**4-10: Landslides and Slope Failures**

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.
* 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 meters and are able to move as quickly as a free fall or as slowly as a multi-century creep[[1]](#footnote-2). 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 cause injuries and fatalities.

This Plan will use the term “landslide” in place of the term ‘Mass Wasting,’ which is defined as any down-slope movement of soil and rock under the direct influence of gravity. Landslides are a specific type of mass wasting[[2]](#footnote-3), however “landslide” is more commonly used and understood than “mass wasting.”

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. Landslides are commonly initiated in the same areas more than once, and if a landslide occurs the best practice is to exercise caution in the area as it may still be unstable[[3]](#footnote-4).

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. A landside mapping protocol developed by the Vermont Geological Survey and their partners is intended to address this shortcoming. However, without recognition of fluvial erosion as a significant hazard worthy of inclusion in flood hazard mapping at the federal level, states like Vermont with a high incidence of landslides and fluvial erosion are unable to address mitigate 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.” This is true of Vermont, where landslides are commonly observed well away from the slopes of the Green Mountains.

**Location**

Landslides in Vermont often involve unconsolidated materials and are most common along rivers where erosion occurs. Vermont’s mountainous areas lie above fractured bedrock with thin soil cover, which led 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[[4]](#footnote-5). With updated LiDAR data, and information received via the Vermont Landslides Inventory Reporting Tool, the Vermont Geological Survey and their academic partners have 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. This reporting tool has also created an inventory for past occurrences and helped researchers better understand the spatial distribution of landslides[[5]](#footnote-6). Vermont’s rugged topography makes many regions susceptible to landslide, with heightened risk around areas with steep slopes or moving water which can erode steep banks.

Landslides History

Outside of buildings bought out through FEMA programming, 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 damages are not well defined.

A landslide in Jeffersonville that failed along the Brewster River in April 1999 cost nearly $300,000 for channel and floodplain restoration as well as the purchase of a vulnerable residence.

In April of 2004, a soil slope failure occurred in Hardwick, resulting in significant engineering and construction activities, 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[[6]](#footnote-7). This report highlighted that rock falls, rockslides, and debris flows have occurred in Smugglers Notch for thousands of years, and can be expected to continue into the future. 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 299,008 cubic meters 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, slides tend to occur between May and December. The Vermont Geological Survey has been working with VTrans to monitor and better understand rockslide activity using drone-based photogrammetry.

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 later that year. 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.

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| **Table 35: Landslide-Vulnerable Properties Purchased With HMGP, BRIC, FRCF, 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 |
| 266 and 268 Texas Hill Road | Huntington | Chittenden | 7/4/2013 | $262,500 |
| 64 Bolder Wood Lane | Bolton | Chittenden | 2019 | $165,000 |
| 389 Riverside Avenue  | Burlington | Chittenden | 10/2019 | $397,680\* |
| 2272 Machia Road | Highgate | Franklin | 8/2020 | $62,000 |
| 2128 Brockways Mills Road | Rockingham | Windham | 7/29/2021 | $187,000 |

\*Estimate

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[[7]](#footnote-8). 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 at the time, 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 and is currently updating our LiDAR dataset with Quality-Level 1 (8 points per square meter) statewide coverage (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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| **Table 36: Significant Landslides in Vermont** |
| **Property Damage** **(Adjusted for inflation)** | **Begin Date** | **End Date** | **Location** | **Fatalities** |
| $11,304.35 | 5/2/1983 | 5/2/1983 | Rutland | 0 |
| $104,000.00 | 5/23/1986 | 5/23/1986 | Lamoille | 0 |
| $91,228.07 | 5/11/1989 | 5/11/1989 | Bennington | 0 |
| $300,000.00 | 4/4/1999 | 7/4/1999 | Jeffersonville | 0 |
| $360,000.00 | Spring 2002 |  Spring, 2002 | Lake Willoughby | 0 |
| $1,433,424.88 | 04/18/2004 | 4/18/2004 | Hardwick | 0 |
| $2,000,000.00 | 12/26/2005 | 12/26/2005 | Montpelier | 0 |
| n/a | 5/30/2019 | 5/31/2019 | Waterbury | 0 |
| $48,413.97 | 5/31/2020 | 5/31/2020 | Cambridge | 0 |

