A Century of Landslide Activity in Glaciolacustrine Deposits in Jeffersonville, Vermont, USA

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ABSTRACT

At least five complex earth slide–flows have occurred over the past century on the side of a 46-m-high terrace adjacent to the Village of Jeffersonville, Vermont, USA. At least two of the landslides crossed the Brewster River and reached the edge of the village. Residences at the top could be at risk and the run-out zone for future slides could include a school, shops, and residences. The slope is underlain by varved glaciolacustrine sands, silts, and clays. The causes of instability include toe erosion by the river and high pore-pressure due to rain or snowmelt. Areas of concern have been identified along the northern part of the slope and above the school.

RÉSUMÉ

Au moins cinq glissement–écoulement de terrain complexes ont eu lieu depuis un siècle sur le flanc d'une terrasse de 46 m de haut près du Village de Jeffersonville, Vermont, USA. Au moins deux des glissements de terrain ont traversé la rivière Brewster et atteint le bord du village. Résidences au sommet pourraient être en péril et la zone de battement pour glissements futures pourrait comprendre une école, commerces et résidences. La pente est sous-tendue par les argiles, limons et sables glacio-lacustres varvées. Les causes d'instabilité incluent orteil l'érosion de la rivière et de la pression interstitielle élevée en raison de la pluie ou de fonte des neiges. Secteurs préoccupants ont été identifiés le long de la partie nord de la pente et au-dessus de l'école.

1 INTRODUCTION

The Deer Run Heights Ridge is located in the Village of Jeffersonville in northwestern Vermont, just south of the Lamoille River and Vermont Route 15 along the eastern bank of the Brewster River. In the valley bottom west of the river there are private residences, businesses, and an elementary school (Figure 1). A series of three landslides occurred in 1999 on the west side of the ridge, resulting in displacement of over 27,000 m^3 of material toward the village (Bierman *et al.* 1999). The slide material moved out over the Brewster River and onto the low terrace on the far side, the mud splashing up against two houses. At the top of the slide a house was undermined and had to be removed. These landslides are only the latest of a series of large slope failures that have occurred at the site over at least the last century. Besides the large landslides described above, there are also several active landslide-gully complexes on the slopes to the north and south of these landslides.

Given the known history of slope failures at the site, the school and numerous residences and businesses in the Village of Jeffersonville are thus situated in a potentially hazardous location. The purpose of this study is to evaluate the stability of the slopes and to develop appropriate mitigation and/or warning options.

In order to understand the potential hazards at the site, Springston (2008) prepared a workplan for the Vermont Geological Survey (VGS). This has since guided several studies undertaken by the authors in collaboration with students from Johnson State College and Norwich University, the results of which are described below.

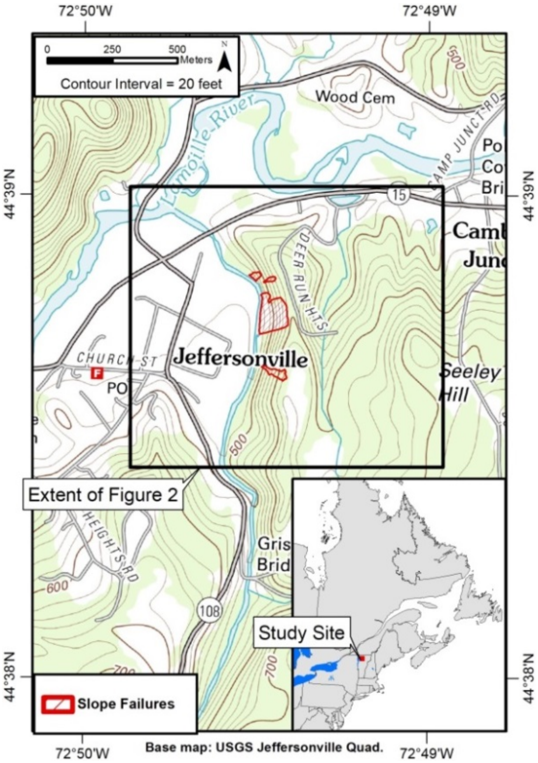
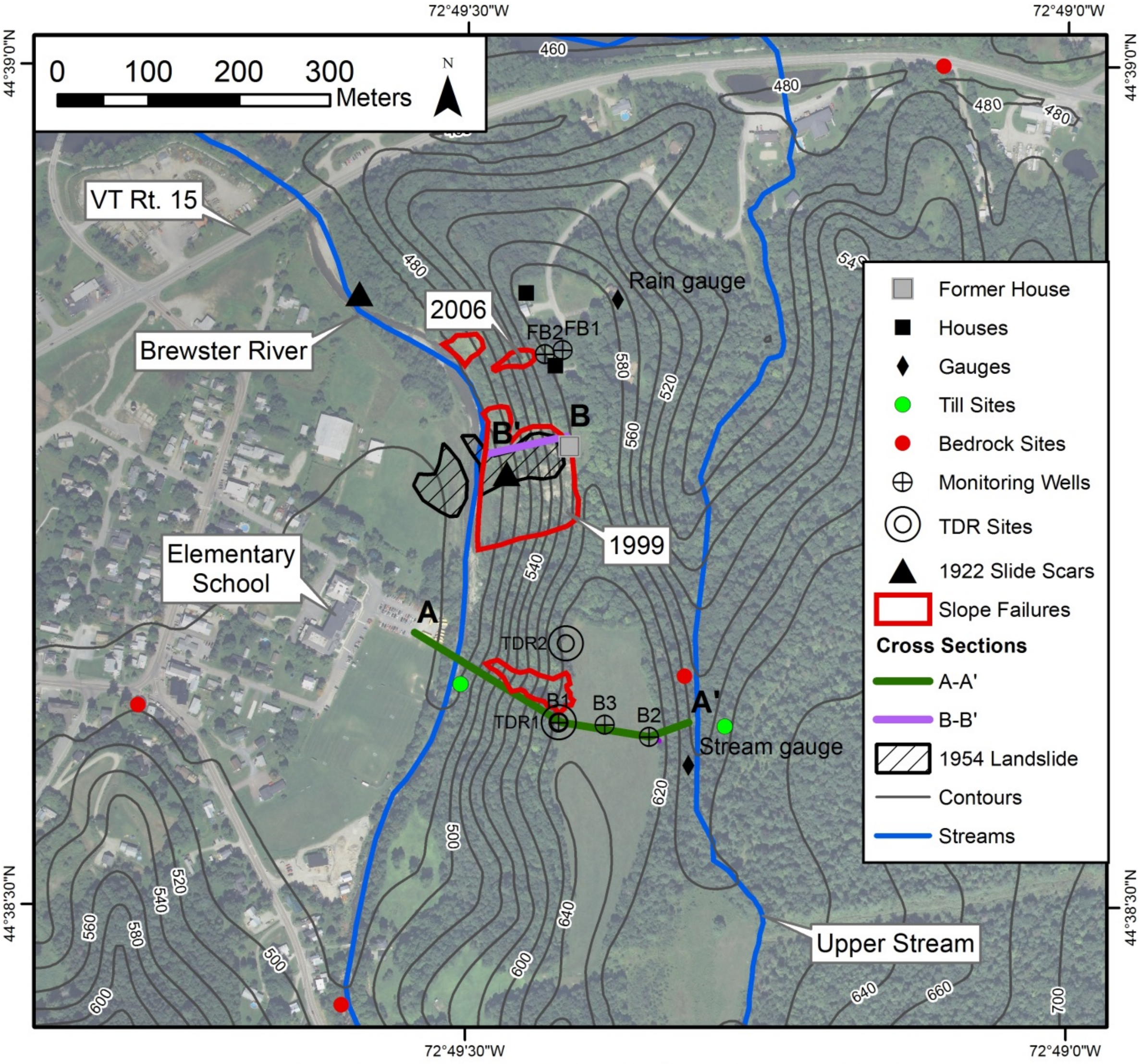


