

# Total Landslide Susceptibility Modelling

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## Abstract

This paper outlines the status of the landslide susceptibility modelling of the Sydney Basin region within the state of NSW, Australia. This area extends from Newcastle in the north to Batemans Bay in the south and west to include the Blue Mountains, an area of approximately 31,000 km<sup>2</sup>. The University of Wollongong NSW Landslide Inventory includes 1863 landslides (134 falls, 278 flows and 1451 slides) to date. The region supports approximately one quarter of the population of Australia. Individual susceptibility models for both slide category and flow category landslides have been developed for the entire Sydney Basin region. Rockfall Susceptibility has also been developed for portions of the Wollongong Local Government Area. The susceptibility models are suitable for use at local scale, Advisory level Local Government Area Development Control Plans. As the models cover the three dominant landslide types identified within the inventory, a trial Total Landslide Susceptibility model has now been developed. As each landslide susceptibility model is a 10 m pixel resolution numerical grid, with values ranging from 0 to 1, the total susceptibility model has been developed, quite simply, by summing the three individual models producing a Total Susceptibility numerical grid. However, classifying this grid into zones is not simple. Furthermore, the Australian regulatory requirements are varied and the outcomes often complex involving a spatial query of the total susceptibility grid and its three contributing landslide susceptibility grids.

## Keywords

Landslide • Susceptibility • Zoning

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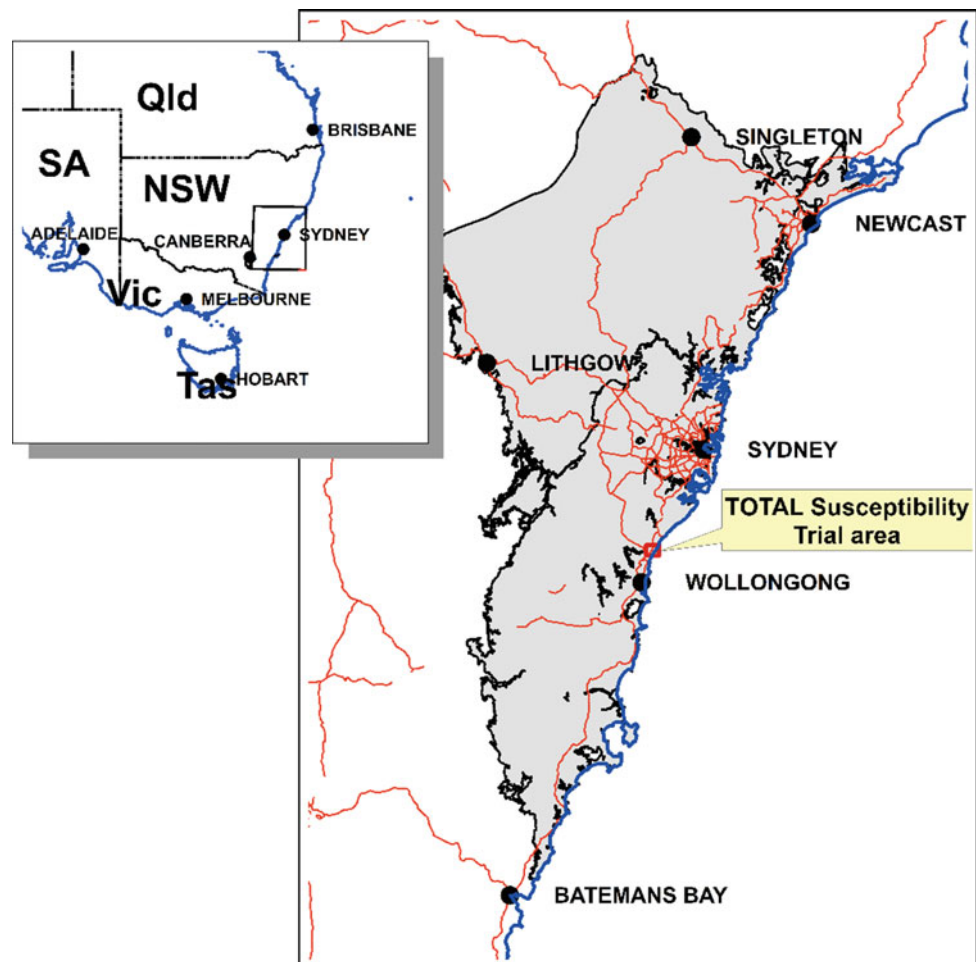
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## 1 The Sydney Basin Region of Australia

