Hazard and Risk

Learning Objectives

- Understand definitions of hazard and risk.
- Understand metrics that may be used in assessing landslide hazard and risk.
- Understand how to facilitate decisions based on landslide hazard and risk.

Landslide Hazard and Risk Assessment

Definitions

- Failure Mode Identification – The process of developing and classifying or ranking the possible ways that a “Slope” will fail
- Risk Analysis – Can be a quantitative or qualitative evaluation of Risk (but usually both)
- Risk Assessment – The process of deciding whether or not to take actions to reduce risk. “Do I really have to do something about this”
- Risk Management – Implementing measures to reduce risk and following up with analyses and assessments to evaluate the effectiveness of those measures

Definitions (cont.)

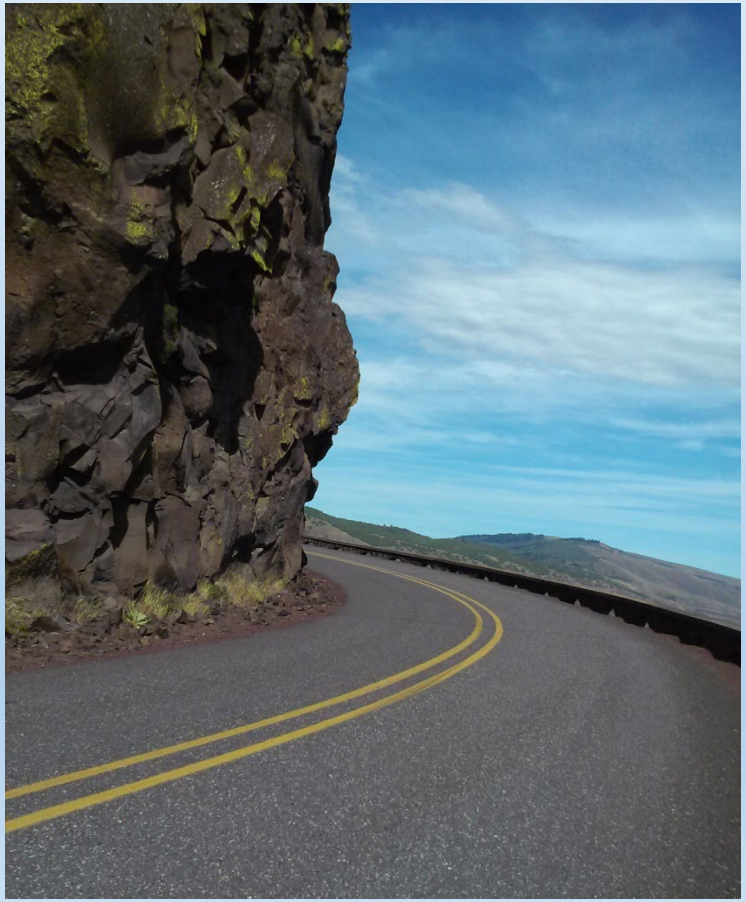
- **Hazard** – A situation that poses a level of threat

AKA: An Undesirable Event

What is Risk?

- The likelihood (Probability) of Something Bad Happening Times the Consequence of it Happening

  - Typically expressed in terms of cost



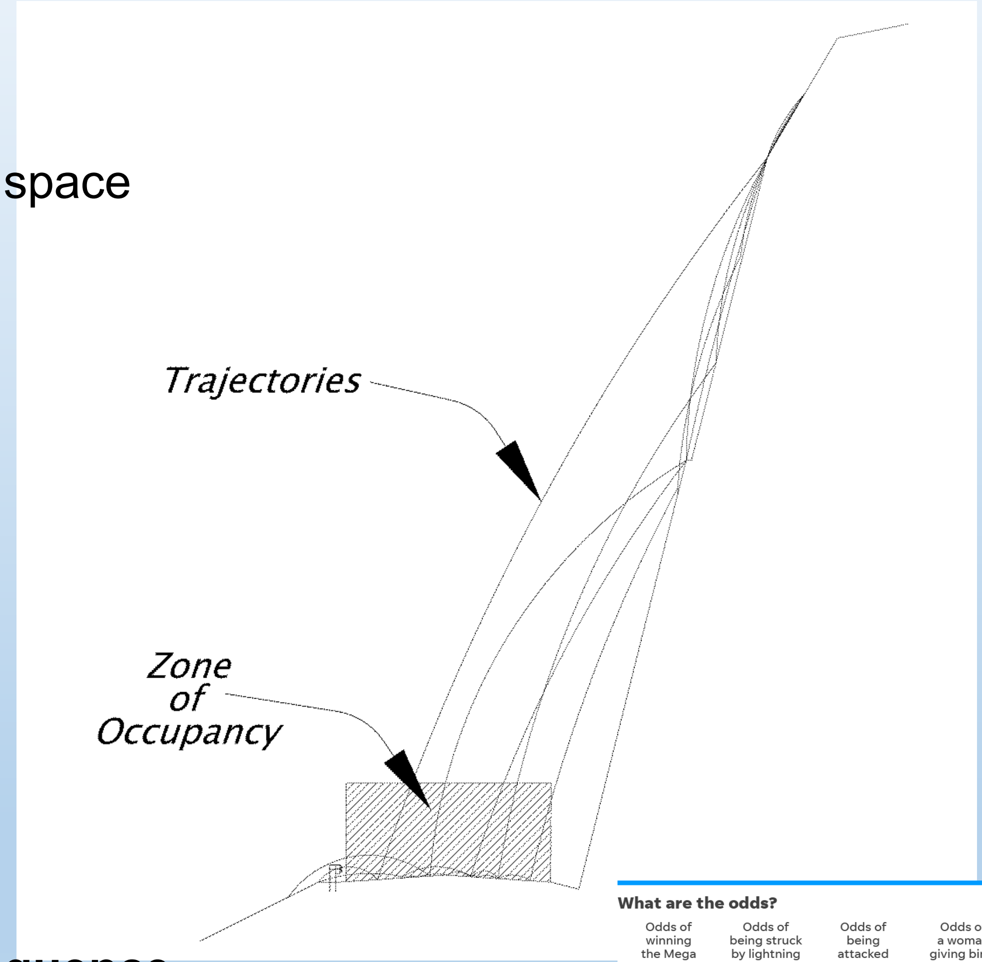
Probability

- An *estimate* of the likelihood of the occurrence of some uncertain event
  - Can also be an uncertain quantity
- The measure of confidence in a prediction based on some evidence
  - May be further modified by the confidence in the evidence
- Typically expressed as a value between 0 and 1 with O being impossible and 1 being certain
  - Also expressed as a percent: 0% chance, 50% chance, etc.

