DEVELOPMENT OF A LANDSLIDE HAZARD MAPPING PROJECT IN PAGE COUNTY, VIRGINIA: PRELIMINARY RESULTS AND METHODS

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• Project is funded by FEMA through a VDEM managed hazard mitigation grant

• Part of this funding also supports research and field work by JMU faculty and students to estimate volume in colluvial hollows
General Page County Stats

Elevation:
- Max: 4032 ft
- Min: 560.6 ft

Slope:
- Maximum: 85.6°
- Mean: 12.6°
- SD: 9.4°

Size of County: 314 mi²

Population: 24,042

* No known or recorded modern landslides before completion of the project *
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Bedrock Geology (Southworth et al, 2009)

Valley and Ridge

Blue Ridge
1949: 500 Landslides, Precip: 15 in/24 hrs

1955: 584 Landslides, Precip: 30 in/14 hrs

1969: 3724 Landslides, Precip: 27 in/8 hrs
Page County Landslide Hazard Mapping - Deliverables

1. Slope Movement/Slope Movement Deposits Map and Inventory

2. Landslide Susceptibility Modeling and Map(s)
   - Show areas susceptible to rapid LS initiation during heavy rainfall
   - Will focus on critical facilities and infrastructure
   - Help guide informed development and emergency management decisions

*Completion Date of August 31, 2013*
File Geodatabase:

- Processes (Landslide Points)
- Deposits (Ancient landslide polygons)
- Landslide Tracks
- Air Photo Points
- Field Notes
- Related Tables – Rock/Soil/Geologic Data
Total # LS in Database as of 7/18/2013: 4817

LS Type: Debris Flow/Slide

Mean Slope at Headscarp: 27°
9 Modern Landslides in Page County

- Type: Weathered Rx Slides; Debris Flows; Debris Slides
- Slope: Min – 15°
  Max – 80°
  *Mean - 32°
- All on “natural” slopes
- 7 of 9 occurred in Blue Ridge
- 6 initiated at the base of geologic contacts
Map Production

- Phase I: Field Work Preparation
  - Aerial Photography Interpretation
  - DTM LS Deposit Interpretation
- Phase II: Field Reconnaissance
  - Adjust Interpreted Data
- Phase III: Slope Stability Modeling
  - SINMAP – Where landslides may start
- Phase IV: Hydrologic Flow Routing
  - Debris Flow Pathways – Where landslides may go
- Phase V: Finalize GIS Map Deliverables
Aerial Photography Interpretation

- 60 Potential landslides identified for further field investigation
- 42 visited; 4 were landslides
- Interpretation done at 1:6,000

Air Photo Point

1998 Infrared DOQQ
Sometimes aerial photography interpretation worked great!
Massanutten:
- Martinsburg shale (Om)
- Devonian/Silurian shale, mudstone, siltstone (DSu)

Blue Ridge:
- Harpers Fm – phyllite (Cch)

Looking downhill from interpreted “headscarp” in the Martinsburg shale (Om)
Landslide Deposit Interpretation

- Identified using DTM data (10 ft resolution), 5 ft contours and aerial photography
- Interpretation done at 1:6,000
- 400+ Polygons in Database
- Mostly ancient debris fan deposits – accumulations of coarse boulder-to-sand sized colluvial particles
3 Types of Deposits

Talus

- Identified using ONLY aerial photography
- Must be able to see patches of bare rock at 1:6,000
- Primarily a maintenance/construction hazard
3 Types of Deposits - Block Streams

- Identified using a combination of aerial photography and DTM
- Some are highly dissected by modern stream channels
- Moderate hazard if remobilized
3 Types of Deposits

Colluvium

Undifferentiated

- Identified ONLY using DTM and contours
- Accumulations of subangular -to- subrounded boulder-to-cobble size fragments in a finer-grained matrix
- Upper reaches may include boulder streams/talus
- Considered moderate hazard

DTM with slope overlay; Index Contour = 100ft
Ancient Deposits (Qd3 and Qd4) Not Mapped

- Thin veneer (~1 ft) of rounded quartzite cobbles-to-boulders
- Red/brown soils with “ghost clasts”
- Higher clay % than younger deposits

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Ancient Deposits (Qd3 and Qd4)
Not Mapped

Massanutten
- Rounded quartzite cobbles-to-boulders (where visible)
- Flatter topography
- Sometimes perched on higher hilltops
Blue Ridge

- Rounded cobbles-to-boulders of various lithologies in a chaotic matrix
- Little surface expression
- Soil rubification
Hike Miles Traversed: 154 mi
Road Miles Traversed: 110 mi
# Field Notes collected DGMR: 1408
# Field Notes collected JMU: 292
• GIS model that shows where debris flows may start
• Based on modified infinite slope stability equation
• > 5 inches of rainfall in 24 hours
• only for unmodified or “natural slopes”

