Landslide Monitoring and Frequency – Towards real-time Landslide Risk Management

Morrison Avenue, Austinmer, May 1975

University of Wollongong

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Collaborative Research
at the University of Wollongong

Industry Partners

- Wollongong City Council
- Roads and Traffic Authority
- Rail Infrastructure Corporation

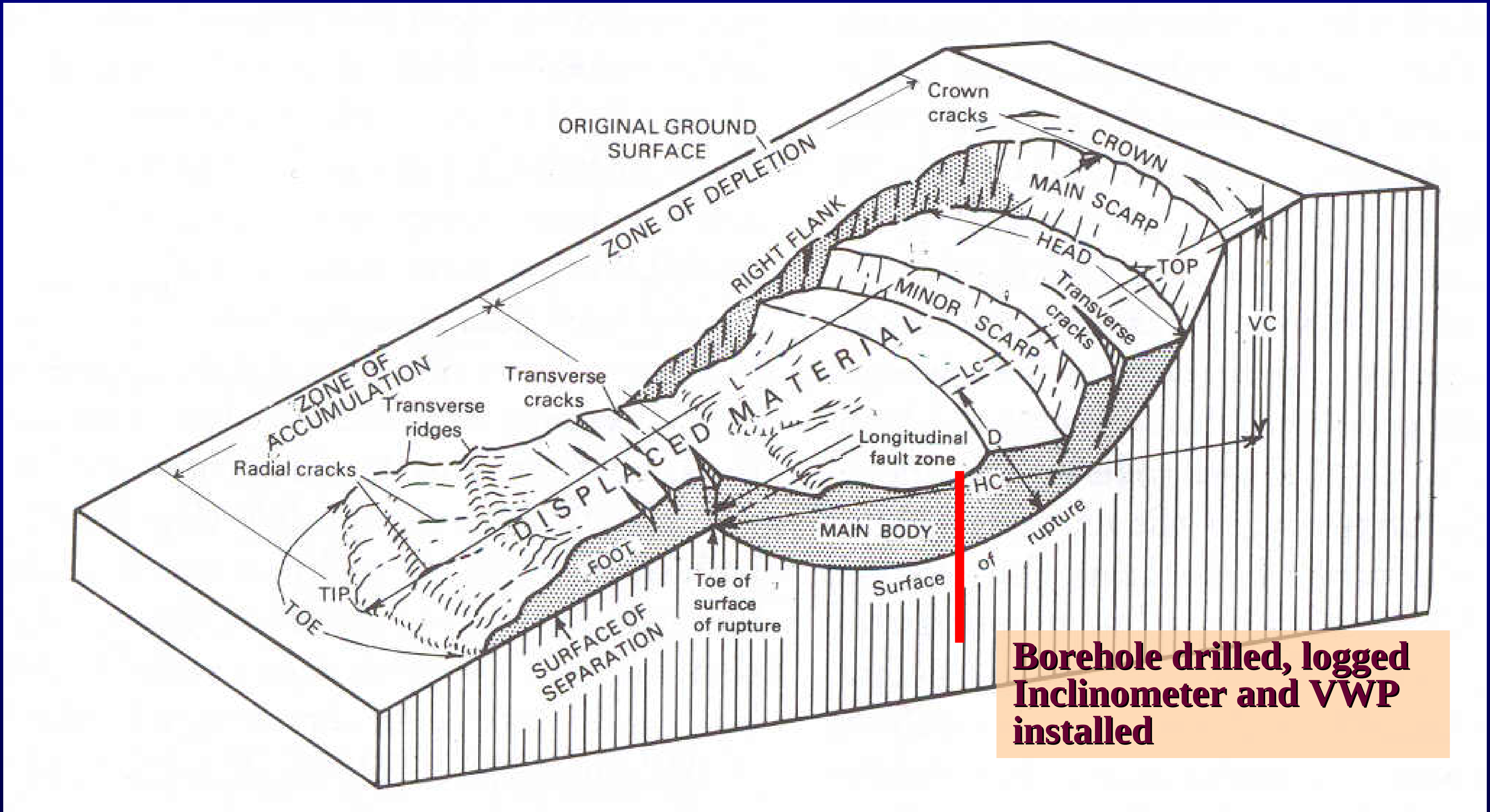
Outline of this Presentation

33 slides

- **Landslides 101**
- **Traditional means of landslide monitoring (WHY)**
- **Risk Management of landslides (WHY - frequency)**
- **Continuous Real Time Monitoring (CRTM - HOW)**
- **Network of Field Stations (WHERE)**
- **Continuous landslide data (WHEN and WHY)**
- **Web-based interface and on-line databases (HOW)**
- **Summary and Conclusions, Future directions**

Landslides 101

- A landslide is defined simply as "The movement of a mass of rock, earth or debris down a slope" Cruden 1991



Landslides 101 - 2

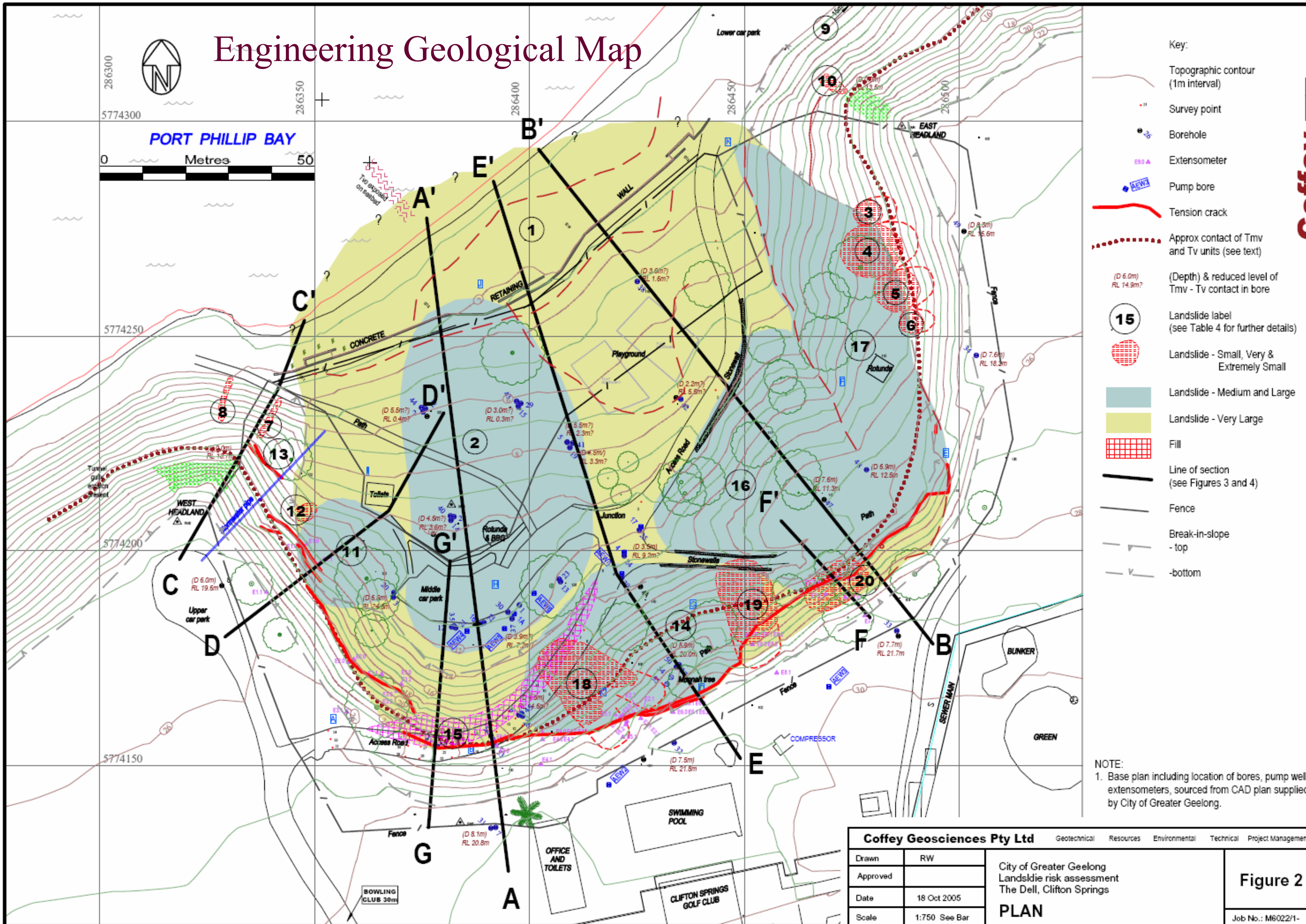
- So, when the landslide happens you are faced with many issues…
- Damage and its consequences
- Extent
- Depth
- Volume
- Trigger
- Remediation

- … in fact, the whole suite of Risk Management issues, and if you are working from a regional management perspective, there may be 150 landslides happening….
- So, before the event, preparedness is essential and that is what CRTM is all about

