COMPASS Education Series: Risk and Resiliency

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CAMBRIDGE SYSTEMATICS

Think Forward

COMPASS

COMMUNITY PLANNING ASSOCIATION

of Southwest Idaho

Redd Engineering

1. Intro and Overview

Agenda

1. Introductions/Overview
2. Definitions and terminology
3. Purpose and context
4. Idaho projections
5. Resilience and risk implementation frameworks, examples
6. Risk register exercise
7. Break
8. Beyond the risk register
9. Benefit-cost exercise
10. Adaptation benefit-cost analysis tool
11. Helpful resources
12. Open Q&A

Workshop Purpose

- What, why, and how of risk and resilience in context of transportation
- Help you think about risk and resilience in your activities – planning, operations, etc.
- Input welcome

2. Definitions and Terminology

Definitions and Terminology

- Risk
  - Potential of gaining or losing something of value
  - Probability of Threat Occurrence x Probability of Failure x Cost of Failure
  - Exposure x Sensitivity x Cost of Failure
  - Likelihood x Consequence
  - Effect of Uncertainty on objectives
  - Different levels and types
- Uncertainty
  - Degree to which a value is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable.
- Resilience
  - Ability to respond and recover from adversity
  - Amount of change a system can undergo without changing state
- Adaptive Capacity
  - Ability to adjust to/moderate/cope with a threat
  - Similar to Resilience

Definitions and Terminology

- Vulnerability
  - The degree to which a system is susceptible to, or unable to cope with, adverse effects
  - Function of Exposure, Sensitivity, and Adaptive Capacity
- Adaptation
  - Action to reduce Vulnerability or increase Resilience
- Criticality
  - Relative importance of an asset
- Risk Management
  - Coordinated activities to direct and control an organization with regard to risk
- Weather vs. Climate
  - Weather refers to conditions of atmosphere over short period of time
  - Climate refers to how atmosphere behaves over long period of time (includes averages, variability, and extremes)
  - Climate change refers to shifts in global or regional climate patterns

3. Purpose and Context

Why Focus on Risk and Resilience

- Create awareness
- Systematic approach to uncertainty
- Consider range of adaptations
- Prioritization of projects, activities
- Enhance existing decisions
- Cost effectiveness

Regulatory Framework

- MAP-21 and FAST Act – Asset Management Final Rule (2016)
  - States "shall develop a risk-based asset management plan that describes how the NHS will be managed to achieve system performance effectiveness and State DOT targets for asset condition, while managing the risks, in a financially responsible manner, at a minimum practicable cost over the life cycle of its assets."
  - Life-cycle planning for asset classes should consider "future changes in demand; information on current and future environmental conditions including extreme weather events, climate change, and seismic activity; and other factors that could impact whole of life costs of assets."

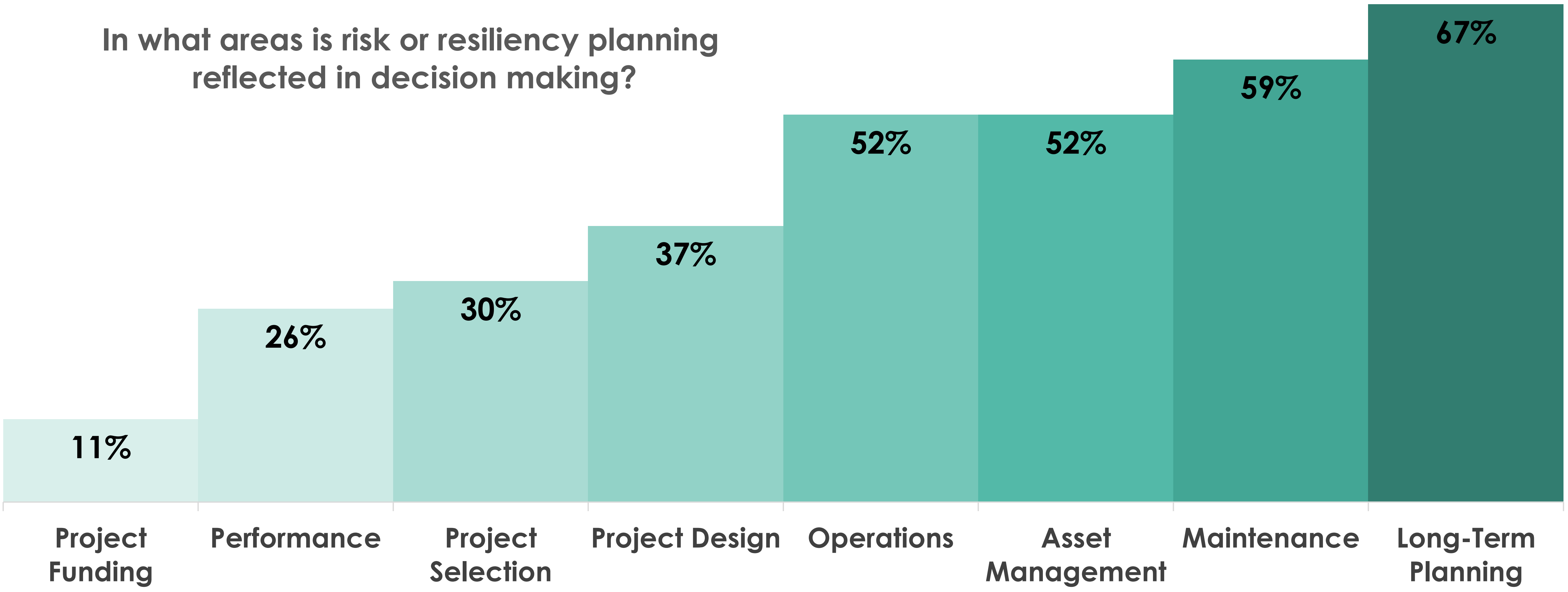
Regulatory Framework

- MAP-21 and FAST Act – Asset Management Final Rule (2016) (continued)
  - State DOTs "shall establish a process for developing a risk management plan". Should include
    - Risk identification
    - Risk assessment – likelihood and consequence
    - Risk evaluation and prioritization
    - Mitigation plan for top priority risks
    - A summary of the evaluations of facilities repeatedly damaged by emergency events
  - State DOTs "shall conduct statewide evaluations to determine if there are reasonable alternatives to roads, highways, and bridges that have required repair and reconstruction activities on two or more occasions due to emergency events."

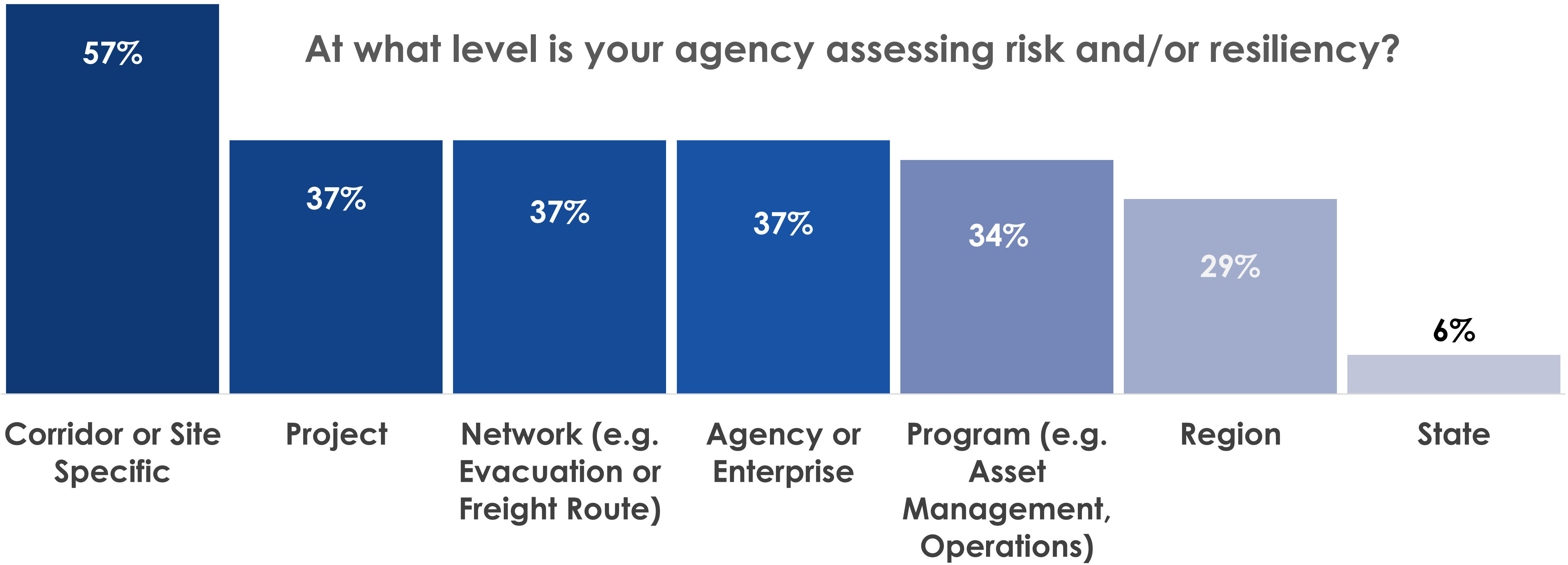
Regulatory Framework

- MAP-21 and FAST Act – Planning Final Rule (2016)
  - Adds “takes into consideration resiliency needs” to purposes of statewide, nonmetropolitan, and metropolitan planning processes
- FHWA Order 5520 (2014)
  - “It is FHWA's policy to strive to identify the risks of climate change and extreme weather events to current and planned transportation systems. The FHWA will work to integrate consideration of these risks into its planning, operations, policies and programs in order to promote preparedness and resilience; safeguard Federal investments; and ensure the safety, reliability, and sustainability of the Nation’s transportation systems.”

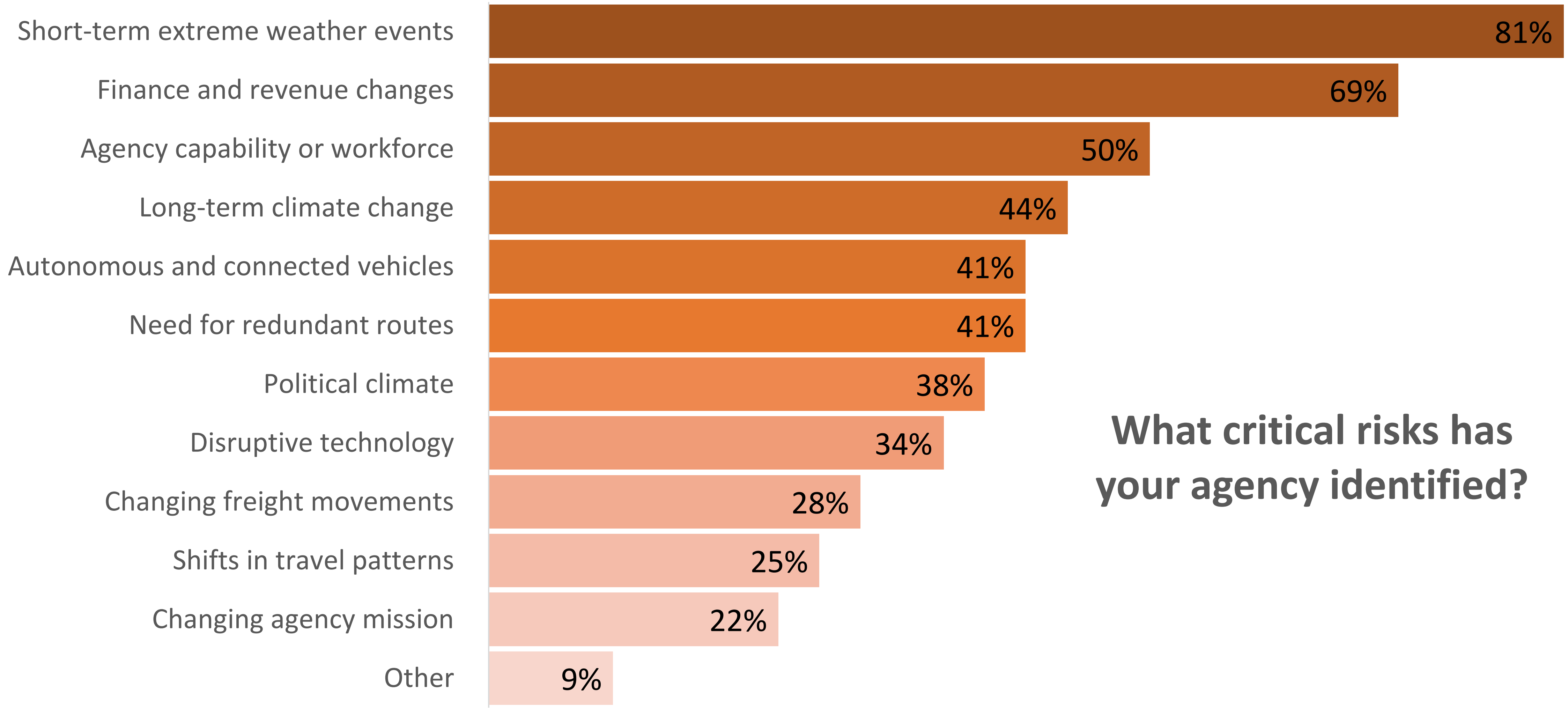
NCHRP Snapshot – Risk and Resiliency Planning – State DOTs



NCHRP Snapshot – Risk and Resiliency Planning – State DOTs

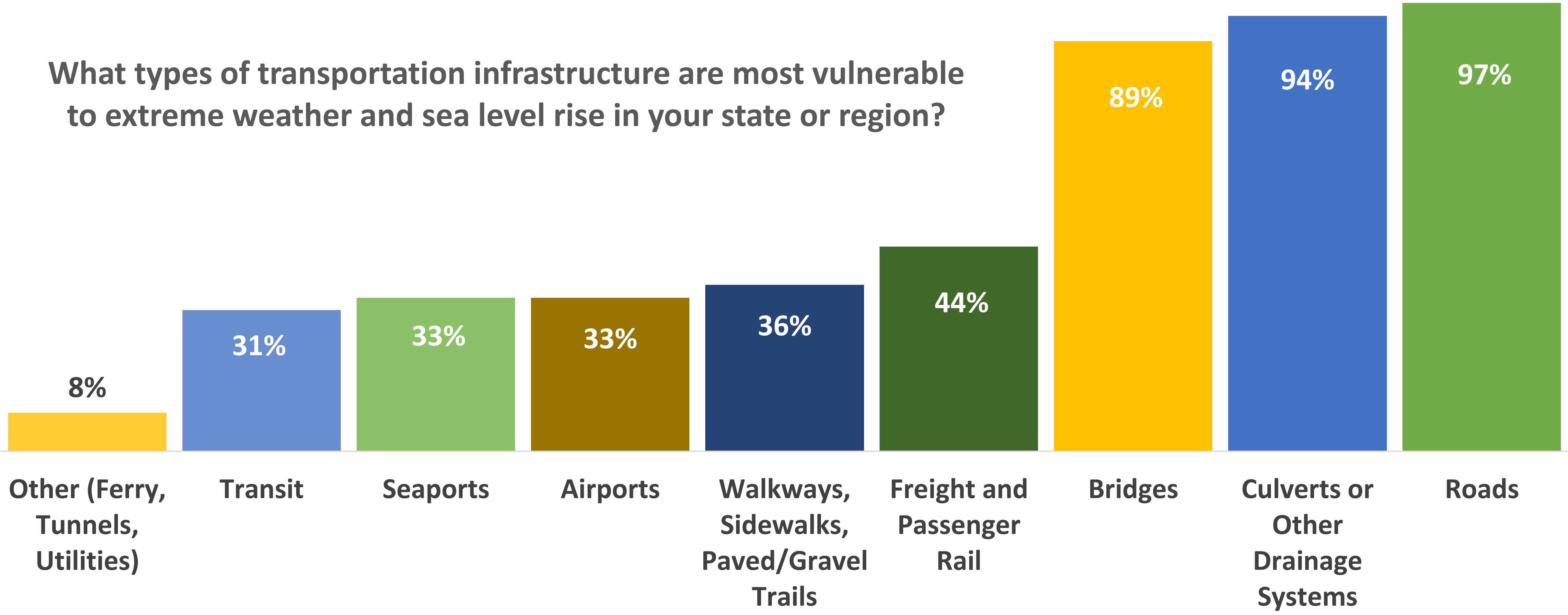


NCHRP Snapshot – Risk and Resiliency Planning – State DOTs



What critical risks has your agency identified?

