Dr. Phil Flentje, Senior Research Fellow (Engineering Geologist)
Civil, Mining, and Environmental Engineering
email: pflentje@uow.edu.au

Landslide susceptibility and landslide hazard zoning in Wollongong

with co-authors Dr Daniel Palamara, Dr David Stirling and Professor Robin Chowdhury

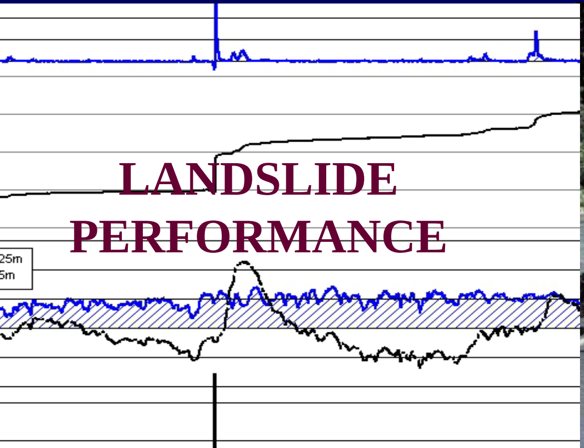
University of Wollongong, NSW, AUSTRALIA

in collaboration with Industry Partners

Wollongong City Council
Roads and Traffic Authority
Rail Corporation

Geotechnics and Railway Engineering Research Centre

GeoQuEST Research Centre



Issues covered in this presentation

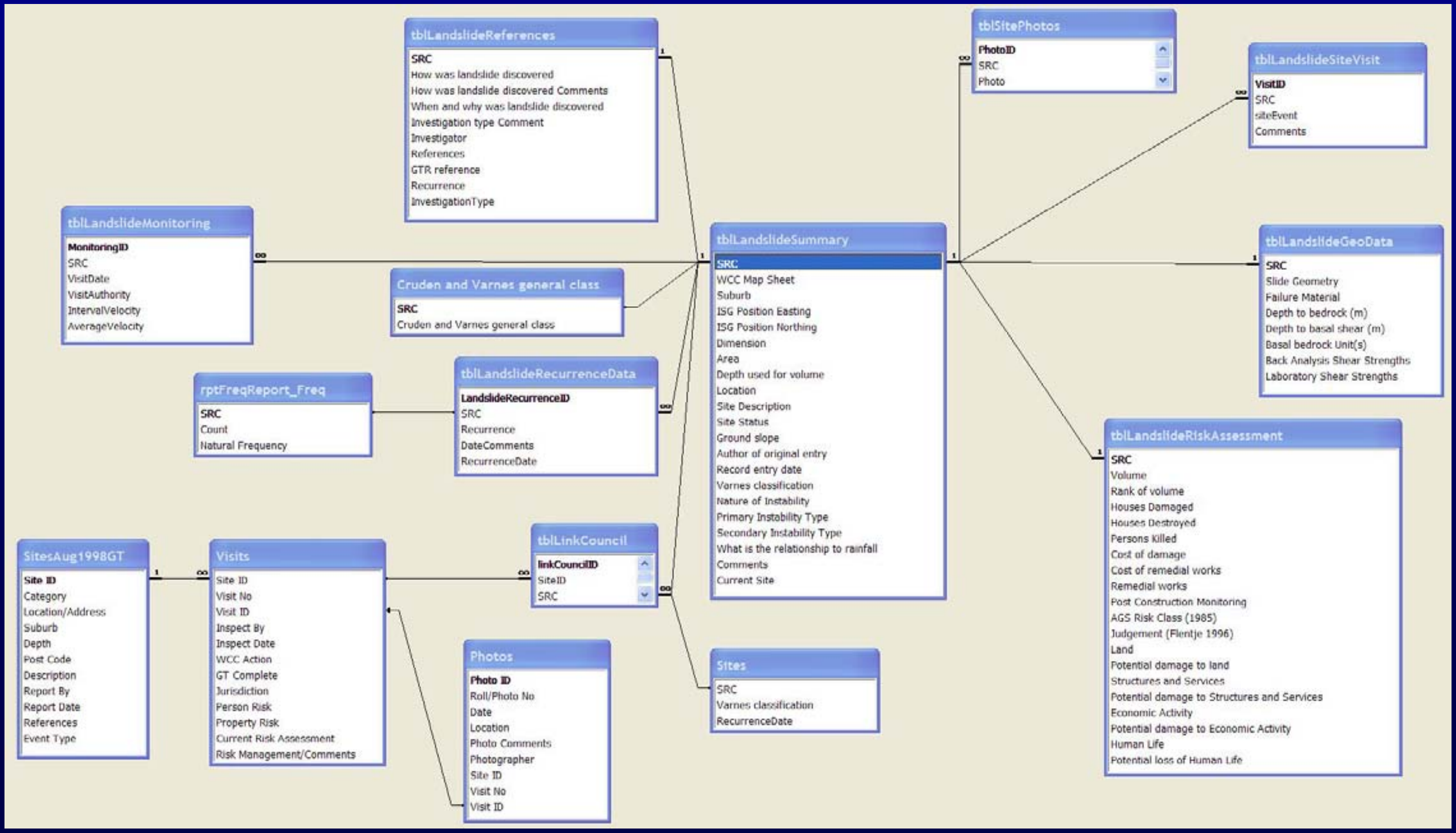
- UoW GIS-based Landslide Inventory
  - 6 slides– but I have to really zip through these
- Landslide Susceptibility Modelling Wollongong LGA
- Determining ‘zones’ within the model grid
- Upgrade landslide Susceptibility to landslide Hazard zoning

… and if there is time …

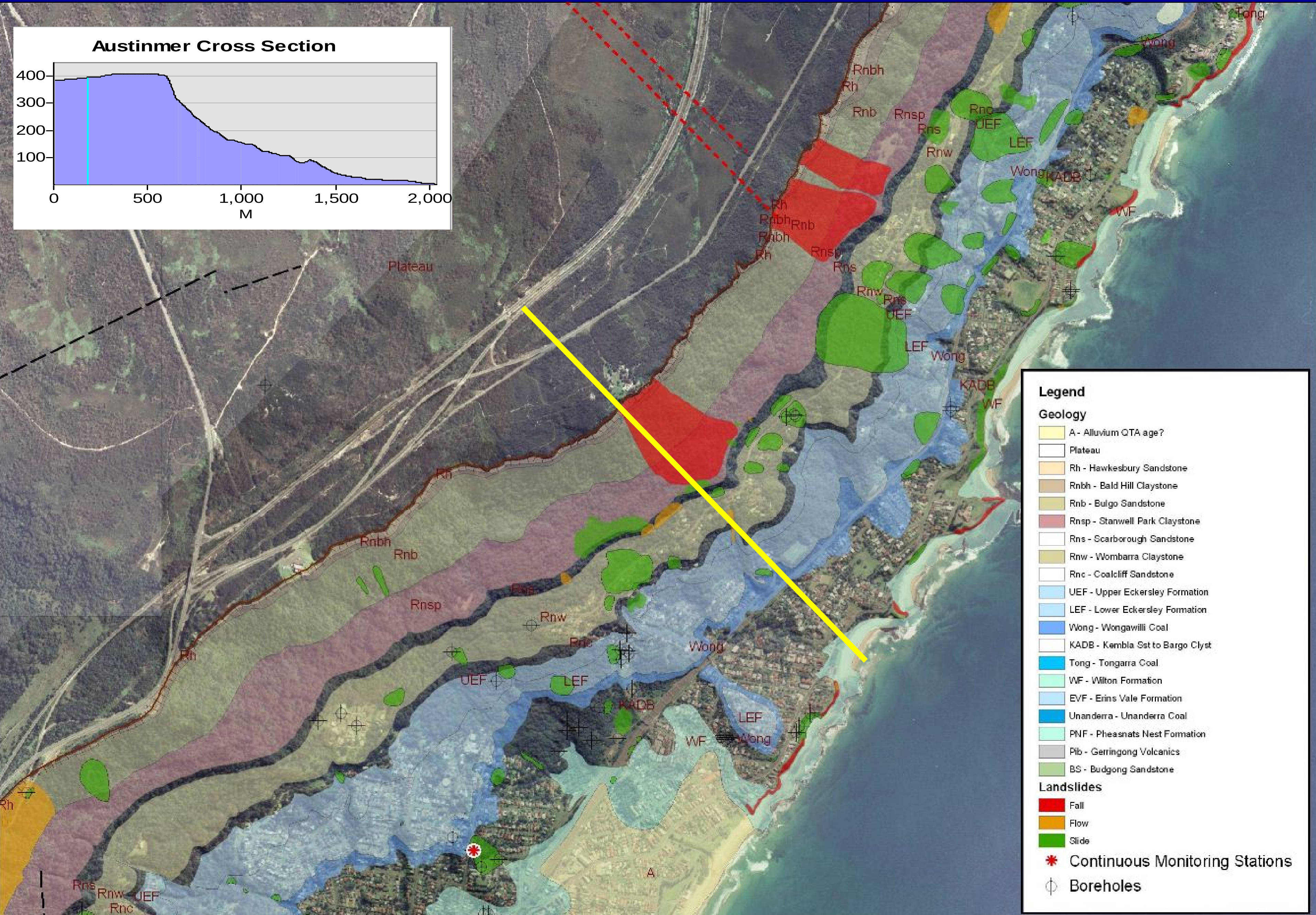
- UoW Sydney Basin wide Landslide Inventory and the preliminary SB Landslide Susceptibility zoning

