Incorporation of Geotechnical Elements as an Asset Class within Transportation Asset Management and Development of Risk Based and Life Cycle Cost Performance Strategies

by

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Project performed in conjunction with FHWA Federal Lands Highway White Paper on Geotechnical Asset Management

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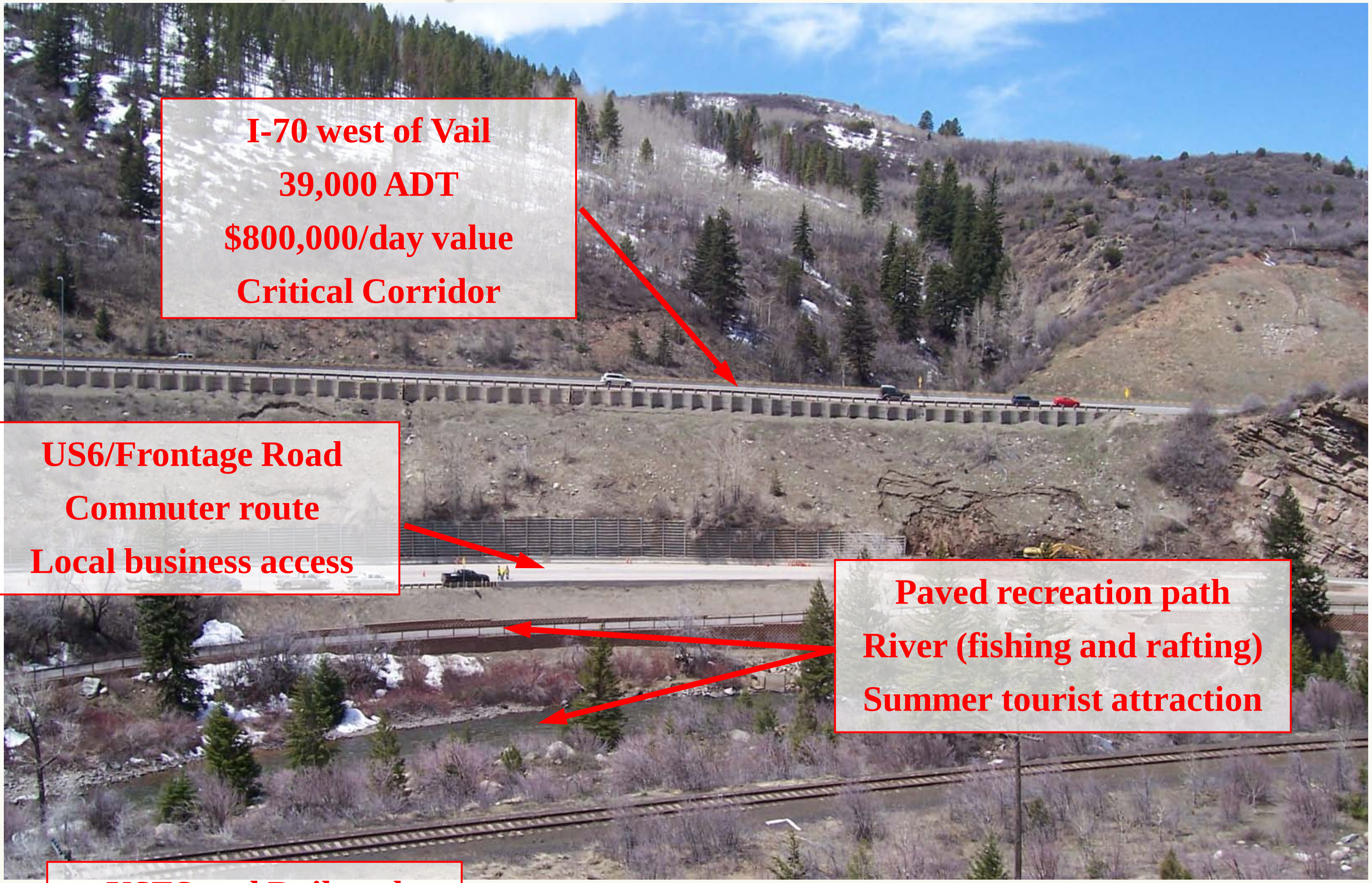
The Benefit of Geotechnical Asset Management

Life-cycle cost savings of **60 to 80 percent** for railroad and motorway embankments in the United Kingdom (as summarized in Perry and others, 2003a and 2003b)

Geotechnical Assets

- Performance and safety throughout the life-cycle depends on the reliability of earth supported components, as well as the reliability of adjacent terrain.



