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Geomorphology and Landslides Along Riverside Avenue

Abstract

Riverside Avenue, along the south side of the Winooski River as it flows through Burlington, VT, has a long and problematic history of landslides linked both to the natural landscape and to human development. As glaciers swept over New England in the last glacial period, the landscape was hugely altered and the sediment that makes up the steep banks was deposited. Though road development started before 1872, the forests and slopes were left intact enough for the slope to remain stable. However, later development near the slope's edge brought marked changes in vegetation type and density, and water flow. These changes resulted in frequent landslides and several dumpings of material were placed to restore the bank. Landslides are still common and they pose a continued danger. To strengthen the slope, several geoengineering solutions are available, though all are resource intensive. A public education campaign could re-alert citizens of the danger and lobby for a city initiative to help businesses along that corridor to relocate.

Glacial History

The last glacial period had huge geomorphological impacts on the northern US. As the ice sheet advanced to its maximum, 20,000 years ago, it caused large amounts of erosion as well as transport of fine sediment and till. As the ice sheet retreated past Vermont roughly 13,000 years ago, several large lakes and seas were formed in the Champlain valley. Glacial Lake Vermont and the Champlain Sea both occupied the region and large amounts of sediment were deposited during this time.

Fig. 1

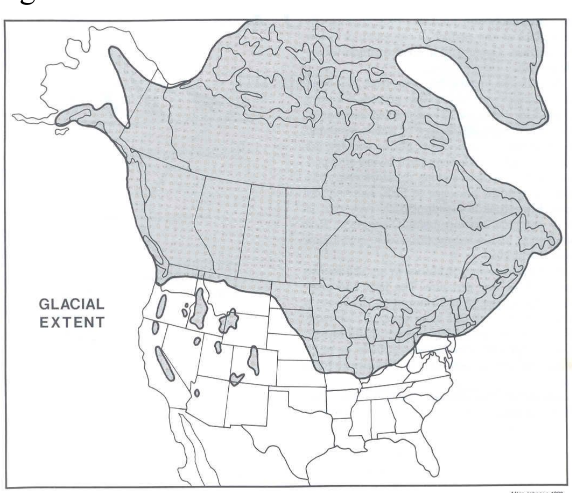

Figure 1: Extent of the Laurentide Ice Sheet at the last glacial maximum
Photo: http://academics.smcvt.edu/vtgeographic/textbook/glaciers/Vermont_glaciers.htm

Post-glaciation, a thick layer of sediment occupied much of the Champlain Valley. As river systems reestablished, river systems incised into sediment of the lower valley. As the Winooksi River incised, steep slopes were formed in the sediment banks along what is now Riverside Ave. Riverside Ave. and the underlying slopes, are depositional terraces composed of glacial sediment. These slopes had thousands of years to stabilize through forestation, soil creep and other processes, but the underlying sediment is still prone to instability by human activity.
Fig. 2

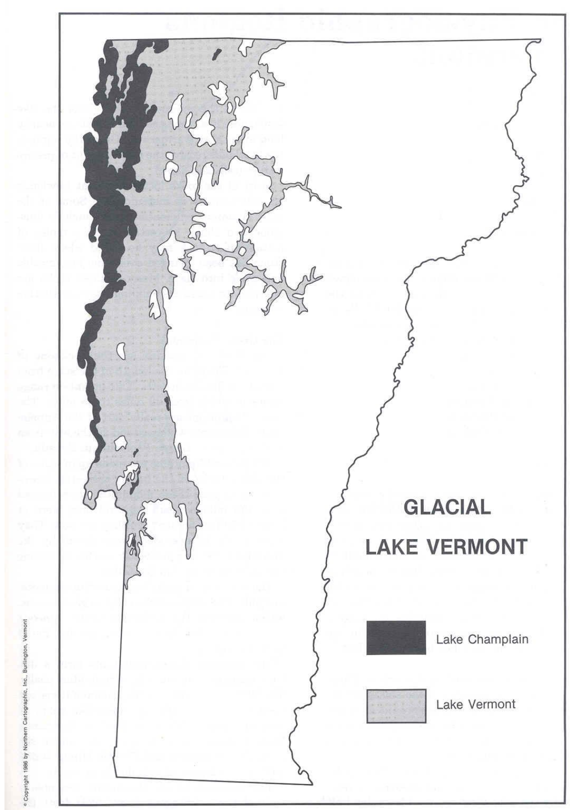

Figure 2: shows the extent of Glacial Lake Vermont
Photo: http://academics.smcvt.edu/vtgeographic/textbook/glaciers/Vermont_glaciers.htm