UoW Illawarra Landslide Inventory

- Please refer to paper
- Developed from 1993, now quite ‘mature’ but have perhaps 50%
- Field mapping at scale of 1:4000 and since with DGPS
- Comprehensive relational MS Access and ESRI Geo-database

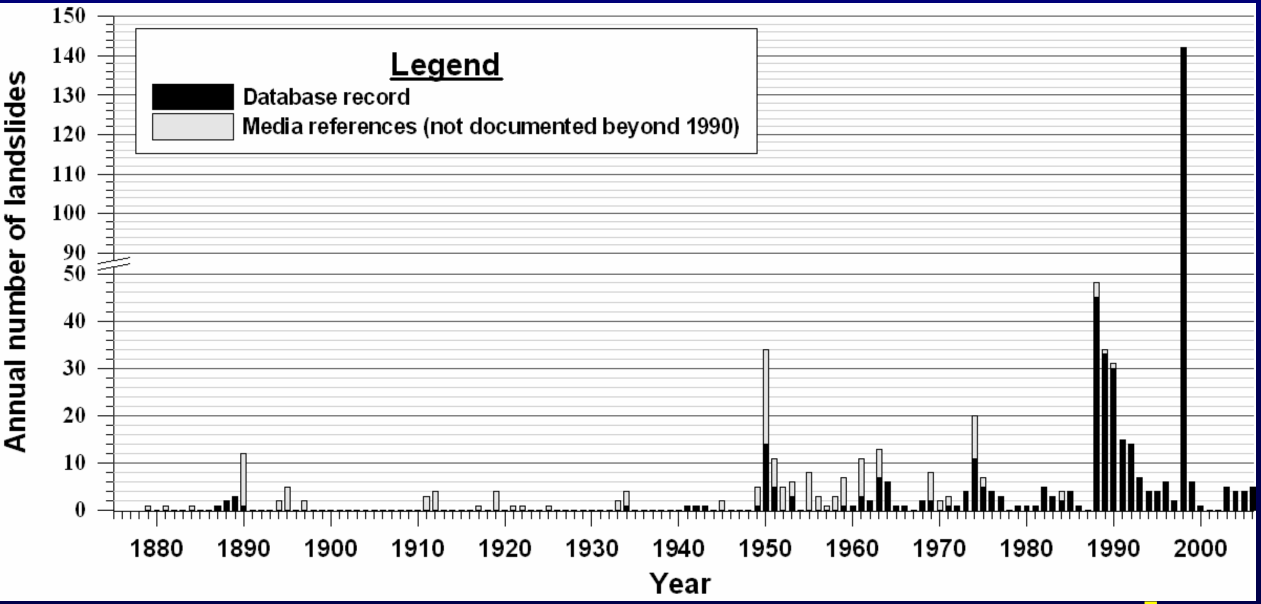


UoW Illawarra Landslide Inventory – Thirroul to Wombarra area



So, what does this Inventory tell us about landsliding within Wollongong? In summary

- 586 landslide locations, 976 ‘events’ includes first time movements, also multiple recurrences at some sites, some meaningful frequency info
- 586 landslides comprise 42 falls, 43 flows and 491 slides according to the Cruden and Varnes 1996 classifications system + a few unclassified
- In the 188 km^2 model area, 2.95% of the ground surface is affected by landslides - 1880 to 2006
- 4 people killed
- 51 houses damaged, 29 destroyed
- Costs are very poorly understood - $18 million in remedial works, $550K in direct costs



Landslide Susceptibility Modeling

- Definition - “quantitative or qualitative assessment of the classification, volume and spatial distribution of landslides in an area” AGS 2007 (a)
- LI shows this must be done for independently for slide, fall and flow category landslides - **the rest of this presentation focuses on slide category landslides**
- Knowledge-based Data Mining modeling within GIS framework
- Datasets - Landslide Inventory, geology, vegetation, DEM and derivatives (slope, aspect, curvatures, Terrain Classification, Flow Accumulation and the Wetness Index)

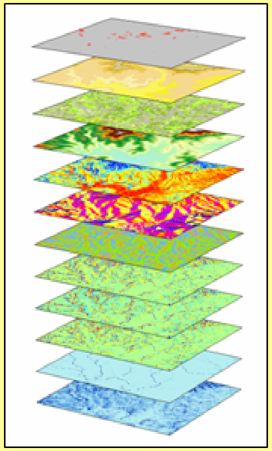
Susceptibility ‘knowledge based’ modeling process

DATA COLLECTION

GIS-based data Management

Study Area comprises 1.88 million 10m² pixels

- Landslide Inventory
- Geology
- Vegetation
- DEM (z)
  - Slope Inclination
  - Slope Aspect
  - Terrain Units
  - Curvature
  - Profile Curvature
  - Plan Curvature
  - Flow Accumulation
  - Wetness Index



GIS-based Data preparation for Data Mining Analysis

- Raster DEM to ASCII xyz
- Raster Intersect Point
- 1.88 million points

Output attributed .csv file

Data Mining Analysis
See5 software

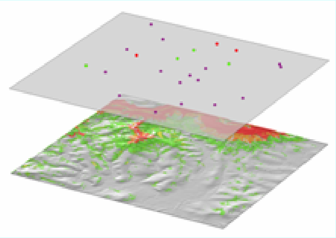
- 1.88 million fully attributed xyz points
- 65,295 training points - 29,480 landslide points + random 35,815 non landslide points (to balance numbers in the model)
- See5 generates Symbolic Decision Tree and rule sets
- Model adjustments, analysis and cross validation
- Performance of each rule summarized, including rule confidence

Landslide Susceptibility Model Layer generated

- Rule sets applied to all 1.88 million pixels in GIS
- Rule confidence mapped as landslide susceptibility

