Effective Use of FLASH in Hydro Operations

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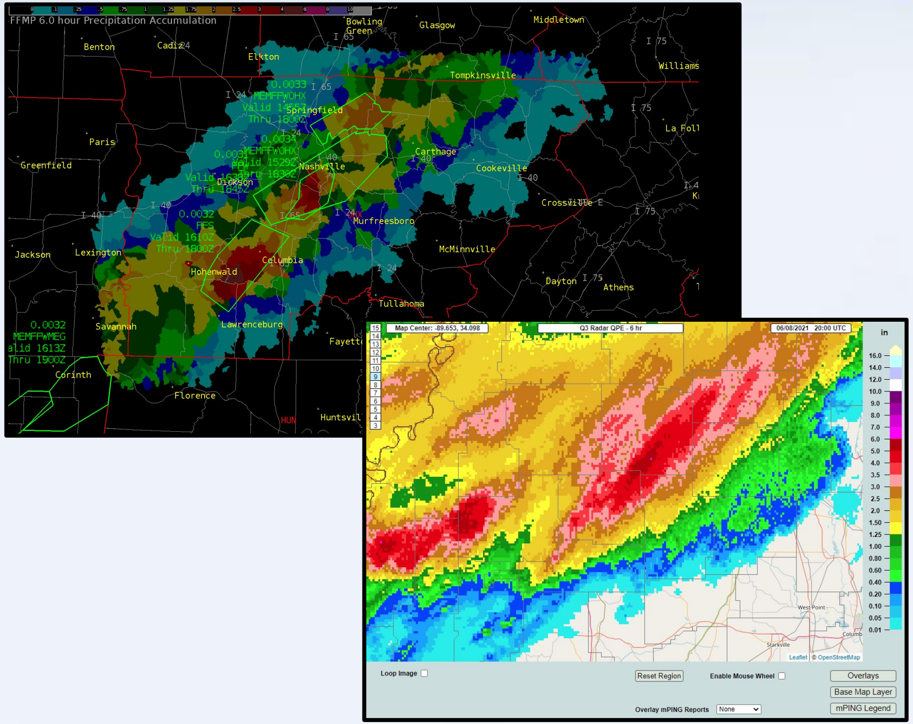
Traditional Flash Flood Warning Methodology

Largely qualitative analysis

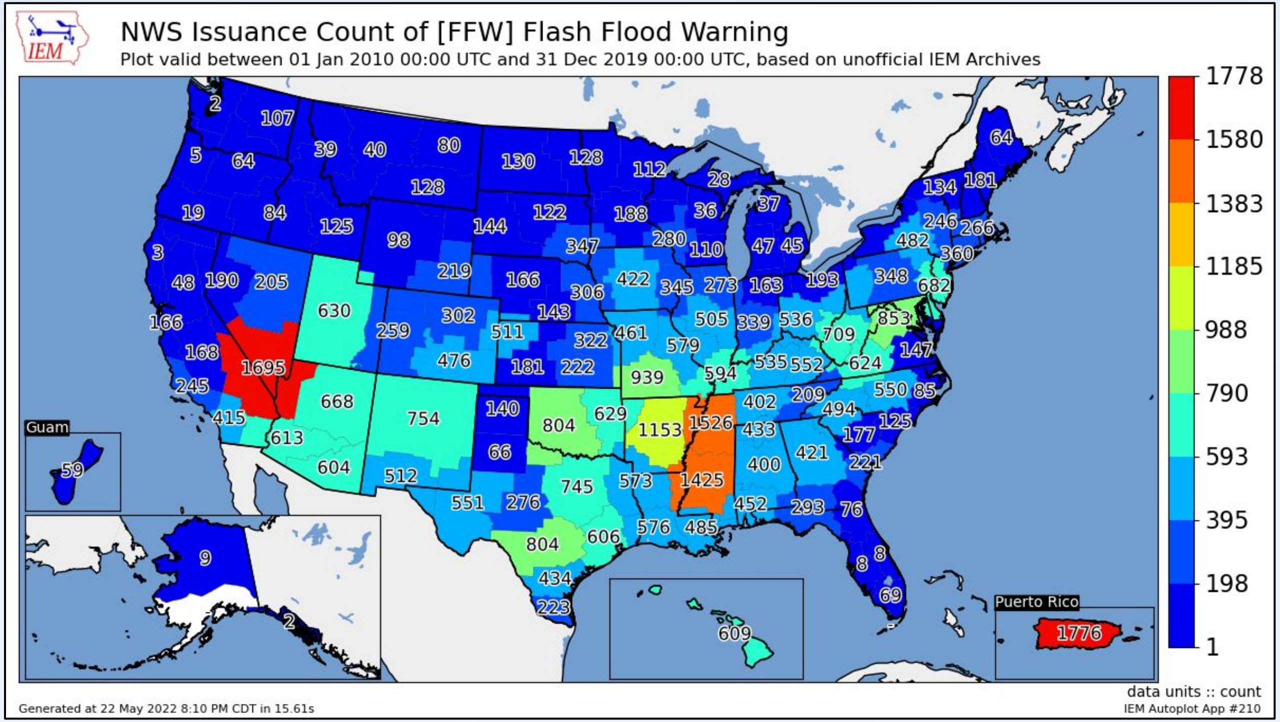
How much rain fell vs flash flood guidance

