



# Rock Mass Indices as a Tool for Management of Rockfall Risk: Lessons from Virginia

Identify  
Risk

Measure

Analyze

Draft  
Policy

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# Virginia's New Rock Slope Design Guide

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- 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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- 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**



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

Identify  
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Measure

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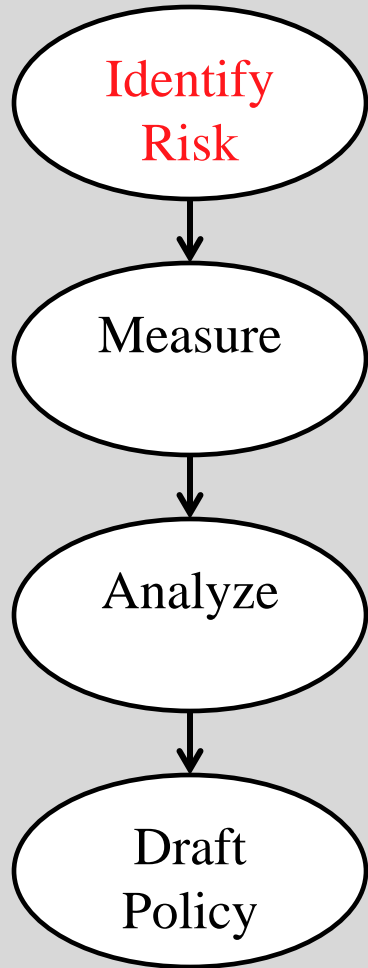
Draft  
Policy

- 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*



- 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



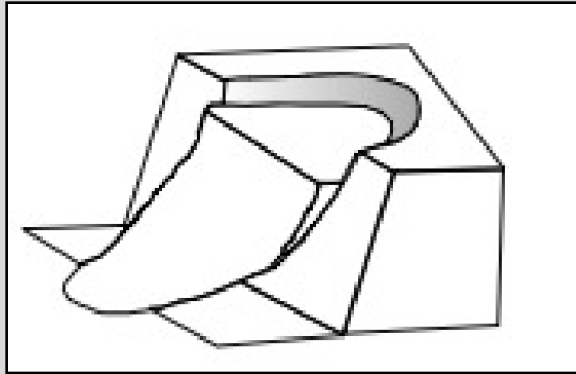
# Global Slope Phenomenology

Identify  
Risk

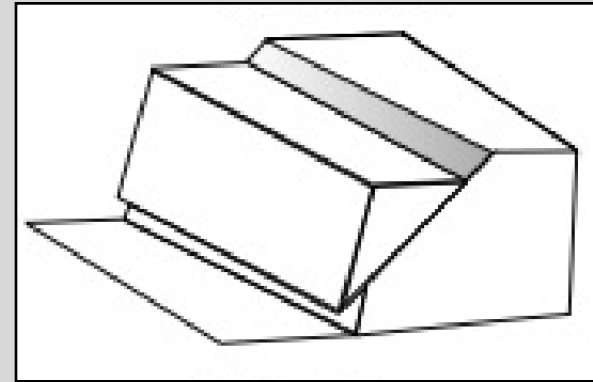
Measure

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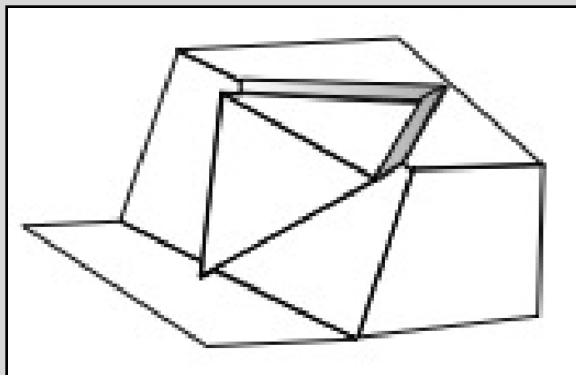
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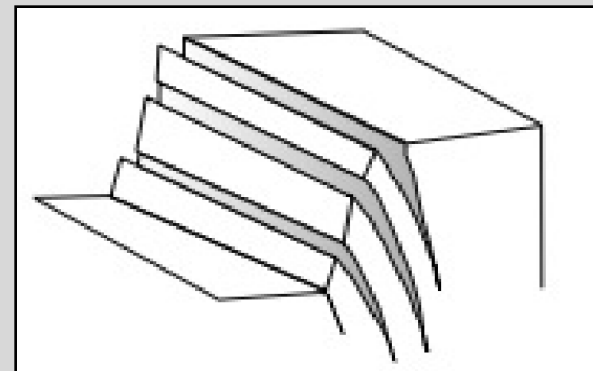
Arc Failure



Slab Failure



Wedge Failure



Toppling Failure

After Department of the Army, 1994



# Global Slope Phenomenology

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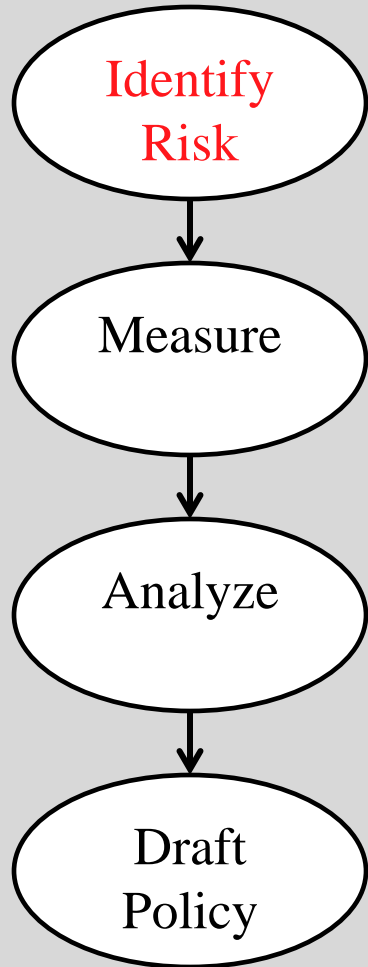
Analyze

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- 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



