



Photo: Jennifer
Varrella, 2018



COLORADO

Department of Transportation

Infrastructure Resiliency Strategies to Accommodate Future Disasters

Brian Varrella, PE, CFM (Resident Engineer)

August 2025



Contributors, Thank You!

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Project Engineer



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Project Engineer



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Engineering Scientist



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Project Manager



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Resident Engineer



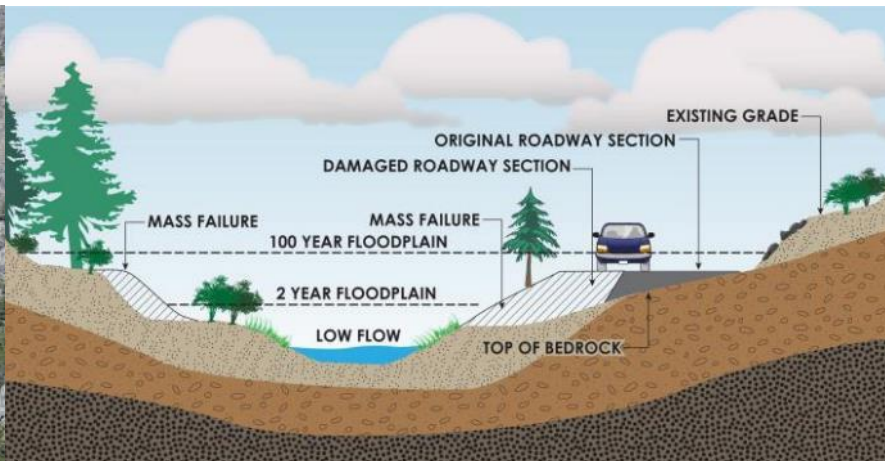
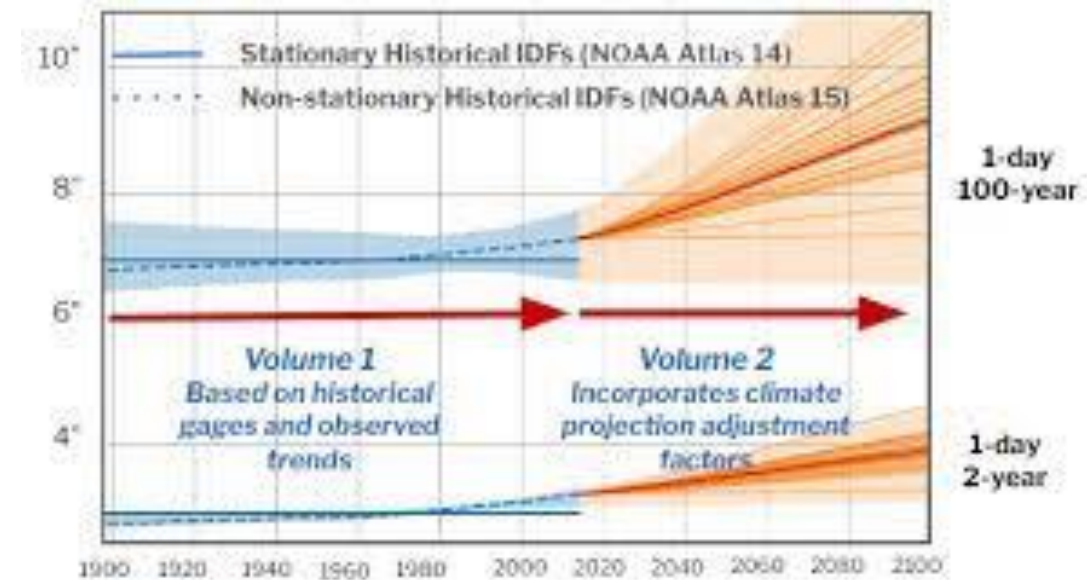
Michael Tanner, PE, CFM
State Hydraulic Engineer





Discussion Agenda

1. Infrastructure Snapshot (NE Colorado)
2. Disaster Trends; Today's Challenge
3. CDOT Resiliency Measures
4. Tomorrow's Solutions
5. Discussion





Order of Precedence; Problems & Solutions

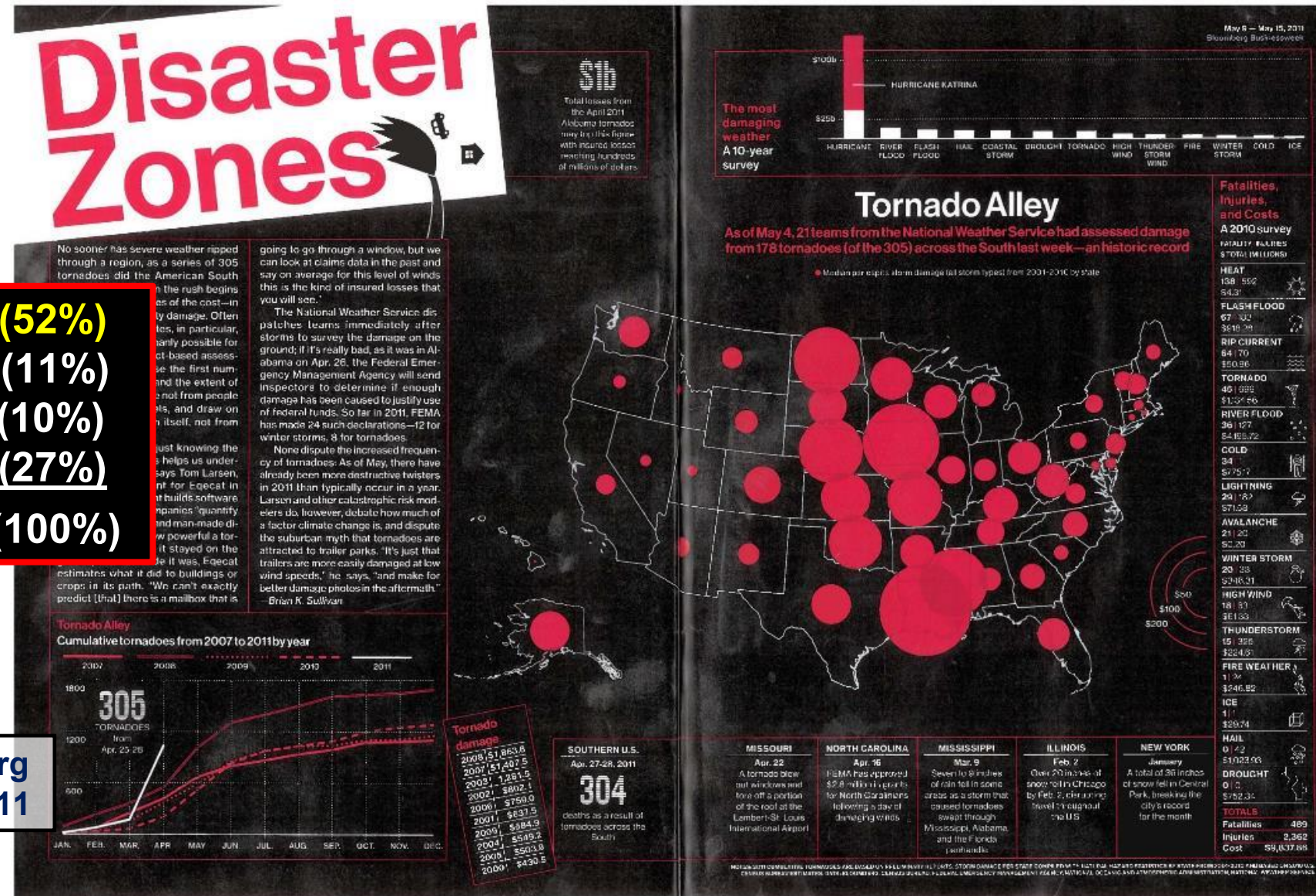
***“What is the problem we
are trying to solve?”***

*-- Dave Bauer, PE, CFM
Weld Co. Public Works Director*

2010 Natural Disaster Costs

Flooding = \$5.1 Billion (52%)
Tornados = \$1.1 Billion (11%)
Hail Storm = \$1.0 Billion (10%)
All Others = \$2.6 Billion (27%)
TOTALS = \$9.8 Billion (100%)

Source: Bloomberg Businessweek, 2011

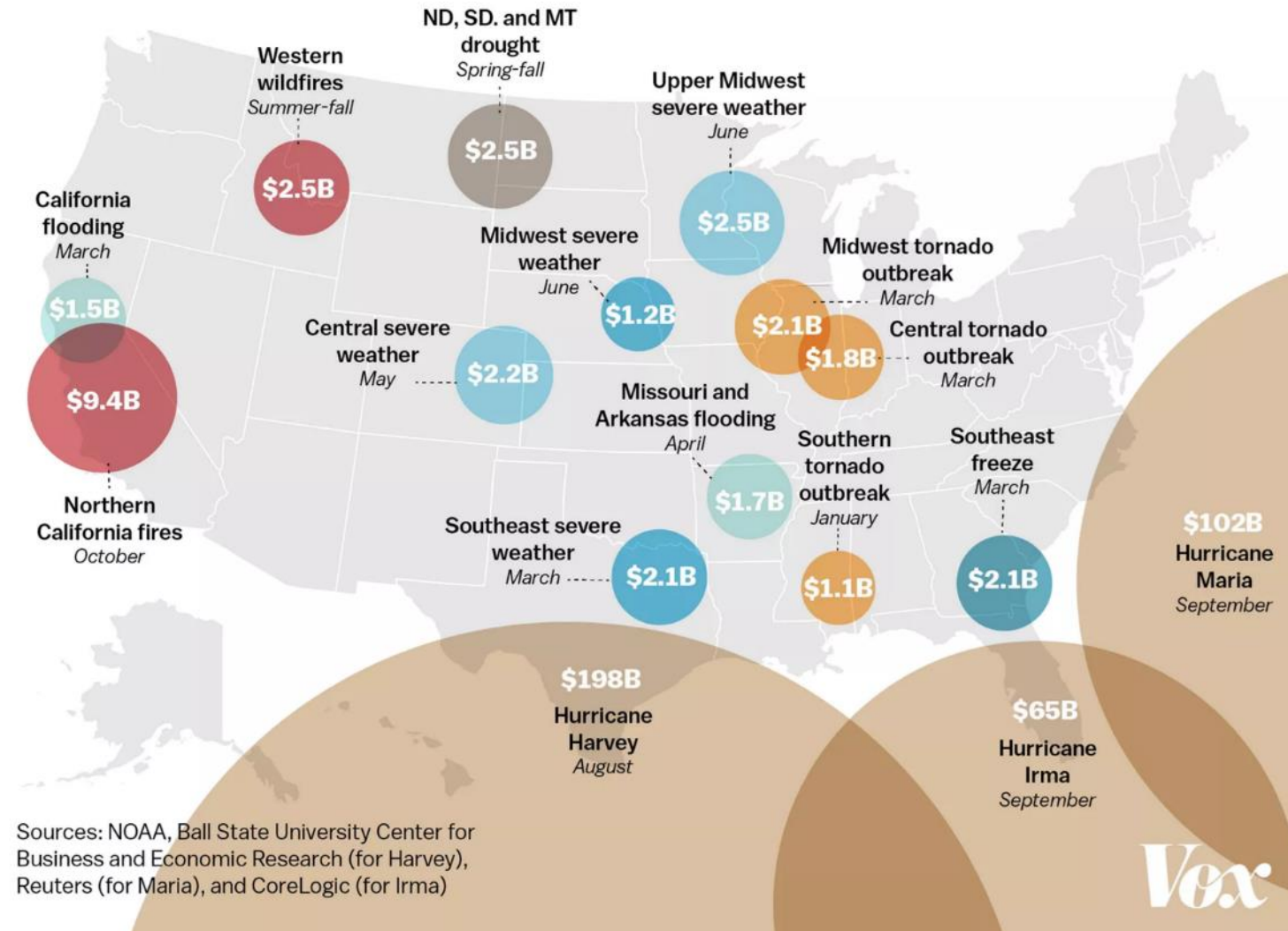




2017 Natural Disaster Costs

Hurricane	=	\$365 Billion	(92%)
Flooding	=	\$3 Billion	(1%)
Tornados	=	\$5 Billion	(1%)
Wildfires	=	\$12 Billion	(3%)
All Others	=	\$13 Billion	(3%)
TOTALS	=	\$398 Billion	(100%)

Billion-dollar disasters of 2017 in the US





Billion-Dollar Disasters, 1980-2020

Billion-Dollar Disasters BY THE NUMBERS (1980-2020)



For more info:
www.ncdc.noaa.gov/billions/



DROUGHT



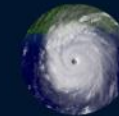
FLOODING



FREEZE



SEVERE STORMS



TROPICAL CYCLONE



WILDFIRE



WINTER STORM

1980

The year NOAA started tracking billion-dollar disasters

119

Number of billion-dollar events from 2010-2019



22

Number of U.S. billion-dollar disasters in 2020—the most on record



7.0

Average number of billion-dollar disasters per year since 1980

285

Number of billion-dollar disasters in the U.S. since 1980

\$1.875
TRILLION

Total cost of the 285 billion-dollar disasters



7

Number of billion-dollar tropical cyclones that struck the U.S. in 2020



15.1

Average number of billion-dollar disasters per year since 2015

50

Number of states that have had at least one billion-dollar disaster

124

Number of billion-dollar disasters that have impacted Texas since 1980—the most of any state