Traditional Landslide Investigations and Monitoring

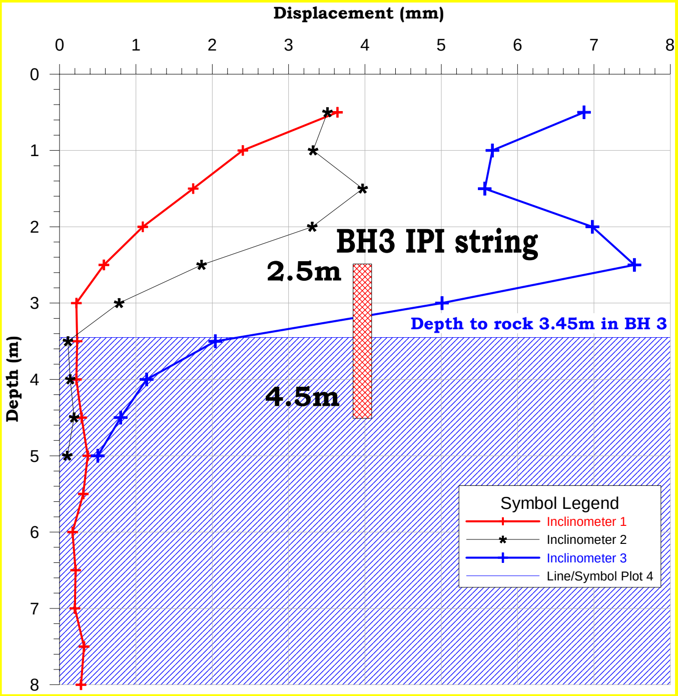
- **Engineering Geological Investigations**
  - **Surface Mapping of geomorphological features**
  - **Subsurface Investigations**
    - **Drilling**
    - **Test Pitting**
    - **Installation of Instruments (Surface/Subsurface)**
    - **Sampling**
  - **Monitoring**
    - **Ground Survey – map features and repeat survey of peg array for movement vectors**
    - **Inclinometer and VWP**
    - **Rainfall**

Engineering Geological Map



Subsurface Investigation

Borehole / Test Pit	Surface RL	Inclinometer / Piezometer	Cored / Augered	Depth of Hole (m)	Depth to Bedrock (m)	Bottom Inclinometer Reading	Depth to Piezometer tip	Intake interval (m)
1	37.77	I	C	8.43	2.5	8	-	-
1A	37.77	P	A	8.35	-	-	4.75	4.14 - 5.1
2	27.94	I	C	5.55	3.15	5	-	-
2A	27.94	P	A	3.4	-	-	2.7	2.2 - 3.4
3	44.75	I	C	7	3.45	5	-	-
3A	44.75	P	A	3.88	-	-	3.48	2.9 - 3.88
4	58.79	P	C	15.95	11.65	-	10	9-16
TP 1	43.98	-	-	3.2	-	-	-	-
TP 2	28.03	-	-	3.4	3.15	-	-	-



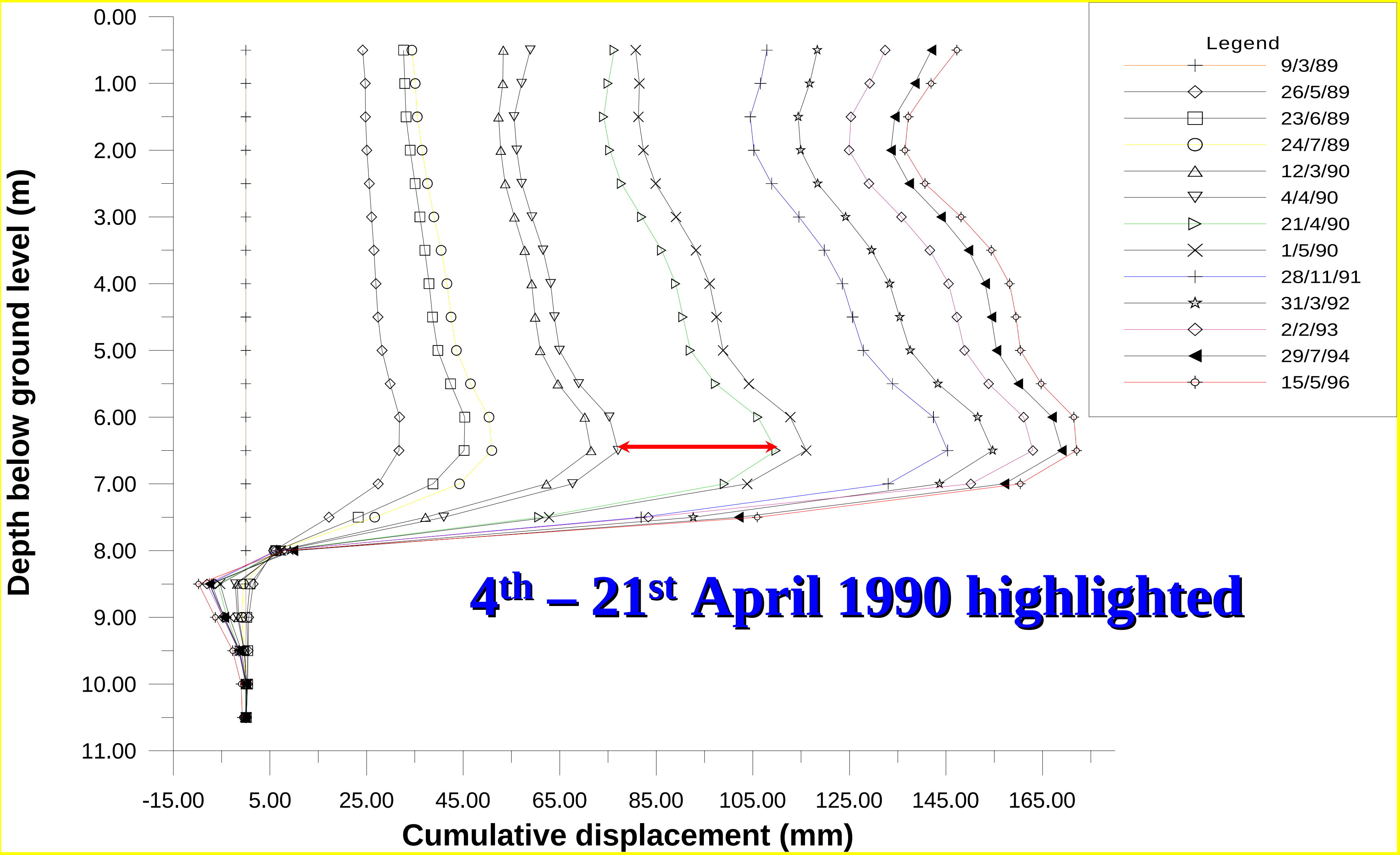
Inclinometer Monitoring

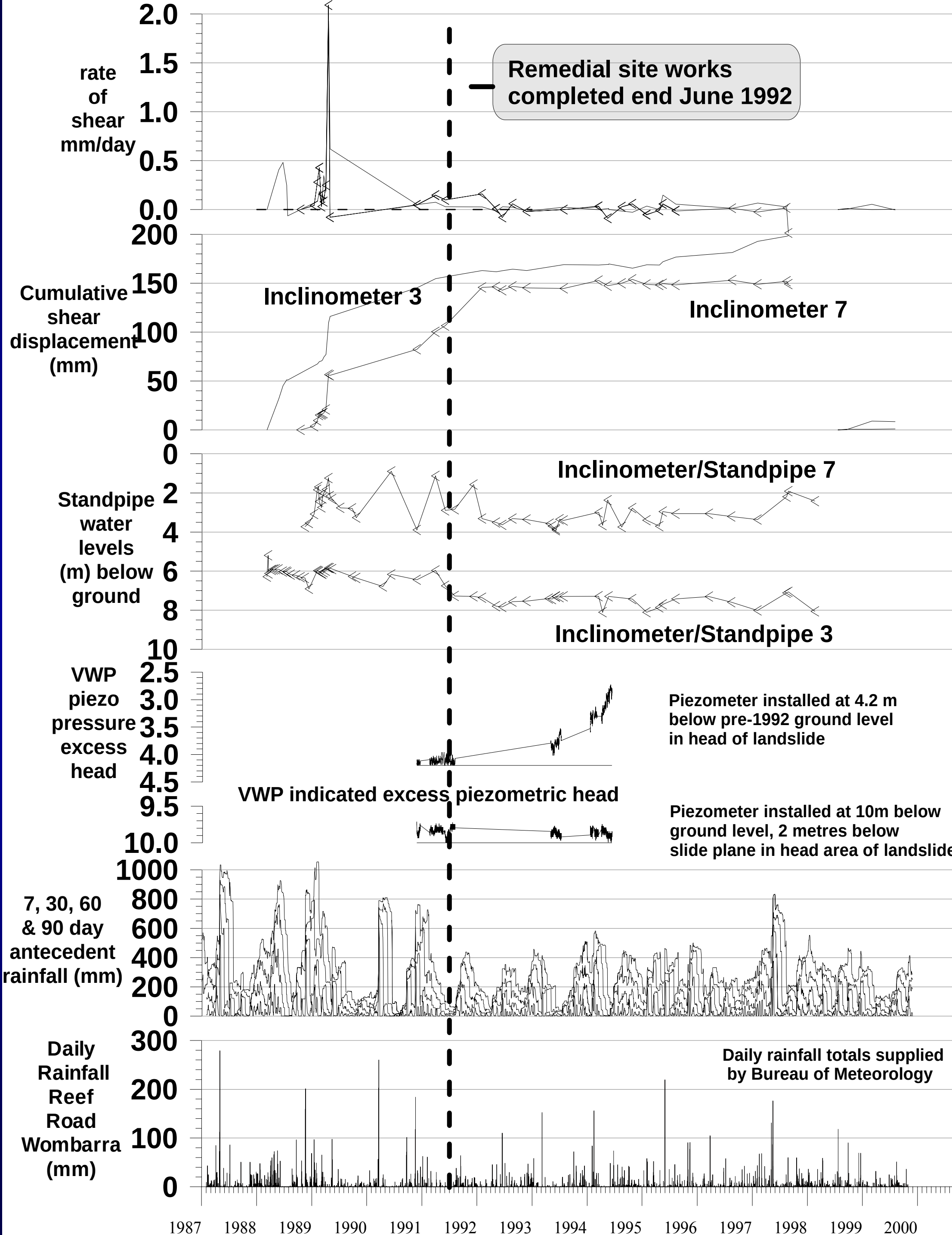
- Consist of casing grouted into borehole, and inclinometer probe to record profile along casing (typically installed vertically)
- Used primarily to measure the depth to and style of subsurface shear movement
- With time, they continue to record this but they also record the rate of movement
- We have and continue to monitor 25 inclinometers across the city, some periodically, but some continuously

