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Landslide susceptibility and landslide hazard zoning in Wollongong

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Landslide susceptibility and landslide hazard zoning in Wollongong
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ABSTRACT

This paper describes ‘knowledge-based’ data-mining techniques, developed for the assessment of landslide susceptibility and hazard with particular reference to its application in the Wollongong area. Large scale maps of geology and a comprehensive Landslide Inventory with regional coverage have been prepared. GIS-based derivatives of the digital elevation model including slope, geomorphology, curvature, flow accumulation and wetness index have been developed. Model performance has been assessed as part of a refined methodology for validation, including field inspections. Susceptibility zones outside known landslide areas have been classified as (a) high (b) moderate, (c) low and (d) very low susceptibility. Results show the high susceptibility zone covers 10% of the study area and contains 60% of known landslides, the moderate zone covers 12% of the study area and contains 32% of known landslides, the low zone covers 6.4% of area and contains 3.3% of known landslides and the very low zone covers 71% of the study area and contains 4% of the landslides. The susceptibility maps have been upgraded to hazard level maps with identification of individual zone landslide likelihoods, specific landslide frequency, volume and ‘profile’ angles. The paper concludes with a preliminary landslide susceptibility map for a segment of the Sydney Basin Region developed using the methodology described in this paper.

1 INTRODUCTION AND STUDY AREA

This paper complements another by the same authors recently presented and published in the proceedings of the First North American Landslide Conference (Flentje et al, 2007) and is herein referred to as the companion paper. Together, both papers outline the methodology, GIS-based datasets and zoning maps that have been developed by the University of Wollongong landslide research team (LRT) for the assessment of landslide susceptibility and hazard in the Wollongong Area. The numbers reported herein present updated information to that reported in the companion paper. The main element of this methodology comprises a comprehensive large scale GIS-based Landslide Inventory with regional coverage. The landslide inventory contains 3 main types of landslides - falls, flows and slides. Additional GIS-based data sets, including large scale geology, vegetation, a 10m pixel Digital Elevation Model (DEM) and various derivatives have also been developed. Data-Mining, and Machine-Learning techniques (Quinlan 1993) are used to develop the Susceptibility classification. As these elements have been discussed in the companion paper, they are only mentioned briefly herein.

Landslide frequency information has been determined from the Landslide Inventory. This work has been undertaken over an extensive period and yet it is generally in accordance with the principles of the recently developed Guidelines on Landslide Zoning published by the Australian Geomechanics Society in March 2007 (AGS 2007a) of which the first author is a Working Group member.

The city of Wollongong is located on a narrow coastal plain approximately 70km south of Sydney in the state of New South Wales (NSW), Australia. The population of the Wollongong area is approximately 200,000 people. The plain is triangular in shape with a coastal length of 45km and is up to 17km wide in the south and extends to its apex in the north near the suburb of Thirroul (figure 1). The coastal plain is bounded to the north, west and south by an erosional escarpment of Neogene Age ranging in height from 300 m up to 500 m.

Processes and mechanisms of slope failure are controlled in Wollongong by factors such as stratigraphy, geotechnical strength parameters, hydrogeology, geomorphology, slope inclination, pore water pressure, rainfall and the actions of man. Prolonged and/or intense rainfall is typically the trigger for significant landsliding. The average annual rainfall for Wollongong varies from 1200mm on the coastal plain and up to 1600mm or more along the top of the escarpment.
Figure 1. The Wollongong Local Government area and the GIS Model Area with known landslides.

2 WOLLONGONG REGIONAL LANDSLIDE INVENTORY AND OTHER GIS-BASED DATA SETS

The Landslide Inventory, developed over the last decade, comprises a relational MS Access and ESRI ArcGIS™ Geodatabase with over 70 fields of information for each landslide site in related tables (Flentje and Chowdhury 2005). Each landslide is referenced by a key Site Reference Code. The Landslide Inventory currently contains 586 landslides with a total of 976 landslide events (including first time occurrences and multiple recurrences at some sites). The 586 landslides comprise 42 falls, 43 flows and 491 slides in accordance with the Cruden and Varnes 1996 classification.