NCHRP Snapshot – Risk and Resiliency Planning – State DOTs



NCHRP Snapshot – Risk and Resiliency Planning – State DOTs

If your agency is planning for risk or resiliency, have you developed tools or methods to:

- **Assess Vulnerability** 51%
- **Prioritize Investment Decisions** 34%
- **Develop Adaptation Strategies** 26%

4. Idaho Climate Projections

Idaho Climate Observations and Projections

- “Temperatures increased across the region from 1895 to 2011, with a regionally averaged warming of about 1.3°F”
- “An increase in average annual temperature of 3.3°F to 9.7°F is projected by 2070 to 2099…The increases are projected to be largest in summer.”
- “While precipitation has generally increased, trends are small as compared to natural variability”
- “Change in annual average precipitation in the Northwest is projected to be within a range of an 11% decrease to a 12% increase for 2030 to 2059 and a 10% decrease to an 18% increase for 2070 to 2099” with decrease in summer precipitation under several scenarios
- The largest hydrologic responses “are expected to occur in basins with significant snow accumulation, where warming increases winter flows and advances the timing of spring melt. By 2050, snowmelt is projected to shift three to four weeks earlier than the 20th century average, and summer flows are projected to be substantially lower”

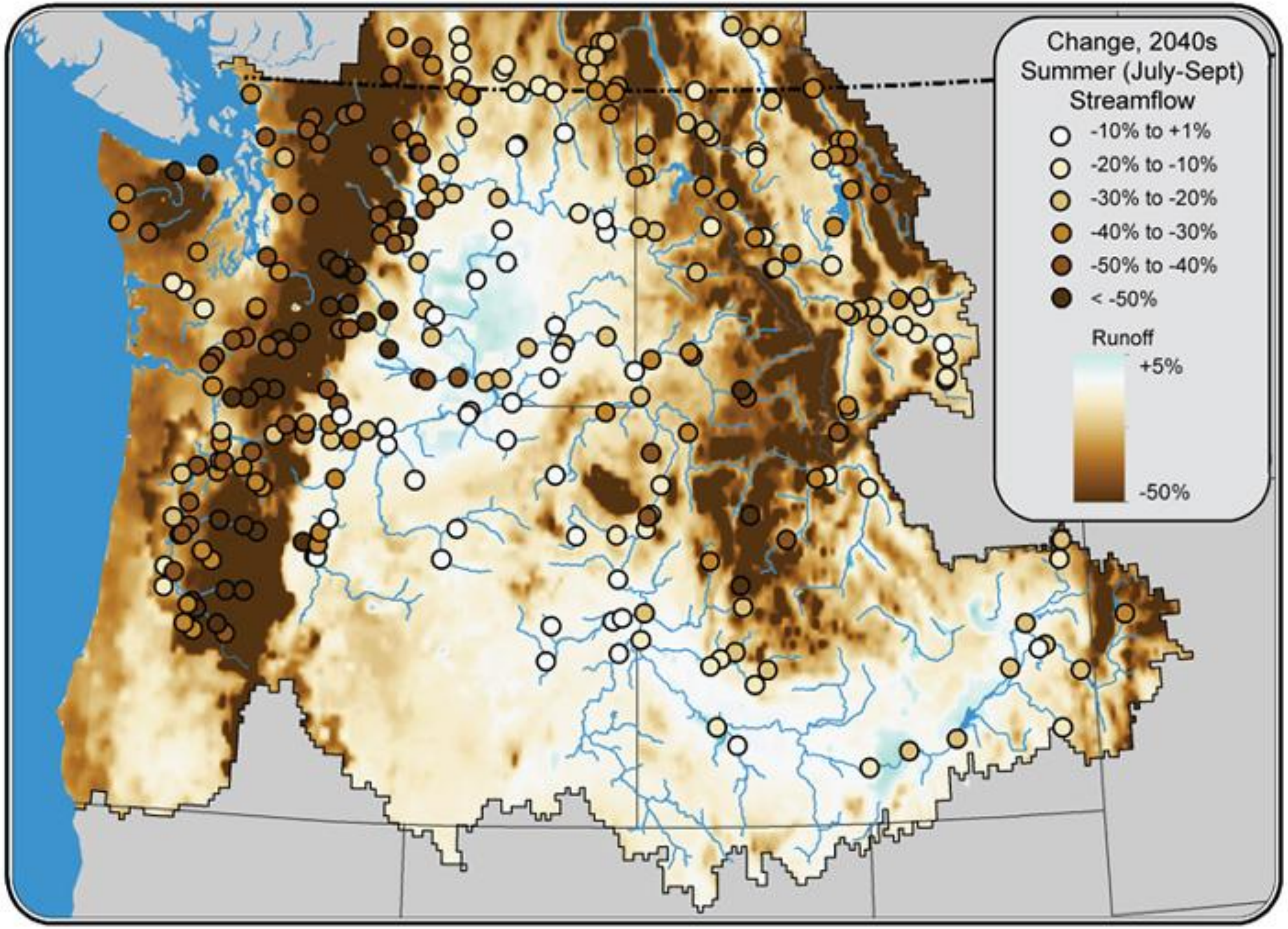
Source: National Climate Assessment

Idaho Climate Observations and Projections

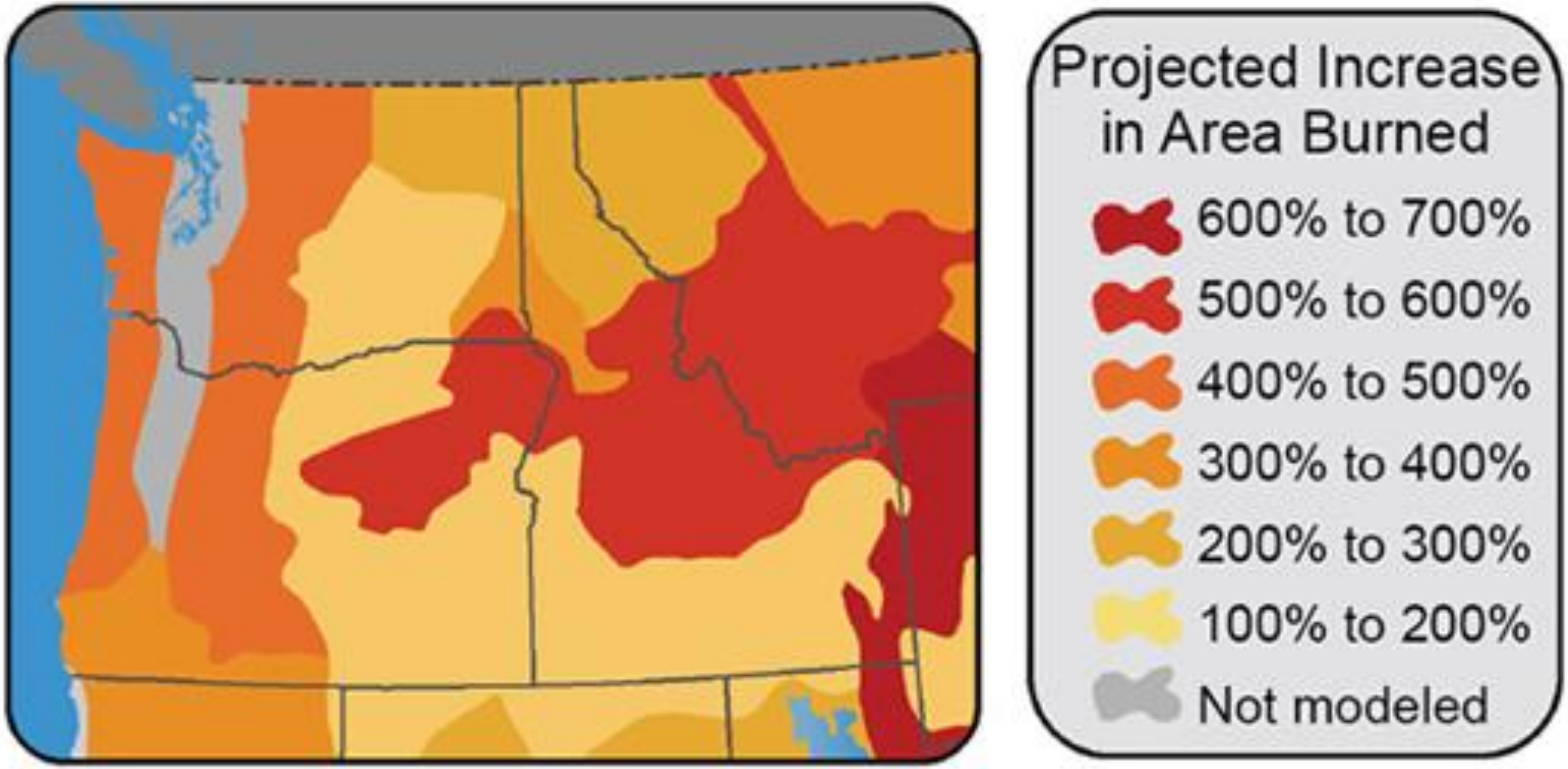
- “Changes in river-related flood risk depends on many factors, but warming is projected to increase flood risk the most in mixed basins (those with both winter rainfall and late spring snowmelt-related runoff peaks) and remain largely unchanged in snow-dominant basins.”
- “Regional climate models project increases of 0% to 20% in extreme daily precipitation, depending on location and definition of “extreme” (for example, annual wettest day).”

