

RAIN-ON-SNOW EVENTS FOR CRITICAL DESIGN INFRASTRUCTURE – A CASE STUDY OF THE JUNE 2022 YELLOWSTONE REGION FLOODING

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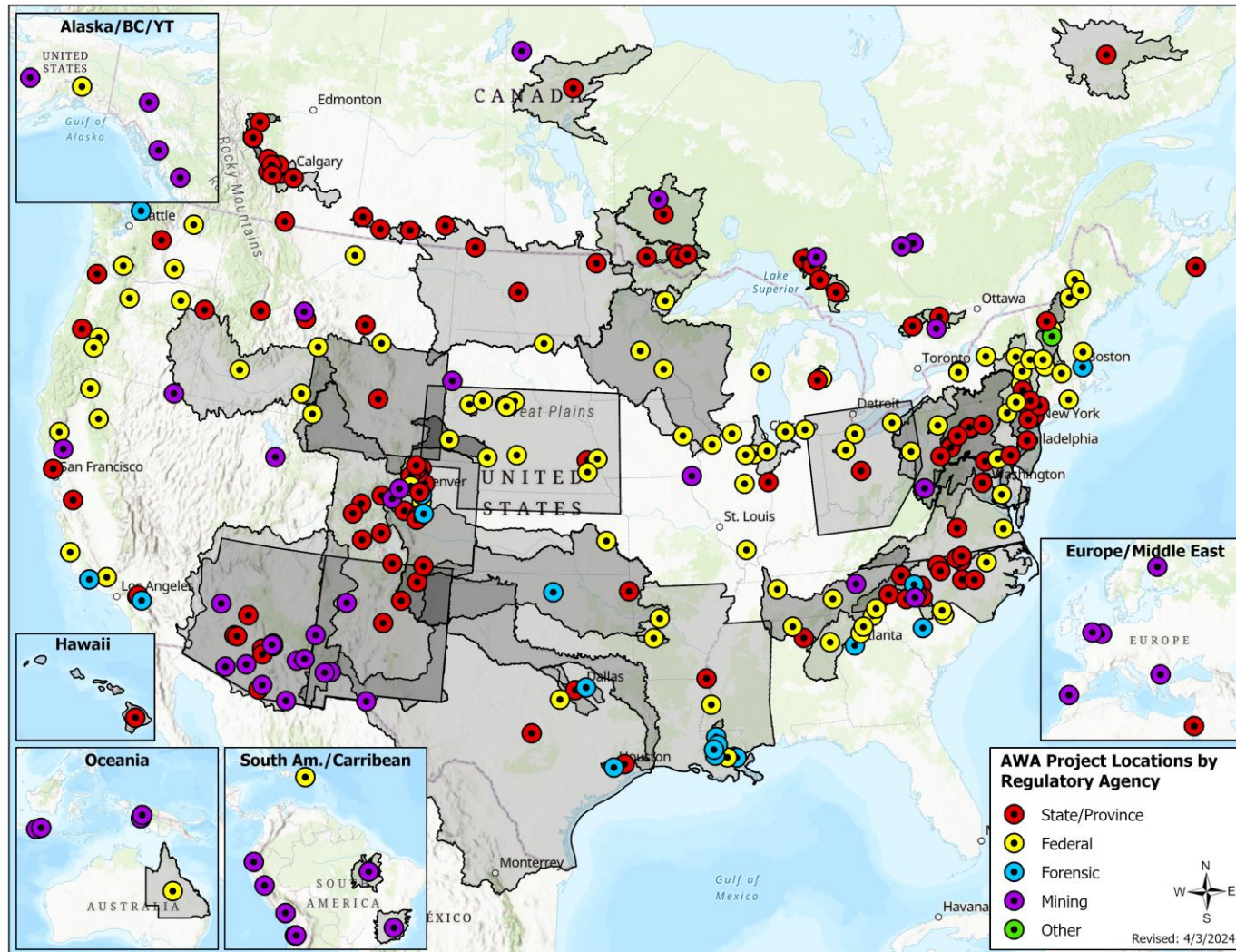
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Design Events: Rain vs Precipitation

- Extreme precipitation (rain, rain on snow, etc.) important for dam design, river management, rainfall-runoff-relations, dam safety
- Important to know frequency of events
 - Also important to delineate between rain vs frozen-makes a big difference in some areas
- In many mountainous regions, seasonal snow accumulation and melt rate can control flood hazards vs rain only
- **Not appropriate to group extremes into single statistical population for frequency analysis**
- Paleohydrology and streamflow studies have shown that floods at higher elevations (~7500-feet) are caused by snowmelt, not rain
 - There is an abrupt transition from rainfall- to melt-dominated peak flows
- Extreme flooding on the Yellowstone River in 2022 a great example