The southern Sydney Basin region of NSW on the east coast of the Australian mainland covers an area of 30,902 km<sup>2</sup> and when extended by a 3 km wide buffer, it's an area of 36,225 km<sup>2</sup> (Fig. 1). The basin contains (and is defined by the extent of) Permian to Triassic age mostly conformable near horizontal sediments with some syn-depositional and post depositional tectonic structuring that rest on a Paleozoic basement of granites and metamorphic rocks of Devonian age from the Lachlan Fold Belt Orogen. The sedimentary sequence has been subject to some uplift with gentle folding and small magnitude faulting during the late stage development of the Great Dividing Range. Fluvial erosion and slope instability has developed a landscape of gorges and plateaus, wide expansive coastal plains with coastal cliffs, prominent deep mature estuaries and abundant beaches. Experiencing a cool temperate climate the region has year round rainfall with annual totals ranging from less than 1 m up to almost 2 m with a gradient generally increasing to the west, up to the crest of the Great Dividing Range, before dramatically dropping further westward. The region is blanketed with eucalypt forests, woodlands and coastal heaths superimposed by anthropogenic modifications including farming, urban development and transport infrastructure.

The region includes the city of Sydney, the largest capital city in Australia, together with the cities of Newcastle and Wollongong and a number of smaller regional centers. The Australian Bureau of Statistics 2016 census data reports that the population within this area is 5.87 million people, approximately one quarter of the population of Australia. Clearly, in this mature and highly governed nation, proper land-use planning is considered essential to cope with the increasing pressure to develop marginal land. In local government areas where landslides have occurred repeatedly, Landslide Risk Assessment and Management is recognized as an important factor in effective land-use zoning practices.

**Fig. 1** Southeastern Australia location plan highlighting the shaded extent of the Sydney Basin region



The Landslide Risk Management Guidelines (AGS 2007) and JTC-1 2008 (Fell et al. 2008) state the development of Landslide Inventories and then Landslide Susceptibility Zoning as the first step of landslide risk assessment for effective land use planning.

## 2 The Sydney Basin Landslide Inventory

Landslide inventories play a crucial role in modelling landslide susceptibility and hazard zoning for land use planning since the historic landslide records are a guide towards assessing the future possibility of landsliding (Fell et al. 2008). Furthermore, the JTC-1 Landslide Risk Management guidelines emphasize that landslide inventories are a vital component of any landslide zoning programs and essential to be included in landslide zoning reports (Fell et al. 2008). The quality and comprehensiveness of a landslide inventory directly affect the reliability of the evaluations derived from it (Galli et al. 2008).

Developed since 1993, a recent doctoral research program has expanded and redesigned the NSW landslide inventory to a comprehensive level and suitable for growth over the next 10 years (Flentje et al. 2012; Palamakumbure 2015; Flentje et al. 2016). The database structure has been developed in MS Access 2007 to facilitate the effective storing and analysis of landslide alphanumeric data linked with the spatial database, all of which has been compiled as an ArcGIS v10 geo-database. Field mapping and compilation work has been carried out using base maps and on the desktop GIS software at 1:4000 or larger scales, field mapping assisted with GPS and more recently high resolution differential GNSS. Aerial photograph interpretation and in recent years with sub meter resolution Airborne Laser Scan data and derived high resolution hill shade models have also been employed. Each landslide is referenced by a key Site Reference Code which does not change over time. The Inventory includes 1863 landslides (134 falls, 278 flows and 1451 slides) to date and only these three main types of landslides are considered significant in this region.

