FAR</th>
<th>CSI</th>
<th>HSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CREST</td>
<td>12,771</td>
<td>0.64</td>
<td>0.79</td>
<td>0.54</td>
<td>0.43</td>
<td>0.38</td>
<td>0.41</td>
</tr>
<tr>
<td>SAC-SMA</td>
<td>18,934</td>
<td>0.57</td>
<td>0.70</td>
<td>0.49</td>
<td>0.48</td>
<td>0.34</td>
<td>0.37</td>
</tr>
<tr>
<td>Hydrophobic</td>
<td>14,573</td>
<td>0.55</td>
<td>0.71</td>
<td>0.93</td>
<td>0.67</td>
<td>0.32</td>
<td>0.37</td>
</tr>
</tbody>
</table>
Surface Permeability and Infiltration

- Derived from National Land Cover Database (2011)
- Percent of rain that is converted directly to surface runoff
- Unique to the CREST model

Higher beta means faster saturation and surface runoff
Max Streamflow

Defined as max total water flow over a specific point

Determined for each model run for a period of 30 min before initialization out to 12 hours into the future

AWIPS units: cfs (research and website m³/s)

Conversion: 1 m³/s = 35 ft³/s

1 km x 1 km spatial resolution. Updates every 10 minutes

Application: Visualize stream and river networks to identify broad areas of high flow. Need to know how much flow is needed to cause overland flow, so it’s not ideal for flash flood forecasting. However, it is useful for detecting model based errors that could propagate downstream into unit streamflow. Can also be used to orient warning polygons to capture downstream effects.
Max Unit Streamflow

Defined as max total water flow over a specific point normalized by basin area at every grid cell.

Determined for each model run for a period of 30 min before initialization out to 12 hours into the future.

1 km x 1 km spatial resolution.

Updates every 10 minutes.

**AWIPS units:** cfs/mi² (research and website units: m³/s/km²)

Conversion: $1 \text{ m}^3/\text{s}/\text{km}^2 = 91.5 \text{ cfs/mi}^2$ (can use 1:100 conversion for fast calculations)

Application: normalizing the streamflow to the basin area, unit streamflow highlights where more significant flows are occurring, especially within smaller basins.
Max Streamflow and Max Unit Streamflow are modeled forecasts for as much as 12 hours into the future (usually much shorter time frame)

Values are NOT necessarily current conditions

Look for spatial continuity (not sporadic pixels reaching specific thresholds)

Learn how it works in various locations with the CWA (study ongoing)

Always use in conjunction with your other flash flooding tools (FFMP, radar QPE, rain rates, etc)
Soil Saturation

Only produced by CREST and SAC-SMA

Valid at the time of the model run

Model output water content in the top-layer soils compared to the max storage capacity (as percentage)

1 km x 1 km spatial resolution. Updated every 10 minutes

Application: Identifying antecedent conditions conducive to flash flooding. **Values > 50% indicate recent significant rainfall** (mind the spatial continuity). Best used qualitatively to examine the spatial extent of antecedent conditions.
FLASH Comparisons

FLASH compares MRMS data to static and dynamic fields to help the forecaster gauge rainfall significance and/or flash flooding potential.

These comparisons include the Average Recurrence Interval and Quantitative Precipitation Estimation (QPE) to Flash Flood Guidance (FFG) ratio.

All comparison products are available on a 1 km x 1 km grid and update every 2 minutes.
Average Recurrence Interval

MRMS radar only output is compared to a static precipitation frequency that is from slightly modified NOAA Atlas 14 data.

Available for 30 min, 1 hr, 3 hr, 6 hr, 12 hr, 24 hr, and maximum* time frames

Data updates every 2 minutes

1 km x 1 km spatial resolution

Think of this as a way to gauge rainfall rarity, not flooding impacts.

However, empirical data suggests flash flooding possible at values of 4-10 years but more likely at 10+ years. Significant flooding likely at 50+ years. Anecdotally has a slight high bias.