Probability

Example:

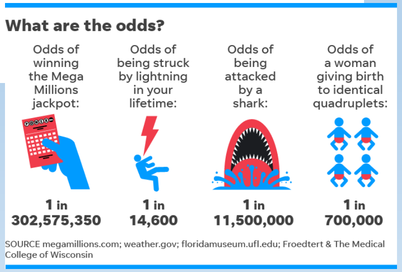
- Length of roadway affected = 100’
- Rockfall initiation point = 100’ vertical
- 100 rocks per year travel through the same space that cars travel through
- ADT = 10,000 (365,000 vehicles/year)
- Speed = 55 miles per hour



Probability of a vehicle and a rock in the same space in a given year:

1 in 40,000,000

Places the emphasis on **Consequence**



Consequences

Generally, the total monetary loss due to the event

- Loss of time
- Loss of capital
- Loss of economic activity
- Repair/replacement cost
- Legal fees or penalties

Risk Formula

$P_{(Occurrence)}$ X $Cost_{(Occurrence)}$ = \$

Or:

$P_{(Some\ event)}$ X $P_{(Failure\ due\ to\ event)}$ X $Cost_{(occurrence)}$ = \$

General Steps in Risk Evaluation

1. Identify Possible Hazards
2. Estimate the Probability of Failure
3. Evaluate the Consequence of Failure
4. Evaluate the Effectiveness and Level of Effort for Mitigation/Repair Strategies

Conveying Risk

Risk Evaluation Matrix

Consequences		Probability: Improbable - Unlikely to happen	Remote - Within the realm of possibility	Infrequent - Known to happen	Occasional - Has happened more than once	Probable - Repeat occurrences	Frequently - Occurs often	Constant - Ongoing occurrence
		1	2	3	4	5	6	7
Negligible - No Consequences	1							
Noticeable - Disturbance would be observed	2							
Minor - Slight damage	3							
Marginal - Repairable damage	4							
Serious - Costly damage or important facility impacted	5							
Severe - Long-term disruption, occupational injury	6							
Catastrophic - Fatality	7							

Example Risk Analysis: "GEO" HAZARDS & BRIDGE OPTIONS

"Geo" Hazards

- Debris flows (small & large)
- "North" rockfall hazard
- Landslides

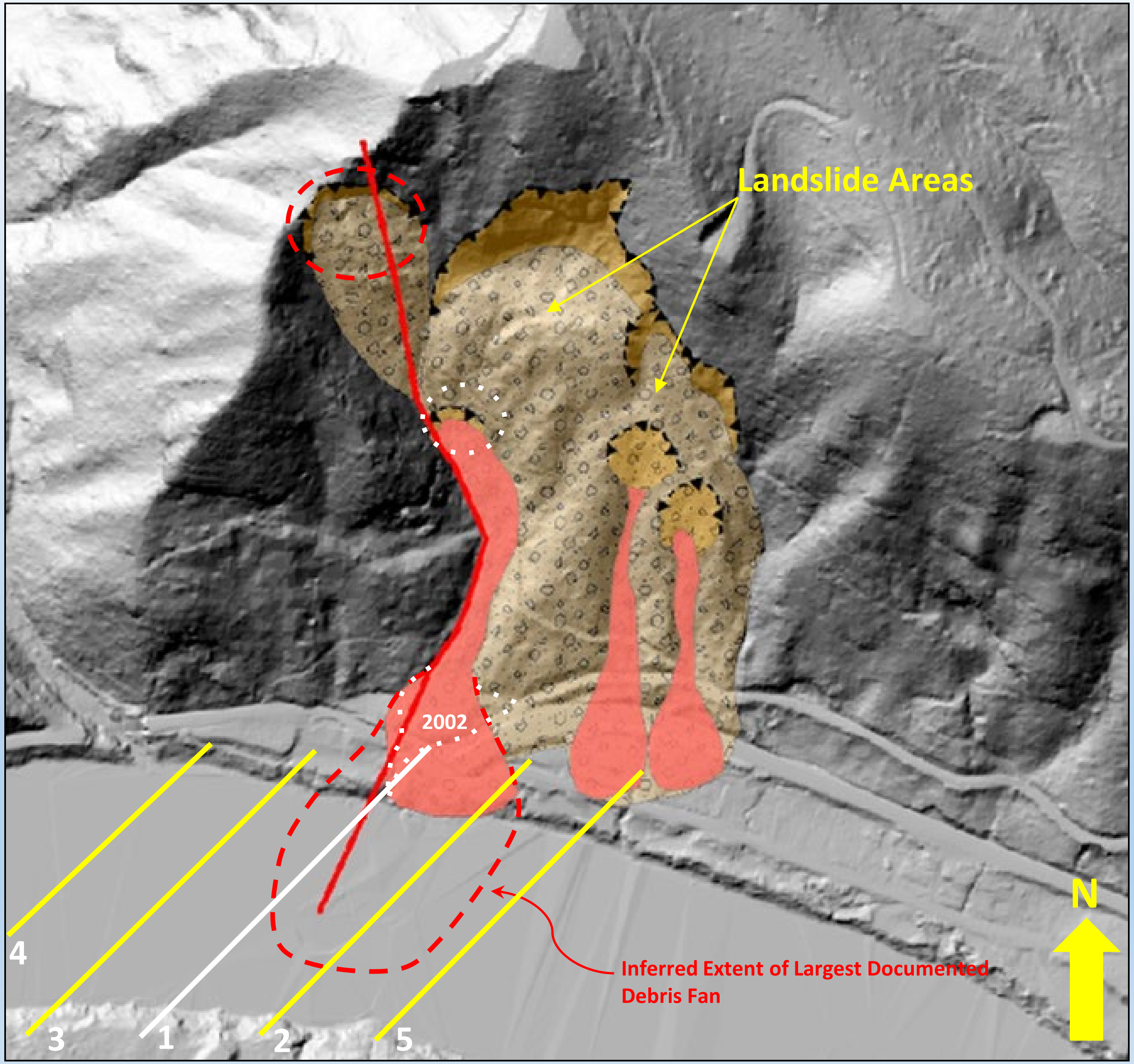
Location Options

- Option 1 – Current design
- Option 2 – 350' upstream
- Option 3 – 350' downstream
- Option 4 – 700' downstream
- Option 5 – 700' upstream

Mitigation Options

*Options 6 – 11; Combination of geotechnical mitigation and bridge locations to determine optimum design

*Geotech mitigations include in-place rock bolting/anchors and/or subsurface water drainage but does not address large debris flow



Example Risk Analysis Cont.

