NATIONAL WEATHER SERVICE

Building a Weather-Ready Nation

# Leveraging Machine Learning and Probabilistic Guidance to Improve Flash Flood Forecasting Across Southern Utah

July 25, 2024

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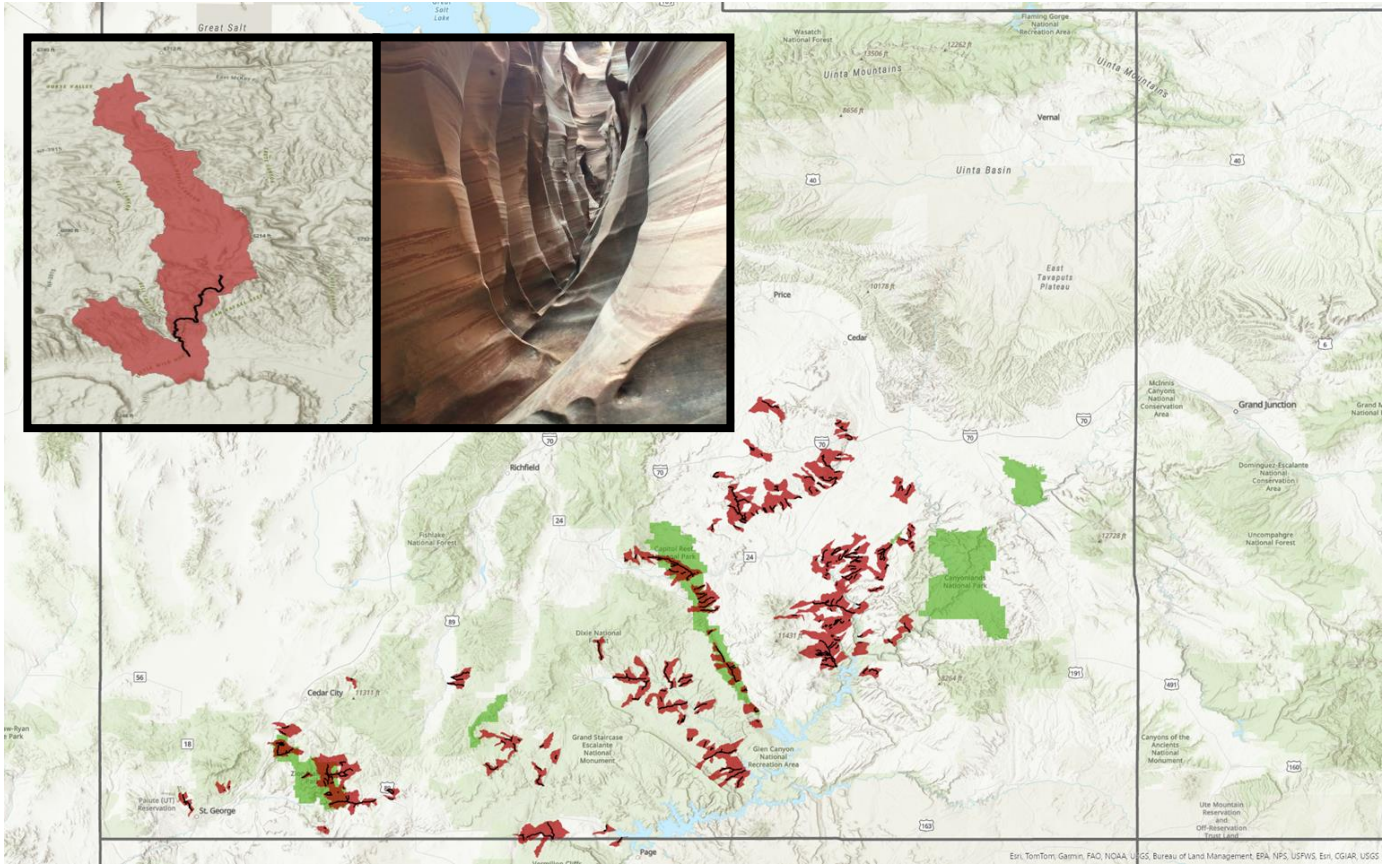
Collaborators: Julie Cunningham, Meteorologist

# Outline

- Unique forecast problem
- Machine Learning Approach
- Hi-res Probabilistic Guidance
- Roadmap and Future Work

# Slot Canyons Across Southern Utah

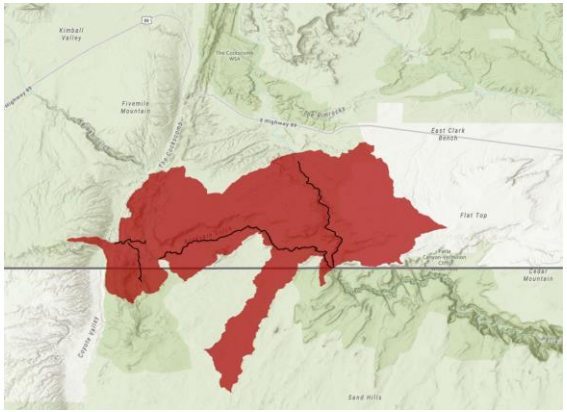


# Buckskin Gulch

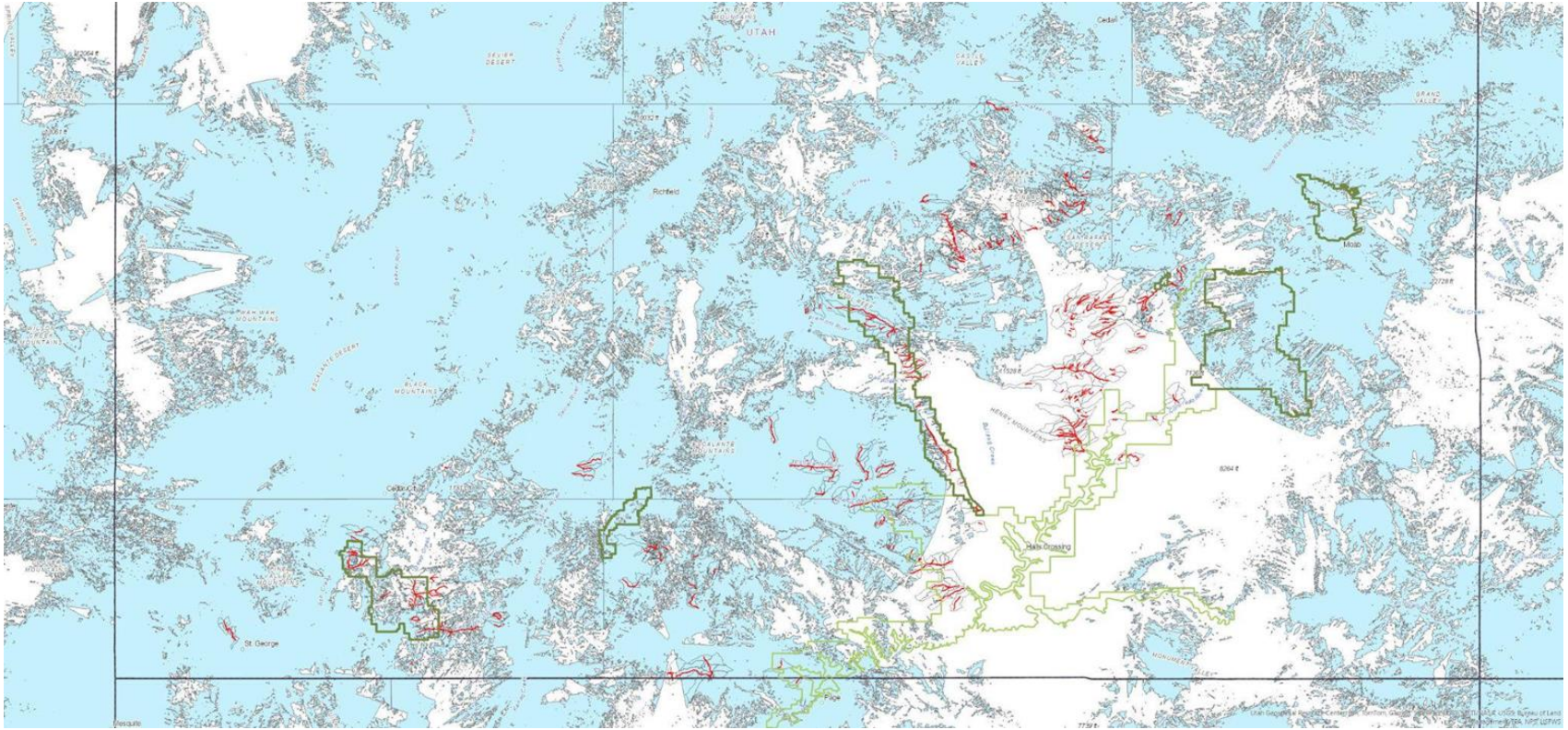
**~16 continuous miles**

**0.50” of rain results in flash flooding**

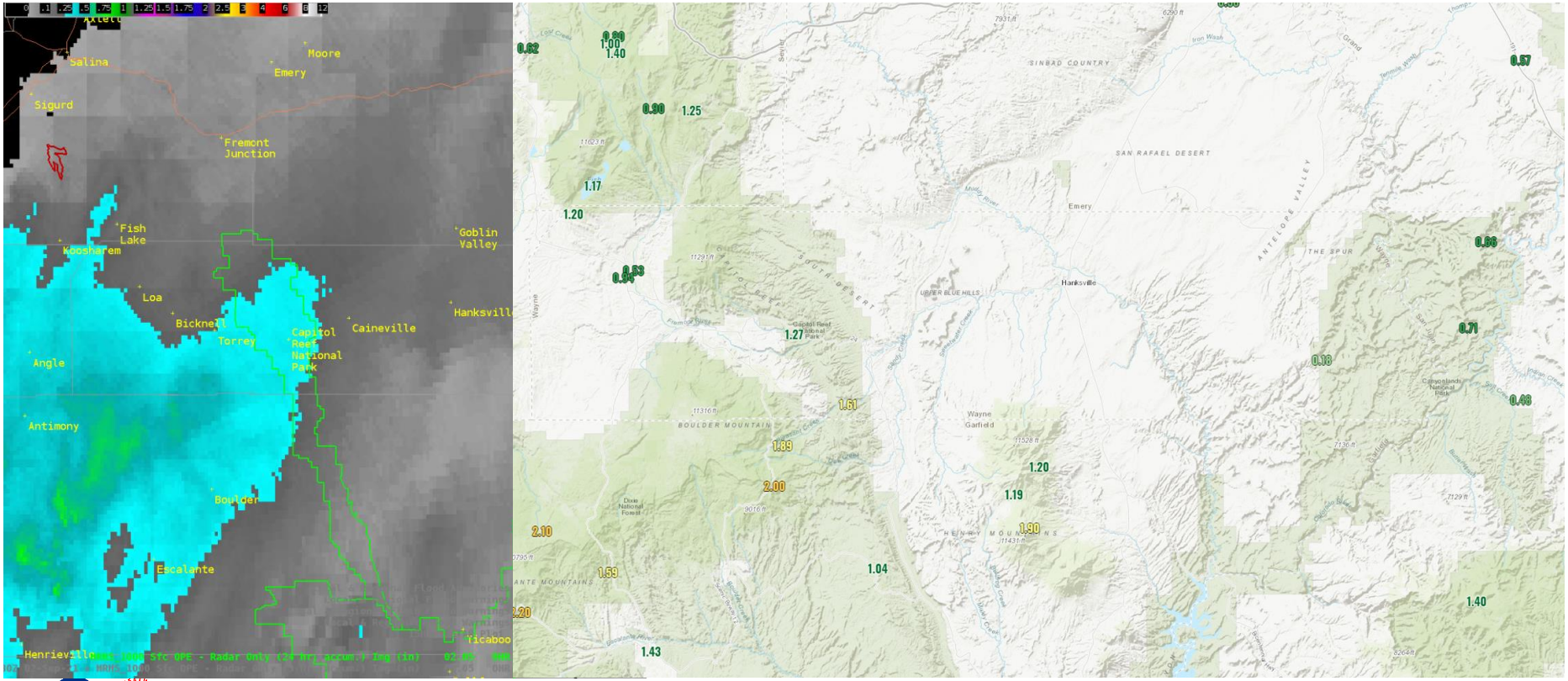
**4 Fatalities in 2023**




# AT&T Coverage Map Across Southern Utah



# Limited Radar Coverage



# Unique Forecast Problem

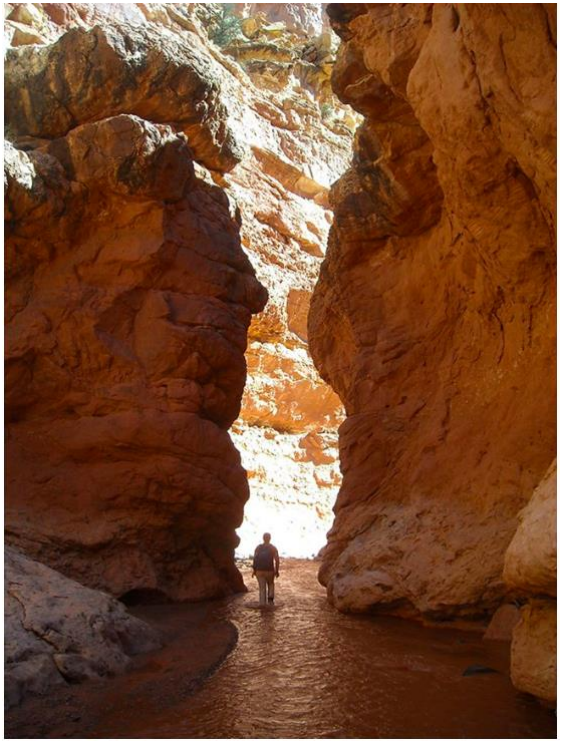
**Flash flood forecasting across the Desert Southwest poses a unique challenge due to the combination of…**

