Does PMP have an AEP? CO-NM REPS Findings Bridge Deterministic and Probabilistic Approaches

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Division of Water Resources
Department of Natural Resources

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Discussion Outline

- REPS Project Background
- PMP and Precipitation Frequency terminology
- Comparing PMP and PF estimates at sites around Colorado
- Why might we expect variation?
- How does Colorado Dam Safety handle variation
- Ideas for the future

Background and Context

3-Task study to answer the following questions:

- How much and how hard can it rain?
- What are the probabilities of it raining very much and very hard?
- What is the AEP of PMP?
- How can we use these independently derived estimates of extreme rainfall in a state dam safety regulatory environment? i.e. standards based and/or risk based
- Are Dynamical Weather Models and techniques a viable methodology for the future of extreme rainfall estimating?

REPS Project documentation:
https://dwr.colorado.gov/services/dam-safety

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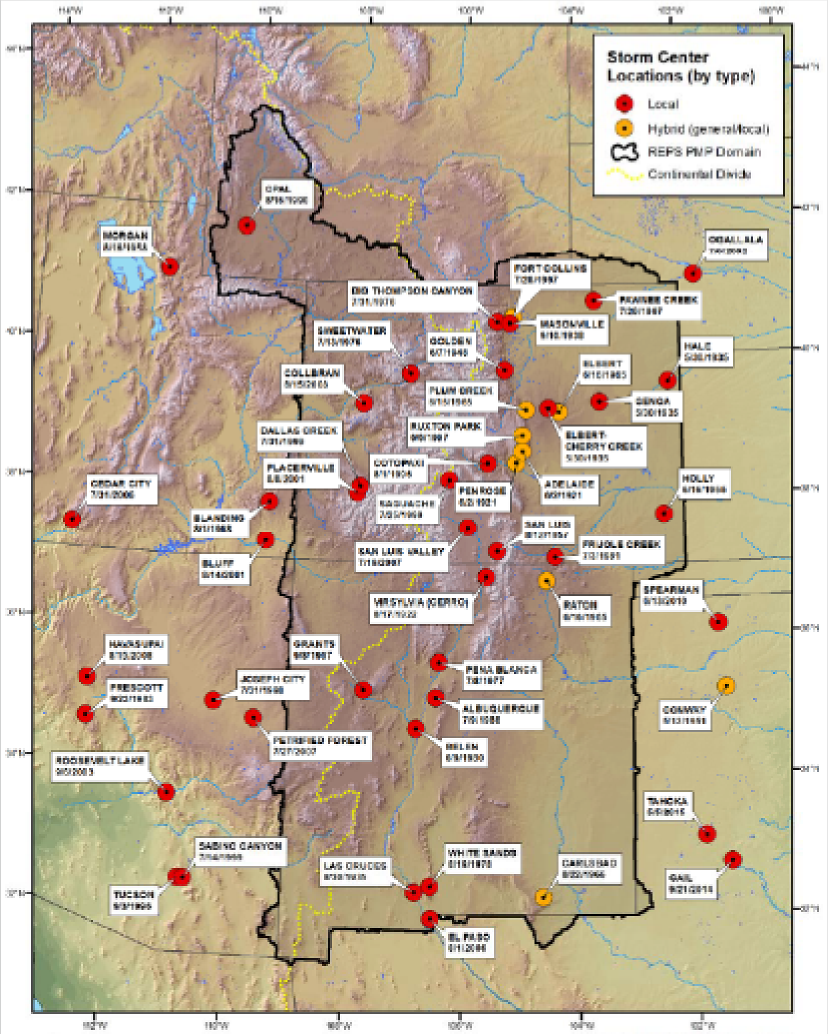
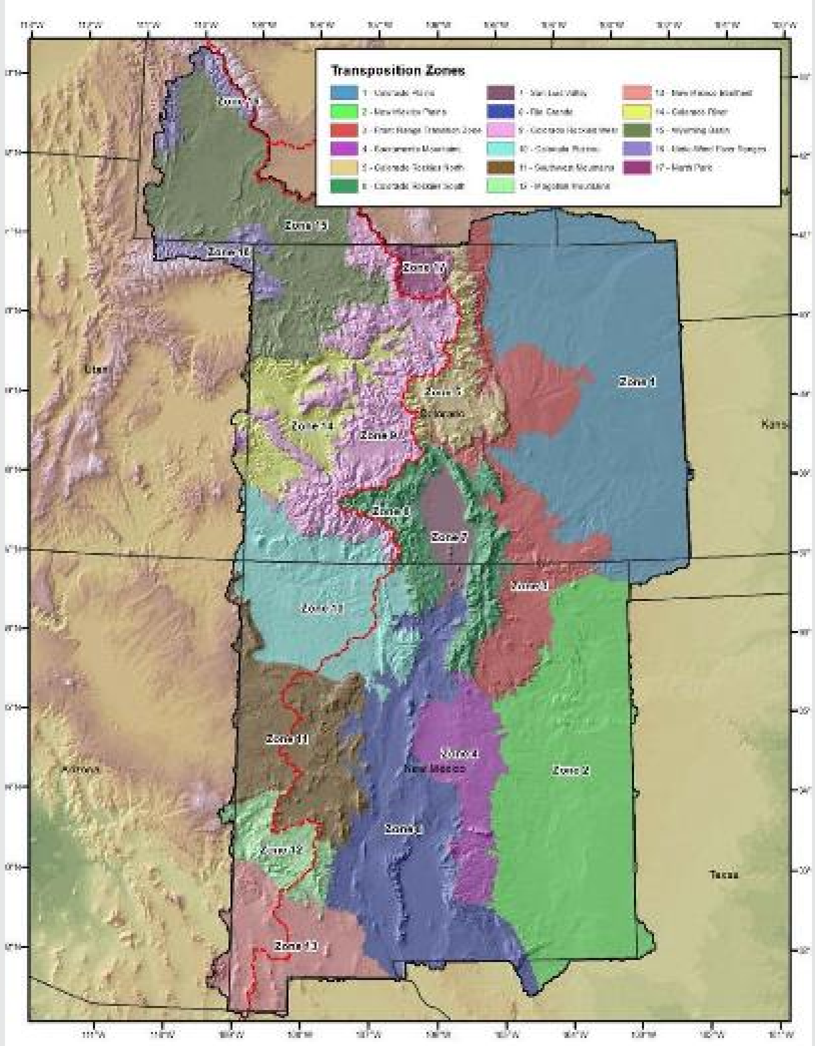
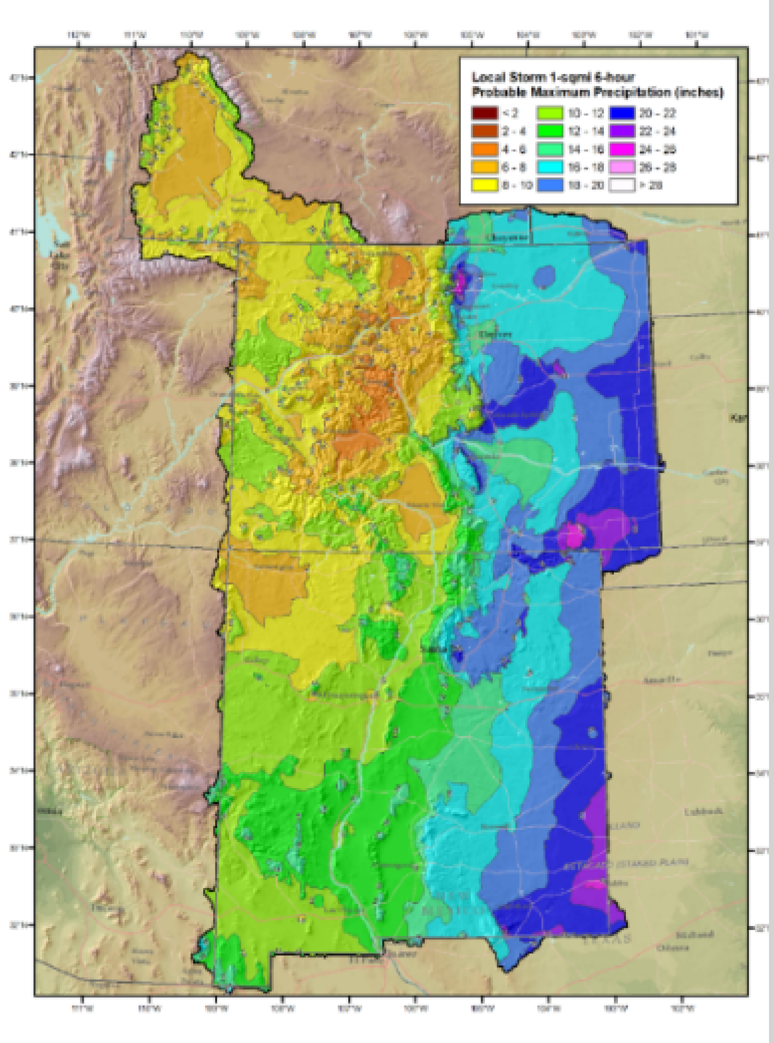
REPS Task 1 – Deterministic PMP