### 3 Methodology for Developing Total Landslide Susceptibility

As the NSW Landslide Inventory clearly demonstrates the presence of slide, flow and rockfall category landslides, a comprehensive assessment of landslide susceptibility must consider these three fundamentally different mechanisms of failure and landslide processes. The approach taken has been to independently assess these three different mechanisms of failure and landslide processes in individual susceptibility zonings and ultimately sum the results as outlined in Eq. 1:

$$\text{Total Susceptibility} = \Sigma \text{Slide, Flow and Fall Susceptibility} \quad (1)$$

This approach requires, of course, that the individual susceptibility zoning grids are numerically similar. In this project, each of the susceptibility grids (ArcGIS Raster grids) have been reduced to floating point values between 0 and 1. After appropriate enumeration of the individual components, the Total Susceptibility grid can also be expressed in terms of values ranging between the limits of 0 to 1. This modelled grid can then also be classified into zones of Low, Moderate and High Total Susceptibility in the same way as the component susceptibility models have been.

## 4 Software Tools and Grid Resolution Employed

### 4.1 Flow and Slide Susceptibility Modelling

For the model development and multilayer data analysis, the ESRI ArcGIS v.10 software environment was used. The See5 software was used to derive decision tree based rule-sets. The application of decision trees, a knowledge-based data-mining technique (Quinlan 1986; Kohavi and Quinlan 1999) in landslide susceptibility mapping has been gaining attention over past few decades due to its enhanced predictive capabilities and independence from subjective expert judgments (Saito et al. 2009; Miner et al. 2010; Yeon et al. 2010). Data mining (DM) can be described as the science of computer modelling heuristic learning processes. It is a computationally fast and a less cumbersome method which is capable of handling input data from different scales without assuming its frequency distribution (Pal and Mather 2003; Saito et al. 2009). Also, the relationship between landslide occurrence and the causative factors is not required to be known prior to the model development as it is depicted by the tree structure itself (Saito et al. 2009). Decision trees have become a preferable modelling method as it allows a

better compromise between clarity, accuracy and efficiency (Ferri et al. 2003; Yeon et al. 2010). The DM learning process extracts patterns from large databases, whether they are concerned with organizational processes or, as in this case, natural phenomena—landslides. These patterns can be used to gain insight into aspects of the phenomena, and to predict outcomes (in this case, pixels with characteristics matching those of known landslides where no landslides have been identified) as an aid to decision-making (Palamakumbure et al. 2015a, b, c). Hence the critical importance of the Landslide Inventory in this methodology. Early work on this was carried out in collaboration with Geoscience Australia (Chowdhury et al. 2002).

The entire data mining and GIS process for Flow and Slide Susceptibility modelling was automated by developing an ArcGIS Landslide Data Mining (LSDM) add-in toolbar (Palamakumbure et al. 2014). The process is carried out separately for each landslide type. This tool automates a series of tedious manual processes involved in data extraction, preparation, deriving See5 rules as summarised below (Palamakumbure et al. 2015a) and preparation of the ArcGIS Slide and Flow susceptibility grids.

Four example rules from a twenty nine strong rule set summarising Flow type landsliding, are shown in Table 1. The full nested rule sets are applied as “AND/IF/THEN” logical operations in Python scripting. Each rule represents a path from one tree node to another and the predicted class (non-landslide or landslide, 0 or 1) represents the terminal node, depicting the relationship between the Landslide causative factors and the landslide occurrence, and the order of relevance of the Landslide causative factors. The confidence of the prediction made is evaluated and validated using the Laplace ratio  $(n - m + 1)/(n + 2)$  where  $n$  is the number of training cases that a specific rule covers and  $m$ , is the number of incorrectly classified cases,  $n$  and  $m$  being the first two numbers in brackets after the rule number, in Table 1. The confidence value (0–1) is given in square brackets at the end of each rule, after the predicted class in Table 1.

### 4.2 Rockfall Susceptibility Modelling

Following some detailed site mapping of numerous recent rock falls and some two dimensional analysis using the Rocscience Rocfall software, the ESRI ArcGIS compatible Rockfall Analyst software extension V9.3.1 and V10.0.1 beta (Lan et al. 2007) from the University of Alberta team has been employed in the development of rockfall Susceptibility zoning. The spatial extent and a network neighborhood count of the modeled rockfall trajectories provides a useful Susceptibility zoning outcome (Flentje et al. 2015).

