CDOT Resiliency Tools – Benefit Cost

June, 2022

COLORADO
Department of Transportation

Lizzie Kemp – CDOT Resiliency Program Manager

CDOT Lessons Learned

1976 and 2013 floods in Colorado destroyed many of the same facilities

US 34 1976

US 34 2013

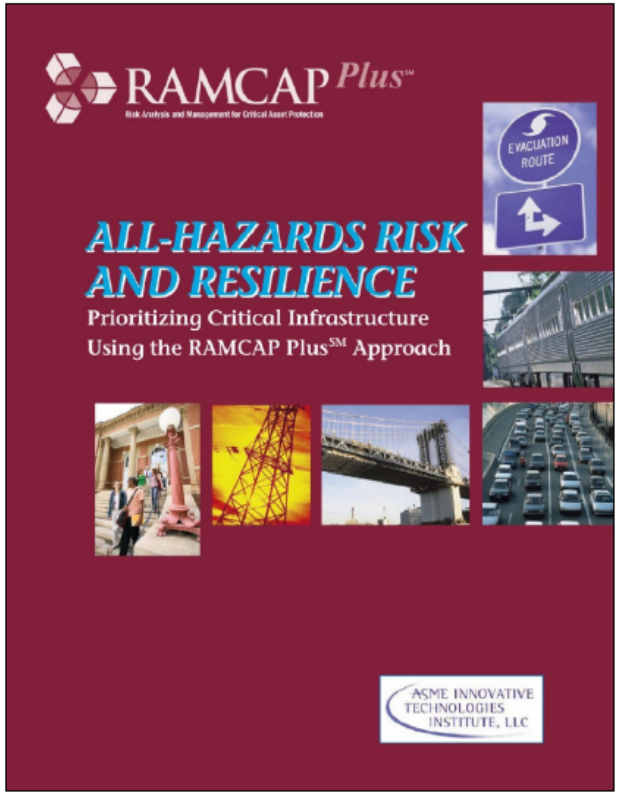
What can we do now… to avoid this in the future?

Primary Threats to CDOT's System

- Flooding
- Rockfall
- Cyberattack
- Drought – Wildfire – Rain/Debris Flow
- Winter Blizzards / Avalanche

Agreement to use 7 Step RAMCAP Model
-- For 2013 ER Flood, and I 70 Resiliency Pilot

RAMCAP Plus℠



R&R for Highways

1) Asset Characterization	What assets exists and which are critical?
2) Threat Characterization	What threats and hazards should be considered?
3) Consequence Analysis	What happens to assets if a threat or hazard occurs? Expected asset losses, economic impacts, injuries, lives lost?
4) Vulnerability Analysis	What are asset vulnerabilities that would allow a threat or hazard to result in expected consequences?
5) Threat Assessment	What is the likelihood that a terrorist, natural hazard or dependency/locational hazard will occur to asset?
6) Risk/Resilience Assessment	What is anticipated total risk and asset resilience? **Risk** = Consequences x Vulnerability x Threat **Resilience** = Service Outage x Vulnerability x Threat
7) Risk/Resilience Management	What options are there to reduce risk and increase resilience? How much will each mitigation measure reduce risk and increase resilience? How much does each mitigation measure cost? What is the calculated benefit/cost ratio?