On May 30th and 31st of 2020, two significant landslide events occurred at Smugglers Notch, Cambridge and Cotton Brook, Waterbury. The Smugglers Notch event occurred the morning of the 31st, a portion of the cliff face high up on the west side just north of Cass's Gully broke off and fell onto the talus slope below. As they fell, large blocks of schist bounced, rolled, or slid down the talus slope. Many trees were damaged, snapped, or swept along by the falling pieces of rock. At least two large blocks reached Vermont Route 108 in the floor of the Notch, damaging at least one vehicle. There were no injuries reported. This event has been one of the largest rock fall events in the Notch in the last 30 years. Of 23 landslide events at Smugglers Notch and Mount Mansfield for which the month of occurrence can be determined, all occurred between April and December, with 20 of them occurring between May and October. The peak occurrence is in July[[8]](#footnote-9).

Two types of slope failures or landslides occur in the Smugglers Notch area. The first broad class of landslides is rock falls and rockslides, which involve one or many large pieces of rock detaching from a cliff and falling, bouncing, or sliding down a slope. Most of the boulders on the floor of the Notch appear to be the result of such rock falls. The rock fall in May of 2020 was in this first class. The second class of landslides is debris flows, which are slurries of water, mud, pebbles, cobbles, and boulders that flow within shifting channels on the talus slopes below the cliffs. In the Notch, they are caused by heavy rainstorms. Both rock falls and debris flows appear to be triggered by intense rainfall events and/or rapid snowmelt. Landslides have occurred in Smugglers Notch for thousands of years and we can expect large rock falls and slides and damaging debris flows to continue long into the future[[9]](#footnote-10).

The landslide that occurred on the slopes along the Cotton Brook sometime between the 30th and 31st of May in 2020 resulted in a landslide area with a primary scarp of approximately 12 acres and with additional failure blocks near the head scarp (additional 2.2 acres). The landslide area increased by more than 10% in the days following the initial landslide, and the site remained unstable with a high risk for future failures; one heavily used hiking trail in the area was permanently closed. The landslide resulted in massive sedimentation in Cotton Brook, from the landslide location to the mouth of the brook at the west shore of the Waterbury Reservoir[[10]](#footnote-11). Additional failures can bring down large blocks of trees and soil, potentially causing additional blockage of Cotton Brook, and the Vermont Geological Survey and partners continue to monitor its development.

Landslide Trends

In the years since the 2018 SHMP was published, the State has developed and published a landslide inventory containing landslide locations from the Vermont Geological Survey's preliminary landslide inventory, verified landslides from the public Geoform, and other technical reports. These data can be accessed from Vermont ANR’s GIS Open Data and are updated regularly. The Vermont Geological Survey responds to and monitors landslide and rockfall events, maps areas prone to erosion and landslides, and is working with partners from Norwich University to implement landslide hazard mapping protocols throughout the state. In 2015 the Division began a program to provide planning-level landslide hazard maps for all Vermont counties, contingent upon funding and availability of LiDAR. Landslide hazard susceptibility maps were prepared for Addison County, the Town of Highgate, and Washington County in 2016 - 2017; Chittenden County was completed in 2018 and added to the statewide GIS data inventory. Caledonia and Orange County were prepared in 2021 and 2019 respectively. Reports for the Mad River Valley, Smugglers Notch, and the Middlebury River Watershed have also been prepared[[11]](#footnote-12). The State continues to produce landslide hazard mapping throughout the state. These maps help Vermont prepare for safer growth and development, develop mitigation and hazard avoidance strategies (FEMA), avoid economic loss, and be prepared (USGS preparedness list) to respond to events.

