APPENDIX I:
BLUFF EROSION DERIVED FROM REPEATED GROUND-BASED LIDAR MEASUREMENTS

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Ground-based three-dimensional (3-D) laser (GBL) scanning technology has been successfully used by Department of Transportation offices throughout the United States to undertake bridge and rockface surveys (e.g., PennDOT), and by researchers for monitoring mass wasting on the central California coast (Collins and Kayen, 2006). The major advantage of GBL over other techniques is that the laser scanner is capable of generating a detailed topographic map of the entire bluff face (data spacing of 2.5 cm^2 with an accuracy of ±0.5 cm (1 in^2 at an accuracy of 0.2 in) providing an unprecedented level of detail of bluff change. Subsequent resurveys of the bluff face using the 3-D laser scanner can thus provide a unique insight into the spatial and temporal variability of bluff erosion that may help resolve the relative importance of coastal erosion and groundwater in triggering landslide movement at places like Johnson Creek and elsewhere on the Oregon coast.

DOGAMI and ODOT staff have trialed GBL on three occasions at the Johnson Creek landslide: a preliminary test was undertaken in May 2004 at three discrete loca-

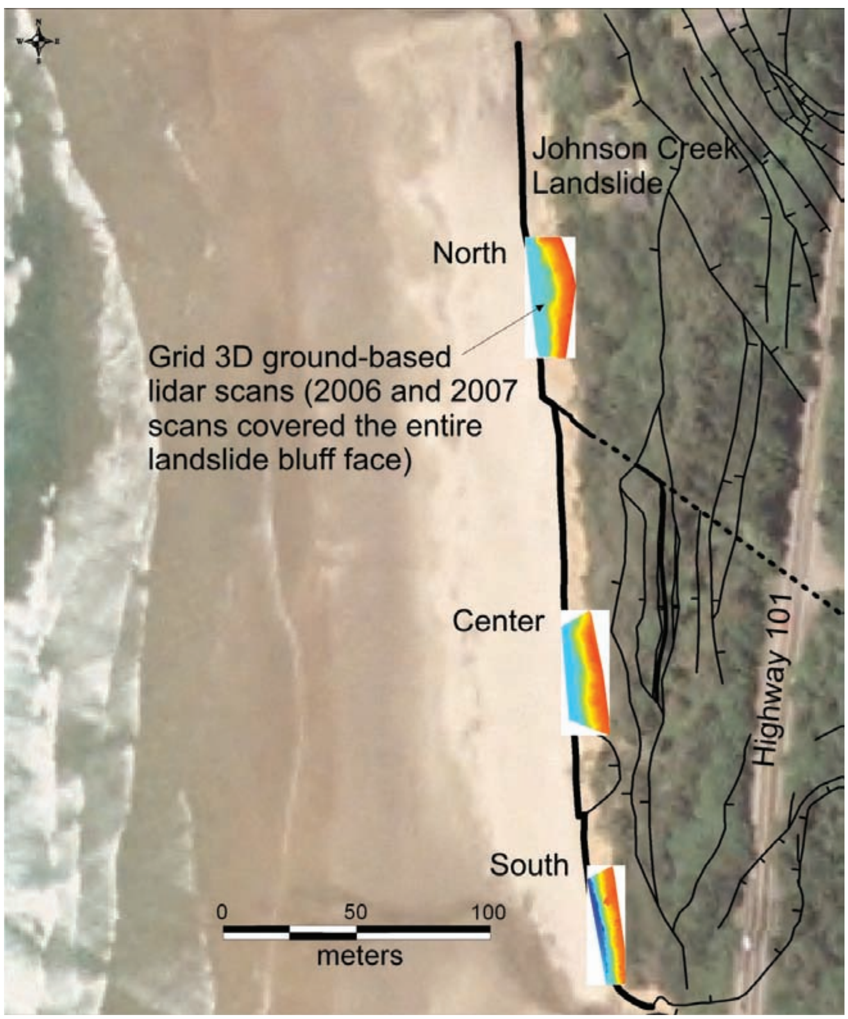

Figure I1. Location map showing those areas repeatedly scanned using ground-based lidar. Note that the 2006 and 2007 surveys covered the entire bluff face, whereas the 2004 pilot survey covered three discrete locations on the bluff face. Slide block boundaries (black lines) are from Priest and others (2006).

