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Lawrence Vale Landslide Investigations: implications for landslide hazard assessment in Launceston

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Department of Infrastructure, Energy and Resources
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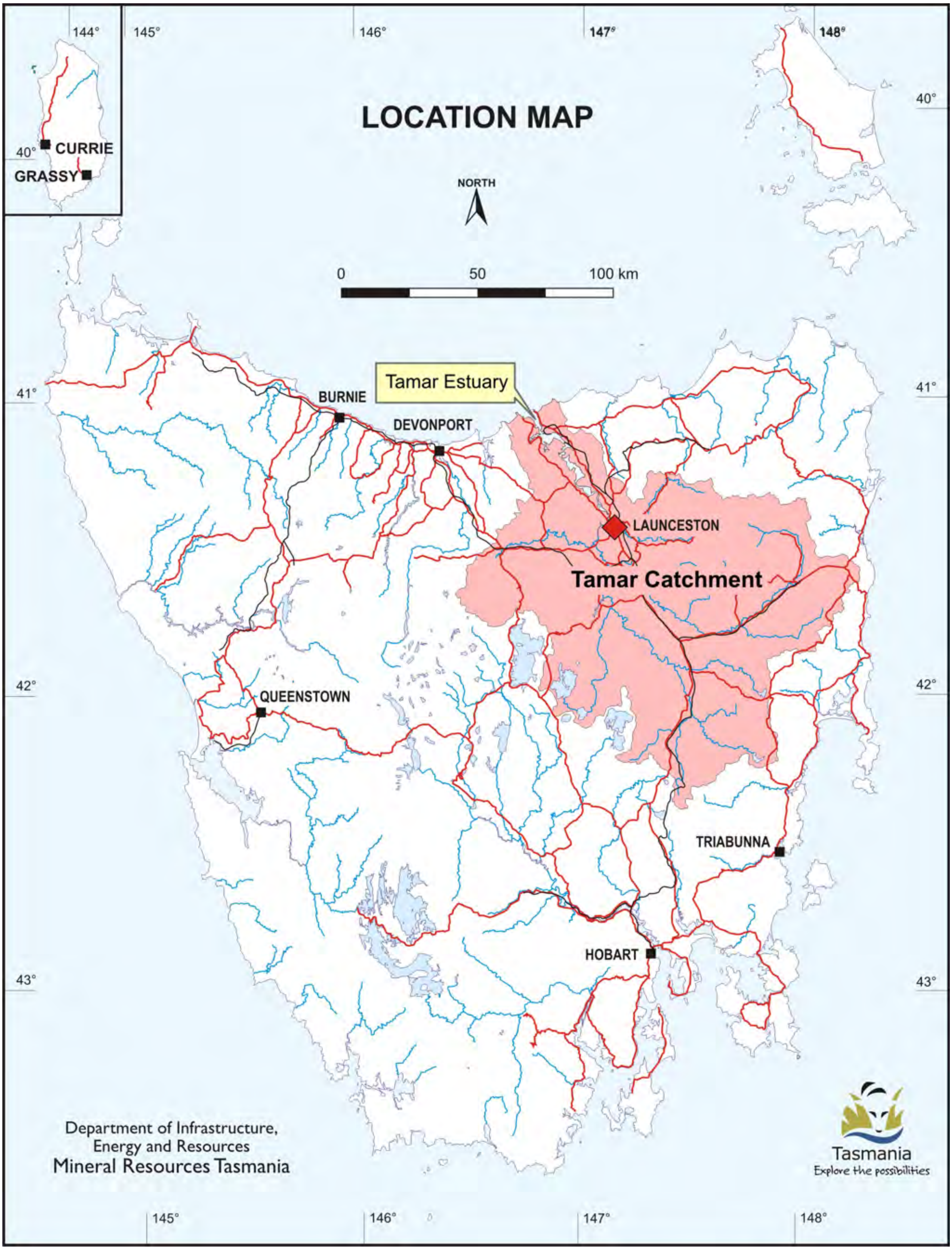

Figure 1

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Abstract

Land instability is widespread in the Launceston area and much work has been undertaken in the past to understand the conditions leading to instability. This has resulted, among other things, in the production of a set of landslide advisory maps that have been used by council for many years. Recently, a revised approach to regional landslide mapping was adopted by Mineral Resources Tasmania that includes a geological study, compilation of a landslide inventory and a geomorphological analysis in order to produce a predictive landslide susceptibility assessment. The Launceston study recognised that landslides occur in a limited number of geomorphic settings. We discuss how changes in base levels of the river system, some of it in response to regional tectonic uplift, have had a major influence in landscape evolution of the Launceston area.

In South Launceston three adjacent landslides were activated in a new residential area beginning in the 1950s, leading to the eventual destruction of about 44 houses (the Lawrence Vale Disaster). These landslides were investigated as part of this study to gain a better understanding of slope processes in this particular geomorphic setting. Our conclusions suggest that the landslides were structurally controlled by tilted bedding in clay and sand of the Tertiary Launceston Group failing on cataclinal slopes. Significant factors leading to instability include transient pore pressures that build up in an aquifer underlying a clay unit that has very high plasticity indices and low shear strength. While the ground conditions are reasonably well understood at this site, the information base is relatively poor elsewhere in this geomorphic setting, making it difficult to make anything other than a conservative estimate of landslide susceptibility throughout the greater Launceston area. Caution is required for investigations in this geomorphic setting to ensure future developments adequately address individual site conditions.

Introduction

Mineral Resources Tasmania (MRT) is undertaking landslide hazard mapping of urban areas of Tasmania to provide communities with information that can assist them mitigate landslide risks. In the course of making predictive landslide susceptibility maps it is necessary to understand the processes that are associated with known landslides. With this knowledge it is possible to justify defining areas with similar ground conditions as having a potential for instability.

In South Launceston, a residential suburb of Launceston (fig. 1, 2), movement on three adjacent landslides (Lawrence Vale, Powena and Effingham landslides; fig. 3) has collectively led to the destruction of 44 houses. The event, here referred to as the *Lawrence Vale Disaster*, triggered a series of geotechnical investigations. Much of the information generated has not been previously published and critically, some of the underpinning data (e.g. drill core and logs) have been located.

Infill development in established parts of Launceston places pressure on councils to allow building consent in areas like South Launceston. While the Lawrence Vale landslides have not been redeveloped, surrounding areas are being infilled and these developments may have an effect on land stability in the greater area.

This document contains details of past geotechnical studies and the findings of an investigation (including drilling) carried out in 2005. The project was designed to verify previous investigations, geological models and the proposed mechanism of failure. Laboratory testing was undertaken on selected sections of the drill core to determine geotechnical properties. A limited hydrological investigation was undertaken to establish the importance of fluids to landslide movement.

Site description and physiography

The area studied (fig. 3), here referred to informally as Lawrence Vale, is situated on the western side of a three kilometre long NNW-SSE to N-S trending ridge, referred herein as Talbot Ridge (fig. 2).

Almost all of the hillsides flanking Talbot Ridge were urbanised in the first half of the Twentieth Century. The land on which the three landslides occur was residential, but most of the houses were subsequently removed or demolished as a consequence of landslide movement (fig. 3). This land has been converted into reserves, with parts planted in trees that have become quite substantial.

The crest of Talbot Ridge has both rounded and flat segments along its length. The flat segments are at several elevations, progressively lowering to the north, ranging from 70 m up to c. 115 mASL and are up to 150 m wide. They have the morphological appearance of elevated river terraces. The general form of slopes surrounding the ridge is concave in profile, progressively steepening up to about 20° before flattening (over a very short distance near the ridge top) (fig. 4). Several gullies occur on the flanks of Talbot Ridge, four of which, at Lawrence Vale, form re-entrants on the valley wall offsetting contours horizontally by as much as 100 metres. None of the gullies are significant enough to be recognised as formal streams on the Launceston 1:25 000 scale topographic map. Rather they were probably ephemeral channels before urbanisation that only carried surface water during and shortly after rainfall events.

Geological Setting

The geological setting of South Launceston and the greater area has been described previously by several authors including Stevenson (1975) and Ingles (1994). The area has been mapped at a range of scales, most recently at 1:25 000 (Calver and Forsyth, 2005). Basement units cropping out in the area comprise Jurassic dolerite (fig. 2) intruding Permo-Triassic Parmeener Group sedimentary rocks. These rocks are faulted and tilted mainly along NNW trends that parallel the River Tamar. The faults were active in the Early Tertiary and constitute an asymmetric graben that was infilled in a syntectonic fashion by fluvial and lacustrine Tertiary sediments (sand, clay and gravel) collectively known as the Launceston Group. The majority of Talbot Ridge, including Lawrence Vale, is composed of Launceston Group rocks. Surface exposures of the group are sparse and while it contains a range of lithologies, the Launceston Group has only been subdivided into formations or informal units in a limited number of places.

From regional studies there are a number of direct and indirect observations to indicate that the Launceston Group has been tilted along with the basement rocks in a WSW direction by as much as 30° (C. Calver, MRT, pers. comm. 2006). This interpretation differs from Stevenson (1975) who considered the Tertiary sediments post-dated graben development and were essentially flat lying. The structural dip is reflected in the cross-section of Calver and Forsyth (2005) and subsequently in Figure 7.

Sporadic occurrences of Tertiary basalt flows occur in and around Launceston (Sutherland *et al.*, 2006). Some of these occur high in the landscape (i.e. not in modern valley floors) and are flat-lying, indicating that they were erupted after deposition of the Launceston Group and regional tilting but before incision by the Tamar tributaries (described below).

A regional peneplain formed following the cessation of graben development and associated deposition of the Launceston Group. Remnants of this are present south of Launceston, for example at Launceston airport and surrounds, the elevation of which is at about 140 to 160 mASL. The peneplain has been deeply dissected by the ancestral River Tamar and its tributaries, down to about 20 m below present sea level

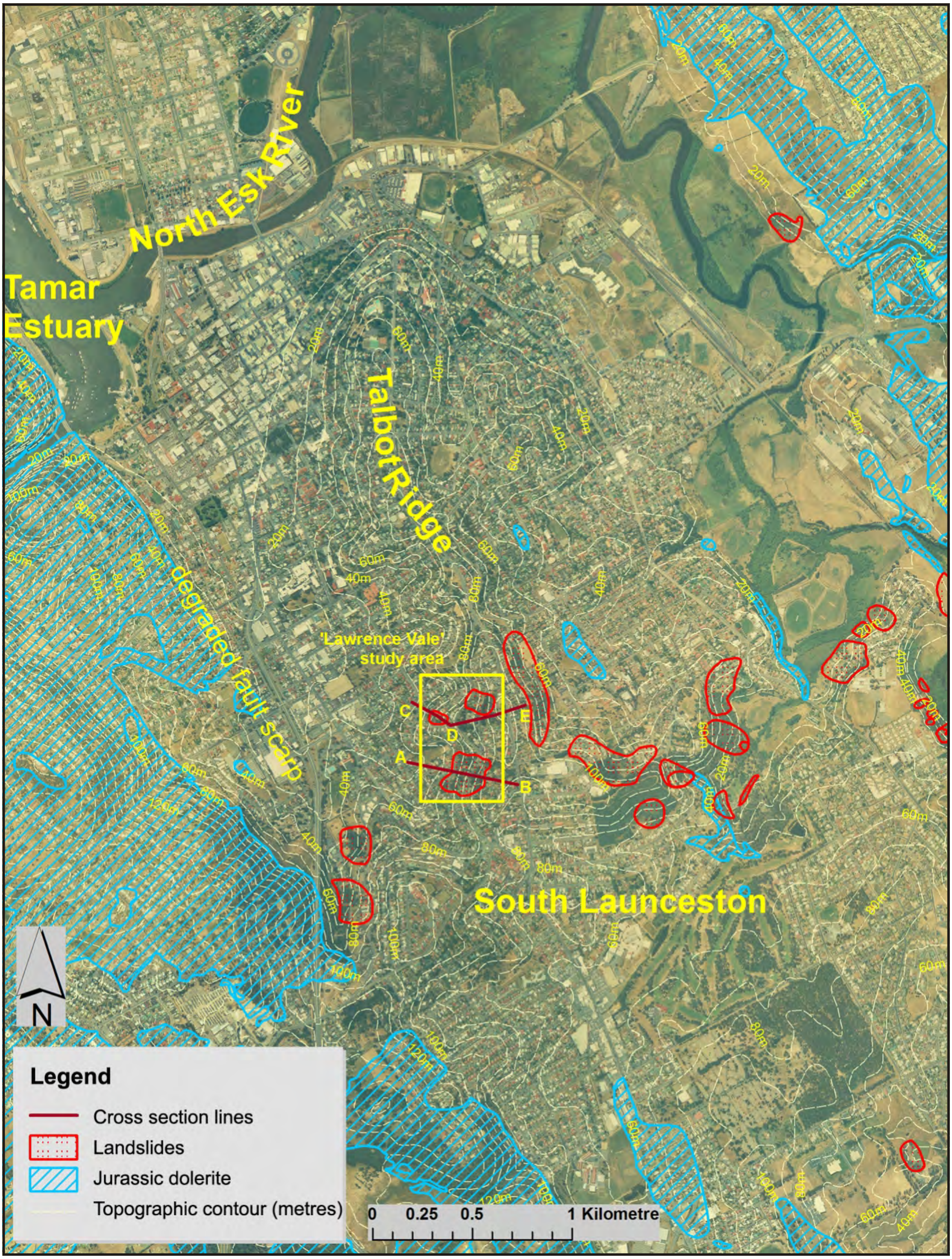

Figure 2

Talbot Ridge area and surrounds showing aspects of the geology and topography. Red polygons indicate position of landslides in MRT database. Yellow polygon indicates position of the three landslides under discussion including the Lawrence Vale Landslide. Orthophoto base from Department of Primary Industries and Water.

Figure 3

Map showing the Lawrence Vale area (informal name) including the three landslides under discussion (red hatching) with headscarps indicated by red ticks. Blue polygons indicate position of demolished houses; red labels indicates year of earliest known damage (from MRT records); black labels indicate year of proclamation under the Lawrence Vale Landslip Act when first damage date is unknown. Topographic contours are from Department of Primary Industries and Water. Orthophoto base (flown in 2003) is the property of MRT.