Analysis of Confidence-based Susceptibility Model

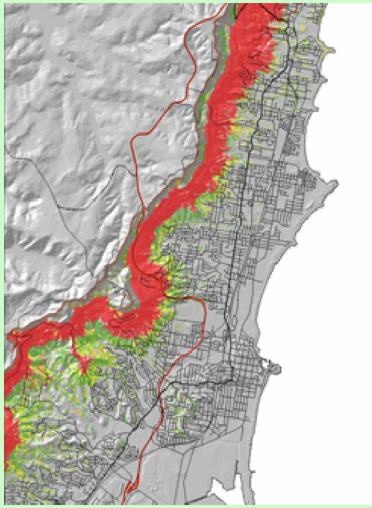
DGPS field-based validation assessed in GIS



Field validation and statistical analysis used to determine appropriate confidence boundaries for zones

Analysis of spatial statistics of existing landslides within zones

Zoned Landslide Susceptibility Map



Slide category landslides

- Volumes up to 600,000m³
- Extremely slow to moderate velocities (Cruden and Varnes 1996)
- Depths of sliding up to 17.5m

Segment of the text file used for See5 Data Mining

- **Data mining rule set generated for the training data ie, all landslide pixels plus an equal number of non landslide random pixels (65,295 points)**

X	Y	Z	flowacc	wetness	ras10ma	ras10ms	plancur	slide	geology	Vegetat	profile	curvatu	geom_10
303109.03	1220096.43	85.65	7	0.00540	230.61	19.81	-0.01	1	3	3	0.082	-0.087	1
303119.03	1220096.43	88.41	7	0.00377	224.67	17.98	0.33	1	3	3	-0.281	0.610	2
302889.03	1220086.43	40.00	26	0.00000	-1.00	0.00	0.00	1	3	3	0.000	0.000	3
302899.03	1220086.43	40.00	1	0.00000	-1.00	0.00	0.00	1	3	3	0.000	0.000	3
302909.03	1220086.43	40.00	61	0.00000	-1.00	0.00	0.00	1	2	3	0.000	0.000	3
302919.03	1220086.43	40.00	79130	0.00000	219.36	1.50	0.00	1	2	3	0.025	-0.025	3
302929.03	1220086.43	40.03	29	0.00001	231.83	7.56	-0.74	1	2	3	2.557	-3.297	2
302939.03	1220086.43	42.12	17	0.00173	232.65	13.54	0.54	1	2	3	0.365	0.172	2
302949.03	1220086.43	44.16	32	0.00154	230.31	14.95	0.04	1	2	13	0.030	0.008	2
302959.03	1220086.43	46.20	5	0.00207	229.45	14.86	0.02	1	1	13	-0.018	0.040	2
302969.03	1220086.43	48.19	26	0.00136	229.11	14.31	-0.10	1	1	13	-0.142	0.047	1
302979.03	1220086.43	50.14	4	0.00266	228.98	12.92	0.19	1	1	13	-0.623	0.818	1
302989.03	1220086.43	51.65	27	0.00117	227.70	11.56	-0.02	1	1	13	-0.077	0.056	2
302999.03	1220086.43	53.11	3	0.00239	223.99	11.15	0.22	1	1	13	0.043	0.174	2
303009.03	1220086.43	54.50	15	0.00197	219.04	11.39	0.45	1	1	13	-0.179	0.631	3
303019.03	1220086.43	55.71	2	0.00344	215.57	11.81	0.30	1	1	3	-0.202	0.507	3
303029.03	1220086.43	56.80	28	0.00125	216.20	12.30	-0.23	0	1	3	0.173	-0.407	1
303039.03	1220086.43	58.19	1	0.00214	219.39	15.38	0.71	0	1	3	0.712	0.000	1
303049.03	1220086.43	59.58	29	0.00110	221.06	24.13	-1.07	0	1	3	4.603	-5.671	1
303059.03	1220086.43	63.68	19	0.00263	222.08	32.43	-0.81	0	1	3	2.607	-3.421	3
303069.03	1220086.43	69.65	14	0.00597	223.50	32.89	1.95	0	1	3	-3.908	5.859	3
303079.03	1220086.43	73.03	5	0.01099	225.66	28.82	-0.86	1	1	3	-0.555	-0.302	3
303089.03	1220086.43	76.92	4	0.00733	226.88	26.48	0.37	1	1	3	-0.621	0.989	2
303099.03	1220086.43	80.65	8	0.00808	228.41	24.23	0.62	1	1	13	-1.954	2.578	1
303109.03	1220086.43	83.44	8	0.00447	230.86	21.02	-0.42	1	1	13	-0.436	0.016	2

3 example rules of 40 in rule set

Data Mining Rules

Rule 3: (22)
flowacc <= 0
aspect > 131.2
slope > 9.5
geology {3, 15, 16, 17}
uowvege {6, 7}
-> class 0 [0.958]

Rule 24: (590/89)
aspect <= 78.8
slope > 9.5
geology = 17
uowvege {4, 8, 16}
-> class 1 [0.848]

Rule 26: (1629/265)
slope > 9.5
plaincur <= -0.14
geology {3, 5, 6, 8 - 17, 19}
uowvege {4, 8, 16}
-> class 1 [0.837]

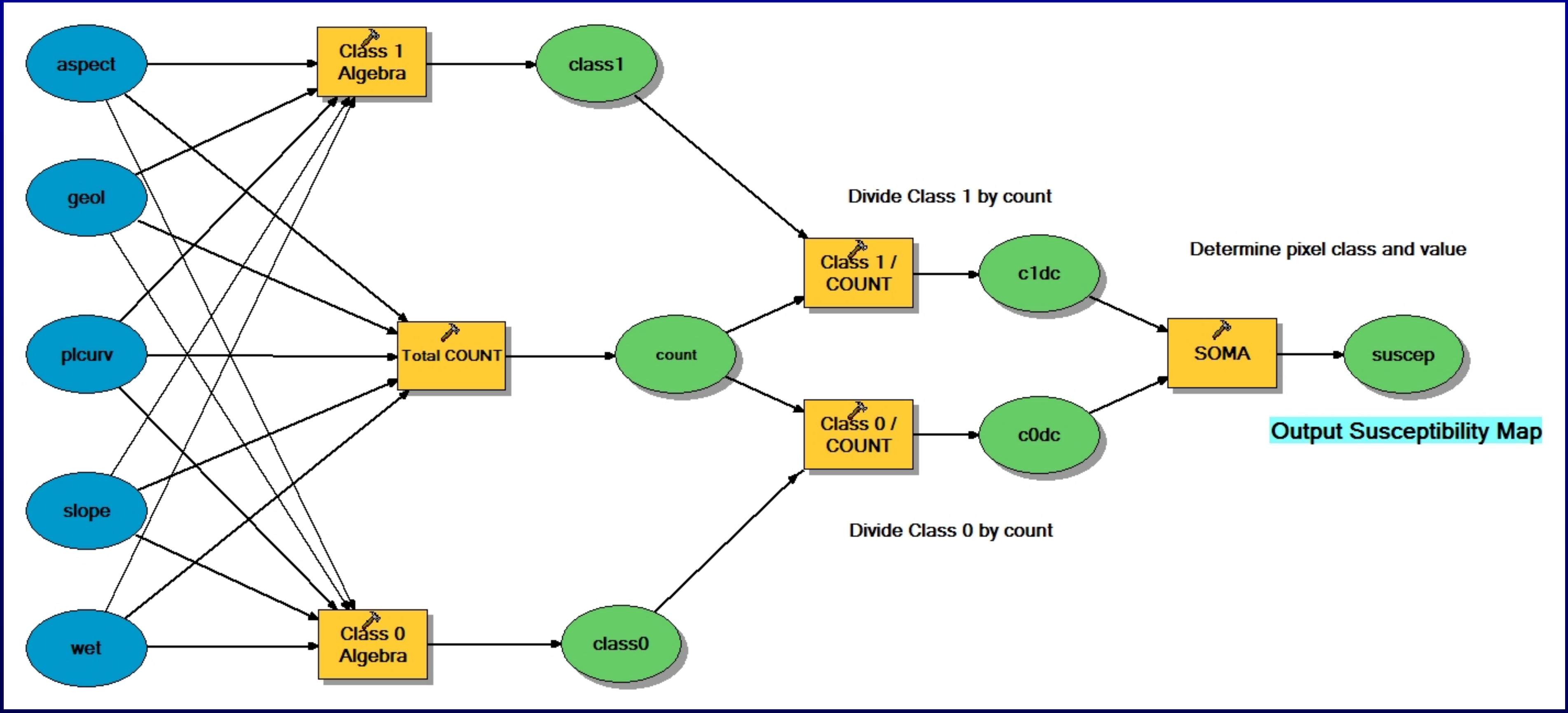
Data Mining rules are generated to define all attributed training data – in layman's terms DM is simply pattern recognition