*Maximum is the max of all time periods for each grid point

Three hour Average Recurrence Interval (ARI) on Jul 1, 2021. Rainfall totals eclipsed the maximum of 200 years.
MRMS output is compared to dynamic FFG data produced ~6 hrs by the RFC

Available for 1 hr, 3 hr, 6 hr, and maximum* time frames

Data updates every 2 minutes

1 km x 1 km spatial resolution

Flash flooding possible at values of 1.0-1.5 but most likely at 1.5 or greater.

Mid-event changes to FFG may result in unrealistically high ratios.

*Maximum is the max of all time periods for each grid point

Three hour QPE to FFG ratio on Mar 28, 2020. QPE was more than 5 times the gridded FFG to the east of Jackson, TN.
Changes to Flash Flood Guidance

QPE to FFG ratio at 2000z

QPE to FFG ratio at 2010z
FLASH Thresholds to Consider

- Gourley and Vergara compiled various subjective thresholds based on NWS forecaster feedback.

- Guidance may perform differently in urban vs rural areas.

- Reliant on good MRMS input.

- Local study ongoing to assess the utility in the Mid-South.

Subjective guidance developed using NWS forecaster experience. Gourley and Vargara, 2021
Local FLASH Recommendations

Based on limited study of the 8-10 June 2021 north Mississippi widespread flooding (Johnson and K McNeil)

Relatively small sample size, so more work is needed

# Recommended use of ARI is to assess the rarity of the event, not the severity

<table>
<thead>
<tr>
<th>FLASH Parameter</th>
<th>Recommended Threshold</th>
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<tbody>
<tr>
<td>CREST maximum unit streamflow</td>
<td>&gt; 180 cfs/mi²</td>
</tr>
<tr>
<td>Maximum ARI</td>
<td>4.3 years#</td>
</tr>
<tr>
<td>Maximum QPE/FFG Ratio</td>
<td>&gt; 120%</td>
</tr>
</tbody>
</table>

2022 AMS Conference Poster
2022 AMS Extended Abstract
FLASH Limitations

- QPE: all limitations of MRMS radar-only QPE are valid
- Snowmelt: not accounted for
- River diverts: does not account for river diversions, dams, etc.
- Future rainfall: only accounts for rain that has fallen up to initialization time
- Calibration: not calibrated in real-time so large discrepancies can exist
- Post-processing: soil saturation is not post-processed so it may not be representative of in-situ or remotely sensed soil saturation observations
- Changes to FFG may cause dramatic shifts in ratio products
Arkansas Example

3-hr MRMS Radar Only QPE at 01 UTC

CREST soil moisture content at 01 UTC
Arkansas Example

- CREST Maximum Unit Streamflow at 01 UTC
- Maximum ARI at 01 UTC
- Maximum FFG-QPE Ratio at 01 UTC
No flooding was observed. In hindsight, a great candidate for an Areal Flood Advisory (FLS)
Kentucky Example

3-hr MRMS Radar Only QPE at 14 UTC

CREST soil moisture content at 14 UTC
Kentucky Example

Maximum ARI at 14 UTC

Maximum FFG-QPE Ratio at 14 UTC

CREST Maximum Unit Streamflow at 14 UTC
Kentucky Example

Looks like a good candidate for a base-level Flash Flood Warning
Kentucky Example

90 minutes later

May be a good time to upgrade to “considerable”
Kentucky Example

Significant flash flooding impacts were observed across much of western Kentucky.

Murray, KY

Fulton, KY

Wingo, KY
In Summary

The addition of FLASH to the warning decision process has been invaluable.

However, FLASH is **NOT** a magic bullet for flash flooding detection.

Do not rely solely on FLASH for warning decisions. It is another tool in the bag.
Flash Flood Probability of Detection

- Best Probability of Detection (POD) since 2011.
- Upward trend since 2019.
Flash Flood False Alarm Rate

- Lowest False Alarm Rate (FAR) since 2011.
- General downward trend since 2018.
Flash Flood Lead Time

- Good lead time of nearly 57 minutes.
- Lead time > 50 minutes 5 of the past 6 years.
Flash Flood Accuracy/CSI

- Best Critical Success Index (CSI) over the past 10+ plus years.
- General upward trend since 2018.