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Final Report on a Landslide Inventory of the Town of Highgate, Vermont

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On the cover: Deposit from a large landslide located west of Vt. Rt. 207 and the power dam at Highgate Falls, Highgate, Vermont. Power lines and fiber optic cables were damaged by this landslide that occurred in the spring of 2011. A large quantity of sediment from the landslide entered the Missisquoi River from this landslide. Photo taken on May 6, 2011 by George Springston.

Executive Summary

Landslides and gullies have long been a problem in Highgate, especially along the banks of the Missisquoi River. This project is intended to produce maps showing areas that are susceptible to slope instability.

All of Highgate except for the easternmost section was covered by glacial Lake Vermont and then the Champlain Sea. The surficial materials (gravel, sand, silt, and clay) that were deposited in these water bodies were deposited as broad sheets and, as the water levels lowered, were subsequently eroded by the Missisquoi River, the Rock River, and their tributaries to leave behind the prominent terraces on which the town has been built. The landslides and gullies identified in this study are largely developed on these terraces.

The maps in this report are primarily derived from lidar (light distance and ranging) topographic data. This data was produced as part of a 2008 project in the Lower Missisquoi watershed, which produced a digital elevation model in the form of a grid of elevations with a 1.4-meter spacing. Trees, buildings, and other structures have been removed in the processing in order to show the shape of the land surface. This highly accurate topographic data allows for new methods of terrain analysis.

The input data is shown in Plates 1 through 4 and is described in the text. Plates 5 and 6 show areas of potentially unstable slopes. These were developed by identifying areas of areas of steep slopes, areas that are close to streams, and areas that are in relatively deep valley bottoms and applying a weighted average to come up with the final areas. Those with a rank of 3 or higher are interpreted to have a high potential for slope instability.

The final values should be interpreted cautiously as there are many other factors that can influence the stability of slopes. These maps successfully identify areas of steep slopes that are near streams, and that are within relatively deep valleys. The maps do also show areas in the uplands of the town that have high scores which will turn out to be steep bedrock slopes and bedrock cliffs. Although most of these areas may not be subject to landslides, they are so steep as to preclude most development activities.

These maps identify areas of potential gully activity as well as areas of potential landslide activity. Gullying is common in the Champlain Sea and glacial Lake Vermont deposits and is intimately connected to landslide activity. For example, initiation of a gully by vertical incision may involve surface water runoff and/or groundwater sapping or piping. As the gully enlarges, landslides commonly form on the margins, leading to enlargement of the unstable area. Alternatively, a landslide initiated on a streambank due to lateral erosion at the toe may be dissected by later gully formation. The two styles of slope failure are considered together on these maps.

The slope maps also revealed several large areas adjacent to the Missisquoi River that appear to be old, formerly active, low-angle, rotational landslides. These are shown on Plates 5 and 6. All of these appear to have formed in Champlain Sea deposits. The original landslides at these sites appear to have occurred long ago, but modern stream erosion and gullying are dissecting the sites. These areas should be viewed with caution and considered hazardous as the type of landslide present at these sites suggests that the materials have very low shear strengths, especially after disturbance.

Gullies and landslides can both be caused by high groundwater levels due to spring runoff or heavy rains or by over-steepening of slopes by stream erosion. Gully and landslide activity may also be caused by changes to stormwater runoff from urban and residential areas or agricultural runoff. Changes in stormwater runoff patterns may destabilize slopes either by direct runoff over the land surface or by means of sapping and piping after the stormwater has infiltrated into the subsurface.

Water levels at the monitoring wells at the Transfer Station appear to fluctuate substantially with long-term precipitation changes and times of high water levels may correspond to times of increased risk of landslide and gully activity. It may be helpful for the Town to make monthly water level measurements at two of the wells in order to understand slope stability issues at the site.

Introduction

The Town of Highgate is located in Franklin County on the eastern shores of Lake Champlain in northwestern Vermont (Figure 1). Most of the town lies within the Missisquoi and Rock River drainage basins. Landslides and gullies have long been a problem in the town, especially along the banks of the Missisquoi River. This project is intended to produce maps showing areas that are susceptible to slope instability. The work has been undertaken at the request of the Town of Highgate with funding provided to the Vermont Geological Survey from the Vermont Division of Emergency Management and Homeland Security.

This inventory is based on the methodology described by Clift and Springston (2012) and Clift and others (2013). Field work was begun in the fall of 2015 with three field visits in October and November. The remaining field work was completed in the spring of 2016. Initial delineation of landslides and gullies using lidar topographic data and recent color orthophotos was undertaken in the winter and spring of 2016.

All of Highgate except for the easternmost section was covered by glacial Lake Vermont and then the Champlain Sea (Figure 1). The surficial materials (gravel, sand, silt, and clay) that were deposited in these water bodies were deposited as broad sheets and, as the water levels lowered, were subsequently eroded by the Missisquoi River, the Rock River, and their tributaries to leave behind the prominent terraces on which the town has been built. Most of the landslides and gullies form in the margins of these topographic features.