The Model — contains a defined number of rules. Example rules are shown to the left. Each rule is ranked with a confidence factor, after repeated evaluation and validation, by the Laplace Ratio (n-m+1)/(n+2) where n is the number of training cases that a specific rule correctly recognises, and m if it appears, is the number of cases that do not belong to the class predicted by the rule.,
i.e. rule x: (n, m). Class 0 is no landslide, 1 is landslide

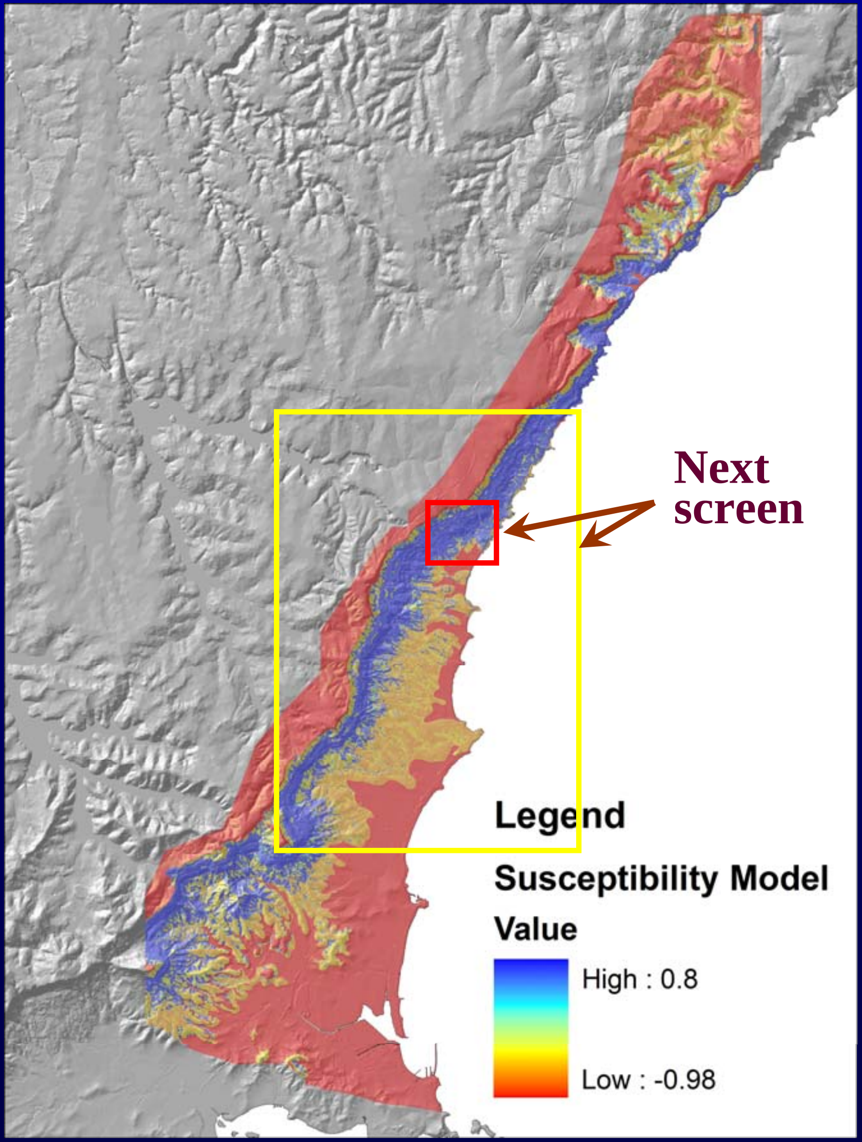
Rule sets then applied to Entire Model Area using ESRI Model Builder

Confidence value as it aplies to each pixel is then mapped as susceptibility distribution

