Report on 2018 monitoring of the Johnsons Landing landslide

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Monitoring of the potentially unstable area above the Johnsons Landing landslide continued in 2018. Stake measurements and site visits were undertaken in May and October. Reflectors along the headscarp were also in September 2018 by Sproulers' Enterprises Limited. We did not observe any visible changes to the headscarp area.

Slope displacement measurements

Eight measurement sites are located along the crack that bounds the top edge of the potentially unstable area (see Figure 1 for measurement site locations). One of these (Site 1) is a line of 6 metal pins, with the top pin drilled into bedrock above the crack; therefore, this site is the most reliable measurement location. The other sites consist of two or three wooden stakes driven into soil above and below the crack. The distance between the stakes is measured manually with a tape measure. Unfortunately, many of these wooden stakes have become damaged or slanted because of rockfall and snowload; therefore, the wooden stake measurements in the past few years have become less accurate or have been destroyed.

The measurement of the displacement of the upper crack over the past five years shows systematic, progressive movement at the apex of the tension crack (e.g. Figure 2), but limited or no movement towards the outer edges. Table 1 summarizes the measurement data.

Figure 1. Measurement locations that are measured by hand are identified in yellow, and measurement sites surveyed by SEL from a base station are shown in red. The dashed line shows the approximate location of the upper crack that bounds the top edge of the potentially unstable area.

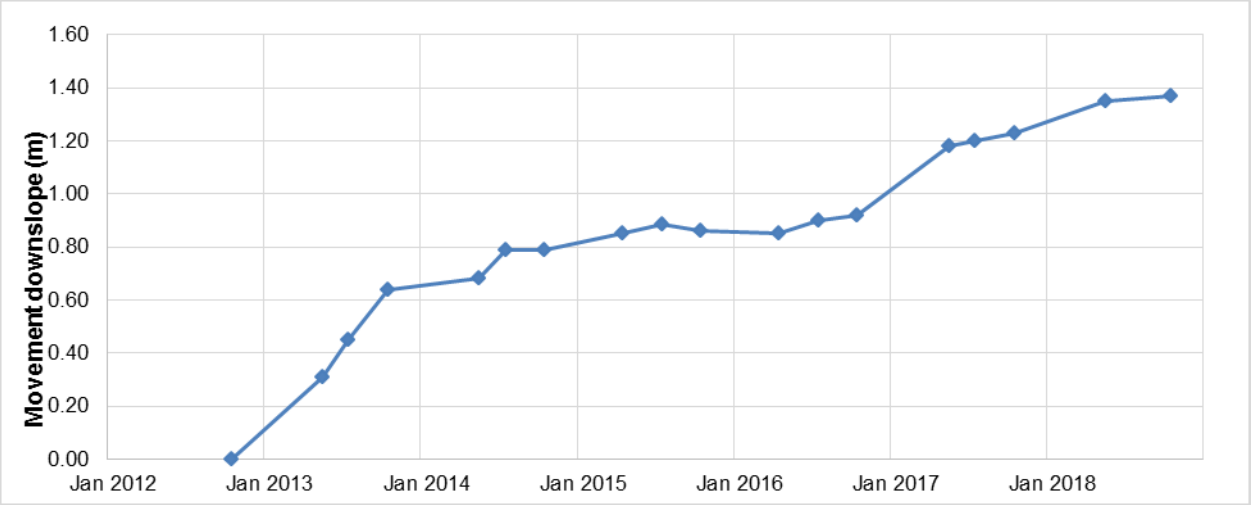

Figure 2. Cumulative downslope movement along the upper crack at Site 1 (see Figure 1 for site location). Downslope movement was measured as the distance between stakes spanning the crack.

Table 1. Summary of total annual movement (year beginning in October). Measurements highlighted in green are considered to be inaccurate due to stake damage because of rockfall or snowload.

Site	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018
1	0.64 m	0.15 m	0.07 m	0.06 m	0.31m	0.14 m
2	-0.47 m	-0.28	Missing stake			
3	Missing stake					
4	0.38 m	0.22 m	0.04 m	0.03 m	0.17 m	0.20 m
5	Installed fall 2013	0.03 m	0.01 m	0 m	0 m	0.01 m
6	Installed fall 2013	0.03 m	0 m	0.02 m	-0.02 m	0.01 m
7	Installed fall 2013	0.21 m	0.04 m	0 m	0.08 m	0.18 m
8	Installed fall 2013	0.05 m	0.07	0.12 m	-0.13 m	0.42 m

Weather record

Table 2 summarizes rainfall for the past five years in the April-June period, as recorded by the Powder Creek fire weather station. Rainfall was slightly above average over this period in 2018 (224 mm as compared to 200 mm average), mostly because April was a particularly wet month. The snowpack over the past five years at Upper Gray Creek Pass to the south is also summarized in the table. In 2018 the snowpack was 127% of average

Table 2. Weather and snow data from 2012-2016 near Johnson's Landing.

Rainfall at Powder Creek (mm)	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**Normal at Kaslo**
April	63	49	75	26	18	76	104	62
May	44	59	77	25	94	50	45	61
June	208	164	48	42	81	45	75	77
3-month sum	314	272	200	93	193	171	224	200
Upper Gray Creek Snowpack (% of Normal)	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**Upper Gray Creek April 1 SWE Normal 1981-2010 (mm)**
April 1	134%	100%	113%	83%	118%	109% (est.[1])	127%	722

[1]No data was collected April 1 2017 at the Upper Gray Creek snow course; therefore, snowpack was estimated based on comparison with the March 1 and May 1 values and the Redfish snow pillow.