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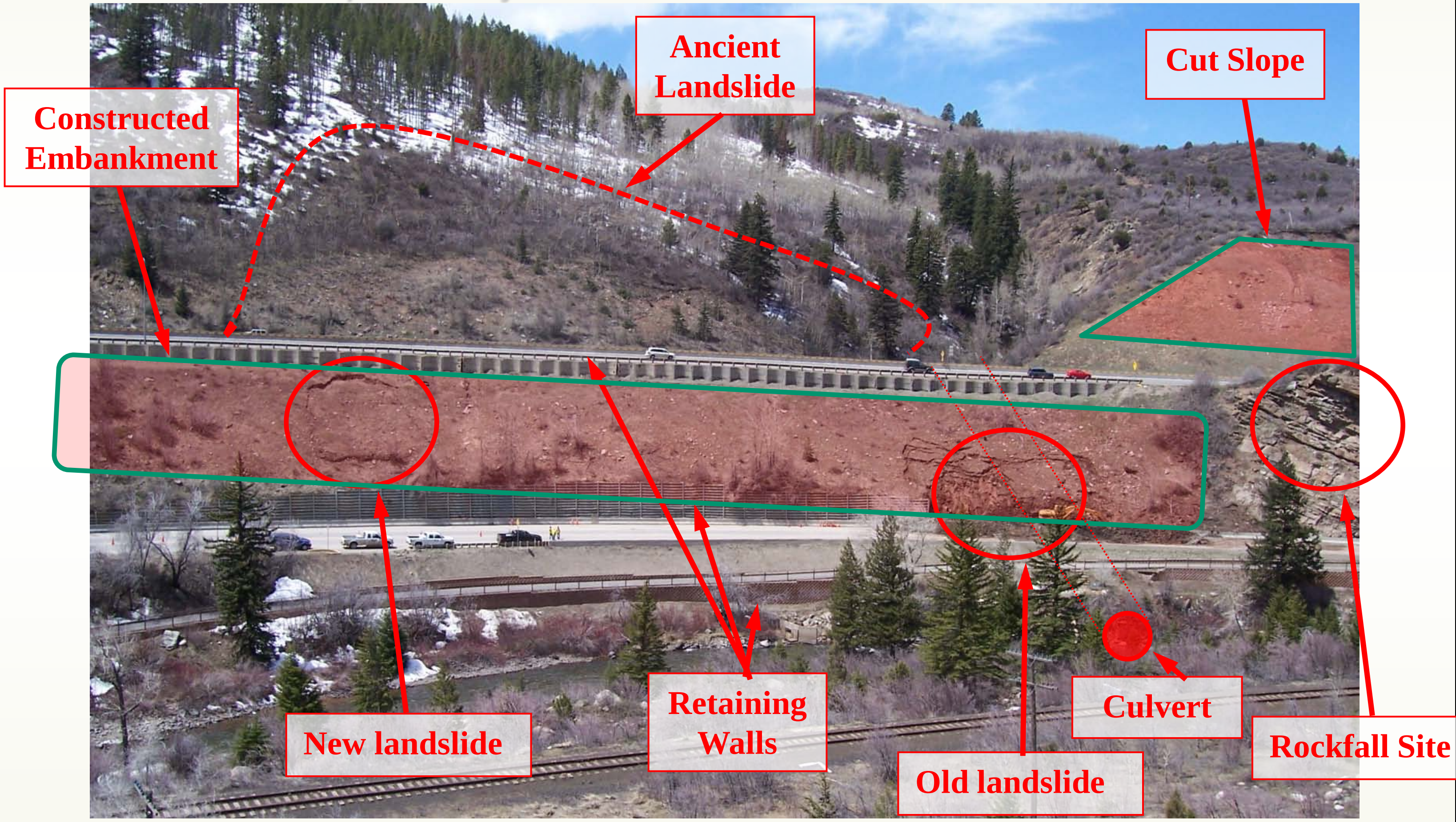

- The geotechnical *features* that could be included in the geotechnical asset class include:

Geotechnical Features

- Tunnels
  - Tangible value: Concrete, ground support, systems
  - Intangible value: Shortened travel time, hazard avoidance, reduces property and environmental disturbance

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Geotechnical Features

- Retaining Walls
  - Tangible value: concrete or modular facing, reinforcement, structural fill
  - Intangible value: reduces travel time, land disturbance, benefits alignment/speed

Geotechnical Features

- Embankments
  - Tangible value: earth fill
  - Intangible value: benefits alignment and travel time

Geotechnical Features

- Unstable slopes
  - Tangible value: stabilization and/or protection measures, instrumentation/monitoring, regular maintenance
  - Intangible value: property, economic, and life safety

The Value of Geotechnical Assets

- Failures of geotechnical features have resulted in environmental damage (water quality, aesthetics, habitat) significant repair costs, and even larger economic costs to corridor users and communities
  - Can be orders of magnitude greater than other transportation assets

- Ferguson Slide, CA
  - 92 day closure on direct route into Yosemite
  - $4.8M in business losses
  - $8M short-term repair cost
  - $18M-$378M long-term (dependent on EIS)

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The Value of Geotechnical Assets

- Tennessee and North Carolina Rock Slides
  - 6 month closures of an Interstate and US Highway
  - 30 to 90% reductions in restaurant, lodging, and retail revenue
  - Estimated $197M cost due to increased vehicle operation, detour travel time, emissions, congestion, and pavement maintenance on alternative routes

- Vail Pass Culvert and Embankment Failure (Colorado)
  - 3 day closure of I-70 during summer tourist season
  - $4.2M repair cost
  - $4M estimated user cost
  - Stakeholder damages

The Value of Geotechnical Assets

- Beartooth Highway Closure
  - Uncontained storm water flow in roadway triggered debris flows that damaged road in 13 locations over 10 miles
  - May to October Closure on important route into Yellowstone Park
  - $19M reconstruction project
  - 13% of earnings for Carbon County, Wyoming due to tourism on corridor

Geotechnical Risk and Hazard

- Hazard:
  A source of danger/impact
- Risk:
  Evaluation of hazard **probability** and resulting **consequence**
- You can be in high hazard area, but have a low risk (i.e. what is the degree of exposure)

High Hazard

ADT < 1,000 - Low Risk

ADT >10,000 - Higher Risk

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Geotechnical Risk and Hazard

- Need to assess within the context of agency performance goals and measures

- Both sites in the same corridor
- Both sites are hazards with a probability of failure
- Both sites have different consequences to:

Safety, mobility, aesthetics, other property damage

Current Standard of Practice for Management Geotechnical Features

Within US Transportation Infrastructure

- 25 agencies use Rockfall Hazard Rating Systems
  - First full implementation in 1990 for rockfall sites
  - Determines a relative hazard score based on factors such as geology, climate, traffic
  - Typically applied statewide or agency wide
  - Several have been modified to fit agency needs
  - Generally implemented outside of transportation asset management efforts (although an early application)
  - In some cases, risk elements included in hazard score
- Slope Management Programs
  - Adaptation of rockfall hazard methodology to all slopes (Washington, Oregon, Alaska)
- Retaining Wall Inventory
  - National Park Service, Oregon

