# Preliminary Field Report on the Route 2 Landslides of Hurricane Irene, August 28, 2011

**Compiled by:**
**Stephen Mabee and Joe Kopera**

**Prepared for:**
**Peter Connors, MA DOT**

**September 29, 2011**

Additional copies of this report and all accompanying documentation are available upon request by contacting the Massachusetts Geological Survey.

Address:
Massachusetts Geological Survey
Department of Geosciences
University of Massachusetts
611 North Pleasant Street
Amherst, MA 01003
Telephone: 413-545-4814
Fax: 413-545-1200
Email: sbmabee@geo.umass.edu
World Wide Web: http://www.geo.umass.edu/stategeologist/

Authors: Stephen B. Mabee, State Geologist, University of Massachusetts at Amherst
Joseph Kopera, Associate State Geologist, University of Massachusetts at Amherst

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Cover: Picture of one of the three translational debris avalanches in the Savoy section of the Route 2 corridor just east of the confluence of Black Brook with the Cold River.

## Executive Summary

The Massachusetts Geological Survey accompanied Massachusetts Department of Transportation personnel in the field on Tuesday, September 6, 2011, to observe the landslide and flooding damage along the Route 2 corridor caused by Hurricane, which struck the area on August 28, 2011. The purpose of the visit was to: 1) identify the type of slides that occurred; 2) estimate the dimensions and volume of material moved; 2) estimate the geological and environmental conditions leading to the slope failures; and, 4) determine the propensity for future occurrence. Four landslides were observed. Slide 1 is immediately east of the confluence of Trout Brook with the Cold River and Slides 2, 3, and 4 are clustered together on a north-facing slope about 1850 feet east of the confluence of Black Brook with the Cold River.

Slide 1 is a rotational landslide that has formed in water-laid ice contact deposits consisting of varved clay, clay, sand and pebbles (CL to ML soils). This has been a chronic problem over this stretch of Route 2 due to the poor soil conditions and excess pore pressures that develop along the underlying clay interface when subjected to periodic heavy rain events and very wet antecedent moisture conditions. Slide initiation is most likely caused by undercutting of the unreinforced toe of the slope during heavy flooding events. The propensity for future movement and rotation at this location is high. It is recommended that: 1) the toe of the slope be stabilized with an retaining wall; 2) relief wells or drains be installed to reduce excess pore pressure within the deposit; and, 3) drainage be improved upgradient of the slide area to convey runoff around the unstable area. A second option would be to span the poor soil area with a structure so that no portion of the roadway bears on the slide area.

Slides 2, 3 and 4 are translational debris avalanches that slid along smooth, sheeting joints formed subparallel to the slope within the metamorphic Moretown Formation. The slides formed three separate shoots with a total aggregate slope length of approximately 2500 feet. Average slope angles ranged from 28° to 38° and the average dip of the sheeting joints was about 35° to 40°. Total area of the slides is estimated to be about 3 acres and the estimated volume of material moved ranges from 7300 to 12,200 cubic yards assuming an average depth range of 1.5 to 2.5 feet. The debris avalanches morphed into debris flows once mobilized. Most of the material was transported away by the river. The possibility of recurring slides in this area is likely in the future but the frequency will depend on the magnitude of future rain events and the antecedent moisture content. The soils on the slope are fairly well indurated (ferricrete observed adhered to the bedrock surface in places) and held together tightly by tree roots. In the short term, nuisance slides from the crown and edges of the slides and controlling runoff from the newly exposed bedrock surfaces will be a primary concern. Ice formation on the slope and on the road surface may also be an immediate concern in winter. It is recommended that improved drainage be developed under the roadway to handle the runoff from the slope. In addition, runoff should be intercepted, collected and conveyed from the top of the slide areas to the river. Stabilization of the exposed soil areas with seeding or other structural control is recommended after the winter.

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## INTRODUCTION

The Massachusetts Geological Survey accompanied the Massachusetts Department of Transportation on Tuesday, September 6, 2011 to inspect the landslide damage along the Route 2 corridor between the towns of Charlemont and Florida. This damage was the result of heavy rains and flooding that occurred from the remnants of Hurricane Irene on August 28, 2011. The purpose of the visit was to:

1. Identify the type of slides that occurred
2. Estimate the dimensions and volume of material moved
3. Estimate the geological and environmental conditions leading to the slope failures
4. Determine the propensity for future occurrence.

## LOCATION AND GENERAL GEOLOGICAL BACKGROUND

Four landslides were observed (Figure 1). Slide 1 is located immediately east of the confluence

