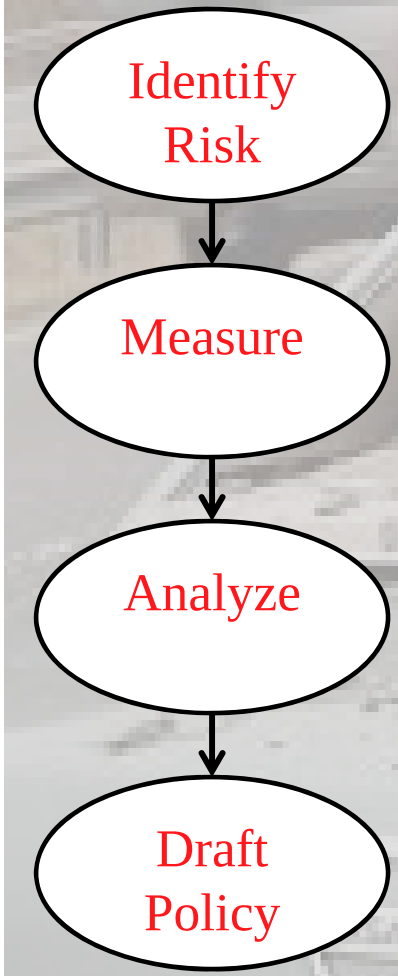
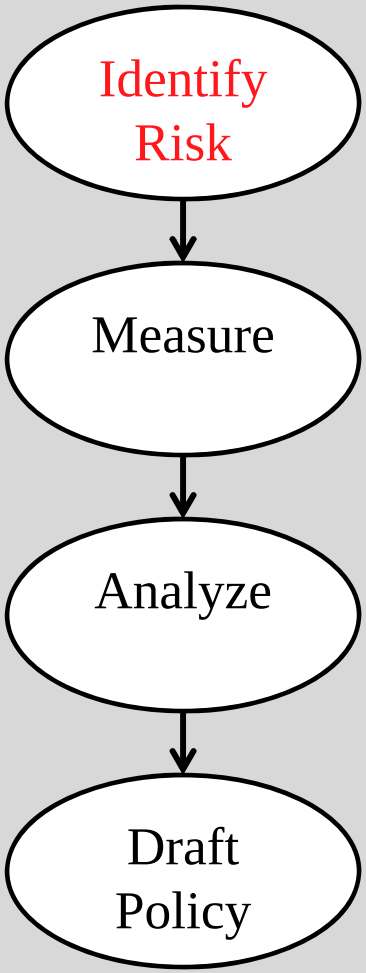
The Road from Data to Policy: Integrated Global and Sub-Global Rock Slope Design



Brian Bruckno
Virginia Department of Transportation

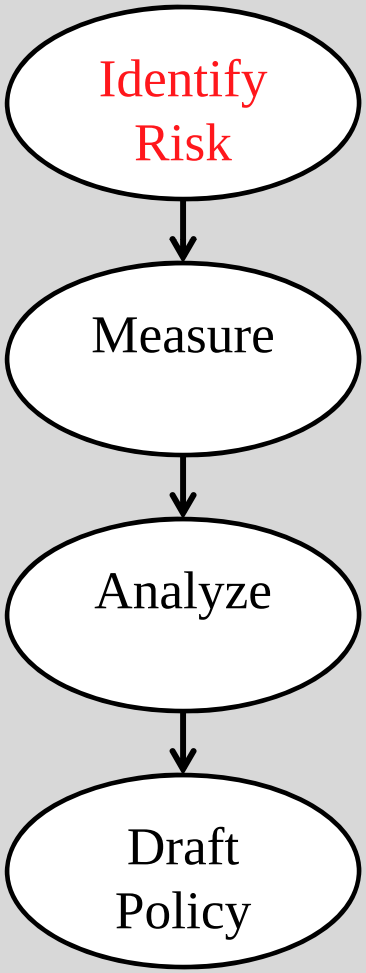
The University of Nebraska-Lincoln

Virginia's New Rock Slope Design Guide



- As of 2012, The Virginia DOT has a policy for the design and maintenance of rock slopes
- Global stability is addressed through FoS
- Sub-global (Rockfall) stability is addressed through rock mass indices

Virginia's New Rock Slope Design Guide



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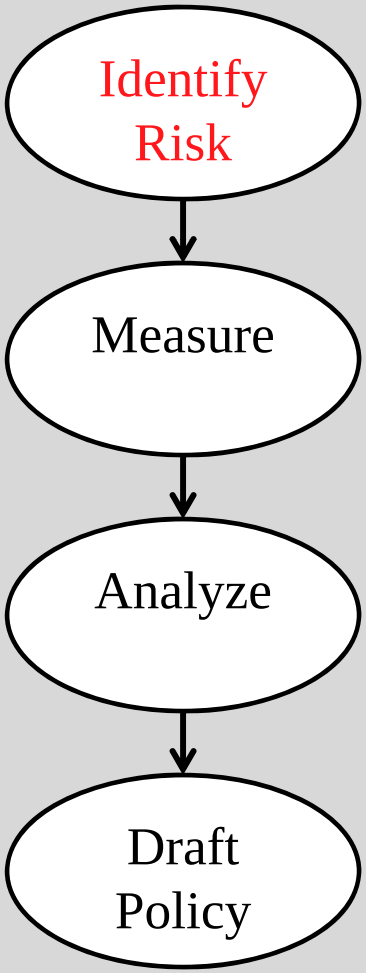
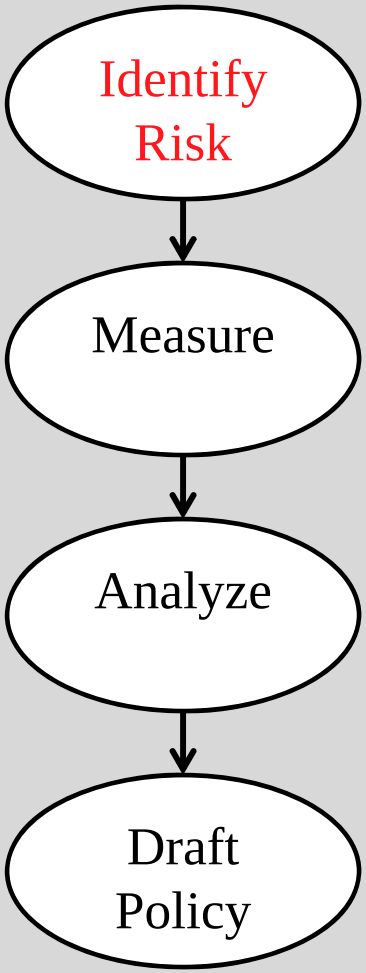
Why Global *and* Sub-Global? Two Different Risks



- Minimum 3 sub-global fatalities since 2000
- No known global rock slope failure fatalities
- Numerous sub-global accidents and near-misses
- Scale = approximately 1200 miles of rock slope



Why Global *and* Sub-Global?

Two Different Phenomena

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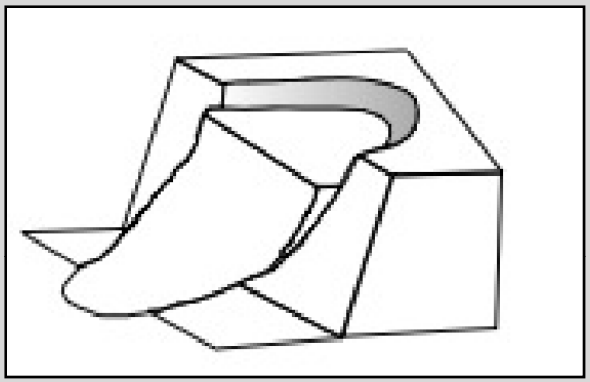
Global Slope Phenomenology