AWA Project Locations

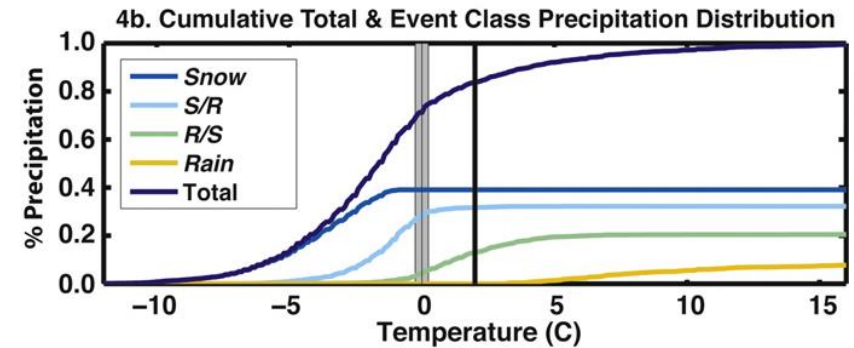
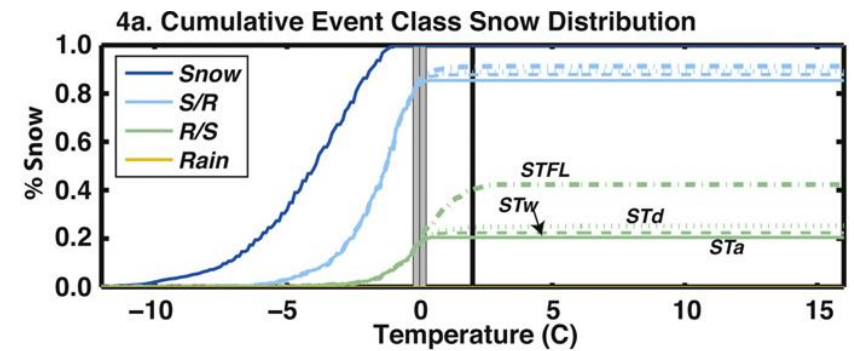
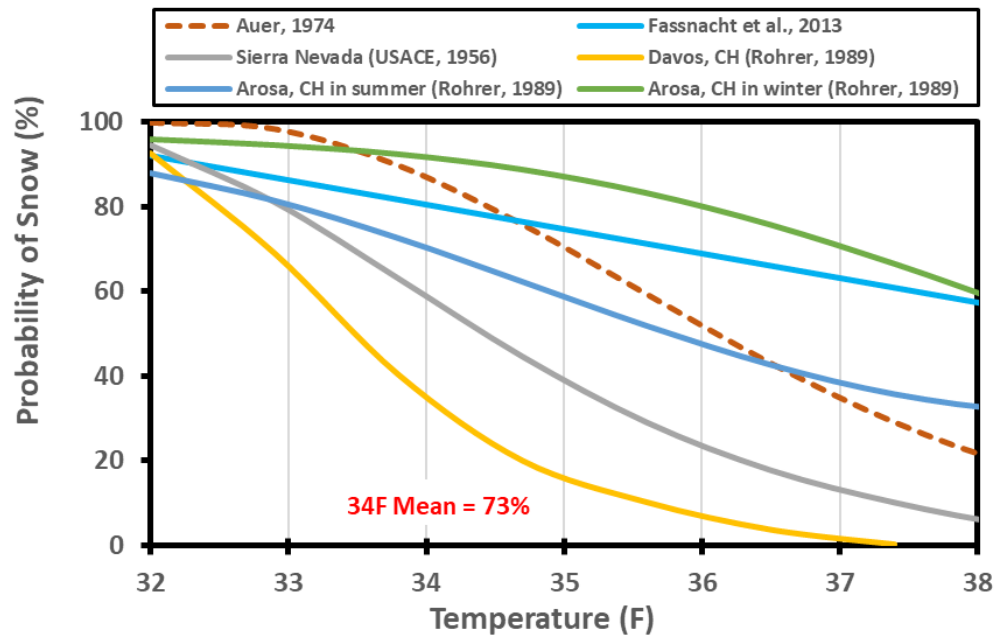


Introduction - Design Events: Rain vs Precipitation

- **Probable Maximum Precipitation (PMP)**
 - Storm based approach uses observed storm data
 - Appropriate Storm adjustments are therefore critical to accurate PMP
 - » This includes representative precipitation frequency depths for storm adjustments
 - Ensure the PMF represents the worst case, yet physically possible scenario for a given basin
 - In areas where rain on snow and snow accumulation are significant, this must be accounted for
 - » Often hasn't been (HMRs, NOAA Atlas 14, NOAA Atlas 2)
- So, what do we do