- **Remote areas**
- **Impervious sandstone and deep narrow canyons**
- **Telecommunications and data sources limited or non-existent**

**With an estimated 10+ million visitors to southern Utah annually, exposure to flash flooding is a significant concern.**

**Once an individual is in the backcountry, there may be little ability to reach them with short fused warnings.**

**Last weather information received may be more than a day old**



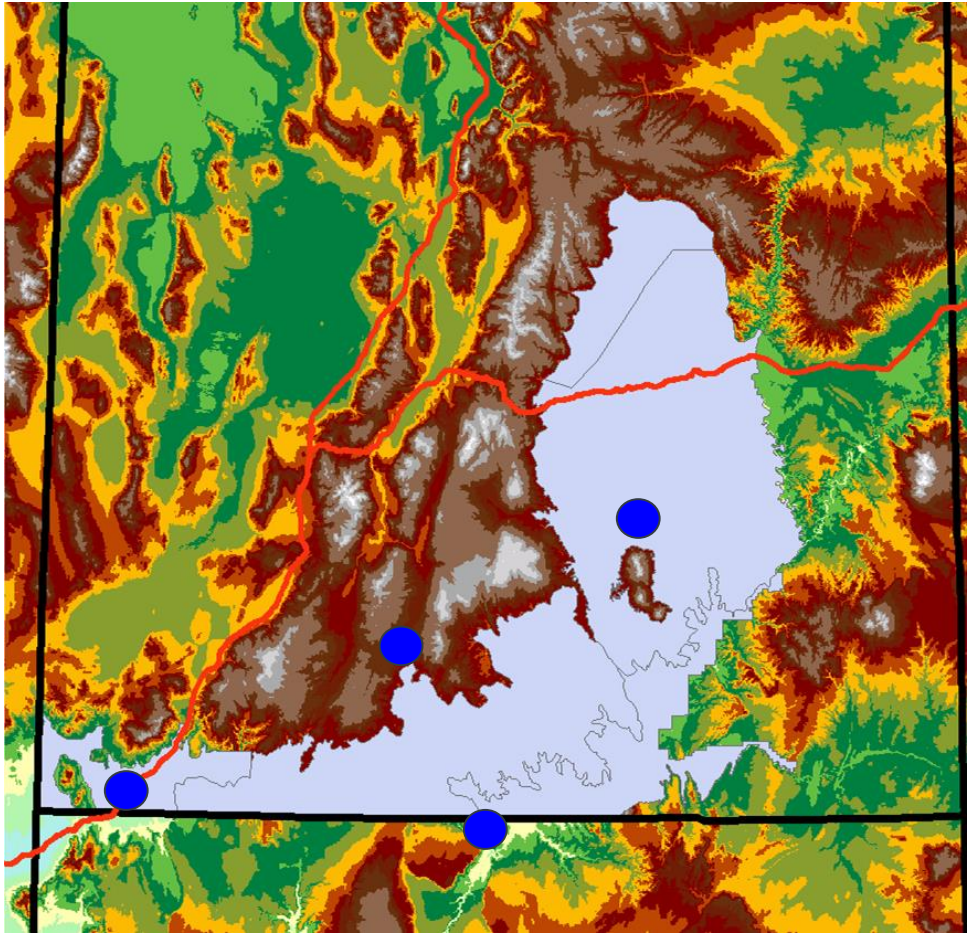
# Background/Motivation

**These users need advance notice of flash flooding threats. This may be met by:**

- **Flood Watches for Flash Flooding (typically day 1 period)**
- **Flash Flood Potential Rating (FFPR) - available in English and Spanish**
- **FFPR traditionally based primarily on precipitable water values and storm motion**


**Goal: Improve flash flood forecasts during the day 1-3 period (watch/outlook period)**

# Study Area

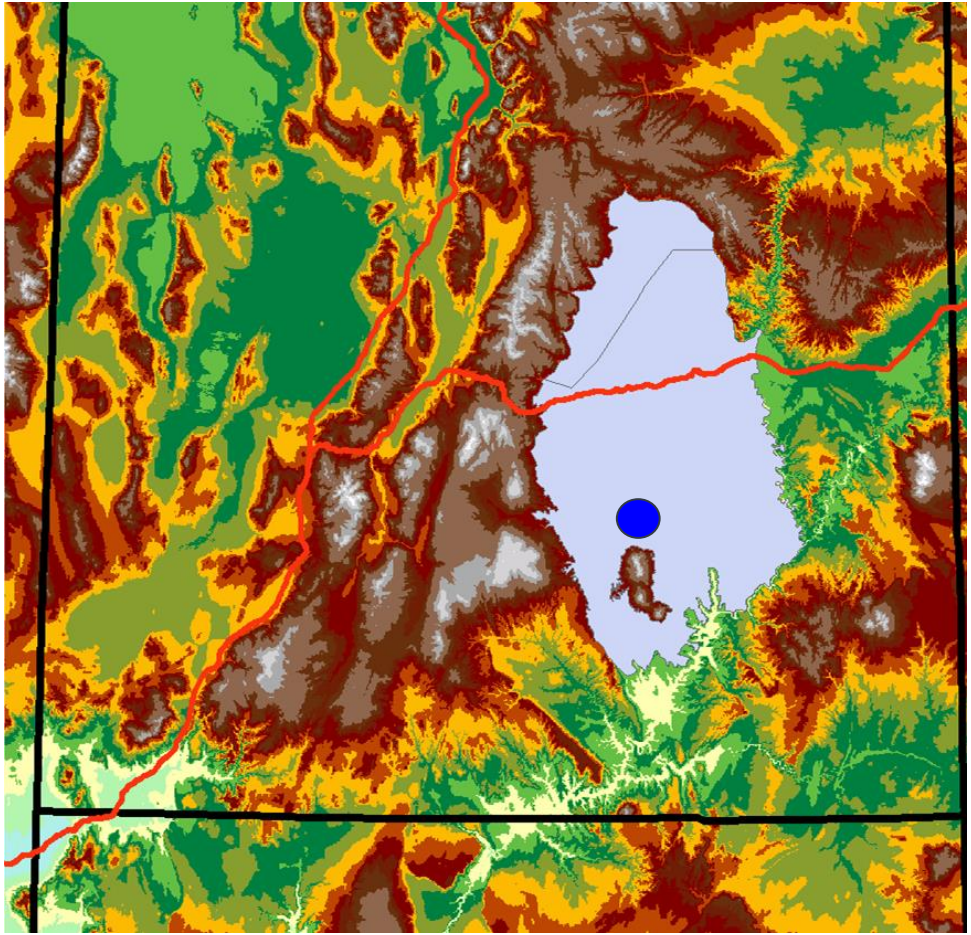


# Study Area

Lower elevations of southern Utah typically characterized by slickrock, dry washes and slot canyons

These areas include multiple national park and monument areas.

Three sub-regions were outlined based on drainages and topography.