Identify Risk

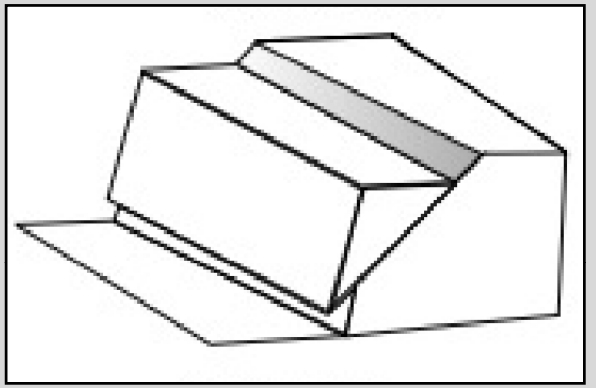
Measure

Analyze

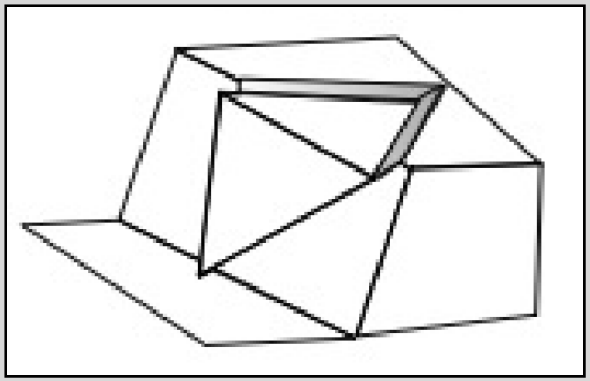
Draft Policy



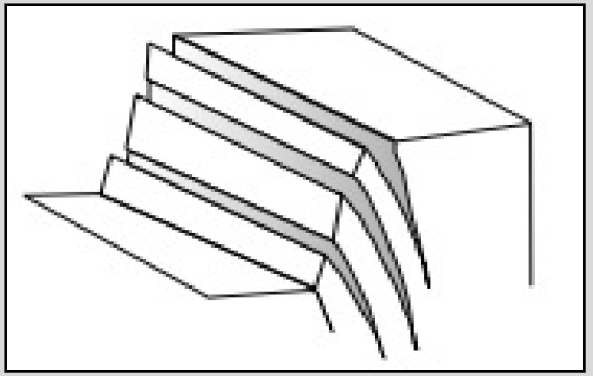
Arc Failure



Slab Failure



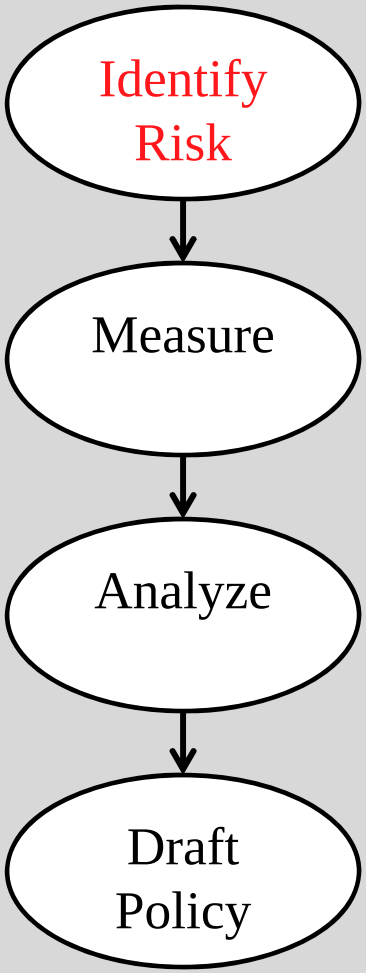
Wedge Failure



Toppling Failure

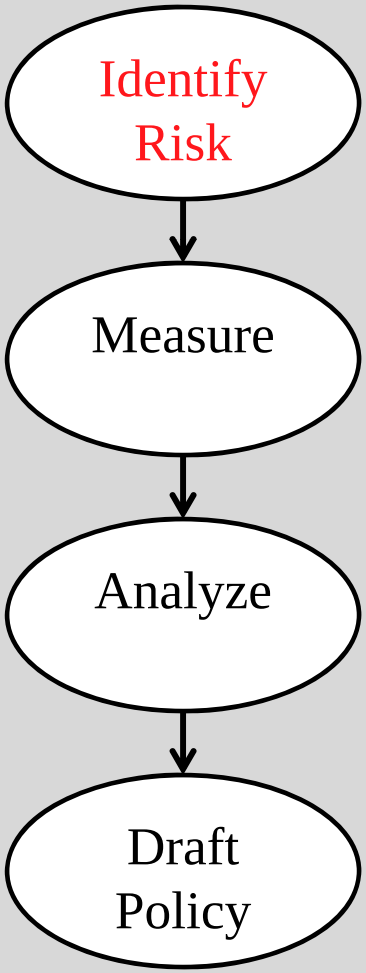
After Department of the Army, 1994

Global Slope Phenomenology



- Global: Large falling mass or masses
- Large-scale, infrequent (annual to greater RI), obvious triggers
- FoS easily calculated
- Require structural controls or remediation

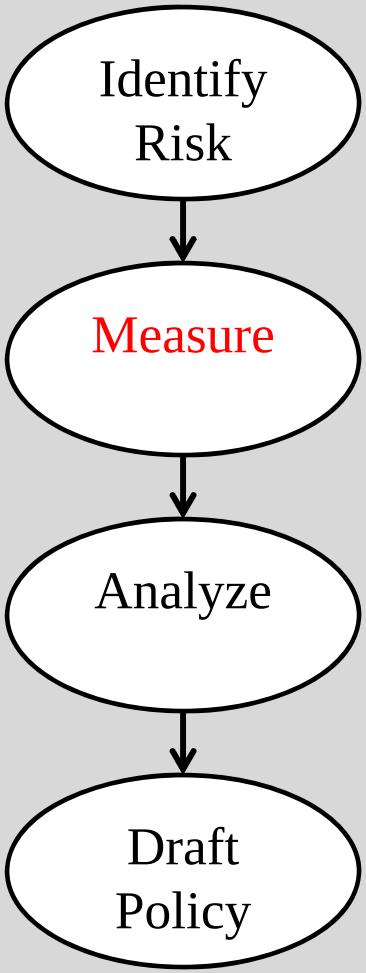
Sub-Global Slope Phenomenology



- Sub-Global = Rockfall: Single or Few Falling Clasts
- Small-scale, frequent (monthly, weekly, daily), no obvious triggers
- FoS can not be calculated
- May be managed by engineering methods -- may be qualified by rock mass indices

Photo: Roanoke Times

Measuring Rockfall: A Phenomenological Approach



- 2006-7: Established test beds at various slopes to measure rockfall
- 2008: Expanded to larger slopes and longer sampling period
- 2009 - Current: Expanded to include LiDAR and digital photogrammetry analysis; InSAR data acquisition

Measuring Rockfall

Identify Risk

Measure

Analyze

Draft Policy

Measuring Rockfall

Identify Risk

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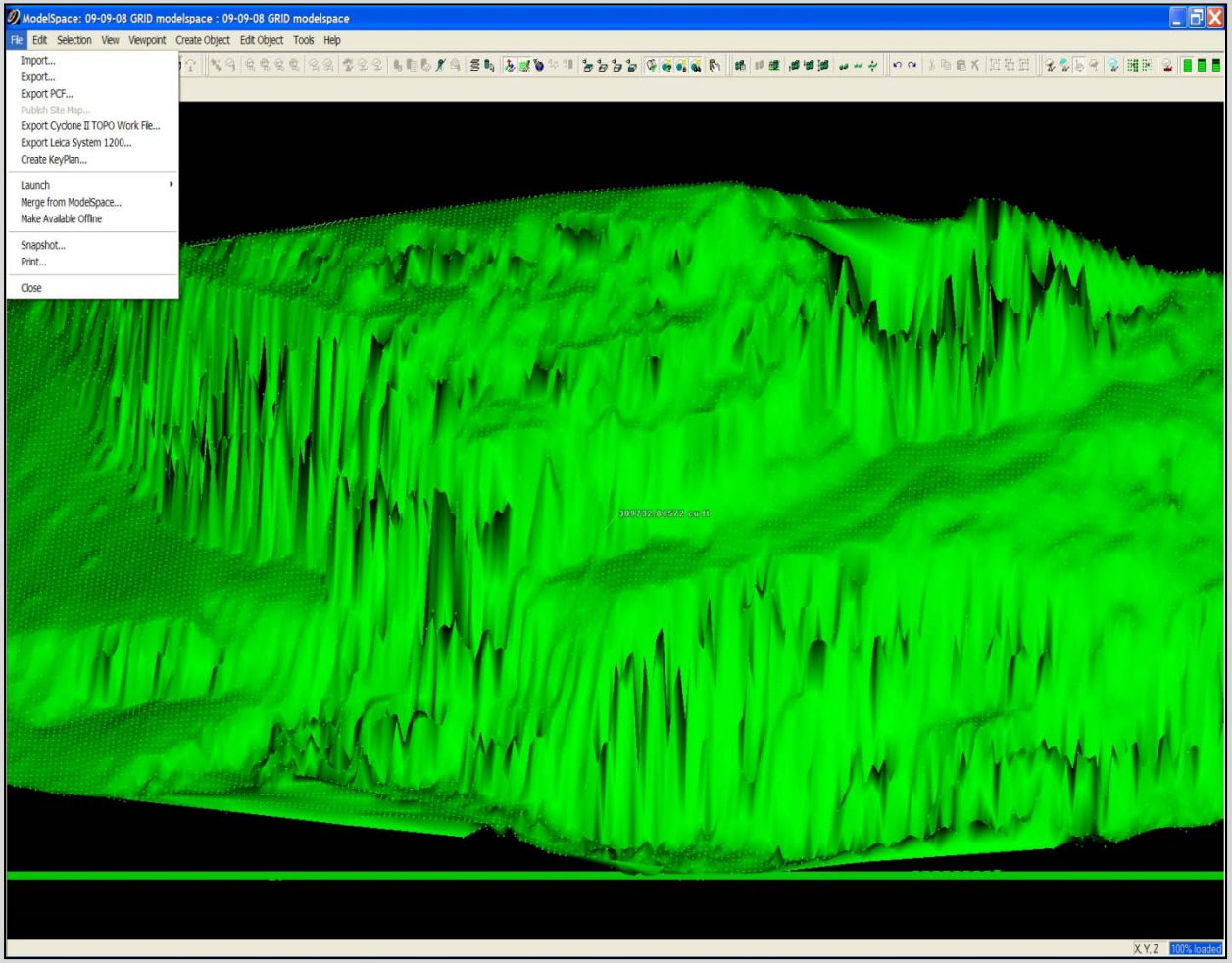