Figure 1. Location map. The study site is outlined by the black rectangle and is shown in more detail in Figure 2. Current slope failures are shown with red hatching.



Base from 2008 orthophotos. Contour interval = 20 feet.

Figure 2. Map of site showing locations of present-day landslides, historic landslides, cross sections, borings, monitoring wells, stream gauge, and rain gauge. Two houses at the top of the slope are shown as black squares and a house removed after the 1999 slides is shown as a grey square. The base map is from 2008 true-color orthophotos and the 20-foot contours are from the U.S. Geological Survey.

2 GEOLOGIC BACKGROUND

The study area is located on the west side of a terrace composed of about 45 m of late Pleistocene glaciolacustrine fine sands, silts, and clays overlying dense glacial till. The lake deposits are capped by several m of early Holocene fluvial sands and gravels deposited by the Brewster River. From the early Holocene to the present, the Brewster River has cut down through the lake deposits to its present elevation. The village of Jeffersonville is built on the alluvial fan formed as the steep Brewster River descended from the mountains to the south and reached the valley of the Lamoille River (Wright 2003). Based on the available maps, the river has been flowing against the base of the slope since at least the mid-nineteenth century. The stratigraphy is shown in Figure 3 and environments of deposition are shown in Table 1. See Wright (2003) for a more complete discussion of the glacial and post-glacial history.

The uppermost surficial materials are early Holocene stream terrace deposits (Unit A in Figure 3). These consist of loose to dense, silty fine sand to coarse sand, pebbly coarse sand, and pebble-cobble gravel on top ofthe main terrace (Figure 4). Bedding is approximately horizontal and fining-upward sequences range from 0.22 to 1.13 m thick. These fluvial materials were deposited on top of the lacustrine sediments by the Brewster River soon after glacial Lake Vermont drained (Wright 2003). Thickness ranges from 1.2 m to about 3.0 m. This is the Old Alluvium of Wright (2003).

Table 1. Environments of deposition and surficial geologic units. Ages (in years before present) are approximate and are based on Ridge (2003) and Wright (2003).

Environment of Deposition		Materials	Units
Stream Terrace (<10,000 years BP)		Sand and gravel	A
Lake Vermont	Fort Ann Stage	Sand-silt varves	B
	Coveville Stage	Silt-clay varves	C (upper)
Lake Mansfield		Silt-clay varves	C (lower)
Subglacial (>13,600 years BP)		Till	D

The next unit consists of sandy Pleistocene lake bottom deposits (Unit B in Figure 3). It includes medium-dense fine sand, very fine sand, and silty very fine sand with thin silt and silty clay laminae (Figure 5). The material consists of couplets of coarser-grained sediment deposited during the melt season and finer-grained sediment deposited from suspension during the winter. These annual layers are known as varves. The thickness of these couplets ranges from 0.46 to 1.0 m, with thickness increasing toward the top of the unit. The overall thickness of the unit ranges from 10.7 m at B2 on the east side of the terrace up to 16.8 m at B1 on the west side. This unit of thick varves is about 16 m thick at the 1999 slide and is interpreted to have formed as bottom-set beds formed by the prograding delta of the Brewster River into the Fort Ann stage of glacial Lake Vermont (Wright 2003).

