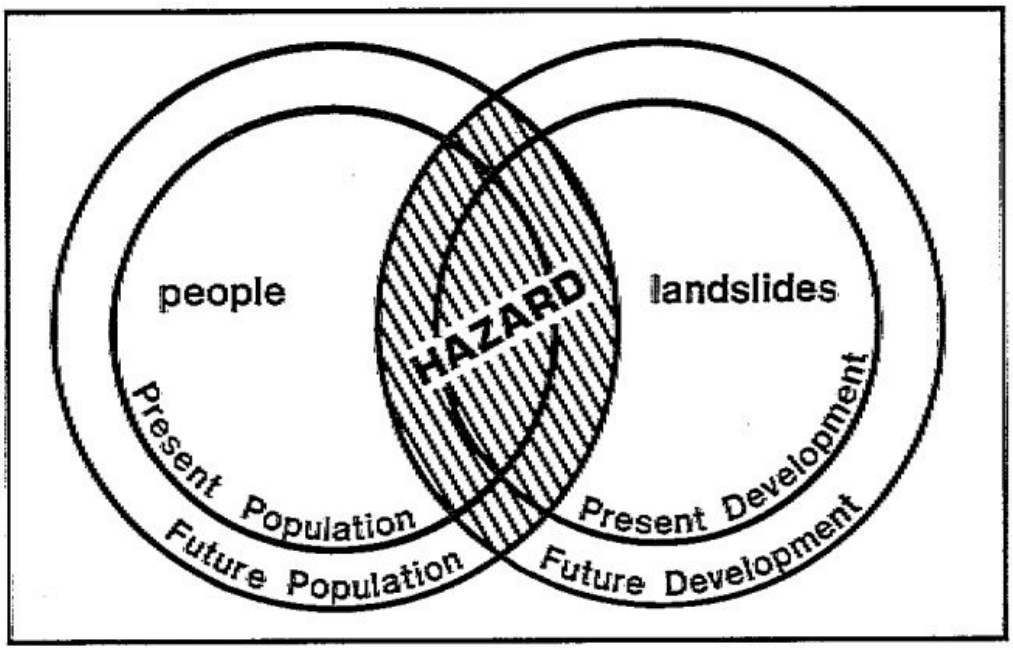
Strategies for Mitigating Landslides: A Case Study on Riverside Ave Burlington, Vermont



(Wold, Jr., Robert L., Jochim, Candace L., 1989).

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Abstract (190 words)

This study intends to explain the spatial distribution and causes of landslides along Riverside Avenue in Burlington, VT. Located along the Winooski River, the hillslope between the river and the avenue has been prone to landslides over the past several decades, with the first recorded slide in 1928 and the most recent in 2019. The history of geomorphic processes and human land-use change were investigated to better understand specifically what factors have led to these frequent landslide occurrences in order to determine effective mitigation strategies. It was found that glacial deposits from the late Pleistocene have resulted in rocky and sandy soils that lack cohesion, leading to soil instability along the banks of the Winooski River. Aerial imagery and newspaper records provide evidence of human land-use changes including dumping, road construction, deforestation, and the expansion of impermeable surfaces that contributed to slope destabilization. To decrease the likelihood of landslide occurrence, we propose multiple mitigation strategies: reintroducing vegetation to the hillslope and adjacent areas, improving drainage systems and road permeability, a reinforced hillslope soil structure, relocation of nearby businesses, and soil removal in the source area to reduce the driving force.

Riverside Ave Landslide History (Main Paper: 1187)

Many landslides have occurred along Riverside Ave over the past century (Figure 1). Throughout the 20th century, more housing, commercial buildings, and impervious surfaces like paved roads and parking lots have caused more shear stress on the Riverside Ave hillslope. The distribution of landslides along Riverside Ave is the result of differences in the topography. More specifically, the distribution relies on pockets of low shear stress thresholds, poor soil cohesion due to lack of vegetation, and areas where the water table could condense runoff. The interplay of these main topographical characteristics determines how likely areas are to surpass their thresholds for sliding when acted upon by forces like heavy rain, weight bearing, and weathering. As visible in Figure 2, certain areas exhibit a colluvial fan pattern in which steep walls splay out into more gently sloped fans—these areas are hotspots for sliding. The distribution of these hotspots happen naturally, but further along, this paper will address the role of human intervention in accelerating, decelerating, and moving these hotspots. Below is a timeline showcasing the landslide history of Riverside Ave.