REPS PMP Local Storm coverage

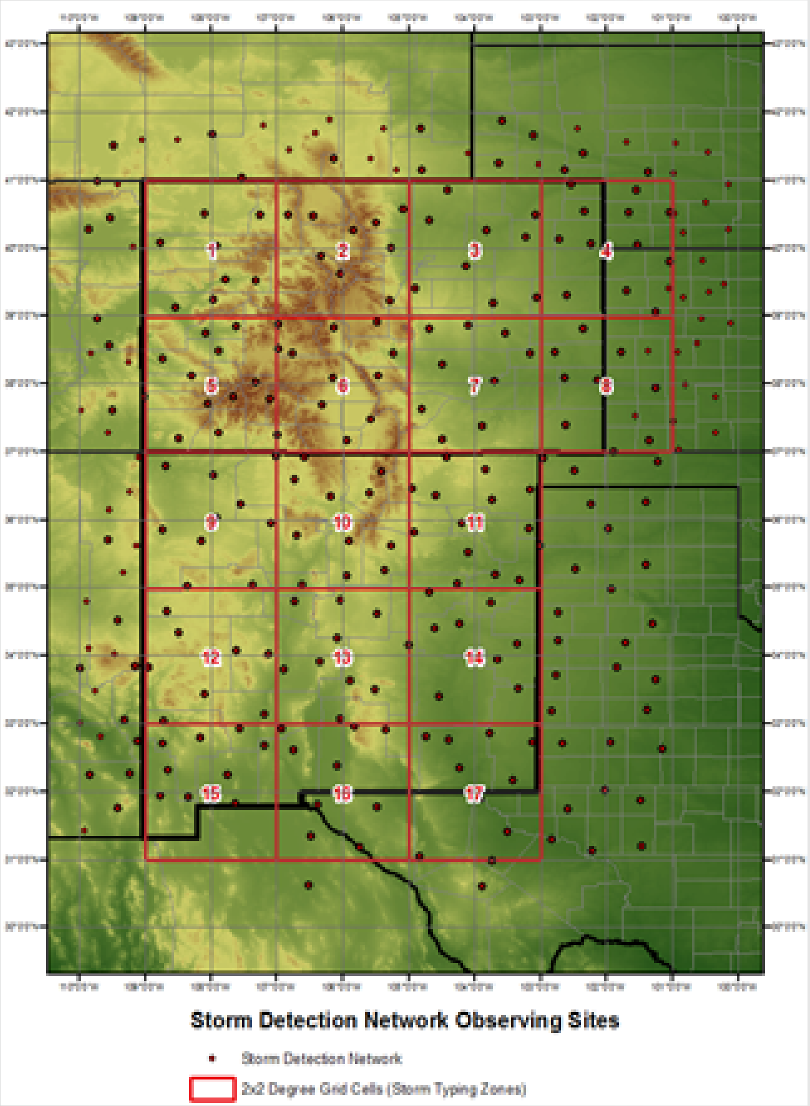


REPS PMP Transposition Zones

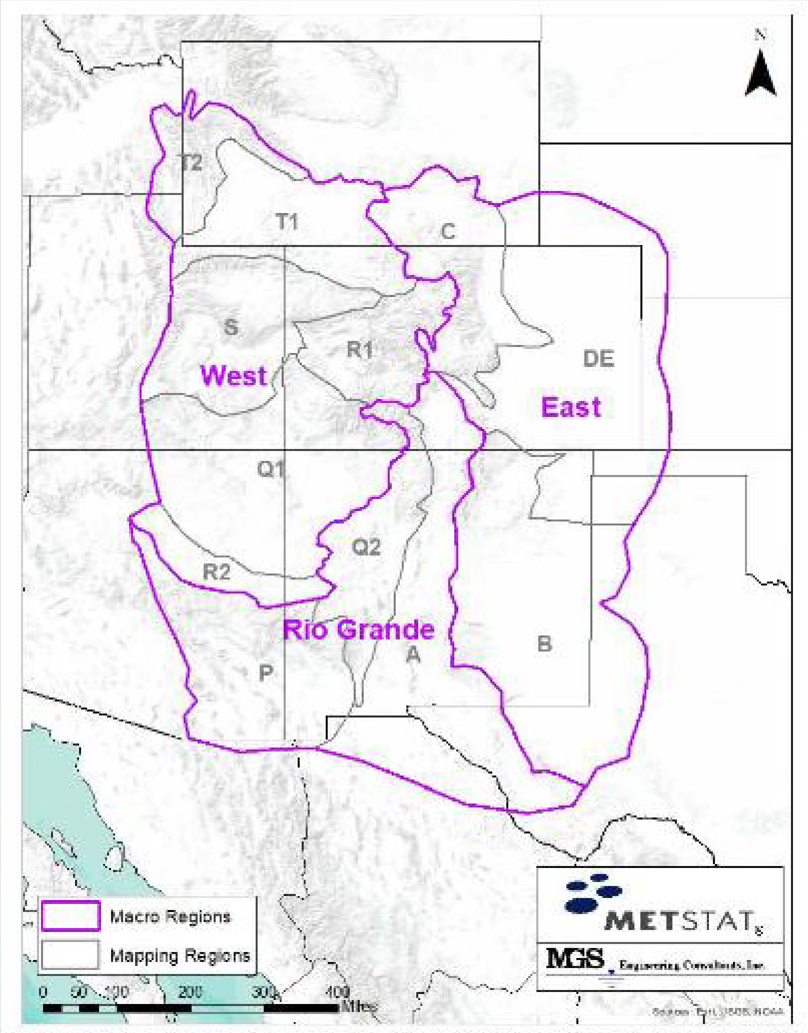


REPS Local Storm PMP 1 sq mi 6-hr duration.

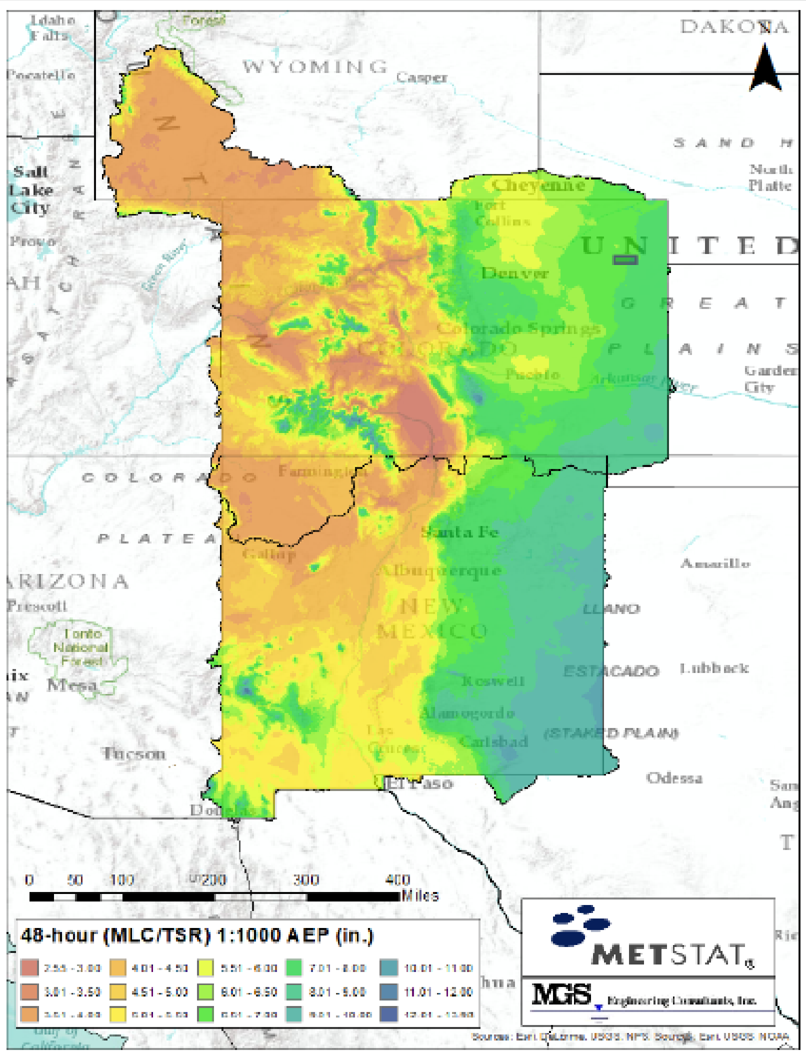
REPS TASK 2 - Probabilistic Regional PF



Network of daily precipitation stations (black dots) and 17 Storm Typing Zones (red boxes)



Macro Regions (purple) and homogeneous mapping regions (grey)

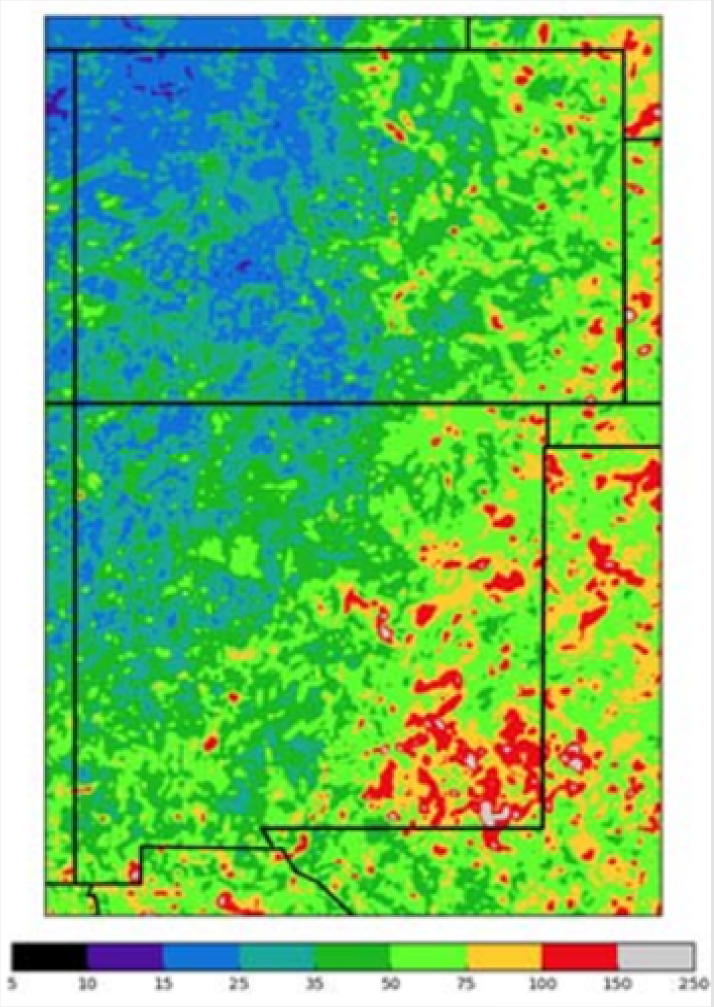


Isopluvial map of 48-hour precipitation maxima for an AEP of 1:1,000 for MLCs

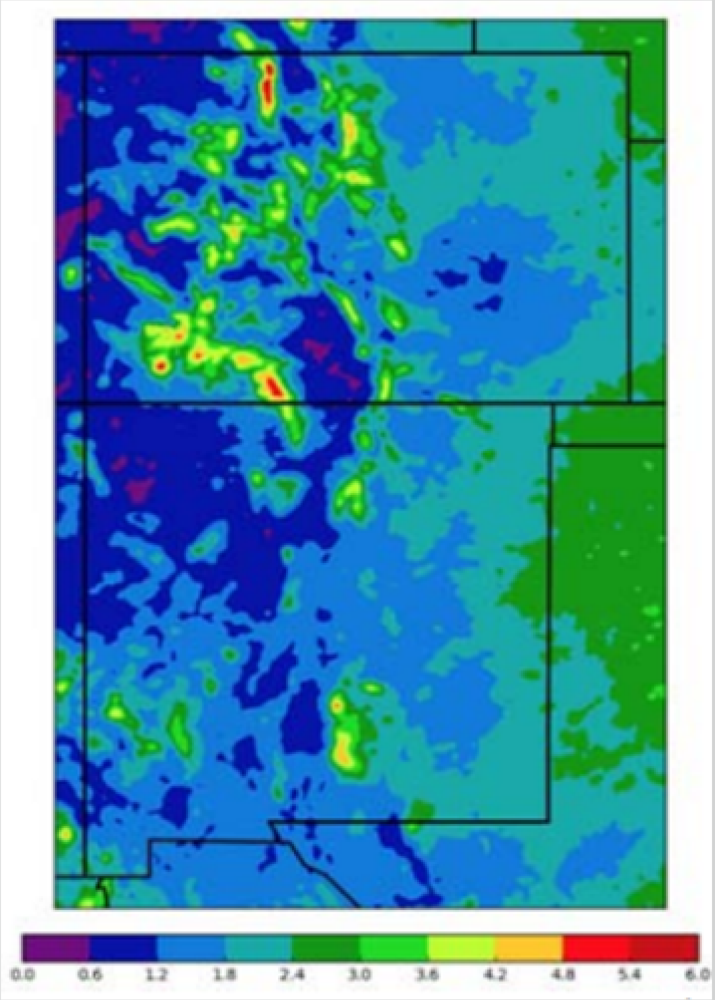
REPS Task 3 - Dynamical Weather Modeling

- Model data: continuous in space and time, can be analyzed for maximum values, frequency statistics using the same dataset, absent additional, inconsistent assumptions
- Allow comparisons between PMP, PF using same data
- (Prototype examples from REPS limited by short period of record)

Max 6h precip (~PMP)
2012-01-24 to 2017-01-24



Probability of 10mm precip
/12 hours (~PF)



*over 5 year prototype period

REPS PMP vs. Probabilistic Precipitation Frequency

REPS PMP

- Cataloging and reconstruction of historical storms and storm transposition within homogeneous climate regions
- Applies in-place maximization factor, moisture-supply factor, and orographic factor
- Warm season, Liquid precip only

REPS Precipitation Frequency

- Storm typing, macro regions, hetero. super regions, homo. mapping regions
- Regional L-moment statistical analysis of annual maximum precipitation series
- Areal reduction factors developed by stochastic storm transposition
- All-phase precip

REPS Storm Typing

REPS PMP and PF use Storm Typing to separate datasets into homogeneous populations of independent weather events.

