Quantifying the effects of the M7.8 November 14, 2016 earthquake on rainfall-induced landslide triggering and reactivation, Kaikoura, New Zealand

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Abstract: The 2016 M_w 7.8 Kaikoura Earthquake in Canterbury, New Zealand produced one of the most complex fault ruptures observed in the historical period and produced strong ground shaking. As a consequence, over twenty-nine thousand landslides were triggered over a total area of about 10,000 km^2 with the majority concentrated in a smaller area of about 3,600 km^2 (Massey et al 2018). In addition, hillslopes in the affected area were severely damaged by tension cracking and dilation. Large volumes of landslide debris generated during the earthquake remain stored in the landscape and the potential for rainfall to trigger landslides on the failed and partially failed hillslopes is anticipated to be elevated for the foreseeable future. Despite this little is known about the increase in landslide hazard and the timeframe over which this hazard will be elevated.

We used airborne LiDAR captured immediately after the earthquake (November 2016), and at six consecutive dates between November 2017 and April 2019 to develop high resolution surface change models to construct an inventory of rainfall-induced landslides and reactivated landslides following the earthquake. The results were compared with landslide inventories for a series of significant storm events between 1880 and 2019 which were compiled from various sources, including mapping from available aerial photography and satellite imagery collected between 1961 and 2019.

Analysis of the landslide inventories indicates that rainfall triggering thresholds for landslides on these highly cracked and dilated slopes is lower than before the earthquake which has resulted in a significant increase in landslide frequency for a given rainfall amount through the initiation of new landslides on weakened slopes, reactivation of existing landslides and reworking of landslide debris stored on the landscape. Most of the landslides triggered by rainfall following the earthquake were highly mobile debris flows that were strongly coupled to the channel network. Preliminary results suggest that the highest rates of post-earthquake landslide initiation (for both new and reactivated landslides) occurred in the first major storm event following the earthquake and the rate has reduced with time since the earthquake. Maximum landslide size (area) also decreased with time following the earthquake. Quantification of rates of post-EQ rainfall-induced landsliding using LiDAR differencing and aerial photo interpretation will further our understanding of post-earthquake landscape recovery.

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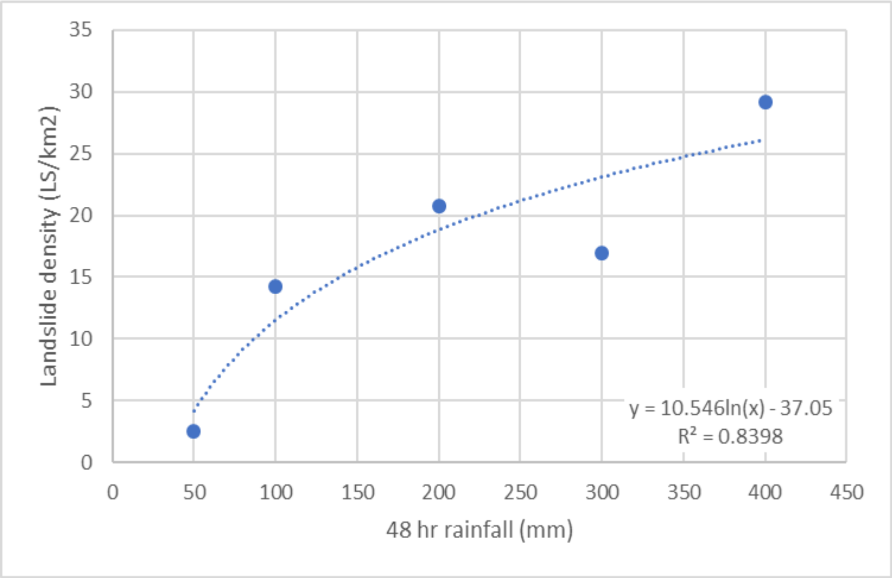
Pre-earthquake rainfall-induced landslides