Source: National Climate Assessment

Reduced Summer Flows



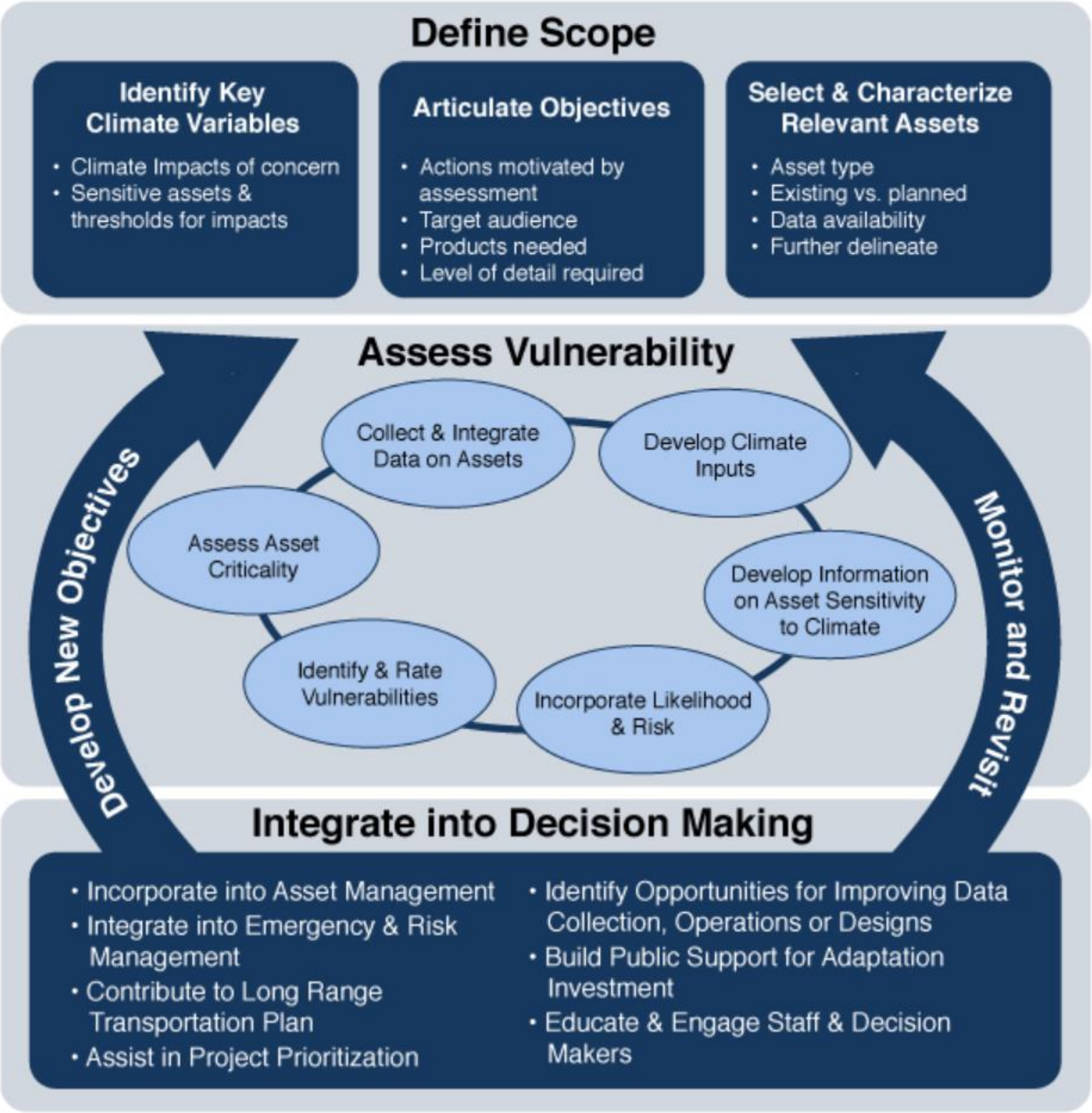
Source: National Climate Assessment



Source: National Climate Assessment

5. Resilience and Risk Management Frameworks and Examples

FHWA Vulnerability Assessment Process

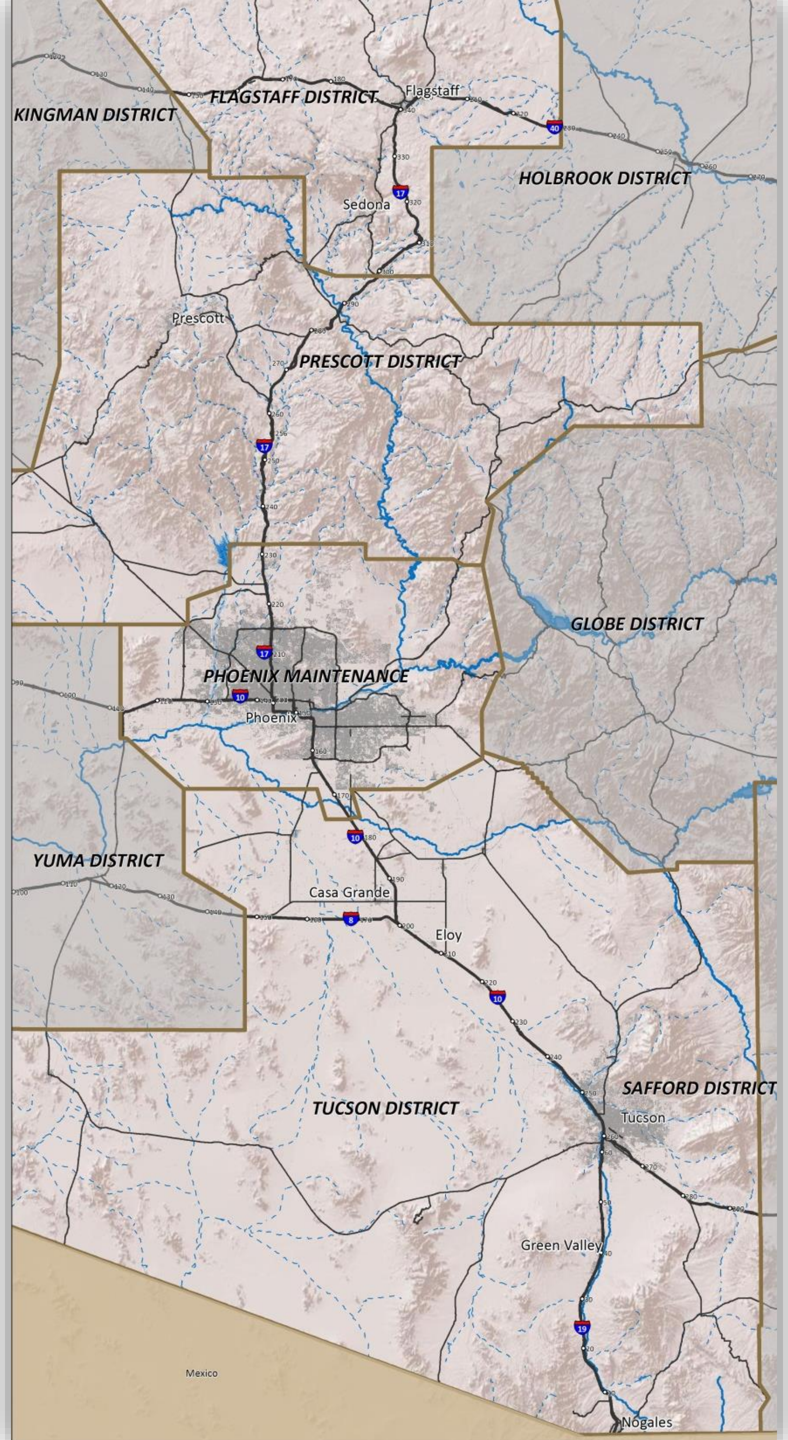


Asset-Level Adaptation Assessment Process

1. Define climate impacts
   a) Sensitivity screening to identify stressors
   b) Establish current and projected scenarios
2. Assess vulnerability
   a) Analyze exposure
   b) Analyze sensitivity
   c) Evaluate adaptive capacity
   d) Summarize results
3. Assess risk
   a) Identify likelihood
   b) Identify consequences
   c) Establish integrated risk
4. Formulate Adaptation
   a) Develop strategy shortlist
   b) Conduct brief benefit-cost analysis
   c) Identify priority adaptation strategy or package of strategies

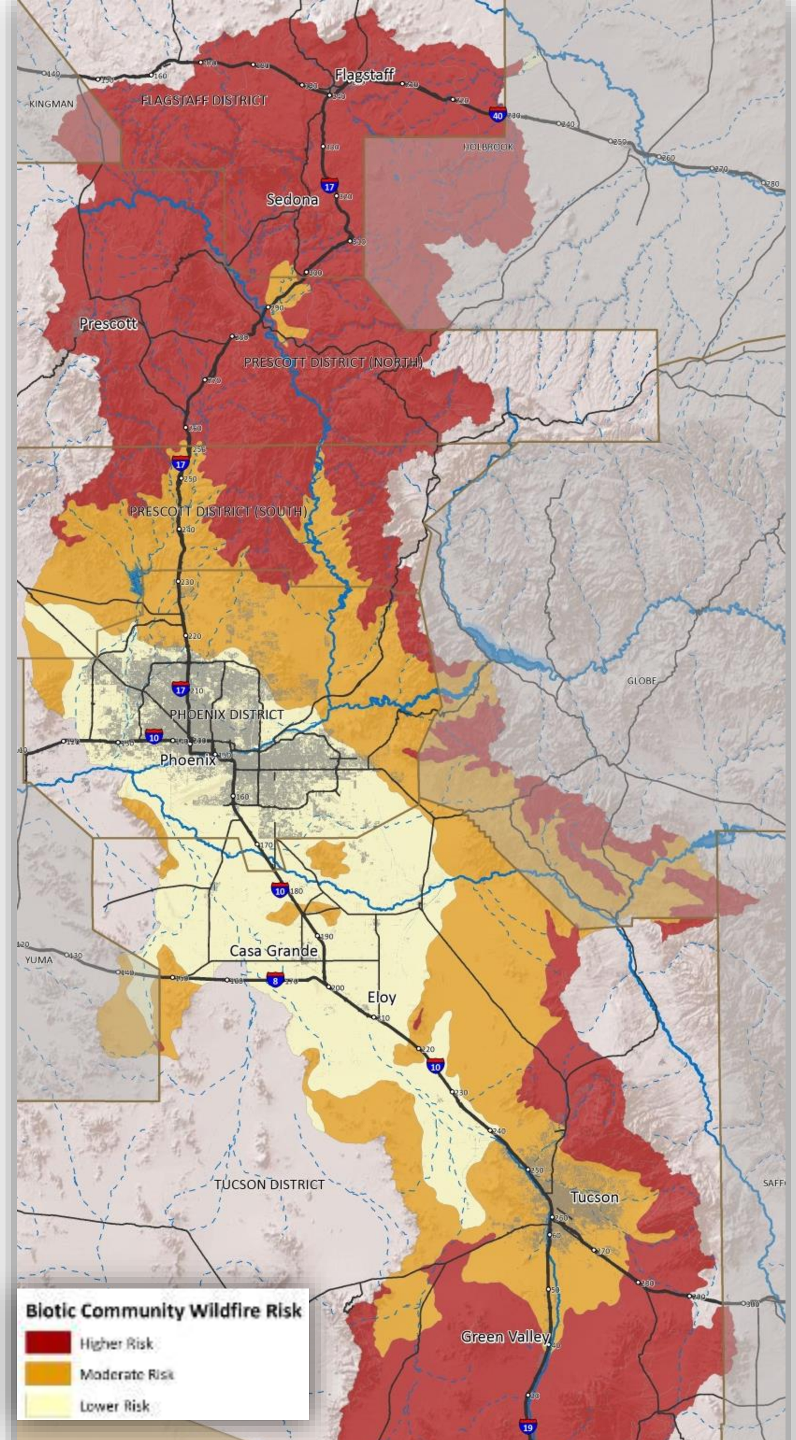
Arizona DOT Extreme Weather Vulnerability Assessment

- Interstates connecting Nogales, Tucson, Phoenix, and Flagstaff (I-19, I-10, and I-17)
  - 4 sub regions (Districts)
- Variety of:
  - Climates
  - Elevations
  - Landscape Contexts
    - E.g., Biotic Communities
  - Climate stressors



Extreme Weather Potential Effects on Transportation System in Study Area

- Shortened pavement life (heat, freeze-thaw, snow plowing)
- Culverts - design capacity, maintenance frequency
- Bridges - design capacity, maintenance frequency
- Roadside erosion
- Road closures from flooding/fire/rockfall/dust/low water crossings
- Shifting periods for paving operations
- Storm drain design
- Other



Source:
Arizona DOT

Source:
Arizona DOT

US 89 Landslide

ADOT

Source:
Arizona DOT

Lessons Learned

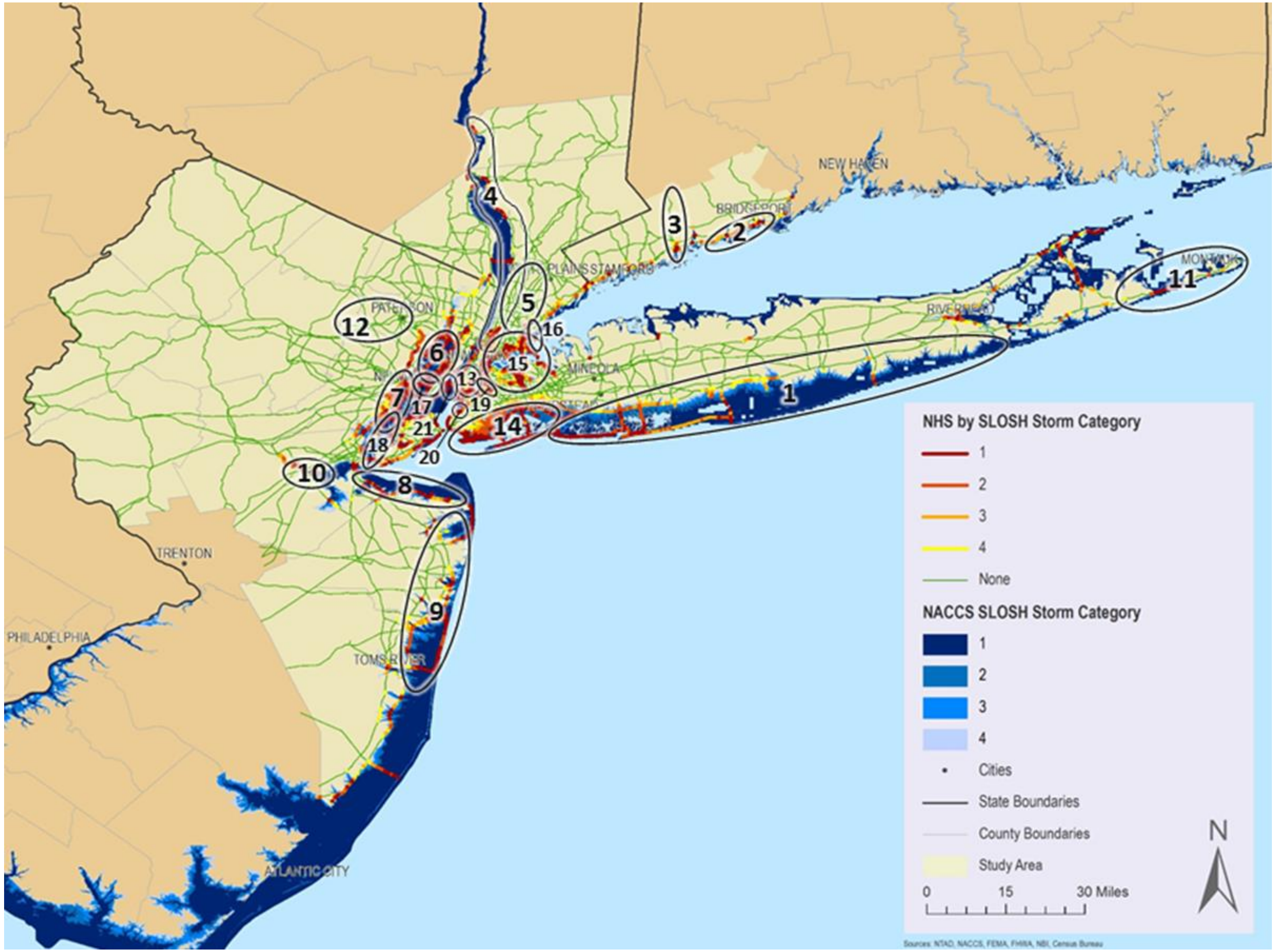
- Work with scientific stakeholders – climate, ecology, etc. – regarding exposure
- Climate projections – data processing challenge given relatively large and geographically diverse study area and high spatial resolution
- Inherent uncertainty of climate projections, particularly pertaining to extreme precipitation
- Secondary stressors, such as wildfire and flooding, influenced by a variety of climate and non-climate factors, compound that uncertainty for localized analyses
- Work with transportation operations and maintenance staff regarding sensitivity and consequence
- Rather than attempting to assign definitive vulnerabilities, study team aimed to characterize current extreme weather vulnerabilities and highlight potential future changes in key risk factors

FHWA Post Hurricane Sandy Transportation Resilience Study (Ongoing)

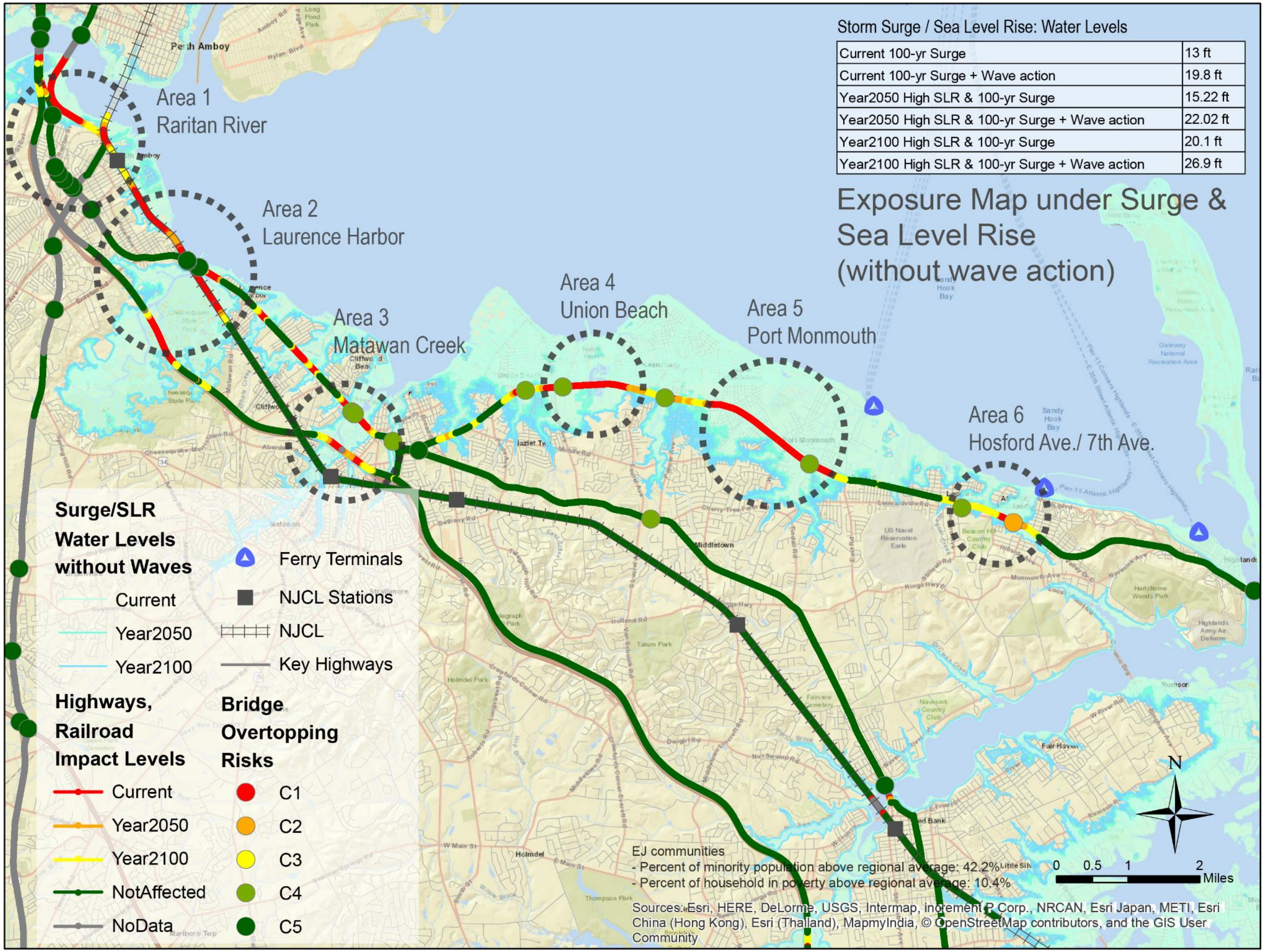
- Collaboration between FHWA, FTA, State DOTs, MPOs, Port Authority of New York & New Jersey, local transit agencies
- Enhance the tri-state region's resiliency to climate change and extreme weather in the longer term, while informing the ongoing Hurricane Sandy recovery process
- Identify feasible, cost-effective strategies to reduce and manage extreme weather vulnerabilities amid the uncertainties of a changing climate
- Advance the state of knowledge and develop methods to assist agencies in the tri-state region—and nationwide—that are seeking to plan and invest for long-term climate resilience