- Makes REPS dataset ideal for analyzing notional AEP of PMP (Nathan et al, 2016)

REPS PMP Storm Types: 2-hr Local Storm, 6-hr Local Storm, 24-hr Local Storm/Hybrid, 72-hr General Storm, 72-hr Tropical Storm

REPS PF Storm Types: 2-hr Local Storm, 6-hr Meso-scale with Embedded Convection (MEC), 48-hr Mid-latitude Cyclone/Tropical Storm Remnant (MLC/TSR)

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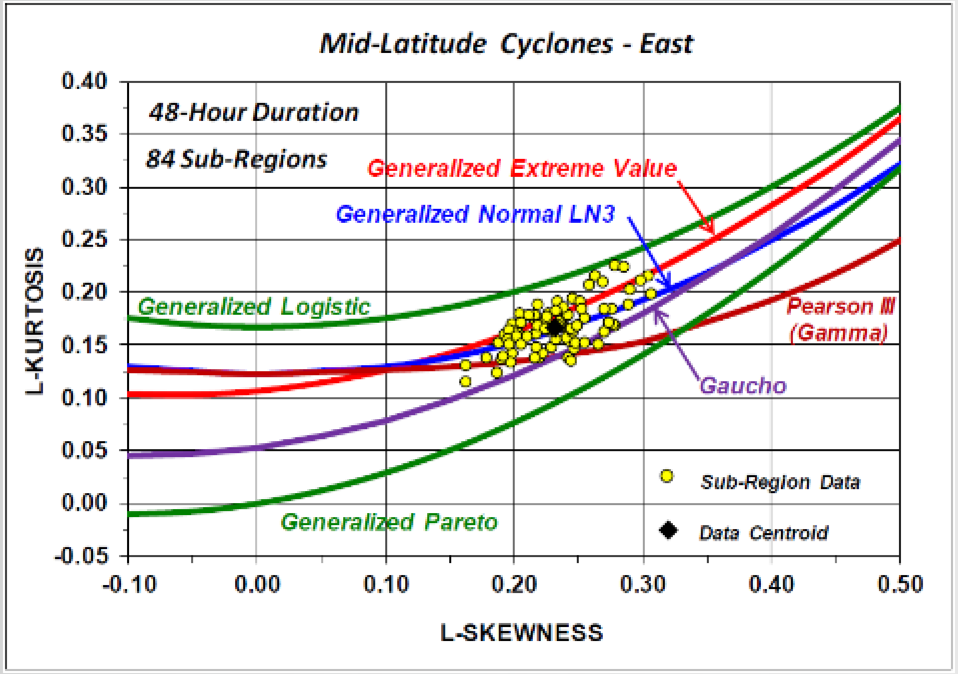
PMP Terminology

Theoretical PMP: Greatest depth of precipitation for a given duration physically possible over a given area size at a geographic location and time of year. Exceedance probability is zero and theoretical PMP is unknown.

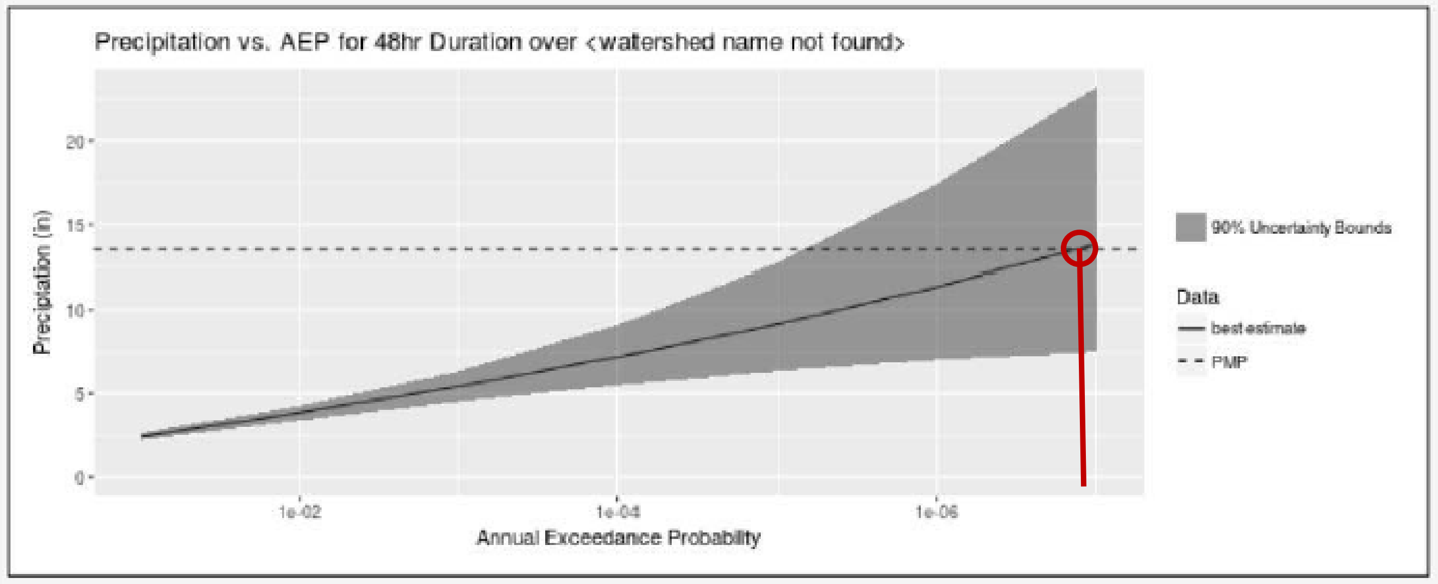
Operational PMP: Estimate of PMP determined by standard procedure by hydrometeologists by storm transposition and adjustment factors.   Has some likelihood of exceedance.

In Practice - PMP, as calculated, has an AEP

<u>**Notional Annual Exceedance Probability (AEP)**</u>: Intersection of extreme precipitation frequency curve and an operational PMP estimate.

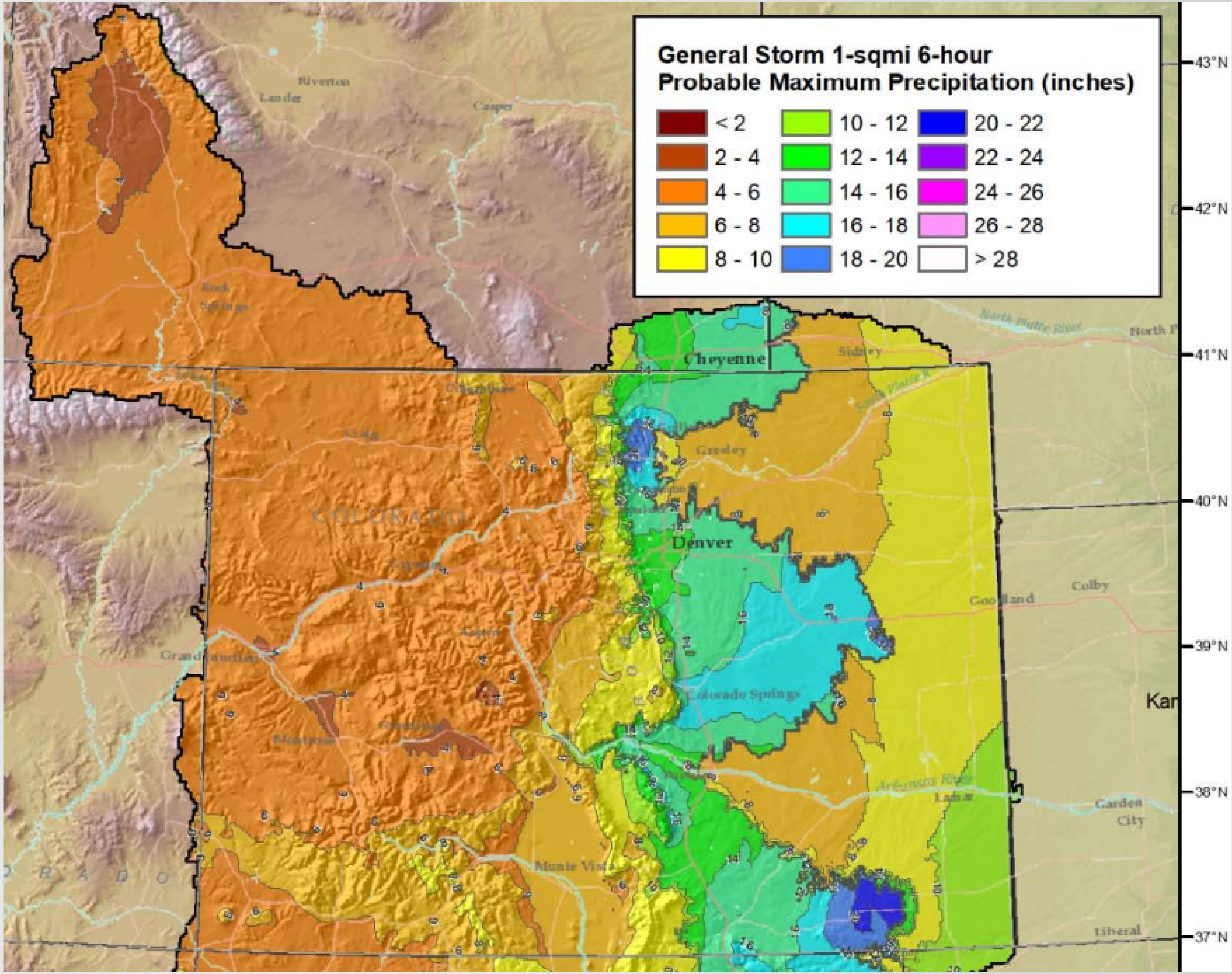


L-Moment ratio diagram depicting regional L-Skewness and L-Kurtosis values for homogeneous sub-regions in the Eastern region of the project area for 48-Hour precipitation maxima for MLCs

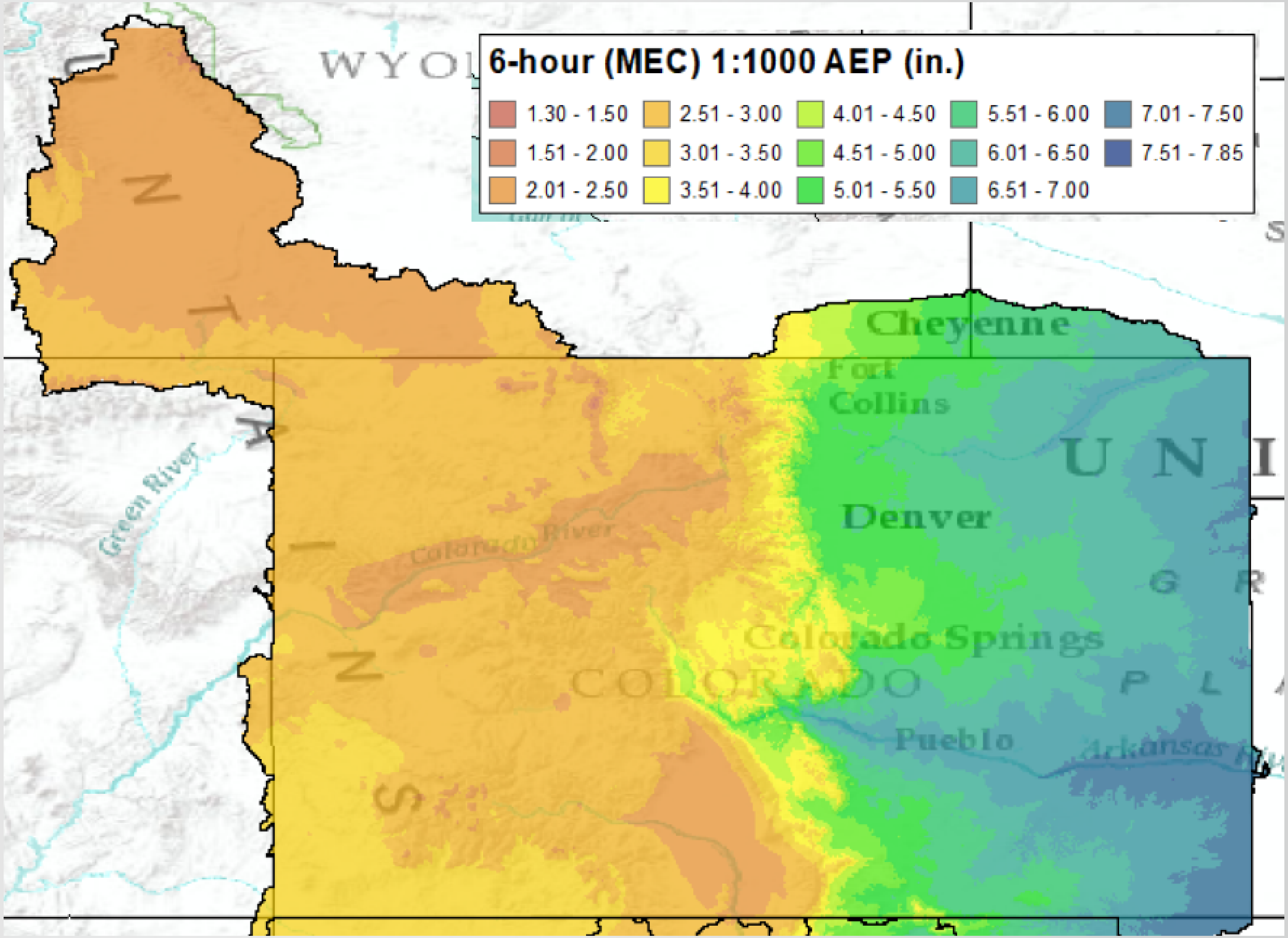


48-hr (MLC/TSR) Precipitation vs AEP best estimate plot with 90% confidence bounds (grey) and PMP value plotted.
Notional AEP of PMP shown in red (~9x10e-6)