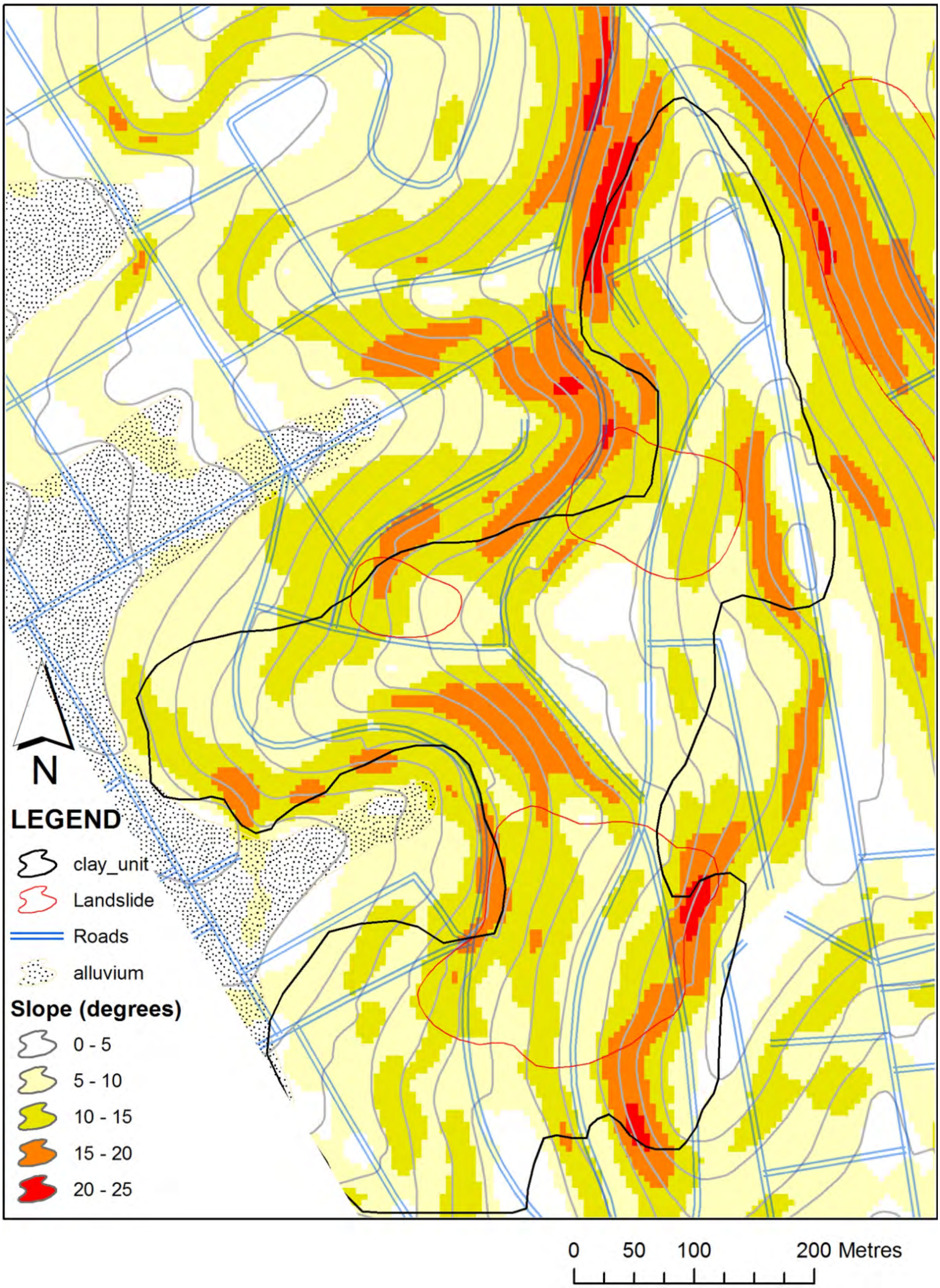

Figure 4

Map showing slope categories at Lawrence Vale, important geological units and landslides.

at Launceston (although the channel is largely infilled by subsequent deposition in the Holocene). The downcutting of the Tamar catchment is suggested to be in response to middle and late Pleistocene regional uplift of Tasmania as postulated by Murray-Wallace and Goede (1991). Murray-Wallace and Belperio (1991) also demonstrated that Tasmania and parts of Victoria have experienced the greatest amount of last interglacial uplift in Australia, ranging up to c. 0.2 mm/ year.

At least two aggradational terrace sets of intermediate elevation exist along valley sides (Calver and Forsyth, 2005; Selkirk-Bell and Mazengarb, 2005) that may be related to high base levels during previous interglacial episodes, although the terraces themselves have not been dated by independent means. A modern flood plain is formed about the strongly meandered North Esk River to the east and north of Talbot Ridge. This flood plain is likely to be Holocene in age, formed as a response to elevated base levels associated with the current climatic regime. In this area, the river is marginally above modern sea level. Alluvial deposits of probably Holocene age, mapped from aerial photographs, are depicted at the base of Talbot Ridge at Lawrence Vale (fig. 4).

Historical summary of site including investigations

A brief history of the site is outlined, with emphasis on previous geological investigations. Extracts from previous work summarising key findings are provided in Appendix 1.

Although the oldest house affected by the landslides was built close to 1900, most of the house construction occurred between 1929 and 1950, prior to which the land consisted of cleared paddocks. Landslide movements were first recorded when the last of the houses was constructed in 1950 (fig. 3) and the term 'Lawrence Vale landslip' was coined (e.g. Carey, 1958). In our report we prefer to use the more modern terminology of 'Lawrence Vale Landslide' to refer to the feature. The destruction of the houses was obviously very unsettling for the local community and was much publicised. The *Lawrence Vale Landslip Act 1961* was passed by the Tasmanian Parliament to provide financial assistance to affected home owners, with 20 properties registered in the first year (fig. 3). Compensation payments were made up to 1984 as further movements occurred.

Carey (1958) described the Lawrence Vale Landslide as a series of slip circle failures that had moved retrogressively up-slope and laterally. He considered that movement was related to a particular clay formation involving a combination of mechanical properties, permeability of beds to water and slope steepness. The clay formation mentioned by Carey has not been mapped by subsequent workers until very recently (the results of our study are included in Calver and Forsyth, 2005).

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) undertook an extensive diamond drilling program in 1959 which was followed by resistivity (Polak, 1964) and seismic (Wiebenga, 1964) surveys. Unfortunately, the results of the drilling component of the investigation were not placed in the public domain and could not be located. A summary of the results is contained in unpublished notes accompanying a public lecture by Gill (1961). No detailed borehole logs were published for the 1959 diamond drilling program but locations (fig. 5) and summary information (Table 1 and cross sections) are recorded in this study. Copies of some cross sections are held by Mineral Resources Tasmania (MRT).

The Tasmania Department of Mines (a predecessor of MRT) investigated the area in 1969 (Jennings, 1971; Stevenson and Jennings, 1971). Jennings (1971) considered that the cause of the slip was due to the houses being placed on a pre-existing landslide, above average rainfall, surface cracking allowing infiltration of surface water into the slip mass, and infiltration of groundwater from other sources. Stevenson and Jennings (1971) considered that deformation was largely plastic in a translational manner. As a result of this work, subterranean drainage was installed. Locations of boreholes and summary logs are shown in Figure 5 and Table 1.

Further work was carried out by Knights (1977). Twenty shallow solid stem auger boreholes were drilled (fig. 5, Table 1) but the drilling method provided only distributed samples, resulting in brief logs with limited use for geological correlation. Additional drainage was installed at this time. Knights discussed the importance of a fine sand aquifer within which water pressures develop as a cause of slope failure.

A range of site-specific investigations was also undertaken in the 1980s and 1990s to assess potential instability on individual properties. Regular surveys of the site have been carried out over the last fifteen years on behalf of MRT to assess movement rates. Recent ground cracking in the headscarp area of the Lawrence Vale Landslide indicates that the landslide has not totally stabilised.

A considerable amount of laboratory testing has been previously carried out on the Launceston Group clays to characterise their geotechnical properties (e.g. Knights, 1974; Knights and Matthews, 1976). The results of this testing are summarised in this report.

As part of a seepage investigation commissioned by the Launceston City Council (LCC), thirteen boreholes were drilled in the greater South Launceston area (Moore, 1996; Roberts, 1996) (fig. 5, Table 1) using a range of drilling techniques. Roberts (1996) provides detailed borehole logs of the nine installed piezometers, while Moore (1996) provides four detailed logs, photographs of diamond drill core and an interpretation of the local hydrogeological setting. Both the 1996 drilling events were outside the Lawrence Vale Landslide footprint as described in

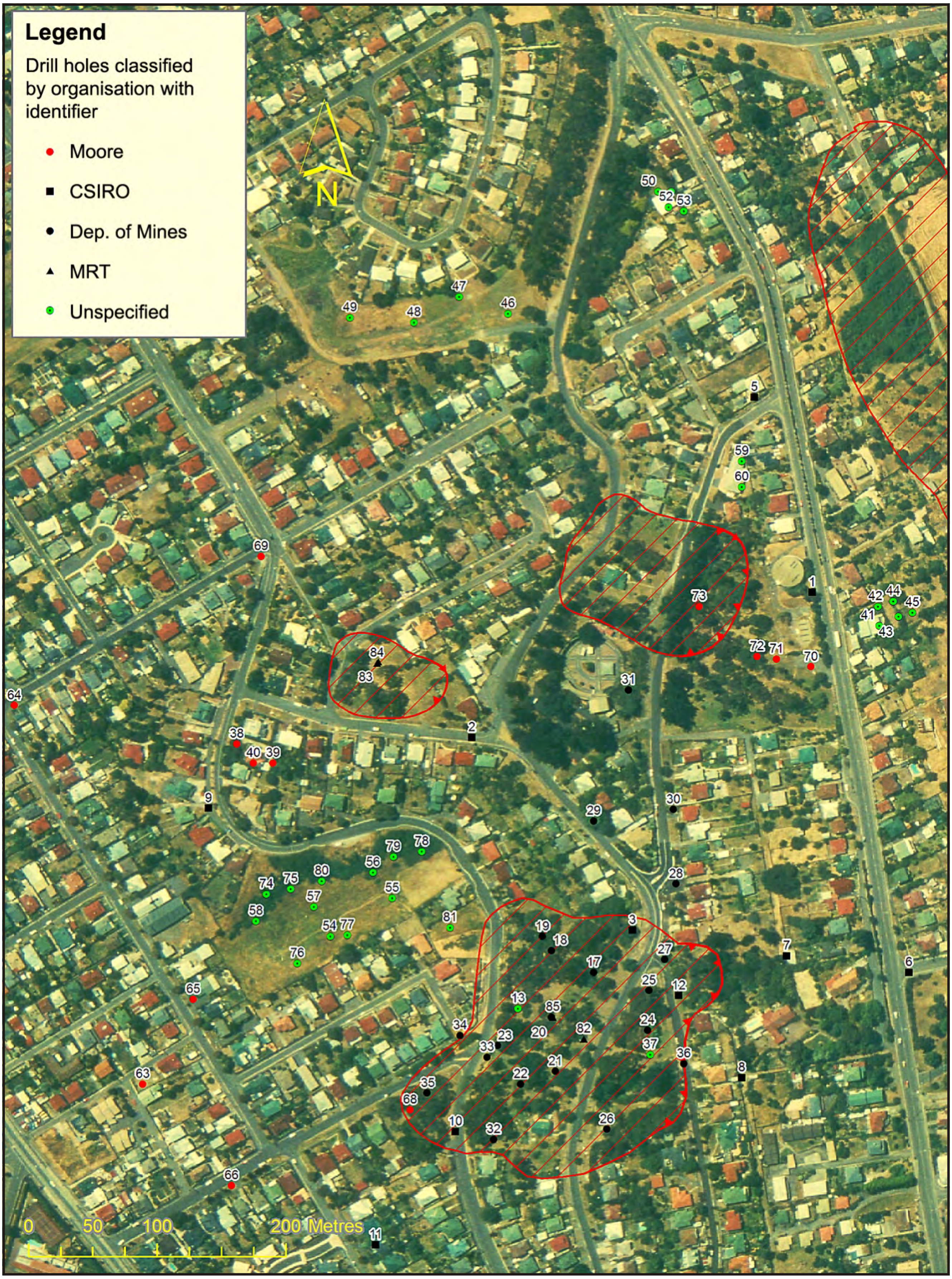

Figure 5

Location of boreholes and test pits referred to in text. Details of these features are summarised in Tables 1 and 2.

Knights (1977). Moore provided additional insights into the importance of groundwater to slope movement in the area.

A detailed history of movement has not been attempted in this report. However, annual rainfall records from the most complete site in the area, at Launceston Airport, provide a valuable insight to a likely contributing factor to instability (fig. 6). The records show a common pattern seen throughout much of Australia, revealing that the climate was wetter in the decades leading up to the mid 1970s, with the average annual rainfall declining sharply to approximately 15% since then to the present.

Specific details of the Lawrence Vale, Effingham and Powena landslides

The three landslides are shown on Figure 3 and significant properties detailed in Table 2. There is limited morphological expression on the ground surface and only subtle indications such as hummocky ground to show landslides are present. This could partly be due to the ground surface modification after the houses were removed. With the exception of the headscarp of the Lawrence Vale Landslide, the boundaries of these features are poorly known and we have adopted the outline of the Lawrence Vale Landslide from Knights (1977). The outline of the other two landslides was interpreted after a field inspection in 2005 by MRT geologists and consideration of previous reports and evidence of damage.

Total distance of movement for the three landslides cannot be precisely determined. In the case of the Lawrence Vale Landslide, the size of the head scarp and the toe mound suggests displacement in the order of 20 m or more. Total displacement on the other two landslides is probably much less based on surface morphology. On consideration of house damage details and previous monitoring results (fig. 3), the rate of movement is classified as Extremely Slow (<15 mm/year) using the Cruden and Varnes (1996) scale. While it is possible to build houses on Extremely Slow moving landslides (Cruden and Varnes 1996), the distribution of damage suggests that the landslide was not moving as a single rigid block. Rather, surface deformation such as warping and faulting has probably occurred over much of the area.

The subsurface geometry of the sites is shown on Figure 7. It was not possible from inspection of the drill core from the Lawrence Vale and Powena landslides to definitively identify a simple failure plane or planes. Inclinometer readings over the period 19 September 2005 to 25 May 2006 show that no detectable movement has occurred in either of the holes.

MRT geotechnical investigations, 2005–2006

Site investigations undertaken in this study consist of a drilling program and a hydrogeological study. Previous information was considered when selecting drill sites for the current drilling program. The locations of all boreholes from the previous investigations, plus subsurface test pit investigations, are shown on Figure 5. Prior to drilling, attempts were made to locate all known drill sites to facilitate their use as groundwater level monitoring sites for the long term. One borehole collar (of DHH19; Plate 1) was located from the 1959 CSIRO drilling program but this was deemed to be unserviceable. The boreholes with pipe installed by Knights (1977) were cleaned of blockages and had lockable collars fitted. Plates 2, 3 and 4 show the initial condition, maintenance work and final upgraded status of Knights' (1977) borehole 14. All boreholes drilled by Roberts (1996), other than piezometers 5 and 7, were located and lockable collar protection installed. Piezometer R4 (Moore, 1996) was located and this already had lockable collar protection fitted. Table 3 details the specifics of maintenance undertaken on all relocated boreholes installed with pipe and piezometers.

Two diamond-drill holes (installed as inclinometers) and two shallow auger holes (installed as piezometers) were drilled in April 2005; the locations of these are shown on Figure 5. Site selection and drilling techniques for each hole were determined after considering the unconsolidated ground conditions, past indications of landslide dimensions (e.g. potential depth of the primary zone of rupture) and the mechanism of movement for known areas of instability. Infrastructure was installed either to monitor future movement (inclinometers) or the behaviour of groundwater levels (piezometers). The diamond holes were sited in the central regions of the two main areas of instability (where houses had been demolished) in an attempt to identify the mechanism of failure and potentially to correlate with the remaining records of the past drilling programs. The installation of the two inclinometers in drill holes LV_IBH1_2005 and LV_IBH2_2005 was completed to industry standards.

Table 2

Detailed significant properties of three landslides in the Lawrence Vale study area.