Below the sandy varved deposits is a thick unit of varved, silt-clay Pleistocene lake bottom deposits (Unit C in Figure 3). The material consists of stiff silt, silty clay, and clay in horizontal couplets of silt overlain by a thin silty clay or clay layer (Figure 6). Individual couplets range in thickness from about 7 to 60 cm. The thickness of the

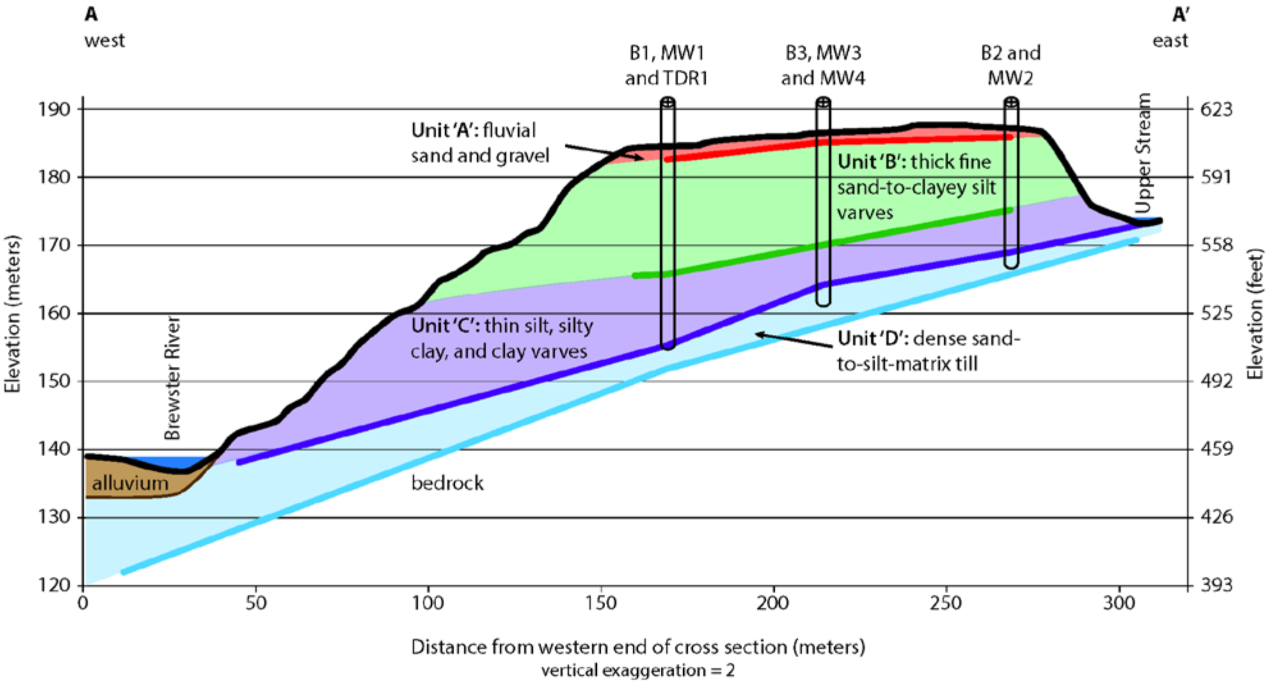


Figure 3. Geologic cross section A – A'. The location is shown in Figure 2. The surficial geologic units are shown in Table 1 and described in the text. Till is observed at the base of the slope on the east side of the Brewster River, in each of the borings, and on the east side of the Upper Stream. Depth to bedrock is based on exposures in the Upper Stream and north-south seismic refraction lines at boring B1 and near the western end of the cross section on the west side of the Brewster River.

unit ranges from 6.4 m at B2 on the east side of the terrace to 10.4 m at B1 on the west side. The unit is approximately 27 m thick at the 1999 slide (Wright 2003). About 10 m above the base of the section at the 1999 slide, Wright (2003) discovered a 5.5-m-thick intraformational slump (underwater landslide deposit) composed of deformed, varved, silt, clay, and rare sand. A second, 0.8 m slump is exposed at about 4 m above the base. Wright (2003) interprets the major slumping to have occurred during a lowering of the glacial lake level at the time of transition from glacial Lake Mansfield to the Coveville stage of glacial Lake Vermont. Deposition of silt-clay-dominated varves resumed after this slumping event and continued until a coarsening of the sediment associated with further lowering of the lake level at the time of transition to the Fort Ann stage of glacial Lake Vermont. Note that these slumped units were not encountered in any of the borings undertaken on the terrace.

Wright (2003) counted 143 couplets in the 29-m section in the lower 2/3 of the section, indicating rapid deposition. Combined with his estimates for the upper part of the section and the covered interval at the base, this suggests that the entire lacustrine part of the section was deposited in about 170 years (Wright 2003). With a rate of deposit of 0.20 m per year, the presence of slumps in the lower part of the section is not surprising.

Pleistocene till comprises the base of the stratigraphic section (Unit D in Figure 3). It consists of dense fine sand to fine-sandy silt-matrix till. Thickness ranges from at least 0.9 m at B1 to at least 2.9 m at B3. The unit is exposed on the hillslope east of the upper stream and in an isolated exposure at the base of the western slope of the terrace on the east side of the Brewster River.

The bedrock consists of schist and phyllite of the Cambrian and Neoproterozoic Underhill Formation (Ratcliffe *et al.* 2011). Exposures are shown in Figure 2.

Figure 4. Upper fluvial sand and gravel (Unit A) exposed at head of landslide-gully complex at Cross Section A-A'.