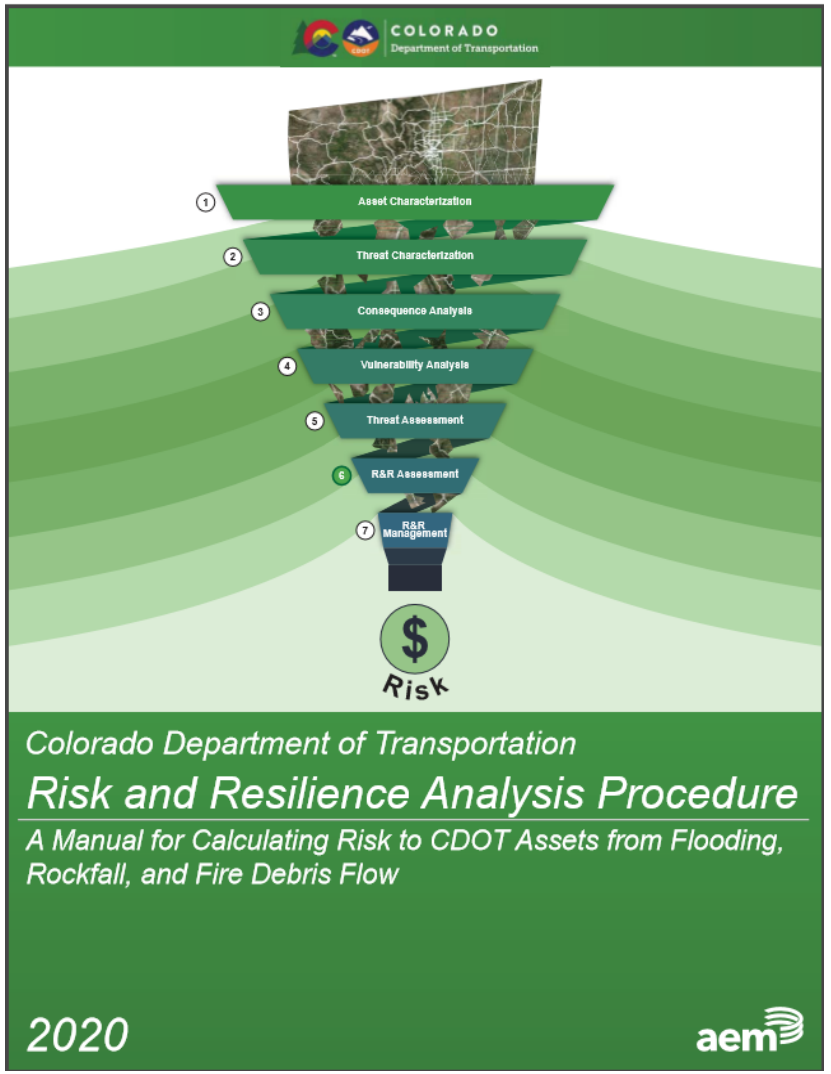
Key Concepts

Risk (R) → C x V x T

Risk *(R)* *($)*	→ *Level of operational uncertainty in a threat-filled environment*
Consequence (C) ($)	→ *Result of failure*
Vulnerability (V) (%)	→ *Susceptibility to the threat*
Threat Likelihood (T) (%)	→ *Potential of threat occurrence*

Risk and Resilience Manual

- Published August 2020 -- https://www.codot.gov/programs/planning/cdot-resilience-program
- Based on RAMCAP methodology used in the 2013 flood recovery.
- Refines and Standardizes the data, assumptions, and methodology for conducting risk assessment
- Step by step "Cookbook" on how to calculate risk
  - Flood
  - Rockfall
  - Fire / Debris flow



Allows us to Quantify Annualized Risk

Given the worst reasonable event, what are the consequences? ($)

Owner Cost

- Asset Replacement Cost

User Cost

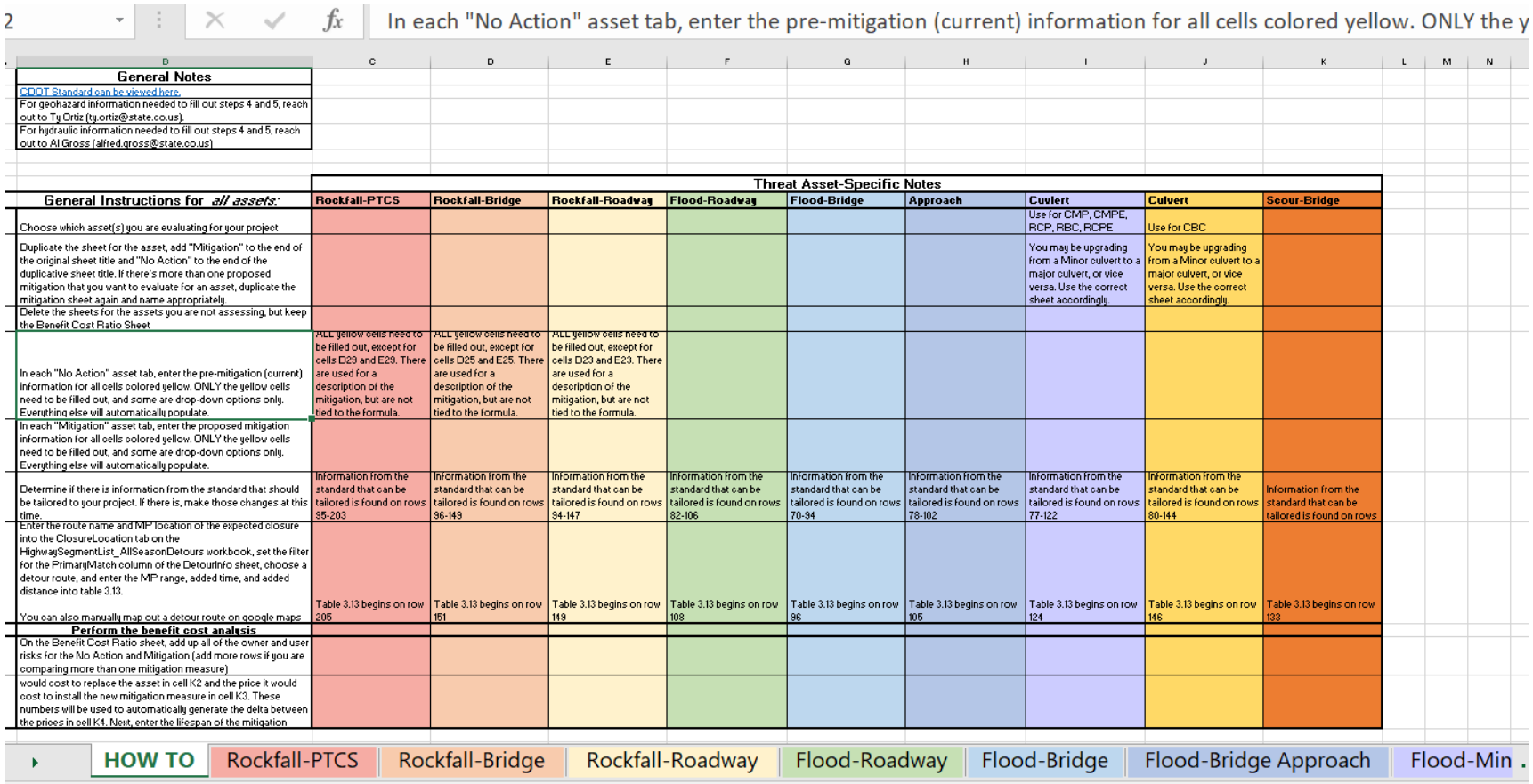
- Value of time (delay/detour)