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

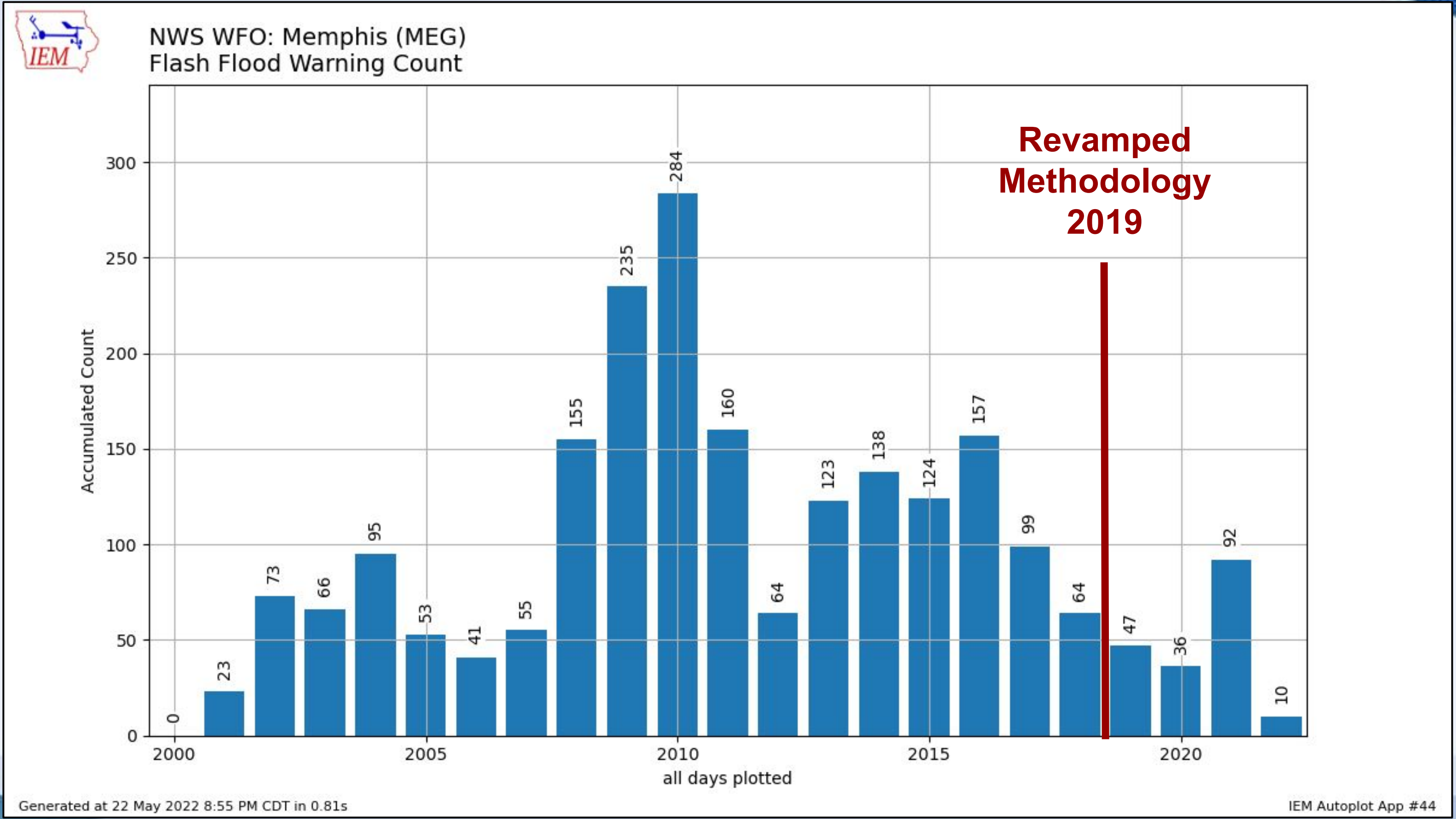


2010-2019

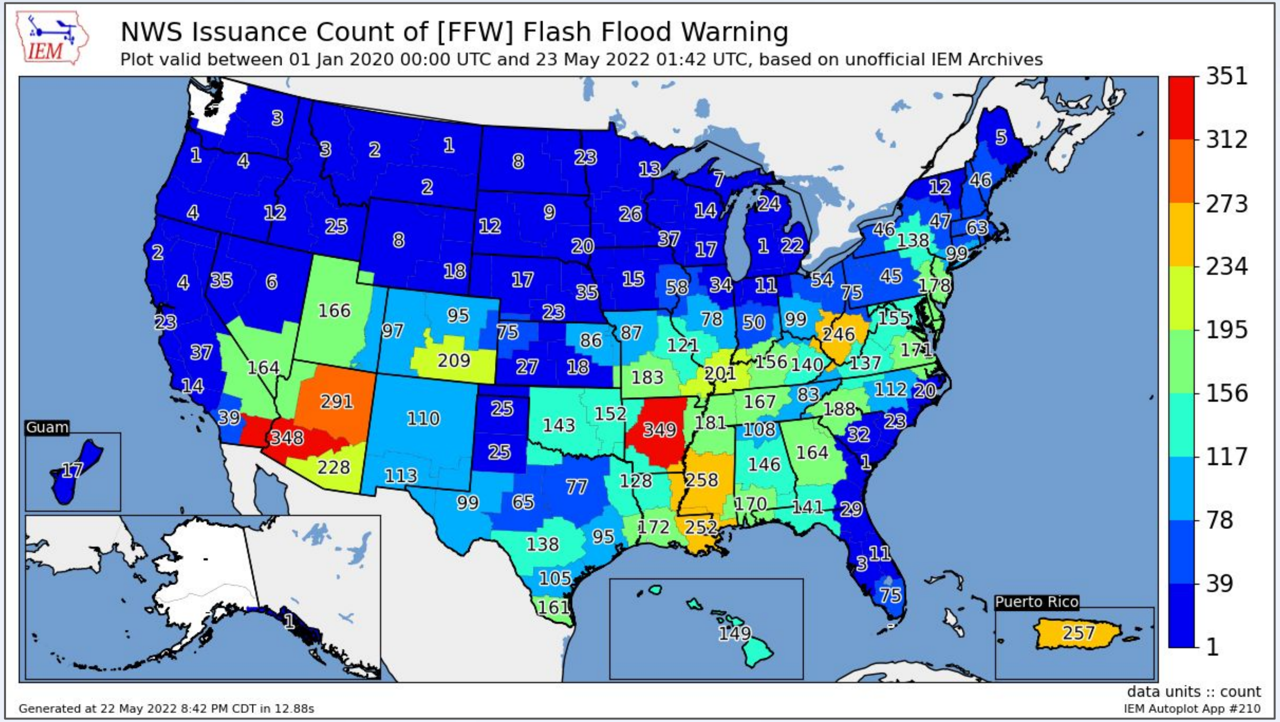
2nd most FFW in the CONUS

False alarm rate > 60% for 7 of 8 years between 2011-2018

WFO Memphis Flash Flood Warnings By Year



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

FLASH
Flooded Locations and Simulated Hydrographs Project

What it is

Ensemble modeling of hydro routing designed to improve forecasters ability to forecast flash flooding

A means to help quantify flash flooding impacts

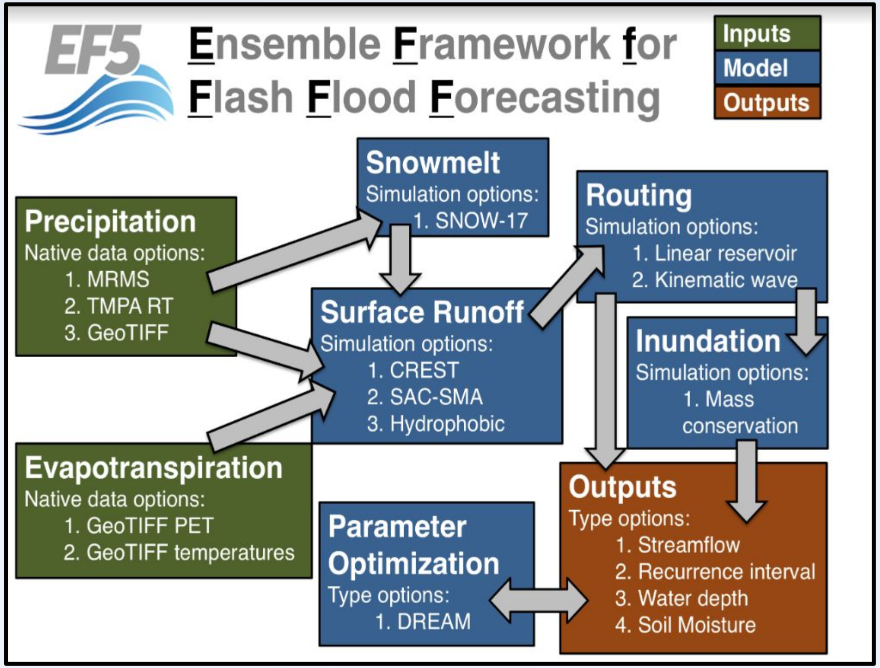
What it's not

A stand-alone prediction tool for flash flooding

An observation of runoff/flooding

Without limitations

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

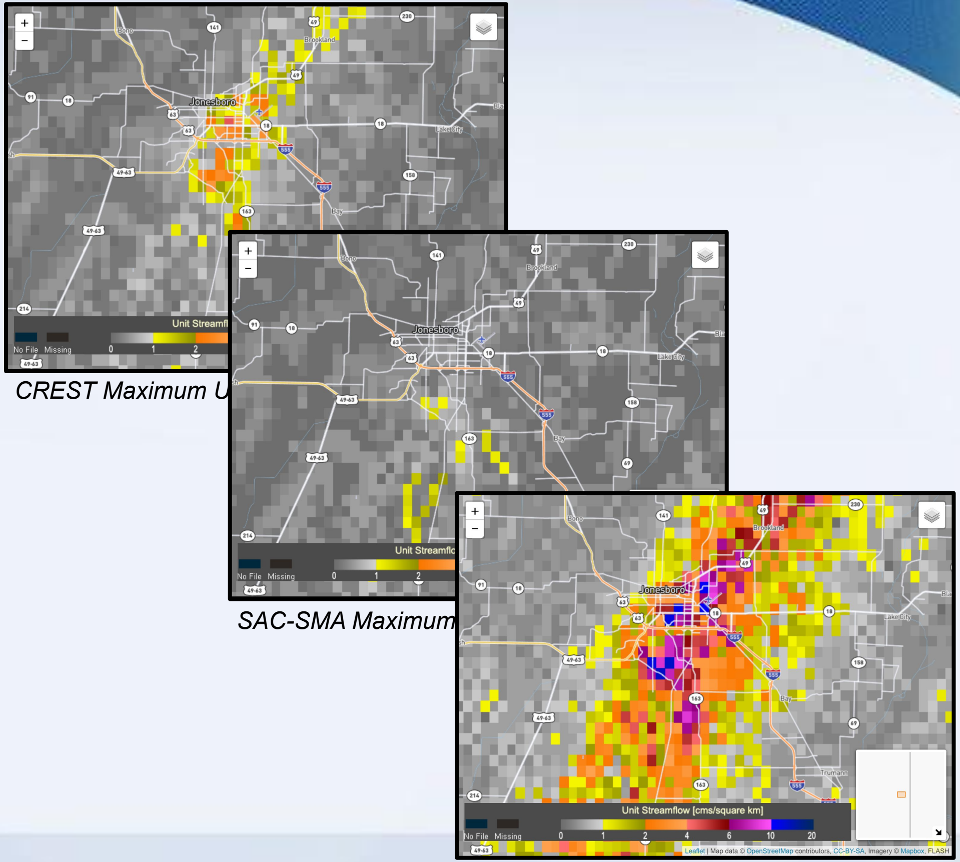
Known for its coupling of upstream runoff into downstream cells to more accurately depict saturation in low-lying areas first. Better performance in urban areas and provides a good first guess for areal extent of flooding.

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 Maximum U

SAC-SMA Maximum

Hydrophobic Maximum Unit Steamflow

CREST vs. SAC-SMA vs. Hydrophobic

CREST

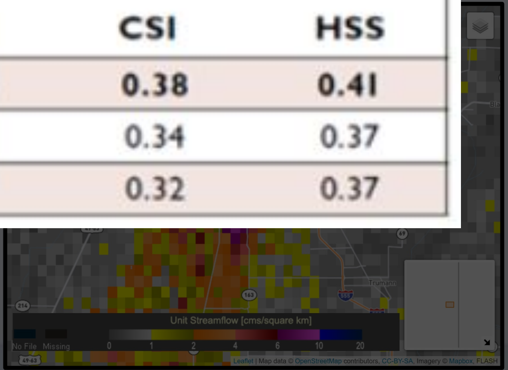
Known for its coupling of upstream runoff into downstream

Gourley et al. (2017)

TABLE 2. Statistics for the three water balance components supported in EF5. The Pearson (linear) correlation and Spearman (rank) correlation correspond to the observed and simulated peak flow values. Contingency table statistics are reported based on the number of hits, misses, false alarms, and correct negatives to compute the probability of detection (POD), false alarm ratio (FAR), CSI, and HSS. Scores in boldface correspond to the best performing water balance component according to each statistical measure.

Water balance module	No. of events	Pearson correlation	Spearman correlation	POD	FAR	CSI	HSS
CREST	12,771	**0.64**	**0.79**	0.54	**0.43**	**0.38**	**0.41**
SAC-SMA	18,934	0.57	0.70	0.49	0.48	0.34	0.37
Hydrophobic	14,573	0.55	0.71	**0.93**	0.67	0.32	0.37

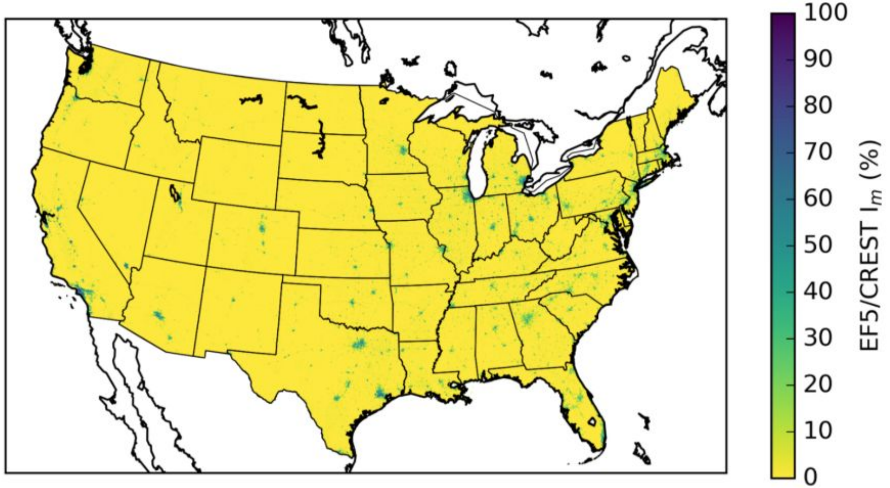
infiltration into the underlying soil layers. More or less the worst-case scenario where everything is runoff.