As glacial ice retreated from the Champlain Valley at the end of the Pleistocene Epoch, drainage northward into the Saint Lawrence valley was impeded by the remaining ice and drainage was to the south into the Hudson River valley. The shoreline elevations that follow are from Van Hoesen and others, 2016). The present-day shorelines rise northward with a slope of approximately 0.8 m/km due to isostatic adjustment following the retreat of the glacial ice. The highest phase of Lake Vermont was known as the Coveville phase. In Highgate, the shorelines from this phase are projected to be at about 239 meters (784 feet) above sea level. Only the easternmost highlands were above this level. The Lower Fort Ann phase was at about 215.5 meters (707 feet) above present sea level. Further retreat of the ice allowed marine waters to intrude into the valley and the drainage to shift to the north. The highest level of the Champlain Sea was at about 149 meters (490 feet) above present sea level. Continued isostatic uplift of the crust cut off the valley from marine waters, leaving behind a freshwater Lake Champlain.

The landslides and gullies identified in this study are largely developed on prominent terraces underlain by Champlain Sea deposits. The upper few feet of the deposits commonly consist of coarse to medium sand. This is underlain by fine sand and silty fine sand, with some silt layers. This is in turn underlain by finer-grained silt, silty clay, and clay. Glacial till has been seen near the base of some of the sections.

Figure 2 shows an example of some of the data that is available for use in the inventory. The base map shows detailed slope data obtained from lidar (light distance and ranging) topographic data that was produced as part of a 2008 project in the Lower Missisquoi watershed. The elevation data source is a bare-earth digital elevation model with 1.4-meter grid cells. Dark areas represent steep slopes and light areas represent flat or shallow ones. Orange represents areas of probable bedrock as derived from NRCS Soil Survey data. The slope data and other layers that are derived from lidar will be of key importance in undertaking the inventory. The soils data does not turn out to be accurate enough for use as a factor in landslide mapping, but it is a good general indicator of where soils are shallow and bedrock outcrops are probably abundant.

Four sites are described in the following sections. The locations of Sites 1 through 3 are shown on Figure 2. The location of Site 4, which is east of the study area, will be shown on Figure 16). These sites are typical of landslides encountered along the Missisquoi River. Landslides on the Rock River and the tributaries are smaller, but substantial landslides can occur even on quite small streams.

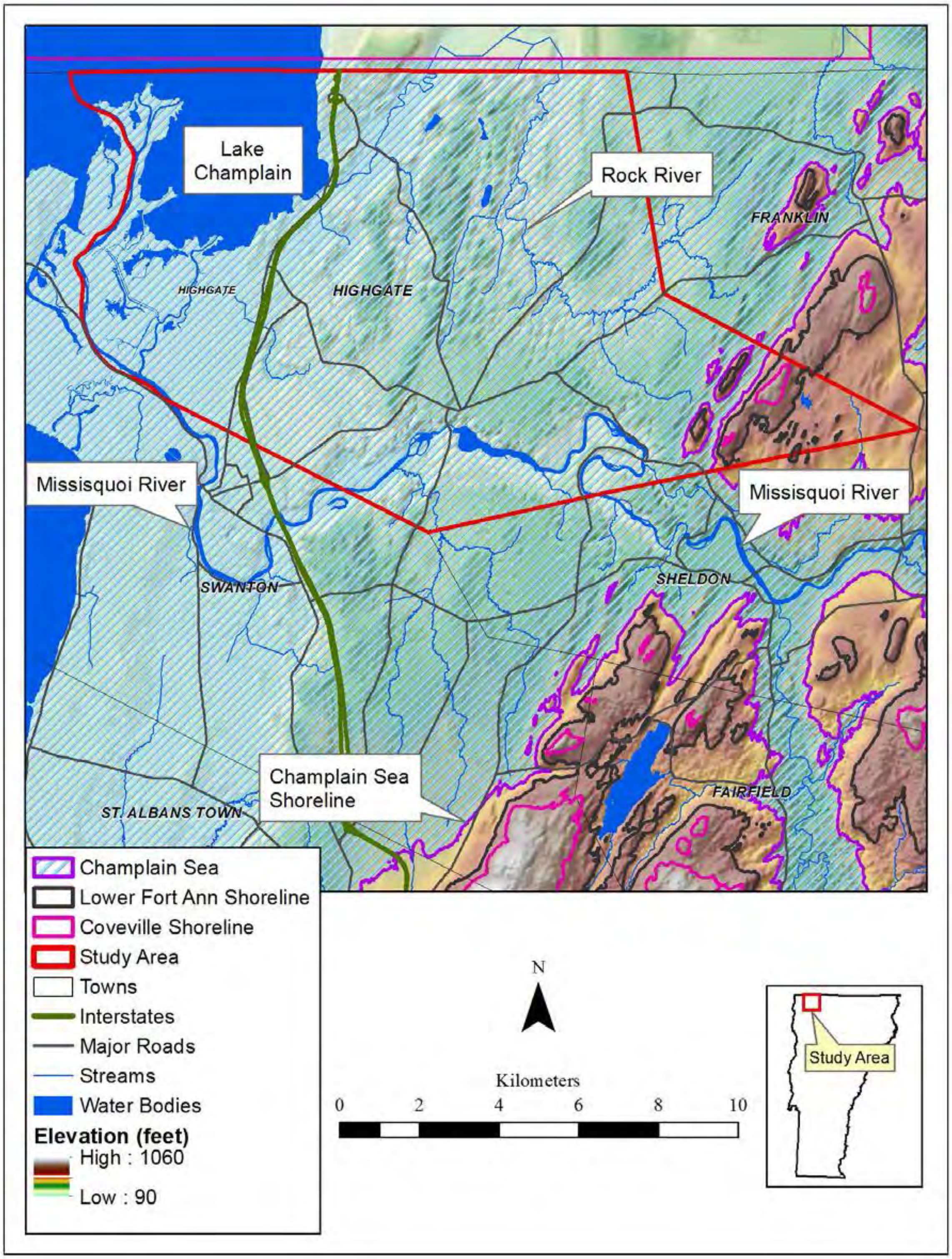

Figure 1. Location map. The shorelines of the Coveville and Lower Fort Ann stages of glacial Lake Vermont and the extent of the Champlain Sea are shown.