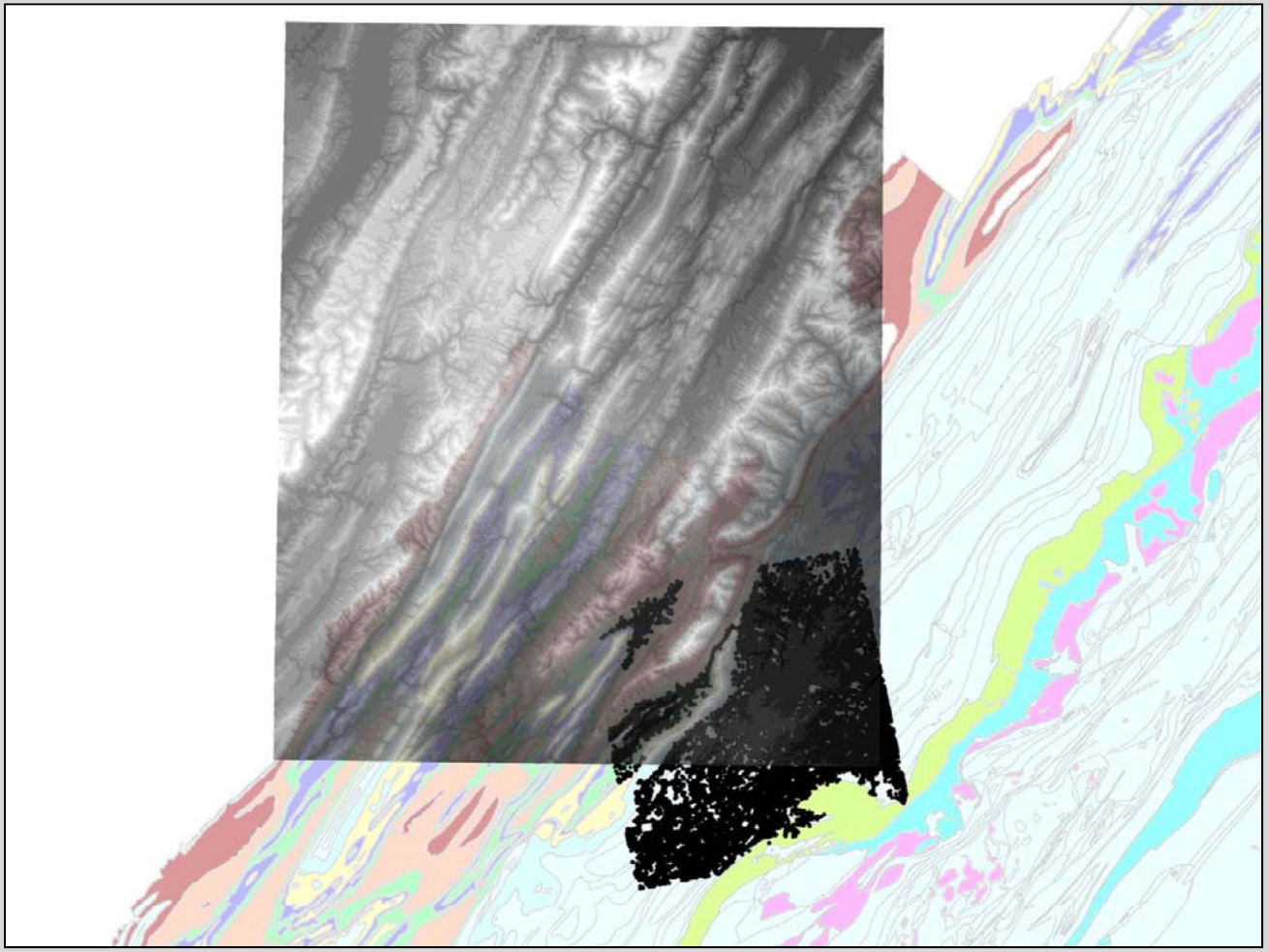
Measuring Rockfall

Identify Risk

Measure

Analyze

Draft Policy



Measuring Rockfall

- Identify Risk
- Measure
- Analyze
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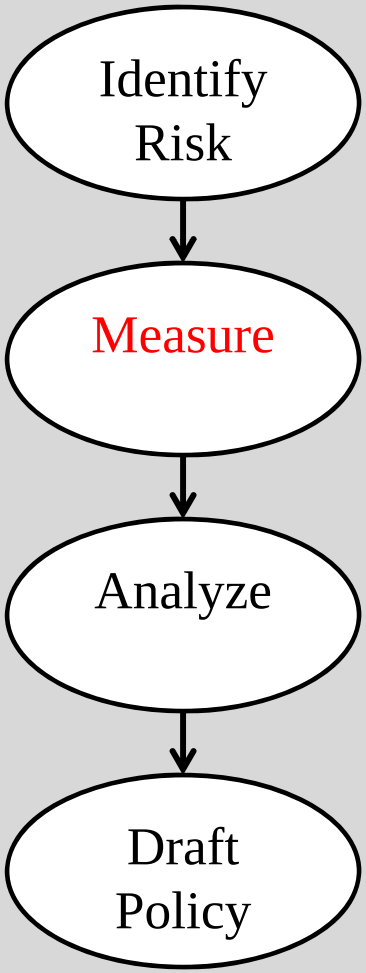
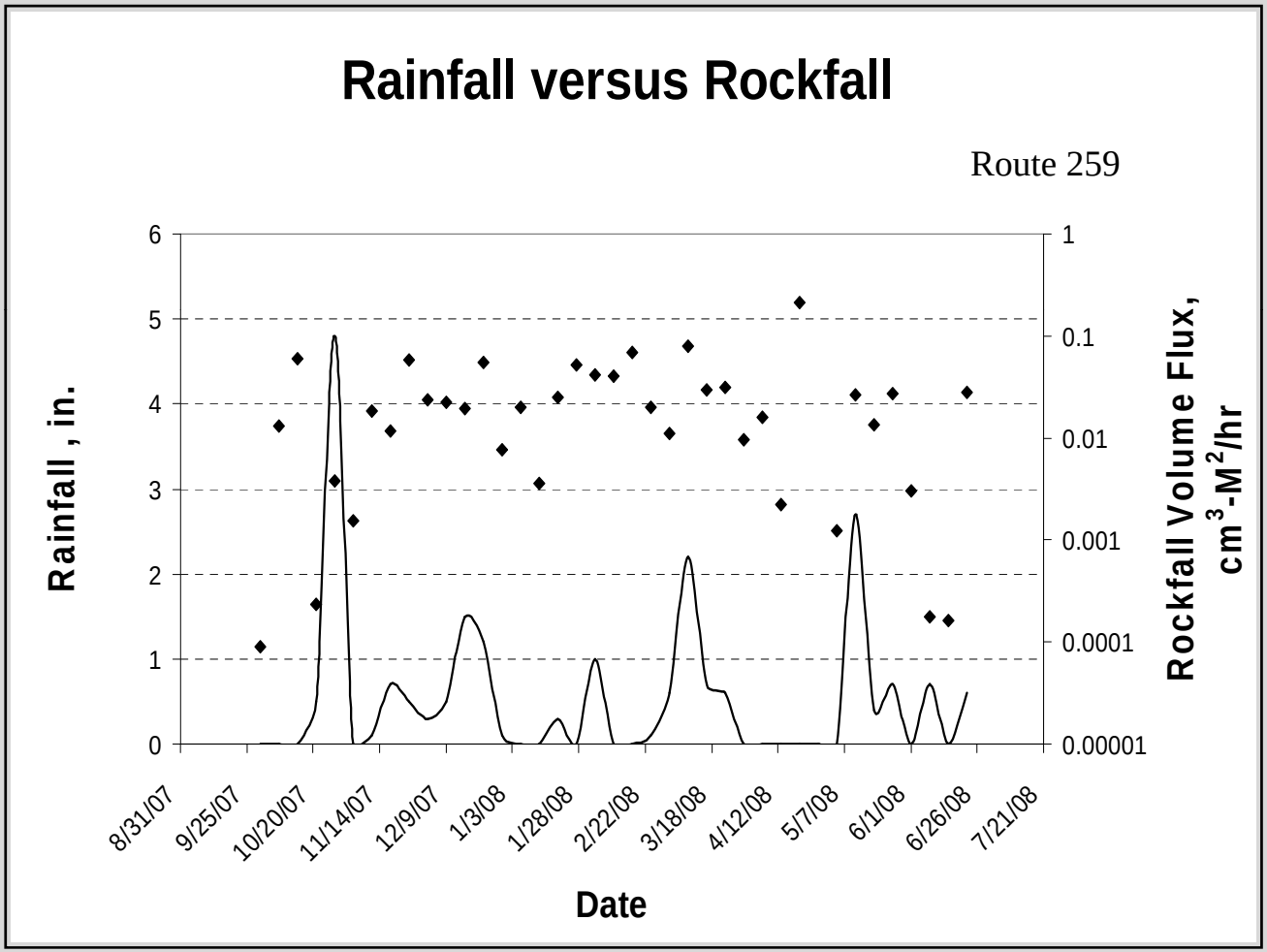
Measuring Rockfall



- Allowed measurement and calculation of volume and energy flux for all represented lithologies
- Allowed evaluation of rockfall behavior with respect to triggers and controls

Controls on Rockfall

- Identify Risk
- Measure
- Analyze
- Draft Policy



Controls on Rockfall

- Identify Risk
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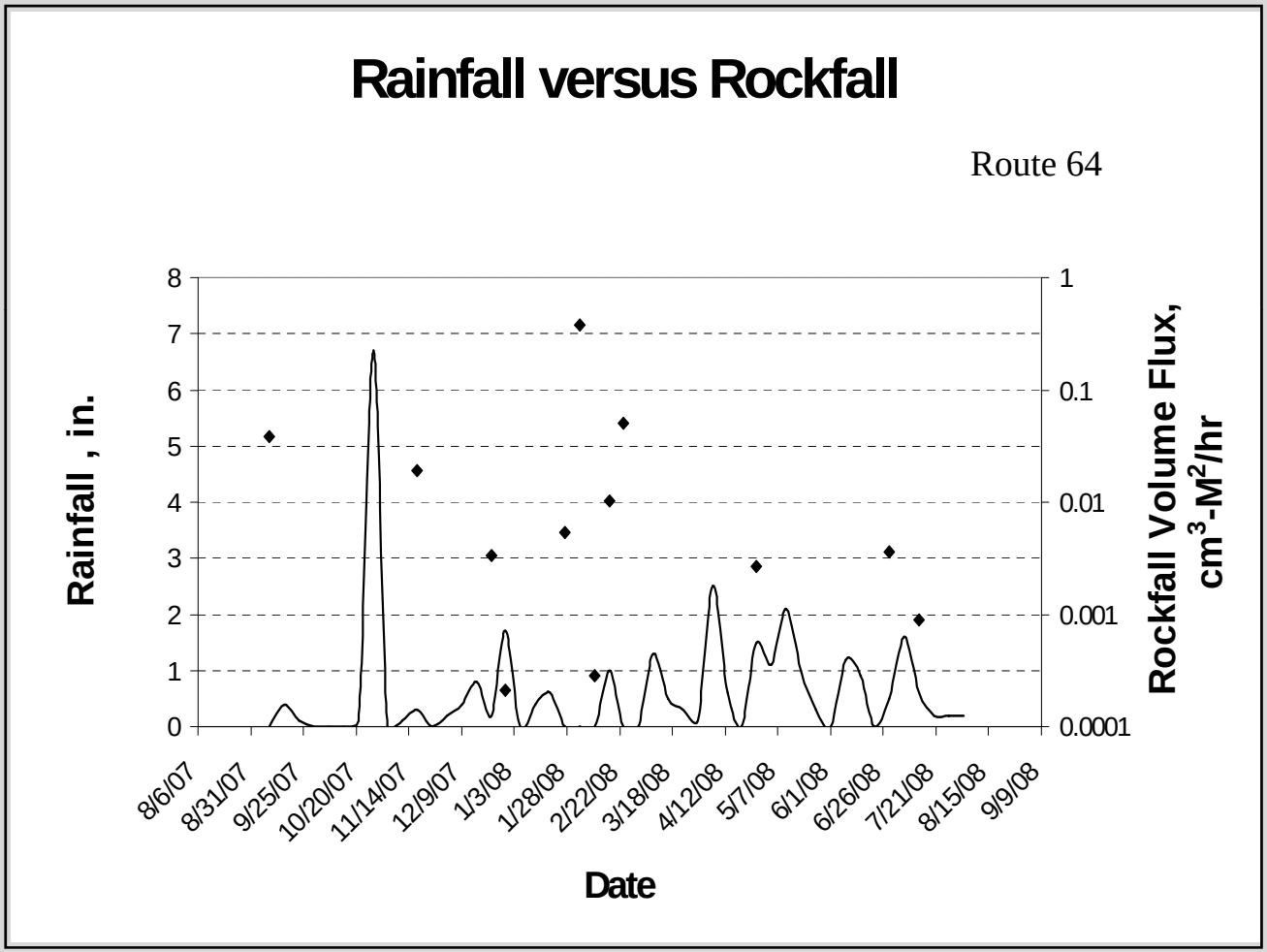