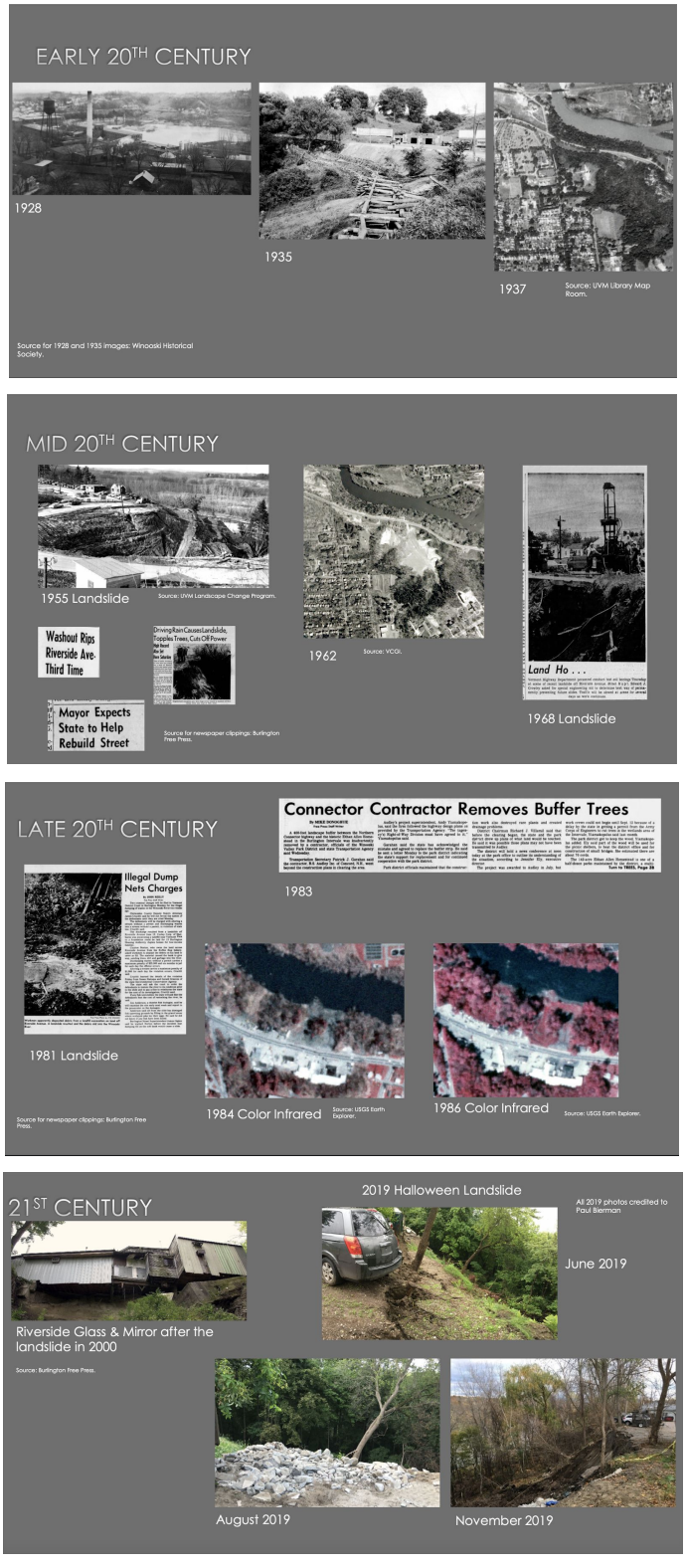

Figure 1:
Timeline of landslides along Riverside Avenue. The first recorded landslide was in 1928, while the most recent occurred in 2019.

