4-7: Landslides

Hazard Impacts	**Probability**	**Potential Impact**					**Score*:**
		Infrastructure	Life	Economy	Environment	**Average:**	
Landslides	3	3	2	1	2	2	6

*Score = Probability x Average Potential Impact

Landslides can be the result of the following:

- Slope saturation from intense Rainfall/Snowmelt, see: Inundation Flooding & Fluvial Erosion.
- Oversteeping of slopes due to stream erosion or undercutting, see: Inundation Flooding & Fluvial Erosion.
- Invasive Species, see: Inundation Flooding & Fluvial Erosion; Invasive Species.
- Reduction of material strength due to weathering.
- Addition of excess load onto slopes, often due to human activity.
- Earthquake or artificial vibration, see: Earthquake.

The term “landslide” describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, organic matter, or artificial fill. The materials may move by falling, toppling, sliding, spreading, or flowing and generally move in either a planar fashion, classified as translational, or curved, classified as rotational or slump. They can be as large as several cubic miles or as small as a few cubic yards, and are able to move as quickly as a free fall or as slowly as a multi-century creep[1]. Landslides that move a significant amount of material quickly and over a large area have the capacity to cause substantial damage to infrastructure, buildings and the natural environment, as well as injure or kill people. Factors that can trigger a landslide or a slope failure include fluvial erosion, soil saturation (especially in areas of increased precipitation), the freeze-thaw cycle in soils and bedrock, human modification of a slope due to excavation and development, surface drainage patterns, loss of vegetation, and earthquakes.

Fluvial erosion is an important contributing factor to landslides. In the past, unless an area is identified as hazardous through a fluvial geomorphic assessment and a river corridor plan, these landslide-vulnerable areas have been mis-identified as non-hazardous because they are located well above the elevation that would be designated as hazardous under FEMA flood hazard area maps. The landside mapping protocol is intended to address this shortcoming, though without recognition of fluvial erosion as a significant hazard worthy of inclusion in flood hazard mapping at the federal level, states with a high incidence of landslides and fluvial erosion will be unable to address, and therefore mitigate, their vulnerability to these hazards.

According to the United States Geological Survey (USGS), “Although landslides are primarily associated with mountainous regions, they can also occur in areas of generally low relief. In low relief areas, landslides occur as cut-and-fill failures (roadway and building excavations), river bluff failures, lateral spreading landslides, collapse of mine-waste piles (especially coal), and a wide variety of slope failures associated with quarries and open-pit mines.”

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[1] https://pubs.usgs.gov/circ/1325/pdf/C1325_508.pdf

Landslides History

Minimal data exists on damages associated with landslides. Often, active landslides occur in tandem with periods of significant rainfall and erosion, so disaster declarations and damage estimates specific to landslide-only damages are not well defined.

The Jeffersonville slide on the Brewster River in April 1999 cost nearly $300,000 to restore the channel and floodplain, as well as purchase a vulnerable residence.

In April of 2004, a soil slope failure occurred in Hardwick, resulting in significant engineering and construction, the buyout of a single residence, and ongoing maintenance totaling $1.4 million in costs. Additionally, in December of 2005, a significant rockslide occurred in Montpelier, affecting Elm and Cliff Streets. The Governor issued an emergency declaration and the Federal Highway Administration (FHWA) approved a $2 million project to stabilize the remaining slope and to make repairs to damaged utilities and roadways under the FHWA Emergency Relief (ER) program.

Significant landslides were observed in Smugglers Notch in the summer of 2006 and in subsequent years. In 2009, a detailed assessment of slope stability issues in Smugglers Notch was completed[2]. This report highlighted that rock falls, rock slides, and debris flows have occurred in Smugglers Notch for thousands of years, and can be expected to continue into the future. In fact, road damage information from VTrans included in this report shows that landslides are nearly annual events. Rock falls in this area can involve large individual blocks, the largest block to fall on record was the 11,500-ton piece that fell off the west face north of Easy Gully in July 1983. Debris flows are the other main type of landslide that occur in the Notch, and can be expected to range from a few cubic meters of mud, pebbles, and boulders, up to many thousands of cubic meters. The largest recorded debris flow occurred on the east side in May 1986 and was about 327,000 cubic yards of material. This blocked VT Route 108 and the West Branch near the Cambridge-Stowe line. Future debris flows can also be expected to sweep down to and across Route 108. Even though the largest debris flow occurred on the east side of the Notch, activity appears to be more frequent on the west side. According to recorded landslide history in the Notch, all slides occurred between May and December.

