A GIS-Based Evaluation of the Caddy Canyon Debris Flow

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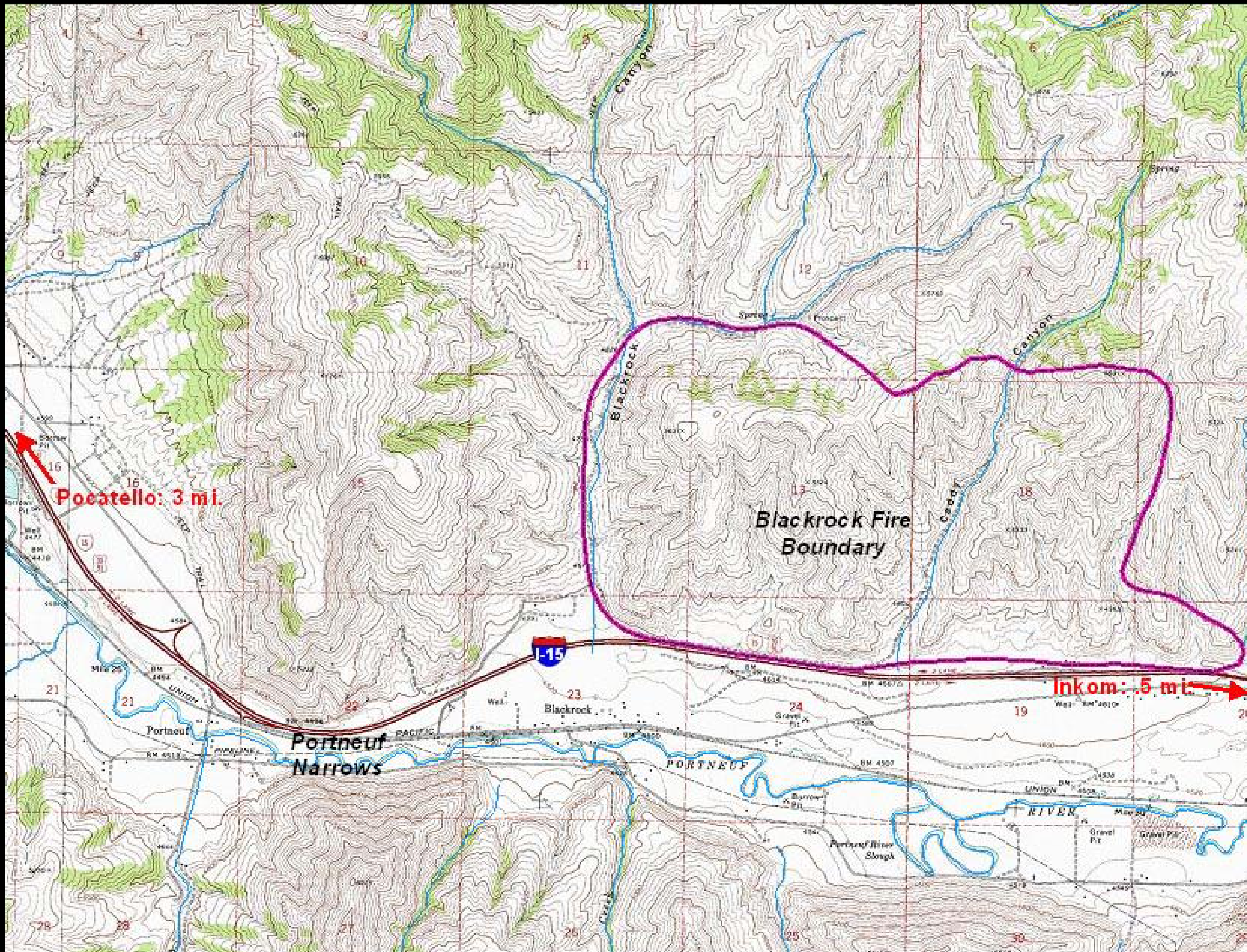
Outline

- Background
  - Reasons for the study
  - Study area
    - Characteristics
    - Sequence of events
- Wildfire/debris flow discussion
- Study objective
- Methodology
  - Data utilized
  - Parameters
- Validation
- Results & conclusions

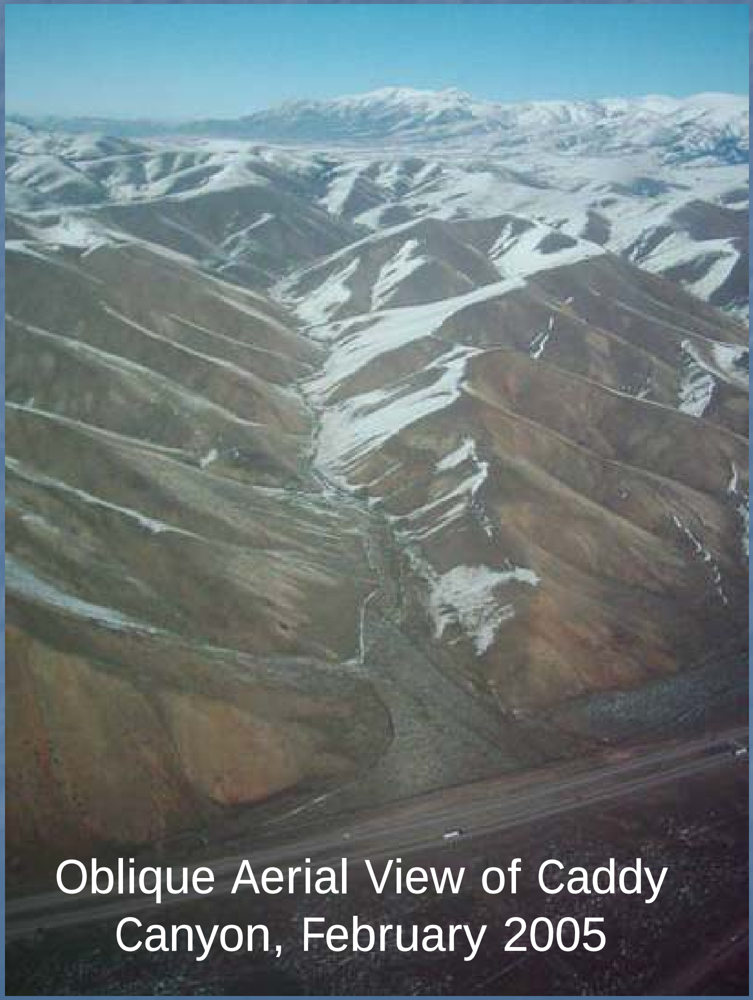
Reason for studying

- Landcover change research
- Lack of research in rangeland areas
- Recent, significant event, causing damage
- Proximity to study area

Study Area


Pocatello: 3 mi.
Blackrock Fire
Boundary
Inkom: .5 mi.
Portneuf
Narrows
I-15
Blackrock
Canyon
Caddy
PORTNEUF
RIVER
UNION
PACIFIC
Portneuf River
Slough

Characteristics of Caddy Canyon



Oblique Aerial View of Caddy Canyon, February 2005

- V-Shaped Valley
  - N-NE
  - ~3 mi. long
  - 0.4 – 1 mi. wide
  - ~6% slope
- Valley Walls
  - 11-47% slope
  - 5500-6200 ft. elevation
  - Intermittent Dendritic Streams
- Burned Hillslopes
  - Sparse Vegetation
- Alluvial Fan
  - 3800 ft. long
  - 800 ft. wide

From Tucket et al., 2004

Caddy Canyon Debris Flow Characteristics

- Confined to channel extending 1400 ft upslope from highway
- Channel: 4-13 ft wide, steep/vertical walls, Upper: 1-2 ft deep, Lower: 4-6 ft deep

Caddy Canyon Debris Flow Characteristics

- Channel banks overtopped during flood event, producing sheet flow across alluvial fan
- Deposited debris flow material consisted of colluvial sand/gravel, and few cobbles/boulders

Sequence of Events

- July 3, 2003: Blackrock Fire
  - ~2050 acres
  - Steep rangeland area 5 mi. southeast of Pocatello, ID
- August 3: Severe Thunderstorm
  - ~1 in. rainfall in 1 hr.
- Erosion Debris Flow
  - Covers & closes Northbound lane of I-15 for ~5 hrs.