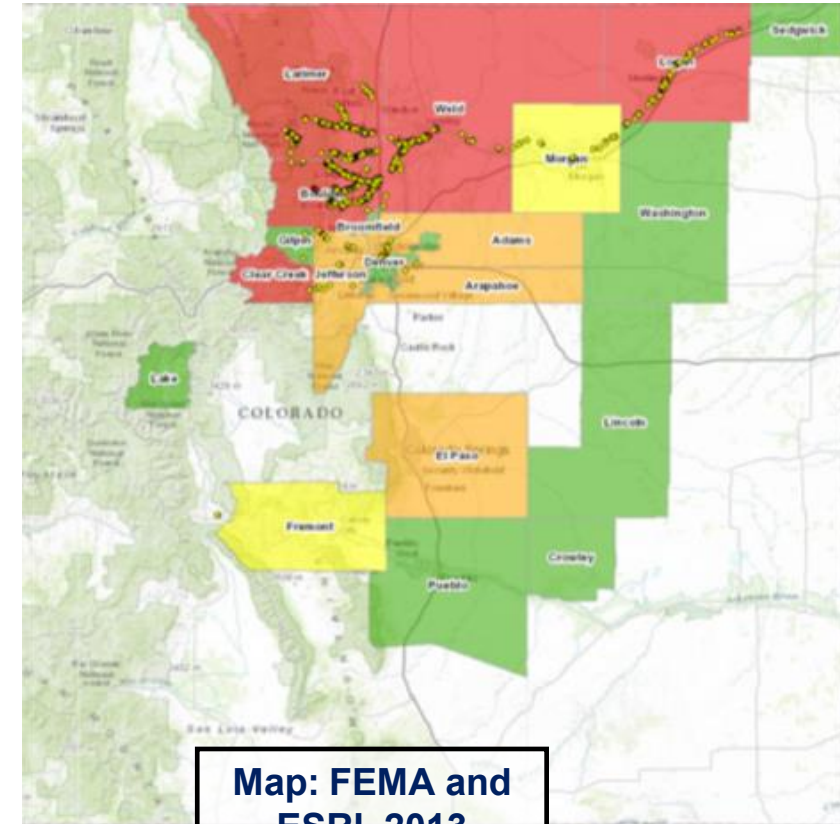


Source: NOAA's National Centers for Environmental Information (NCEI), <https://www.ncei.noaa.gov/> (2023)

Colorado 2013 Regional Flood Disaster

A *Human* Disaster

- 10 lives lost
- 28,000 people displaced
- 2nd largest airlift in U.S. history
- \$3.9 billion in total damages
- 2,000 square mile area over 24 counties
 - 120 CDOT bridges damaged
 - 39 roadways closed



Map: FEMA and ESRI, 2013

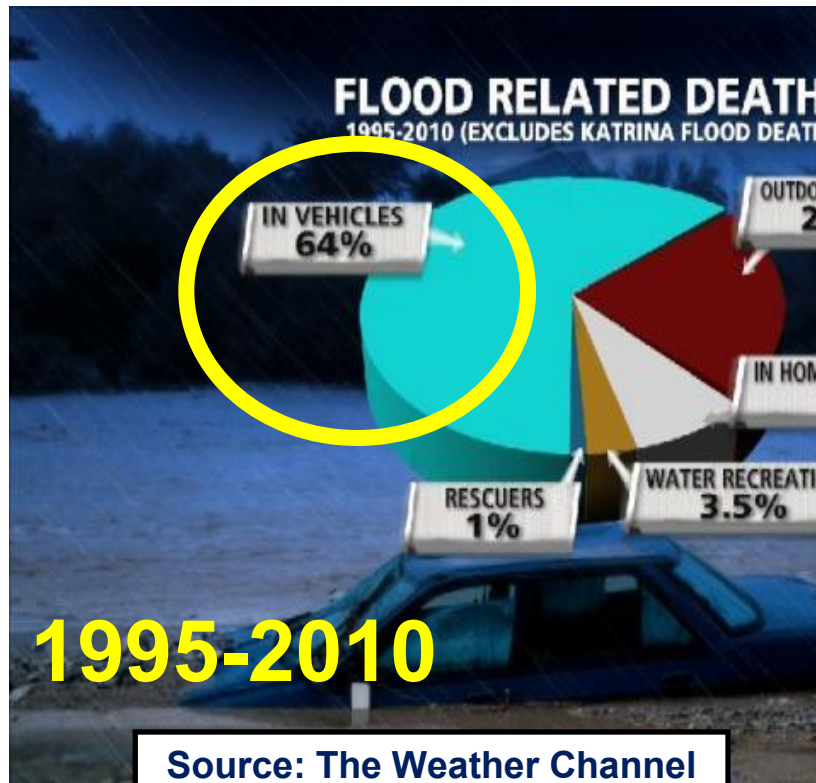
Photo: Brian Varrella, 2013



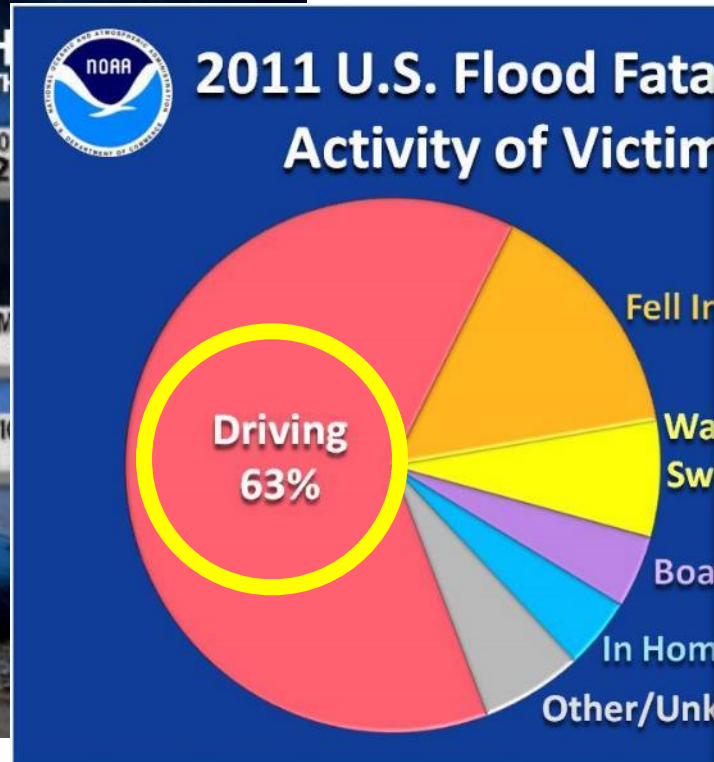
Infrastructure & Nature; the Price of Conflict

Why should transportation be concerned about Flooding?

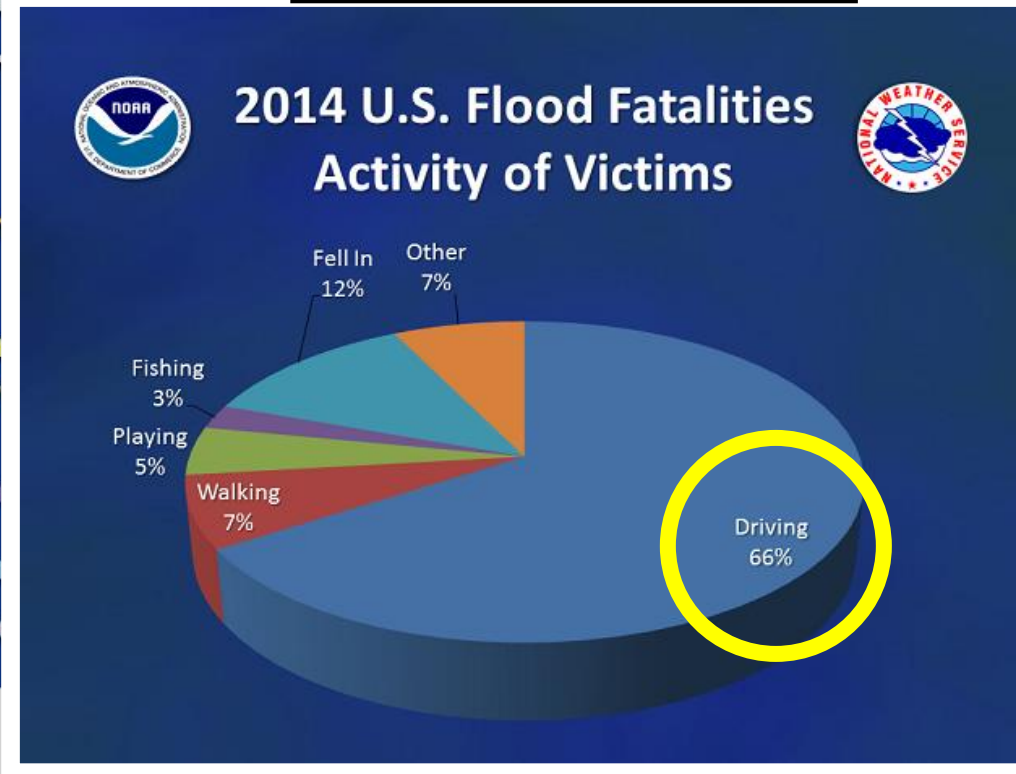
- #1 cause of death in floods = drowning in cars



Source: The Weather Channel
(www.weather.com)

