Impacts of Climate Change on Urban Infrastructure & the Built Environment

A Toolbox

Tool 2.3.2: Collection and analysis of historical landslide information and other data required for modelling rainfall-induced landslides

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1. Introduction

1.1 Background

Accurate modelling of rainfall-induced landslide hazard requires determining when and where landslides will occur, how many there will be, and their size distribution. Rainfall-induced landslides occur in response to rainstorms, so knowing when, where and how much rain will fall constrains when, where, and how many rainfall-induced landslides will occur. The ‘where’ also requires knowing the relationship between rainfall and landslides with respect to a number of parameters (e.g. topography, geology and vegetation). For example, more landslides are likely to occur on steep slopes, with the fewer landslides occurring on gentle slopes. Knowing how much rain will fall also provides an opportunity to determine how many landslides will occur.

Data show that with increasing rainfall an increasing number of landslides will occur per unit area if other factors are the same (e.g. topography, geology, vegetation). Determining ‘how many’ requires knowledge of the amount and spatial extent of the rainfall and the relationship between rainfall and topography, geology and vegetation. Knowing ‘how big’ requires knowing how many landslides are likely to occur as landslides have characteristic size distributions for different factor combinations (Joyce *et al.*, 2009).

1.2 Overview of Tool

This tool is written in two sections. The first section describes in generic terms the datasets needed to calculate the probability of a rainstorm-induced landslide occurring at any point in New Zealand. These generic datasets must include landslide, rainfall, topographic, geologic and vegetation datasets. The way these datasets are combined to produce a probabilistic rainfall-induced landslide hazard model (PRILHM) that spatially and temporally distributes the rainfall-induced landslide hazard on a national scale is described in [Tool 2.3.3].

The second part of the tool describes the specific datasets used for a study in Wellington to assess the rainfall-induced landslide hazard. These datasets include three landslide datasets, an open-space landslide dataset, a road network landslide dataset and a domestic dwelling landslide dataset. Other required datasets include daily rainfall, geology, vegetation, water bodies, water courses and a digital elevation model (DEM).

2. The Generic PRILHM Methodology

The PRILHM uses historical (empirical) landslide/rainfall data at a site to forecast the probability of a landslide occurring at the site in the future in response to a given rainfall. The datasets required to calibrate historical landslide distributions against rainfall include:

- Landslide data (date, location, size);
- Historical daily rainfall data;
- Geological data;
- Vegetation data;
- Water course/water body data;
- Digital elevation model (DEM).

The PRILHM model has been developed to be applied on a national scale, so datasets available on a national scale are specified as the default datasets in the generic model. In the following sections (2.1 to 2.6) the default datasets for the generic PRILHM methodology are described.

2.1 Landslide data

Landslide data can be obtained from a range of sources. However to be of use in this probabilistic methodology the landslide data must have all the following attributes:

- Date, preferably of the day of occurrence (to link with daily rainfall data),
- Location (to tie in with spatial data, e.g. geology, vegetation, DEM), and
- Magnitude (to calculate size distributions).

The preferred method for obtaining landslide data is from remotely sensed images such as aerial photographs or optical satellite images. The images need to be ortho-rectified to enable accurate capture of landslide location and area. The quality of the datasets is improved by using high-resolution images (one-metre-square pixel size or better) from both pre- and post- a rainstorm with the smallest possible time difference between them. The landslide location and area can be obtained directly from the images, either manually or using semi-automated processing techniques. Previous work (Joyce *et al.*, 2008) has shown that manual on-screen digitizing currently delivers the most accurate landslide datasets.

2.1.1 Landslide size distribution data

Landslide size is commonly measured in two ways:

- Volume (either of the source or the debris), or
- Area (usually the source and debris areas combined together).

In terms of landslide risk or the impact of landslides on assets, infrastructure and people, area is the preferred measure of landslide size because the elements at risk will be dominated by those on or very near the ground surface (e.g. people, roads, buildings). Also, when using landslide data derived from remotely sensed data, the measurement of area is more accurate than an estimate of volume.