ESRI Model Builder used to re-apply rules within ArcGIS Sydney Basin Model shown

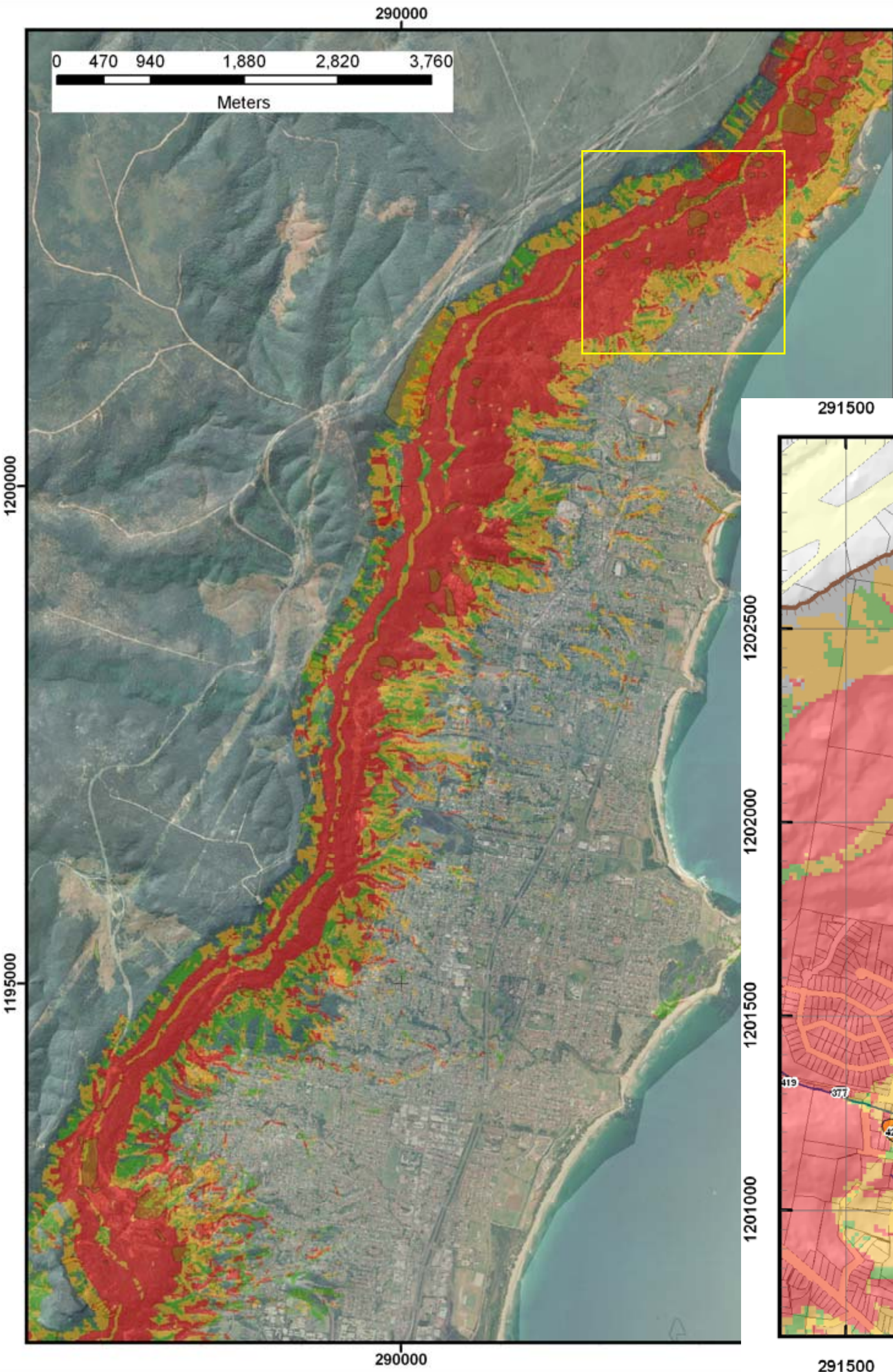


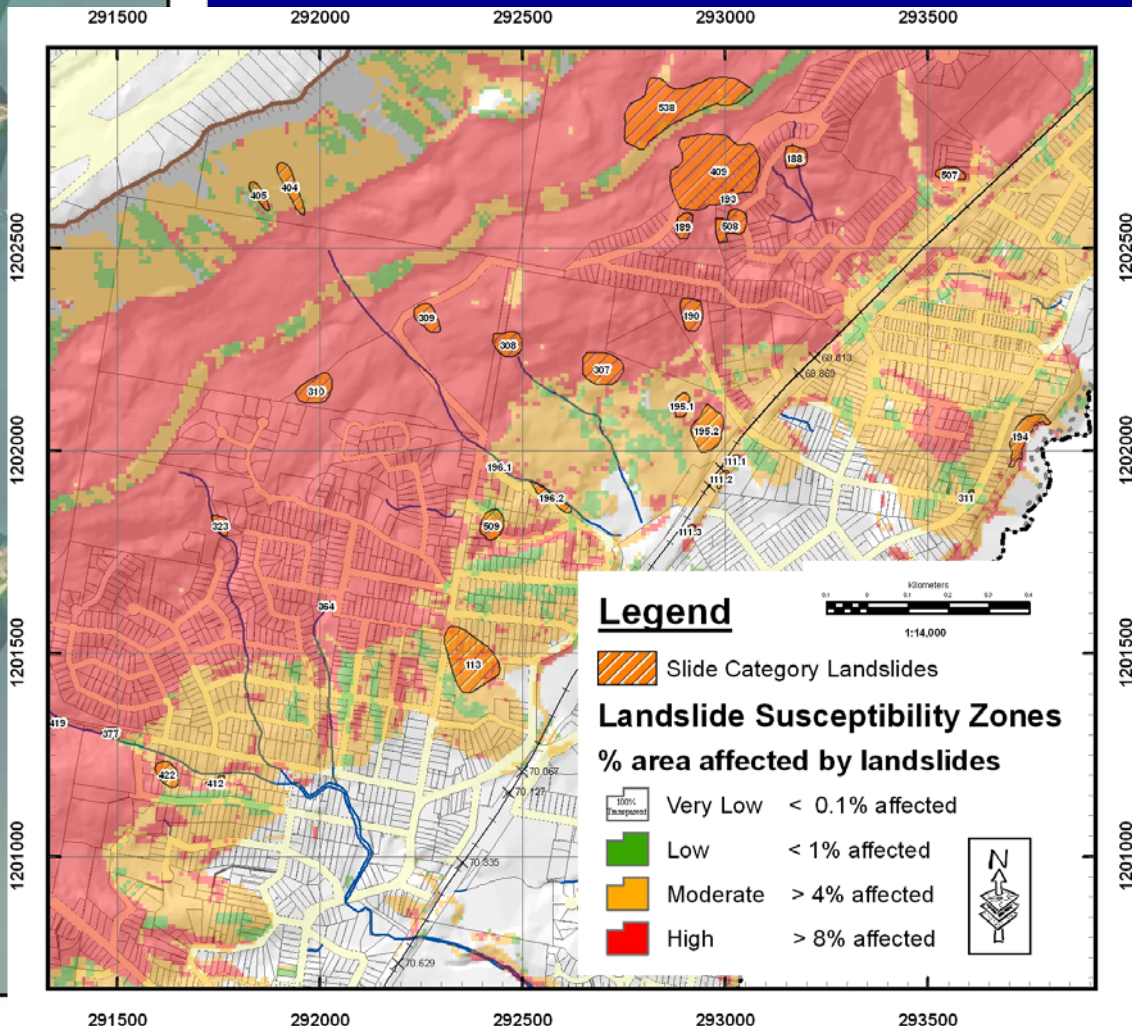
The resulting Susceptibility Grid



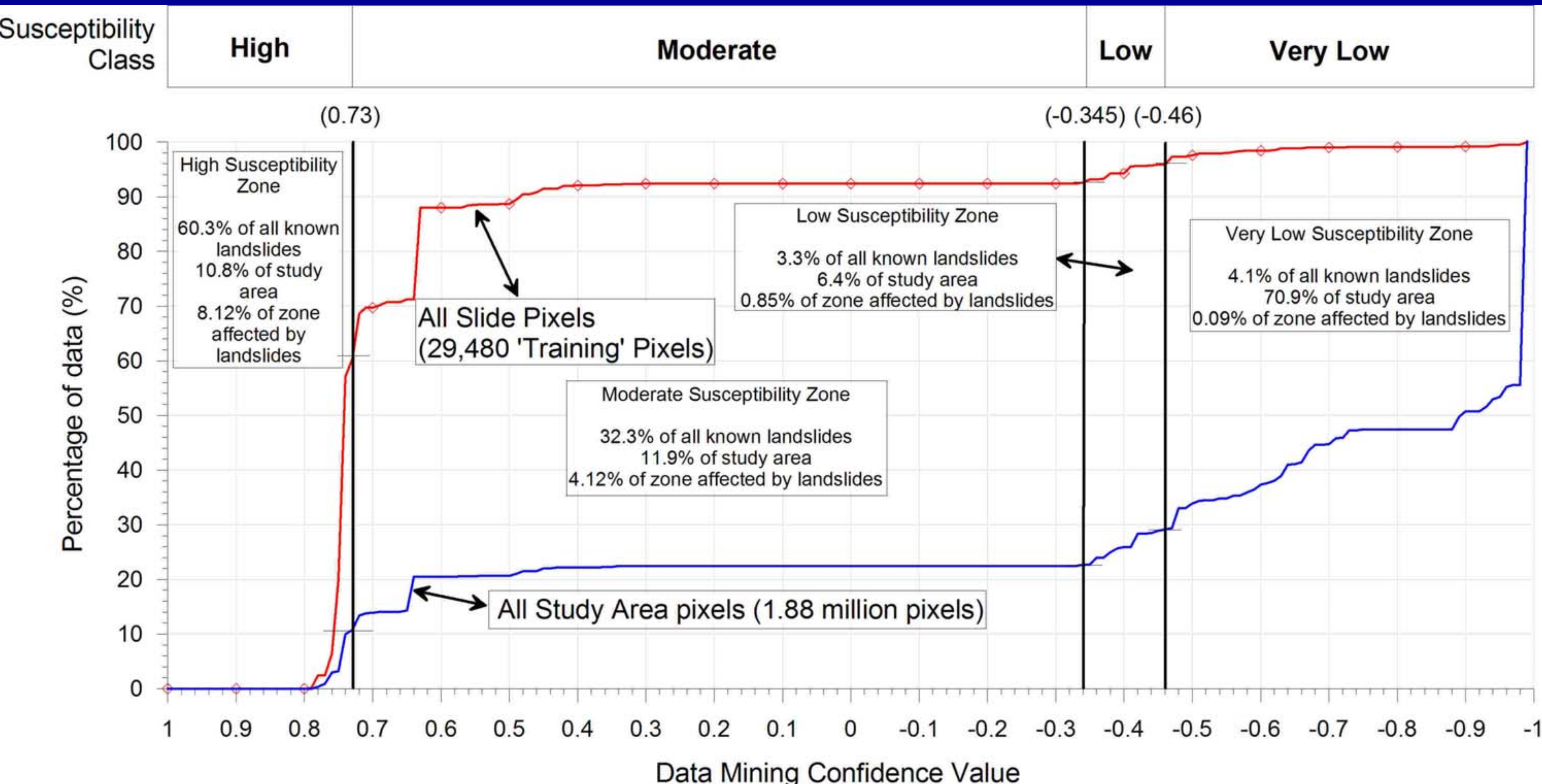
- Getting the ‘model’ is one step in this process
- But how do you categorize or differentiate ‘zones’ in this model
- Will these zones and stats be meaningful to compare to other ‘zones’ in adjacent regions, let alone elsewhere nationally and internationally ?
- If not, what’s the point ?