PRIORITY SCENARIOS REVIEWED

Scenario A – Geotech Risk (50%), Project Delay (30%), Construction Costs (15%), R/W (5%)

Scenario B – Project Delay (50%), Geotech Risk (30%), Construction Costs (15%), R/W (5%)

Scenario C – Construction Costs (50%), Geotech Risk (30%), Project Delay (15%), R/W (5%)

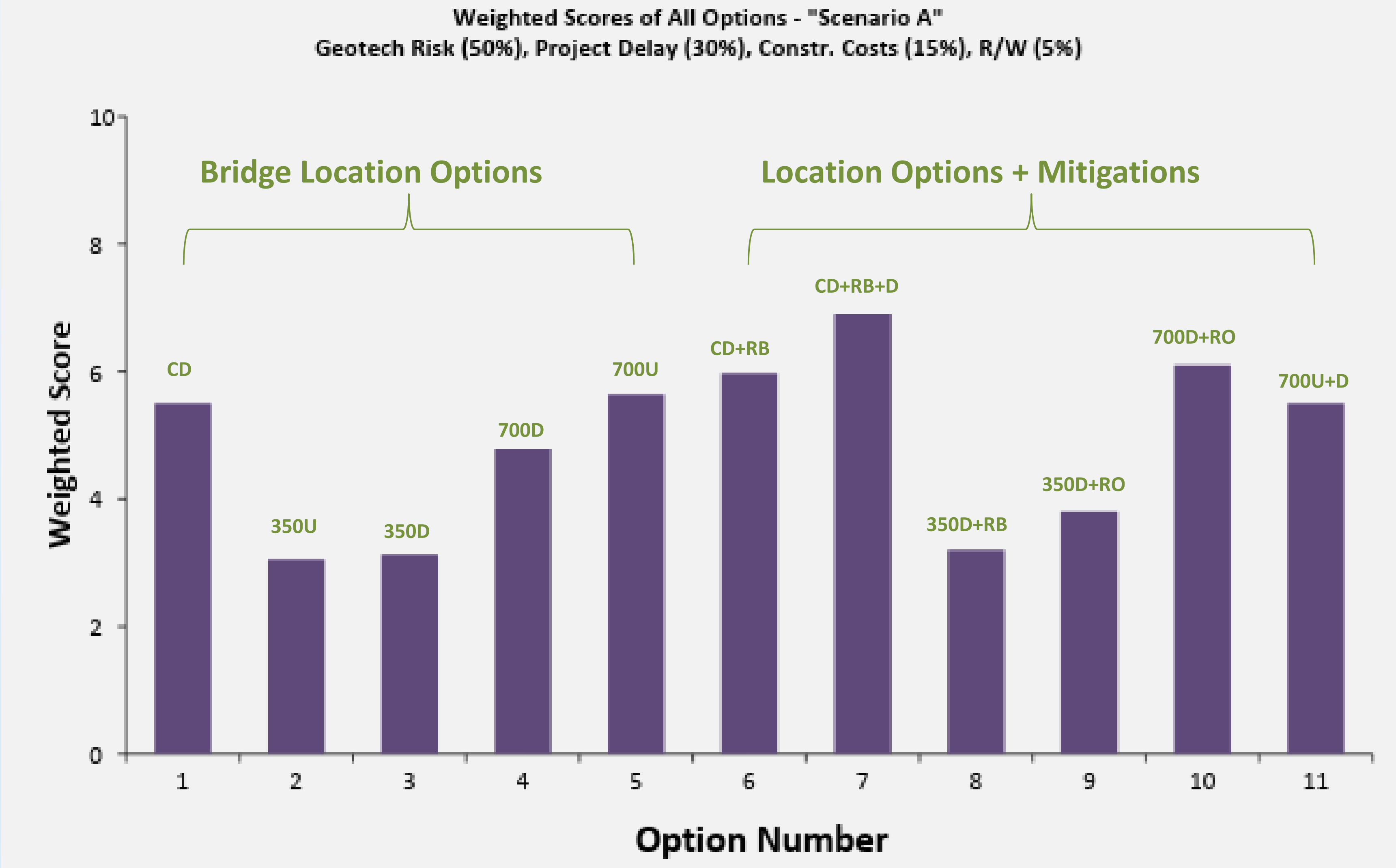
Scenario D – Geotech Risk (50%), Project Delay (30%), R/W (15%), Construction Costs (5%)

Scenario E – Construction Costs (50%), Project Delay (30%), Geotech Risk (15%), R/W (5%)

Scenario F – Project Delay (50%), R/W (30%), Construction Costs (15%), Geotech Risks (5%)

Example Risk Analysis Cont.

SUMMARY OF FINDINGS – SCENARIO A



Multiple Hazards, Multiple Location Risk Assessment

Multiple Hazards, Multiple Location Risk Assessment

Hazard Score

Failure Hazard	Very small or insignificant failures that do not affect the roadway (Not Scored)	**Low Hazard:** Slower slides with low potential for causing a road hazard (9 Points)	**Medium Hazard:** Slides that have not moved suddenly in the past but have the potential to cause a road hazard (27 Points)	**High Hazard:** Rapid slides that have created road hazards in the past; and all debris flows and rockfalls (81-100 Points based on sight distance)

Roadway Impact	**Landslide:**	Would only affect shoulder during major failure (3 Points)	Two-way traffic would remain after a major failure (9 Points)	One-way traffic would remain after a major failure (27 Points)	Total closure in the event of a major failure with 0-3 mile detour (54 Points)	Total closure in the event of a major failure with 3-10 mile detour (70 Points)	Total closure in the event of a major failure with 10-60 mile detour (85 Points)	Total closure in the event of a major failure with >60 mile detour (100 Points)
	Rockfall:	Rocks are completely contained in the ditch (3 Points)	Rocks fall onto the shoulder (9 Points)	Rocks enter the roadway (27 Points)	No ditch; all rocks enter the roadway (81 Points)	Rocks occasionally fill all or part of a lane (100 Points)		

Annual Maintenance Frequency	Once every 5 years or less (0 Points)	Once every 4 years (13 Points)	Once every 3 years (17 Points)	Once every 2 years (25 Points)	Once every 1 to 2 years (38 Points)	Once a year (50 Points)	1 to 2 times a year (56 Points)
	2 times a year (63 Points)	2 to 3 times a year (69 Points)	3 times a year (75 Points)	3 to 4 times a year (81 Points)	4 times a year (88 Points)	4 to 5 times a year (94 Points)	5 times a year or more (100 Points)

Average Daily Traffic	0-499 (11 Points)	500-999 (22 Points)	1,000-2,999 (33 Points)	3,000-5,999 (44 Points)	6,000-11,999 (56 Points)	12,000-23,999 (67 Points)	24,000-47,999 (78 Points)	48,000-95,999 (89 Points)	96,000 and over (100 Points)