2.1.2 Landslide areal-frequency data for different rainfall intensities

The PRILHM requires the number of landslides per unit area for a range of rainfall intensities. The measure that is used here to model the areal distribution of landslides in the landscape is the areal frequency – the number of landslide initiation sites per square kilometer for a given rainfall. The areal frequency is calibrated with respect to topography, geology, vegetation, and a digital elevation model (DEM) (Joyce *et al.*, 2009).

By combining this measure of areal frequency and landslide size-distribution data the percent area affected by landslides, a measure of landslide severity commonly reported in the literature (e.g. REFs), can be determined.

2.2 Rainfall data

The PRILHM is national in scope. The most widely available rainfall data on a national scale are daily records taken at selected sites at 24-hour intervals (nominally 9.00 am each day). More frequent rainfall readings are available at some sites, but the coverage of more detailed rainfall data is uneven nationally. For this reason rainfall data used to calibrate landslide occurrence is the nearest daily (or 24 hour) readings. These readings are obtained from organizations such as NIWA (National Institute of Atmosphere and Water), NZ Metrological Service and regional councils.

The necessity of extrapolating point-data sources (rainfall readings) over a wider area leads to large uncertainties in the amount of rainfall remote from the measurement point. This uncertainty is accommodated by assessing rainfall in 50-mm bands for the purpose of assigning a rainfall value to an individual landslide.

Other possible sources of rainfall data are virtual climate station (VCS) data (Tait *et al*, 2006). The advantage of VCS data is that the virtual stations are 'located' on a 5 km^2 grid throughout New Zealand and so the rainfall coverage is relatively uniform. The drawback of the VCS data is that it is based on point data sources of actual readings and requires interpolation between the VCS stations to provide the spatial rainfall distribution required by the PRILHM.

Satellite- or airplane-based images used to extract the landslide data may be weeks or even months apart and an assumption is made that all the observed landslides can be attributed to the largest rainstorm occurring in the time interval between the two images. The assumption is valid where the rainstorms are extreme events and the time interval between pre- and post- images is short (weeks or months). The assumption is less valid for rainfall around the threshold for initiating landslides and/or where the time interval between pre-and post- rainstorm images is greater than a year. The assumption can be tested for each rainstorm by analysing daily rainfall records between the pre- and post- rainstorm images to determine if the rainstorm is the largest event in the time interval or if it is one of two or more events of a similar size.

Daily rainfall data needs to be converted into a rainfall-index for use in the PRILHM. This process is designed to account for moisture levels in the ground prior to the time period of the daily rainfall reading. Work by Glade (1998) analysing New Zealand landslide and rainfall data produced a method for calculating the rainfall-index. This method is used in the PRILHM because it is derived from New Zealand wide data and the only input data required is daily rainfall readings.

2.3 Geological data

Previous work (e.g. Dellow *et al.*, 2005; Joyce *et al.*, 2009) shows different geological materials (rocks and soils) have different landslide size-distributions. Similar rainfall will produce different landslide size distributions in different geological units (Figure 3.1). The recently updated digital geological map of New Zealand at a scale of 1:250,000 is the source of geological data in the PRILHM. The accuracy of the geological data (± 100 m) is better than the accuracy of the rainfall datasets (± 1000 m).

2.4 Vegetation data

Previous work (e.g. Marden and Rowan, 1994) has also shown that the type of vegetation cover strongly influences the incidence of landslides. Where forest is present (exotic or indigenous) the number of landslides can be reduced by up to 90% when compared with areas of similar topography and geology under pasture (e.g. Marden and Rowan, 1994). The preferred source of vegetation data used in the PRILHM is from the satellite-images landslide data is sourced from. In the PRILHM the vegetation is classed as woody (forest, scrub) or non-woody (pasture and bare ground).