**Table 1** Example 2014 data mining rules from the Sydney Basin flow modelling work

<p><b>Rule 1: (17741/355, lift 1.2)</b></p> <p>a &gt; 193.797 s &lt;= 10.96276 -&gt; class 0 [0.980]</p>	<p><b>Rule 7: (1318/202, lift 4.2)</b></p> <p>a &gt; 83.69223 a &lt;= 143.3372 rc &gt; 0.333963 s &gt; 29.28903 w &gt; 3.105168e-007 -&gt; class 1 [0.846]</p>
<p><b>Rule 2: (13887/473, lift 1.2)</b></p> <p>pc &lt;= 1.831974 rc &gt; -1.831455 rc &lt;= 0.333963 s &lt;= 13.76796 t = 2 w &gt; 0.002031242 -&gt; class 0 [0.966]</p>	<p><b>Rule 8: (509/88, lift 4.1)</b></p> <p>a &gt; 83.69223 a &lt;= 143.3372 f &gt; 43 rc &gt; 0.333963 s &gt; 12.21367 w &gt; 3.105168e-007 -&gt; class 1 [0.826]</p>
<p>Attributes</p>	
<p>a = aspect f = flow accumulation pc = plan curvature rc = profile curvature s = slope t = terrain 3 classes w = wetness class 0 class 1</p>	<p>Floating point Floating point Floating point Floating point Floating point Classified integer Floating point Non-landslide pixel Landslide pixel</p>

These four examples include two from the class 0 (non landslide) and two from the class 1 (landslide predicted) rule set (comprises twenty nine rules)

### 4.3 Grid/Pixel Resolution and the Delta ( $\delta$ ) Ratio Parameter

The selection of which pixel resolution is the most beneficial has been considered in some detail (Palamakumbure et al. 2015a). An analysis was conducted for several trial regions with 7 different pixel resolutions varying from 2 m up to 30 m. For the data sets available at that time and examined in that study, and reported herein, a 10 m pixel resolution was considered optimal. The delta ( $\delta$ ) ratio parameter has been developed as one measure of modelling rigor, by taking the ratio of the square root of a representative (mean) landslide area (A) of the inventory and the area of a pixel where P is the pixel size (Eq. 2).

$$\delta = \sqrt{A}/P^2 \quad (2)$$

In summary, a delta ratio of  $1.5 \text{ m}^{-1}$  is considered an optimum value for the Sydney Basin work. Delta ratios less than 1 may be considered as lower resolution, regional guidance, whereas Delta ratios of greater than 5 may be considered as highly resolved. However, each project is heavily dependent on the level of detail contained within the Landslide Inventory.

## 5 Slide Category Landslide Susceptibility

Preliminary studies covering the entire Sydney Basin region, which were described as ‘proof of concept’, were completed (Flentje et al. 2011) up to a decade ago. The GIS data layers employed in the modelling for both Slide and Flow susceptibility, and the respective layer usage in developing the rule sets, are summarised in Table 2. The most recent slide susceptibility modelling outcomes for the Sydney Basin are summarised in Table 3 (Palmakumbure et al. 2015a). The Slide Susceptibility values range from 0.01 up to 0.87.

## 6 Flow Category Landslide Susceptibility

Modelling of Flow category landslides has been conducted using the same See5 methodology as for Slides discussed above (Palmakumbure et al. 2015b). Data from eight different layers derived from the Digital Elevation model was extracted corresponding to the landslide and randomly selected non-landslide pixel locations (Table 4).

It is of note that the Geology data layer was ultimately not used in modelling of the flow category landslides as it has

**Table 2** Attribute usage in data mining rules in flow and slide category modelling

Attribute/GIS layer	Flow %	Slide %
Slope	100	38
Plan curvature	39	7
Profile curvature	26	11
Curvature	26	9
Aspect	16	11
Terrain	14	4
Wetness index	12	12
Geology	–	100
Flow accumulation	<1%	<1%
Landslide pixels—training cases	32,862	670,164

**Table 3** Statistical summary of the Sydney Basin slide category modelling

Susceptibility class	% of the study area	% Slide population	Area of slides (km <sup>2</sup> )	Area (km <sup>2</sup> ) of class	% of area effected by slides
Very low - 1	84	1.51	0.5	25.900	0.002
Low - 2	6.23	4.99	1.65	1.650	0.08
Moderate - 3	5.2	15.9	5.27	1.590	0.33
High - 4	4.8	77.55	25.64	1.480	1.73