Vegetation characteristics

After Wild Fire

Before Wild Fire

Debris Flow Characteristics

Debris Flow Materials

Debris Flow Channel

Fire-Related Debris Flows

Post-fire conditions that affect and cause debris flow initiation

- Easily erodible sediment due to:
  - Fire-removed litter and organic layers
  - Intense heating, soil drying, decreased cohesiveness
- Decreased infiltration rates due to formation of water-repellant layers
  - Increased raindrop impact velocities
  - Increased amount of precipitation-induced runoff
- Removal of Vegetation
  - Decreased interception and evapotranspiration
  - Controlled by burn severity – relationship with runoff generation unclear

Study Objective

- Evaluate the Caddy Canyon debris-flow and its initiating mechanism
- Determine if debris flow initiation points are within critically analyzed areas
  - Based on generalized scenarios of the study area with the aid of GIS
- Not Evaluating Susceptibility, Hazard, Risk

Methodology

SHALSTAB ArcView Extension

- Montgomery and Dietrich, UC, Berkeley (1994)
- ArcView 3.x
- Requires Spatial Analyst extension
- Data Files required:
  - DEM grid files
  - ArcView shapefile of mapped landslides or debris flows
- Analyzes DEM's to compare mapped landslide distribution with random location statistics

Methodology

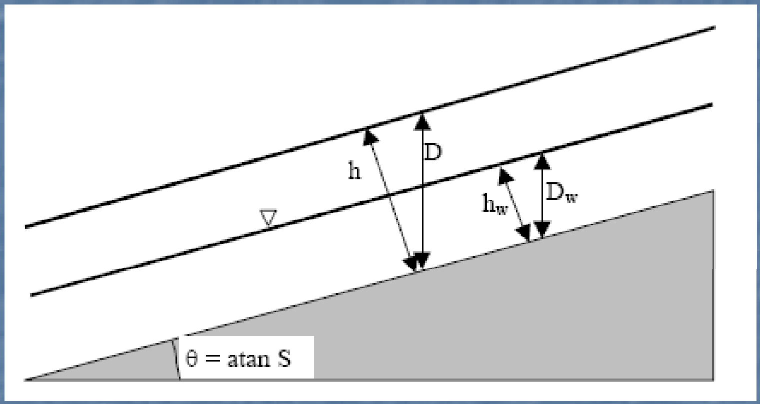
- Assumes steady state, **saturated flow** parallel to the slide surface
- Utilizes Darcy's law for estimating the spatial distribution of pore pressures.
- Based on INFINITE SLOPE MODEL

$$FS = \frac{C + (\gamma - m\gamma_w) * Z * \cos^2\beta * \tan\Phi}{\gamma * Z * \sin\beta * \cos\beta}$$

Original Infinite Slope Model by Skempton & Delory (1959)

Methodology

Infinite Slope Model



$$FS = \frac{Cr + Cs + \cos^2\alpha[\gamma_s(D - Dw) + (\gamma_s - \gamma_w)D_w]\tan\Phi}{[\gamma_s\ D]\sin\alpha\cos\alpha}$$

Infinite Slope Model modified by Hammond et al. (1992)

<u>Darcy's Law</u>

Q = -TLi/A

Q: Discharge

T: Transmissivity

L: Flux length

A: Cross sectional area

i: Hydraulic gradient

- Valid for saturated flow
  - Assuming shallow lateral subsurface flow follows the topographic slope
  - Lateral discharge equals recharge

Parameters (SHALSTAB Inputs)

- Internal Friction Angle ϕ (based on soil type)
  - 35-50 degrees (possible soil particle sizes) *
    - Uniform Sand, Rounded Particles
    - Well-Graded Sand, Angular Particles
    - Sandy Gravel

      * From Craig (1997)

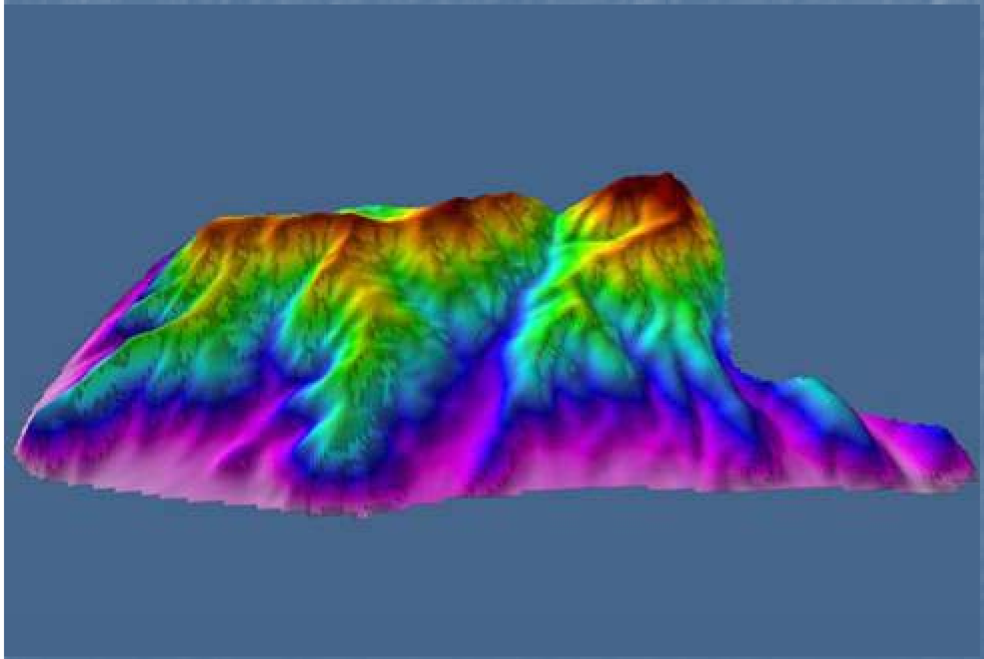
- Unit weight of soil: $\gamma =$ 17-22 kN/m^3

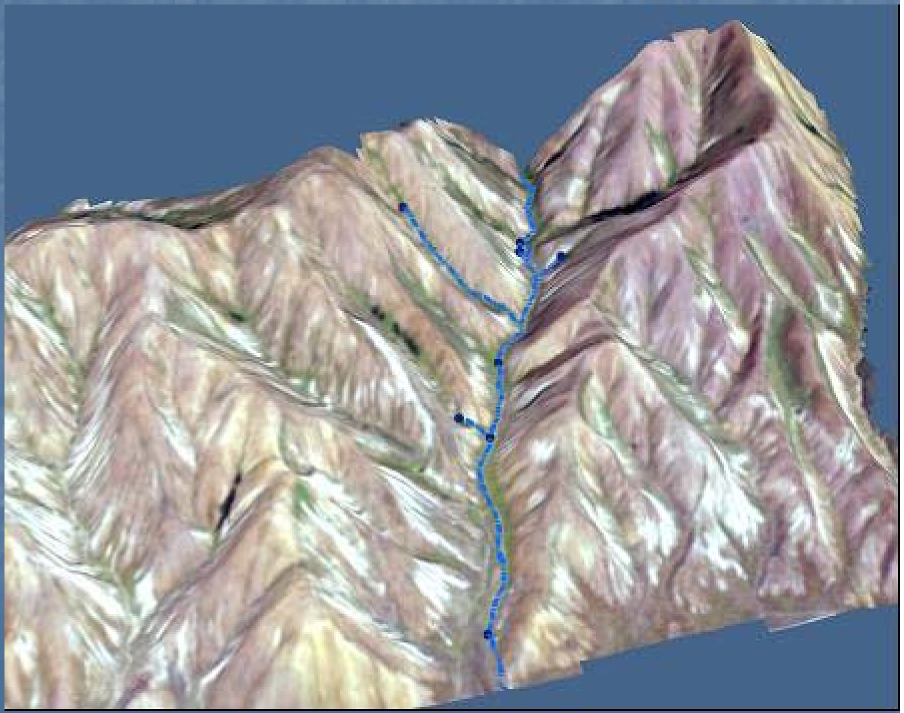
- Depth of Soil: z= 1-2 m (assumed)