Risk Tolerance

What level of risk are we willing to accept?

- What is our annual / programmatic risk threshold?
- Mitigating “owner risk” and “user risk” – what are our priorities?
- What is the B/C ratio at which we think it’s a good idea to invest in a resilient betterment?

Risk and Resiliency Excel Tool



In each "No Action" asset tab, enter the pre-mitigation (current) information for all cells colored yellow. ONLY the y

General Notes
CDOT Standard can be viewed here.
For geohazard information needed to fill out steps 4 and 5, reach out to Ty Ortiz (ty.ortiz@state.co.us).
For hydraulic information needed to fill out steps 4 and 5, reach out to Al Gross (alfred.gross@state.co.us)

	Threat Asset-Specific Notes								
General Instructions for *all assets:*	Rockfall-PTCS	Rockfall-Bridge	Rockfall-Roadway	Flood-Roadway	Flood-Bridge	Approach	Culvert	Culvert	Scour-Bridge
Choose which asset(s) you are evaluating for your project							Use for CMP, CMPE, RCP, RBC, RCPE	Use for CBC	
Duplicate the sheet for the asset, add "Mitigation" to the end of the original sheet title and "No Action" to the end of the duplicative sheet title. If there's more than one proposed mitigation that you want to evaluate for an asset, duplicate the mitigation sheet again and name appropriately.							You may be upgrading from a Minor culvert to a major culvert, or vice versa. Use the correct sheet accordingly.	You may be upgrading from a Minor culvert to a major culvert, or vice versa. Use the correct sheet accordingly.	
Delete the sheets for the assets you are not assessing, but keep the Benefit Cost Ratio Sheet									
In each "No Action" asset tab, enter the pre-mitigation (current) information for all cells colored yellow. ONLY the yellow cells need to be filled out, and some are drop-down options only. Everything else will automatically populate.	ALL yellow cells need to be filled out, except for cells D29 and E29. There are used for a description of the mitigation, but are not tied to the formula.	ALL yellow cells need to be filled out, except for cells D25 and E25. There are used for a description of the mitigation, but are not tied to the formula.	ALL yellow cells need to be filled out, except for cells D23 and E23. There are used for a description of the mitigation, but are not tied to the formula.						
In each "Mitigation" asset tab, enter the proposed mitigation information for all cells colored yellow. ONLY the yellow cells need to be filled out, and some are drop-down options only. Everything else will automatically populate.									
Determine if there is information from the standard that should be tailored to your project. If there is, make those changes at this time.	Information from the standard that can be tailored is found on rows 95-203	Information from the standard that can be tailored is found on rows 96-149	Information from the standard that can be tailored is found on rows 94-147	Information from the standard that can be tailored is found on rows 82-106	Information from the standard that can be tailored is found on rows 70-94	Information from the standard that can be tailored is found on rows 78-102	Information from the standard that can be tailored is found on rows 77-122	Information from the standard that can be tailored is found on rows 80-144	Information from the standard that can be tailored is found on rows
Enter the route name and MP location of the expected closure into the ClosureLocation tab on the HighwaySegmentList_AllSeasonDetours workbook, set the filter for the PrimaryMatch column of the DetourInfo sheet, choose a detour route, and enter the MP range, added time, and added distance into table 3.13. You can also manually map out a detour route on google maps	Table 3.13 begins on row 205	Table 3.13 begins on row 151	Table 3.13 begins on row 149	Table 3.13 begins on row 108	Table 3.13 begins on row 96	Table 3.13 begins on row 105	Table 3.13 begins on row 124	Table 3.13 begins on row 146	Table 3.13 begins on row 133
Perform the benefit cost analysis									
On the Benefit Cost Ratio sheet, add up all of the owner and user risks for the No Action and Mitigation (add more rows if you are comparing more than one mitigation measure)									
would cost to replace the asset in cell K2 and the price it would cost to install the new mitigation measure in cell K3. These numbers will be used to automatically generate the delta between the prices in cell K4. Next, enter the lifespan of the mitigation									