Susceptibility Zones





Post Modelling Analyses



Susceptibility Summary

Legend

Landslide Susceptibility Zones

Sus. Class - % area affected by slides

Very Low ~ 0.1% affected

Low < 1% affected

Moderate > 4% affected

High > 8% affected

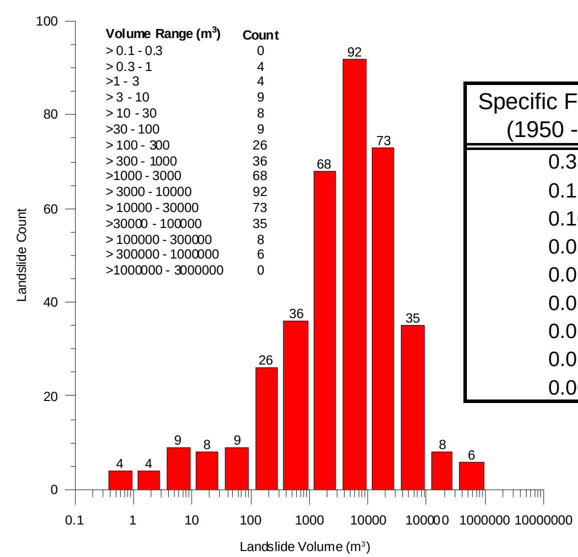
Statistics of Susceptibility Model Area (188 Square Kms)

Susceptibility Class	Map Colour	C5 Model Confidence Range	% of Susceptibility Class area affected by Slides	Susceptibility Class as % of Study Area	% of Total Slide Population in Susceptibility Class
Very Low		(min) -0.98 to -0.46	0.10	70.86	4.1
Low		> -0.46 to -0.345	0.85	6.47	3.7
Moderate		> -0.345 to 0.73	4.12	9.23	35.1
High		> 0.73 to 0.81 (max)	8.12	13.44	57.1

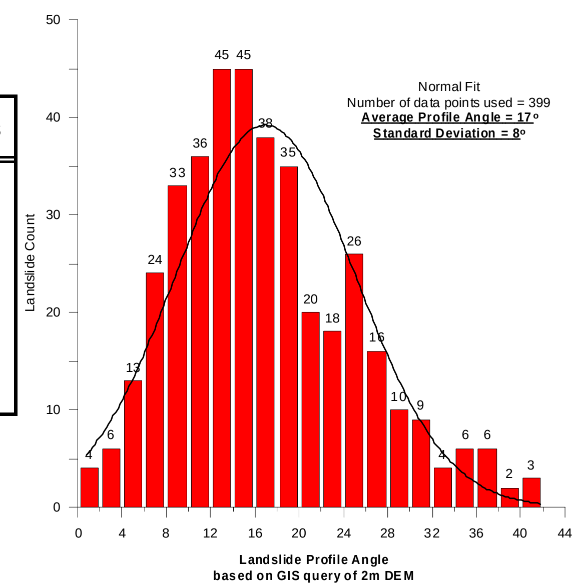
Regional Landslide Hazard

- Hazard - a condition with the potential to cause an undesirable consequence. Should also include location, volume, classification, velocity and probability
- Now that some reasonable ‘zones’ have been defined this all becomes entirely possible, particularly with the aid of the GIS.

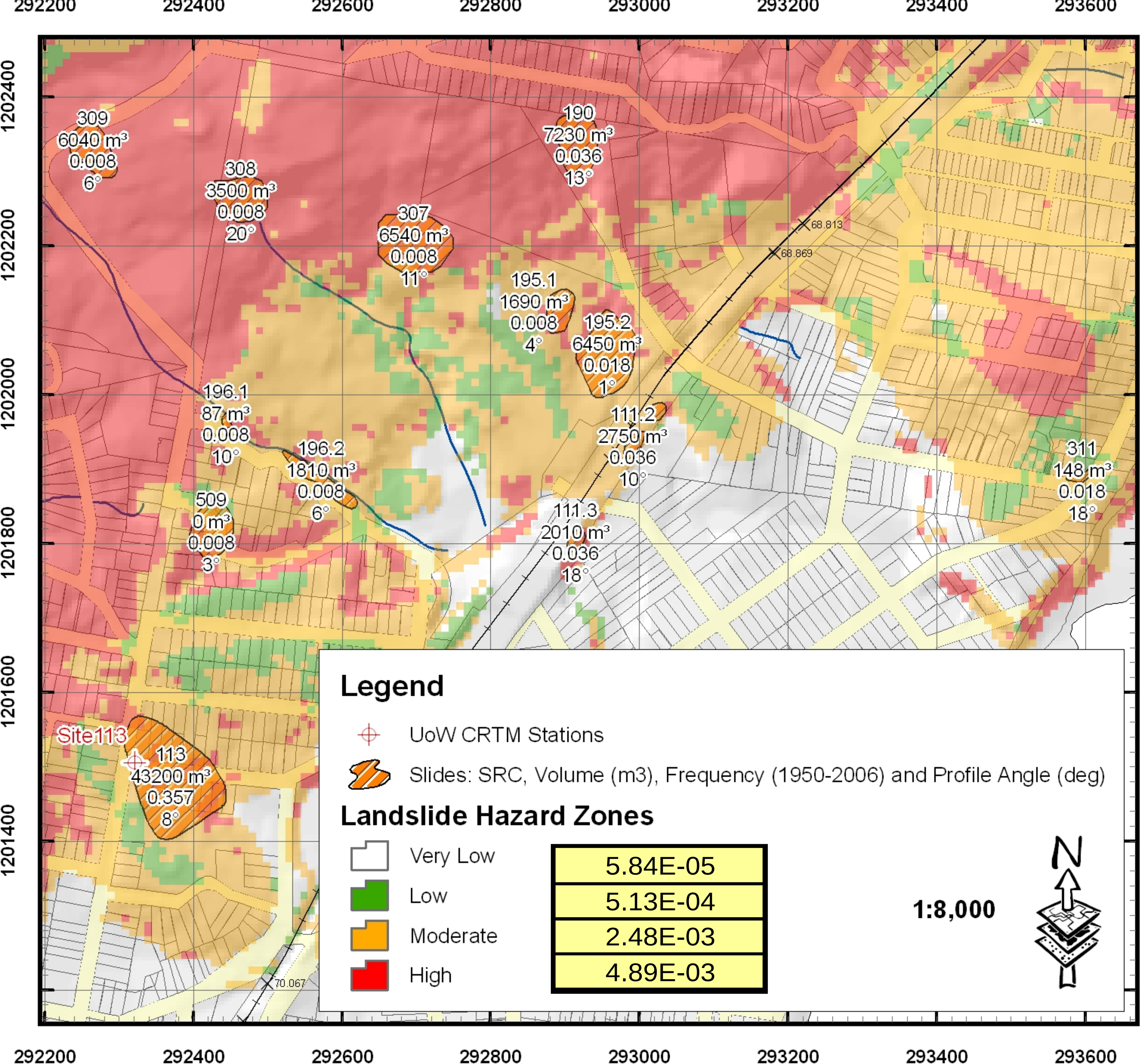
Hazard Description	Map Colour	% of Zone affected by Slides (S)	Zone area as % of Study Area (Sa)	% of Total Slide Population in Hazard Zone (Sp)	Landslide Annual Average Frequency (1950 - 2006)	Relative Susceptibility of Zone (S/Stotal) = Sr	Relative Annual Likelihood (Hazard) (Sr/T)	Maximum Landslide Volume (m³)	Average Landslide Volume (m³)	Weighted (volume) Hazard
Very Low		0.10	70.86	4.1	1.65E-02	7.36E-03	5.84E-05	36,300	3,500	5.20E-04
Low		0.85	6.47	3.7	1.72E-02	6.46E-02	5.13E-04	4,700	1,450	1.89E-03
Moderate		4.12	9.23	35.1	2.21E-02	3.12E-01	2.48E-03	45,000	5,700	3.59E-02
High		8.12	13.44	57.1	2.47E-02	6.16E-01	4.89E-03	720,000	28,700	3.56E-01

