M7.8 Kaikoura earthquake: methodology for landslide inventory mapping

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Landslide inventory mappers

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NSF funded RAPID collaborative research project being led by The University of Michigan (USA) “Topographic change and cascading hazards following the November 14th M_W 7.8 Kaikoura earthquake”.

Objective of the landslide inventory

To capture the spatial distribution of landslides triggered by the 14 November 2016, M7.8 Kaikoura earthquake, and to provide information for response and recovery activities and to provide a high quality dataset for future research.

What is the inventory

The inventory captures information on landslide:

1. Type (material and style of movement),
2. Magnitude (areal size, and volume where possible),
3. Runout (distance the debris travels down slope),
4. Connection/interaction with rivers (e.g. occlusions, blockages, buffered),
5. Surface deformation such as evidence of potential/incipient landslides, e.g. areas of cracking or incomplete failures where landslide debris may still be present in the source and has potential to remobilise.

Value of the dataset

The data will be useful for recognizing immediate hazards (potential for failures/reactivations), outburst floods (dam breaches), short- to longer-term potential for debris flow and valley floor aggradation impacts, sediment budgets for catchments, and assessing landslide causes (i.e. relationships with topography, geology, fault structures, shaking). One of the main uses of this data will be to assess how slopes performed in particular rock and soil (material) types during the earthquake. This data will be especially useful for those similar-sized slopes in Wellington, where much of the city is formed in similar materials (greywacke sandstones and argillites) to those forming the slopes, albeit in the more mountainous Kaikoura region. Such data will allow us to better constrain the response of the slopes in Wellington to strong shaking e.g. a Wellington Fault earthquake.

Data capture and availability

Capturing the landslide data is an ongoing process as new information becomes available (e.g. satellite images, LIDAR survey data). It therefore takes time to collate such high quality landslide datasets, however, we recognize that there is a need to get data to stakeholders and other affected parties in a timely manner. To facilitate the transfer of this data, we have been sending out near-weekly updates of the inventory to those parties who would like them. All data is being made freely available to anyone. Once the inventory has been completed it will be uploaded to the NZ landslide database maintained by GNS Science.

The inventory will be compiled in two stages:

1. Initial compilation – based on post event satellite images and georeferenced aerial oblique photographs, along with pre-event orthorectified aerial photographs. Completion data late January/early February 2017
2. Revised compilation – Using the initially compiled data, but updated using the post event orthorectified aerial photographs and LIDAR (LINZ), along with the surface change models generated from LIDAR and aerial and satellite photogrammetry (captured pre- and post-earthquake event). Completion date June 2017, contingent on the aerial photograph capture and orthorectification being commissioned by LINZ. The completion data is contingent on when the post event imagery and LIDAR data are captured, processed and made available.

Data sources

The initial inventory

The initial compilation is based on the following post 14 November 2016 earthquake data:

- WorldView- 2 (WV2) 2.4 m resolution (multispectral bands). Imagery date: 22 November 2016
- WorldView- 3 (WV3) is 1.4 m resolution (multispectral bands). Imagery date: 25 November 2016
- GeoEye (GE) 2 m resolution. Imagery date: 15 November 2016

The WV2 and WV3 images (provided by Digital Globe) have been processed by GNS Science. These have good positional quality (X, Y and Z) but in some mountainous areas the images have been poorly stretched (relief stretch). The same images have been processed by EAGLE Technology. These have better relief stretch but poor positional quality. The images from the different data sources do not cover the entire area affected by landslides, but together they do cover all of the main area affected by landslides.

In addition to the satellite imagery, low level aerial oblique photographs are also being used to help define the landslides. These (many thousands) of photographs have been captured by the team and others post-earthquake, mainly from helicopters. The photographs are georeferenced, and they cover most of the area affected by landslides. They are made available to the mappers via a geodatabase structure in ESRI ArcMap.

The national LINZ 8 m by 8 m digital elevation model (DEM) covers the entire area affected by landslides. This is also being used for the mapping. In addition to this, there is also a 1 m by 1 m DEM generated from pre-earthquake LIDAR, however, this is confined to a small coastal strip, but is still useful.

The USGS landslide program team and members of the Landslide GEER team have also contributed their field data collected over the past few weeks. Some of this information comprises a preliminary landslide inventory based on Landsat imagery (carried out by the University of Texas), which covers some of the main area affected by landslides. These data are also being used to generate the initial landslide inventory.

Revising the inventory

The initial compilation will be revised once the following data sources are made available:

- Post-earthquake orthorectified aerial photographs (captured by Aerial Surveys Limited and commissioned by LINZ), 0.3 m resolution. Date available: from now until April/May 2017.
- Post-earthquake digital elevation models derived from airborne LIDAR. Date available: April 2017.
- Post-earthquake digital surface models derived from stereo satellite imagery (NSF RAPID project). Date available: January 2017 and onwards.
- Pre- and post-earthquake digital surface models derived from the aerial photographs. Date available: April/May 2017.