(SINMAP (Stability Index MAPping))¹

¹Pack et al., 1998
Upper and Lower Bounding Parameter Values:

- Soil Friction Angle ($\phi$)
- Soil Cohesion ($C_s$)
- Root Cohesion ($C_r$)
- Soil Hydraulic Conductivity ($K_{sat}$)

Parameters Derived from:

- Soil Testing (9 field sites)
- USDA-NRCS Soil Mapping
- County Water Well Logs
- Level I Stability Analysis (LISA) Manual; Hammond et al., 1992
# Stability Index Map Zones and Rankings

<table>
<thead>
<tr>
<th>Map Color Code</th>
<th>Predicted Stability Zone</th>
<th>Relative Debris/Earth Flow/Slide Hazard Ranking</th>
<th>Stability Index Range</th>
<th>Factor of Safety (FS)</th>
<th>Probability of Instability</th>
<th>Predicted Stability With Parameter Ranges Used in Analysis</th>
<th>Possible Influence of Stabilizing or Destabilizing Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstable</td>
<td>High</td>
<td>0 - 0.5</td>
<td>Maximum FS &lt;1</td>
<td>100%</td>
<td>Range cannot model stability</td>
<td>Stabilizing factors required for stability</td>
<td></td>
</tr>
<tr>
<td>Upper Threshold of Instability</td>
<td>Moderate</td>
<td>0.5 - 1</td>
<td>&gt;50% of FS ≤1</td>
<td>&gt;50%</td>
<td>Optimistic half of range required for stability</td>
<td>Stabilizing factors may be responsible for stability</td>
<td></td>
</tr>
<tr>
<td>Lower Threshold of Instability</td>
<td></td>
<td>1 - 1.25</td>
<td>Minimum FS = 1</td>
<td></td>
<td></td>
<td>Cannot model instability with most conservative parameters specified</td>
<td>Minor destabilizing factors could lead to instability</td>
</tr>
<tr>
<td>Nominally Stable</td>
<td>Low</td>
<td>1.25 - 1.5</td>
<td>Minimum FS = 1.25</td>
<td></td>
<td></td>
<td>Cannot model instability with most conservative parameters specified</td>
<td>Moderate destabilizing factors are required for instability</td>
</tr>
<tr>
<td>Moderately Stable</td>
<td></td>
<td>&gt;1.5</td>
<td>Minimum FS = 1.5</td>
<td></td>
<td></td>
<td>Cannot model instability with most conservative parameters specified</td>
<td>Significant destabilizing factors are required for instability</td>
</tr>
</tbody>
</table>
SINMAP Results

- County-wide Relative Hazard
  - High: 11.2%
  - Moderate: 13.9%
  - Low: 78.8%

- All landslides fall into medium or high relative hazard areas
Debris Flow Pathways

Methodology

• Hydrologic flow paths generated from high hazard SINMAP zones using the DEM
• Flow paths buffered to 65 ft (20 m) wide
• Flow paths terminated:
  • At slopes of 3 degrees in areas > 0.25 acres
  • When they encounter the 500-year floodplain
  • When they encounter mapped impoundments >0.25 acres
  • At bases of cut slopes

Mapped debris flow pathways
Potential debris flow pathways
Past debris flow activity (deposits)
No known past or potential debris flow activity
Mapped debris flow pathways

Potential debris flow pathways (from SINMAP)

Past debris flow activity (deposits)

No known past or potential debris flow activity

Relative Hazard:
- Increasing
- Decreasing

Debris Flow Pathways Map
Further Work

- Complete LS Hazard Modeling
- Final Delivery to Page County – Summer 2013
- Field Review – Fall 2013
- Debris Flow Volumetric Analysis – JMU Research
Thanks!

Grant Support: FEMA – VDEM

From JMU: Dr. Scott Eaton Billy Cheung Steve Stone

From UNCW: Dr. Michael Smith

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DTM with slope overlay
Basic Field Work Stats

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STABILITY INDEX MAPPING¹ (SINMAP) INPUT PARAMETERS

Modified Infinite Slope Equation
Slope parallel seepage  Steady-state shallow groundwater flow

\[
FS = \frac{C + \cos \theta \left[ 1 - \min \left( \frac{R}{T \sin \theta} \frac{a}{r}, 1 \right) r \right] \tan \phi}{\sin \theta}
\]

\(C = \) dimensionless cohesion
\(a = \) catchment area
\(R = \) recharge
\(T = \) transmissivity
\(\theta = \) slope
\(\phi = \) soil friction angle

¹Pack, Tarboton, Goodwin, 1998