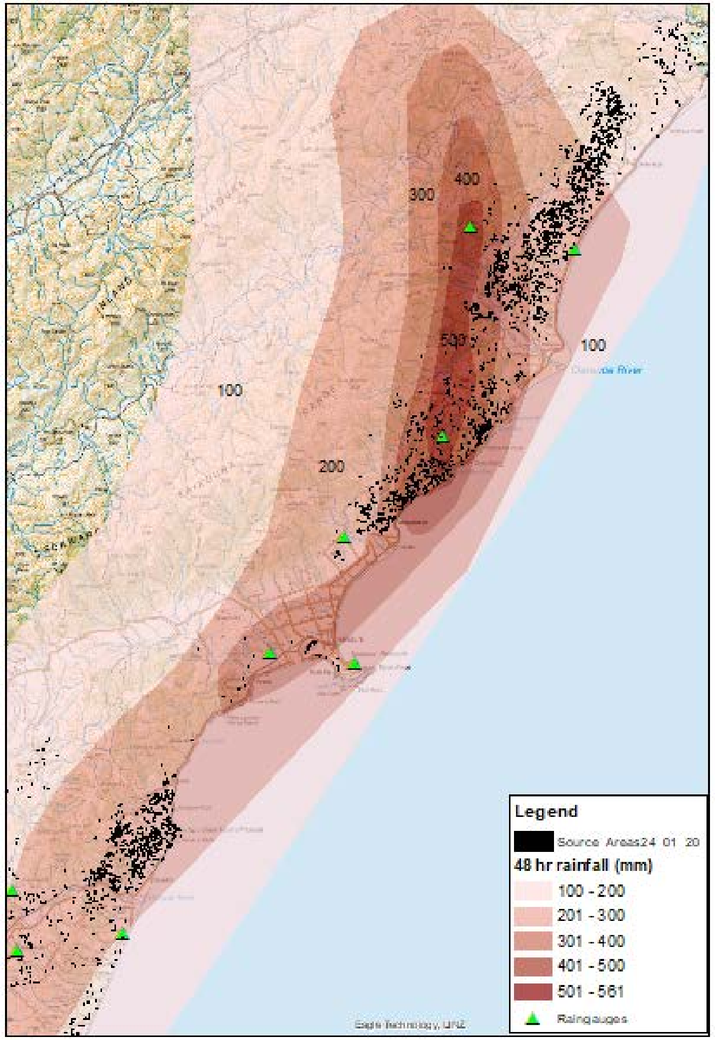
- Mapping landslides triggered by historic storm events using historic and recent aerial photography
- 4 Storms: 1961, 1966, 1975, 2014
- Landslide distributions were compared with the rainfall distribution for each storm
- Landslide locations to be used in logistic regression analysis to develop a RIL forecast tool (pre-earthquake)

Cyclone Alison 1975, SH1 (Kaikoura Museum)

Example: Cyclone Alison 1975
- Largest rainfall event in historic times
- >560 mm of rain in 48 hrs in Kaikoura area
- Maximum rainfall intensities of 40-70 mm/hr
- Triggered thousands of landslides across the region
- 19,000 landslides mapped



Relationship between rainfall and landslide density

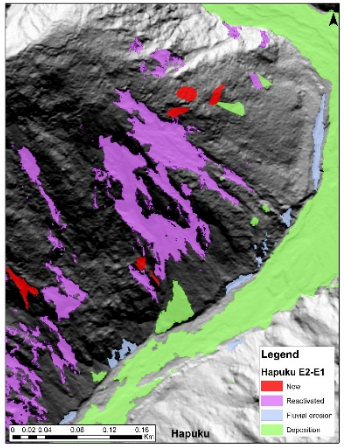


Mapped landslide locations in relation to storm rainfall

Post-earthquake landslide mapping: LiDAR differencing

Post-earthquake ortho image (E1 Dec 2016).