Hydrophobic Maximum Unit Steamflow

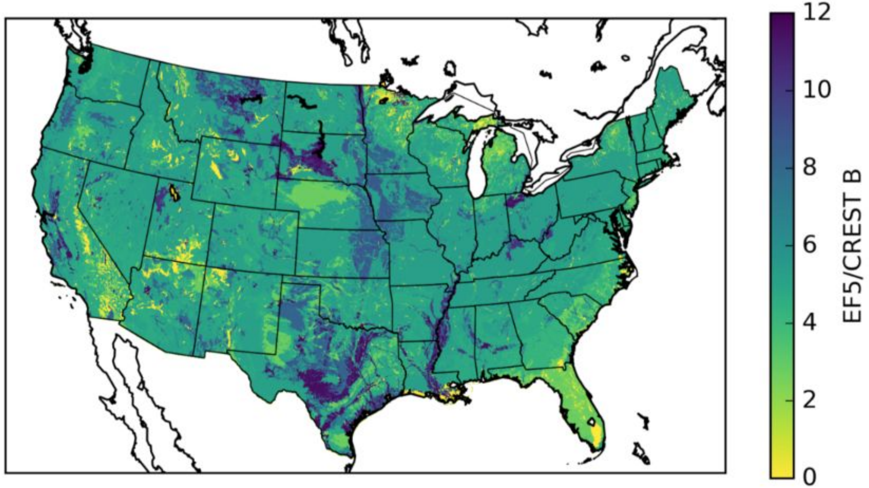
Surface Permeability and Infiltration

Impervious area



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

Infiltration Rate



Higher beta means faster saturation and surface runoff

Max Streamflow

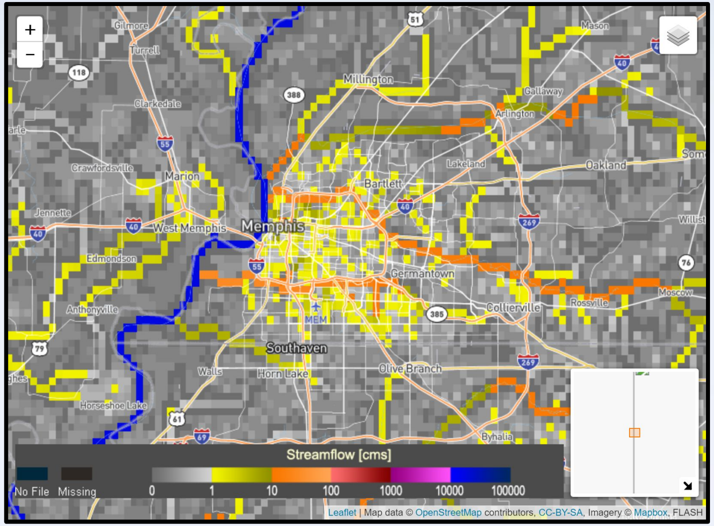
Defined as max total water flow over a specific point

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 m^3/s)

Conversion: 1 m^3/s = 35 ft^3/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

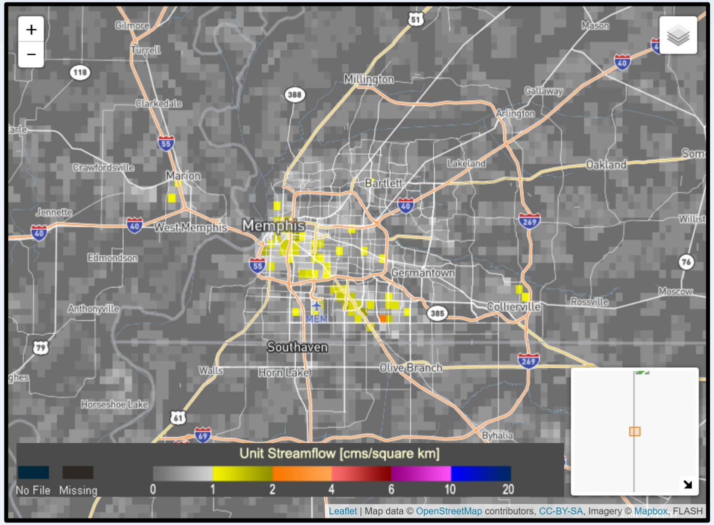
Determined for each model run for a period of 30 min before initialization **out to 12 hours into the future**

1 km x 1 km spatial resolution

Updates every 10 minutes

AWIPS units: cfs/mi^2 (research and website units: m^3/s/km^2)

Conversion: 1 m^3/s/km^2 = 91.5 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.

Using Max Unit Streamflow

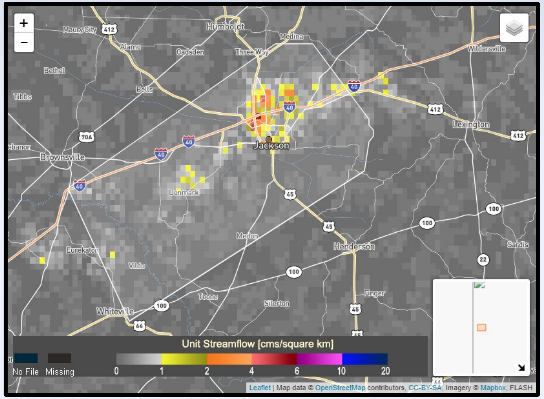
Max Streamflow and Max Unit Streamflow are modeled forecasts for as much as 12 hours into the future (usually much shorter time frame)

Values are NOT necessarily current conditions

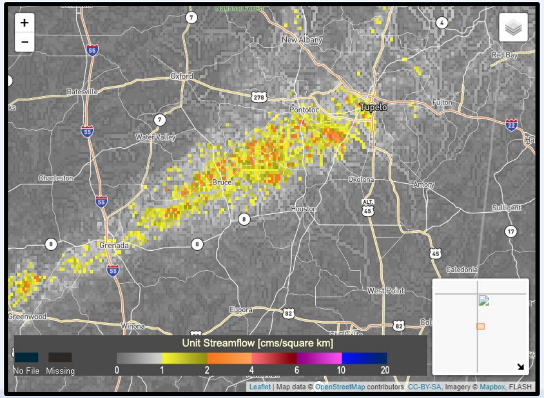
Look for spatial continuity (not sporadic pixels reaching specific thresholds)

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)



Urban flooding example



Rural flooding example

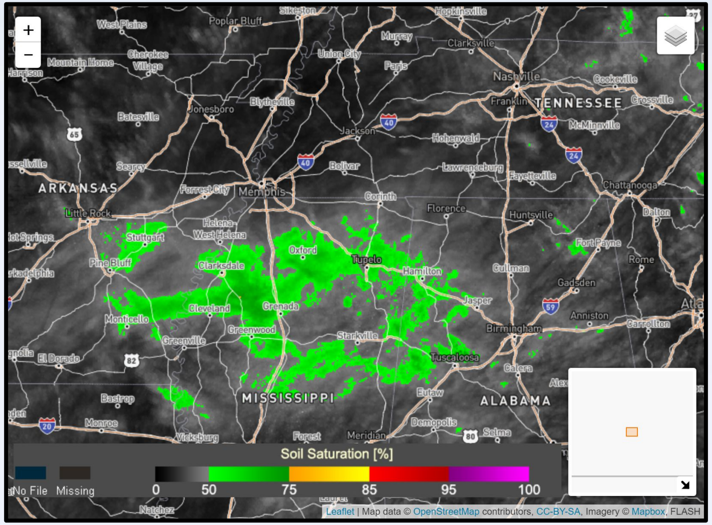
Soil Saturation

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

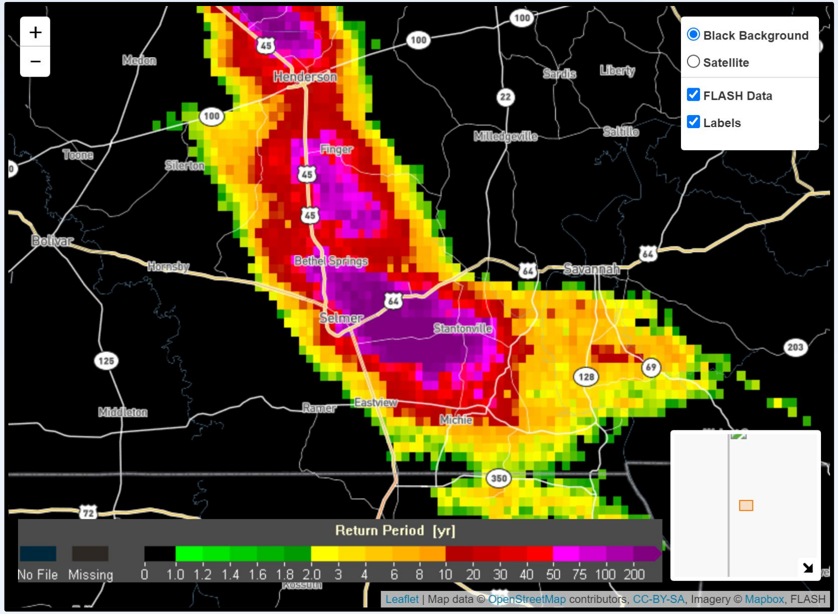
Data updates every 2 minutes

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.

