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Long-term monitoring of a seasonally active landslide in the semi-arid Thompson Plateau, British Columbia, Canada

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ABSTRACT: A landslide-prone stretch of railway weaves through the Thompson River Valley between Ashcroft and Lytton in British Columbia, Canada. The rail corridor forms an ideal route through the Rocky Mountains to the Port of Vancouver. As a result, it has been shared by both of Canada's primary rail operators since 1915. The shared corridor is a high consequence section of infrastructure that is critical to the Canadian economy. Bypassing the valley corridor between Ashcroft and Lytton would require > 1000 km detour via Prince George or Cranbrook. Approximately 6 km southwest of Ashcroft, a reactivated portion (< 1 Mm^3) of the larger historic "North Slide" (15 Mm^3 landslide that occurred in 1880) intersects the rail right-of-way and seasonally requires track maintenance. A detailed site investigation and desktop study was conducted in collaboration with the Geological Survey of Canada (GSC) to identify the landslide movement triggers. Clifton has collected drone imagery since 2022 at this site, including high resolution photogrammetry, light detection and ranging (LiDAR), and multispectral (MS) imagery. Change detection analysis generated a heat map for landslide movement based on annual LiDAR imagery. The MS imagery supplemented historical satellite imagery (Sentinel-2) to assess temporal and spatial variance in surface water content based on the normalized difference vegetation index (NDVI). A key observation from the MS analysis was the influence of topographic effects governing drainage above the reactivated portion of the landslide. Upslope irrigation, blocked drainage infrastructure, and the horst and graben topography caused by the original 1880 landslide have resulted in problematic groundwater ponding. Poor drainage combined with seasonal river level changes (upwards of 8 m) and ongoing riverbank erosion create ideal conditions for continued landslide displacement. Efforts are currently underway to remediate the reactivated area and mitigate future maintenance costs.

KEYWORDS: River erosion, change detection, groundwater, normalized difference vegetation index, electrical resistivity tomography.

1 INTRODUCTION

The active portion of the historical 1880 North Slide is the focus of the current site investigation and monitoring activity. The landslide is located near Canadian Pacific Kansas City (CPKC) Thompson Subdivision Mile 51.70 south of Ashcroft, British Columbia (Figure 1). Tension cracks run underneath the railway ballast along a 30 m section, causing a vertical sag and a loss of superelevation in the curve (Figure 2). This section of track is responsible for having the most frequent maintenance schedule of any location between Kamloops and North Bend in British Columbia. Regular track lifting and ballast addition is required to meet rail tolerances for continued operation.

A long history of research has been published for the numerous landslides in the Thompson River Valley rail corridor since the late 1800s. In the last two decades, increased research and instrumentation has been completed along this stretch of railway as part of a collaborative effort with the Canadian Railway Ground Hazards Research Program (RGHRP). The general stratigraphy was described by Clague and Evans (2003) and has been confirmed by subsequent authors (Eshraghian et al. 2007; Hendry et al. 2015; Huntley et al. 2023). The region has experienced at least three separate glaciation events which have eroded the underlying andesite bedrock. Subsequent glacial retreats caused the formation of long, narrow ribbon-shaped lakes which created an environment conducive to the deposition of laminated silt and clay. Rapid drainage of the most recent glacial lake contributed to the deposition of coarse materials overlying the laminated silt and clay (Johnsen and Brennand 2004). As a result, the current stratigraphic profile consists of colluvium and till overlying laminated silt and clay over bedrock. The formation of the modern Thompson River resulted in downcutting through the stratigraphic profile, exposing laminated silt and clays found on the shoreline of the North Slide (Huntley et al. 2023).

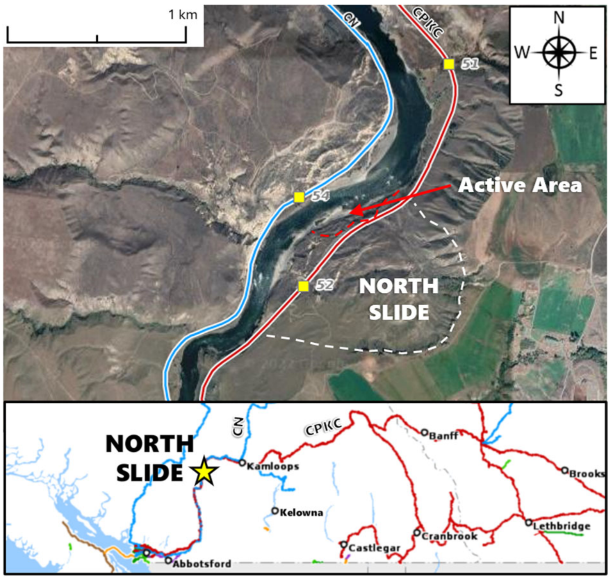

Figure 1. Original landslide compared to active area of movement.