- Cohesion
  - Cs = 0 Pa (Cohesionless soil) – based on field observations
  - Cr = 0 & 20 Pa (root strength) - From Wawer & Nowocien (1998)
    - Reflects vegetated conditions

Data Utilized

- USGS 20m DEM
- Debris Flow Channel Centerline and Initiation Points
  - Delineated from DOQQ
  - Validated with Trimble Geo XT





Methodology

- Initial calculations from DEM
  - Pit-filled DEM (20-m)
  - Flow Direction
  - Slope
  - Contributing Area
  - Contours (10-m interval)
- Additional calculations
  - q/T (discharge over transmissivity) calculated based on above calculations
    - Discharge (q) rain minus evaporation
    - Transmissivity – The grounds subsurface ability to convey water downslope
- Calculations of Chronic Instability for different scenarios based on:
  - Physical properties
  - Geotechnical properties of soil & slope

SHALSTAB Modeling Based on Assumptions

- Depth of Soil
- Physical and shear strength parameters accepted in certain ranges

- SHALSTAB simulates only shallow debris flow initiation and is not applicable to deep-seated landslides
- In our study various scenarios are tested & modeled in order to obtain a generalized assessment of study area based on input parameters

8 Scenarios tested based on:

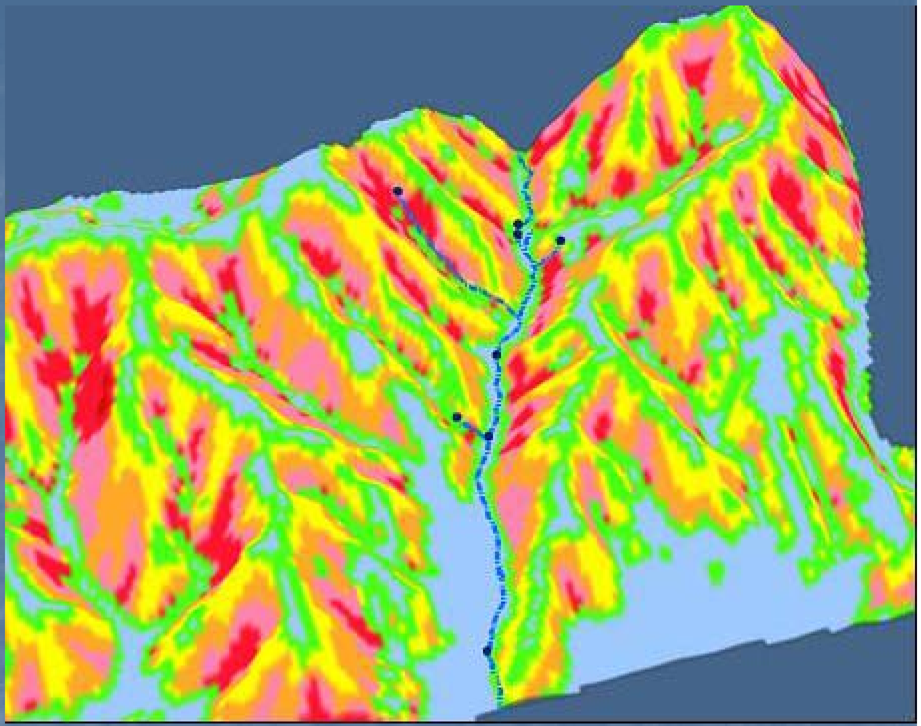
- Internal Friction Angle (ϕ)
  - 35-50 degrees – change because observed material is not homogeneous
- Depth of Soil (z)
  - 1-2 m.
- Unit weight of soil (γ)
  - 17-22 kN/m^3
- Cohesion
  - 0 Pa (cohesionless)
  - 20 Pa (root cohesion)

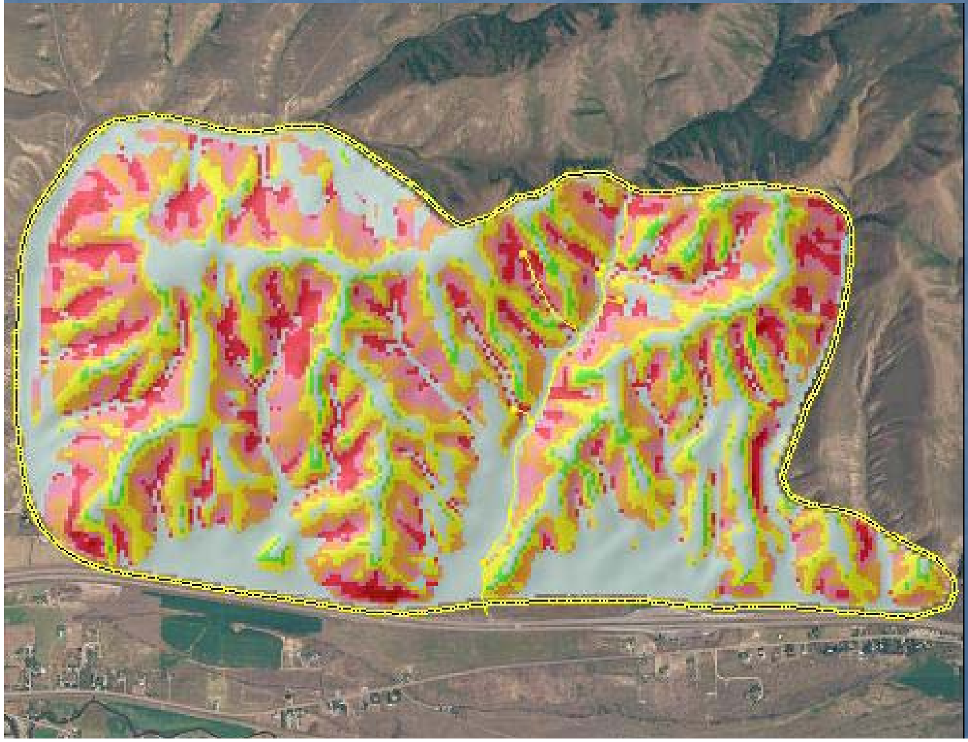
Scenario 1

- $\Phi = 35$
- $\gamma = 17\ kN/m^3$
- Soil Depth = 1m
- Cr = 20 Pa

Debris Flow initiation points are within critically analyzed areas

>Failure





Q/T

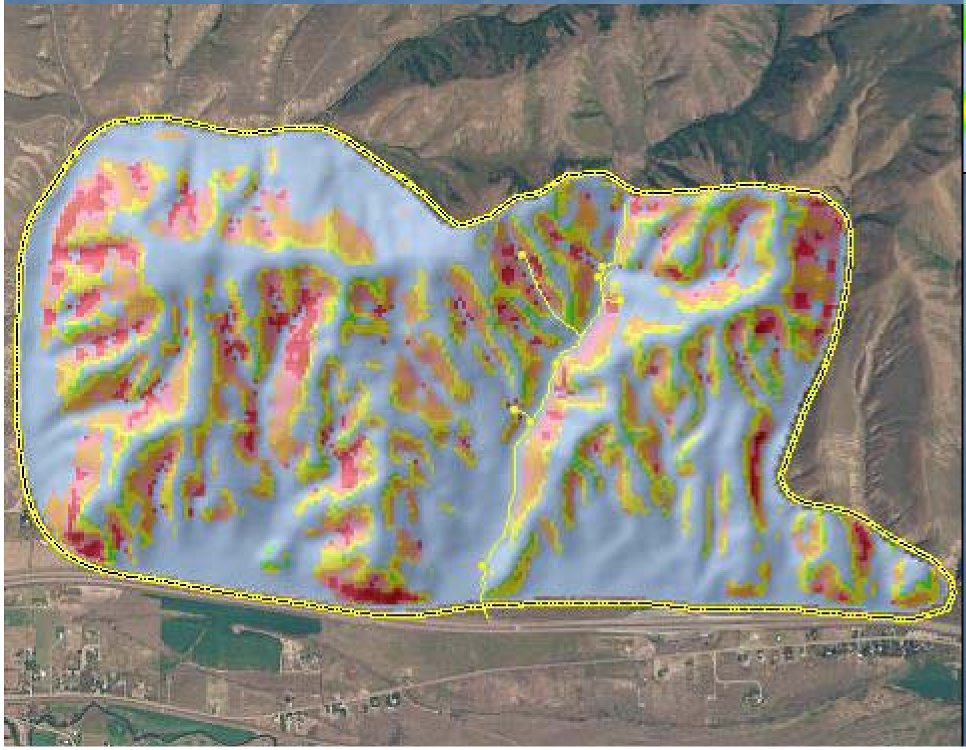
- Chronic Instability
- -9.9 - -3.1
- -3.1- -2.8
- -2.8 - -2.5
- -2.5 - -2.2
- > 2.2
- Stable