Alternatively published maps, such as the NZMS260 series can be used but these invariably reflect vegetation cover at a discrete time and land use may have changed in the time interval between map compilation and the time of a landslide-inducing rainstorm. However, vegetation data is now routinely mapped on a four-yearly cycle through the Land-use carbon accounting system (LUCAS) as part of New Zealand's commitment to the Kyoto protocols and this will provide a more regular compilation of vegetation cover.

2.5 Water course/water body data

Water-course and water-body data are used as criteria for ending the landslide movement calculation algorithm in the PRILHM. An assumption is made that once a landslide reaches a water-course or water-body then the landslide enters the water and becomes diluted such that the hazard changes from a landslide hazard to a flooding hazard to be mitigated by flood protection schemes. Hence, the presence of permanent water-course or water-body is used to end the landslide movement component of the probability calculation in the PRILHM. The water course/water body data is sourced from the LINZ NZMS260 1:50,000 map series.

2.6 Digital elevation model (DEM)

The basic spatial unit of the PRILHM is a 10 m by 10 m DEM pixel. The DEM information is derived from the Land Information New Zealand (LINZ) NZMS260 DEM 20-metre contour information with a pixel size of 30 m by 30 m. For the PRILHM each LINZ DEM pixel is divided into nine 10 m by 10 m pixels using an interpolation process to match the resolution of satellite imagery sourced landslide data.

Every pixel in the DEM is attributed with a slope angle (assigned to the centre of the pixel) using the difference in elevation between the adjacent pixels with the highest and lowest elevations.

Once the landslide data has been collected from an ortho-rectified image it is compared against the DEM. The DEM pixel with the highest elevation within each landslide polygon is assigned as the initiation site of the landslide.

Each pixel is then also attributed with the following information:

- The slope is assigned to a slope angle band (5° increments; e.g. $15° \leq \theta < 20°$);
- Down-slope direction (i.e. identify the adjacent pixel with the lowest elevation; if two or more pixels have the same elevation then the pixel that provides for the straightest path is selected);
- Geological unit at the pixel location;
- Vegetation class at the pixel location;
- Presence or absence of a water course/water body at the pixel location
- The number of pixels in the PRIHLM DEM with the same slope band, the same underlying geology and the same vegetation cover.

3. Wellington Case Study

In this section the datasets used to produce a PRILHM for Wellington City are described. The uncertainties and limitations of these datasets are identified where possible.

3.1 Wellington landslide data

Three separate landslide datasets have been used to assess and calculate the landslide hazard in Wellington. The landslide datasets were sourced from the national PRILHM, the Wellington City Council (WCC) and the Earthquake Commission (EQC). Each dataset has been collected by a different agency and the datasets are therefore not able to be combined. Collectively the datasets provide a relatively complete picture of rainfall-induced landslides in Wellington City allowing an assessment of landslide hazard to be made. Each of the three landslide datasets is described below.

3.1.1 Open-space landslide data

The open-space landslide dataset is sourced from landslides in greywacke terrain from around New Zealand. The data is produced by processing satellite images to establish the location and size of landslides that have occurred in response to a rainstorm on greywacke terrain (Joyce et al, 2008). Ortho-rectified images from pre- and post-rainstorms are analysed to capture a polygon for each landslide spatially constrain its location. Only new landslides in the post-event image are used to compile the landslide dataset for a particular rainstorm.

For the open-space dataset the only currently available data is from a rainstorm in 2007 that caused landslides on greywacke terrain with a rainfall index of between 250 and 300 mm. Landslide distributions for other rainfall index values are interpolated from this dataset. This is the most poorly constrained of the landslide datasets and has the greatest uncertainty around the consequent landslide hazard.

3.1.2 Road network landslide data (the WCC Slips Database)

The road network landslide data was obtained from the Wellington City Council (WCC) and included a ten year record (21.08.1999 – 15.03.2010) of landslides occurring on council land, principally the road network. The total number of landslides recorded in the dataset was 4033 (Figure 3.1) after processing the provided data to remove non-landslide events (e.g. flooding events related to problems with the storm-water system) and duplicate landslide entries.