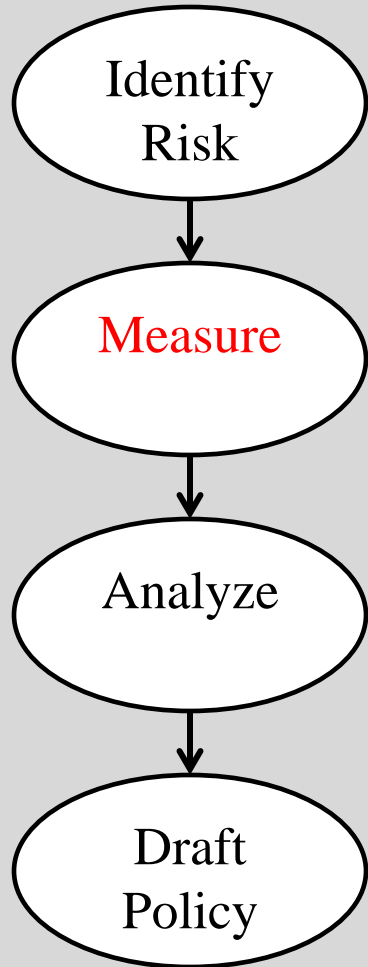




Photo: Roanoke Times



# 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

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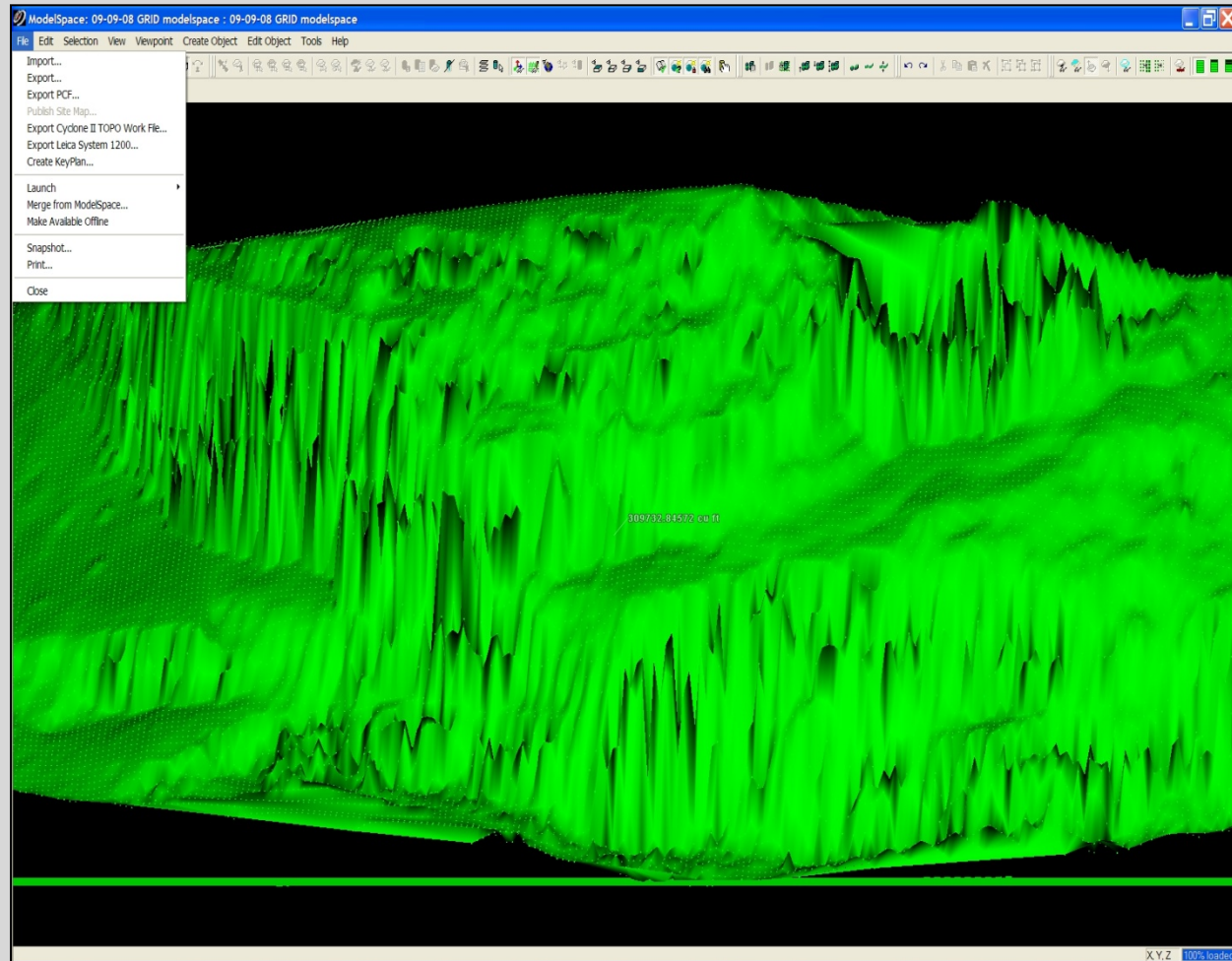
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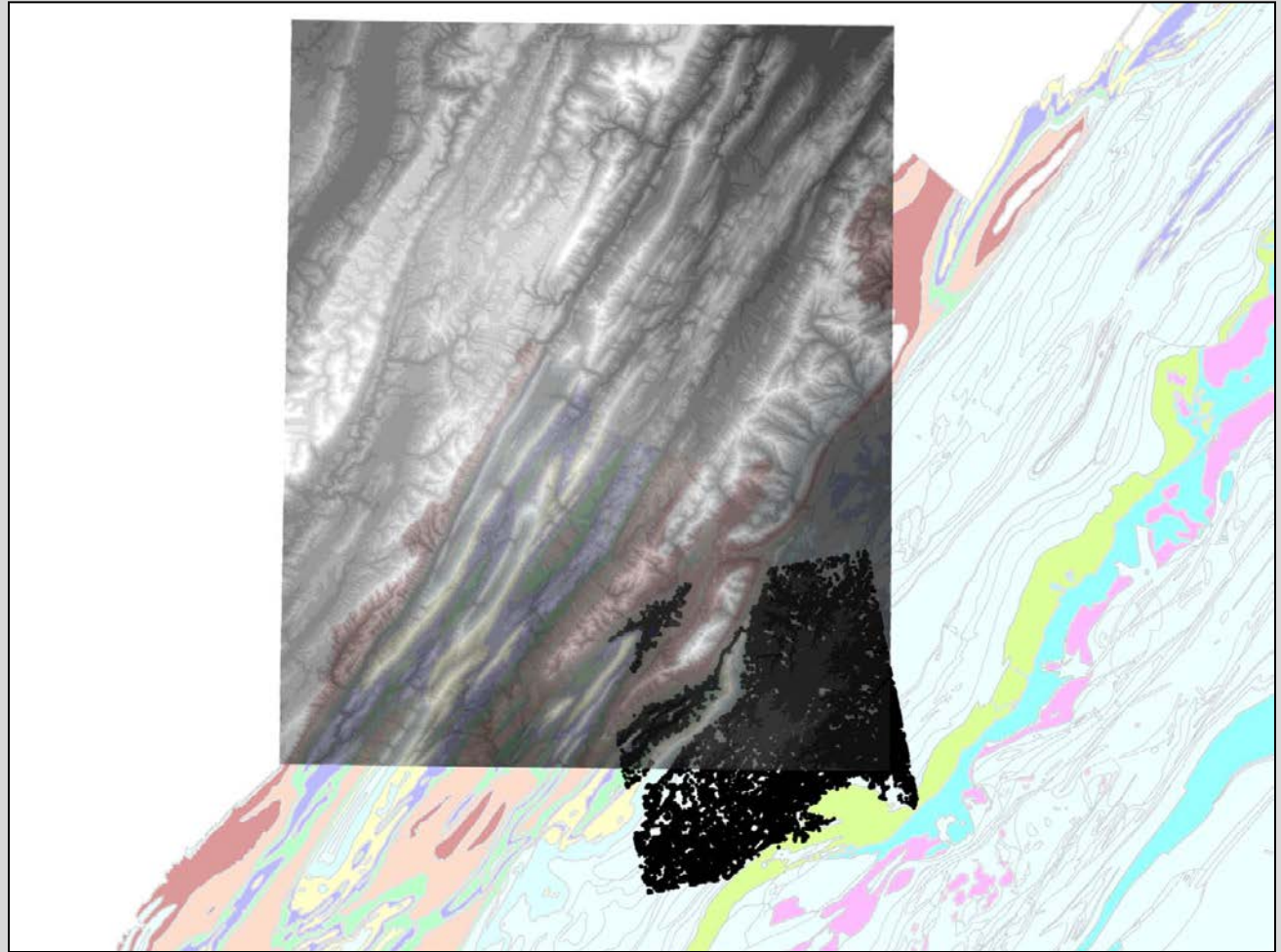
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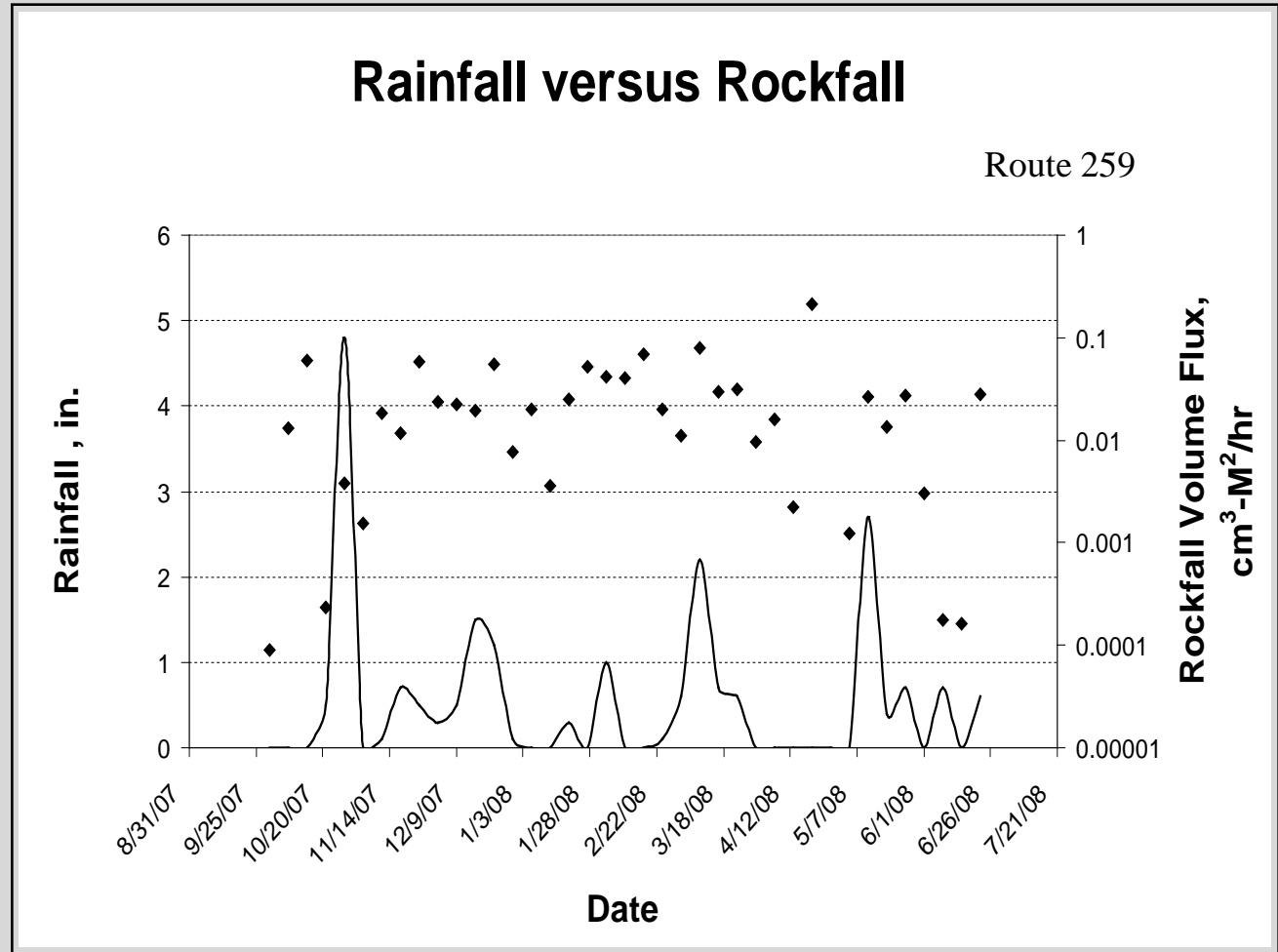
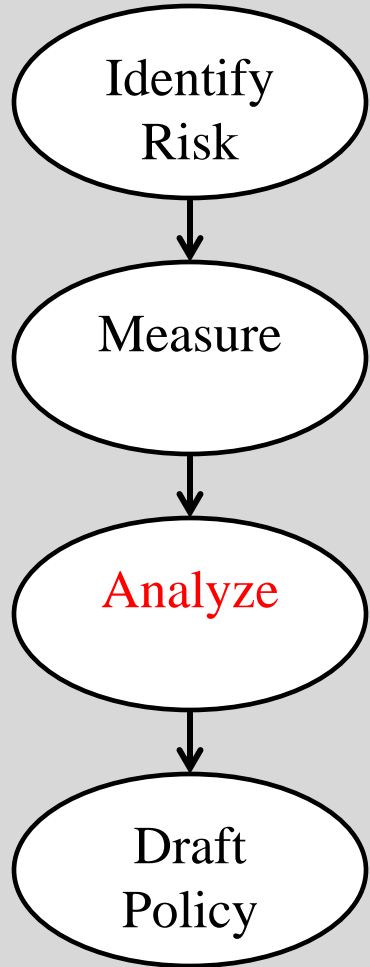
Analyze