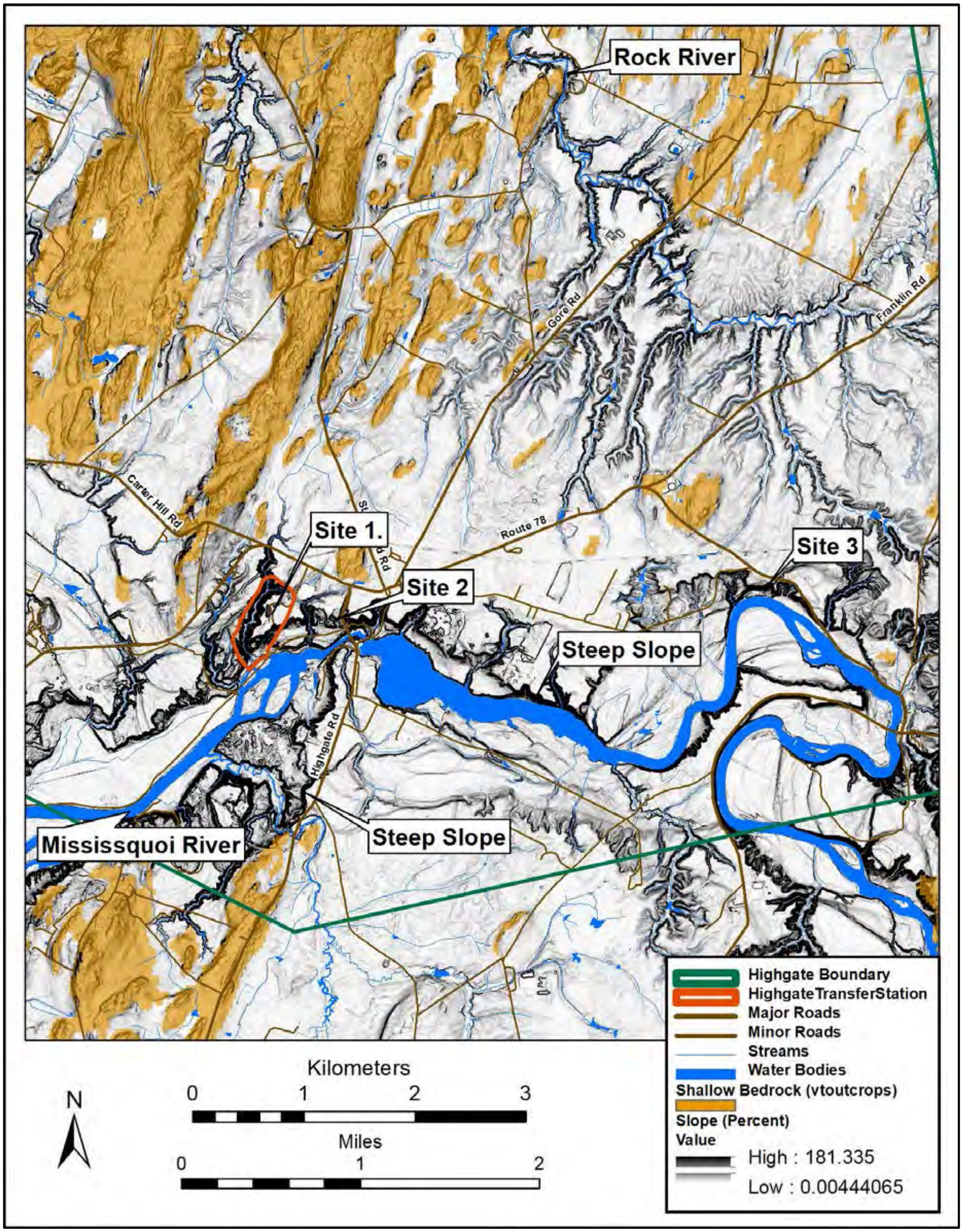

Figure 2. Map of south-central Highgate showing Sites 1 through 3. Steep slopes derived from lidar are shown as dark gray and black and areas of possible shallow bedrock derived from NRCS Soil Survey data are shown in orange.

1. Landslides and Gullies at the Highgate Transfer Station

I have made several visits to the Highgate Transfer Station, including visits in 2011 and 2013, two visits in the fall of 2015, and a visit in the spring of 2016. The property is on Transfer Station Road, south of VT Route 78 in Highgate. The site currently contains a capped landfill and a transfer station and is owned by the Town. Photos of one of the landslides at the site are shown in Figures 3 to 5.