Route 131 in Cavendish devastated by slope failure.
Photo Credit: www.mansfieldheliflight.com/flood/

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[2] https://anrweb.vt.gov/PubDocs/DEC/GEO/HazDocs/SMuggs2009Rpt2Pls.pdf

Extensive landslide activity occurred as a result of the heavy rains of 2011. In central Vermont, high water conditions resulting from the melting of thick snowpack and heavy spring rains, as well as from a flash flood event in late May, led to an increase in reported landslides. Widespread slope failures also occurred throughout much of central and southern Vermont as a result of Tropical Storm Irene. Many of these landslides appear to have occurred on the sites of earlier slides that were reactivated by the heavy rains and powerful floodwaters (for more information on impacts from Tropical Storm Irene, see: Inundation Flooding & Fluvial Erosion).

As a result of the landslides associated with Tropical Storm Irene, the May 2011 period of heavy precipitation, and previous landslide occurrences, the following properties were subject to continued risk warranting purchase through the Hazard Mitigation Grant Program (HMGP). While fluvial erosion and stream toe erosion of steep slopes are major contributing factors to landslides in Vermont, the Protocol for Identification of Areas Sensitive to Landslide Hazards in Vermont (discussed below) includes larger scale landslides which are not or may not be captured by floodplain mapping. Since low eroding banks are adequately captured by floodplain mapping, a somewhat arbitrary bank height of 3-4 meters is used to differentiate the larger scale landslides. The landslide properties listed in Table 35 have been selected based on the following criteria:

- They were awarded an HMGP grant using FEMA's Landslide BCA Methodology and/or
- The damaged structure sat atop a bank higher than 3 meters.

Table 35: Landslide-Vulnerable Properties Purchased With HMGP, CDBG and/or Vermont Housing & Conservation Board (VHCB) Funds

Name/Time	Town	County	Date of Occurrence	Cost of Buyout
40 School Street	Readsboro	Bennington	8/28/2011	$142,212
42 School Street	Readsboro	Bennington	8/28/2011	$155,668
62 School Street	Readsboro	Bennington	8/28/2011	$191,998
3013 Danby-Pawlet Road	Danby	Rutland	8/28/2011	$76,859
15 Hilltop Avenue	Barre City	Washington	5/29/2011	$227,976
21 Hilltop Avenue	Barre City	Washington	5/29/2011	$152,732
86 Waterman Hill Road	Hartford	Windsor	8/28/2011	$238,219
104 Waterman Hill Road	Hartford	Windsor	8/28/2011	$235,778
36 Town Garage Road	Westminster	Windham	8/28/2011	$58,090
280 Cameron Road	Plainfield	Washington	8/28/2011	$251,700

In 2009, a PDM grant award allowed the Vermont Geological Survey (VGS) to further study landslide-prone areas and develop a useful protocol to assess future risks[3]. The report notes that accurate LiDAR data provides the best starting point for landslide analysis in Vermont; therefore, VGS selected seven sites to attempt to represent conditions in various parts of the State. Since LiDAR coverage was limited in the State, six of these study sites were conducted in Chittenden County and one in Lamoille County. The protocol was found to work best for translational landslides. The report states that, "the most important parameters for identifying translational landslides are slope angle and roughness, although soil type and topographic wetness index are also important at some site areas." The State has since been successful in generating statewide LiDAR data (see: State Capabilities List).

Table 36 lists significant landslides that have impacted the State of Vermont, excluding those associated with Tropical Storm Irene.

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[3] http://dec.vermont.gov/sites/dec/files/geo/TechReports/VGTR2012-1LandslideProtocol.pdf

Table 36: Significant Landslides in Vermont

Property Damage (Adjusted for inflation)	Begin Date	End Date	Location	Fatalities
$1,433,424.88	04/18/2004	4/18/2004	Hardwick	0
$2,000,000.00	12/26/2005	12/26/2005	Montpelier	0
$360,000.00	Spring 2002	Spring, 2002	Lake Willoughby	0
$300,000.00	4/4/1999	7/4/1999	Jeffersonville	0
$104,000.00	5/23/1986	5/23/1986	Lamoille	0
$91,228.07	5/11/1989	5/11/1989	Bennington	0
$11,304.35	5/2/1983	5/2/1983	Rutland	0

In addition to the information above, over the past five years (March 2013-April 2018), VTrans has spent approximately $27 million protecting banks and slopes near vulnerable infrastructure and $110,000 on small slope repair projects associated with water quality. This amounts to approximately $5.4 million in annual expenditures devoted to public infrastructure landslide mitigation.