Introduction - Design Events: Rain vs Precipitation

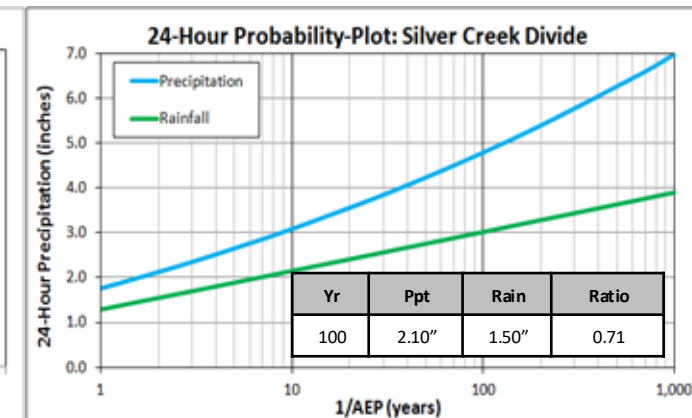
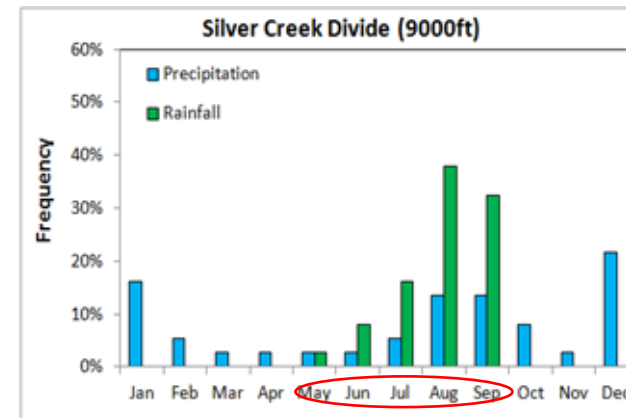
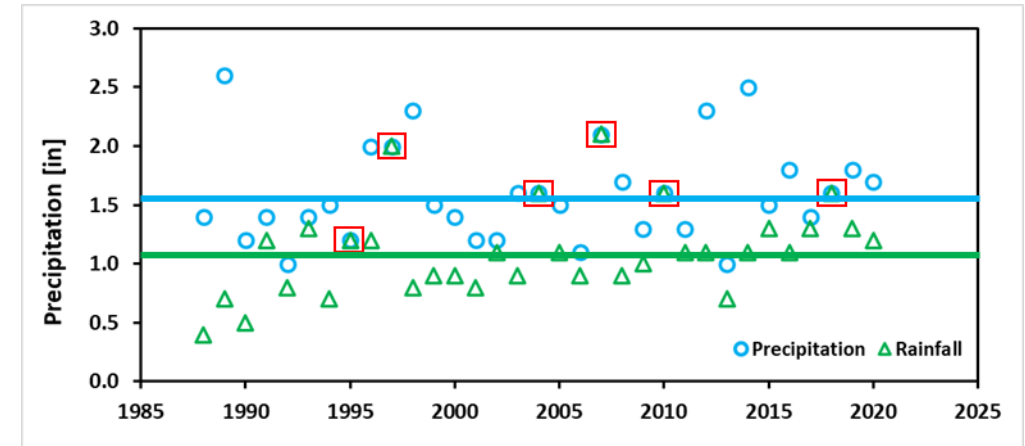
- Delineation of rain versus snow events
 - Season; e.g., Winter season is Nov-Mar with 70% of precip occurring and falls as snow
 - Elevation
 - Temperature; time step daily/hourly (T_a , T_d , RH , ...)