Vermont has not previously developed an adequate tracking system to establish frequency of this hazard. In general, landslides tend to fail during wetter periods including springtime, with the combined effects of snowmelt, early spring rains, and low evapotranspiration, and in fall when high-intensity storms commonly originating as Nor’easters bring heavy rains to the state. Vermont continues to experience increasing precipitation with an additional 1.4” per decade (since the 1960s; rates which fluctuate depending on which season is being observed)[[12]](#footnote-13), which reduces slope stability. Based on increasing precipitation trends and on reported landslides in the Vermont Landslides Inventory Reporting Tool[[13]](#footnote-14). The Steering Committee graded the probability of a landslide occurring to be “Likely” which would be a significant event at least once in the next ten years. The impacts of landslide events were rated Moderate for the built environment, Minor for people and the natural environment, and Negligible for the Economy.

The population trends within Vermont indicate that there will be a population increase throughout the 21st century[[14]](#footnote-15). While Vermont is in no way immune to the impacts of climate change, the state is expected to see fewer extreme impacts compared to other states[[15]](#footnote-16). As a result, more people may move to Vermont from hazard-prone areas for safety reasons. In the event of rapid migration, Vermont needs to be prepared both socially and structurally to handle newcomers. Regional Planning Commissions (RPCs) around the state have made assessments that many communities are not prepared for increased migration[[16]](#footnote-17). One of Vermont’s main planning goals is to develop in a way that maintains historic development patterns of compact centers surrounded by rural landscape[[17]](#footnote-18). This is done to prevent suburbanization and the fragmentation of Vermont’s natural landscape. As neighborhoods expand to include areas adjacent or away from these centers, alterations to the landscape can be harmful in the long run. Development pressures can put more structures at risk of landslide events. For example, multiple businesses and housing units exist along a slope on Riverside Ave in Burlington, VT. This slope has a long history of filling, development, and mitigation that has left 80ft of unconsolidated materials overlaying bedrock, which can be unstable. Damaging washouts and slides along this slope have occurred due to over-steepened slopes, unstable fill, poorly maintained storm drains, and surface runoff. Major failures occurred in 1955 and in 2019 and several smaller events were triggered between that moved large amounts of fill material. Three structures were under review to determine if they posed an imminent risk of failure (within the next 5 years); two businesses and one residential structure. Structures were assessed for their integrity, pointing out cracks in the foundations and landscape indicators of weakened earth. While the State has gone ahead with recommending the buyout of one of the three properties in question (the residential building), there is still a risk of slope failure which can endanger remaining occupied properties, nearby road infrastructure, and the Winooski River at the base of the slope[[18]](#footnote-19). As our population increases and puts pressure on further development, careful consideration of existing unstable slopes and lessons learned from previous failures are important to minimize the future risk of landslide hazards.

[Fig 55, town of highgate landslide map]

Vulnerability

**People**

The effects of landslides on people and communities in Vermont is most pronounced in identified at-risk regions. In remote and mountainous regions, landslides can impact hikers and other people engaging in outdoor recreation, sweeping them away or crushing them under the weight of the failed materials. Due to the changing landscape and unstable ground, search and rescue operations can prove difficult. Throughout the US, landslides result in an average of 25-50 deaths annually. Human health hazards that can result from landslides include physical bodily harm from debris, illness resulting from disrupted systems (i.e., sewage), and the loss of road access restricting access to other regions including medical care[[19]](#footnote-20). The impact on access and communication will be discussed further in the Built Environment section.

**Built Environment**

Slope instability, which can result from increased ground saturation due to heavy rainfall or significant snowmelt, is further exacerbated by human activity, often in the form of infrastructure construction that either mishandles surface runoff, overloads the tops of slopes, or undercuts the bases of slopes. Roads that sit along steep slopes near rivers are especially vulnerable to damage or complete failure from a landslide event. Bridges and culverts placed near waterways similarly can be damaged or swept away by the debris of a landslide. Buildings and other structures can be damaged as well, especially if they are in historical landslide sites, steep slopes, slopes altered by construction, channels along streams or rivers, and areas where humans have directed surface runoff[[20]](#footnote-21). Recreational spaces like trails can be drastically altered by slope failures, as was the case for the Monroe Trail that was destroyed by the Cotton Brook landslide. The destruction of roadways can limit the transportation corridors between regions, making it difficult to respond to emergencies caused by landslides as well as other emergencies in the near future.