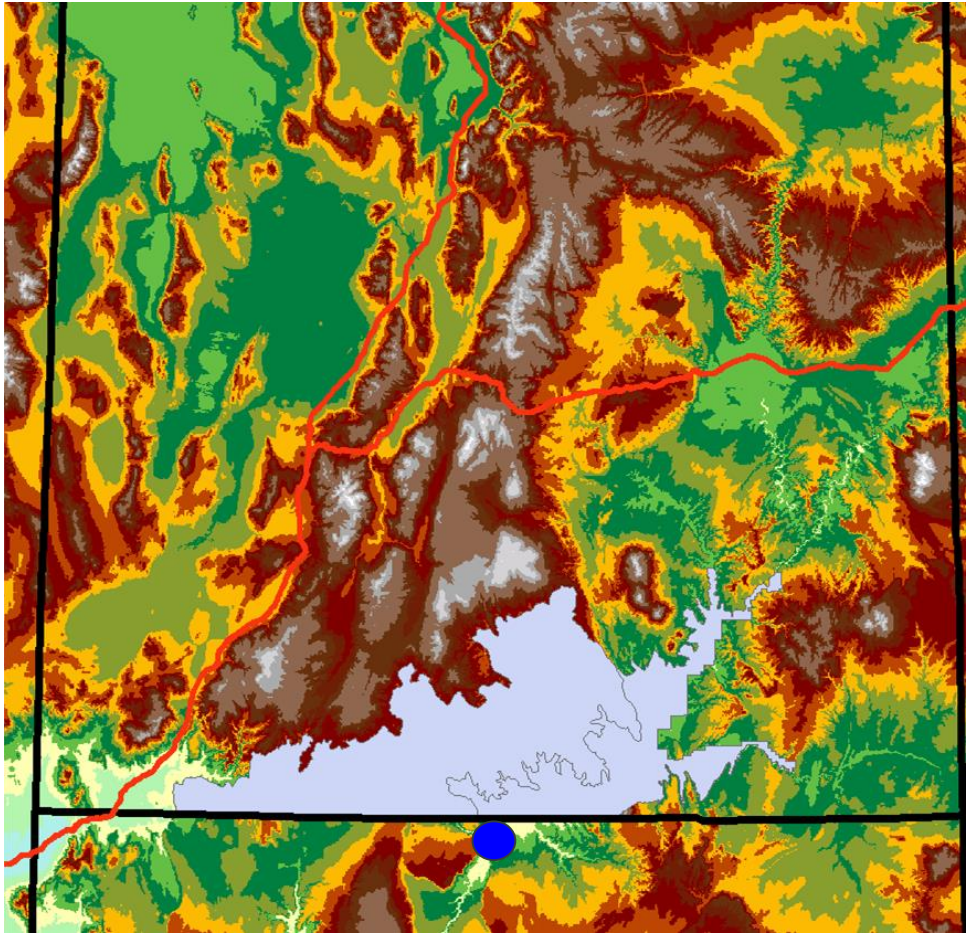


# Eastern Drainages

## Includes:

- Capitol Reef National Park
- San Rafael Swell
- Canyonlands

**BUFR point: Hanksville, UT**

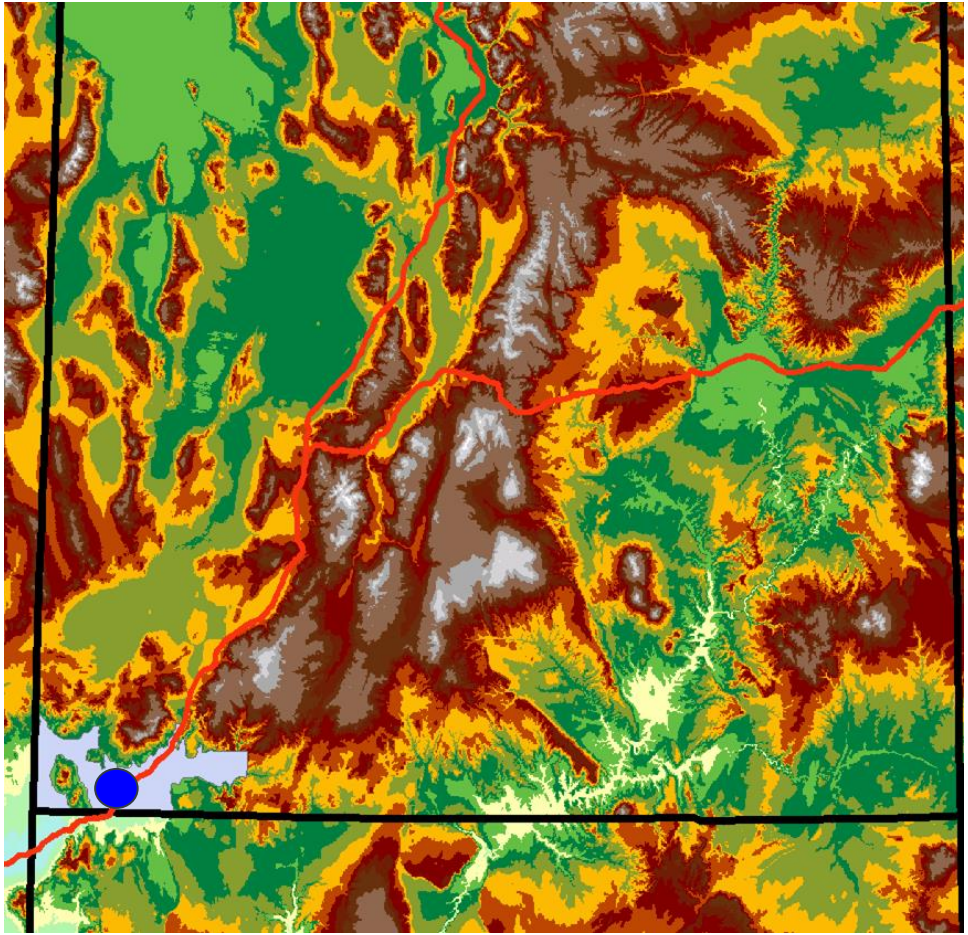


# Southern Drainages

## Includes:

- Escalante River Drainage
- Glen Canyon National Recreation Area
- Grand Staircase-Escalante National Monument

**BUFR point: Page, AZ**



# Southwestern Drainages

## Includes:

- Zion National Park
- St George area
- Virgin River Drainage

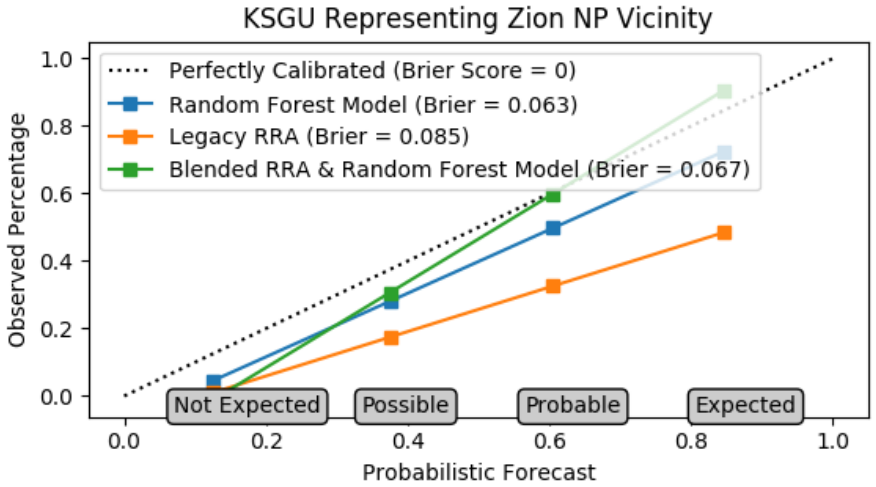
**BUFR point: St George, UT**

# Machine Learning Approach

## Random Forest Model

- Focused on flash flood environments ‘08-’20
- Trained on thermodynamic and kinematic parameters
- NAM out to 84 hours
- Showed skill in identifying potential flash flood days across southern Utah

## Reliability Plot




| | No Flooding Forecast | Flooding Forecast |
|---|---|---|
| No Flooding Observed | 445 | 12 |
| Flooding Observed | 27 | 11 |

# Machine Learning Approach

## Random Forest Model Updates for 2024

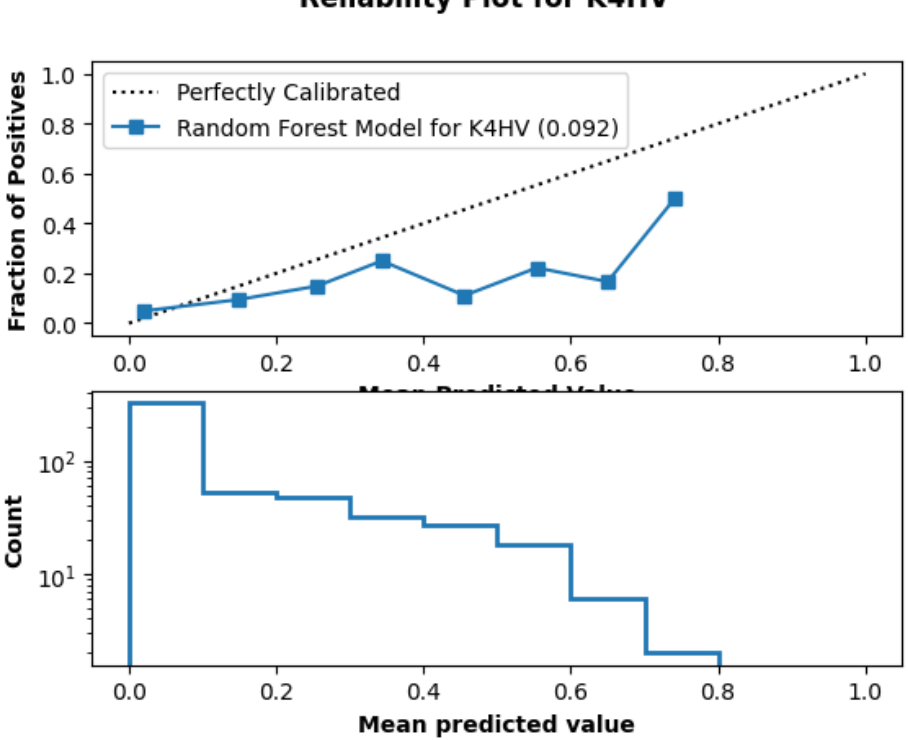
- Study Period May 2008 - Jul 2020 extended to 3.5 years to Oct 2023
- Bug fixes in the data set and code
- Converted kinematic variables to u/v vectors
- Removed high dewpoint depression filter

## Continued with 4 models based on 4 BUFR points

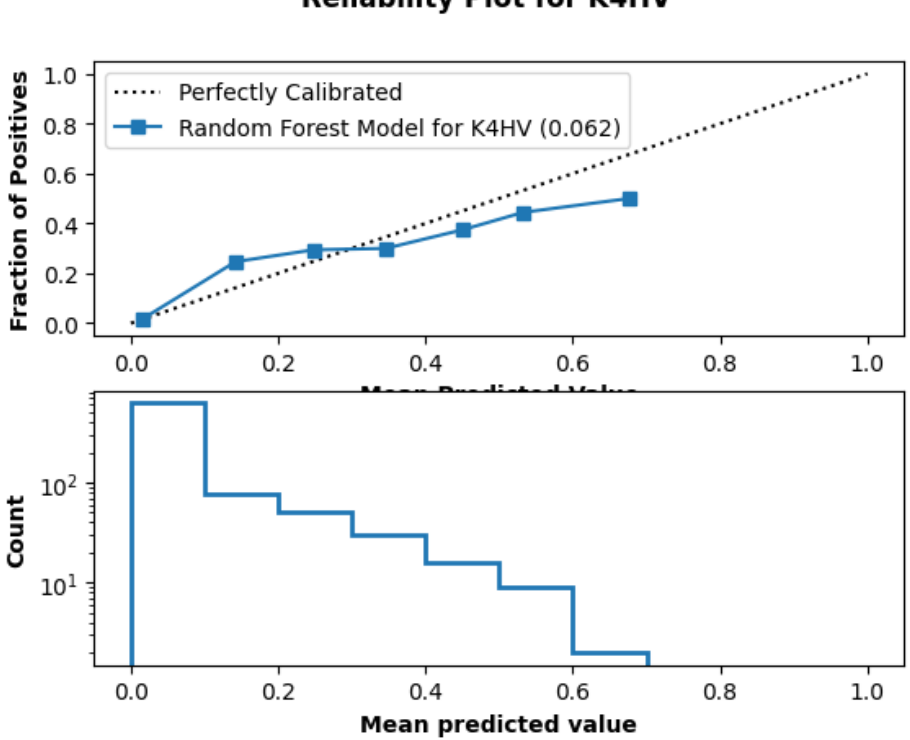
- Events geographically matched to representative BUFR
  - KSGU: SW Utah
  - 4HV: E Utah
  - KPGA: SC Utah
  - KBCE: All Events (SW + SC + E)

# 4HV - 32% Improvement (BSS)

2008 - 2020 (Old)

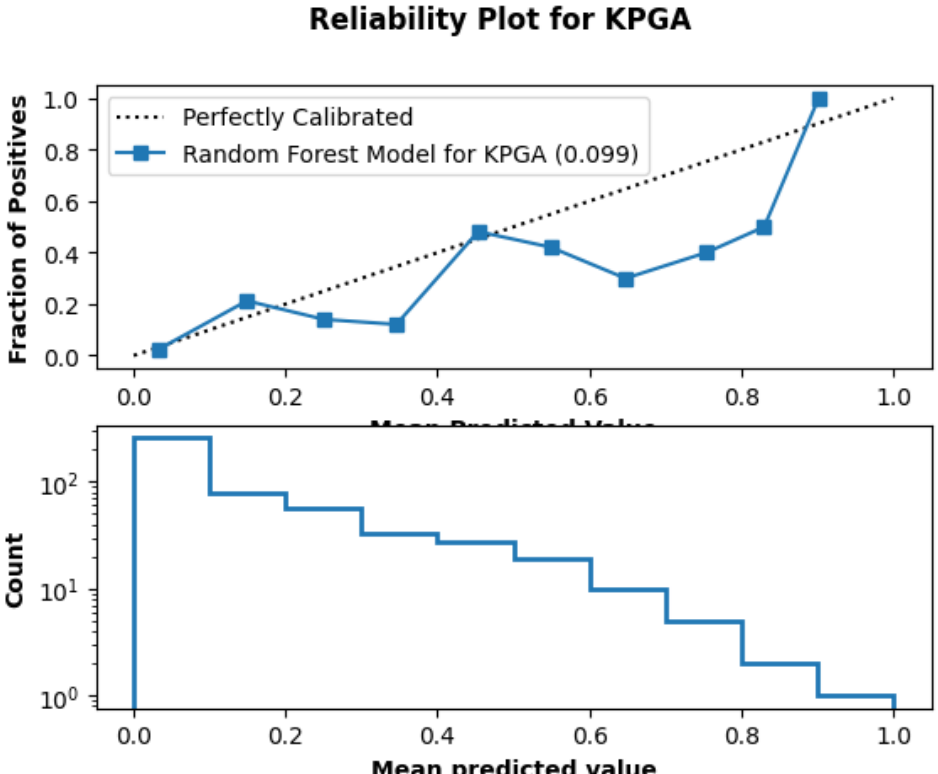



2008 - 2023 (New)