Figure 5. Looking up at top of 2006 slide. Material consists of thick varves composed of 0.46 – 0.76 m layers of fine sand separated by thin silty clay layers (Unit B). Photo courtesy of Jonathan Kim, Vermont Geological Survey.

Figure 6. Stiff, varved lacustrine deposit at the site of the 2011 landslide (Unit C). Very fine sand and clayey silt are brown and silty clay is grey. Trowel for scale.

3 LANDSLIDE HISTORY

Ongoing slope stability studies in Vermont show that the locations of past landslides are good predictors of future slides (Clift and Springston 2012; Springston and Thomas 2014). As described below, the Jeffersonville site has been the site of slope failures for over a century.

According to Wright (2003) the steep slope on the east side of the Brewster River has long been known to locals as the “Jeffersonville clay bank,” suggesting a long history of slope instability.

A photo taken by Harold Thomas in the fall of 1911 shows an extensive, partly healed slide scar on the upper part of the slope downstream of the school building, on or near the site of the 2006 slide (Figure 7). This is downstream of the scar visible in the 1942 photo cited below. The 1911 photo shows an area of bare soil behind and to the west of the school that appears to be a landslide scar. This may represent fresh toe erosion by the Brewster River. Thus, slope failure at the site appears to be ongoing from at least 1911.

Stratigraphic sections were measured by Ernst Antevs in 1922 at two slides on the east side of the Brewster River (Antevs 1928). His Site 169 is described as being a "...slide on brook at eastern edge of village, 125 yards S of the highway to Cambridge Junction" and his Site 170 is "...300 yards S of profile 169, slide on the brook" (Antevs 1928, p. 199). Site 169 is near a minor slide scar visible on the 1942 aerial photos described below. Site 170 plots within the 1954 and 1999 landslide sites that are described below.

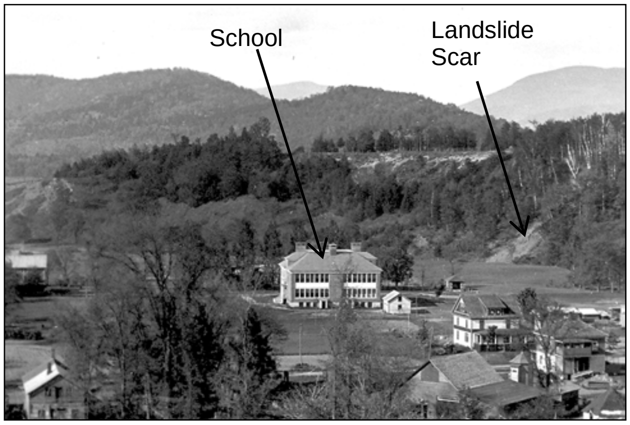


Figure 7. View of Jeffersonville looking northeast in 1911. The prominent building in the center is the present-day Cambridge Elementary School. The Brewster River is behind it at the base of the slope. Note a landslide scar behind and to the right of the school and the break in the treeline at the top of the slope. Photo by Harold Thomas, from the collection of Wendell “Stub” Wells, Jeffersonville.

Aerial photos taken in 1942 show a well-defined landslide scar just downstream of the school building (Figure 8, circled). As there appears to be low vegetation on the lower parts of the slide scar, the movement must have taken place at least a few years previously. The location of the scar at an outside bend of the Brewster River suggests that toe erosion was an important factor in the slope failure. This site appears to be at the south end of the 1999 slide.

Landslides occurred at the site on 10 and 11 May 1954 (Anonymous 1954). Figure 9, which was taken soon after, shows slide debris and whole trees on the west side of the river with the landslide scarp in the background. Although an eyewitness reports that most of the material was immediately trucked away (Stub Wells, personal communication, 2004), aerial photos taken in 1962 show that a remnant of the toe deposit is still visible on the west shore of the Brewster River (Figure 10). This landslide is within the area of the 1999 slide described below.

A series of three landslides occurred at the site on 11 April, 18 April, and 4 July, 1999. The location is shown in Figure 2. These are described in detail in Bierman *et al.* (1999) and Wright (2003). Using the classification of Cruden and Varnes (1996), the landslides were complex translational to rotational earth slide–flows. Figure 11

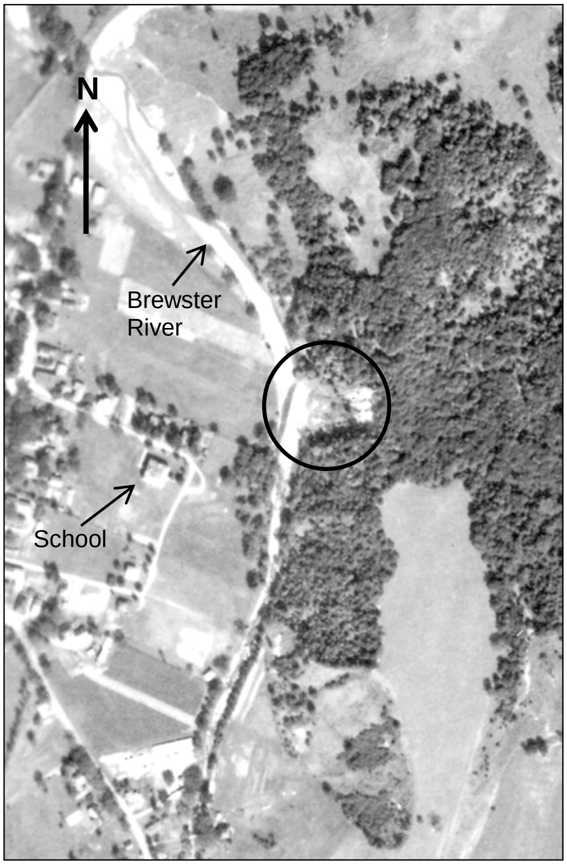


Figure 8. Aerial photo taken on 1 August 1942. The Brewster River flows northward through the center and a landslide scar is visible on the right bank in the center of the photo (circled). Detail from photo DCC-6-15 from Vermont Department of Forests, Parks and Recreation.