Current Standard of Practice for Management Geotechnical Features

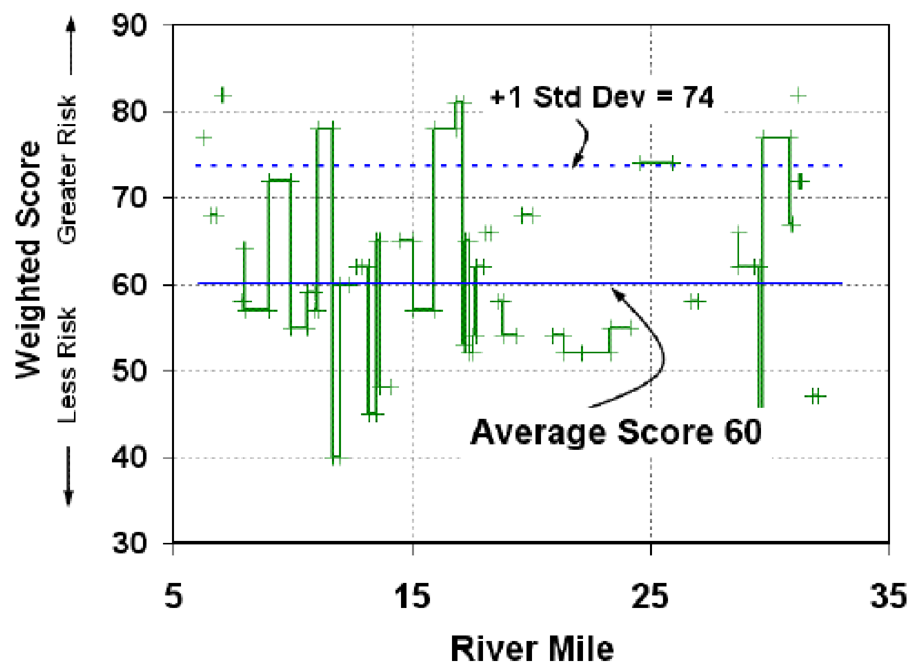
Other Countries or Infrastructure Types

- Risk based landslide risk management in Australia
  - Methods for quantitative analysis of slope hazards
  - Also applied for mitigation strategy of over 900 landslide, rockfall, and debris flow sites along a railway corridor in India
- UK embankment and cut slope asset management
  - Two-tier risk based asset management program (strategic and tactical level assessment)
  - Mitigation selected on basis of greatest cost-benefit ratio that also reduces risk to an acceptable level
- Water Utilities
  - Asset management required for bonding (5 to 30 year capital maintenance programs)
  - Group assets into classes to reduce assessment and analysis burden

Current Standard of Practice for Management Geotechnical Features

Other Countries or Infrastructure Types

- King County Levee Reliability Assessment
  - Two phase risk based approach to focus intensive quantitative analysis on high risk sites
  - 5 continuous miles of levee assessed per day



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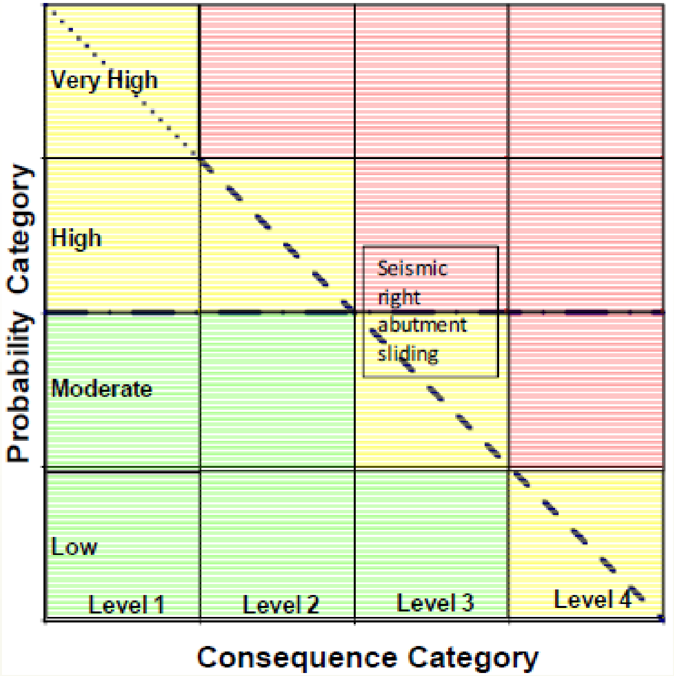
Current Standard of Practice for Management Geotechnical Features

Other Countries or Infrastructure Types

- USACE dam risk assessment (Scott, 2011)
  - Multi-tier assessment approach to concentrate resources on most critical failure modes
  - Semi-quantitative initial inventory of failure modes with risk screening among several dams