Methodology (workflow)

Landslide inventory geodatabase

To ensure a consistent methodology for capturing landslide information, several feature classes in an ArcGIS geodatabase have been set up, with fields containing drop down (restricted) lists for capturing the key landslide information (discussed below).

The wider affected area has been roughly divided into catchments, with some catchments sub-divided. Each landslide mapper has been assigned one or more catchment areas to work in. Landslide mappers have been chosen from GNS Science, Massey University and the University of Canterbury, with GEER and USGS helping to selectively field truth some of the data.

Each mapper works within a separate copy of the landslide inventory, identified by a unique file name suffix. Within the geodatabase, for any data added (i.e. feature classes being populated) individual mappers' work can be identified by the name or initials in the 'originator' field.

After mapping the respective areas (and weekly updates during mapping), the data is collated and sent to various parties. A sample of each area is checked by another mapper. Following this, further samples of the mapped data have been targeted for field verification.

Landslide information being collected

For each landslide, the following is being collected:

Geodatabase feature classes

Polygons:

1. Extent of source area (polygon). Note that as best as possible, this should define the whole source area (not just the exposed source area), and may therefore overlap with the landslide debris.
2. Extent of landslide debris. If debris trails from multiple source areas merge then the polygons also need to merge.

Points:

3. Landslide crown: A point at the top of the landslide crown/headscarp (highest point).
4. Debris Toe: A point at the distal end of debris tail (lowest down slope point).

Lines:

5. Slope deformation: evidence of surficial cracking (scarps), bulging or other deformation indicating mass movement not captured within the landslide polygon areas. These are potential sites of water ingress during later rainstorm events that may destabilize the slope.

Each of these features is linked by a common feature ID, in the 'SourceID' field within each feature class. If there are multiple source areas linked to one debris trail, each Source ID number is added into the 'SourceID' field in the landslide debris attribute table, each entry separated/followed with a comma, but with no space (e.g.: 1002,1003,1004,).

Landslide attributes:

For each landslide **source area** polygon, as much information as possible is entered into the attribute table. There are drop down lists for landslide type information (material type and movement style/mechanism), which are based on the Hungr et al. (2014)[1] classification. There are potentially other terms that can be added later that are not included in the classification. There are also a few landslide types that we are unlikely to observe (such as peat failures) but have included for completeness. Below are the fields for the source area feature class, with an explanation and example of each.

Fields	***ObjectID***	**Source ID**	**Primary material**	**Secondary material**
Explanation	*Auto*	A unique number for your copy of the database. Each source area should have a unique number. Number does not have to be unique to the whole database, as 'Originator' field will be used to differentiate duplicate id numbers.	The main material type that failed. This is not the geology or description of the origin of the material, but rather related to the material properties and their genesis (origin) which influence the failure and runout behavior. If it cannot be easily assessed use the 'undifferentiated' term.	If there is a second material type involved which appears to have had a significant influence on the failure or runout mechanics, then can include a second material type. If only one major material type, just leave this field as 'Null'
Examples		1000	Rock, clay, mud, coarse clastic (e.g. non-plastic silt, sand, gravel and boulders), peat, ice, undifferentiated	Same options as primary material

[1] Hungr, O., Leroueil, S., Picarelli, L., 2014. The Varnes classification of landslide types, an update. Review article. Landslides. April 2014. Volume 11. Issue 2, pp 167-194.

Attribute table continued…

Landslide style	Activity/history	Connectivity	Comment	Method & Confidence
The movement mechanism	Indicated whether landslide appears to be a first-time failure or a reactivation of a previous movement	This describes the relationship of the landslide debris to streams/rivers or major drainage lines.	Additional notes or clarifications	Initial mapping method (i.e. imagery etc) used to digitize the landslide, and confidence in the mapping
Fall, topple, slide (can differentiate into rotational, planar, wedge), flow (can differentiate into avalanche, dry flow, flowslide, earthflow), slope deformation, or creep. Use 'undifferentiated' if you cannot tell which style of movement.		Uncoupled (i.e. sediment has remained on the slope); Coupled (at least some of the sediment has entered a drainage line (including active floodplain, but **not** including well-vegetated terraces); Blocked (any evidence of blockage even if blockage has since breached)		For each of the methods (Satellite, Orthophoto, Oblique photo, Ground visit, or Multiple [i.e. some combination of these methods]), specify the confidence of the mapping by either 'High' or 'Low'. 'Low' confidence may indicate strong uncertainty in the landslide boundary, uncertainty in the type of landslide mapped, or uncertainty in co-seismic occurrence (in Kaikoura EQ sequence). 'High' confidence can be used if you are fairly confident on the mapping.