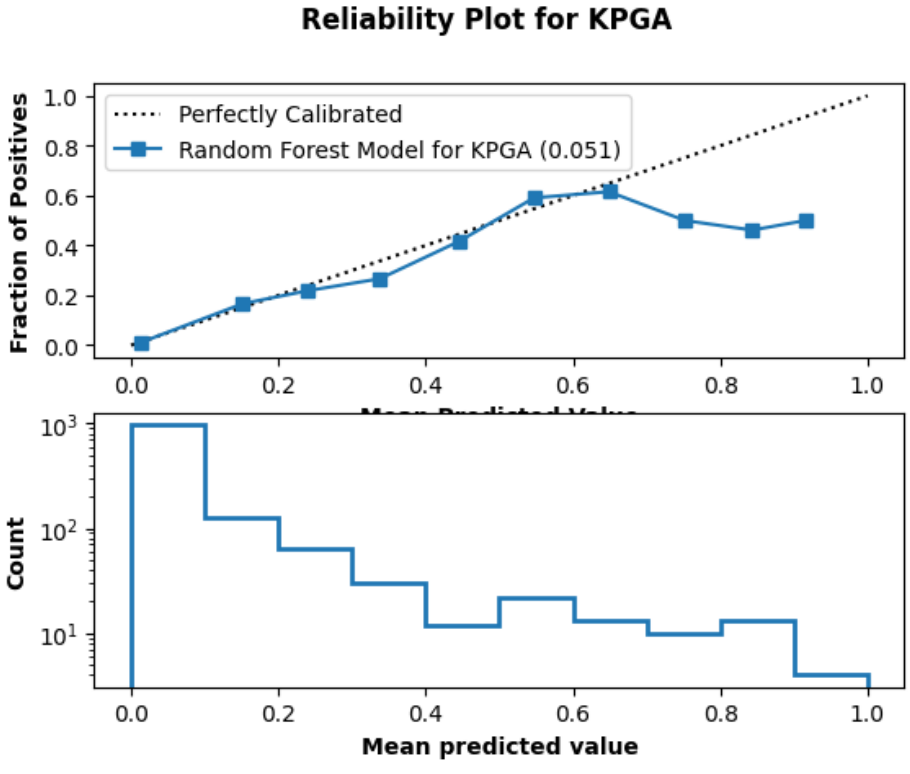


# KPGA - 48.5% improvement (BSS)

2008 - 2020 (Old)

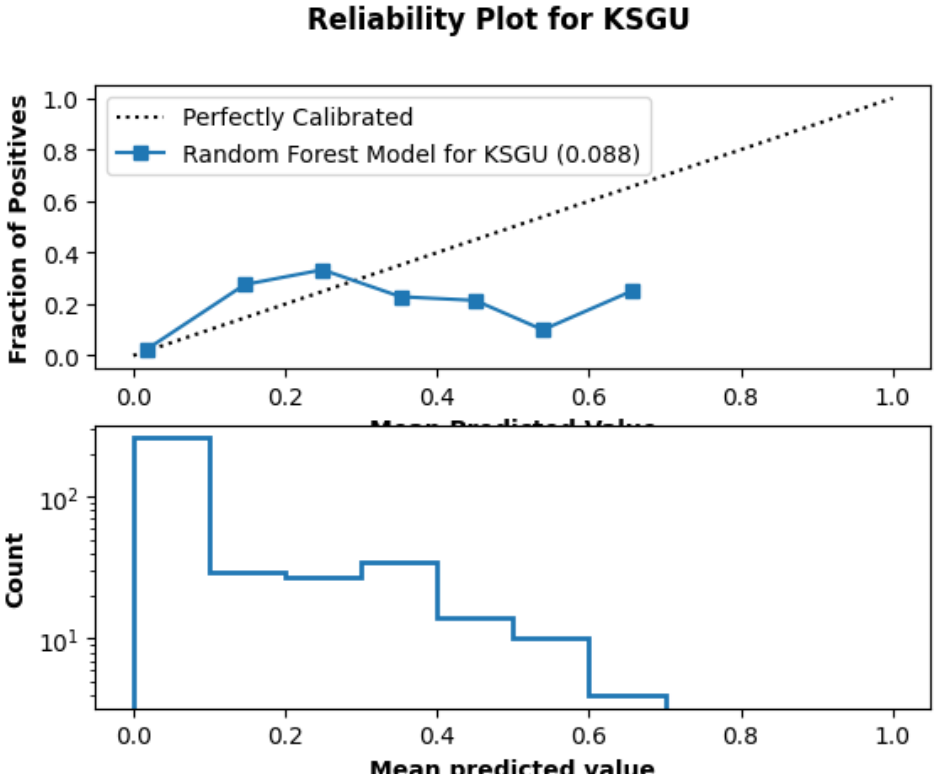



2008 - 2023 (New)

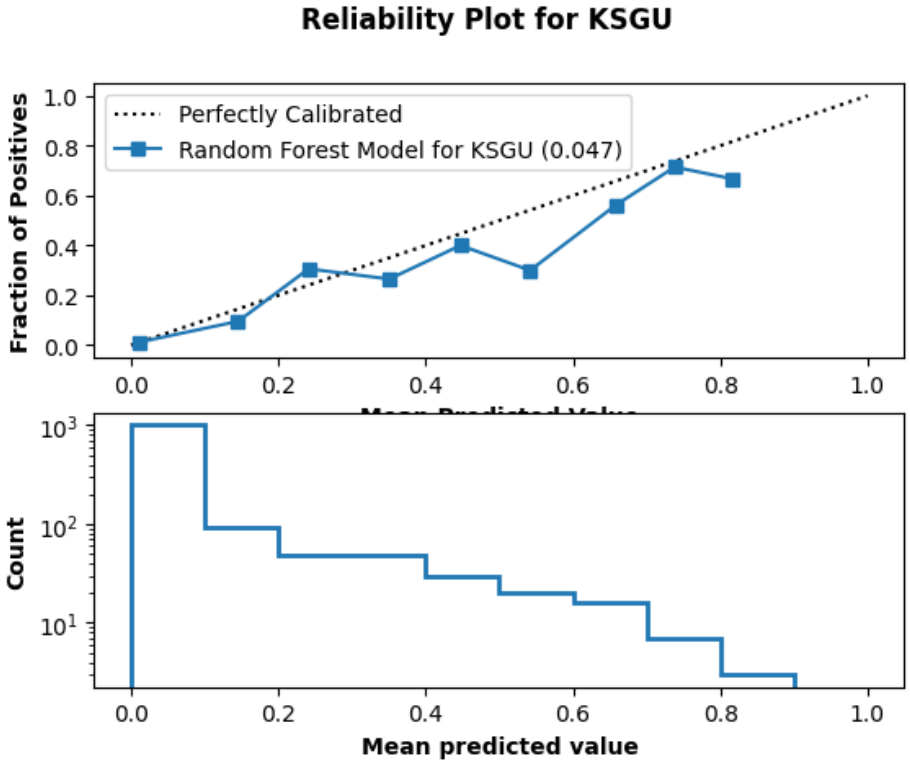


# KSGU - 46.6% improvement (BSS)

2008 - 2020 (Old)

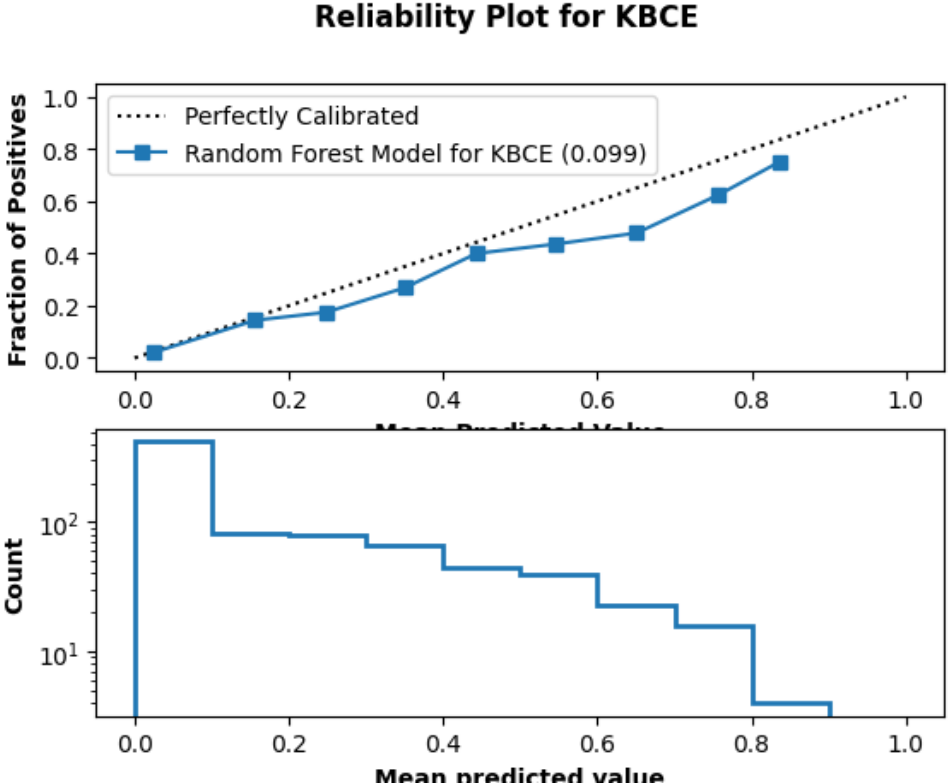



2008 - 2023 (New)

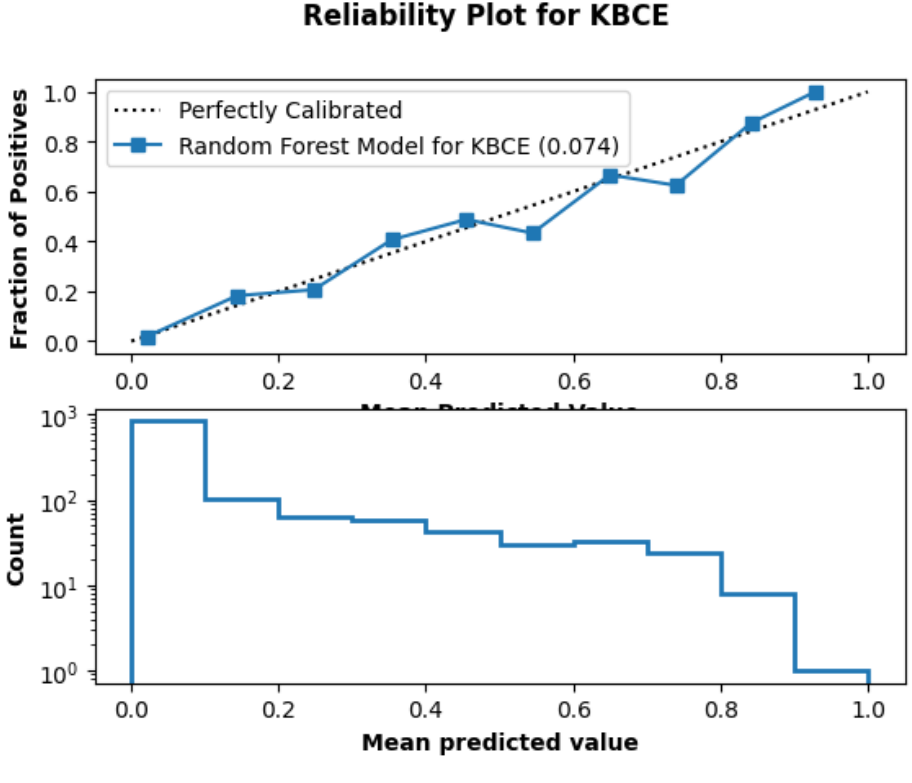


# KBCE - 25.3% improvement (BSS)

2008 - 2020 (Old)

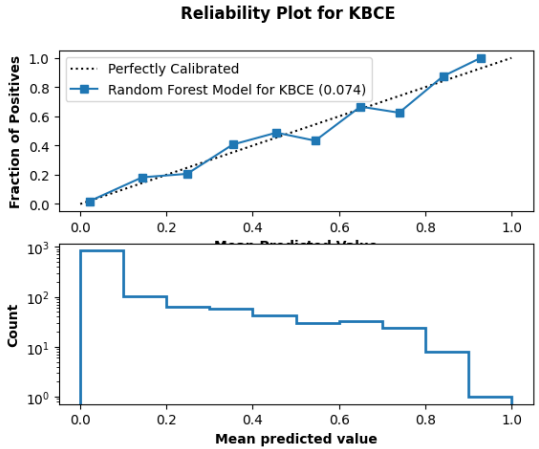



2008 - 2023 (New)



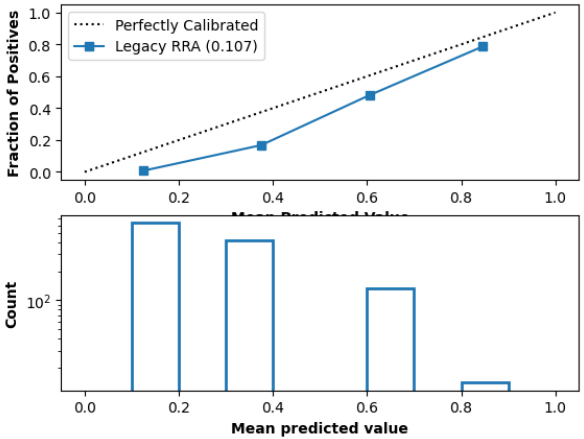
# Does it Blended?

