Remote-sensed detection and characterization of the St. Cyr Rockslide, British Columbia, Canada

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Abstract: In 2020, ALOS-2 Fine SAR data was first collected and processed to provide the first L-Band InSAR data set an existing hydroelectric reservoir in the Canadian Selkirk Mountains. This data highlighted a large active mass adjacent to St. Cyr creek whose extents had not been previously characterized. Subsequent acquisition of airborne lidar and field reconnaissance was utilized to characterize the morphology of the slope and additional two-dimensional analysis of two-dimensional C-Band InSAR data was utilized to determine that the rock slide mass likely ranged from 1.3 x 10^7 m3 to 1.9 x 10^9 m3 with a rupture zone likely up to 200 meters below the ground surface. Two boreholes advanced in 2022 confirmed the existence of shear zone located up to 250 m below the ground surface (mbgs) along the highway near the edge of the reservoir, indicating that the rockslide toe is located within the reservoir. Additional coarse and fine SAR data dating back to 2014 indicates that the slide has been moving at velocities ranging from 20 mm/year to 30 mm/year over the past decade.

Keywords: *Rockslide, InSAR, lidar, characterization, remote sensing.*

1 Introduction

BC Hydro is the Province of British Columbia's Crown Corporation charged with managing the province's hydroelectric assets, including the management of slope hazards. Only one reservoir for a dam commissioned 2024 to 2025 has been characterized with remote sensing techniques such as lidar and InSAR for the entire reservoir area. The remaining legacy reservoirs were characterized utilizing the technologies and knowledge available at that time, with remote sensing assessments undertaken at select slopes or areas within the reservoirs, and the inventory of known slope hazard reflects this. As part of an initiative to modernize their understanding of reservoir slopes, BC Hydro retained BGC Engineering and partnered with the Canadian Space Agency to fund a pilot project to assess the utility of both C-Band and L-Band InSAR to support mapping of activity of known hazards and to detect any active areas that had not been previously identified.

The Revelstoke Reservoir in Southeast BC was selected as a test site for this program.

Figure 1: Aerial view of the St Cyr landslide with lateral extents corresponding to pavement damage on highway.

2 Remote Sensing Characterization

When designing the InSAR program a review of available data sets was undertaken. An existing archive of C-Band Sentinel-1 data covering the reservoir was available from 2017, there were no existing footprints of L-Band data. ALOS-2 Fine data was tasked over the southern extents of the reservoir during the snow free period between April and October 2020. When compared to the C-Band data, there was a significantly higher point density obtained from the L-Band data and a distinct signal obtained for the highly vegetated reservoir slopes (Figure 2). As shown in Figure 2, the area with warm colours identified in the ALOS-2 data had not been previously identified as active. Measured velocities during the 2020 monitoring period averaged 33 mm/year.