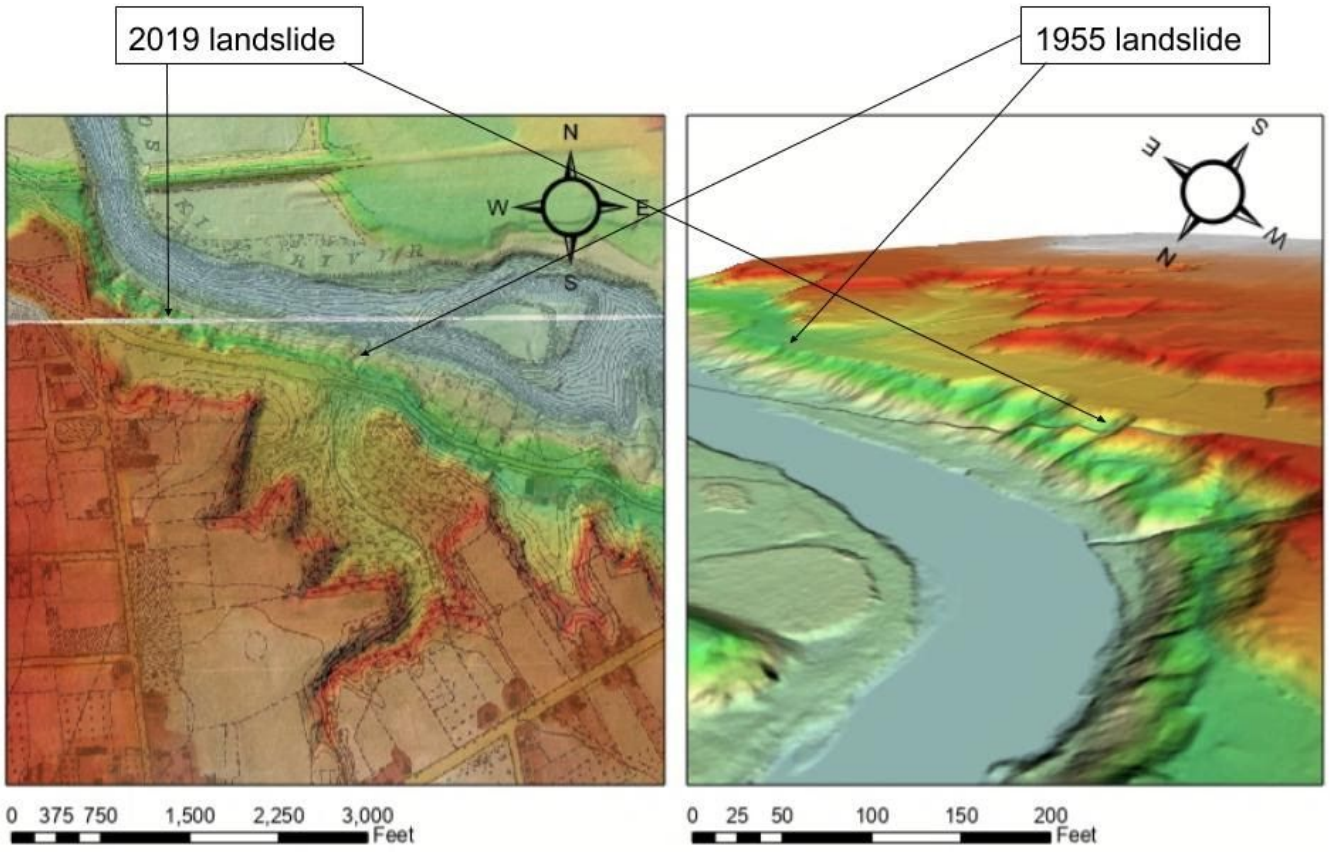

Figure 2:
The map on the left showcases the Geological Survey of 1872 map overlaid with a shaded relief derived from a 2014 hillshade. The map on the right shows a 3D view of Riverside Ave hillslope facing southeast. Both show where the 2019 and 1955 landslides occurred.