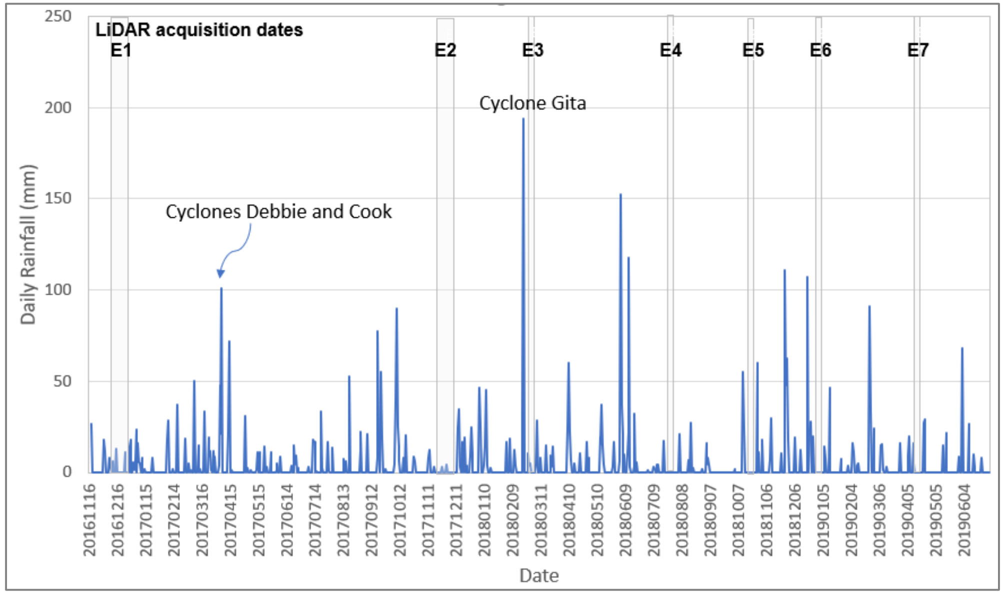
Ortho image Epoch 2 (E2 Dec 2017)

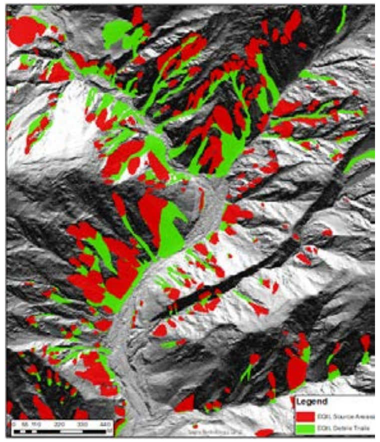


1m LiDAR difference model showing erosion and deposition (E2-E1)

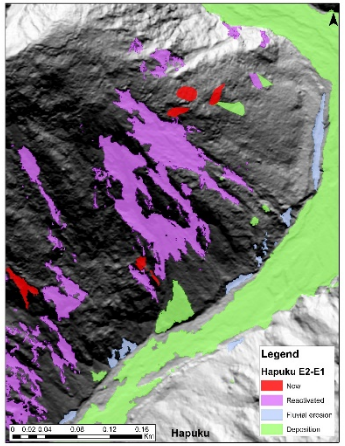
Example is a reach in the Hapuku River catchment