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

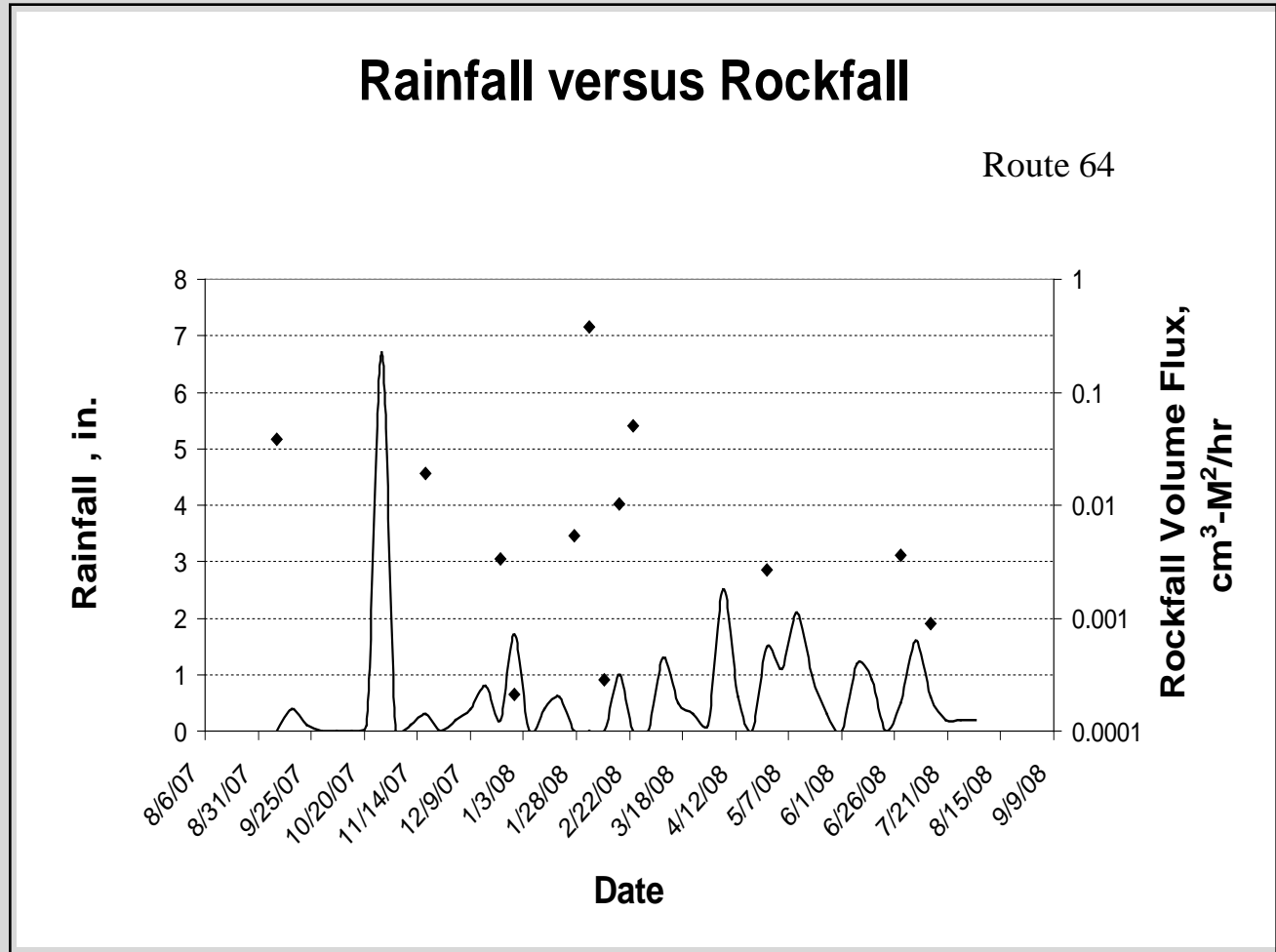
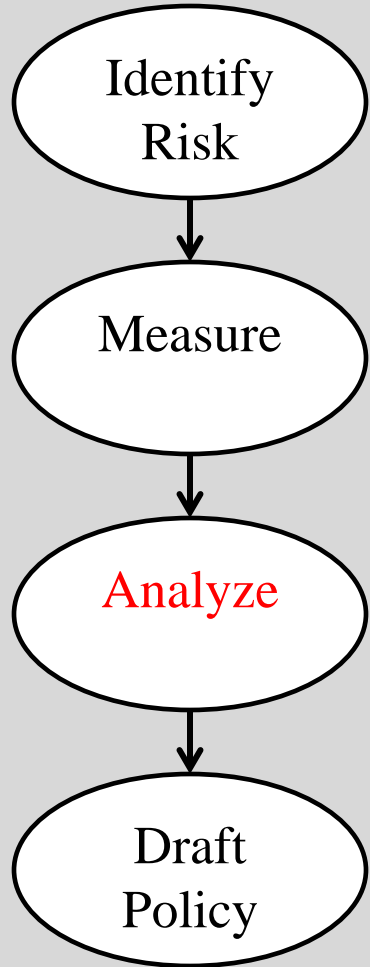


# Controls on Rockfall



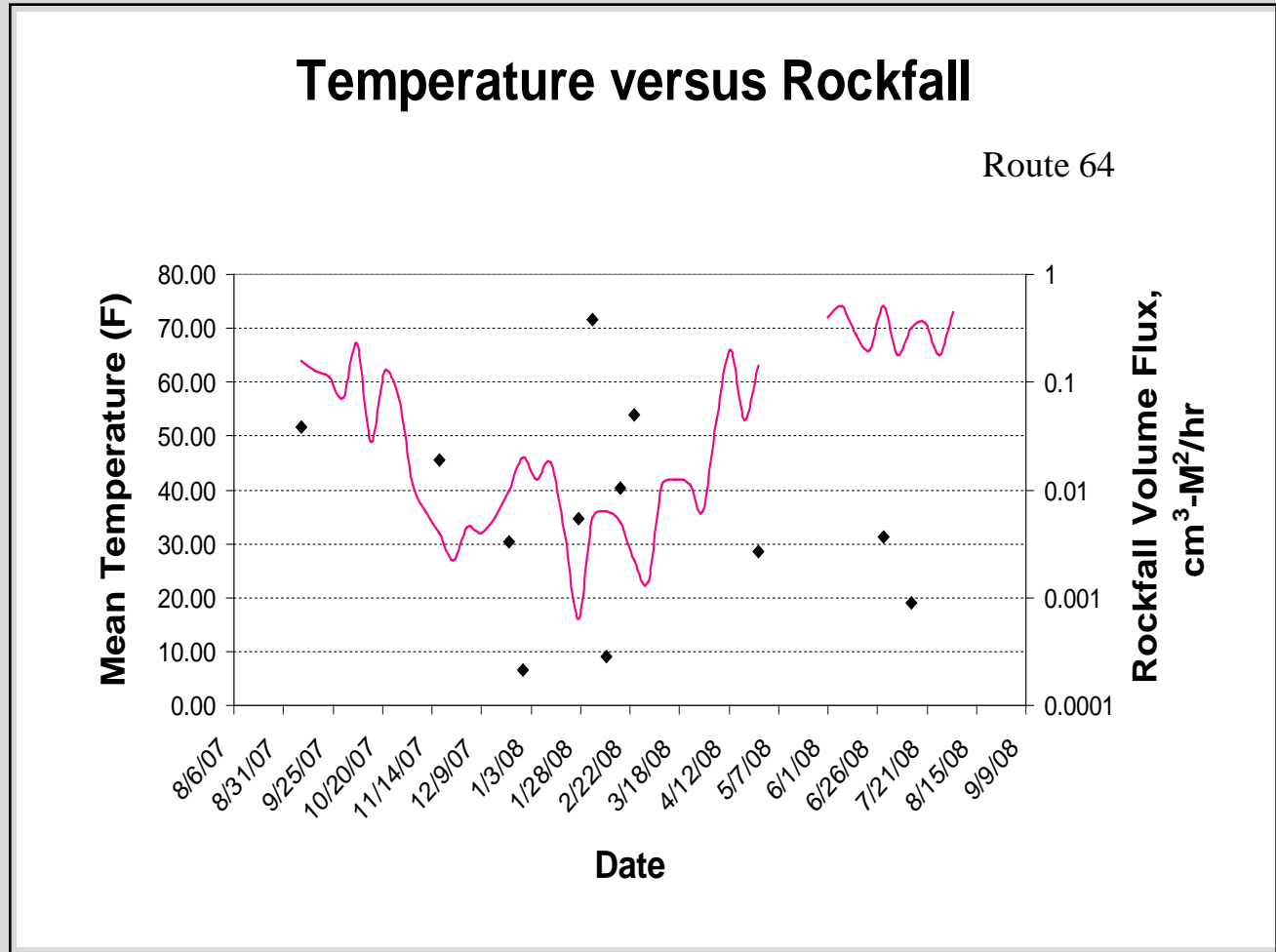
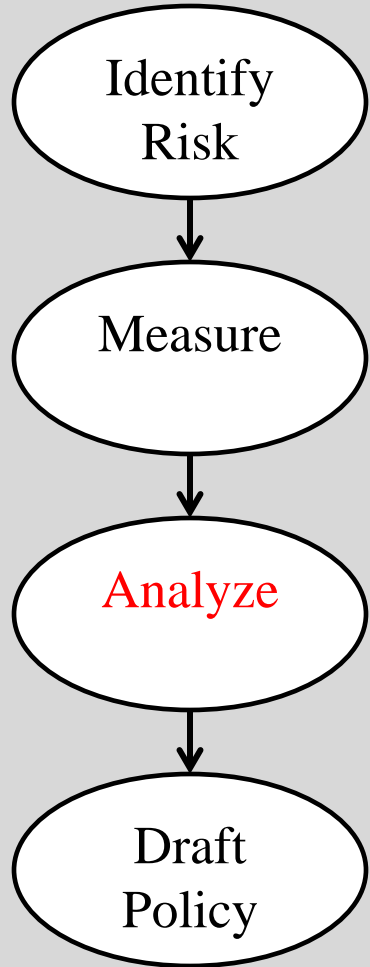