Accident History	No accidents (3 Points)	Vehicle or property damage (9 Points)	Injury (27 Points)	Fatality (100 Points)

total possible: 500 points

Multiple Hazards, Multiple Location Risk Assessment

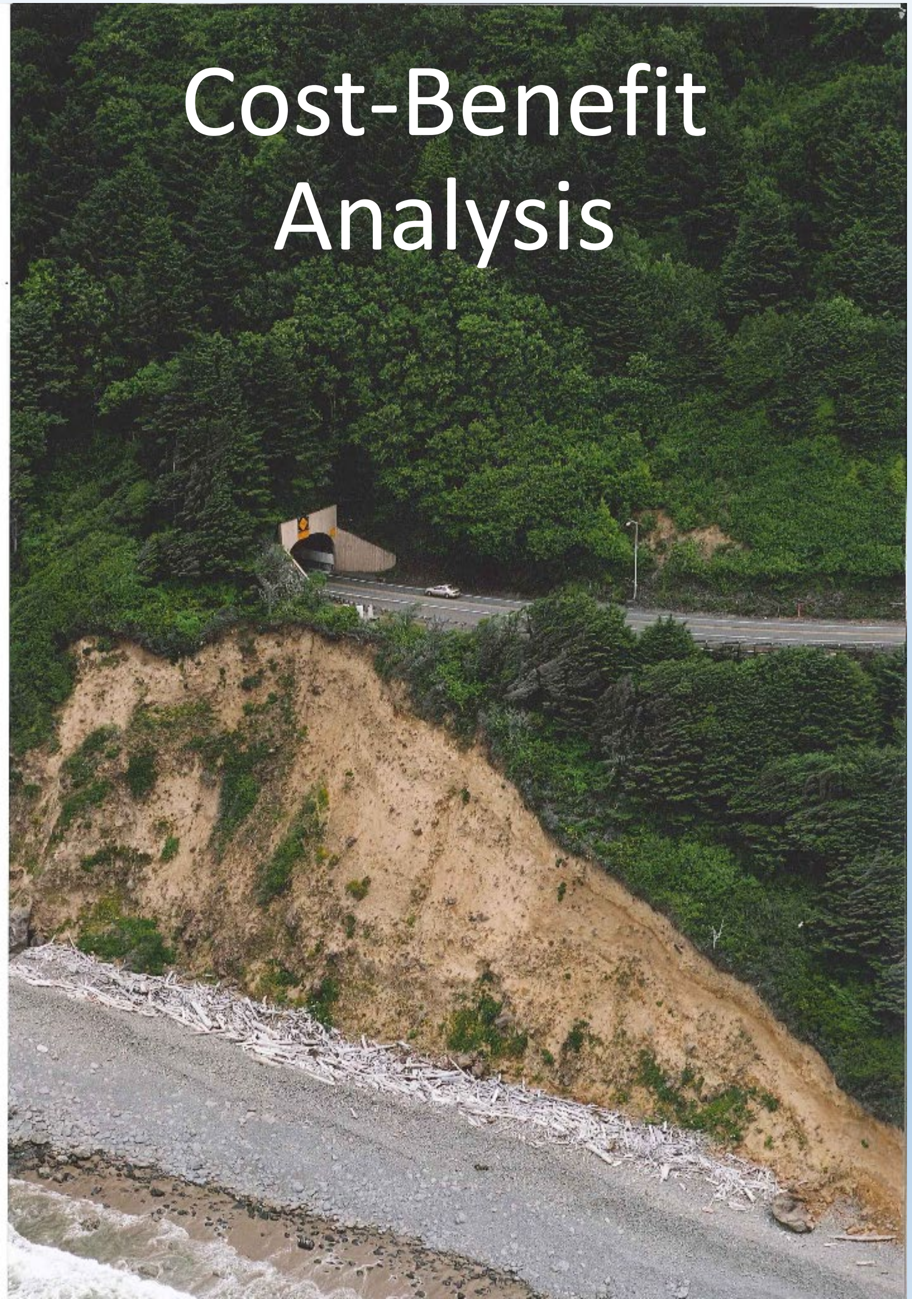
Maintenance Benefit-Cost Factor

20-Yr Maintenance Cost / Repair Cost	Factor
> 0.0 - 0.2	0.5
≥ 0.2 - 0.4	0.75
≥ 0.4 - 0.6	1
≥ 0.6 - 0.8	1.06
≥ 0.8 - 1.0	1.12
≥ 1.0 - 1.2	1.18
≥ 1.2 - 1.4	1.24
≥ 1.4 - 1.6	1.3
≥ 1.6 - 1.8	1.36
≥ 1.8 - 2.0	1.42
≥ 2.0	1.5

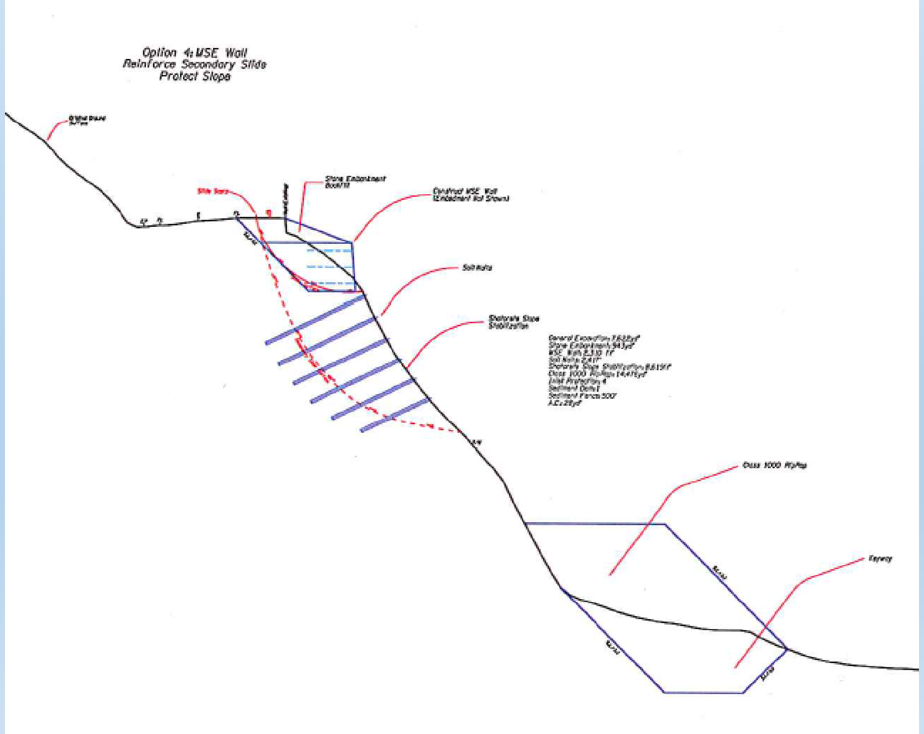
Highway Classification Factor

District	Regional	Statewide	Interstate
1	1.05	1.1	1.2

Cost-Benefit Analysis



- Evaluate range of options and strategies
- Compare long-range maintenance and construction costs
- Economic impact of delays