## ML Only



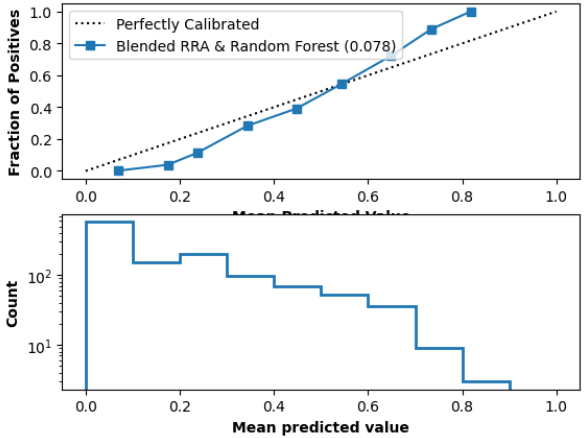

Briar: 0.074
AUC: 0.90

## Legacy Only



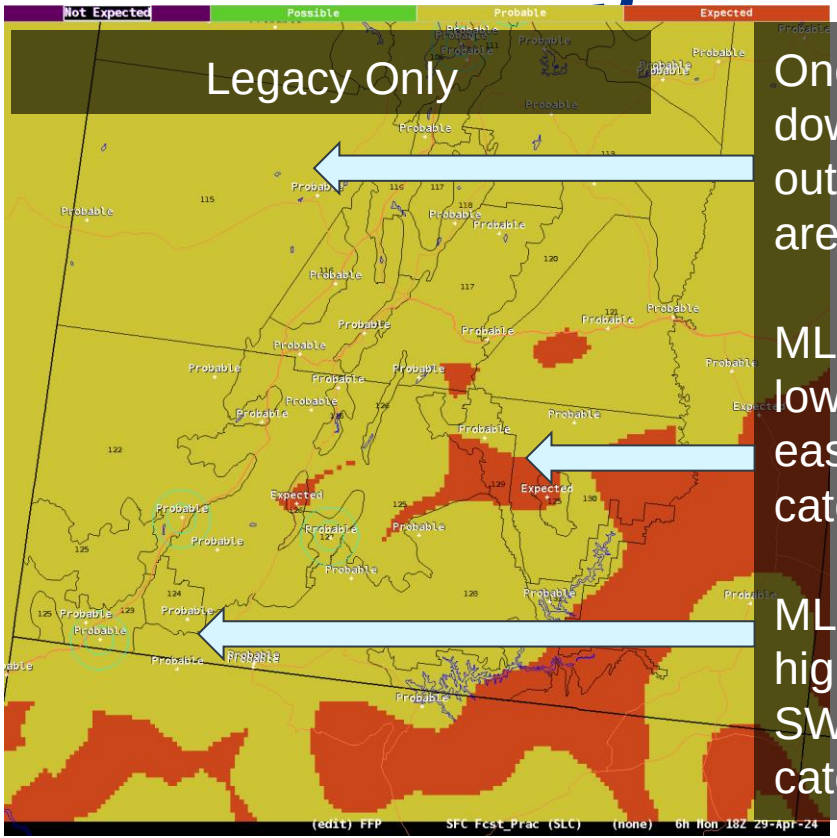

Briar: 0.107
AUC: 0.85

## Combined




Briar: 0.078
AUC: 0.92

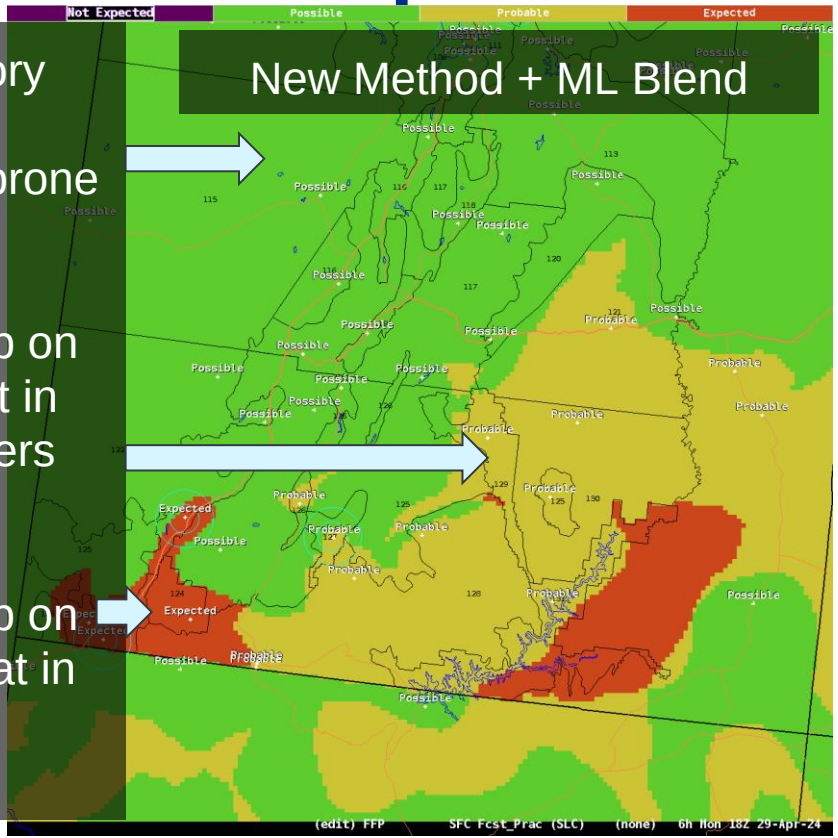
# Blending Technique - Example



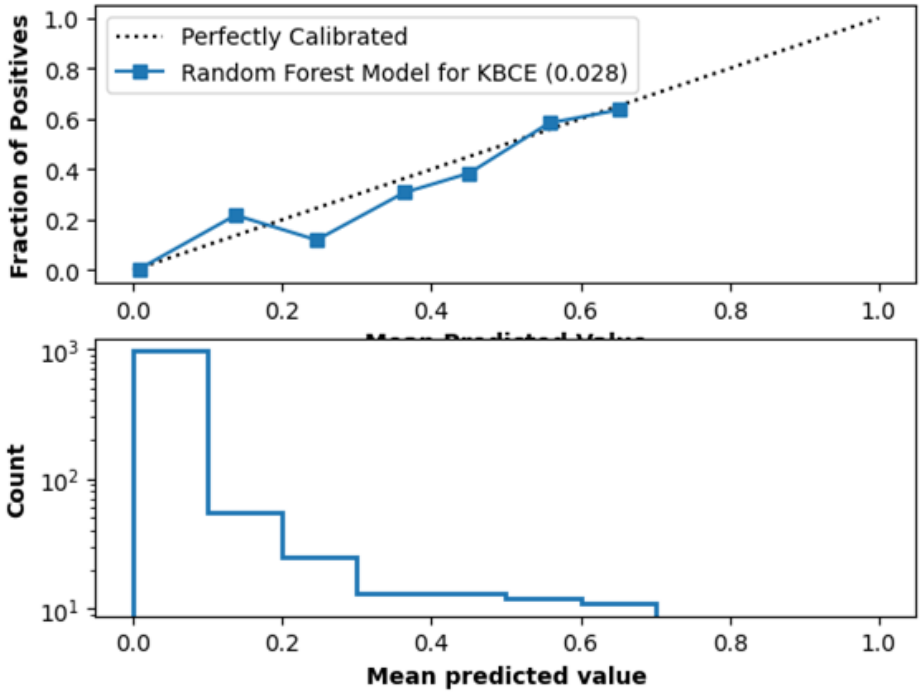

One category downgrade outside of prone areas

ML picks up on lower threat in easter, lowers category

ML picks up on higher threat in SW, raised category

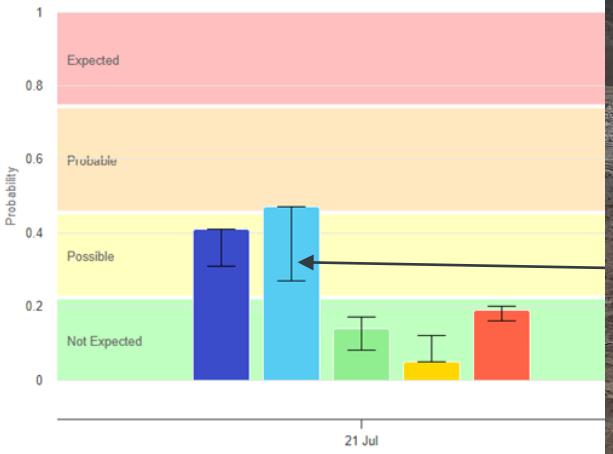


# New: Prob 3+ Flash Floods




- 3+ events across all of southern Utah
- Well calibrated, but never forecast above 70%
- Decision aide for FF Watches?