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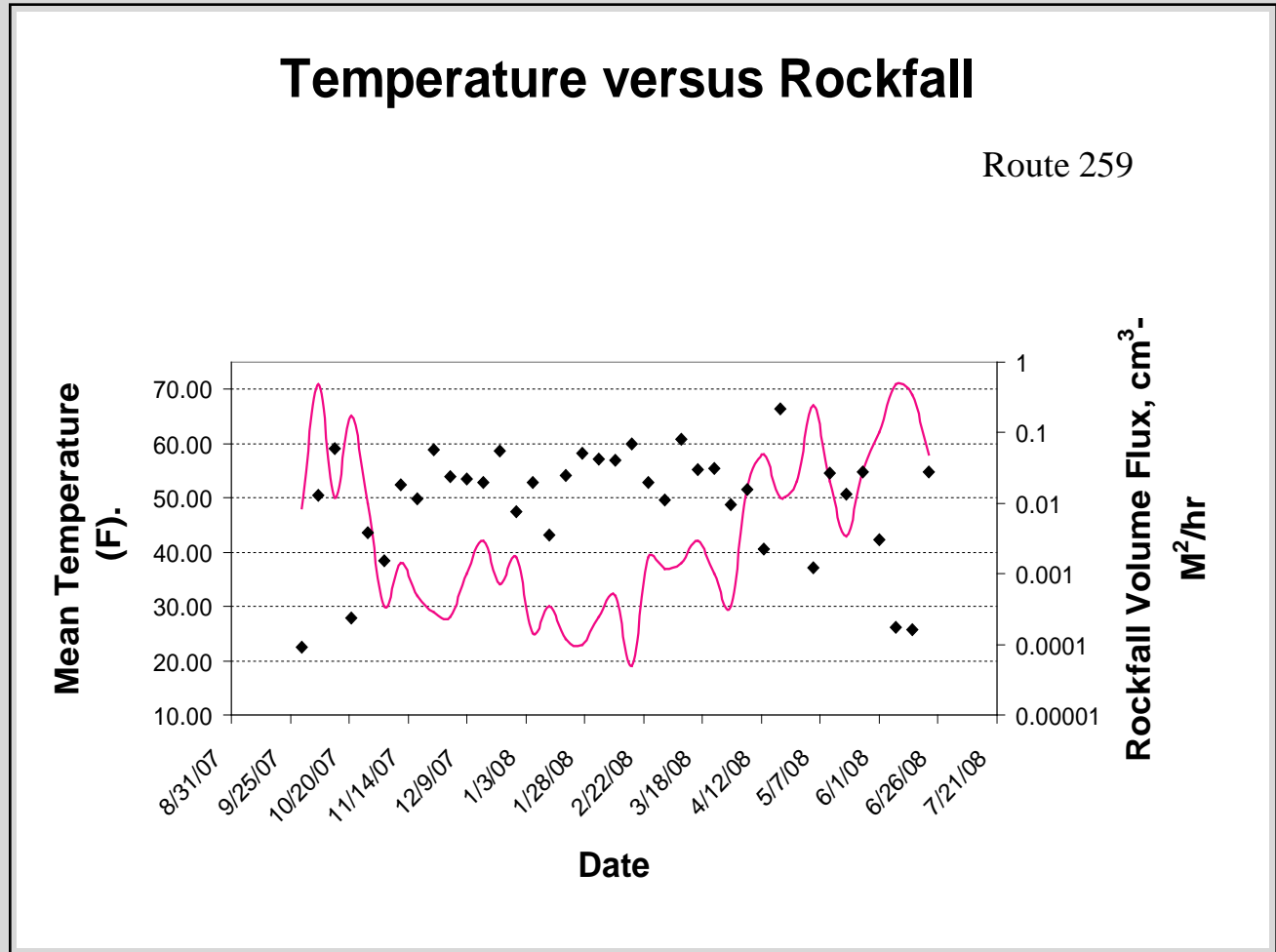
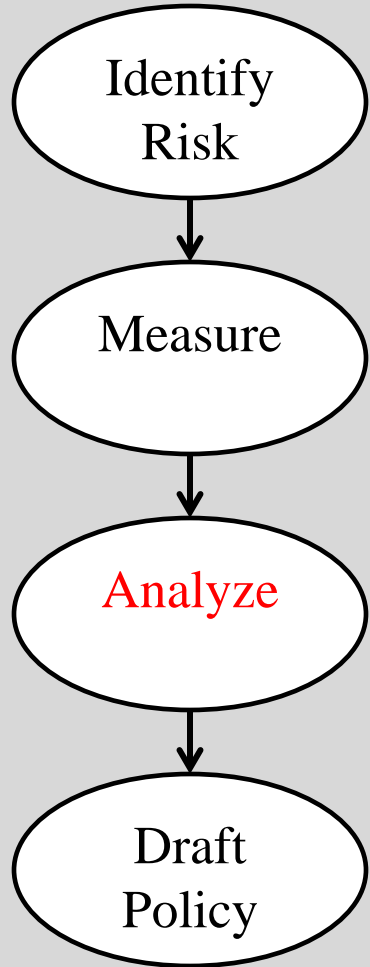


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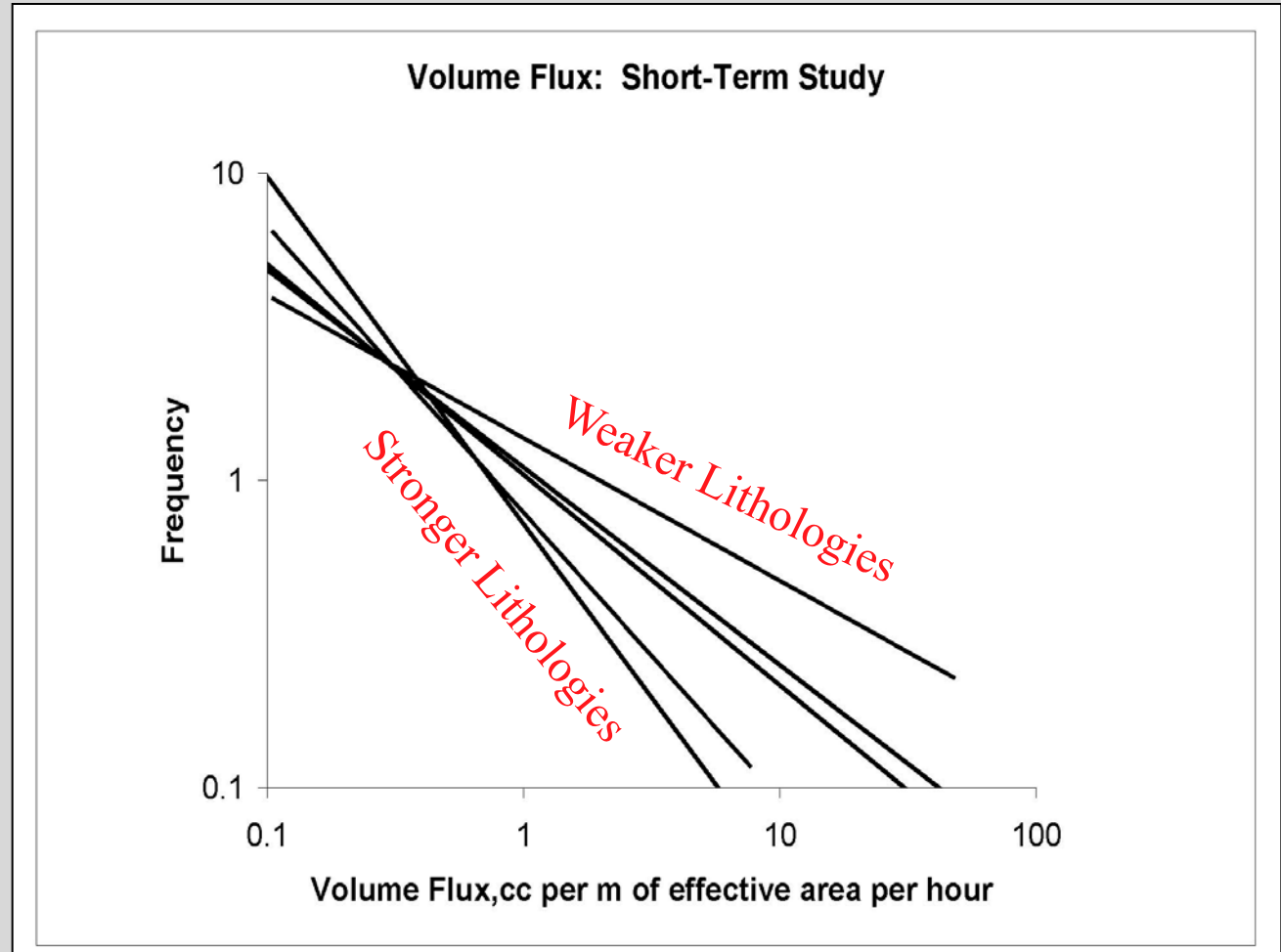
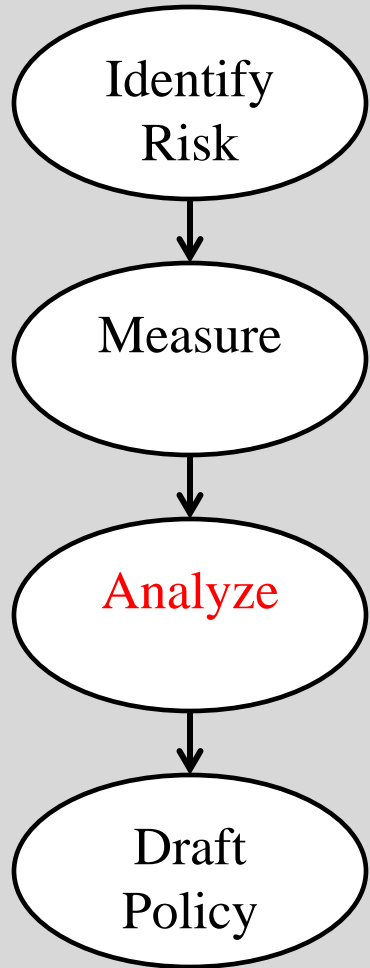
# Controls on Rockfall