Attribute table continued…

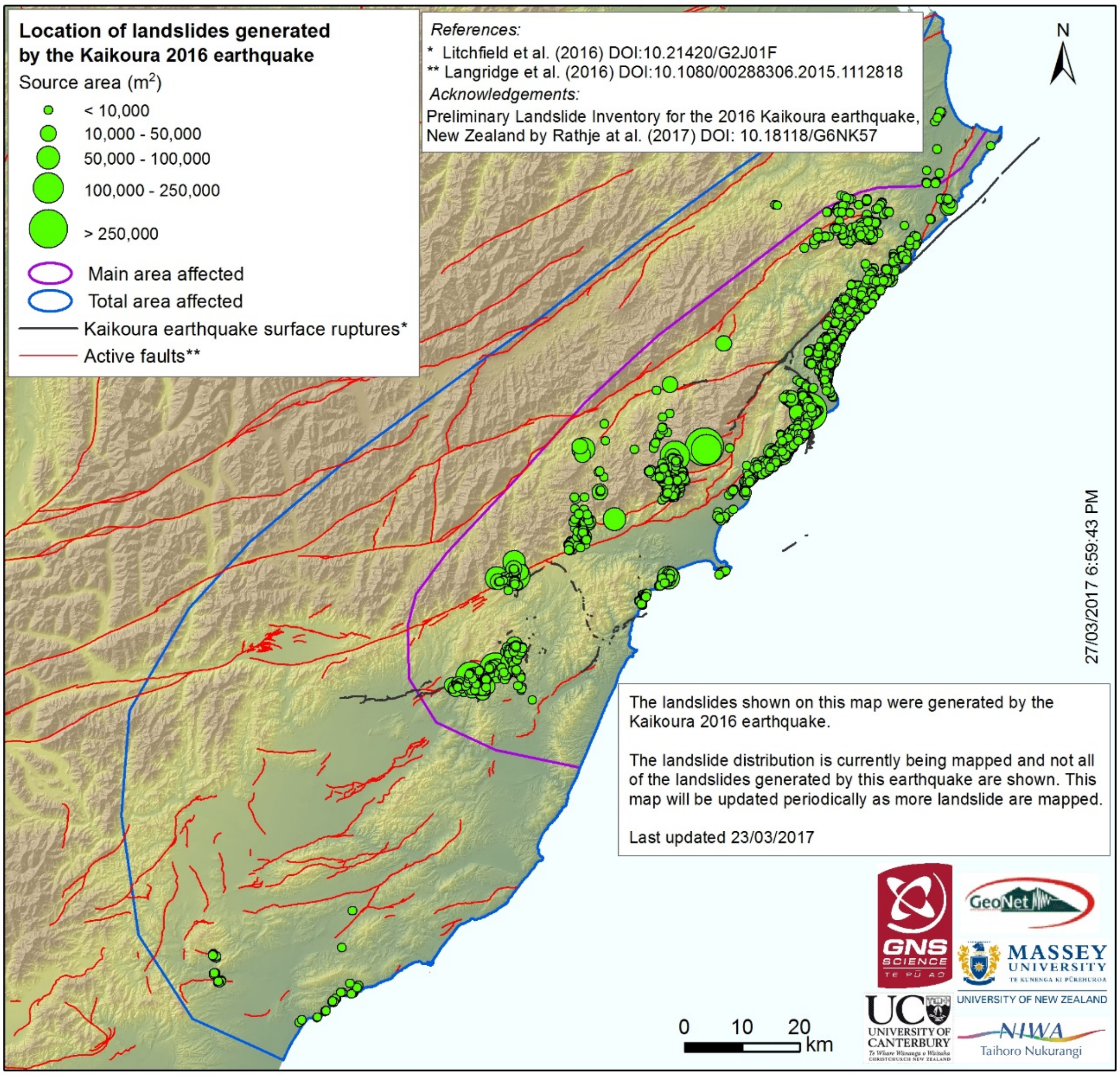
Shape Area	Length	Geology	Originator
Auto generated	*Auto generated*	*Will auto generate from QMAP data later*	Who digitized the landslide
			C. Massey

For the **debris trail** polygon feature class, and the crown and debris toe points, only the SourceID is used to link to the landslide source area.

In addition to discrete landslides, where you observe linear slope deformation indicators (i.e. evidence of incipient failures, such as scarps, antiscarps, or cracks that occur outside of the landslide polygons), these can be mapped using the Surface Deformation feature class. The only key information to add to the attribute table for now is the type of surface deformation (from the 'Type' dropdown list).

Unmapped areas: It is important to know which areas within the work area have not been able to mapped (e.g. due to cloud cover or very poor quality imagery). For these areas, a polygon shapefile (e.g. named 'obscured areas') is created and the obscured areas outlined.

Mapped landslides as at 23 March 2017



Reference for the map updated on 27/01/2017

Massey CI, Townsend DB, Rosser BJ, Villeneuve M, McColl S, Davidson J, Carey JM, Lyndsell BM, Lukovic B, Singeisen C, Dellow GD, Cox SC. 2017. Landslides generated by the Kaikoura 2016 earthquake. Version 1. GNS Science. http://dx.doi.org/10.21420/G2D59Z

The map above has now been updated with the landslide mapping as it was on the 23/03/2017.