In addition to the GIS-based landslide inventory, other GIS-based data sets have been developed for this project including engineering geological mapping, data acquired through external agencies and data sets generated by the GIS software using the Digital Elevation Model. In total, ten GIS-based data sets have been compiled. The data sets include:

- Geology (21 variables representing the mapped geological formations)
- Vegetation (15 variables representing the mapped vegetation categories)
- Slope Inclination (continuous floating point distribution)
- Slope aspect (continuous floating point distribution)
- Terrain Units (buffered water courses, spur lines and other intermediate slopes)
- Curvature (continuous floating point distribution)
- Profile Curvature (continuous floating point distribution)
- Plan Curvature (continuous floating point distribution)
- Flow Accumulation (continuous integer)
- Wetness Index (continuous floating point distribution)
The Data Mining (DM) process has been discussed in the companion paper and hence will not be repeated here. Suffice to say that the process involves the use of known landslide areas as one half of the model training, the other half comprising randomly selected points from within the model area outside known landslide areas. Using a fully attributed data set representing all the above data sets, the DM analysis undertakes a process of pattern recognition and develops a rule set which defines the data set. This process is automated by the DM software and is confined by several user defined parameters, such as the number of rules required and the number of occurrences required before a rule is generated, etc. Each rule is assigned a numerical confidence value defined by the Laplace ratio. Rules which relate to the presence of a landslide are assigned positive confidence values and rules which indicate the non-presence of a landslide are assigned negative confidence values. The rule set is then re-applied within the GIS software using the ESRI Model Builder extension to produce the Susceptibility grid with floating decimal point values ranging from 1 to -1.

3 ANALYSIS OF “KNOWLEDGE BASED MODEL” AND LANDSLIDE SUSCEPTIBILITY ZONING

To aid in the post DM analyses of the Susceptibility grid and particularly to aid the definition of credible Susceptibility Zone categories and zone boundaries, a script was written in Visual Basic code to produce the distributions shown in Figure 2. This code ranked the complete 1.88 million data points and separately all the landslide pixels (29,480 points) according to decreasing model confidence and determined the cumulative percent each data value represented in the ranked list. Figure 2 shows the distribution of DM model ‘confidence’ for the preferred final slide model. The graph displays two curves, the upper dashed curve shows the distribution of model confidence for the ‘known landslide’ pixels, and the lower dash-dot curve shows the distribution of model confidence for each pixel in the entire model (1.88 million points). Also shown on Figure 2, are the landslide Susceptibility zone boundaries. The confidence values used to define the Susceptibility zone boundaries are arbitrary values. However, the simple logic has been followed whereby the maximum numbers of known landslides are incorporated into the highest Susceptibility zones, whilst at the same time keeping the extent of these highest susceptibility zones to a minimum.

The graph highlights the excellent performance of the modelling with approximately 70% of the known landslides being identified with a high model confidence. This same strong result is also reflected for the entire model area where a smaller but significant proportion of the entire model area (~10%) is also predicted as being highly susceptible to landsliding with a relatively high confidence.

![Figure 2. Classification of Susceptibility Zones using the distribution of the Data Mining model confidence for both the Training data and the complete model area.](image)

This quantitative ‘review’ validates the methodology to a significant extent, and ensures that the process of susceptibility zone classification it is completely transparent and open for review. Some field validation work has also been undertaken and this has been reported in the companion paper.
In summary, the susceptibility zones have been classified as (a) high susceptibility with 8.12% of this area subject to landslides and containing 60.3% of the known landslide population, (b) moderate susceptibility with 4.12% of this area subject to landslides (contains 32.3% of known landslides), (d) low susceptibility with 0.85% of area subject to landslides (contains 3.3% of known landslides), and (e) very low susceptibility with 0.09% of the area subject to landsliding (contains 4.1% of known landslides) and yet representing 70.9% of the study area. These statistics are compatible with Table 4 of AGS (2007a). The high landslide susceptibility zone identifies over 2,300 hectares of land, outside of known landslides, as being highly susceptible to landsliding. Furthermore, the model also identifies over 13,000 hectares as having a very low susceptibility to landsliding.

4 LANDSLIDE HAZARD ASSESSMENT AND ZONING

The spatial frequency of landsliding has been determined for each Susceptibility Zone as summarised in Table 1 and thereby giving each zone Hazard status. Here, the percentage of each zone affected by landslides has been normalised and divided by the number of years represented by the coverage of the Landslide Inventory. In this case, the Wollongong landslide Inventory covers a period of 126 years, 1880 to 2006. Other techniques of assessing annual likelihoods of landsliding (i.e. process rates) are being investigated.

Table 1. Summary of landslide zoning frequency and volume.