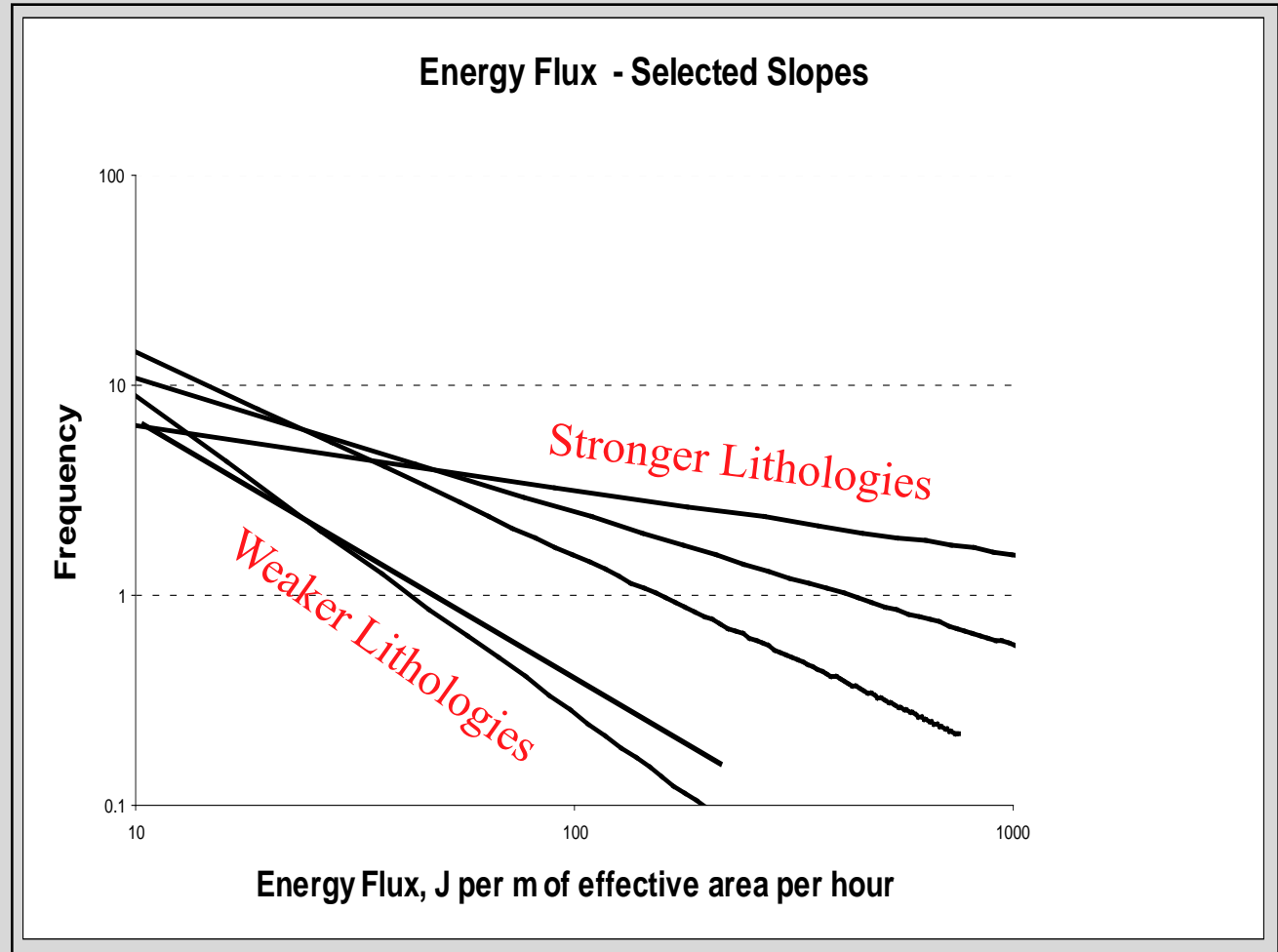
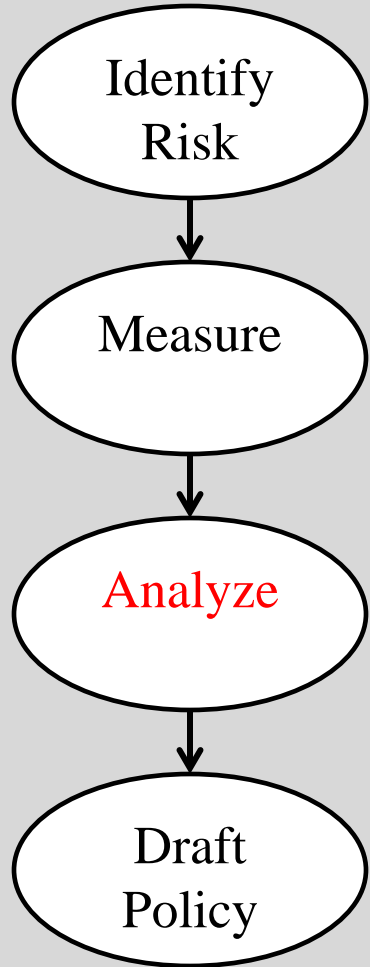


# Controls on Rockfall Volume Flux – Short Term



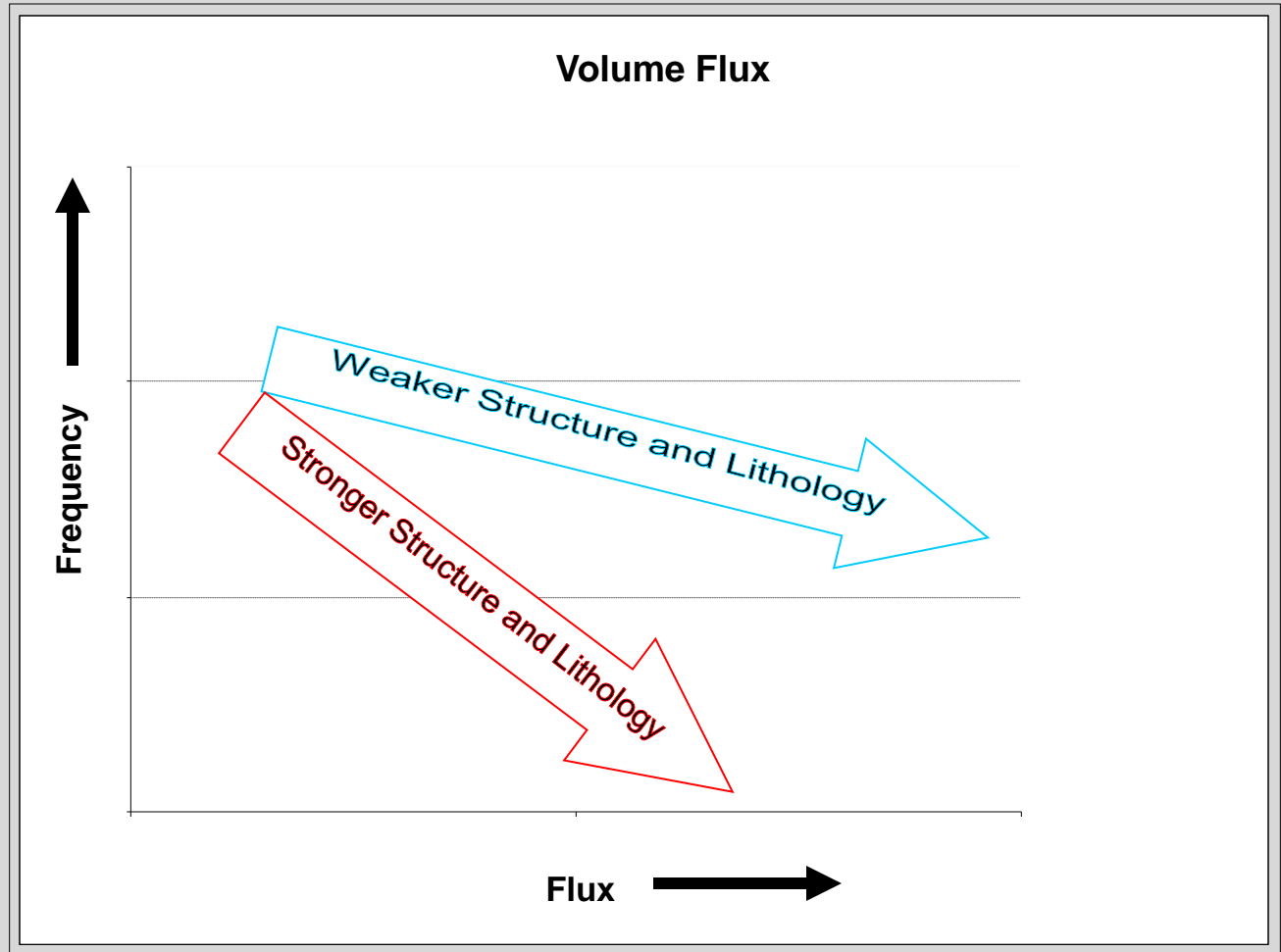
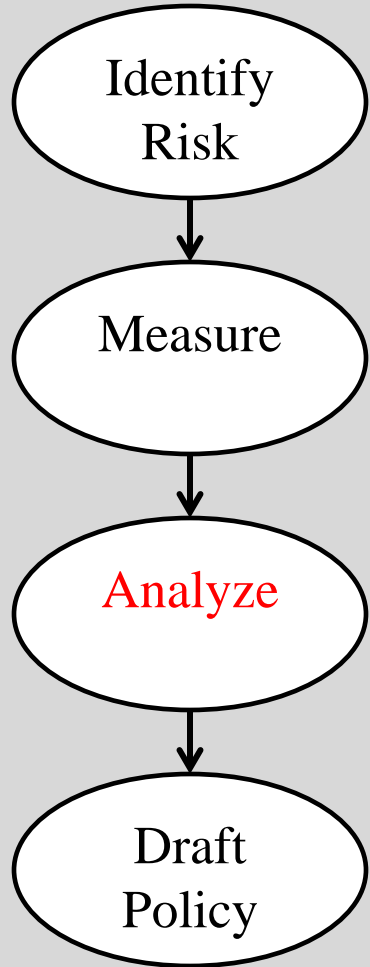