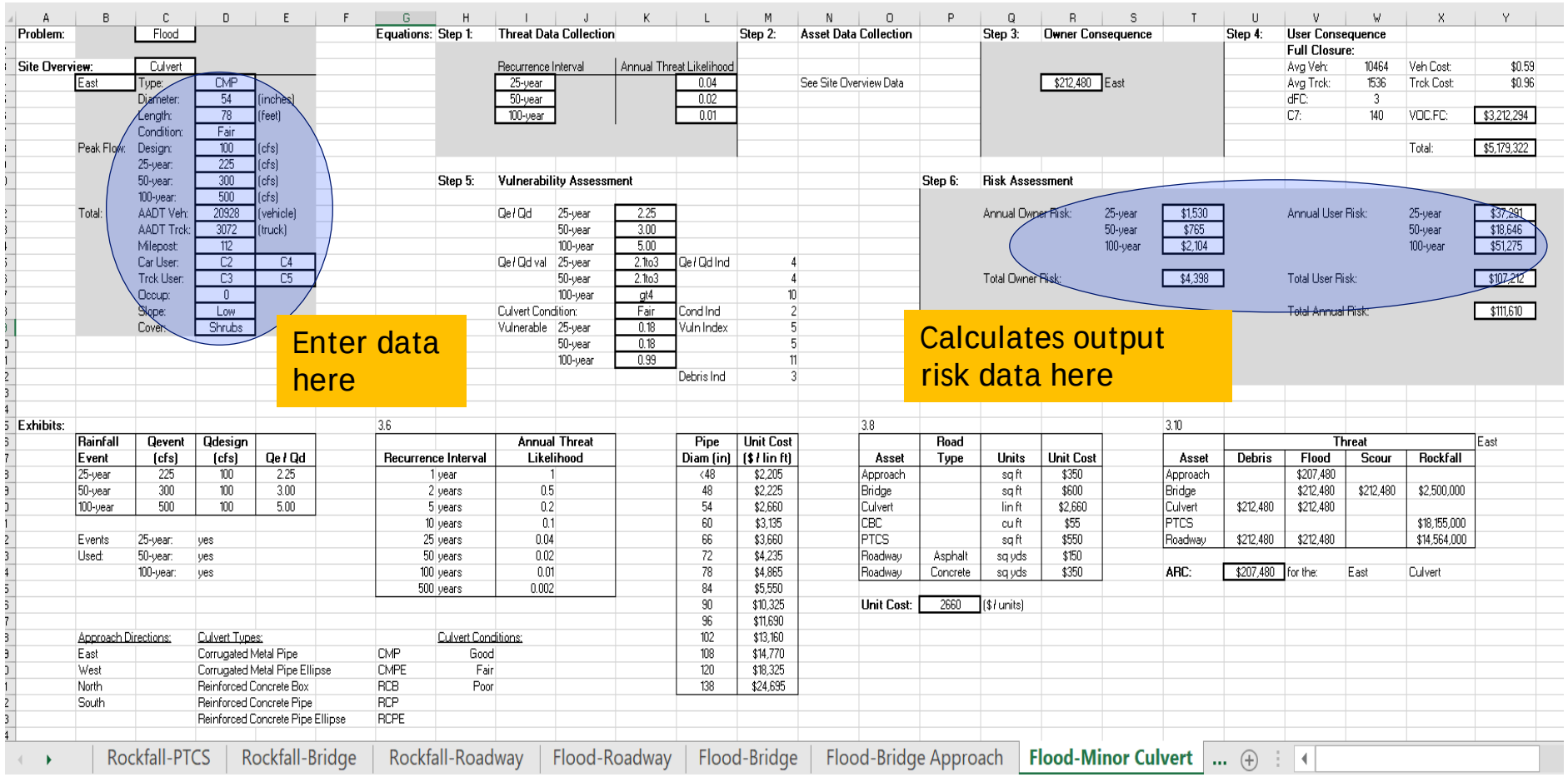
HOW TO | Rockfall-PTCS | Rockfall-Bridge | Rockfall-Roadway | Flood-Roadway | Flood-Bridge | Flood-Bridge Approach | Flood-Min

Spreadsheet tabs for each threat asset pair

Built in Benefit/ Cost calculater

Video Tutorial available on CDOT Resiliency Website

New Excel Templates
Based on Standard Model and Assumptions



Spreadsheet tabs for each threat asset pair

Calculating Reduced Risk and Benefit Cost

Run the risk model twice

- Once to determine the existing condition and establish baseline risk costs
- A second time to analyze the risk reduction of the mitigation proposed
- Estimate cost of proposed mitigation
- Those values can be used to determine a Benefit to Cost ratio

EQUATION 5.1.3

$$Mitigation\ Annual\ Cost = Mitigation\ Present\ Cost\ x\ \frac{i\ x\ (1+i)^n}{(1+i)^n - 1}$$