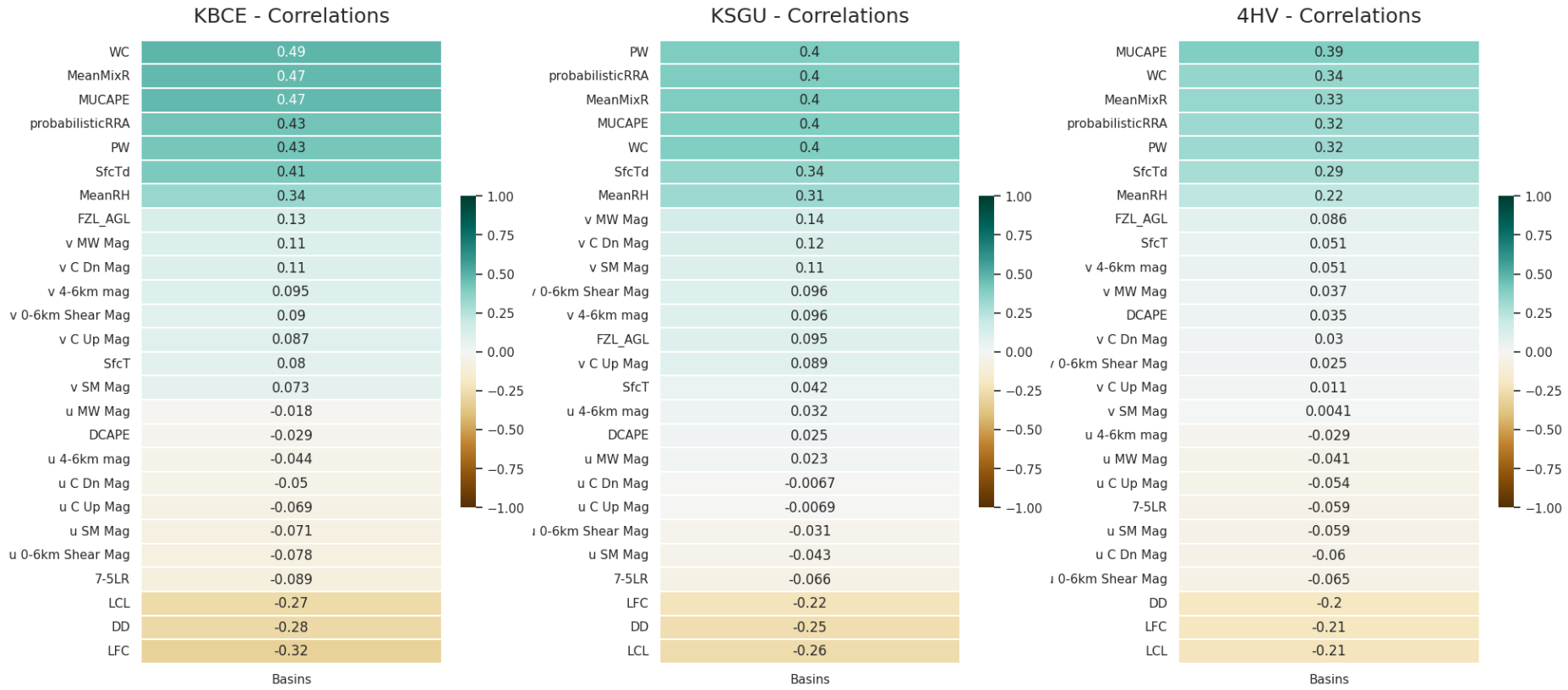
# Example - Internal Guidance



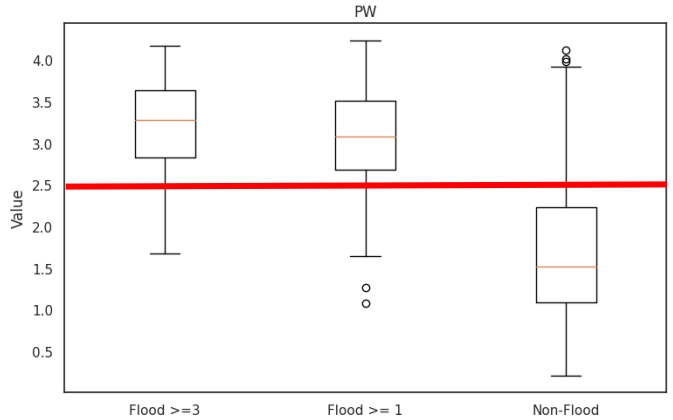

# Flash Flood Environment - Correlations All Sites

1. 41.0% - MUCAPE
2. 40.5% - Warm Cloud Depth
3. 39.3% - Mean Mixing Ratio
4. 37.5% - Precipitable Water
5. 34.0% - Surface Dew Point
6. 29.3% - Mean RH
7. 25.5% - LFC (negative)
8. 24.5% - Dewpoint Depression (negative)
9. 24.0% - LCL (negative)

# Flash Flood Environment - Correlations

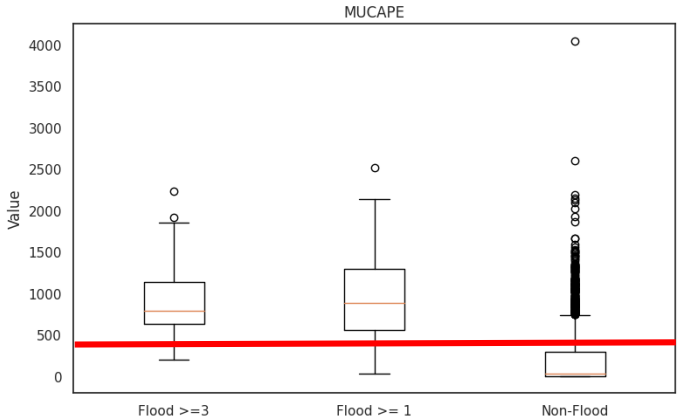


# Flash Flood Environment - Meaningful Values




## PW - 2.52 cm / 0.99 inches

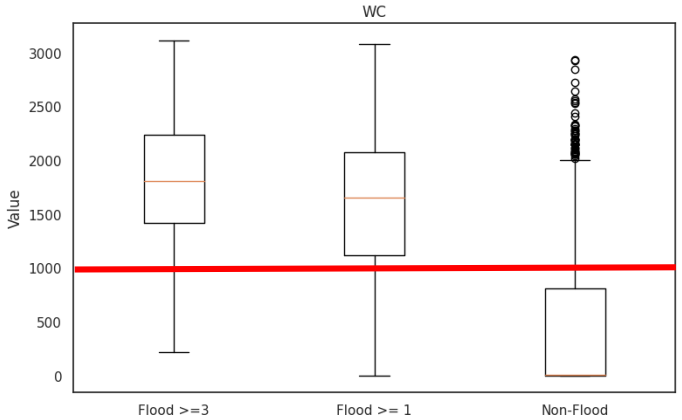
Above: 82% of flash flood days
18% of non flash flood days




## MUCAPE - 440 J/kg

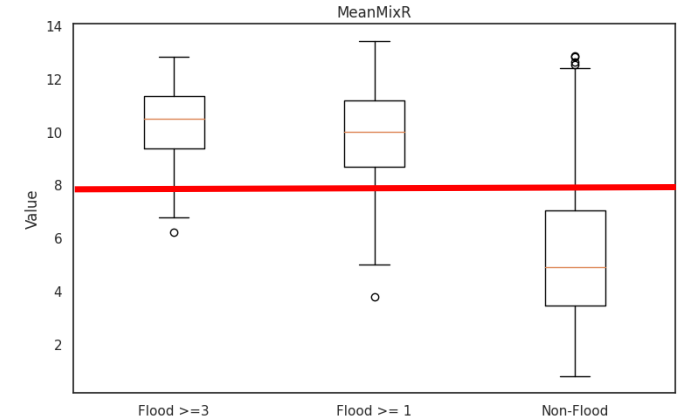
Above: 83% of flash flood days
17% of non flash flood days

# Flash Flood Environment - Meaningful Values




## Warm Cloud - 1025 meters

Above: 81% of flash flood days
19% of non flash flood days




## Mean Mixing Ratio- 8.05

Above: 83% of flash flood days
17% of non flash flood days

# High Resolution Probabilistic Guidance

## Utilize high resolution probabilistic output to improve flash flood potential outlooks across southern Utah, both spatially and temporally

### Southern Utah Flash Flood Potential Rating

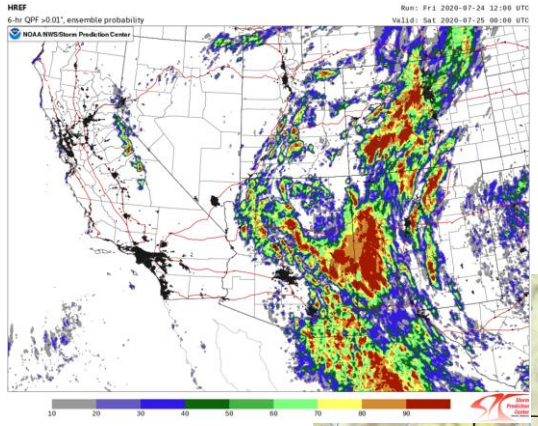
| Recreation Area | TODAY | FRIDAY |
|---|---|---|
| Arches National Park | Possible | Probable |
| Bryce Canyon National Park | Probable | Possible |
| Canyonlands National Park | Probable | Probable |
| Capitol Reef National Park | Probable | Probable |
| Glen Canyon National Rec Area | Probable | Probable |
| Grand Staircase/Escalante NM | Probable | Probable |
| Natural Bridges/Grand Gulch | Probable | Probable |
| San Rafael Swell | Possible | Probable |
| Zion National Park | Possible | Possible |

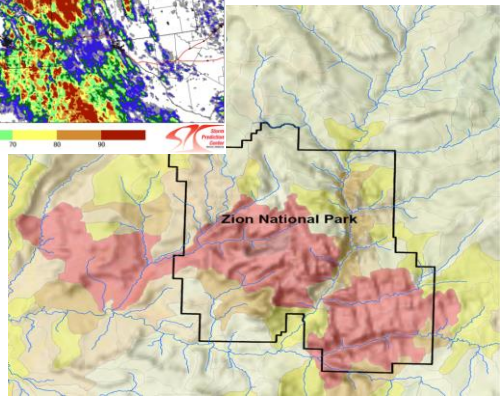
Flash Flood Potential Rating Definitions

- Not Expected – Flash flooding is not expected
- Possible – Some slot canyons, dry washes and small streams may experience flash flooding
- Probable – Some slot canyons, dry washes and small streams are expected to experience flash flooding
- Expected – Many slot canyons, dry washes and small streams are expected to experience flash flooding

Salt Lake City

National Weather Service – Salt Lake City www.weather.gov/slc/flashflood Created: 07/23/2020 03:08 AM



# Methodology

- Utilize operationally available High Resolution Ensemble Forecast (HREF) products for 2023 convective season

- Focusing on Probability of Exceedance (POE) QPF products

- Study area focused on Zion and Capitol Reef National Parks, where confidence is high with respect to whether or not flash flooding occurred.

- Identify flash flood days using reports of flash flooding occurring with the 18-06Z time frame.

- Use these days to identify potential utility of using to verify HREF POE forecasts to identify flash flood potential during day 1-2 timeframe.

# Methodology

## 12Z HREF QPF 12 hour Probability of Exceedance Values (POE) Used

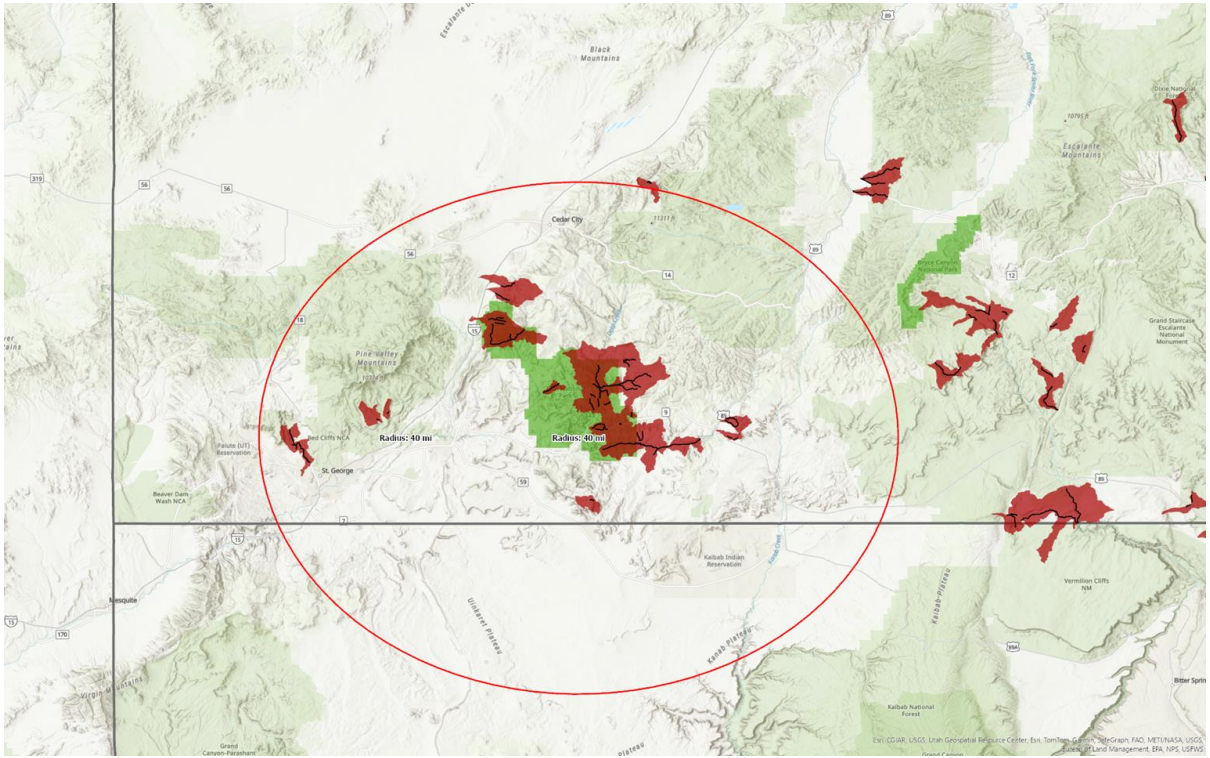
- 0.25” - Ensemble Agreement Scale
- 0.50” - 40km neighborhood probability
- 1.00” - 40km neighborhood probability
- 2.00” - 40km neighborhood probability

- **Focus on 18-06Z window (most likely flash flood time range)**
- Day 1: forecast hours 6-18
- Day 2: forecast hours 30-42

# 40km Radius for Zion

- 40km neighborhood probability includes higher terrain to the northeast and west of Zion

- Frequent convective initiation in these areas during monsoon season



# Methodology

## 12Z HREF Probability of Exceedance Values (POE) Used

| Flash Flood Potential Rating | Prob of Exceedance Bins |
|---|---|
| Not Expected | 0-14% |
| Possible | 15-54% |
| Probable | 55-74% |
| Expected | 75-100% |