**Table 4** Sydney Basin flow category modelling distribution

Susceptibility class	% of the study area	% Flow population	Area of flows (km <sup>2</sup> )	Area (km <sup>2</sup> ) of class	% of area effected by flows
Very low - 1	59	9	0.15	18.233	0.0008
Low - 2	11	5	0.08	3.399	0.0024
Moderate - 3	14	32	0.53	4.326	0.0122
High - 4	16	54	0.89	4.944	0.0179

been assumed that the occurrence of flows, in the Sydney region, does not largely depend on Geology. Debris flows are generally shallow seated landslides and therefore, underlying geology is less relevant. Our model is based on the mapped location of relatively few (only 267 flows), in 2014, within an area of 30,603 km<sup>2</sup>. In early trials, with the Geology was included in the modelling, the spatial extent of the modelled Debris Flow susceptibility was limited by the Geology in which they occur, which we considered to be unnecessarily restrictive for the application—developing a debris flow susceptibility map with wide application. If alternatively, say 1000 debris flows had been mapped within

a single local government area, modelling within that small area may be more appropriate using geology.

The Flow category landslide susceptibility results are summarized in Table 4. The Flow Susceptibility values range from 0.01 up to 0.89.

## 7 Rockfall Category Landslide Susceptibility

The rockfall susceptibility was developed quite differently as discussed previously. Trajectories were modelled from a seeder line along the crest of the escarpment, at 1 m spacing



with a high resolution Airborne Laser Scan (Lidar) 2 m pixel DEM. Once modelled, a ‘susceptibility grid’ was developed using a neighborhood count, counting every trajectory that comes within 5 by 5 neighborhood matrix of 2 m pixels and summing the results of the analysis for every pixel. The process to this point, whilst moderately complex, is completed after considerable field work and then by employing the University of Alberta Rockfall Analyst extension (Flentje et al. 2015) provided the user inputs certain parameters. Simply dividing the numerical value for each pixel by the highest total (5600 in this case) provided a grid with totals ranging from 0 to 1.

A total of only 16 rock falls from the total 134 within the inventory, represented by 6889 10 m pixels, exist within the  $\sim 30 \text{ km}^2$  trial area reported herein. The rockfall category landslide susceptibility results with respect to the distribution of rockfalls are summarized in Table 5. The Fall Susceptibility values range from 0.01 up to 0.99.

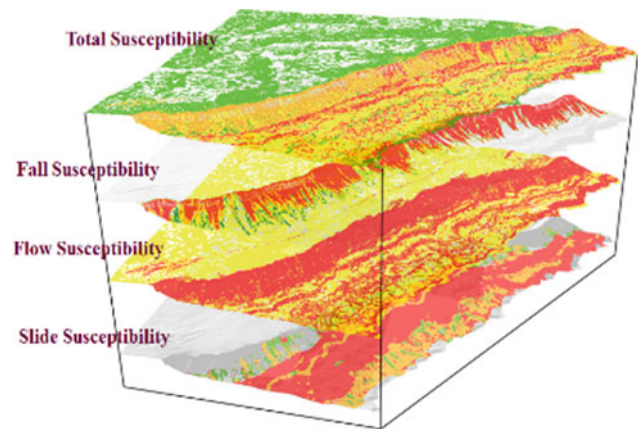
## 8 Total Landslide Susceptibility

### 8.1 Developing the Model

Once the individual slide, flow and fall susceptibility grids are processed to have value ranges between 0 and 1, it’s a simple process of numerically assessing the individual components to produce a grid with values ranging between 0 and 1. The total susceptibility for this  $\sim 30 \text{ km}^2$  small trial area ranges from 0.007 up to 0.691. An image showing the stacked grids is included in Fig. 2. The distribution of the 4 zones (Very Low, Low, Moderate and High) within the Total Susceptibility grid together with the distribution of the Slide, Flow and Fall landslides within each of the zones are summarised in Table 6.

### 8.2 Understanding and Using the Model

We have become used to the fact that ‘Hazard’ models (Susceptibility models should be the fundamental basis of



**Fig. 2** Stacked 3D image of the slide, flow and fall susceptibility models that sum to make the total susceptibility zoning

Hazard Models) are composed of traffic light colors demarking the various hazard zones. As such many zoning maps have some areas of red (most susceptible or hazardous), some areas of orange and grade out through yellow and or green to lesser hazard, and hopefully have large tracts of land with little or no susceptibility/hazard. Generally at least that’s the intention, to enclose the highest hazards in the smallest areas of land, whilst identifying large portions of any given study area as safe for development, whatever that may be. The three zoning models discussed above certainly follow this trend and logic as summarised in Tables 3, 4 and 5.