11 10 2001

Site 64 - Borehole 3 - Inclinometer profiles

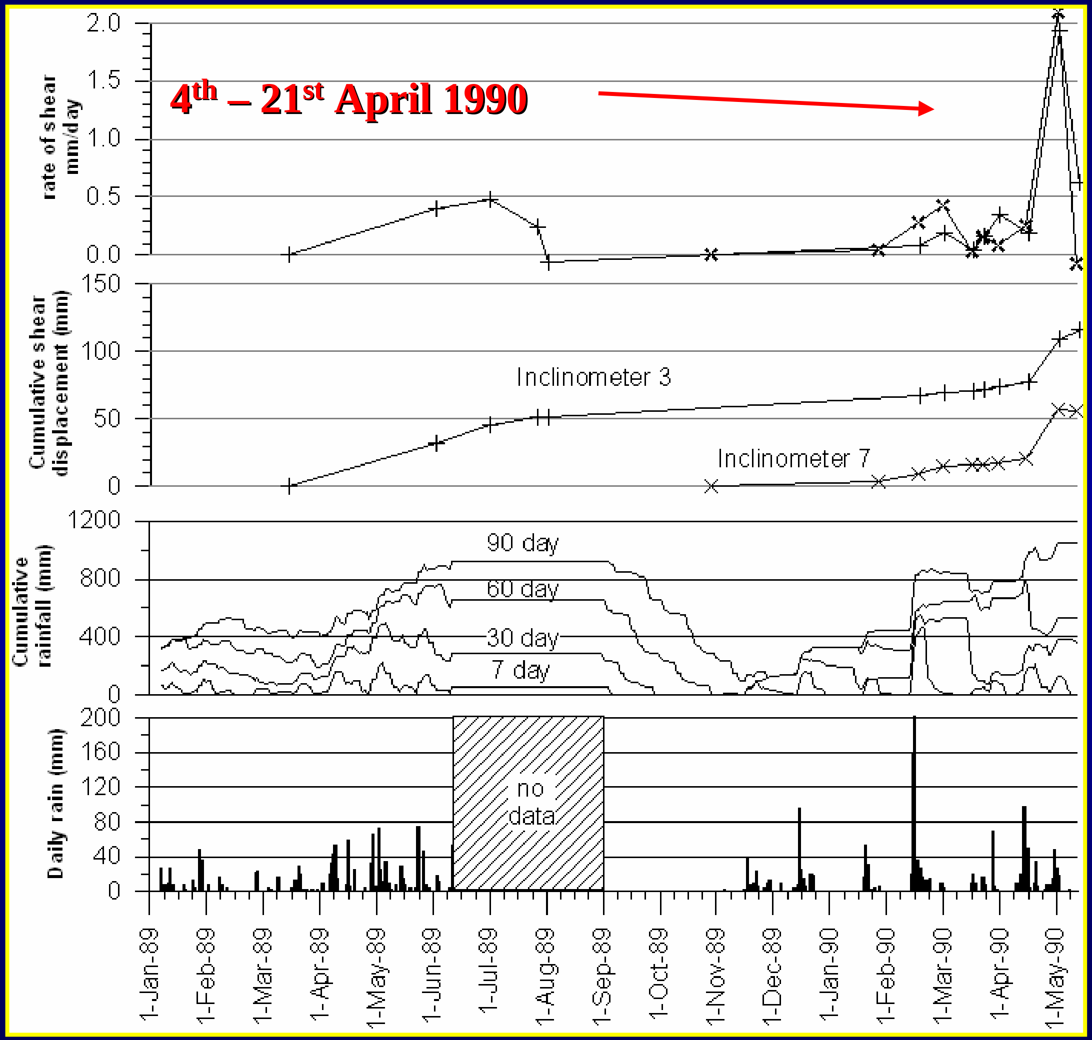
Graph covers 8 year period





Site 64 Scarborough

…Site 64 continued…



- Clear Acceleration of landslide shear during period 4-21st April 1990
- Graph covers 17 month period with only 15 data points relating to landslide movement

Risk Management issues

- **Instrumentation is essential, of that there is no doubt**
- **Timely supply of data is also essential**
- **Typically with inclinometers, vwp, extensometers etc the data is used for modelling after the event, in the design of remedial works and associated back analyses**
- **Re-active (after the event) and data arrives hours, weeks and even months after the event! At one desk, and the cost!**
- **Clearly then, for Emergency Risk Management, and Asset Management during our high and extreme rainfall events such monitoring is not particularly usefull – not an EWS**

Risk Management issues, continued

- **Landslide frequency (inclo rate) (used as an indicator of the probability of a landslide occurring) is an essential component in assessing Landslide Hazard**
- **Landslide Hazard is, in turn, one component of assessing Landslide Risk**

Risk = Hazard × Consequences

- **We have devoted a considerable amount of effort into considering methods of calculating landslide frequency**
  - **Landslide Inventory**
  - **Manual Inclinometer Monitoring**
  - **Return period of triggering agent (rainfall, as its more accessible than PWP)**
  - **and now CRTM**

Landslide Frequency/Likelihood/Probability

COMPARISON OF QRA MATRIX - LEVELS OF RISK TO PROPERTY 9-Feb-06

Post Taskforce Version 3
Assumes Consequence Cost is TOTAL COST
including consequential costs

(Consequence based on Rob Fell comments at indicative values + Tony Phillips
Likelihood steps at 5 times based on AGS (2000)
risk levels revised as per RF commnet on probability and the home owner risk aversion plus consideration of de Ambrosis & Mostyn (2004)

CONSEQUENCES (Total Cost as percentage of Market Value = $1,000,000)

LIKELIHOOD (pa)	Indicative Value	Notional Boundary	1: CATASTROPHIC		2: MAJOR		3: MEDIUM		4: MINOR		5: INSIGNIFICANT			
			200%	100% $1,000,000	60%	40% $400,000	20%	10% $100,000	5%	1.0% $10,000	0.5%	0.1% $1,000	0.05% Note 1	0.01% $100
		1		1.0E+00		4.0E-01		1.0E-01		1.0E-02				1.0E-04
A: ALMOST CERTAIN	1.E-01		VH 2.0E-01 $200,000		VH 6.E-02 $60,000		VH 2.E-02 $20,000		H 5.E-03 $5,000		M 5.E-04 $500		L 5.E-05 $50	
		5.E-02		5.0E-02		2.0E-02		5.0E-03		5.0E-04				5.0E-06
B: LIKELY	1.E-02		VH 2.0E-02 $20,000		VH 6.E-03 $6,000		H 2.E-03 $2,000		H 5.E-04 $500		L 5.E-05 $50			
		5.E-03		5.0E-03		2.0E-03		5.0E-04		5.0E-05				5.0E-07
C: POSSIBLE	1.E-03		VH 2.0E-03 $2,000		H 6.E-04 $600		M 2.E-04 $200		M 5.E-05 $50		VL 5.E-06 $5			
		5.E-04		5.0E-04		2.0E-04		5.0E-05		5.0E-06				5.0E-08
D: UNLIKELY	1.E-04		H 2.0E-04 $200		M 6.E-05 $60		L 2.E-05 $20		L 5.E-06 $5		VL 5.E-07 $1			
		5.E-05		5.0E-05		2.0E-05		5.0E-06		5.0E-07				5.0E-09
E: RARE	1.E-05		M 2.0E-05 $20		L 6.E-06 $6		L 2.E-06 $2		VL 5.E-07 $1		VL 5.E-08 $0			
		5.E-06		5.0E-06		2.0E-06		5.0E-07		5.0E-08				5.0E-10
F: BARELY CREDIBLE	1.E-06		L ≤ 2.0E-06 $2		VL 6.E-07 $1		VL 2.E-07 $0		VL 5.E-08 $0		VL 5.E-09 $0			

