PROTECTING OUR WATER SUPPLIES AND COMMUNITIES

Southwestern Water Conservation District
Annual Seminar

Durango, CO
April 26, 2018

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Division of Water Resources
Department of Natural Resources

Dam Safety Branch

Presentation Overview

- Colorado Dam Safety Program Overview
- Tools Used by Colorado Dam Safety to Achieve Program Goals?
- What New Tools Are in Use and Under Development?

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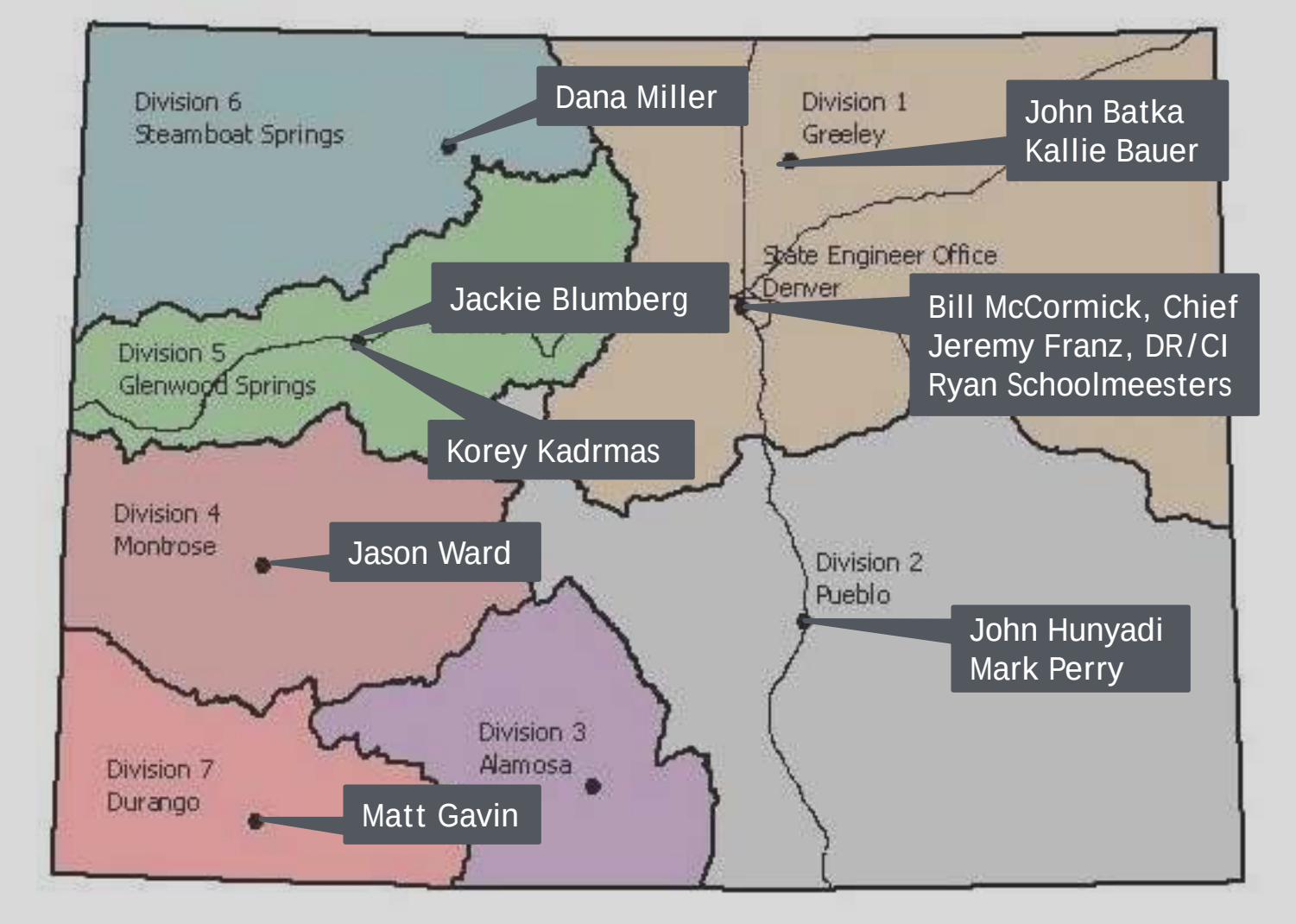
Colorado Dam Safety Mission Statement

"…to prevent loss of life and property damage and protect the state's water supplies from the failure of dams."

