Good evening. I am Malcolm Cameron and I live in Mt. Crawford, Va. My background includes a Bachelors in Geology and 23 years as an Environmental Engineer at Staunton District of VDOT. I monitored all VDOT construction for environmental compliance in the Shenandoah Valley. I'm now engaged in analyzing studies of slope failure potential along the Atlantic Coast Pipeline route.

There is significant risk from building a 42 inch pipeline across at least 15 steep mountain ridges. While at VDOT, I saw several slides close roads, including I-64. Landslides and debris flows have occurred on nearly 10,000 documented sites in the Blue Ridge and Alleghenies within a 50 mile radius of Staunton since 1949.Those are just the sites researched, and few studies exist west of the Blue Ridge.

We know the death and devastation from Hurricane Camille's landslides and debris flows in Nelson County in 1969. The nearly 3800 slides and debris flows extended an average 2500 feet downslope. This 2-day storm event dumped 26 inches of rain over much of Nelson Co., most falling during the night. Saturated soils and weathered bedrock, gave way, carrying trees and everything beneath as swift- flowing, liquefied masses while people slept. Camille also caused nearly 1600 slides and debris flows in Greenbrier Co., West Va. The slopes at both Camille locations averaged 33 degrees, but on the sedimentary rock in Greenbrier Co., slopes as flat as 17 degrees on forest land failed.

Other events ranged from a one-day cloudburst on Shenandoah and North Fork Mountains along the West Va. border in 1949 to isolated thunderstorms in 1995 on the Blue Ridge in Madison and Albemarle Counties. One debris flow in the 1949 event traveled 1.5 miles. The 1995 event on the Blue Ridge caused 690 debris flows from rainfall totals and intensities roughly one half as much as Camille.

The ACP route has many miles of terrain as steep as, or steeper than, the historic event sites. Rock formations, soils, slope angles, hydrology, and elevations and slope aspect are the same or very similar. These are the factors which hundreds of research studies since the 1960's have identified as contributing to slope failures worldwide.

One researcher I talked to at JMU described these steep slope as “loaded guns “.

Do we really want to risk the safety of people living at the base of these slopes or the quality of the waters we depend on for our livelihood and recreation?

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Debris Flows, Landslides and Other Slope Failures in the Blue Ridge and Alleghenies of West Va. and Virginia from 1949 to 2003
A Compilation and Summary of Studies

Compiled by Malcolm Cameron
January 22, 2015

Sources including: U.S. Geological Survey, Virginia Division of Geology and Mineral Resources, West Va. University & others

Critical Factors Contributing to Slope Failures

1. **Excessive Rainfall**: High rates of rainfall (inches/hour) are more critical than total rainfall for the storm event. Debris flows often began during rapid increases in the rate of rainfall. The Blue Ridge area studies yielded critical rainfall rates ranging from 20mm (0.8 in.) per hour for 24 hours to 180mm (7.1 in.) per hour for 1 hour. Antecedent rainfall events, which brought the soils closer to saturation before the storms, were important factors in at least 2 localities. Rainfall data is often scattered, making detailed plots of slide concentrations vs. localized rainfall difficult. Other factors such as surface material and bedrock types and slopes yielded differing results for the same rainfall.

2. **Elevated Terrain with Steep Slopes**: Most slide events occurred near the head of higher elevation drainage hollows with concave cross sections and relatively steep (greater than 20 degree) slopes. The higher terrains were more conducive to heavier precipitation. Slopes averaged about 30 degrees, varying from 19 to 34 degrees.

3. **Supply of Susceptible Surface Material**: The bedrock type and degree of weathering are key. Certain sedimentary bedrock slopes, such as shales in Pendleton Co., W.Va. have failed in rainfall events with 300 mm (11.8 in.) less rainfall than for similar events on the metagranitic rocks of the Virginia Blue Ridge. The depth and type of soils are a factor. Soils with high mica content and/or a higher percentage of large cobble-boulder cover from upslope sources are more susceptible to failure. Shales and intercalated thinly bedded shale and sandstones respond relatively easily to debris flow triggering. Quartzites and sandstones with a high degree of jointing were involved in a debris flow event in Buena Vista, Va. in 1995.

4. **Groundwater at or near the surface, i.e. permanent or seasonal seeps:** This impacts the pore pressure in the soils, decreasing shear strength of the soils by increasing buoyancy and capillary tension. It can also increase fracturing at the surface from repeated freeze/thaw cycles. Groundwater can lubricate the top of a buried impermeable clay layer, thus increasing the likelihood of rotational slip slope failures.