Reports reviewed include the *Town of Highgate Sanitary Landfill Certification Application* prepared by Dubois & King, Inc. and dated December, 1985, a site plan and boring logs from a Wehran EnviroTech report dated January 5, 1992, and a report from Geodesign Inc., entitled *Town of Highgate Landslides (May 2011) Highgate, VT Preliminary Geotechnical Review and Initial Stability Analysis*, dated May 25, 2011.

The transfer station is sited on top of a terrace that is underlain by thick surficial deposits. The terrace elevation ranges from about 270 to 278 feet. The side slopes are largely wooded and quite steep, with angles commonly exceeding 32 degrees. Several of the upper unstable sections have slopes steeper than 45 degrees. Groundwater seeps are reported at 7 sites in gullies around the margin of the site and serve to define where the water table surfaces. The upper deposits consist of coarse to medium sand of variable thickness (about 15 feet appears to be the maximum and disturbance of the upper layers of the terrace has modified this material considerably). Below this, fine sand, silty fine sand, and some silt layers extend to 30 to 36 feet below the surface. Below 30 to 36 feet the material appears to be finer, consisting of fine sandy silt, silt, and silty gray clay. The Wehran Engineering plan notes glacial till in a stream valley bottom to the northwest of the site at an elevation of about 175 feet. Small exposures of till were encountered at the bases of the slopes on the north side of the site and till boulders were common in the streambed. At the time of our visit in 2011, the water table was exceptionally high: at one of the monitoring well on the west side it was only 16.6 feet below the land surface (well number uncertain). Note that this is higher than the water levels indicated on the Wehran EnviroTech plan.

Slope instability appears to be an ongoing problem on the margins of the terrace. One site had been remediated at the time of my October visit and another was being stabilized while I was there. Slope stability modeling by Geodesign suggests that parts of the slopes may be quite unstable, at least during times of high groundwater levels. Factors that may at times contribute to slope instability here also include weighting of the upper parts of slopes due to emplacement of soil or other materials and surface or subsurface runoff of storm water from the site.

One site of particular concern to the Town is an active gully located in the northern part of the site and immediately west of the Sand Shed. The edge of this gully is located within 25 feet of the building and I observed that erosion is occurring in the gully bottom, with trees falling into the gully as the sides collapse. Thus, the slope immediately to the west of the Sand Shed building is unstable and will eventually threaten the stability of the building.

Figure 3. Upper edge of landslide at Highgate Transfer Station with Transfer Station in background. Photo taken on May 6, 2011.

Figure 4. Upper edge of landslide at Highgate Transfer Station, looking toward salt shed. Photo taken on May 6, 2011.

Figure 5. Looking down the landslide towards the toe. Photo taken on May 6, 2011.

An analysis of groundwater levels in monitoring wells at the site is shown in Figure 6. A peak in average rainfall (12 month moving average) coincides with a peak in water levels in the spring of 2011. The spring of 2011 was one of the wettest on record, which perhaps would be reason enough for the landslides that occurred in several parts of northern Vermont in the late spring of 2011, but the graph also reveals that this was near the end of a two-year period of increasing precipitation. Renewed monitoring of these wells would be helpful in understanding slope stability problems at the site. I recommend monthly monitoring of at least two of the wells.

