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Landslide Inventory of Orange County, Vermont

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On the cover: Active landslide on the Third Branch of the White River at the Randolph Landfill, October, 2003. Photo by George Springston.

Executive Summary

Landslides and gullies were inventoried in Orange County in east-central Vermont.

Over 250 features were identified using a combination of field investigations and remote sensing using lidar (light distance and ranging) topographic data and recent, high-resolution orthophotos from the Vermont Center for Geographic Information.

Most of the landslides are located on steep slopes close to streams at sites of active streambank toe erosion. When long-term data is available, the landslides are generally in locations that have been failing for a long time. By mapping the present locations of landslides we can predict many of the locations where slopes will fail in the future.

In comparison to Washington and Chittenden Counties, unstable gullies are relatively uncommon in Orange County. The few actively eroding gullies in the County appear to be closely associated with stormwater runoff from roads and developed areas, with a lesser amount associated with agricultural fields. The lower density of gullies may be due mostly to a lower population density and less development.

The principal causes of the slope failures appear to be the over-steepening of slopes due to fluvial erosion of banks and stream beds during flash floods and decreases in shear strength of soils due to increases in soil water pore pressures due to the heavy rainfall.

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Introduction

This report presents the results of a detailed study of the existing landslide, gullies, and other slope instability indicators in Orange County in east-central Vermont (Figure 1). This study is intended to provide an accurate basis for local, state, and Federal hazard planning in the area.

The current State Hazard Mitigation Plan identifies mapping of landslides gullies, and other slope instability hazards as an important component of hazard mitigation efforts in Vermont (http://vem.vermont.gov/plans/SHMP). This inventory of Orange County is based on the Phase 1 inventory method outlined in Clift and Springston (2012).

The inventory was undertaken using a variety of sources. Sources of locations of existing landslides and other features included:

1. Landslide Protocol study conducted for the Vermont Geological Survey (VGS) by Clift and Springston (2012).

2. Surficial geologic mapping projects produced for the VGS.

3. Data from individual site visits conducted by the author for the VGS.

4. Data from the stream geomorphic assessment data provided by the Vermont Rivers Program. Of critical importance is the Phase 2 field data on mass failures and eroding banks derived from the Feature Indexing Tool (FIT).

Lidar (light distance and ranging) topographic data from the Vermont Center for Geographic Information was an essential component of the study. Lidar is very detailed airborne laser topographic mapping. Trees, buildings, and other structures have been removed in the processing in order to show the shape of the land surface. The data was used both as an accurate source for determining elevations and heights of features, and as the basis for calculating the steepness of slopes. In the slope maps shown in this report steep slopes are shown as black, intermediate slopes are gray, and flat areas are shown as white. The slope data was also classified to produce a GIS layer showing ranges of slope: 0 to 33%, 33-50%, 50-73%, 73-100%, and greater than 100%.

Interpretation of slope instability features was undertaken by viewing existing site data in combination with the coded lidar slope map, streams (1:5,000 surface waters from the Vermont Hydrologic Dataset), and recent high-resolution orthophotos.