QPE to FFG Ratio

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

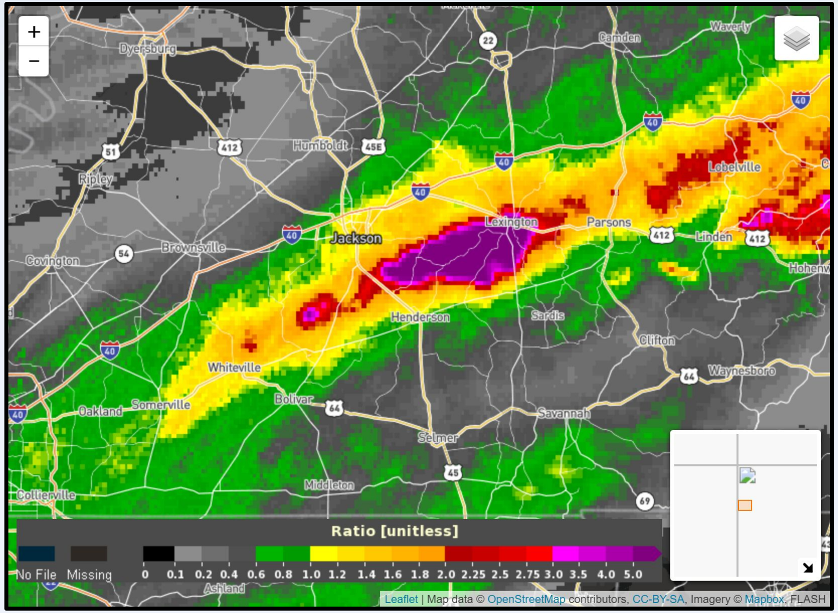
Data updates every 2 minutes

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.

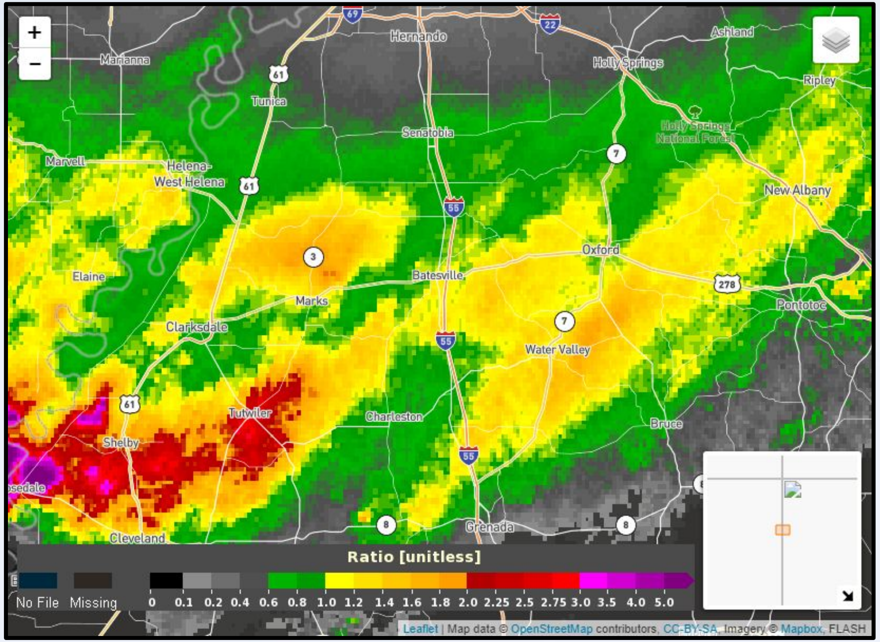
Mid-event changes to FFG may result in unrealistically high ratios.

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

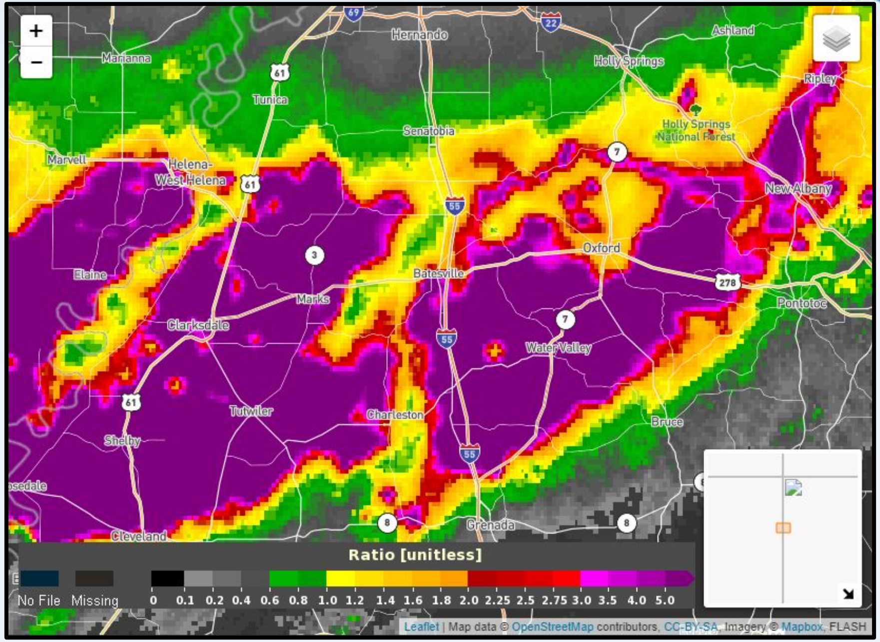


Three hour QPE to FFG ratio on Mar 28, 2020. QPE was more than 5 times the gridded FFG to the east of Jackson, TN.

Changes to Flash Flood Guidance



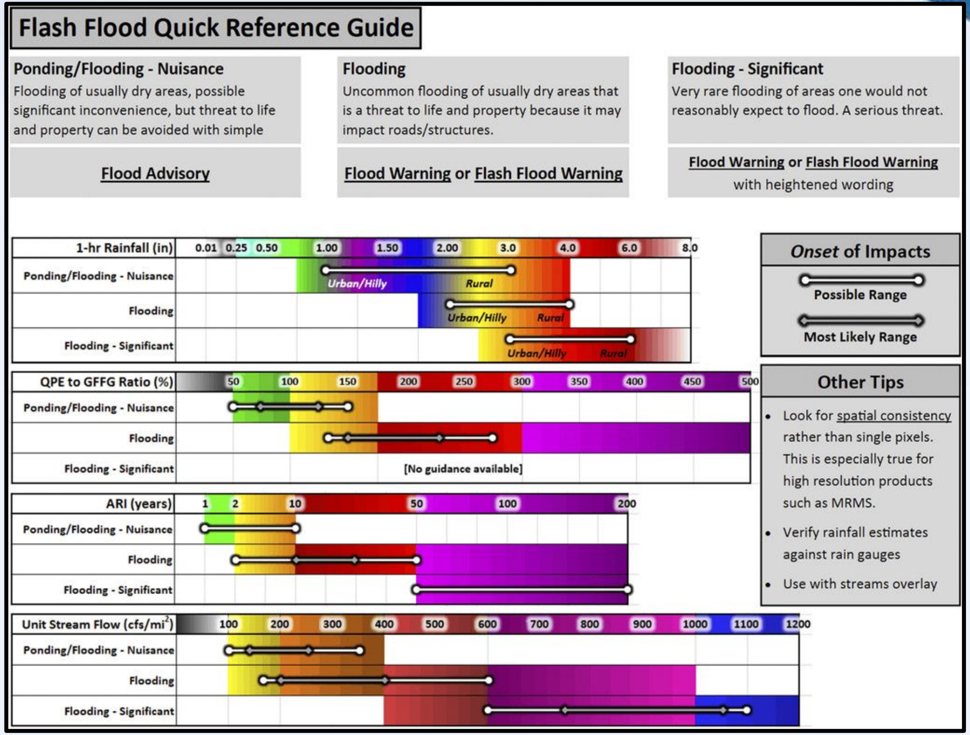
QPE to FFG ratio at 2000z



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)

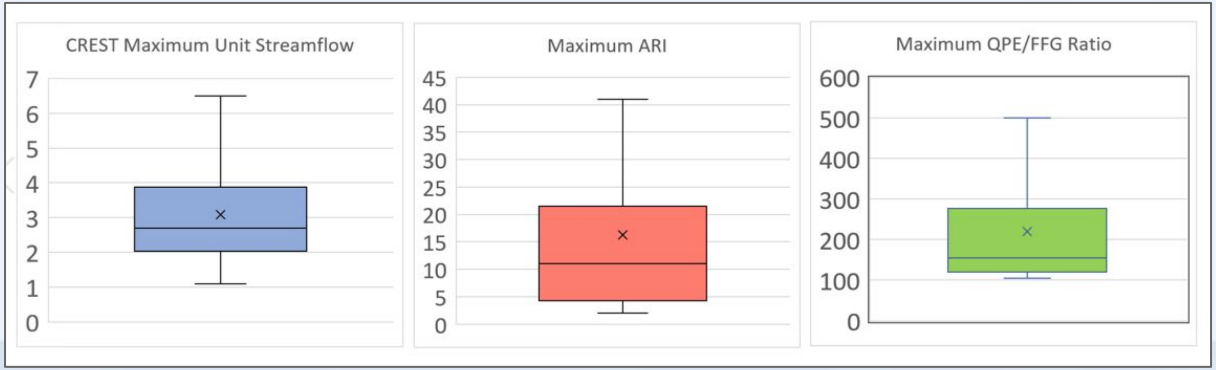
Relatively small sample size, so more work is needed

FLASH Parameter	Recommended Threshold
CREST maximum unit streamflow	> 180 cfs/mi^2
Maximum ARI	4.3 years#
Maximum QPE/FFG Ratio	> 120%

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

[2022 AMS Conference Poster]

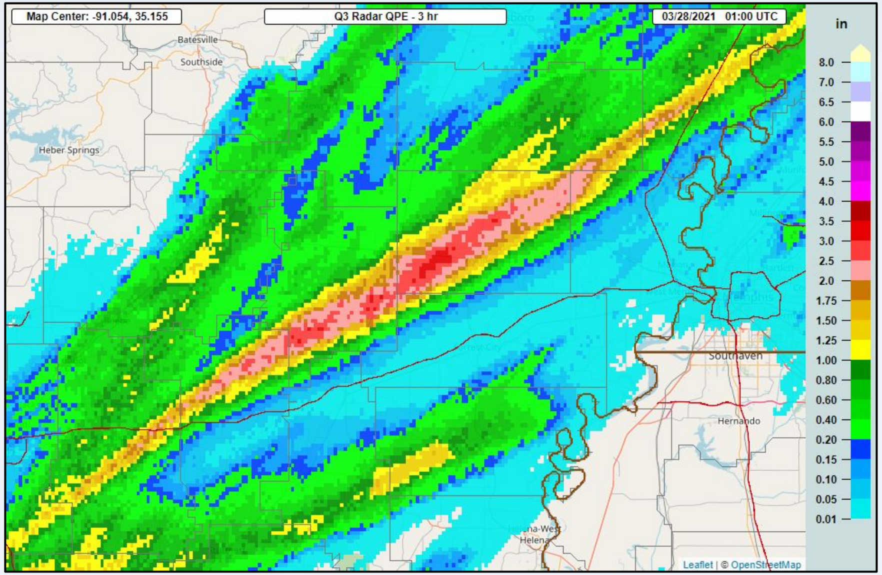
[2022 AMS Extended Abstract]