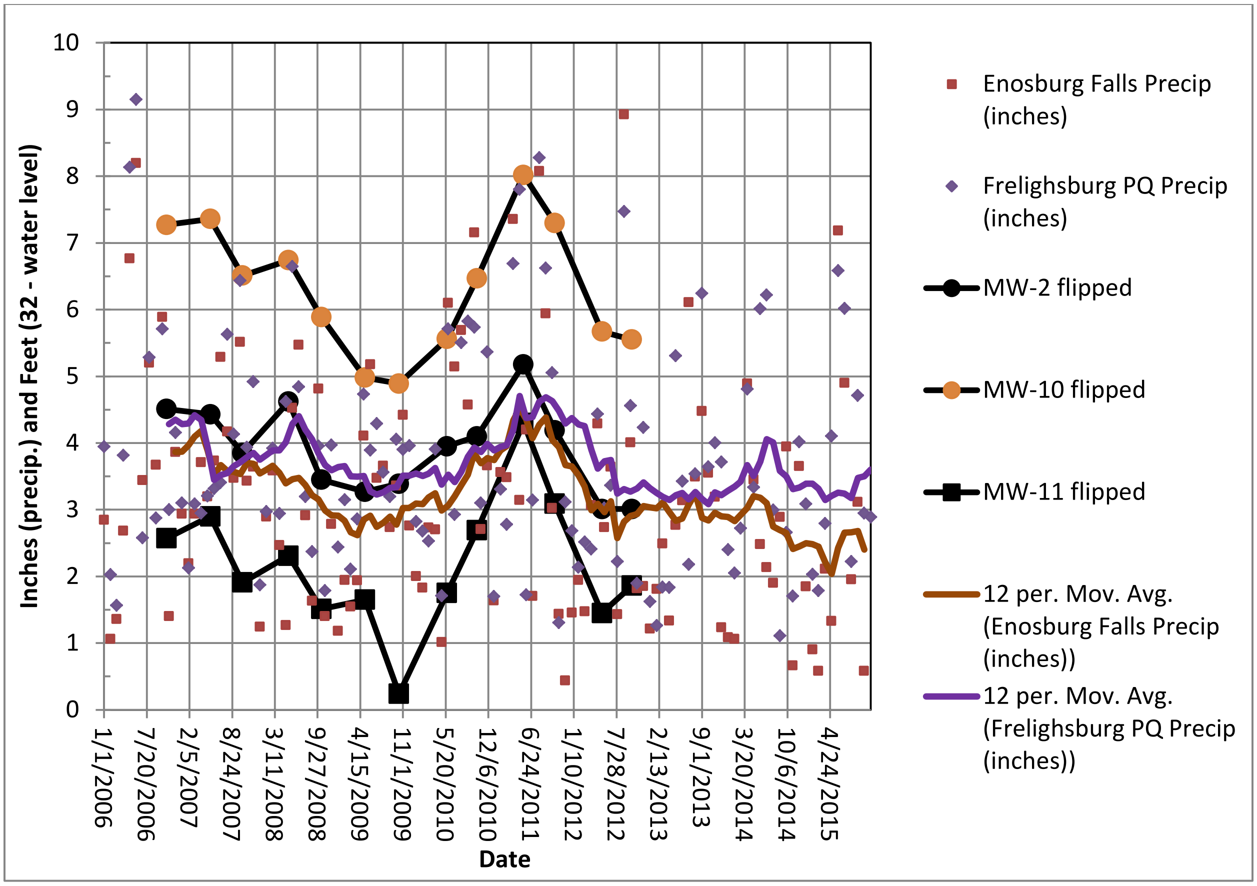

Figure 6. Comparison of water levels in monitoring wells at Highgate Transfer Station with monthly precipitation at Enosburg Falls and Frelighsburg, Quebec, from 2000 to the present. A peak in average rainfall (12 month moving average) coincides with a peak in water levels in the spring of 2011. Precipitation data downloaded from http://www.ncdc.noaa.gov/data-access/land-based-station-data . Water levels are plotted in feet as 32 feet minus depth of water below surface. This effectively flips the line to allow comparisons between water levels and precipitation.

2. Large Landslide West of Rt. 207 and Highgate Falls

This large, highly mobile rotational slide-flow originated in a ravine on the west side of Vermont Rt. 207 (Highgate Road) and the power dam at Highgate Falls. The material flowed over 900 feet before the material cascaded over the steep drop-off into the Missisquoi River (see Figures 7 and 8). This occurred in early May of 2011. As described above, this had been a very wet spring. The materials around the head of the landslide were difficult to access at the time of the site visit due to saturation with water, but they appeared to be fine sands over silt-clay. The landslide originated in a ravine that had experienced slope failures in the past as the landowner had built retaining walls of old tires in an attempt to stabilize the slopes. The landslide deposits, as shown below, were studded with some of these tires.

Figure 7. Deposit from the large landslide located west of Rt. 207 and the power dam at Highgate Falls, Highgate, Vermont. Power lines and fiber optic cables were damaged by the landslide. A large quantity of sediment from the landslide entered the Missisquoi River from this landslide.

Figure 8. Head of the landslide west of Highgate Falls.

3. Landslide on South Side of Riverview Lane, Highgate

A substantial landslide located to the north of the Missisquoi River was the site of a recent FEMA buyout of two homes (Figure 9). This site is important for the landslide study as it is an example of a site where a slope failure has occurred that is not due to riverine erosion. On May 9, 2013 I visited the Simmons property on the south side of Riverview Lane, which is on the south side of VT Route 78. The top of the landslide is located south and southeast of the Simmons house and is about 130 feet above the Missisquoi River. This steep slope consists of a wooded, gullied slope. The upper 60 feet of the slope is very steep, with an average angle of 42°. The top 10 feet or so is even steeper.

At the time of the site visit the river was not eroding the base of this slope. Whatever the cause may be, it is operating higher up on the slope. At the base of the slope I observed a fan or flow of mud that had washed out of the base of the gully (Figure 10). Exposures on the side of the gully showed wet, plastic silty clay (Figure 11). Seeps partway up the slope appear to mark the transition from fine-grained material below (silty clay or similar material) to coarser-grained material above. The materials exposed in the upper part of the landslide consist of bedded very fine sand, fine sand, and medium sand (Figures 12, 13). These sands appear to be on the order of 55 to 60 feet thick.

Subsurface erosion appears to be occurring near the base of the sand, leading to the flow of mud at the base and to collapse of the sands above.

Mr. Simmons stated that he first noticed that the slope was failing after Hurricane Sandy. Since then, landslide movements have led to displacement of substantial blocks of soil and trees have toppled outward onto the landslide. It does appear that the primary cause of this landslide was high groundwater levels due to precipitation.

The edge of the landslide was 25.0 feet from the southeast corner of the house at the time of my visit. The top of the slide is shown in Figures 14 and 15. I did not observe any cracks on the outside of the foundation and Mr. Simmons stated that he did not know of any cracks visible on the inside. I recommended that a qualified engineer evaluate this site as soon as possible. Subsequent evaluations led the Town to conduct FEMA buyouts of this and an adjacent property.