Introduction - Design Events: Rain vs Precipitation

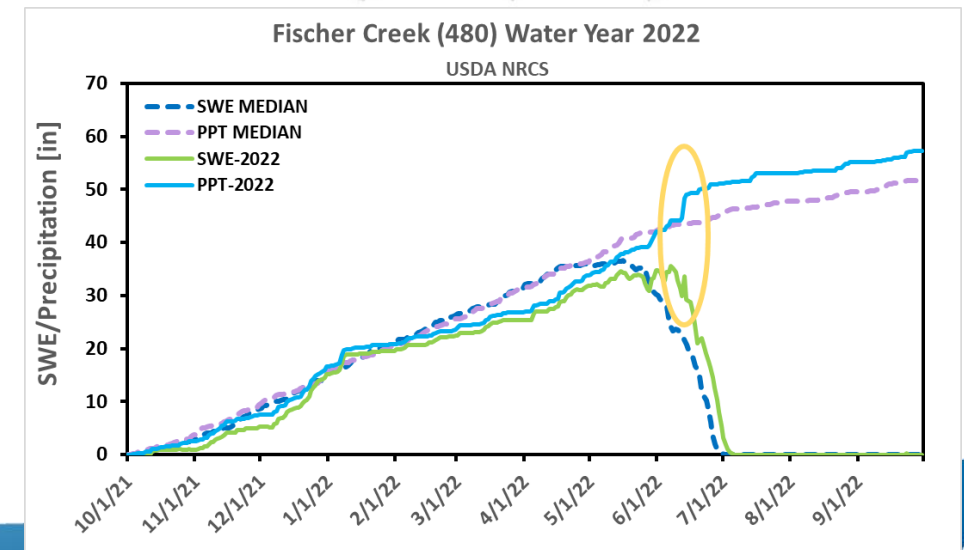
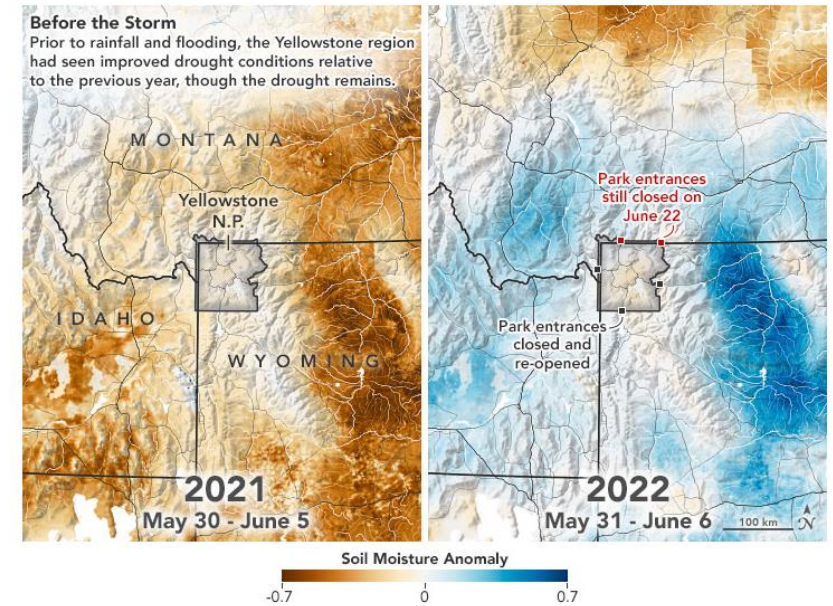
- Regional Frequency Analysis

- Annual maximum series (AMS) extraction
 - » AMS seasonality
- Homogeneous Regions
 - » Trade space for time
- Identification of Regional Probability distribution
 - » Goodness-of-fit
- Spatial mapping
 - » mean annual maximum
 - » L-Cv
 - » L-Sk
- Derivation of Uncertainty bounds
- Develop Areal Reduction Factors
- AEP Estimates



Case Study: June 2022 rain-on-snow flood event

- Greater Yellowstone Ecosystem region experienced a slow start to the 2021–2022 water year
 - Cool wet spring brought water to the region
 - April higher than average precipitation helped to build snowpack to 30-year average by May
 - June 10 and 13, Absaroka and Beartooth ranges received between **0.8 and 5.0 inches of rainfall**
 - June 10 and 13, region had **2.0 to 5.0 inches of snowmelt.**
 - Combined rain and snowmelt, **equivalent to 4 to 10 inches,**
 - » Saturated soils = catastrophic flooding rarely or never seen before across many rivers and streams in the region