tions on the bluff face (south, middle, and north end), while follow-up surveys were carried out in October 2006 and again in April 2007 of the entire 300 m (1000 ft) long bluff face (Figure I1). Precise survey control was provided by various "stable" survey monuments located outside the landslide area, enabling the scans to be precisely georeferenced to the same coordinate and elevation datums during each setup. Figure I2 shows an example of the reduced point cloud data file for a small section of the Johnson Creek bluff near its southern end. Due to the dense sampling of the scanner, the resultant point cloud captures virtually every feature of the bluff face and beach (i.e., it is akin to a photo of the bluff face). For example, Figure I2 clearly shows the location of the Johnson Creek culvert, the presence of woody debris strewn about the creek, and a cobble berm constructed along the toe of the landslide.

As additional GBL lidar surveys are undertaken, changes in the morphology of the bluff face can be documented, while analyses of static features in the image (e.g., tree trunks) provide a means of assessing the extent of differential landslide movement over time (i.e., the data are subsequently adjusted to reflect the movement of the landslide). However, because of limited processing capabilities at this stage, we are unable to document the degree of landslide movement along the Johnson Creek bluff face, an issue that we hope to resolve in the near future. Accordingly, the results presented here reflect the "unadjusted" state of the landslide face, whereby movement of the landslide between each sampling interval has not been backed out of the original data set. Figure I3 is a location map showing the three sections of the bluff where GBL data are available for all three years and the locations of the transect lines used to document changes across the bluff face. The degree of bluff change between 2004 and 2007 based on six representative transects is shown in Figure I4. As can be seen in Figure I4, in general the amount of profile change in the north is comparatively less than in the central and southern portions of the bluff face. This pattern is consistent with analyses of erosion as measured by the erosion pins described in Appendix H. Furthermore, analyses of the response of the bluff over time indicate generally greater erosion at lower elevations (i.e., above the 4.5-m elevation and below about 8 to 10 m), while the upper portions of the bluff face show much less change. There are of course exceptions to this, such as the responses shown for the north profile 8 and south profile 4 sites, which indicate significant erosion at higher elevations. At both these sites, the erosion probably reflects a slump failure.