Figure 9. Landslide at site in May of 1954. Bulldozer for scale. The landslide occurred on the slope east of the river and is visible in the back, right. The trees in the foreground at left are part of the toe deposit and are on the west side of the river. Photo by Harold Thomas, from the collection of Wendell "Stub" Wells, Jeffersonville.

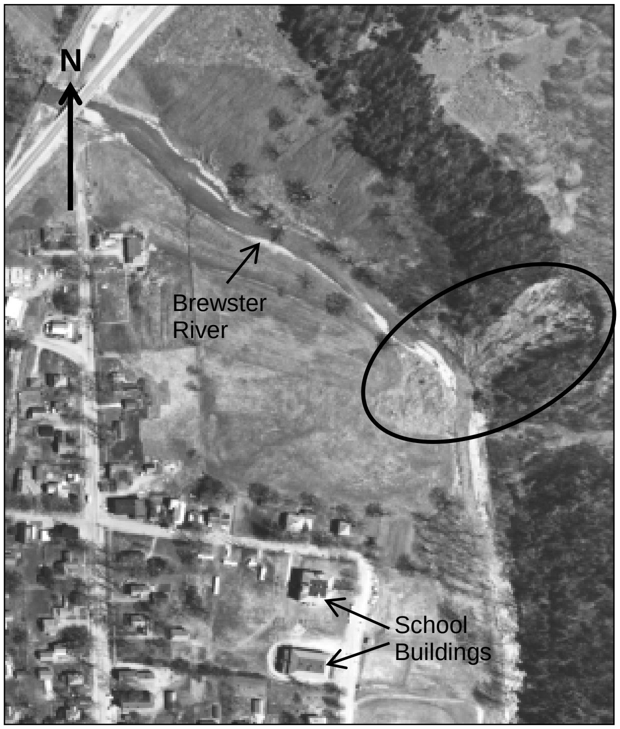


Figure 10. Portion of aerial photo taken in the spring of 1962. The Brewster River flows northward from bottom right to upper left. The 1954 landslide and a remnant of the toe deposit are outlined by the ellipse. Photo VT-62-L 11-188, from the collection of the VGS.

shows the landslide as it appeared after the second of the three 1999 events. The toe deposits extended more than 150 m westward from the west bank of the Brewster River and mud from the runout splashed onto two houses. One residence was directly affected by the landslides: A house at the top of the slope was evacuated after the April landslides and was later bought out by the local government with funding from the Vermont Emergency Management Agency.

In the weeks and months following the slides, Bierman *et al.* (1999) mapped the extent of the toe deposits and made many valuable observations regarding the dynamics of the slides. Surveying of the landslide after the April 18 slide indicated that approximately 23,000 m^3 of slide material was deposited on the west side of the river and that an additional 4,200 m^3 was deposited there by the July 4 slide (Bierman *et al.* 1999, Nichols *et al.* 2004). Once the slide material was mobilized, it extended over 150 m west of the base of the slope. Their observations of flood marks show that the river did not dam up significantly behind any of these three slides. Saturation of the toe deposits is indicated by abundant dewatering structures (mud volcanoes ranging from 50 to 200 cm in diameter) observed after the 18 April slide. Although some of that water may have been derived from the river, much of it would have originated within the slope. Dewatering of these deposits is reported to have taken days to weeks. Observations of steep snouts associated with the April slides suggest that at least parts of the toe material moved as debris flows.

The first of the 1999 landslides (11 April) removed material from the outer part of the slope. This may have been a predominantly translational earth slide–flow. The second landslide (18 April) was the largest and appears to have had a major rotational component. The failure surface appears to have rooted on the top of the intraformational slump deposit within the lower part of the glaciolacustrine deposits (Unit C of Figure 3). The third landslide (4 July) seems to have been the smallest of the three.

The causes of the 1999 slides appear to be at least two-fold. An analysis of monthly rainfall data from the National Weather Service station in Burlington by Bierman *et al.* (1999) indicated that precipitation in the several months preceding the 1999 landslides had been well below normal. Bierman *et al.* (1999) did suggest, however, that heavy rains during the preceding summer played a role in the slope failures via two mechanisms: by flood waters undercutting the toe of the slope and by precipitation causing an increase in pore pressure in the low permeability silt-clay deposits. In this scenario, the low permeability of the material allowed pore pressure to remain high throughout the winter and into the following summer.

Besides the large landslides described above, there are several active landslide-gully complexes on the slopes to the north and south of the 1999 landslide. On 2 July 2006 the owners of a house located immediately north of the 1999 slide returned home after an absence of several days to find a lot more sunlight reaching their home – a slide had occurred sometime in the preceding week and removed part of the tree canopy on the slope to the west of their house. Examination showed this to be a landslide-gully complex which ends in a small alluvial fan at the base. The landslide at the head was a translational earth slide and is shown in Figure 11. As the material moved downslope it appears to have broken up into an earth flow. Toe erosion was not a cause of this slope

Figure 11. View of landslide on 20 April 1999 from field on west side of river looking east, two days after the second 1999 slide. Toe deposits are in the foreground and the landslide scarp on the east side of the Brewster River is in the background. Note house (circled) at top of scarp. House was removed later in year. Panorama of three photos courtesy of Jon Kim, Vermont Geological Survey.

failure. Instead, the cause appeared to be high pore-pressure due to heavy rains in the preceding weeks. Another landslide-gully complex is located directly opposite the Cambridge Elementary School (Figure 2) and has been actively eroding over at least the last 20 years. In April of 2009, accelerated slumping occurred at the head of this complex, apparently due to seepage forces due to snow-melt (Figure 7). Sediment from the slump flowed down and into the Brewster River. The stability of this section of the slope will be discussed in Section 5.1 below.