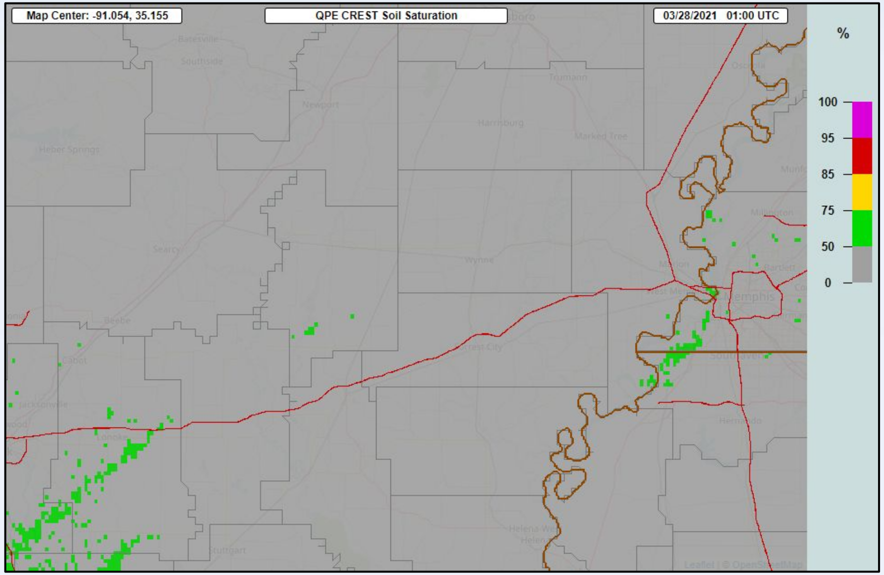
FLASH Limitations

- 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



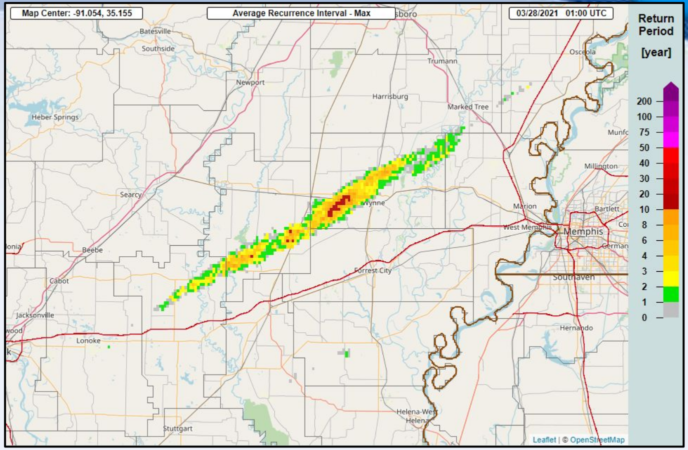
3-hr MRMS Radar Only QPE at 01 UTC

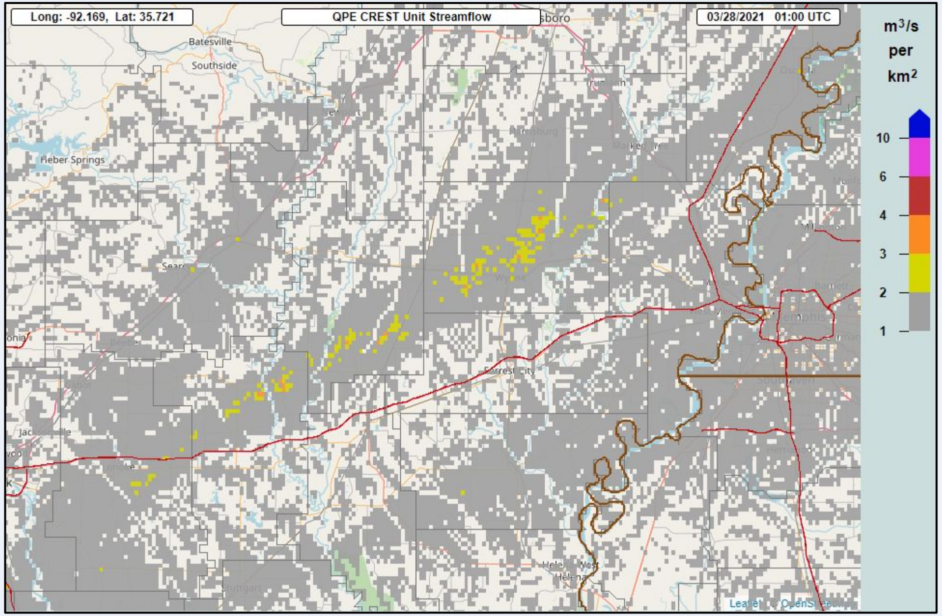


CREST soil moisture content at 01 UTC

Arkansas Example

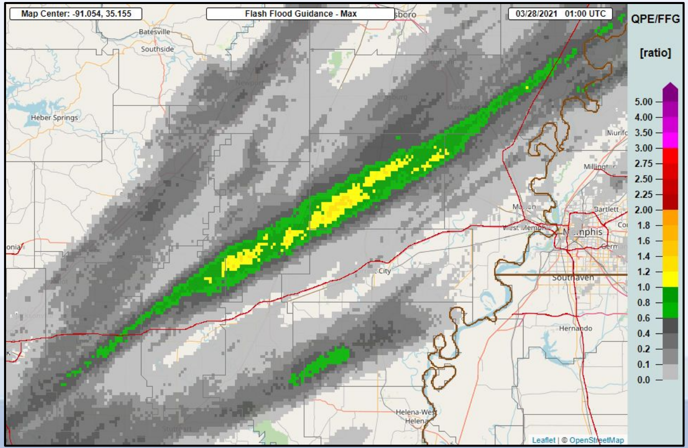
Maximum ARI at 01 UTC



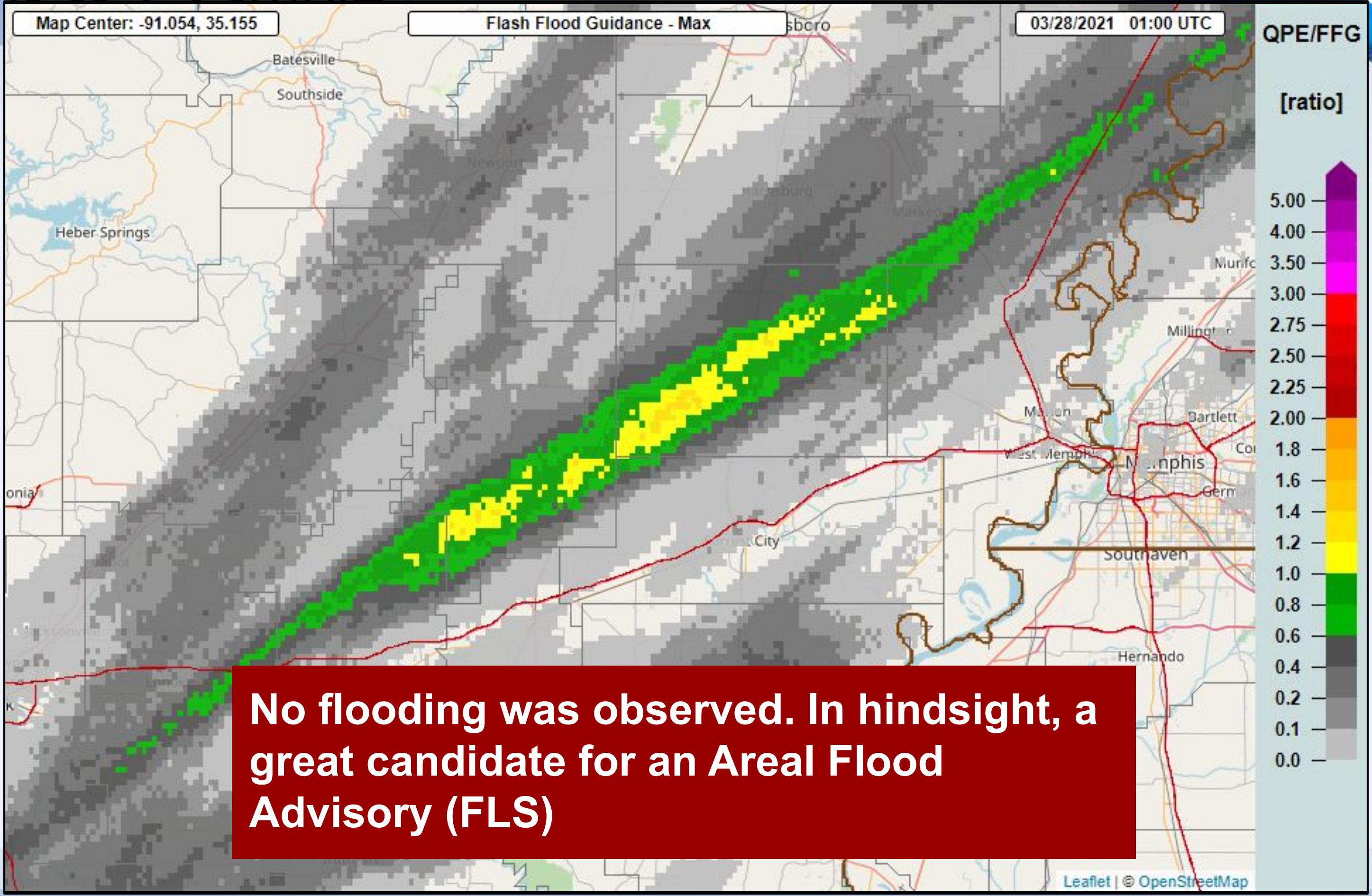


CREST Maximum Unit Streamflow at 01 UTC

Maximum FFG-QPE Ratio at 01 UTC

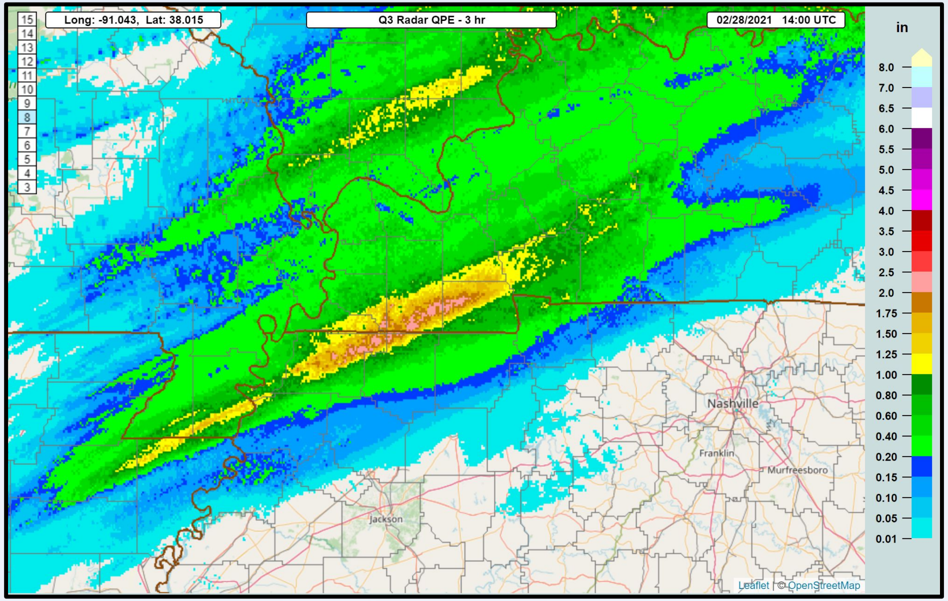


Arkansas Example

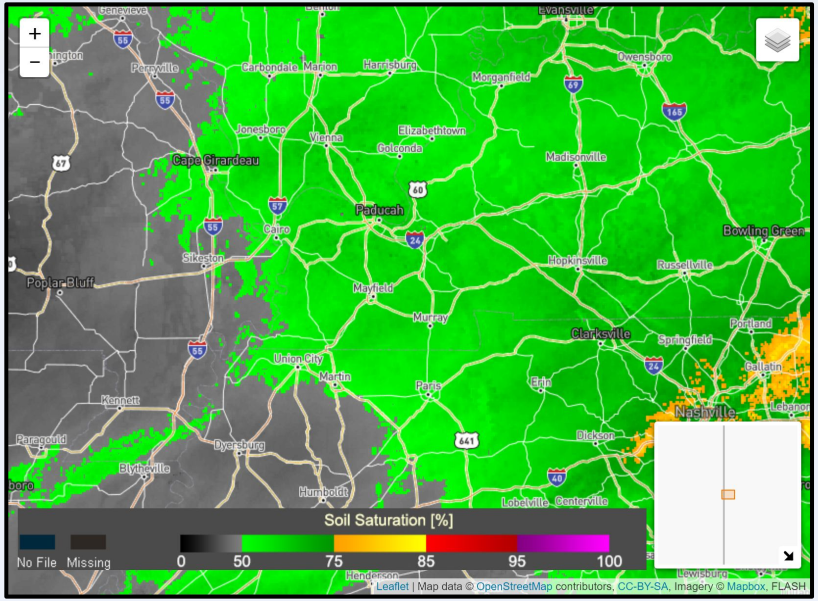


No flooding was observed. In hindsight, a great candidate for an Areal Flood Advisory (FLS)