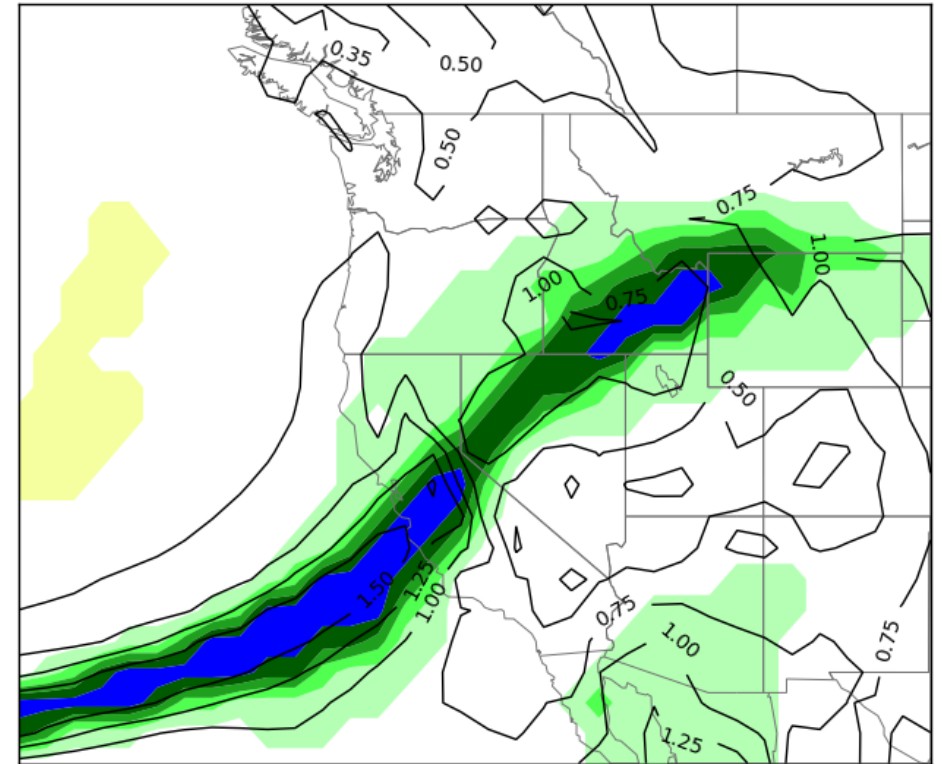


Case Study: June 2022 rain-on-snow flood event

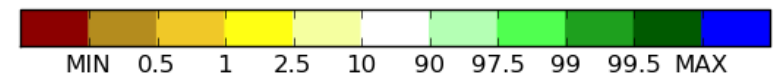


Radar (Sunday June 12 6pm – midnight)

GEFS Mean Precipitable Water (in) and M-Climate Percentile
HOUR 054 - VALID 18:00 UTC Sun Jun 12 2022



relative to GEFS reforecasts initialized
02-Jun to 23-Jun (1985-2012)

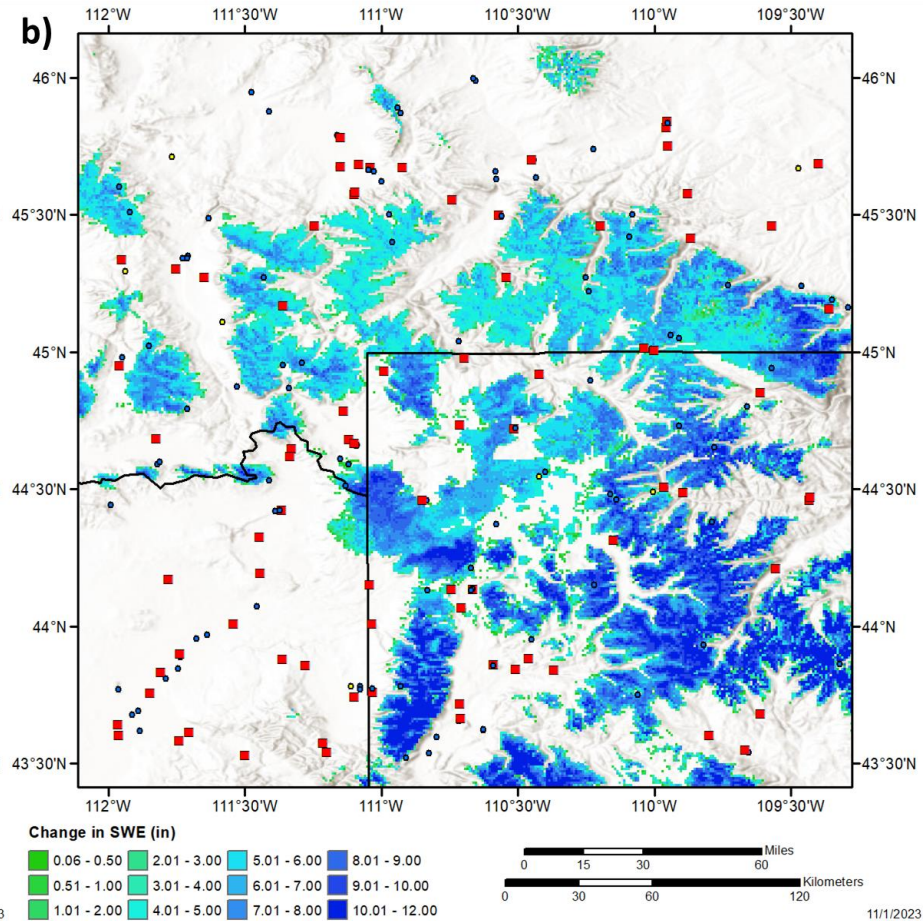
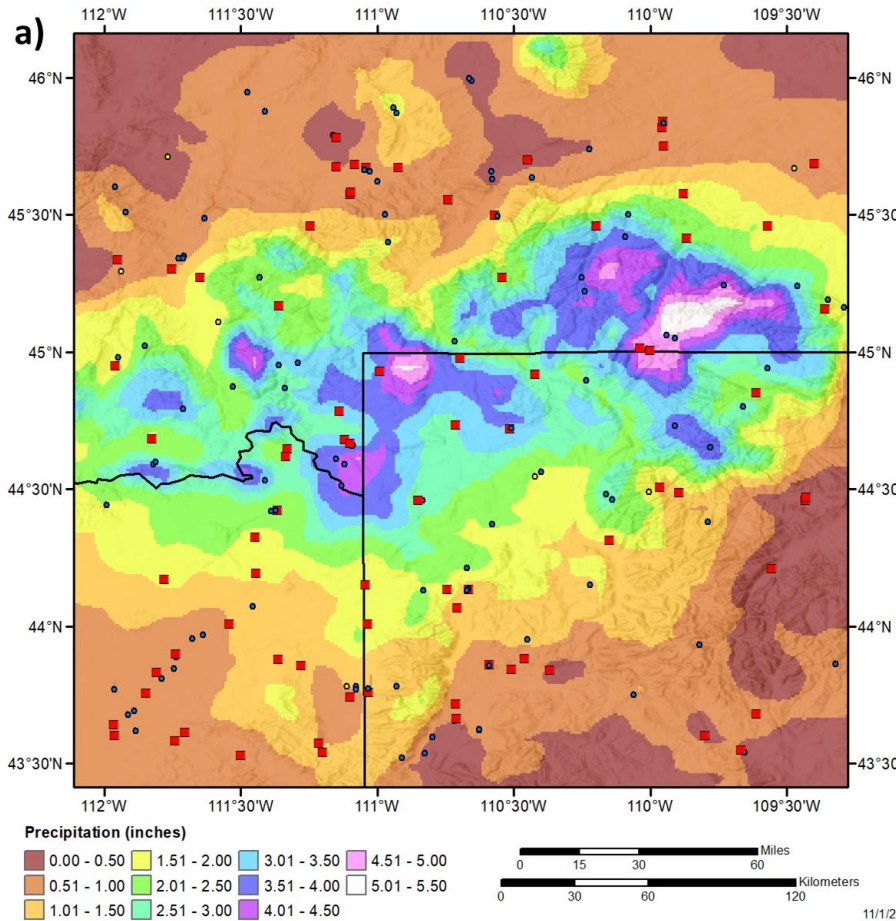