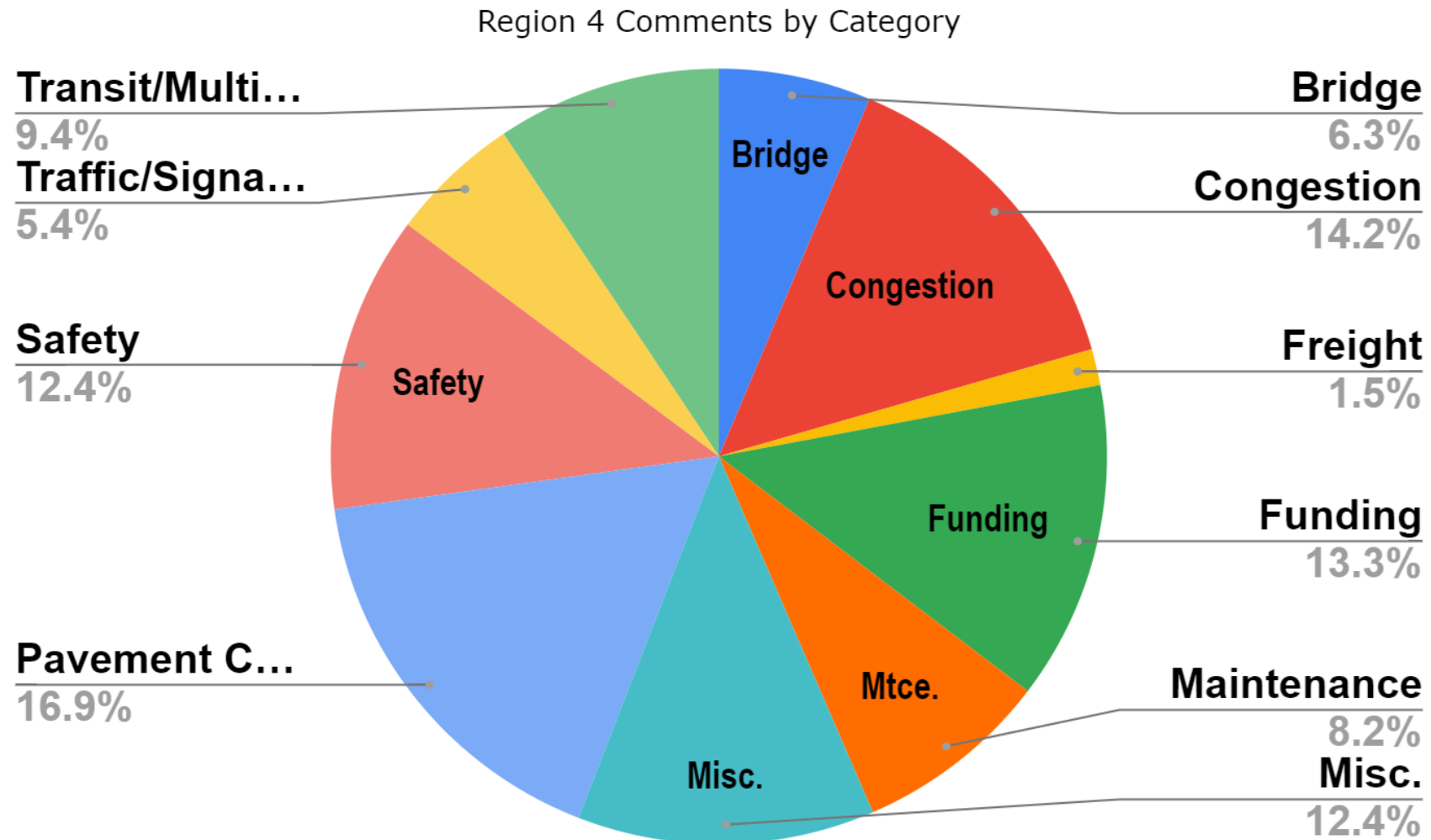


Source: National Oceanic & Atmospheric Administration





CDOT Public Comments and Planning Priorities

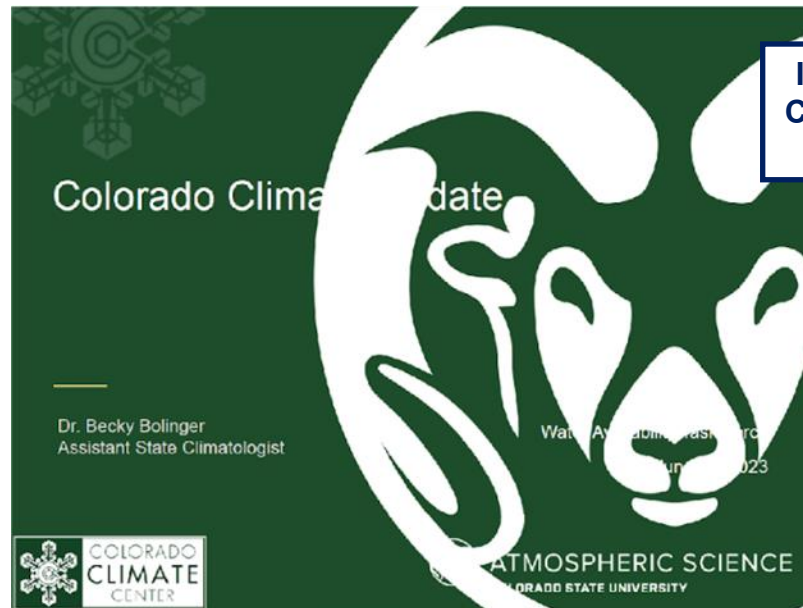




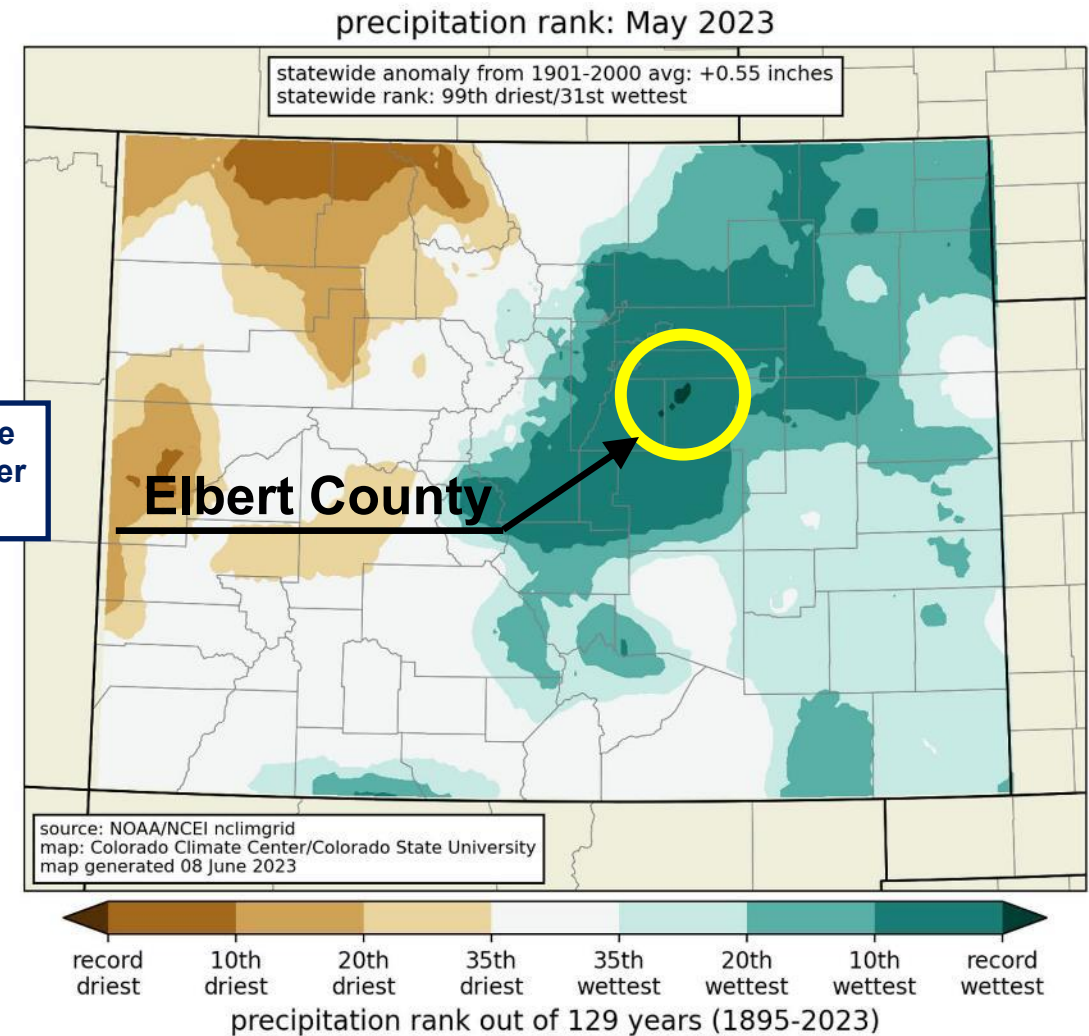
2023 Local Rainfall Disaster, 1 of 2

Colorado Climate Center (CSU):

- **June 2023** Report to the Colorado Water Conservation Board (CWCB)
- **May & June 2023** = rainy!



Images Courtesy of the Colorado Climate Center at CSU, and CWCB



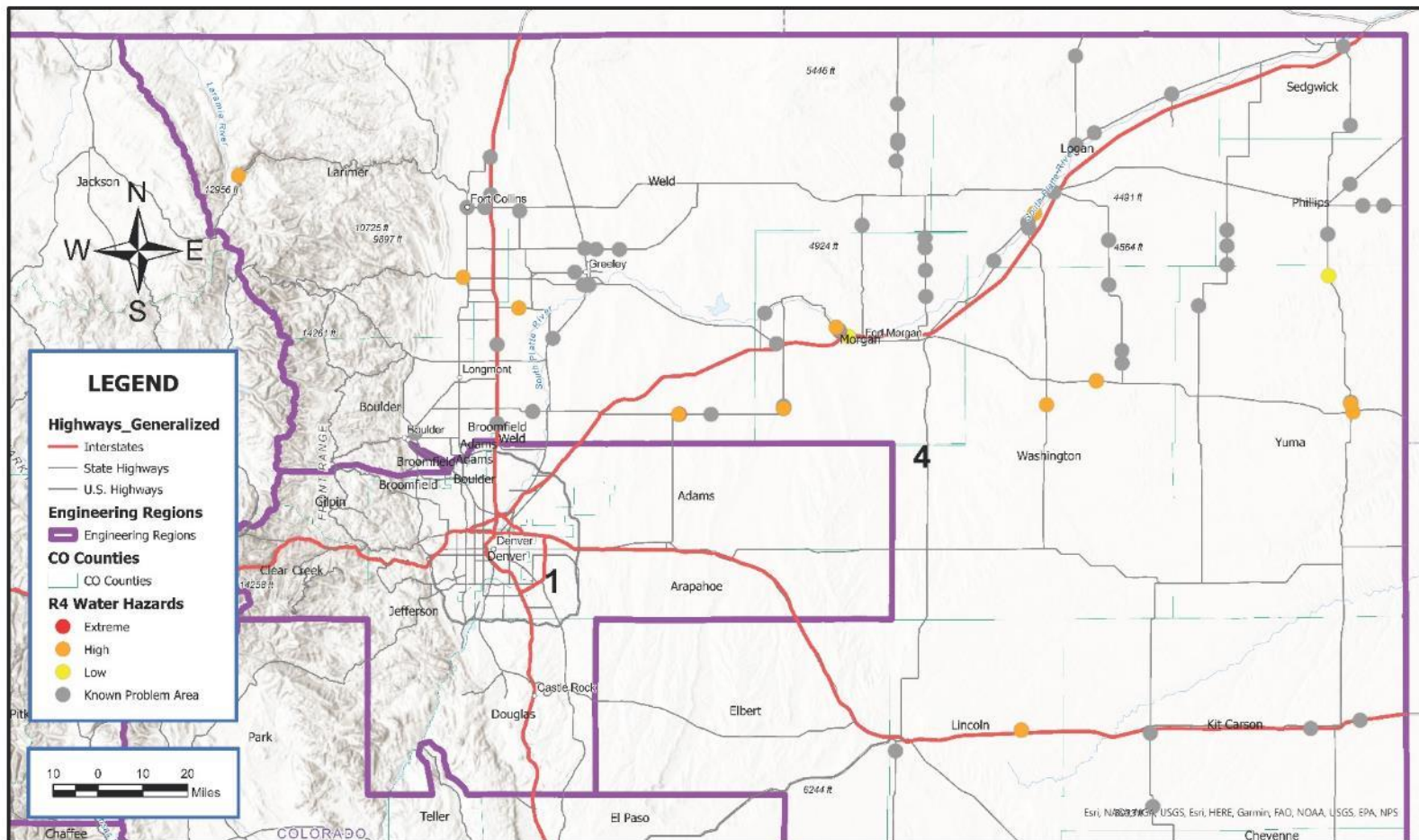


Lessons from 2023 Rainfall Disaster

2023 CDOT R4 Weather Trouble Spots:

COLORADO DEPARTMENT OF TRANSPORTATION
FLOOD DAMAGE TROUBLE SPOT AWARENESS

COLORADO
Department of Transportation
Last Update: November 2023



- **Mapping trouble-spots**
 - GIS layer initiated
 - 81 reported incidents in May/June (6 weeks)
- **Records → trends**
 - Minor rains are producing major floods
 - Most highways flooding is outside regulatory floodplains
 - Natural hazard mitigation is not a priority the 10-year plan of projects



The Future of Natural Hazards in Colorado

How Flooding Will Look Moving Forward

- The biggest floods in the future will still be traditional floods like 1997, 2013 & 2015
- Heavy snowpack always gets media attention, but rarely results in flooding
- On a frequent basis, the most common problem moving forward is post-wildfire flooding



Source: Kevin Houck,
CWCB 2021



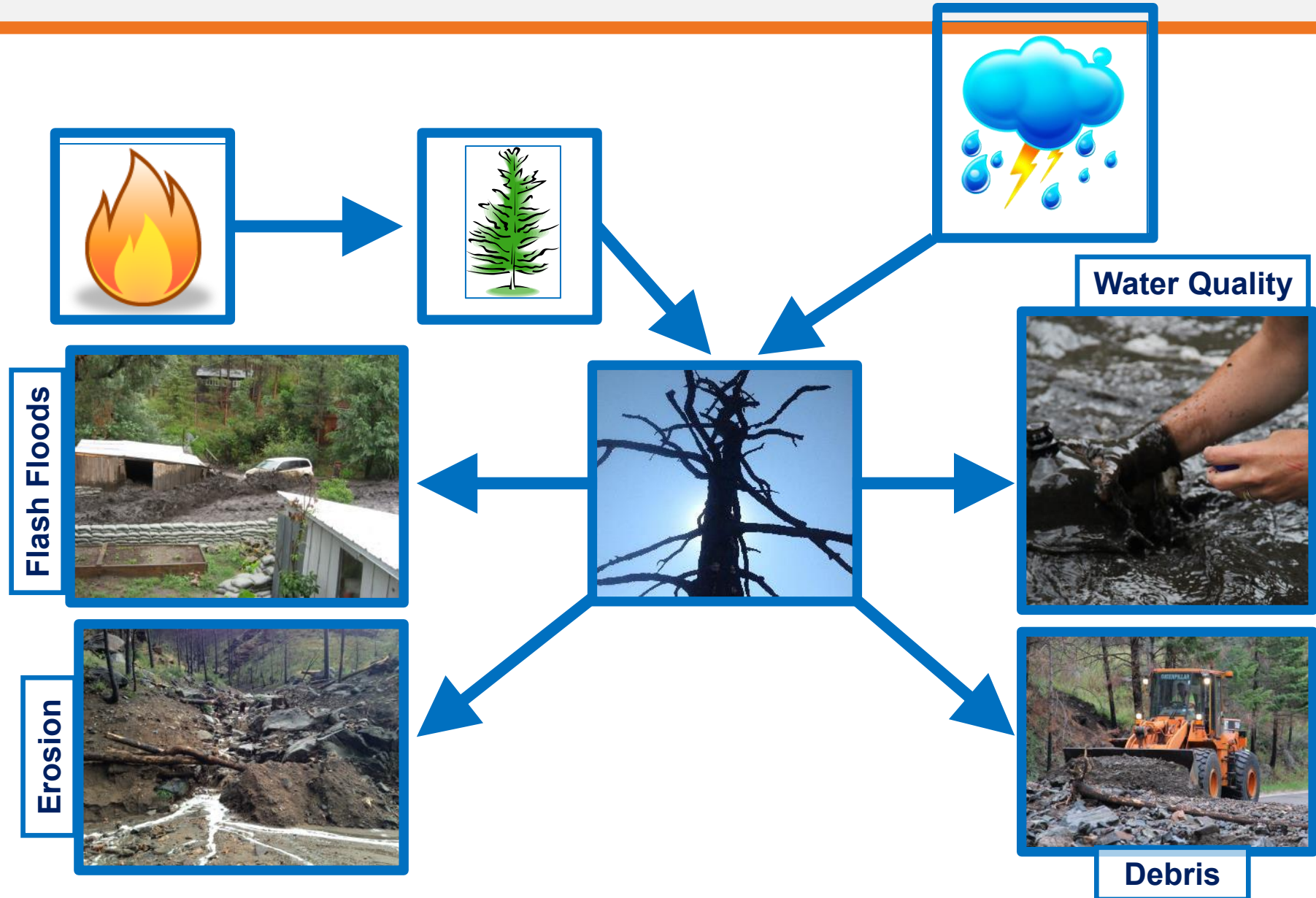
Colorado 2020 Wildfire Disasters

- Grizzly Creek Fire -- 33,000 acres, Glenwood Canyon
- East Troublesome Fire -- 194,000 acres, Grand & Larimer Counties
- Cameron Peak Fire -- 209,000 acres, Larimer County
- CalWood Fire -- 10,000 acres, Boulder County
- Total = 446,000 acres = 700 mi.² (*Denver* = 155 mi.²)