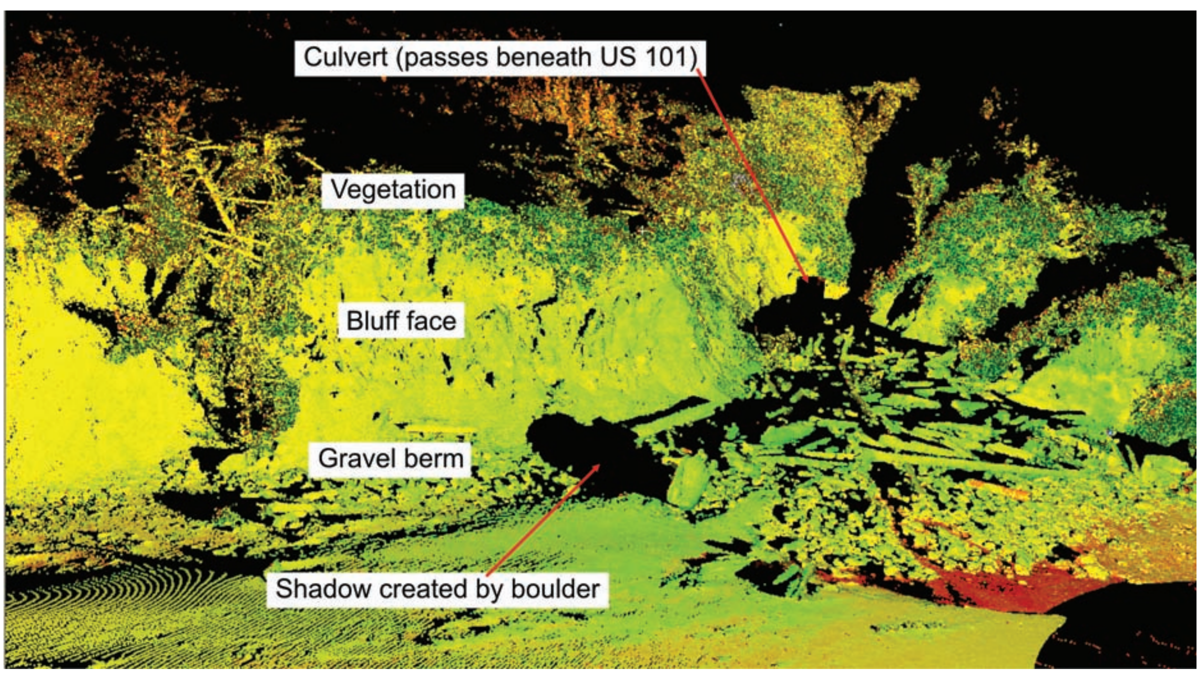

Figure I2. Point cloud example derived from a survey in October 2006 at Johnson Creek (point density