



**COLORADO**  
Department of Transportation

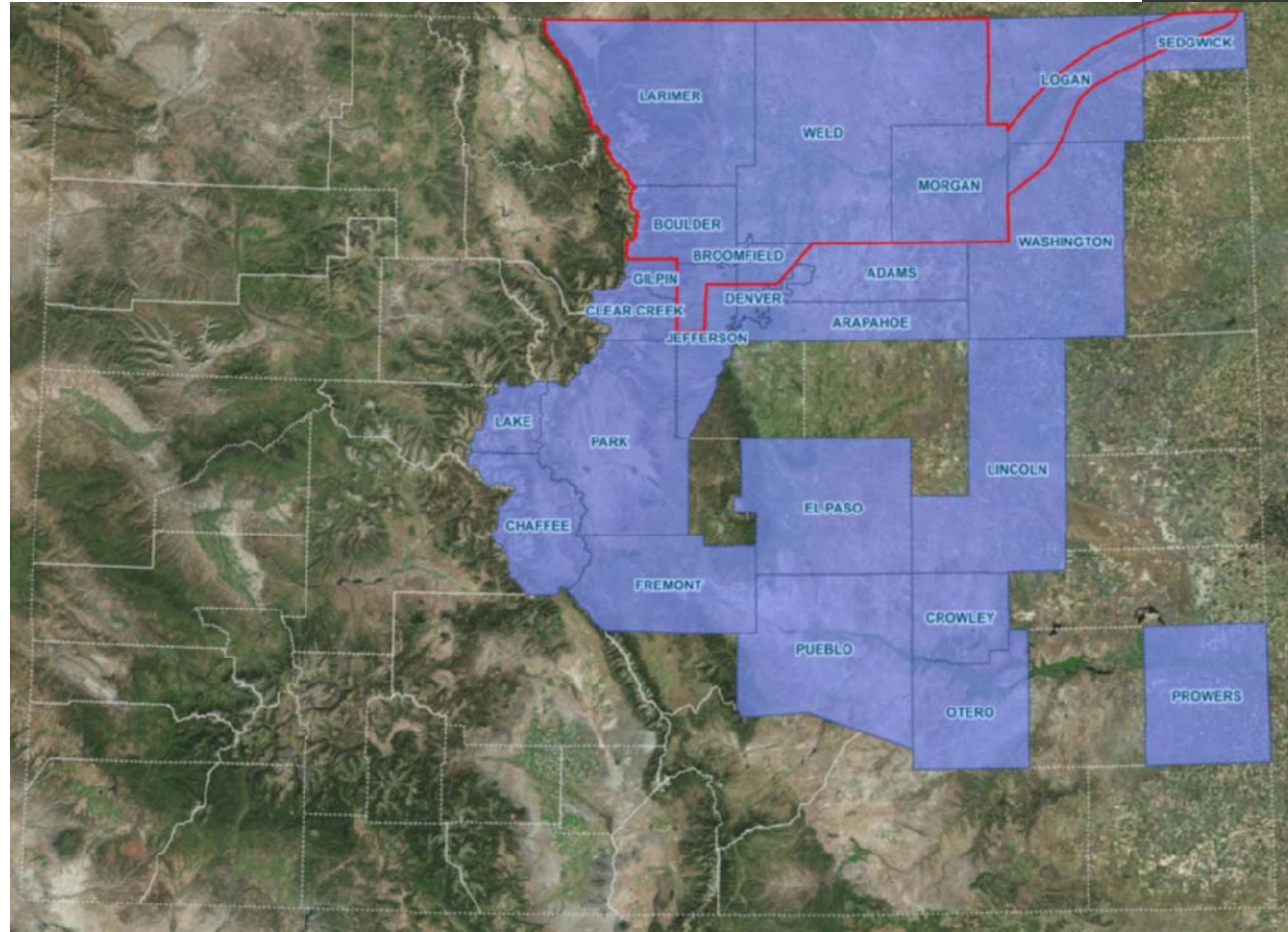


Jeff Sudmeier  
Colorado Department of Transportation

Flooding, Vulnerability and Risk, Oh My!  
July 2015

# 2013 Flood Event

- Sept. 12<sup>th</sup> 2013 – Historic Flood Event
- Over \$1B in damages
- Disaster Area:
  - 2380 square miles affected;  
400 miles of roadway
  - 120 bridges & structures impacted
  - 1800 homes destroyed; 17,000 homes damaged



**Flood Impacted Counties. Counties with impacted Federal-Aid Roads outlined in Red.**



# 2013 Flood Event

Governor Hickenlooper declared disaster emergency on Sept. 12 2013 and directed CDOT to make all roadways passable by Dec. 1 2013.