Most of the landslides in the Thompson River Valley rail corridor, including the North Slide, are seated in the weak interbedded silt and clay. A complicating factor for many of these landslides is the seasonally variable river elevation which can increase up to 8 m from the minimum in late winter to the seasonal maximum in late spring/early summer, following spring melting of snowpack from the mountains to the northeast. Artesian porewater pressures exist below the lower hydraulic conductivity silt and clay layers. This artesian pressure may be the function of a regional groundwater regime that originates in the upland areas and potentially discharges into the river valley.

During the spring and summer months when the river level is at its peak (spring freshet), the surface water total head is greater than the underlying artesian aquifer total head and a downward seepage gradient exists. In the autumn and winter months, when the river level recedes, the artesian pressure within the bedrock and below glaciolacustrine silt exceeds the river level and the local groundwater level. This reduction in surface (river) water results in an upward gradient, which in turn reduces the effective stress within the clay layer. Additionally, as the river level recedes following the spring freshet, there is a reversal in porewater pressures from infiltration into the riverbank (from the Thompson River) to exfiltration from the slope into the river. Therefore, there is also a seasonal rapid drawdown scenario that is also driving local porewater pressure responses. Both the upward gradient and rapid drawdown conditions result in the perfect drivers of ongoing, reactivation of the seasonally dormant landslide observed at the North Slide.

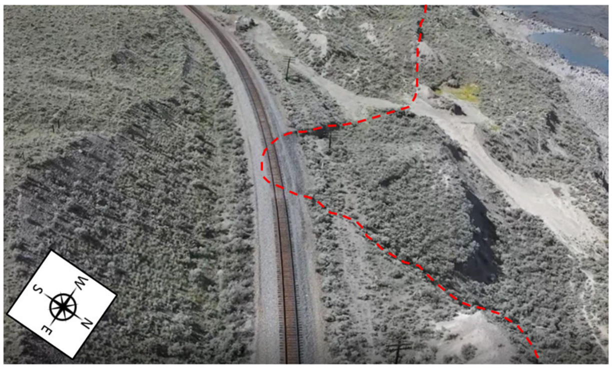

Figure 2. Active landslide slump block impacting 30 m of track.

2 PROGRESSIVE SHORELINE EROSION

One of the challenges at the North Slide is that the river pathway through the valley was modified recently, in geological terms. In October 1880, one square kilometer of riverbank failed into the Thompson River at North Slide, damming the river's flow for 44 hours (Daily British Colonist, 1880). A recent example was displayed by the Chilcotin Landslide in 2024 (Huntley et al. 2026). Similar to the Chilcotin Landslide, the Thompson River had to re-route itself around the landslide debris to re-establish flow. As a result, there is a noticeable "kink" in the Thompson River at the North Slide. In the years since 1880, the river has been trying to straighten itself out to re-establish the path of least resistance. At the north edge of the North Slide, the south flowing river cuts sharply to the west to avoid the 1880 landslide debris. A previous study by Porter et al. (2002) indicated that the current rate of riverbank erosion is 0.7 m/year based on air-photo comparisons between 1928 and 2002. An updated review of aerial imagery at the toe of North Slide indicates that erosion rates are now shown to average 0.8 m/year since 1928 (Figure 3). In the past 5 years, localized shoreline erosion has increased to a rate of 2.0 m/year near the landslide toe bulge.