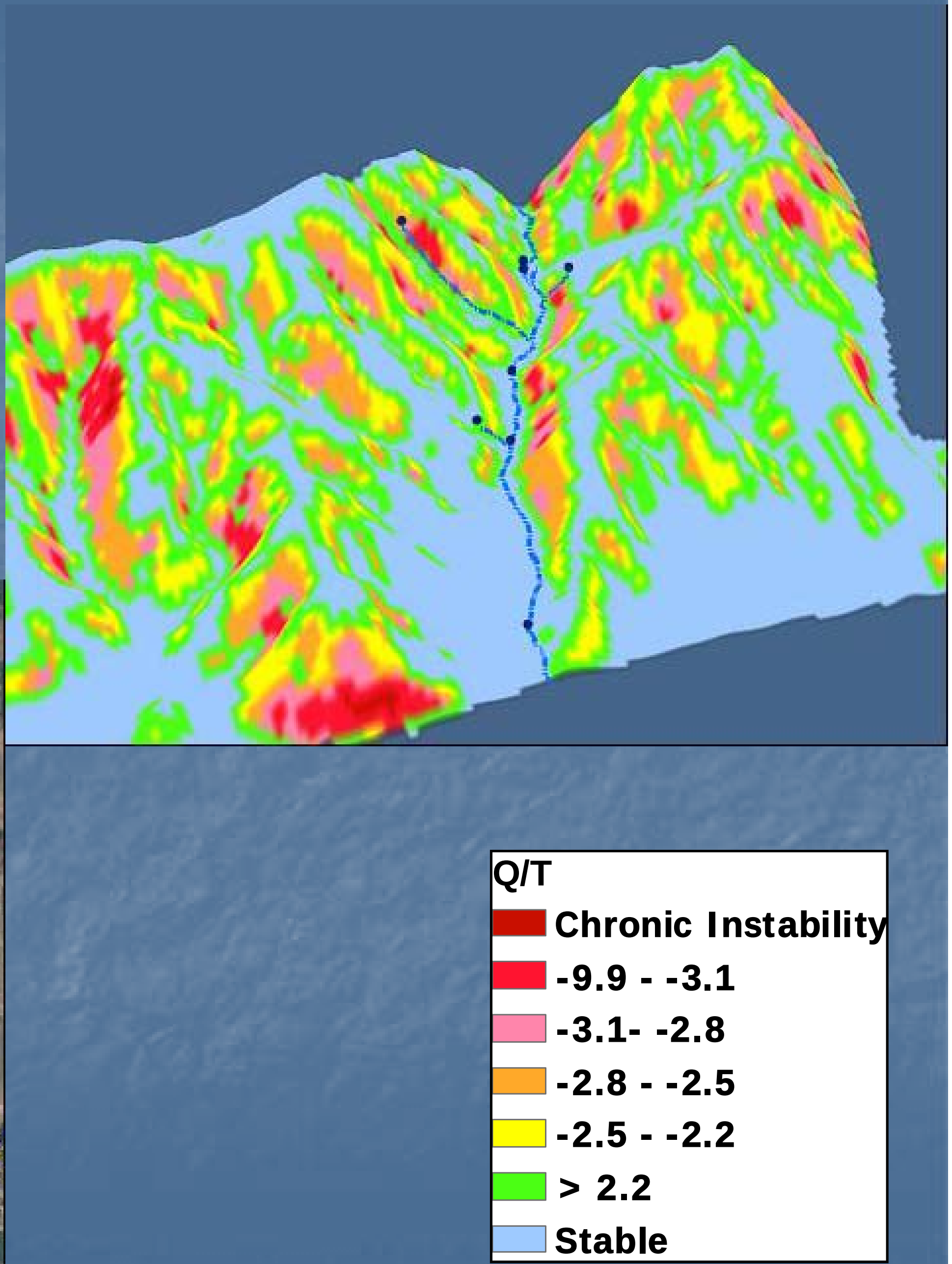
Scenario 2

- Φ = 35
- γ = 22 kN/m^3
- Soil Depth = 1m
- Cr = 20 Pa

Debris Flow initiation points are within critically analyzed areas

>Failure



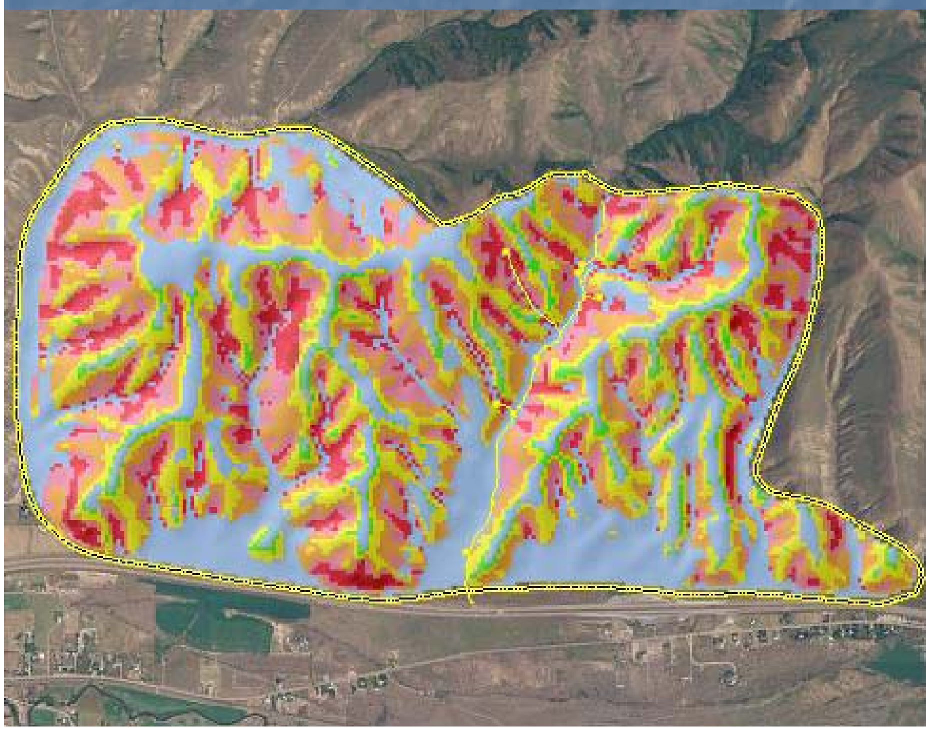


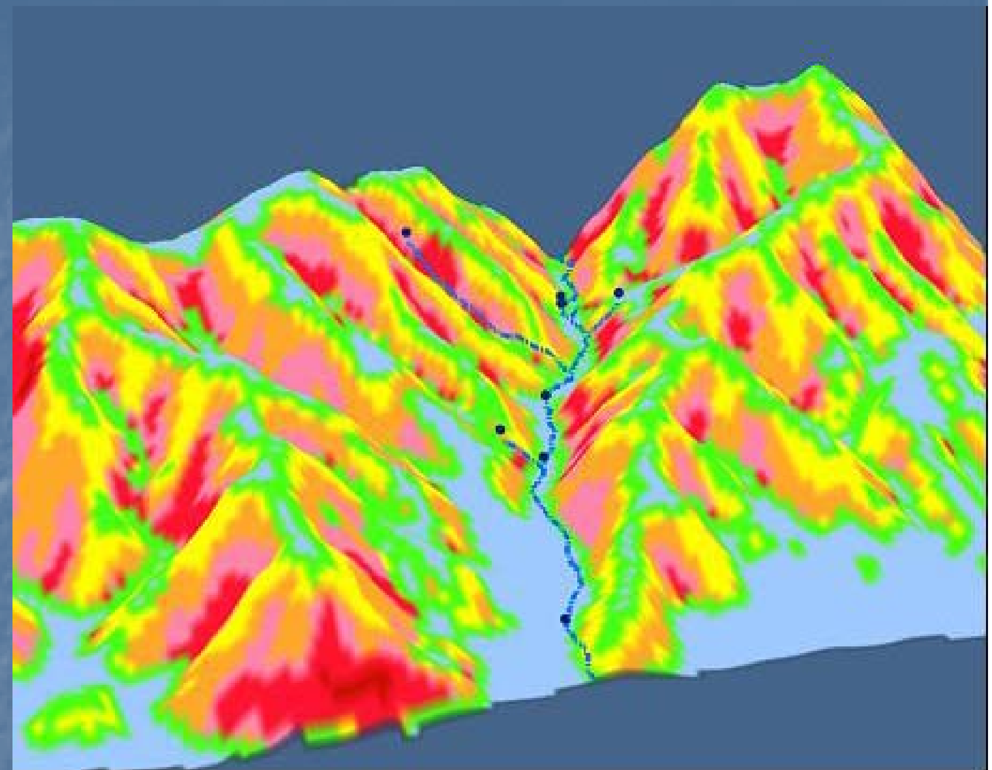
Scenario 3

- Φ = 35
- γ = 17 kN/m^3
- Soil Depth = 2m
- Cr = 20 Pa

Debris Flow initiation points are within critically analyzed areas

>Failure