is approximately 2 cm^2).

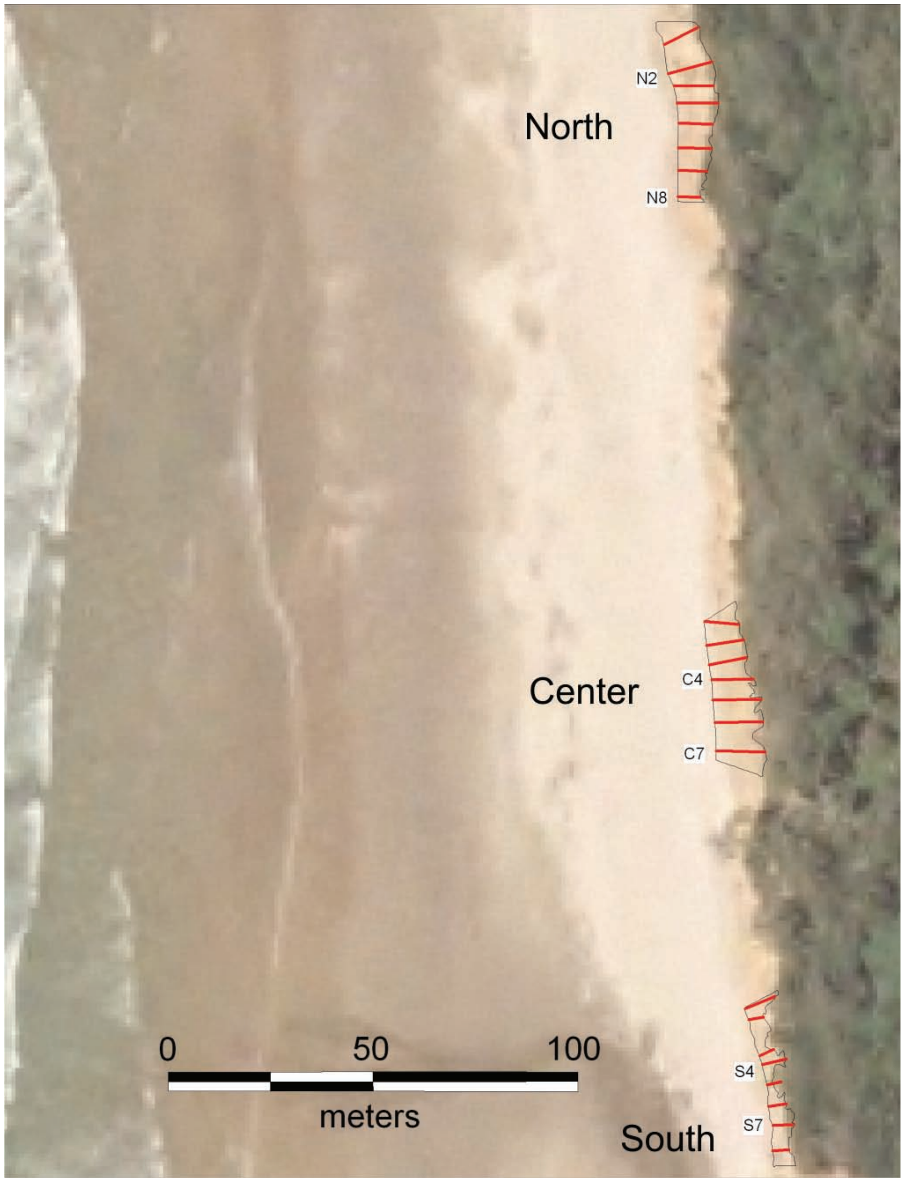

Figure I3. Map showing locations of representative bluff profile sites.