Colorado Dam Safety Personnel



Achieving Program Goals

Existing Dams

- Routine dam safety inspections
- Determine Safe Storage Level

New and Enlarged/Modified Dams

- Review Plans and Specifications
- Construction Inspections

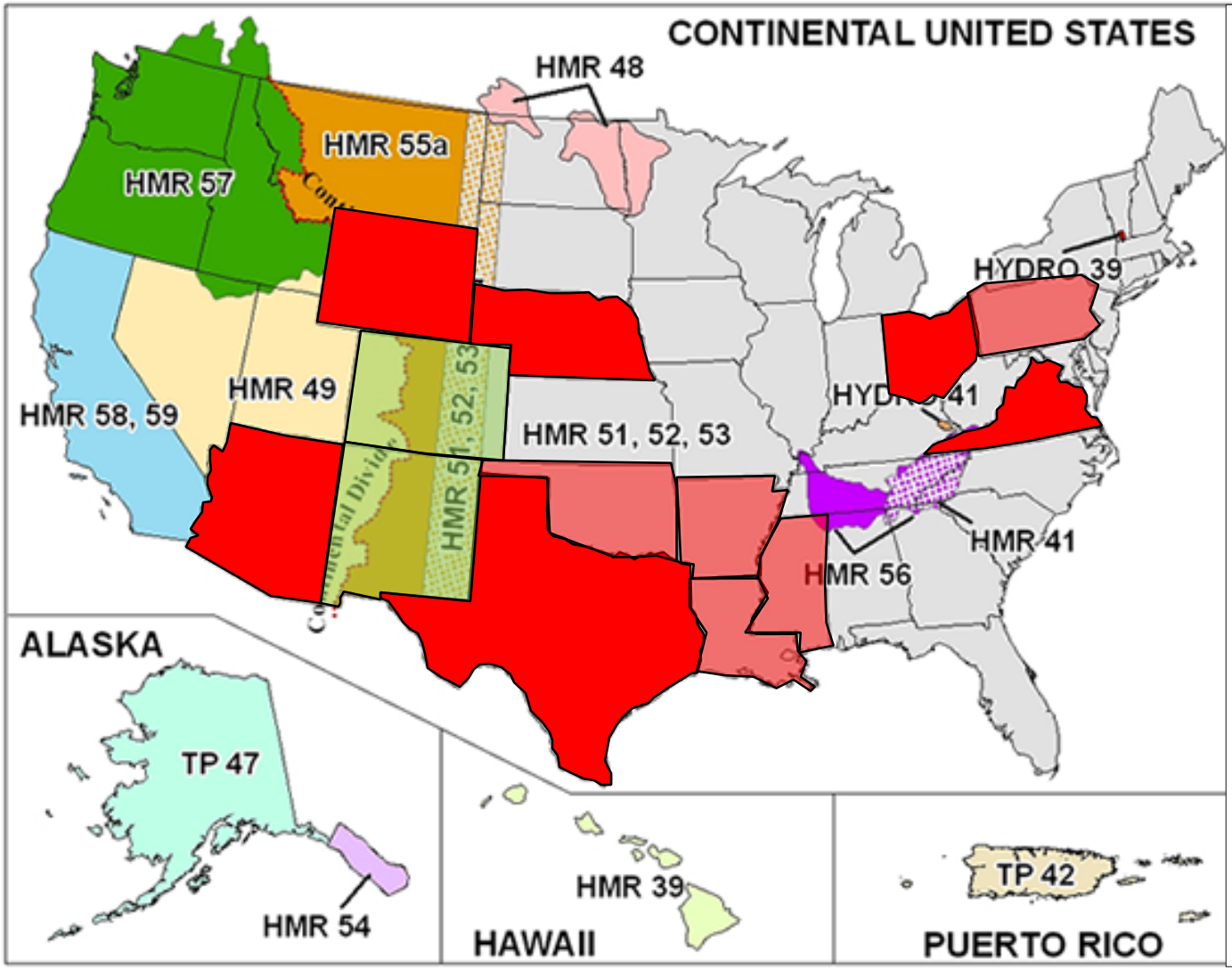
Emergency Preparedness Planning

- Emergency Action Plans
- Dam Breach Inundation Mapping

New and Updated Tools

- **Colorado & New Mexico Regional Extreme Precipitation Study**
  - Probable Maximum Precipitation Estimates
  - Frequency Based Estimates - NOAA Atlas 14 & Beyond
- **CDSE Comprehensive Dam Safety Evaluations**
  - A risk-based approach to dam safety
- **Emergency Preparedness**
  - Emergency Action Plans
  - Dam Breach Inundation Mapping

PMP Efforts by States/Consultants



Statewide PMP Studies

- CO – Jan 2007, 2018
- NE – Dec 2008
- NM – March 2009, 2018
- OH – Feb 2013
- AZ – July 2013
- WY – Dec 2014
- VA – June 2015
- TX – Jan 2017
- PA – In Progress
- OK, AR, MS, LA

Regional coverage of generalized PMP reports in the United States from NOAA/NWS Website: http://www.weather.gov/oh/hdsc/studies/pmp.html).

Historical Basis for Determining Probable Maximum Precipitation

- 1977 - HMR 49 published by NOAA
- 1982 – HMR 51/52 published by NOAA
- 1984 – HMR 55 published by NOAA
- 1986 – Jarrett and Costa, USGS Paleoflood Study

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CO-NM REPS Objective

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)