Implied Probability of Landslide within nominated Design Life

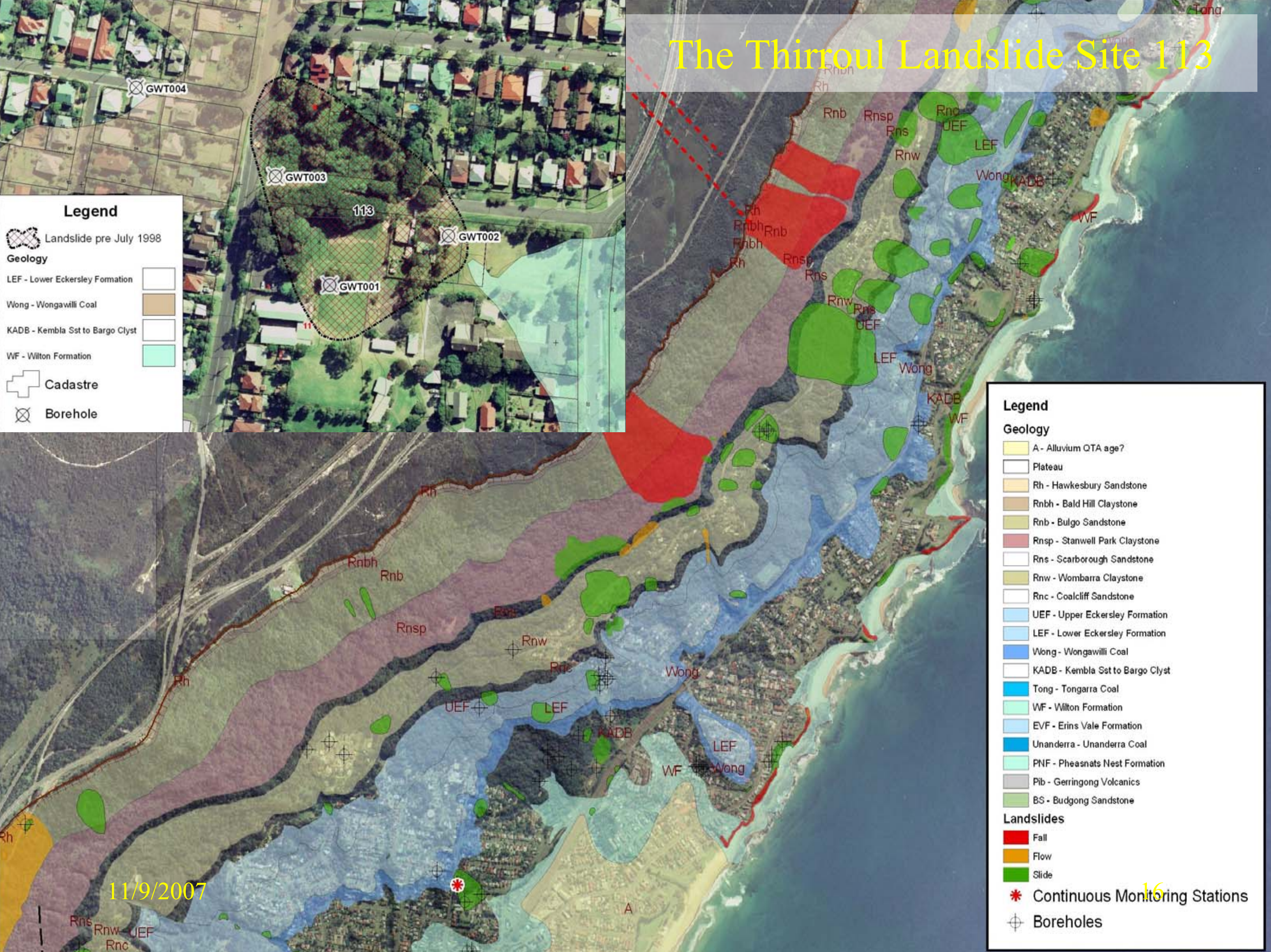
DESIGN LIFE (Years)	20	50	100
	100%	100%	100%
A	1 in 1 **88%**	1 in 1 **99%**	1in1 **100%**
	64%	92%	99%
B	1in 6 **18%**	1 in 2.5 **39%**	1 in 1.5 **63%**
	10%	22%	39%
C	1 in 50 **2.0%**	1 in 20 **4.9%**	1 in 10 **9.5%**
	1.0%	2.5%	4.9%
D	1 in 500 **0.2%**	1 in 200 **0.5%**	1 in 100 **1.0%**
	0.1%	0.2%	0.5%
E	1in 5000 **0.02%**	1 in 2000 **0.05%**	1 in 1000 **0.10%**
	0.0%	0.0%	0.0%
F	**0.00%**	**0.00%**	**0.01%**

Showing indicative annualised cost based on Market Value

Note 1 Cell A5 is partitioned at a Consequence value of 0.2% , does not apply to rows below A

Risk Levels	Indicative Annualised Cost		Upper Bound Annualised Cost	Risk Cell	Risk Evaluation	
VH	$2,000 to	$200,000 >	$1,000,000	A1	UNACCEPTABLE	
H	$200	$5,000	$100,000	A4	UNACCEPTABLE	
M	$20	$500	$10,000	A5	TOLERABLE	for existing structures, but treatment to reduce risk to L should be identified and implimented as soon as practicable
L	$2	$50	$1,000	A5 (1)	ACCEPTABLE	for new slopes/works,
VL	≤	$5	$50	C5	ACCEPTABLE	for new slopes/works,

The Thirroul Landslide Site 113



Thirroul Landslide Reported and recently monitored History

Date	Historical Movement	Estimated amount of movement (m)
March - April, 1950	Portion of the Primary School (two classrooms, library, sewing room and basement rooms) damaged by landslip. Asphalt assembly area also damaged. Retaining walls damaged.	0.4
February, 1956 September, 1956	Further movement of area where building demolished. Steps to Infants school from Primary School damaged. Retaining walls severely affected by this date.	0.1
October, 1959 11th November, 1959	Serious movement of slide area. Local residents first noticed movement, at number 70, then at other houses	0.6
September, 1960 December, 1960	Cracks developed in asphalt area. Ground-water seepage across Infants playground. Subsidence reported to have damaged steps and playground.	0.1
March, 1961 20th November, 1961 17th December, 1961	Slip on site of new building caused its resiting. Further slippage of steps at northeastern corner of building. Subsidence of playground and breakage of drain pipes. Slip at back of teacher's residence continued into playground. Drops of several centimetres just below absorption pit. Further lean of retaining walls. Back room of school residence affected.	0.1
7th March, 1962	Slip occurred below absorption pit.	> 0.1
21st March, 1963 10th April, 1963	Movement of trees and incinerator. Movement occurred during work. Path across slip area failed. Two springs developed on western side of access road to Roxborough Avenue. Spring on paths near toilets.	0.1
13th August, 1964	Subsidence in Infants playground. Gratings above sumps were above dish-drain level.	0.1
1972	Number 27, Seafoam Avenue (south side) abandoned (Bowman, 1972. Plate 7, Figure 2)	0.2
1988 & 1989	Wollongong City Council reports development of tension cracks and pavement subsidence (possibly up to 10cm) in Phillip Street	0.1
20th August, 1998 29 October 1998	1mm-2mm cracks in bitumen pavement along headscarp following major August 17th rainfall Site Monitoring of UoW instruments by Coffey's - movement detected	0.01 >0.01
27 October 1999 30th October 1999	Site Monitoring of UoW instruments by Coffey's - movement detected Tension cracks noted on 20 Aug 1998 have widened and extended, now 2-3mm	>0.01 0.01
24 March 2000 8 November 2000	Site Monitoring of UoW instruments by Coffey's - movement detected Site Monitoring of UoW instruments by Coffey's - movement detected	0.04 0.04
March 23, 2003 May 27, 2003 July 25, 2003 December 27, 2003	Continuous Real-Time Monitoring station installed - downslope movement detected in May CRTM and manual monitoring of UoW instruments by Coffey's - movement detected CRTM monitoring detects movement over 10 days CRTM monitoring detects movement over several days	0.04 >0.01 >0.01 >0.01
January 1, 2004	CRTM monitoring detects movement throughout January 2004	>0.01
(yellow)	yellow is an extremely slow velocity - WP/WLI 1995, Cruden and Varnes 1996	
(orange)	orange is a slow velocity	
(red)	red is a slow to moderate velocity	

Likelihood Assessment based on the observational approach

- Site 113 has moved 27 times in 16 years between March 1950 and February 2004 – 54 years
- Annual frequency:
  54 year period, movement in 16 years = 0.3
- Annual Event frequency:
  54 year period, 27 events = 0.5
- Frequency of movement ≥ 0.1m (9 times) = 0.17
- 0.5 to 0.17 range - Almost Certain (QRA Matrix)
- Frequency of movement ≥ 0.4m (twice) = 0.04
- Likely Range (QRA Matrix)