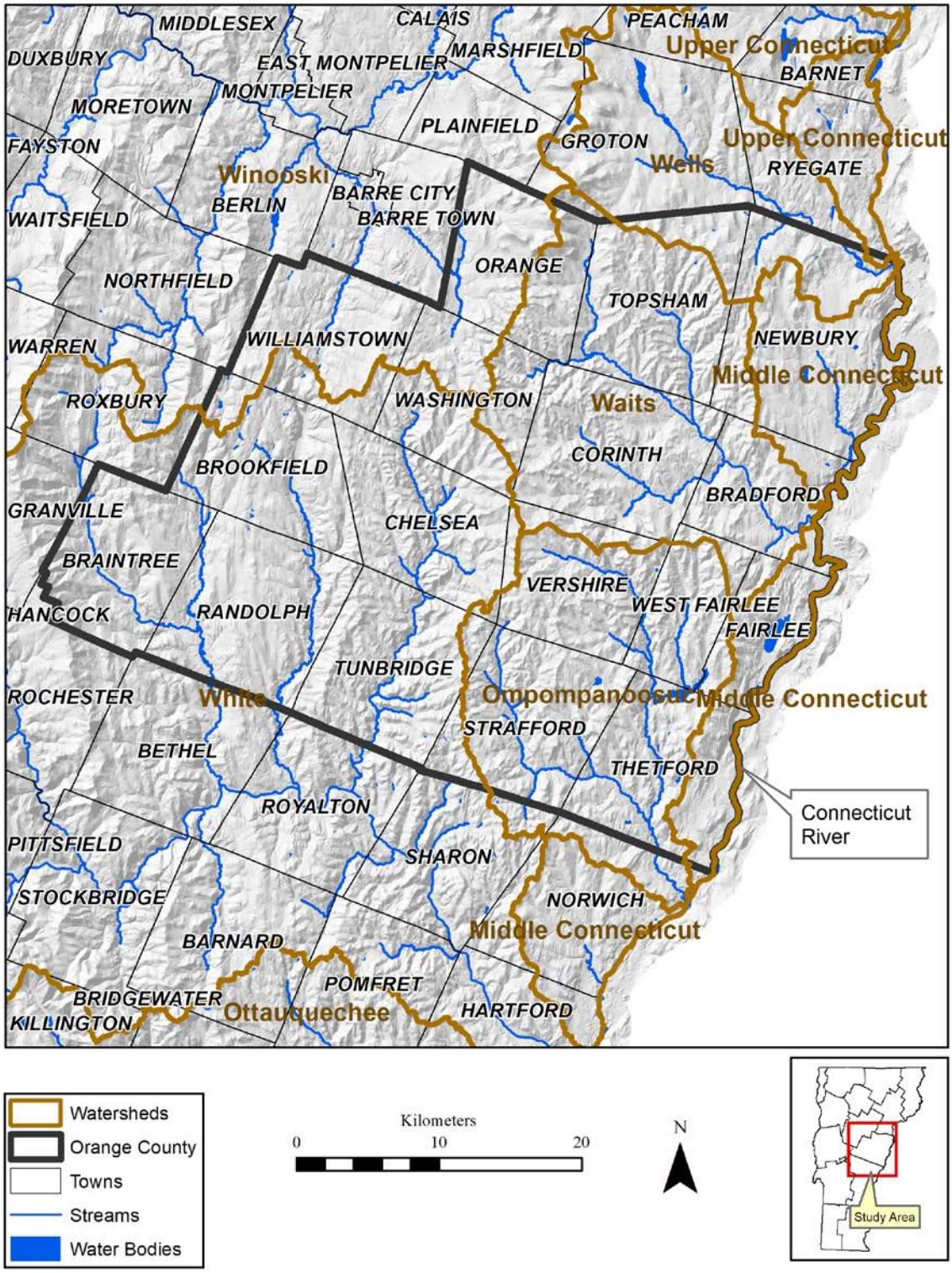

Figure 1. Location map.

Previous Work

Although there have been many studies of landslides and associated slope instability hazards in Vermont, most were focused only on small areas or specific sites and a detailed inventory that is useful for hazard planning has been lacking. A detailed chronology of the earlier studies is given in Clift and Springston (2012). The only previous statewide inventory is that of Baskerville and Ohlmacher (2001), but that is a somewhat rough reconnaissance study on small-scale base maps. The Vermont Geological Survey is currently undertaking a series of landslide inventories (Springston, 2017; Springston, 2018; Springston and Gale, 2018).

Landslide Inventory

The inventory is shown in detail on Plate 1 and includes landslides, gullies, and other slope instability hazards. A much-reduced version of the inventory is shown in Figure 2. A landslide is a feature formed by the downslope movement of rock and/or soil under the influence of gravity. A good general discussion of landslides is given in Highland and Bobrowsky (2008). The term "landslide" as used in this report includes a wide variety of falls, slides, and flows. The material can range from rock, through debris, to earth (predominantly <2 mm). A classification of slope movements based on the general type of movement and type of material is shown in Table 1. A further subdivision of the earth slides and earth slumps into rotational and translational types is shown in Figure 3 and the terminology used to describe the geometry of a typical landslide is shown in Figure 4. A landslide is commonly identified by the presence of steep slopes and/or evidence of soil movement and surface or subsurface erosion. Most originate near streams, although they may extend quite far from the streams. The mass failures identified during stream geomorphic assessment studies are landslides.