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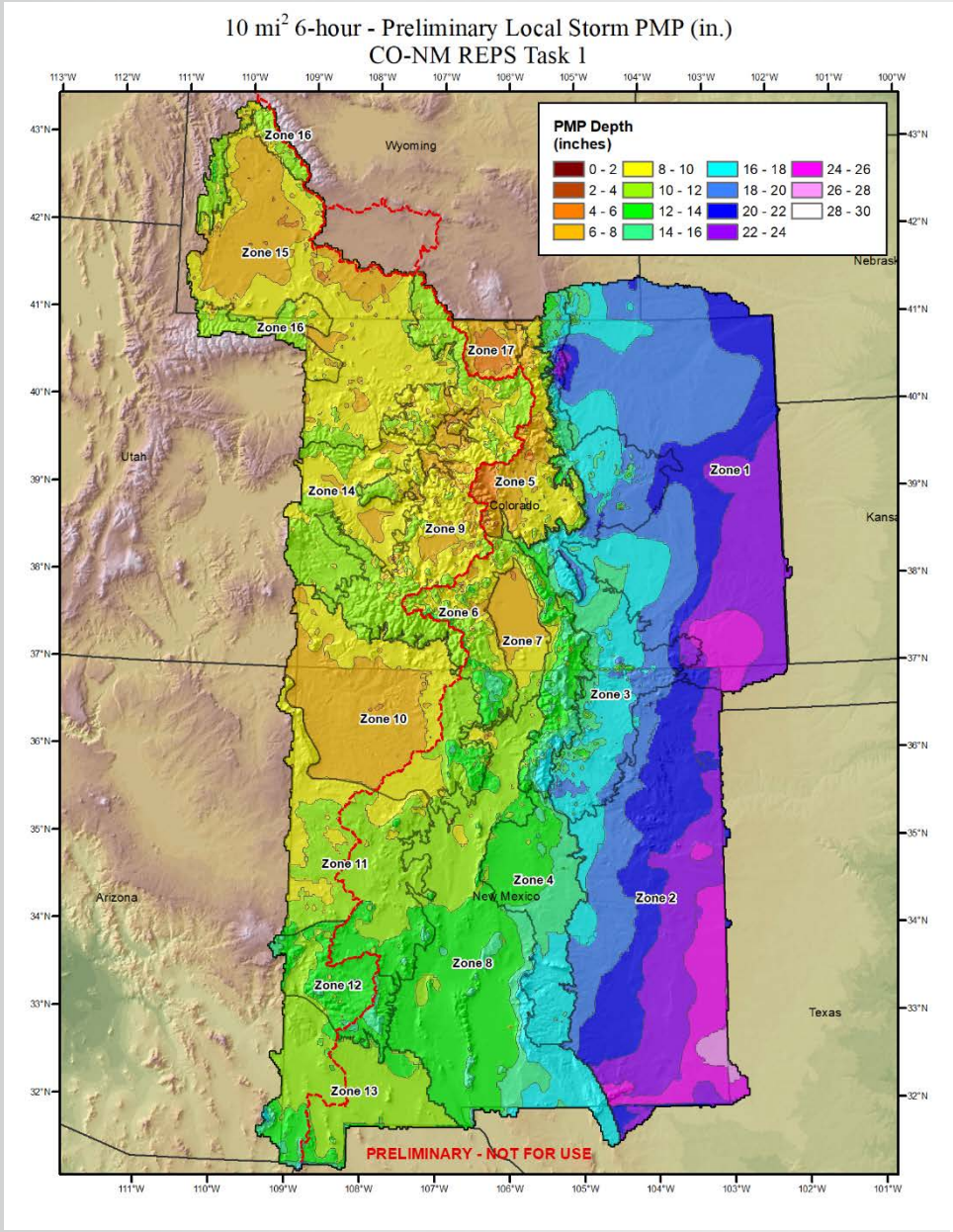
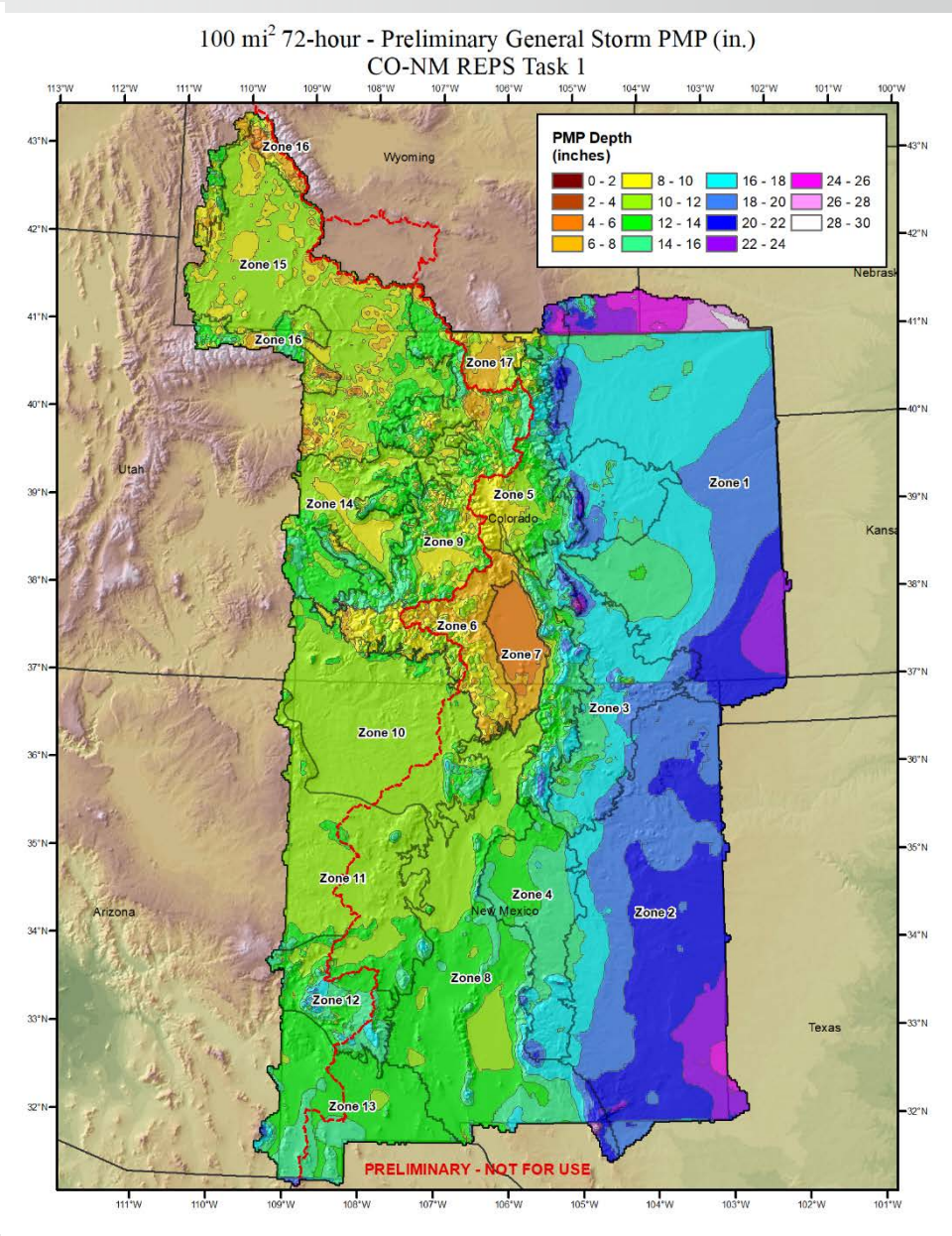
Key Features of CO-NM REPS