Post-Sandy Study Tasks

- Multi-modal damage/disruption assessment based on recent storms
- Region-wide vulnerability assessment
- “Mesoscopic” assessments of three subareas
- Adaptation analysis
- Engineering-based adaptation assessment of ten assets
- Process refinement
- Coordination and collaboration



Mesoscopic Vulnerability Assessments



Adaptation Toolbox

Strategy	Parent Strategy	Strategy Scale	Asset Type (for Asset Specific)	Type	Cost	Stressors Addressed	Primary Climate Risk Impact Type (Likelihood, Consequence, or Better Risk Information)	Timing
Tidegates	Water barriers (heavy)	General	Waterway Management	Engineering	$$$$	Flood, Erosion	Likelihood	Longer term
Levees (elongated naturally occurring ridge or artificially constructed wall, typical earthen)	Water barriers (heavy)	General		Natural or Nature-based	$$$	Flood, Waves	Likelihood	Longer term
Widening/ channelization of waterways	Waterway modification	General	Waterway Management	Engineering	$$$$	Flood, Erosion	Likelihood	Longer term
Enhanced ITS Infrastructure allowing for increased capacity on alternate roadways and demand management by giving up-to-date information to travelers, coordinating access to aux lanes/ shoulders, planning/ communicating time of day restrictions/ incentives. ITS can better inform event response system.	Enhance ITS system	System		Operational	$$	All	Consequence	Shorter term
Increase roadway capacity on alternate/ priority routes to create redundancy	Parallel transportation capacity	System		Engineering	$$$	All	Consequence	Mid term
Improve transit capacity to compliment physical strategies	Parallel transportation capacity	System		Engineering	$$$	All	Consequence	Mid term
Ferry and barge systems for movement								

Adaptation Matrices

	Shorter Term	Longer Term
Higher Risk Tolerance/ Lower Investment	• Update and maintain event notification and response system for roadways, including evacuation routes. Make explicit operational plans for sections of GSP in two highest vulnerability areas. • Transit coordination and contingency plan for flooding and high-wind events on North Jersey Coast Line and of ferry terminals. Should leverage bus lines. Should be flexible enough to address different flooding scenarios. • Regularly coordinate with US ACE and other stakeholders to ensure complementary adaptation strategies and identify gaps. • Better tracking of disruption and damage information to inform planning. • Use resilience best practices and incorporate SLR projections for new infrastructure projects/ updates that are already planned - work this into existing process. • Prune branches and other vegetation susceptible to wind. • Floodproof South Amboy Substation.	• Implement flood prevention measures for most vulnerable sections of GSP (Matawan Creek, Laurence Harbor). • Concrete sealant/surface treatment for surfaces not previously inundated. • Cathodic protection for metal elements. • Raise or relocate vulnerable electrical/communications assets (related to roadway or transit systems). • Erosion control aimed at surface protection (e.g. vegetative cover, mats/ blankets) for areas that flood regularly. • Revise rail speed guidance given effects of extreme heat on tracks. • Consider capacity enhancements for bus transit and road network. • More frequent inspection of infrastructure vulnerable to heat (e.g., rail buckling, catenary systems). • Increase regular maintenance of drainage ways. • More aggressive floodproofing for South Amboy Substation; consider raising or relocating.
Lower Risk Tolerance/ Aggressive Investment	• Strategies included above for higher risk tolerance/lower investment in shorter term (transit contingency plan, event response, etc.). • Investigate and implement flood prevention measures (e.g., watertight barriers on roadside, added culverts) for most vulnerable sections of GSP (Matawan Creek, Laurence Harbor). • If NBI info outdated, conduct scour criticality assessment for bridges. Prioritize bridges over Raritan River given their high flooding consequence. • Investigate and implement flood prevention measures (e.g., adding more culverts or widening culvert) for Route 36 at Many Mind Creek given its relatively high flooding likelihood. • Enhanced ITS Infrastructure allowing for increased capacity on alternate roadways and demand management by giving up-to-date information to travelers. ITS can better inform event response system. • Enhance capacity on N-S evacuation routes leading away from NHS facilities and North Jersey Coast Line in study area. • More aggressive floodproofing for South Amboy Substation; consider raising or relocating.	• Strategies included above for higher risk tolerance/lower investment in longer term. • Coordinate to with stakeholders to add general coastal protection measures (e.g., floodwalls, levees, beach nourishment) in vulnerable areas that have do not already have them. • For coastal bridges in areas of frequent flooding, consider superstructures that can resist lateral flow and wave forces. • Berms and other measures in places on roads and North Jersey Cost Line with frequent flooding. • More aggressive erosion control strategies. • Further enhance capacity on N-S evacuation routes. • Improve bus transit capacity. • Enhance electricity infrastructure so that it remains functioning in extreme events and continues to power transit, traffic signals, ITS. • Strengthen mooring/berthing fixtures at docks, ferry terminals, Earle. • Fender or dolphin systems to protect vulnerable piers and other infrastructure from vessel impact. • Floodprone land acquisition / incentivized relocation.

General Risk Management Steps (mostly from ISO 31000 Guidebook)

1. Identify the organization’s goals and objectives
2. Identify risks to reaching those goals and objectives
3. Score or rank/prioritize risks
4. Consider mitigation methods, strategies
5. Manage each type of risk
6. Communicate risks, and management strategies
7. Monitor results and update accordingly
8. Improve the process

Equation for Calculating Risk

Risk (Cost) = Probability of Event Occurrence X
Impact (Cost) of the Event Occurring

Example: a certain large rock has a 1% chance of falling onto westbound Interstate 70 in Glenwood Canyon each year, with expected damage of $1,000,000.

This represents a $10,000 annualized “risk cost”

Risk Impacts in Transportation

- Safety – crashes, injuries, fatalities, property damage
- Mobility and trip time reliability
- Costs of fixing the damage
- Other economic costs – lack of access, interrupted commerce
- Performance costs – not delivering projects as intended, and/or not hitting targets

Risk Register Excerpt

				Consequence Score				
Risk Level	**Asset Class**	**Event/Occurrence**	**Prob**	**Safety**	**Mobility**	**Asset Damage**	**Other Financial Impact**	**Risk Score**
Project	All	Flooding (or any inclement weather event) (resulting in long term impacts -- damage to assets, requiring replacement)	4	5	5	5	5	20.0
Agency	ALL	Uncertainties that affect reaching performance targets; including revenue, costs, processes, etc.	4	3	3	2	4	12.0
Project	Traffic	Wind damage to high-mast lighting, signals, overhead signs, VMS	4	1	2	3	2	8.0
Program	ALL	Uncertainties that affect the ability to deliver projects as intended, and on time, within budget	5	3	3	1	3	12.5

Risk Scoring Matrix

		Consequence (Level/Descriptor)				
Likelihood		1	2	3	4	5
Level	Descriptor	Negligible	Minor	Major	Critical	Catastrophic
1	Low	1	2	3	4	5
2	Medium Low	2	4	6	8	10
3	Medium	3	6	9	12	15
4	Medium High	4	8	12	16	20
5	High*	5	10	15	20	25

Initial Risk Register (excerpt)

					Consequence Score				Other Considerations					
Level	Risk ID	Voted Priority	Event / Occurance	Likelihood	Safety	Mobility	Asset Damage	Other Financial Impact	Funding	Insurance	Regulatory	Political	Reputation	Risk Score
Project	3b	10	Flooding (resulting in long term impacts -- damage to assets, requiring replace	4	5	5	5	5	x	x		x	x	24.0
Project	3g	12	Burn area - post-fire debris flows, blocked culverts -- loss of service	5	4	4	4	2	x	x		x	x	21.0
Project	3l	11	Scour Critical Bridges are vulnerable to a storm event of sufficient size resultir	4	5	5	4	3		x			x	18.7
Project	3e	10	Rockfall incident with loss of function/mobility (several days) or fatality	4	5	4	3	3	x	x		x	x	18.0
Project	3j	11	landslide - loss of road and mobility	4	4	4	4	2	x	x			x	16.1
Program	2g	8	Unfunded maintenance requirements -- e.g. regulatory	5	3	3	2	3	x		x		x	15.8
Project	3r	9	Hazardous materials (need more of an event description) -- spill, e.g. Hwy 6	5	3	2	4	2		x	x		x	15.8
Project	3i	9	Retaining walls (failing and impacting traffic)	4	4	3	4	2	x	x			x	15.0
Project	3w	9	Subsurface utilities impacts by others in ROW (and below roadways)	4	3	3	4	2		x		x	x	13.8
Project	3f	11	Crash with fire occurs inside a tunnel resulting in a loss of service	3	4	4	4	3	x	x		x	x	13.5
Project	3m	9	Overhead bridges are in danger of being hit -- over height	5	3	3	2	1		x			x	12.4
Program	2f	9	Will I-70 viaduct pull funding from other projects	4	2	3	3	2	x	x		x	x	12.0
Program	2a	9	Retirement of key people, loss or turn-over of staff*, resulting in loss of knowle	4	3	2	2	3				x	x	11.0
Program	2e	9	Data management (that impacts ability of CDOT to document accomplishments	5	1	2	2	3			x		x	11.0
Project	3k	10	ITS or traffic control failure -- resulting in safety impact	5	4	2	1	1		x			x	11.0
Project	3q	10	Avalanche causing delay	5	3	3	1	1		x			x	11.0
Project	3d	9	Bridge failure -- structural, other than hits, scour, resulting in loss of service	2	5	5	4	4	x	x		x	x	10.8
Agency	1d	6	Revenue variations/uncertainties -- inability to predict/project total funds ava	5	1	1	2	3	x	x		x	x	10.5
Project	3q	10	Avalanche requiring maintenace but no/minimal delay	5	3	2	1	1		x			x	9.6
Project	3c	9	Culverts less than 48 inch diameter (failing and closing road - not managed cu	3	3	3	3	2	x	x			x	9.5
Project	3a	11	Project delay due to environmental, utility, RR, or right-of-way issues, or landc	5	1	2	1	2				x	x	8.3
Agency	1l	7	Return of commodity price volatility	4	1	1	2	3	x			x	x	8.1
Project	3e	10	Rockfall incident requiring maintenance, but no or minimal mobility impact	5	2	1	2	1	x					7.9
Project	3j	11	landslide - mainenance required	5	1	1	3	1	x					7.9
Agency	1f	9	Politics -- COMBINE WITH LEADERSHIP CHANGES (Dept. Leadership)	4	1	2	1	2	x	x	x	x	x	7.5
Project	3m	9	All bridges that are in danger of being hit	3	3	3	2	1		x			x	7.4
Program	2b	9	Project delivery risks due to organizational or systemic issues, e.g. communica	3	2	1	1	4	x	x		x	x	7.2

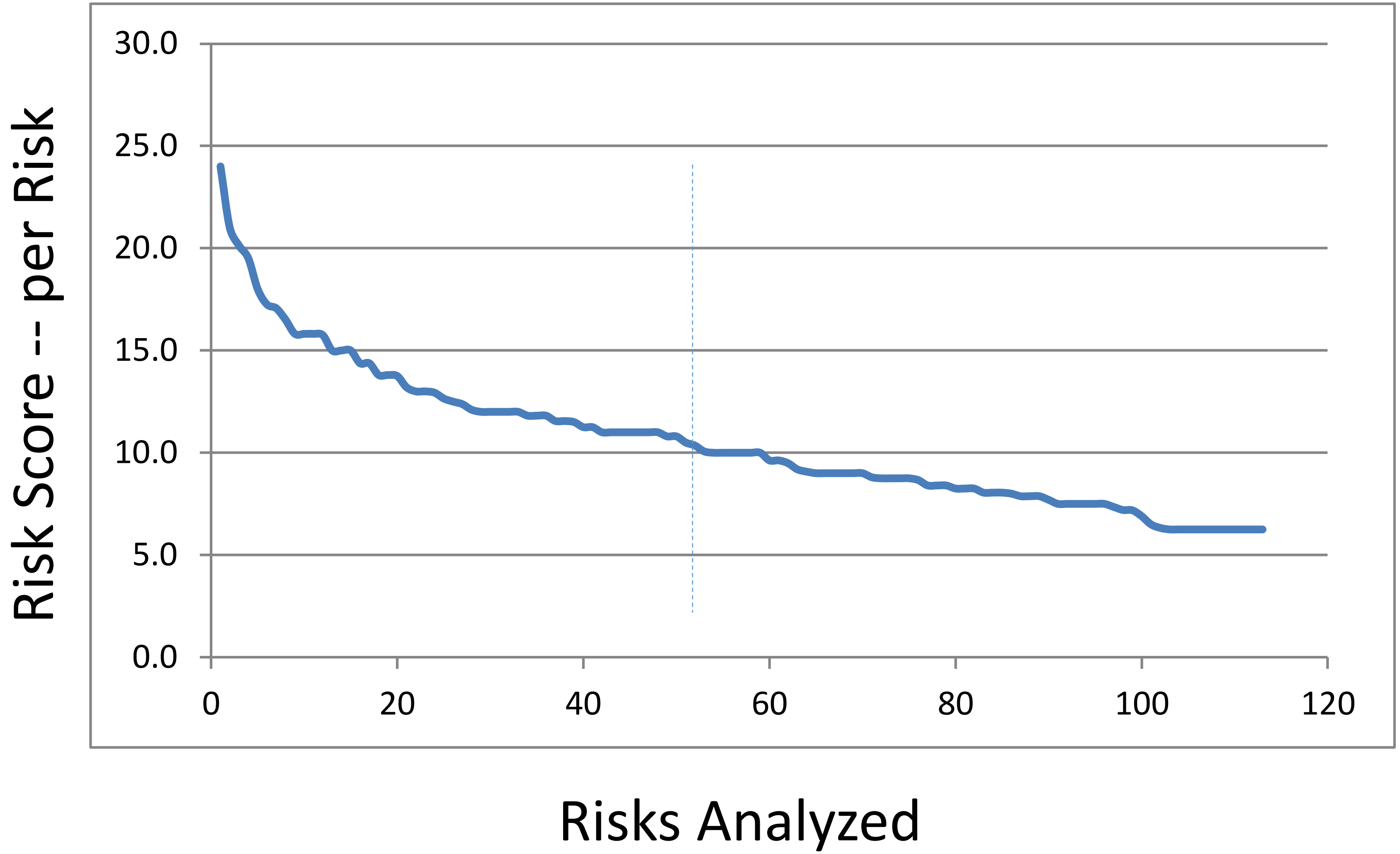
Top Ten Risk Scores (24.0 to 15.8)