Landslide name	Type	Area (m^2)	Depth (m)	Volume (m^3)	Failure angle (°)	Mean surface slope (°)	Mean aspect (°)
Lawrence Vale landslide	Earth slide	35 737	12	214 422	13	13	288
Effingham landslide	Earth slide	12 950	3	19 425	12	12	285
Powena landslide	Earth slide	4 652	12	27 912	10.5	9	273

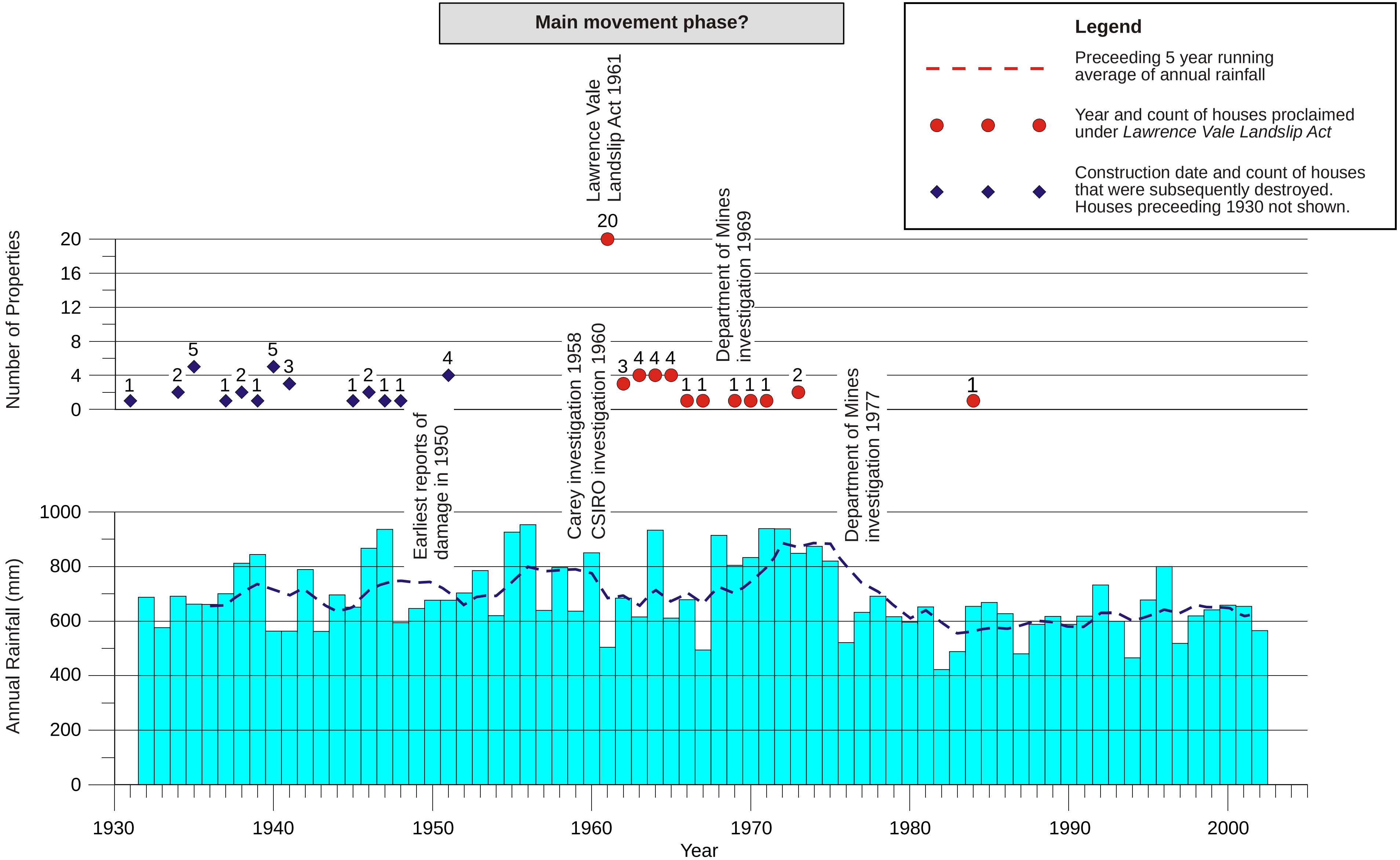

Figure 6

Annual rainfall record for Launceston Airport (from Bureau of Meteorolgy) and a time line of significant events in the Lawrence Vale area, post 1930.

Table 3

Register of maintenance undertaken on boreholes.

Drilling supervisor, year and specific project borehole ID	Easting (m)	Northing (m)	Status of infrastructure	Maintenance 2005	Serial number of Odyssey data logger
CSIRO 1959 DDH1	512750	5410828	No sign of collar	N/A	N/A
CSIRO 1959 DDH2	512485	5410715	No sign of collar	N/A	N/A
CSIRO 1959 DDH3	512610	5410565	No sign of collar	N/A	N/A
CSIRO 1959 DDH4	512530	5410250	No sign of collar	N/A	N/A
CSIRO 1959 DDH5	512570	5411330	No sign of collar	N/A	N/A
CSIRO 1959 DDH6	512705	5410980	No sign of collar	N/A	N/A
CSIRO 1959 DDH7	512825	5410532	No sign of collar	N/A	N/A
CSIRO 1959 DDH8	512730	5410545	No sign of collar	N/A	N/A
CSIRO 1959 DDH9	512695	5410450	No sign of collar	N/A	N/A
CSIRO 1959 DDH10	512280	5410660	No sign of collar	N/A	N/A
CSIRO 1959 DDH13	512472	5410408	No sign of collar	N/A	N/A
CSIRO 1959 DDH18	512410	5410320	No sign of collar	N/A	N/A
CSIRO 1959 DDH19	512650	5410510	Steel collar located, casing blocked at 0.3 metres	Unable to remove blockage	N/A
C Knights 1977 BH1	512580	5410532	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH2	512547	5410549	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH3	512540	5410560	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH4	512547	5410497	Open borehole collar	Blockages removed from casing, cemented new lockable collar with turf cover	16277
C Knights 1977 BH5	512550	5410455	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH6	512523	5410445	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH7	512505	5410475	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH8	512622	5410487	Open borehole collar	Blockages removed from casing, cemented new lockable collar with turf cover	16280
C Knights 1977 BH9	512623	5410518	Open borehole collar	Blockages removed from casing, cemented new lockable collar with turf cover	Not installed
C Knights 1977 BH10	512590	5410410	Covered by shed	N/A	N/A
C Knights 1977 BH11	512635	5410542	Open borehole collar	Blockages removed from casing, cemented new lockable collar with turf cover	Not installed
C Knights 1977 BH12	512644	5410601	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH13	512580	5410650	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH14	512642	5410659	Open borehole collar	Blockages removed from casing, cemented new lockable collar with turf cover	16287
C Knights 1977 BH15	512607	5410752	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH16	512502	5410402	Open borehole collar	Blockages removed from casing, cemented new lockable collar with turf cover	16290
C Knights 1977 BH17	512497	5410466	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH18	512476	5410483	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH19	512450	5410438	No remaining evidence of drilling	N/A	N/A
C Knights 1977 BH20	512650	5410461	No remaining evidence of drilling	N/A	N/A
W Moore 1996 PBH1	512011	5410931	Turf cover over collar	Lockable cap installed	16281
W Moore 1996 PBH2	512074	5410969	Turf cover over collar	Lockable cap installed	16276
W Moore 1996 PBH3	512229	5410445	Open borehole collar	Cemented new lockable collar with turf cover	16292
W Moore 1996 PBH4	512129	5410740	Open borehole collar	Blockages removed from casing, cemented new lockable collar with turf cover	16288
W Moore 1996 PBH5	512268	5410511	Not found	N/A	N/A
W Moore 1996 PBH6	512298	5410366	Turf cover over collar	Lockable cap installed	16289
W Moore 1996 PBH7	512088	5410592	Not found	N/A	N/A
W Moore 1996 PBH8	512437	5410425	Open borehole collar	Blockages removed from casing, cemented new lockable collar with turf cover	Not installed
W Moore 1996 PBH9	512321	5410856	Turf cover over collar	Lockable cap installed	16279
W Moore 1996 PBH R1	512749	5410770	No remaining evidence of drilling	N/A	N/A
W Moore 1996 PBH R2	512722	5410776	No remaining evidence of drilling	N/A	N/A
W Moore 1996 PBH R3	512707	5410778	No remaining evidence of drilling	N/A	N/A
W Moore 1996 PBH R4	512662	5410817	Turf cover over collar	Lockable cap installed	16278

Moore (1996) suggested that diamond drilling of the soft sediments in the South Launceston area is technically difficult, producing common core loss due to rapid lithological variations. Drilling was undertaken during April 2005 and was completed in two working weeks with over 95% core recovery. The diamond-drilled holes were installed as inclinometers; LV_IBH1_2005 (LV_ARE_2005_1) and LV_IBH2_2005 (LV_ARE_2005_2) (64.5 and 26.5 m respectively); and the shallow auger holes as piezometers; LV_PBH3_2005 (LV_ARE_2005_3) and LV_PBH4_2005 (LV_ARE_ 2005_4) (13.5 and 12.75 m respectively). Plate 5 shows the diamond drilling set up at drill hole LV_IBH1_2005 with Plate 6 showing inclinometer installation in the same hole. Both drill holes LV_PBH3_2005 and LV_ PBH4_2005 were drilled to the maximum available auger drilling capacity, however neither piezometer made water at the time of drilling or on installation of the pipe. A hydrogeological investigation was carried out; this is described in a subsequent section.

The drill cores were field logged and photographed (Plate 7). The logs and core photographs are presented in Appendix 2 and are in accordance with AS1726-1993 standard. The engineering logs contain descriptions of defects seen in the core (e.g. slickensides; Plate 8 and 9) and details of individual layers within the various MRT-defined lithofacies intercepted by the drilling (see below).

The core was sampled (Table 4) for laboratory testing to gain an understanding of the physical properties of the subsurface materials and to verify the units recognised in the logs. Sections of the core were tested for Atterberg limits and shear strength. Results of the laboratory testing are presented in Appendix 3. Some high quartz content samples were not tested in the shear box as it was assumed they would return high values similar to other sandy samples previously measured.

Our results are consistent with previous work (referenced earlier) that indicates that the clays are overconsolidated but not lithified, sensitive, highly plastic and fissured. Compositionally the sediments contain kaolinite, montmorillonite, quartz, gibbsite and occasionally illite (Knights and Matthews, 1976). Overconsolidated clays typically have a peak strength far greater than their residual strength, making them susceptible to progressive failure.

Geological model

Based on consideration of previous work and the results of this investigation, six units (lithofacies) are recognised. However, some of the previous work has inconsistencies and errors, and interpretations should be regarded as tentative. For example the hand-drawn CSIRO cross sections are inconsistent with those published in the associated report by Polak (1964). Relative levels for interception interval lengths and the base of each of the lithofacies for each borehole or test pit are compiled in Table 1.

The six lithofacies recognised are:

- ☐ **LF1** — Medium to high plastic clays with banded silt, fine clayey sand and ironstone (dominant colours greys and reds — streaked appearance) belonging to the Launceston Group.
- ☐ **LF2** — Dominantly clayey sand layers with banded gravel, ironstone, clay, and silt (dominant colours

Table 4

Register of geotechnical samples collected from drill core.

Core sample	MRT sample ID	Drill hole name	Sampling interval (m)	Brief description of sample
LL1	E201612	LV_IBH1_2005	6.02 to 6.10	Clay — mottled dark red, yellowish brown, light grey
LL2	E201613	LV_IBH1_2005	6.20 to 6.25	Clay — high plasticity, mottled yellowish brown, strong brown, light grey
LL3	E201614	LV_IBH1_2005	8.90 to 8.98	Sandy clay — light yellowish brown, flecked organics, black
LL4	E201615	LV_IBH1_2005	38.38 to 38.42	Clay — high plasticity, grey to dark grey
LL5	E201616	LV_IBH1_2005	46.11 to 46.19	Clay — high plasticity, greenish grey
LL6	E201617	LV_IBH2_2005	13.45 to 13.55	Clay — high plasticity, very dark greyish brown
LL7	E201618	LV_IBH2_2005	23.53 to 23.58	Clay — high plasticity, olive brown, brownish yellow
LL8	E201619	LV_PBH4_2005	1.86 to 1.94	Sandy clay — mottled yellowish brown, grey, brown
SB1	E201620	LV_IBH1_2005	15.87 to 15.97	Clay — high plasticity, mottled banded light olive brown, reddish brown
SB2	E201621	LV_IBH1_2005	37.95 to 38.05	Sand — medium, yellowish brown
SB3	E201622	LV_IBH1_2005	39.95 to 40.05	Clayey sand — fine, yellowish brown, reddish brown, banded clay, high plasticity, dark grey
SB4	E201623	LV_IBH1_2005	41.00 to 41.10	Clayey sand — fine, yellowish brown, reddish brown, banded clay, high plasticity, dark grey
SB5	E201624	LV_IBH1_2005	57.45 to 57.55	Clayey sand — fine, greenish grey
SB6	E201625	LV_IBH2_2005	9.90 to 10.00	Sand — fine, brownish yellow
SB7	E201626	LV_IBH2_2005	19.00 to 19.10	Sandy gravelly clay — yellowish brown
SB8	E201627	LV_PBH4_2005	6.40 to 6.60	Clay — high plasticity, dark grey brown, organics, black
SB9	E201628	LV_PBH4_2005	8.70 to 8.90	Clay — high plasticity, dark yellow brown
SB10	E201630	LV_IBH1_2005	15.05 to 15.10	Sand — fine to medium, yellowish brown, flecked feldspar, quartz, banded ironstone

greys and yellowish brown) belonging to the Launceston Group.

- ☐ **LF3** — Claystone and sandstone with banded coal, silty sand and clay (dominant colours greys and black) belonging to the Launceston Group.
- ☐ **LF4** — Conglomerate and sandstone with banded claystone (dominant colours greenish grey and red) belonging to the Launceston Group.
- ☐ **LF5 (Jurassic dolerite)** — Weathered and fresh dolerite basement rock.
- ☐ **LF6** — Clay, gravel and sand deposited in an alluvial valley floor setting during the Holocene.

Lithofacies 1 to 4, belong to the Launceston Group and are in stratigraphic order, starting with the youngest. LF1 is most likely to be the 'clay formation' previously described by Carey (1958) that is directly involved with landslide movement. This unit, whose appearance is suggestive of a lacustrine origin, is approximately 10 m thick in LV_IBH1_2005, although the true original thickness is unknown because of erosion. The material consistency ranges from firm to very stiff clay with plasticity indices ranging from 59 to 98. Residual friction angles and cohesion values calculated from two samples are 11° and 24° and 2 and 4 kPa respectively (Appendix 3). The results are consistent with previous studies mentioned above.

The streaked appearance of LF1 in drill core suggests that the unit is plastically deformed.

LF2 occurs below LF1, although the nature of the contact is uncertain. The unit is probably the equivalent to the 'aquifer of fine sand' recognised by Knights (1977) and based on its composition suggests a fluvial deposit. The unit has a complex internal architecture of lithologies in both vertical and lateral directions. While this unit appears to be an aquifer, the observed sedimentary complexity would suggest fluid pathways are likely to be complex.

The remaining lithofacies are not described further in this discussion as they appear to have little direct relevance to the principal topic.

Correlation of drill core and surface observations in cross section indicates that Launceston Group sediments are inclined between 10° and 20° to the west (fig. 7), consistent with regional observations concerning fault-related tilting. The older strata (LF3 and LF4) appear to be tilted at slightly steeper angles than the younger units, compatible with growth folding, although it must be stated that the correlations are tentative. The contact between LF1 and LF2 is locally more complex within the Lawrence Vale Landslide. This complexity could be due to incorrect correlation but given that the units are sufficiently distinct, we suggest the complexity is real. The complexity may be a primary feature such as a lateral facies change, a deformation event caused by the landslide along the main failure plane, or a much earlier tectonic folding and/or faulting event.