<table>
<thead>
<tr>
<th>Hazard Description</th>
<th>% of Zone affected by Slides (%)</th>
<th>% of Total Slides Population in Hazard Zone</th>
<th>Landslide Annual Average Frequency (1950 - 2006)</th>
<th>Relative Susceptibility of Zone (Sr/Stotal) = Sr</th>
<th>Relative Annual Likelihood (Hazard) (Sr/T) where T = 126 years</th>
<th>Maximum Landslide Volume (m³)</th>
<th>Average Landslide Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>0.10</td>
<td>70.86</td>
<td>4.1</td>
<td>1.65E-02</td>
<td>7.36E-03</td>
<td>5.84E-05</td>
<td>36,300</td>
</tr>
<tr>
<td>Low</td>
<td>0.85</td>
<td>6.47</td>
<td>3.7</td>
<td>1.72E-02</td>
<td>6.46E-02</td>
<td>5.13E-04</td>
<td>4,700</td>
</tr>
<tr>
<td>Moderate</td>
<td>4.12</td>
<td>9.23</td>
<td>35.1</td>
<td>2.21E-02</td>
<td>3.12E-01</td>
<td>2.48E-03</td>
<td>45,000</td>
</tr>
<tr>
<td>High</td>
<td>8.12</td>
<td>13.44</td>
<td>57.1</td>
<td>2.47E-02</td>
<td>6.16E-01</td>
<td>4.89E-03</td>
<td>720,000</td>
</tr>
</tbody>
</table>

Figure 3. Segment of the Landslide Hazard Map.
The landslide hazard zoning maps have been enhanced with additional detail regarding landslide volume, frequency and travel distance (Table 1 and Figure 3). This information appears as unique landslide site labels for each site and with text boxes appearing on the AO map sheet frames outlining the distributions and averages of these values for each of the individual hazard zones.

On both the landslide Susceptibility and landslide Hazard maps, each landslide site is identified and labelled with its own unique Site Reference Code. On the Hazard maps, the label for each landslide also includes its volume (m$^3$) as the second label component. Landslide Frequency has been calculated from the total number of known recurrences at each landslide site as recorded in the Landslide Inventory. The specific landslide frequency for each landslide appears as the third label for each landslide.

The ‘profile angle’ appears as the fourth label for each landslide site. This profile angle has been determined by digitising a point mid way along the rear main scarp and at the toe and querying the elevation at each of these points using a 2m DEM elevation grid. The profile angle of known landslides is important as it has implications for landslide mobility. It is also very useful to consider the distribution of the profile angles (the average is $17^\circ$) and this is also featured in one text box.

5 PRELIMINARY SYDNEY BASIN WIDE SUSCEPTIBILITY ZONING

To further investigate and validate the DA methodology, it is currently being applied to the entire Sydney Basin region and we are currently assembling data sets to refine this modelling process. At 25m pixel resolution, this involves a GIS-based raster grid of approximately 220 million pixels notwithstanding that this is at a resolution significantly coarser than is preferable. Using similar data sets as described above for the Wollongong study (at 25m pixel resolution), a preliminary landslide Susceptibility model (proof of concept ONLY) has been developed for a trial area of the Sydney Basin region extending from Sydney Harbour in the south and extending north to include Lake Macquarie and the southern Newcastle area. This trial area involves a raster grid of approximately 15 million pixels.

Figure 4. Preliminary Susceptibility Zoning for the Sydney to Newcastle trial area.
The same regional Landslide Inventory, complemented by additional coverage of the Sydney and Central Coast region provided by the Geoscience Australia’s National Landslide database (downloaded from the GA online web portal), has been used to develop the ‘training data set’. This combined inventory includes 575 ‘slide’ and ‘flow’ category landslides within the geological extent of the Sydney Basin. This training data, and hence the output model, will be greatly improved as the Landslide Inventory coverage of this area is enhanced and we are working towards that.

Over the next 1 - 2 years, as the GIS-based data sets are assembled and refined and as the Landslide Inventory coverage is developed and refined with external assistance, we are confident that this wider area regional modelling will be successful. This type of regional modelling, which can be carried out at quite high resolution (large scale) given input data of sufficient resolution, will assist decision makers determine which areas need further landslide zoning investigations, as are also recommended by the guidelines published in AGS 2007.

6 SUMMARY

A comprehensive, large scale regional GIS-based Landslide Inventory has been used with other GIS data and Data Mining techniques to develop a transparent, entirely data-driven non-statistical Landslide Susceptibility and Hazard model. The modelling methodology is flexible, quantifiable and non-subjective and readily allows the generation of GIS-based map outputs, the scale of which are determined by input data alone. The modelling technique is already being applied to other areas and at other scales within Australia. A preliminary model of a wider area application is also presented. It is important to note that for the susceptibility zoning, only landslide outlines and landslide classification is required, which simplifies the requirements of the landslide inventory for this level of mapping. The authors look forward to reporting more and detailed results of this continuing work at a later time.

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7 REFERENCES