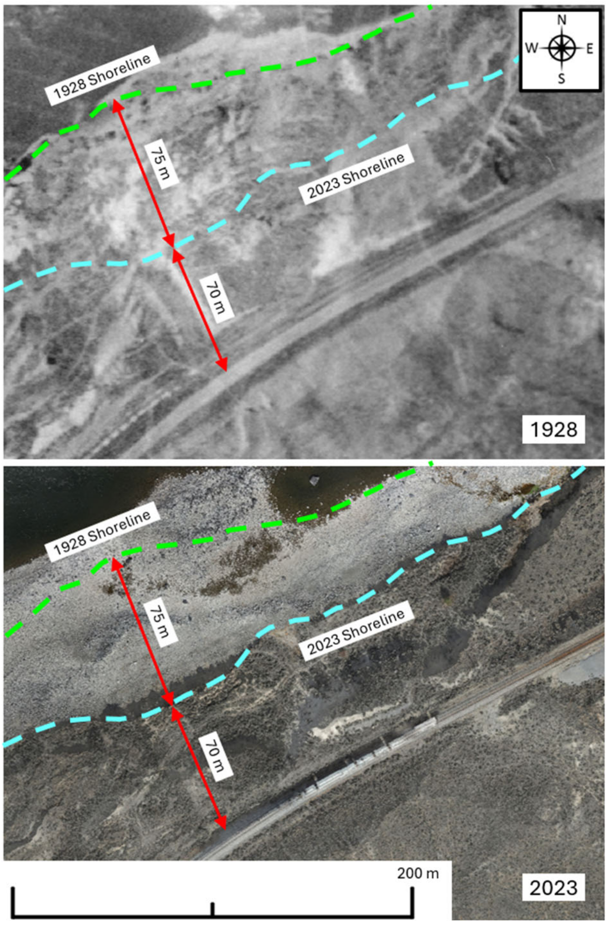

Figure 3. Progressive shoreline erosion between 1928 (top) and 2023 (bottom).

The ongoing erosion is expected to continue to result in loss of material until the Thompson River returns to equilibrium. As a result, a heightened risk for train operations will continue to exist along this stretch of rail infrastructure for the foreseeable future without mitigation measures. As engineers, we can attempt to slow the rate of erosion to protect the existing track infrastructure, or we can shift the track infrastructure to reduce the risk of catastrophic failure and potential loss of life. Based on the current riverbank erosion rate, the river will fully erode the shoreline to the track alignment within 75 to 100 years.

However, because the shoreline has been eroded sufficiently to over-steepen the till slope which the track is constructed on, a tension crack already extends beneath the rail ballast for a distance of approximately 30 m. Furthermore, historical studies in the area have noted that significant erosion can occur during extreme flooding events. For example, the Thompson River experienced high levels of flow in 1997 that were significant enough to damage erosion protection berms at the nearby South Slide and cause deep scour holes adjacent to that landslide. The North Slide is particularly susceptible to flood events because the landslide toe is exposed in the Thompson River and occurs along the outer meander of the river. As a result, increased flow velocity has the potential to remove material from the toe and further accelerate displacement rates when the river levels subside. A combination of shoreline protection and avoidance of the existing, active, tension cracks may provide a long-term solution that minimizes future maintenance.

3 CHANGE DETECTION

As part of the monitoring program, Clifton conducted unoccupied aerial vehicle (UAV) light detection and ranging (LiDAR) surveys of the entire 1880 landslide area between 2022 and 2024. As a result of a heightened interest in the Thompson River valley landslides during recent years, a 2019 LiDAR survey of the area is available as an open resource on the British Columbia government's LidarBC database (Government of British Columbia, 2025). A comparison with the 2024 LiDAR dataset provided Clifton with a detailed visual record of changes that have occurred across the entire landslide area over the past 5 years.

Figure 4 confirms the relative activity experienced by the active portion of the landslide. At least 3 m of settlement has been observed in various parts of the active zone extending towards the railway right of way. Significant shoreline loss can be seen at the high-water mark (red circled area), where up to 10 m has locally eroded over the past five years (Figure 4). Uplift of the landslide toe has resulted in a toe bulge, indicated by the green circled area in Figure 4. Initially, it was thought that the uplift could be colluvial material; however, given the relative energy of the river, any till colluvium would be eroded during the first spring freshet. Uplift was verified by observing the exposed weak laminated clay along the landslide toe bulge.