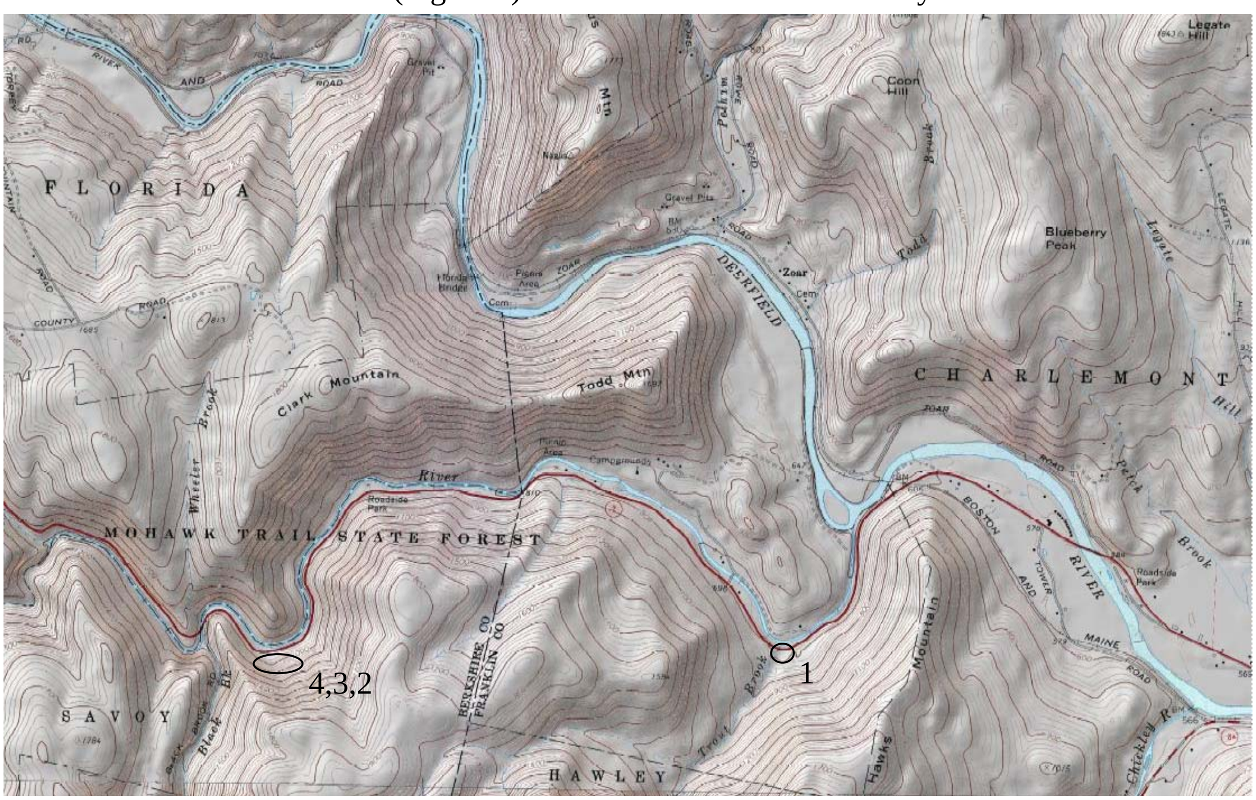


*Figure 1. Location of the four slides examined during the site visit. Base is 1:24,000 scale topographic map draped on hillshaded DEM (modified from MassGIS).*

of Trout Brook with the Cold River. Slides 2, 3 and 4 (from east to west) are located in Savoy just east of the confluence of Black Brook with the Cold River (Figures 1 and 2).

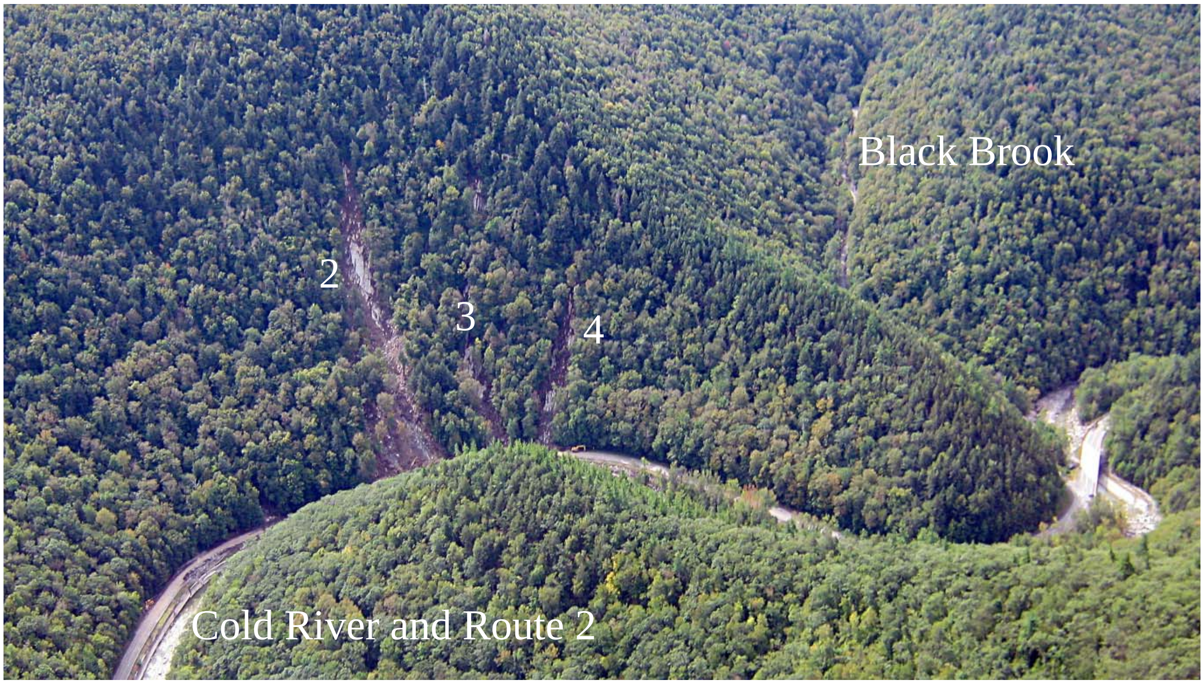


*Figure 2. Oblique aerial photo taken of landslides 2, 3 and 4 looking south southwest. Photo courtesy of Chris Condit (pilot) and John Fellows (photographer). Taken September 17, 2011.*