Table 1 - Simplified classification of slope movement types.
Modified from Varnes (1978). Types common in Vermont are in bold.

Type of Movement	Type of Material		
	Bedrock	Engineering Soils	
		Predominantly coarse	Predominantly fine
Falls	**Rock fall**	Debris fall	**Earth fall**
Topples	**Rock topple**	Debris topple	**Earth topple**
Slides*	**Rock slide**	**Debris slide**	**Earth slide or slump**
Spreads	Rock spread	Debris spread	Earth spread
Flows		**Debris flow**	**Earth flow**
Complex	**Combinations of two or more types of movement**		
Creep	**Several types**		

*Slides may be subdivided into rotational and translational types. Rotational slides in relatively homogeneous materials are commonly called "slumps". The term "rotational slump", although somewhat redundant, will be used here to emphasize the distinction from translational slides.

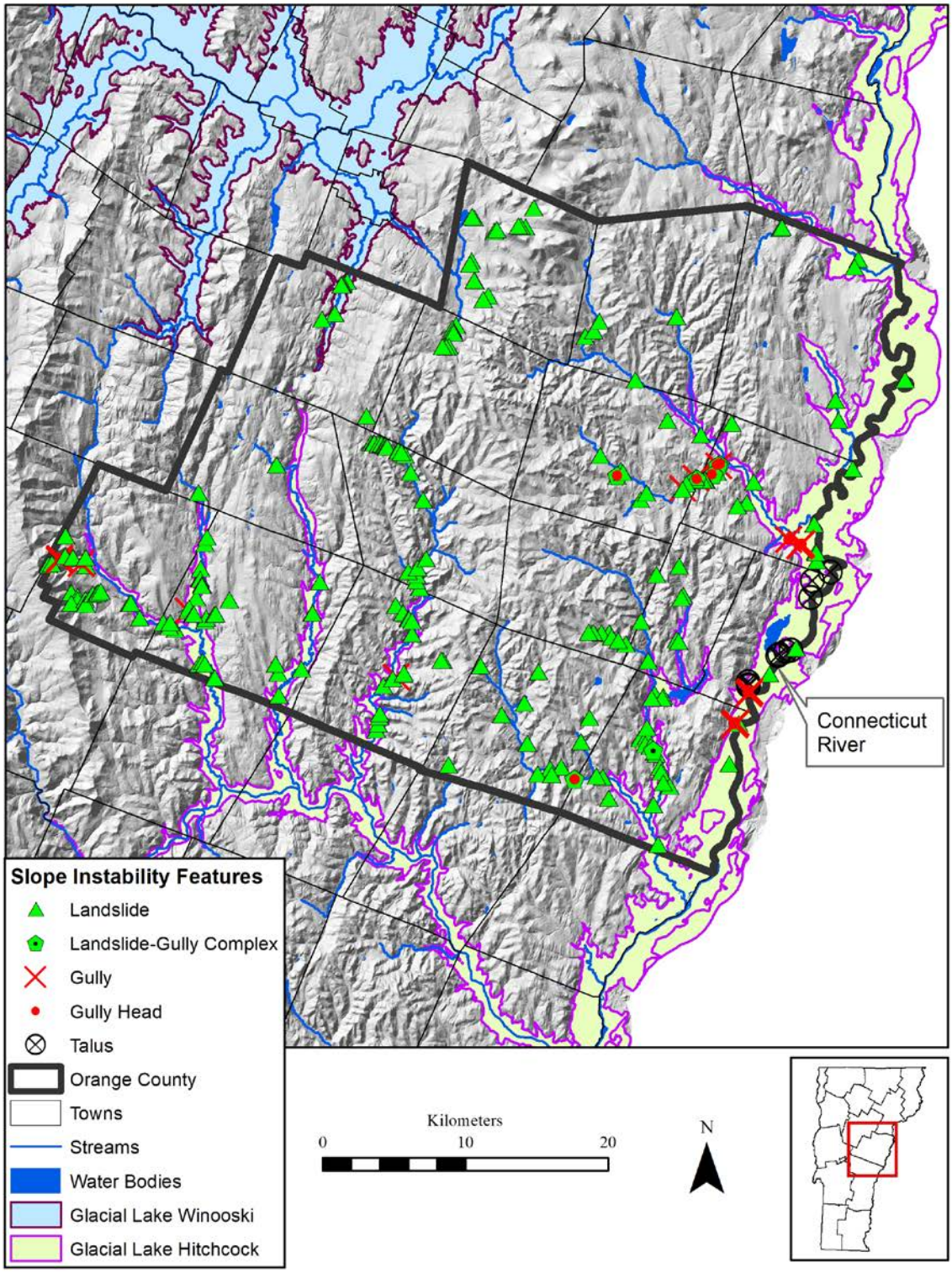

Figure 2. Generalized map of all slope instability hazard sites. These include landslides, landslide-gully complexes, gullies, and talus slopes. These are shown at a larger scale on Plate 1.

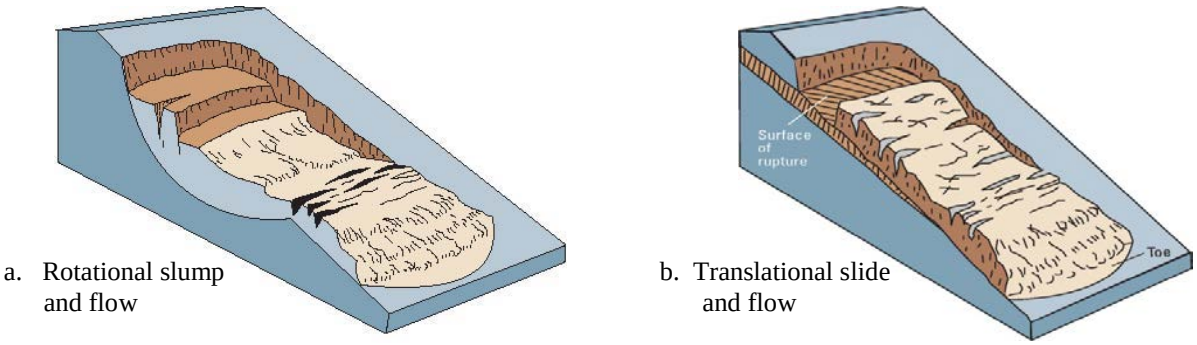

Figure 3. Two common types of landslides in Vermont. a) rotational slump and flow, b) translational slide and flow. From Highland and Bobrowsky (2008).