# Controls on Rockfall Energy Flux – All Terms



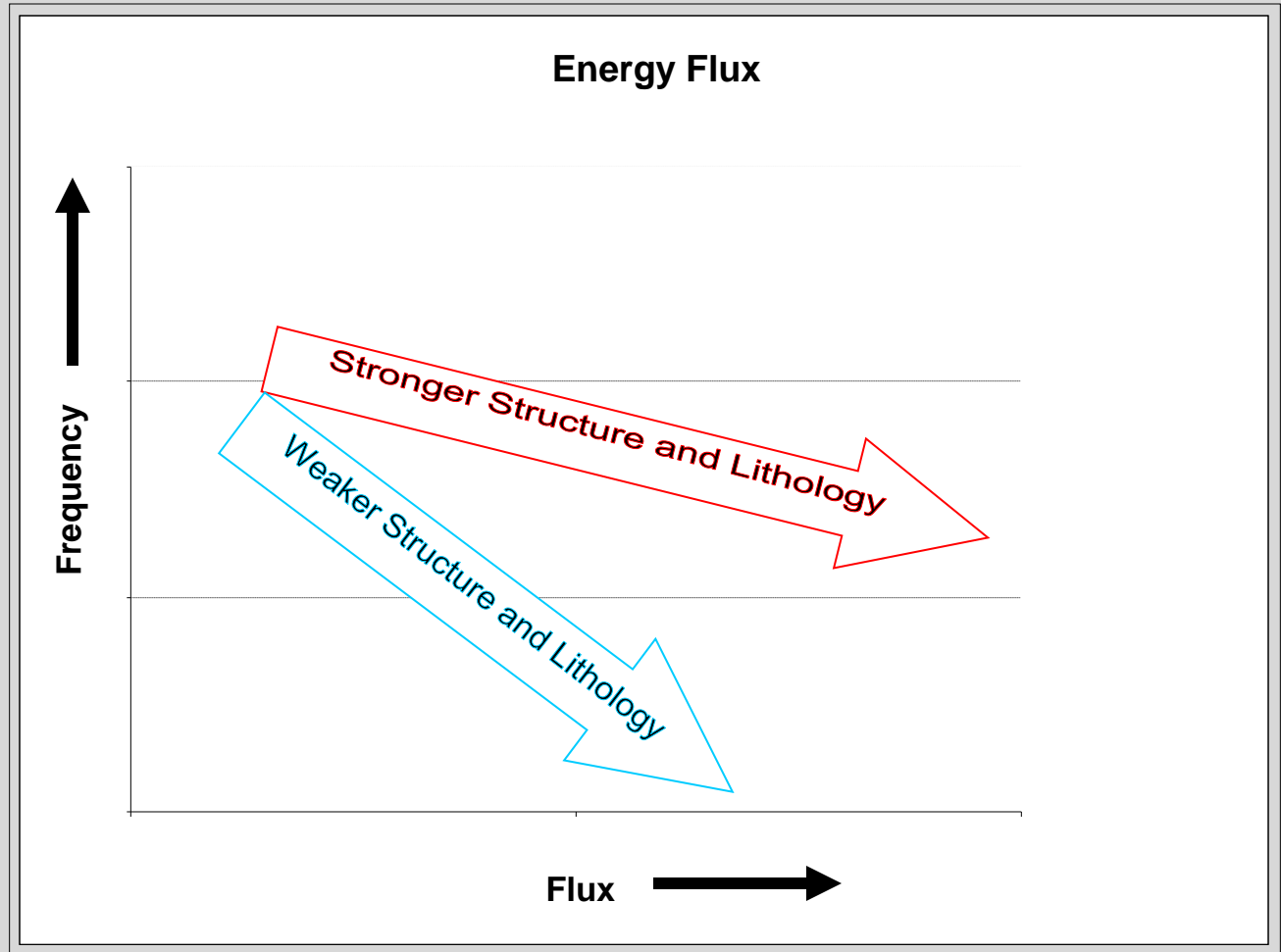
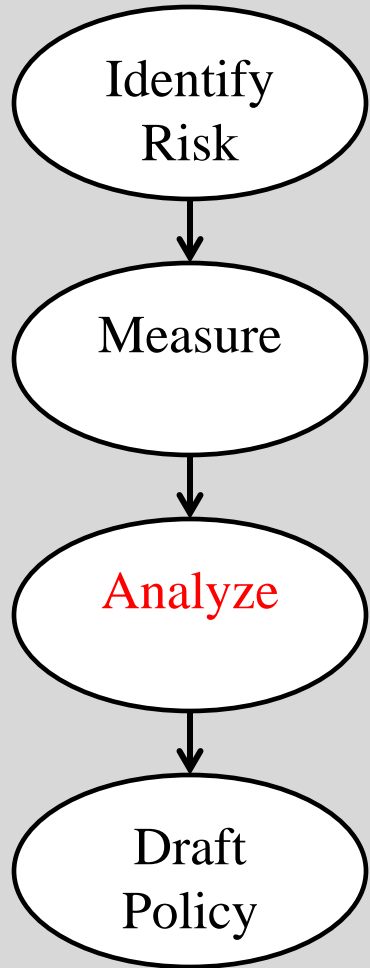


# Controls on Rockfall Volume Flux – Trends



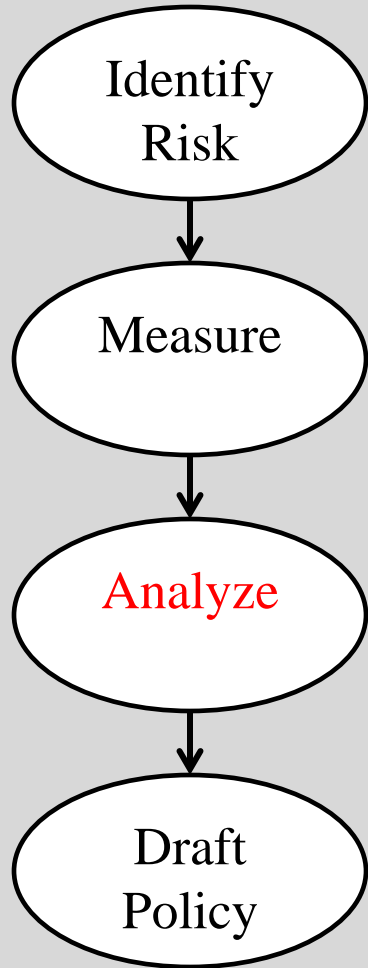


# Controls on Rockfall Energy Flux – Trends





# Quantifying Rockfall Behavior



- $V_{90}$ : The volume of the 90<sup>th</sup>+ 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