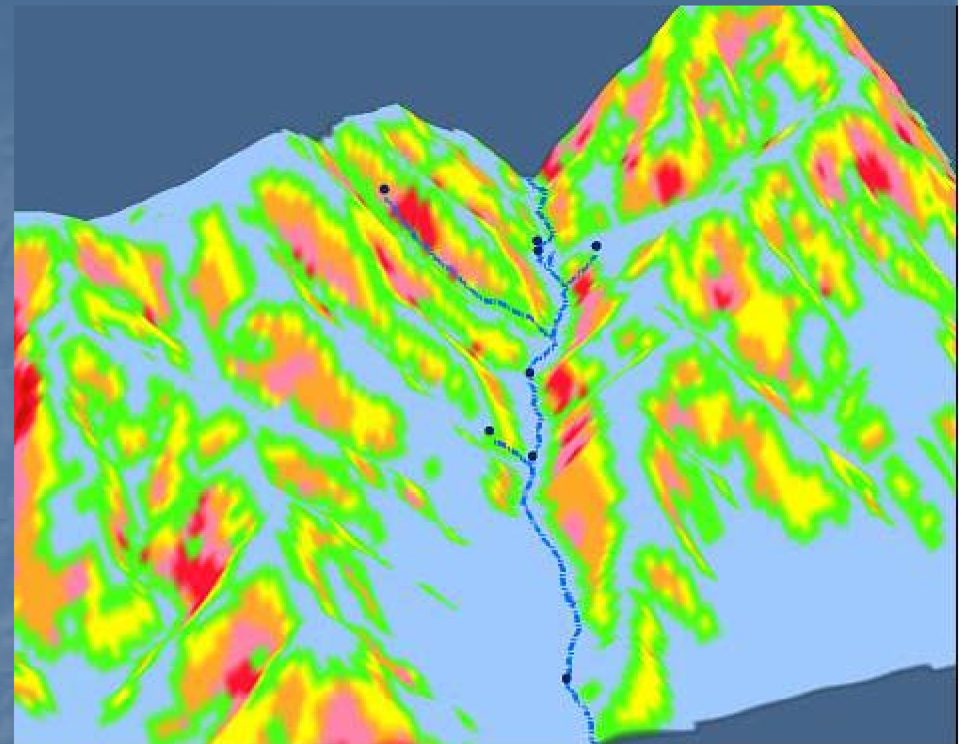


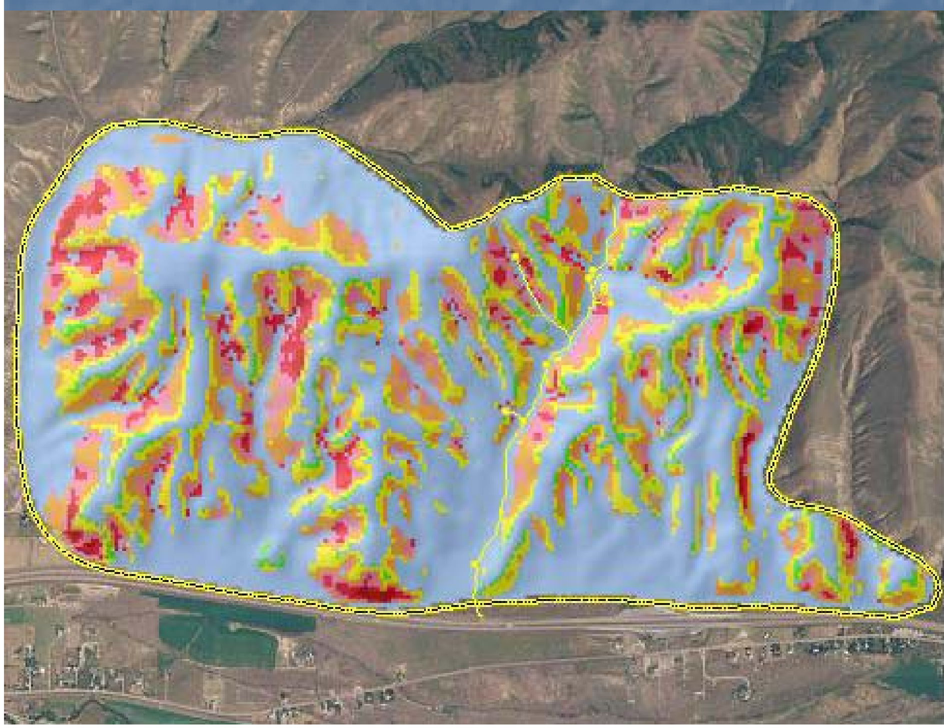


Scenario 4

- $\Phi = 35$
- γ = 22 kN/m^3
- Soil Depth = 2m
- Cr = 20 Pa

Debris Flow initiation points are within critically analyzed areas
>Failure



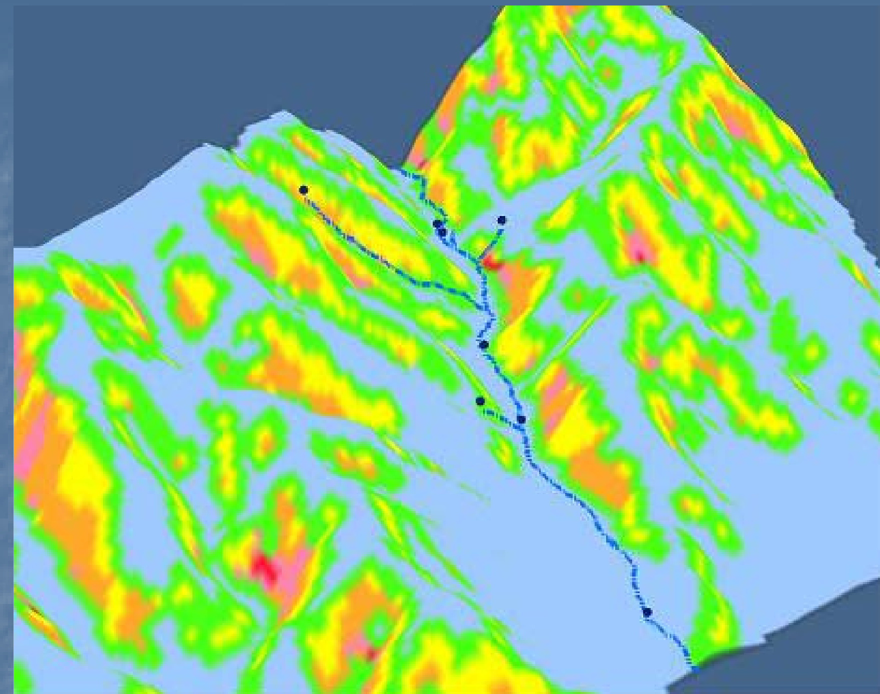


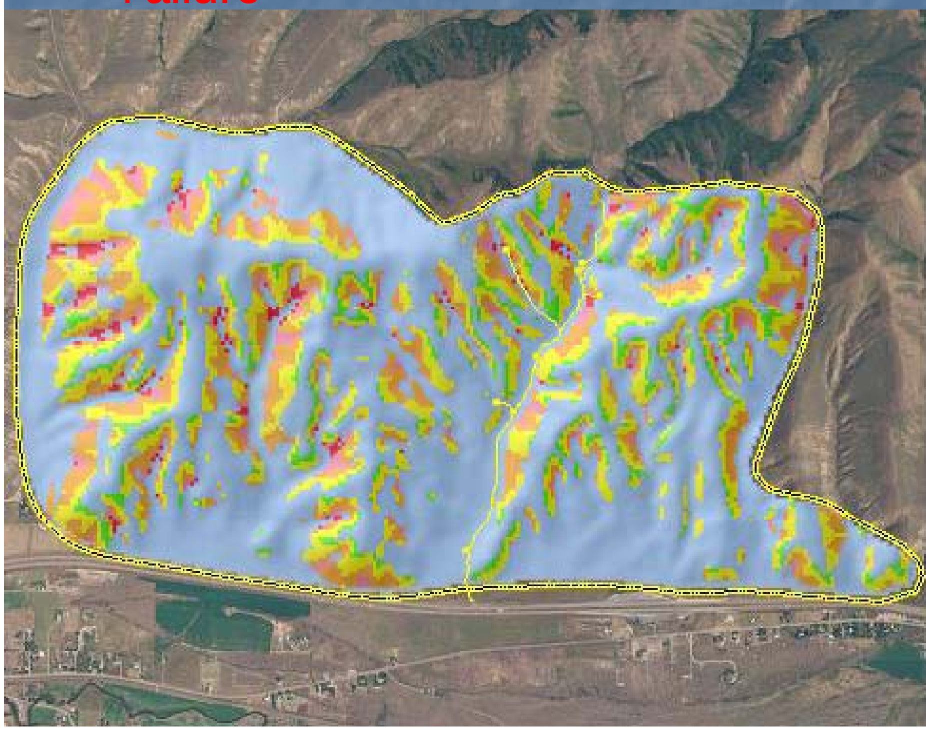
Q/T
- Chronic Instability
- -9.9 - -3.1
- -3.1- -2.8
- -2.8 - -2.5
- -2.5 - -2.2
- > 2.2
- Stable

Scenario 5

- $\Phi = 45$