Rainfall and Snowmelt

June 9–15, 2022

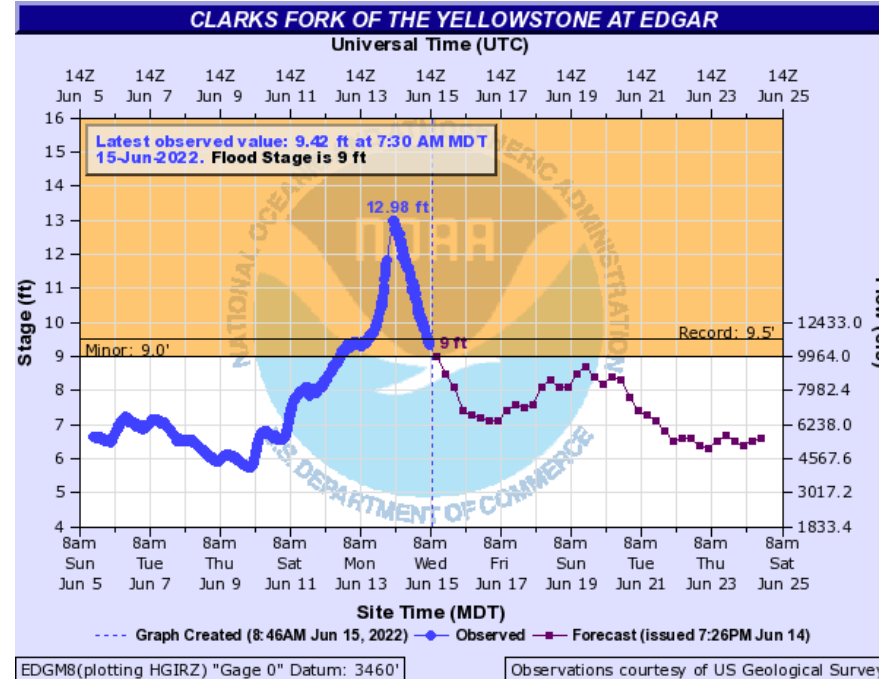
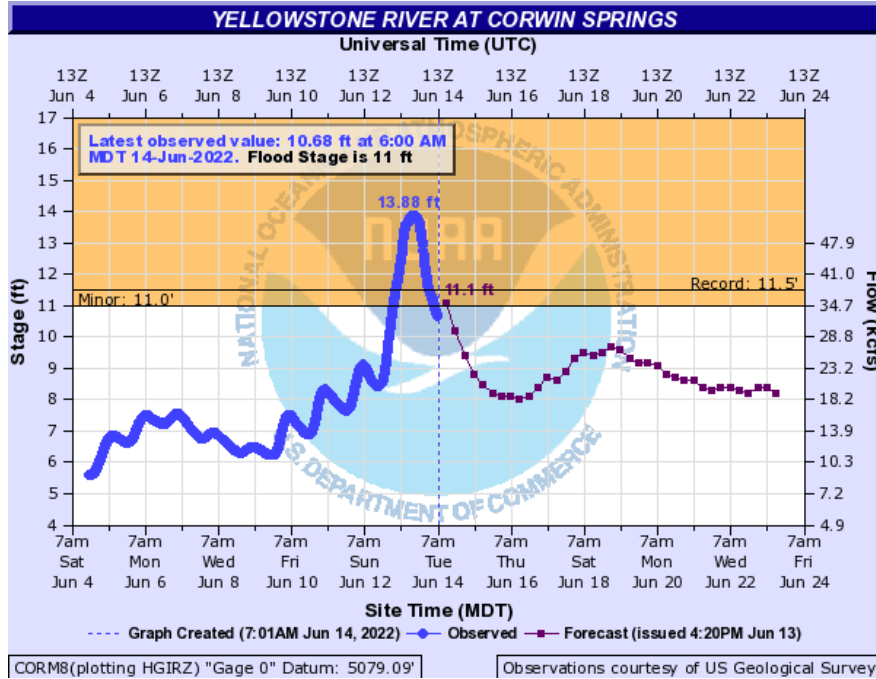
Precipitation