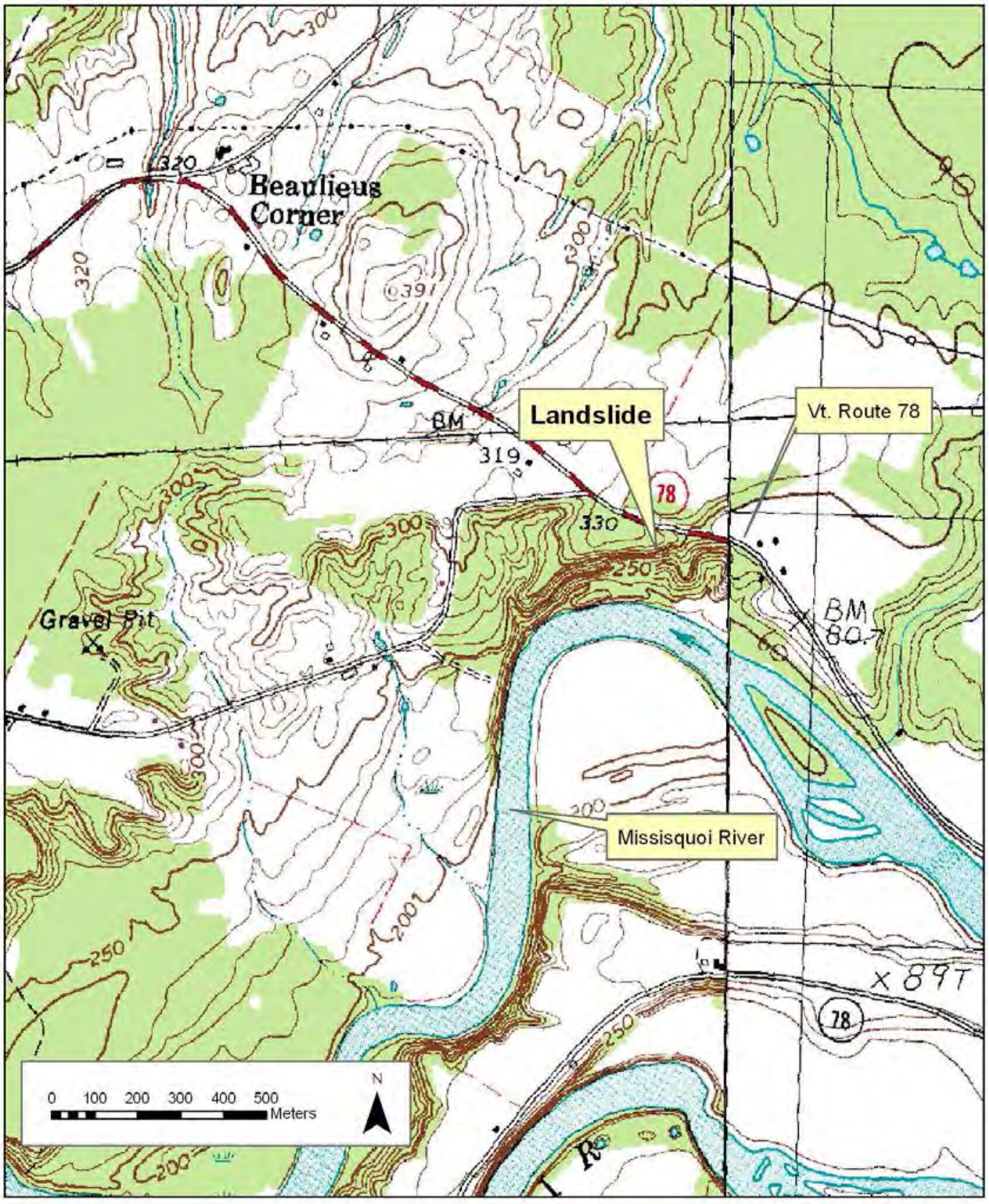

Figure 9. Location Map.

Figure 10. Mudflow at base of landslide.

Figure 11. Gully exposing silty clay near base of slope.

Figure 12. Upper part of slide.

Figure 13. Sands exposed in upper part of slide.

Figure 14. Top of landslide.

Figure 15. The top of the landslide is to the left of the line of blocks.

4. Large Landslide on the Missisquoi River in Sheldon

This site is a large landslide on the south side of the Missisquoi River in the Town of Sheldon (Figure 16). It is included here because it is a large, well-exposed rotational slide-flow that has formed in similar surficial materials to those along the river in Highgate. Similar landslides have occurred in the past along the banks of the Missisquoi River in Highgate. The last major failure at the Sheldon site was in the spring of 2009. I visited the site on May 28, 2009 and on June 7, 2011. The slope is 60 to 70 feet high and the landslide has an overall angle of 10 degrees. The landslide toe deposit pushed far out into the river as shown in Figures 17 and 18. Views from the top are shown in Figures 19 and 20.

The general stratigraphy is a thin unit of sand and gravel over fine sands over silt-clay (Figures 21 and 22). The uppermost unit consists of 2.3 to 5.7 feet of pebbly medium to coarse sand and coarse sandy pebble gravel. This overlies 3.6 feet of laminated fine sand with ripple-drift cross lamination. Below this is 4 feet or more of dense, varved silt and silty clay. Penetrometer readings in the silt-clay unit varied from 4.0 to greater than 4.5 tons per square foot. The silt-clay unit appears to make up the bulk of the section, although the only materials encountered on the lower parts of flanks are deformed landslide deposits from earlier slope failures.

This landslide is located on the outside of a meander bend of the river and appears to have been caused principally by erosion of the toe of the deposit. The landowner on the north bank of the river reported that landslides had occurred here in earlier years. This fits with observations made on the site and interpretation of the lidar slope data.