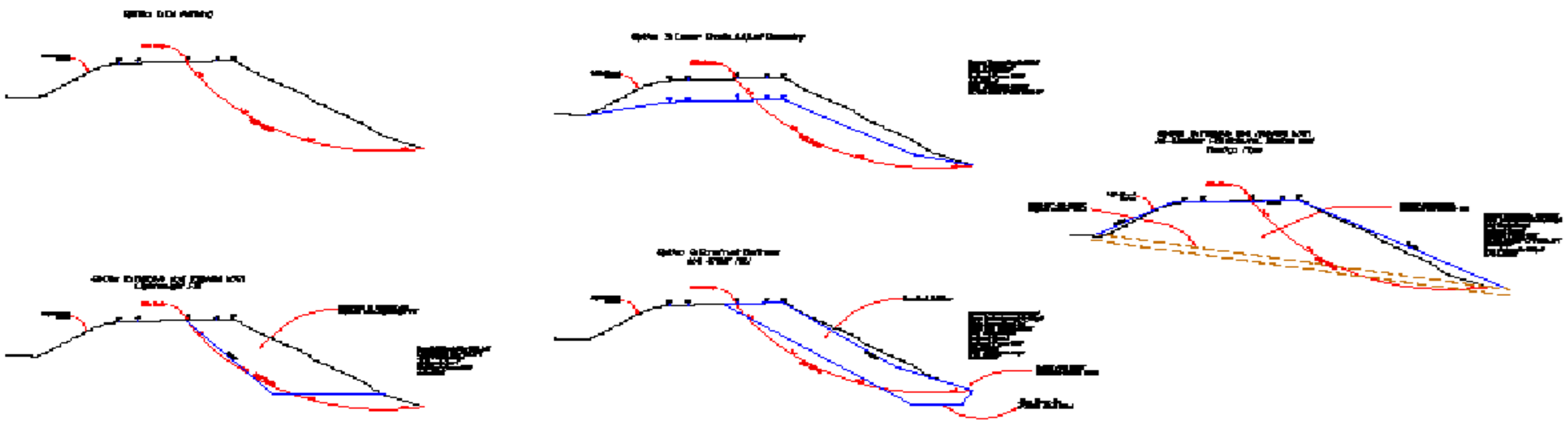


Maintain or Fix or Somewhere In-Between?

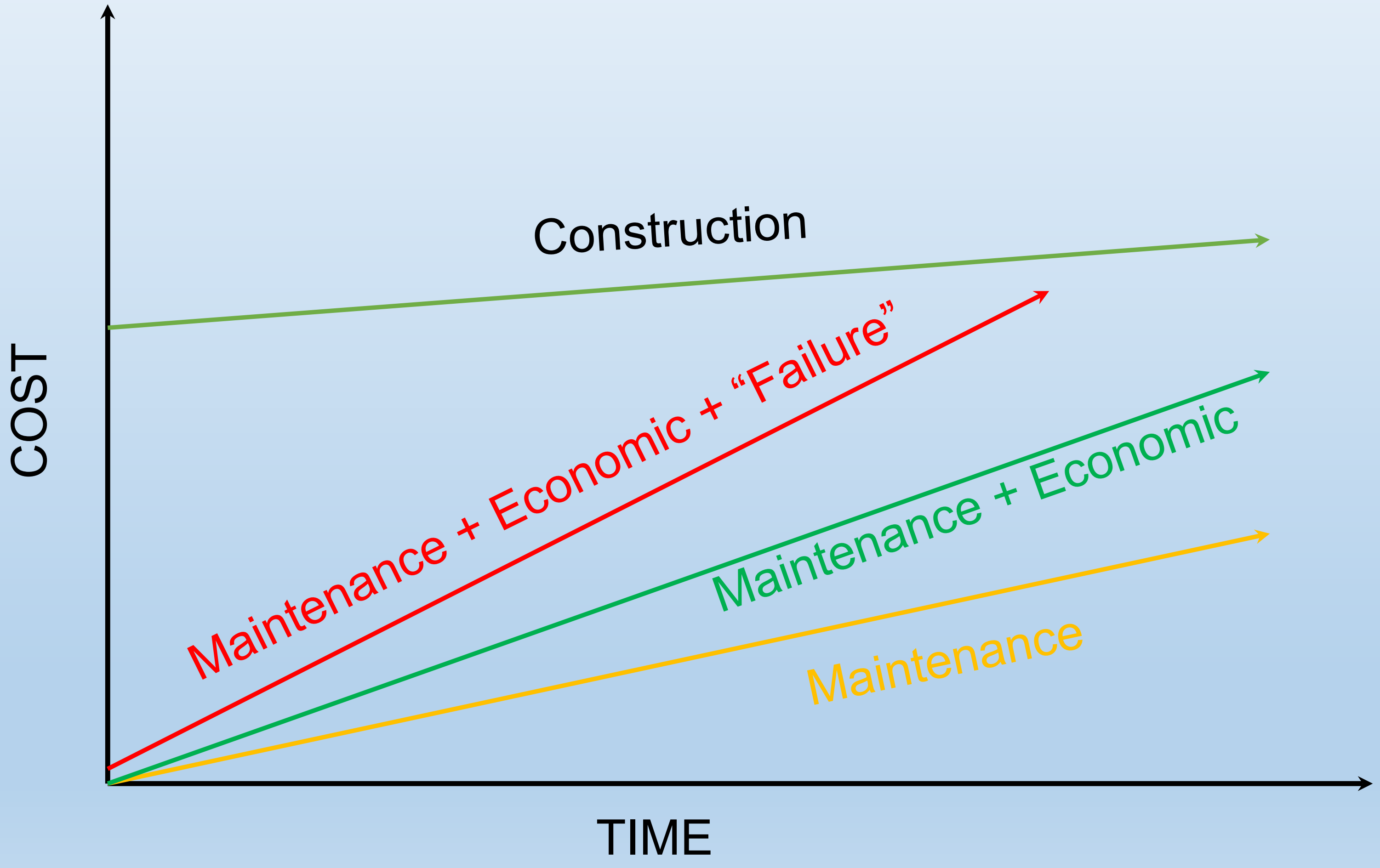
Falcon Cove Slide: US 101, MP 37.31

Mitigation Option	Description	Mitigation Effect	Total Cost	Annual Maintenance Cost (Current)	Annual Maintenance Cost @ 30 Years
1	Do Nothing	No Effect - Failure continues to NB Lane. Traffic restricted to one-way flagger control for 4-hour period 1.5 times per year	$0	$8,957	$10,509
2	Lightweight Fill	Decrease Driving Force on Slide. Reduces Maintenance Frequency to once in 5 years at current level of effort and closure time. Must be Reconstructed twice in 30 years.	$182,611	$1,194	$1,994
3	Lower Grade	Decrease Driving Force on slide, decrease roadway exposure to slide. Reduces Maintenance Frequency to once in 3 years at reduced level of effort and closure time. Allow 2-way traffic during maintenance.	$276,615	$1,131	$1,889
4	Construct Buttress and Shear Key	Increase Resising Forces against slide, Increase embankment drainage. Reduces Maintenance Frequency to once in 15 years.	$212,550	$376	$628
5	Reconstruct with all-weather material. Resize Pipe.	Removes slide, replaces embankment with resistant material that facilitates drainage. Increases culvert size to address higher streamflow.	$668,097	$0	$0