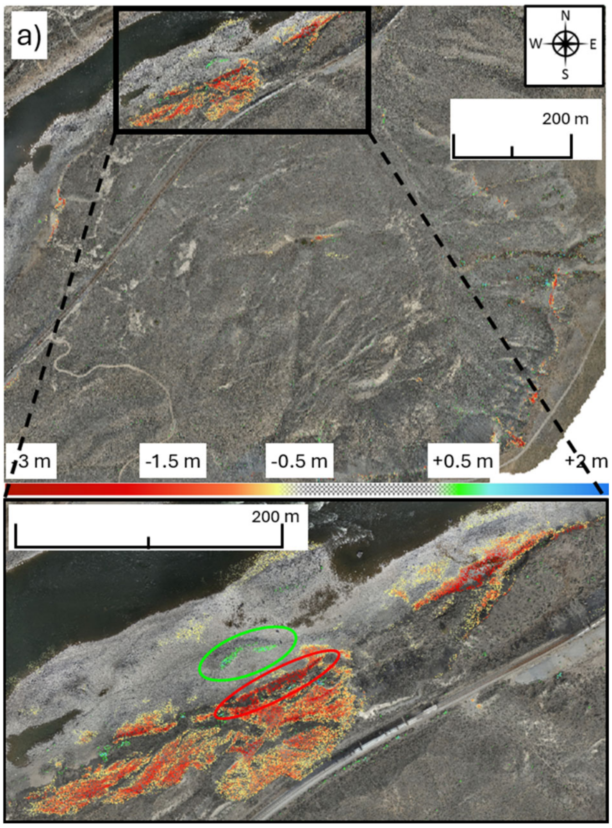

Figure 4. UAV LiDAR change detection, 2019 - 2024. Expanded view of active area (bottom) underneath full slide area results (top).

In addition to the LiDAR change detection, Clifton has worked in collaboration with the Geological Survey of Canada (GSC) and the University of Alberta (U of A) to document the surface changes with interferometric synthetic aperture radar (InSAR). While satellite InSAR provides a coarser overview of the surficial displacements, new satellite imagery is available every 1-2 weeks. To increase the accuracy of the measurements, corner reflectors have been positioned throughout the landslide by the GSC. The InSAR reported deformations are also verified using SparkFun differential GPS units at each corner reflector. The line of sight (LOS) velocity estimate between July 2020 and November 2023 is shown in Figure 5. These results reinforce the findings of the LiDAR change detection analysis and provide a framework for long-term and repeated monitoring of the active landslide area. Furthermore, the InSAR analysis can be completed remotely which provides a convenient tool in a multi-faceted approach to monitoring the North Slide.

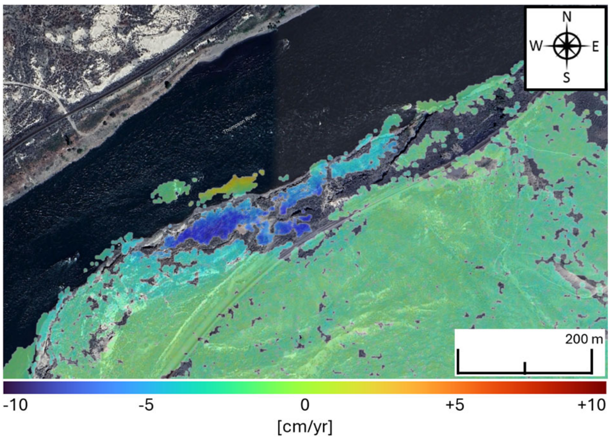

Figure 5. Satellite InSAR line of sight velocity, 2020 – 2023.

4 MULTISPECTRAL ANALYSIS

A further desktop study was conducted with satellite imagery from Sentinel-2 to assess the vegetation health and identify drainage issues within the landslide-affected area. The Normalized Difference Vegetation Index (NDVI) was calculated from the near infrared (NIR) and red bands of the satellite imagery. Negative values indicate water while NDVI values greater than 0.0 indicate increasing vegetation health to a maximum of 1.0. For example, a value of 0.0 denotes barren ground while a value of 1.0 suggests densely vegetated surfaces with a high water retention capacity.

The goal of the study was to determine the influence of irrigation from the uplands on the landslide, with particular attention to the drainage from these areas. The site is located in the semi-arid climate of the Thompson Plateau. Ashcroft averages only about 260 mm of precipitation throughout the entire year (Environment Canada, 2025). Multi-year drought cycles can limit the precipitation totals even further, as seen in recent years. In addition to the limited precipitation, the area regularly experiences up to 10 days per year where temperatures exceed 30°C (Environment Canada, 2025), as such, this region is classified as a semi-arid desert biome. As a result, irrigation is required to support agricultural practices primarily consisting of rangeland for grazing, though other crops are present within the river valley.