Despite the uncertainties over the origin of the irregularities, the base of the upper clay layer (LF1) was modelled in a geographical information system (GIS) assuming that the surface is relatively simple. A spline interpolation technique was chosen with the options of tension, 0.5 weight and 12 control points (in ArcMap Spatial Analyst®). The intersection of the modelled surface with the present day topographic surface allows the outcrop pattern of LF1 to be estimated (fig. 8). It is readily apparent that the area of LF1 almost entirely encompasses the areas of the three landslides under discussion. It is suggested that the spatial relationship between the LF1 clay and the landslides is more than coincidence given our observations and conclusions about landslide mechanisms presented in previous reports. Furthermore, the spatial coincidence of the features gives us a measure of confidence in the modelling technique.

Hydrogeology

It is well known that one of the main causes of slope instability is the introduction of groundwater into the slope. This study reviews previous work and conducts additional tests to understand the local groundwater setting. Jennings (1971) considered that movement of the Lawrence Vale Landslide was influenced by high rainfall, with water infiltrating the slip mass via surface cracks and from unspecified groundwater sources. Knights (1977) investigated the latter by deploying an array of piezometers in the vicinity of the landslide. She identified a local aquifer containing water under pressure and concluded that seepage from it contributes to the movement of the landslide. Moore (1996) established that the upper section of the hillside aquifer is pressurised and perched. He considered that water levels could peak briefly (by interconnected fissures in the impermeable clay), leading to failure as a result of a rise in the water table or by uplift from pressure build up in an associated aquifer. All of these authors recommended further investigation to gain a better understanding of the mechanism of failure and geometry of the landslide.

The aim of our limited study was to monitor standing water with time and to measure hydraulic conductivity tests in selected bores. Utilising modern data recorders to measure water levels allowed hourly data to be collected, thereby providing a distinct advantage over previous studies that only collected infrequent data. It is realised that some of the existing bores may not have been constructed to modern standards and/or with the passage of time since they were installed may not be functioning as reliable indicators of water level.

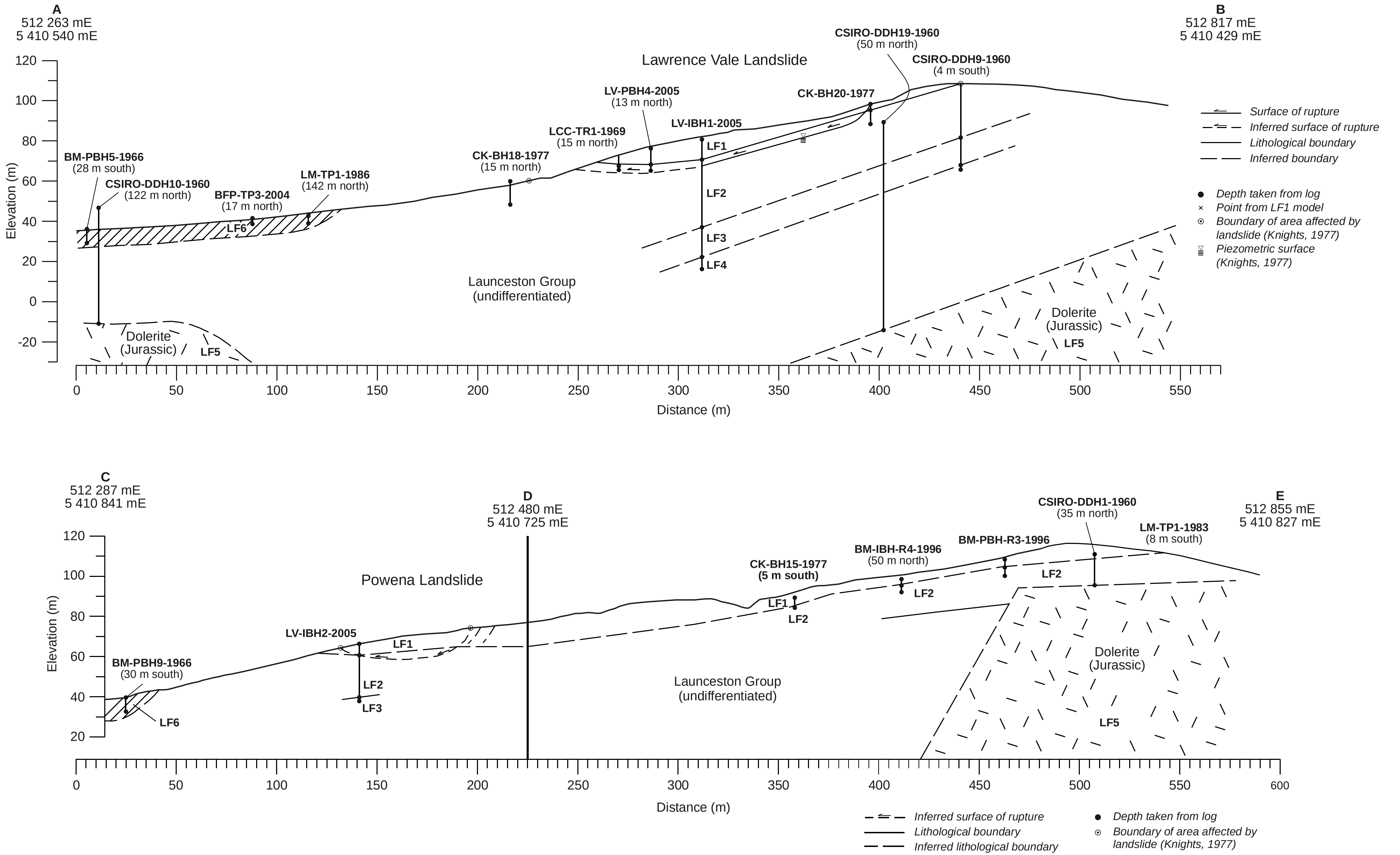

Figure 7

Interpretative cross sections based on drill hole data in the Lawrence Vale area.

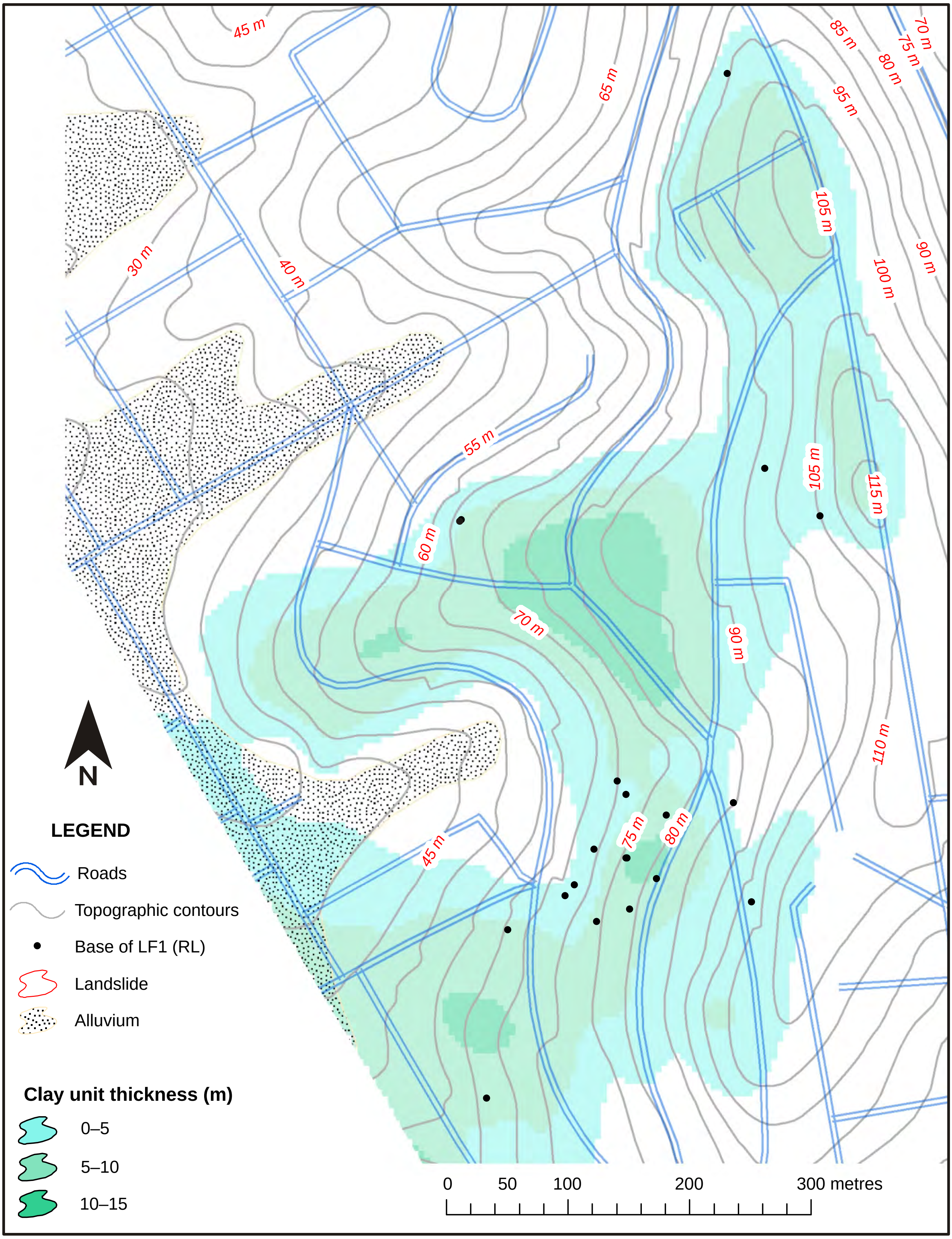

Figure 8

Modelled extent and depth of the upper clay layer, lithofacies LF1.

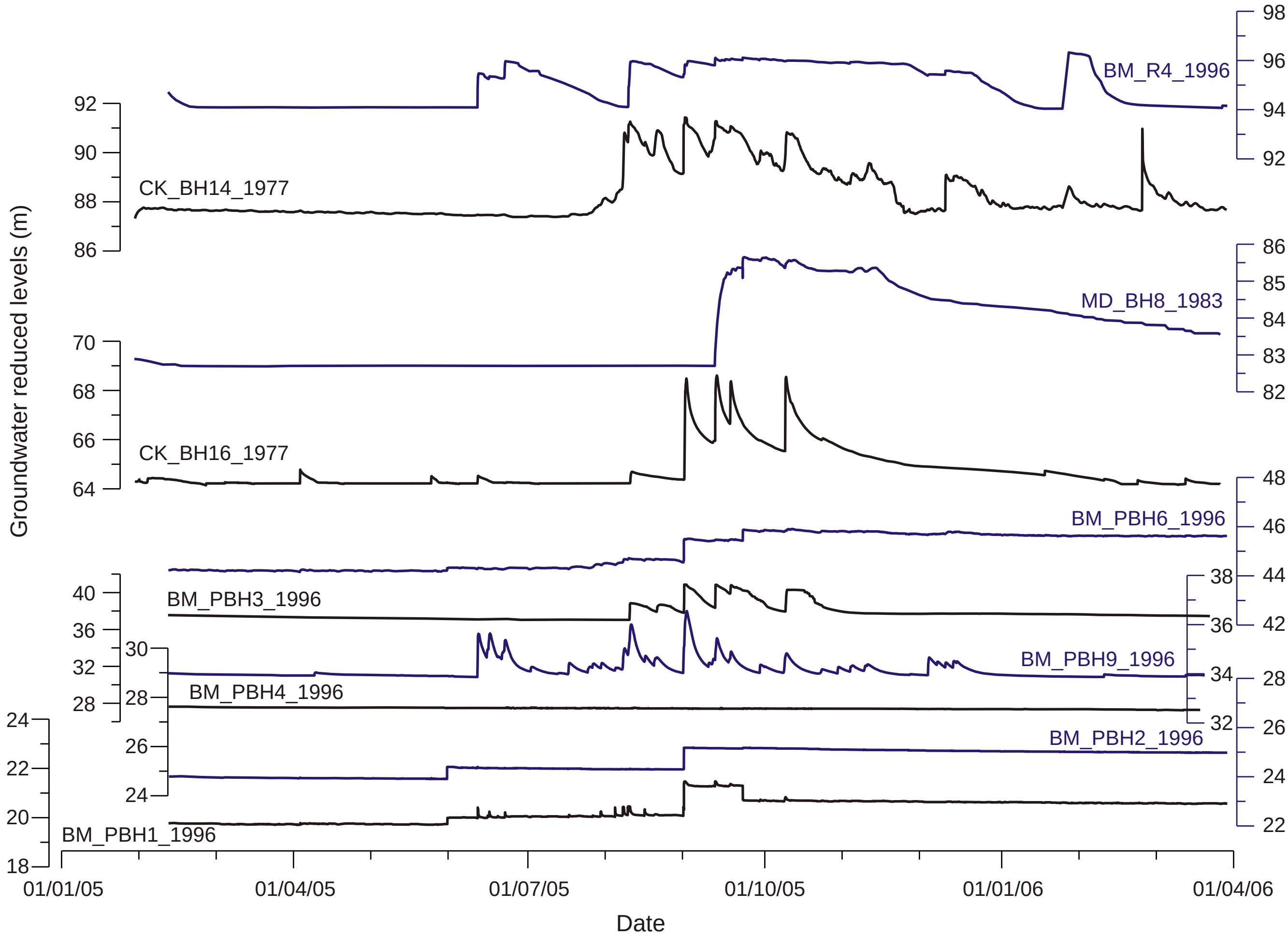

Figure 9

Hydrographs of standing groundwater levels in the study area.

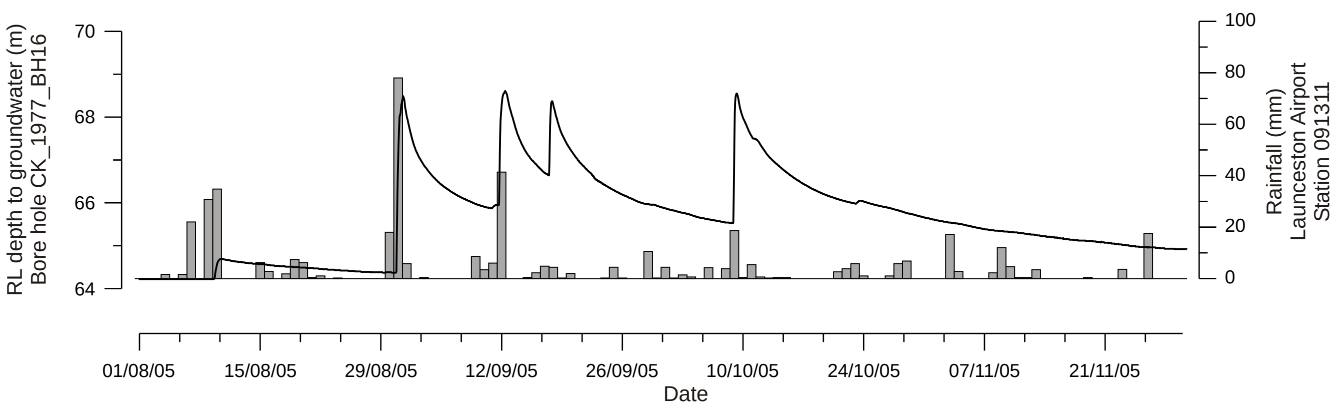

Figure 10

Comparison of winter 2005 Launceston rainfall record to hydrograph of borehole CK_BH16_1977.