5. **Bedding or Fracture Planes Parallel to the Slope Surface:** This is most likely in sedimentary and some metamorphic bedrock types. This condition can result in friction along a bedding or joint fracture plane becoming less than the force of gravity, usually when a new fracture across the slope opens up, or the base of the slope is undercut by a river or construction with removal of material or overloading the slope with too much extra weight.

<u>Summary of Historical Events Studied</u>

Virginia Blue Ridge

Hurricane Camille, Aug. 19-20, 1969; Nelson Co., Va.

Max. Total Rainfall: 800mm; 31.5 inches
Measured Rainfall Range: 710-800mm; 28- 31.5 in.; 25-27 in. several locations
Rate: (generally over 8 hrs, 27/8= nearly 3.4 in/hr.
Bedrock: metagranite and granitic gneiss
Slopes: Ave. elev. 550m. (1800ft.); 32 degree ave.
No. & Size of Debris Flows: 3793 flows; average size 2500 X 49 ft.

Thunderstorms, June 27, 1995; Madison Co., Va.

Max. Total Rainfall: 770 mm; 30.3 in.
Measured Rainfall Range: not given, but antecedent rains, over 5 days preceding ranged from 75-170 mm; 3-6.7 in.
Rate: 14 hr. at most severe site: 30.3/14=2.16 in/hr.
Bedrock: weathered granitic and gneissic rock
Slopes: Avg. 1140 ft. elev.; Slopes avg 30+/- 3.7 degrees
No. & Size of Debris Flows: 629 flows;

Same Day, (June 27, 1995) different T-storm; Moorman's River area, Albemarle Co., Va.

Max Total Rainfall**:** 635mm (25 in. rain total)
Measured Range: 279-635 mm; 11 - 25 in.
Approx. Rate: 1.3 + in/hr.
Bedrock: metabasalt overlain by clay-rich saprolite
Slopes: 19 – 26 degrees
No. & Size of Debris Flows: 61 debris-slide scars, usually less than 300m long

Thunderstorms, June 27, 1995; Buena Vista, Va. (same event as prev.)

Max. Total Rainfall: 213mm; 8.4 in. estimate
Measured Rainfall Range: not given (Maury River had 3rd. largest flood of record since 1936)
Rate: not available
Bedrock: mainly Antietam quartzite, also conglomerate, phyllites, metasiltstone
Slopes: mainly greater than 28 degrees; 50 km.2 area of steep rugged terrain
No. & Size of Debris Slides/ Flows: 53 failures, no sizes given

Allegheny Mountains; West Virginia and Virginia

1 Day Cloudburst, June 17-18, 1949; Augusta Co. Va. & Pendleton Co. W. Va., Little River (Augusta & Rockingham Co.) ; North Fork Mtn. area Pendleton Co.

Max. Total Rainfall: 400mm; 15.75 in. N. Fork Mtn.
Measured Rainfall Range: not given
Rate: 15.75/24hr.= 0.65 in/hr. avg.
Bedrock: sandstone
Slopes: steep upper slopes, angles not given
No. of Slides/Flows: 466 total; N. Fk. Mtn.; **largest began 160 ft. below ridge crest & traveled 2.5 km.,** narrow: 12m wide at beginning; 43m wide at base

Hurricane Camille, August 19-20, 1969; Spring Creek, Greenbrier Co. W.Va.

Max Total Rainfall: 635mm; 25 in. over approx. 58km.\2
Measured Rainfall Range:
Rate: 25/8hr. = 3.12 in/hr.
Bedrock: sedimentary
Slopes: 35degree Ave.; min.: 17deg.-timbered; 19deg. – cleared /
No. of Slides: 1584, Range: 2 m.\3 to 24,369m.\3 removed

Remnants Hurricane Juan, 3-5 Nov. 1985; North Fork Mtn., Pendleton Co. W.Va. & Highland Co. Va.

Max. Total Rainfall: 240mm; 7.9inches in 48 hrs. +; 10-15+ in. over 3 days, mostly late on Nov. 3 & during the 4th
Measured Rainfall Range: 170-240mm. 6.7-9.5 in.; 100 yr. plus flood event in Potomac and Shenandoah Basins.
Rate: 6in/hr. during intense period
Bedrock: Various sedimentary, sandstone residuum & colluvium
Slope: not given
No. & size of slides: 3000+ slides, slide flows, or slump flows, **max. 2m. deep**

Hurricane Fran, September, 1996; __?__ (research in progress)

Max. Total Rainfall:
Measured Rainfall Range:
Rate:
Bedrock:
Slopes:

Hurricane Isabel, Sept 18-19, 2003; Shenandoah Valley, VA, no counties specified

Max. Total Rainfall: 513mm; 20.2 in.
Measured Rainfall Range:
Rate: 1 day; approx. 1 inch/hr?
Bedrock: Various
Slopes: ?
No. & Size of Slides: 6

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