Colorado and New Mexico Regional Extreme Precipitation Study (CO-NM REPS)

Western Water Assessment Stakeholder Community Meeting
Boulder, CO
October 9, 2018
Presentation Outline

- Why we needed it
- What we wanted from it
- How we did it
- What we got out of it
- What remains to be done
Dams in Colorado - 3000 ish
Hazard Classification

- Based on an evaluation of consequences of dam failure, NOT condition of the dam
- Establishes standards for design and prioritization of inspection, monitoring and emergency preparedness

<table>
<thead>
<tr>
<th>Hazard Classification</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>HIGH</td>
<td>Loss of human life is expected in the event of a failure</td>
</tr>
<tr>
<td>SIGNIFICANT</td>
<td>Significant damage is expected, but no loss of human life</td>
</tr>
<tr>
<td>LOW</td>
<td>No significant damage and no loss of human life</td>
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</table>
### Hazard Classifications - How Many

<table>
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<th>Hazard Classification</th>
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<tr>
<td>High</td>
<td>426</td>
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<td>Significant</td>
<td>297</td>
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<td>Low</td>
<td>1014</td>
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<tr>
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<td>1737</td>
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</table>

- Colorado Dam Safety is a Risk-Based program
- Focus efforts on higher consequence dams
Why Do Dams Fail? - Failure Modes

Earth Dams

Overtopping (48%)
Piping/Internal Erosion (46%)
Foundation (4%)
Seismic (2%)
Dam Overtopping
Spillways Operations
Spillway Design

- Rainfall
  - Extreme Precipitation
  - Area size and Duration
  - Intensity
- Runoff
  - soil, slope, basin area, length
- Routing
  - Reservoir area, dam configuration

From HMR 55A
10 sq mi, 72-hr
CO PMP Efforts - Historically

- HMR program discontinued 1999
CO-NM REPS Goals and Objectives

Three Goals - Goal 1

**New/Updated Tools:** To create updated, broadly accepted tools and procedures for estimating extreme precipitation depth, area, and duration relationships and precipitation frequency estimates for individual basins within the regional area that includes Colorado and New Mexico.

“Essentially, PMP methods as applied in the HMRs, are static and outdated.”

“There are readily-available probabilistic alternatives to PMP for assessments and designs of critical infrastructure.”

(USBR, 2011 England, Sankovich, Caldwell)
CO-NM REPS
Project Organization Chart

- Two States, 1 MOU
- Four Tasks
- PRB participation
- Dam owner support/oversight
- Project funding through CWCB, CDWR, NM OSE, NM Dam Owners Coalition, WWA

CO-NM Regional Extreme Precipitation Study Org Chart

- Contract 1: HMR Update AWA ($605K)
- Contract 2: Regional P-F MetStat ($516K)
- Contract 3: HRRR Analysis NOAA ($260K)
- Contract 4: Project Manager Activity ($170K)

Total Project Budget - $1.55 mil

11/18/2016
Task 1 - Deterministic PMP Analysis

- Storm-Based
- Generally follows NOAA HMR/WMO procedures (with updates)
- Gridded, GIS-based
- Select a Storm List
  - Storm Types
    - Local
    - General
    - Tropical
Storm Analysis

- Generally follows NOAA HMR/WMO procedures (with updates)
- Gridded, GIS-based
- Select a Storm List
- Analyze Storms
  - SPAS
    - Modern take on historic storms
    - Sometimes data limited
Generate DAD Tables

- Generally follows NOAA HMR/WMO procedures (with updates)
- Gridded, GIS-based
- Select a Storm List
- Analyze Storms
  - SPAS vs older methods

<table>
<thead>
<tr>
<th>Storm 1231 Zone 1</th>
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<table>
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<th>Difference (SPAS 1231 - USBR)</th>
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<table>
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<th>Percent Difference (SPAS 1231 - USBR)/USBR</th>
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<td>35%</td>
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<td>25</td>
<td>48%</td>
<td>22%</td>
<td>18%</td>
<td>8%</td>
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<tr>
<td>50</td>
<td>81%</td>
<td>50%</td>
<td>49%</td>
<td>36%</td>
<td>36%</td>
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</table>
Storm Analysis Improvements

- Generally follows NOAA HMR/WMO procedures (with updates)
- Select a Storm List
- Analyze Storms
  - SPAS
  - WRF - Re-analysis
Storm Analysis Improvements

- Generally follows NOAA HMR/WMO procedures (with updates)
- Gridded, GIS-based
- Select a Storm List
- Analyze Storms
  - SPAS
  - WRF adjusted
Storm Transposition

- Generally follows NOAA HMR/WMO procedures (with updates)
- Select a Storm List
- Analyze Storms
- Define Transposition Limits
Storm Transposition

- Generally follows NOAA HMR/WMO procedures (with updates)
- Select a Storm List
- Analyze storms
- Define Transposition Limits
  - Transpose from original to target location
Adjustment Factors