Controls on Rockfall

- Identify Risk
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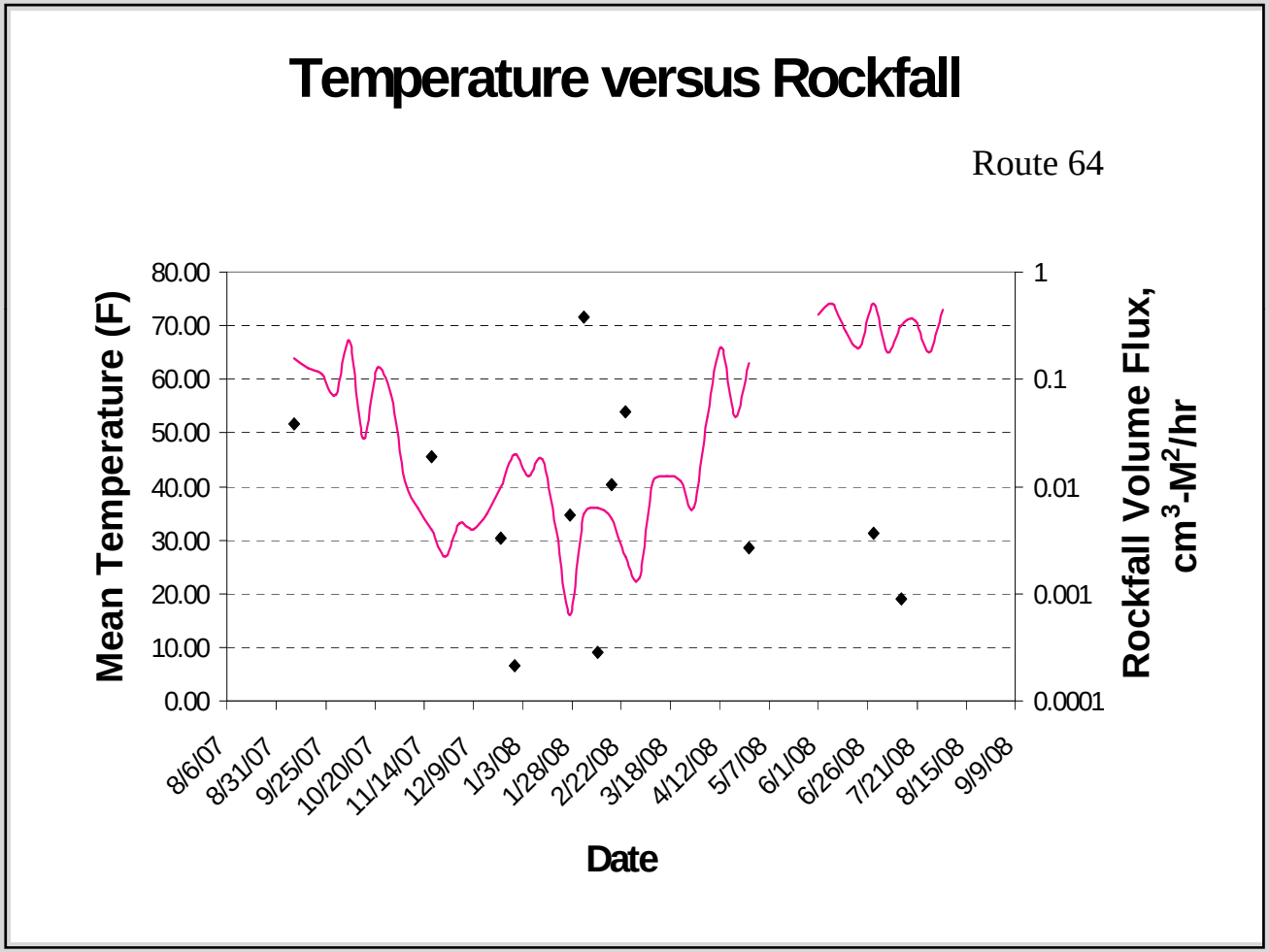

Controls on Rockfall

- Identify Risk
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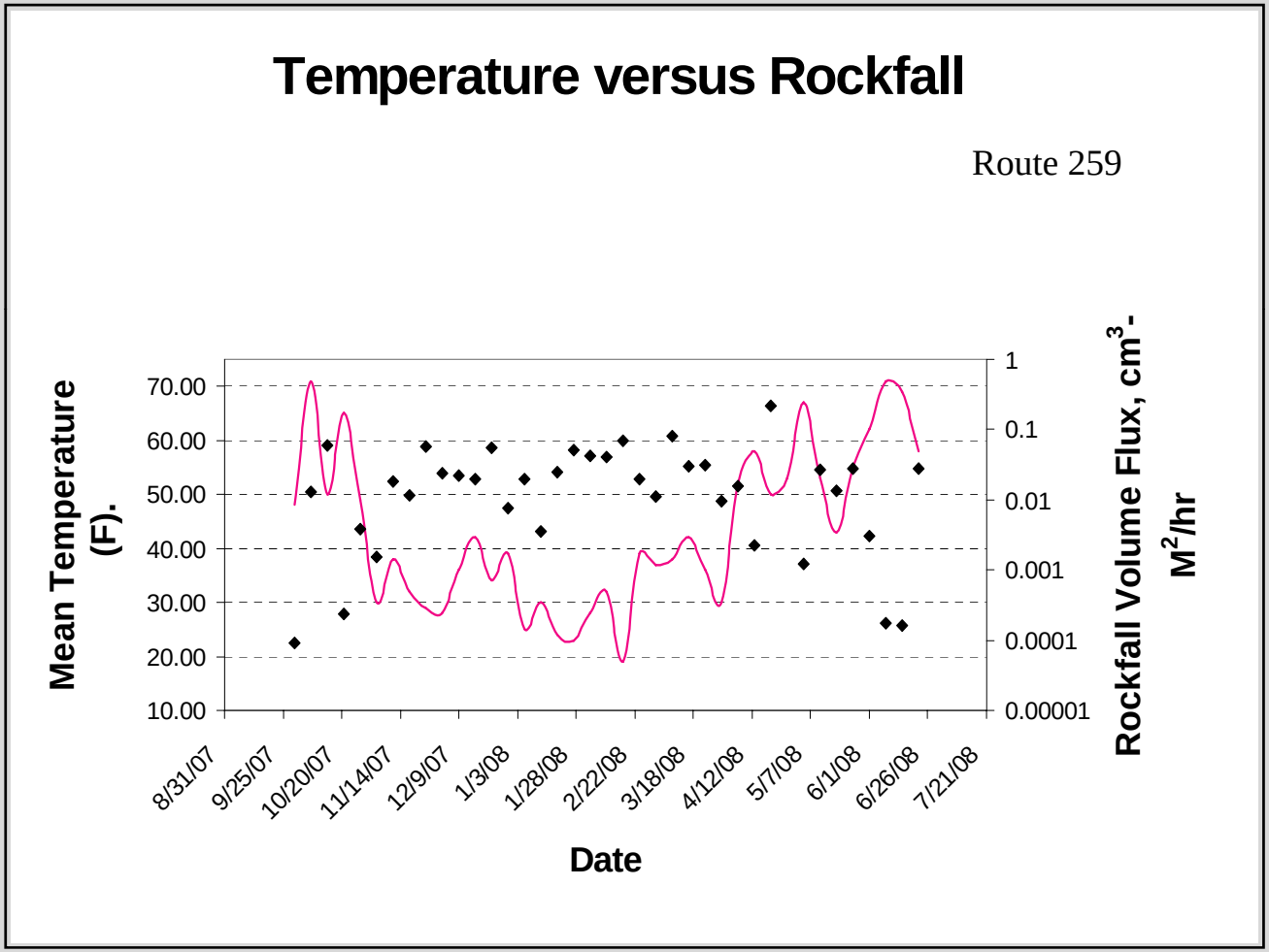
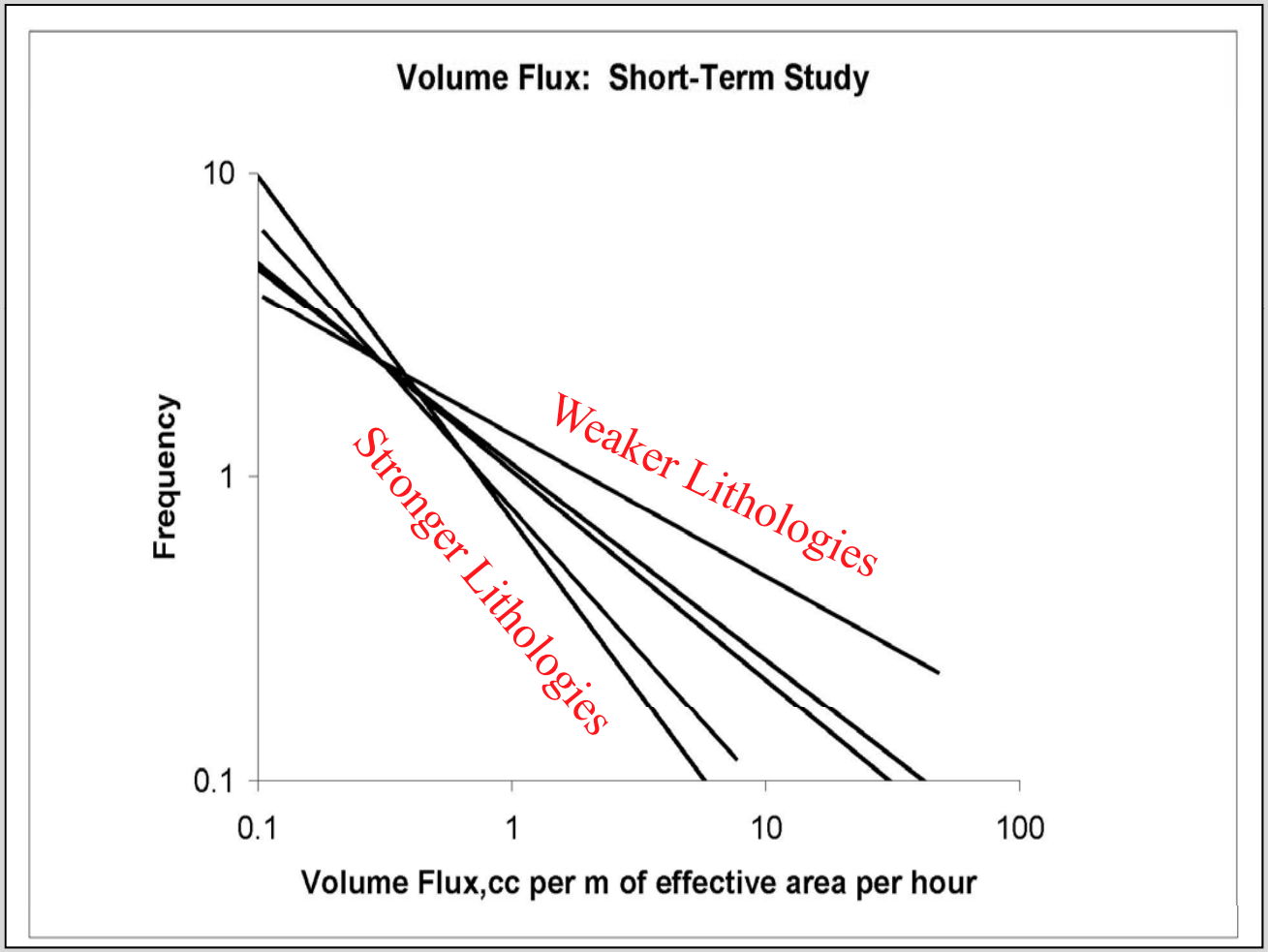


