Missionary Ridge
Rockfall Study

J. Andrew Gleason/ David L. Trautner
Debris Flow reaches CR 250 on March 1, 2008
• Potential for Debris Flow to reach CR 250 in different location than past road hits. Debris could reach road to the north or south of existing channel.
• Alluvial Fan/Debris Fan morphology example.
Analysis

- **Laboratory tests**
  - Permeability tests
  - Void Ratio (S.G.) tests
  - Sieve/Atterberg tests

- **Landslide Analysis**
  - SLOPE/W slope stability analysis
  - Climate data

- **Rockfall Analysis**
  - CRSP (Colorado Rockfall Simulation Program)
Test Pit Locations

TP-1
TP-2
TP-5
TP-7
TP-8
TP-6
TP-9
TP-10
TP-3
TP-4 in lower debris flow channel
Soil Test Results

- Sieve Atterberg test results
- Sandy Clays with gravel
Laboratory Analysis

- Falling Head Permeability test results:
  - Test Pit 5- Clay $4.13 \times 10^{-4}$ cm/sec
  - Test Pit 6- Sandy Clay $5.31 \times 10^{-5}$ cm/sec
  - Test Pit 9- Sandy Clay $5.99 \times 10^{-4}$ cm/sec

It would take about 17 days for water to go 20’ into soil without any large voids.

Presence of Voids decreases this time to about 3-5 days

About 1 inch of water to fully saturate 20’ of soil, assuming a tributary area 10 times the slide mass area

- Void ratios:
  - Test Pit 6- 0.73
  - Test Pit 9- 0.76
  - Test Pit 10- 0.76
DURANGO WATER RESOURCES, COLORADO (052441)


Precipitation Probability in a 1-day period

Probability (%)

Jan 1   Feb 1   Mar 1   Apr 1   May 1   Jun 1   Jul 1   Aug 1   Sep 1   Oct 1   Nov 1   Dec 1

Day of Year

Quantity
- 0.01"  - 0.10"  - 0.25"  - 0.50"  - 1.00"  - 1.50"  - 2.00"  - 2.50"

Probability of indicated precipitation quantity in a 1-day period starting on the plotted date. Smoothed with a 29-day running mean filter.

Data from Desert Research Institute / WRCC
CRSP Analysis

Colorado Rockfall Simulation Program
## CRSP Analysis 5’ spherical rock

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CRSP Analysis 10’ spherical rock

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Conclusion: Rockfall highly unlikely to reach CR 250

Note: Rocks will still reach CR 250 via debris flow and from rockfall in other areas
Landslide Analysis
Slope Stability Analysis

- Factor of safety: ratio of driving forces to resisting forces
- Less than 1 unstable and moving
- Greater than 1 conditionally stable

- Looking for theoretical FOS of 1.3 for roads, 1.5 for residences
Slope stability analysis pre-landslide.

Theoretical Short-term Factor of safety 0.47
Slope stability analysis post-landslide, dry; no water. Theoretical Short-term Factor of safety 0.8

1.25 X Vertical Exaggeration
Slope stability analysis post-landslide, with water. Theoretical Short-term Factor of safety 0.54
Conclusions and Recommendations

- **Landslide**: Upper rockmass between the 2 scarps is moving and has potential to mobilize during wet conditions.
  - Rainfall event during snowmelt of 0.8 inches/hour
  - Rainfall event after ~ 3 to 5 days of steady rain.
  - Intense rain storm of 1.3 inches/hour for one hour
  - Snowmelt for 17 consecutive days
Conclusions and Recommendations

- **Debris Flow** - Source areas below 2nd scarp, and below “narrrows”. This has highest hazard for CR 250.
  - Events that have reached the road this year are relatively small compared to potential events.
  - Debris Flow discharge hazard similar to post-fire conditions for similar sized basin. Initial Debris flow at ~0.8 inches in 1 hour storm.
Recommendations

- **Monitoring Systems**
  - Used to analyze movement of rocks and debris over time to understand which parts are moving and how fast.

- **Warning Systems**
  - Used to warn public and homeowners of impending hazards.

- **Mitigation**
  - Remove part of water flowing into upper landslide
Potential Monitoring Devices

- **Survey Prisms** - An optical prism that is used for surveying by precisely reflecting a laser beam back to a survey instrument, called a Total Station.

- **Cable Extensometers** - Instruments that measure the increase in distance between two fixed points.

- **Laser Extensometers**
Potential Monitoring Devices

- **Fixed or Manual Inclinometers** - Inclinometer tools can precisely measure the change in deflection or tilt of a casing pipe, installed and cemented into a drill hole that extends through the landslide deposit.