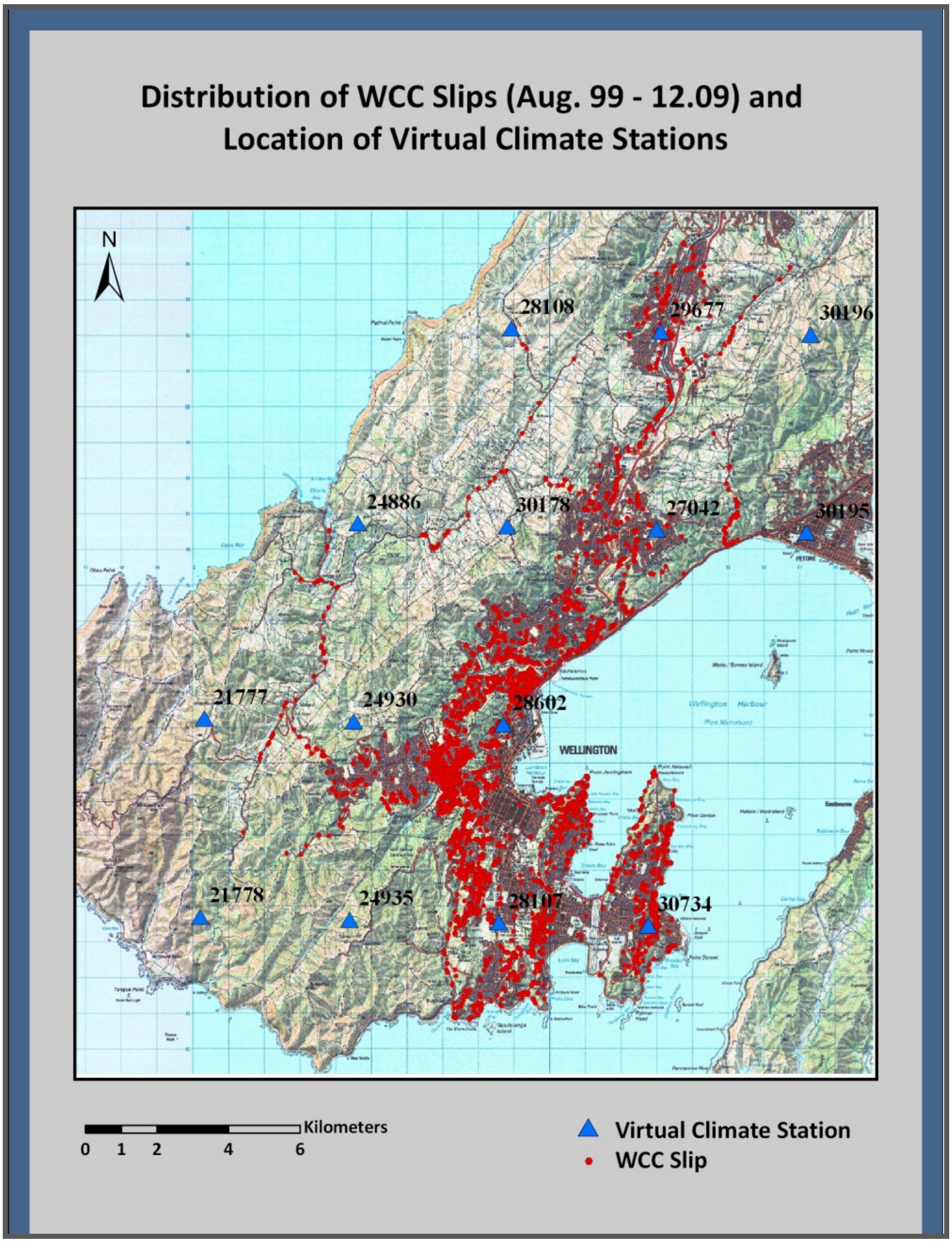

Figure 3.1: Map of WCC slips and virtual climate station (VCS) locations.