Where:

i = discount rate (3.3% for CDOT)

n = life expectancy of mitigation

EQUATION 5.1.1

$$B/C = \frac{Mitigation\ Benefit}{Annual\ Cost\ of\ Mitigation}$$

RnR Tool Results

70A (3 different rockfall treatments)

3000 kJ Barrier

	Annual Risk		
	Owner Risk	User Risk	**Total Risk**
No Action	$101,565	$4,252,321	**$4,353,886**
Mitigation	$48,017	$2,010,388	**$2,058,406**

Average Mitigation Benefit		
Owner	User	**Total**
$53,548	$2,241,932	**$2,295,480**

Mitigation Cost Analysis	
Cost of asset replacement:	$462,333.00
Cost of new mitigation:	$736,568.00
Cost delta:	**$274,235.00**
Life span of mitigation:	**20**
Mitigation Annual Cost	
$18,948	

B/C		
Owner	User	**Total**
2.8	118.3	**121.1**

Attenuator

	Annual Risk		
	Owner Risk	User Risk	**Total Risk**
No Action	$101,565	$4,252,321	**$4,353,886**
Mitigation	$64,477	$2,699,507	**$2,763,984**

Average Mitigation Benefit		
Owner	User	**Total**
$37,088	$1,552,814	**$1,589,902**

Mitigation Cost Analysis	
Cost of asset replacement:	$462,333.00
Cost of new mitigation:	$887,890.00
Cost delta:	**$425,557.00**
Life span of mitigation:	**20**
Mitigation Annual Cost	
$29,403	

B/C		
Owner	User	**Total**
1.3	52.8	**54.1**

Concrete Barrier

	Annual Risk		
	Owner Risk	User Risk	**Total Risk**
No Action	$101,565	$4,252,321	**$4,353,886**
Mitigation	$69,963	$2,929,213	**$2,999,176**

Average Mitigation Benefit		
Owner	User	**Total**
$31,602	$1,323,108	**$1,354,710**

Mitigation Cost Analysis	
Cost of asset replacement:	$462,333.00
Cost of new mitigation:	$594,310.00
Cost delta:	**$131,977.00**
Life span of mitigation:	**10**
Mitigation Annual Cost	
$15,710	

B/C		
Owner	User	**Total**
2.0	84.2	**86.2**

RnR Tool Results

550B (Rockfall Barriers installed)

	Annual Risk		
	Owner Risk	User Risk	**Total Risk**
No Action	$134,135	$265,632	**$399,767**
Mitigation	$63,416	$125,584	**$189,000**

Average Mitigation Benefit		
Owner	User	**Total**
$70,719	$140,048	**$210,767**

Mitigation Cost Analysis	
Cost of asset replacement:	$812,778.00
Cost of new mitigation:	$2,396,085.00
Cost delta:	**$1,583,307.00**
Life span of mitigation:	**20**
Mitigation Annual Cost	
$109,397	

B/C		
Owner	User	**Total**
0.6	1.3	**1.9**

24A – (5 Culverts replaced)

	Annual Risk		
	Owner Risk	User Risk	**Total Risk**
No Action	$305,782	$3,908,143	**$4,213,925**
Mitigation	$202,432	$2,449,558	**$2,651,989**

Average Mitigation Benefit		
Owner	User	**Total**
$103,351	$1,458,585	**$1,561,935**

Mitigation Cost Analysis	
Cost of asset replacement:	$7,665,555.00
Cost of new mitigation:	$7,676,555.00
Cost delta:	**$11,000.00**
Life span of mitigation:	**100**
Mitigation Annual Cost	
$378	

B/C		
Owner	User	**Total**
273.6	3861.8	**4135.5**

2D Quick Check Statewide Demo (1)

I-13-G (Park County, CO)

EXISTING:
69-ft long by 30-ft wide timber bridge

CDOT CRITERIA:
25-year storm event

MITIGATION OPTIONS (2dQC):
1. Replace-In-Kind
2. Concrete Box Culvert
   (3 cells of 10-ft x 7-ft)

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Problem:**		Flood									
2												
3												
4	**Step 1:**	**Threat Data Collection**										
5												
6		Recurrence Interval			Annual Threat Likelihood							
7		50			0.02							
8		100			0.01							
9												
10												
11												
12												
13	**Step 2:**	**Asset Data Collect**										
14	**Site Overview:**		CBC									
15		East	Type:	CBC		NBI 120A	CDOT Structure Type			Staff Bridge Major Structure Inventory (link)		
16			Width:	10	(feet)	NBI 48	Max Spans (round to integer)			Staff Bridge Major Structure Inventory (link)		
17			Length:	40	(feet)	NBI 49	Structure Length			Staff Bridge Major Structure Inventory (link)		
18			Height:	7	(feet)					Staff Bridge Major Structure Inventory (link)		
19			# of Cells:	3		NBI 45	Maint Spans Unit			Staff Bridge Major Structure Inventory (link)		
20			Culv Cond:	7	*assumed*	NBI 62	Culvert			Staff Bridge Major Structure Inventory (link)		
21			Ch&Pr Cnd:	7	*assumed*	NBI 61	Channel & Chnl. Protection Condition			Staff Bridge Major Structure Inventory (link)		
22		Peak Flow:	Design:	679	(cfs)							
23			25-year:	360	(cfs)							
24			50-year:	483	(cfs)							
25			100-year:	679	(cfs)							
26		Total:	AADT Veh:	2200	(vehicle)	OTIS	Avg. Annual Daily Traffic (all	CDOT OTIS Data Search Platform				
27			AADT Trck:	152	(truck)	OTIS	Avg. Annual Daily Traffic (tru	CDOT OTIS Data Search Platform				
28			Milepost:	227.2		NBI 11	CDOT Mile Post	Staff Bridge Major Structure Inventory (link)				
29			Car User:	C2	C4							
30			Trck User:	C3	C5							
31			Occup:	0								
32			Slope:	3.30%								
33			Slope Val:	Low								
34			Cover:	Shrubs								