Kentucky Example



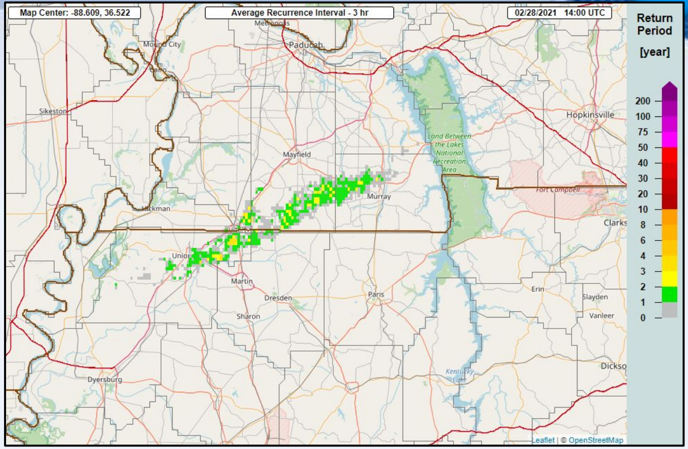
3-hr MRMS Radar Only QPE at 14 UTC

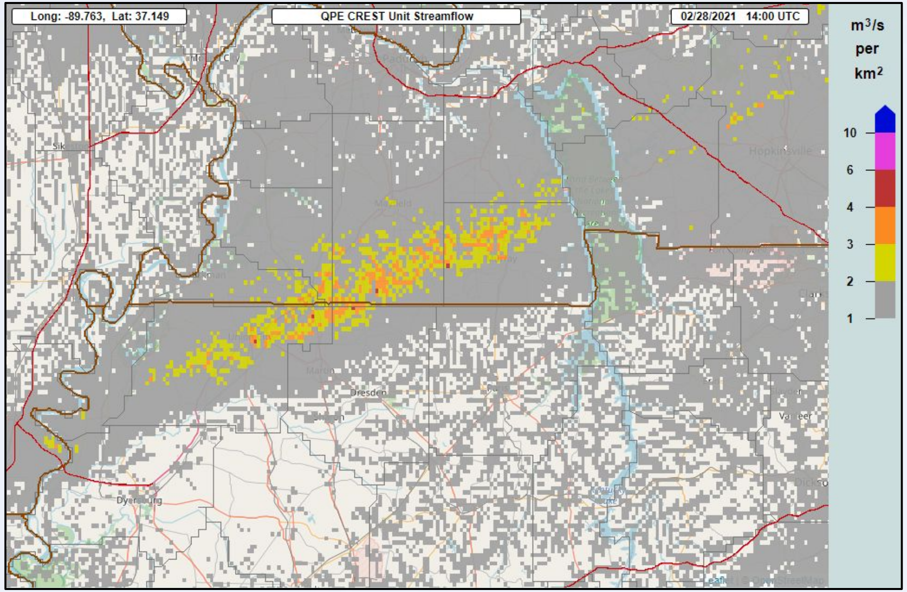


CREST soil moisture content at 14 UTC

Kentucky Example

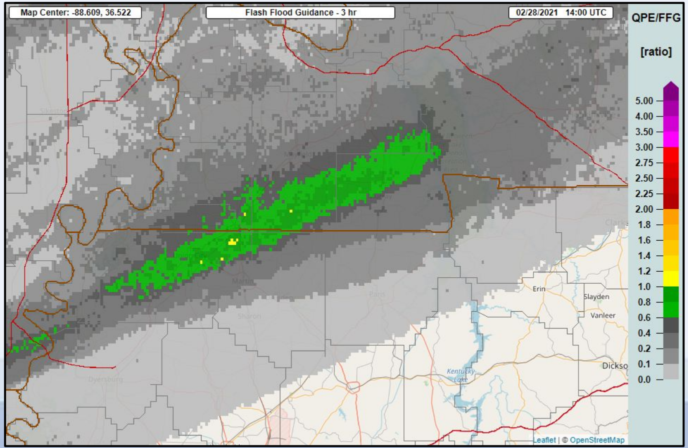
Maximum ARI at 14 UTC



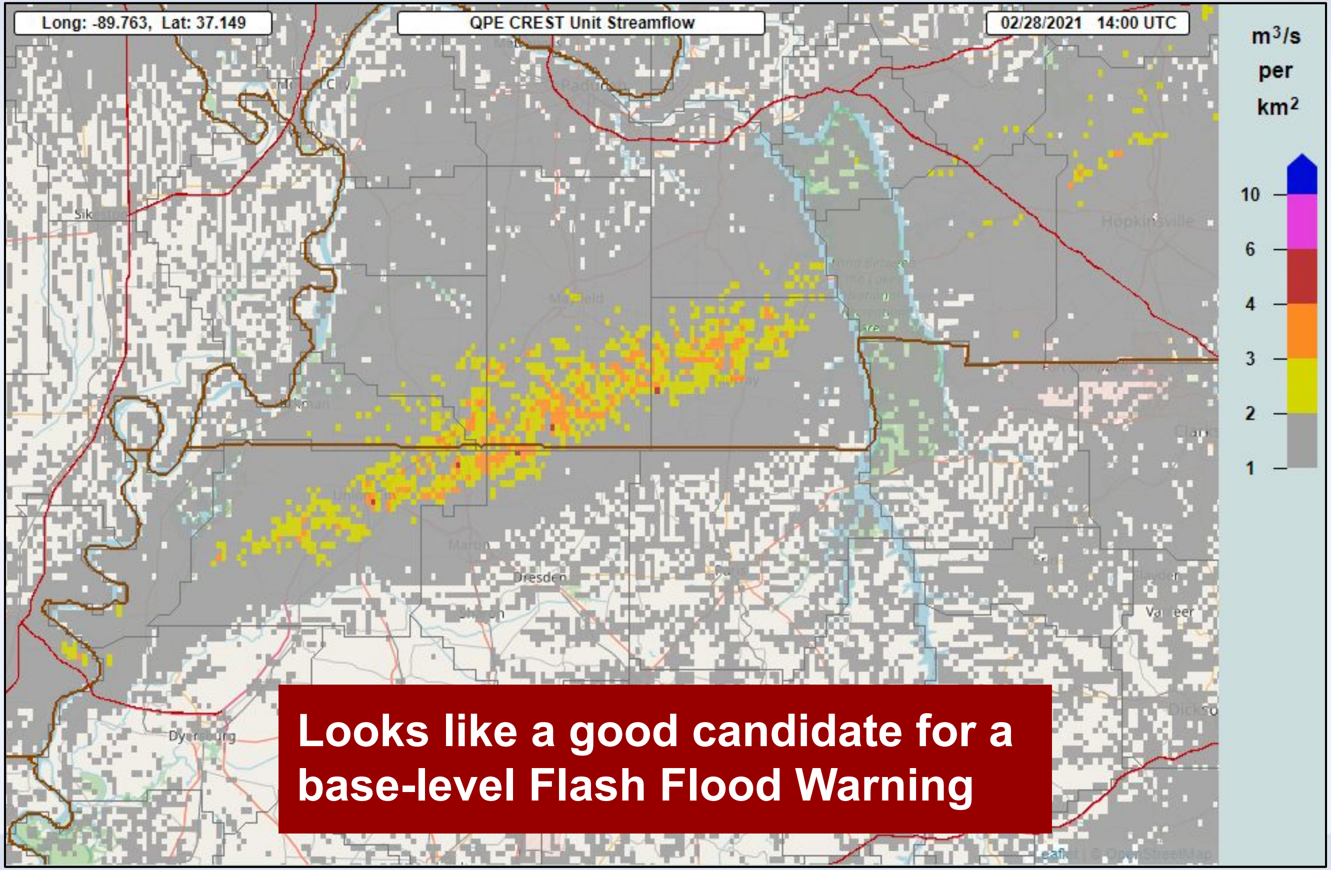


CREST Maximum Unit Streamflow at 14 UTC

Maximum FFG-QPE Ratio at 14 UTC

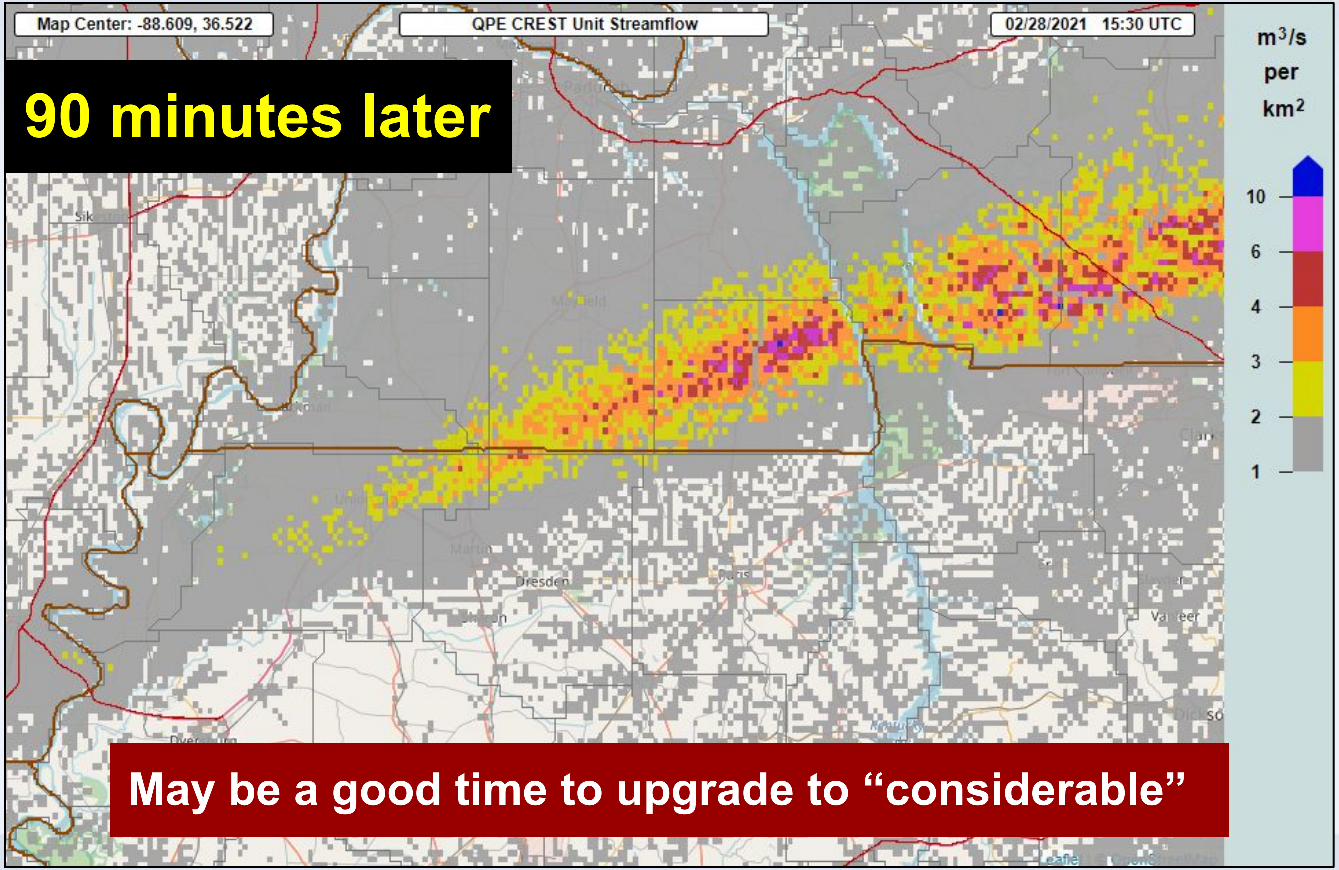