- Generally follows NOAA HMR/WMO procedures (with updates)
- Select a Storm List
- Define Transposition Limits
  - Transpose from original to target location
  - Apply adjustment factors
    - IPMF, MTF, GTF
    - Product = TAF
Example Results - Basin of Interest

TROUT_CREEK (61sqmi) Local Storm Basin Average PMP Depth Duration Chart

Rainfall Depth in Inches

Storm Duration in Hours

COLORADO Division of Water Resources
Department of Natural Resources
Example Results - Regional GS
Task 2 - Regional Precipitation-Frequency Analysis

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
  - Local - 2 hr

Spatial Pattern of 2-Hour Precipitation for Local Storm of July 28, 2014

Local storm temporal and spatial signatures
**Task 2 - Regional Precipitation-Frequency Analysis**

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
  - MEC - 6 hr

**MEC storm temporal and spatial signatures**
Task 2 - Regional Precipitation-Frequency Analysis

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
  - MLC - 48hr

MLC storm temporal and spatial signatures
Gauge/Station Data

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
  - From gauge data - MLC
  - From gauge data - MEC
  - From gauge data - Local

<table>
<thead>
<tr>
<th>PRECIPITATION GAUGE TYPE</th>
<th>NUMBER OF STATIONS/GAUGES</th>
<th>TOTAL STATION DATA YEARS</th>
<th>AVERAGE STATION YEARS</th>
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<tbody>
<tr>
<td>Daily Stations</td>
<td>1,052</td>
<td>60,019</td>
<td>57</td>
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<tr>
<td>Hourly Stations</td>
<td>91</td>
<td>3,373</td>
<td>37</td>
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<tr>
<td>TOTAL</td>
<td>1,143</td>
<td>63,392</td>
<td>55</td>
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**Statistical Mapping**

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
- Regional Statistical Mapping
  - Heterogeneous Regions (41)
Statistical Mapping

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
- Regional Statistical Mapping
  - Heterogeneous Regions (41)
  - Mapping Areas (12)
  - Macro Regions (3)
Statistical Analysis

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
- Regional Statistical Mapping
- Statistical Analysis
  - GEV
  - L-Kurtosis
  - L-skewness
  - L-cinco
Uncertainty Analysis

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
- Regional Statistical Mapping
- Statistical Analysis
- Uncertainty Analysis

![Contribution to Uncertainty Variance](image)

![Dimensionless 90% Uncertainty Bounds](image)
Areal Reduction Factors

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets
- Key Durations: 2, 6, 48 hour
- Storm Typing
- Regional Statistical Mapping
- Statistical Analysis
- Uncertainty Analysis
- Areal reduction factors
  - Watershed PF

### Areal Reduction Factors

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<thead>
<tr>
<th>MACRO REGION</th>
<th>LS (2-HOUR)</th>
<th>MEC (6-HOUR)</th>
<th>MLC (48-HOUR)</th>
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<tbody>
<tr>
<td>East</td>
<td>Up to 200 mi²</td>
<td>Up to 500 mi²</td>
<td>Up to 1,000 mi²</td>
</tr>
<tr>
<td>Rio Grande</td>
<td>Up to 200 mi²</td>
<td>Up to 500 mi²</td>
<td>Up to 500 mi²</td>
</tr>
<tr>
<td>West</td>
<td>Up to 100 mi²</td>
<td>Up to 200 mi²</td>
<td>Up to 500 mi²</td>
</tr>
</tbody>
</table>

Watershed PF-ARFs for East Macro Region
Results - Web-based Tool

- Storm typing
  - avoids mixed populations
- Spatial mapping
- Homogeneity
- Grouping of stations
- Regional behavior
- Reduced sampling variability
- Decreased uncertainty
- Point PF
  - User defined point
- Watershed PF
  - User provided watershed

### Precipitation (in) for 6hr Duration and Given AEP at 40.453N, 103.413W

<table>
<thead>
<tr>
<th>AEP (10^-4)</th>
<th>lower bound (in)</th>
<th>best estimate (in)</th>
<th>upper bound (in)</th>
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</thead>
<tbody>
<tr>
<td>10^-1</td>
<td>2.08</td>
<td>2.75</td>
<td>3.44</td>
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<tr>
<td>10^-2</td>
<td>2.99</td>
<td>3.99</td>
<td>4.98</td>
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<td>10^-3</td>
<td>3.41</td>
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<td>13.32</td>
<td>18.02</td>
<td>22.53</td>
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### Precipitation vs. AEP for 6hr Duration at 40.453N, 103.413W

- Data
  - PMP
  - Point AEP
Task 3-Dynamical Model Approaches to PMP using the HRRR and WRF

Goal: Perform a feasibility study to test and evaluate the potential benefits of adopting a high-resolution dynamical modeling-based framework for estimating the probable maximum precipitation (PMP) across Colorado and New Mexico.