To demonstrate the use of the Total Susceptibility model and its contributing Landslide Inventory and Slide, Flow and Fall Susceptibility models, in a land use planning application, Fig. 3, shows 4 separate zoning maps of the same area, each with a central highlighted property parcel. This parcel is large,  $55,400 \text{ m}^2$  in area. Using a spatial query in ArcGIS, and the Zonal Statistics tool, each layer is queried with respect of the parcel area to determine the actual zoning distribution (area and percentage). The results of these queries are summarised in Table 7.

Table 7 shows the property parcel is classified as 82.5% of its area ( $44,900 \text{ m}^2$ ) being High Total Susceptibility, 71%

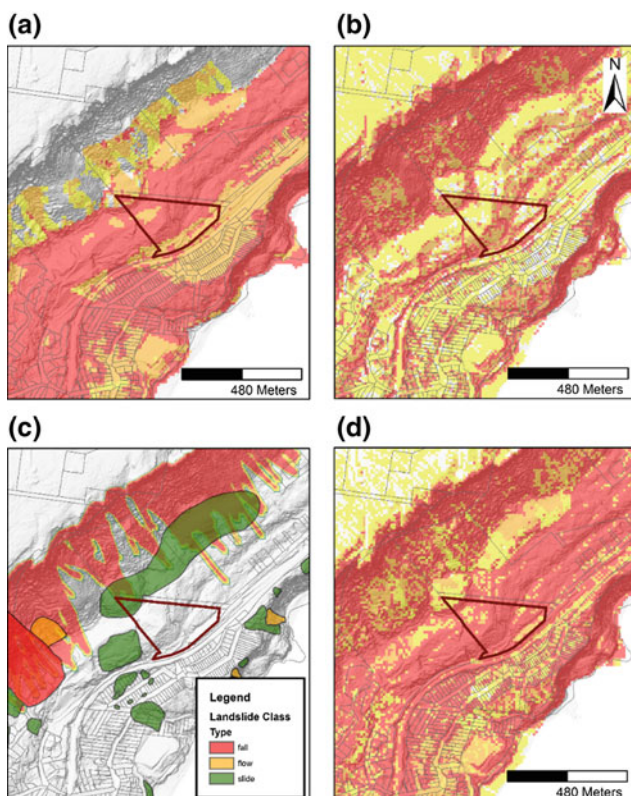
**Table 5** Wollongong  $\sim 30 \text{ km}^2$  trial rockfall modelling distribution

Susceptibility class	% of the study area	% Fall population	Area of falls ( $\text{km}^2$ )	Area ( $\text{km}^2$ ) of class	% of area effected by falls
Not susceptible	91.96	5.03	0.01	27.28	0.04
Very low - 1	1.30	27.85	0.06	0.39	15.56
Low - 2	1.28	25.90	0.06	0.38	14.78
Moderate - 3	1.40	29.89	0.06	0.42	15.53

**Table 6** Trial area total susceptibility categories with % area landslide distributions within each zone

Pixel count	Total susceptibility		Slides		Flows	Falls
	class	Min	Max	%	%	%
108788	Very low - 1	0.01	0.03	0.00	0.00	0.00
35721	Low - 2	0.03	0.10	0.12	0.02	0.07
14664	Moderate - 3	0.10	0.26	0.18	0.04	0.35
53868	High - 4	0.26	0.69	0.10	0.40	0.21

High Slide Susceptibility, 33% High Flow Susceptibility and essentially not susceptible to rockfalls. The one element not actually captured outside of Fig. 3c is the green slide category landslide that does effect the property parcel. This landslide covers approximately 8% of the parcel and details from the Inventory could, if available, be provided as required.