The NDVI analysis shown in Figure 6 demonstrates the impact of irrigation on the uplands in August 2023. The densely vegetated croplands show excellent vegetative health, which extends into the upper reaches of the North Slide through various erosion gullies. The red circled areas in Figure 6 show areas that may be impacted by the excess irrigation runoff. One of the consequences of the runoff is the potential to raise the water table upslope of the track. Historical drainage infrastructure used to channel the upslope runoff is currently in a state of disrepair. As a result, poor upslope drainage to the river has begun to manifest itself in the form of ponding water and marshy areas in an otherwise dry desert landscape.

Figure 6. Vegetation health index map from 13 August 2023 (top). Corresponding photogrammetric imagery from 13 April 2023 (bottom).

5 GEOPHYSICAL SURVEY

In December 2022, a geophysical survey was completed for the stratigraphy downslope of the rail infrastructure. The work consisted of two electrical resistivity tomography (ERT) survey lines combined with two multichannel analysis of surface waves (MASW) seismic profiles which provided a 3D visualization of the stratigraphy and groundwater table beneath the active portion of the slide mass. The purpose of the ERT was to identify potential areas of subsurface seepage and delineate major stratigraphic boundaries. This goal was accomplished by measuring resistivity and noting changes to the resistance within different soil and bedrock units across the surveyed cross section. Areas of high resistivity (shown in red on Figure 7) are typically indicative of either coarse-grained materials or dry soils (air gaps in the soil resist the flow of electric current). Dark blue areas indicate the opposite case of low resistivity, characteristic of fine-grained soil or increased water content.

The ERT plot shown in Figure 7 noted pore pressure build-up (circled dark blue areas) that intersect the annual high river level mark on the slope (approximately 278 m). During subsequent site inspections, Clifton noticed that there was evidence of historical internal erosion from groundwater seepage (piping) on the slope face that coincided with the high-water mark and pore pressure accumulation from the ERT plot. The survey was conducted in the winter to ensure that the shoreline was captured during the low river level. During the survey, relatively high groundwater seepage was observed to the north of the survey line. Pore pressure accumulation was also noted well below the tension cracks that undercut the tracks and near surface upslope of the tracks. A thick layer of high resistivity (dry/coarse) material was located underneath the track. Previous investigation identified a thick (> 1.5 m) layer of ballast, possibly a remnant following years of track lifting and ballast addition. The material appears to trap water while surrounding clay till restricts the flow of water and causes a build-up of pore pressures, as indicated in Figure 7.

6 INSTRUMENTATION MONITORING

In 2023, Clifton completed two 60 m deep boreholes through the active landslide mass downslope of the rail right of way (Figure 8). The geotechnical investigation at North Slide expanded upon the original geophysics investigation and early borehole logs completed over two decades ago. Clifton's investigation probed deeper into the subsurface stratigraphy, re-established displacement and porewater pressure monitoring, and collected strength and stiffness parameters via pressuremeter, which was a first in the Thompson River valley. Geotechnical instrumentation was installed in each borehole, consisting of vibrating wire piezometers (VWP) and a ShapeAccelArray (SAA) in BH23-1. The instrumentation installed in these boreholes was used to monitor porewater pressures and subsurface displacements. These findings improved our understanding of the landslide mechanism, local geology, and groundwater.

Piezometric measurements collected since installation have identified the presence of strong upward hydraulic gradients (on the order of 10 m) in the vicinity of the actively sliding region (Figure 9). Changes to the river level have an increasing effect on piezometers with increasing depth. The deepest piezometer seasonally rises by about 1 m during spring freshet. However, a strong upward hydraulic gradient is maintained throughout the year. These gradients also indicate strong uplift pressures on the landslide toe. Upward hydraulic gradients can contribute to destabilization of a landslide, particularly when these forces exist near the toe of an active landslide. Uplift forces help drive landslide rotation, causing