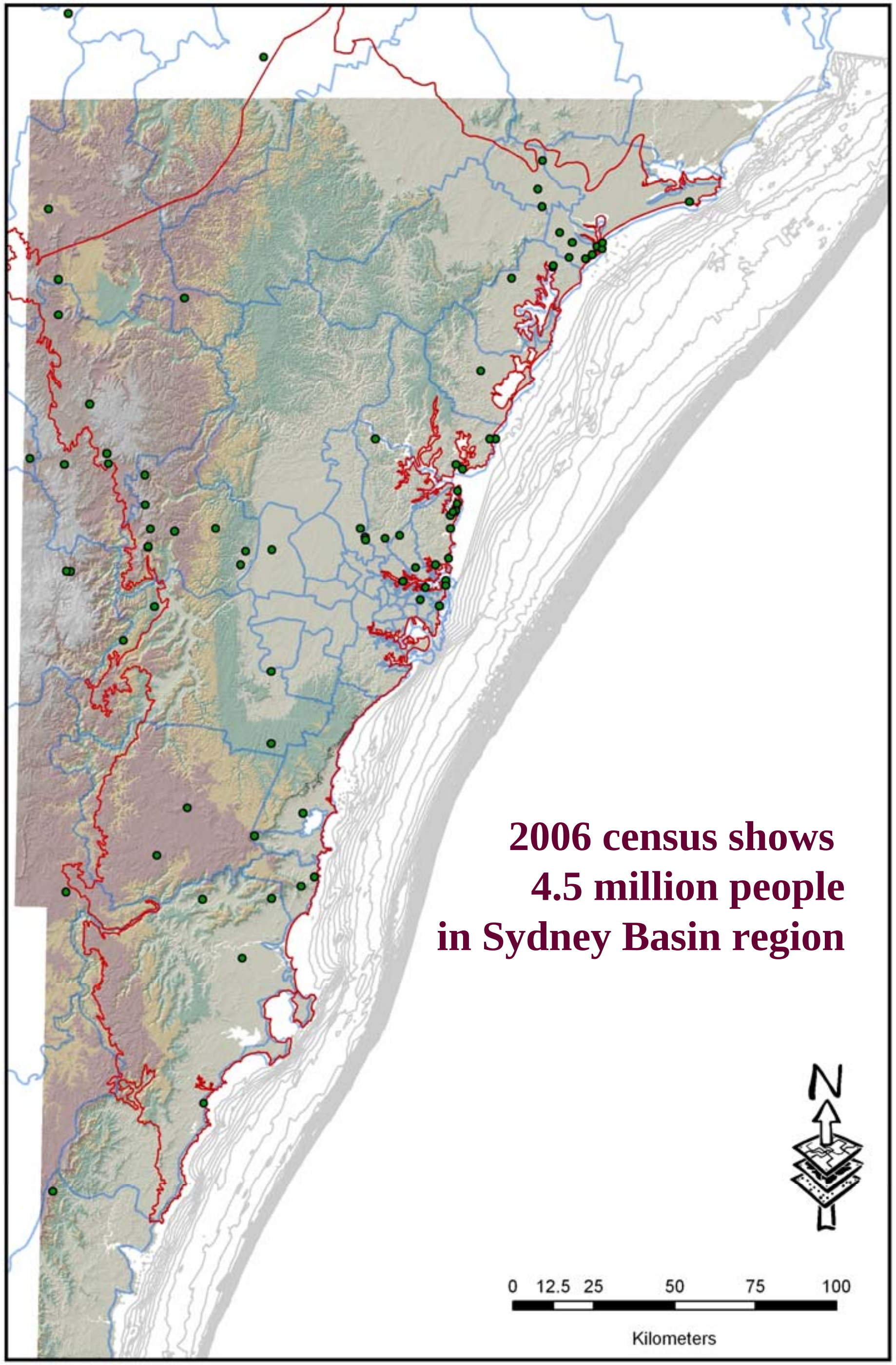


Specific Frequency (1950 - 2006)	# of events per site	# of sites
0.357	20	1
0.125	7	7
0.107	6	7
0.089	5	2
0.071	4	10
0.054	3	25
0.036	2	42
0.018	1	137
0.008	0.5	249