**Fig. 3** Susceptibility grids within the trial area highlighting the query cadastral parcel; **a** slides—legend is Table 3, **b** flows—legend is Table 4, **c** falls—legend is Table 5 and also showing the landslide inventory and **d** total—the legend for the total susceptibility zoning is shown in Table 6. The susceptibility distributions within the high-lighted parcel are summarised in Table 7

## 9 Landslide Management

The legislation on land-use planning and development in Australia is different from state to state, and still between different Local Government Councils, within each of the states. The states of NSW, Queensland, Victoria and Tasmania have rules and regulations concerning the constructions on sites that are prone to landside hazard. In NSW, State Environmental Planning Policies (SEPP) provide a framework for the development of planning policies at the local government level. The Local Environmental Plans (LEP) are integral parts of NSW planning system. They are created by local councils in consultation with local communities and guide planning decision for local government areas. The Wollongong Development Control Plan (DCP 2009) outlines planning controls for the Wollongong City and Chapter E12 of this DCP addresses the geotechnical assessment of slope instability. As per these regulations, it is a requirement to assess the area of a proposed development for slope instability.

Some state governments have policies regarding the application of landslide risk management (LRM) concepts while some do not, but this work is generally carried out by local governments. During this process adaptation of AGS (2007) guidelines is essential. It is in part due to these regulatory requirements that the Australian Geomechanics Society developed the Landslide Risk Management (LRM) Guidelines from 1985 (AGS 2007). The AGS 2007 Guidelines are often referenced in the Local Government regulations and the required “Geotechnical Reports” are required to be compliant with these guidelines. To invoke the requirements, some local governments will have paid consultants to develop Susceptibility or Hazard maps (sometimes incorrectly called Risk maps), possibly even with simple landslide inventories, although typically not. These maps will be used as a binary form of capture and if a parcel is zoned as affected then a ‘geotechnical report’ is required. The process works well enough, if applied

**Table 7** Summary of cadastral parcel query of all susceptibility grids shown in Fig. 3

Zone	Total susc. m <sup>2</sup>	Total susc. %	Slide susc. m <sup>2</sup>	Slide susc. %	Flow susc. m <sup>2</sup>	Flow susc. %	Fall susc. m <sup>2</sup>	Fall susc. %
Very low - 1	0	0.0	0	0.0	6700	12.3	54,000	99.3
Low - 2	4200	7.7	300	0.6	14,000	25.7	200	0.4
Moderate - 3	5300	9.7	15,300	28.1	15,800	29.0	100	0.2
High - 4	44,900	82.5	38,800	71.3	17,900	32.9	100	0.2

correctly and only if the local government has a useful Susceptibility or Hazard zoning map. Unfortunately many do not and of those that do exist, most have been prepared by individual consultants using a unique technique such that comparisons between local government areas is not possible. Hence across the states, and indeed around the Nation there exists an incomplete patchwork of LRM procedures.

Clearly the parcel shown in Fig. 3 would be captured in the quite effective Wollongong City Council Local Government managed Development Application process. Based on the Landslide Inventory and these Susceptibility Zoning maps, which the Local Government may use, any development of the land parcel would require some form of geotechnical investigation to investigate the known landslide and potential for any type of landsliding that may affect the proposed development during its design life. The zonings at some locations, not necessarily at the selected parcel, may even be sufficient to preclude any development at all.

## 10 Summary and Conclusions

The Total Susceptibility modelling and zoning methodology detailed in this paper quite accurately accounts for the presence of slide, flow and rockfall category landslides and the three fundamentally different mechanisms of failure and landslide processes they represent. Whilst they are not independent, but co-related in time and space, this methodology allows a comprehensive management process to be developed. Application of this methodology within local government may well be enhanced with provision of preliminary landslide inventories, specific landslide type susceptibility zonings (even if only regional in nature) and possibly even Decision Support Matrices to aid non specialist planning assessment of submitted development applications such that those for moderate or higher susceptibility parcels may need assessment from suitably qualified geo-hazard professionals. This review may be external to the local government organization if in-house geo-hazard

expertise is not available. This is a process the authors hope to see being applied more widely and systematically across Australia into the future.

The authors and several other colleagues have been trying to secure funding to develop large scale landslide inventory and susceptibility tools, similar to those described herein for application across southeastern Australia. Unfortunately, our attempts so far have been unsuccessful although we are still working towards that goal.