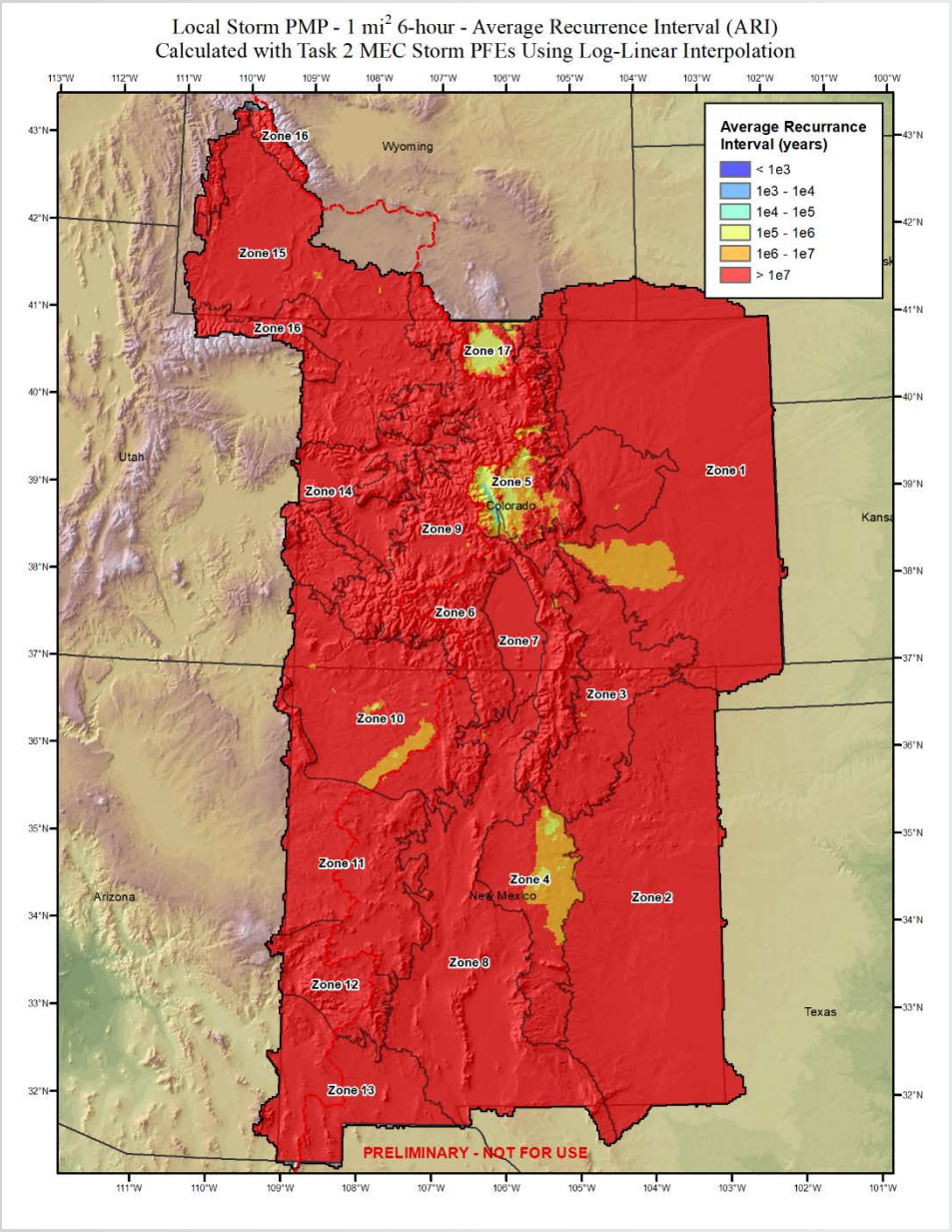
- Provide Updated PMP Storms Based on Current Procedures & Practices
- Regional Precipitation Frequency Analysis Beyond NOAA Atlas 14
- Data-mine HRRR Model output and other numerical modeling as possible (NOAA/ESRL/PSD)
- Project schedule, 24 months (June 30, 2018)