Photo: Brian
Varrella, 2020

Compounding Hazards; One Disaster to Many





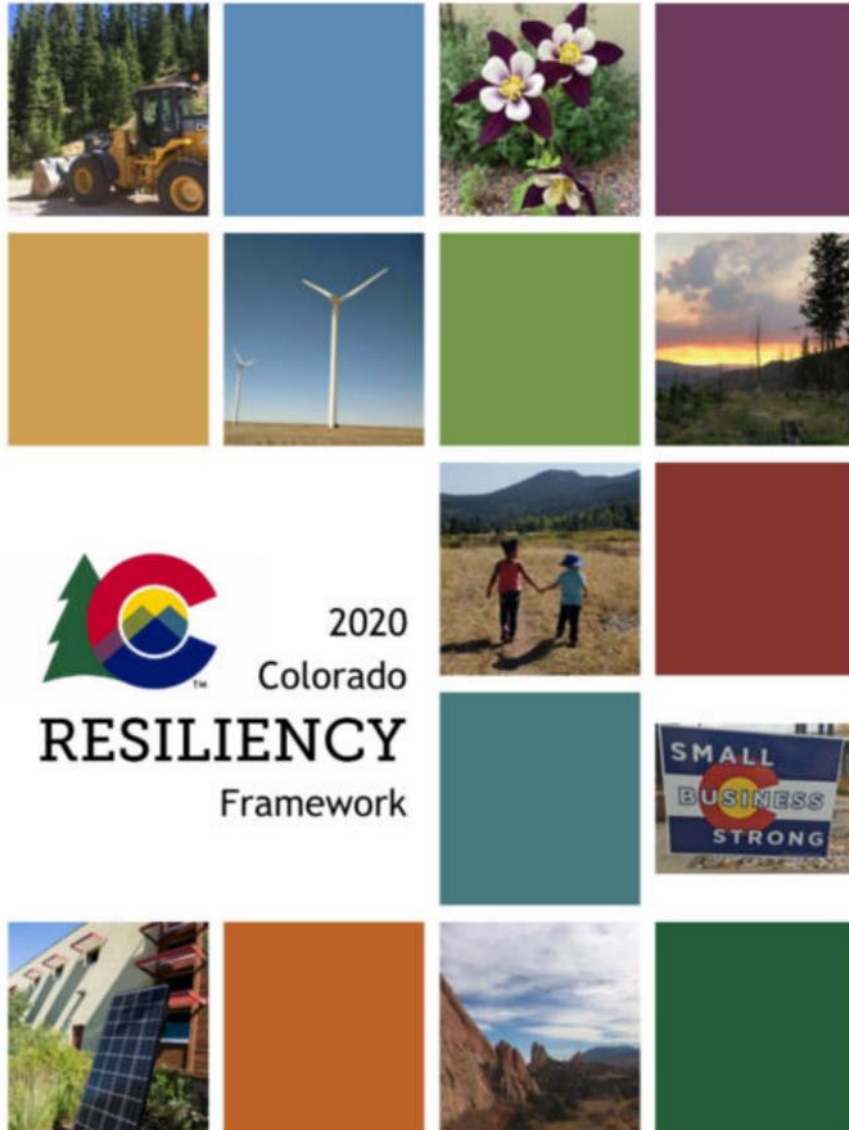
High Park Fire Flash Flood



**48-second
Video:
Lucas Mouttet,
2013**



The Colorado Resiliency Framework



Established 2015, Gov. Hickenlooper

- **Managed by the Colorado Resiliency Office (CRO); *Anne Miller***
- **Outlines a structure for resilience**
- **Four themes of risk and vulnerability**
 - Adapt to climate change
 - Identify risks from all hazards
 - Address social inequities
 - Pursue economic diversity

Source: Colorado Dept. of Local Affairs at

<https://www.coresiliency.com/colorado-resiliency-framework>

I-70 Corridor Risk & Resilience Pilot (2017):

- Analyze risk & review system resilience of I-70 from Kansas to Utah
- Proactive look at optimal investments
 - Develop pre-disaster mitigation strategies
 - Build system resilience over time
- Created from 7-step RAMCAP process used in flood recovery

NOVEMBER 30, 2017



East Entrance to Hanging Lake Tunnels, I-70

I-70 CORRIDOR RISK & RESILIENCE PILOT FINAL REPORT



13880 Dulles Corner Lane
Suite 300
Herndon, VA 20171
Principal Investigator:
Aimee Flannery, Ph.D., PE
(703) 464-7030

Statewide Highway Criticality Map:

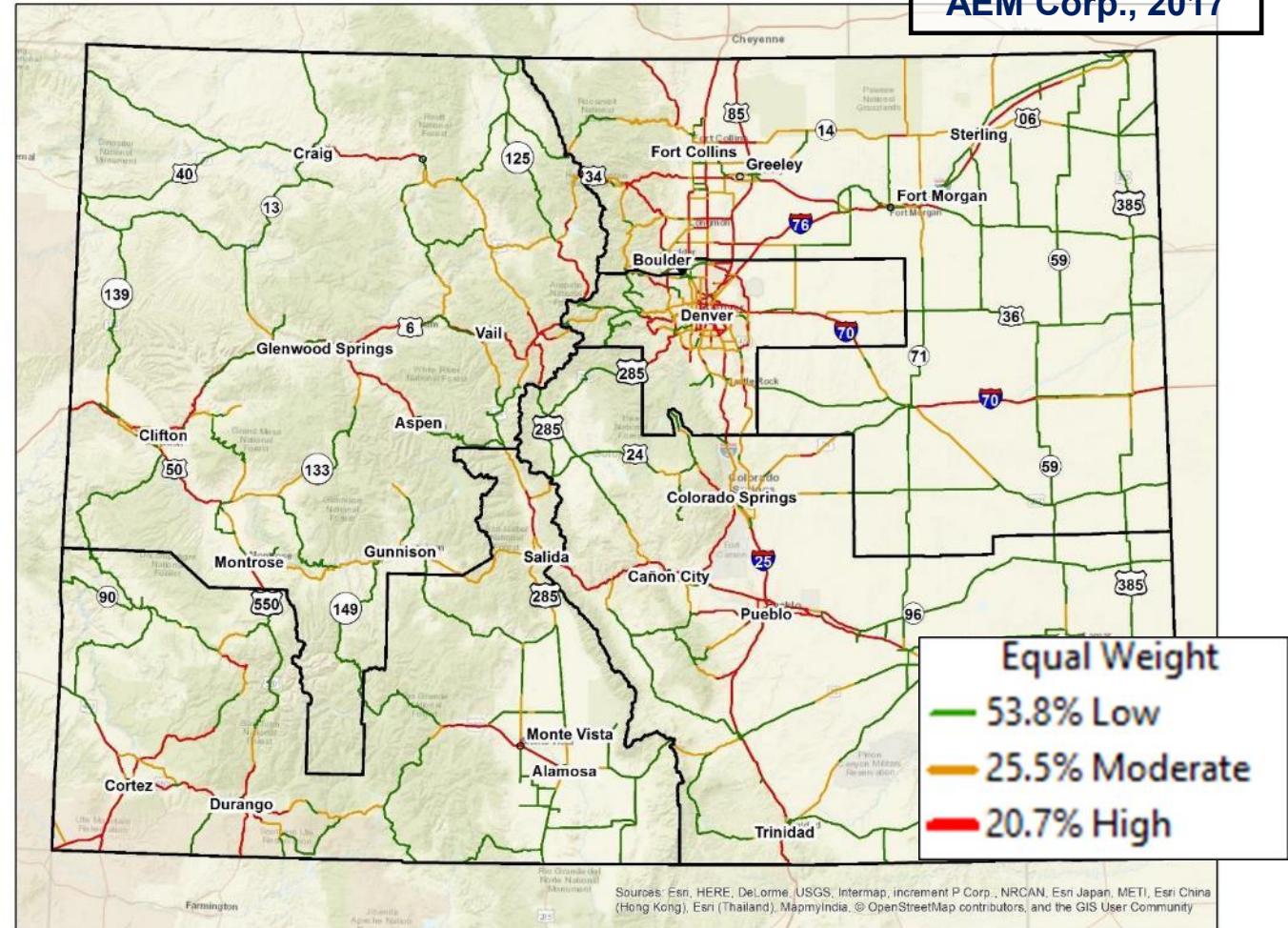
Graphics:
AEM Corp., 2017

- **Threat Assessment**

- Flood
- Rockfall
- Avalanche
- Landslide
- Wind
- Vehicle Strike

- **Metrics**

- AADT (Volume)
- Social Vulnerability
- Roadway Classification
- System Redundancy
- Freight (Economic)
- Tourism (Economic)