Controls on Rockfall
Volume Flux – Short Term

- Identify Risk
- Measure
- Analyze
- Draft Policy



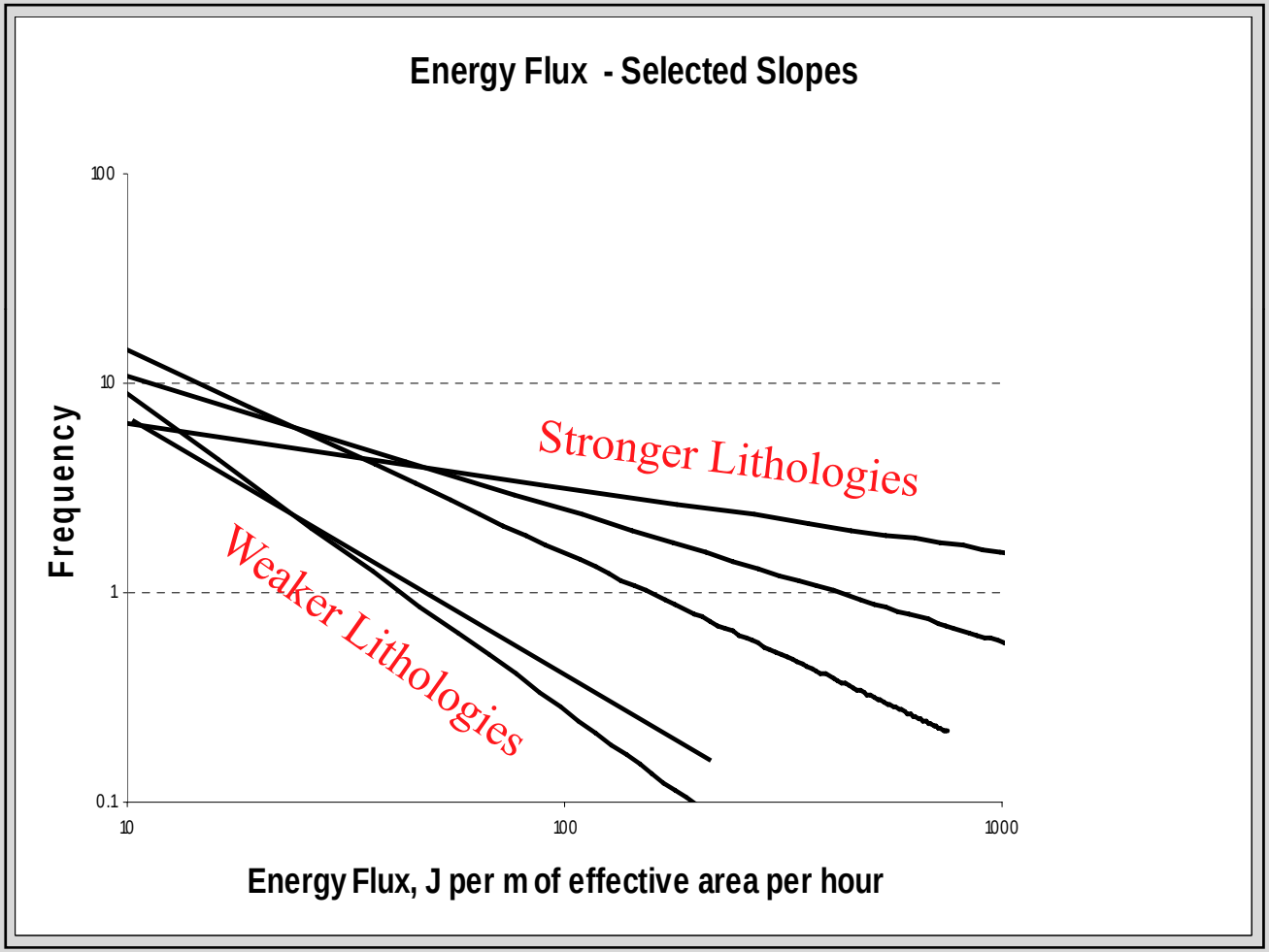
Controls on Rockfall
Energy Flux – All Terms

Identify Risk

Measure

Analyze

Draft Policy



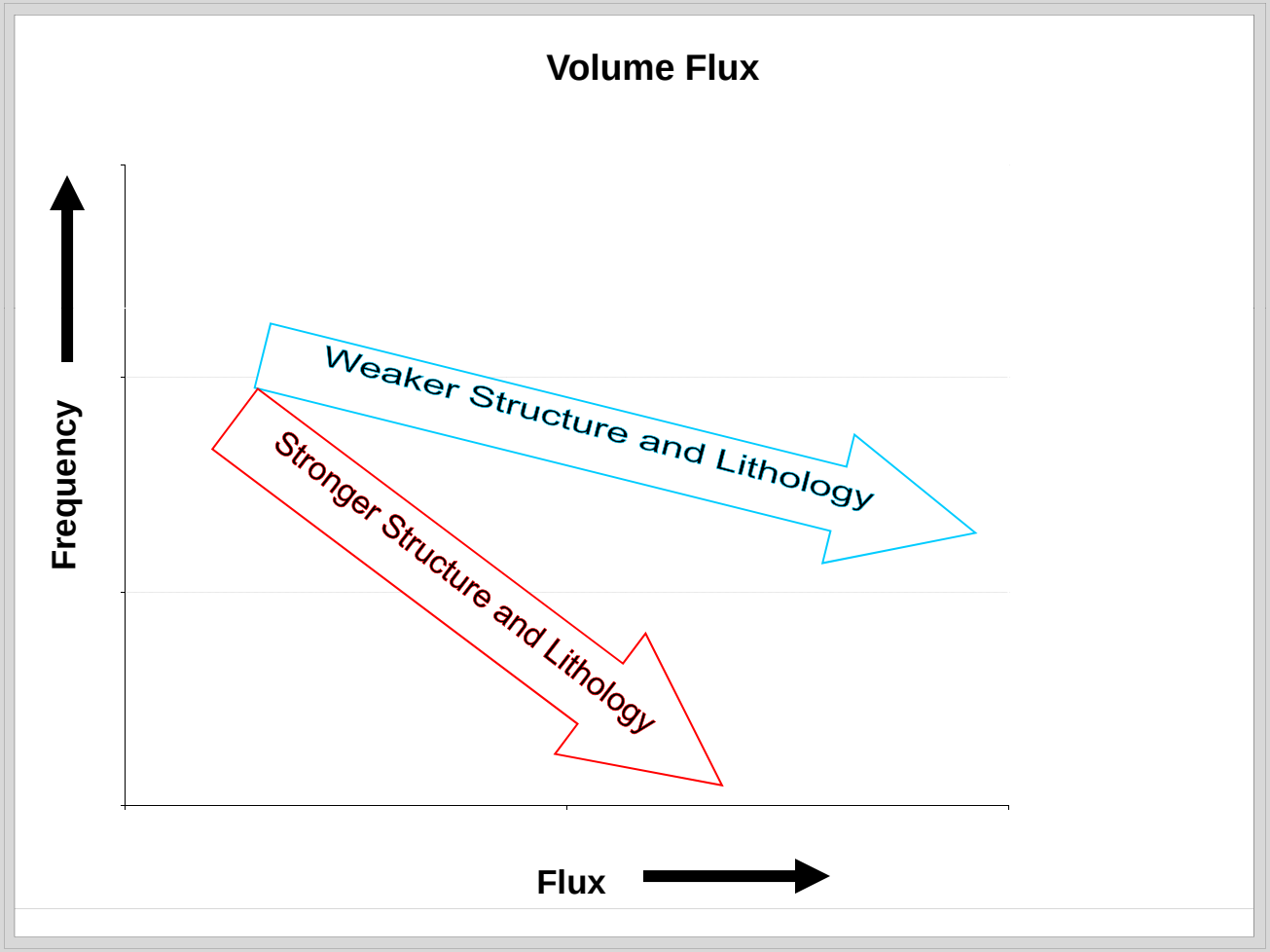
Controls on Rockfall
Volume Flux – Trends