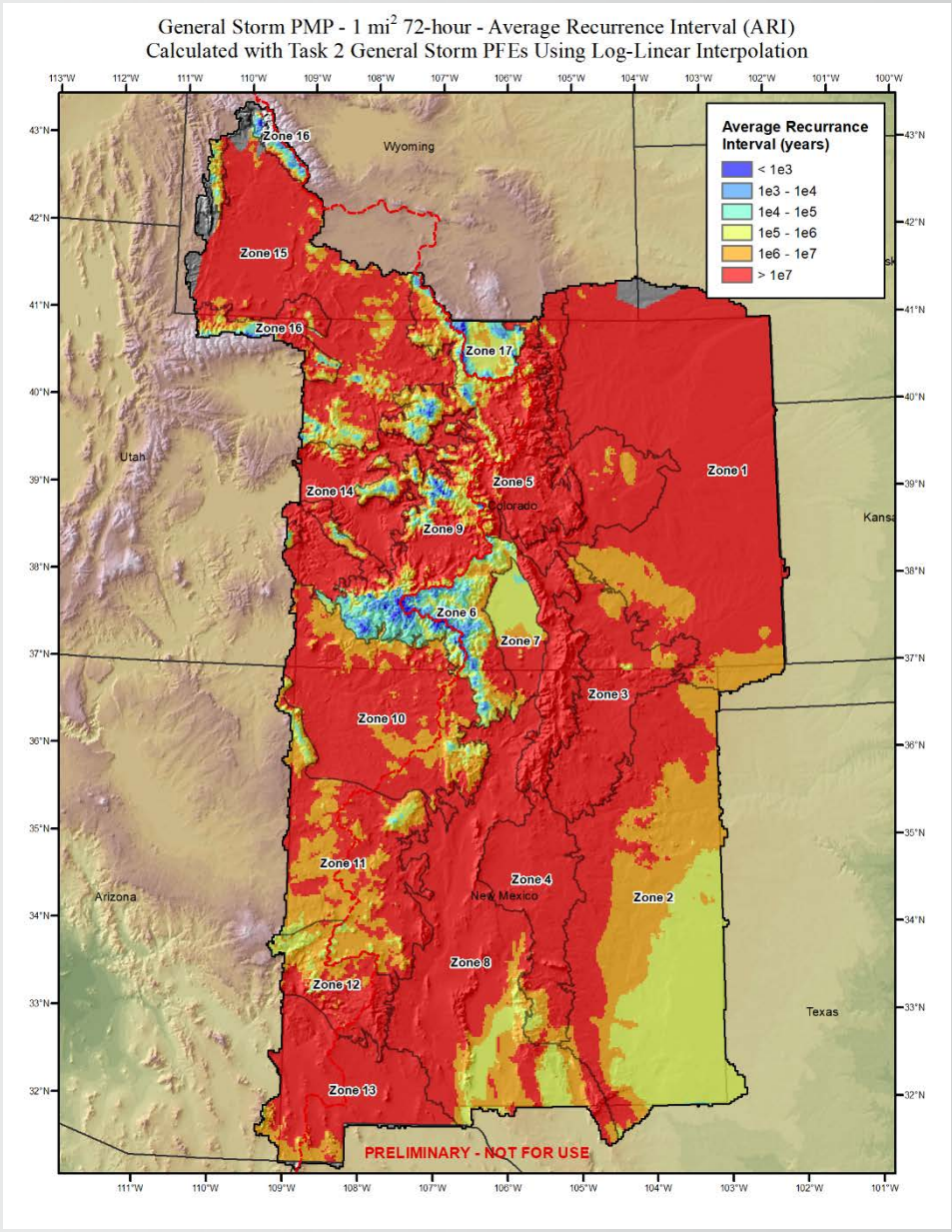
Deterministic PMP - Draft Results





Deterministic PMP - Draft Results





Comprehensive Dam Safety Evaluations – A Risk-Based Approach

- The Dam Safety Industry has moved toward a risk-based approach to identify and remediate dam safety issues
- Colorado Dam Safety developed the CDSE Process
  - ✓ Identify Potential Failure Modes
  - ✓ Screen PFMs as Credible or Non-Credible
  - ✓ Evaluate Credible PFMs

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Core of CDSE Process

Step 1 – Data Gathering

- List all available data to be gathered and reviewed
- **Diligently** review background material sufficiently to become familiar with the project
- Develop Summary Lists for documentation and reference

Step 2 – Identify Potential Failure Modes

- Identify PFMs from library of Failure Modes
- Identify PFMs specific to the dam
- Consider All Loading Conditions
  - Normal (also includes ice and mis-operation)
  - Flood
  - Earthquake
- Do not consider likelihood, just physical possibility
- Perform site examination with eye toward potential vulnerabilities

Step 3 – PFM Screening

- Identify whether PFM is credible or non-credible with following considerations:
  - Physical possibility
  - Are you combining multiple rare events?
  - Can it be seen that it would be too remote to be credible without further review
- **Document which PFMs were screened out from further evaluation and reasoning on** Carry all credible PFMs to PFM Evaluation

Step 4 – Evaluate Credible PFMs

- Develop detailed, step-by-step description of Potential Failure Mode aka “Event Tree”
- Develop positive and adverse factors for each node on event tree
- Estimate likelihood category and confidence level