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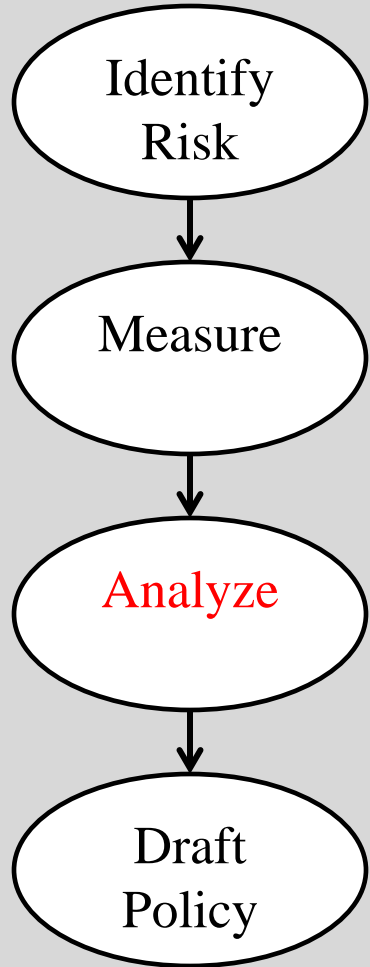
Analyze

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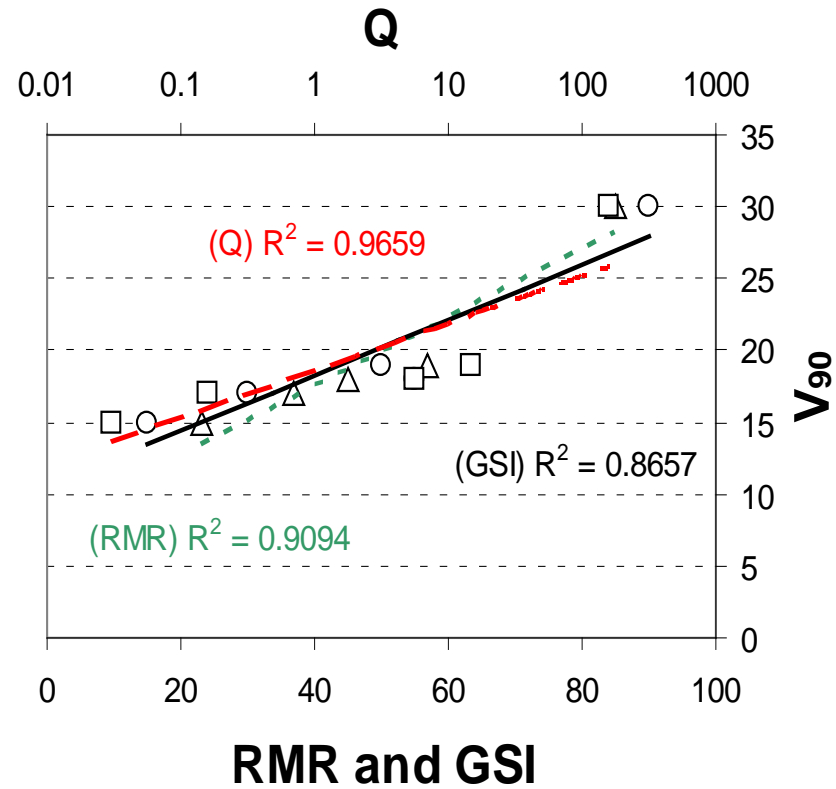
- RMR: Rock Mass Rating
- GSI: Geological Strength Index
- Q: Tunneling Index



# Quantifying Structure



## Strength Indices versus V90





# Quantifying Structure

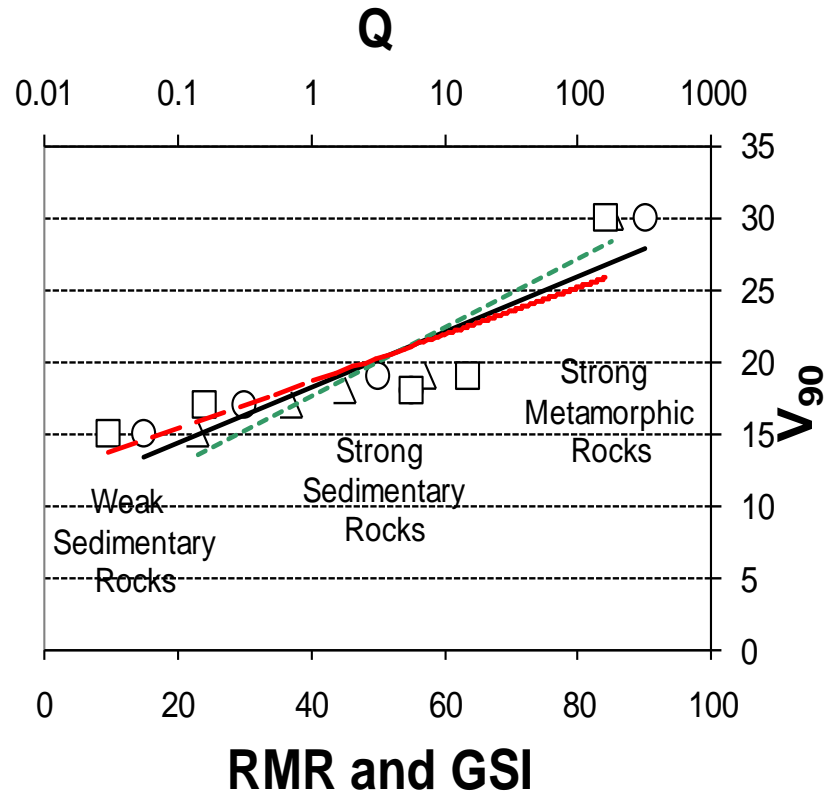
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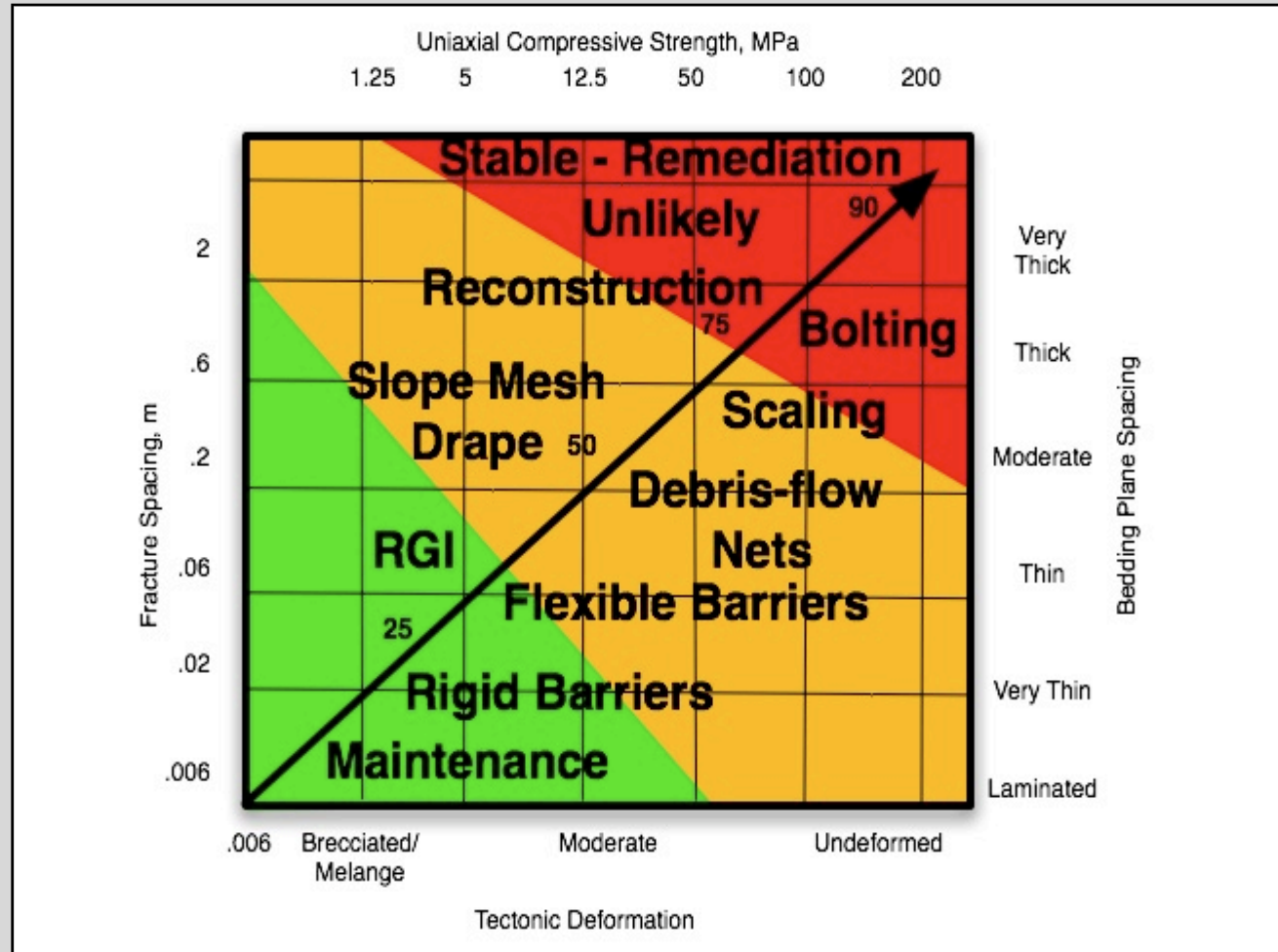
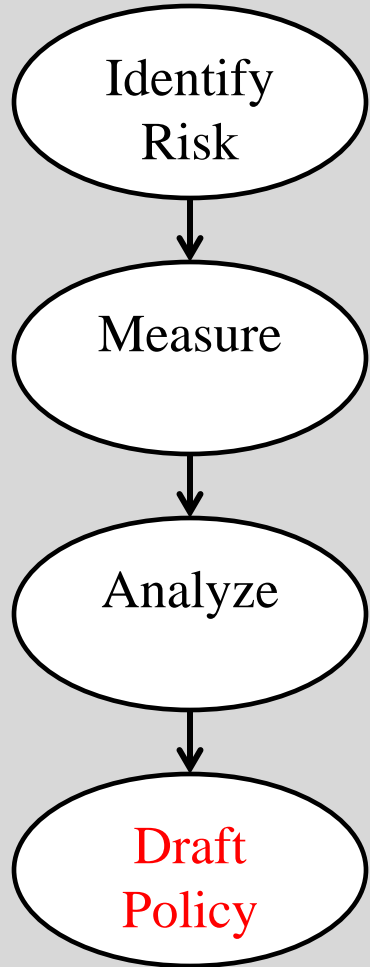
## Strength Indices versus $V_{90}$