- $\gamma = 17$ kN/m^3
- Soil Depth = Not Needed
- Cr = Not Applied

Debris Flow initiation points are within critically analyzed areas >Failure





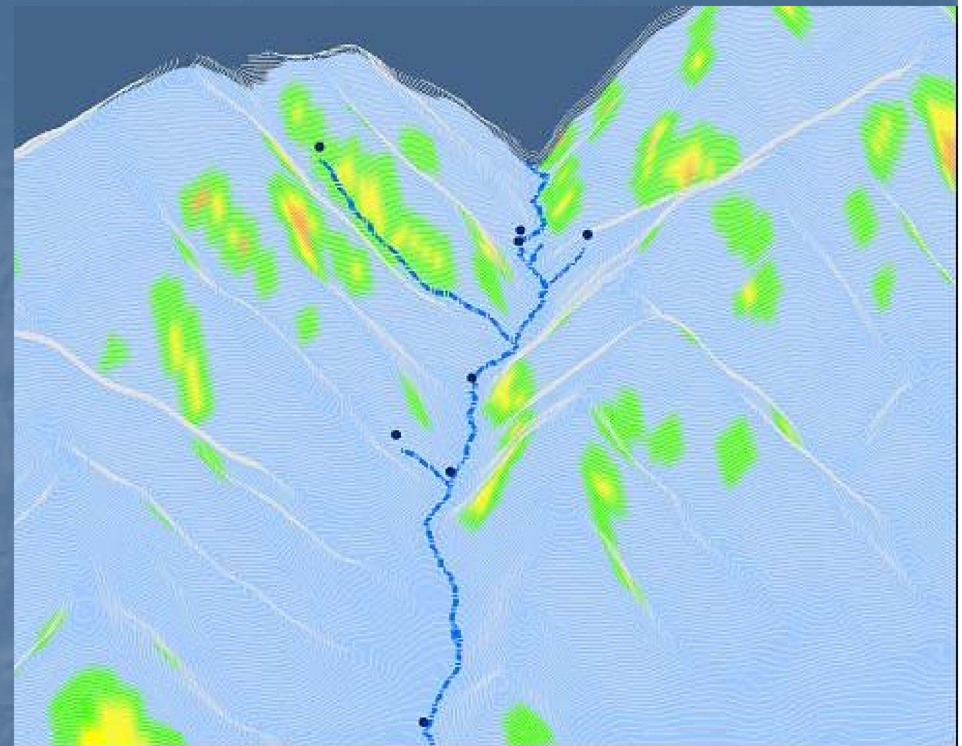
Q/T
- Chronic Instability
- -9.9 - -3.1
- -3.1- -2.8
- -2.8 - -2.5
- -2.5 - -2.2
- > 2.2
- Stable

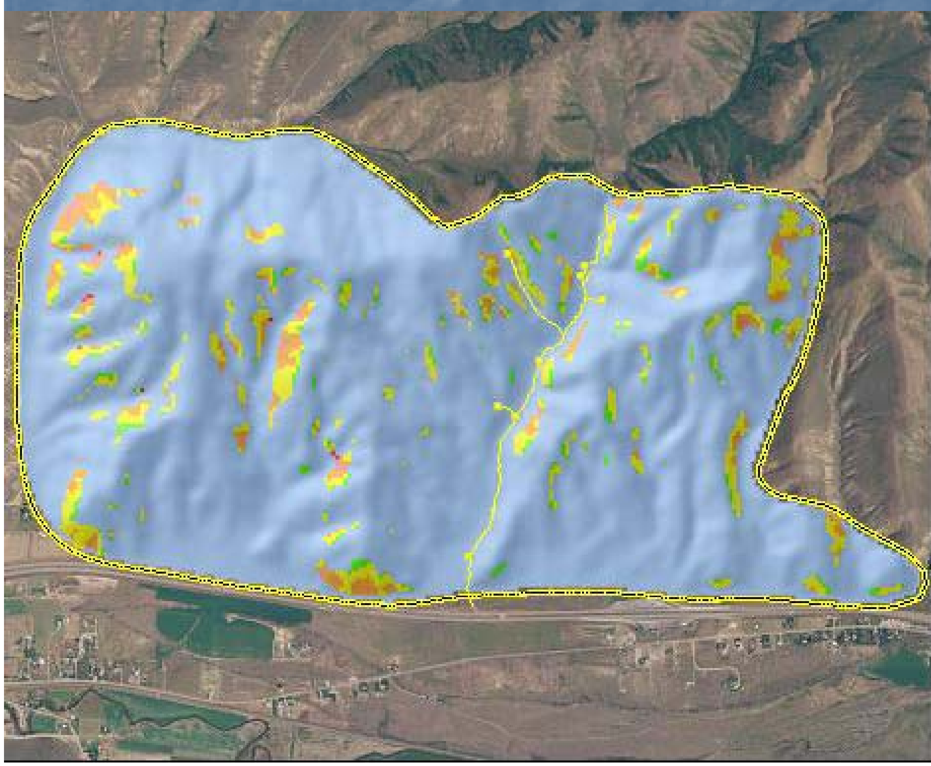
Scenario 6

- $\Phi = 45$
- $\gamma = 22\ kN/m^3$
- Soil Depth = Not Needed
- Cr = Not Applied