The responses shown for the central profiles indicate much greater horizontal movement, with the bluff face having moved seaward by as much as 0.2 to 0.4 m; recall that the results presented here reflect the unmodified GBL data with the landslide movement not having been 'backed out' of the data set. This contrasts with the almost negligible movement characterized by the north end of the landslide, which showed average offsets of only a few centimeters. Given that the total movement from April 2004 to April 2007 was about 0.13 m, determined by the inclinometer data, the GBL data provide evidence for differential movement along the landslide face with much greater movement in the central portion of the landslide and seaward of the inclinometer holes. This response may be due to the presence of numerous block failures that characterize the central part of the landslide and that respond at different rates compared with the entire block feature.

A major limitation of conventional two-dimensional (2-D) profile plots as shown in Figure I3 is that as more surveys are completed, interpreting the changes becomes difficult; this is because the profile lines begin to overlap and merge. Excursion distance analysis (EDA) can resolve this problem as EDA depicts the

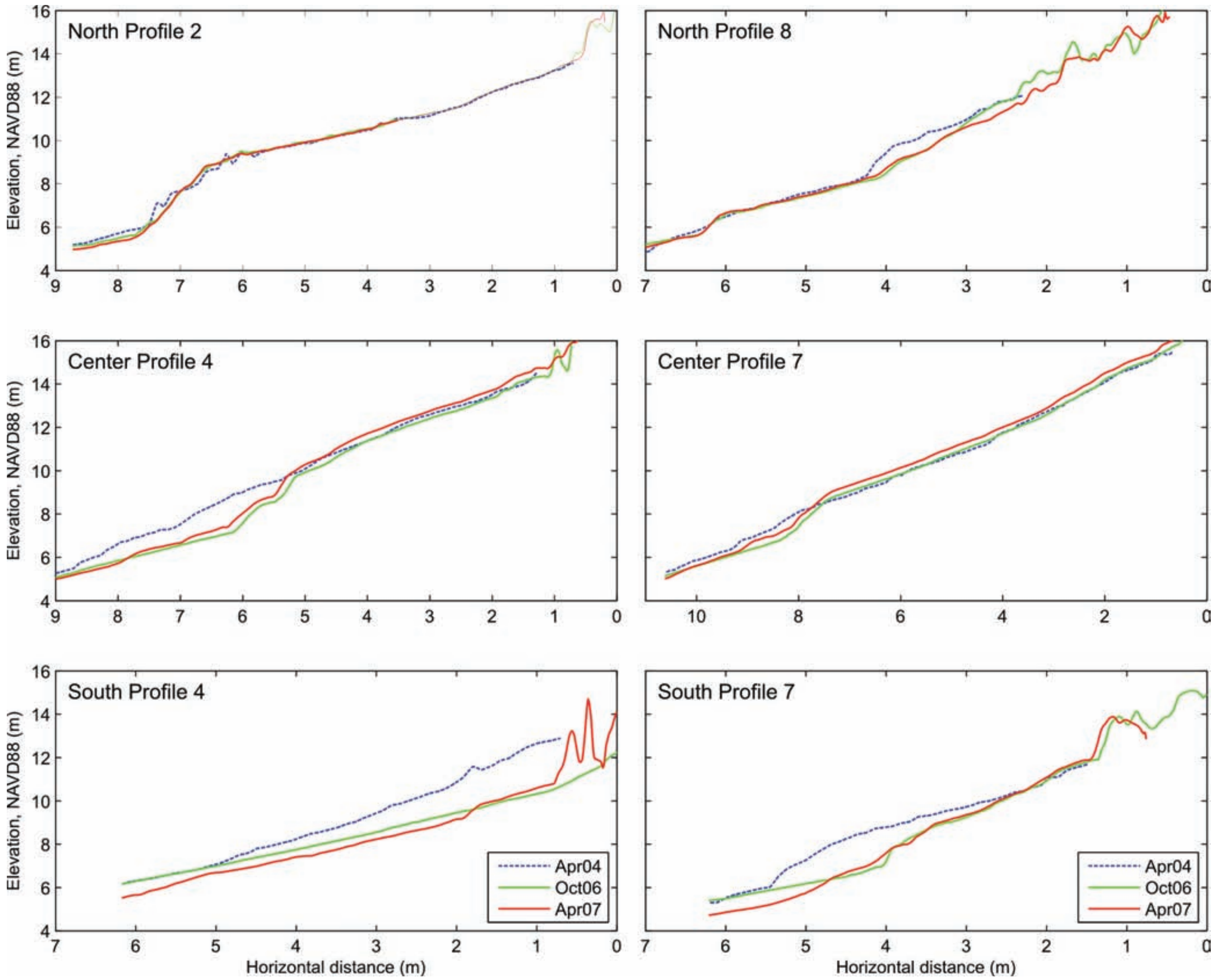

Figure I4. Six representative bluff profiles derived from the three sections along the Johnson Creek bluff face (the locations of these sites are provided in Figure I3). Note that the elevation data are relative to the North American Vertical Datum of 1988 (NAVD 88).

change in position of the bluff face (i.e., its excursions) for different contour elevations against time. In this respect, EDA is analogous to a "time stack" of how the beach is responding to variations in the incident wave energy, currents, and the sediment budget. One can take such an approach one step further and plot the response of the excursions along a feature of interest, such as the Johnson Creek bluff face, to better appreciate the alongshore variability in bluff response (erosion and accretion). Here we have used the 2004 GBL data set as the baseline from which the 2006 and 2007 scans have been related. Figure I5 presents the results of such analyses for the period 2004 to 2006 and from 2004 to 2007 for two contour elevations, the 7-m and 11-m elevations. Respectively, these two elevations characterize the response of the lower and upper bluff face. The alongshore position (x axis) of the excursions is plotted in northings (meters) and reflects the approximate position of the bluff profile sites from south to north. As can be seen in Figure I5, the lower bluff face is characterized predominantly by erosion, with the greatest degree of erosion, –1.8 m, occurring in the south between 2004 and 2006. Significant erosion also characterizes the central part of the landslide, while erosion in the north is considerably lower. At the higher 11-m elevation, the response is generally more uniform in the central and northern portions of the landslide, while the southern end shows more variable responses;