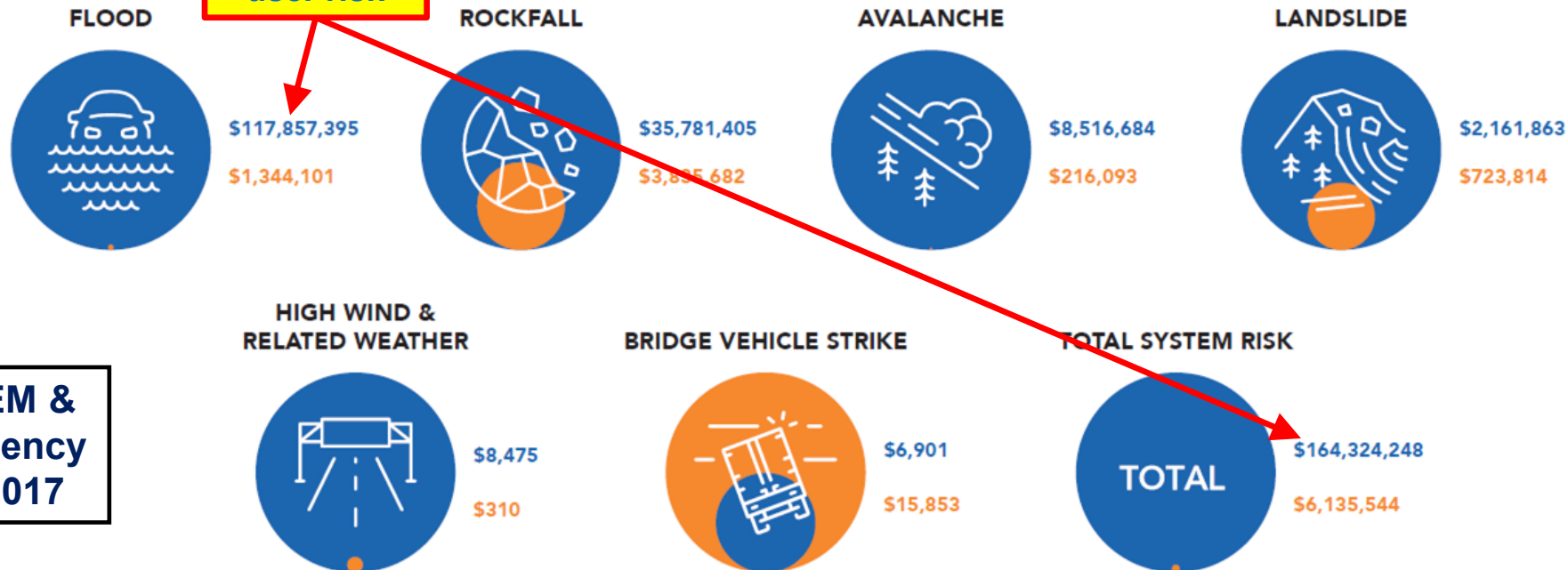


The costs of flooding are carried by the travelling public

ANNUAL RISK SUMMARY BY THREAT

TOTAL RISK I-70

● USER RISK ● OWNER RISK



Source: AEM & CDOT Resiliency Program, 2017

TOTAL = \$170.5 M

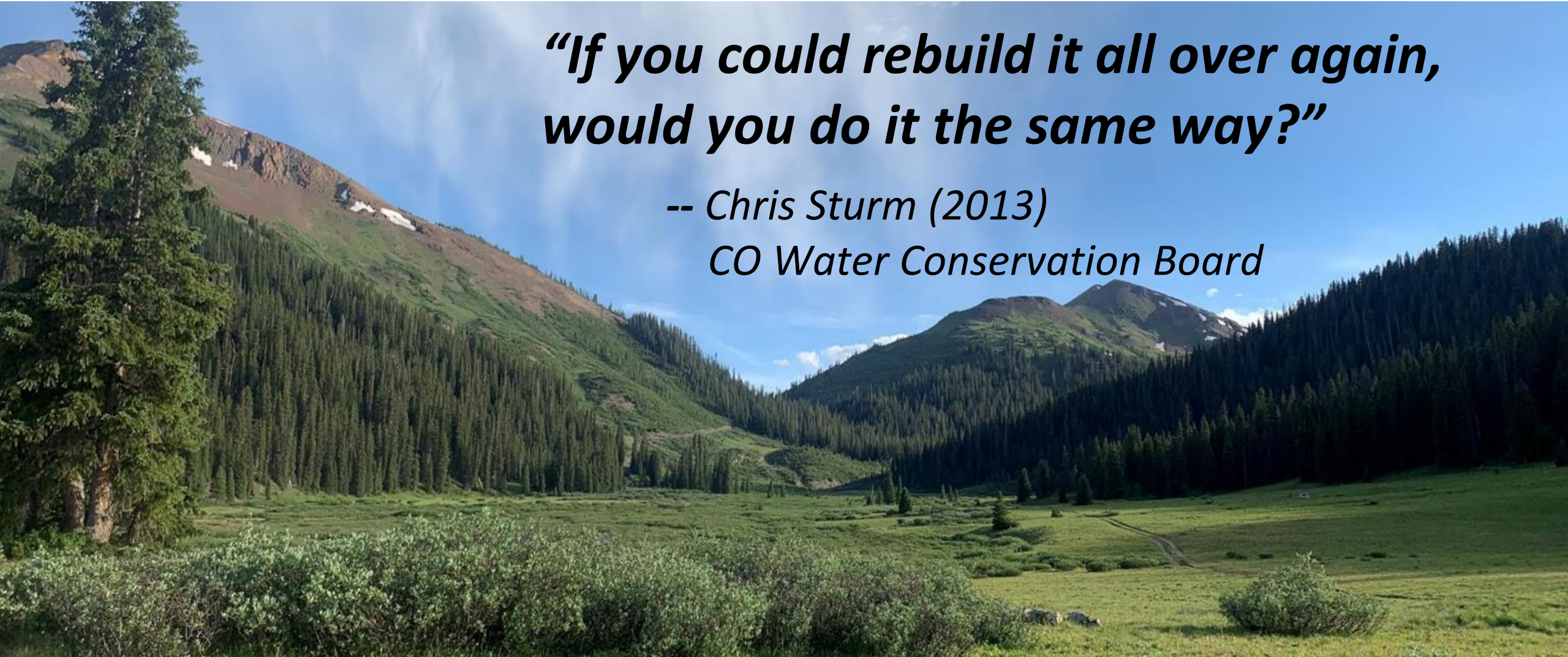


Mitigating Risk in Colorado Infrastructure

***“If you could rebuild it all over again,
would you do it the same way?”***

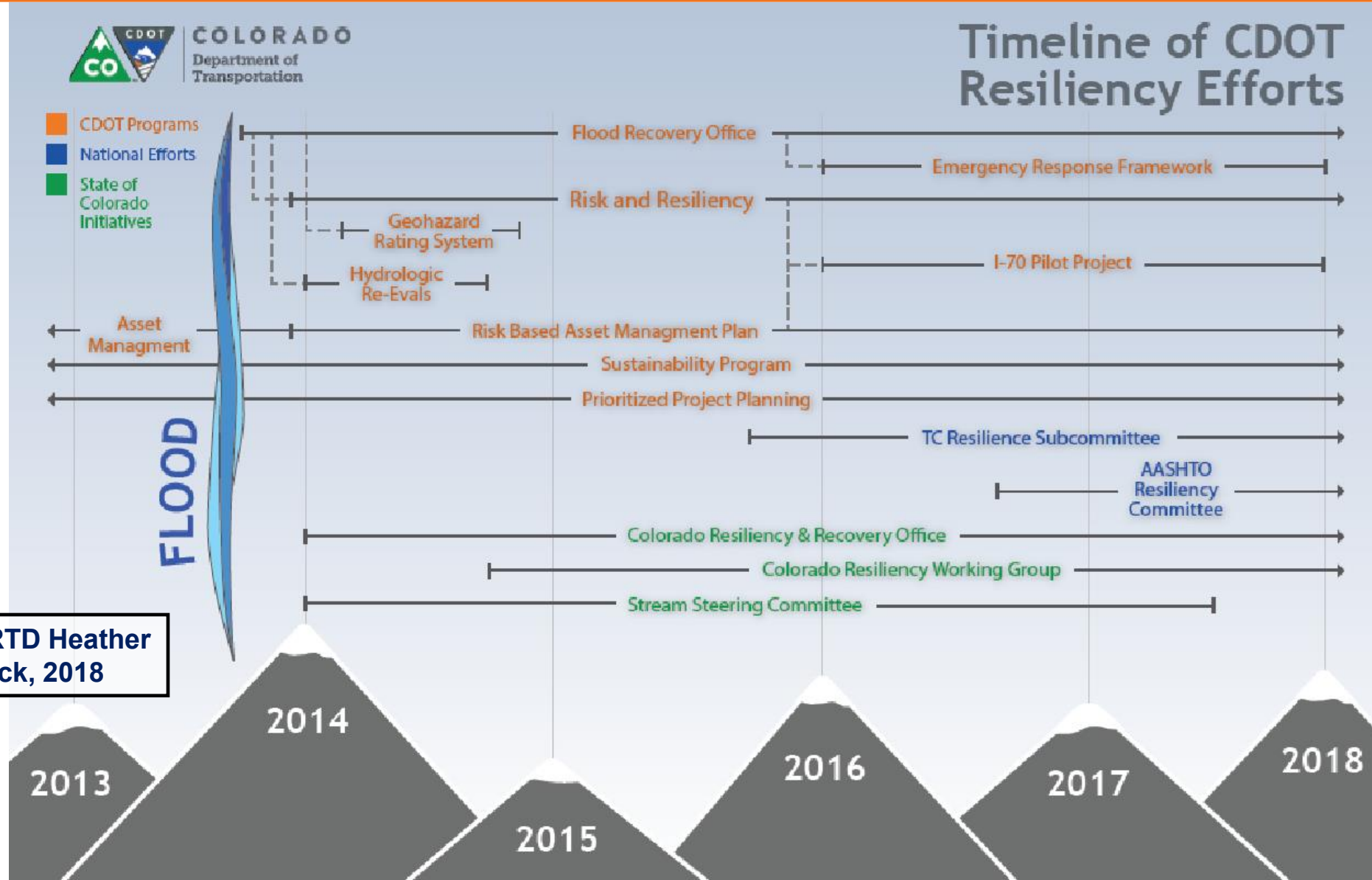
-- Chris Sturm (2013)

CO Water Conservation Board





CDOT Evolution for Disaster Preparation



Source: RTD Heather Paddock, 2018



Flood Recovery Program

2013 - 2022

**Graphics:
Muller Engineering
& JWO Engineering**

On September 12, 2013 Colorado Governor John Hickenlooper declared a disaster emergency for large areas of the Northern Front Range and Northeastern Plains of the State. The disaster impact areas was unprecedented, affecting over 400 miles of roadways and impacting more than 120 bridges and structures. Permanent repair and recovery efforts continue to this day.

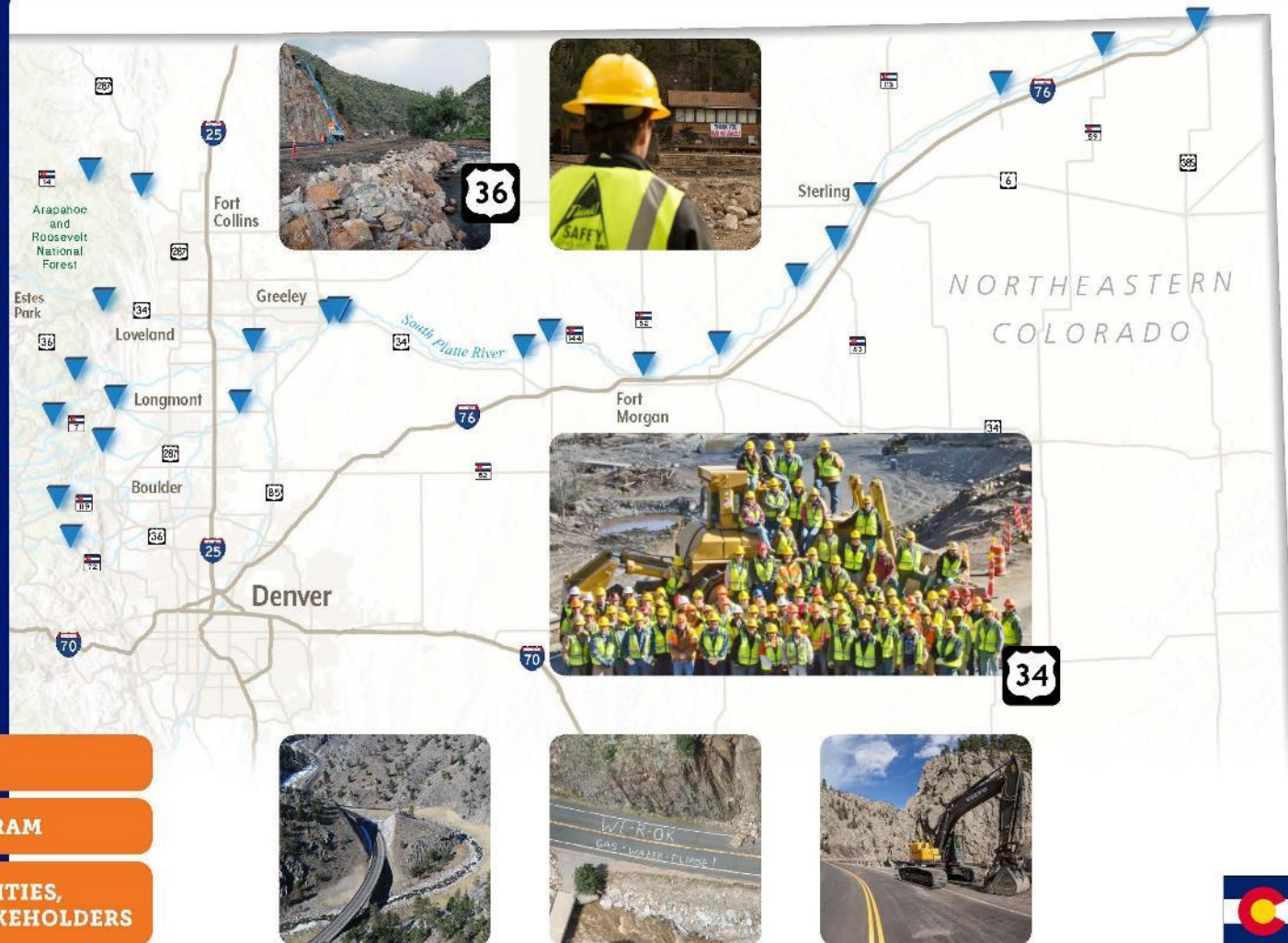
OVER 200 PROJECTS

\$750 MILLION PROGRAM

**OVER 30 MUNICIPALITIES,
COUNTIES, AND STAKEHOLDERS**

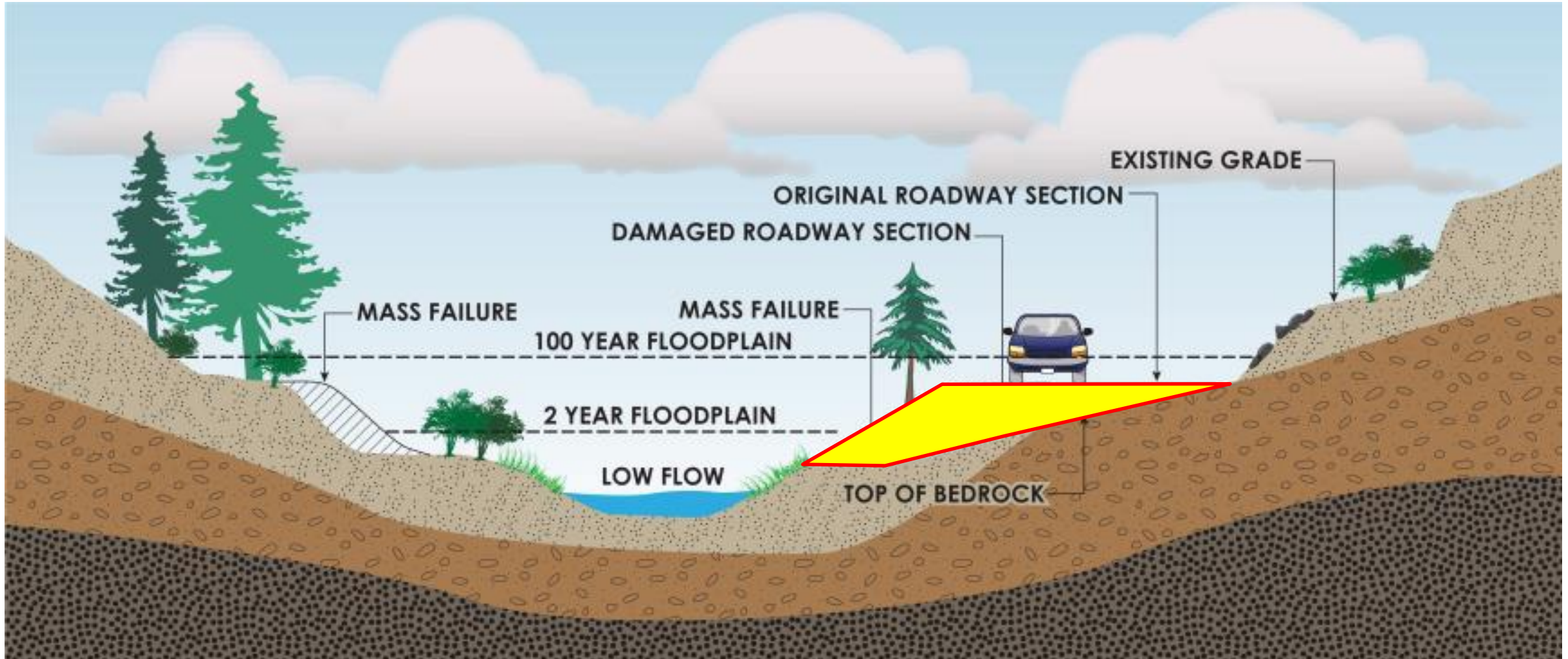
"We're not just going to build it back to what you had before we're going to build it back better than before."

— Gov. John Hickenlooper



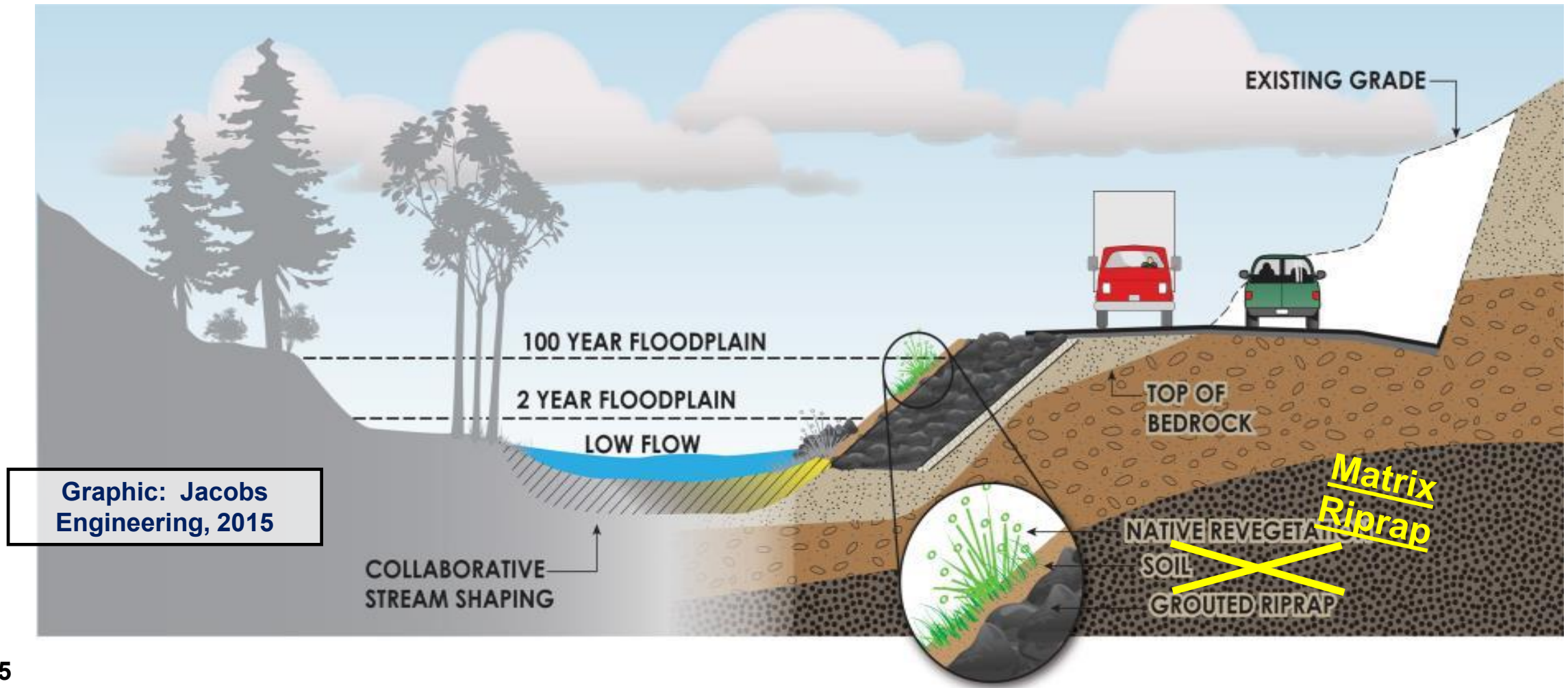


Pre-2013 River Corridor Roadway Standard



Resilience by Backup Planning

Work with nature instead of against it (*planned failure*)