Kentucky Example



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

Kentucky Example



Kentucky Example

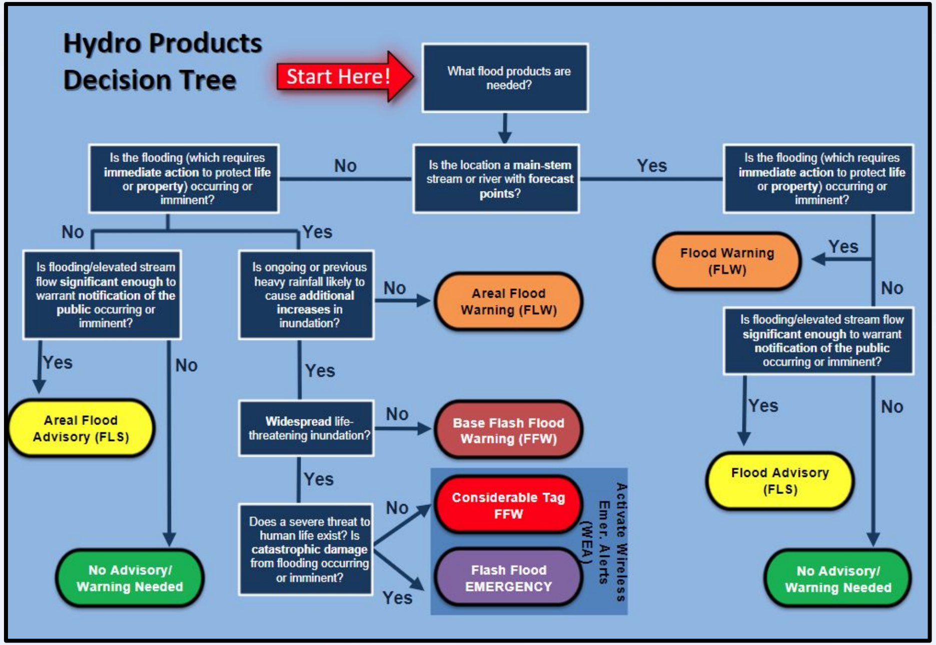
Significant flash flooding impacts were observed across much of western Kentucky.

Murray, KY

Fulton, KY

Wingo, KY

In Summary

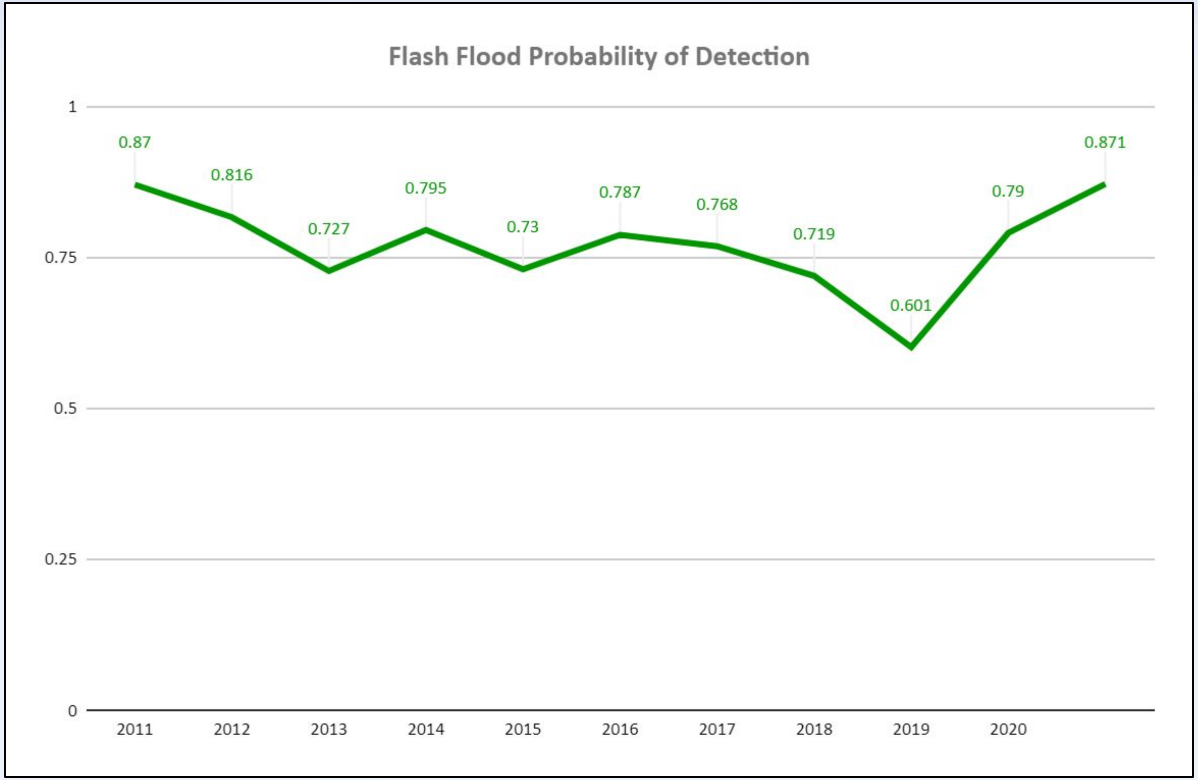


The addition of FLASH to the warning decision process has been invaluable.