## References

- Flentje, P., Stirling, D., Chowdhury, R.N.: Landslide inventory, susceptibility, frequency and hazard zoning in the Wollongong and wider Sydney Basin Area. In: *Landslide Risk Management Roadshow 2011 National Seminar Series*. Aust. Geomech. J. **46**(2), 41–49 (2011)
- Flentje, P., Stirling, D., Palamakumbure, D.: An Inventory of landslides within the Sydney Basin to aid the development of a refined susceptibility zoning. Ground engineering in a changing world. In: *Proceedings of the 11th Australia New Zealand Conference on Geomechanics*. Published by the Australian Geomechanics Society, Melbourne, July 15th–18th (2012)
- Flentje, P., Palamakumbure, D., Thompson, J.: Assessing rockfall along the Illawarra escarpment. In: Lollino, G., Giordan, D., Crosta, G.B., Corominas, J., Azzam, R., Wasowski, J., Sciarra, N. (eds.) *Engineering Geology for Society and Territory*, vol. 2, pp. 2031–2036. Springer International Publishing, Switzerland (2015). [http://link.springer.com/chapter/10.1007/978-3-319-09057-3\\_361](http://link.springer.com/chapter/10.1007/978-3-319-09057-3_361)
- Flentje, P., Miner, A.S., Stirling, D., Palamakumbure, D.: Landslide inventory and susceptibility zoning across South-eastern Australia. In: Eggers, M.J., Griffiths, J.S., Parry, S., Culshaw, M.G. (eds.) *Keynote Presentation for Theme 30, Session 30.1 Session 3* (2016)
- Lan, H., Martin, C.D., Lim, C.H.: RockFall analyst: a GIS extension for three-dimensional and spatially distributed rockfall hazard modelling. Department of Civil and Environmental Engineering, University of Alberta. *Comput. Geosci.* **33**, 262–279 (2007). <http://doi.org/10.1016/j.cageo.2006.05.013>
- Miner, A.S., Vamplew, P., Windle, D.J., Flentje, P., Warner, P.: A comparative study of various data mining techniques as applied to the modeling of landslide susceptibility on the Bellarine Peninsula, Victoria, Australia. Paper presented at the 11th IAEG congress of the international association of engineering geology and the environment, Auckland, New Zealand (2010)



- Palamakumbure, D.: GIS-based landslide inventory and landslide susceptibility modelling across the Sydney Basin. Ph.D. thesis, Faculty of Engineering and Information Sciences, University of Wollongong, Unpublished, 341 pages (2016)
- Palamakumbure, D., Flentje, P., Stirling, D.: Consideration of optimal pixel resolution in deriving landslide susceptibility zoning within the Sydney Basin, New South Wales, Australia. *Comput. Geosci.* **82**, 13–22. Published by Elsevier, and available online via Science Direct (2015a)
- Palamakumbure, D., Flentje, P., Stirling, D.: Flow category landslide susceptibility modelling of the Sydney Basin. *Changing the Face of the earth: geomechanics and human influence*. In: Proceedings of the 12th Australia New Zealand Conference on Geomechanics, February, Wellington, New Zealand (2015b)
- Palamakumbure, D., Stirling, D., Flentje, P., Chowdhury, R.: ArcGIS V.10 landslide susceptibility data mining add-in tool integrating data mining and GIS techniques to model landslide susceptibility. In Lollino, G., Giordan, D., Crosta, G.B., Corominas, J., Azzam, R., Wasowski, J., Sciarra, N. (eds.) *Engineering Geology for Society and Territory*, vol. 2, pp. 1191–1194. Springer International Publishing, Switzerland (2015c). [http://link.springer.com/chapter/10.1007/978-3-319-09057-3\\_208](http://link.springer.com/chapter/10.1007/978-3-319-09057-3_208)
- Saito, H., Nakayama, D., Matsuyama, H.: Comparison of landslide susceptibility based on a decision-tree model and actual landslide occurrence: The Akaishi Mountains, Japan. *Geomorphology* **109**(3–4), 108–121 (2009). <https://doi.org/10.1016/j.geomorph.2009.02.026>
- Yeon, Y.K., Han, J.G., Ryu, K.H.: Landslide susceptibility mapping in Injae, Korea, using a decision tree. *Eng. Geol.* **116**(3–4), 274–283 (2010)