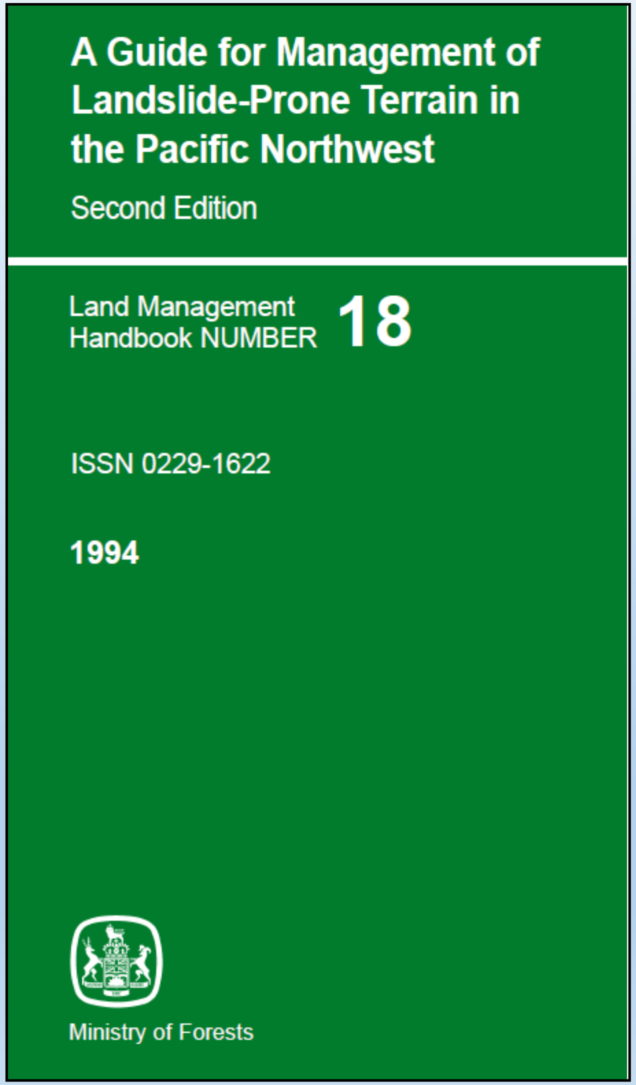
Falcon Cove Slide Options:

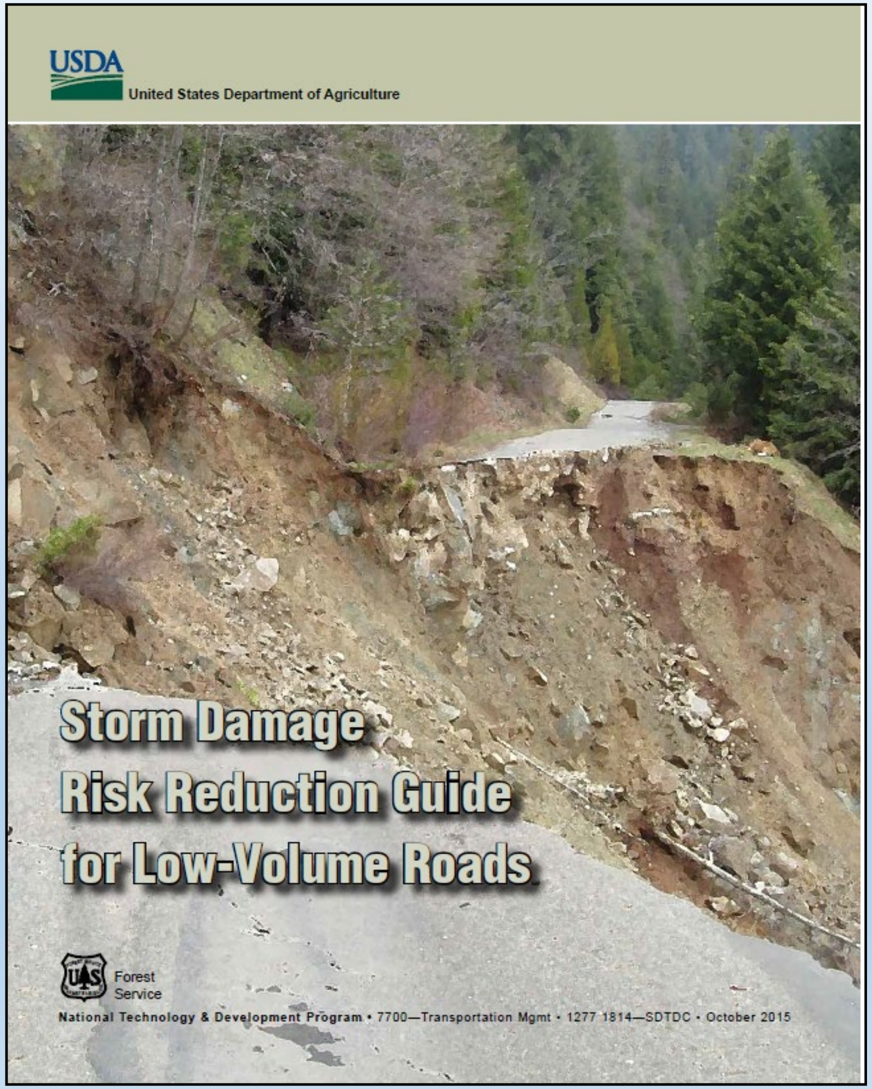


Benefit-Cost Analysis (Economics)



Considerations For Harvest Layout





Slope Stability…Take What We've Learned…

Land-Area Considerations (BC)	Harvest-Road Considerations (SDRR)