2D Quick Check Statewide Demo (2)

K-16-Y (Fremont County)

EXISTING:
63.5-ft bridge

MITIGATION BENEFIT(2dQC):
Removed from scour critical list

1. Updates to scour calculation
2. Reduced assumptions in 2D
3. Riprap countermeasures

Problem: Scour

Step 1: Threat Data Collection
See Vulnerability Assessment

Step 2: Asset Data Collect
Site Overview: Bridge

South	Type:	2	(lanes)
	Width:	60	(feet)
	Length:	63.5	(feet)
	Class:	17	
	Water Adq:	8	
	Ch Prot:	6	
	Sub Cond:	7	
Road:	Width:	30	(feet)
Total:	AADT Veh:	5100	(vehicle)
	AADT Trck:	224.4	(truck)
	Milepost:	7.83	
	Car User:	C2	C4
	Trck User:	C3	C5

Step 3: Owner Consequence
$38,867,000 South

Step 4: User Consequence
Full Closure:

Avg Veh:	5100	Veh Cost:	$0.53	Dt:	7 mins
Avg Trck:	224.4	Trck Cost:	$0.36	Veh:	$10.62
dFC:	180			Trck:	$25.31
CT:	3.1	VOC.FC:	$1,799,229	O:	1.77
				LW.FC:	$2,132,472
		Total:	$3,931,701		

Step 5: Vulnerability Assessment

Functional Classification:	17	Overtopping Frequency:	5
Substructure Condition:	7	Annual Probability:	0.02
Channel Protection:	6	Return Period:	11to100
Water Adequacy:	8	Scour Vulnerability:	6
Culvert Condition:	6	Probability of Failure:	0.00025

Step 6: Risk Assessment

Annual Owner Risk:	$9,717	Annual User Risk:	$983

Risk: $10,700

Routine Inspection
Colorado Department of Transportation
Structure Inspection and Inventory Report (English Units)

Bridge Key: K-16-Y | Inspection Date: 08/14/2018 | Sufficiency Rating: 57.5 | ND

CDOT Asset Resiliency Mapping Application

Present Value of Avg. Mitigation Benefit
$154,857

Assume:
3.3% inflation
20-years

2D Quick Check Statewide Demo (1)

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   (3 cells of 10-ft x 7-ft)

	Annual Risk		
	Owner Risk	User Risk	**Total Risk**
No Action - Existing Bridge (69'x30')	$9,153	$38,550	**$47,703**
Mitigation - Replace-in-kind (69'x30')	$1,571	$6,618	**$8,189**
Mitigation - Concrete Box Culvert (3-10'x7')	$5,744	$1,077	**$6,821**

Average Mitigation Benefit		
Owner	User	**Total**
$3,409	$37,473	**$40,882**

Present Value of Avg. Mitigation Benefit
$1,190,653

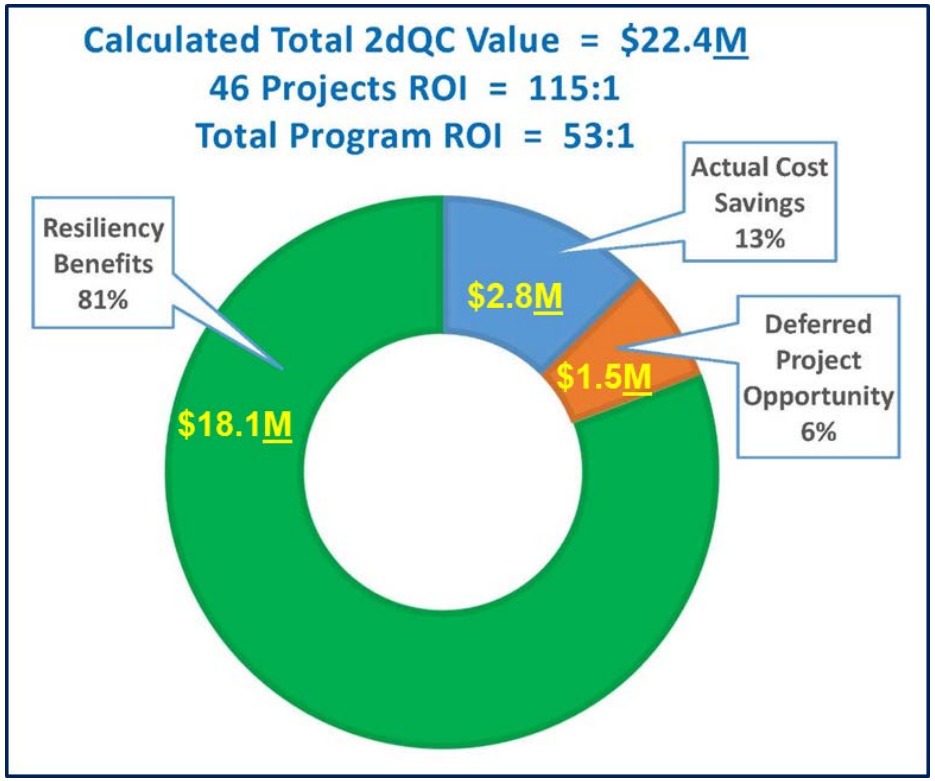
$$P = A\left[\frac{(1+i)^n - 1}{i(i+i)^n}\right]$$