*Initiation not in Critical Zone

>No Failure





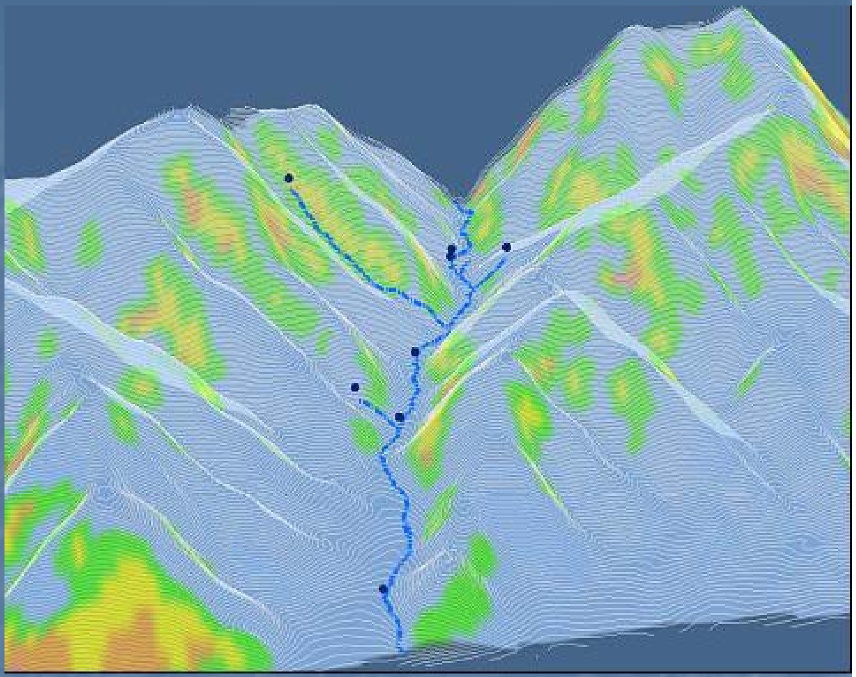
Q/T
- Chronic Instability
- -9.9 - -3.1
- -3.1- -2.8
- -2.8 - -2.5
- -2.5 - -2.2
- > 2.2
- Stable

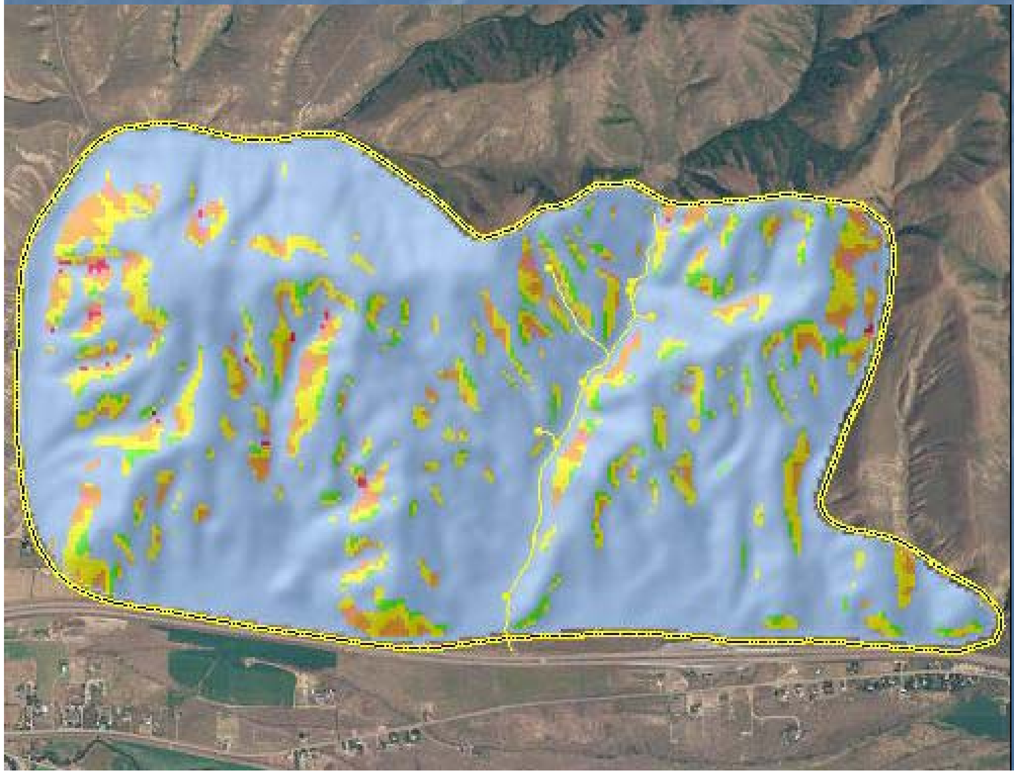
Scenario 7

- $\Phi = 50$
- $\gamma = 17\ kN/m^3$
- Soil Depth = Not Needed
- Cr = Not Applied