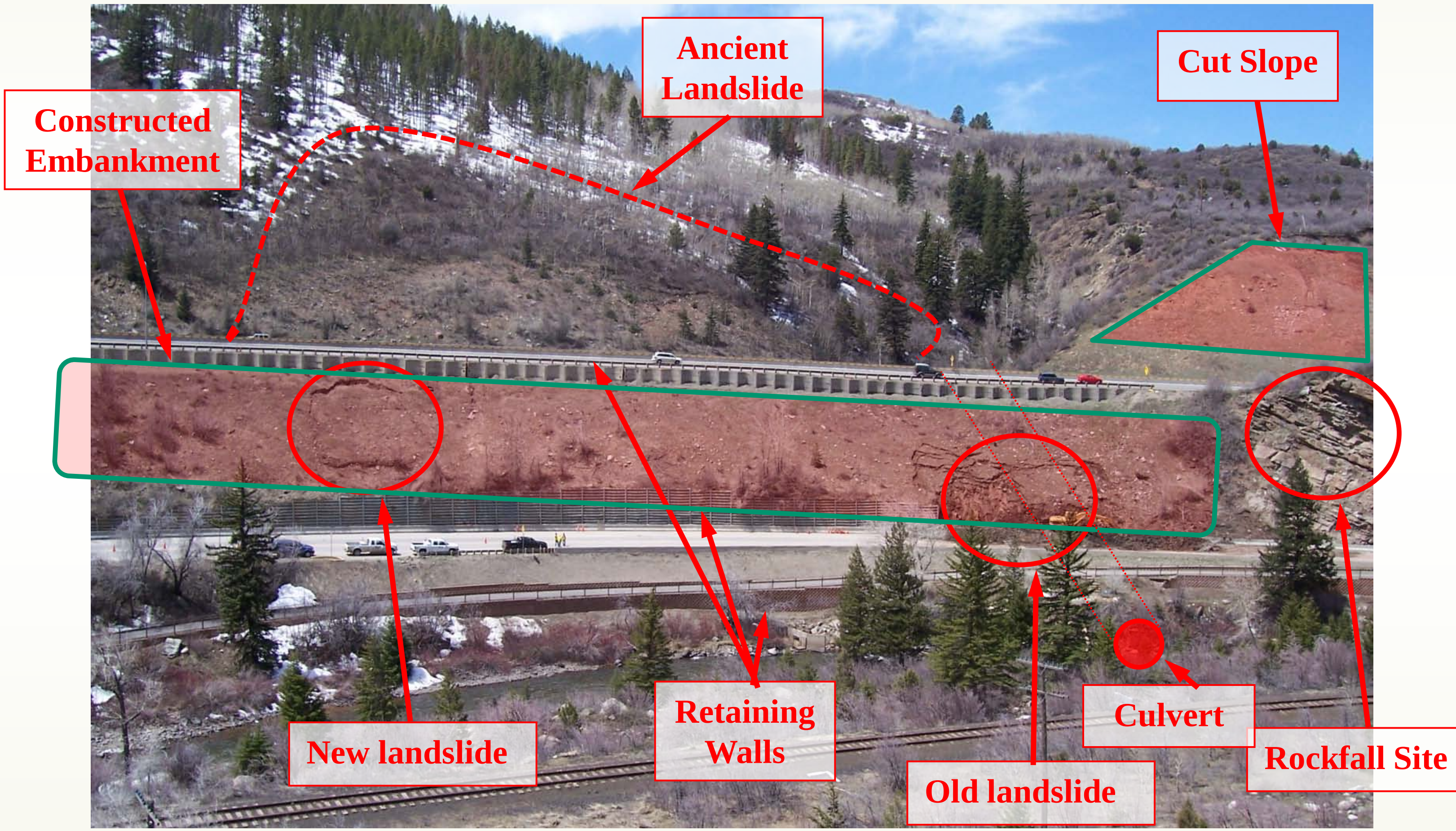


Proposed Geotechnical Asset Management Approach

- Multiple features within a "Geotechnical Class"
- Risk based
- Multi-tier
- Based on corridor or other performance boundary
- Performance measures that relate to agency transportation asset management plan

Proposed Geotechnical Asset Management Approach

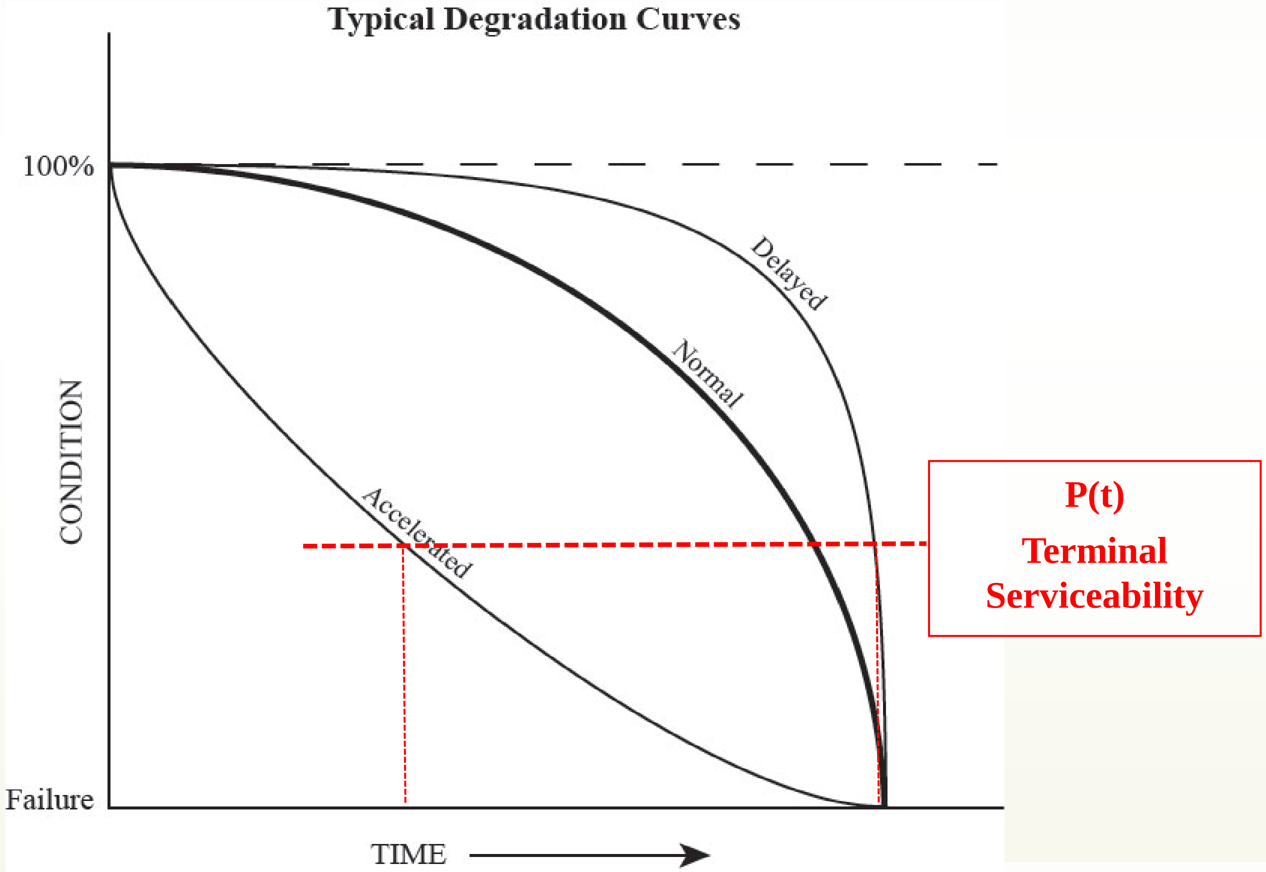
- Multiple features grouped into a geotechnical asset class