REPS 6-hr LS PMP



REPS 6-hr MEC
10e-3 Precipitation
Frequency



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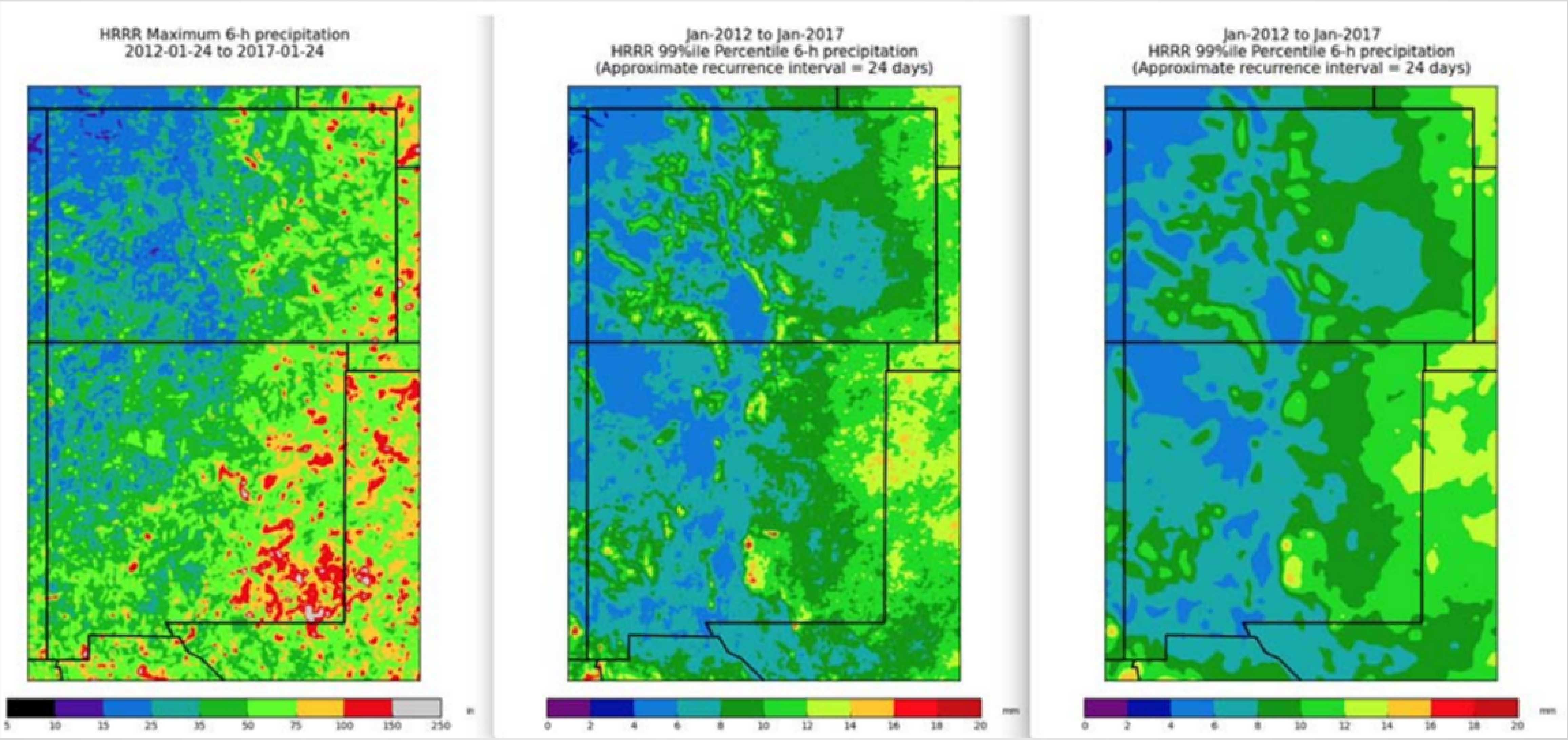
HRRR Model 6-hr Data Analysis



HRRR 6-hr (a) Maxima, (b) 99th percentile and (c) 99th percentile smoothed with Gaussian filter. Jan 2012-Jan 2017 data

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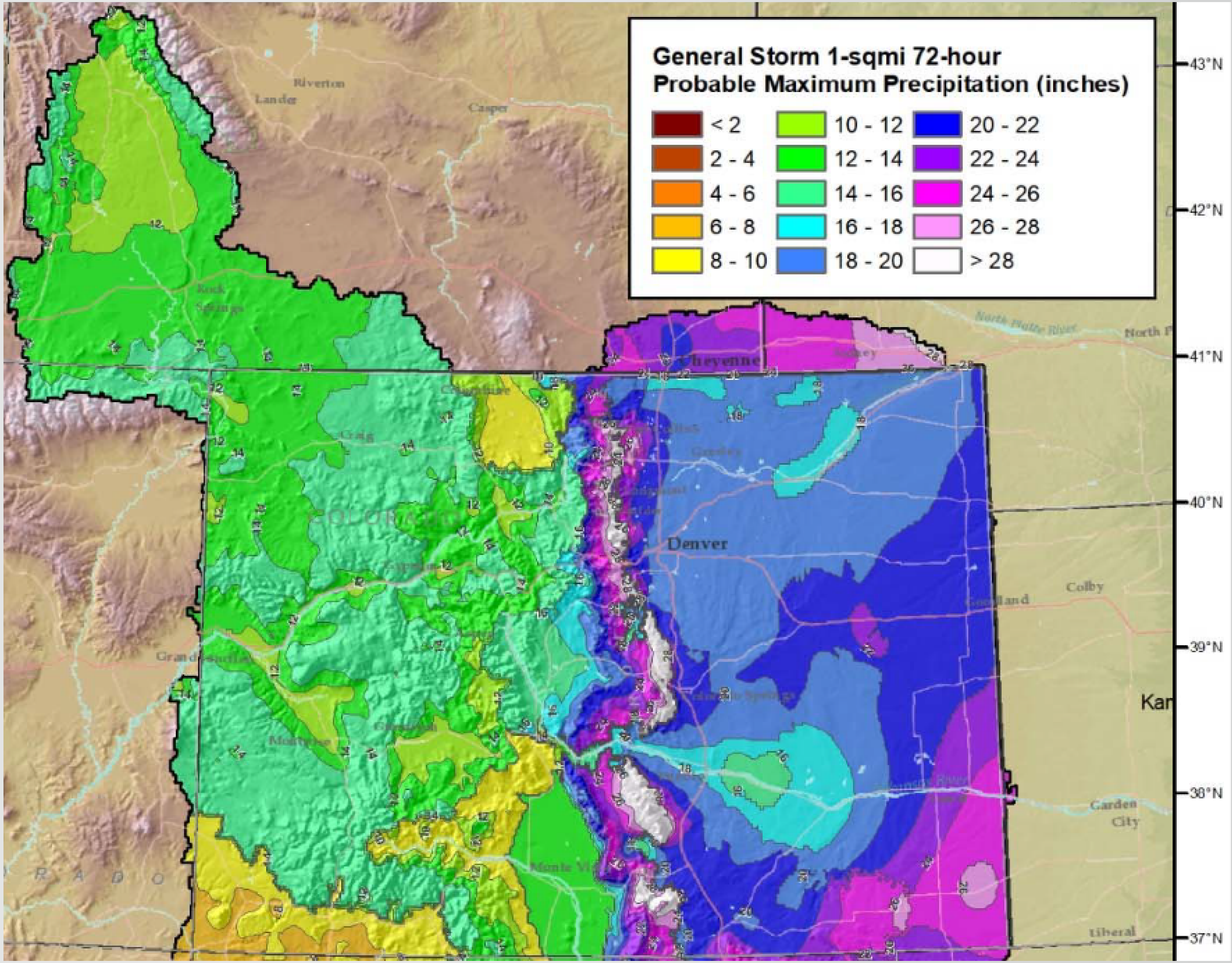
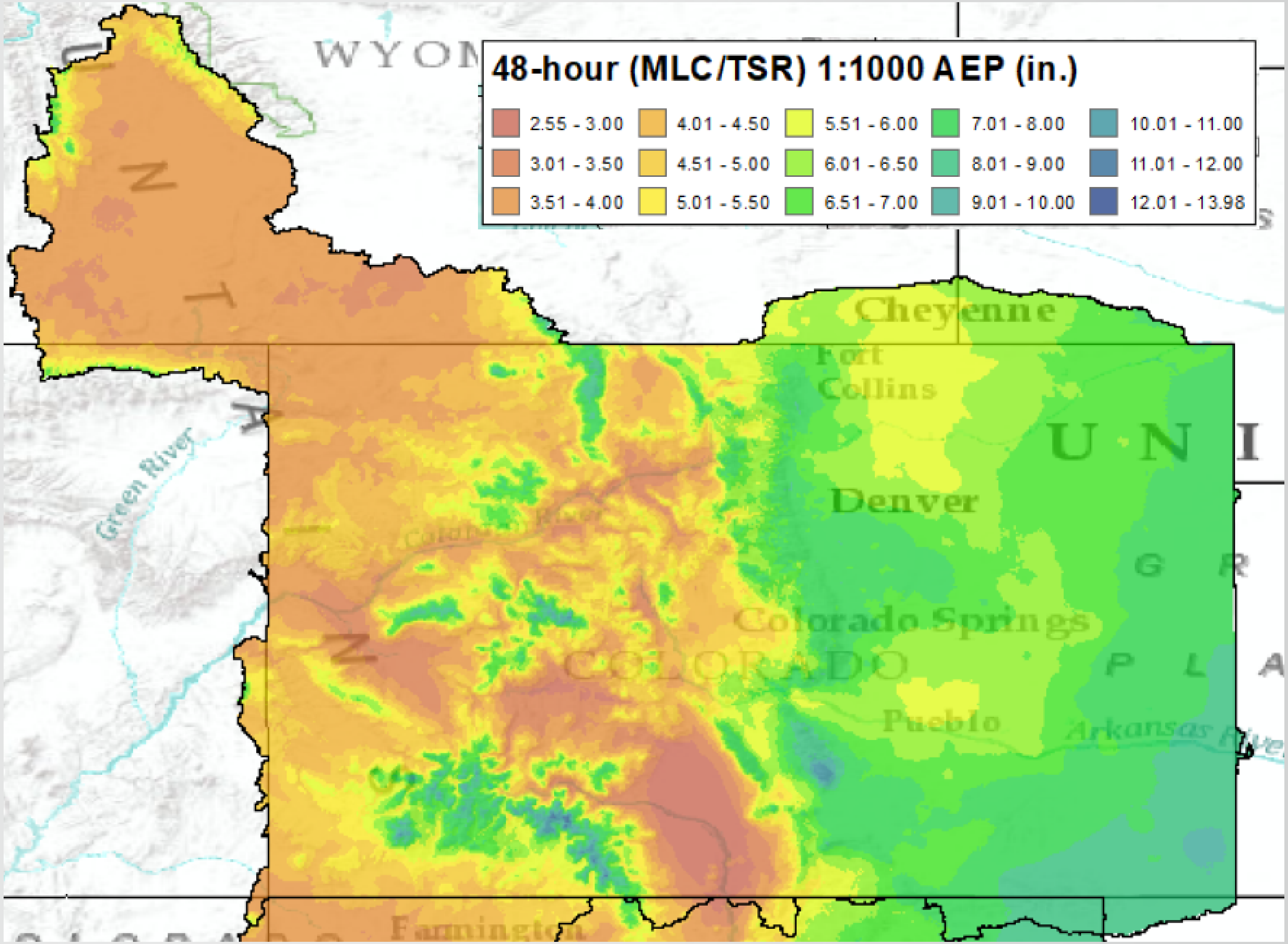
REPS 72-hr GS PMP