Landslide Triggers

Landslides are triggered when shear stress becomes higher than the shear strength of a slope. Heavy rainfall may saturate the slab, increasing pore pressure and density. Deforestation also contributes to a loss of shear strength as root networks are critical in holding material in place. The material comprising the slab also affects stability in that certain materials such as clays have higher cohesion than other materials. Fill may initially be stable, but it is less cohesive than undisturbed material and thus, more prone to slab failure. With impervious surfaces, such as the pavement along Riverside Avenue, water can not infiltrate and may run down the slope increasing infiltration into the slope and thereby increasing pore pressure. All of these factors may trigger a landslide.

Surface and Groundwater Hydrology

Elevated watertable levels may destabilize a slope. Below the major watertable, pores and fractures in the soil fill up water and increase pore pressure of the slope material. This pressure cancels out some of the slope's cohesion forces and reduces shear strength. A multitude of studies show that as groundwater content increases, shear strength of a slope is reduced dramatically.

Rising watertables (and therefore pore pressure) are often caused by heavy amounts of precipitation. In the case of Riverside Avenue, a flash flood on the night of Halloween in 2019 overwhelmed the watertable by oversaturating the soils and building up pore water pressure. The flood was quickly followed by a devastating landslide, a similar pattern to many other slides in the area. Hydrologic factors that likely contributed to the slides include different elements of the soil profile, infiltration rate, and volume of precipitation.

Spatial Distribution and Causes of Landslides along Riverside Avenue

To the first engineers constructing Riverside Avenue, the steep slope north of the road was not a concern. Mature forest reassured them that the slope would surely remain stable. However, the river bank comes as close as 95 meters to the center of the avenue. With an estimated elevation change from river to road of 80 meters, slope in some areas may have been as great as 40 degrees. Near the intersection of Riverside and Intervale Avenues the river meanders north and tends to emplace a cutbank at that location. All these conditions conspire to make the north side of Riverside Avenue a perfect setting for landslides. Prior to human intervention, landslides were likely rare and small, but with deforestation, paving and dumping of fill, landslides became larger and more frequent. Now, they pose imminent danger to properties in this area. Most of the landslides have occured along the western half of the segment of the Avenue studied. This region has steeper slopes. Moreover, applications of fill occurred primarily in this region, which significantly decreased resisting shear strength of the slope's material, thereby reducing the resisting forces and increasing the chance of slope failure.

Figure 3: Image of Riverside Avenue taken in 2020.

Anthropogenic and Natural

Landslides along Riverside Avenue likely occurred before development, but human intervention has made them larger and more frequent. Humans have made the bank much less cohesive by dumping fill material. They have increased the runoff onto the bank by creating impervious surfaces surrounding Riverside Avenue. The removal of vegetation by humans along the slope has also weakened the slope's cohesiveness. However, some of the problems on Riverside Avenue are natural and unavoidable, such as the steep slope, and erosion at the bottom due to the Winooski River. While the slope is naturally steep, human-induced changes have had a large impact on landslides in the last century.

Risk Mitigation and Public Education

Slope strengthening strategies may be applicable to the area along Riverside Ave. Currently, Burlington engineers could consider adding plastic mesh reinforcements and rock-fill buttresses to stabilize the slope. Given the natural ecosystem that runs through the shore north of Riverside Avenue, another approach may better apply, that of building a crib wall check dam, pictured in

This dam comprises a series of knickpoints with sediment storage dams built below each knickpoint. It is made of reinforced concrete. Spacing of the dams depends on channel gradient and dam height.

Figure 4: A crib wall check dam (Photo taken in Trafoi, Italy, courtesy of “Erosion Control” Forester Communications, Santa Barbara, CA.) It appears that the sediment storage dams are already filled.

Equally important will be the education of the city officials and the general public regarding the landslide danger in this area. Eventually one or more of those businesses will need to be relocated and the city could facilitate the move by starting an escrow account to help the businesses make the move. The city could also implement monetary incentives in order to make these moves feasible. Public education regarding potential environmental hazards is the first step towards risk mitigation in the Burlington community.

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