Eleven *Odyssey* data recorders were installed during February 2005 in a variety of positions on the hill slope and adjacent valley floor. Standing groundwater level data was recorded hourly over thirteen months; hydrographs of the data are presented in Figure 9.

In situ permeability testing was undertaken in January 2006; data collected during these tests are presented in Appendix 4.

Daily rainfall data from Launceston Airport, the nearest available station with a complete record of the monitoring interval, has been obtained from the Bureau of Meteorology to analyse the response of the piezometers to climatic events. Hydrographs of the piezometers are depicted in Figure 9 and many of them show convincing relationships to rainfall events (fig. 10). In particular, borehole CK_BH14_1977, above the Lawrence Vale Landslide and situated in the sand dominated unit (LF2), shows rapid response to rainfall events. A slug test in this hole indicated a hydraulic conductivity of 10^{-2} m/d using the Bouwer and Rice

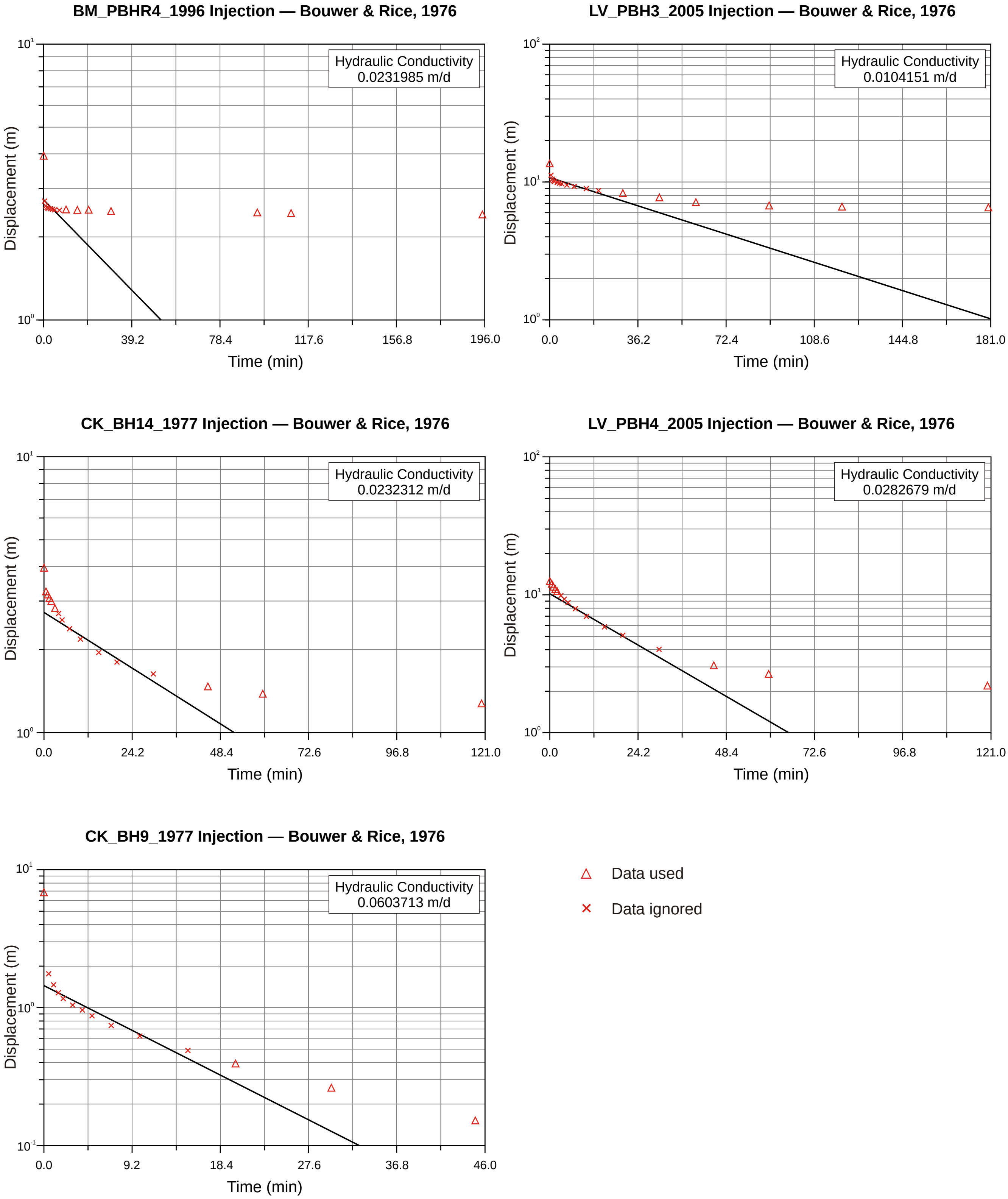

Figure 11

Solutions of in situ permeability tests and hydraulic conductivity values.

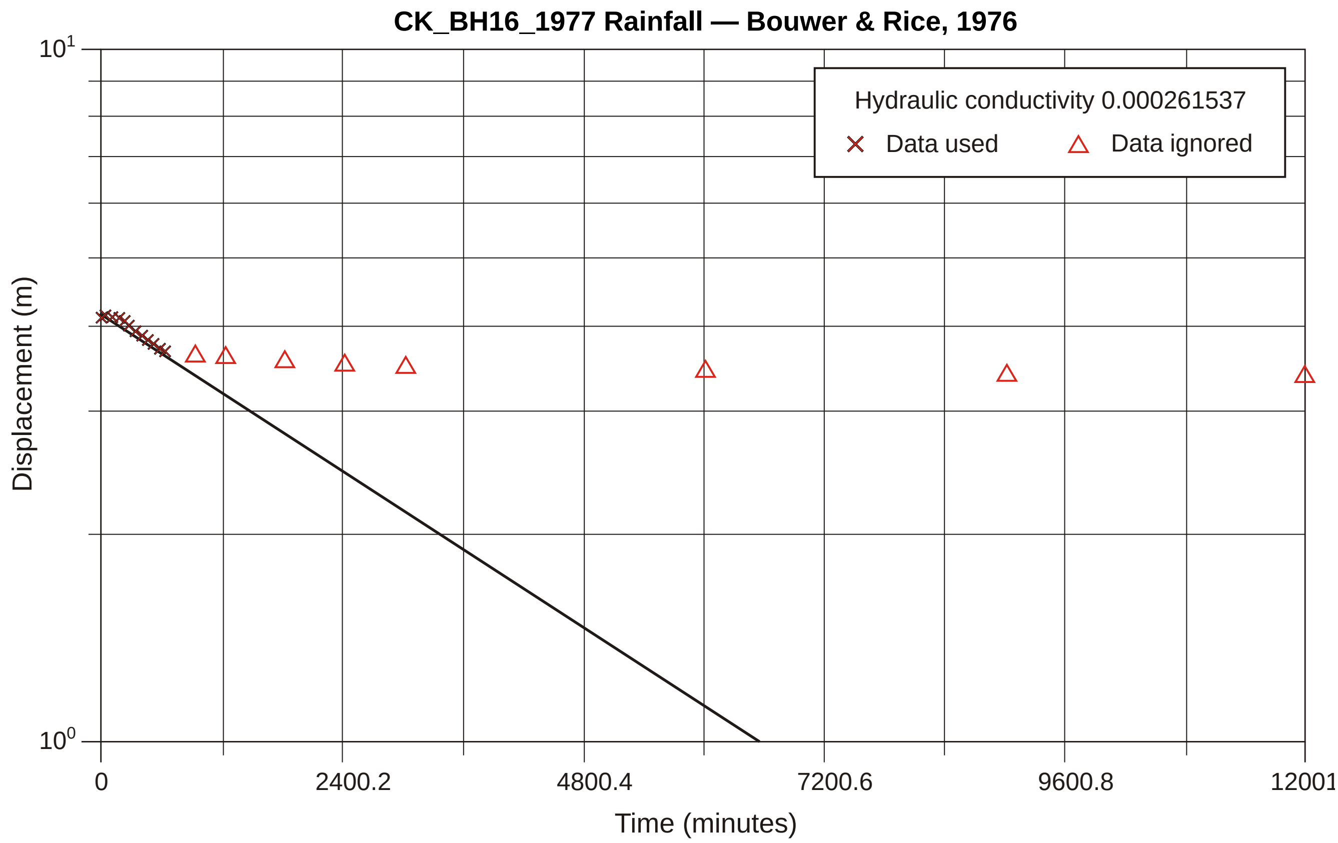

Figure 12

Solution of base flow recession curve for borehole CK_BH16_1977.

(1976) method (fig. 11) and is consistent with theoretical values of this lithology. Figure 12 also indicates that all other slug tests undertaken produced the same order of hydraulic conductivity. Hydraulic conductivity was calculated on borehole CK_BH16_1977 for the falling head component of the base flow recession curve, i.e. the section following significant rainfall events (fig. 12). The result is two orders of magnitude less (10^{-4} m/d) than a slug test on the same bore (10^{-2} m/d). In short the aquifer at this location is quick to recharge but slow to drain.

The high apparent conductivity for borehole CK_BH16_1977 (fig. 12), situated in clay, is possibly because the porosity is dominated by fissures in the clay medium. Fissuring has been observed in the clay and these features would allow water to flow readily, although it is not known how deep the fissures penetrate the subsurface and they may not necessarily extend to the base of LF1. In the case of the borehole CK_BH14_1977, uphill of the landslide and situated in the second sandy lithofacies with the same order of K (10^{-2} m/d), we suggest that while the local conductivity is normal for sand, there are impediments to flow over a larger area. A likely explanation is the effect of complex internal stratification that has been observed directly and is theoretically likely for fluvial deposits such as sand channels intercalated with overbank mud deposits. The sand aquifer in LF2 is complex in that it contains confining lenses of interbedded ironstone and high plasticity clay (as indicated by the borehole logs for LV_IBH1_2005 and LV_IBH2_2005). The hydrographs indicate that individual aquifers within LF2 are interconnected to some degree, allowing the passage of water and rapid pressure changes with time through these heterogenous deposits.

Time series data indicate that recharge on the ridge appears to occur where LF2 is exposed at the surface (as seen in the hydrograph of borehole CK_BH14_1977) and potentially via clay fissures in LF1 (as seen in the hydrograph of borehole CK_BH16_1977). As the hillside semi-confined aquifer is recharged, anisotropic flow rapidly increases the pore pressures within the aquifer (with a theoretical hydrostatic head of up to 40 m), perching water on the upper slopes of Talbot Ridge. During the winter months of 2005 the upper slopes of the Talbot Ridge aquifer remained perched, as seen in the hydrograph of borehole BM_R4_1996 (fig. 9). Recharge migrates downslope beneath LF1 to discharge from hillside springs topographically below LF1 or into the valley floor aquifer (LF6). This conceptual model is depicted in Figure 13.

Overall our conceptual model is consistent with that of Moore (1996).

Failure mechanism

Based on the spatial coincidence of LF1 with the landslides, the occurrence of cataclinal slopes (the dip direction is the same as the aspect of the hill slope) where the dip of the structure is equal to or less than

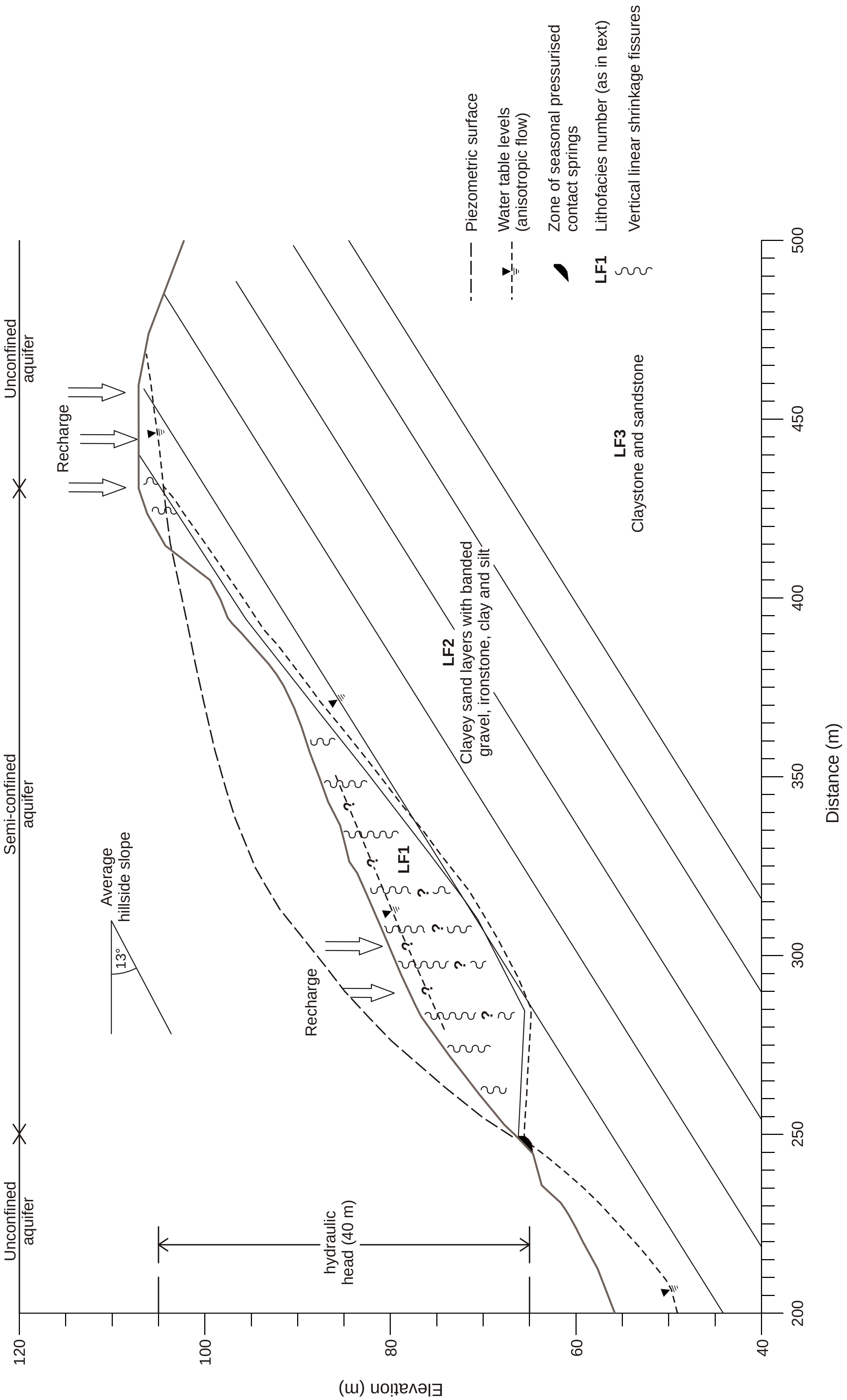

Figure 13

Hydrogeological conceptual model for the western side of Talbot Ridge.

the hillside slope, and the contrast in hydrological properties between LF1 and LF2, we have interpreted the failure surface to be situated approximately along this boundary over much of its length. With this geometry the three landslides would appear to be a combination of rotational and translational failure styles. Modelling of slope stability (Appendix 5) indicates that pressure changes in the LF1 fissured clay aquifer in the toe of the landslide are as important to landslide movement as LF2 pressure changes.