<u>Bedrock Geology</u> - The bedrock geology at all sites consists of the Moretown Formation (Figure 3). The Moretown is described by Chidester et al. (1967) as: "light-gray-green to buff, fine to medium grained quartz-feldspar-muscovite-chlorite-biotite-(garnet) schist and granulite. Upper part of unit typified by "pinstripe" structure consisting of light colored granular layers 1 to 5 mm thick of quartz and feldspar interlaminated with paper-thin schistose layers of mica and chlorite…" The bedrock exposed at slides 2, 3 and 4 is characterized by the pinstripe structure and has a greenish cast due to the chlorite. The rock is also strongly foliated. Foliation generally strikes 010° (N10°E) and dips 80° to the southeast or is nearly vertical. Accordingly, the direction of foliation is normal to the slope direction and did not play a role in the initiation of the landslides.

The Moretown Formation also exhibits well developed sheeting joints (Figure 4). Sheeting joints are extension fractures that occur subparallel to the land surface. There are two common mechanisms for their formation. They can form by the release of confining stress when rocks buried at depth are slowly brought to the surface through exhumation over millions of years or they can form during isostatic rebound during retreat and/or melting of the glaciers. Sheeting joint frequency displays an exponential decay from the surface to the interior of the rock. They are more closely spaced and frequent in the top 30 feet of the earth's surface but

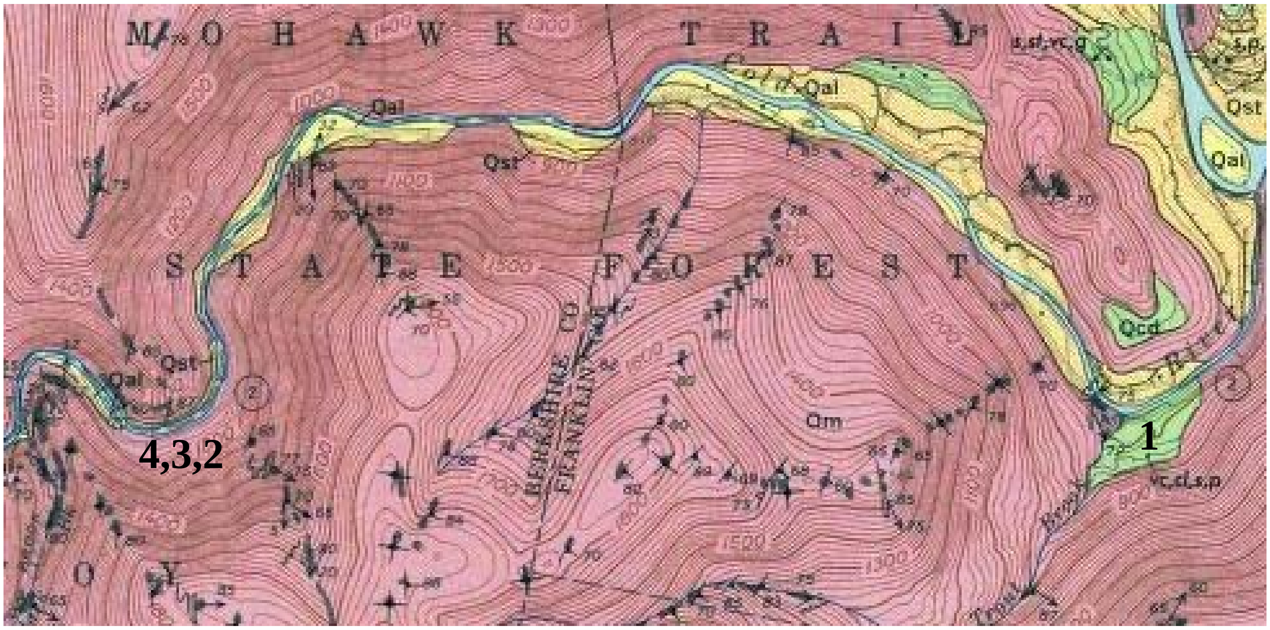


*Figure 3. Bedrock and surficial deposits map of the Route 2 corridor along the Cold River. Slides 1-4 are noted. Pink area is the Moretown Formation. Green areas are water-laid ice contact deposits (from Chidester et al., 1967).*

increase in spacing as well as decrease in frequency with depth, all but disappearing by about 300 feet. Truesdale (unpublished data, Wise personal communication, 2011) mapped slope-parallel sheeting joints in a tunnel at the Bear Swamp pump storage facility located three miles due north of Slides 2, 3 and 4. His work showed an exponential decay in the frequency of sheeting fractures with distance from the tunnel entrance. Recent geophysical logging by the Massachusetts Geological Survey in boreholes in the Nashoba terrane in eastern Massachusetts showed very few sheeting joints in the boreholes below 300 feet.