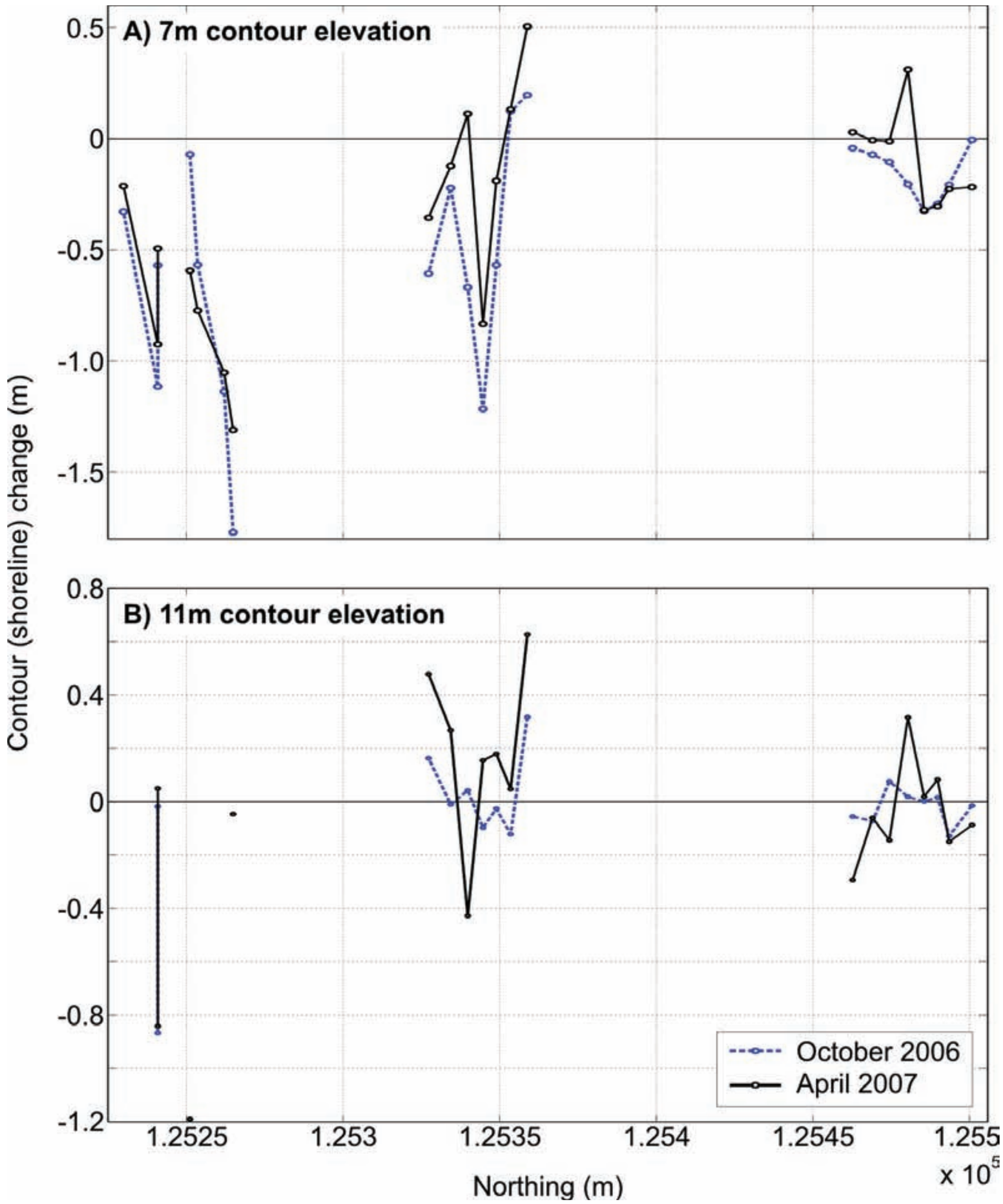

Figure I5. Alongshore response of the 7-m (lower bluff face) and 11-m (upper bluff face) contour elevations. Note that negative values indicate erosion while positive values indicate accretion or progradation of the bluff face.

in the south the bluff elevation is lower and transects at some locations did not extend above 11 m — hence the missing data points. Finally, here, Figure I5 shows that for the most part the 2007 survey places the bluff face seaward of the 2006 survey, indicating that the entire landslide has moved.

Aside from developing cross sections, it is possible to determine volumetric changes between consecutive surveys. Figure I6 is a 3-D digital terrain model (DTM) generated for the southern end of the landslide and is the product of subtracting the 2004 data set from the 2007 scan. To eliminate erroneous data associated with trees and bushes along the bluff top, a contour plot was initially developed and a boundary line was designated, above which the data were "blanked" and ignored. As can be seen in Figure I6, the southern end of the landslide is dominated by significant erosion with some areas having seen as much as 2 m of bluff retreat, while the bulk of the landslide has eroded landward by approximately −0.25 m to −0.5 m. The total volume change for