It is interesting to note that both the Lawrence Vale and Effingham landslides are situated on planimetrically concave slopes that tend to concentrate surface and near-surface water. However, the Powena Landslide is conspicuous in being situated on a ridge, suggesting that very local natural surface water ingress is not a vital factor in all cases. The conspicuous Lawrence Vale Landslide headscarp and concave/convex slope profile indicates that at least this landslide had formed prior to urbanisation and that natural causes must be considered significant prior to development. A simple hydrogeological model, where excessive pore pressures are developed below LF1, is a likely setting to promote instability. Hillside stability was further undermined in the toe areas of each of the landslides when roads were established without provision of significant support such as retaining walls. Surface cracking of the clay presents another opportunity for water ingress into the landslide. Stevenson (1975) described an important process affecting the overconsolidated clays of the Launceston Group that, when eroded, cause expansion, fissuring and a significant loss of strength due to the reduction of load. Saturation of the LF1 clays from groundwater recharge and surface infiltration is another factor that will conspire to lower hillside stability. A further process that may be important is strain softening. Strain softening can occur on slopes involving materials with marked differences in peak and residual shear strengths over time, leading to progressive failure. The slope stability models (Appendix 5) use residual shear strengths in LF1 clays.

The point to this discussion is that there are factors other than merely the simple strength parameters of the materials involved influencing the choice of threshold angles for landslide susceptibility modelling. Structure, lithology and groundwater (controlled by the two former attributes) are important controls but these are not easily modelled on a regional scale.

Implications for regional landslide assessment

Previous studies, such as Stevenson (1975), have shown that most of the landslides in the Launceston area occur within Launceston Group sediments. Furthermore, based on regional mapping in the Tamar Valley, Knights and Matthews (1976) contend that most of the slopes underlain by these sediments have, at some time, slipped.

It is our view that in order to understand regional landslide susceptibility it is important to understand how the landscape has evolved in the recent past.

Selkirk-Bell and Mazengarb (2005) have classified the landslides in the Tamar Valley according to a narrow range of geomorphological settings:

- Meander bends of major rivers where the outer bank of the river has eroded the adjacent valley side.
- Shorelines of the Tamar Estuary, where wave action has cut into the slope.
- Slopes below basalt caps and river terraces that are influenced by water percolation through the basalt. This is known as the reservoir effect (Denness, 1972), described previously by Stevenson and Sloane (1980).
- Slopes associated with incised side tributaries, where the slope is adjusting to lowering base levels.
- Slopes in a middle to upper slope position but adjacent to aggrading streams that are still adjusting to long-term lowering of base levels.
- Human influences such as urbanisation.

It is a well known phenomenon that river systems and related landscapes respond in various ways to relative rises and falls of sea level. In most of the settings above we present an argument to show that the geomorphological processes listed are substantially influenced by base level changes. Furthermore, because the Pleistocene tectonic uplift (a relative fall in sea level) previously discussed is restricted to a small part of Australia, the landscape evolution processes operating here may be substantially unique. This study does not consider changes in rainfall, weathering rates etc. associated with major climatic regimes that have an affect on rates of incision and mass wasting.

It is widely accepted that during the last two million years the climate has been dominated by cool periods (glacials) with short warmer (interglacial) events. During glacial times, when sea levels were substantially lower than today, the mouth of the Tamar was far removed (seaward) from its present position. In response to long-term regional uplift, catchment base levels have adjusted through channel incision. Typically, incision in catchments of considerable size experiencing uplift, such as the Tamar, begins at the river mouth and progressively extends up into the headwater regions. Where preserved, the boundary separating the younger incised landscape from older landscapes is often expressed as a nick point. Slopes upstream of a nick point are unaffected by the uplift at the point of time considered. With time the younger landscape enlarges and nick points migrate upstream, including side tributaries. Nick points occur widely in the Launceston area and are depicted by Selkirk-Bell and Mazengarb (2006). In a number of locations at Launceston, the up-valley migration of nick points is impeded by resistant geological units, such as dolerite.

A major nick point in the head of Rose Rivulet provides a good example of contrasting surficial processes within the catchment. Upstream of the nick point is the mature peneplain terrain described previously. In contrast, downstream of this, the hillsides are incised and landslides are prevalent (a more juvenile landform). It is well known that incision of channels undermines the support of adjacent slopes, eventually leading to mass wasting.

The mechanical processes leading to failure of Launceston Group clays are complex and probably include progressive failure including unloading effects, fissuring and chemical weathering (Knights, 1975; Stevenson, 1975). The process may take considerable time to develop on a slope and conceivably it could be out-of-sync with climatic cycles. Hence, the mapping of landscape features such as nick points and associated mature and more juvenile landforms is an important part of regional landslide susceptibility.

During interglacial periods (such as the present Holocene) when sea levels are high, there is a contrasting effect on landscape evolution and mass wasting processes according to conventional geomorphology theory. Based on global sea level curves the Tamar Valley was inundated by the sea reaching a maximum at approximately 6000 years BP to form a ria-type estuary. The rise in sea level would have been accompanied by coastal erosion and the removal of toe support, leading to an increase in slope instability. Upstream of the estuary, the lowland rivers were forced to adjust their base level through aggradation and by adopting a meandering channel system mode, given that the rate of sea level rise greatly exceeded tectonic uplift. In parts of the area, such as adjacent to Talbot Ridge, the aggradation has formed a buttress, up to 20 m thick, reducing land instability in the lower part of the slope. Higher parts of the hillside adjacent to buttressed areas may still fail because this portion of the slope is graded to the previous lower base level and long-term progressive failure mechanisms are occurring. The Lawrence Vale area lies in this setting.

In other parts of the lowland, geomorphic theory predicts that the change to a meandering river mode will locally accelerate mass wasting processes as rivers migrate laterally and widen the valley. It is worth noting that projected sea level rises for this century will tend to increase the meandering activity of the lowland streams and associated erosion unless the river channel is controlled by human intervention. An increase in sea level will also accelerate coastal attack of hillsides along the Tamar Estuary, further promoting land instability.

While lowland waterways have, and are adjusting to, high base levels, further upstream and in most mid to upper slope settings below the nick points, the stream gradients are unchanged and mass wasting processes will not be affected.

Structural controls (e.g. dipping strata) and associated hydrogeological processes have been shown previously to be locally important for regional landslide susceptibility. It is reasonable to suggest that cataclinal slopes in the Launceston area may have a higher susceptibility to failure than anaclinal slopes when all other factors are essentially similar. The style of failure may also differ between the two settings, which has implications for risk mitigation options for new and existing developments. The paucity of structural information, combined with a lack of detailed lithological mapping, makes it unwise to consider this factor in regional assessments beyond the Lawrence Vale area.

Conclusions

- Land instability is a widespread process in the Launceston area that can be categorised according to a restricted number of geomorphic settings, all of which to some degree can be attributed to base level changes controlling landscape evolution.
- An investigation of the Lawrence Vale area and a review of previous information was undertaken to understand the local processes leading to instability.
- The Launceston Group is a heterogeneous assemblage of lithologies containing a range of materials with contrasting geotechnical properties, all of which impact on slope stability. Unfortunately poor exposure means that the units recognised are difficult to map at a regional scale, hence the recent landslide susceptibility map (Mazengarb, 2005) is by necessity conservative.
- Investigations confirm that the Launceston Group sediments are locally dipping westward and are a critical factor in the development of the landslides at Lawrence Vale. It is reasonable to suggest that cataclinal slopes in the Launceston area may have a higher susceptibility to failure than anaclinal slopes when all other factors are essentially similar. The style of failure may also differ between the two settings, which has implications for risk mitigation options for new and existing developments.

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[24 September 2007]

Plate 1

Bore hole collar of DHH19 from 1959 CSIRO drilling program.

Plate 2

Initial collar condition of bore hole 14 (Knights, 1977) January 2005.

Plate 3

Maintenance works being undertaken on bore hole 14 (Knights, 1977) during January 2005.

Plate 4

Upgraded bore hole 14 (Knights, 1977), end of January 2005.

Plate 5

Drilling set up at drill hole LV_IBH1_2005, April 2005.

Plate 6

Inclinometer being installed in drill hole LV_IBH1_2005, April 2005.

Plate 7

Field logging of diamond core from drill hole LV_IBH1_2005, April 2005.

Plate 8

Polished slickenside defect in coal at 46.50 metres in drill hole LV_IBH1_2005.

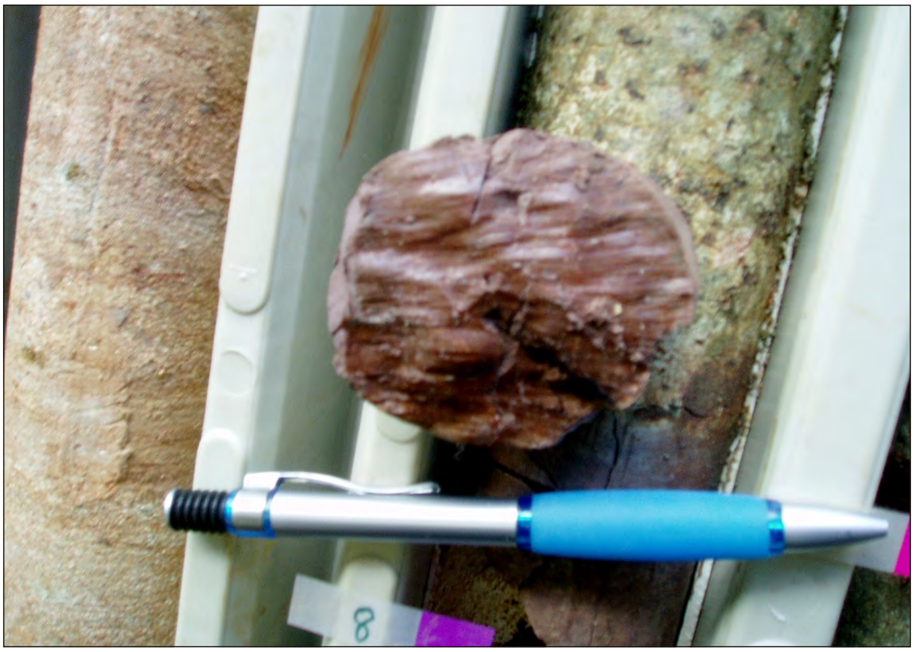


Plate 9

Polished slickenside defect in claystone at 62.80 metres in drill hole LV_IBH1_2005.

Table 1

Interception lengths and relative levels for the base of lithofacies 1, 2, 3, 4, and 6 defined by MRT, based on historical information and data collected during the April 2005 MRT drilling program

Figure 5 number	Borehole/ Test pit name	Date of investigation	Easting (m)	Northing (m)	RL (m)	Total depth of borehole/ test pit (m)	Start interception of LF 1 (m)	Finish interception of LF 1 (m)	Base of LF1 (m)	Start interception of LF 2 (m)	Finish interception of LF 2 (m)	Base of LF2 (m)	Start interception of LF 3 (m)	Finish interception of LF 3 (m)	Base of LF3 (m)	Start interception of LF 4 (m)	Finish interception of LF 4 (m)	Base of LF4 (m)	Start interception of LF 6 (m)	Finish interception of LF 6 (m)
1	CSIRO_DDH1_1960[1]	1/06/1960	512750	5410828	111.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	CSIRO_DDH2_1960[1]	1/06/1960	512485	5410715	76.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	CSIRO_DDH3_1960[1]	1/06/1960	512610	5410565	85.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4	CSIRO_DDH4_1960[1]	1/06/1960	512530	5410250	77.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5	CSIRO_DDH6_1960[1]	1/06/1960	512705	5410980	89.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	CSIRO_DDH7_1960[1]	1/06/1960	512825	5410532	107.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	CSIRO_DDH8_1960[1]	1/06/1960	512730	5410545	109.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	CSIRO_DDH9_1960[1]	1/06/1960	512695	5410450	108.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	CSIRO_DDH10_1960[1]	1/06/1960	512280	5410660	48.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	CSIRO_DDH13_1960[1]	1/06/1960	512472	5410408	66.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11	CSIRO_DDH18_1960[1]	1/06/1960	512410	5410320	58.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12	CSIRO_DDH19_1960[1]	1/06/1960	512646	5410514	90.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
13	LCC_TR1_1969[2]	30/09/1969	512521	5410504	71.0	5.5	71	67	67	67	65.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
14	CK_TP1_1974[3]	19/02/1974	513034	5410256	87	3	NA	NA	NA	87	84	NA	NA	NA	NA	NA	NA	NA	NA	NA
15	CK_TP2_1974[3]	19/02/1974	512971	5410256	89	2.3	NA	NA	NA	89	86.7	NA	NA	NA	NA	NA	NA	NA	NA	NA
16	CK_TP3_1974[3]	19/02/1974	512985	5410254	87	1.6	NA	NA	NA	87	85.4	NA	NA	NA	NA	NA	NA	NA	NA	NA
17	CK_BH1_1977[4]	1/10/1977	512580	5410532	78.4	10	78.4	69.3	69.3	69.3	68.4	NA	NA	NA	NA	NA	NA	NA	NA	NA
18	CK_BH2_1977[4]	1/10/1977	512547	5410549	73.1	10.9	73.1	68.6	68.6	68.6	62.2	NA	NA	NA	NA	NA	NA	NA	NA	NA
19	CK_PBH3_1977[4]	1/10/1977	512540	5410560	69.5	6.3	69.5	65	65	65	63.2	NA	NA	NA	NA	NA	NA	NA	NA	NA
20	CK_PBH4_1977[4]	1/10/1977	512547	5410497	76.2	10	76.2	66.2	66.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
21	CK_BH5_1977[4]	1/10/1977	512550	5410455	79.7	10	79.7	71.5	71.5	71.5	67.7	NA	NA	NA	NA	NA	NA	NA	NA	NA
22	CK_BH6_1977[4]	1/10/1977	512523	5410445	74.6	7.3	74.6	68.2	68.2	68.2	67.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
23	CK_BH7_1977[4]	1/10/1977	512505	5410475	67.2	3.6	67.2	66.3	66.3	66.3	63.6	NA	NA	NA	NA	NA	NA	NA	NA	NA
24	CK_PBH8_1977[4]	1/10/1977	512622	5410487	89.7	7.2	89.7	82.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
25	CK_PBH9_1977[4]	1/10/1977	512623	5410518	86.5	7.2	86.5	79.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
26	CK_PBH10_1977[4]	1/10/1977	512590	5410410	86.4	5.4	86.4	81	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
27	CK_PBH11_1977[4]	1/10/1977	512635	5410542	85.5	8.2	85.5	84.6	84.6	84.6	77.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
28	CK_PBH12_1977[4]	1/10/1977	512644	5410601	87.6	6.4	NA	NA	NA	87.6	81.2	NA	NA	NA	NA	NA	NA	NA	NA	NA
29	CK_BH13_1977[4]	1/10/1977	512580	5410650	83.1	7.3	83.1	75.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
30	CK_PBH14_1977[4]	1/10/1977	512642	5410659	91.8	6.4	NA	NA	NA	91.8	85.4	NA	NA	NA	NA	NA	NA	NA	NA	NA
31	CK_BH15_1977[4]	1/10/1977	512607	5410752	88.2	4.5	88.2	83.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
32	CK_PBH16_1977[4]	1/10/1977	512502	5410402	72.3	8.2	72.3	64.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
33	CK_PBH17_1977[4]	1/10/1977	512497	5410466	68.3	12.1	68.3	66.5	66.5	66.5	56.2	NA	NA	NA	NA	NA	NA	NA	NA	NA
34	CK_BH18_1977[4]	1/10/1977	512476	5410483	60.2	11.4	NA	NA	NA	60.2	48.8	NA	NA	NA	NA	NA	NA	NA	NA	NA
35	CK_BH19_1977[4]	1/10/1977	512450	5410438	63.1	9	63.1	54.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
36	CK_BH20_1977[4]	1/10/1977	512650	5410461	98.1	9	98.1	96.3	96.3	96.3	89.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
38	BM_BH1_1983[5]	8/02/1983	512302	5410710	49.5	5	49.5	44.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
39	BM_BH2_1983[5]	8/02/1983	512330	5410695	56	2.4	56	53.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
40	BM_BH3_1983[5]	8/02/1983	512315	5410695	53.5	2.4	53.5	51.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
41	LM_TP1_1983[6]	6/05/1983	512802	5410802	107	2.1	NA	NA	NA	107	104.9	NA	NA	NA	NA	NA	NA	NA	NA	NA
42	LM_TP2_1983[6]	6/05/1983	512801	5410817	108	1.2	NA	NA	NA	108	106.8	NA	NA	NA	NA	NA	NA	NA	NA	NA
43	LM_TP3_1983[6]	6/05/1983	512817	5410809	105	2.7	NA	NA	NA	105	102.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
44	LM_TP4_1983[6]	6/05/1983	512813	5410821	105	2.7	NA	NA	NA	105	102.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
45	LM_TP5_1983[6]	6/05/1983	512828	5410812	102	2.1	NA	NA	NA	102	99.9	NA	NA	NA	NA	NA	NA	NA	NA	NA
37	MD_PBH8_1984[7]	1/06/1982	512624	5410468	91	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
46	LM_TP1_1984[8]	12/06/1984	512513	5411045	72.5	3.1	NA	NA	NA	72.5	69.4	NA	NA	NA	NA	NA	NA	NA	NA	NA
47	LM_TP2_1984[8]	12/06/1984	512475	5411058	65	3.1	NA	NA	NA	65	61.9	NA	NA	NA	NA	NA	NA	NA	NA	NA
48	LM_TP3_1984[8]	12/06/1984	512440	5411038	65	3.1	NA	NA	NA	65	61.9	NA	NA	NA	NA	NA	NA	NA	NA	NA
49	LM_TP4_1984[8]	12/06/1984	512390	5411042	56.5	3.3	NA	NA	NA	56.5	52.2	NA	NA	NA	NA	NA	NA	NA	NA	NA
50	BW_TP1_1985[9]	12/11/1985	512630	5411140	94	2.7	94	91.5	91.5	91.5	91.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
51	BW_TP2_1985[9]	12/11/1985	512640	5411140	95	3.2	95	91.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
52	BW_TP3_1985[9]	12/11/1985	512638	5411128	97	1.9	97	95.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
53	BW_TP4_1985[9]	12/11/1985	512650	5411125	99	3	99	96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
54	LM_TP1_1986[10]	21/04/1986	512375	5410560	42.5	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	42.5	40.5
55	LM_TP2_1986[10]	21/04/1986	512423	5410590	47	2.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	47	44.6
56	LM_TP3_1986[10]	21/04/1986	512408	5410610	48	2.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	48	45.3
57	LM_TP4_1986[10]	21/04/1986	512362	5410583	43	2.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	43	40.4
58	LM_TP5_1986[10]	21/04/1986	512317	5410572	40.5	2.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	40.5	37.6
59	LM_TP1_1988[11]	6/10/2005	512695	5410930	103	2.5	103	100.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
60	LM_TP2_1988[11]	6/10/2005	512695	5410910	103	2.65	103	100.35	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 1 (continued)