- **Piezometers** - tools that read water pressures and ground water elevations within a drill hole.
DeBeque Landslide vector movements at prism locations
from August 1999 to January 2006

Vector Scale
- 6 inches
- Sheared inclinometer
Potential Warning Systems

- Advance Warning systems
  - Rain gauges

- Event Warning systems-
  - Instruments that detect debris movement, See Table 2

- Post-event warning systems- instruments at roadway to detect debris on road.
  - See Table 2
Precipitation Stations in the Missionary Ridge Burn Area
<table>
<thead>
<tr>
<th>Sensors</th>
<th>Operation</th>
<th>Advantages</th>
<th>Limitations</th>
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<tbody>
<tr>
<td>Ultrasonic, radar and laser sensors.</td>
<td>Measurement of the flow stage.</td>
<td>Easy to set warning thresholds.</td>
<td>Ultrasonic sensors have to be hung over the channel; installation can prove difficult if the channel banks are unstable.</td>
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<tr>
<td>Geophones and seismometers.</td>
<td>Measurement of ground vibrations caused by debris flow.</td>
<td>Easy and safe installation (the sensors are buried in safe places on stream banks).</td>
<td>Setting warning thresholds can be quite complicated. Risk of false alarms due to other sources of ground vibration (passage of trains or trucks, rockfalls, etc.). The need to filter the signal may increase system complexity.</td>
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<tr>
<td>Pendulums.</td>
<td>Detection of the debris-flow from the tilting of the pendulum.</td>
<td>Simple and robust device.</td>
<td>The pendulum must be hung over the channel; installation can prove difficult if the channel banks are unstable.</td>
</tr>
<tr>
<td>Wire sensors.</td>
<td>Detection of the debris-flow from wire breaking.</td>
<td>Simple and robust device.</td>
<td>Need for restoration after activation. Risk of false alarms due to accidental circumstances (passage of animals, falling trees, etc.).</td>
</tr>
<tr>
<td>Photocells (infrared photobeams, etc.).</td>
<td>Detection of debris-flow passage.</td>
<td>Non-contact detectors: do not need restoration after activation.</td>
<td>A careful installation is needed to avoid having the sensors come into contact with the flow.</td>
</tr>
<tr>
<td>CCD camera for machine-vision detection.</td>
<td>Recognition of debris flows.</td>
<td>Safe installation (the camera can be placed beside the channel).</td>
<td>The presence of fog or the occurrence of debris flow at night may complicate the use of the system and its workability.</td>
</tr>
</tbody>
</table>
Potential Warning Systems

- Rockfall fence- Standard wire and T-Post fence with closed circuit connected to Telemetered Datalogger and Cell Phone alert. (Cost ~15-18k)

- Inclinometers connected to Telemetered Datalogger and Cell Phone alert. (Cost ~20-25k)
Figure 10. Sketch of the components of a debris-flow warning system.
Mitigation

• Divert water flowing from Dakota sandstone to the north of landslide.

• This reduces pore pressure on sliding layer.
Potential Problems:
- Water could reactivate a different part of landslide
- Only part of water input could be diverted
Recommendations

- Advanced Warning System- recommend rain gauge
  - Longer warning time
  - Works for other debris flows on CR 250
  - Fewer False alarms
  - Expensive

- Event Warning systems- Not currently recommended
  - Little warning time
  - False alarms
  - Expensive

- Monitoring Systems-
  - Useful for large events
  - Some are expensive

- Recommend Prisms with County Total Station
  - Monthly monitoring or after large rainfall events.
  - Prisms ~$200 each. Will need ~ 10 prisms

- Mitigation- possible but due to potential problems needs further study
  - Divert spring on north side further north around main mass of landslide
  - Potential problems include activating other parts of the landslide

- Public Awareness Campaign
  - Wet periods are more hazardous
  - Similar to Post-Fire debris flows
Hazard During Wet Periods

- Steady Rain for ~ 3 to 5 days
- Intense Rain for 1.3 inches/hour for one hour
- Snowmelt for 17 consecutive days

- Rain event of ~ 0.8 inches/hour or greater during or after snowmelt is most dangerous situation!

- Note: These are estimates based on the slope-area method for determination of peak discharge estimates, which is generally not assumed to be applicable to non-Newtonian debris flows.
Prism Pros and Cons

- **Survey Prisms- Advantages:**
  - Relatively inexpensive
  - Can detect rockfall and landslide movement
  - Useful for long-term monitoring

- **Disadvantages:**
  - Not as good for short term monitoring
  - Requires continued commitment from county surveyor
  - Will detect debris flow movement only if large rocks are entrained
Potential Prism Locations

2008
Wish list with more funding

- Early warning systems - Rain gauge with telemetered cell phone alert
- Debris Flow warning system - Pendulum or camera with cell phone alert
- Wire sensor - across lower part of channel to alert county crews to debris flows on road (high maintenance requirements)
Potential sources of funding

- GOCO grant
- USGS
- National Weather Service Flash Flood Monitoring and Prediction (FFMP) system
- Colorado Geological Survey - In house funding