# Building Back Better



SEPTEMBER 26, 2013

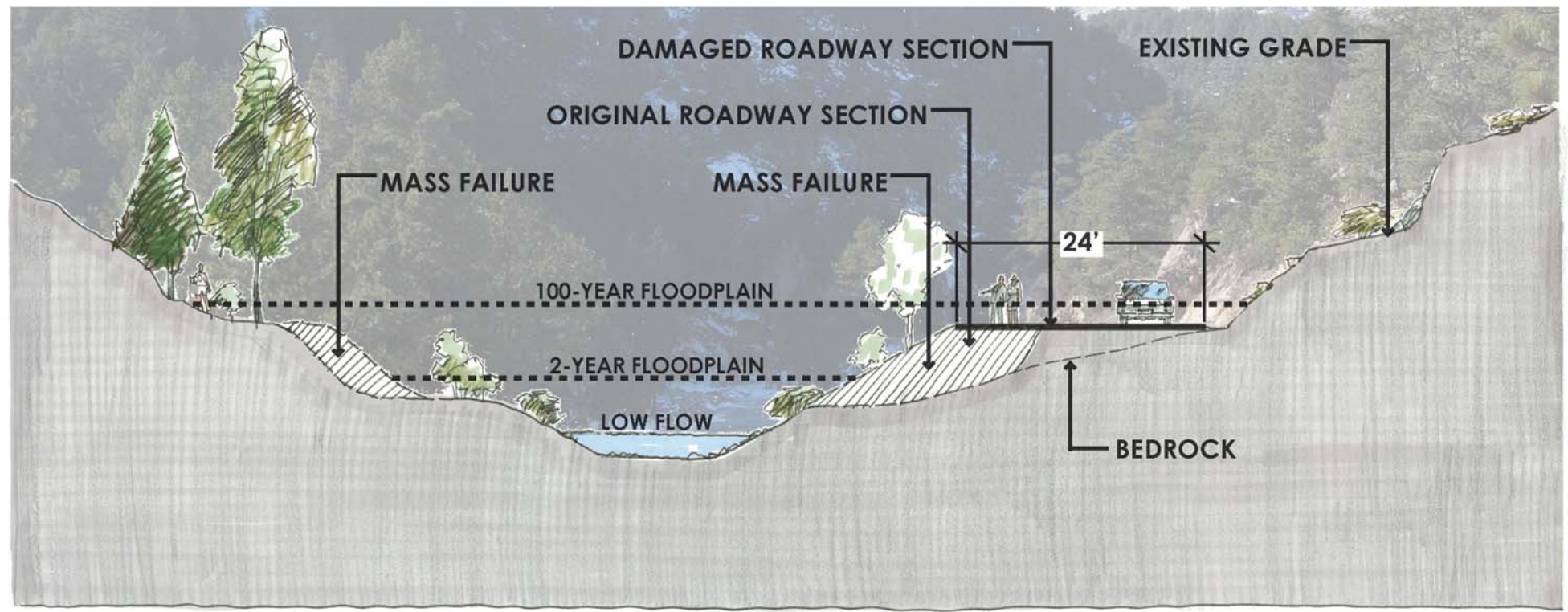


NOVEMBER 11, 2013

*“Resilience is the ability of communities to rebound, positively adapt to, or thrive amidst changing conditions or challenges – including disasters and climate change – and maintain quality of life, healthy growth, durable systems and conservation of resources for present and future generations.”*