Snowmelt



Flooding

- USGS gauges on the Yellowstone River showing the stream level (a) and discharge (b) during June 9–16, 2022.



- Carbella Bridge (~ 4mi downstream of Corwin Springs, MT) constructed in 1918 and destroyed by the June 2022 floods
- Corwin Springs USGS sites previous record flooding event was in 1918, when the Yellowstone River level was 11.5 feet

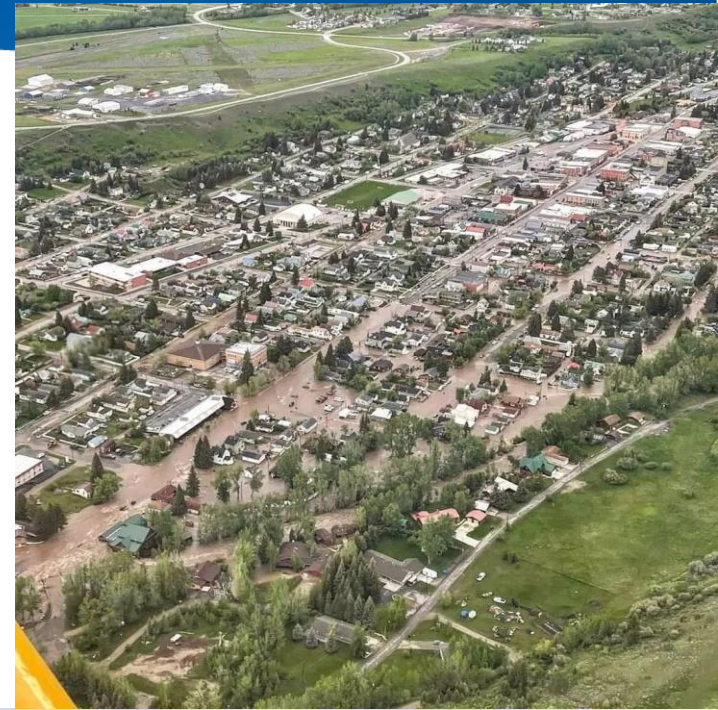
Flooding Images



Livingston, MT



Red Lodge, MT



Impact on Design Storms and PMP

- These types of unique events need to be considered
 - Even if they haven't been observed previously
- Important that consultant has the experience and data to support these types of evaluations
 - Don't want to miss the worst-case scenario
- These types of events show up in the many references
 - Costa, 1987; Jarret and Costa, 1987; Jarrett, 1993; Smith et al., 2018
- If it's happened before, it can happen again.....