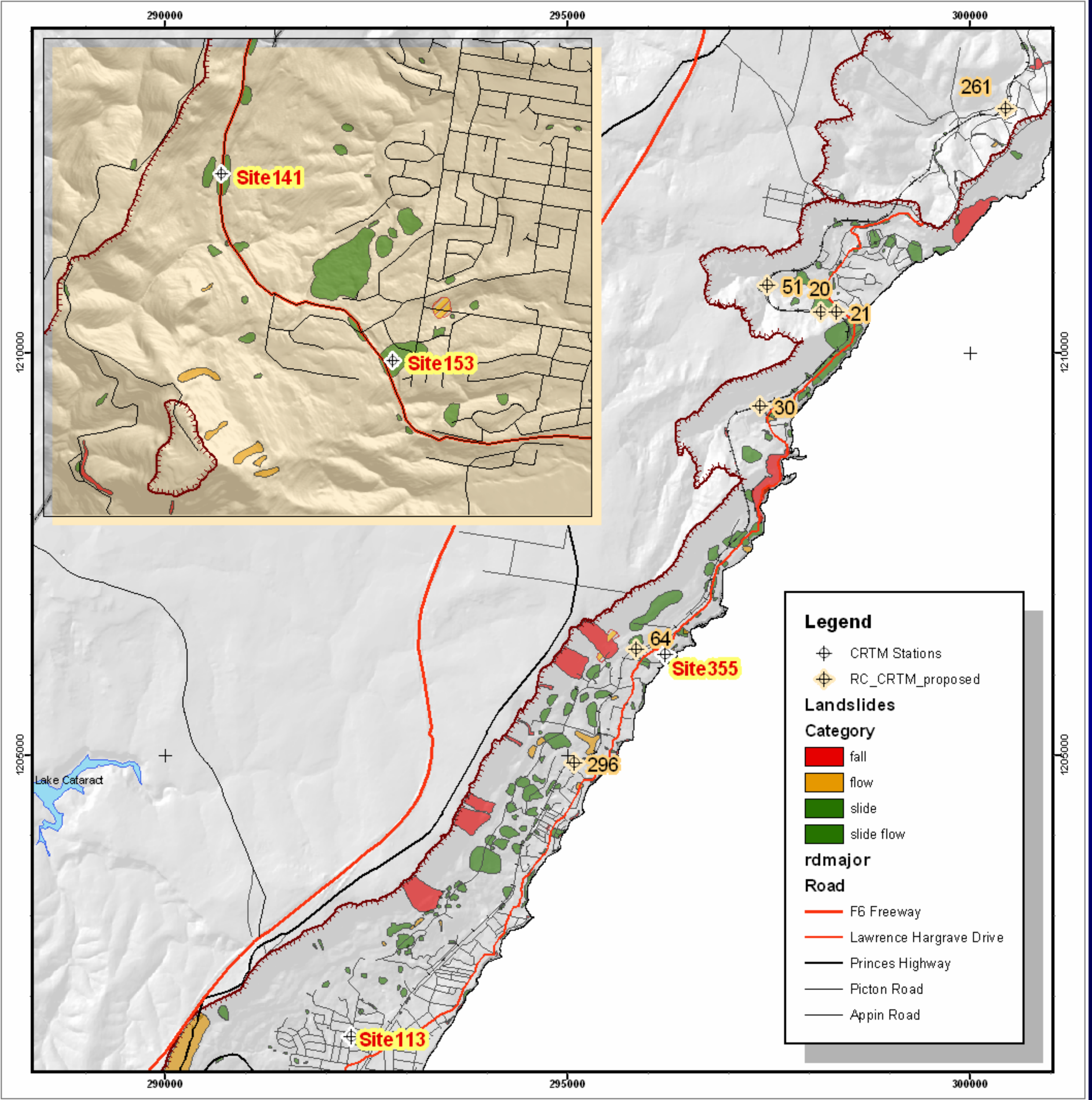
Review of Outline

- Landslides 101
- Traditional means of landslide monitoring (WHY)
- Risk Management of landslides (WHY - frequency)
- **Continuous Real Time Monitoring (CRTM - HOW)**
- **Network of Field Stations (WHERE)**
- **Continuous landslide data (WHEN and WHY)**
- **Web-based interface and on-line databases (HOW)**
- **Future directions**

Continuous Real-Time Monitoring CRTM

- 5 existing stations
  - 2 initial UoW-WCC in 2003
  - 2 RTA on Mount Ousley Road in 2004
  - 1 site in Victoria near Geelong
- Web-based interface operational for over 12 months
- 1 site at a large troublesome urban landslide site in Hobart in collaboration with MRT to be announced shortly
- 14 proposed with RailCorp in 2005(?) - 2008

Existing and proposed Wollongong CRTM locations



Taroona Landslide – Hobart
Collaboration with Mineral Resources Tasmania will see the location of the 6th CRTM field Station later this year

Instrumentation Used

- In Place Inclinometers (IPI – shear displacement)
- Vibrating wire piezometers (pore water pressure)
- Pluviometer (rainfall 0.2mm buckets)
- Extensometers (Geelong)
- Any instrument with a digital output
  - Catch fences
  - TDR
  - Camera etc
- CR10X Data logger and driver software
- Battery, Solar Charging, Digital mobile phone
- Data logged hourly