The information contained in the database was received from the public via telephone (and occasionally by letter). The public were reporting landslides that had affected their property or landslides they had encountered on council owned land. Notes from the phone calls were included in the database.

The date of the phone call was used as the date of the landslide unless the date was otherwise specified. The location of the landslide in the database was a street address.

Variations in property size mean the street address has a varying degree of accuracy. The location was refined because often a house number was given, or a description of the whereabouts of the slip, enabling a reasonably accurate identification of the landslide site. The street view in Google Maps was also capable of refining the location as landslides frequently occurred on the roadside and with a description of the location more accurate identification of the site was often possible.

The addresses had to be converted into a coordinate system in order to load the information into a GIS. This was achieved using mapping software (TUMONZ) to allocate an easting and northing to each landslide. An estimated degree of accuracy (EDA) was also assigned to each individual landslide. The minimum EDA for a landslide is 10 m, whereby the value indicates the radius from the point representing a slip.

The size of the landslide was often not available, but where it was the way the size was reported was often in terms of material removed from the site on clean-up. As the volumes were usually small it was decided to assign a maximum size of 100 m^2 to the landslides in this dataset as this also corresponds to the size of the DEM pixel used in the PRILHM. When modeling the WCC landslide dataset what is being modeled is the initiation of a landslide which is often smaller than 100 m^2.

3.1.3 The domestic dwelling landslide data (EQC claims dataset)

The third landslide dataset used was compiled from Earthquake Commission (EQC) insurance claims for landslide damage to domestic housing. This dataset also provided information on the fragility and vulnerability for different types of building construction and the consequence risk to occupants of any dwelling. The time period covered by the dataset was January 1999 to December 2009 and 1303 landslides are in the dataset.

The date of the EQC data is only recorded by month so two methods for assigning a day to the landslide were analyzed. The first method simply assigns the day in the month with the highest rainfall-index as the date of the slip. The second method assigns the day in the previous month with the highest rainfall-index as the date of the slip. Although the methods are not ideal they allow landslide-data and rainfall to be correlated, albeit with a larger uncertainty around the date of the landslide than other landslide datasets.

Again the location of the landslide is associated with an address and the address had to be converted into a coordinate system in order to load the information into a GIS. Again this was achieved by determining an easting and a northing for each landslide via mapping software (TUMONZ) and the knowledge that for an EQC insurance claim to be successful the landslide would usually be within eight metres of a house or its access. An estimated degree of accuracy (EDA) was assigned to each landslide. The minimum EDA for a landslide is 10 m where the value indicates the radius from the point representing a slip.

The size of the landslide was often not available. Using knowledge of the characteristics of landslide distributions (e.g. Joyce *et al.*, 2009) it was decided to assign a maximum size of 100 m^2 to the landslides in this dataset as this also corresponds to the size of the DEM pixel used in the PRILHM. When modeling the EQC landslide dataset what is being modeled is the initiation of a landslide which is often smaller than 100 m^2.

3.2 Rainfall data

Rainfall data was obtained from the National Institute of Water and Atmospheric Research (NIWA). The rainfall data used for this project is taken from NIWA's Virtual Climate Stations (VCS) for the period Jan. 1999 – Dec. 2009. These data are estimates of daily rainfall records on a 0.05° latitude/longitude grid (Figure 3.1) covering all of New Zealand using a second order derivative tri-variate thin plate smoothing spline spatial interpolation model (for a detailed description of the method, refer to Tait *et al.*, 2006). This interpolated rainfall record for each VCS is based on 24 hour measurements of rainfall starting and finishing at 9 a.m. Because the rainfall data used for this analysis extended only until the end of 2009, the slips occurring during the first three months of 2010 were excluded from the assessment, reducing the total count of slips in the road network landslide dataset to 4004.