The low runout angle of the landslide suggests that the material has, when saturated, a very low shear strength. Similar materials are present in the deeper layers in the deposits downstream in Highgate.

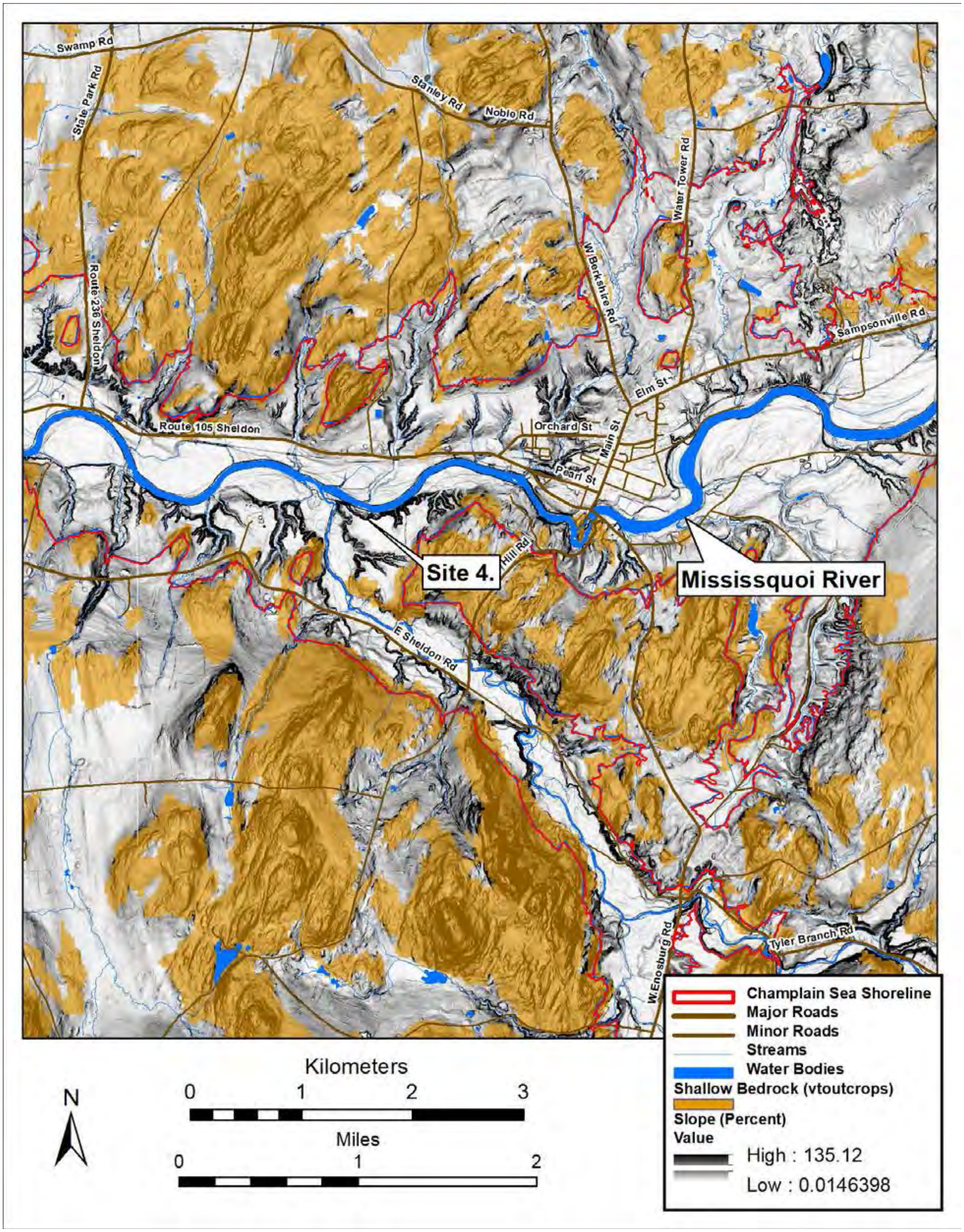

Figure 16. Location map for the Sheldon landslide. This site is a well-exposed example of one of the types of landslides that occurs in the Highgate study area.

Figure 17. View of the Sheldon landslide from upstream on May 12, 2009. The landslide toe deposit seen at left has pushed far out into the channel. Photo by Chris Brunelle, VT DEC.

Figure 18. Looking across at back-rotated blocks on south shore of river on May 12, 2009. Photo by Chris Brunelle, VT DEC.

Figure 19. Looking downstream and across landslide from top on May 12, 2009. Photo by Chris Brunelle, VT DEC.

Figure 20. Looking down landslide at blocks of silt-clay in toe deposit on May 28, 2009.

Figure 21. Fluvial sand and gravel over lacustrine fine sand at the top of the section. June 7, 2011.

Figure 22. Upper portion of Sheldon landslide on May 28, 2009. Stratigraphic units visible are fluvial sand and gravel, lacustrine fine sand, and the upper portion of the lacustrine varved silt and silty clay.

Identification of Potentially Unstable Slopes

This work was undertaken by a combination of field work and computer-based terrain analysis. The data used to produce the final maps is shown on Plates 1 through 4, which are described below.