Monitoring equipment

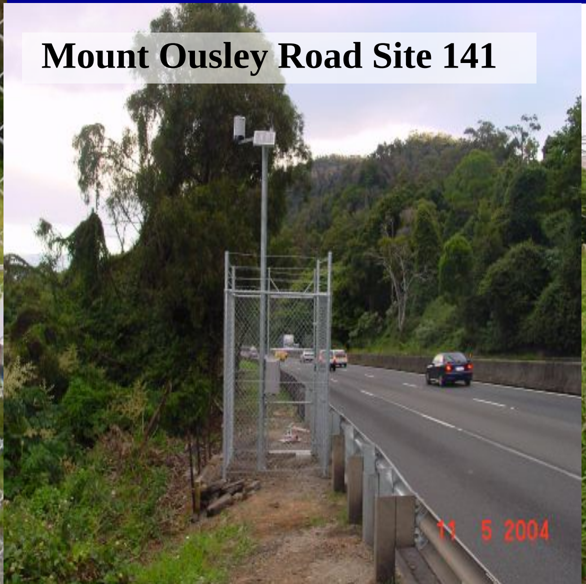

Pluviometer Internal


In Place Inclinometer ready to install


Manual inclinometer monitoring

VW Piezometers

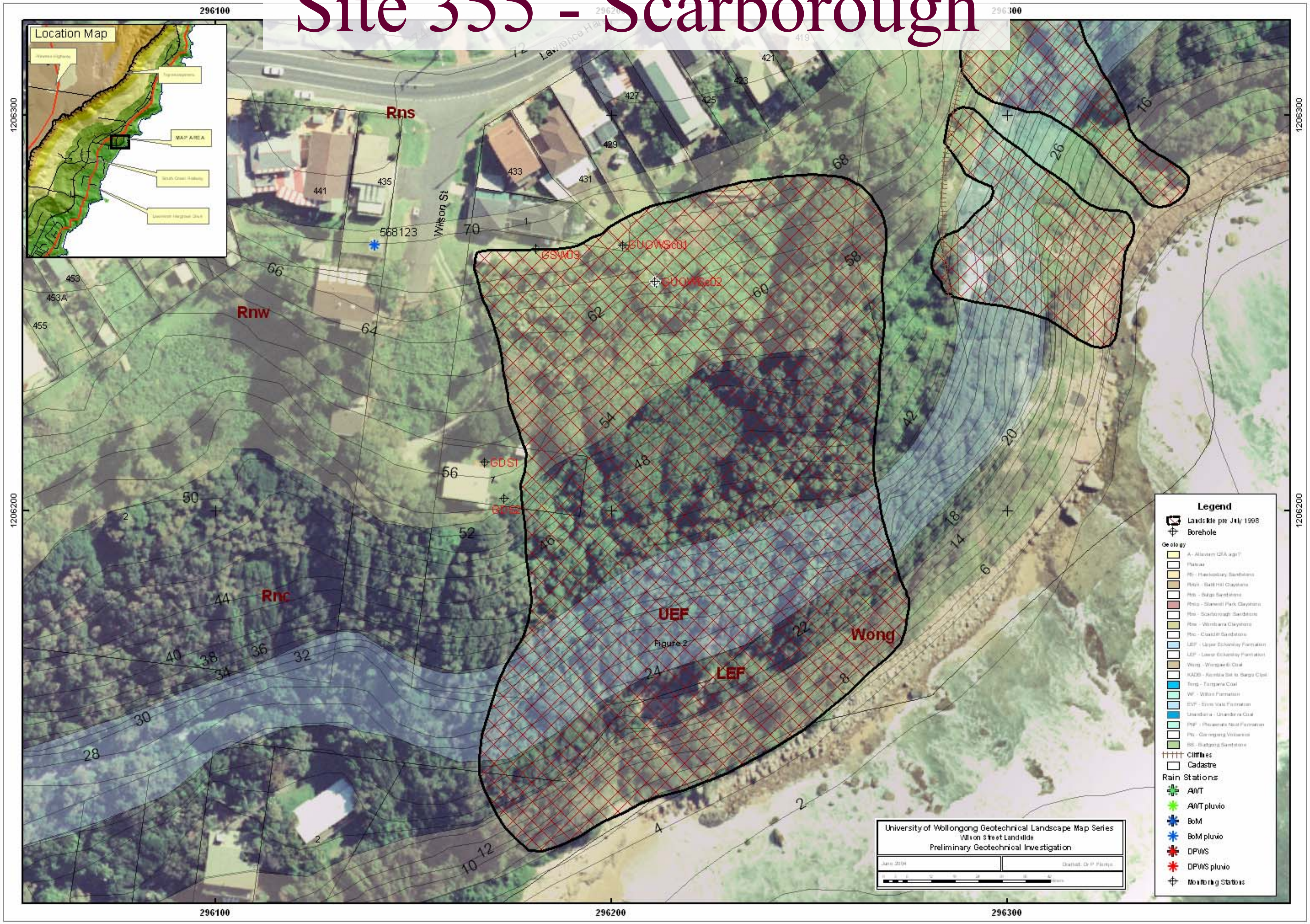

Field Control Box



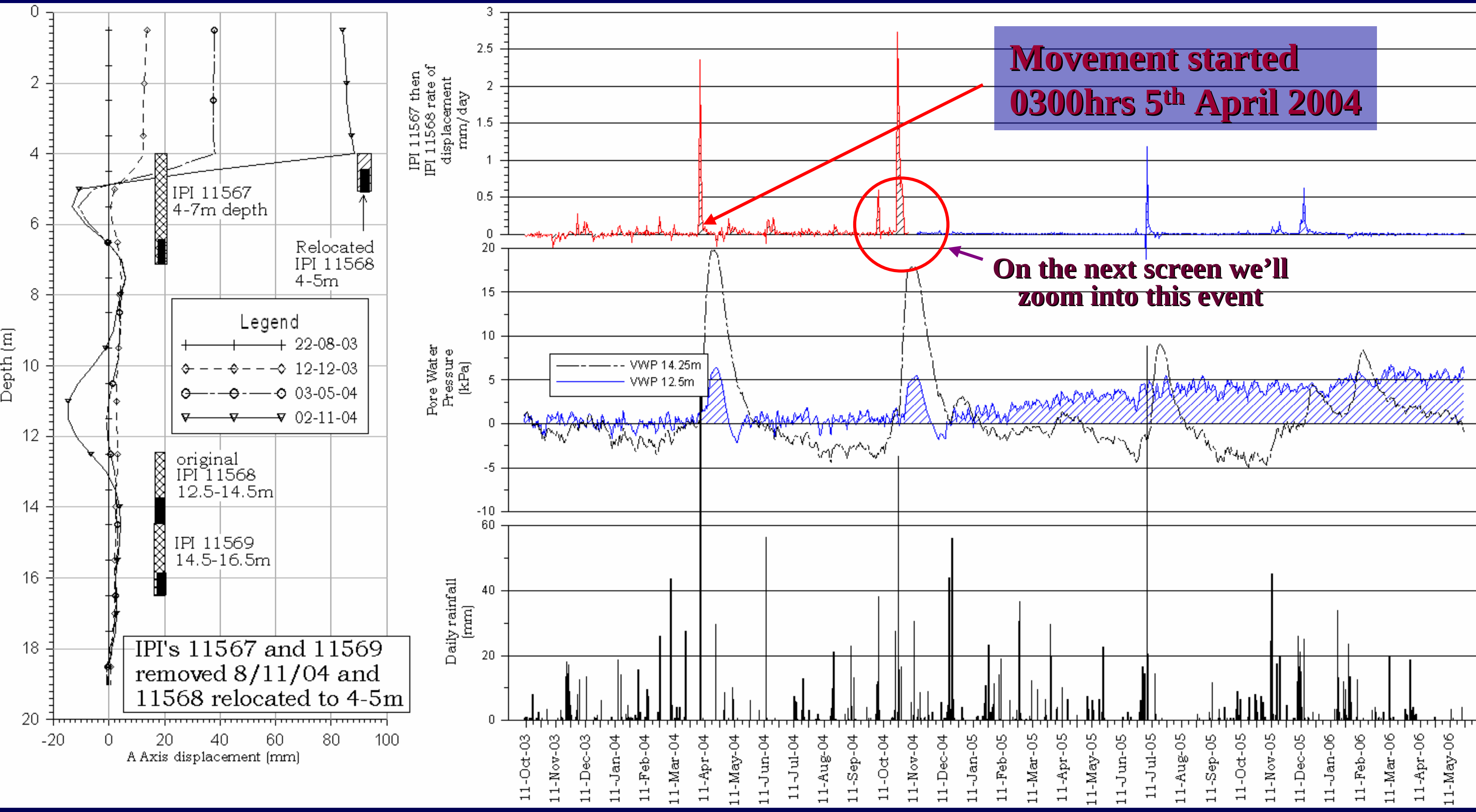
Mount Ousley Road Site 141

Thirroul

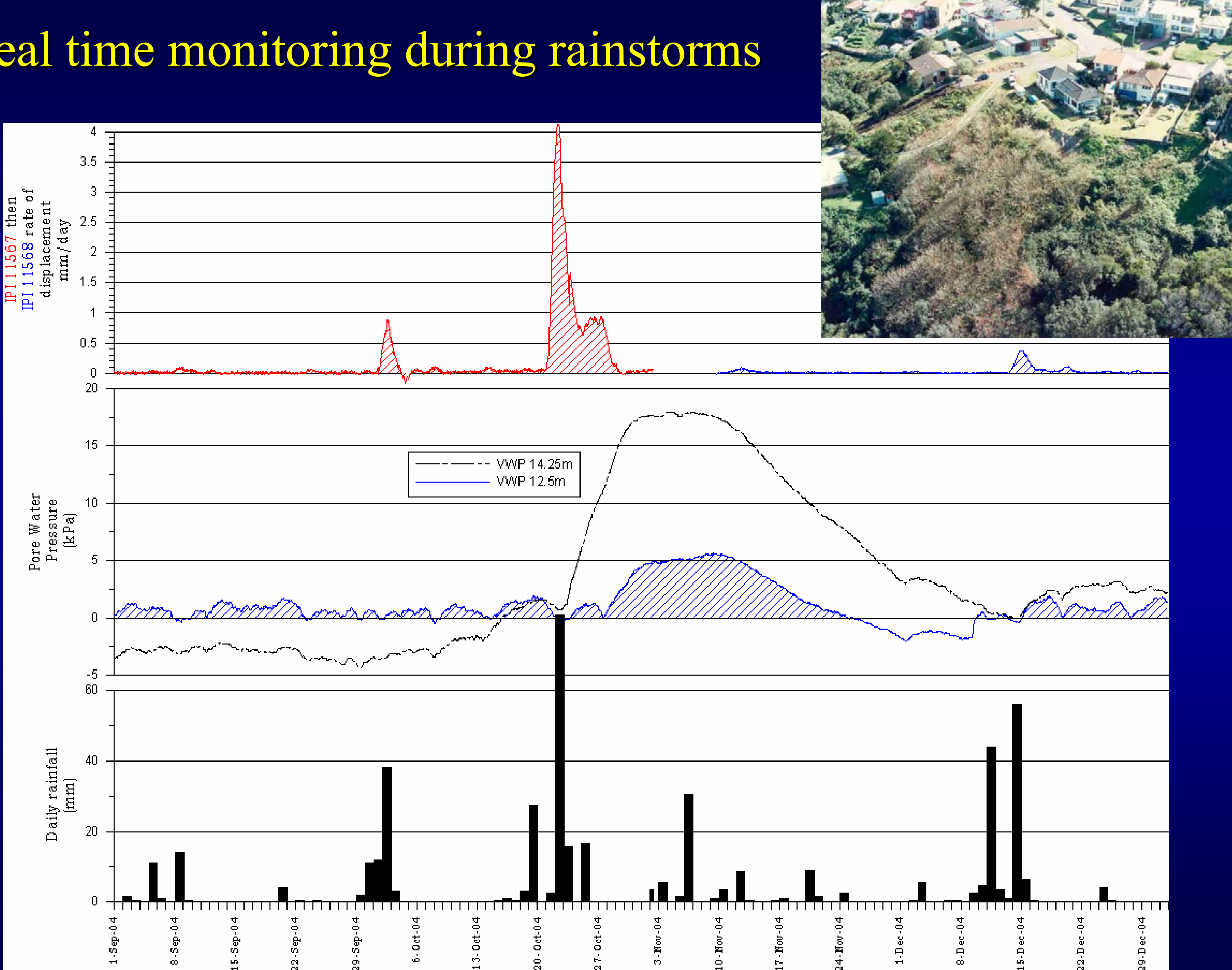