Why Landslides Occur Along Riverside Ave

Both natural and human factors have contributed to landslides along Riverside Ave. After the first recorded landslide of 1928, wooden cribbing was used along with fill to stabilize the slope. Later, rocks were placed on top of the fill before the area was paved to rebuild the street. The 1955 landslide likely occurred due to less cohesive materials like fill and a combination of both poor maintenance and increased urbanization (Bierman et al., 2005). The 2019 Halloween slide likely occurred due to the over saturation of the soil from heavy precipitation. The steepness of the slope, combined with the impervious nature of pavement, hard compact gravel parking lots, roads, and other impervious surfaces above the hill were likely a contributing factor to the landslide, as they increased run-off volume. The extent of the 2019 landslide is visible in Figure 3. The lack of strong tree root cohesion was likely also a contributing factor to the landslide.

Figure 3:
Panorama of where the 2019 landslide occurred (taken in October 2020). It's worth noting that a lot of vegetation has regrown, however, no maintenance has been put into place except for some riprap stones at the very top of where the parking lot meets the edge.
Photo Credit: Luc Burnier

Glacial/Ground Water Hydrology Influences

Riverside Avenue's proximity to the Winooski River plays heavily into the area's instability. Figure 2 shows a narrow stream running from the south to the north side of the road down to the river. In combination with the steep slope of the hill, the moving water in this stream encouraged erosion. Soils in the Burlington area are mostly deposited glacial sediment left by the retreating Laurentide ice sheet during the late Pleistocene as well as low-cohesion sand deposited in the Winooski River delta by the Champlain Sea. The loose nature of the Riverside Ave hill soil encouraged both gravity and infiltration-based erosion, especially when combined with the loose sand and gravel placed there in attempts to stabilize the slope starting in the 1930s. In the area's 1955 slide, water from an unused culvert further eroded the road foundation, causing the slope to cascade into the river below. Though the landslide-prone nature of the area is in part due to the dumping outlined above, most slides were triggered by precipitation events that led to heavy runoff. Later slides were induced by high levels of runoff caused by an increase in impermeable surfaces as the area became more urbanized. The increased runoff from these events flowed into the Riverside Ave hillslope which increased pore pressure, destabilizing soil debris, and inciting a landslide.

Landslide Mitigation for the Future

There are many possible steps to minimize the occurrence of landslides along Riverside Ave. One technique for reducing the risk of future landslides could be improving surface and subsurface drainage systems. The overflow of runoff is a large factor for landslides and improving these systems can stabilize a landslide-prone slope. In order for this to work, a drainage channel needs to be put into place to divert the surface water away from the landslide

region. This will make sure that water doesn't accumulate near the landslide prone area (Kansas Geological Survey, 1999). Another technique is removing the soil and rock at the head of where the landslides occur to reduce driving pressure. In the case of Riverside Ave, this wouldn't be an adequate technique because the businesses, housing, parking lots, and roadways that are all resting on the flat before the slope pitches. Buttressing the toe is another technique where fill is added at the toe (bottom) of the hillslope so there are resisting forces to stop landslide debris. Creating some sort of barrier at the bottom of the hillslope would also prevent any soil from eroding into potential nearby water bodies like the Winooski River. Preserving vegetation on landslide hillslopes can also have a huge impact on increasing soil cohesion due to root structure holding the soil, but also reduce the amount of water that percolates through the soil causing erosion to occur. Reinforced soil structures like geogrids can be effective slope stabilizers. Geogrids are constructed by placing alternative layers of metal reinforcement and compacted soil to create a structure hindering lateral forces (Mandavkar and Weldu, 2019). These methods are relatively cost-effective with prices ranging from $110/m² to 260/m² of reinforcement. However, this excludes both safety and drainage factors (Christopher, 2014).

Figure 4:
A reinforced soil structure being constructed.
Source: (Mandavkar and Weldu, 2019)

Landslide mitigation strategies on Riverside Ave should be prioritized as a way of educating the public on the issues at play. Being able to effectively communicate to the Office of City Planning in Burlington and other regional planning commissions will be part of the process in explaining the problems that lie ahead. Efforts need to be done on the public awareness front, making sure people know about the landslides, especially people who either own businesses or live on Riverside Ave. Creating timelines and maps on educational signs along the Riverside Ave river walk would be an informative way of presenting the landslide data to the average person. It's important to understand that major weather events will occur in the future and that better hillslope infrastructure needs to be implemented. Figuring out the best ways to educate

people on thinking about long-term rather than short-term strategies for climate adaptability in mitigating future landslides.

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