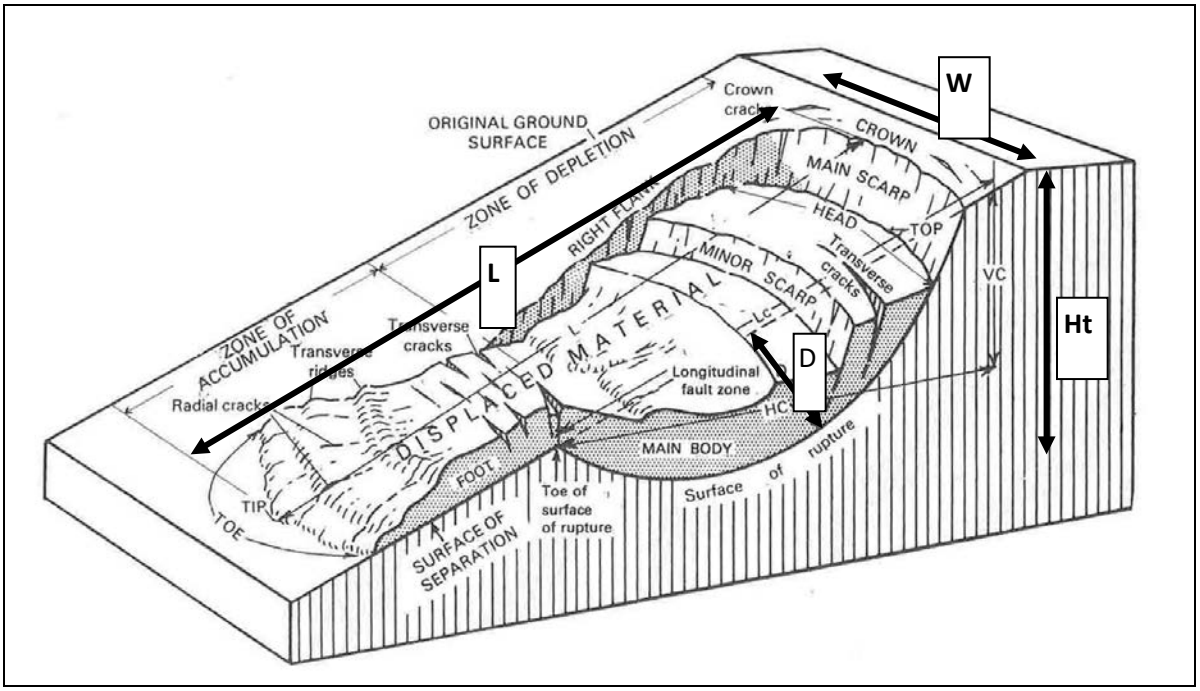

Figure 4. Generalized complex rotational slump/flow. Landslides with this overall form are common on clayey to sandy lacustrine deposits throughout Vermont. In many cases the displaced material has been at least partially eroded away by stream flow. Length (L) refers to the total slope length from crown to the tip of the toe. Width (W) refers to the width of the feature measured across the slope at the location of greatest width. Depth (D) is measured in a vertical plane and perpendicular to the original slope. Height (Ht) refers to the vertical height from the toe up to the top of the slide. Modified from Cruden and Varnes (1996, Figure 3-3).

Eroding banks are common along many of the streams in the county but are not included in this inventory. Eroding banks are formed by the same mechanisms as landslides, but a cutoff has been set at about 4 meters in height, with eroding banks being below that height and

landslides above it. A typical example is shown in Figure 5. Although the distinction may seem arbitrary, it is commonly the case that eroding banks are forming on the sides of low terraces that are themselves subject to inundation flooding. In contrast, landslides are generally high enough that they are not going to have their tops flooded (at least during normal floods of short recurrence intervals). Thus, the landslide hazard may be more of a fluvial erosion hazard than an inundation hazard.

Figure 5. Eroding bank of the Dog River, Northfield, Vermont. Shovel and notebook for scale. Flow is away from observer. Sandy alluvium has been undercut during recent high flows and is in the process of collapsing. Photo by George Springston, April, 2007.

A gully is a steep, narrow channel incised into surficial deposits. The stream is usually a first-order stream and the flow in the bottom is usually intermittent. Unstable gullies have very steep sides and commonly show signs of fresh erosion in the bed or at the gully heads. The heads of gullies have been indicated for many of the unstable gullies. These serve to give some idea of the extent of the features. A landslide-gully complex includes one or more gullies with associated landslides.

A talus deposit is a fan or apron of fallen rock at the base of a cliff. Talus deposits are mapped in order to indicate the presence of unstable rock slopes that are prone to failure. In Orange County extensive talus deposits are present at the bases of the tall, steep cliffs in and near Fairlee near the Connecticut River (Figure 6). These are shown on Figure 2 and Plate 1.

Figure 6. Looking up from U.S Rt. 5 in Fairlee at extensive talus deposit at base of cliff. The heavy steel fence has been constructed to reduce the likelihood of falling rocks reaching the highway. Photo courtesy of Ethan Thomas, VTrans.

A typical streamside landslide is shown in Figures 7 and 8. This site is on the east side of the Second Branch of the White River in East Randolph. The landslide exposes an alluvial terrace deposit of sand and gravel overlying glaciolacustrine silt and silty clay interpreted to have been deposited in glacial Lake Hitchcock. The landslide appears to have been driven largely by toe erosion.

Figure 7. Landslide in alluvial terrace deposits overlying lacustrine silt-clay deposits on Second Branch of White River in East Randolph. Photo by George Springston, 2006.

Figure 8. Close-up view of alluvial sand and gravel overlying grey lacustrine silt and silty clay in landslide scar shown in Figure 7. Photo by George Springston, 2006.