Resilience by Retreat



Graphics: Jacobs
team, 2015-2018





Resilience by Design Iteration

Continuous improvement; *test, review, revise, try again*

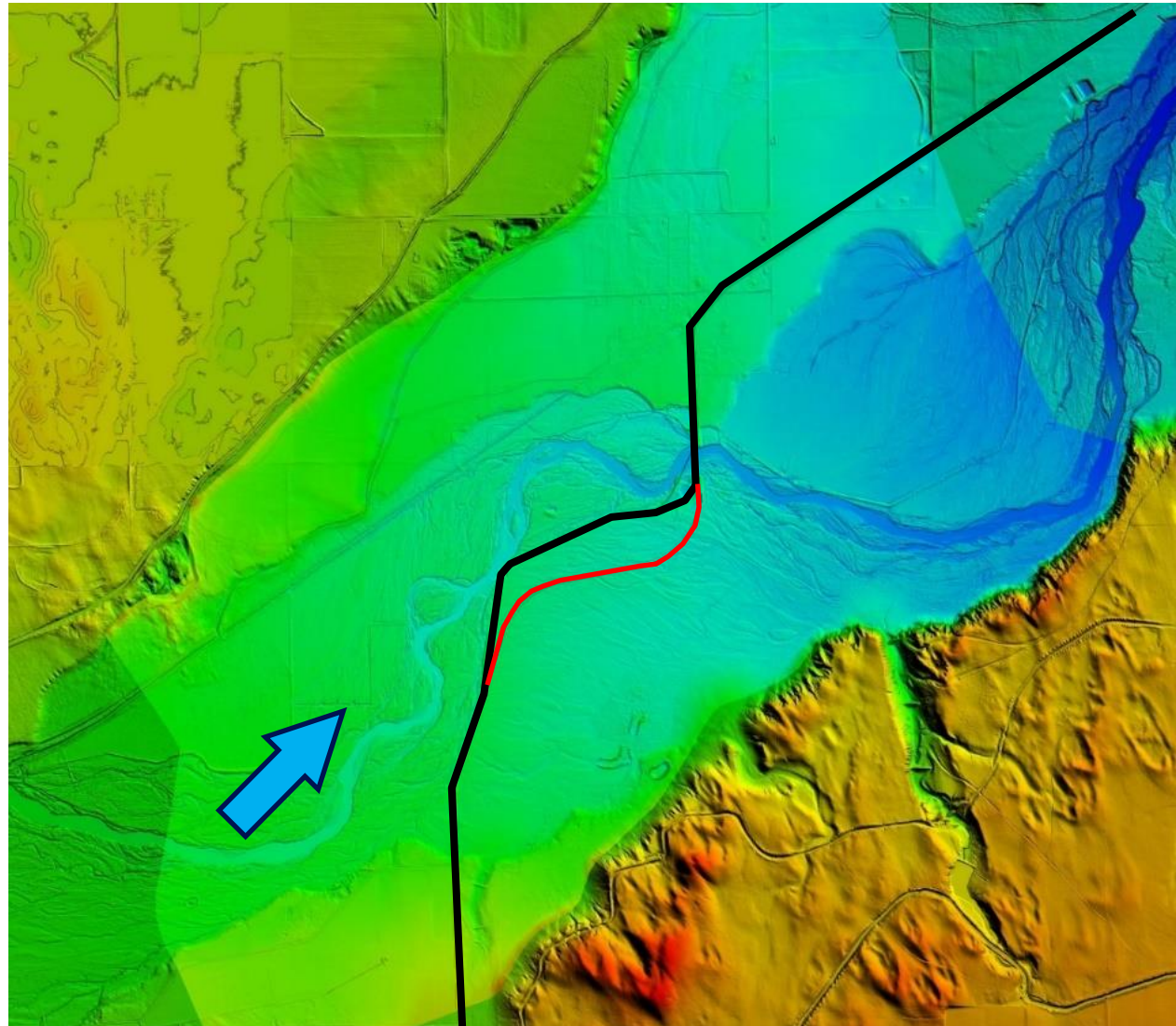




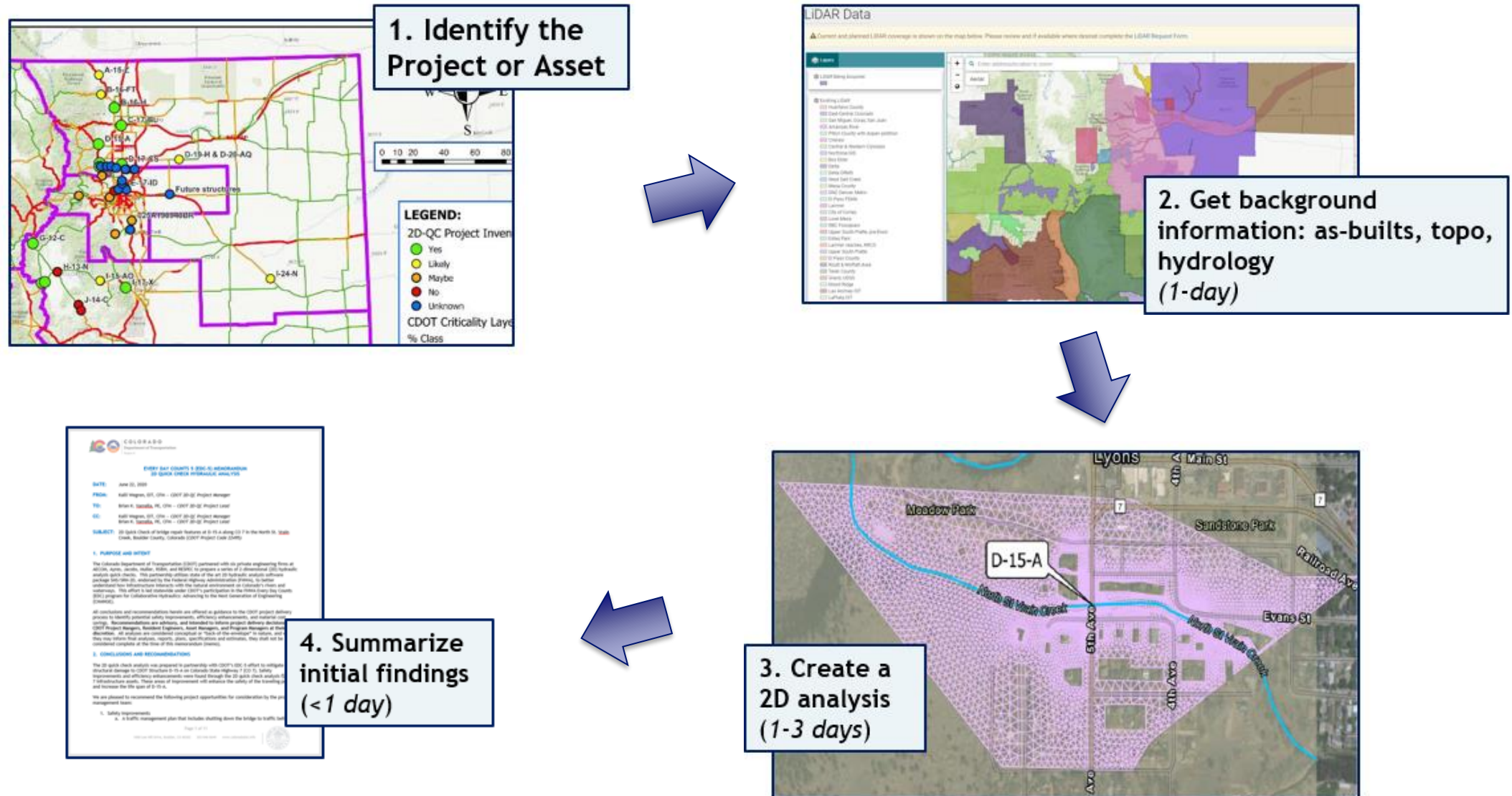
2dQC, Resilience by Technology, 1 of 3

2-D Quick Check (2dQC) Practice at CDOT:

- **Back-of envelope hydrologic and hydraulic analysis**
- **Requires 10-20 hours of analysis**
- **Informs project decisions after planning and before design**
- **Identifies fatal flaws and new value or benefits before a scope of work is complete**



2dQC, Resilience by Technology, 2 of 3



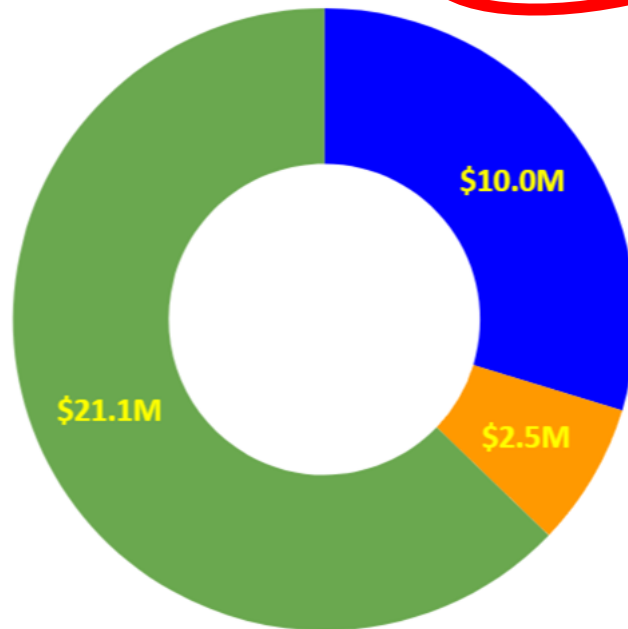


2dQC, Resilience by Technology, 3 of 3

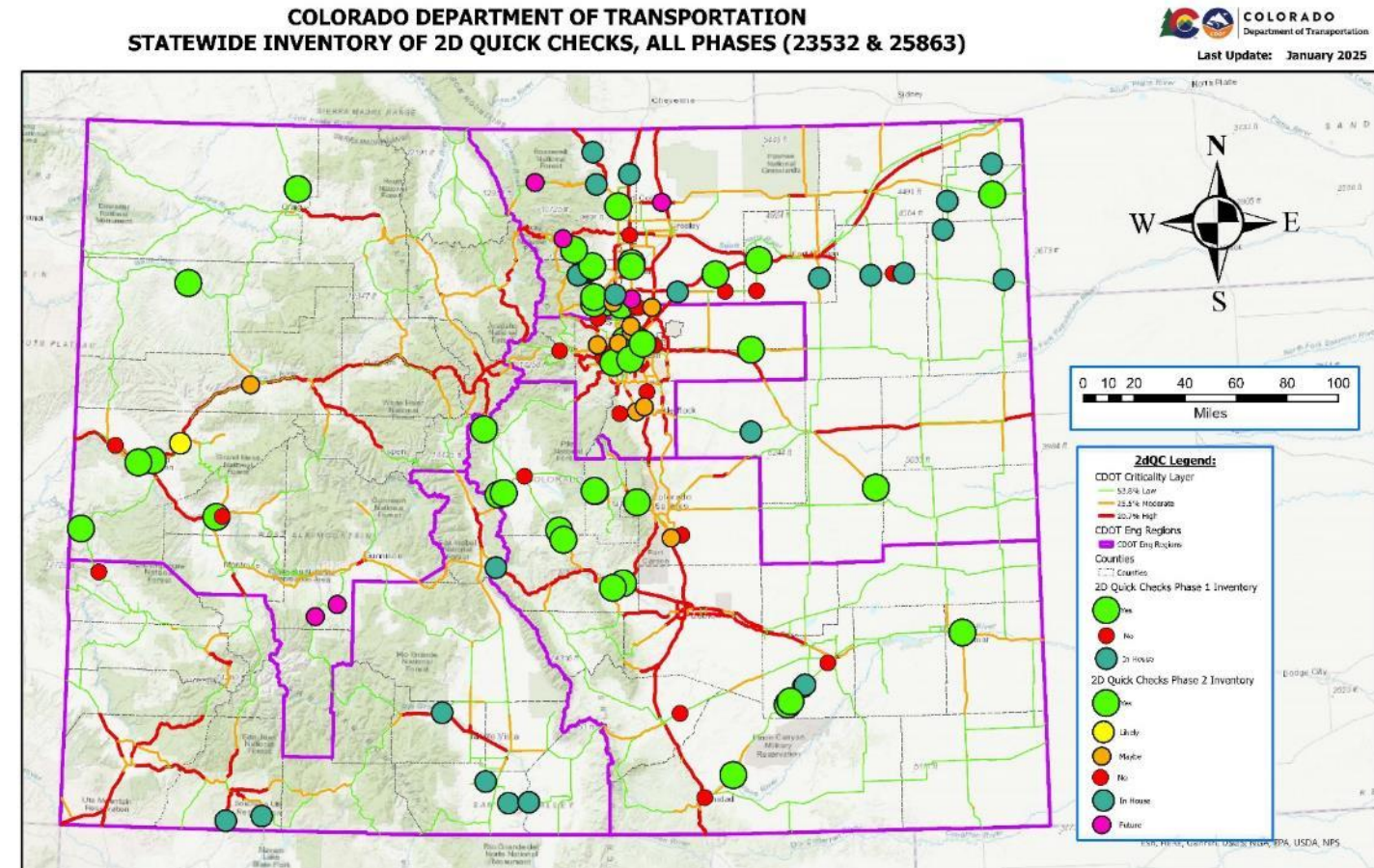
2dQC, All Phases, 1 and 2
(2020-2025)