Not Expected – Flash flooding is not expected

Possible – Some slot canyons, dry washes and small streams may experience flash flooding

Probable – Some slot canyons, dry washes and small streams are expected to experience flash flooding

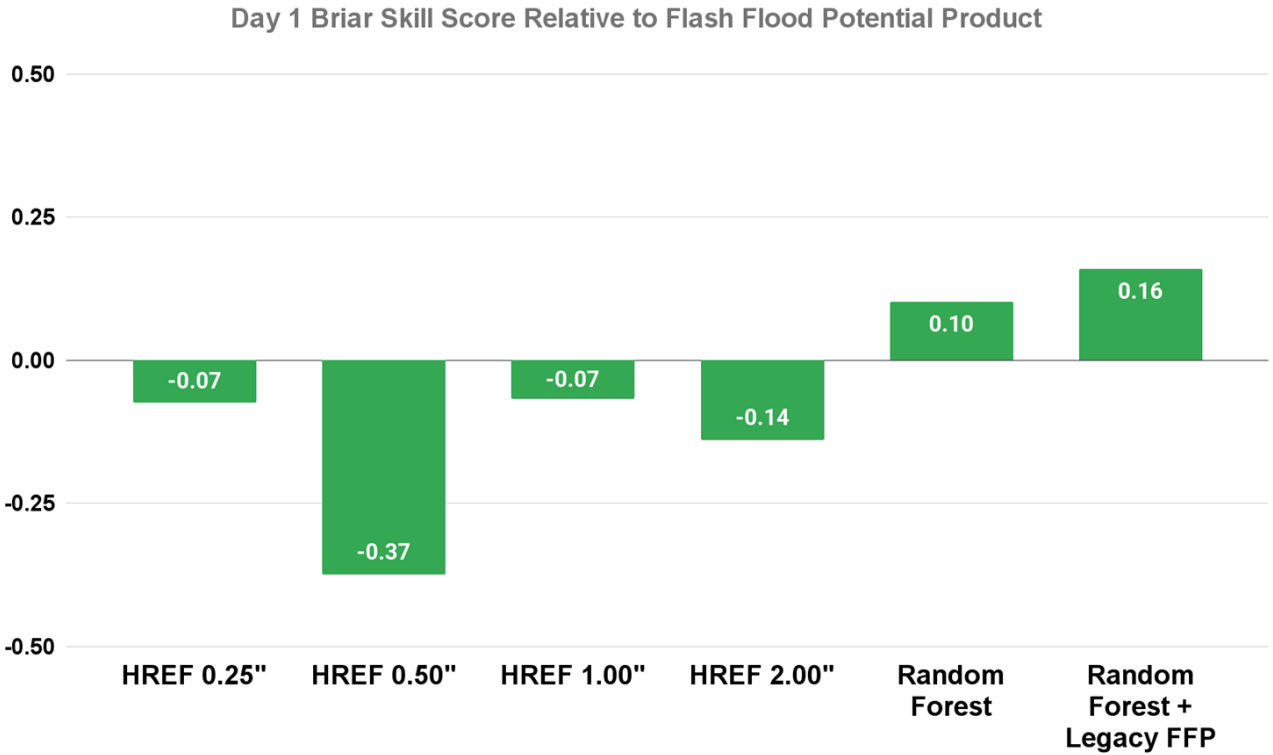
Expected – Many slot canyons, dry washes and small streams are expected to experience flash flooding

# Total Cases

## Probability of Exceedance Values

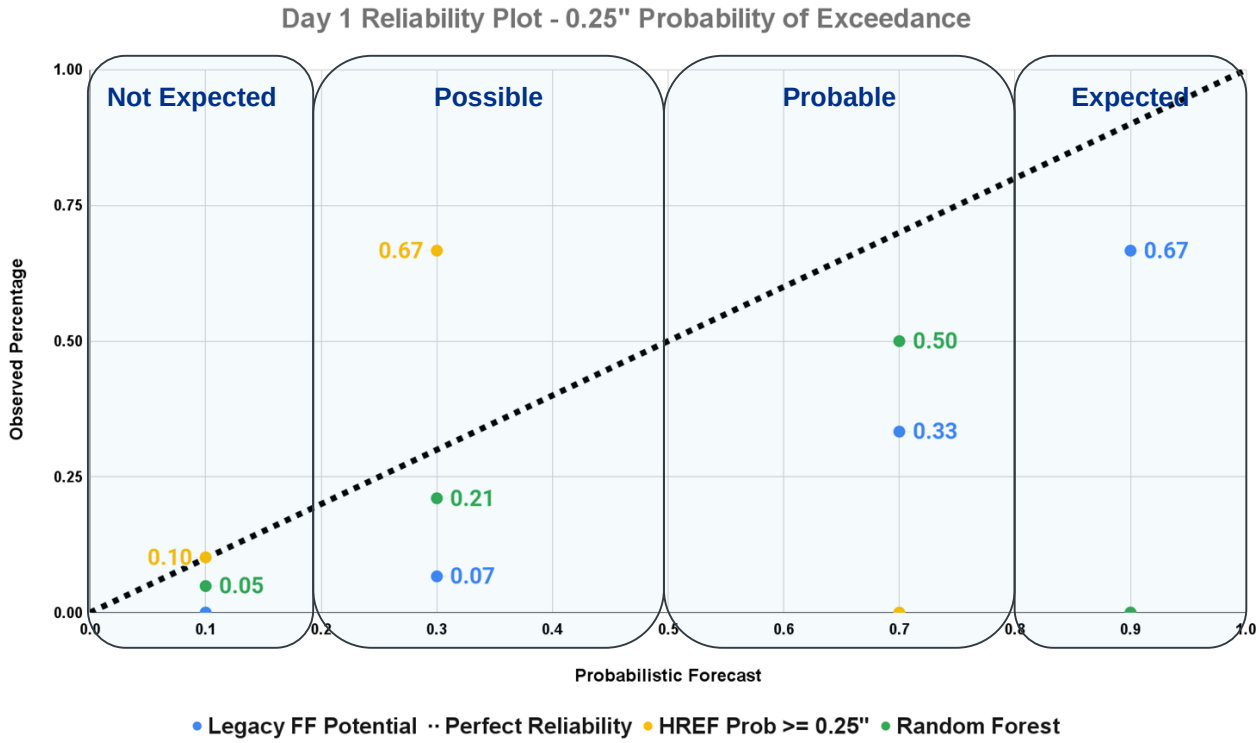
- 67 Days in Study Period (August 1st - October 6th 2023)
- 9 Days with Flash Flooding in Zion National Park
- 5 Days with Flash Flooding in Capitol Reef National Park

# Day 1 Briar Skill Scores - Zion



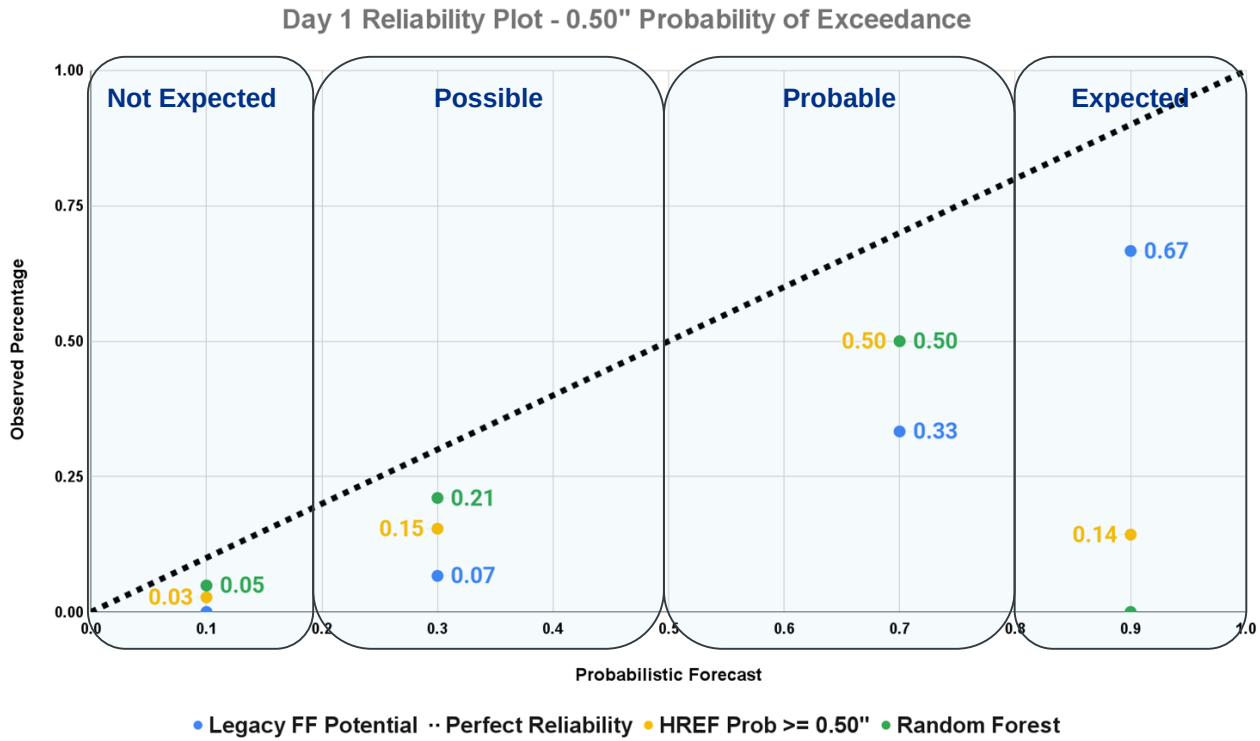
# Day 1 Reliability Plot for Zion - 0.25”

- Flash Flood Potential Rating over-forecasts across all bins
- Random Forest slightly over-forecasts but shows improvement over legacy FFP
- HREF 12 hour POE of 0.25” never forecasts > 50% probability



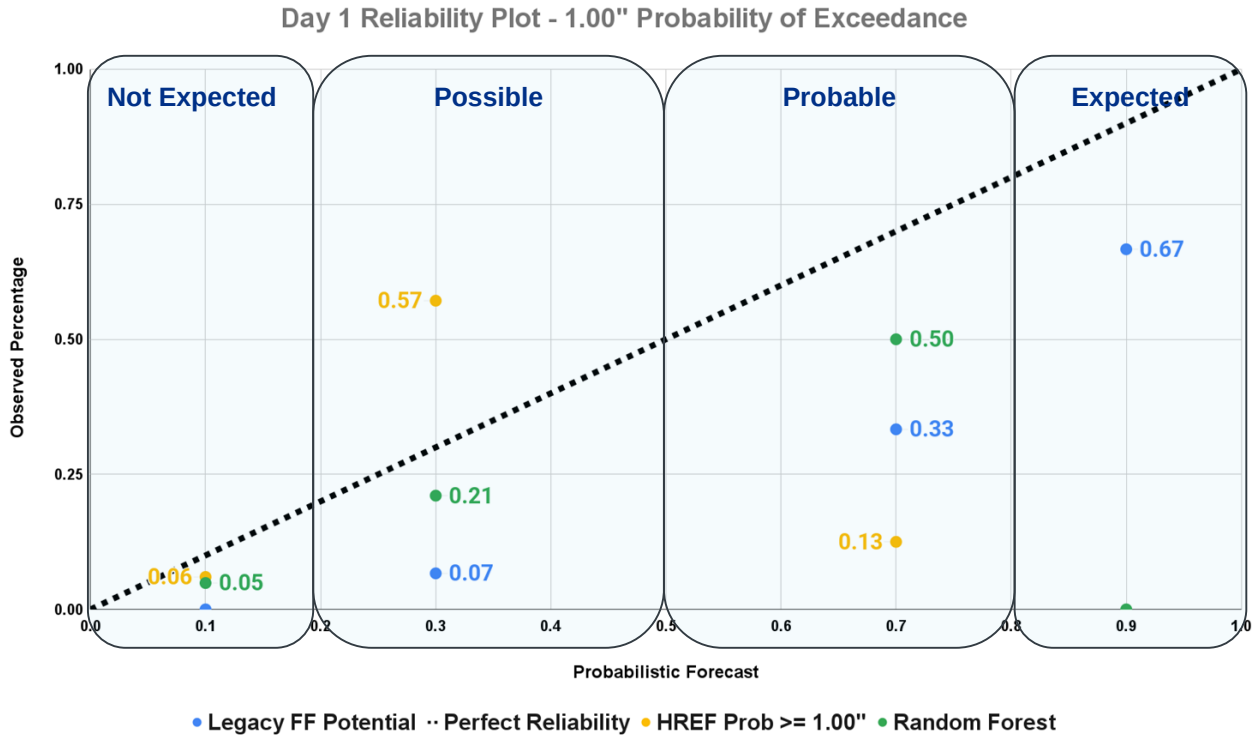
# Day 1 Reliability Plot for Zion - 0.50”