Team:
- Kelly Mahoney (NOAA ESRL PSD)
- Eric James (NOAA ESRL GSD and CIRES/Univ of CO)
- Trevor Alcott (NOAA ESRL GSD)
NOAA - HRRR Model Process

Strengths
- 3 km grid, CONUS coverage
- 1-hr forecasts, looking ahead 18 hrs
- Real time data assimilation
- Solves physical equations of the atmosphere
- Fewer assumptions
- Continuous updating & improved since 2012
- Increases in computing power

Weaknesses
- Short period of record
- Rare events not captured
- Not used explicitly for PMP “forecasting” or “estimating”
Figure 16. Maximum precipitation (mm) within the 5-year HRRRX dataset occurring for (left) 1 h, (center) 2 h, and (right) 3 h durations.
Mean Annual Maximum

Strengths
• Multiple 6 hour forecasts summed
• Obvious climatological patterns

Weaknesses
• Missing HRRRX 6-hr forecasts, results in incomplete data (30% complete)
Seasonality

Mean monthly precipitation form the HRRRX dataset (constructed from 6-12-h forecasts)
Rain vs Snow

Ratio of 5-year maximum snow water equivalent (SWE) to 5-year-maximum precipitation from the HRRR model dataset for (left) 1-h, (center) 3-h, and (right) 6-h durations. Red colors indicate that the maximum precipitation during these 5 years occurred in the form of snow.
Precipitation-altitude relationship for the Front Range and San Juan Mountain regions of Colorado, in the HRRR 6-12-h QPF, Stage-IV QPE, and the PRISM climatological precipitation datasets, showing similar changes in total precipitation for the HRRR forecasts and Stage-IV analysis in both regions.
Specific storms of interest for CO-NM REPS were initially selected by Task 1’s assessment of:

- Importance in existing (previous) PMP values,
- Lack of observations from which to derive robust storm patterns and magnitudes, and
- Uncertainty in the previous analysis results from the USACE/USBR/NWS
- Uncertainty in the previous basemap utilized by AWA to accurately capture the spatial distribution
- Limited surface observation data for rainfall analysis and storm maximization
Storm Re-Analysis, WRF Model
Colorado – New Mexico
Regional Extreme Precipitation Study

Summary Report
Volume VI
Considering Climate Change in the Estimation of Extreme Precipitation for Dam Safety

Prepared by:
Kelly Mahoney,
NOAA Earth Systems Research Laboratory, Physical Sciences Division
Jeff Lukas,
Western Water Assessment, CIRES, University of Colorado Boulder

September 25, 2018
Increase in Temperature

- Extensive Literature review
- Search for Operations methods being used by others
- Qualitative or quantitative
- Some policy statements, no operational methods
### Summary of Findings - Others

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<tr>
<th>Study</th>
<th>Region of study</th>
<th>Projected change in PMP due to climate change</th>
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</thead>
<tbody>
<tr>
<td>Kunkel et al. (2013a)</td>
<td>US</td>
<td>Changes in maximum water vapor concentrations, which are a principal input to PMP estimation techniques, will change by an 20%-30% by 2071-2100</td>
</tr>
<tr>
<td>Beauchamp et al. (2013)</td>
<td>Canada (Summer-Fall PMPs)</td>
<td>+0.5-6% over 2071-2100 period</td>
</tr>
<tr>
<td>Stratz and Hossain (2014)</td>
<td>South Holston Dam in Tennessee, Folsom Dam in California, and Owyhee Dam in Oregon</td>
<td>Significant increase over current PMP values when future changes in dew points extrapolated from observational trends or numerical models are taken into account</td>
</tr>
<tr>
<td>Ishida et al. (2016)</td>
<td>Northern California</td>
<td>+14.6% by middle of 21st century +27.3% by end of 21st century</td>
</tr>
<tr>
<td>Rastogi et al. (2017)</td>
<td>Alabama-Coosa-Tallapoosa River basin (southeastern US)</td>
<td>+20% in 2021-2050 near-future +44% in 2071-2100 far-future periods</td>
</tr>
<tr>
<td>Chen et al. (2017)</td>
<td>Pacific Northwest</td>
<td>+50% ± 30% by 2099 under RCP8.5 scenario</td>
</tr>
<tr>
<td>Clavet-Gaumont et al. (2017)</td>
<td>Canada</td>
<td>Projected increases in spring PMP except for the most northern basin.</td>
</tr>
</tbody>
</table>
Increase in Moisture

- Numerical modeling shows potential
- No “one-size-fits-all” approach available
- Paper provides 3 “families” of recommended approaches

Recommended approaches
- Qualitative-standards based
- Quantitative-standards based
- Quantitative probabilistic
Thank You,
Questions?

CO Eastern Plains, evening of 4/2/15
Photo credit, Darcy Janssen, Cheyenne County EM Director