68 of 125 Project Sites

Calculated All-Phase Benefits = \$33.6M
68 Projects ROI = 100:1



● Materials Savings ● Other Benefits ● Resilience Benefit





- Prevent a third major washout
- Return river to pre-1938 oxbow channel
- Reduce wildlife strikes
- Reduce head-on vehicle accidents



Little Thompson River headwaters:

2022



2023



2024





s, 2 of 2

Little T





Mitigating Risk in Colorado Infrastructure

***“Process improvement is
an evolution.”***

*-- Heather Paddock, PE
Region Transportation Director
Colorado DOT, Region 4*



- Michael Baker, CWCB and FEMA Region VIII partnership
- Uses the Coupled Model Intercomparison Project Phase 6 (CMIP-6) data

35



Climate-Informed Design Standards, 2 of 2

Uses Existing National Oceanic & Atmospheric Administration (NOAA) Data

- Collect multiplier from [Colorado Hazard Mapping](https://coloradohazardmapping.com/) website
- Apply multiplier to NOAA Atlas 14 data to adjust rainfall to future conditions

Example Project Application

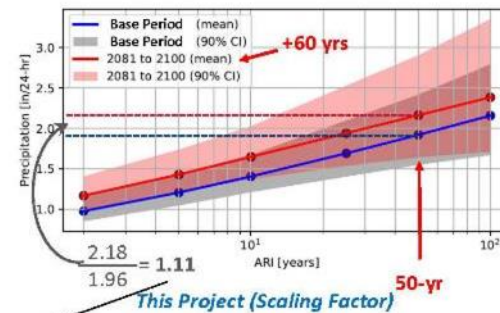
Designing a bridge for 50 yr, 6 hr storm assuming SSP5-8.5 and 60 yr lifespan



PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)¹

Duration	1	2	5	10	25	50	100	200	500
5-min	0.133 (0.112-0.157)	0.182 (0.152-0.215)	0.269 (0.217-0.309)	0.322 (0.267-0.388)	0.405 (0.318-0.507)	0.466 (0.354-0.598)	0.525 (0.381-0.701)	0.582 (0.399-0.815)	0.655 (0.427-0.958)
10-min	0.195 (0.163-0.230)	0.267 (0.223-0.315)	0.381 (0.317-0.452)	0.472 (0.390-0.563)	0.593 (0.483-0.742)	0.683 (0.518-0.878)	0.769 (0.558-1.02)	0.853 (0.595-1.19)	0.959 (0.625-1.40)
15-min	0.239 (0.199-0.291)	0.325 (0.272-0.385)	0.454 (0.387-0.522)	0.576 (0.478-0.689)	0.723 (0.565-0.905)	0.832 (0.632-1.07)	0.938 (0.685-1.25)	1.04 (0.713-1.45)	1.17 (0.782-1.71)
30-min	0.294 (0.247-0.348)	0.406 (0.340-0.481)	0.589 (0.483-0.689)	0.716 (0.592-0.857)	0.899 (0.692-1.11)	1.01 (0.769-1.36)	1.13 (0.810-1.50)	1.24 (0.847-1.72)	1.37 (0.888-1.96)
60-min	0.376 (0.315-0.445)	0.494 (0.413-0.585)	0.676 (0.543-0.833)	0.819 (0.676-0.979)	0.999 (0.775-1.24)	1.13 (0.855-1.44)	1.25 (0.903-1.56)	1.38 (0.929-1.89)	1.49 (0.990-2.18)
2 hr	0.459 (0.389-0.537)	0.582 (0.491-0.682)	0.772 (0.649-0.915)	0.920 (0.787-1.08)	1.11 (0.871-1.36)	1.24 (0.958-1.57)	1.36 (0.987-1.78)	1.48 (1.02-2.03)	1.61 (1.06-2.32)
3 hr	0.553 (0.469-0.644)	0.664 (0.563-0.778)	0.864 (0.707-0.982)	0.974 (0.816-1.15)	1.15 (0.914-1.41)	1.28 (0.984-1.59)	1.40 (1.03-1.84)	1.52 (1.06-2.08)	1.66 (1.10-2.38)
6 hr	0.782 (0.619-0.954)	0.876 (0.706-1.08)	1.04 (0.862-1.26)	1.17 (0.962-1.37)	1.37 (1.11-1.69)	1.53 (1.28-1.83)	1.69 (1.37-2.22)	1.86 (1.32-2.58)	2.09 (1.41-3.01)

NOAA Atlas 14

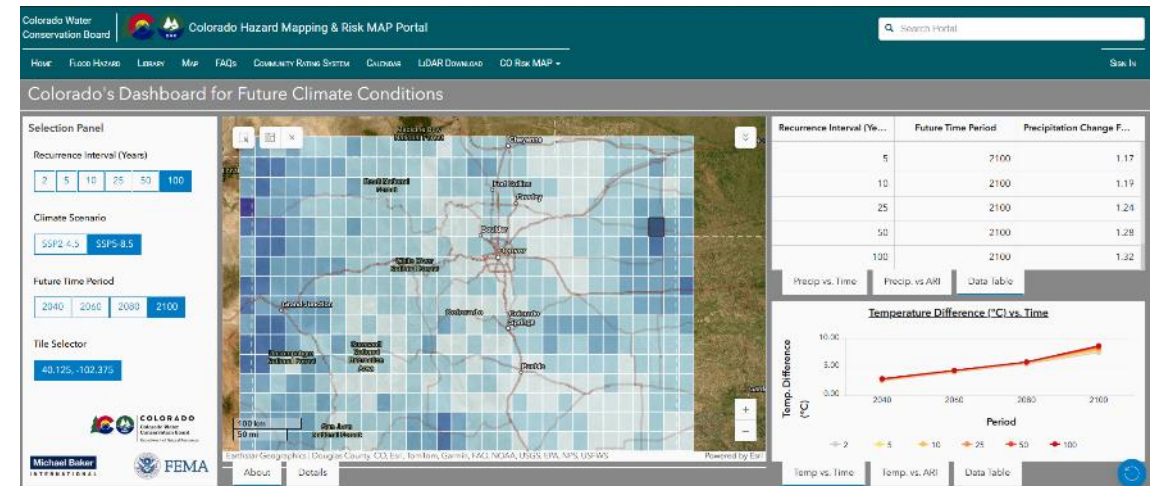


$$1.53 \times 1.11 = 1.70 \text{ inches}$$

Depth for Analysis

11% ΔP → >11% ΔQ

We Make a Difference





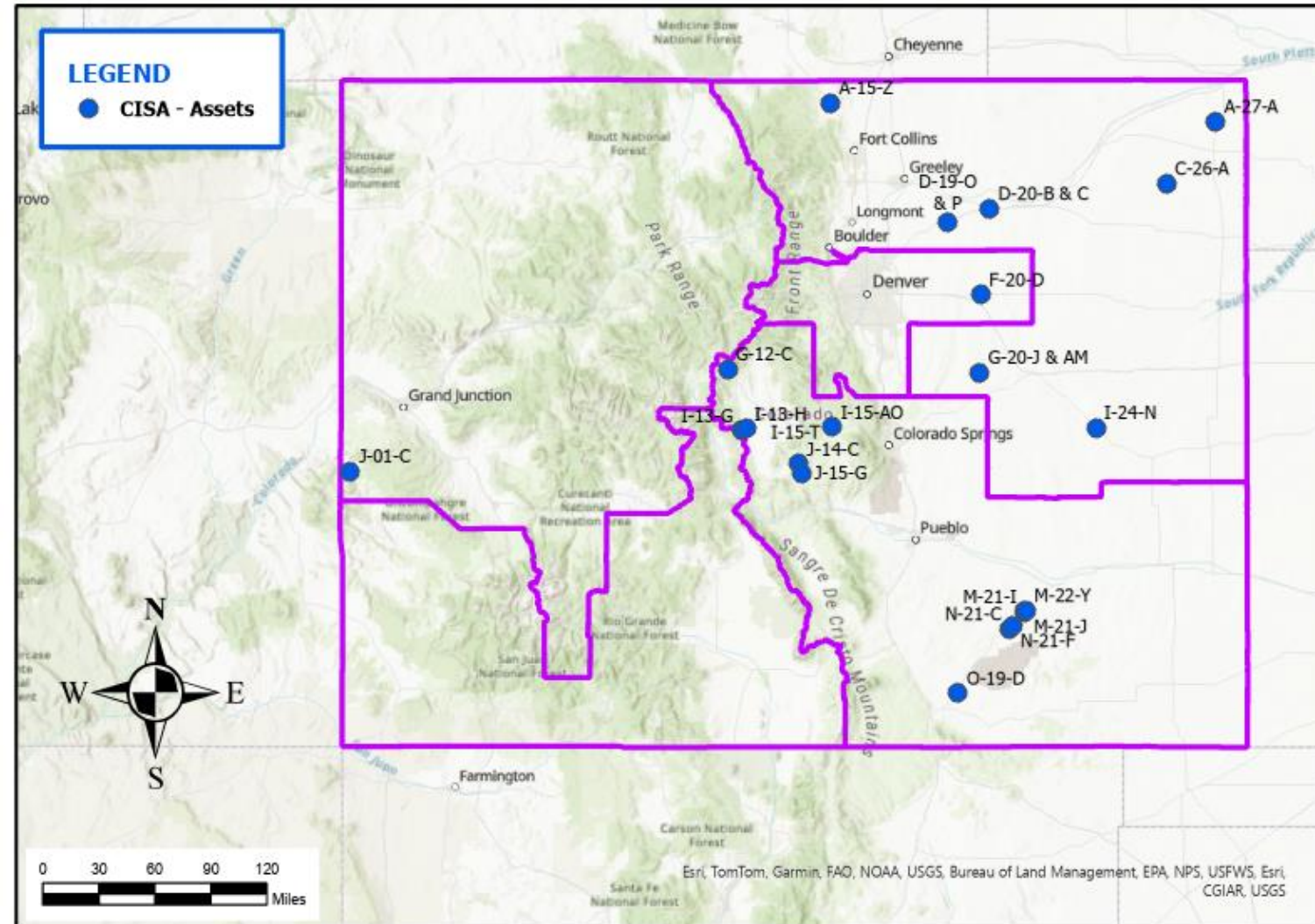
CISA Pilot Project Locations

CISA Investigation Framework

- 22 locations reviewed for modified hydrology
 - Calculated new hydrology for 10-, 25-, 50- and 100-year 24-hour storms
- 16 CISA-informed structure size analyses with 2dQC
 - Iterate on new structure sizes by changing width of openings
 - No other variables were tested

Colorado Department of Transportation, Region 4
2D Quick Check Project Locations, All Phases, 2020-2025

COLORADO
Department of Transportation
Last Update: January 2025





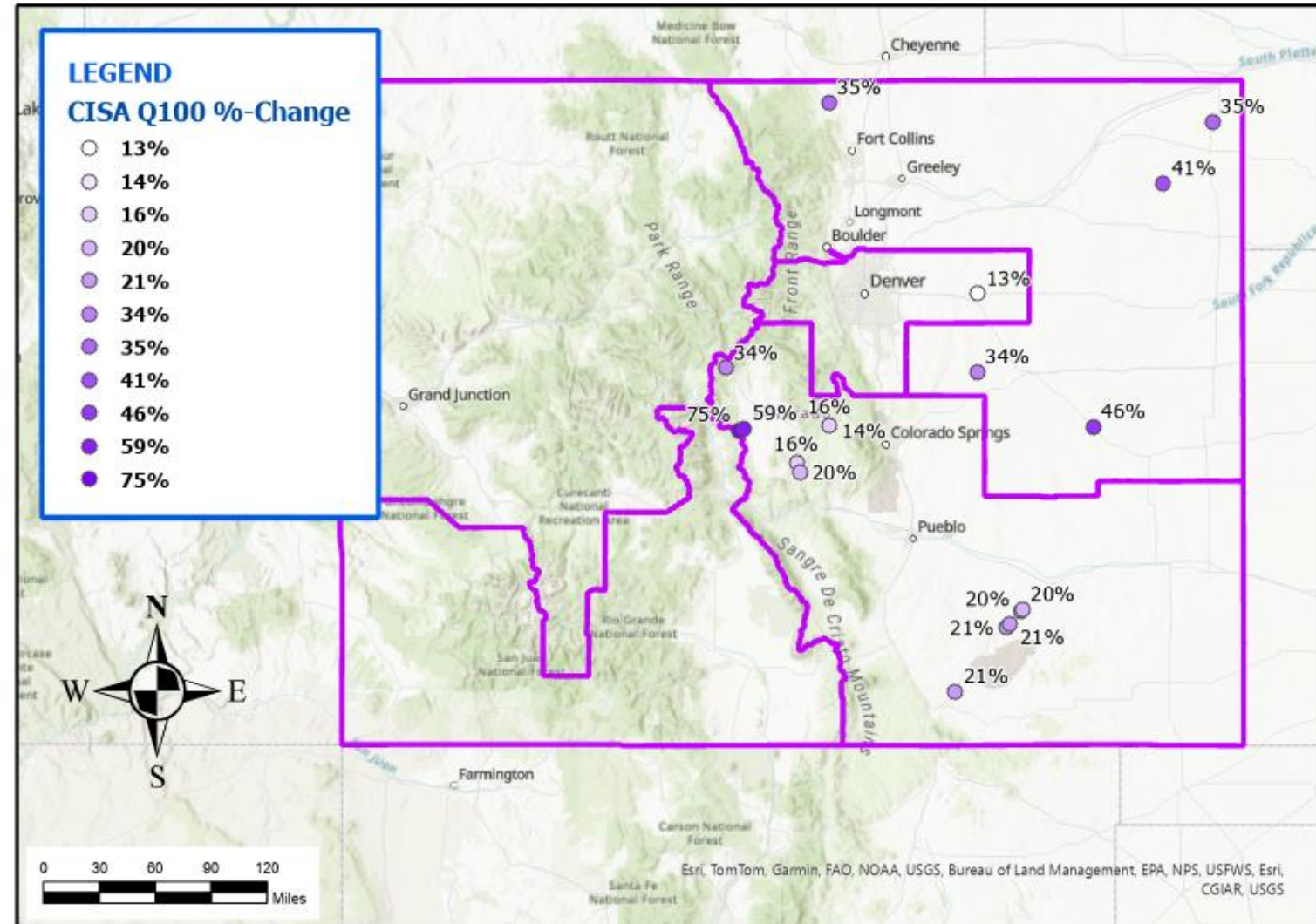
CISA Hydrologic Response to Precipitation