Questions

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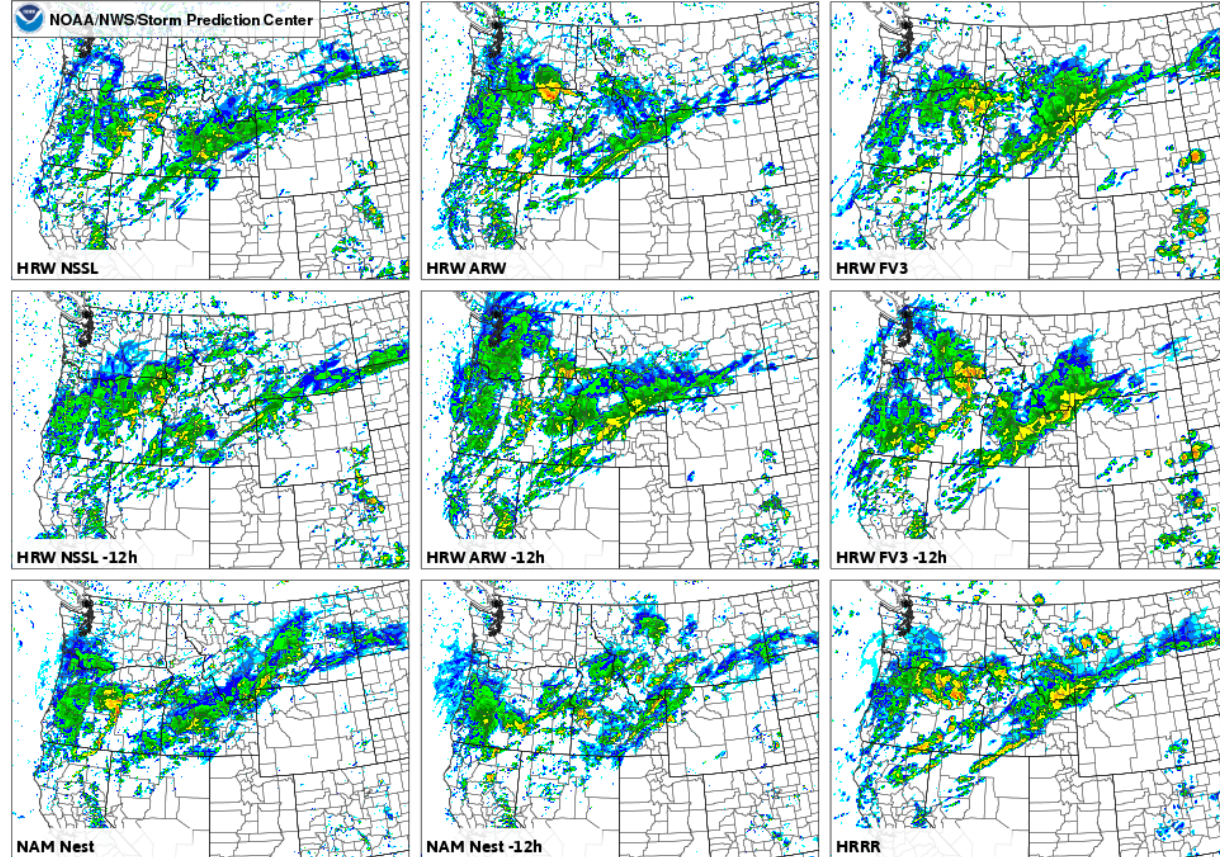
Case Study: June 2022 rain-on-snow flood event

HRF

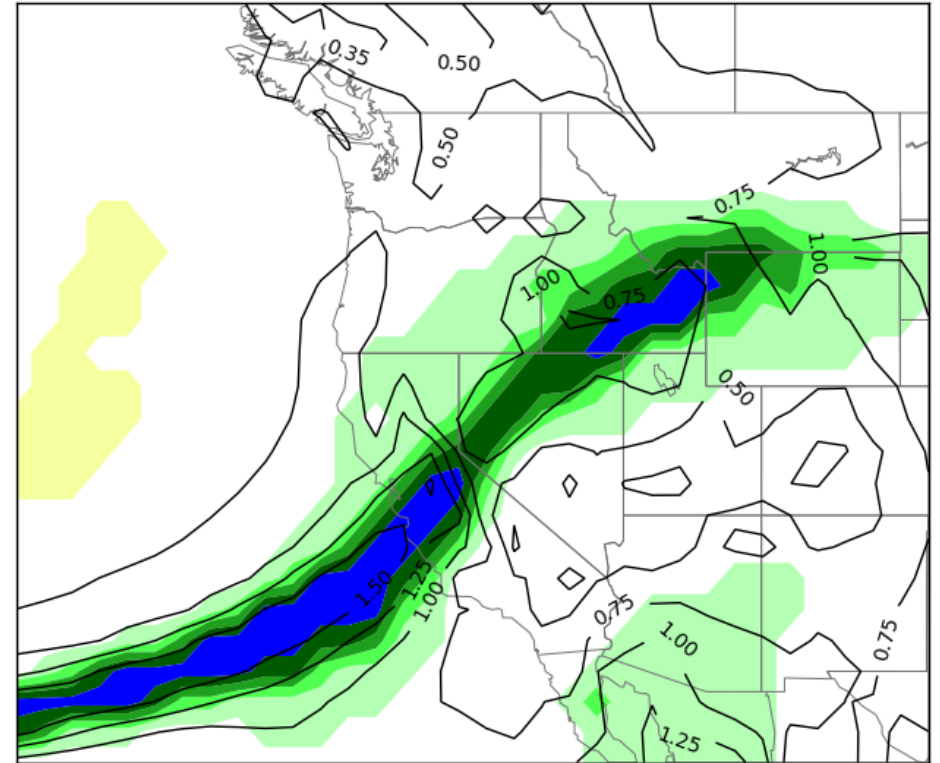
Composite reflectivity (dBZ), ensemble postage stamp

Run: Sat 2022-06-11 12:00 UTC

Valid: Sun 2022-06-12 20:00 UTC



GEFS Mean Precipitable Water (in) and M-Climate Percentile
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