Sheeting joints at Slides 2, 3 and 4 are prevalent and are subparallel with the slope (Figures 4 and 5). The joints strike 280° and dip at about 40° to the northeast. The joint sets provide a smooth, slope-parallel surface along which translational sliding can occur and form a strong permeability disparity between the bedrock surface and the till/colluvium overburden.

<u>Surficial Geology</u> - The surficial geology above the valley floor at Slides 2, 3 and 4 consists primarily of a mixture of thin till and colluvium (slope wash material) over shallow bedrock. The overburden ranges in thickness from 0 to a maximum of 4 feet thick in the upper two-thirds of the slope with a typical range of 1.5 to 2.5 feet. The material is a mixture of cobbles and gravel in a matrix of sand, silt and minor amounts of clay.

In the lower portions of the slope, the surficial geology varies between the two sites. At Slide 1, the surficial materials consist of water-laid ice contact deposits (Chidester et al., 1967)(Figure 3). Textures reported in the deposit include varved clay, clay, sand and pebbles and may indicate

*Figure 4. Photo looking up Slide 4 from Route 2.  Smooth surface is bedrock exposed along sheeting joints.  Photo by Joe Kopera.*

*Figure 5. Example of sheeting joints on Slide 2. Note parallelism between sheeting joint and slope of hill. Spacing on sheeting joints in the near surface is about 6 inches to 1 foot. Spacing is expected to increase with depth into the hill. Dip of joints is about 38°. Photo by Steve Mabee.*

lake-bottom sediments from a temporary glacial lake. Small temporary glacial lakes in narrow mountainous valleys are not uncommon in this part of Massachusetts (Byron Stone, personal communication, 2011). Recent borings taken by MA DOT for the new box culvert where Trout Brook crosses Route 2 also report artesian (flowing) conditions at a depth of approximately 50 feet. Observations of the sediment in a fresh cut in the toe of the slope along the river at Slide 1 suggests that an impermeable clay layer may exist at depth below the road surface and may be the cause of chronic rotational sliding and tension cracks in the roadway.

A sample of Slide 1 material was acquired and tested to determine the Unified Soil classification. The sample is considered mixed and representative of the material above the varved clay. The material had about 20% sand and gravel above the No. 40 sieve and 80% less than the No. 40 sieve. The Atterberg Limit test classified the material at the lower boundary of the CL-ML zone (Figure 6). The material had an LL of 22%, PL of 18% and PI of 4%. It is an inorganic clayey silt and clayey fine sand of low plasticity.