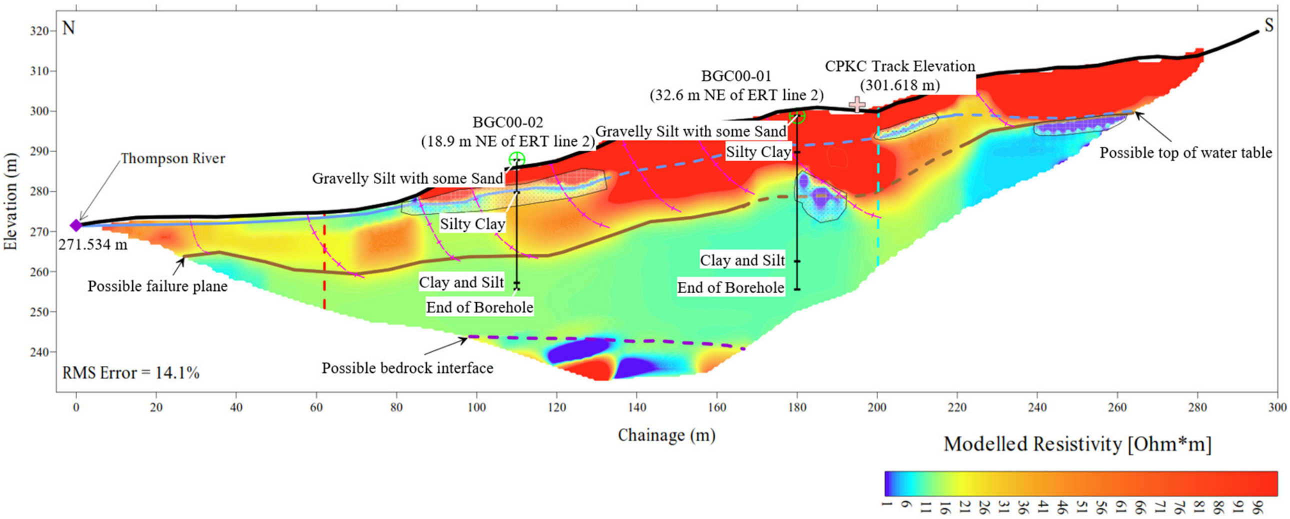

Figure 7. Electrical resistivity tomography cross section through the active landslide area.

further settlement near the head scarp. In the actively moving landslide toe at North Slide, settlement in the local head scarp region coincides with sagging of the rail infrastructure, resulting in additional maintenance to correct rail alignment, cross-level, and track sag.

Figure 8. Clifton borehole investigation layout in 2023.

ShapeAccelArray displacement monitoring indicated that there are two distinct shear planes in BH23-1. The upper shear plane occurs around 275.9 m with a displacement rate of up to 0.86 mm/day (Figure 10). The lower shear plane, located at approximately 267.5 m, is currently moving with a higher displacement rate of up to 0.88 mm/day (Figure 10). The displacement rates since installation in August 2023 are shown in Figure 10. The measurements indicate seasonality to the movement that is not always repeated from one year to the next. Another apparent pattern is that rapid movement follows periods of little to no movement. Finally, the plots show that movement on the upper shear plane is highly dependent on movement of the lower shear plane. As a result, it may be possible to simplify the analysis and focus on the lower shear plane displacement. The resolved direction of movement for the lower shear plane is depicted in Figure 8. Ongoing monitoring continues to provide an uninterrupted record of porewater pressures and landslide displacement, which is critical to understanding this complex landslide.