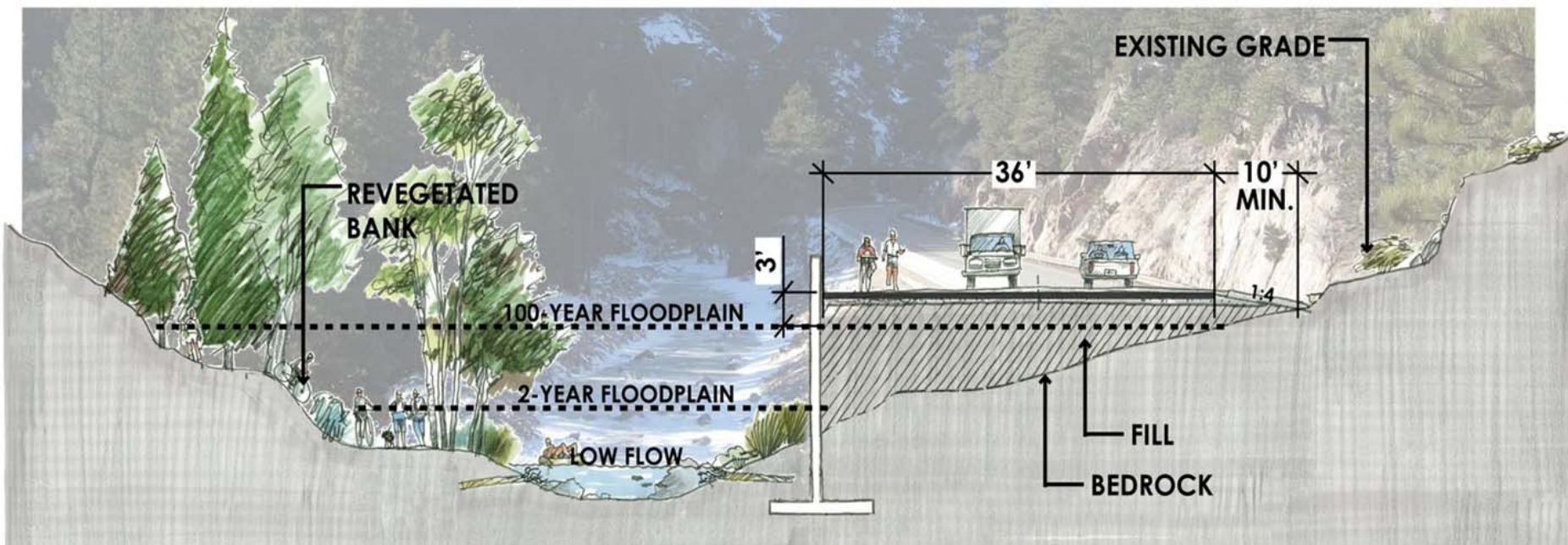
# ORIGINAL & DAMAGED TYPICAL SECTION



Philosophy of Repairs – US 36 Example 1



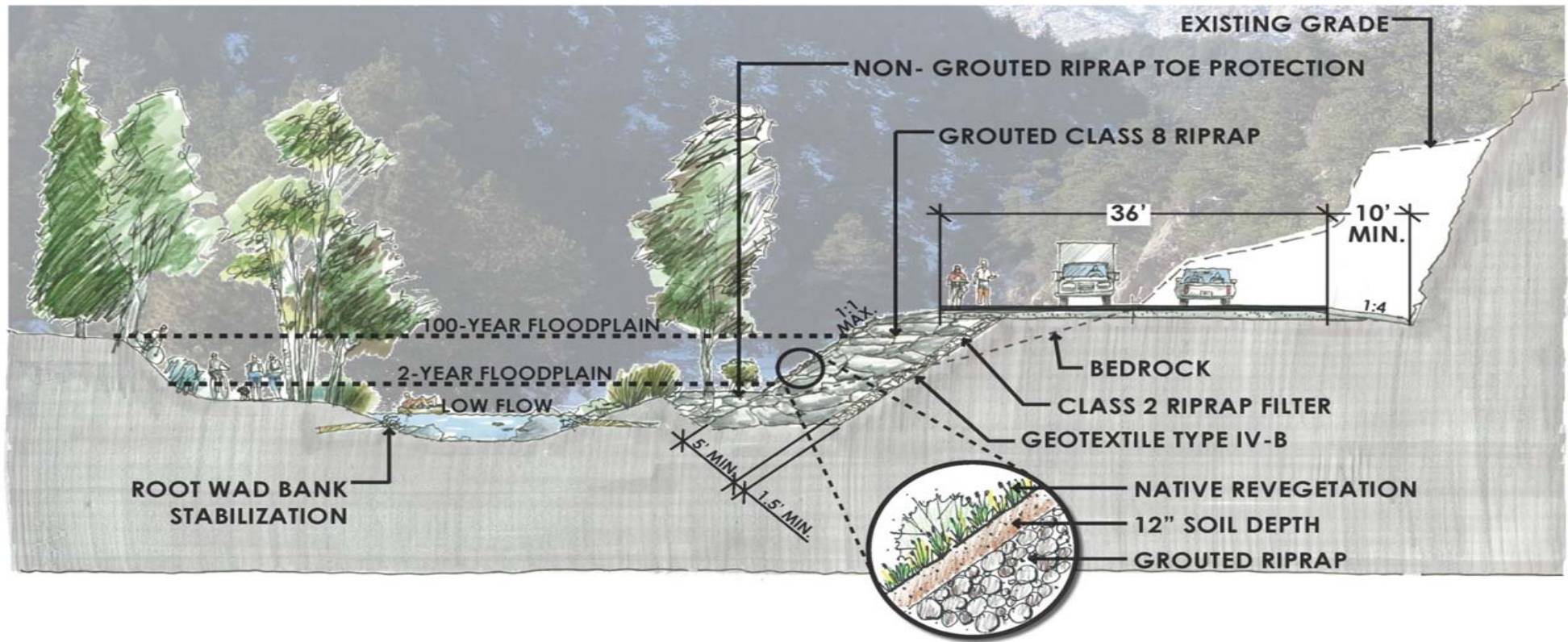
# CONVENTIONAL REPAIR TYPICAL SECTION



## Philosophy of Repairs – US 36 Example 2



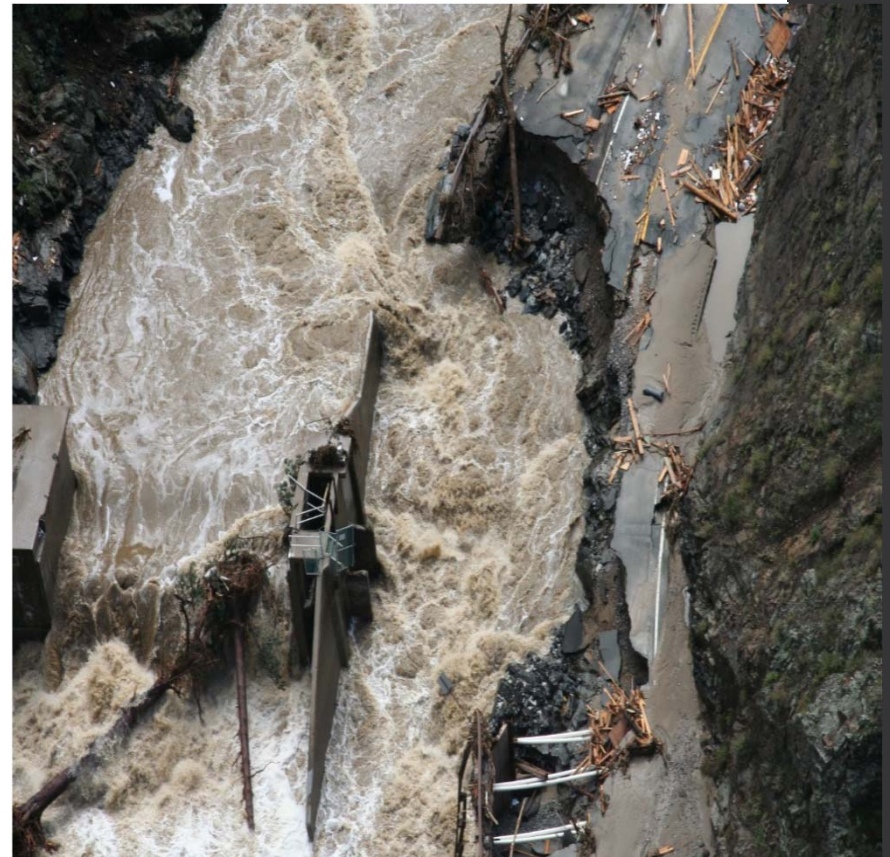
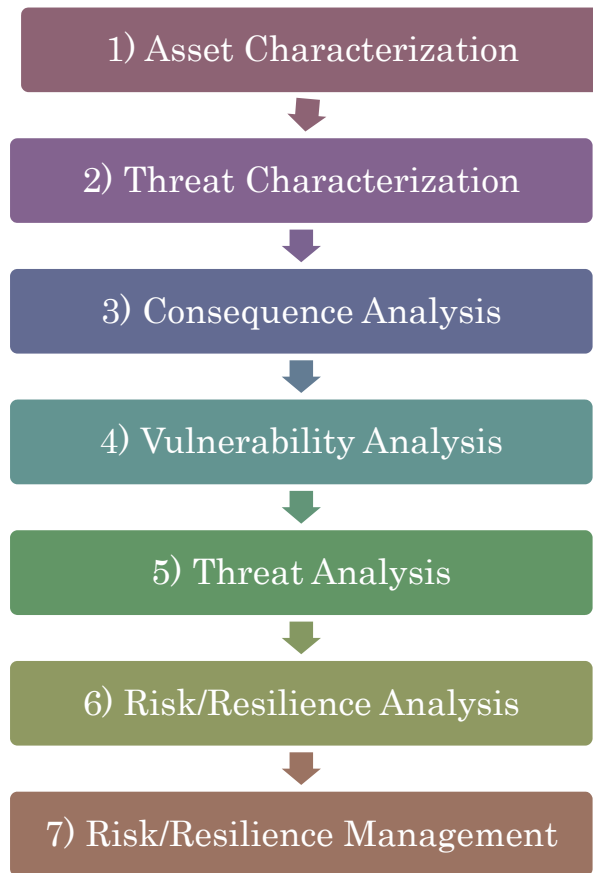
# PROPOSED REPAIR TYPICAL SECTION