Identify Risk

Measure

Analyze

Draft Policy



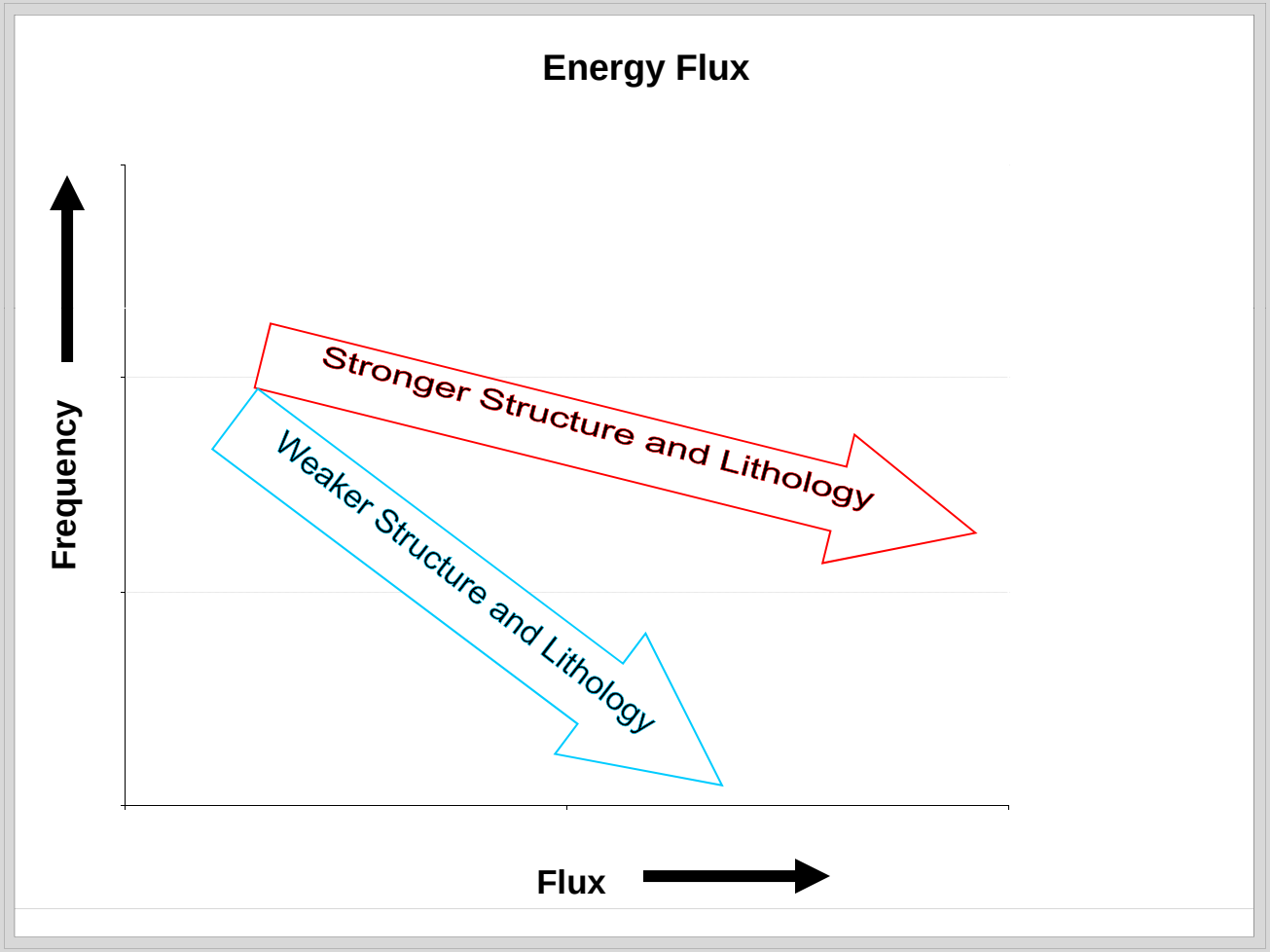
Controls on Rockfall
Energy Flux – Trends

Identify Risk

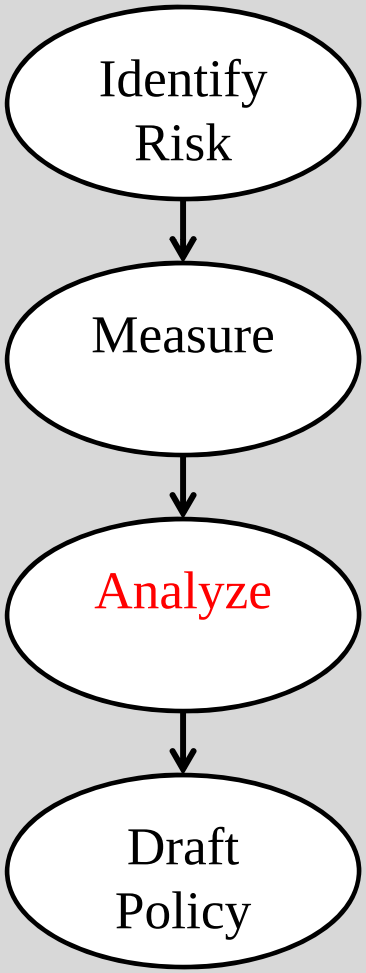
Measure

Analyze

Draft Policy

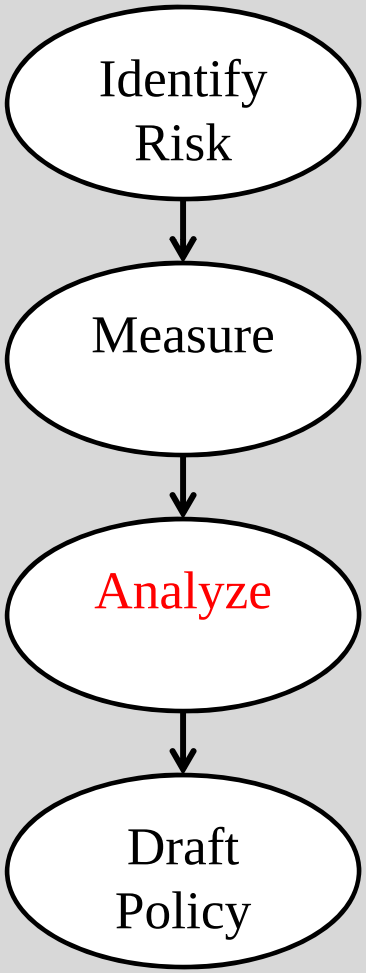


Quantifying Rockfall Behavior



- V_{90}: The volume of the 90th+ percentile size clasts as a percentile of the total volume fallen during the entire measurement period
- Range in Virginia Valley and Ridge: 9-30%
- Can be estimated from talus
- V_{90} Reflects Lithostructure