Initial CISA Hydrology Results at 18 CDOT Structures

- 100-yr hydrology (runoff) response
 - Range = +13% to +75%
 - Average = +30%
- Other runoff intervals were calculated but are not reported here

Colorado Department of Transportation, Region 4
CISA Investigation Results, 100-Year 24-Hour Percent Change in Runoff

COLORADO
Department of Transportation
Last Update: January 2025





Climate-Adjusted Bridge Design Impacts

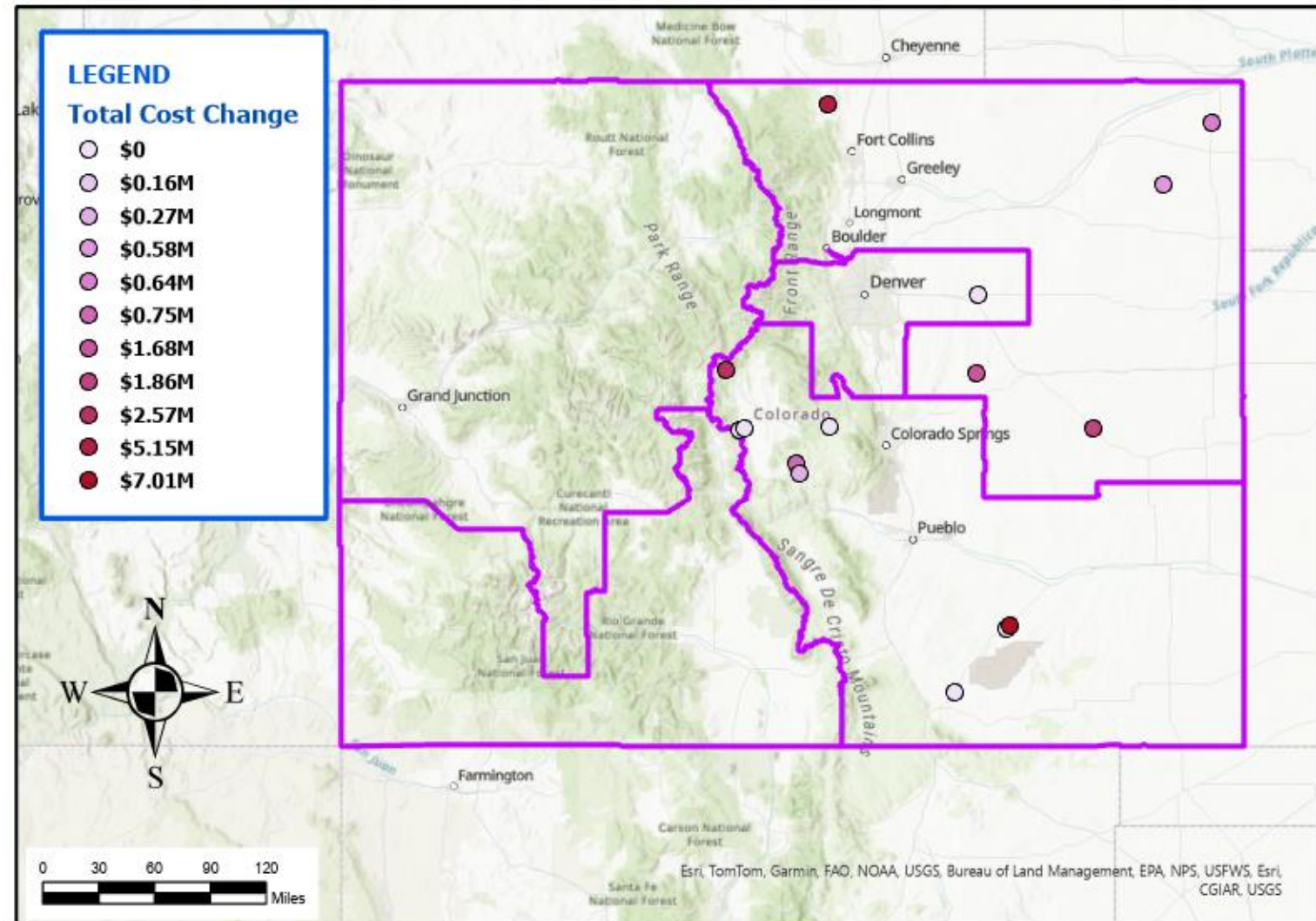
Initial CISA Structure Size Change in Cost (\$) at 16 CDOT Structures

- Total change in cost for a CISA-ready structure as compared to existing
 - Range = \$0 to \$7.0M
 - Average = \$1.3M
- Analyses did not consider roadway profile changes, taller structures, extra bridge piers, grading, or temporary structures

January 29, 2025

Colorado Department of Transportation, Region 4 CISA Investigation Results, Total Change in Structure Cost

 **COLORADO**
Department of Transportation
Last Update: January 2025





Tomorrow's Solutions; Team Up

1. Keep Making Friends – *team up outside your industry*

- **Develop relationships like neighbors** (*like Watershed Coalitions*)
- **(Diverse Workforce) + (Mutual Goals) = Your Goals Become Achievable**

CASFM Newsletter
Summer 2014

"In your personal and professional lives you will face a crisis and your relationships will get you through them."

-- Michael D. Brown, 2012



2. Prepare for All Hazards – *keep disasters from being disastrous*

- Factor in climate change-affected hydrology, drought, wildfires...
- Wildfire = a prelude to other disasters
 - “I say fire, you say flood” (*Varrella, 2014 ASFPM Plenary*)

Photo: RJ Sangosti, published in the Denver Post, 2012



Photo: Lucas Mouttet, Poudre Canyon, 2012



Photo: Varrella, St. Vrain Creek, 2013





Tomorrow's Solutions; Event vs. Disaster

2. Prepare for All Hazards – *keep disasters from being disastrous*

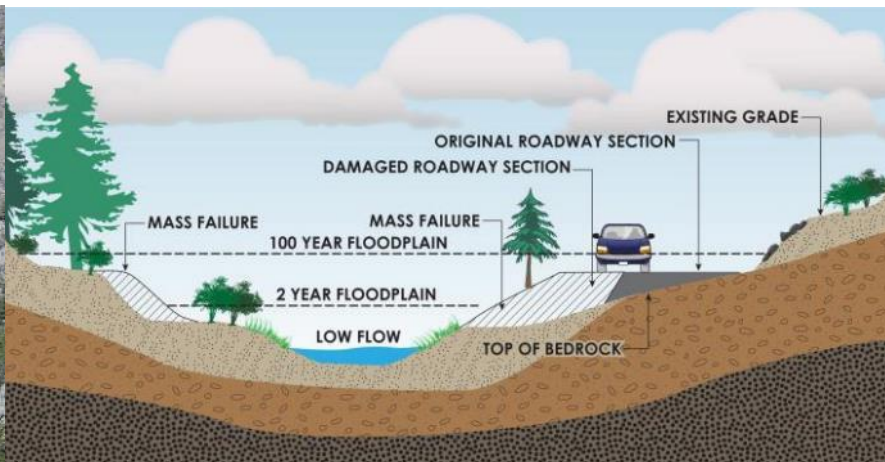




Tomorrow's Solutions; Use All Plans

3. Update Your Plans – *know your risks & menu of solutions*

- Multi-disciplined, multi-objective & adaptable
- (Current Needs) * (Future Conditions) = Innovation Needed
 - “Build Back Better”
 - Risk & Resiliency Measures
 - Strategic Failure
 - Watershed Scale Planning & Design
 - Nature-Based Design
 - “Let It Grow” (Katie Jagt)

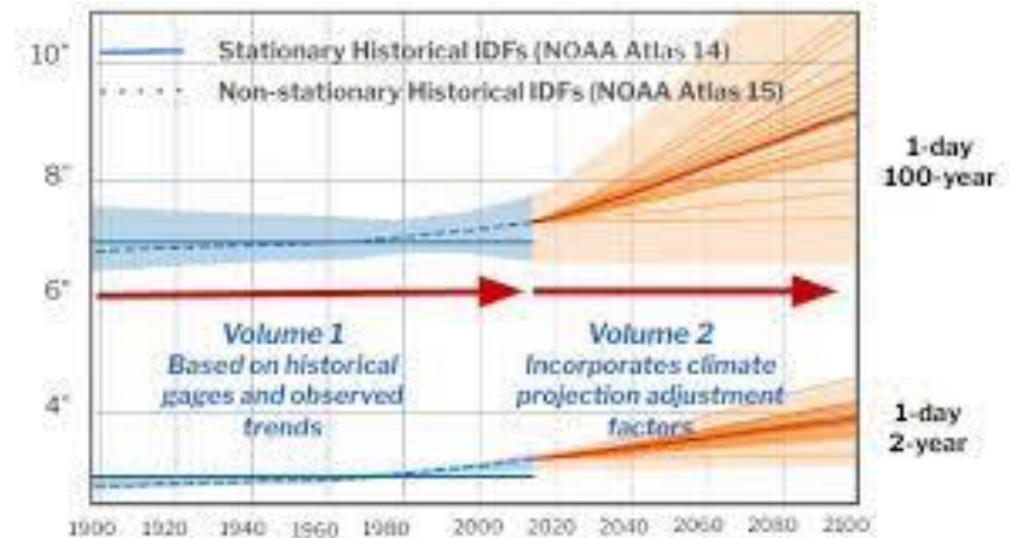




Tomorrow's Solutions; Advance the Science

4. Support Better Practices – *new science, new change*

- **When the data changes, we change too**
 - Adapt → Innovate → Influence
- **Climate changes are changing the future of floods we manage**
 - Shift in rainfall intensity → new hydrology
→ new design targets
- **If roads will flood, close them**

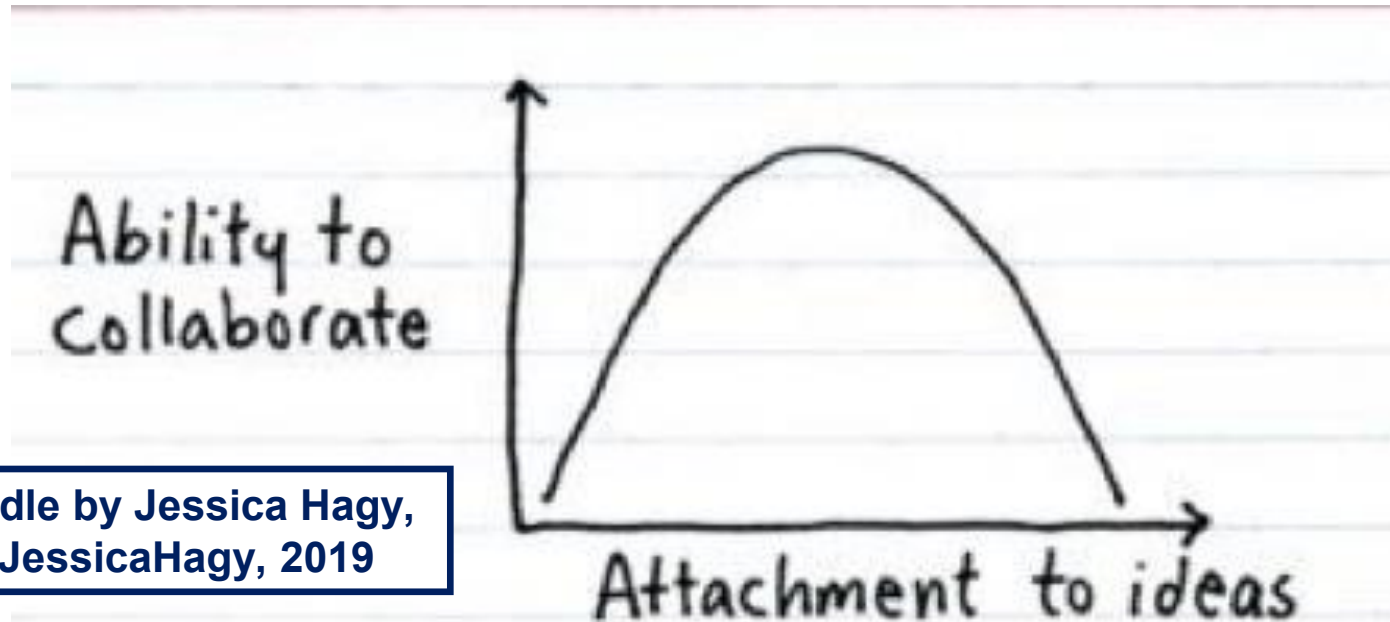




Tomorrow's Solutions: Never Quit

5. Never Give Up – *run the marathon*

- Do the right thing & don't look back
- *You will work in a collective of experts: trust and rely on one another daily*





Thank You for Including CDOT!

Group Discussion

Brian Varrella, PE, CFM

Resident Engineer

CDOT Region 4 Hydraulics

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