Assume:
3.3% inflation
100-yr CBC lifespan

2D Quick Check Statewide Initiative

Design Enhancements & Savings

Innovation Functions	
Structure Updates	25
Channel/Bank Improvements	10
Scour Evaluation	18
Roadway Enhancements	6
Methodology Alternatives	18
Safety	14
Savings	17
Total =	**108**

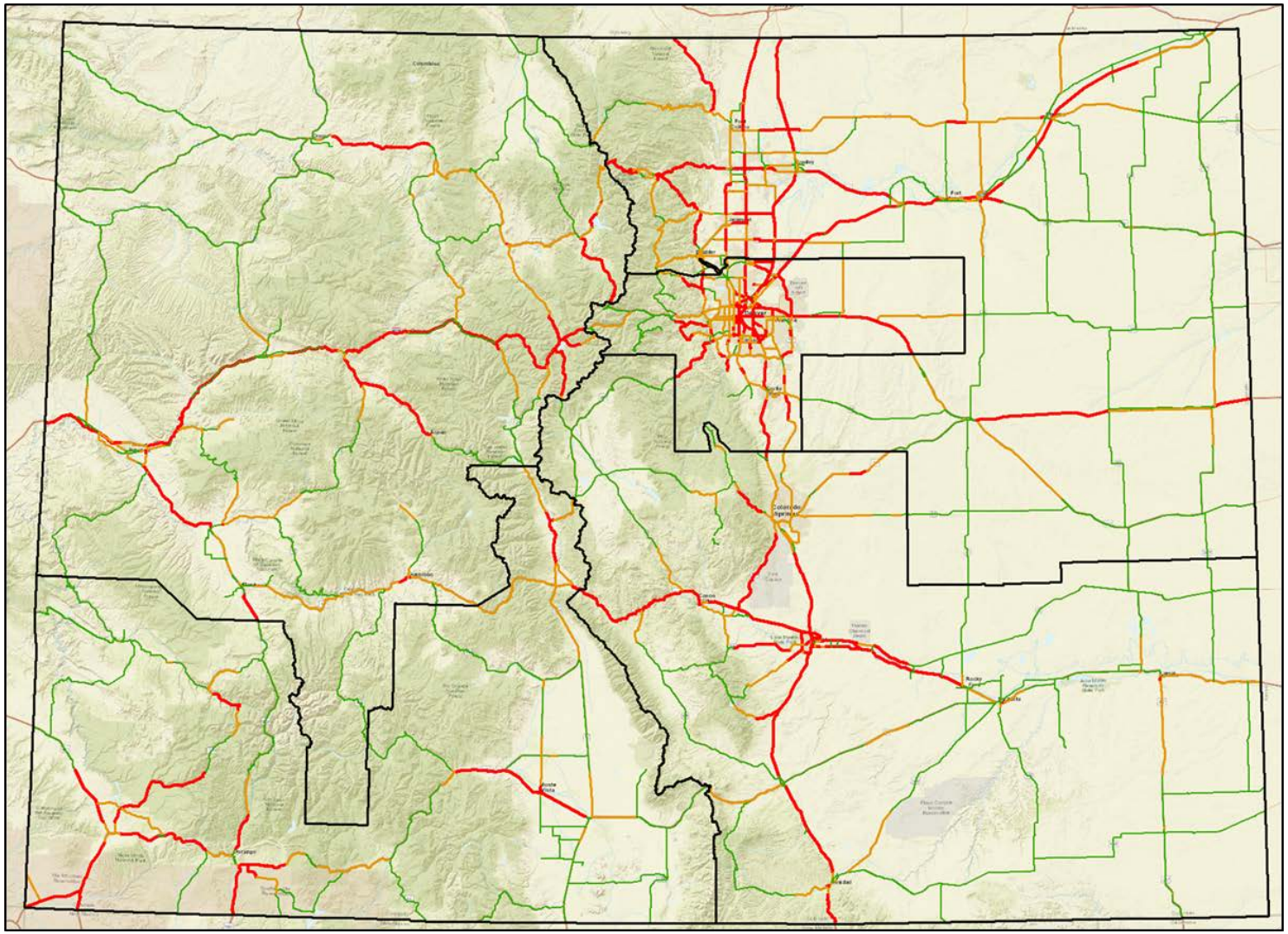


Criticality Metric

AADT	16.7%
ASHTO Road Classification	16.7%
Freight $ (County)	16.7%
Tourism $ (County)	16.7%
SoVI	16.7%
Redundancy (2015 v)	16.7%