The Third Branch of the White River between Braintree and Bethel shows abundant evidence of rapid stream migration, which appears to be at least partly due to thick deposits of highly erodible glaciolacustrine silt and silty clay deposits (Figure 9). From the 1990s through the spring of 2007 a meander bend of the Third Branch at the Randolph Landfill underwent particularly rapid migration, with the top of the bank retreating up to 30 feet over the course of two years (Figures 10 and 11). In the spring of 2007 a neck cut-off of the bend in the river occurred, leaving the former meander bend as an abandoned oxbow (see final panorama in Figure 11).

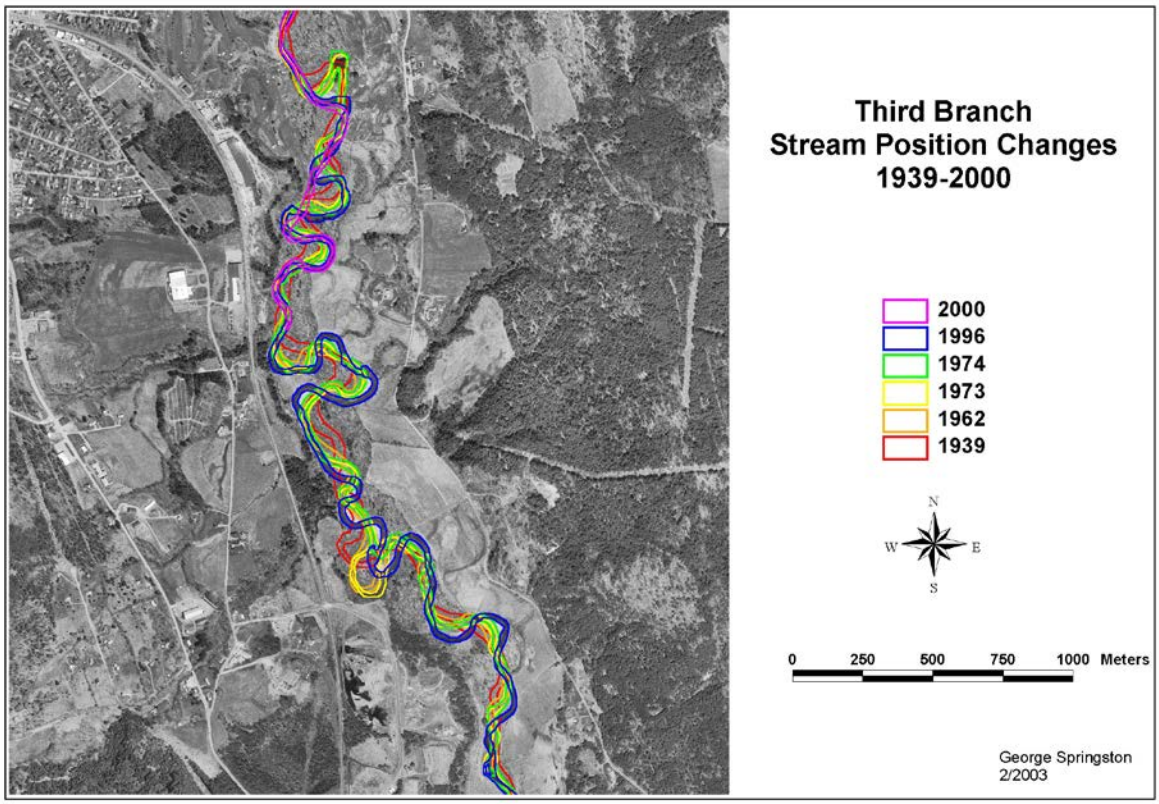

Figure 9. Planform changes along the Third Branch of the White River in southern Randolph from 1939 to 2000. Extensive landslides and bank erosion are associated with these dramatic channel shifts.

Figure 10. Landslide in fine-grained deposits of glacial Lake Hitchcock on the Third Branch of the White River at the Randolph Landfill. Photo by George Springston, 2004. The slope is about 9 meters (29 feet) high.

10/2003

5/2006

7/2007

Figure 11. Panoramas showing changes from 2003 to 2007 at a rapidly elongating meander bend of the Third Branch at the Randolph Landfill. In the spring of 2007 the neck of the meander (seen in the background) had cut off and the channel became an abandoned oxbow as shown in the final photo taken in July of 2007.

