Jeff Sudmeier
Colorado Department of Transportation

Flooding, Vulnerability and Risk, Oh My!
July 2015
2013 Flood Event

- Sept. 12\textsuperscript{th} 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

"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.”
Philosophy of Repairs – US 36 Example 1
CONVENTIONAL REPAIR TYPICAL SECTION

- Revegetated Bank
- 100-Year Floodplain
- 2-Year Floodplain
- Low Flow
- Exisiting Grade
- Fill
- Bedrock

Philosophy of Repairs – US 36 Example 2
PROPOSED REPAIR TYPICAL SECTION

Philosophy of Repairs – US 36 Example 3
Risk & Resilience Analysis 101

1) Asset Characterization
2) Threat Characterization
3) Consequence Analysis
4) Vulnerability Analysis
5) Threat Analysis
6) Risk/Resilience Analysis
7) Risk/Resilience Management
Step 1 – Asset Characterization

Assets categorized as:
- Roadway prism
- Structures

Assessments conducted at three levels:
- Site Level
- Segment Level
- Corridor Level

1) Asset Characterization
2) Threat Characterization
3) Consequence Analysis
4) Vulnerability Analysis
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7) Risk/Resilience Management
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

\[ \text{Risk} = C \times V \times T \]

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

\[ \text{Resilience} = V \times T \times D \times \text{Capacity Reduction} \]

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

<table>
<thead>
<tr>
<th>Critically Scored</th>
<th>1 Very Low Impact</th>
<th>2 Low Impact</th>
<th>3 Moderate Impact</th>
<th>4 High Impact</th>
<th>5 Very High Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion 1 Road Classification</td>
<td>Local Private</td>
<td>Non-NHS Local Federal-Aid</td>
<td>Non-NHS Collector</td>
<td>Non-NHS Arterial</td>
<td>Defense Route Interstate Freeway Expressway Other NHS Road</td>
</tr>
<tr>
<td>Criterion 2 Need for Access by Essential Traffic</td>
<td>More than 48 Hours After Event</td>
<td>Within 48 Hours of Event</td>
<td>Within 12 Hours of Event</td>
<td>Within 2 Hours of Event</td>
<td>Immediately Following Event</td>
</tr>
<tr>
<td>Criterion 3 Traffic (AADT)</td>
<td>0 - 400</td>
<td>401 - 1000</td>
<td>1001 - 2000</td>
<td>2001 - 10,000</td>
<td>&gt;10,000</td>
</tr>
<tr>
<td>Criterion 4 Capital Cost of Damaged Site</td>
<td>&lt;$500K</td>
<td>$500K - $1M</td>
<td>$1M - $5M</td>
<td>$5M - $10M</td>
<td>&gt;$10M</td>
</tr>
<tr>
<td>Criterion 5 Redundancy</td>
<td>Multiple Redundant Routes with No/Minimal Loss in Capacity</td>
<td>Single Redundant Routes - Some/Moderate Loss of Capacity</td>
<td>Multiple Redundant Routes - Some/Significant Loss of Capacity</td>
<td>Single Redundant Route - Significant Loss of Capacity</td>
<td>Single Point of Failure (No redundant routes or reroute distance &gt;40 miles)</td>
</tr>
</tbody>
</table>

1) Asset Characterization
2) Threat Characterization
3) Consequence Analysis
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Step 7 – Risk/Resilience Management

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

<table>
<thead>
<tr>
<th>Criticality Score</th>
<th>Criticality Rating</th>
<th>Resilience Index Score (RI)</th>
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<tbody>
<tr>
<td>6 to 13</td>
<td>Low</td>
<td>1.0</td>
</tr>
<tr>
<td>14 to 21</td>
<td>Moderate</td>
<td>2.0</td>
</tr>
<tr>
<td>22 to 30</td>
<td>High</td>
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1) Asset Characterization
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### Example Application

**US 34A Milepost 115.00-115.60**

**Criticality Score - 23**

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<tr>
<th>Criticality Ranking</th>
<th>Description</th>
<th>Score</th>
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<tr>
<td><strong>Criteria 1: Road</strong></td>
<td>Classification Principal Arterial</td>
<td>4</td>
</tr>
<tr>
<td><strong>Criteria 2: Need for</strong></td>
<td>Access by Essential Traffic Need to restore essential traffic within 12 hours of event</td>
<td>3</td>
</tr>
<tr>
<td><strong>Criteria 3: Traffic</strong></td>
<td>(AADT) 12,000 veh/day</td>
<td>5</td>
</tr>
<tr>
<td><strong>Criteria 4: Capital Cost</strong></td>
<td>of Damaged Site $14,903,600</td>
<td>5</td>
</tr>
<tr>
<td><strong>Criteria 5: Redundancy</strong></td>
<td>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</td>
<td>5</td>
</tr>
<tr>
<td><strong>Criteria 6: Roadway</strong></td>
<td>Designation No unique roadway designation</td>
<td>1</td>
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**Total score** 23
Example Application
US 34A Milepost 115.00-115.60
Criticality Score - 23

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Benefit-Cost Analysis

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

\[ B/C_{RnR} = B/C_{risk} \times RI \]

**Resilience Index**

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Benefit-Cost Analysis

Site Criticality Rating (RI)

Low Criticality (RI=1)

- Was the site severely damaged?
  - YES
    - Is the $B/C_{\text{util}} \geq 0.7$?
    - YES
      - FHWA ER funding provided at normal funding levels for federal-aid eligible roadways for Replace to Standard.
      - Betterments will be evaluated utilizing $B/C_{\text{cost}}$ and engineering judgement to determine eligibility and funding.
    - NO
      - FHWA ER funding provided for betterments and Replace to Standard will be evaluated utilizing $B/C_{\text{cost}}$ and engineering judgement to determine eligibility and funding.
  - NO

Medium Criticality (RI=2)

- Was the site severely damaged?
  - YES
    - Is the $B/C_{\text{util}} \geq 0.6$?
    - YES
      - FHWA ER funding provided at normal funding levels for federal-aid eligible roadways for Replace to Standard.
      - Betterments will be evaluated utilizing $B/C_{\text{cost}}$ and engineering judgement to determine eligibility and funding.
    - NO
      - FHWA ER funding provided for betterments and Replace to Standard will be evaluated utilizing $B/C_{\text{cost}}$ and engineering judgement to determine eligibility and funding.
  - NO

High Criticality (RI=3)

- Was the site severely damaged?
  - YES
    - Is the $B/C_{\text{util}} \geq 0.5$?
    - YES
      - FHWA ER funding provided at normal funding levels for federal-aid eligible roadways for Replace to Standard.
      - Betterments will be evaluated utilizing $B/C_{\text{cost}}$ and engineering judgement to determine eligibility and funding.
    - NO
      - FHWA ER funding provided for betterments and Replace to Standard will be evaluated utilizing $B/C_{\text{cost}}$ and engineering judgement to determine eligibility and funding.
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.