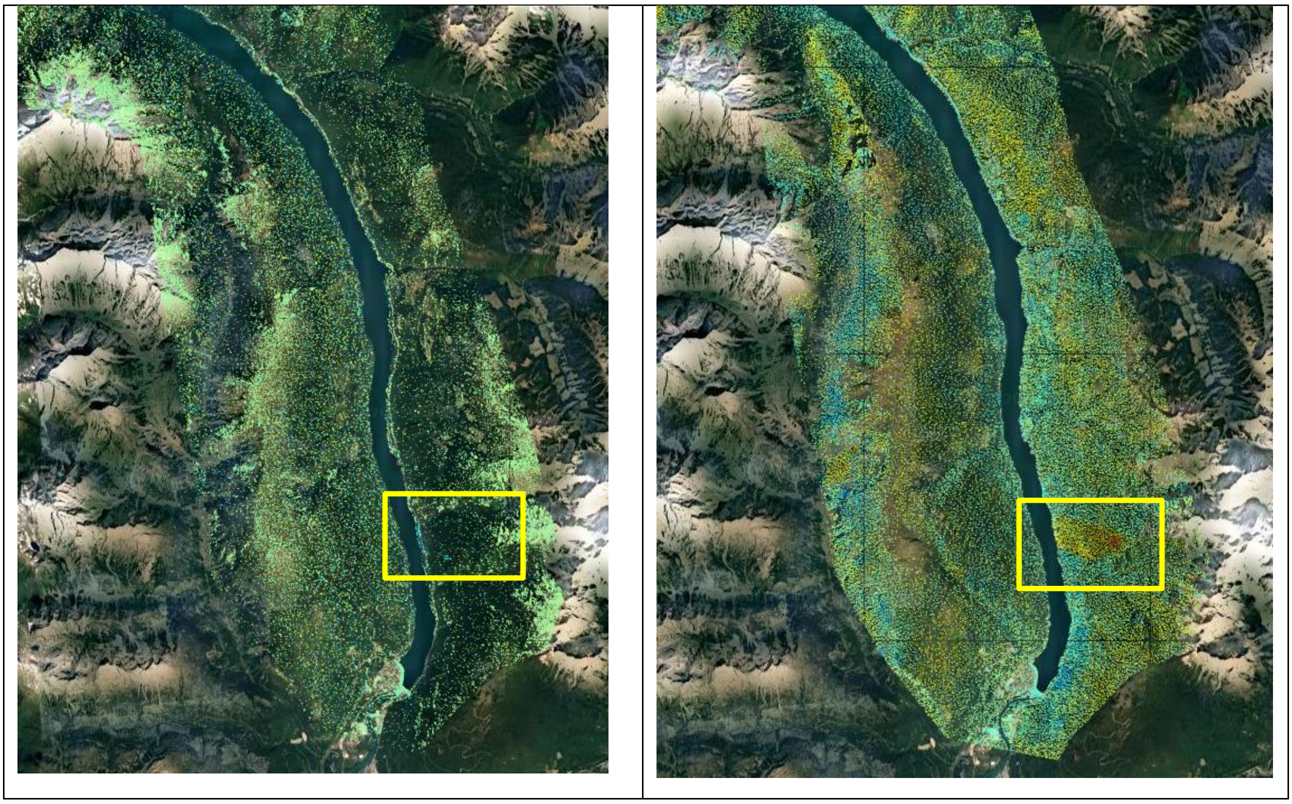

Figure 2. (Left) Ascending Sentinel-1 InSAR data (2017-2020) and (Right) Descending ALOS-2 Fine InSAR Data (April to October 2020). Yellow box indicates St. Cyr rockslide.

3 Geomorphic Characterization

Following the identification of the active portion of the reservoir slope in the ALOS-2 InSAR data, airborne LiDAR data was obtained over the area in the summer of 2021 covering the area surrounding the InSAR anomaly. The base earth model provided clear delineation of structures that were hypothesized to constrain a large rock slide and this data was utilized to divide the mass into zones based on surface morphology and variability in displacement rates obtained from the InSAR data.

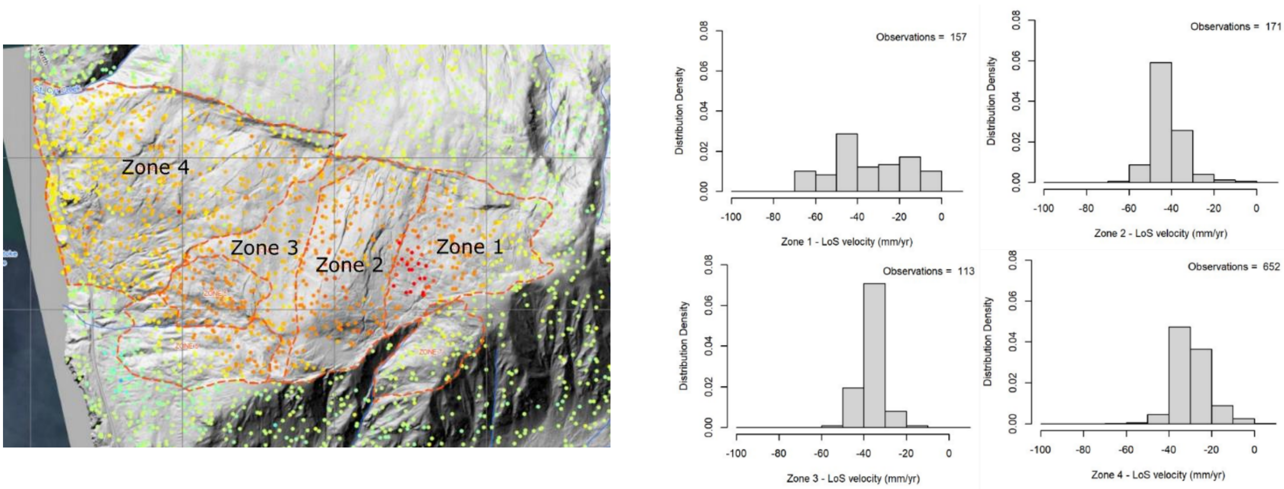

Figure 3. Initial landslide segmentation and ALOS-2 Descending Line-of-Sight velocity distributions.

4 Volumetric Estimation

As a supplement to the previously processed InSAR results, a subset of both ascending and descending Sentinel-1 SAR data was processed over the rock slide extents to obtain two-dimensional motion in the east-west direction to provide an indication of the displacement vector in that plane, which was sufficiently close to the actual fall line of the slope that it could be used to reasonably represent the displacement vector of the sliding mass. The lidar data and displacement vectors data were utilized to support rupture surface orientation estimates derived using the sloping local base level (SLBL) technique (Jaboyedoff et al.,200) and empirical area-volume relations (Guzzetti et al., 2009; Larsen et al., 2010). These techniques yielded volume estimates ranging from 1.3 x 10^7 m^3 to 1.9 x 10^9 m^3 for the mass and rupture surface depths of up to 210 mbgs .