- HREF 12 hour POE 0.50” slightly over-forecasts most bins, but tracks close to RF
- HREF 0.50” reliability looks better despite worse BSS



# Day 1 Reliability Plot for Zion - 1.00”

- **HREF 12 hour POE of 1.00” similar to 0.25”**

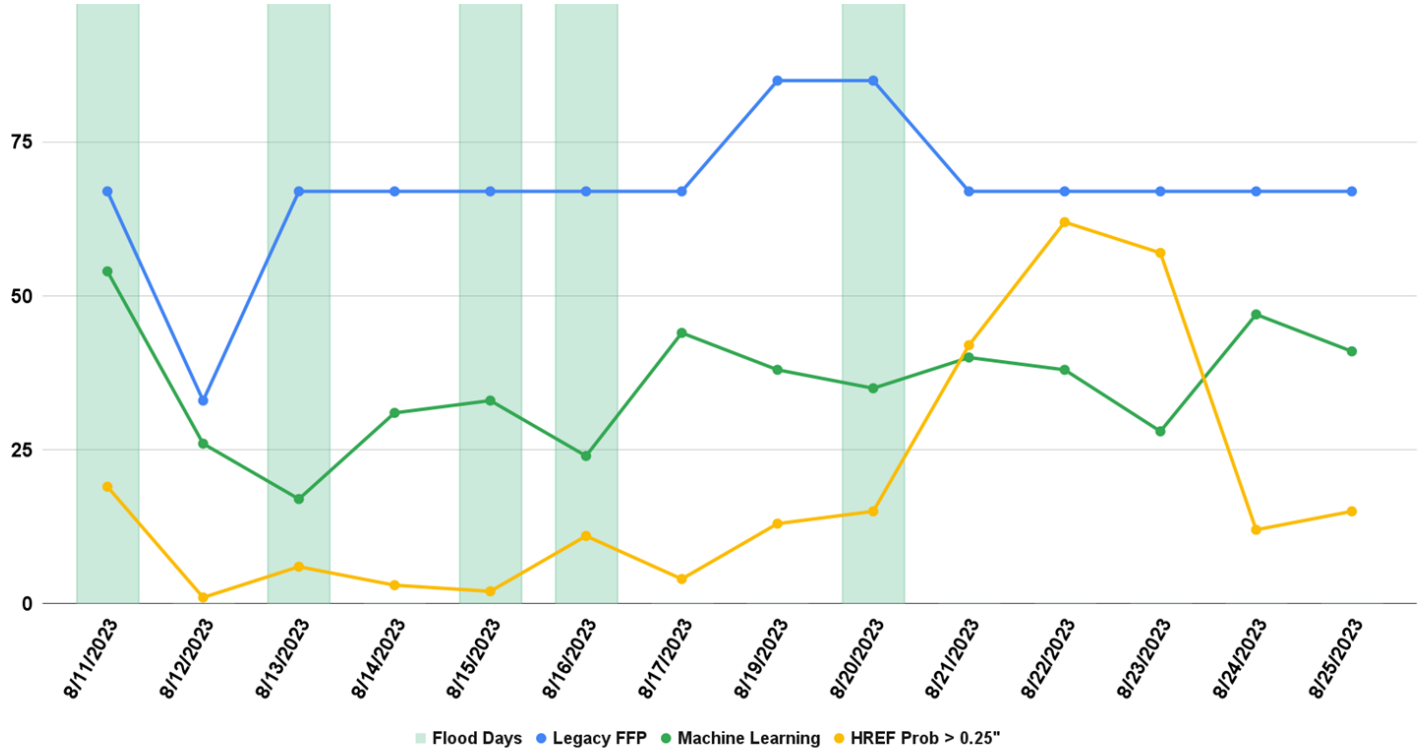


# Day 1 Forecasts - 0.25” HREF Probability of Exceedance

**Aug 11-25 2023**

**Monsoon surge 8/11-8/20**

**Hurricane Hilary remnants 8/21-8/25**

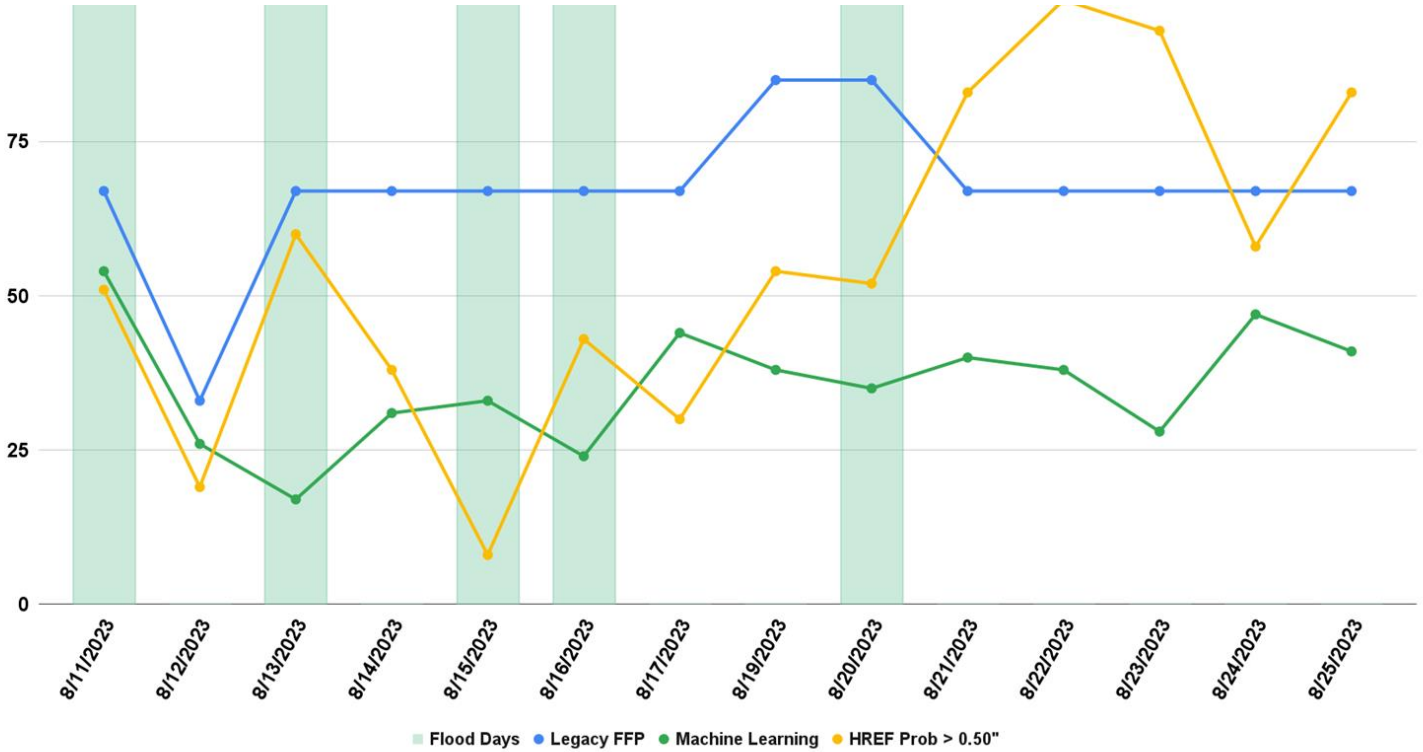


# Day 1 Forecasts - 0.50” HREF Probability of Exceedance

**Aug 11-25 2023**

**Monsoon surge 8/11-8/20**

**Hurricane Hilary remnants 8/21-8/25**

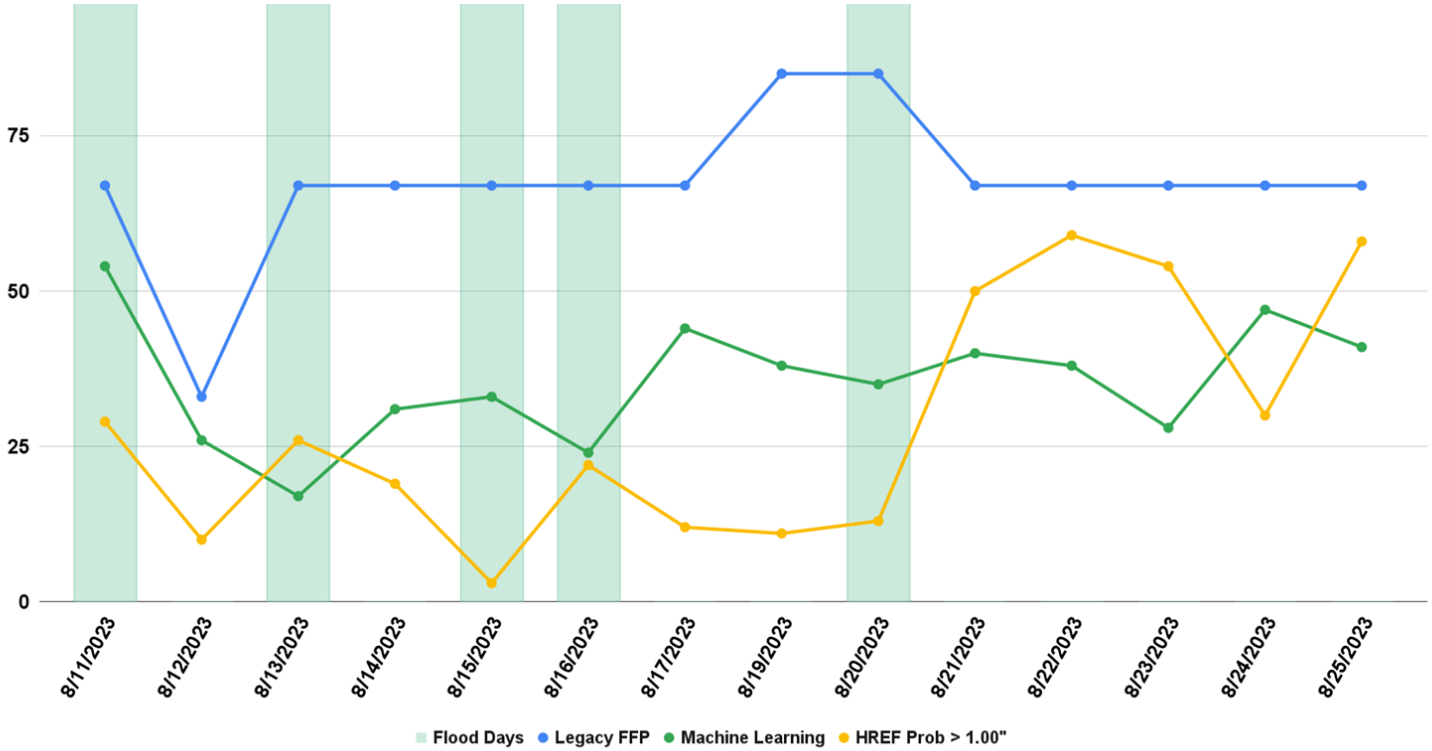


# Day 1 Forecasts - 1.00” HREF Probability of Exceedance

**Aug 11-25 2023**

**Monsoon surge 8/11-8/20**

**Hurricane Hilary remnants 8/21-8/25**



# Future Work

- Continue building dataset with ‘24 cases
- Explore additional HREF parameters not available in AWIPS
- Develop small scale basin specific Flash Flood Guidance
- Utilize radar data to expand dataset from remote areas
- Long term vision: Generate basin specific flash flood potential based on hi-res probability of exceedance guidance

# Questions?

# Thank you!

Contact Info:

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mike.seaman@noaa.gov