1. Flooding (resulting in long term impacts -- damage to assets, requiring replacement)
2. Burn area - post-fire debris flows, blocked culverts -- loss of service
3. Bridge Strike (Highest frequency) -- clearance less than 16 ft
4. Not having enough funds to meet targets
5. Rockfall incident with loss of function/mobility (several days) or fatality
6. Roadway washout from pipe failure (structural) e.g. Vail Pass -- Road failure
7. Fiber optic backbone severed, resulting in loss of communication
8. Impacts/crashes of traffic with fleet vehicles
9. Hazardous materials -- spill, e.g. Hwy 6
10. Essential repairs (Bridge) -- Major cost/risk

Second Ten Risk Scores (15.8 to 12.9)

11. Parts availability limiting number of vehicles in use
12. ITS devices impacted by vehicles (VMS signs, signals, etc.)
13. Local control of NHS segments
14. Unfunded maintenance requirements -- e.g. regulatory
15. Changing functional needs for the buildings, regarding the needs in an existing location
16. Landslide causing loss of road and long term mobility impacts/delay
17. Subsurface utilities impacts by others in ROW and below roadways
18. Retirement of key people, loss or turn-over of staff, resulting in loss of knowledge (Maintenance Program specifically)
19. No internal buy-in on the asset management philosophies re: implementation; thus compromising condition goals
20. Load-restricted bridges -- uncertainty of ability to support loads

Overall Risk Score Pareto



Overall Risk Scores by Asset Class – From the Risk Register

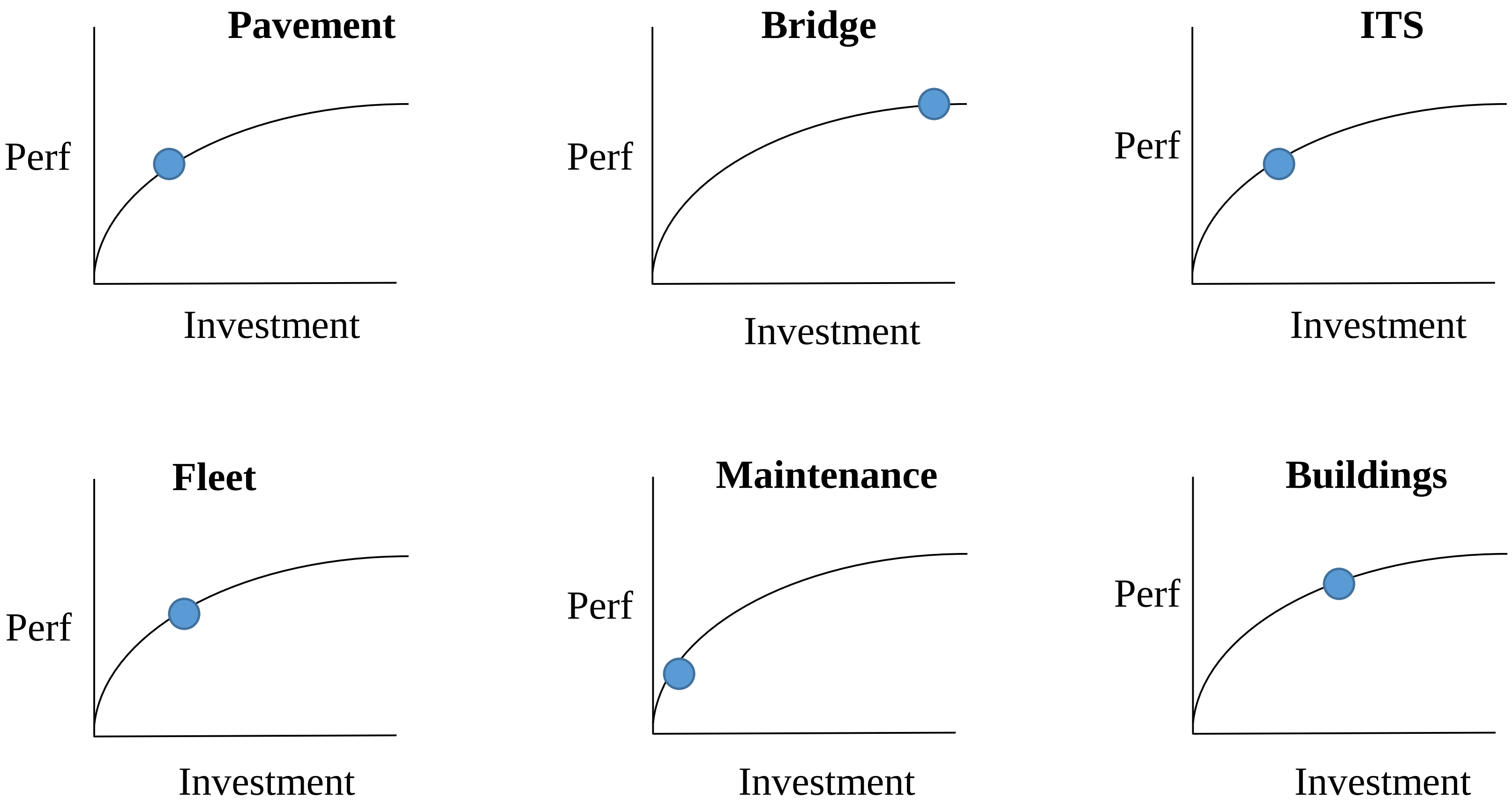
Fully Develop the Risk Register

1. Risk event types – considering the "extremes"
   a) Rare, catastrophic events
   b) More frequent, but less impacting events
2. Scoring – making sure "extremes" are properly evaluated
3. Strategy Identification – considering multiple options for each risk
   a) "Tolerate, Treat, Transfer, Terminate", etc.
4. Benefits – estimating reduction in "Risk Score" (or annualized costs) with each strategy
5. Costs – estimating the cost of implementing the strategy

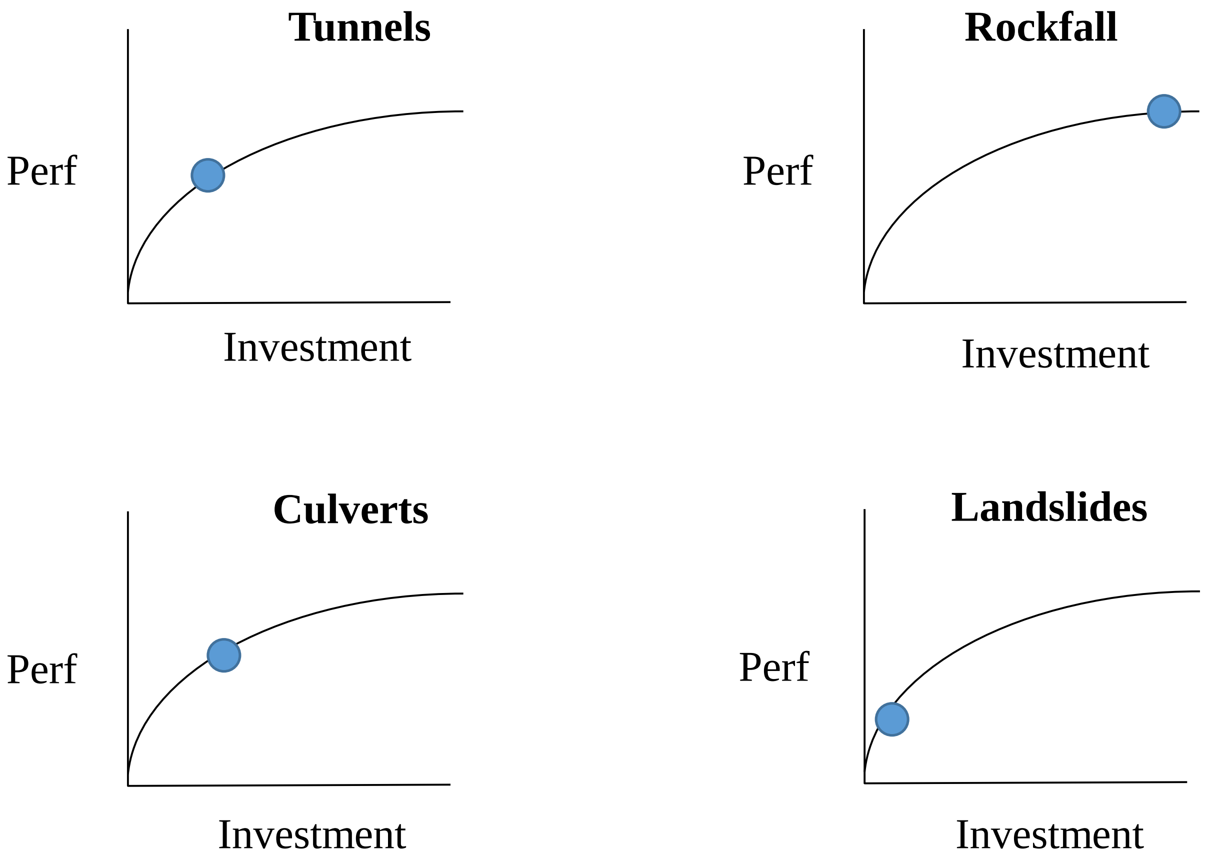
Extended Risk Register

			Consequence Score				Other Considerations								
Level	Event/Occurance	Likelihood	Safety	Mobility	Asset Damage	Other Financial Impact	Funding	Insurance	Regulatory	Political	Reputation	Risk Score	**Mitigation Strategy**	**Benefit**	**Cost**
Agency	Not communicating to and getting	3	1	1	1	1	x			x	x	3.5			
Agency	Not having enough funds to meet	5	3	4	4	2	x		x	x	x	19.5			
Agency	Local control of NHS segments --	5	3	2	3	2	x		x	x	x	15.0			
Agency	Revenue variations/uncertainties	5	1	1	2	3	x	x		x	x	10.5			
Agency	Public perception of CDOT (Negativ	2	2	4	3	2	x			x	x	6.3			
Agency	Politics -- COMBINE WITH LEADERSH	4	1	2	1	2	x	x	x	x	x	7.5			
Agency	Underestimating the impact of Dr	3	1	2	2	1	x			x	x	5.2			
Agency	Contractors cannot handle drama	2	2	3	4	2	x			x	x	6.3			
Agency	Lack of appropriate project cost c	4	1	1	2	2	x			x	x	6.9			
Agency	Return of commodity price volatili	4	1	1	2	3	x			x	x	8.1			
Agency	Financial collapse of a privately-o	1	1	1	3	4	x	x	x	x	x	2.8			
Program	Retirement of key people, loss or	4	3	2	2	3				x	x	11.0			
Program	Project delivery risks due to organ	3	2	1	1	4	x	x		x	x	7.2			
Program	Construction cost variations	3	1	1	2	4	x	x			x	6.9			
Program	Data management (that impacts a	5	1	2	2	3			x		x	11.0			
Program	Will I-70 viaduct pull funding from	4	2	3	3	2	x	x		x	x	12.0			
Program	Unfunded maintenance requireme	5	3	3	2	3	x		x		x	15.8			
Project	Project delay due to environmenta	5	1	2	1	2				x	x	8.3			
Project	Flooding (resulting in long term imp	4	5	5	5	5	x	x		x	x	24.0			
Project	Culverts less than 48 inch diamet	3	3	3	3	2	x	x			x	9.5			
Project	Bridge failure -- structural, other t	2	5	5	4	4	x	x		x	x	10.8			
Project	Rockfall incident requiring mainten	5	2	1	2	1	x					7.9			
Project	Rockfall incident with loss of functi	4	5	4	3	3	x	x		x	x	18.0			
Project	Crash with fire occurs inside a tur	3	4	4	4	3	x	x		x	x	13.5			
Project	Burn area - post-fire debris flows, b	5	4	4	4	2	x	x		x	x	21.0			

Investment Tradeoffs and Target-Setting for Traditional Performance-Based Assets/Programs



Risk Classes Can Be Analyzed and Traded Off in the Same Manner as Asset (Performance) Classes



SUMMARY -Steps to Addressing “Risk” in Your TAM Plan

1. Identify risk event types, levels, etc.
2. Build a “Risk Register” – quantify probabilities and consequences for each event type
3. Identify risk mitigation strategies – and define their costs and benefits
4. Determine how to “package” risk mgmt efforts
5. Evaluate and prioritize candidate solutions
6. Include risk opportunities in overall asset management investment tradeoff analysis

Risk Register Excerpt

				Consequence Score				
Risk Level	Asset Class	Event/Occurrence	Prob	Safety	Mobility	Asset Damage	Other Financial Impact	Risk Score
Project	All	Flooding (or any inclement weather event) (resulting in long term impacts -- damage to assets, requiring replacement)	4	5	5	5	5	20.0
Agency	ALL	Uncertainties that affect reaching performance targets; including revenue, costs, processes, etc.	4	3	3	2	4	12.0
Project	Traffic	Wind damage to high-mast lighting, signals, overhead signs, VMS	4	1	2	3	2	8.0
Program	ALL	Uncertainties that affect the ability to deliver projects as intended, and on time, within budget	5	3	3	1	3	12.5