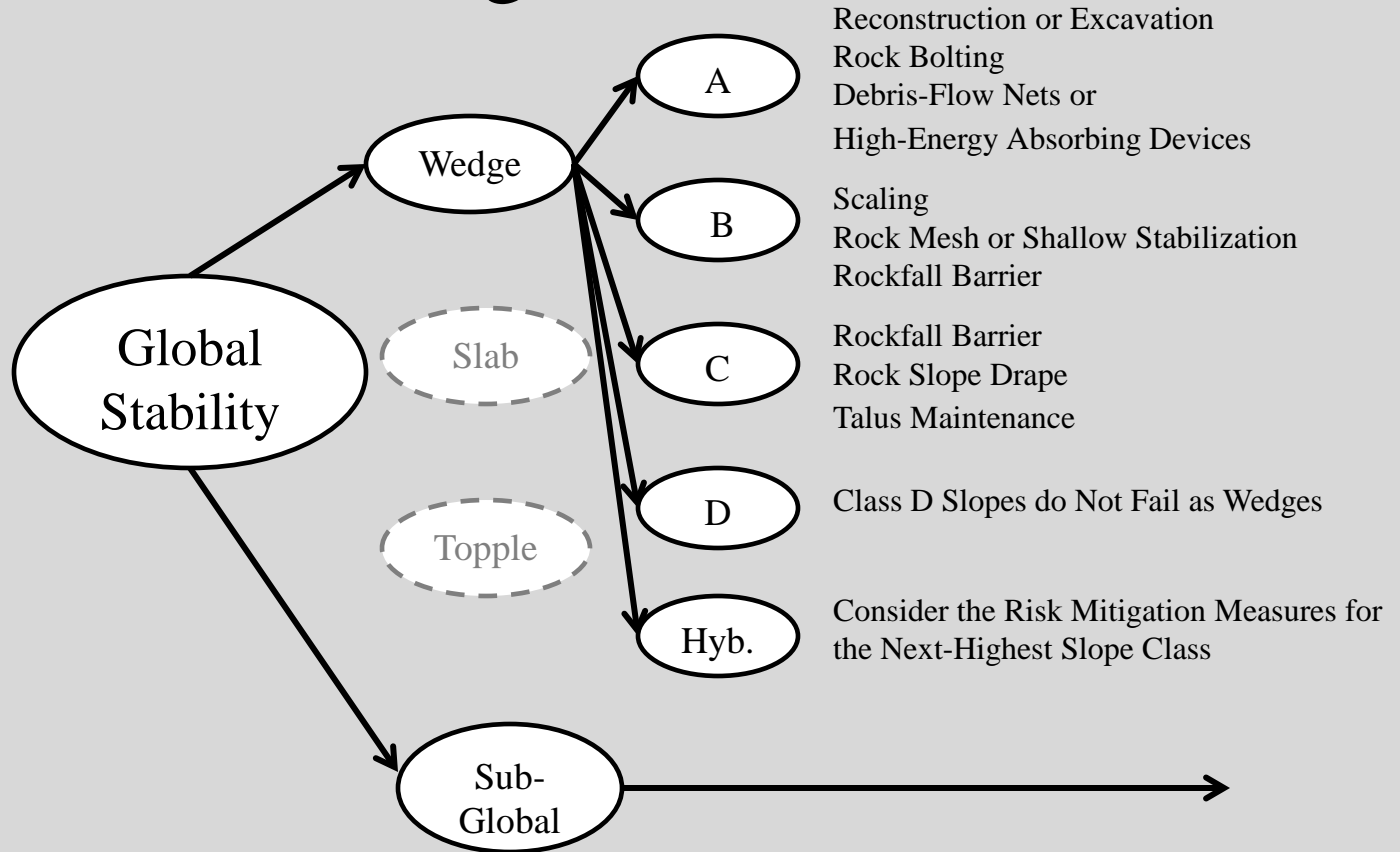
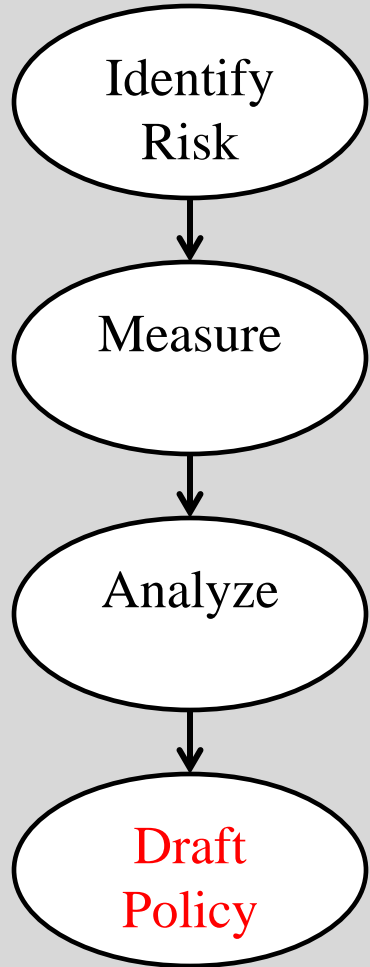


# RMR vs. Risk Management



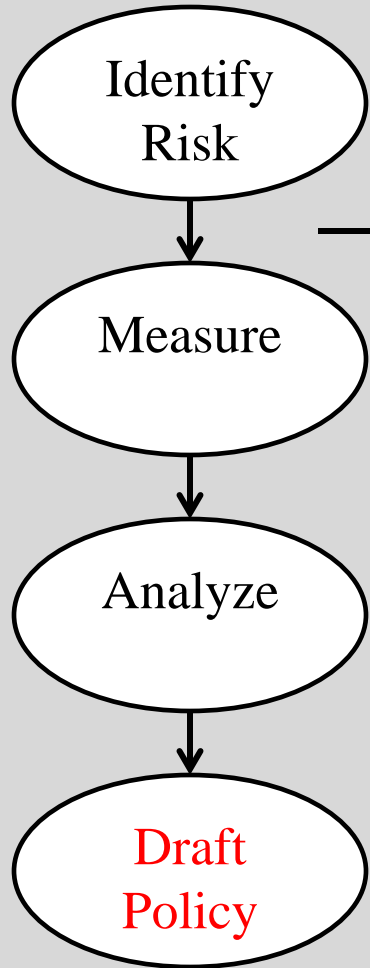


# Risk Management Flowchart





# Risk Management Flowchart



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

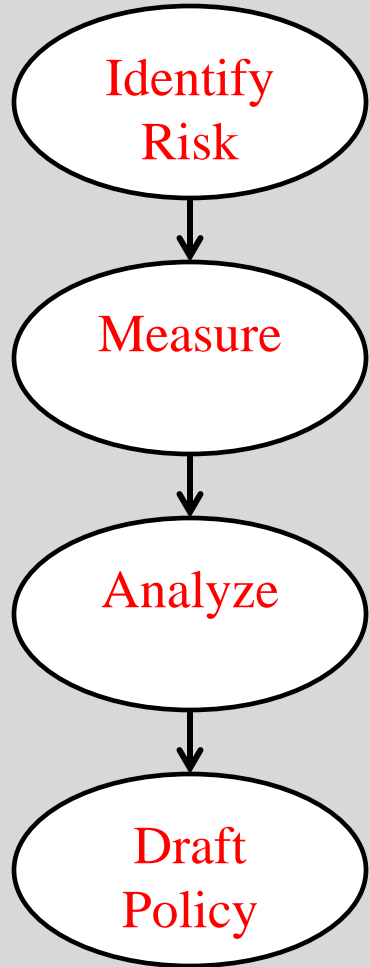
Rockfall Barrier  
Rock Mesh  
Rock Drape

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

Talus Maintenance



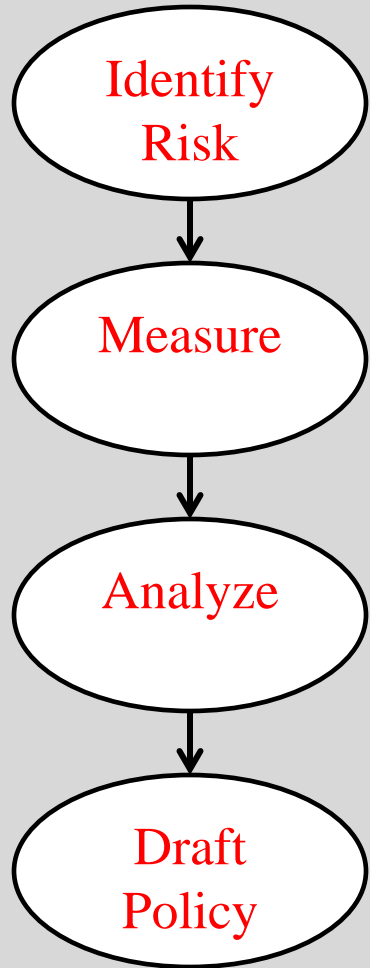
# Conclusions



- 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