- Assessment and risk screening are incomplete if a failure mode is omitted

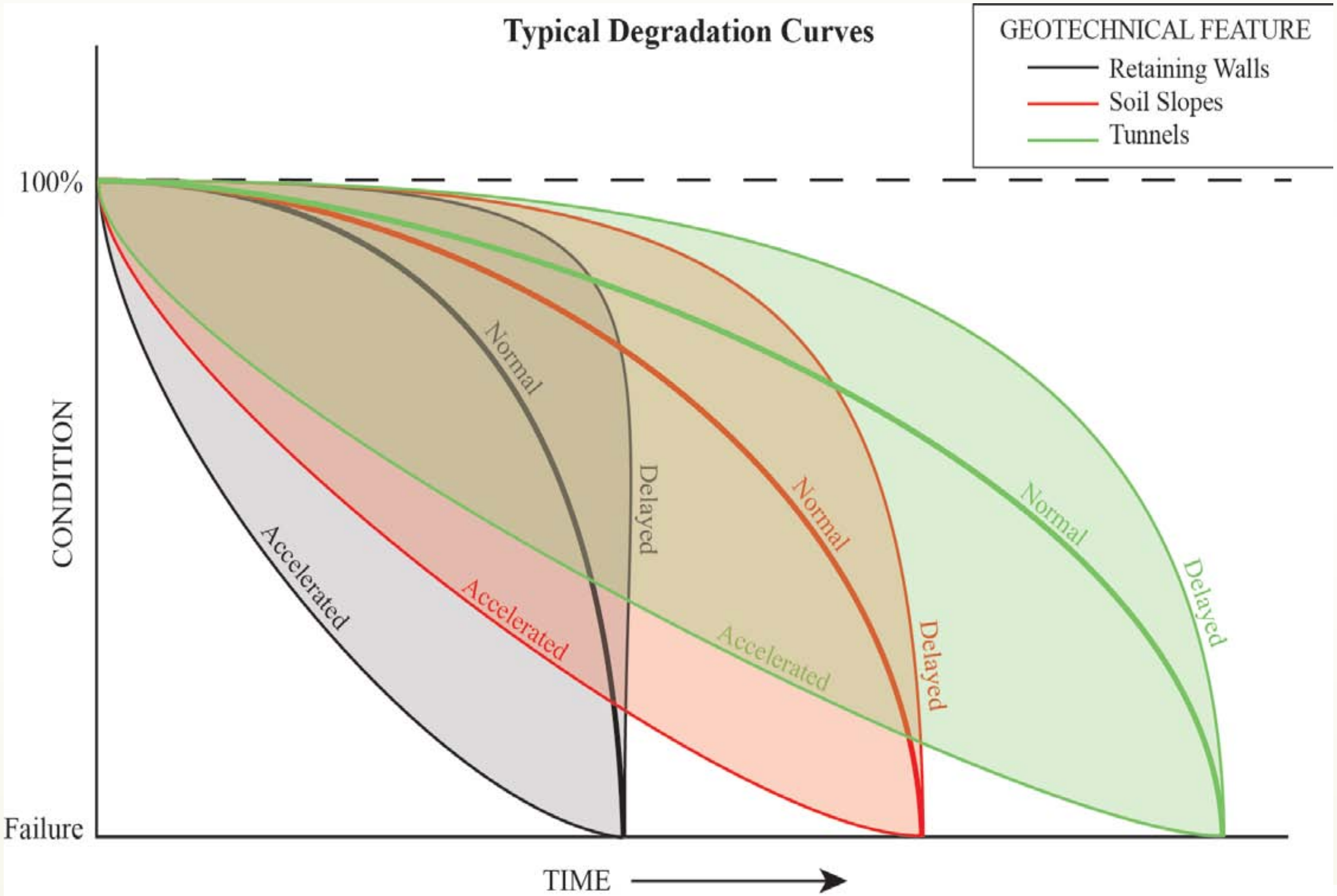
Proposed Geotechnical Asset Management Approach

- Risk based
  - More uncertainty with geotechnical features relative to constructed elements and major consequences
  - Condition curves don't exist or are variable



Proposed Geotechnical Asset Management Approach

- Risk based and when considering performance
  - Means to address variability in condition curves for different features



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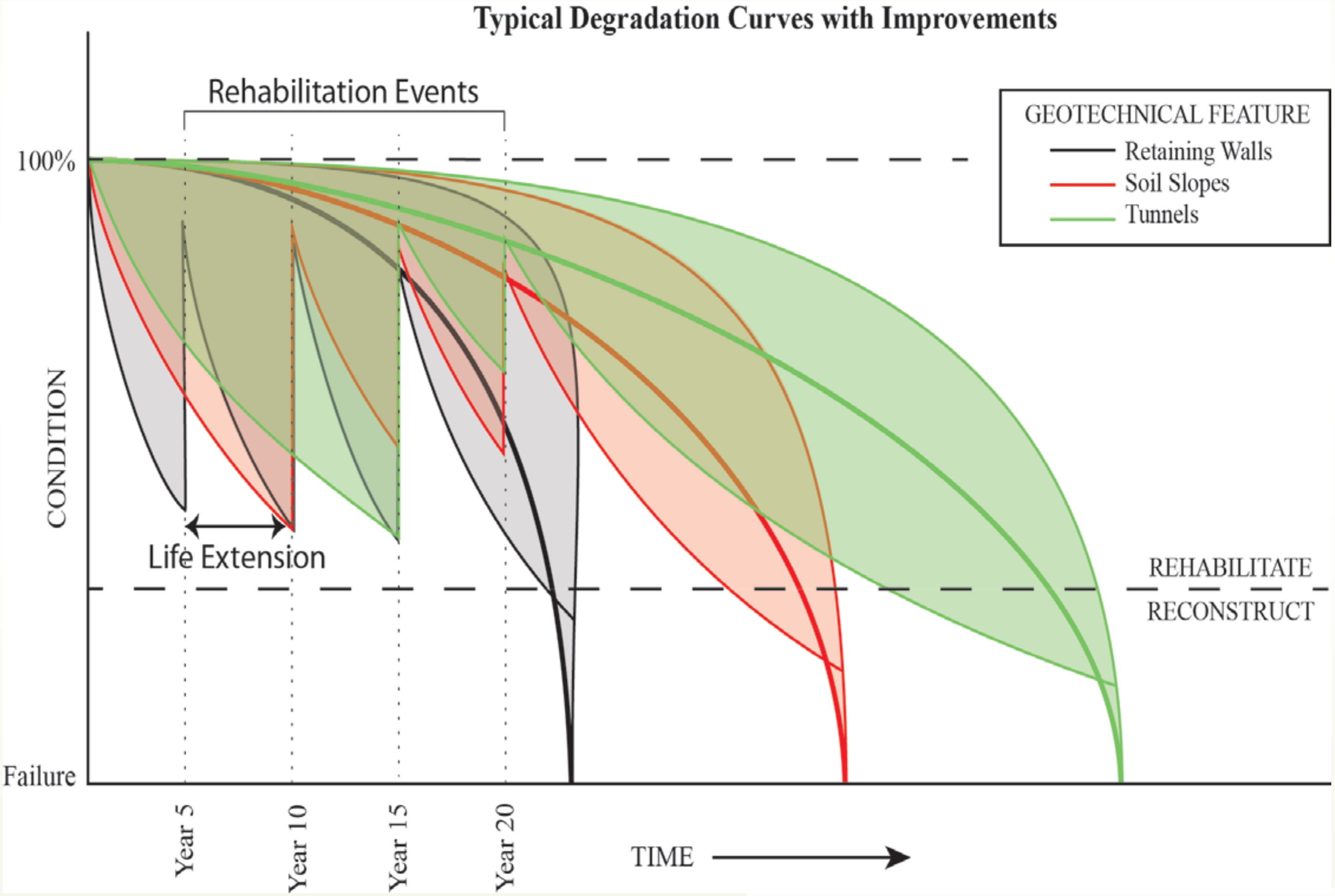