6. Risk Register Exercise

7. Beyond the Risk Register

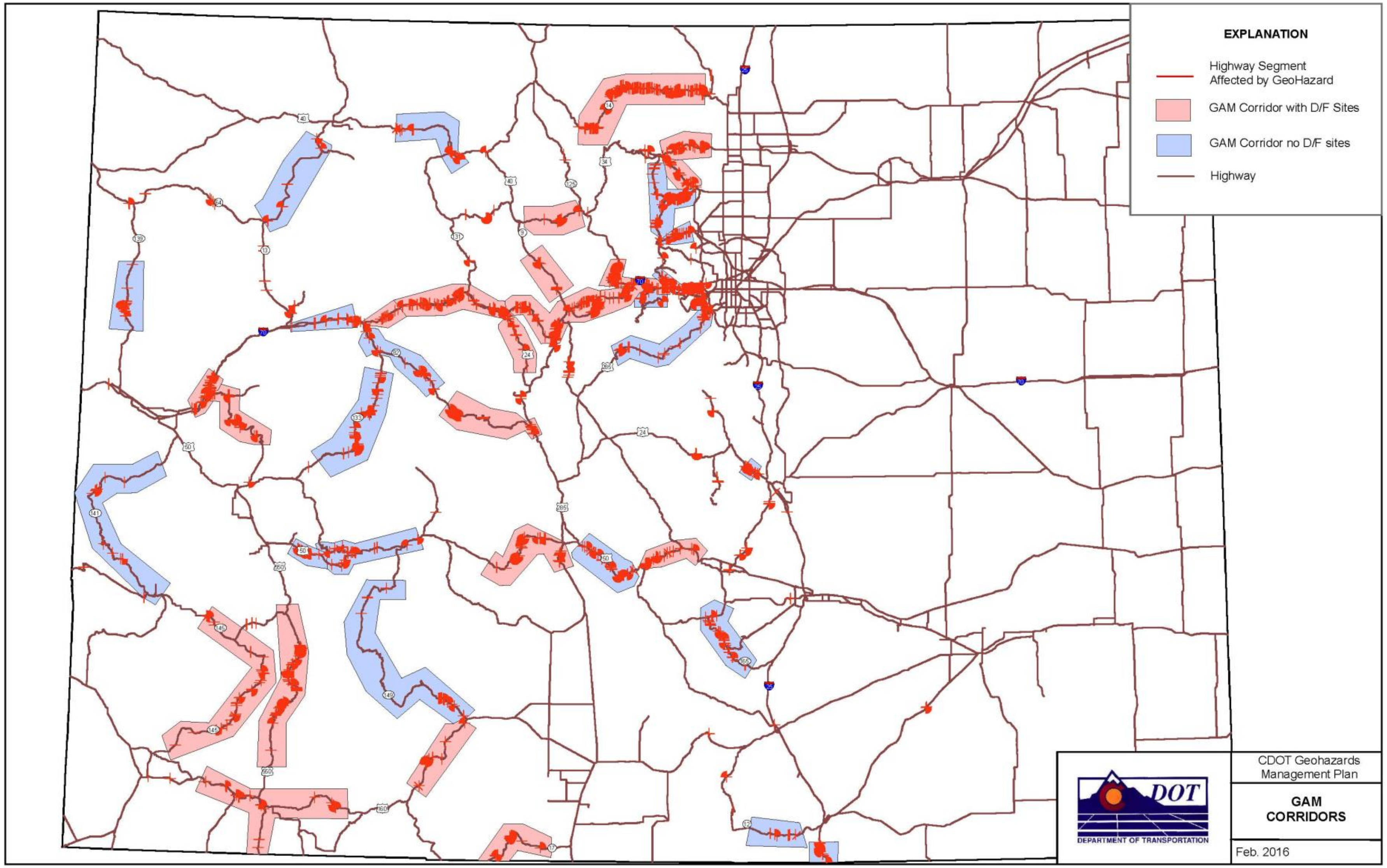
A Completed Register – *But…"Where do we go from here?"*

- Corridor-based risks
  - Risks that have a location (geospatial) component
  - Examples -- rock fall, culvert failure, ITS/signs, etc.
- Risks to infrastructure or agency performance
  - Uncertainties regarding the achievement of performance goals (costs, revenue, modeling, project formulation processes)
- Project Delivery risks
  - Programmatic/systemic issues -- chronic delays, splits, overruns, & not delivering projects as intended
  - Project-specific risks to cost and schedule

Overall Risk Scores by Asset Class – From the Risk Register

What information is needed to do more in-depth risk assessments?

Ultimate Site-Specific Analysis

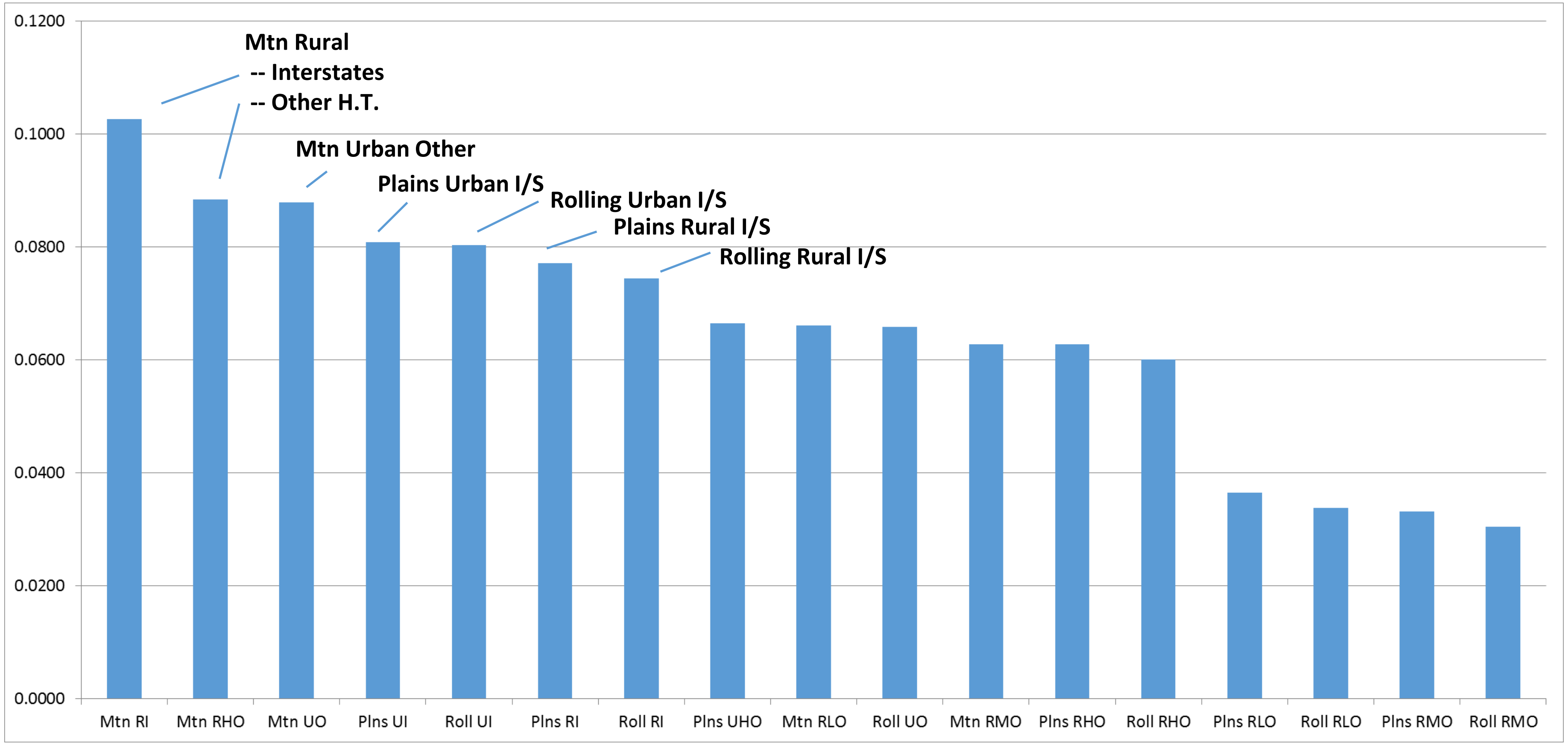


Approaches to modeling risk

Increasing Effort & Complexity ↓

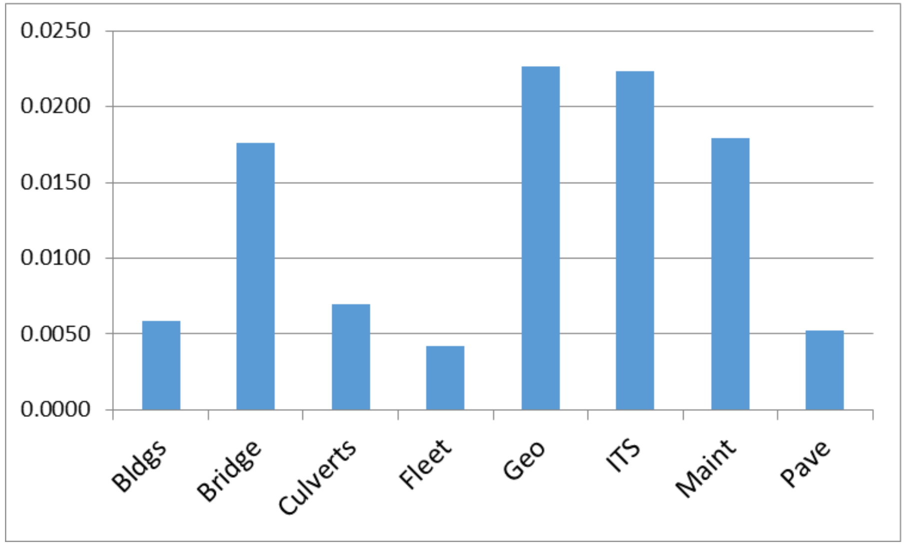
Hazard/Risk Index (top down)	Pros: fast, low data requirements, output easy to understand Cons: Low resolution, subjective
Historical Scenario (mix of top down and bottoms up)	Pros: based on event-specific data, good for frequent hazards Cons: misses extreme events, and site-specific risk event outcomes
Probabilistic (bottoms up)	Pros: accounts for both frequent/low-impact and rare/extreme events, for each site Cons: high data/expertise requirements, need to ensure outputs can be understood

Total Risk Score per Mile for Each Corridor Type

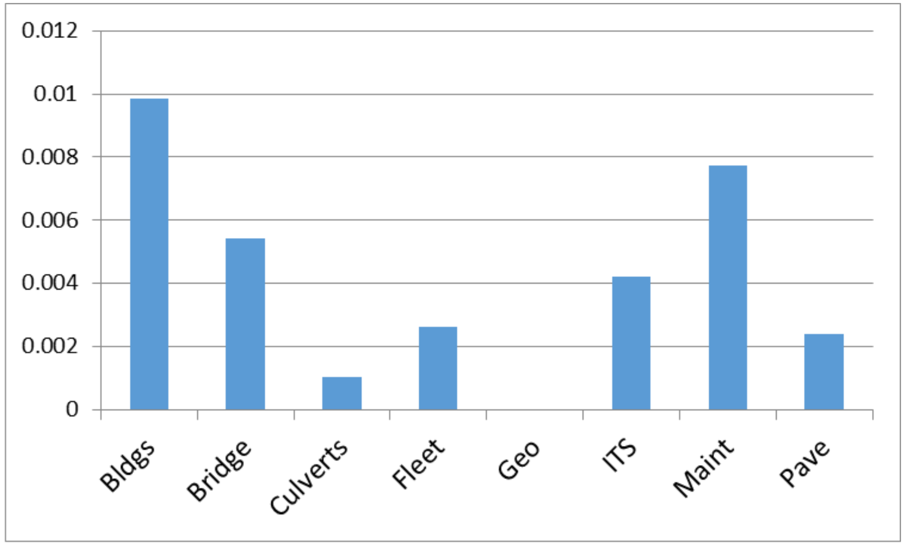


Risk per Mile for Each Asset Class (two corridor types shown here)

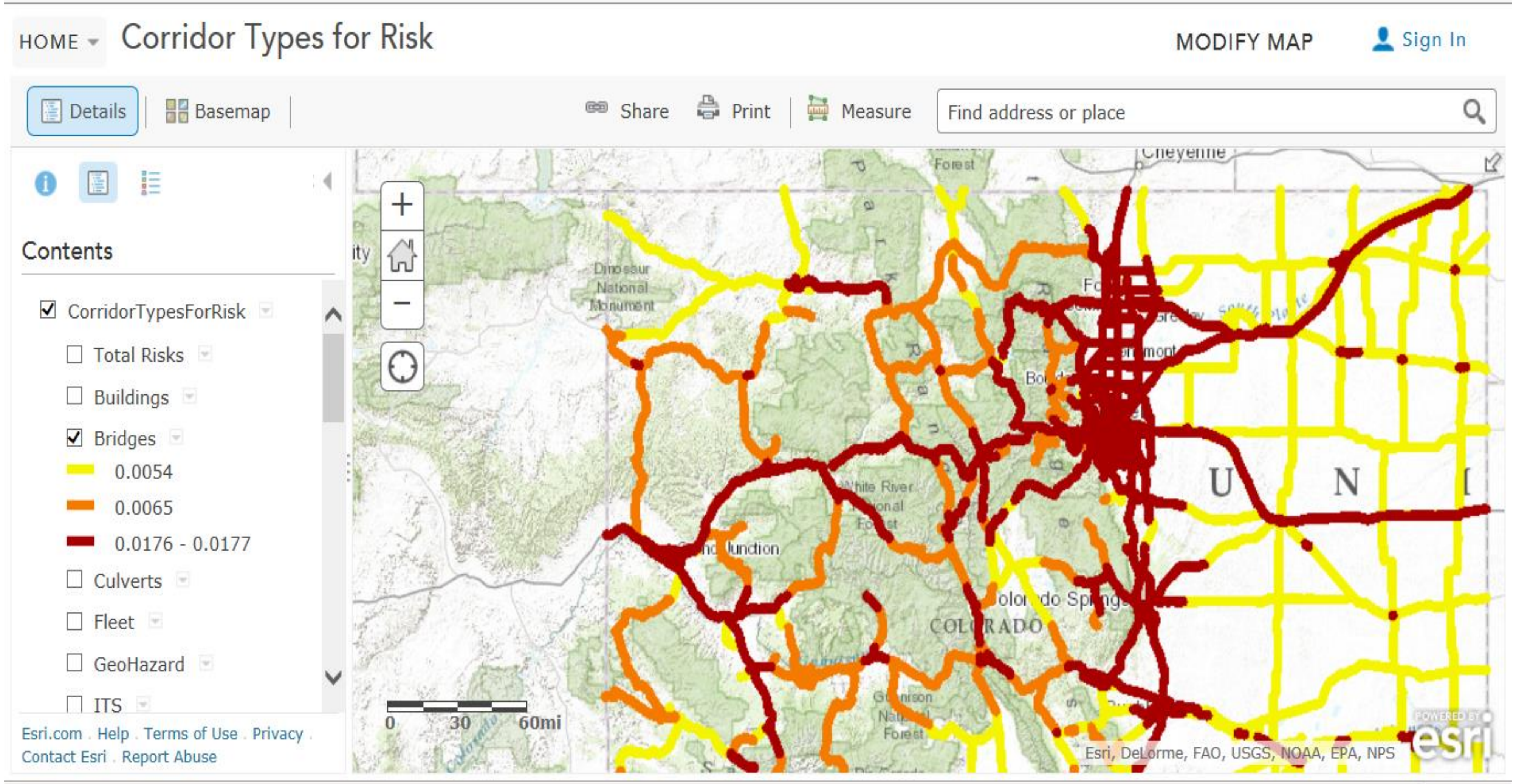
Risk score per mile
Mountain Rural Interstates