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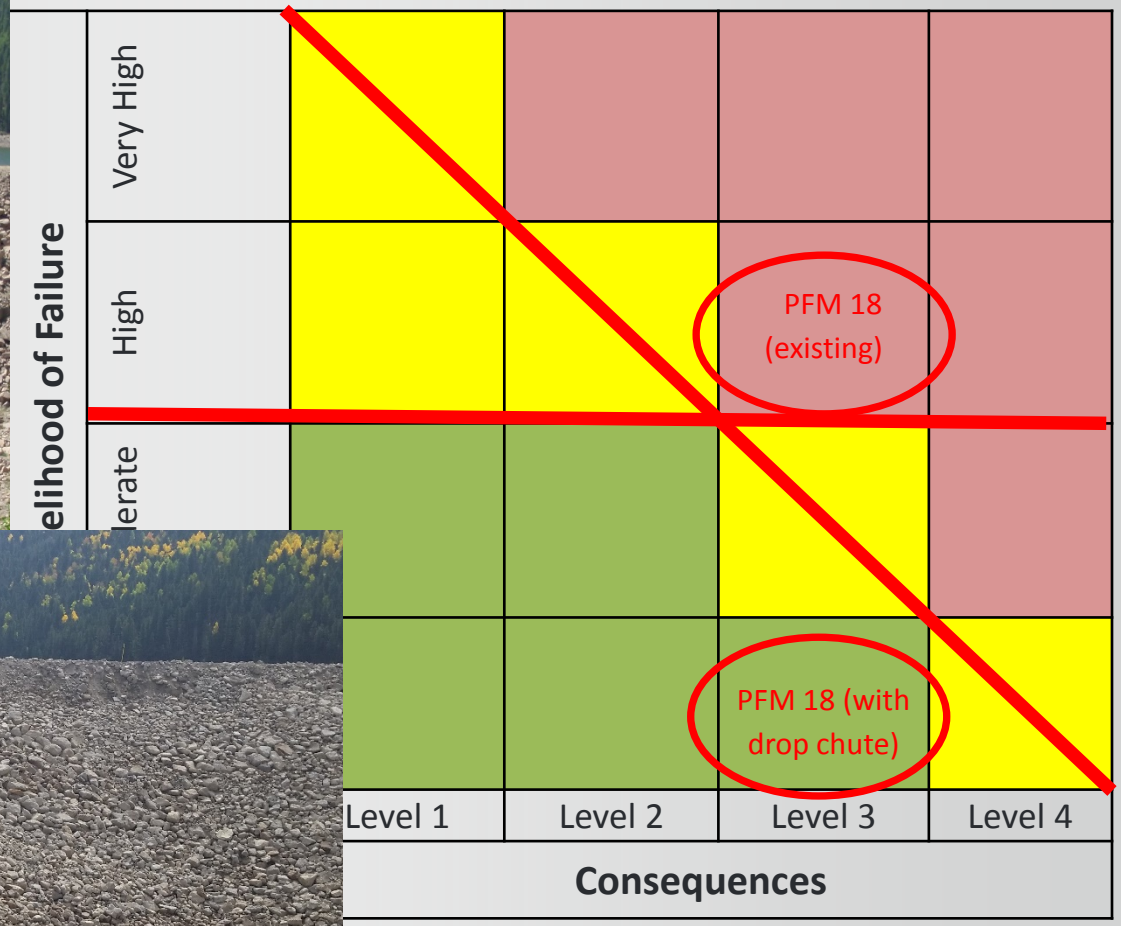
Event Tree Example

PFM #18	SPILLWAY CHANNEL FAILURE (LINED)
Initiation:	• A flood up to and including the Inflow Design Flood occurs. o 9888.9 pool of record in 1995, june 18. - ~3 ft over spillway. ~729cfs Reservoir level rises to the service spillway crest elevation. El. 9886.64. • Failure of the structural portion of the spillway initiates. • Excessive hydrostatic uplift pressures develop beneath the slab at lower end of service spillway chute causing hydraulic jacking of the slab. (STA 1+72 to 1+80).
Continuation:	• Head-cutting of the spillway foundation soil progresses upstream.
Progression:	• The duration of the flow is long enough to permit the head-cutting erosion to progress upstream through the spillway crest width eventually reaching the reservoir.
Intervention:	• The spillway erosion is not observed; or if detected, methods to stop the erosion are not deployed in time and as a result, intervention is unsuccessful.
Breach:	• Down-cutting of the spillway crest leads to breach by widening and deepening of the head-cut through the spillway channel. • A large increase in flood discharge occurs as most of the reservoir storage is released through the enlarged spillway channel. • Downstream consequences result.

Potential Failure Mode Factors

Event Tree Node	Adverse Factors (PFM More Likely to Occur)	Positive Factors (PFM Less Likely to Occur)
Initiation	• 9888.5 (2015 flow event), Stantec post-event structural calculations indicate FS=0.61 for positive flexure and 1.03 for uplift. Cracks have grown in length and actively weeping when reservoir elevation is below spillway crest. • Measured piezometer readings are not available for pool of record.	• History of cracks in spillway slab between 1+72 and 1+80 • 0.6 factor of safety would indicate that the slabs should have failed already. Are piezometer readings reflective of pressures under slab? • Other joints weeping within higher portions of spillway, however no signs of spalling/buckling of cracks. • Models show some discrepancy between calibrating to piezometer readings vs. laboratory values.
Continuation	• Critical section is at steepest portion of spillway where headcutting would occur. • Lab tests indicate slab foundation soil is not very resistant to erosion. Fines would be susceptible to erosion at expected velocities	• Soil anchors provide some slab support in chute. • Boulders in fill might provide some resistance to erosion. • Estimated at 40 to 50% boulders which might add to slope stability.
Progression	• Critical event driven by long progression is weeks of snowmelt from 42 sq mile during spring runoff • Outlet provides little flood routing capacity.	
Intervention	• Difficult to provide enough sizable rockfill quickly enough at downstream side of chute. • Closest pit for adequate rock at I=70 and 6, long distance. • Difficult to stop spillway from operating.	• Awareness of concerns and heightened monitoring. • Instrumentation will be tied into a SCADA system to provide early alarms to initiate EAP.