Plate 1 shows the slope of the land surface. The map is derived from lidar (light distance and ranging) data. This data was produced as part of a 2008 project in the Lower Missisquoi watershed, consisting of a bare-earth digital elevation model in the form of a 1.4 meter raster grid with a 9.25 centimeter root mean square error in the vertical direction. Trees, buildings, and other structures have been removed in the processing in order to show the shape of the land surface. Steep slopes are shown as black, intermediate slopes are gray, and flat areas are shown as white.

Plate 2 shows the slope data shown on Plate 1 reclassified into three classes that are used as components of the map of potentially unstable slopes shown on Plates 5 and 6. The map is divided into classes as follows:

Class 1 - 0 to 30 % (0 to 16.5 °)
Class 2 - 30 to 72.7 % (16.5 to 36°)
Class 3 - > 72.7 % (>36°)

Plate 3 shows distance to streams and large water bodies. The streams and water bodies are from the Water_VHDCARTO line and polygon layers from the Vermont Center for Geographic Information. This is used as a component of the map of potentially unstable slopes shown on Plates 5 and 6. The map is divided into classes as follows:

Class 1 - > 30 meters
Class 2 - 0 to 30 meters

Plate 4 shows areas with valley depth greater than 10 meters. This is based on an analysis of local topographic relief and is used as a component of the map of potentially unstable slopes shown on Plates 5 and 6. It emphasizes the lower portions of valleys in areas of moderate to high relief. The map is divided into classes as follows:

Class 1 - 0 to 10 meters depth
Class 2 - > 10 meters depth

Plates 5 and 6 show a model of potential slope instability. Plate 5 uses a shaded-relief base map and Plate 6 uses a color orthophoto base map. The model of slope stability is shown on both plates and is based on the data shown in the preceding plates. This data consists of raster classifications of the steepness of slopes, distance to streams and large water bodies, and valley depth. Weighted scores are calculated by summing up the values as listed below. Note that steep slopes are weighted the heaviest.

Slope:

Class 1 - 0 to 30 % (0 to 16.5 °) , Score = 0
Class 2 - 30 to 72.7 % (16.5 to 36°), Score = 2
Class 3 - > 72.7 % (>36°), Score = 3

Distance to Stream:

Class 1 - > 30 meters, Score = 0
Class 2 - 0 to 30 meters, Score = 1

Valley Depth:

Class 1 - 0 to 10 meters depth, Score = 0
Class 2 - > 10 meters depth, Score = 1

The sum of the three factors can range from 0 to 5. Sums of 0 and 1 are interpreted to represent low potential for slope failure. Sums of 2 represent intermediate or moderate potential. Sums of 3 through 5 represent high potential. The classification is designed to give greatest weight to steepness of slope.

The final values should be interpreted cautiously as there are many other factors that can influence the stability of slopes. These maps successfully identify areas of steep slopes that are near streams, and that are within relatively deep valleys. The maps do also show areas in the uplands of the town that have high scores which will turn out to be steep bedrock slopes and bedrock cliffs. Although most of these areas may not be subject to landslides, they are so steep as to preclude most development activities

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The slope maps also revealed several large areas adjacent to the Missisquoi River that appear to be old, formerly active, low-angle, rotational landslides. These are shown on Plates 5 and 6. All of these appear to have formed in Champlain Sea deposits. The original landslides at these sites appear to have occurred long ago, but modern stream erosion and gullying are dissecting the sites. These areas should be viewed with caution and considered hazardous as the type of landslide present at these sites suggests that the materials have very low shear strengths, especially after disturbance.

Conclusions

A set of maps was developed using highly accurate lidar topographic data to identify areas that have a high potential for slope instability. These were identified by combining areas of steep slopes, areas that are close to streams, and areas that are in relatively deep valley bottoms together by means of a weighted average to come up with the final areas. Those with a rank of 3 or higher are interpreted to have a high potential for slope instability.

Although there are many possible causes of slope instability problems (Cruden and Varnes, 1996), this and other studies in Vermont have shown that gullies and landslides are most likely to occur during and after times of prolonged rainfall or rapid snowmelt that lead to increases in groundwater levels and pore-water pressures and also after episodes of extensive stream bank erosion, which results in over-steepening of slopes. Gully and landslide activity may also be caused by changes to stormwater runoff from urban and residential areas or agricultural runoff. Changes in stormwater runoff patterns may destabilize slopes either by direct runoff over the land surface or by means of sapping and piping after the stormwater has infiltrated into the subsurface.

Water levels at the monitoring wells at the Transfer Station appear to fluctuate substantially with long-term precipitation changes and times of high water levels may correspond to times of increased risk of landslide and gully activity. It may be helpful for the Town to make monthly water level measurements at two of the wells in order to understand slope stability issues at the site.

Acknowledgements

This project was undertaken through a grant from the Vermont Geological Survey to Norwich University with funding from the Vermont Division of Emergency Management and Homeland Security. Numerous discussions with Marjorie Gale, Vermont State Geologist, and Laurence Becker, former Vermont State Geologist, were off great importance in the development of the methodology used in this project. Thanks to Heidi Britch-Valenta, Highgate Town Administrator, for all her help with developing and completing this project. Andrew King, Highgate Public Works Director, was extremely helpful in showing us known problem areas and providing access to sites. Caroline Alves, Soil Scientist and GIS Specialist at the USDA Natural Resources Conservation Service, generously shared her work on gully identification in the Rock River watershed and helped examine the Sheldon landslide site.

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