Risk score per mile
Plains Rural Medium Traffic, Non I/S

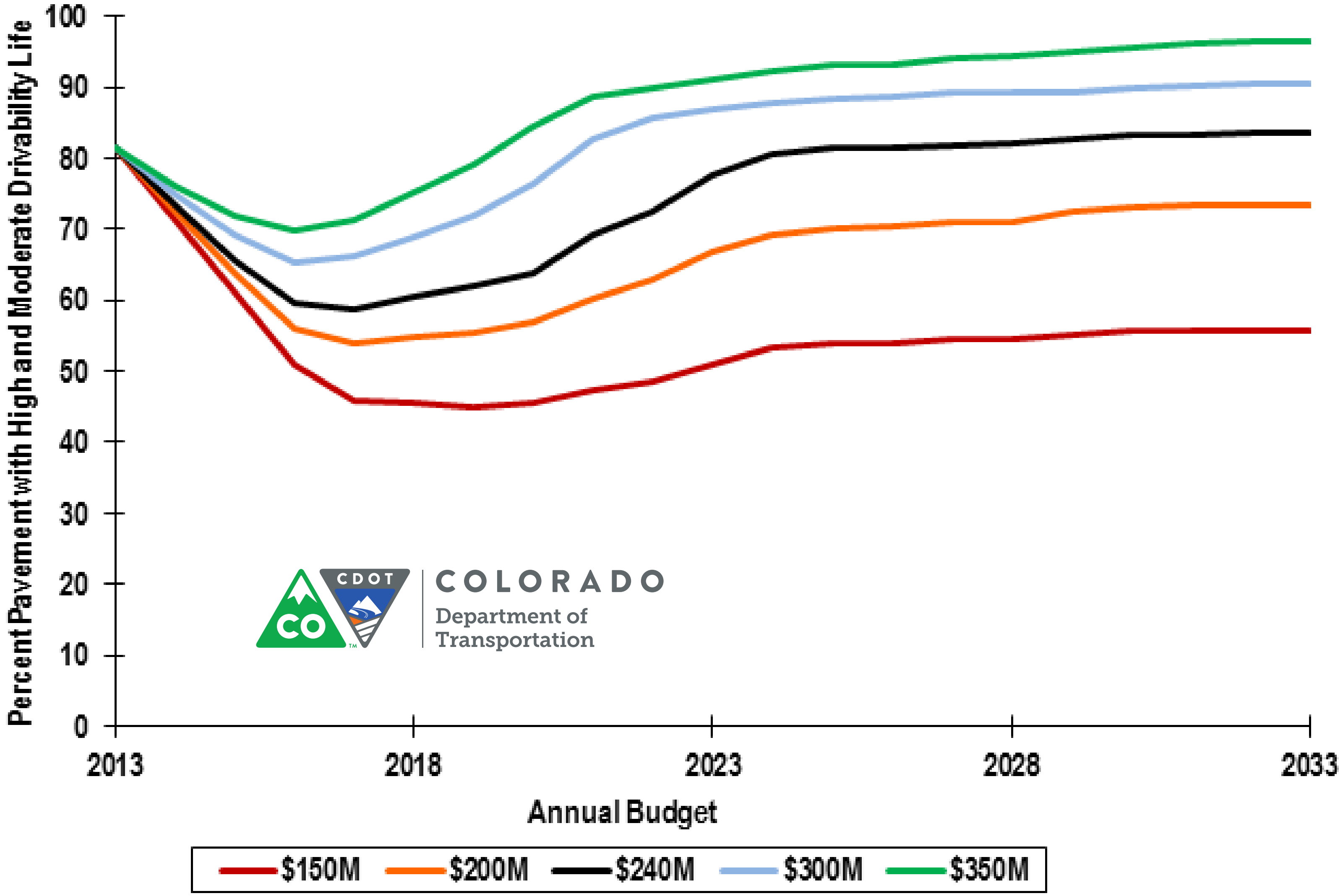


Bridge Risk Scores by Corridor

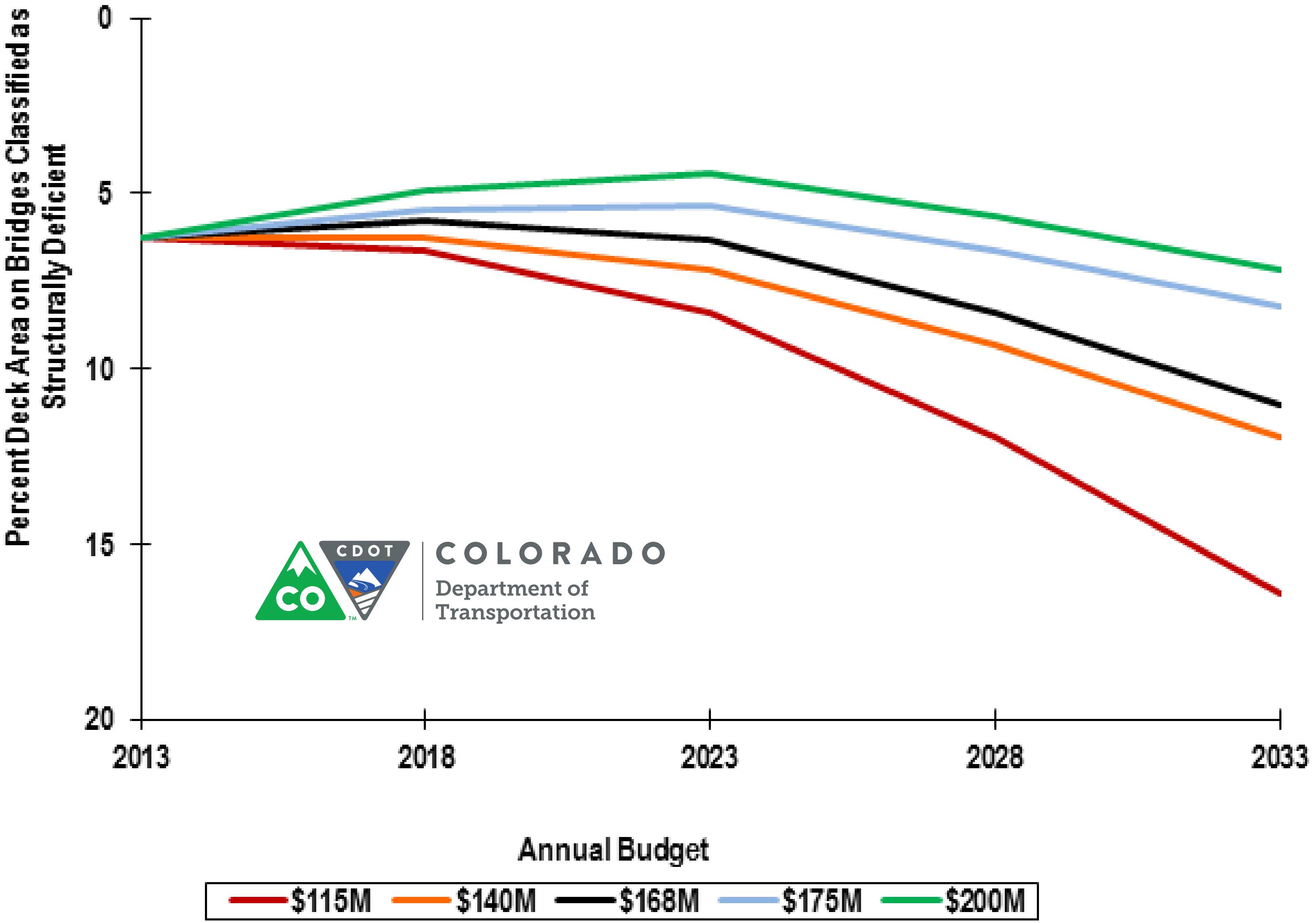


What other types of risk are there?