Site 355 - Scarborough

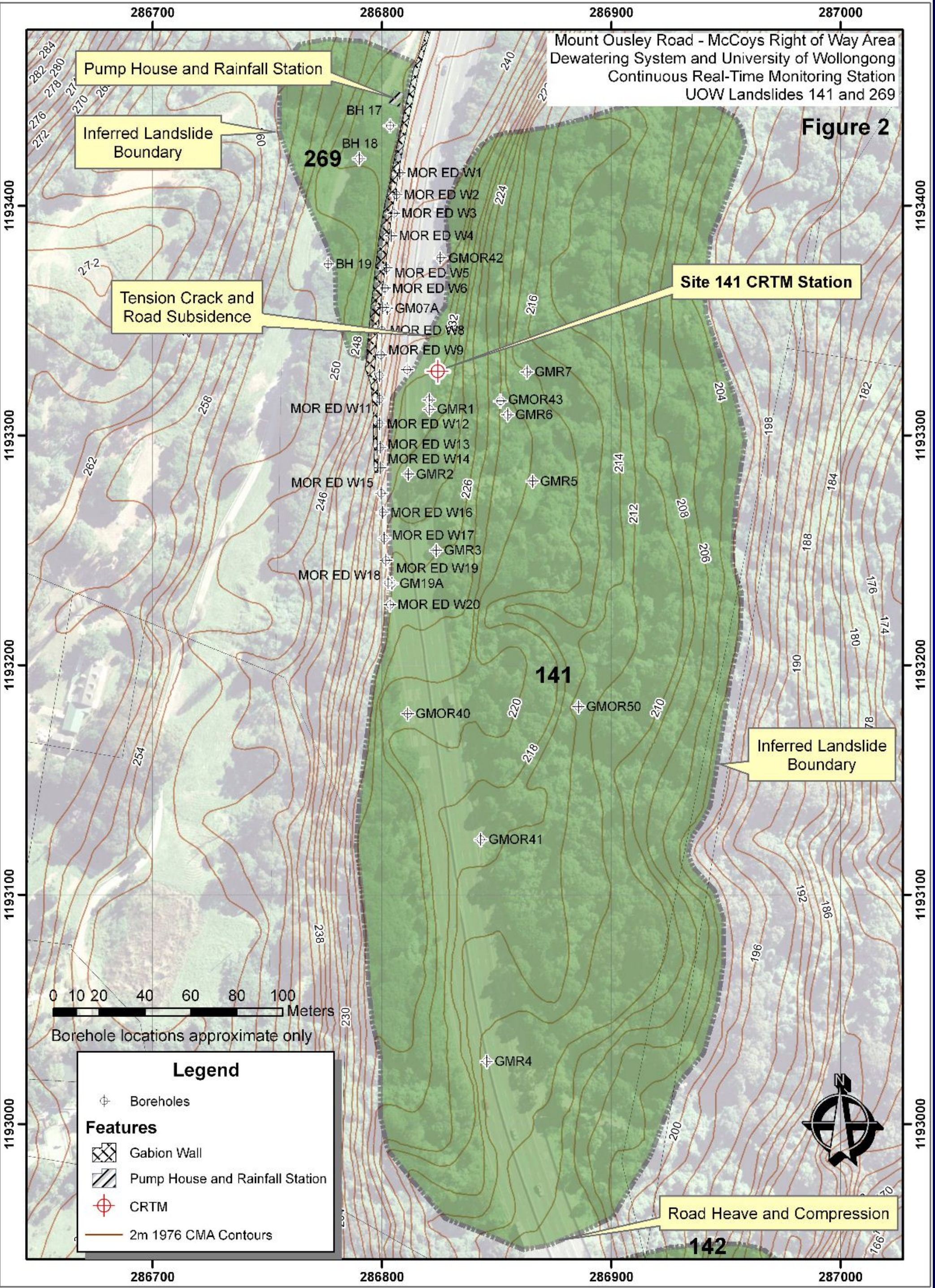


CRTM data Site 355 in Scarborough to 15 May 2006



Real time monitoring during rainstorms





Site 141

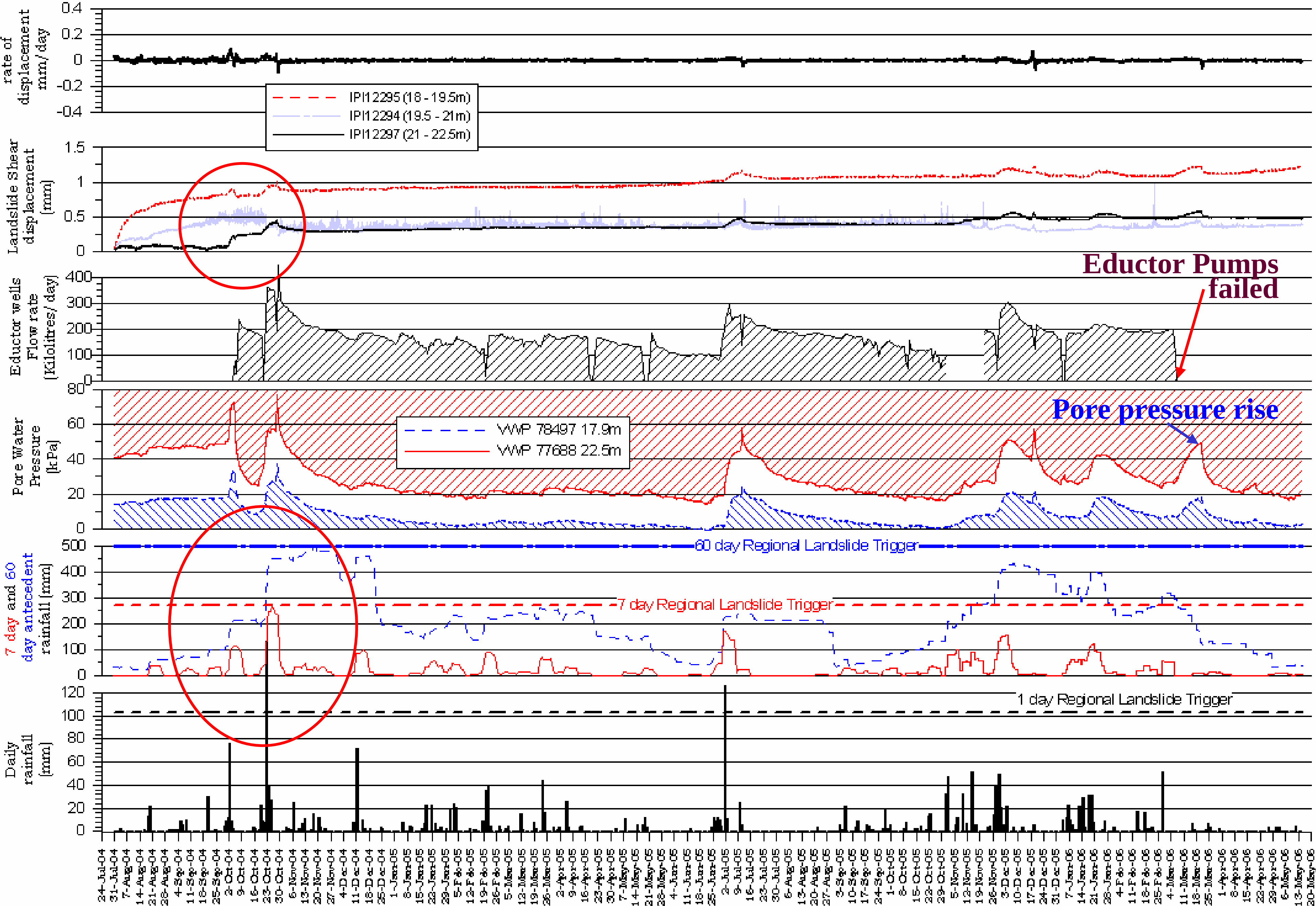
Mount Ousley Road
35,000 Vmpd (1994)
6 lane Freeway to Sydney, all lanes affected

Largest landslide documented in Wollongong.