REPS 48-hr MLC/TSR 10e-3 Precipitation Frequency



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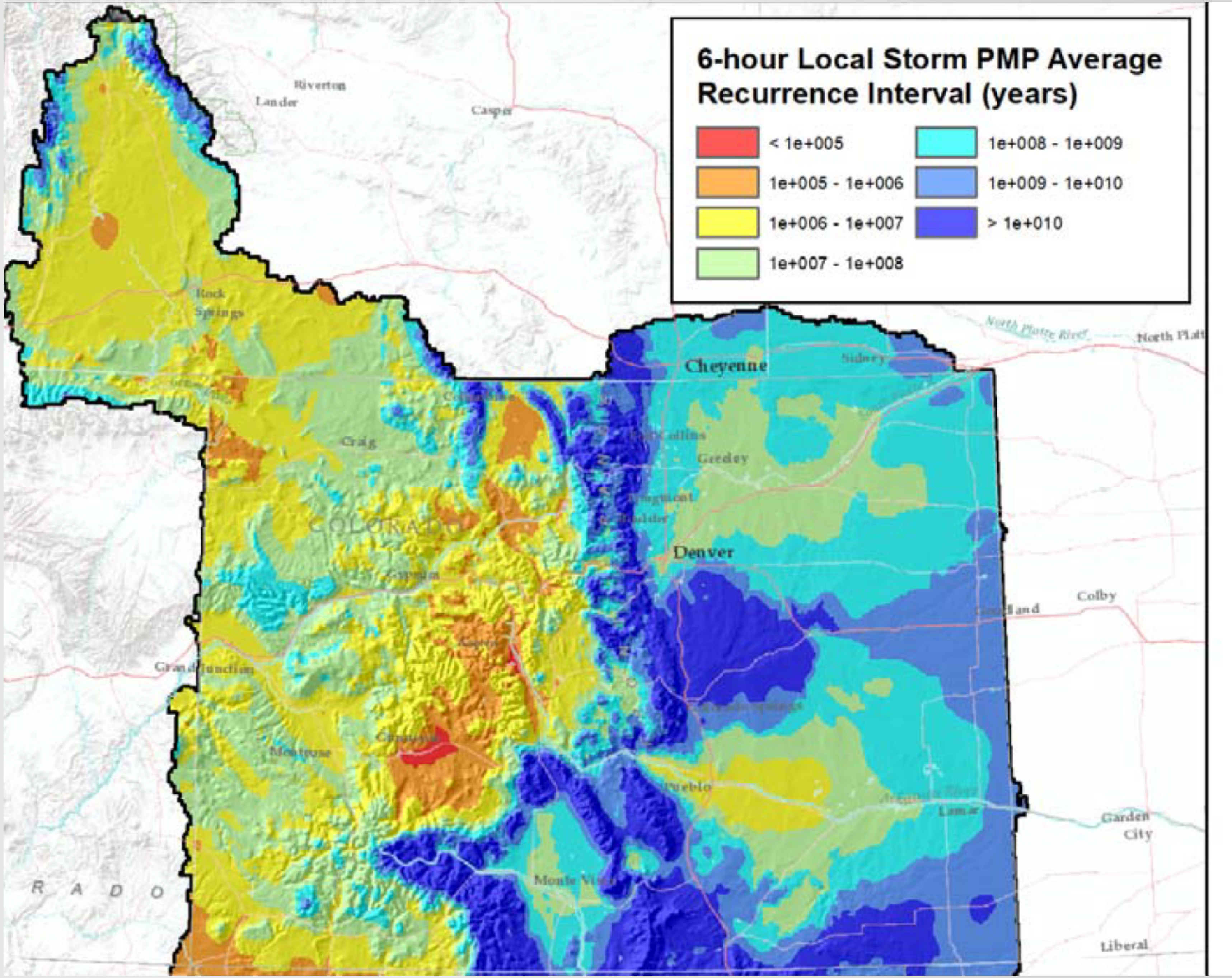
Notional ARI of REPS 6-hr LS PMP (from REPS 6-hr MEC PF), 1sqmi

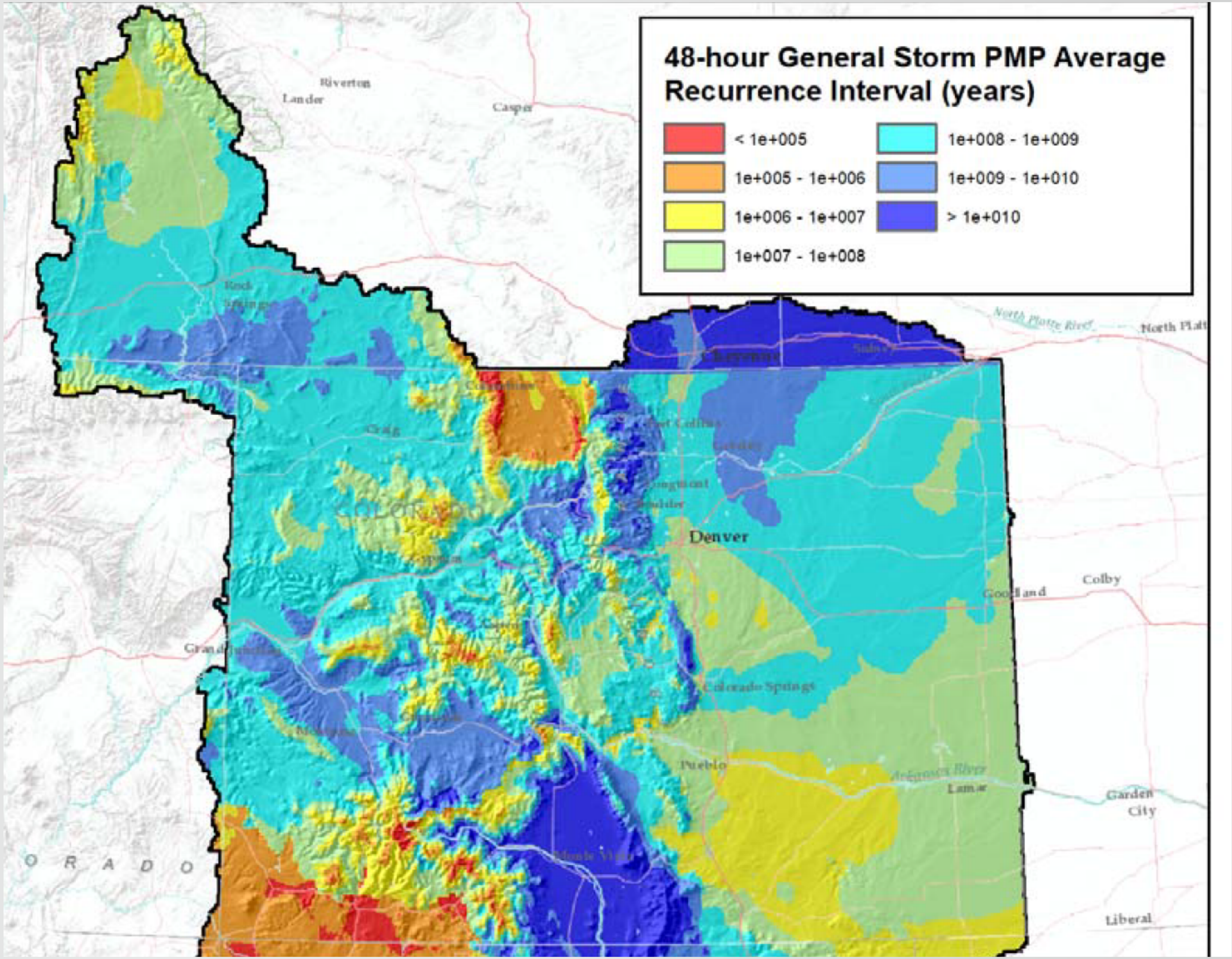
- >1x10e10 along Front Range
- <1x10e5 in central mountains

Higher ARI east of Rockies & closer to Gulf moisture sources is contrary to results from Schaefer (1999) along Gulf coast [Implications for operational PMP estimates (historical

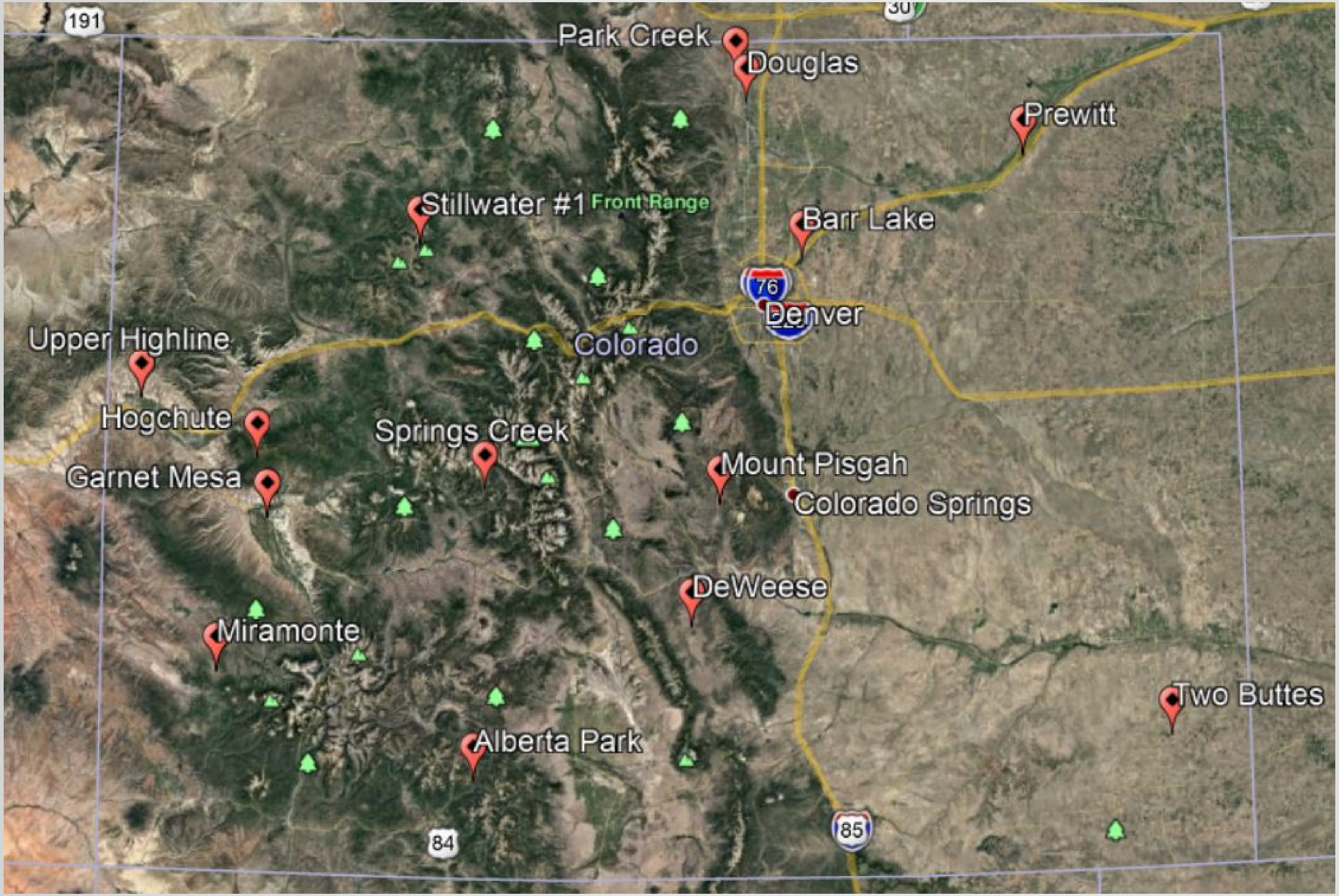


Notional ARI of REPS 48-hr GS PMP (from REPS 48-hr MLC/TSR PF)