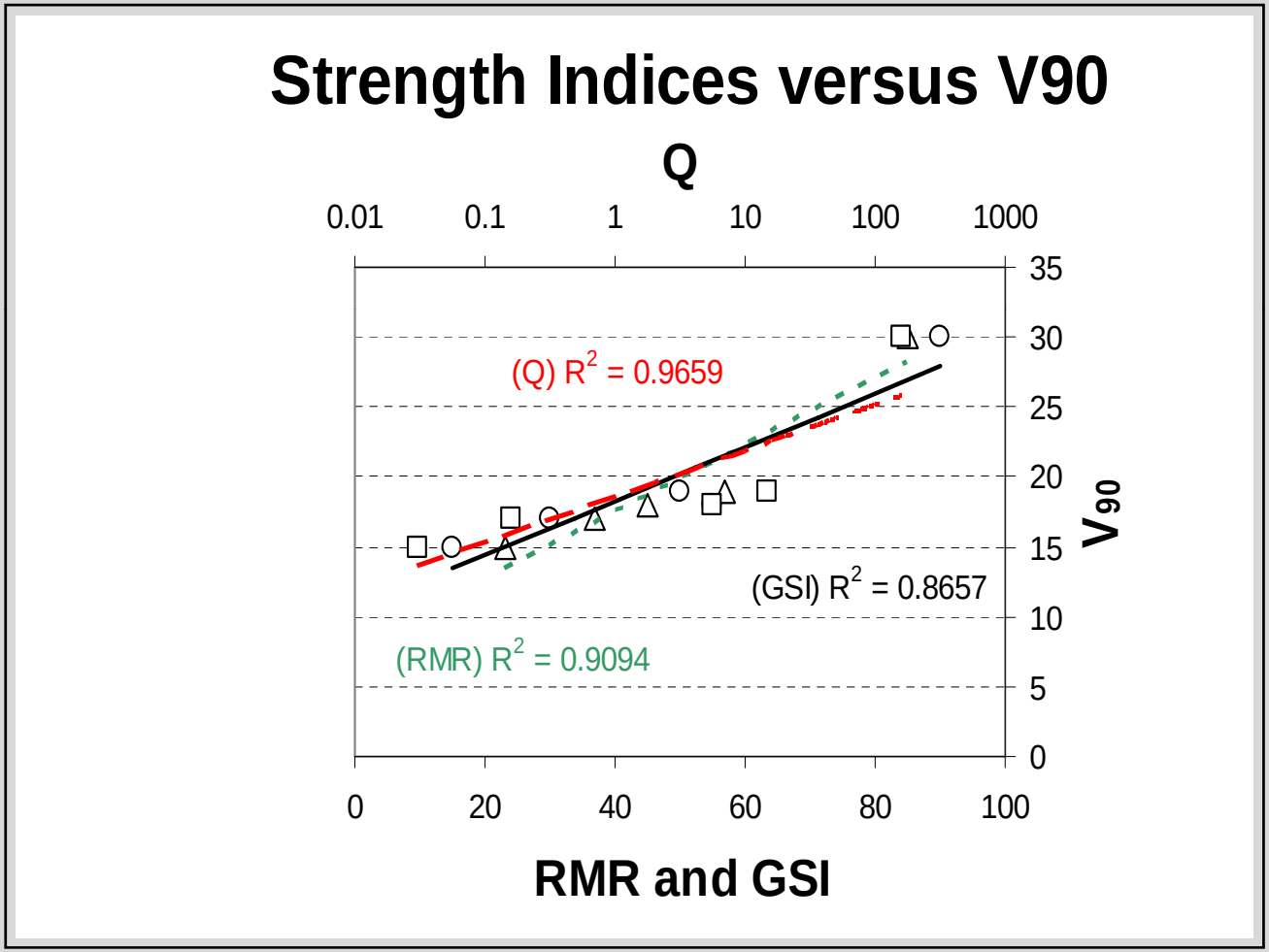
Quantifying Structure



- RMR: Rock Mass Rating
- GSI: Geological Strength Index
- Q: Tunneling Index

Quantifying Structure

- Identify Risk
- Measure
- Analyze
- Draft Policy



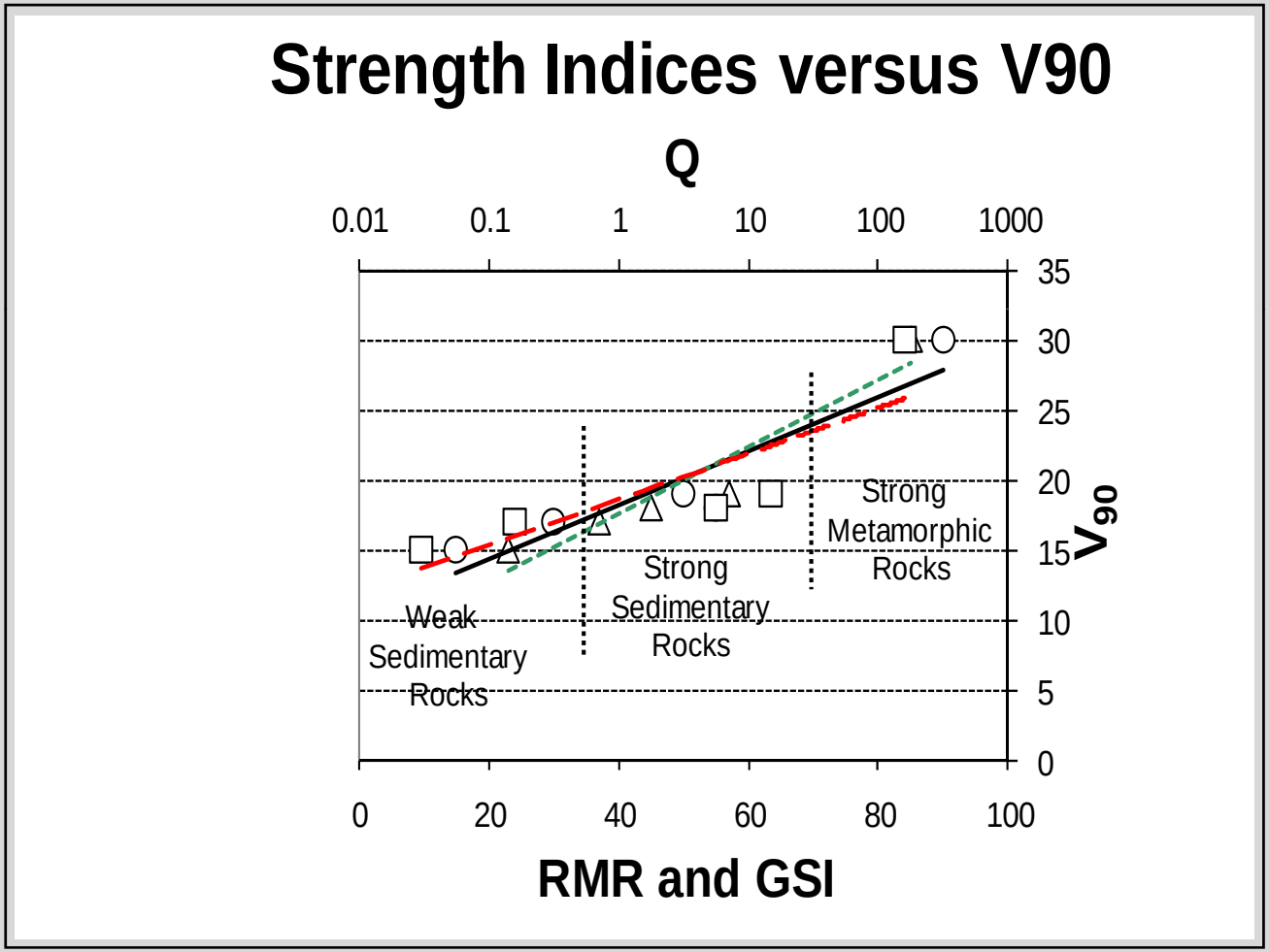
Quantifying Structure

Identify Risk

Measure

Analyze

Draft Policy



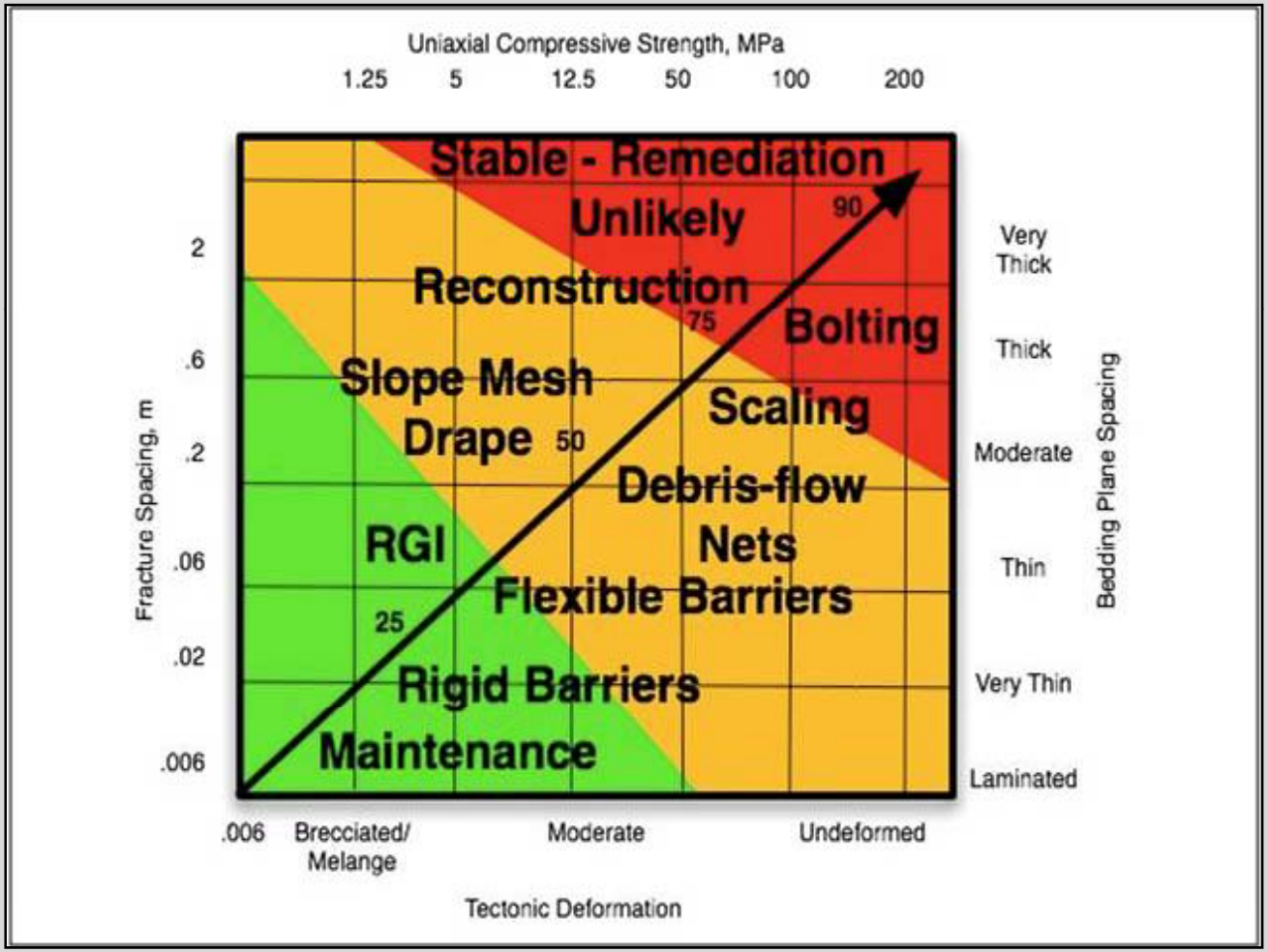
RMR vs. Risk Management

Identify Risk

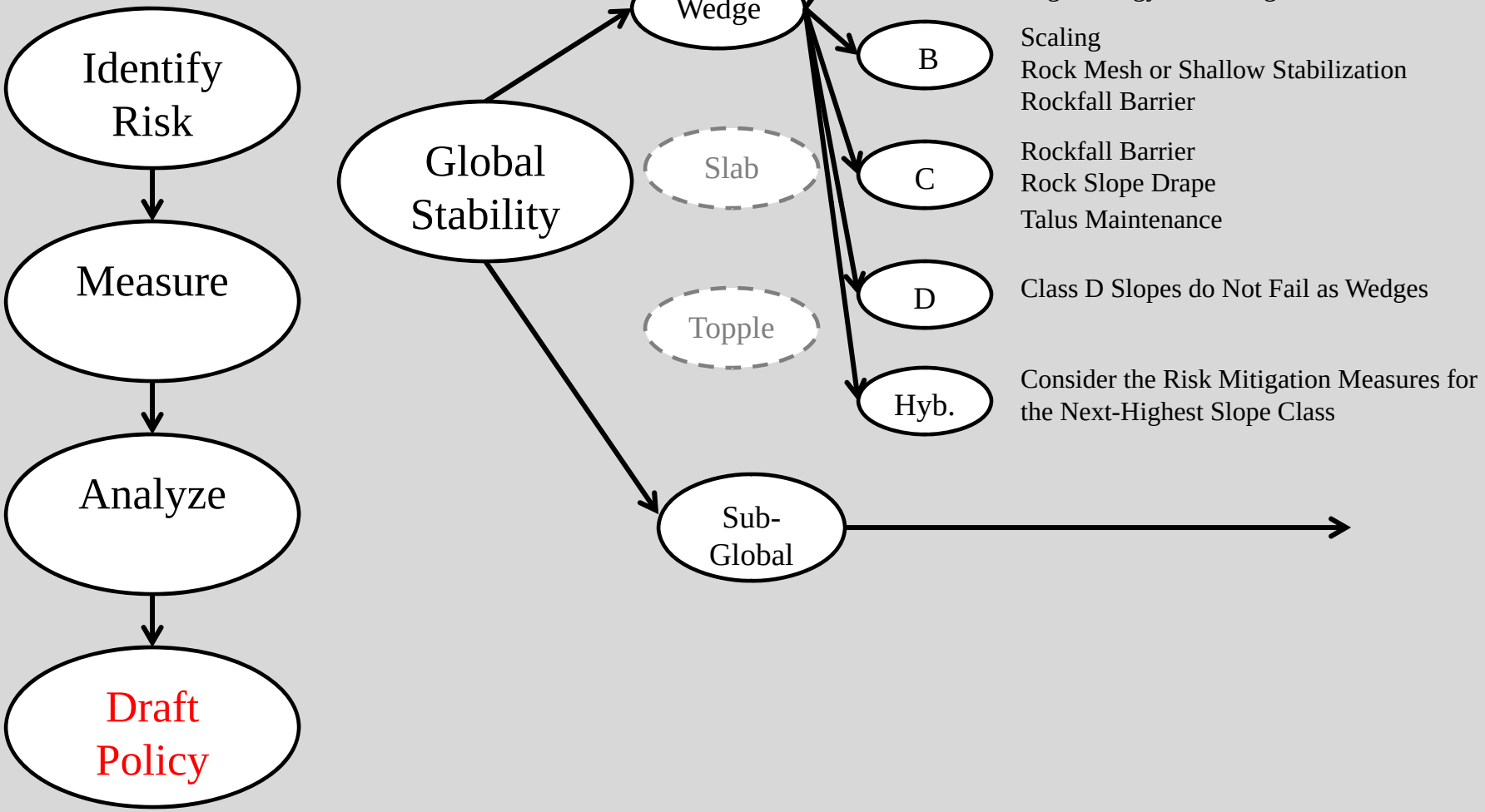
Measure

Analyze

Draft Policy



Risk Management Flowchart



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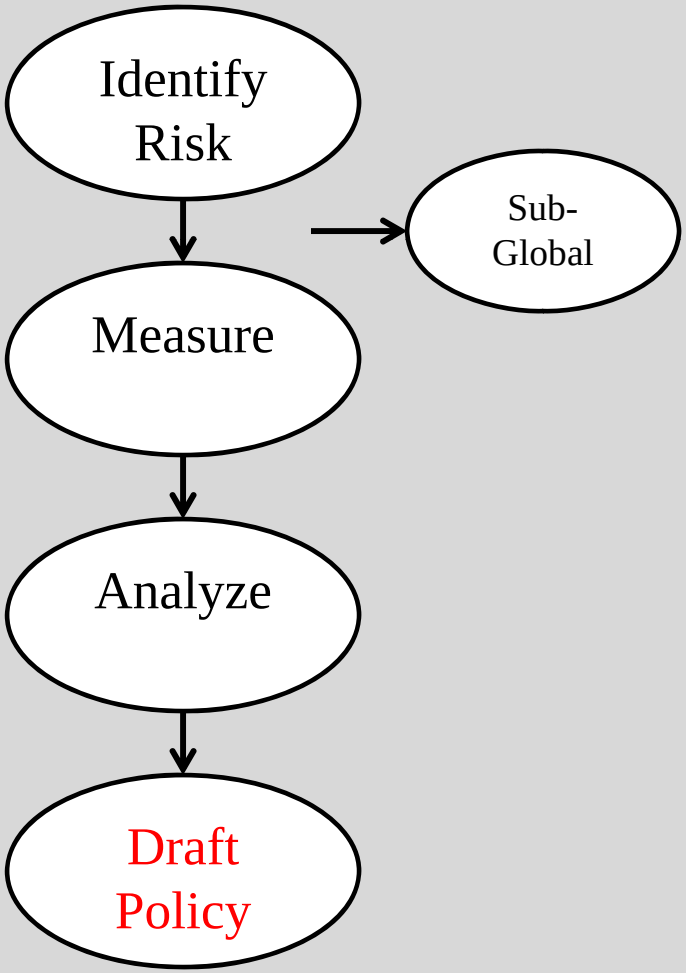


a. RMR 61-100:
(High-energy events, low activity

Debris-Flow Nets
High-Energy Absorbing Devices
Rockfall Barrier

b. RMR 41-80:
(Intermediate-energy events, moderate-activity)

Rockfall Barrier