Rainfall since EQ and LiDAR acquisition dates

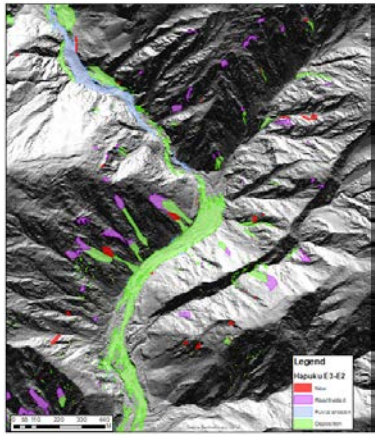




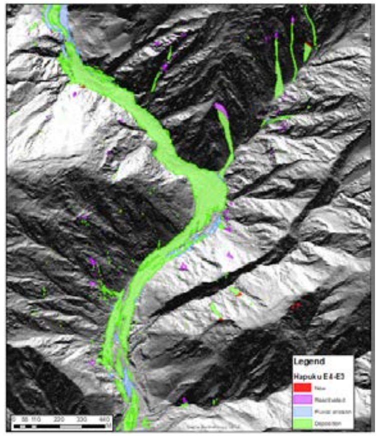
Kaikoura Earthquake-induced landslides



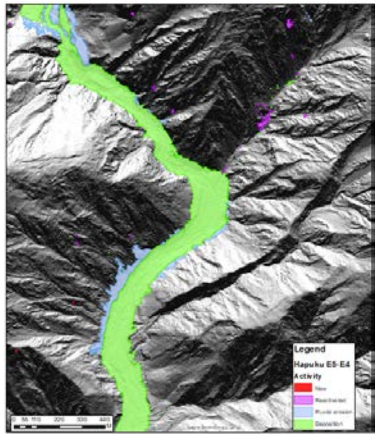
E2 – E1



E3 – E2



E4 – E3



E5 – E4

We are using LiDAR differencing, high resolution aerial photography and satellite imagery differencing to map landslides triggered by post-earthquake storm events. We have 9 LiDAR captures so far for 2 study catchments (Hapuku and Papatea), data processing completed up to Epoch 5 (Oct 2018).

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Preliminary results – post-earthquake landslide rates

Study area	Epoch	Days since EQ	No. Landslides Total	New	Reactivated	LS/km^2	% EQILS reactivated
Hapuku	EQ	1	612	612	na	21.3	
area = 28.8 km^2	E2-E1	382	664	220	444	7.6	78
	E3-E2	477	218	92	126	3.2	29
	E4-E3	610	76	30	46	1.0	20
	E5-E4	776	80	19	61	0.7	17
Papatea	EQ	1	1103	1103	na	32.1	
area = 34.4 km^2	E3-E1	477	968	328	640	9.5	62

The number of both new and reactivated landslides decreases with time since the earthquake
The landslide density decreases with time since earthquake
The percentage of the original Kaikoura Earthquake induced landslides reactivated decreases with time