Figure 5 number	Borehole/ Test pit name	Date of investigation	Easting (m)	Northing (m)	RL (m)	Total depth of borehole/ test pit (m)	Start interception of LF 1 (m)	Finish interception of LF 1 (m)	Base of LF1 (m)	Start interception of LF 2 (m)	Finish interception of LF 2 (m)	Base of LF2 (m)	Start interception of LF 3 (m)	Finish interception of LF 3 (m)	Base of LF3 (m)	Start interception of LF 4 (m)	Finish interception of LF 4 (m)	Base of LF4 (m)	Start interception of LF 6 (m)	Finish interception of LF 6 (m)
61	BM_PBH1_1996[12]	2/04/1996	512011	5410931	22.6	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	22.6	15.6
62	BM_PBH2_1996[12]	2/04/1996	512074	5410969	25.66	8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	25.66	17.66
63	BM_PBH3_1996[12]	2/04/1996	512229	5410445	41.09	6.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	41.09	34.89
64	BM_PBH4_1996[12]	3/04/1996	512129	5410740	27.93	6.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	27.63	21.63
65	BM_PBH5_1996[12]	4/04/1996	512268	5410511	37.59	6.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	37.59	31.29
66	BM_PBH6_1996[12]	4/04/1996	512298	5410366	47.01	6.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	47.01	40.51
67	BM_PBH7_1996[12]	10/04/1996	512088	5410592	37.21	6.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	37.21	30.71
68	BM_PBH8_1996[12]	11/04/1996	512437	5410425	60.86	6.25	60.86	54.61	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
69	BM_PBH9_1996[12]	11/04/1996	512321	5410856	39.45	6.25	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	39.45	33.2
70	BM_PBH_R1_1996[13]	2/07/1996	512749	5410770	115	11.8	115	103.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
71	BM_PBH_R2_1996[13]	3/07/1996	512722	5410776	111	14.5	111	96.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
72	BM_PBH_R3_1996[13]	3/07/1996	512707	5410778	108	8.05	108	104	104	104	99.95	NA	NA	NA	NA	NA	NA	NA	NA	NA
73	BM_PBH_R4_1996[13]	1/07/1996	512662	5410817	98	4.5	98	95	95	95	93.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
74	BFP_BH1_2004[14]	3/12/2004	512325	5410593	44	5.6	44	41.6	41.6	41.6	38.4	NA	NA	NA	NA	NA	NA	NA	NA	NA
75	BFP_BH2_2004[14]	3/12/2004	512344	5410597	45	4.7	45	43.6	43.6	43.6	40.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
76	BFP_BH3_2004[14]	3/12/2004	512349	5410539	41	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	41	39
77	BFP_BH4_2004[14]	3/12/2004	512388	5410561	44	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	44	42
78	BFP_BH5_2004[14]	3/12/2004	512446	5410626	53	5.6	NA	NA	NA	53	47.4	NA	NA	NA	NA	NA	NA	NA	NA	NA
79	BFP_BH6_2004[14]	3/12/2004	512424	5410622	50.5	4.7	NA	NA	NA	50.5	45.8	NA	NA	NA	NA	NA	NA	NA	NA	NA
80	BFP_BH7_2004[14]	3/12/2004	512368	5410603	47	4.7	NA	NA	NA	47	42.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
81	BFP_BH8_2004[14]	14/12/2004	512468	5410567	55	1.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	55	53.5
82	LV_IBH1_2005[15]	18/04/2005	512572	5410480	81	64.5	81	71	71	71	38	38	38	23	23	23	16.5	NA	NA	NA
83	LV_IBH2_2005[15]	26/04/2005	512412	5410774	67	26.5	67	61	61	61	42	42	42	40.5	NA	NA	NA	NA	NA	NA
84	LV_PBH3_2005[15]	27/04/2005	512411	5410773	67	13.5	67	61	61	61	53.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
85	LV_PBH4_2005[15]	28/04/2005	512548	5410497	76.2	12.75	76.2	66	66	66	63.45	NA	NA	NA	NA	NA	NA	NA	NA	NA

1. CSIRO drilling program 1961 (Polak, 1964; Wiebenga, 1964)
2. Stevenson and Jennings, 1971
3. Knights, 1975
4. Knights, 1977
5. Letter from Department of Mines to Mr Darkin, Gutteridge, Haskins & Davey, Consulting Engineers, Launceston, 29 March 1983
6. Letter from Department of Mines to The Town Clerk, Launceston City Council, 6 May 1983
7. Letter from Department of Mines to Mr Phillip Bell, Smith, Sale and Burbury, Consulting Engineers, Launceston, 25 May 1984
8. Letter from Department of Mines to Mr C. J. Cohen, Cohen and Associates Pty Ltd, Surveyors and Town Planners, Launceston, 12 June 1984
9. Letter from Department of Mines to Mr R. Holwill, South Launceston, 2 January 1986
10. Letter from Department of Mines to Mr R. Langridge, Launceston, 21 April 1986
11. Letter from Department of Mines to Mr R. Holwill, South Launceston, 6 October 1988
12. Roberts, 1996
13. Moore, 1996
14. BFP Consultants Pty Ltd, site investigation and slope stability appraisal, reference number : 230416, 22 December 2004
15. MRT April 2005 drilling program

APPENDIX 1

Selected extracts from previous studies pertinent to the Lawrence Vale Landslide

Carey, 1958

"The Lawrence Vale Meredith slip area is larger and more complex than the others. It is not a single slip circle but a group of slip circle failures. Originally, before the houses were built, there seems to have been a single old slip circle failure with its head at the present position of Lawrence Vale Road near numbers 96 to 106 and its toe behind the present position of the houses on numbers 53 to 57 Meredith Crescent. Subsequently new slips have developed uphill and laterally from the original slip. The one behind the original slip takes a deeper slice so that its heave appears in front of the heave of the old slip."

"The movement of the last couple of years, while still of slip circle type is compound, with two principal lobes side by side, each of which is divided into two masses one above the other."

"Still another slip seems to be commencing with its heave lobe along the east side of Leslie Street. All of the houses from No. 47 to No. 59 show incipient damage and strain in their front portions, and a breakthrough has developed on the road in front of No. 59. This is a new slip which could wreck all of these houses if it gets away."

"…there is a particular clay formation in the region which is more prone to slipping than others. Such susceptibility is a combination of mechanical properties, the water permeability of the beds above them and the steepness of the slopes."

"A severe earth tremor would be likely to trigger off a catastrophic slip. To sum up, my judgement is that the probability of a catastrophic slide is low. However this must not be read as an assurance that it could not occur."

Polak, 1964

"The area affected by landslip is characterised by a very-low-resistivity layer. Neighbouring areas of high resistivity represent sandstone or siltstone and no damage resulting from landslip is evident there."

Wiedenga, 1964

"Therefore, it is considered that any place where the salt content has been leached out of the clay sediments should be regarded as a potential landslip zone."

Jennings, 1971

"Whilst the causes for the general instability of the area may be many and complex, the cause of the present slip is probably due to the following factors:

1. Previous movements in the area resulting in the formation of unstable sedimentary slices with inherent slip planes.
2. Above average rainfall over the past couple of winters and particularly this winter.
3. Surface cracking of the clay during the summer allowing infiltration of the water into the slip mass during the winter.
4. Infiltration of water into the slip mass from unspecified groundwater sources.

. . . . Nevertheless, the slip is a potential danger to nearby property and close vigilance is essential; any sign of collapse of the road embankment should be taken as sufficient cause to evacuate residents immediately down slope of the road."

Stevenson and Jennings, 1971

"Deformation has been largely plastic as evidenced by the failure in the lateral trench, by the mudflows and indirectly by the tensional nature of the surface: this has resulted in downhill slope movement rather than backward tilting. . . . . Very moist but shallow (<12 ft) zones which are connected with surface cracks are abundant in the excavations, though not visually obvious."

Knights, 1977

"An aquifer of fine sand exists in the vicinity of Effingham Street and Lawrence Vale Road. This aquifer has a channel downwarp and it contains water under pressure, which maybe supplemented by sewage. Materials in, and closely above the aquifer, are weak, and form a base upon which the upslope land can slip. Land downslope of the aquifer receives seepage and the sediments are soft and moist. Clay is close to it c′ = 0 condition. Landslipping below the aquifer takes place in these softened materials. The movements are at variable depths. . . . . The conditions which caused this landslip extend along the slope."

"More work is needed to determine the extent and nature of the sandy aquifer, and to determine the extent of hillside which is underlain by moist, fully softened clay. This may be done by auger drilling and geophysical methods, working outwards from the known area. . . . . More work should also be done on the analysis of groundwater of the sandy aquifer to determine whether it is contaminated by sewage."

Moore, 1996

"Which . . . . groundwater model is correct is not an academic question. The answer could possibly provide a guide as to the mechanism and an explanation for the seepages and the periodic down slope movements of South Launceston of which the Lawrence Vale 1959 landslide appears to have been but one major episode."

"Given these factors the weekly monitoring results could be misleading. The water level could peak briefly . . . . by interconnected fissures in the impermeable clay. Either by a rise in the watertable or a sub artesian, uplift confined pressure, in a clay soft zone could provide the mechanism for a slope failure."

"A slope stability assessment should be a major component of any further investigation of this site. For this assessment to be realistic, requires an input of more soil laboratory testing, geohydrology and geological data."

APPENDIX 2

Engineering logs and photos of drill core

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - **LV_IBH1_2005** **(LV_ARE_2005_1)**

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
0–0.5	SA	OL	SILTY CLAY, SILT - dark yellowish brown.					0 to 0.75 m Solid stem auger drilling.
0.5–0.75	SA	CL	SILTY CLAY - medium plasticity, dark yellowish brown.					
0.75–2.35	SS	CL	CLAY - medium plasticity, mottled red, reddish grey.	D	VSt	11+		0.75 to 6.00 m Split spoon sampling Hollow stem auger drilling.
2.35–4	SS	CL	CLAY - medium plasticity mottled red, light grey, banded ironstone to 1 mm (3.00 to 3.75 m).		St	5.1		

Cement

70 mm Inclinometer casing

Cement / Bentonite Grout


0.50m
0.75m
1.50m
2.25m
3.00m
3.75m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 1 SAMPLE No. N/A
DEPTH FROM 0 M TO 4.00 M
FILM No. N/A FRAME No. N/A
0.50m
0.75m
1.50m
2.25m
3.00m
3.75m

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - **LV_IBH1_2005** **(LV_ARE_2005_1)**

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering
4	SS	CL		D	St	5.1	
	SS	CL	CLAY - medium plasticity, mottled red, light grey.	D	St	2.6	
5	SS	CL	CLAY - medium plasticity, yellowish brown.	D	St	4.4	
	SS	CH	CLAY - high plasticity, dark yellowish brown.	D	St	9.1	
	SS	CH	CLAY - high plasticity, mottled light yellowish brown , light grey, black.	D	F	3.8	
6	SS	CH	CLAY - high plasticity, mottled dark red, yellowish brown, light grey.	D	VSt	10.2	
	DC	CH	CLAY -high plasticity, strong brown.	D	F	5.4	
	DC	CH	CLAY - high plasticity, mottled yellowish brown, strong brown, light grey.	D	F	7.6	
	DC		IRONSTONE - black	D	H		
	DC	CH	CLAY - high plasticity, banded yellowish brown, dark greyish brown.	D	F	5.3	
7	DC	CL	CLAY - medium to high plasticity, greyish brown, banded and mottled black.	D	St	6.1	
8	DC	CH	CLAY - high plasticity, yellowish brown, mottled black.	D	St	6.2	

REMARKS, and defect descriptions

6.00 to 64.5 m
Triple tube
HQ3 diamond drilling.