Risk Informed Decision Making



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Emergency Preparedness

- Emergency Action Plans
- Interfacing with Emergency Managers
- Inundation Mapping

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Emergency Action Plans

- Required by Dam Safety Rules & Regs for High and Significant Hazard Dams
- Identifies Hazards below dams and provides critical information for Emergency Responders
- Provides step-by-step plan for Owners Response in a Dam Safety Emergency

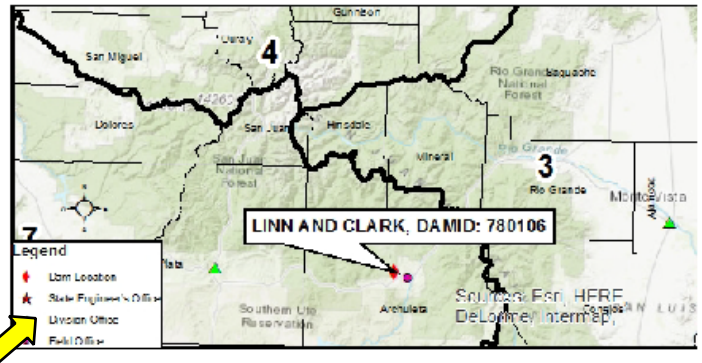
Location & Vcinity Maps

EMERGENCY ACTION PLAN (EAP)

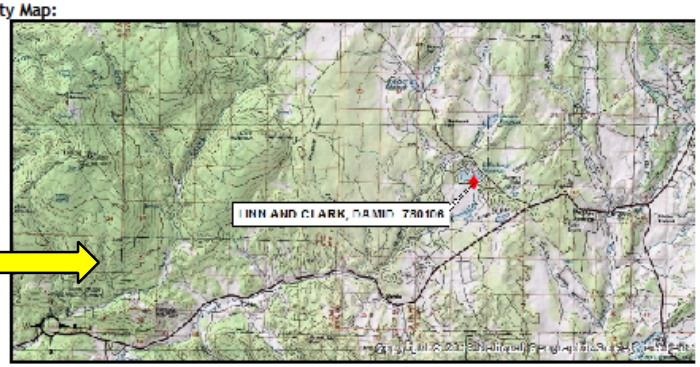
Notifications and Essential Information

LINN AND CLARK DAM
ARCHULETA COUNTY, COLORADO
HAZARD CLASSIFICATION: SIGNIFICANT
State of Colorado DAMID: 780106

Location Map:



Vcinity Map:



EAP Date: April 04, 2018

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Dam Breach Inundation Mapping

- Dam Breach Inundation Maps provide Emergency Managers with information critical to response coordination
- Current state of the practice uses 2D modeling techniques
- State Grant Program – Matching fund available to assist Owners
- Modeling and Mapping done in-house by Colorado Dam Safety