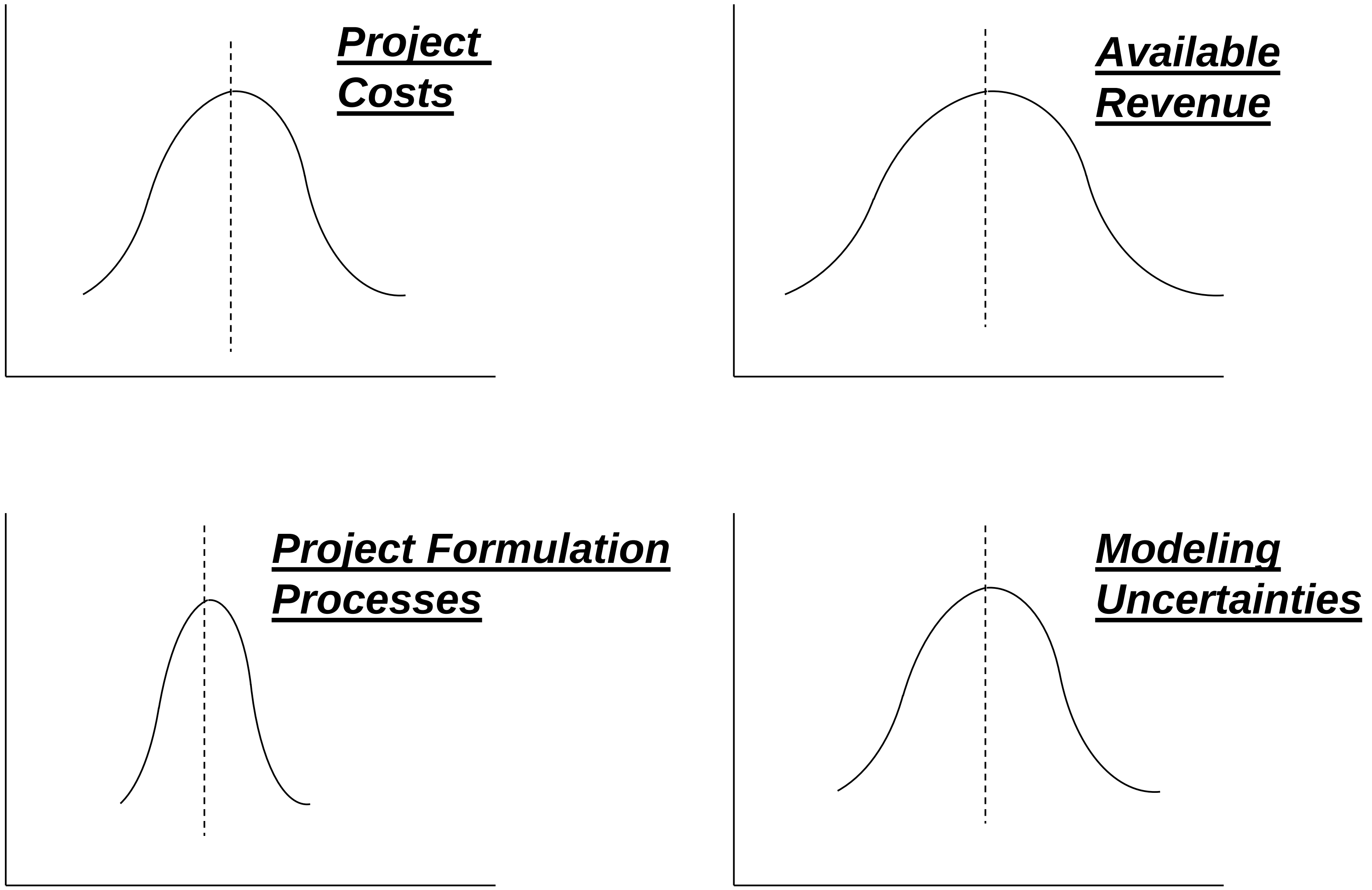
Pavement Performance versus Funding --



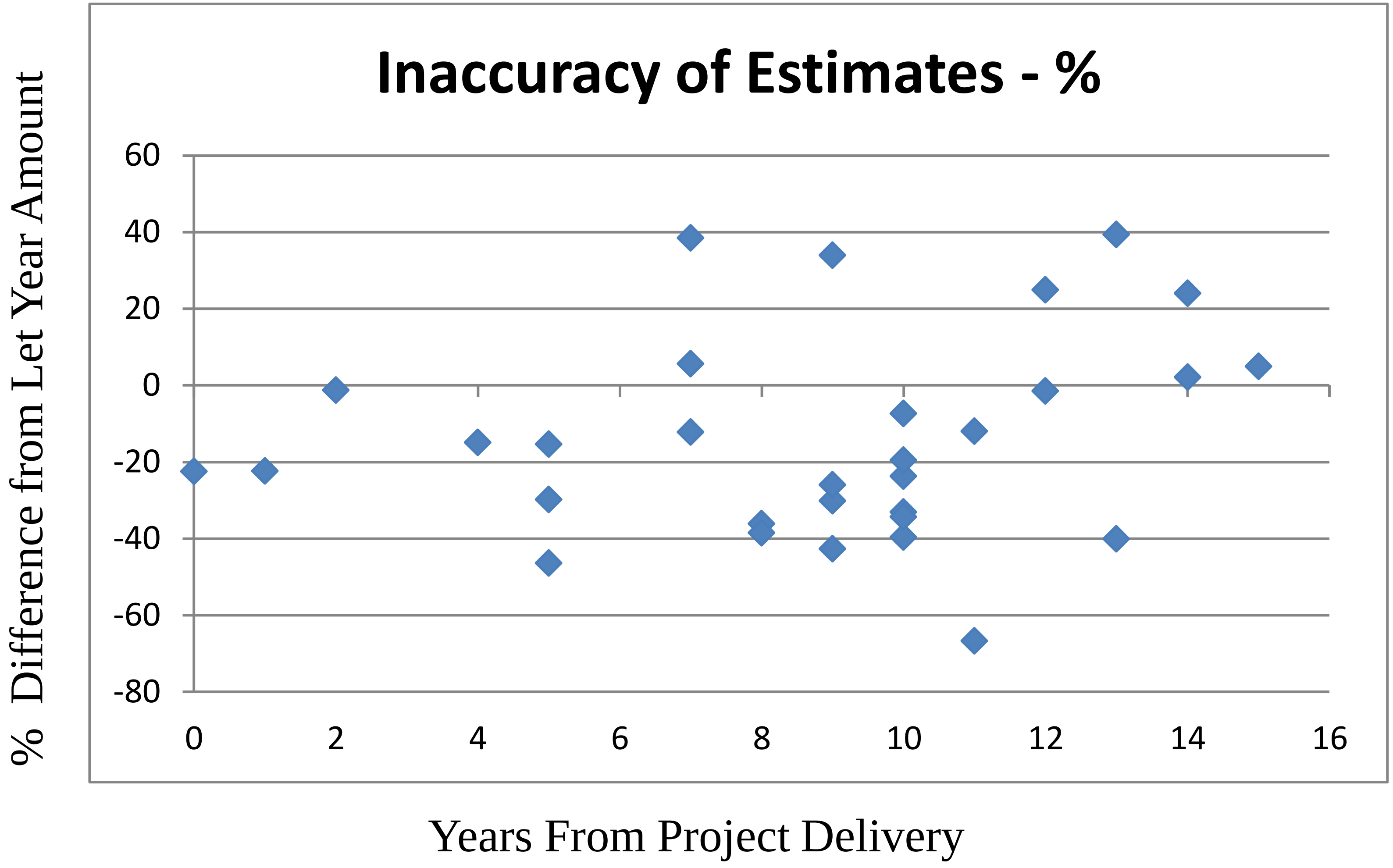
Bridge Performance versus Funding



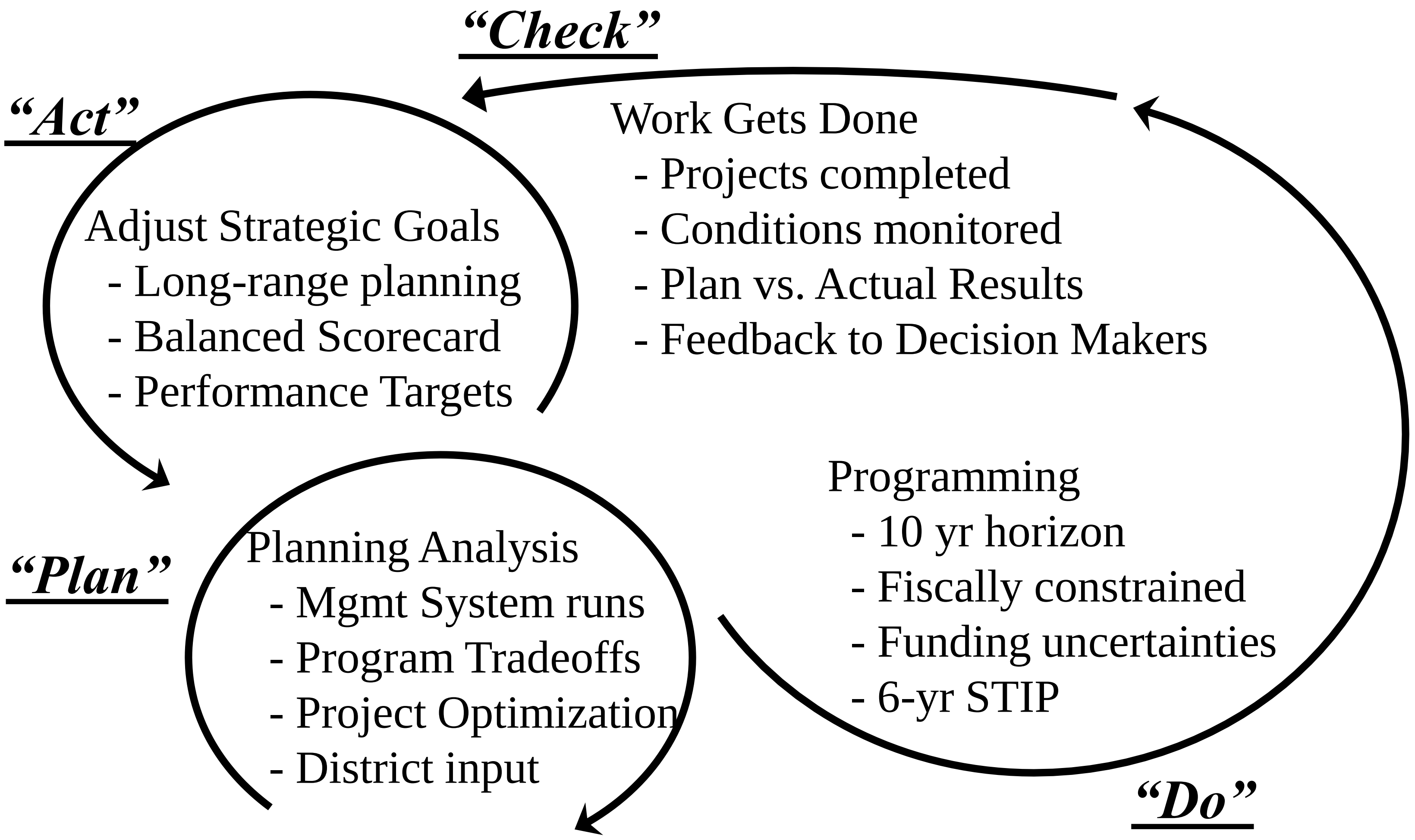
Performance Uncertainties - *Variability, Volatility of Parameters*



Cost Estimates – Medium Size



Performance Risks and Process Improvement -- *Leading and Lagging Indicators*



8. Benefit-to-Cost Exercise

Summary and Other Thoughts

Goals in Overall Results

- Ability to analyze risks by location (geospatially), along with performance-based opportunities
- Processes and tools to formulate projects, considering both performance and risk-based opportunities
- Ability to include risk in overall investment and resource allocation decisions
- Ability to consider performance-related uncertainties in planning, target-setting, and project delivery processes
  - Gap analysis of projected (planned) performance versus actual
  - Making improvements in planning and project scoping processes
  - Reducing losses due to chronic project delivery issues

So, that's all there is, correct?

- We have the definition of risk
  - "Uncertainties in reaching your goals"
- We know the steps (see ISO 31000)
- What could possibly be missing?
- Sometimes the best cookbooks are no substitute…
- There are some rules of thumb and lessons learned regarding risk management that are worth knowing
  - For discovering and evaluating various risk opportunities
  - For selecting and packaging solutions to reduce risk

What about the synergies and compromises between traditional asset management efforts and resilience efforts?

Risk & Resilience Tradeoffs

Canyon "A" and Resilience

Frequency of Flood	Light Rehab	Medium Rehab	Heavy Rehab
500 year	X	X	X
100 year	X	X	OK
50 year	X	OK	OK
25 year	OK	OK	OK

Lessons Learned…

Anecdotes, Lessons Learned

- 500 yr event – “not gonna happen again in my lifetime…” (are you sure?)
- ‘We have thousands of culverts, let’s analyze the “average” one…’ – NOTE: in order to properly assess risks, extremes matter, and there is no “average culvert”. Rare, high-impact events are important
- Some things are not risk items, but are management decisions:
  - Whether to buy or lease equipment
  - Pavement management, bridge management (??)

Discoveries re: Good Risk Analysis

- "Extremes matter!"
  - Consider full range of frequent vs. "rare" occurrences
  - There is no "average culvert"
  - *"The Black Swan"*, by Nassim Taleb

- Consider a full range of strategies, such as:
  - "Tolerate, treat (mitigate), transfer,…" etc.
  - How much to invest in a strategy? Are there tradeoffs?
  - Packaging of risk-based solutions
    - Site-specific
    - Corridor-based
    - State-wide or regional/district-based programs/projects

Key Discoveries (cont.)

- It ***is*** lucrative to manage risk opportunities --
  - Thorough analysis can identify the best opportunities, e.g.:
    - Geohazards "risk costs" in the tens of $millions (CDOT)
    - Performance and project delivery uncertainties can cost up to 5% in losses (WYDOT)
  - "***Hey, we can fix that***", with good management strategies:
    - Using new and innovative methods and tools
    - Lower the impact, transfer the risk, lessen the uncertainty, fix your processes, etc.
    - Lead time on risk analysis can be long, so get started

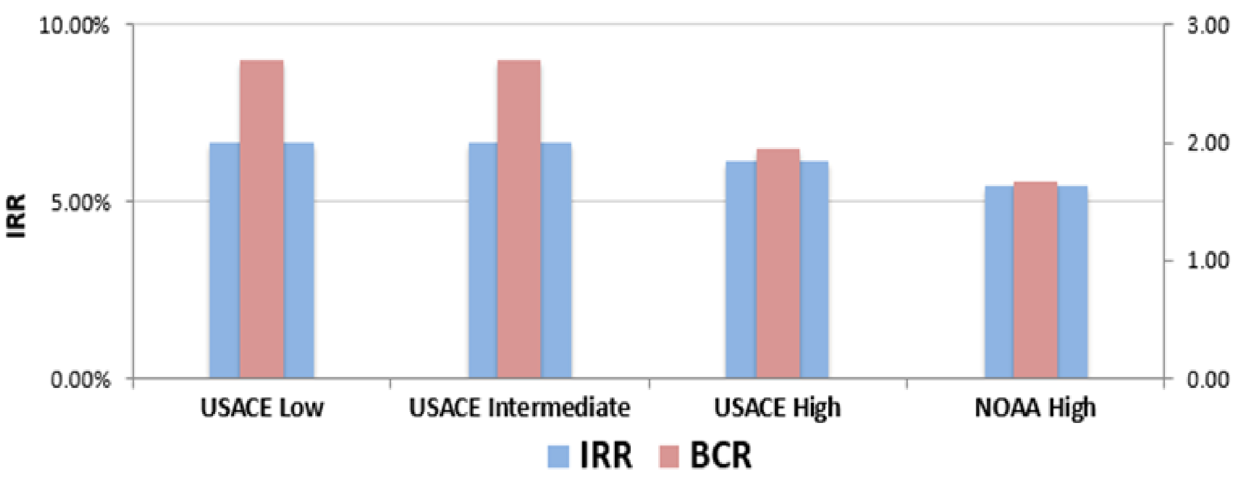
9. Adaptation Benefit-Cost Analysis Tool and Lessons

Inputs (Please enable Macros)

BCA

Summary Results

Event	Scenario	IRR	BCR
SLR/Surge	USACE Low	7%	2.71
SLR/Surge	USACE Intermediate	7%	2.71
SLR/Surge	USACE High	6%	1.95
SLR/Surge	NOAA High	5%	1.67



Name	Value	Units	Notes & Sources
Sea Level Rise/Surge			
Failure Threshold Details			
No Build Failure Threshold (feet) - NAVD88	15	feet	Surge elevation at which asset fails without improvement. Given in NAVD88 vertical datum. User should override placeholder v
Build Failure Threshold (feet) - NAVD88	18	feet	Surge elevation at which asset fails with improvement. Given in NAVD88 vertical datum. User should override placeholder valu
Tidal Datum	MSL	datum	Choose Mean Sea Level (MSL) or other
Tidal Datum name		name	If "Other" tidal datum selected, input name
Tidal Datum, difference from NAVD88 (feet)		feet	If "Other" tidal datum selected, input difference between NAVD88 and "Other" tidal datum
Zone Type	VE	type	See FEMA website for guidance: https://www.fema.gov/flood-zones
Elevation Type	Flood Elevation	type	Flood elevation includes base flood elevation. See FEMA website for further guidance.

Sea Level Rise Projection Information (Please enable Macros)

Title | Introduction | Legend | Inputs | BCA | Results | Surge Map | Precipitation Map | NYSDOT Segments | USACE SLR | USACE NAVD88 to MSL | C ...

Adaptation BCA Tool Purpose and Basics

- Perform benefit-cost analysis for climate adaptation investments in transportation infrastructure
- Incorporate climate projections and associated risks for:
  - Sea level rise/storm surge
  - Precipitation
- Planning level
- Spreadsheet-based

BCA Inputs

- Project and Asset Information
  - Construction cost, completion year, etc.
  - Project lifecycle and repair cost
  - No-Build repair cost
  - Discount rate
  - Disruption closure length
  - Detour length and time
- Transportation
  - Annual Average Daily Traffic with % breakdowns between auto/truck/bus and business/personal travel
  - Fuel cost and economy
  - Value of time
  - Vehicle occupancy

BCA Inputs

- Climate
  - Sea Level Rise/Storm Surge
    - Build and No-Build failure elevations
    - Sea level rise projections by gauge location
    - Tidal datum shift for gauge locations
    - 10-year, 50-year, 100-year, and 500-year event elevations
      - User specifies elevation type (flood, stillwater, etc.) and VE versus AE
      - FEMA supporting info on elevations
  - Precipitation
    - Exceedance event (i.e., 50-year event) with projected return intervals by projection
    - Probability of withstanding event for Build and No-Build

Benefits and Costs

- Benefits incorporate (1) the difference between probabilities of asset failure in No-Build and Build and (2) the difference between costs of asset failure in No-Build and Build
  - Can be interpreted as avoided costs under Build vs. No-Build
- Benefits
  - Avoided asset repair costs
  - Avoided delay costs for autos, buses, and trucks
  - Avoided fuel costs for autos, buses, and trucks
- Costs
  - Capital cost
  - Construction asset closure cost

BCA Results Format

- Metrics
  - Net Present Value (NPV): Discounted Benefits – Discounted Costs
  - Benefit Cost Ratio (BCR): Discounted Benefits / Discounted Costs
  - Internal Rate of Return (IRR): Rate of return that makes NPV equal to 0, or the rate at which an investment breaks even
- Results provided for each Sea Level Rise or Precipitation projection

RESULTS SUMMARY
Sandy Vulnerability Assessment Scenario

Costs	USACE Low	USACE Intermediate	USACE High	NOAA High
with adaption	$5,730,459	$5,730,459	$5,730,459	$5,730,459
Discounted	$5,563,553	$5,563,553	$5,563,553	$5,563,553
Benefits (Avoided Losses)	$2,355,376	$2,355,376	$5,146,450	$6,775,355
NPV	-$3,208,177	-$3,208,177	-$417,103	$1,211,803
IRR	**-5%**	**-5%**	**0%**	**1%**
BCR	**0.42**	**0.42**	**0.93**	**1.22**

Findings and Implications

- Economic performance depends heavily on a number of variables, including roadway volume, project cost, closure length, disruption cost per day (including productivity losses and detour time), build and no build failure thresholds, and recurring damage costs
- If projects or activities are already planned, consider marginal costs and benefits of adapting them to climate risks – start with activities, projects that are happening anyway
- Early notification, effective evacuation, and enhancing productivity of evacuees can help reduce the larger disruption costs and allow practitioners to delay or forego massive disruption prevention projects such as raised roadways

Findings and Implications

- Allowing infrastructure to flood can be an option provided that individuals are safe and disruption costs are relatively low (e.g., individuals not having to spend days in evacuation shelters due to failed transportation infrastructure alone)
    - Under this and other strategies, practitioners should investigate how to minimize recurring damages that need to be repaired after every inundation event
- When individuals are cut off from their homes for substantial periods due to transportation infrastructure failure alone, larger projects that prevent this disruption can be more feasible
- In cases where larger construction projects can be economical but construction delays are substantial, it might be more cost-effective to begin construction after a storm event when the asset is already closed

Findings and Implications

- Parallel adaptation efforts can affect the economics of a particular project substantially; coordination is key
- Status of non-transportation assets (e.g., households, workplaces, electrical infrastructure, water infrastructure, power infrastructure) is important to consider.
  - E.g., roadway flood prevention project can be less cost effective if the homes and infrastructure it leads are going to be damaged or disrupted anyway. The transportation network's benefits rely on the value of the origins and destinations that it connects
- Practitioners should conduct sensitivity testing and ground truthing when using BCA and related analyses

10. Helpful Resources

Helpful Resources

- FHWA HEC-17 – Highways in the River Environment – Floodplains, Extreme Events, Risk, and Resilience, 2nd Edition (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif16018.pdf)
- FHWA HEC-25 – Highways in the Coastal Environment, Volume 1 (2nd Edition) and Volume 2 (1st Edition) (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/07096/07096.pdf; https://www.fhwa.dot.gov/engineering/hydraulics/pubs/nhi14006/nhi14006.pdf)
- FHWA - Transportation Risk Management: International Practices for Program Development and Project Delivery (https://international.fhwa.dot.gov/scan/12029/12029_report.pdf)
- FHWA Resilience website (https://www.fhwa.dot.gov/environment/sustainability/resilience/)
- NCHRP Strategic Issues Facing Transportation, Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report (http://www.trb.org/Main/Blurbs/169781.aspx)

Helpful Resources

- NCHRP Integrating Extreme Weather Into Asset Management Plans (http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25(94)_FR.pdf)
- NCHRP Managing Risk Across the Enterprise (http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP08-93_FullGuide.pdf)
- ISO 31000 Risk Management (https://www.iso.org/iso-31000-risk-management.html)
- Intergovernmental Panel on Climate Change (IPCC) Assessments (http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml)
- EPA Climate Resilience Evaluation and Awareness Tool (CREAT) 3.0 (https://www.epa.gov/crwu/build-resilience-your-utility)
- NOAA Climate.gov (https://www.climate.gov/)

Helpful Resources

- Downscaled Climate and Hydrology Projections (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html)
- Climate Corps Sea Level Change Curve Calculator (http://www.corpsclimate.us/ccaceslcurves.cfm)
- USGS StreamStats Tool (https://water.usgs.gov/osw/streamstats/)
- Georgetown Climate Center Clearinghouse (http://www.adaptationclearinghouse.org/)
- California DOT - Addressing Climate Change Adaptation in Regional Transportation Plans (http://www.dot.ca.gov/hq/tpp/offices/orip/climate_change/documents/FR3_CA_Climate_Change_Adaptation_Guide_2013-02-26_.pdf)
- Thinking, Fast and Slow – Daniel Kahneman

11. Questions