## Philosophy of Repairs – US 36 Example 3



# Risk & Resilience Analysis 101





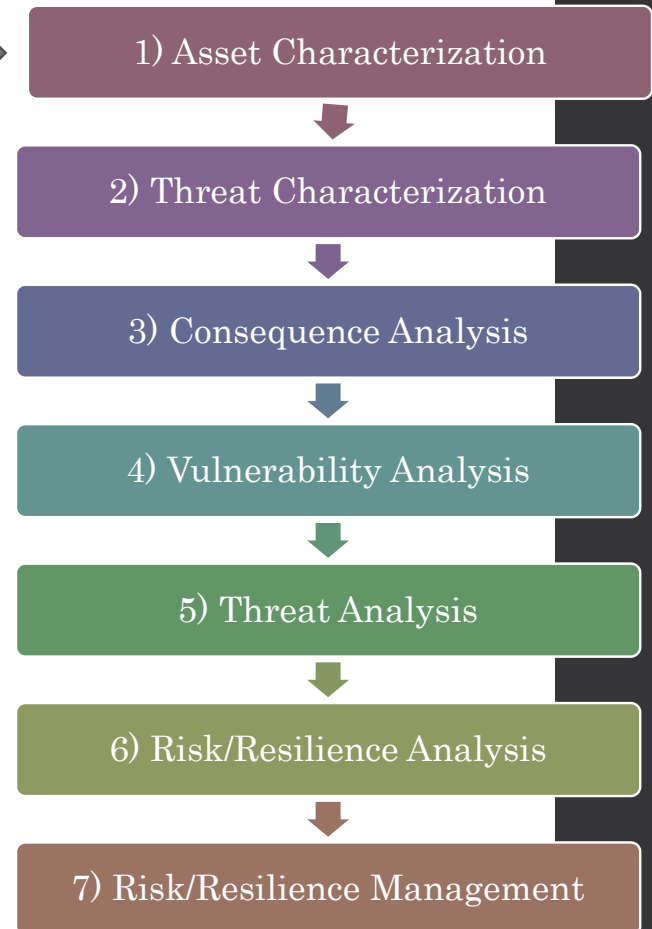
# Step 1 – Asset Characterization

Assets categorized as:

- Roadway prism
- Structures

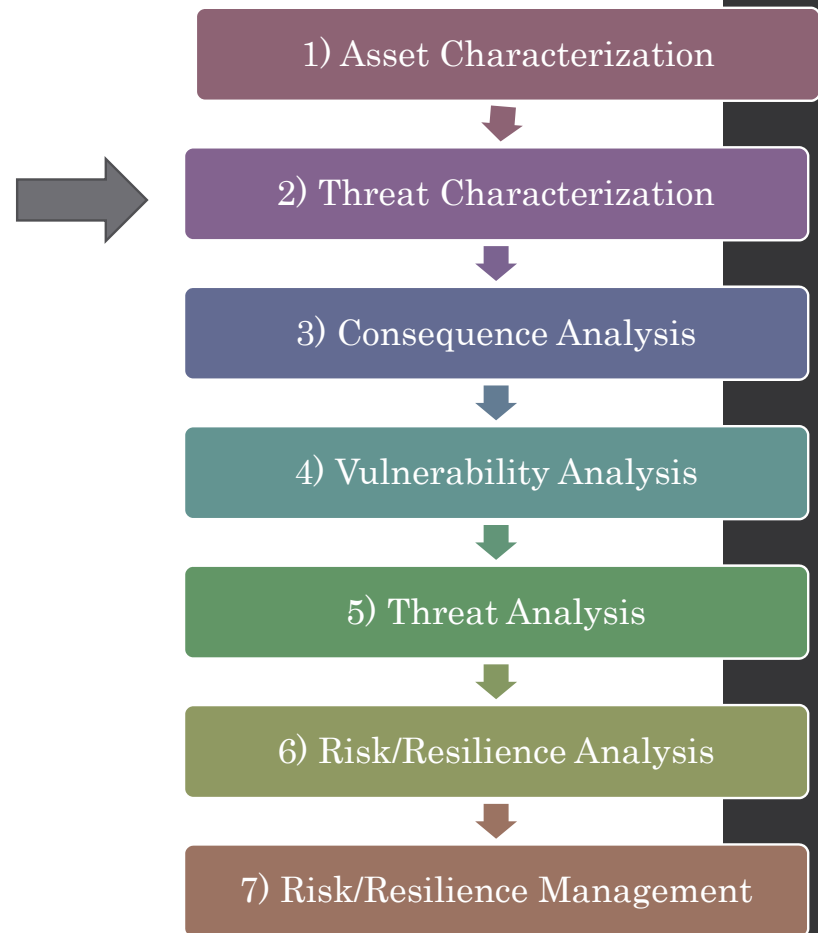
Assessments conducted at three levels:

- Site Level
- Segment Level
- Corridor Level



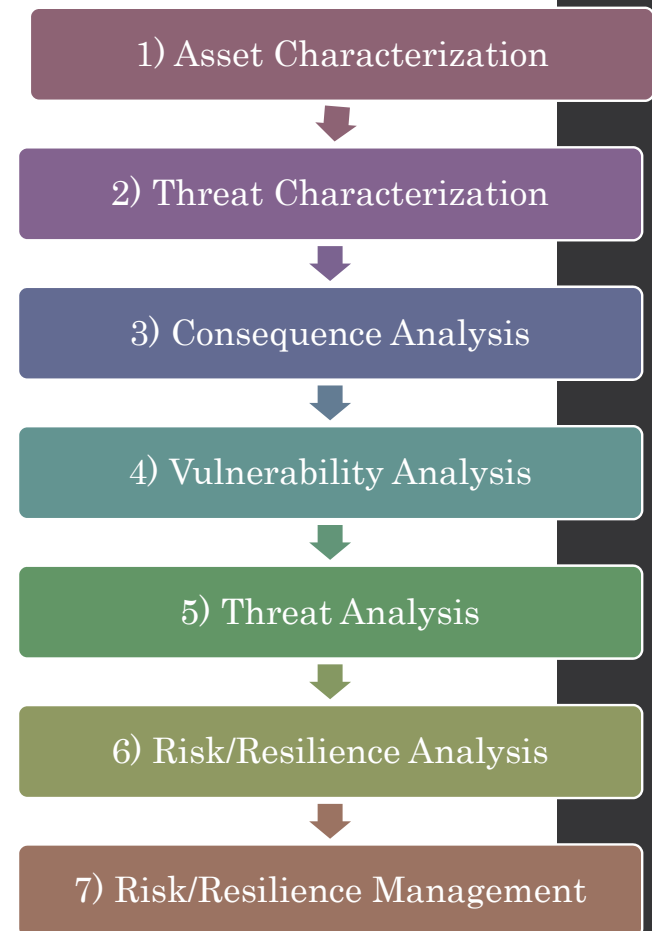
# Step 2 – Threat Characterization

- Flooding (25, 50, 100, 500, and greater than 500 year flood events)
- Rockfalls (where applicable)
- Mudslide/debris flow (where applicable)
- Landslides (where applicable)