In May of 2011, at the end of a heavy snowmelt season and after very heavy rains, a renewed slope failure occurred in the northern portion of the 1999 landslide scar. Although only about 17 m wide at the base and approximately 17.3 m high, the shallow translational earth slide did carry material out into and halfway across the Brewster River.

4 SITE CHARACTERIZATION

In 2008 a network of survey monuments was installed and surveyed using a Leica TC407 total station instrument. Topographic surveys were made in parts of the study area in 2009.

Borings have been undertaken in two clusters. Geoprobe borings were made in the northern part of the study area in 2007, and piezometers and Time Domain Reflectometry (TDR) cables were installed in the holes (locations marked as FB1 and FB2 in Figure 2). Geotechnical borings were undertaken along Cross Section line A-A’ (Figure 2) in the summer of 2009. Piezometer and TDR locations are shown in Figure 2.

Two north-south seismic refraction surveys were made in 2009 using a Geometrics Model 1220 12-channel Engineering Seismograph at Boring B1 and near the western end of the Cross Section A-A’ on the west side of the Brewster River.

4.1 ENGINEERING CHARACTERISTICS OF MATERIALS

Assessment of the engineering characteristics of materials was performed using field data, laboratory testing, and correlation techniques. Figure 12 shows Standard Penetration Test and moisture content data for boring B1. Both split spoon and Shelby tube samples were available from the 2009 borings.

Laboratory testing of strength parameters for the soils included unconfined compression, unconsolidated-undrained triaxial, angle of repose, and direct shear testing. Selected samples were classified using the Unified Soil Classification System (USCS). Coupling these results with standard penetration testing data, strength and unit weight characteristics were assigned using correlations available in the literature. The results are shown in Table 2.

4.2 SURFACE AND GROUNDWATER CONDITIONS

Groundwater level monitoring for one year suggests that the height of the water table at Monitoring Well MW1 varies minimally throughout the year (± .033 m or 0.11 feet; see the red line in Figure 13). Monitoring Well MW2 exhibits larger fluctuations (± 0.10 m or 0.33 feet) and tends to reflect changing water levels in the Upper Stream that are coupled to large precipitation events (for example, Tropical Storm Irene on 26 Aug 2011; see the green line in Figure 13). This suggests that the Upper Stream (blue line in Figure 13) supports the water level in the nearby well (MW2) but has no influence on more distal wells.

The slow decline in water table heights, as recorded in MW2, suggest that groundwater levels persist for months after significant precipitation events thus, maintaining high pore pressure in the Unit C and reducing slope stability.

Table 2. Engineering characteristics of materials. Stratigraphic units are as shown in Table 1 and Figure 3.

Characteristics				
Units	A	B	C	D
Average SPT N_{field}	36	23	16	>100
USCS Group Symbol	SP-SM	SM	CL	SC-SM
Soil Classification	Poorly graded SAND with silt and gravel	Silty SAND w/ sandy lean clay lenses	Lean CLAY with silty lenses	Silty clayey SAND with gravel
Unit Weight (kN/m^3)	20	18	17.5	21
Cohesion (kPa)	0	0	62	200
Effective Angle of Internal Friction (deg.)	40°	31°	30°	40°
Hydraulic Conductivity (m/s)	1.5×10^{-4}	3×10^{-5}	2×10^{-7}	7×10^{-8}

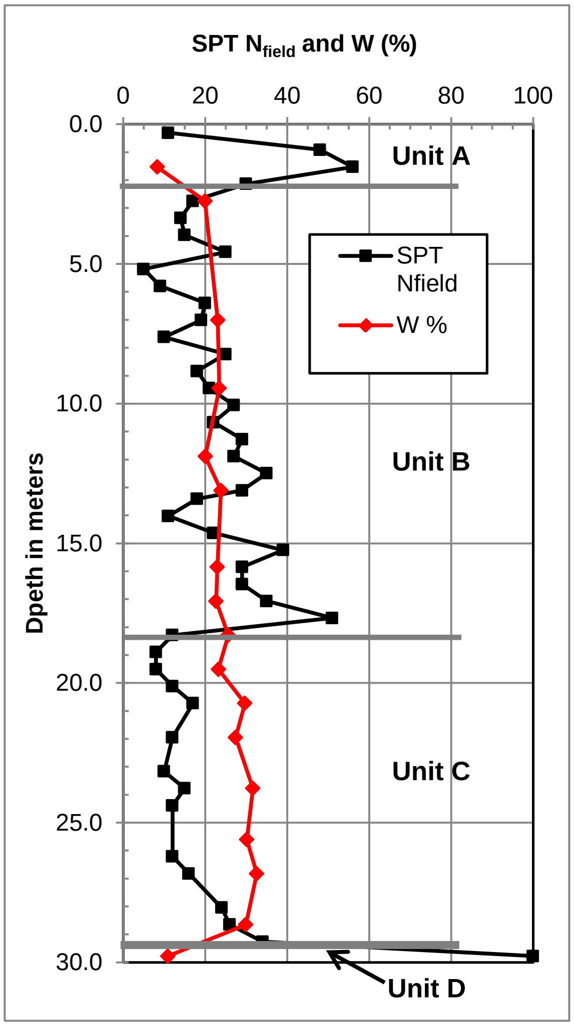


Figure 12. Geotechnical properties at Boring B1 on Cross Section A-A'. SPT N_{field} is Standard Penetration Test . W is water content in percent. Other properties shown in Table 2.