In comparison to Washington and Chittenden Counties, unstable gullies are relatively uncommon in Orange County. The few actively eroding gullies in the County appear to be closely associated with stormwater runoff from roads and developed areas, with a lesser amount associated with agricultural fields. The lower density of gullies may be due mostly to a lower population density and less development. However, these unstable gullies are also largely within

the portions of the lowlands that were formerly occupied by glacial lakes. As these lowland areas are often the sites of the larger towns, it is somewhat uncertain whether the unstable gullies are more due to the increased density of population, roads, and buildings or to the highly erodible sand and silt/clay deposits that underlie these areas.

A typical unstable gully is shown in Figures 12 and 13. The gully is part of a landslide-gully complex on the southwest bank of the Ompompanoosuc River in Thetford that has eroded into about 20 feet of loose, coarse-sandy boulder cobble gravel overlying 11 feet of dense fine-sand to silt-matrix till over bedrock. The culvert outfall shown in Figure 12 drains onto the slope. In this particular case it appears that road runoff has contributed significantly to the formation of the gully.

Figure 12. Looking down at a typical unstable gully near the Ompompanoosuc River in Thetford.

Figure 13. Looking up the center of the gully at highly erodible gravel deposit.

Rock Slope Failures and Debris Flow Hazards

Rock slope failures and debris flows are two types of landslide that occur on steep, bedrock-dominated terrain in Vermont. Debris slides and debris flows have not been identified in Orange County, but they have been identified in the more mountainous parts of the state, including Smugglers Notch (Springston, 2009).

Patterns of Slope Failure on Till Slopes

Many of the landslides in Orange County originate in glacial till deposits. A typical landslide in till is shown in Figure 14. Observations of the landslides here and elsewhere in Vermont suggest the following as a common sequence of events on till-dominated slopes in response to catastrophic flood events (Springston and Thomas, 2018). Note that the events described below will not always take place in a sequence of discrete steps. For example, a translational slide on the upper part of a landslide may be occurring at the same time that the base is being undercut by flood waters. The model is illustrated in Figure 15.

- Fluvial shear results in erosion of the bank and/or bed, over-steepening the slope and, if bed erosion occurs, increasing the effective height of the slope. Dense till and lacustrine diamict typically are detached as irregular blocks. Loose materials typically are detached as single grains. At sites where the material is very strong, the stream may undercut the bank, leaving an overhang. Infiltration of rainfall results in an increase in pore-pressure in the surficial material, reducing the effective shear strength of the material.
- Translational slides occur off the upper slope, commonly carrying blocks of soil and trees, with depths of 1.5 to 5 feet (0.5 to 1.5 meters). Parts of the sliding blocks may break up into flows. A rotational slump may occur in place of or following a shallow translational slide. This type of slope failure is more common in lacustrine or ice-contact or stream terrace deposits than in till, but a few examples of rotational slumps have been observed in dense till deposits that were severely undercut by catastrophic flooding.
- Material reaching the base of the slope may either be swept away by the stream or accumulate to form a toe deposit.
- The water level of the stream recedes, perhaps leading to additional slope failure as the support of the water on the lower face is removed.
- Overhangs begin to fail and translational slides and flows remove material from the upper parts of the landslide.
- With the passage of time, mass-wasting and weathering processes begin to alter the deposits. Material continues to fall, topple, slide, or flow off of the upper slopes. Weathering of the fresh deposits becomes evident after the first winter, with the outer 0.5 to 1 inch (1 to 2.5 cm) of even the densest till beginning to soften. Rills begin to dissect parts of the upper faces and the toe deposits. Even after only a single year, pioneer vegetation such as coltsfoot and horsetails begin to colonize the slopes.

Figure 14. A typical large landslide in till. From the Great Brook watershed in Plainfield, Vermont. Photo taken in 2013 by George Springston.