*Initiation not in Critical Zone

>No Failure



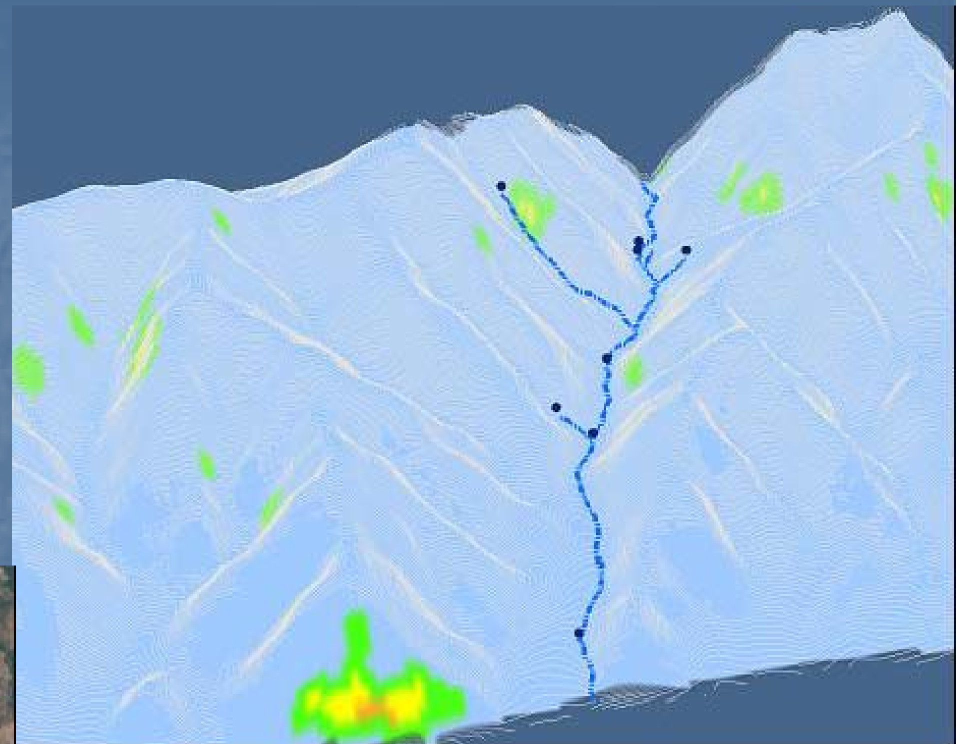


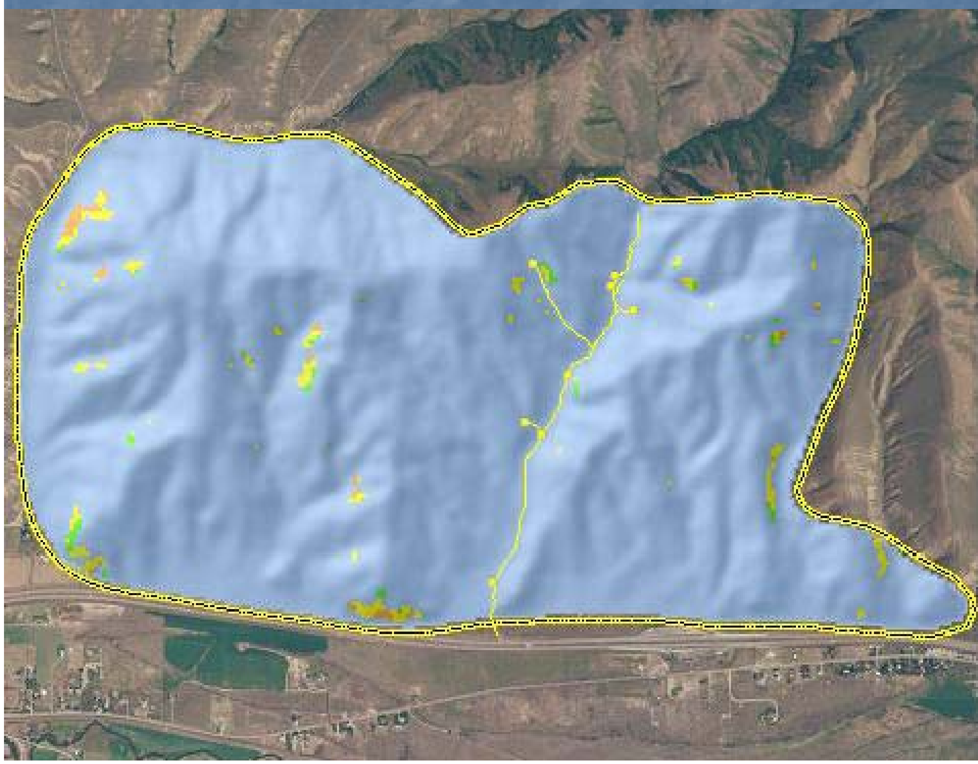
Scenario 8

- $\Phi = 50$
- $\gamma = 22$ kN/m^3
- Soil Depth = Not Needed
- Cr = Not Applied

*Initiation not in Critical Zone

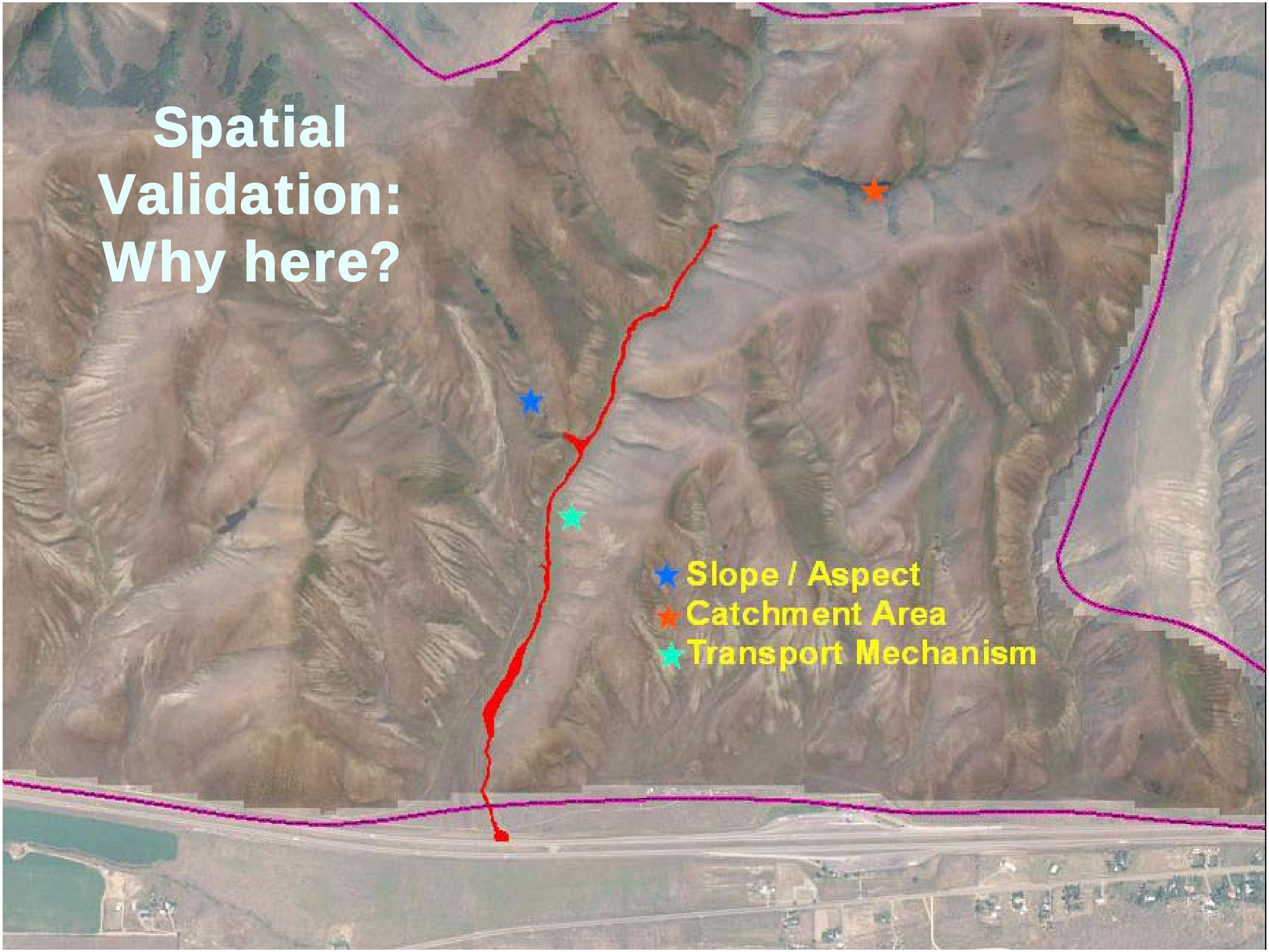
>No Failure





Q/T

- Chronic Instability
- -9.9 - -3.1
- -3.1- -2.8
- -2.8 - -2.5
- -2.5 - -2.2
- > 2.2
- Stable


Spatial
Validation:
Why here?
Slope / Aspect
Catchment Area
Transport Mechanism

Temporal Validation:
Why at this date?

August	Avg Temp	Precip.
1-Aug	81.0	0.00
2-Aug	77.5	**0.11**
3-Aug	69.0	**0.13**
4-Aug	70.5	0.00
5-Aug	72.0	T
6-Aug	73.0	0.00
7-Aug	74.5	0.00
8-Aug	74.0	0.00
9-Aug	76.0	0.00
10-Aug	77.0	0.00
11-Aug	82.0	0.00
12-Aug	73.5	0.00
13-Aug	79.5	0.00
14-Aug	77.5	0.00
15-Aug	81.5	0.04

Precipitation – significant amount recorded for day of sedimentation event, indicating saturation

Temperature – a factor in soil mechanics because of freezing and thawing, however, not a factor in August

Results & Conclusions

Scenario	Internal Friction Angle ϕ	Unit Weight of Soil γ	Soil Depth z	Root Cohesion Cr	Soil Cohesion Cs	Result
Scenario 1	35	17	1	20	0	Failure
Scenario 2	35	22	1	20	0	Failure
Scenario 3	35	17	2	20	0	Failure
Scenario 4	35	22	2	20	0	Failure
Scenario 5	45	17	N/A	N/A	0	Failure
Scenario 6	45	22	N/A	N/A	0	No Failure
Scenario 7	50	17	N/A	N/A	0	No Failure
Scenario 8	50	22	N/A	N/A	0	No Failure

Inferences in data:

- As Φ increases, chance of failure decreases
- Root Cohesion (Cr) not a factor (20 Pa very low value)
- Most important factor: ϕ
- Assuming soil-saturation, Study area was most stable with high ϕ

Results & Conclusions

- Debris flow not strictly a result of wildfire effects
- Combination of parameters led to debris flow:
  - Increased runoff and sedimentation due to Water-repellant layers – assumption (not tested)
  - Intense rainfall enough to mobilize debris flow
- In-situ verifications can assist in mechanism determination, most importantly Shear Strength
  - Infiltration Capacity
  - Erodibility

Results & Conclusions

- Densely vegetated, subsequently burned slopes are assumed most likely to fail following fire
- Sparsely vegetated, moderately burned slopes are assumed less likely to fail following fire
    - ***Burn-Severity – Debris Flow Initiation Relationships are in need of research.***

Thank You, Questions?

Thanks to:

GIS Center Staff

Geosciences Faculty

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Consultant Extraordinaire