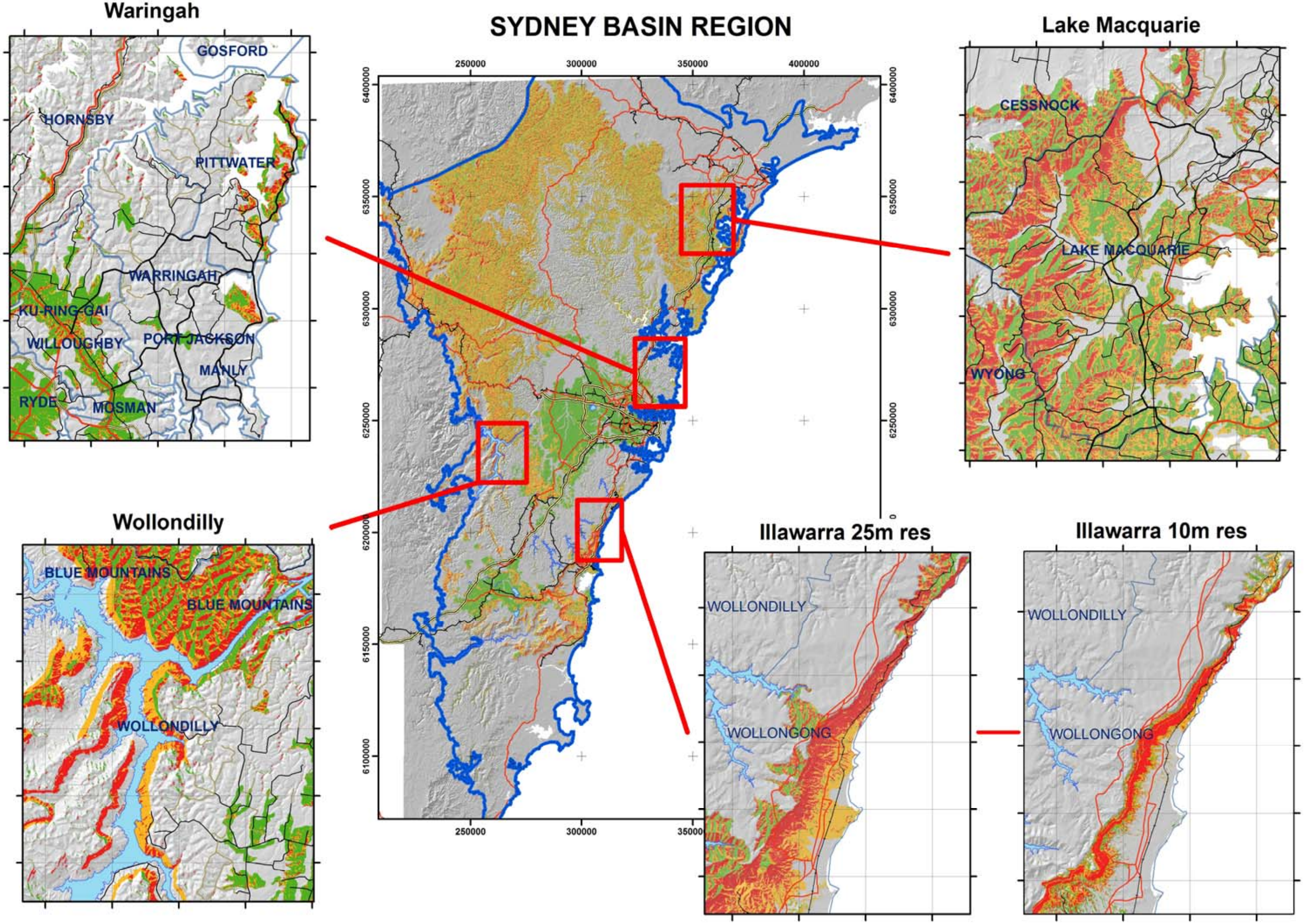
Landslide Hazard Zoning





Extent of UoW Sydney Basin Landslide Inventory

- UoW Landslide Inventory – 586 landslides
- GA - National Landslide database within Sydney Basin excluding the Illawarra – 130
- Total 716 landslides
- Vegetation mapping at least 500 +
- Pittwater LGA also has 220 landslides + SCCG etc collaboration may add more



SYDNEY BASIN REGION
Waringah
GOSFORD
HORNSBY
PITTWATER
WARRINGAH
KU-RING-GAI
WILLOUGHBY
PORT JACKSON
MANLY
RYDE
MOSMAN
Lake Macquarie
CESSNOCK
LAKE MACQUARIE
WYONG
Wollondilly
BLUE MOUNTAINS
BLUE MOUNTAINS
WOLLONDILLY
Illawarra 25m res
WOLLONDILLY
WOLLONGONG
Illawarra 10m res
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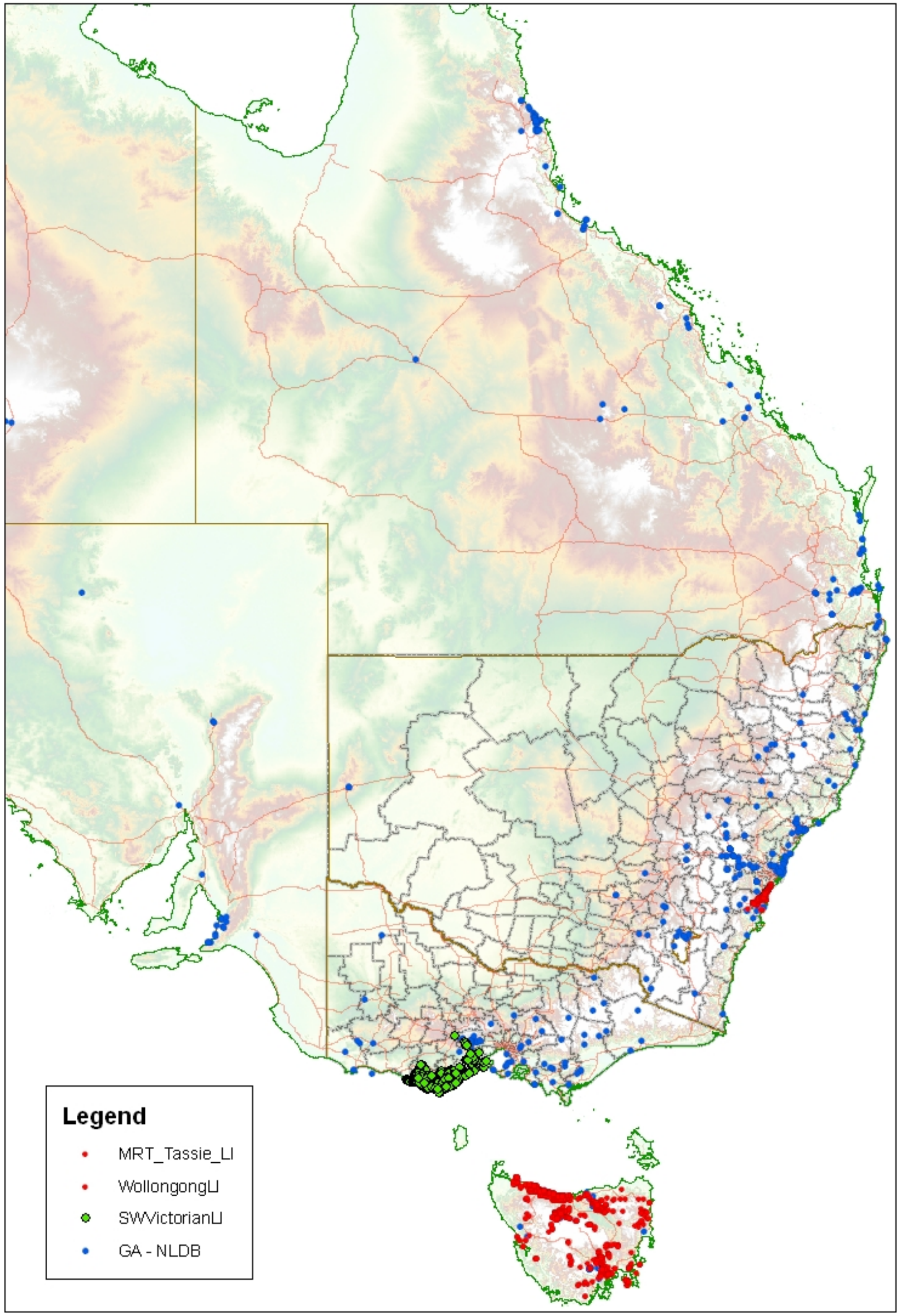

UoW composite National Landslide Inventory

MRT 1584 landslides
SW Victorian 1924 + landslides
GA's 'Australian LI' 492 landslides
Wollongong UoW LI 586
Warragamba Area 158
20 from S. Greene PhD in SA
& hopefully 'Pittwater Council 223'
& possibly even others from wider SCCG

~ roughly 4987 landslides nationally that we know about
~ 4700 are on the eastern seaboard and Tasmania

Doesn't include many in Camden Picton Area, Alpine Regions, Parwan Valley and Shire of Yarra Ranges in Victoria etc

Recent geomorphic photo interpretation in SW Victoria has identified almost 10,000 areas of instability

Conclusions

- The base Landslide Inventory data is the essential first step in this type of work and its compilation requires sound and thorough engineering geological mapping – there is no substitute for this ! Repeat, no substitute!
- ONLY if the LI is comprehensive is this type of modeling possible
- Knowledge based Data Mining is a sound functional technique to aid development of landslide Susceptibility and Hazard zoning.
- Proven for high resolution, large, regional – perhaps even Australia wide applications
- GIS techniques are only a tool to aid balanced decision making