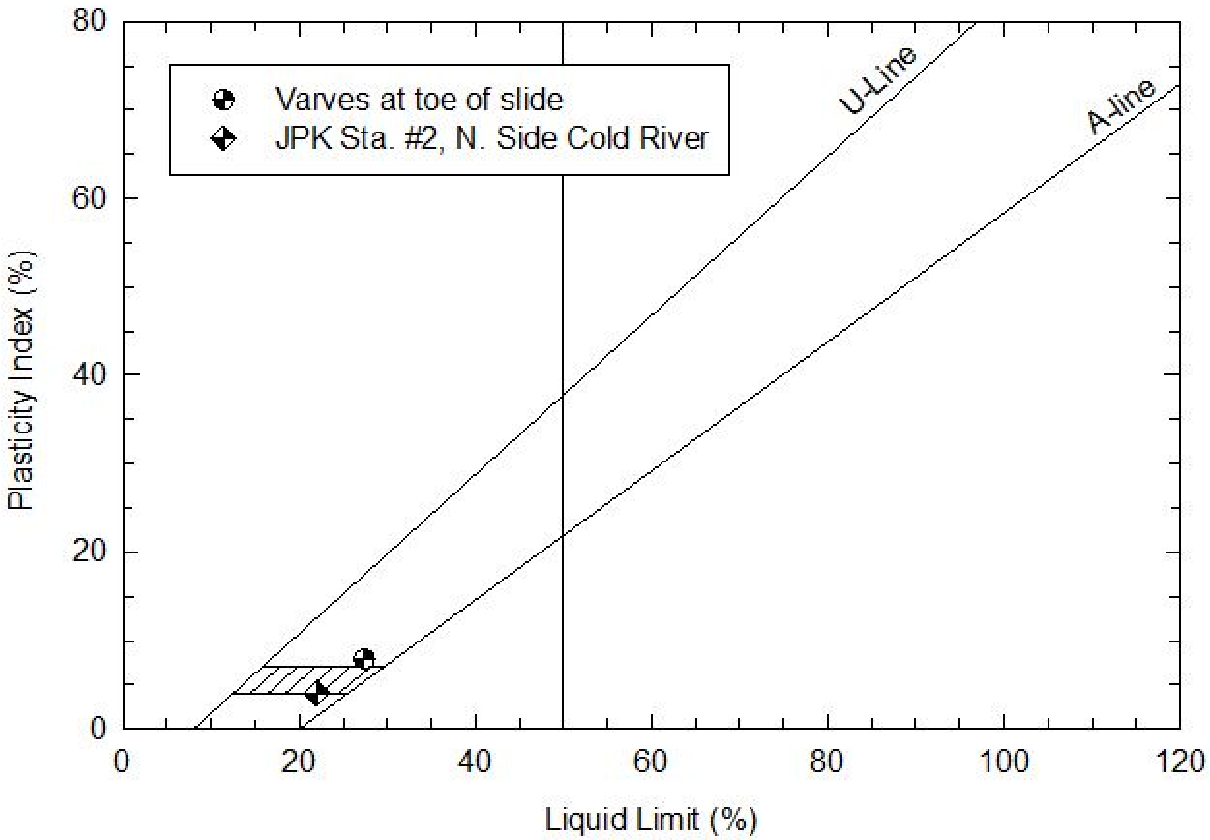


*Figure 6. Atterberg limit plot of two samples. JPK Sta.#2, N. Side of Cold River is the sample from Slide 1. Varves at toe of slide is from Slide 2. Data provided by Don DeGroot.*

The surficial materials at the Slide 2 area also contain lake-bottom sediments at the base of the slope above the road. However, these deposits do not appear on the geologic map. There is a subtle bench approximately 50 to 100 feet above the road surface at Slide 2 that is supported by flat lying, laminated lake-bottom sediments (Figure 7). Laminations are 0.5 to 3 cm thick (Figure 8) and contain numerous dropstones (Figure 9). Over time debris and slope wash material derived from the slope above the bench has accumulated on top of the lake bottom sediments obscuring their presence. These sediments were exposed only as a result of the landslide and subsequent fluvial erosion. The laminated sediments are not observed at Slides 3 and 4. At slide 4, the bedrock surface (sheeting joints) are exposed directly at the base of the slope at road level (Figure 4).

The geologic history of this location can be summed up this way. A temporary glacial lake formed in the narrow valley following ice retreat. The lake bottom sediments were deposited during this time. However, because the valley is narrow numerous ice-rafted cobbles and rocks from the adjacent slopes tumbled into the lake and settled in the sediments producing the numerous dropstones. After the lake drained the Cold River cut through the sediments removing most of the lake material except for a few remnants plastered on the valley sidewall. Over time, debris, colluvium and slope wash material accumulated on top of the lake clays