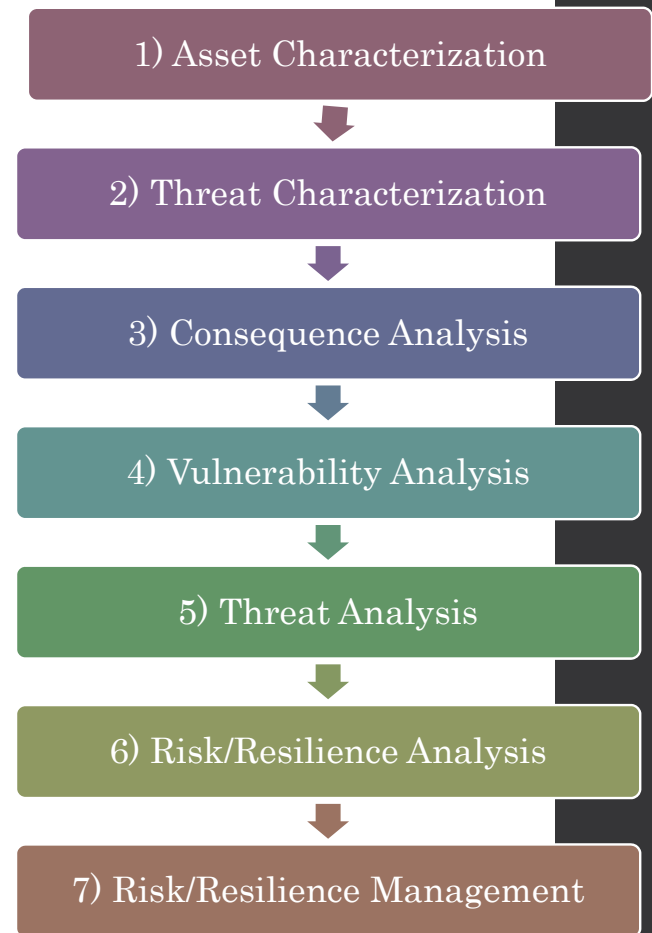
# Step 3 – Consequence Analysis

- **Full replacement** – the cost to replace the damaged facilities at each site if the entire site, segment or corridor were destroyed in a future event. (This information supports the estimation of consequences to future events.)
- **Restore-in-Kind** – the cost to restore the site to its pre-event condition
- **Replace to Standard** – the cost to restore the site to current design standards.
- **Any identified design alternative** – the cost for design alternatives (those design alternatives or “betterments” that are specifically considered to reduce the likelihood asset loss in a future event).



# Step 4 – Vulnerability Analysis

- Vulnerability is the *probability* that the estimated consequences will occur if a specific threat were to occur in the future.
- Vulnerability values are represented as percentages ranging from zero to one, with zero meaning the estimated consequences will not occur, and one meaning the estimated consequence will occur.



# Step 5 – Threat Analysis

- Determine likelihood of identified threats from Step 2.
- Flood events assessed for 25yr, 50yr, 100yr, 500yr, and greater than 500yr flood events.



# Step 6 – Risk & Resilience Analysis

$$Risk = C \times V \times T$$

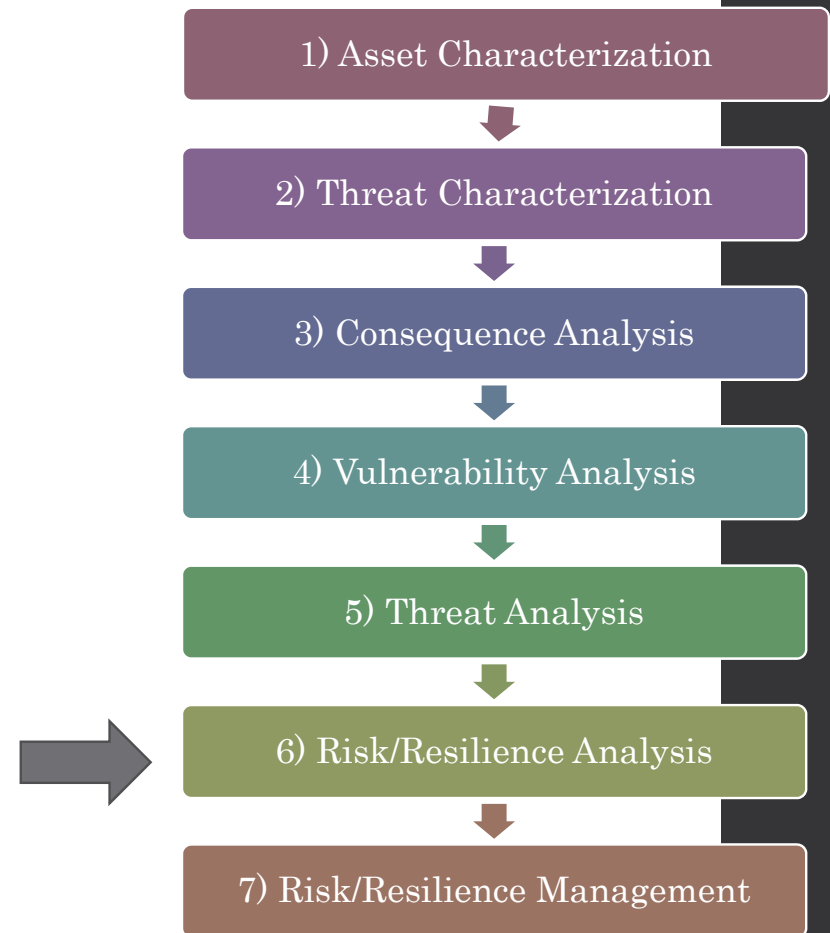
Where:

Risk = annual monetary risk to the asset(\$)

C = consequences for threat (\$)

V = vulnerability of the asset to a specific threat to incur the estimated consequences (probability)

T = threat likelihood within a given year (probability)



# Step 6 – Risk & Resilience Analysis

$$\textit{Resilience} = V \times T \times D \times \textit{Capacity Reduction}$$

Where:

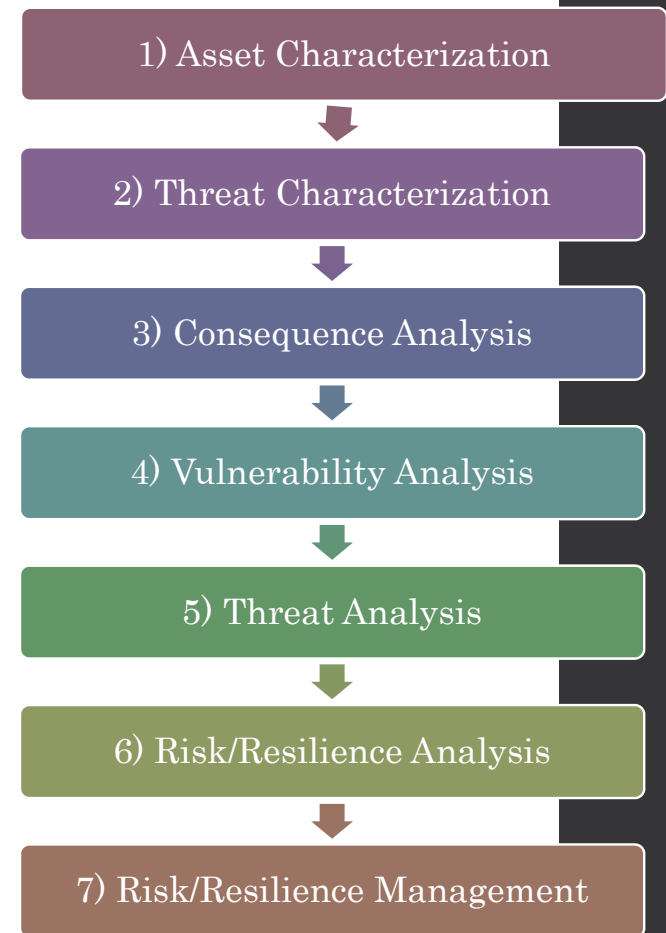
Resilience = Potential number of vehicles affected by natural threats in any given year (vehicles)

V = Vulnerability of the asset to a specific threat to incur the estimated consequences (probability)

T = Threat likelihood for a given threat within any given year (probability)

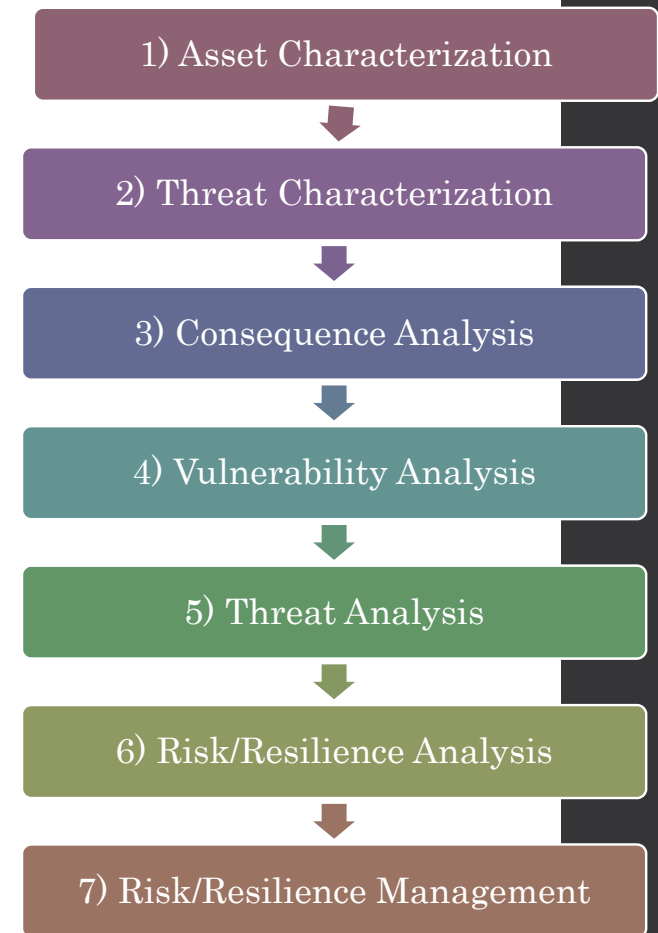
D = Duration of closure of asset (days)

Capacity Reduction = Average Annual Daily Traffic, or AADT, not serviced due to closure (vehicles/day)



# Step 7 – Risk/Resilience Management

Criticality Score		Score				
		1 Very Low Impact	2 Low Impact	3 Moderate Impact	4 High Impact	5 Very High Impact
Criterion 1	Road Classification	Local Private	Non-NHS Local Federal-Aid	Non-NHS Collector	Non-NHS Arterial	Defense Route Interstate Freeway Expressway Other NHS Road
Criterion 2	Need for Access by Essential Traffic	More than 48 Hours After Event	Within 48 Hours of Event	Within 12 Hours of Event	Within 2 Hours of Event	Immediately Following Event
Criterion 3	Traffic (AADT)	0 - 400	401 - 1000	1001 - 2000	2001 - 10,000	>10,000
Criterion 4	Capital Cost of Damaged Site	<\$500K	\$500K - \$1M	\$1M - \$5M	\$5M - \$10M	>\$10M
Criterion 5	Redundancy	Multiple-Redundant Routes with No/Minimal Loss in Capacity	Single Redundant Routes - No/Minimal Loss of Capacity	Multiple Redundant Routes - Some/Significant Loss of Capacity	Single Redundant Route - Significant Loss of Capacity	Single Point of Failure (No redundant routes or reroute distance >40 miles)
Criterion 6	Roadway Designation	No Unique Roadway Designation	Access to Non-Federal Recreational Facilities (ex. State parks, ski resorts, scenic by-ways)	High Level Social/historical Concern Areas (ex. historical bridges, battlefields)	High Level Environmental Concern Areas (ex. Wildlife, endangered species)	Federal Land Access (ex. National Parks)