Proposed Geotechnical Asset Management Approach

- Multi-tier assessment – First tier methodology (rapid)

First Tier Assessment Parameter	Criteria	Explanation
Inventory	Type of Feature	Rockfall site, landslide, tunnel, retaining wall, large diameter culvert crossing, engineered and reinforced rock slope, or embankment
	Physical Location	Location referenced to existing agency GIS format
	Condition	Note approximate geometry and observations of distress.
	Relative Location	Roadway, Uphill or Downhill Shoulder, Within or Beyond Right-of-Way
Failure Scenario	-	Description of potential failure scenario. For example, the facing for the fill side retaining is deteriorating and resulting in soil loss. Progression of soil loss will undermine the roadway and could cause a sink hole in the travel lane.
Failure Likelihood	Very High	There is significant evidence failure has occurred or will occur without any further triggering events. The subjective probability would be near 0.99.
	High	There is evidence a failure will occur with only a minor triggering event. The subjective probability may be 0.9 for this category.
	Moderate	A failure could occur but evidence suggests the event could be either unlikely than likely. The subjective probability is near 0.5 in this category.
	Low	A probability of failure may exist but would require a remote circumstance to trigger failure. The subjective probability may be near 0.1.
	Unlikely	A series of remote and low probability events would need to concurrently occur to cause failure. A subjective probability value would be less than 0.01.
Failure Consequence	Level 0	Minimal to no impact to the corridor from a failure. The failure of the feature would be off the roadway and confined within the right-of-way or easement. A failure event may not require any immediate maintenance or repair.
	Level 1	The failure would have a minor effect to the roadway shoulders and require some degree of maintenance or reconstruction. The traffic speed may be reduced to accommodate the failure or repair activity, but travel lanes can remain open throughout the event.
	Level 2	A failure and/or repair would impact one lane of the road requiring a temporary onsite detour or lane closure for greater than one day. The event also may create negative publicity or short term economic effects for regular users of the corridor. The repair of this failure would likely involve non-agency maintenance or construction personnel.
	Level 3	The failure damages or blocks the entire road width and causes a full road closure for more than one day. Temporary stabilization or earthwork can reopen the road to restricted travel within a few days of the event, but a significant repair, reconstruction, is required to restore the roadway to pre-failure conditions. There is a likely potential for property damage to vehicles or adjacent private property as well as measurable economic loss to users and communities within or beyond the corridor. Additionally, there could be a temporary increase to the safety of traveling public due to poor driving surface, below standard detour alignments, and driver expectations.
	Level 4	The failure causes a prolonged road closure that could extend for weeks or months before temporary stabilization is performed. Significant economic effects result to the corridor and surrounding region. The financial burden of a permanent repair requires emergency relief funds or exceeds the available contingency budgets. During the event, there is a significant potential for fatalities.

Proposed Geotechnical Asset Management Approach

- Multi-tier assessment – First Tier Methodology
  - What, where, how, and probability of occurrence

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Proposed Geotechnical Asset Management Approach

- Multi-tier assessment – First Tier Methodology
  - Judgment of consequence of failure

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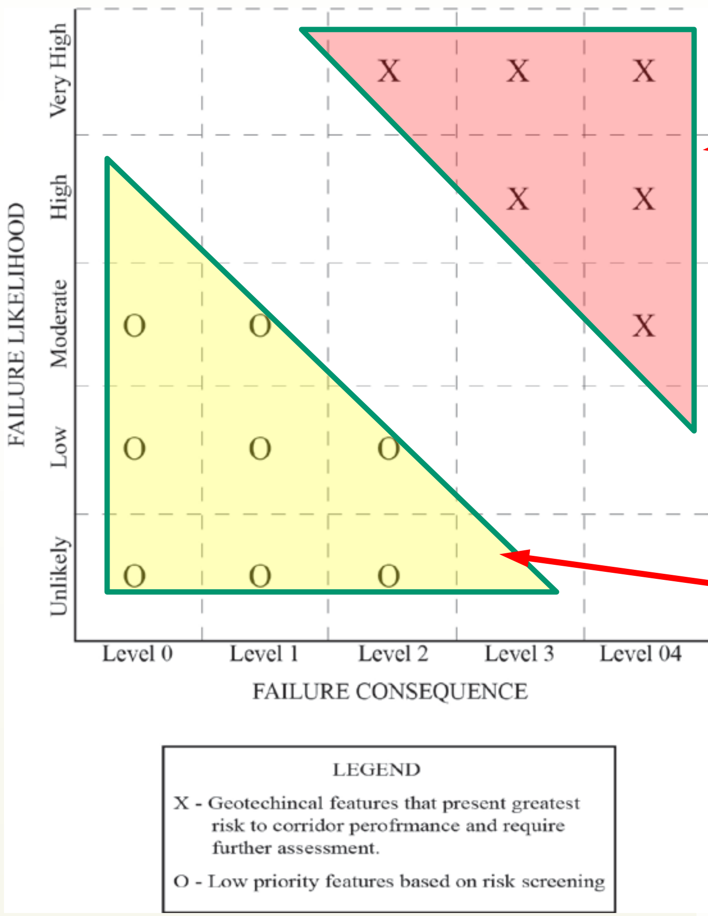
Proposed Geotechnical Asset Management Approach