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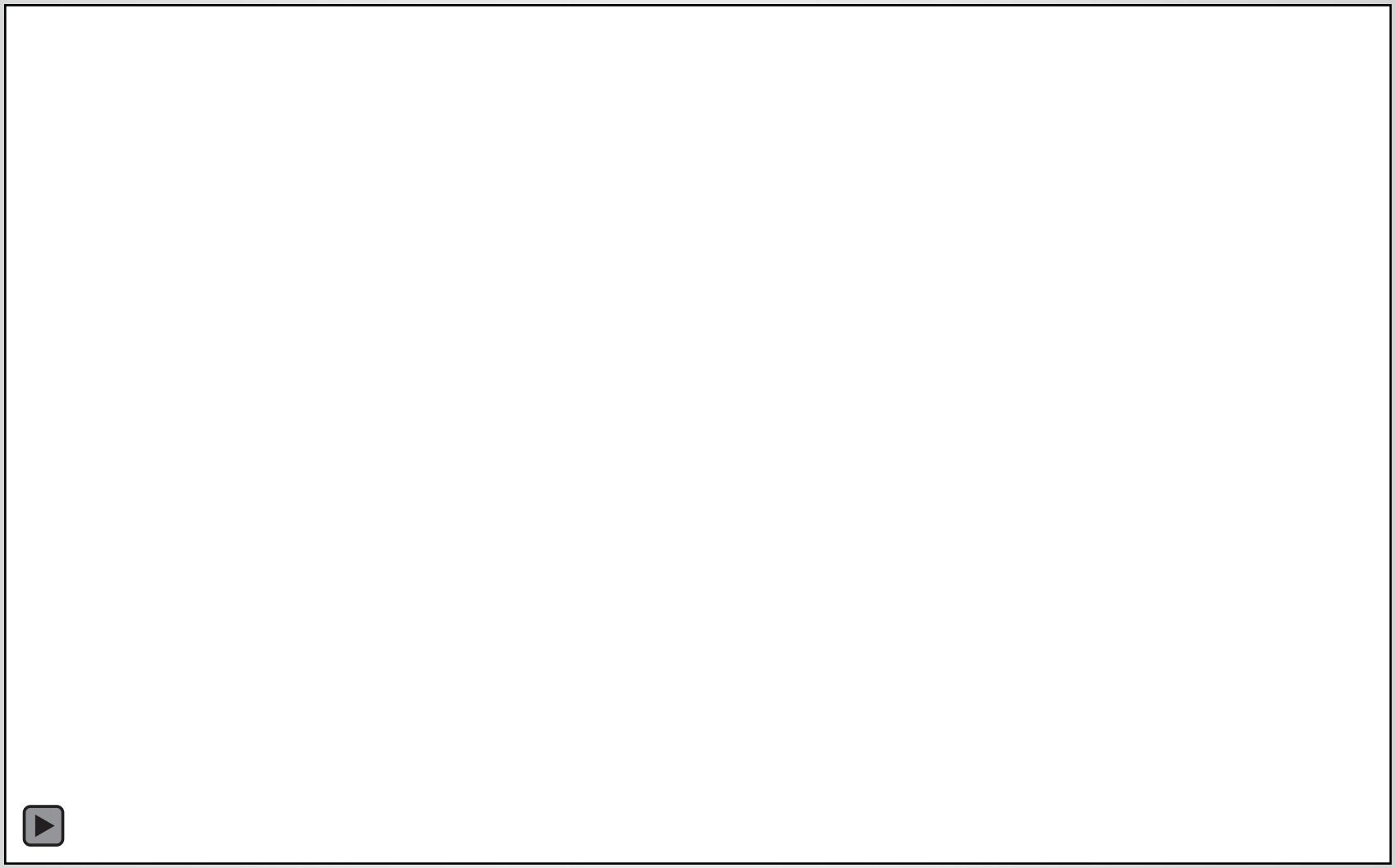
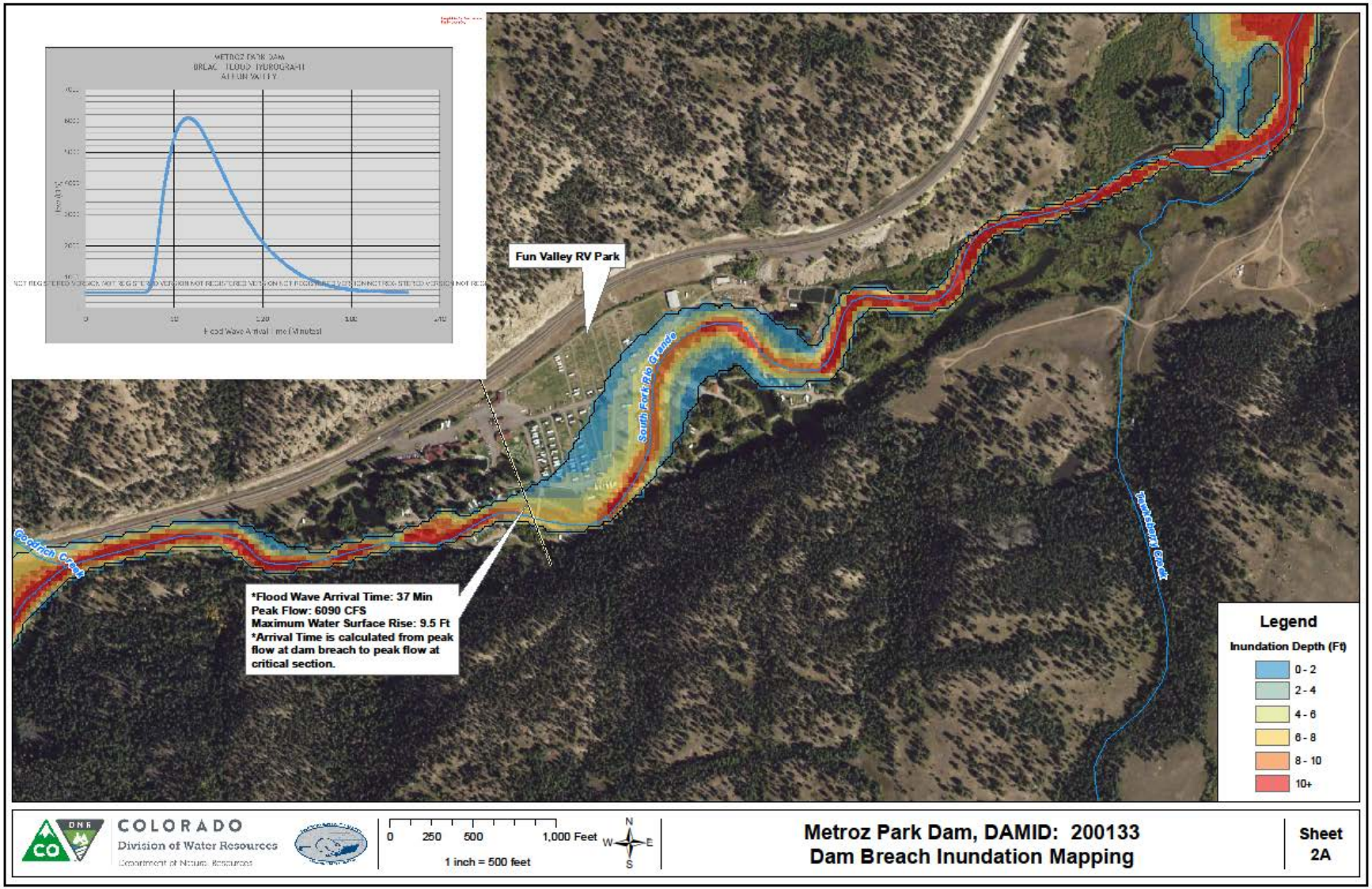
Dam Breach Inundation Modeling



Dam Breach Inundation Mapping



Thank You, Questions

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