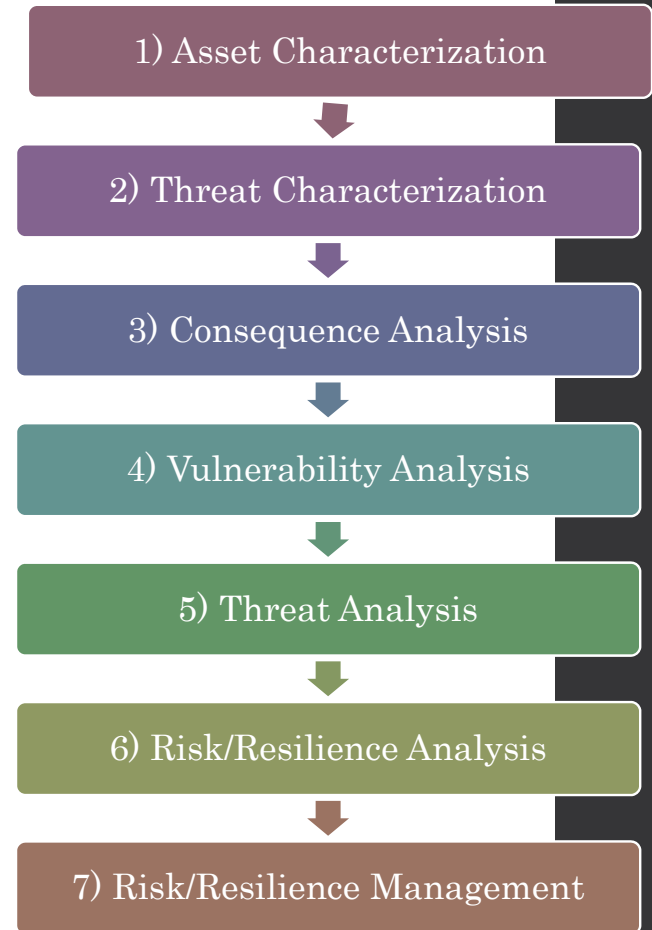


# Step 7 – Risk/Resilience Management

Utilizing the Criticality Score of each site, asset, corridor, a Resilience Index was developed.

## Resilience Index

Criticality Score	Criticality Rating	Resilience Index Score (RI)
6 to 13	Low	1.0
14 to 21	Moderate	2.0
22 to 30	High	3.0



# Example Application

US 34A Milepost 115.00-115.60

Criticality Score - 23



Criticality Ranking	Description	Score
Criteria 1: Road Classification	Principal Arterial	4
Criteria 2: Need for Access by Essential Traffic	Need to restore essential traffic within 12 hours of event	3
Criteria 3: Traffic (AADT)	12,000 veh/day	5
Criteria 4: Capital Cost of Damaged Site	\$14,903,600	5
Criteria 5: Redundancy	US 34A (AADT=12,000) - US 85C (AADT=18,000)- SH 52A (AADT=9,700)-I-76 (AADT= 12,000) - US 34A Total re-route distance 105.5 miles	5
Criteria 6: Roadway Designation	No unique roadway designation	1
<b>Total score</b>		<b>23</b>



# Example Application

US 34A Milepost 115.00-115.60

Criticality Score - 23

Criticality Score	Criticality Rating	Resilience Index Score (RI)
6 to 13	Low	1.0
14 to 21	Moderate	2.0
22 to 30	High	3.0