- Multi-tier assessment
  - Based on other asset management approaches
  - Concentrates effort on most critical features
    - Tier 1 example outcome:



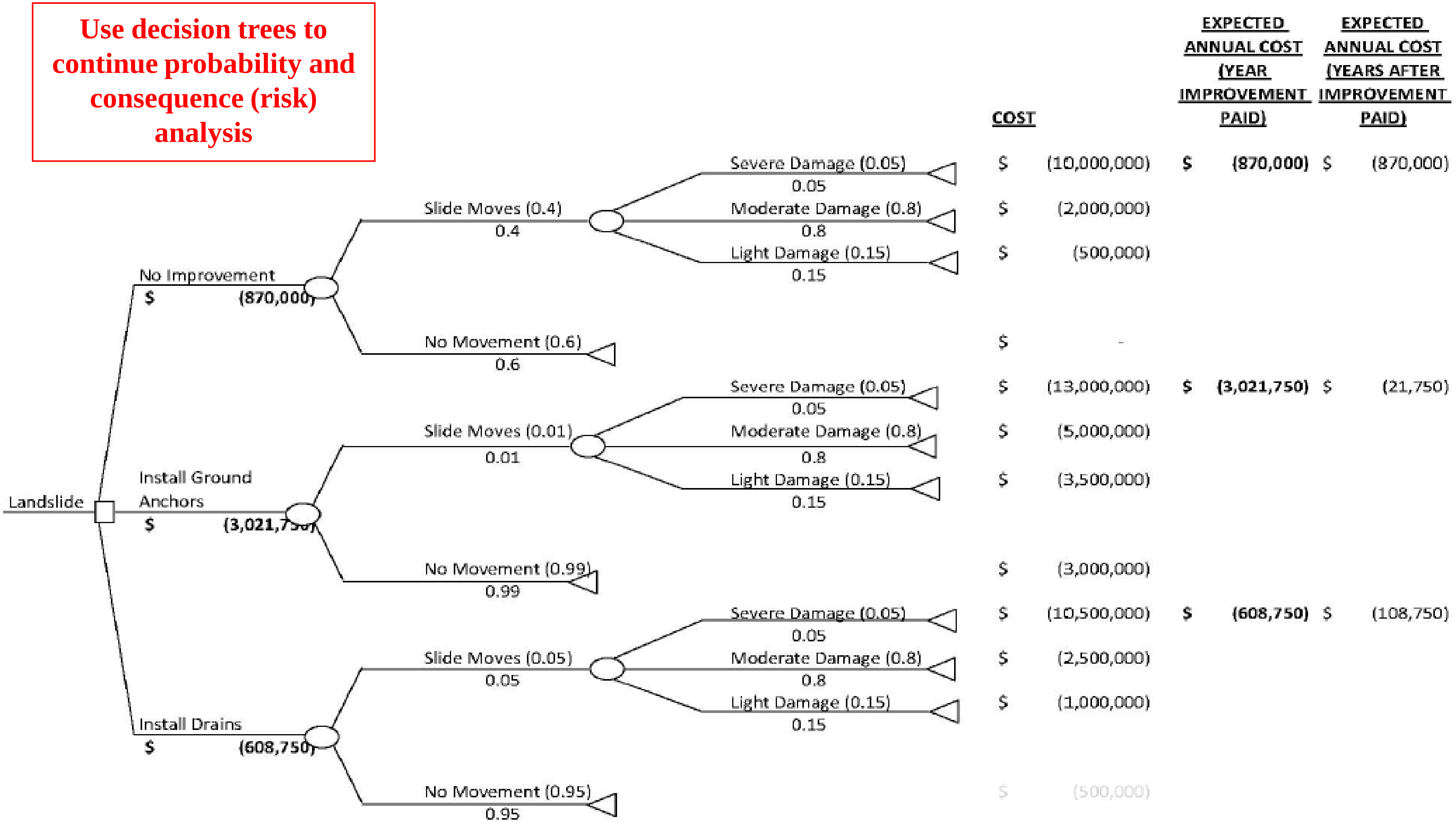
Focus quantitative inventory and assessment for these features

Important to record in data management and re-assess in future

Proposed Geotechnical Asset Management Approach

- Multi-tier assessment – second tier methodology
  - Quantitative analysis (may require expert elicitation)

Use decision trees to continue probability and consequence (risk) analysis



Proposed Geotechnical Asset Management Approach

- Multi-tier assessment – second tier methodology
  - Quantitative analysis (may require expert elicitation)
    - AGS (2000) methods may be better suited for risk analysis when considering fatalities

$$R_{(\text{annual probability of fatality})} = P_{(H)} \times P_{(S:H)} \times V_{(\text{Individual})} \times P_{(T:S)}$$

Where:

$P_{(H)}$: Probability of the event (0 to 1.0)

$P_{(S:H)}$: Probability of spatial impact by the hazard (probability of rockfall striking vehicle)

$V_{(\text{Individual})}$: Vulnerability (probability) of life loss due to impact of event

$P_{(T:S)}$: Temporal probability of spatial impact by hazard (i.e. the probability of vehicle occupant in area of impact)

Proposed Geotechnical Asset Management Approach

- Multi-tier assessment – second tier methodology
  - Second tier risk analysis outcome (relative evaluation)

Feature	Action	Consequence	Annual Probability	Cost for Year of Improvement	Expected Annual Cost After Improvement (if performed)
Landslide	No Improvement	Mobility: Long term lane loss Economic: Revenue loss for corridor Preservation: Pavement damage	40%	$870,000	$870,000
	Install Ground Anchors		1%	$3,021,750	$21,750
	Install Groundwater Drains		5%	$608,750	$108,750
Culvert Crossing	No Improvement	Preservation: Embankment failure Environmental: Sediment contamination in river	40%	$20,500	$20,500
	Culvert Cleaning		10%	$25,125	$5,125
	Culvert Replaced		1%	$100,513	$513
Retaining Wall	No Improvement	Preservation: Retaining wall and roadway damage Mobility: Temporary lane closures for repair	15%	$80,625	$80,625
	Maintenance Option A		10%	$103,750	$53,750
	Maintenance Option B		1%	$105,375	$6,375
Rockfall Site	No Improvement	Safety: Fatality and injury of public Economic: Litigation and public perception	90%	$663,750	$663,750
	Scale Slope		60%	$842,500	$442,500
	Scale Slope and Install Rockfall Fence		25%	$2,184,375	$184,375