Following the volume estimations, BC Hydro initiated the drilling of two test holes along the roadway located in the lower portion of the rockslide that was exposed above the reservoir level. The test holes encountered a distinct shear zone at depths ranging from 200 mbgs to 250 mbgs, corresponding well with the lidar-based estimates.

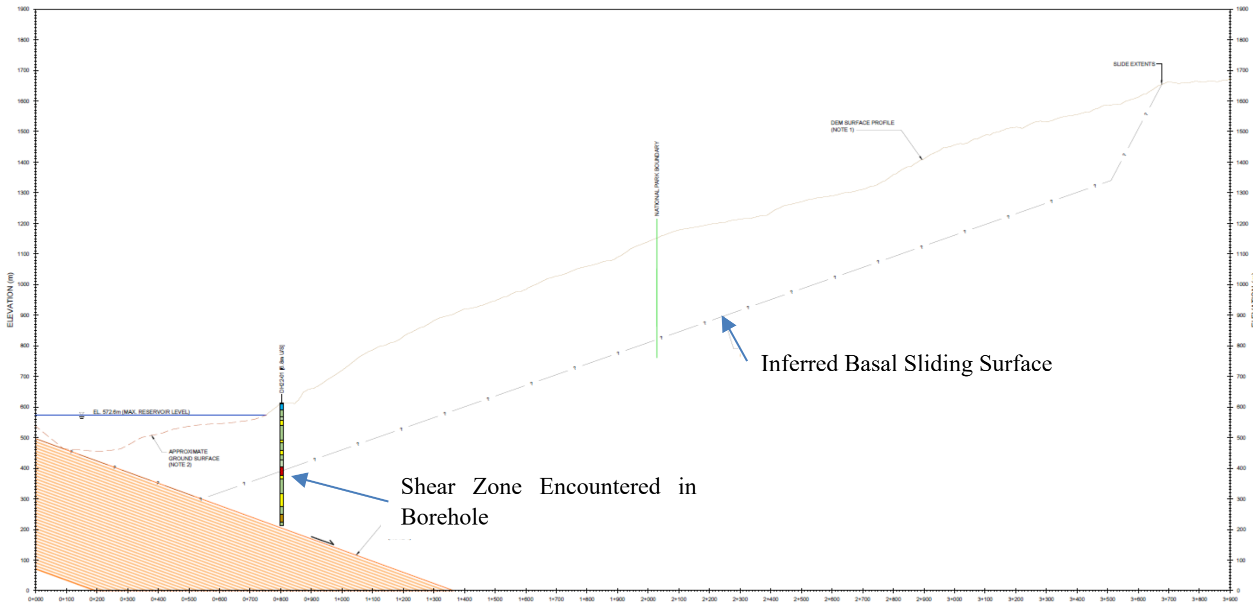

Figure 4. Schematic showing inferred orientation and depth of the rupture surface derived from empirical estimates in relation to the depth of the shear zone encountered in a test hole drilled in 2022.

5 Future Characterization and Management

Much of the St. Cyr Rockslide is located within Revelstoke National Park and therefore the permitting associated with advancing test holes and subsurface monitoring require significant lead time and therefore the current approach to monitoring has focused on the location of surface GNSS stations and the continued use of L-Band InSAR to track surface displacements. Following the 2021 ALOS-2 data acquisitions, scheduling conflicts led to the shift to the use of L-Band data from the Argentinian SAOCOM satellite. The SAOCOM data (2022 to 2025) with ALOS-2 ScanSAR data (2014-2024), the ALOS-2 Fine (2020-2021) have been utilized to generate a 10-year record of displacements for the rockslide providing an average line-of-sight velocity range of 20 mm/year to 30 mm/year over the past decade. It is expected that the newly available L-Band data from NISAR will start to be assessed in late 2026 and the ascending and descending, left-looking NISAR data could possibly be coupled with the SAOCOM data to support additional refinement of the three-dimensional understanding of the displacements.

6 Conclusion

Although the slopes along the Revelstoke reservoir were extensively characterized utilizing available data and expertise in the 1970's, the advent of L-Band InSAR data and airborne lidar has allowed for detection, mapping and initial characterization of an active rock slide with an estimated volume of up to 1.9 x 10^9 m3. With the upcoming availability of freely available L-Band SAR data with standard global acquisitions from NISAR and the European Space Agency's ROSE-L satellites, BC Hydro and other asset managers in vegetated terrain will have the opportunity to better understand and communicate on slope hazards.

7 References

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