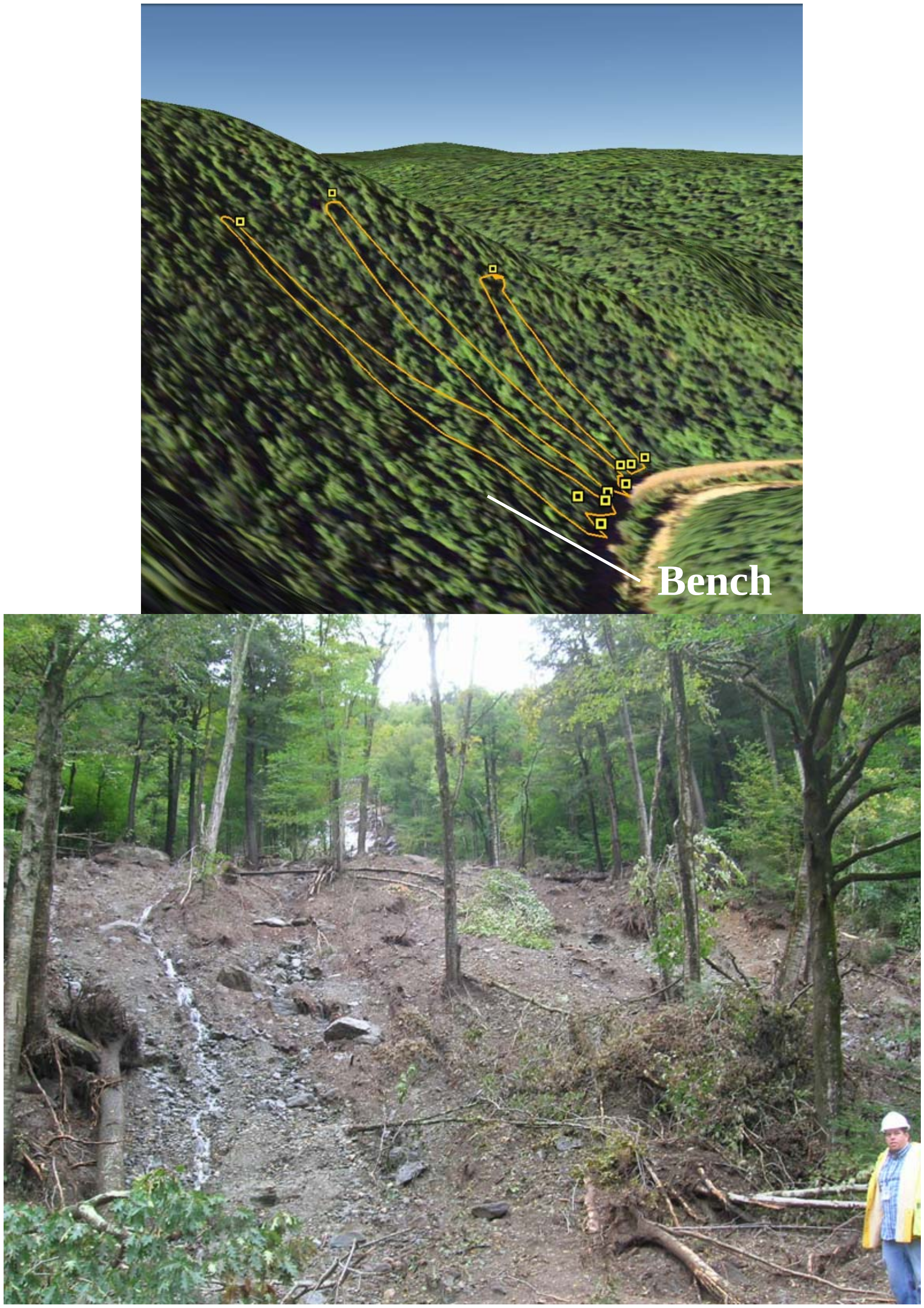


*Figure 7. Upper figure is a google maps image showing the approximate location of slides 2, 3 and 4 (yellow outline). Note the bench in slope near slide. In lower figure bench is evident by break in slope near top of picture. Bedrock sheeting joint is exposed in distance. Debris avalanche slid off the sheeting joint surface as a translational slide then flowed up and over the bench before spilling out on to the roadway. Laminated sediments exposed in gulley to right. Photo by Joe Kopera.*

*Figure 8. Laminated lake bottom sediments in gulley at slide 2 exposed by the landslide and subsequent fluvial erosion. Photo by Joe Kopera.*

*Figure 9. Dropstone in laminated lake bottom sediments at Slide 2. Photo by Steve Mabee.*

obscuring them. The lake bottom sediments are only evident at Slide 2 and have been completely eroded away at slide 4 where the bedrock is exposed directly adjacent to the roadway (Figure 4).

A sample of the laminated lake bottom sediments was acquired to determine its Unified Soil classification. The sample was relatively dry compared to the colluvium and till. The soil is classified as CL, an inorganic silty clay or fine sandy clay of low plasticity (Figure 6). The LL is 27%, PL is 20% and PI is 7%.

**DESCRIPTIONS OF INDIVIDUAL SLIDES**

Each landslide was visited on the ground. This included climbing to the top of each slide. GPS measurements were made at the bottoms and tops of slides 2, 3 and 4 to get an approximation of their physical extent. These data were then plotted in GIS and the perimeter of each slide approximated using the GPS points, aerial photos, orthophotos and topographic maps. From these plots horizontal lengths and vertical extents of each slide were measured and used to calculate the slope length of each slide and the average slope angle. Widths of slides as well as average depth of material removed were estimated in the field and not measured. The pertinent data are summarized in Table 1.

Table 1. Approximate Dimensions, Areal Extent and Volume of Slides 2, 3 and 4.

| **Parameter** | **Slide 2** | **Slide 3** | **Slide 4** |
|---|---|---|---|
| Bottom Width (ft) | 120 | 58 | 48 |
| Top Width (ft) | 45 | 42 | 38 |
| Ave. Slope Angle (°) | 28 | 33 | 33 |
| Horizontal Length (ft) | 868 | 813 | 520 |
| Slope Length (ft) | 902 | 969 | 620 |
| Elevation Difference (ft) | 460 | 522 | 337 |
| Area (sq.ft) | 66,881 | 39,854 | 25,149 |
| Area (Ac) | 1.54 | 0.91 | 0.58 |
| Thickness Range (ft) | 1.5-2.5 | 1.5-2.5 | 1.5-2.5 |
| Min. Volume (CY) | 3716 | 2214 | 1397 |
| Max. Volume (CY) | 6193 | 3690 | 2329 |
| Ave. Volume (CY) | 4954 | 2952 | 1863 |

**Slide 1**

Slide 1 is a slow moving rotational slide that generally extends 800 to 1000 feet from the west side of the Trout Brook box culvert eastward. The slide generally encompasses the water laid ice contact deposits as mapped by Chidester et al. (1967) (Figure 10). Periodic erosion of the toe of the formation during flood events combined with heavy rainfall and excess pore pressure at the interface with the underlying clay (see geology section) leads to slumping and the formation of tension cracks in the deposit and the roadway. During the field visit tension cracks were observed in the deposits downgradient from the road as well as slip scarps in the road surface (Figures 11 and 12).