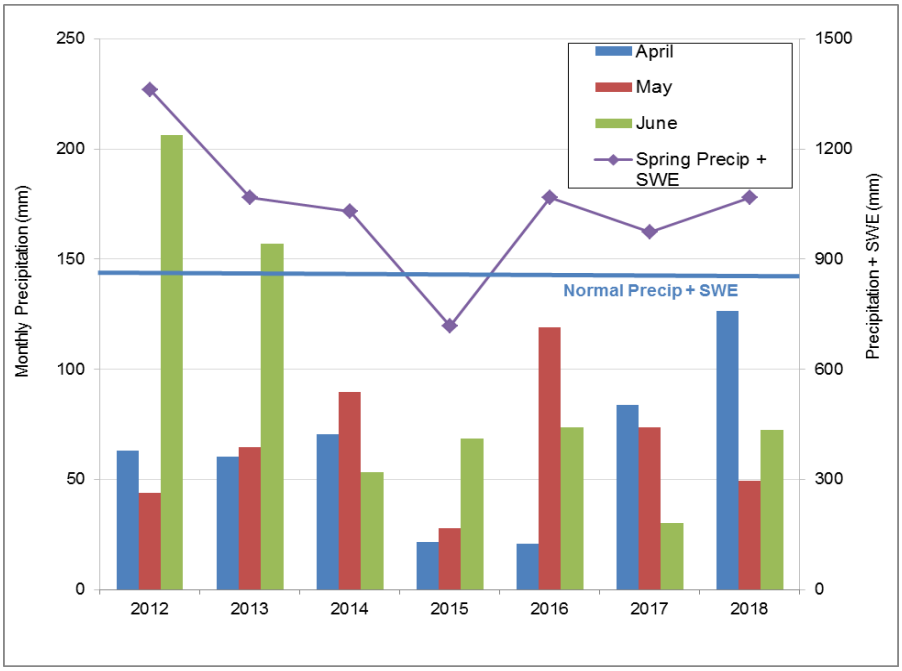

Figure 6. Record of monthly spring precipitation at the Kaslo Environment Canada station 20 km SSW of Johnsons Landing and the spring (April to June) precipitation from the Kaslo station plus the snow water equivalent (SWE) on April 1 at the Upper Gray Creek snow survey site 55 km south of Johnsons Landing.

Given that one of the main triggering factors of the landslide was elevated groundwater levels after a particularly wet spring, the spring precipitation and snowpack are assumed to also be a factor in any ongoing instability. Since 2012 the spring precipitation and snowpack have been remarkably consistent, with the exception of 2015 which was drier. However, there does not seem to be an obvious association between the annual displacement at the upper crack and the precipitation and snowpack records. The movement that has been observed at the upper crack and headscarp could simply by progressive settling of the disturbed area rather than year-to-year variation in groundwater or pore water pressure levels. Alternatively, the interannual variations in precipitation may not have been sufficient to have a detectable impact on the movement. The spring snowpack and precipitation was almost 150% of normal in 2012, whereas in the years since the snowpack and precipitation has been within 15% of normal.

Survey of Reflectors at the Headscarp

A set of reflectors were installed on the rim of the headscarp in 2014 to provide a more sophisticated method of measuring movement of the slide in addition to the manual measurement of stakes. The reflectors have been measured once a year by Sproulers' Enterprises Limited (SEL). See Figure 1 for reflector locations.

The spatial and temporal pattern of movement of the surveyed reflectors along the headscarp rim indicates that there has been some minor (10-17 cm) westerly movement of the headscarp over the past four years. This corresponds to an annual displacement of approximately 2.5 to 4.5 cm per year. Less movement was observed at MON10 (the reflector on the dropped block), and no movement (within measurement error) was observed at MON11, which is located on stable ground outside the landslide source area.

LiDAR differencing

Cooper Creek Cedar provided the provincial government access to their 2017 LiDAR data for the Johnsons Landing area. By comparing this dataset to the 2012 LiDAR data, we were able to calculate elevation changes over the slide area. Raveling and deposition along the headscarp were detectable as well as erosion and deposition along Gar Creek. Along the upper crack, it appears as though up to 100 cm of subsidence has occurred over 5 years.

Conclusions and recommendations

<u>Summary of measurements</u>

- The cumulative downslope movement at the apex of the upper crack has been 130 cm over the past 6 years
- The LiDAR differencing data shows approximately 100 cm of subsidence at this location.
- The survey data indicates 10-17 cm of westerly horizontal movement along the headscarp since 2014. Over the equivalent time period, the cumulative downslope movement at the upper crack has been 58 cm.

The greater displacement at the upper crack relative to the headscarp may indicate that the unstable area is settling and will eventually reach a new static equilibrium. In this case the movement would be expected to diminish with time. Significant displacement was observed in

the first year after the slide, with decreasing movement over the following four years. However, an increase in displacement was observed at the upper crack in 2017 despite that spring not being particularly wet.

In view of the increased displacement over the past two years and the progressive movement at the headscarp, ongoing monitoring of the site is planned for at least the next few years. Ideally monitoring will continue until a particularly wet spring occurs with no consequent increased displacement or until movement at the headscarp and upper crack slows to zero.

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