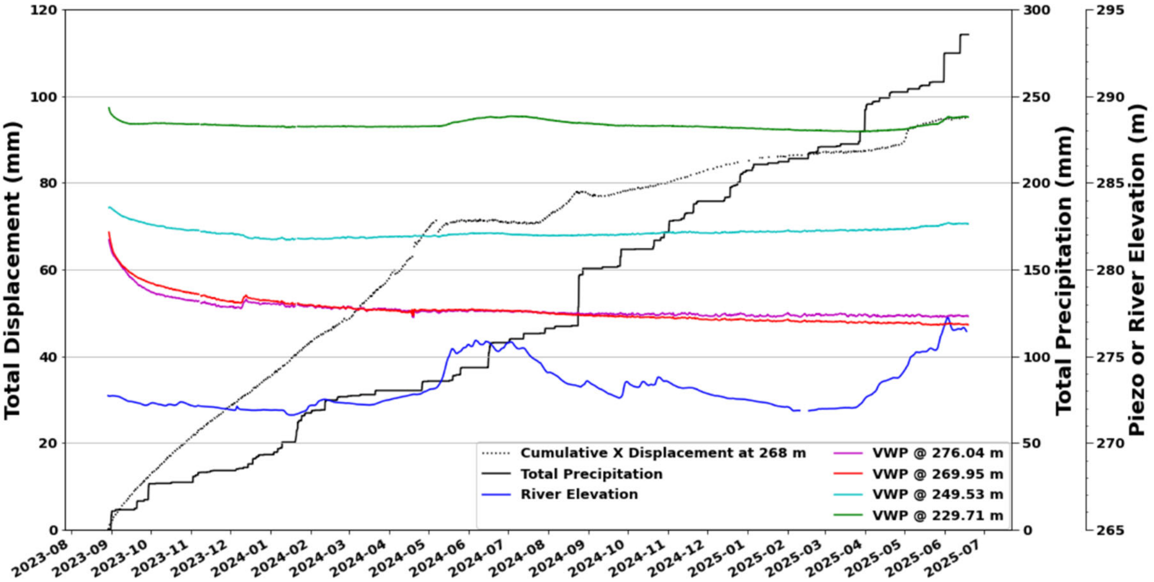

Figure 9. Record of displacement, precipitation, piezometric head, and river elevation since the 2023 site investigation.

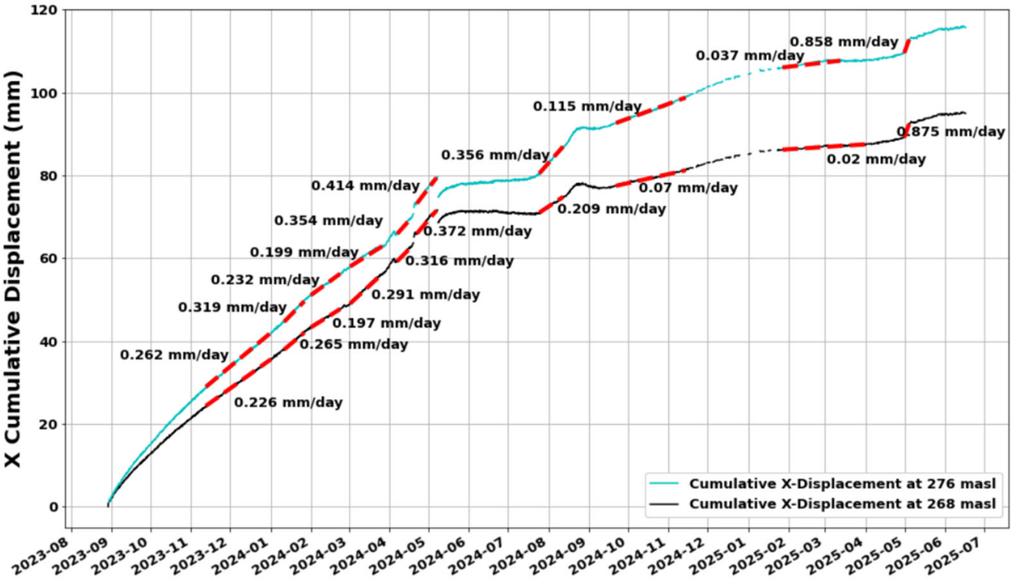

Figure 10. Rate of displacement on the upper and lower shear planes since 2023.

7 CONCLUSIONS

A detailed long-term monitoring program was completed at Mile 51.70 of the CPKC Thompson Subdivision which improved our understanding of the localized instability that intersects 30 m of railway infrastructure and causes regular track maintenance. A desktop study of historical imagery provided a method to quantify shoreline erosion rates. UAV and satellite InSAR were used to plot change detection maps and identify areas of soil loss due to erosion. Change detection also provided bounds to the active area of movement at the base of the original 1880 landslide. Multispectral analysis provided visualization of irrigation runoff channels and identified problem areas that require drainage remediation. A geophysical survey identified stratigraphic boundaries and zones of pore pressure buildup. The geotechnical drilling program installed instrumentation to measure pore pressure and displacement. The piezometer data identified strong upward hydraulic gradients near the landslide toe that were not previously well understood at the North Slide. Furthermore, the subsurface displacement observations provided accurate rates of movement which will be used to calibrate UAV and satellite methods of surface displacement measurement.

The ongoing monitoring program at the North Slide in the Thompson River valley provides a detailed record of landslide movement, both seasonally and over multiple years. The results of this study are vital to understanding the landslide mechanism and selecting a practical remediation method. Only by understanding the landslide triggers and the impact of seasonality, is it possible to achieve our goal of lowering the displacement rate to a manageable level. A collaborative effort will be key to providing a cost-effective solution tailored to the North Slide that addresses the complex array of destabilizing factors present at this site.

8 ACKNOWLEDGEMENTS

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