Rock Mesh or Shallow Stabilization

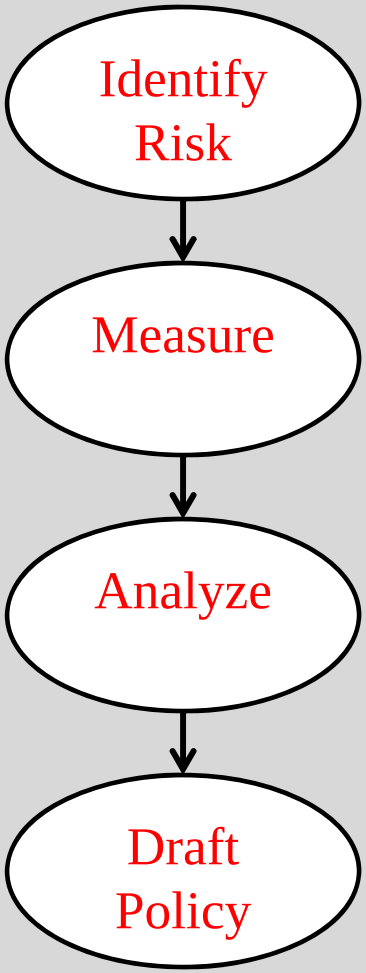
c. RMR 21-60:
(Intermediate- to low-energy events, High activity)
Increase Catchment

Rockfall Barrier
Rock Mesh
Rock Drape

d. RMR <20:
(Very low-energy events, very high activity)

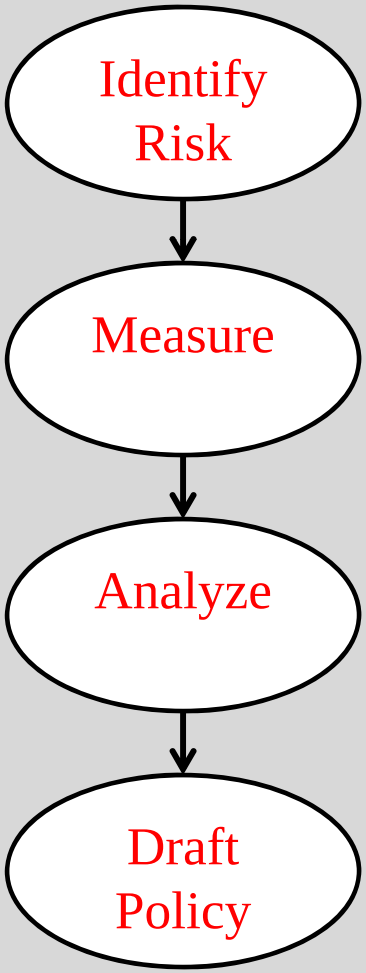
Talus Maintenance

Conclusions



- Focusing only on global stability will miss a significant component of risk
- Not all rockfall is triggered by external events; a significant component of rockfall occurs absent obvious triggers

Conclusions



- "Sub-global" stability, or rockfall, must be addressed
- Not all rockfall can be avoided: Global stability is a remediation issue; Rockfall is a risk-management issue
- Rock Strength Indices offer a very good proxy for rockfall and allow risk-calibrated management