- Lower notional ARIs of GS PMP (vs LS PMP), consistent trend as 100-YR ratios
- Again, hot spot at Northern Front Range (active weather region) but also SLV (inactive)

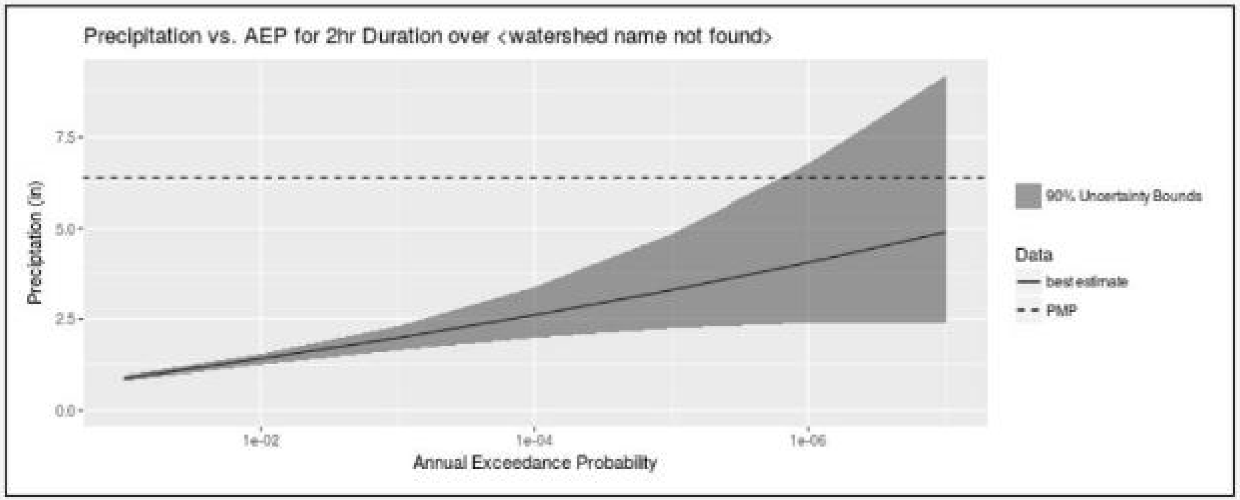


Summary of Results at Selected Sites in Colorado

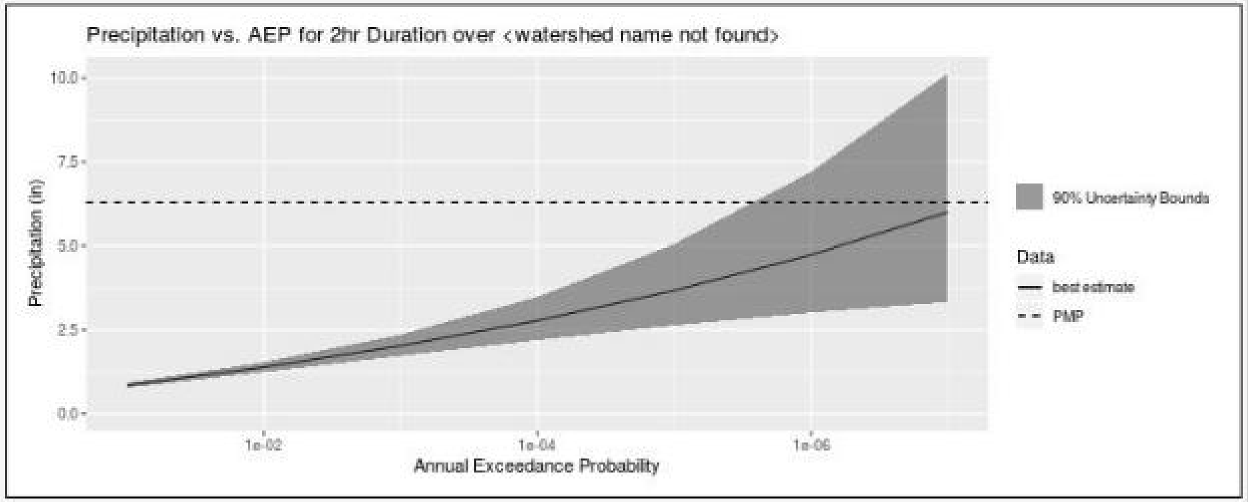


- Comparison of:
  - 2-hr Local
  - 6-hr MEC
  - 48-hr MLC/TSC
- With PMP at these key durations
- All 3 Macro Regions
- 6 of 10 TZ’s

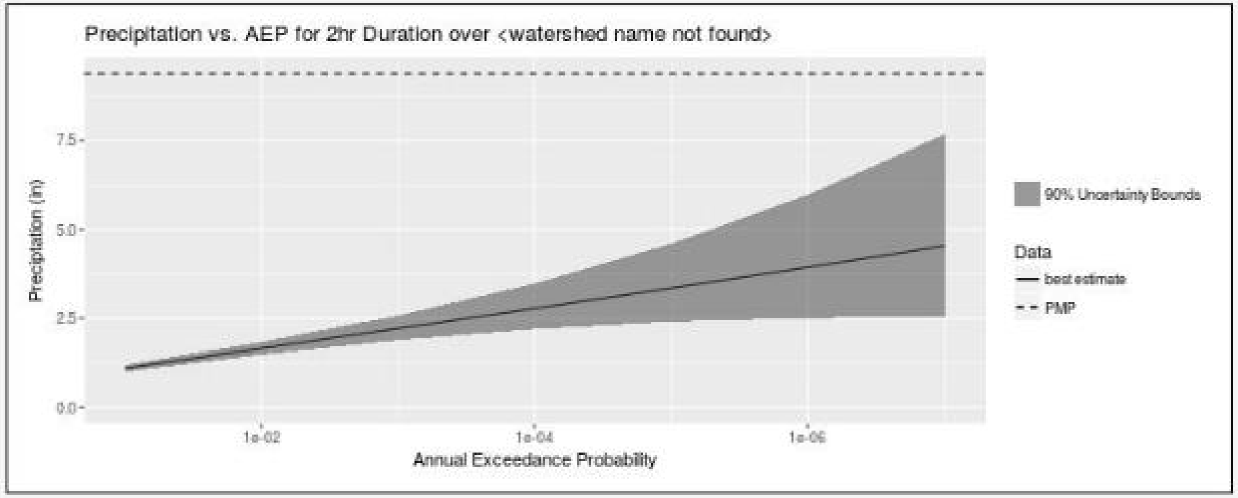
Representative AEP of PMP Plots, 2-hr Local



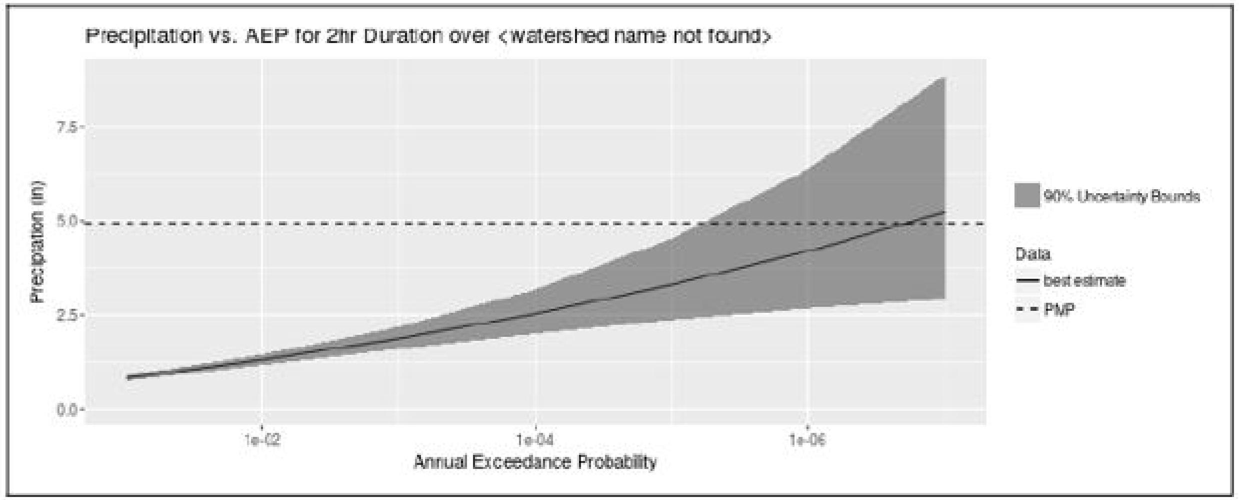
Mount Pisgah (E), PMP/AEP ratio = 1.30



Miramonte (W), PMP/AEP ratio = 1.05



Alberta Park (RG), PMP/EAP ratio = 2.07



Spring Creek (W), PMP/AEP ratio = 0.94

Summary of Results in Colorado

Summary of AEP of PMP Analyses Across Colorado							
Dam Name	DAMID	Basin Size (sq mi)	Tranposition Zone	Macro Region	Ratio 2-hr PMP/AEP (10e-7)	Ratio 6-hr PMP/AEP (10e-7)	Ratio 48-hr PMP/AEP (10e-7)
Park Creek	030308	3	3	E	1.47	1.76	1.29
Barr Lake	020101	15	1	E	1.03	1.04	1.17
Douglas	030126	44	3	E	1.51	1.52	1.25
Mount Pisgah	120129	73	5	E	1.30	0.95	0.98
Prewitt	640108	105	1	E	1.24	1.20	1.21
DeWeese	130103	371	6	E	1.44	1.21	1.12
Two Buttes	670236	470	1	E	1.48	1.32	1.21
Alberta Park	200101	2	6	RG	2.07	1.98	0.79
Garnet Mesa	410107	8	14	W	1.02	0.88	1.41
Stillwater #1	580135	9	9	W	1.20	1.16	
Hogchute	420127	11	9	W	1.39	1.33	0.89
Upper Highline	720234	13	14	W	1.16	0.97	1.34
Spring Creek	590108	20	9	W	0.94	0.90	1.05
Miramonte	600113	36	14	W	1.05	1.02	1.19
Averages		84	6 out of 10	rg-1, e-7, w-6	1.31	1.23	1.15

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Why Might There Be Differences?

- **Conceptual Difference:** Operational PMP is an attempt to calculate an upper limit, regardless of likelihood. PF tells us how likely extreme precip may be.
- **Correlations:**
  - Skewness - Nathan et al (2016) calculated lower notional AEP for shorter duration PMP (by SST) due to low skewness in arrival distribution
  - Storm Typing - also reported that separating annual maxima by storm type resolved inconsistencies in the upper tails of arrival distributions for SST
  - Area size - Laurenson and Kuczera (1999) estimate notional AEP of PMP is more remote for smaller area sizes
  - Access to moisture supply: Schaefer found more likely PMP closer to moisture supply
- **Errors & uncertainty:**
  - PMP: Availability of historical storms for PMP, transposition limits, adjustment factors, REPS PMP is liquid-phase precipitation only
  - PF: Epistemic & Aleatory uncertainty (look at confidence bounds), spatial interpolation, REPS PF is all-phase precipitation