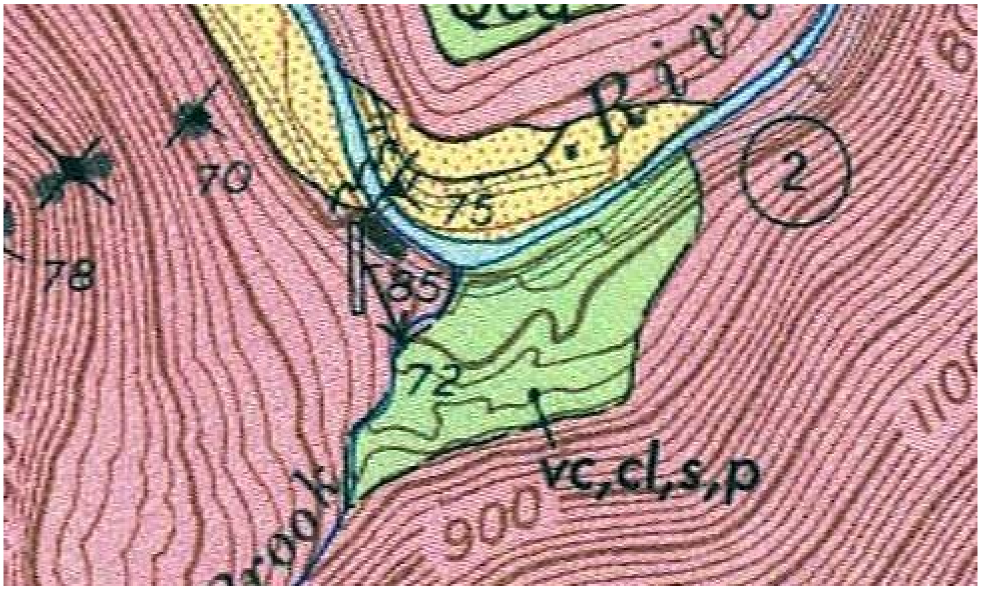


*Figure 10. Green area on south side of the river consists of varved clay, clay, sand and pebbles and has been an area of chronic rotational slumping.*

*Figure 11. Slip scarps in roadway at Slide 1 due to rotational slumping. Slumping caused by erosion of toe, excess pore pressure, low strength soils and excess loading from precipitation.*


*Figure 12. Tension cracks in soil downgradient from roadway at Slide 1. Note bend in tree trunks at top of slope indicating slope instability.*

<u>Recommendations</u>: Without question this area will continue to exhibit instability due to the poor soil conditions. Two possible remediation strategies are suggested.:

<u>Option 1</u>

1) Stabilize the toe of the slide along the river with a retaining wall to reduce erosion potential.
2) Install relief wells and drains to reduce any excess pore pressure within the slide area during large rain events.
3) Improve drainage upgradient of the slide area, collect and convey excess runoff away from the water laid ice contact deposits.

<u>Option 2</u>

1) Span the entire poor soil zone with a bridge structure so that no part of the roadway bears on the water laid ice contract deposits. Bedrock is exposed just west of the Trout Brook box culvert and could provide good bearing material on the west end.

**Slides 2, 3 and 4**

Slides 2, 3 and 4 (Figure 2) initiated as translational debris avalanches and upon mobilization downgradient became debris flows. These were fast moving events with most of the debris ending up in the river where it was redistributed by the flood waters. Estimated extent of each slide is shown in Figure 13 and approximate dimensions presented in Table 1. The total volume of material mobilized is estimated to be 7300 to 12,200 cubic yards assuming an average depth of material removed of between 1.5 and 2.5 feet.

Slide 2 is the largest of the three with an estimated slope length of about 900 feet and area of 1.5 acres. The slide also widens at the bottom. The positioning of the lake bottom sediments, which forms a noticeable bench at the base of the slope, forced the debris avalanche to hydraulically jump the bench and spread near the base of the slope. Estimated volume of material displaced is 3700 to 6200 cubic yards.

Slide 3 is the longest slide with an estimated slope length of 969 feet but it is narrower than slide 2. Estimated area involved is 0.9 acres and the material displaced is approximately 2200 to 3690 cubic yards. Average slope angle is about 33° but is as steep as 38° in places.

Slide 4 is the smallest of the three slides. Estimated slope length is 620 feet and an area of approximately 0.6 acres. Volume of material removed is estimated to be 1400 to 2300 cubic yards. Average slope angle is 33 degrees.

All failure planes near the bottom of the slope consist of smooth, polished sheeting joint surfaces, often exhibiting glacial striations. The joint surfaces become rougher up slope and form miniature benches, approximately 0.5 to 1m in width, which follow the contour of the slope. The relationship of the benches to ductile structure or fracture sets could not be determined clearly.

Evidence of past slope movement was observed above one of the slides. An arc-shaped vegetated scarp with about 6 inches to 1 foot of reveal was observed about 25 to 30 feet above the existing crown. The trees in the area between the existing crown and older scarp were less than 6 inches in diameter.

Initiation of these three slides no doubt was caused by several compounding factors: the steep, slope-parallel sheeting joints that formed a smooth failure surface and an impermeable barrier to infiltration, the increase in pore pressure that reduced the shear strength at the bedrock/overburden interface, and the additional driving force of the saturated soil column brought on by the 5 to 7-inch rain event of Hurricane Irene that occurred in less than 18 hours.

Another key component that probably played a major role was the antecedent moisture content. July and August were wet months in western New England after a dry June. Examination of rainfall data from two CoCoRaHS stations (Community Collaborative Rain, Hail and Snow network) located in Becket and Tyringham approximately 25 miles south southwest of the slides and parallel to the storm track of Irene, show 8.44 inches and 9.24 inches of rainfall in the