5 ANALYSIS

5.1 SLOPE STABILITY MODELLING

Stability modelling was performed using the steepest portion of the slope, located at the northern edge of the 1999 slide (Cross Section B-B' on Figure 2). This 34° slope is 46 m high. Modeling of the lean clay with silty lenses of Unit C (Figure 6) represents a significant challenge in the slope stability analysis. Cohesion is exhibited in the portion of each varve that consists of clay, and silt, but is not present in the fine sand portion of each of the varves. Therefore, modelling of this layer utilized a weighted average of the strength parameters of the materials in the layers. The frictional and cohesion values for Unit C were weighted according to their relative thicknesses within the varves.

As ground water flows through the subsurface from the area of the upper stream and finally exits the face of the slope, seepage forces are exerted parallel to the direction of flow as a force per volume of saturated soil. As the seepage forces are directed close to perpendicular to the slope face they contribute to the instability.

Using a total stress analysis with the parameters outlined in Table 2, this slope is relatively stable. However, taking into account weighted averages for the frictional and cohesive capacities of the layered Unit C and seepage forces diminishes the factor of safety of the 34° slope to very close to 1.

Bierman *et al.* (1999) and Nichols *et al.* (2004) proposed that at least one of the 1999 landslides rooted on top of the massive intraformational slump deposit that was about 10 m above the base. A failure reaching to this intraformational slump decreases the stability of the slope, as the mechanism of failure is not in the clay, but rather at the clay to basal material interface. Terzaghi *et al.* (1996) refer to this failure mechanism as a spreading failure, common in varved sequences. Additionally they note these spreading failures are likely to "occur almost suddenly" and the stability depends to a large extent on

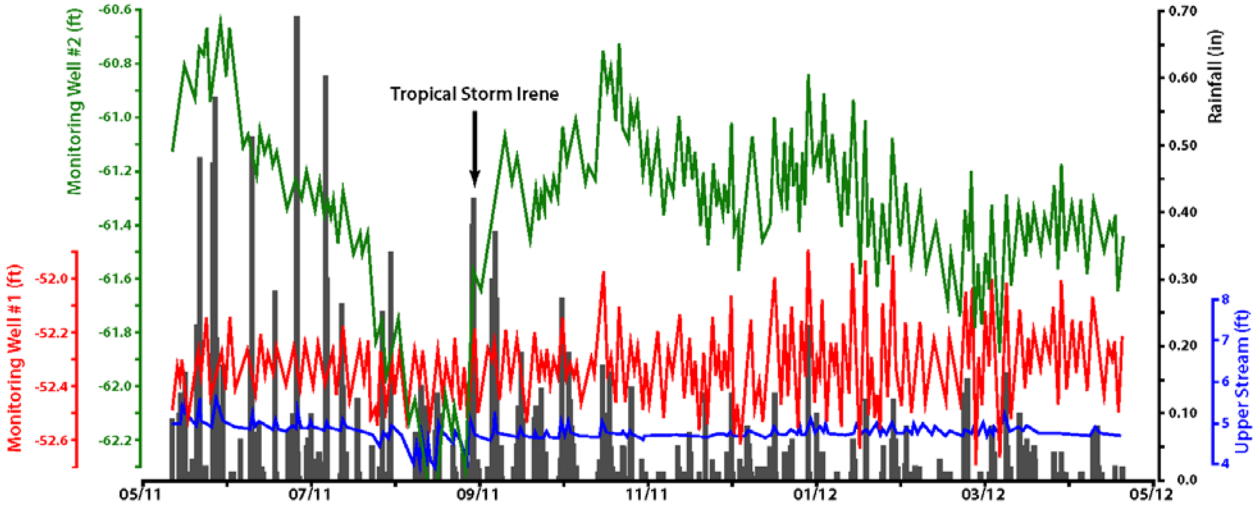


Figure 13. Precipitation and water table levels at Deer Run Heights. The series run from May of 2011 to May of 2012. Monitoring well and gauge locations are shown in Figure 2. MW1 red; MW2 green; upper stream gauge dark blue; hourly precipitation grey (Weiss 2012).

the pore water pressure at the clay - basal material surface" (Terzaghi *et al.* 1996).

The analysis described above is limited to the site of the 1999 slides. Additional slope stability modelling will be needed to understand the likelihood of major slope failures at the landslide-gully complexes at the site.

5.2 CAUSES OF SLOPE FAILURES

Although there are many possible causes or triggers for landslides (Wieczorek 1996), the operating causes at this site are probably limited to toe erosion by the Brewster River, decreased shear strength due to infiltration of snowmelt or rainfall that result in increased pore pressure, and seepage forces acting parallel to groundwater flow.

Seismic shaking can be a trigger for slope failures (Wieczorek 1996), but a review of regional seismic records for 1999 and 2006 does not reveal any substantial earthquake in Vermont or the nearby region during the times of the slope failures (Lamont-Doherty Cooperative Seismographic Network 2014).

It appears likely that both toe erosion and above-average precipitation played roles in triggering the 1999 landslides. The above-average precipitation contributed to instability through increased pore pressure in the deeper levels.