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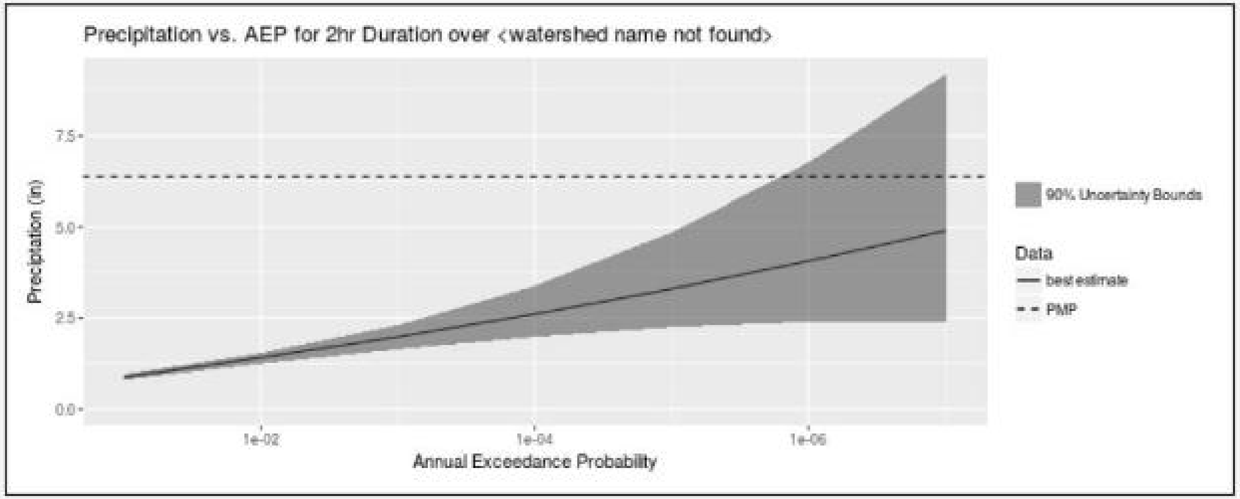
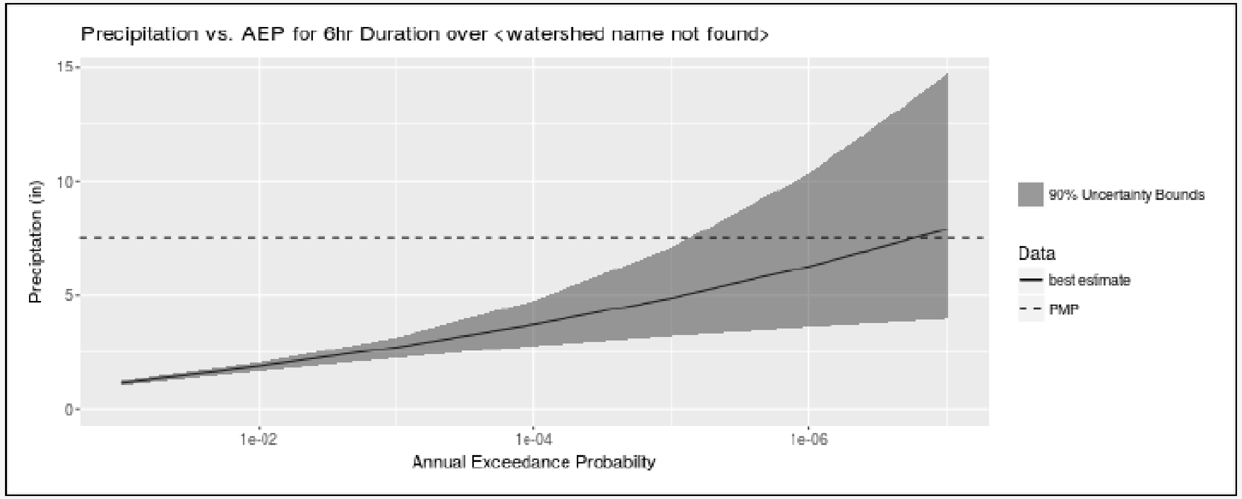
State Regulation in the Absence of Certainty



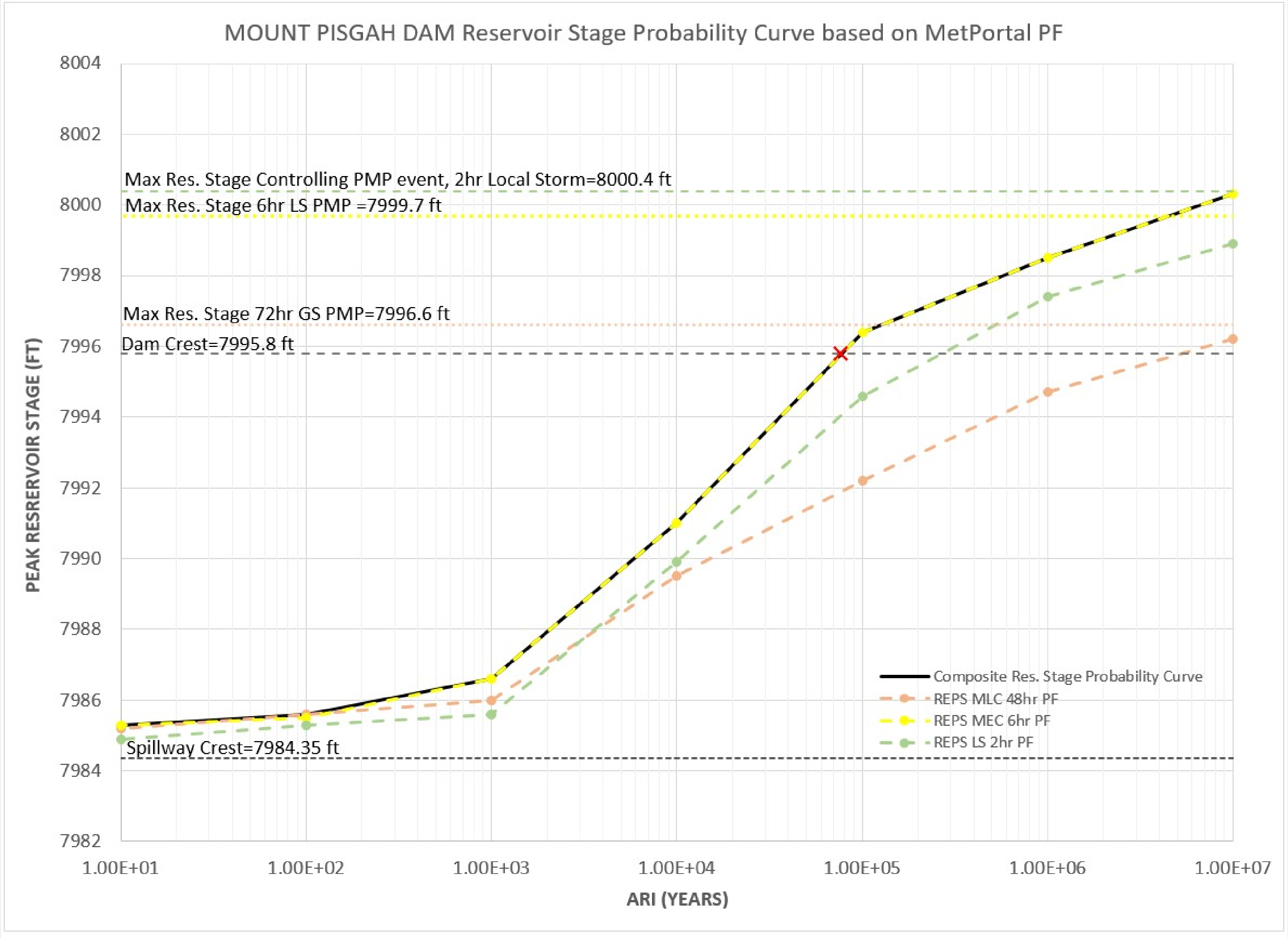
Mount Pisgah (E), PMP/AEP ratio = 1.30



Mount Pisgah (E), PMP/AEP ratio = 0.95

- Risk-Based Approach
  - REPS Rainfall
  - Mountain Hydrology Runoff
  - Hydrologic Hazard Analysis (LL)
  - Peak Flow Verification
    - Res. Stage Hydrologic Loading Curves
    - Bulletin 17C analyses
    - Historic Flood Research
    - Peak flow envelope curves
  - Risk Assessment
    - Residual (non-breach) risk
    - ALARP principles
  - Consequence reduction Recommendations

Existing Spillway Evaluation



- Res. Stage Hydrologic Loading Curves
- 6-hr MEC rainfall controls
- Critical Loading ARI = 76,500 yrs.

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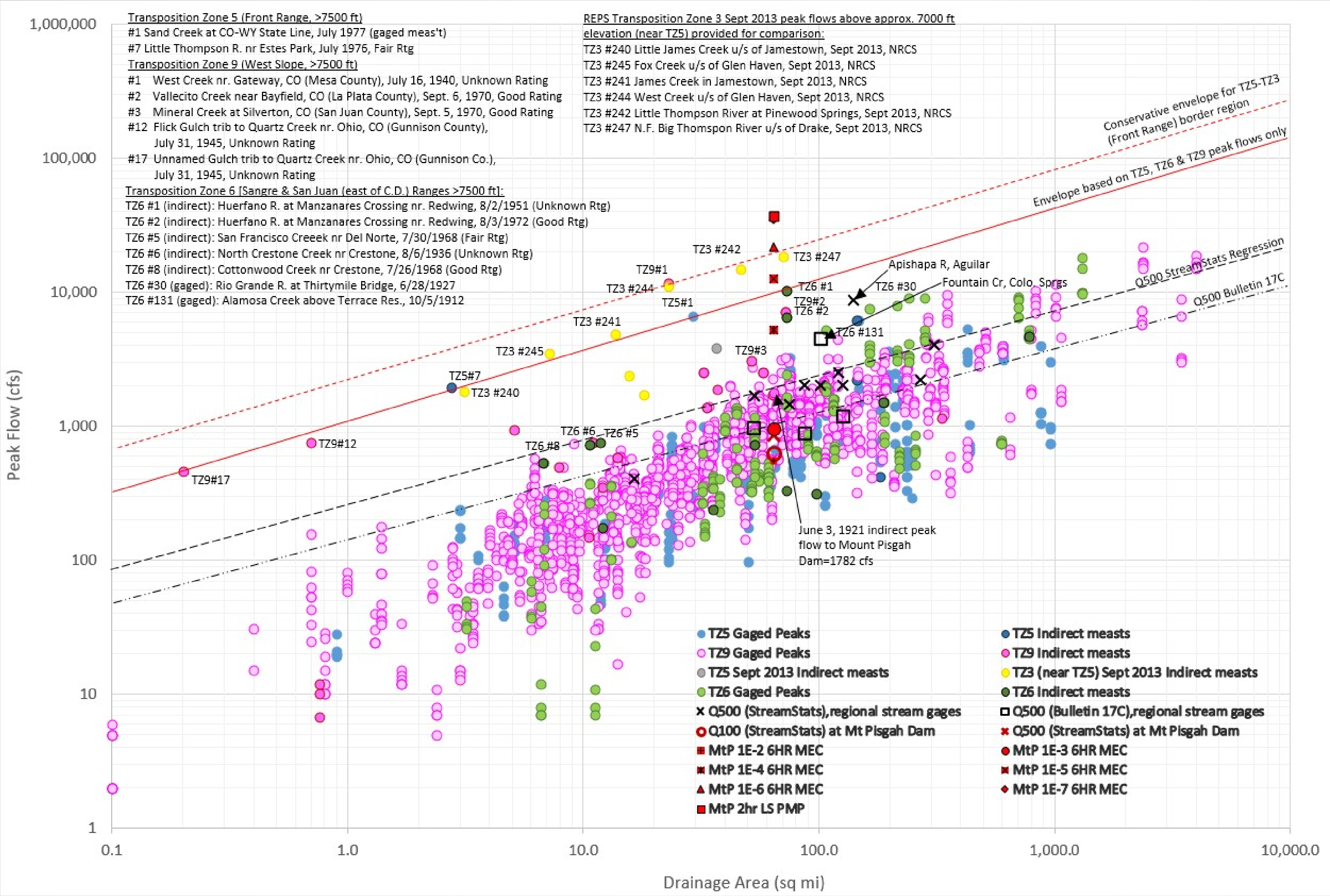
Verification - Regional Envelope Plots



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Existing Dam - Risk Assessment

PFM Failure Likelihood Rating	PFM Failure Likelihood Description
VERY HIGH	The annual failure likelihood is more frequent (greater) than 1/1,000 (10^{-3}). There is direct evidence or substantial indirect evidence to suggest it has initiated or is likely to occur in the near future.
HIGH	The annual failure likelihood is between 1/10,000 (10^{-4}) and 1/1,000 (10^{-3}). The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward "more likely" than "less likely".
MODERATE	The annual failure likelihood is between 1/100,000 (10^{-5}) and 1/10,000 (10^{-4}). The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward "less likely" than "more likely".
LOW	The annual failure likelihood is between 1/1,000,000 (10^{-6}) and 1/100,000 (10^{-5}). The possibility cannot be ruled out, but there is no compelling evidence to suggest it has occurred or that a condition or flaw exists that could lead to initiation.
REMOTE	The annual failure likelihood is more remote than 1/1,000,000 (10^{-6}). Several events must occur concurrently or in series to cause failure, and most, if not all, have negligible likelihood.