• Avoidance
  • Scheduling/Avoiding - storms
  • Harvest method/locate landings
  • Windthrow boundaries
• Prevention
  • Road…
• Stabilization
• Protection
	• Identify areas of historic or potential vulnerability
	• Avoid local problematic and high-risk areas
	• Use appropriate minimum design standards
	• Employ self-maintaining concepts into the selection and implementation of treatments

Harvest-Road Considerations (continued-A)

- Incorporate relevant, cost-effective technology
- Perform scheduled maintenance
- Use simple, positive, frequent roadway surface **drainage** measures and use restrictions
- **Properly size, install, and maintain culverts**
- Use simple fords or vented low-water crossings (as appropriate)
- Stabilize cut and fillslopes
- Use deep-rooted vegetation to “anchor” soils

Harvest-Road Considerations (continued-B)

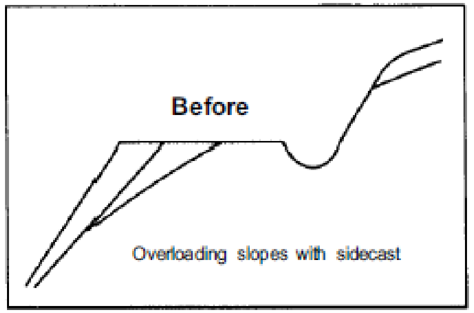
- Design high-risk bridges and culverts with armored overflows
- Eliminate diversion potential
- Use scour prevention measures for structures on questionable foundation materials
- Be aware of channel morphology and stream channel changes near a bridge, culvert, ford, or road along a creek

- EIGHT OF FIFTEEN RECOMMENDATIONS INVOLVE WATER!

Prevention!

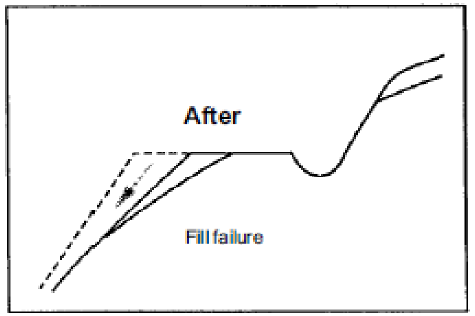
Sidecast

Overloading and oversteepening already steep slopes with sidecast material during road construction is the single largest cause of landslides.

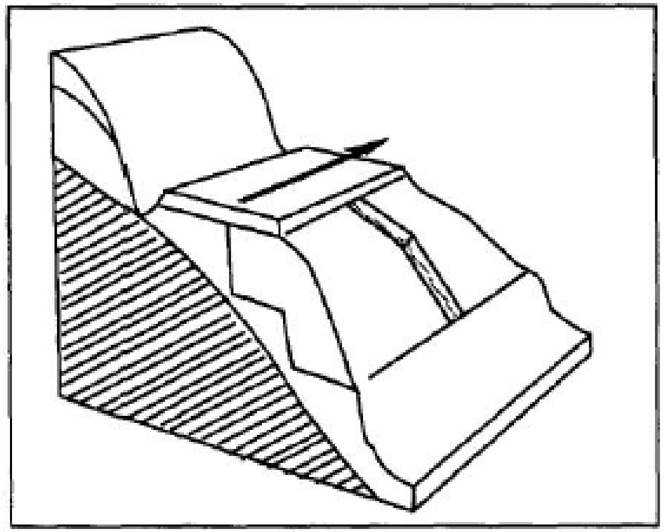


Sidecast failures are usually associated with ground slopes steeper than 70%. They are most common on:

- convex slopes
- mid- to upper-slopes
- colluvial soils



Slight regional differences in critical slope angles for different terrain types occur, but 70% is a good "rule of thumb." However, care should be taken to recognize those soil types where the failure angle can be much less, as shown in the table on page 110.



Multi-benching

- A small bench excavated below grade
- A second, higher bench excavated, with sidecast supported on lower bench
- The road bench then excavated with sidecast supported on the second bench
- Drainage carried over fill slopes in 1/2 culverts or riprap

Short-Term Gain, Long-Term Loss!

To avoid surface ravelling on "sliverfills", 55-60% is maximum ground slope for stable sidecasting. Side slope failures on lesser slopes occur mainly where breakdowns in the road drainage redirect ditch water onto fill slopes. The main contributing factors are:

- lack of ditches
- blockage in ditches or culverts by logging debris or cut bank failures
- culverts too far apart or poorly located
- culverts that are too small

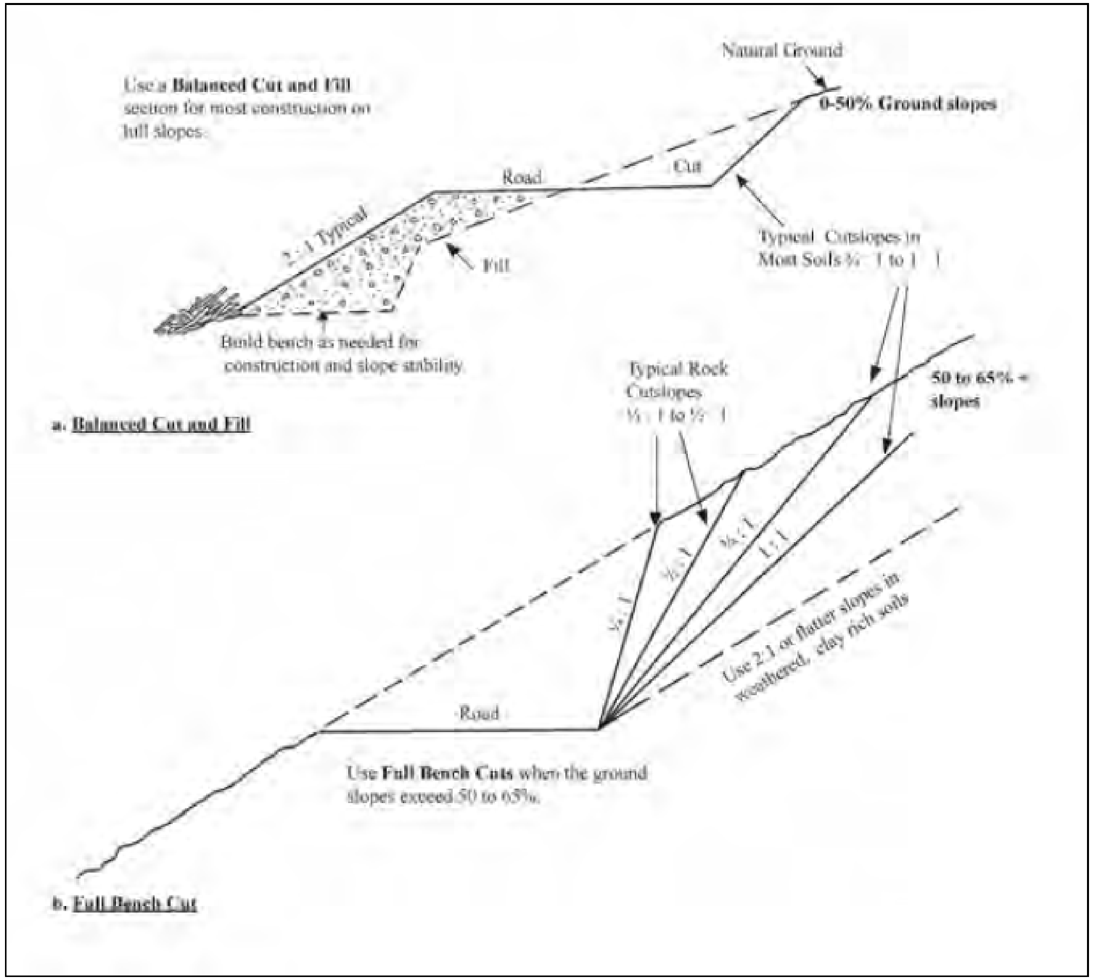
Incorporating logs into the fill material only stabilizes the slope in the short term. After 5-7 years, the logs rot and the sidecast failure rate increases drastically. It is not possible to "seal off" a buried stump and prevent rot.