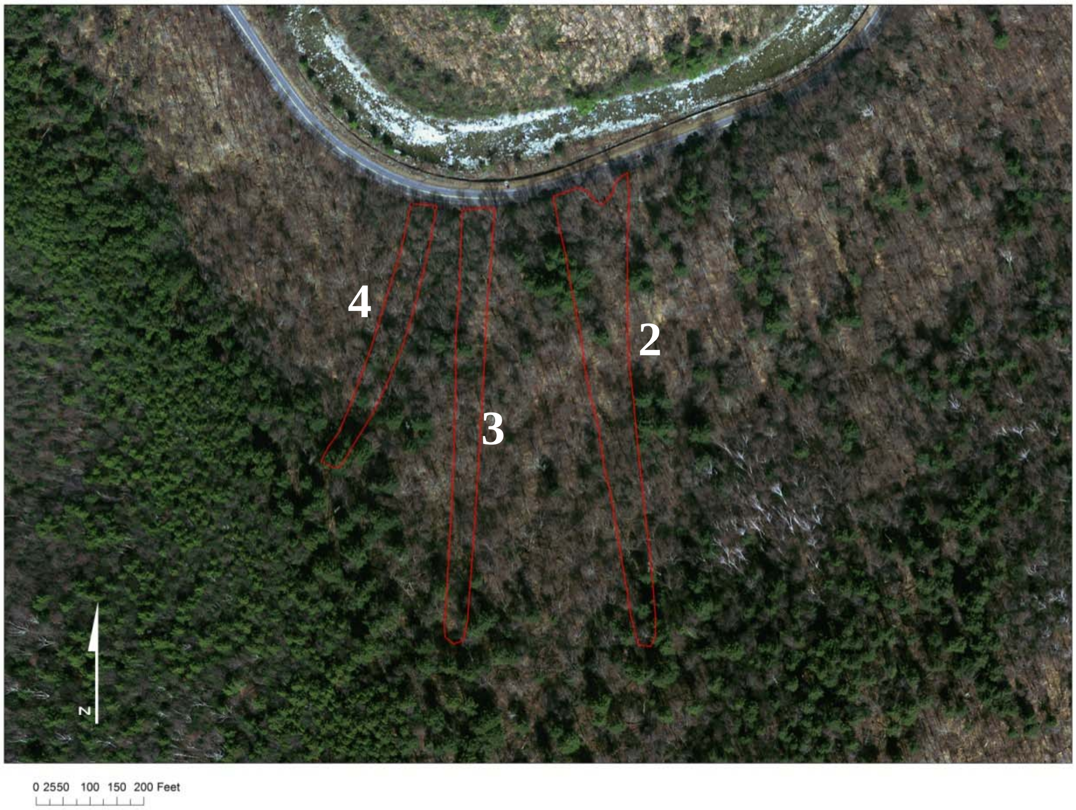


*Figure 13. Approximate extent of Slides 2, 3 and 4 on Route 2, Savoy, Massachusetts. Extent of slides estimated from GPS measurements, aerial photographs, and ground inspection.*

months before Hurricane Irene, respectively (Table 2). More significant are the events leading up to Hurricane Irene. At Tyringham, there was a 1.4 inch event on August 17, 1.2 inch rain on August 20, 1.1 inches on August 23 and another 1.3 inches on August 26 two days prior to Hurricane Irene, which produced another 5.43 inches of rain in less than 18 hours.

Table 2. Rainfall totals before and during Hurricane Irene

| | Tyringham (42.25295; -73.231291) | Becket (42.25906; -73.13213) |
|---|---|---|
| July 2011 | 2.2” | 3.21” |
| August 1-27, 2011 | 7.04” | 5.23” |
| August 29-30 (Irene) | 5.43” | 6.74” |

Anecdotal reports indicate that throughout western New England and eastern New York, seepage and springs were noted high on ridge lines even during peak evapotranspiration in the height of summer. In addition, this condition is compounded on north-facing slopes (Francis Ashland, USGS, personal communication, 2011). Another critical condition inherent in debris avalanche initiation is the speed with which the effective stress changes (Francis Ashland, USGS, personal communication, 2011). If the rate infiltration exceeds the rate of outflow along the failure surface, an imbalance is created favoring failure. Landslide initiation appears to be dependent on the rate at which this imbalance is created.

In the long term, if conditions in this area exist in the future that are similar to those prior to the arrival of Irene, future landslides are possible. However, their recurrence interval may be somewhat low. It is unlikely that a single event generating 5 to 7 inches of rain in an 18 hour period by itself would have initiated the landslides if the summer had been completely dry. Also, tree roots have bound the soil column tightly as evidenced by the survival of some isolated trees within the slide path. In addition, ferricrete (iron) hardpan was noted adhered to the bedrock sheeting joint surfaces.

In the short term, additional sloughing of the crown and edges of the slides may continue with additional rain events through the winter and spring. Furthermore, efforts will need to be made to stabilize the exposed edges of the slides as well as convey safely the increased runoff under the roadway. Significant runoff will be produced from the exposed bedrock surfaces.

<u>Recommendations</u>: Some general recommendations include:

1) Install improved drainage under the roadway at the base of each slide to handle the increased runoff from the exposed bedrock surface. Icing will be a problem in winter.
2) Provide temporary stabilization of exposed soil in the near term with hydroseeding and/or planting in the spring.
3) Intercept and collect runoff from the top of the slides and convey to bottom of hill bypassing the slide area
4) Install soil moisture probes, inclinometers and/or observations wells to monitor soil moisture and water level on the slope.

## REFERENCES CITED

Chidester, A.H., N.L. Hatch, P.H. Osberg, S.A. Norton, and J.H. Hartshorn. 1967. Geologic map of the Rowe quadrangle, Franklin and Berkshire Counties, Massachusetts and Bennington and Windham Counties, Vermont. U.S. Geological Survey, Geologic Quadrangle Map GQ-642.