Consequence Categories	
LEVEL 1	Downstream discharge results in limited property and/or environmental damage. Average life loss is less than 1. Although life-threatening releases occur, direct loss of life is unlikely due to severity of location of the flooding, effective detection and evacuation.
LEVEL 2	Downstream discharge results in moderate property and/or environmental damage. Average life loss is in the range of 1 to 10. Some direct loss of life is likely, related primarily to difficulties in warning and evacuating recreationists/travelers and small population centers.
LEVEL 3	Downstream discharge results in significant property and/or environmental damage. Average life loss is in the range of 10 to 100. Large direct loss of life is likely, related primarily to difficulties in warning and evacuating recreationists/travelers and small population centers, or difficulties evacuating large population centers with significant warning time.
LEVEL 4	Downstream discharge results in extensive property and/or environmental damage. Average life loss is in the range of 100 to 1,000. Extensive direct loss of life can be expected due to limited warning for large population centers and/or limited evacuation routes.
LEVEL 5	Downstream discharge results in extremely high property and/or environmental damage. Average life loss is greater than 1,000. Extremely high direct loss of life can be expected due to limited warning for very large population centers and/or limited evacuation routes.

Confidence Level	Description
STRONG	The team *is confident* in the risk characterization, and it is *unlikely that additional information would change the order of magnitude* of the assigned category to the point where the decision to take (or not take) action to reduce risk or reduce uncertainty would change.
MEDIUM	The team *is relatively confident* in the risk characterization, *but key additional information might possibly change the order of magnitude* of the assigned category to the point where the decision to take (or not take) action to reduce risk or reduce uncertainty may change.
POOR	The team *is not confident* in the risk characterization, and it is *entirely possible that additional information would change the order of magnitude* of the assigned category to the point where the decision to take (or not take) action to reduce risk or reduce uncertainty could change.

- Likelihood
- Consequences
- Confidence

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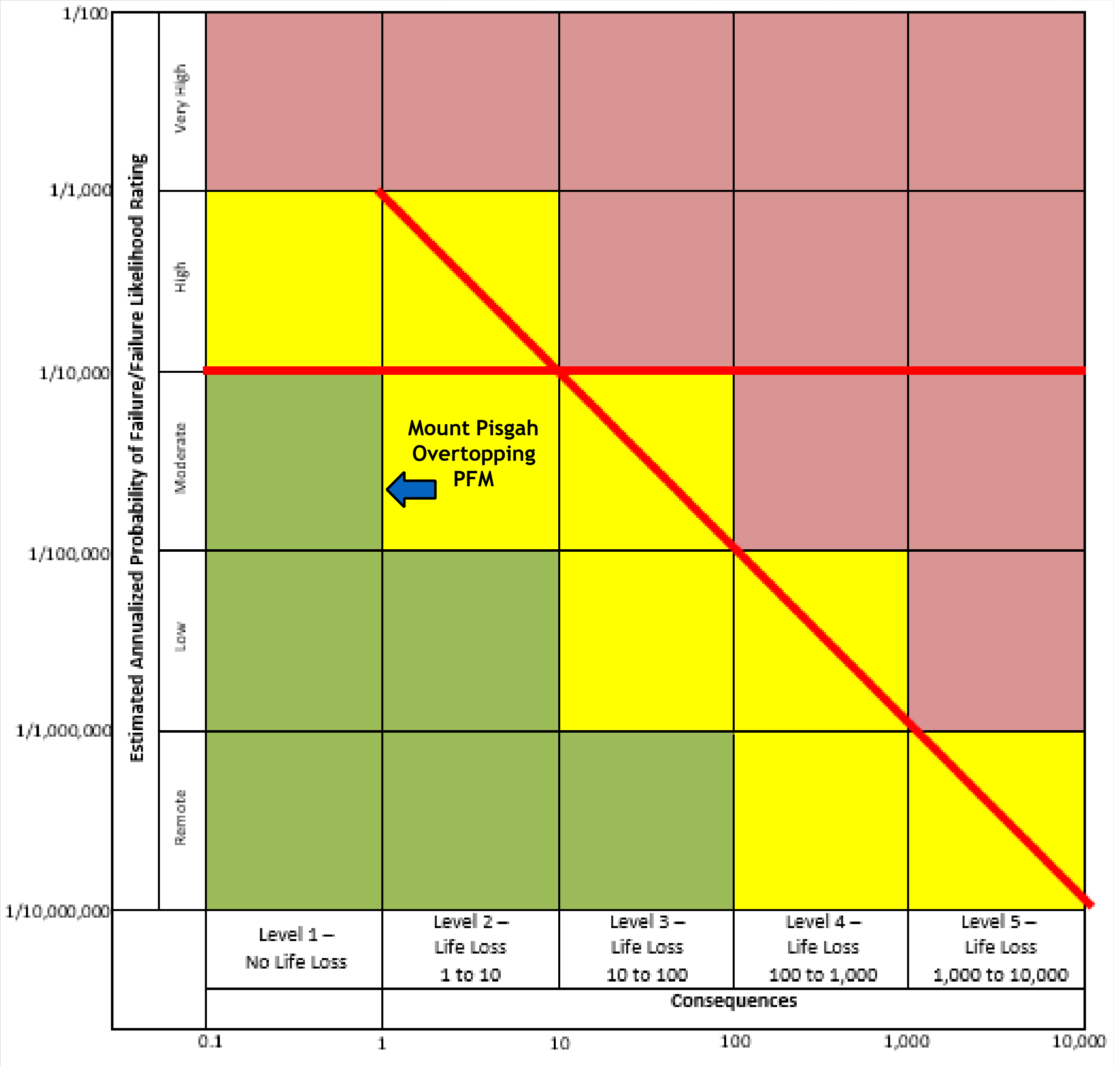
Risk Based Conclusions and Recommendations



Spillway Capacity Q (cfs)	Loss of life estimate by RCEM method			Hydrologic Hazard Category
	Overtopping dam breach + spillway base flood	Spillway base flood	Incremental life loss	
7000	1.7	~0	1.7	Extreme
15,000	2.2	~0	2.2	Extreme
25,000	2.7	0.1	2.6	Extreme
50,000	3.0	0.8	2.2	Extreme

Shows additional expense to enlarge spillway not justified due to limited risk reduction and increased residual risk.

(red)	Unacceptable level of risk. Actions required to reduce risk.
(yellow)	Increased justification to reduce or better understand risks. ENSURE ALARP principles are addressed.
(green)	Risk monitoring zone, decreased justification to reduce or better understand risks. REVIEW ALARP.

Recommendations to reduce consequences

- Early Warning System (blue arrow shows reduced consequence level)

Recommendation to reduce failure likelihood:

- Reinforce existing spillway and embankment against spillway flow erosion

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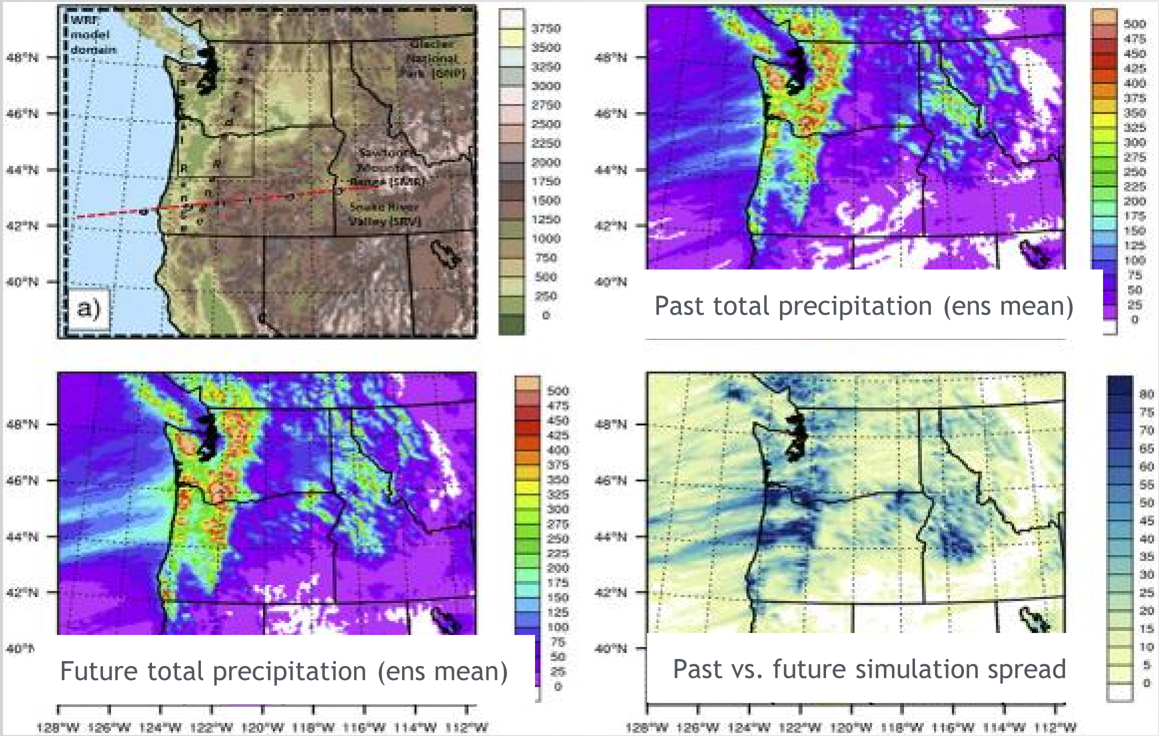
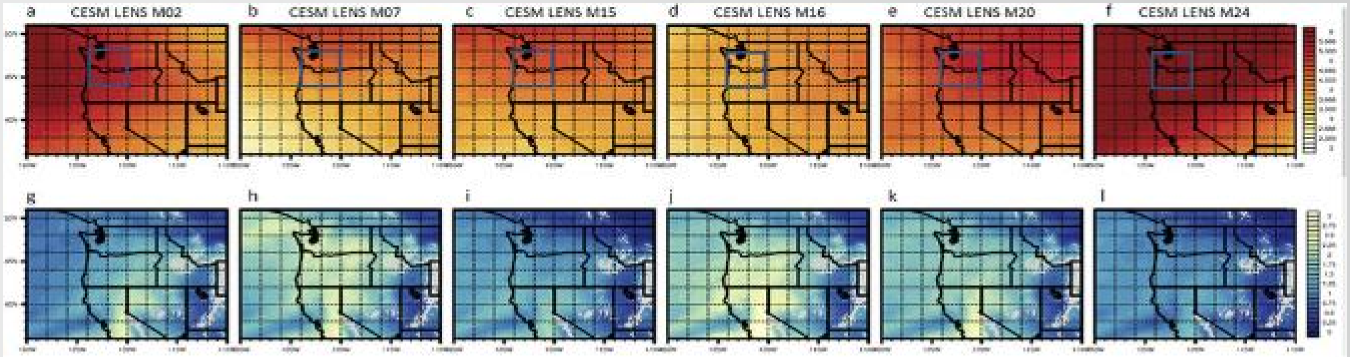
Next Steps to Improve Extreme Rainfall Estimates

Dynamical weather models can help shift from historical-looking approaches:

- Existing methods are backward-looking, only incorporating events *after* they happen.
- For both PF and PMP, model data bolsters coverage in space and time for both past *and* future extreme precipitation estimation
- Climate change projections suggest an increasing upper bound on extreme precipitation
- Dynamical weather models can be used to assess the impact of potential future climate scenarios on extreme rainfall





Various climate scenarios tested (change in temperature top, change in moisture bottom)

- ➢ Example of re-simulating extreme precipitation events in future climate scenarios
- ➢ Can also use future climate projections to adjust future probability frequencies, etc.

Questions?

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