**Natural Environment**

The impacts that landslides can have on the natural environment is more concentrated yet often leads to greater changes than some of the other listed hazards. Landslide events can quickly and significantly alter the topography of the earth’s surface with massive amounts of debris moving downslope. In turn, that debris can impact the character and quality of rivers and groundwater flow when large amounts of earth and organic materials enter streams as sediment resulting from landslides and erosion activity, thus reducing the potability of the water and quality of habitat for fish and wildlife[[21]](#footnote-22). Sedimentation can lead to many waterway issues by clogging fish gills, reducing resistance to disease, lowering growth rates, and affecting fish egg and larvae development[[22]](#footnote-23). Increased turbidity of the water can prevent the growth of vegetation disrupting the Biochemical Oxygen Demand (BOD) of the water, making it more difficult for marine species to breathe[[23]](#footnote-24). The habitat destruction and disruption caused by landslides is not confined to waterways, as forested ecosystems in the path the landslide can be swept away, stripping forest cover away, impacting wildlife habitat[[24]](#footnote-25). The changes in the natural environment experienced by this hazard are fast acting and severe, requiring plenty of time for ecosystems to recover.

**Economy**

The economic impacts that landslides cause is dependent on where the event took place. Vermont has recorded over 3,000 landslides, with many occurring in the northern and central parts of the State along the spine of the Green Mountains[[25]](#footnote-26). These regions are often sparsely populated and home to numerous ski resorts and hiking trails. The Green Mountains act as the heart of Vermont, not only physically, but also culturally as the rural idyll used to generate tourism brings many people to Vermont to ski and explore the outdoors, especially during the fall. Outdoor recreation accounts for 4.1% of Vermont’s GDP as of 2021, the third highest in the nation behind Hawai’i and Montana[[26]](#footnote-27). Damage to this sector can have an impact on the State’s economy. Other economic impacts come in the form of lost stock if a landslide occurs on a plot of land being used for timber, sugaring, or other kind of production.

Landslides Mitigation

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[[27]](#footnote-28) 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. Further increasing public knowledge and engagement in landslide hazard mitigation can help improve local resiliency. An action outlined under the strategy to: increase public knowledge and literacy of hazards and mitigation aims to develop a resource for the incorporation of hazard mitigation and water quality projects into local capital planning and budgeting processes.

The strategy to access seismic vulnerability outlines three actions conduct seismic analyses and install monitoring stations at critical facilities, select bridges, and cultural sites in conjunction with educational institutions across the State. Analyses conducted are to use the 2016 NESEC study, HAZUS, ROVER, and the UVM Seismic Vulnerability Ranking System.

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 six 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.

Accordingly, structural and infrastructural landslide mitigation projects are also taking place across Vermont. As mentioned in the History of Landslides 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. The first phase of this project, funded by FEMA, was completed in early 2018 at a cost of approximately $230,000; second phase of work is expected to begin in summer 2023 at a cost of approximately $2M.

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 hazardous areas along this landslide-prone 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, funded by FEMA, was completed in January of 2020 at a cost of $516,677.19.

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3. <https://www.uvm.edu/news/cas/landslides-take-team-solve-geology-professor-says> [↑](#footnote-ref-4)
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5. [https://anrgeodata.vermont.gov/datasets/landslides/explore?](https://anrgeodata.vermont.gov/datasets/landslides/explore?location=43.796990%2C-72.527777%2C8.63) [↑](#footnote-ref-6)
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19. <https://www.cdc.gov/disasters/landslides.html> [↑](#footnote-ref-20)
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