Landslide Trends & Vulnerability

Vermont has not previously developed a landslide inventory or an adequate tracking system to establish frequency of this hazard. Slope instability, which can be the result of increased ground saturation due to increased rainfall or significant snowmelt, is further exacerbated by human activity, often in the form of infrastructure construction. Roads that sit along steep slopes near rivers are especially vulnerable to damage or complete failure from a landslide event.

Considering Vermont's increasing precipitation trend since the 1960s of 1.5" per decade[4], which leads to increased slope instability due to ground saturation, coupled with the State's expanding ability to identify locations of landslides through the Vermont Landslides Inventory Reporting Tool[5], the Steering Committee considered the probability of a plausibly significant landslide hazard to occur once every ten years, and for the impact of such an event to be most substantive to the State's infrastructure.

Landslides in Vermont often involve unconsolidated materials and are likely most common along rivers where erosion occurs. Vermont's mountainous areas lie above fractured bedrock with thin soil cover, which lead to increased rock-slope instability. Avalanches of debris, defined as material containing a relatively high percentage of coarse fragments, occur most commonly in the western and central portions of the State, typically on south-facing slopes[6]. With updated LiDAR data, and information

A house sits atop an active landslide in Plainfield, VT. This house was acquired and demolished by the Town using Vermont Housing & Conservation Board funding.

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[4] http://climatechange.vermont.gov/our-changing-climate/dashboard/more-annual-precipitation

[5] https://vtanr.maps.arcgis.com/apps/GeoForm/index.html?appid=505af0d19dd44faaa912ef3d5c80a3b6

[6] https://pubs.usgs.gov/bul/2043/report.pdf

received via the Vermont Landslides Inventory Reporting Tool, the Vermont Geological Survey has been developing high resolution landslide hazard maps, county-by-county, as funding is available, which allows the State to better understand locations that are more vulnerable to landslides.