# Benefit-Cost Analysis

$$B/C_{Risk} = C \times V \times T$$

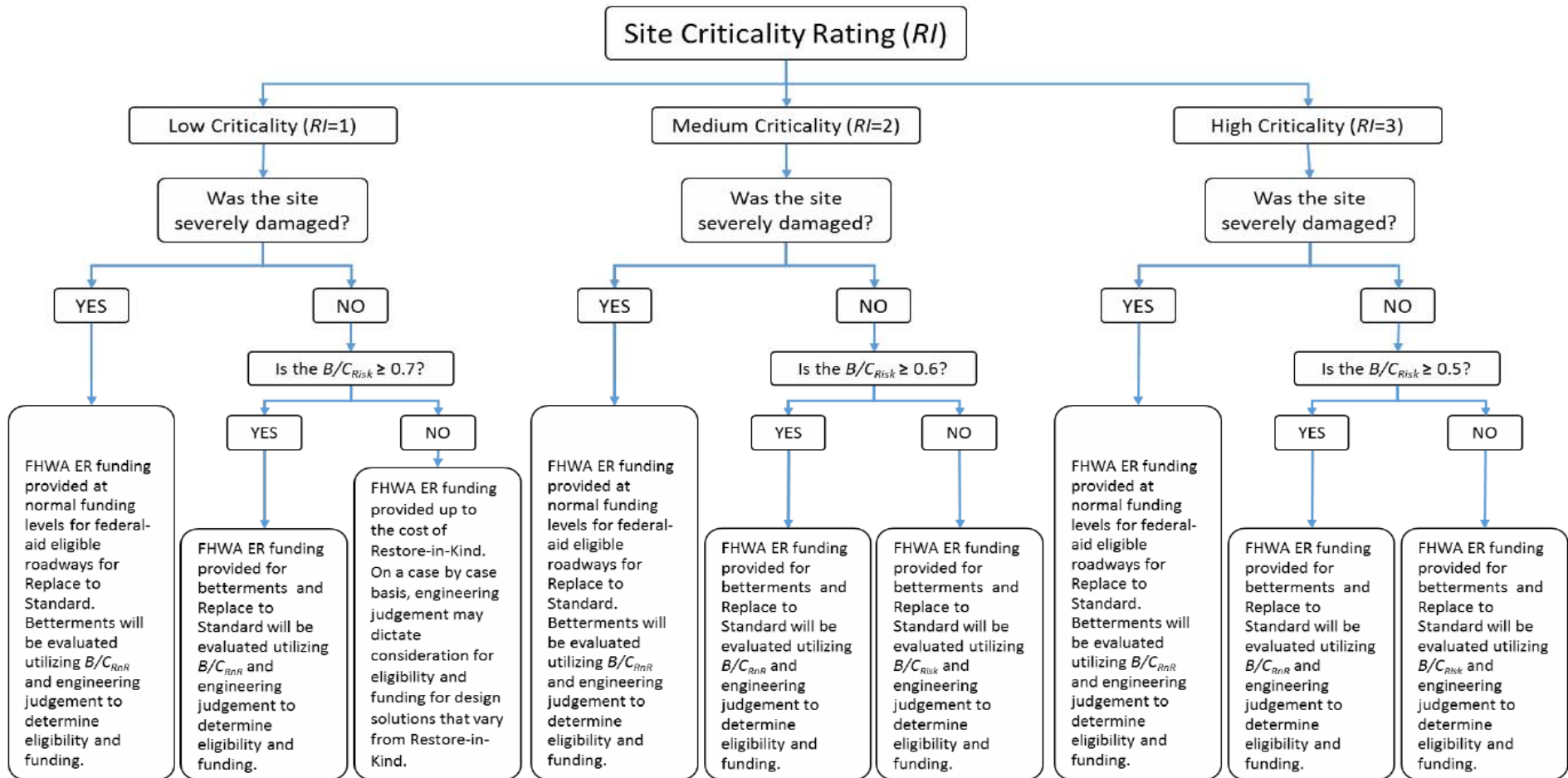
$$B/C_{RnR} = B/C_{risk} \times RI$$

## Resilience Index

Criticality Score	Criticality Rating	Resilience Index Score (RI)
6 to 13	Low	1.0
14 to 21	Moderate	2.0
22 to 30	High	3.0



# Benefit-Cost Analysis

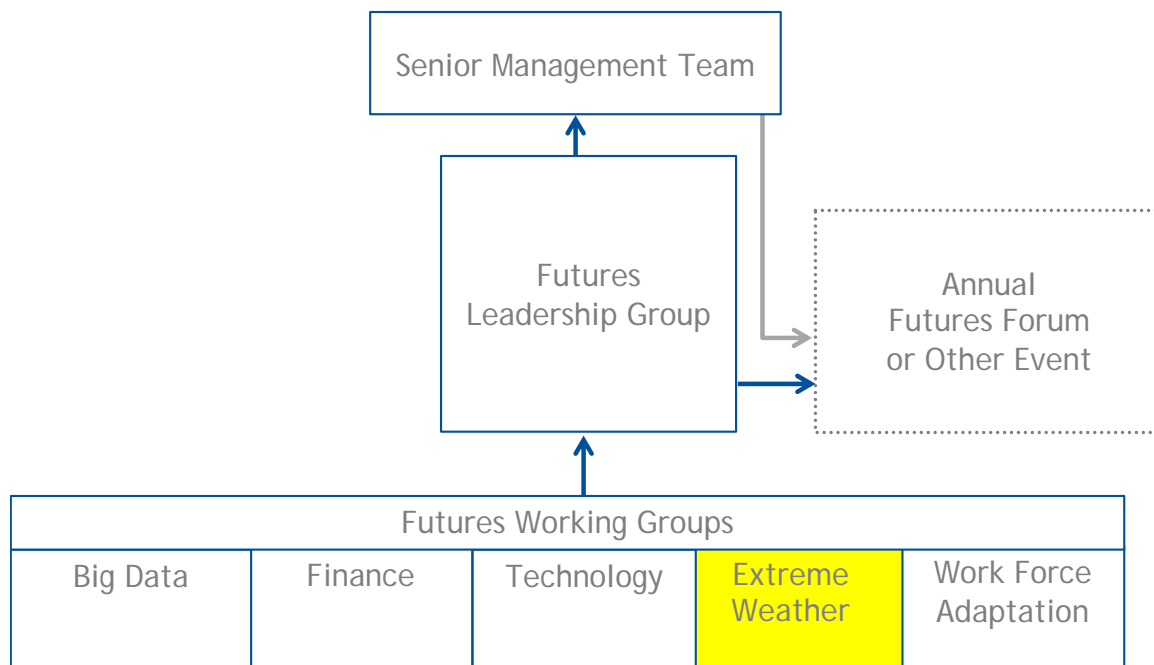


# Challenges

- Lack of Data Points
- Evaluation of assets against other natural threats (such as fire and debris flow)
- Federal policy constraints



# Next Steps: CDOT Futures Forward Initiative



## Mission Statement and Work Group Structure

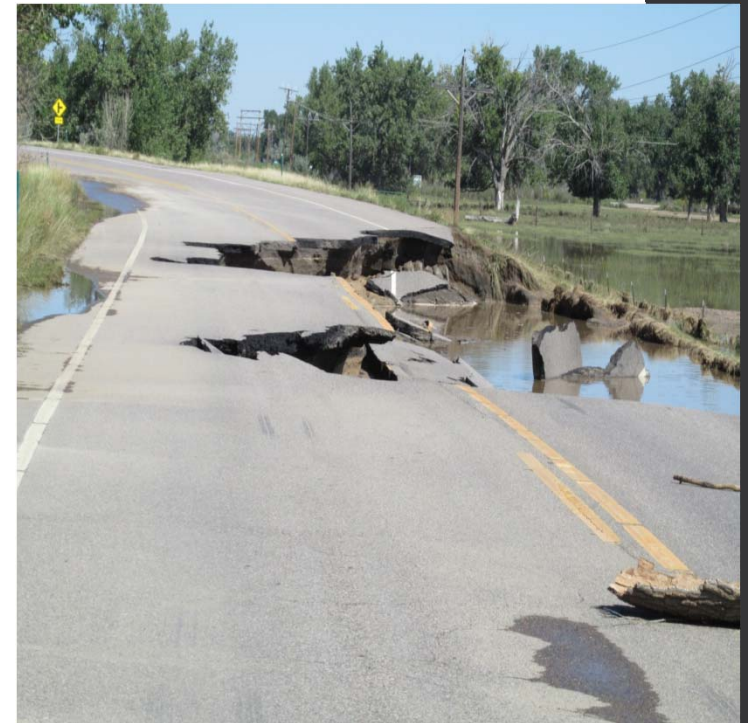
*Mission Statement: CDOT is taking proactive steps to ensure that short-term (5 years or less) and long-term (5-20 years) planning anticipates a variety of potential future trends and scenarios. The Futures Forward Initiative will identify, and develop strategies to ensure that the Department is prepared to address short-term and long-term needs and requirements.*



# Next Steps: Extreme Weather Work Group

**Purpose:** Enhance resiliency of transportation infrastructure to extreme weather events.

**Intent/Goal:** Develop a framework for a CDOT Risk and Resiliency Plan.





# Next Steps:

- Incorporating Criticality into CDOT Asset Management Systems
- FHWA is also using CDOT's work as a pilot for replication. Findings from CDOT's flood efforts will be considered during future updates to the FHWA ER Manual.