6 CONCLUSIONS

Given that landslides have occurred on this slope for more than 100 years and that the river is still removing material at the base of the slope, it is highly likely that additional landslides will occur here in the future.

The present-day pattern of slope failures at the site suggests that the most likely area for a large failure is to the north of the 1999 slide. The toe of this slope needs to be protected from erosion by the Brewster River as substantial toe erosion at this location would make slope failure much more likely.

A second area of concern is in the vicinity of Cross Section A-A', to the east of the school. This is currently the site of an active landslide-gully complex that is gradually eroding back into the field on top of the terrace. Although preliminary analysis suggests that the likelihood of a major slope failure is less than in the area to the north of the 1999 slide, monitoring will be continued.

Although the major 1954 and 1999 events and the minor 2006 and 2011 events did not result in significant damming of the river, a larger landslide or one containing more trees could conceivably result in damming of the river and consequent flooding in the village.

In terms of the timing of slope failure, this site stands in contrast to most others that we have encountered in Vermont. The general case is that slope failures are far more likely to occur during or soon after heavy snowmelt and/or rainfall events. Here, by contrast, the 1999 failures occurred during a relatively dry spring and summer, with the last period of above-average precipitation having taken place during the previous summer. As pointed out by Weiss (2012) the slow decline of water levels in Monitoring Well MW2 is consistent with the fact that pore-pressure can remain high within the slope for long-periods of time, resulting in a long-term reduction in the stability of the slope.

7 ACKNOWLEDGEMENTS

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The late Wendell "Stub" Wells generously shared his knowledge of the site and loaned us historic photos taken by his uncle, Harold Thomas.

Jonathan Kim read a draft of the manuscript and made many valuable suggestions.

8 REFERENCES

Anonymous. 1954. Landslide buries meadow in Jeffersonville, Burlington Free Press, Burlington, Vermont USA, May 12.

Antevs, E. 1928. The last glaciation with special reference to the ice retreat in northeastern North America*. American Geographical Society Research Series 17,* American Geographical Society, New York, NY, USA.

Bierman, P., Wright, S., and Nichols, K. 1999. Slope stability and late Pleistocene/Holocene history, northwestern Vermont: In *New England Intercollegiate Geologic Conference Guidebook*, Edited by S.F. Wright, Burlington, VT USA, 91: 17-50.

Clift, A.E., and Springston, G.E. 2012. Protocol for identification of areas sensitive to landslide hazards in Vermont, Manuscript report submitted to the Vermont Geological Survey, Montpelier, VT USA. Available from http://www.anr.state.vt.us/DEC/GEO/pdfdocs/TechReports/LandslideProtocol2012.pdf. [accessed 20 February 2014].

Cruden, D.M., and Varnes, D.J. 1996. Landslide types and processes. In *Landslides: Investigation and mitigation*. Edited by A.K Turner and R.L. Schuster, Transportation Research Board Special Report, Washington, D.C. USA, 247: 36-75.

Lamont-Doherty Cooperative Seismographic Network. 2014. LCSN Earthquake Catalog search [online]. Available from http://almaty.ldeo.columbia.edu:8080/data.search.html [cited 11 March 2014].

Nichols, K., Bierman, P., Klepeis, K., and Wright, S. 2004. Landslide data fix before non-geologists "fix" the landslide. *Northeastern Section Meeting*, Abstracts with Programs, Geological Society of America, Washington, D.C. USA, 36(2): 142.

Ratcliffe, N.M., Stanley, R.S., Gale, M.H., Thompson, P.J., and Walsh, G.J. 2011. *Bedrock geologic map of Vermont,* U.S. Geological Survey Scientific Investigations Map 3184. Available from http://pubs.usgs.gov/sim/3184/. [accessed 20 February 2014].

Ridge, J.C. 2003. The last deglaciation of the northeastern United States: A combined varve, paleomagnetic, and calibrated ^{14}C chronology. In *Geoarchaeology of landscapes in the glaciated northeast*. Edited by D.L. Cremeens and J.P. Hart, Bulletin 497, New York State Museum, Albany, NY U.S.A., pp.15-45.

Springston, G.E. 2008, Workplan for geotechnical study of the Jeffersonville landslide, northwestern Vermont, 2008, Report to the Vermont Geological Survey, Montpelier, VT USA.

Springston, G.E., and Thomas, E. 2014. Landslide hazard analysis of the Great Brook watershed, Plainfield, Vermont, Report to the Central Vermont Regional Planning Commission, Montpelier, VT, USA.

Terzaghi, K., Peck, R.B. and Mesri, G. 1996. *Soil Mechanics in Engineering Practice*, 3rd edition. John Wiley and Sons, Inc. New York, NY U.S.A.

Wieczorek, G.F. 1996. Landslide triggering mechanisms. *In Landslides: Investigation and mitigation*. *Edited by* A.K. Turner and R.L. Schuster, Transportation Research Board Special Report, Washington, D.C. USA, 247: 76-90.

Weiss, N. 2012. Analysis of Hydrologic Factors at the Deer Run Heights landslide in Jeffersonville, VT. Available from http://kanat.jsc.vsc.edu/drh/weiss2012.pdf. [accessed 20 February 2014].

Wright, S. F. 2003. Surficial geology of the Jeffersonville quadrangle, northern Vermont. Manuscript report submitted to the Vermont Geological Survey, Montpelier, VT, USA. Available from http://www.anr.state.vt.us/DEC/GEO/images/digitalofrs/JeffQuadFinalRp.pdf. [accessed 20 February 2014].