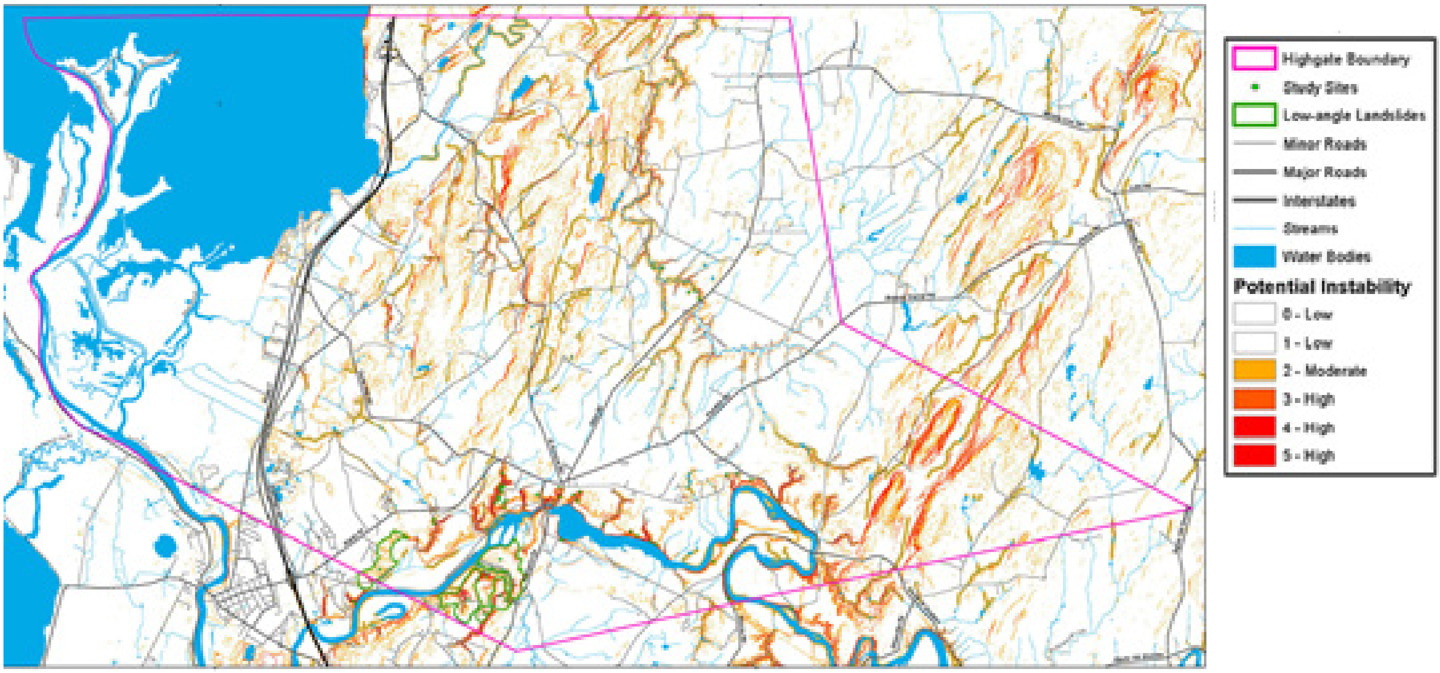

Figure 55: Town of Highgate landslide map
Source: http://dec.vermont.gov/sites/dec/files/geo/TechReports/VGTR2016-1AddisonCtyLS.pdf

Landslides Mitigation

In an effort to reduce Vermont's vulnerability to landslides, the Vermont Geological Survey, a division under the Department of Environmental Conservation (ANR-DEC), has developed a web-based reporting tool[7] for the general public to submit information to the State Geologist regarding potential landslides in real-time. As outreach efforts are made to increase awareness about the tool, the visibility to both known and unknown landslide-prone areas is expanded. This will allow the Vermont Geological Survey team to have access to more data, thereby increasing the ability to predict future slope failures.

The Vermont Geological Survey then use these data to prioritize towns and counties that are in need of high resolution landslide hazard maps, which are being developed currently, as funds are available.

When these landslide data are then overlaid with development in a town or region, vulnerability can be better understood and mitigation strategies defined. Though landslides are identified throughout this Plan's mitigation actions, reducing structural vulnerability to landslide hazards was identified as its own, standalone mitigation strategy with three separate actions created to accomplish the strategy (see: Mitigation Strategy). Those actions identified under the hazard mitigation mapping, data and research strategy have direct implications to landslide mitigation, as the State continues to seek out funding sources to better locate and understand Vermont's vulnerability to the hazard.

Given an increased understanding of landslide hazards and where they exist in Vermont, the Steering Committee considered the probability of a plausibly significant landslide event to be likely, with the most significant impacts to infrastructure.

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[7] https://vtanr.maps.arcgis.com/apps/GeoForm/index.html?appid=505af0d19dd44faaa912ef3d5c80a3b6

Accordingly, structural and infrastructural landslide mitigation projects are also taking place across Vermont. As mentioned in the history section above, ten landslide-vulnerable houses were purchased and removed as a result of the landslides associated with Tropical Storm Irene (Table 35). Two of these structures were located in the Town of Highgate, whose landslide hazards have been mapped by the Vermont Geological Survey (Figure 55). Using this map to identify vulnerable infrastructure and structures, the Town applied for a landslide slope stabilization project under the HMGP for their transfer station, which was built near a failing slope and requires significant mitigation work. This project is expected to be awarded by FEMA in early 2018 at a cost of approximately $230,000.

The Town of Shrewsbury had to have substantial work done after Tropical Storm Irene due to significant slope failures along the Cold River, including approximately $887,000 in Public Assistance funds for road repair and slope stabilization. The Town, recognizing there were several landslide areas along this stretch that required immediate attention, then submitted a PDM application to relocate a portion of the Upper Cold River Road identified as being an imminent threat of catastrophic failure. This project, approved by FEMA in early 2018, is estimated to cost nearly $750,000 to complete.

Major slope failure along the Cold River in Shrewsbury, VT. *Photo Credit: Alan Shelvey*