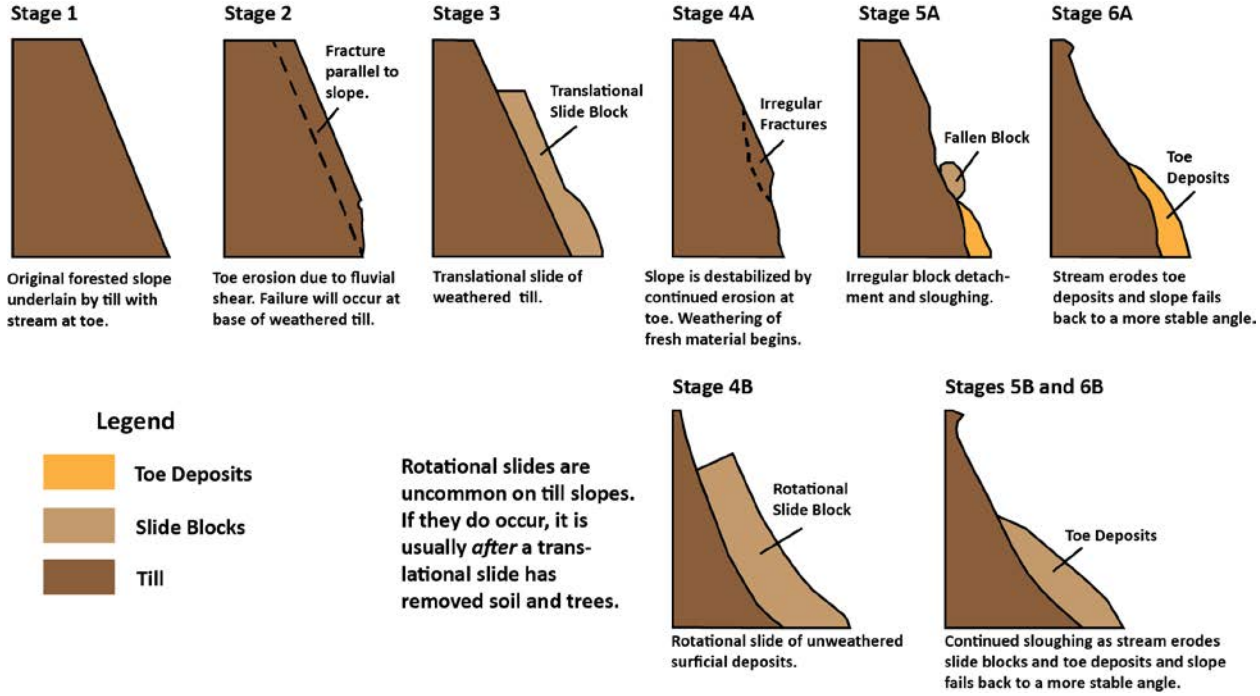

Figure 15. Model for landslides on till slopes. The initial stages of failure of a wooded streambank by a translational failure are shown in Stages 1 to 3. Stages 4A to 6A show the continued failure of the slope by the detachment of irregular blocks of till. Stages 4B to 6B show an alternate style of rotational failure in till that may occur after heavy stream erosion.

Conclusions

This study identifies over 250 unstable slope features in Orange County. The maps are sufficiently accurate to help landowners and planners consider slope instability hazards.

As in the Washington County and Chittenden County studies of Springston (2017, 2018), the current lidar topographic data was successfully used to produce an accurate and cost-effective landslide inventory. Lack of signal return from areas of heavy conifer coverage remains a problem with some of the lidar data, but it is hoped that future projects will supply increasingly detailed penetration in these areas.

As shown by Springston (2017, 2018), and Springston and Thomas (2014, 2018), most of the landslides are located on steep slopes close to streams at sites of active streambank toe erosion. When long-term data is available, the landslides are generally in locations that have been failing for a long time. Thus, by mapping the locations of present landslides we are identifying sites that are likely to fail in the future.

Most of the actively eroding gullies in the county appear to be closely associated with stormwater runoff from roads and developed areas, with a lesser amount associated with agricultural fields.

The principal causes of the slope failures appear to be the over-steepening of slopes due to fluvial erosion of banks and stream beds during flash floods and decreases in shear strength of soils due to increases in soil water pore pressures due to the heavy rainfall.

The detailed (Phase 2) stream geomorphic data from the Vermont Rivers Program is critical to understanding the patterns of stream channel adjustment that are underway in the river corridors. The mass failure locations the river studies compared very well with site location from geologic field work and from lidar. It would be highly desirable to have similar Phase 2 data available for the streams in any areas where landslide mapping is to be undertaken.

Acknowledgements

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