The PRILHM was also run using daily rainfall readings for the same time period from four sites in the WCC area. This was done to allow comparison of the results derived from regularly spaced virtual data with results from a few irregularly spaced recording stations.

3.3 Geological data

The geology of the WCC area is relatively uniform with most of the area being either old greywacke (> 70 million years old) or young sediments (< 2 million years old). Given that the sediments are dominantly in the flatter areas the geology of the area has been treated as uniformly greywacke in the PRILHM.

3.4 Vegetation data

Vegetation data from the NZMS260 map series (Sheets R26 and R27) is used as the default vegetation dataset for this study. As the vegetation data is only used in the open-space landslide hazard model this is not expected to bias the results. Vegetation data is not used in conjunction with the road network or domestic dwelling landslide datasets because it is not readily available at the required scale. For the road network or domestic dwelling landslide datasets an assumption is made that the vegetation cover is the equivalent of pasture (lawns) or bare-ground (cut slopes in rock).

3.5 Water body/ water course data

The water body/water course data is sourced from from the LINZ NZMS260 1:50,000 map series, sheets R26 and R27.

3.6 Digital Elevation Model data (DEM)

The DEM information used in the Wellington study is derived from the Land Information New Zealand (LINZ) NZMS260 20-metre contour data. The 20-metre contour data has been converted to a DEM raster with a pixel size of 30 m by 30 m. For the PRILHM each LINZ DEM pixel is divided into nine 10 m by 10 m pixels using an interpolation process to match the resolution of satellite imagery sourced landslide data.

Every pixel in the PRILHM DEM is attributed with a slope angle (assigned to the centre of the pixel) using the difference in elevation between the adjacent pixels with the highest and lowest elevations.

Each pixel is then also attributed with the following information:

- The slope is assigned to a slope angle band (5° increments; e.g. $15° \leq \theta < 20°$);
- Down-slope direction (i.e. identify the adjacent pixel with the lowest elevation; if two or more pixels have the same elevation then the pixel that provides for the straightest path is selected);
- Geological unit at the pixel location;
- Vegetation class at the pixel location;

- Presence or absence of a water course/water body at the pixel location

- The total number of pixels in the PRIHLM DEM that share the same geology, vegetation and slope band.

4. References

Dellow, G.D.; McSaveney, M.J.; Stirling, M.W.; Berryman, K.R., 2005: A probabilistic landslide hazard model for New Zealand. p. 24 IN: Pettinga, J.R.; Wandres, A.M. (eds) *Geological Society of New Zealand 50th annual conference, 28 November to 1 December 2005 ... Kaikoura : programme & abstracts.* [s.l.]: Geological Society of New Zealand. *Geological Society of New Zealand miscellaneous publication 119A.*

Glade T., 1998: Establishing the frequency and magnitude of landslide-triggering rainstorm events in New Zealand. *Environmental Geology* 35(2-3), 160-174.

Joyce, K.E.; Dellow, G.D.; Glassey, P.J., 2008: Assessing image processing techniques for mapping landslides. paper II-1231 IN: *Proceedings : IGARSS 2008 : geoscience and remote sensing, the next generation, July 6-11, 2008, Boston, Massachusetts, USA.* Boston, Mass: IEEE.

Joyce, K.E.; Dellow, G.D.; Glassey, P.J., 2009: Using remote sensing and spatial analysis to understand landslide distribution and dynamics in New Zealand. p. III-224-III-227 (paper WE2.05.5) IN: *IGARSS 2009 : 2009 IEEE International Geoscience and Remote Sensing Symposium proceedings : earth observation, origins to applications, July 12-17, 2009, Cape Town, South Africa.* Cape Town, South Africa: IEEE.

Marden, M.; Rowan, D. 1994: Protective value of vegetation on Tertiary terrain before and during Cyclone Bola, East Coast, North Island, New Zealand. *New Zealand Journal of Forestry Science 23:255-263.*

Tait, A., Henderson, R., Turner, R., and Zheng, X., 2006: Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology 26:2097-2115.*