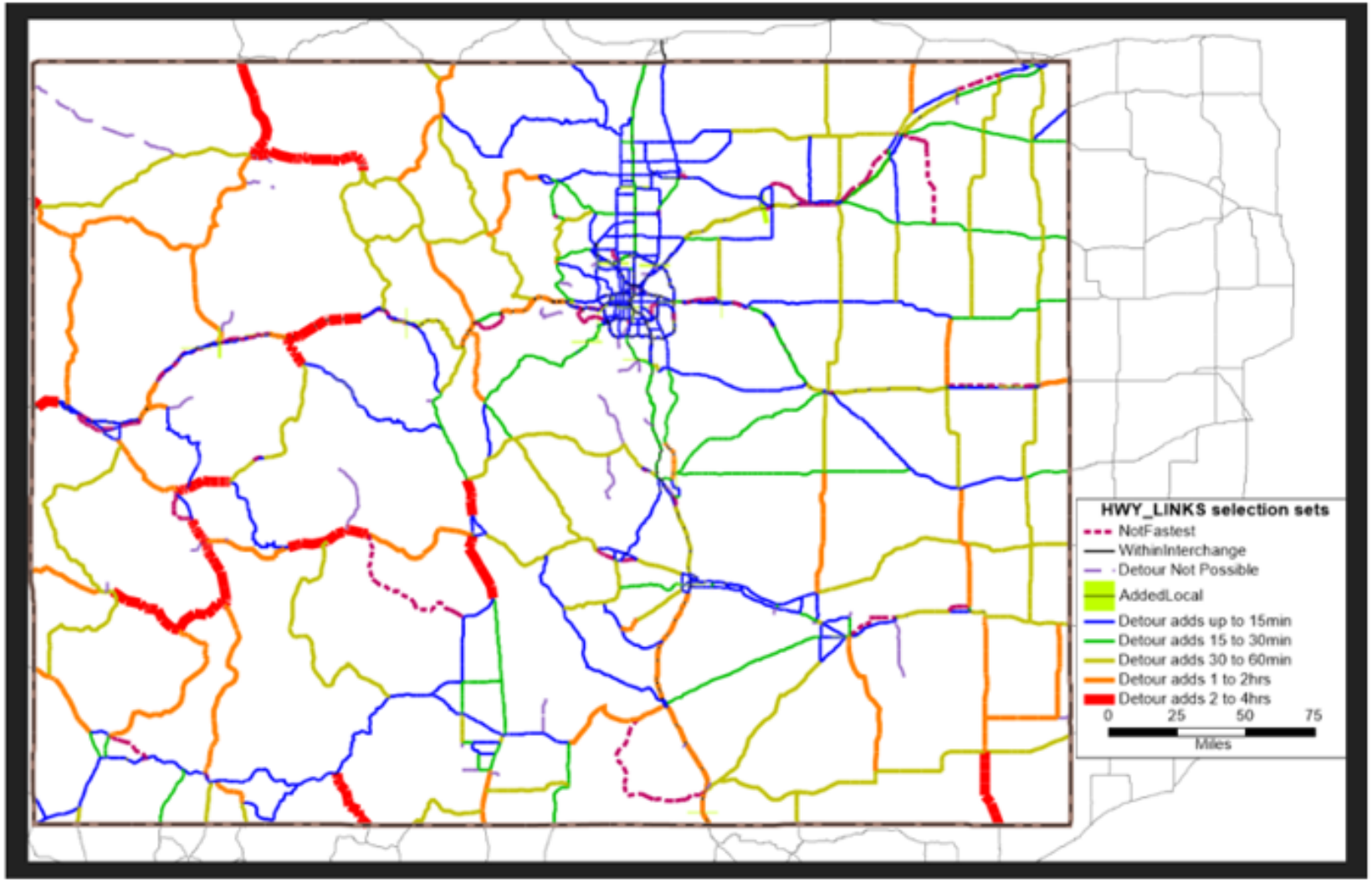
Equal Weight

- 53.8% Low
- 25.5% Moderate
- 20.7% High



https://www.codot.gov/programs/planning/assets/risk-and-resiliency/asset-criticality-i-70-pilot.pdf

Detour Calculation Tool



Developed by: Scott Ramming- CDOT Statewide Model Team
Nate Rodgers- CDOT GIS

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Thank You! For more information:

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