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

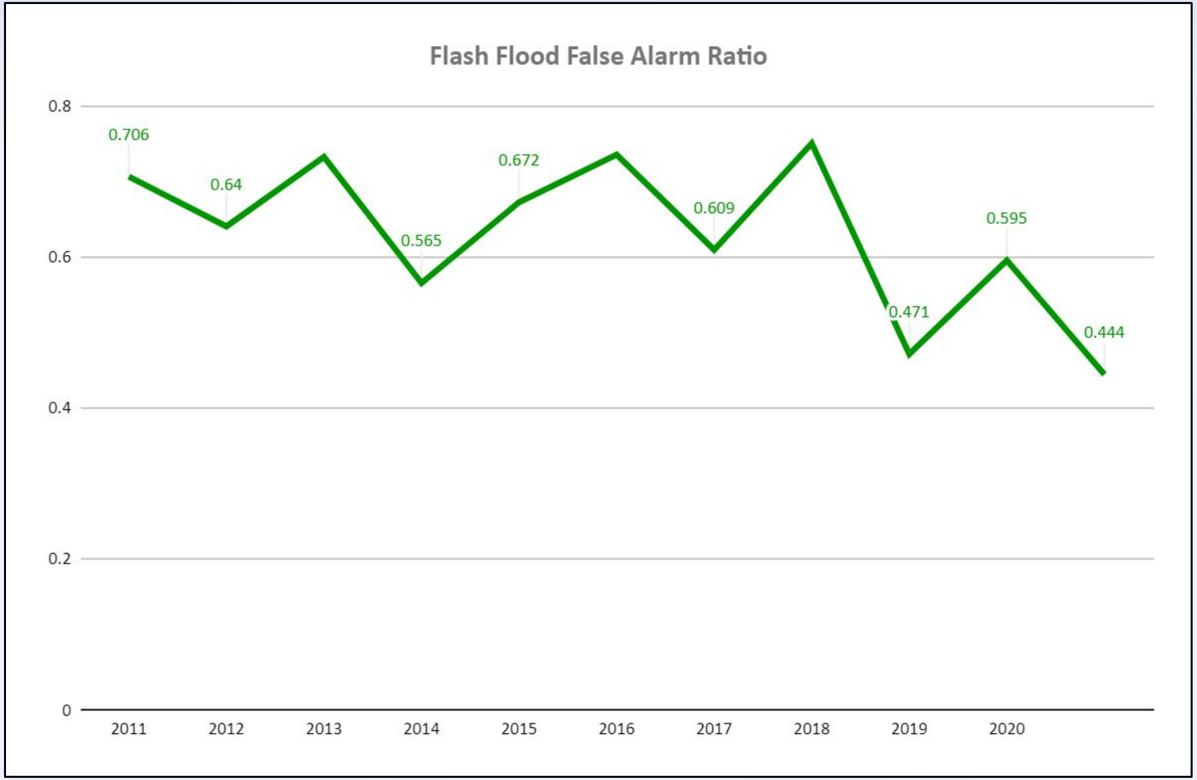
Do not rely solely on FLASH for warning decisions. It is another tool in the bag.

Flash Flood Probability of Detection



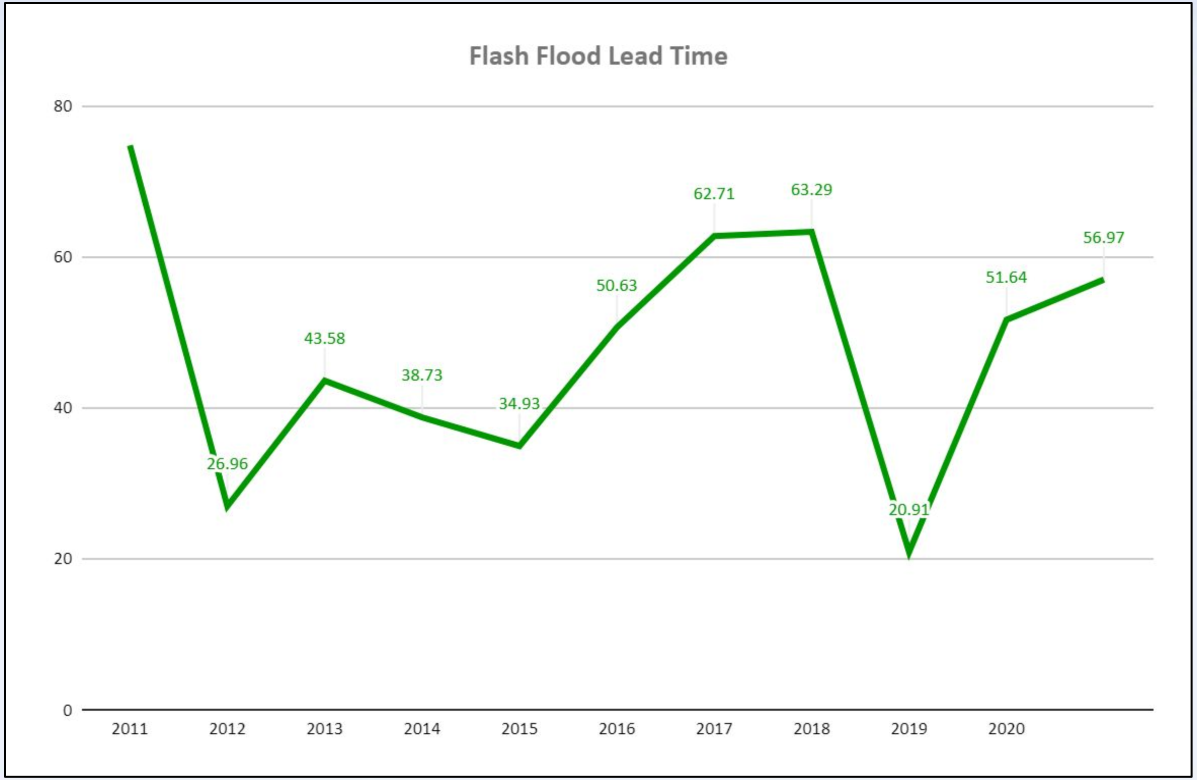
- Best Probability of Detection (POD) since 2011.
- Upward trend since 2019.

Flash Flood False Alarm Rate



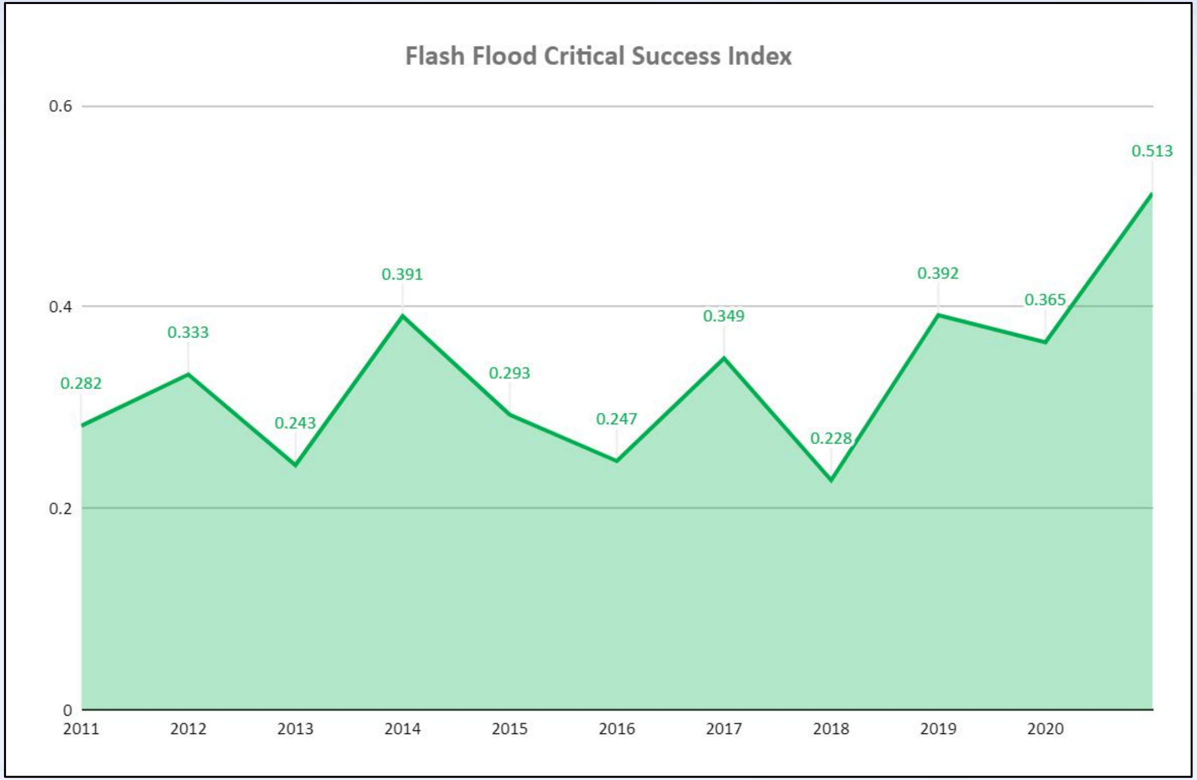
- Lowest False Alarm Rate (FAR) since 2011.
- General downward trend since 2018.

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.