Proposed Geotechnical Asset Management Approach

- Corridor approach is recommended for geotechnical features:
  - Features may vary by geography and geologic conditions
    - Urban versus rural
  - Data set can be focused on the specific needs of each roadway/corridor or differences in risk tolerance
    - Economic, mobility, tourism, safety
  - Corridor approach allows an agency to prioritize corridors and concentrate resources appropriately

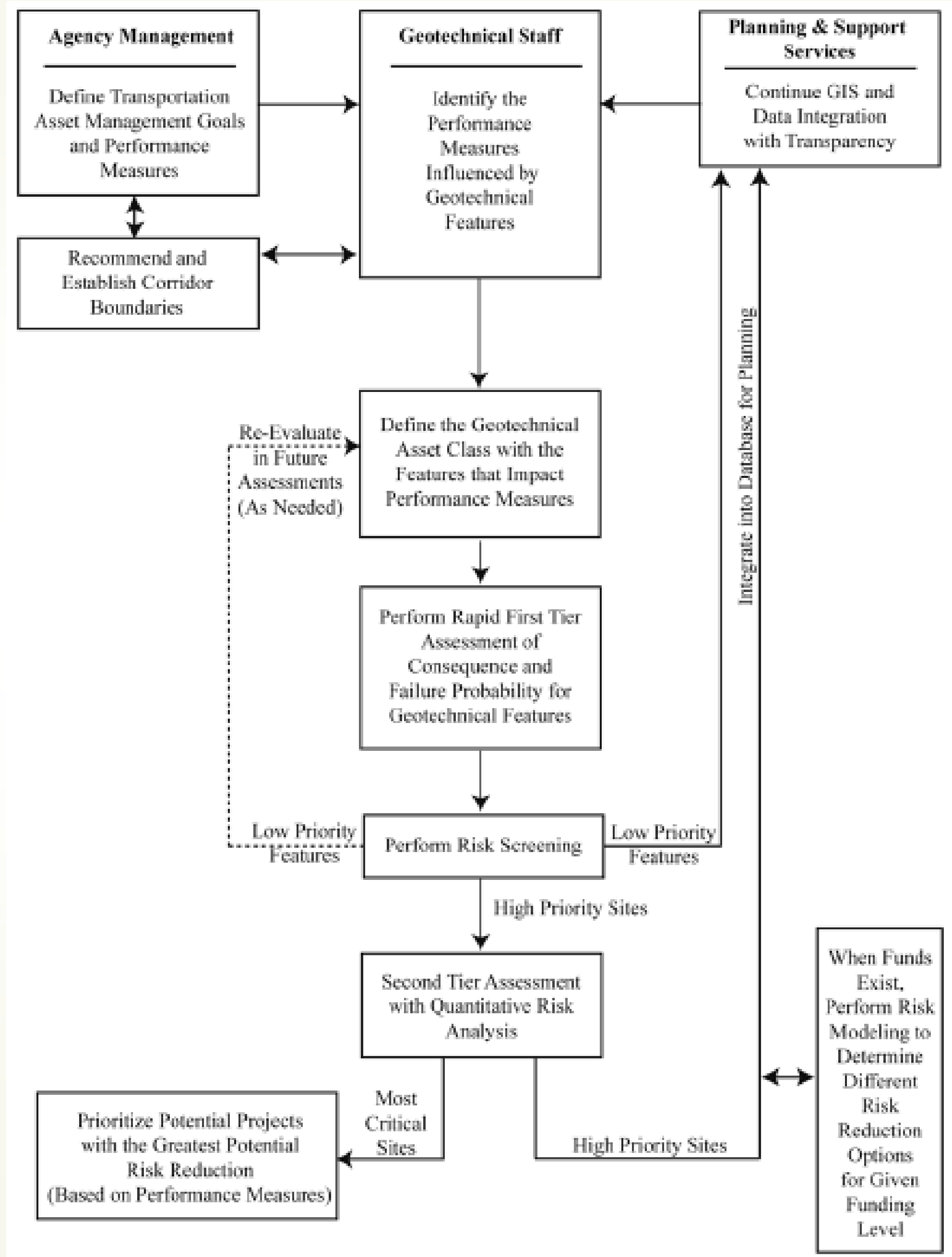
Performance Measures

- Different owners = different performance goals
- Same owner = different performance goals
- Life cycle definition
  - What is the analysis period
- Geotechnical asset management needs to integrate with transportation asset management and/or agency performance measures

Performance Measures

Agency Goal	Performance Measure	Quantitative Assessment Parameters
Safety	Fatalities	Fatalities per vehicle mile traveled
	Injuries	Traffic injuries per vehicle mile traveled
	Accidents	Number of accidents caused by debris on road or poor road condition (not weather or wildlife related)
Mobility	Closure	Number of hours of full closure per year
	Delay	Hours of travel delay per year
	Capacity	Number of hours permitted for lane blockage; percent of vehicles travelling at posted speed
	User Cost	Maximum allowable road user cost per year
	Economic Indicator	Corridor business survey score
Preservation	Pavement Condition	Number of locations with fair to poor pavement condition that is due to subgrade structure deficiency
	Cultural Resources	Number of cultural and historical resources at risk from geotechnical features
	Environmental	Percent of storm water discharge sites not in compliance
	Sustainability	Favorable cost/benefit ratio, considering tangible and intangible costs and benefits

Summary of Process



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Summary

- Define performance goals and measures
  - Vary by owner and within transportation network
- Utilize best practices from others to efficiently inventory and assess risk
  - History of rockfall and retaining wall asset management programs (mostly inventory and hazard ranking) would suggest several years (decades) are required at the current pace
- Commit to the process
  - There is a cost of inaction: studies suggest 60 to 80 percent savings over the life cycle
  - Significant value associated with failure of geotechnical features