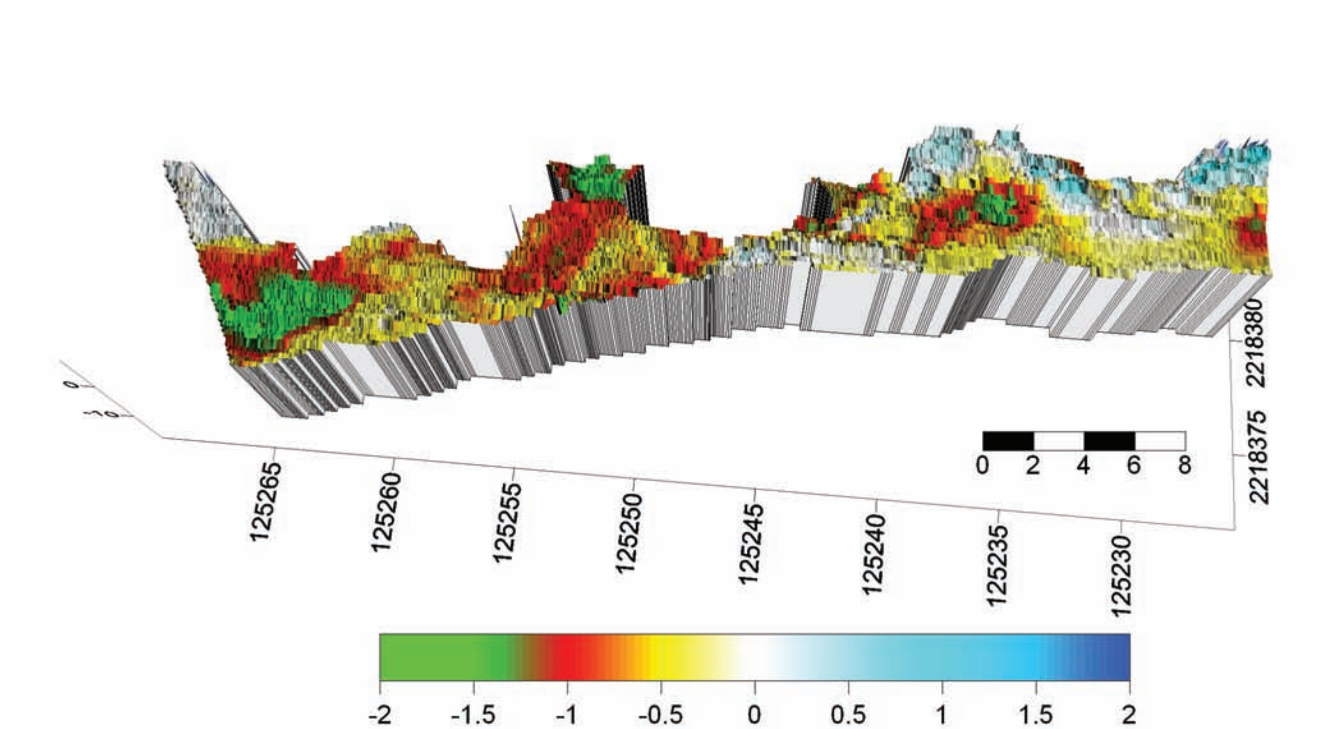

Figure I6. Digital terrain model generated for the south end of the landslide looking east at the toe of the slide (i.e., west = bottom of figure; north = left). Negative and positive changes reflect horizontal responses (gains and losses) on the bluff face. Axes are in Oregon State Plane North coordinates in meters for the North American Horizontal Datum of 1983; north. Vertical axis is in meters (NAVD 88).

Table I1. Volume change estimates derived from the three ground-based lidar scans.

Time Period	Northern Section (m^3)	Central Section (m^3)	Southern Section (m^3)
2004–2006	−14	−62	−32
2006–2007	−40	+239	−92
2004–2007	**−54**	**+172**	**−124**

Data reflect the unadjusted lidar data.

the southern site between 2004 and 2007 was −124 m^3. Table I1 shows the results of similar analyses undertaken for the other two sections along the bluff face. Recall again that these estimates are based on unadjusted data so that landslide movement has not been backed out of the data set. Table I1 show that erosion is generally highest in the south, decreasing to the north. The large gain in volume along the central section probably reflects the larger seaward movement of the landslide blocks in this area, which would need to be backed out of the data to get a true sense of the volume. It is interesting that all three sites experienced erosion between 2004 and 2006, while the 2006 to 2007 period was characterized by erosion and a large volume gain along the central portion of the landslide, indicating differential rates of movement along the seaward face of the Johnson Creek landslide.

Finally, an attempt has been made to quantify the gross volume change expected were the landslide to retreat by 3 m (~10 ft). Recall that numerical modeling of the landslide (Landside Technology, 2004) suggests that the loss of 1.5–3 m of bluff is enough to decrease the factor of safety (FOS) by −3.6% to −6.8%, triggering landslide movement. Analyses were undertaken using a combination of programs including Surfer (DTM modeling) and the Coastal Engineering Design and Analysis suite of software. Volume changes were estimated from the six transects depicted in Figure I4, from which the gross volume change was estimated. The analysis indicated that 3 m of bluff retreat would equate to a loss of about 11,000 m^3 of material. Using the data shown in Table I1 for the period 2004 to 2007, a volume change based around the three discrete sections was estimated for the full length of the landslide. Furthermore, because the landslide has moved so significantly in the central part of the block, the rate of erosion was assumed to be comparable to the south end. Assuming this is correct, the amount of bluff erosion over the 2004 to 2007 period is conservatively estimated to be about 900 m^3. This would imply that it would take something on the order of 30+ years to achieve a volume of erosion significant enough to trigger a landslide failure movement comparable to the December 2002 event. Thus, it would appear that the degree of erosion occurring along the Johnson Creek bluff face is indeed significant enough to enhance landslide movement when coupled with heavy precipitation events and may help account for the episodic nature of major movement events.

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