Learn Your Site-Specific Conditions

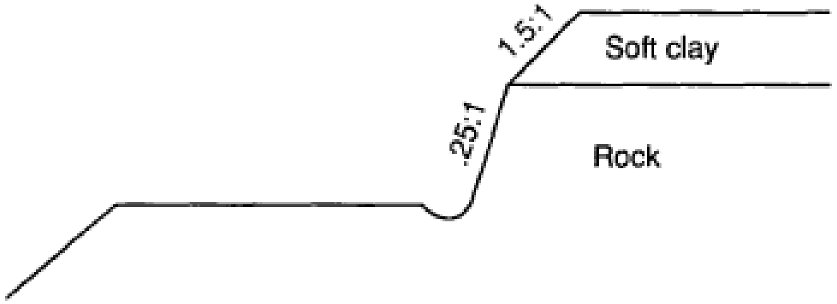
Geographic area	Morainal soils	Colluvial soils	Broken rock
SE Vancouver Island	80% (dry) 65% (wet)	75%	78%
NE Vancouver Island	70% (dry) 65% (wet)	75%	78%
Queen Charlotte Islands	70% (dry) 45% (wet)	70%	75%
Vancouver Island West Coast	70% (dry) 50% (wet)	75%	78% range: 68-100%
Cascades	75% (dry) 65% (wet)	75%	80%

Critical gradients of hillside on which sidecast failures typically occur

Cutslopes



When two different materials are present, one on top of another, the cut slope ratio should be varied, where possible, to take advantage of steeper slopes.



Landing Locations

The following terrain conditions should be avoided when sites for landings are selected:

OBVIOUSLY UNSTABLE SITES. These are made even more unstable by landing or road construction.
OPEN SLOPES IN EXCESS OF 30 DEGREES with no natural benches. Full benches are necessary for all landings to withstand the machine vibration and weight loads. Full benching these sites involves tremendous amounts of excavation. The material is often disposed of as sidecast, destabilizing the slope below. Also, open slopes usually have very little room for landing debris, which can accumulate, oversteepen the slope, and eventually lead to failure.
GULLY HEADWALLS. Apart from being naturally unstable sites, there is usually little room to accumulate landing debris safely. Stumps and debris are often cast downslope into the gullies, where they can initiate debris flows.
NARROW RIDGES BETWEEN GULLY HEADWALLS. These sites are attractive for their excellent deflection. The ridges are commonly unstable sites, however, as they develop by retrogressive slumping of the headwalls.
AREAS UNDERLAIN BY STEEPLY DIPPING SEDIMENTARY ROCK OR FRACTURED ROCK. Where the underlying bedrock occurs in layers that are steeply inclined out of the hillslope, machine vibration and blasting can initiate a rockslide.

Gullies

Avoidance of unstable gullies

Use the previous sections on site assessment of gully stability to determine the hazard of road building or harvesting. The characteristics of unstable gullies are summarized below:

GULLY SIDEWALLS steeper than 70%
GULLY CHANNEL steeper than 45%
DEEP MATERIALS in gully sidewalls
WET SOILS and lots of seepage
SIDEWALL SLUMPS and debris slides
DISTURBED VEGETATION PATTERNS
COMMON WINDTHROW
OVERSIZED FANS at toe of gully

Stable or Unstable?

Application - SDRR Risk Assessment Matrix

- Consider Probability of Damage/Loss to Magnitude of Consequences
  - HAZARD = Likelihood of Damage
  - VALUES AT RISK (consequences) = What's Important? Site Specific

Table 1—Risk assessment matrix

Probability of Damage or Loss	Magnitude of Consequences		
	RISK		
	Major	Moderate	Minor
Very likely	Very high	Very high	Low
Likely	Very high	High	Low
Possible	High	Intermediate	Low
Unlikely	Intermediate	Low	Very low

SDRR Risk Assessment Matrix – Example Culvert

- Consider Probability of Damage/Loss to Magnitude of Consequences
  - HAZARD = A creek culvert designed for 25-year flood at top/mid of watershed (likely damage i.e. annual probability in 25 years = [1-(1-1/25)^25] = 67%)
  - VALUES AT RISK (consequences) = tributary to Blue Ribbon steelhead fishery (Moderate-Major consequences)
  - = HIGH RISK >> so lower "likelihood", such as design to 100-year (Possible = 22%)

Table 1—Risk assessment matrix

Probability of Damage or Loss	Magnitude of Consequences		
	RISK		
	Major	Moderate	Minor
Very likely	Very high	Very high	Low
Likely	Very high	High	Low
Possible	High	Intermediate	Low
Unlikely	Intermediate	Low	Very low

SDRR Risk Assessment Matrix – Example Cutslope

- Consider Probability of Damage/Loss to Magnitude of Consequences
  - HAZARD = A soil cutslope at 1V : 0.75H (very likely slough >> divert ditch water, plug culvert or cross roadway and wash-out fill)
  - VALUES AT RISK (consequences) = tributary to Blue Ribbon steelhead fishery (Moderate-Major consequences)
  - = VERY HIGH RISK >> so lower "likelihood", such as flatten cut to 1:1, move roadway?

Table 1—Risk assessment matrix

Probability of Damage or Loss	Magnitude of Consequences		
	RISK		
	Major	Moderate	Minor
Very likely	Very high	Very high	Low
Likely	Very high	High	Low
Possible	High	Intermediate	Low
Unlikely	Intermediate	Low	Very low

Questions?