Area of approximately 7 hectares, colluvium 20m deep

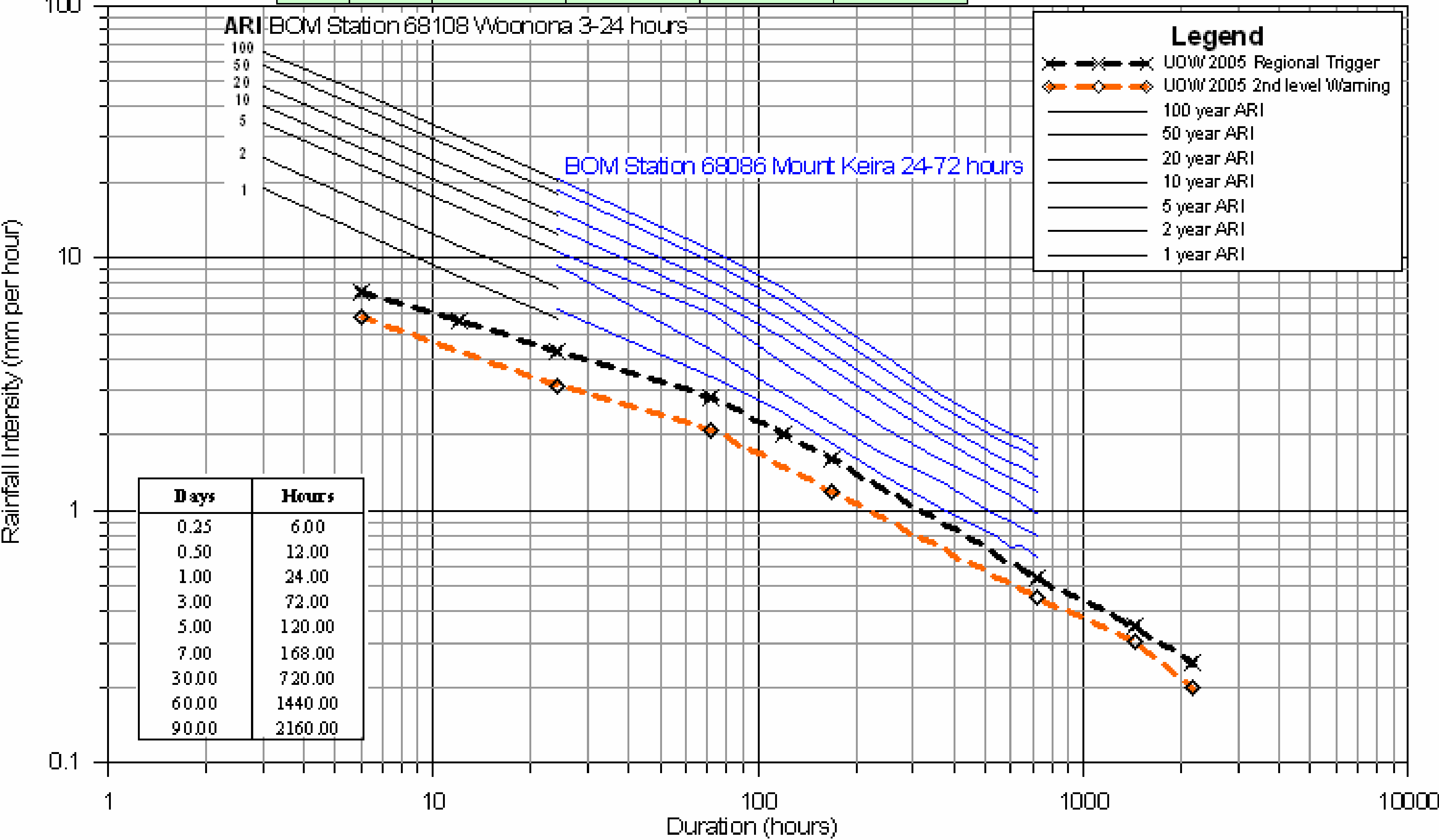
Volume of approximately 720,000 m³

CRTM data for Site 141 on Mount Ousley Road

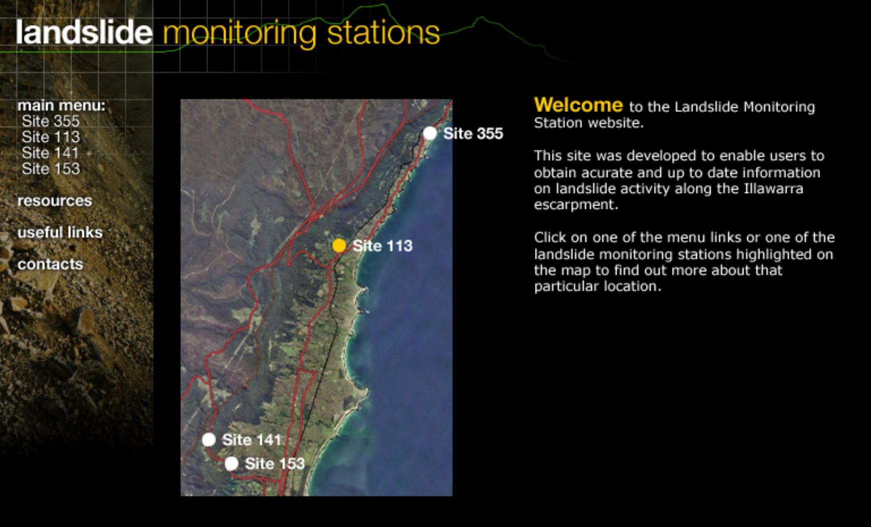


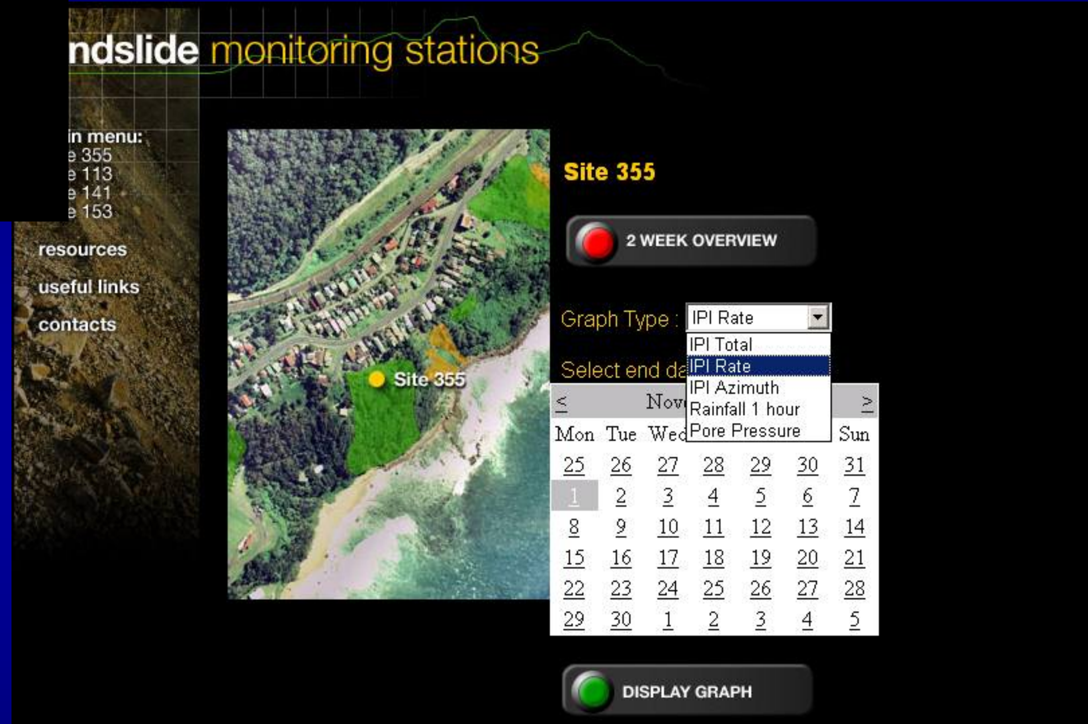
Regional Synthesis

Antecedent period		UOW 2nd Level		Regional Landslide Trigger	
Days	Hours	Intensity mm/hour	Cumulative rain (mm)	Intensity mm/hour	Cumulative rain (mm)
0.25	6	5.83	35	7.37	44
0.50	12	4.17	50	5.42	65
1	24	3.13	75	4.29	103
3	72	2.08	150	2.80	201
7	168	1.49	250	1.61	270
30	720	0.45	325	0.54	390
60	1440	0.30	435	0.35	500
90	2160	0.25	540	0.25	540



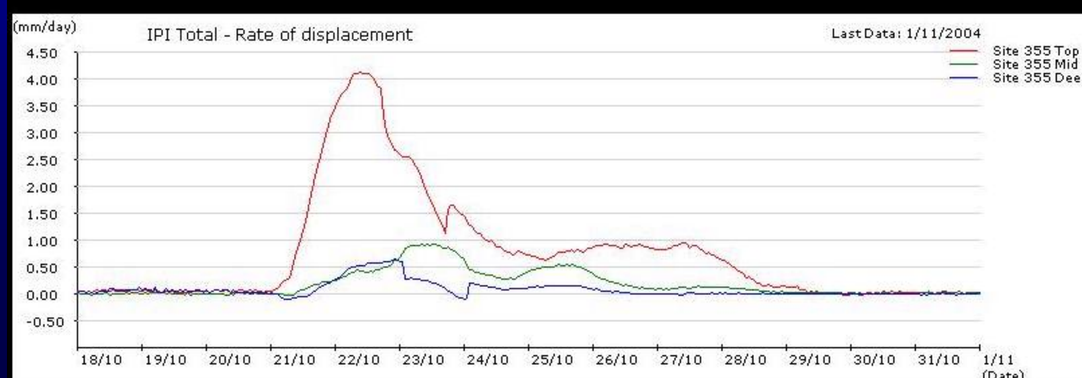
Web Access to Landslide Monitoring data





…in near real time…

…if we have time I will log onto our site and have a little play…



Summary and Conclusions

- Landslide performance data being collected is unprecedented and extremely valuable
- True Landslide Early Warning Capability being used TODAY
- Limitations of periodic monitoring for hazard and risk management
- Regional management perspective is essential
- Longer term weather and performance trends cannot be ignored
- Real time continuous monitoring has an exciting future

Future Directions

- Funding considerations beyond 2008
- Refine CRTM strategy and web interface
- Move from Digital Phone comms to Wireless IP to achieve true RT comms and hence true warning capability
- Expand CRTM network to incorporate significant Australian landslides
- Establish site-specific landslide triggering thresholds wrt rainfall, pore water pressure and magnitudes of movement for said landslides