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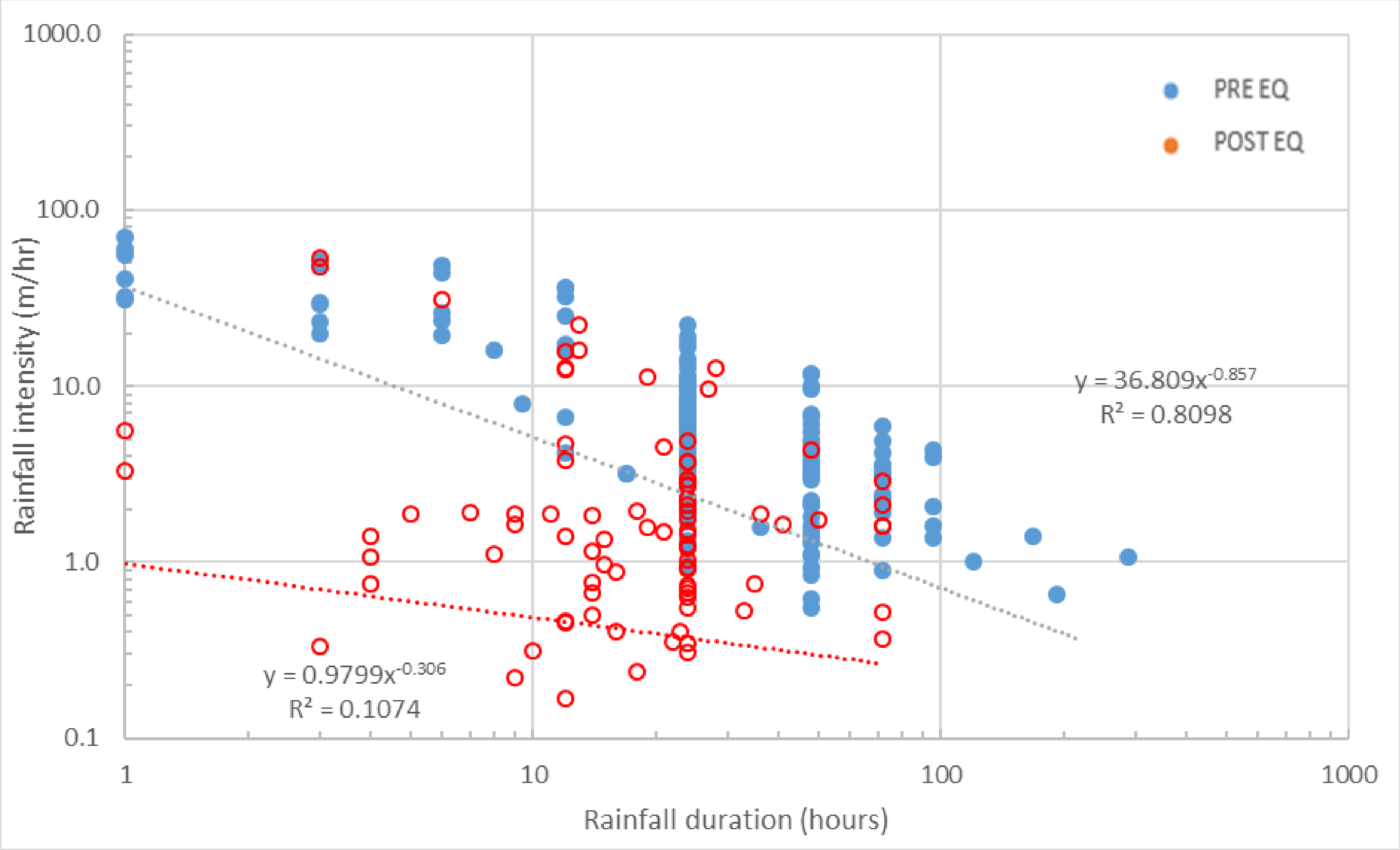
Rainfall intensity-duration thresholds for triggering landslides

- The pre-earthquake threshold was about 60 mm/24 hrs and reduced to 9 mm/24 hrs after the earthquake
- A reduction in the rainfall threshold for triggering landslides means that landslides are triggered at much lower rainfalls than previously, and more landslides are triggered for a given rainfall amount
- We will continue to monitor this relationship to see how it changes through time.



174 pre-EQ events
88 post-EQ events

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Summary and Conclusions

- The M7.8 Kaikoura earthquake triggered ~29,000 landslides over an area of 10,000 km^{2}, and many slopes were left broken and dilated
- The landslide rate increased following the earthquake, triggering new landslides on weakened slopes and reactivating and reworking landslide debris stored on the landscape
- Post earthquake storms have been moderate events but triggered many landslides
- There are more new and reactivated landslides since the earthquake and numbers have decreased with time since the earthquake
- Sediment generation from landslides has reduced through time, despite higher rainfall events occurring

Debris flow deposit from reactivation of co-seismic landslide, SH1, Cyclone Gita, Feb 2018

References

Caine N (1980) The rainfall intensity–duration control of shallow landslides and debris flows. Geografiska Annaler Series A62: 23–27.

Guzzetti F, Peruccacci S, Rossi M, Stark CP (2008) The rainfall intensity-duration control of shallow landslides and debris flows: an update. Landsides 5: 3-17. DOI 10.1007/s10346-0070112-1.

Litchfield NJ et al (2018) Surface Rupture of Multiple Crustal Faults in the 2016 Mw 7.8 Kaikoura, New Zealand, Earthquake. Bulletin of the Seismological Society of America, Vol. 108, No. 3B, pp. 1496–1520, July 2018, doi: 10.1785/0120170300

Massey CM et al (2018) Landslides Triggered by the 14 November 2016 Mw 7.8 Kaikōura Earthquake, New Zealand. Bulletin of the Seismological Society of America, Vol. 108, No. 3B, pp. 1630–1648, July 2018, doi: 10.1785/0120170305