Atterberg limits
Sample LL1
6.02 to 6.10 m
MRT Sample ID
E201612

Atterberg limits
Sample LL2
6.20 to 6.25 m
MRT Sample ID
E201613

6.45 m
0 to 23 degrees
ironstone
rough
3 mm

7.28m
2 degrees
organic wood
rough irregular
2mm

70 mm Inclinometer casing

Cement / Bentonite Grout


4.50m
5.25m
6.00m
6.18m
7.60m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 2 SAMPLE No. N/A
DEPTH FROM 4.00 M TO 8.00 M
FILM No. N/A FRAME No. N/A
4.50m
5.25m
6.00m
6.18m
7.60m

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT of INFRASTRUCTURE, ENERGY and RESOURCES

ENGINEERING LOG - LV_IBH1_2005 (LV_ARE_2005_1)

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
8	DC	CH		D	St	6.2		
		CH	CLAY - high plasticity, brown, mottled dark yellowish brown, black, sedimentary gravel.			5.6		
9		CL	SANDY CLAY - medium plasticity, light yellowish brown, flecked organics, black.			10.8		Atterberg limits Sample LL3 8.90 to 9.98 m MRT Sample ID E201614 9.10 m Start drilling 19/04/05.
		MH	CLAYEY SILT - reddish yellow.	M				9.45 m 11 degrees rough irregular 8 mm (Possible crushed seam)
		MH	CLAYEY SILT - mottled brownish yellow, light yellowish brown.	D	D	7.0		
10		SC	SILTY SAND - fine, yellowish brown, light brownish grey.			6.0		
		SC	CLAYEY SAND - fine, flecked pale brown, yellowish brown.	M		8.3		
11–12		SM	SILTY SAND - fine, brownish yellow, light yellowish brown.	M	MD			10.70 m 15 degrees rough irregular 2 mm 11.73 m 0 degrees organics smooth 1mm

70 mm Inclinometer casing

Cement / Bentonite Grout


9.10m
10.60m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 3 SAMPLE No. N/A
DEPTH FROM 8.00 M TO 11.80 M
FILM No. N/A FRAME No. N/A
9.10m
10.60m

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - LV_IBH1_2005 (LV_ARE_2005_1)

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penertrometer (kg)	Weathering	REMARKS, and defect descriptions
12	DC	SM		M	MD			Drilling fluid loss high in this sand layer.
13			IRONSTONE - dark red.		H			12.95 m 3 degrees ironstone coated rough 1mm
		CH	CLAY - high plasticity, light olive brown.	D	St	6.5		
			IRONSTONE - dark red.		H			
		CH	CLAY - high plasticity, light olive brown.	D	St	6.5		Rapid falling drill head, 13.60 to 15.10 m. Zones of softer material.
		SW	SAND - fine to medium, yellowish brown.					
14		SW	SAND - fine to medium, yellowish brown, flecked feldspar, quartz, banded ironstone.	M	MD			Vey soft material, maybe first aquifer level.
			NO CORE					Possible aquifer level. Most likely same sand as above and below core loss.
15		SW	SAND - fine to medium, yellowish brown, flecked feldspar, quartz, banded ironstone.	M	MD			Shear box test Sample SB10 15.05 to 15.10 m MRT Sample ID E201629
			NO CORE					
		SW	SAND - fine to medium, yellowish brown, flecked feldspar, quartz, banded ironstone.	M	MD			15.51 m 40 degrees rough irregular 1mm
			IRONSTONE - dark red.		H			
		CH	CLAY - high plasticity, greyish brown.	M	F	4.0		Shear box test Sample SB1 15.87 to 15.97 m MRT Sample ID E201620
			IRONSTONE - very dark greyish brown.	D				
16		CH	CLAY - high plasticity, brownish yellow, very dark greyish brown.	M	S	0.3		

70 mm Inclinometer casing

Cement / Bentonite Grout


12.10m
13.05m
13.60m
0.25m Core loss
15.10m
0.10m Core loss
15.45m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 4 SAMPLE No. N/A
DEPTH FROM 11.80 M TO 15.55 M
FILM No. N/A FRAME No. N/A
12.10m
13.05m
13.60m
0.25m Core loss
15.10m
0.10m Core loss
15.45m

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - **LV_IBH1_2005** **(LV_ARE_2005_1)**

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
16	DC	CH			S			
		SM	SILTY SAND - medium, yellowish brown, light yellowish brown, flecked quartz, mottled organics, black, banded ironstone to 3mm.	M	D			
		SC	SILTY SAND - medium, brownish yellow, flecked quartz, feldspar, intergranular organics, black, iron oxide.					
17		CH	CLAY - high plasticity, light brownish grey, yellowish brown.		S	1.4		High drilling fluid loss 17.10 to 17.30 m.
			NO CORE					
18		SC	SILTY SAND - medium, brownish yellow, flecked quartz, feldspar, intergranular organics, black, iron oxide.	M	D			18.65 and 18.90 m 10 to 15 degrees rough iron oxide spacing 25 mm thickness 2 mm
								Possbile base of aquifer.
20			IRONSTONE - dark red.		H			

70 mm Inclinometer casing

Cement / Bentonite Grout


15.80m
16.60m
0.20m core loss
18.10m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 5 SAMPLE No. N/A
DEPTH FROM 15.55 M TO 19.50 M
FILM No. N/A FRAME No. N/A
15.80m
16.60m
0.20m core loss
18.10m

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

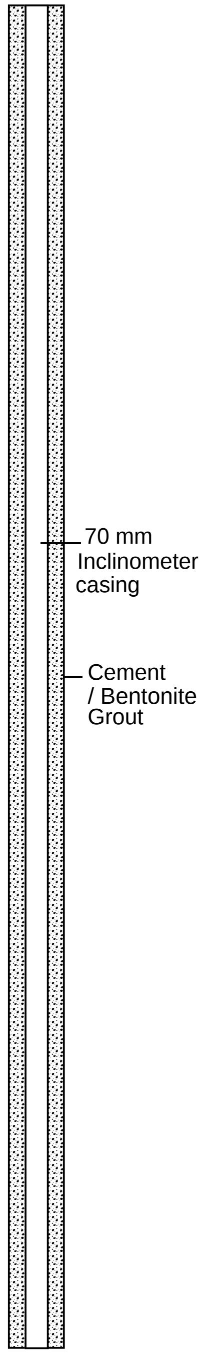
ENGINEERING LOG - LV_IBH1_2005 (LV_ARE_2005_1)

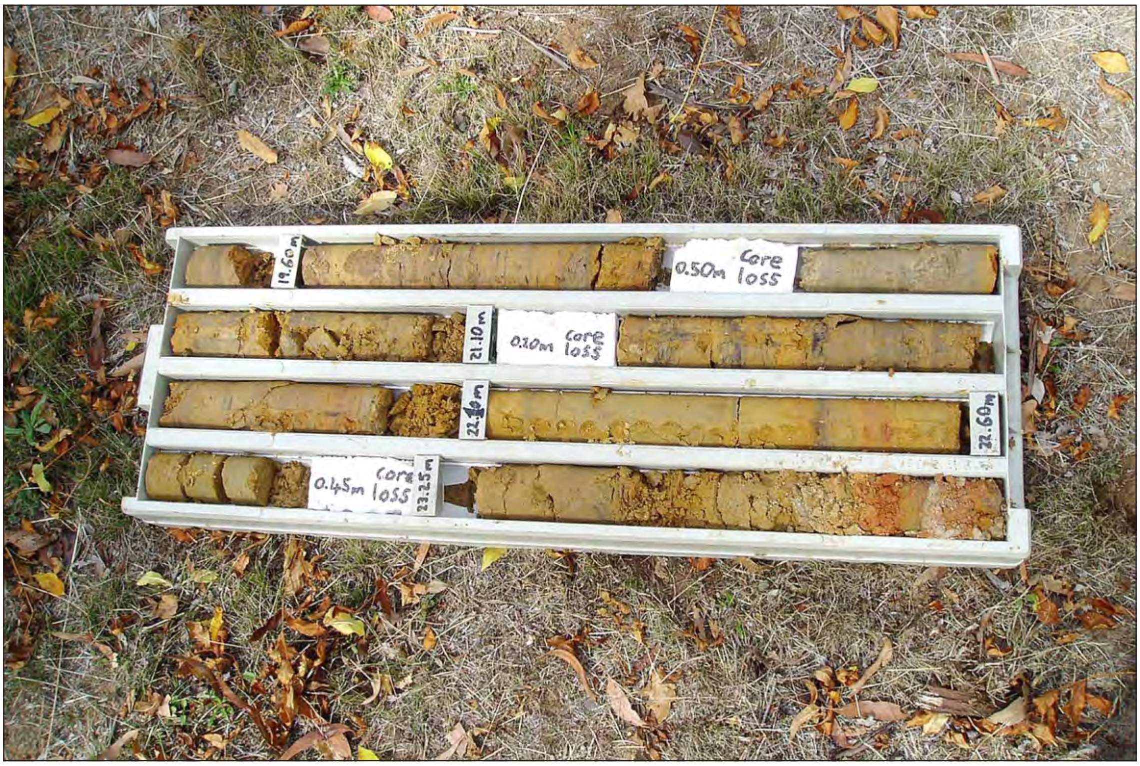
Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
20	DC		NO CORE					
		CH	CLAY - high plasticity, light olive brown.	M	St	5.2		
		SC	SILTY SAND - fine to medium, yellowish brown, flecked quartz, feldspar.	M	MD			
21			NO CORE					
		SC	CLAYEY SAND - fine to medium, banded yellowish brown, light yellowish brown, dark red, flecked quartz, intergranular organics, black.	M	D	2.2		
22								
			NO CORE					Major loss of all drilling fluid, rapid drop of drill head, 22.60 to 23.25 m. Possible failure plane.
23								
		SC	CLAYEY SAND - fine, brownish yellow.	M	MD	0.8		
		SC	SAND - fine, light grey, red, yellowish brown.	D	MD			
		SC	IRONSTONE - dark red.	D	H D H			
		SC	SAND - fine, light grey, red, yellowish red.	D	D			
			IRONSTONE - dark red.					
24			SAND - fine to medium, yellowish brown, yellowish brown, quartz, organics, black.					




19.60m
0.50m Core loss
21.10m
0.10m core loss
22.60m
0.45m Core loss
23.25m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 6 SAMPLE No. N/A
DEPTH FROM 19.50 M TO 23.70 M
FILM No. N/A FRAME No. N/A
19.60m
0.50m Core loss
21.10m
0.10m core loss
22.60m
0.45m Core loss
23.25m

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - LV_IBH1_2005 (LV_ARE_2005_1)

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Columns: Depth in Meters | Sample | GRAPHIC | USCS | DESCRIPTION | Moisture condition | Consistency Density index | Average hand penetrometer (kg) | Weathering | REMARKS, and defect descriptions

Depth: 24 – 28 m. Sample: DC

USCS (top to bottom): SC, SM, SC, CH, SC, SC, CH, GC, CH, CH, CH, CL, CL, CH, SM, SC, SC, CH, SC

DESCRIPTION
SILTY SAND - fine, brownish yellow, banded plastic clay, very dark grey.
SAND - yellowish brown, ironstone.
CLAY - high plasticity, banded greyish brown, grey.
IRONSTONE - dark red.
CLAYEY SAND - fine, yellowish brown.
CLAYEY SAND - fine, brownish yellow.
CLAY - high plasticity, grey, banded sand, medium, yellowish brown.
CLAYEY GRAVEL - black, grey, cemented.
CLAY - high plasticity, grey, banded sand, fine, brownish yellow.
IRONSTONE - red.
CLAY - high plasticity, grey, banded sand, fine, brownish yellow.
IRONSTONE - dark brown.
CLAY - high plasticity, light brownish grey.
CLAY - medium plasticity, yellowish brown, ironstone.
NO CORE
CLAY - medium plasticity, yellowish brown, ironstone.
CLAY - high plasticity, grey, yellowish brown, red, black, ironstone.
SILTY SAND - fine, yellowish brown.
SAND - medium, flecked yellowish brown, red, white, grey, black, quartz.
NO CORE
SAND - medium, flecked yellowish brown, red, white, grey, black, quartz.
CLAY - high plasticity, very dark grey.

Moisture condition (top to bottom): D, M, M, D, M, M, M, M, D, D, M, M

Consistency / Density index (top to bottom): D, MD, H, St, VD, MD, St, H, St, H, St, H, St, St, F, D, D, S

Average hand penetrometer (kg) (top to bottom): 8.2, 11+, 4.4, 7.1, 3.3, 3.3, 6.6, 4.8, 4.8, 6.2, 0.8

REMARKS, and defect descriptions:

26.44 m
15 to 40 degrees
iron oxide
rough
spacing 5 mm
thickness 2 mm

27.90 m
smooth
1mm

70 mm Inclinometer casing

Cement / Bentonite Grout


24·10m
25.10m
25.60m
0.10m core LOSS
27.10m
0.20m CORE LOSS


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 7 SAMPLE No. N/A
DEPTH FROM 23.70 M TO 27.60 M
FILM No. N/A FRAME No. N/A
24·10m
25.10m
25.60m
0.10m core LOSS
27.10m
0.20m CORE LOSS

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - LV_IBH1_2005 (LV_ARE_2005_1)

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Sample: DC (28–32 m)

Depth in Meters	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
28	SC	CLAYEY SAND - fine to medium, brownish yellow, flecked quartz.	M	D	4.5		
	CL	SILTY CLAY - plastic, yellowish brown.	M	St	9.2		
	CH	CLAY - high plasticity, grey.		F	3.1		
	CL	SANDY CLAY - medium plasticity, yellowish brown.	D	VSt	11+		
	CH	CLAY - high plasticity, grey.	M	F	4.3		
		NO CORE					
29	CH	CLAY - high plasticity, grey, banded ironstone (hard).		F	3.8		
	SM	SAND - fine to medium grained, flecked grey brown, reddish yellow, quartz, feldspar.	M				
30	SM	SAND - medium, flecked reddish yellow, brown, black, quartz.		MD			
	CH	CLAY - high plasticity, dark to very dark grey, gravelly sand, fine, cemented yellowish brown.	M/D	F	3.0		30.25 to 30.55 m Dipping beds 12 degrees
31	SM	SAND - fine to medium, banded reddish brown, yellowish brown.	M	MD			
	CH	CLAY - high plasticity, dark grey.		S	1.1		31.38 m smooth planar 1 mm
	SC	CLAYEY SAND - fine to medium, cemented grey, yellowish brown, banded ironstone.	D	D	6.3		
	SW	SAND - medium, flecked yellowish brown, quartz.	M	MD			
		NO CORE					
32	SC	CLAYEY SAND - fine to medium, flecked yellowish brown, yellow, quartz.	M	MD	3.5		

70 mm Inclinometer casing

Cement / Bentonite Grout


28.60m
0.15m CORE LOSS
30.10m
0.15m CORE LOSS
31.60m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 8 SAMPLE No. N/A
DEPTH FROM 27.60 M TO 31.60 M
FILM No. N/A FRAME No. N/A
28.60m
0.15m CORE LOSS
30.10m
.15m CORE LOSS
31.60m

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - **LV_IBH1_2005** **(LV_ARE_2005_1)**

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
32–33.6	DC	SC		M	MD	3.5		
33.6–34.75	DC	CH	CLAY - high plasticity, grey, banded cemented sand, yellowish brown, (hard).	M	F	3.8		Start drilling 20/04/05.
34.75–35.8	DC	SW	SAND - medium, yellowish brown, flecked quartz, feldspar.	M	D			
35.8–35.82	DC	CH	CLAY - high plasticity, grey.	M	S	1.8		
35.82–36	DC	SW	SAND - fine to medium, yellowish brown, 36.05 to 36.10 iron oxide, dark reddish brown.	M	MD			

Depth scale: 32, 33, 34, 35, 36

70 mm Inclinometer casing

Cement / Bentonite Grout


0.15m CORE LOSS
33.10m
34.60m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 9 SAMPLE No. N/A
DEPTH FROM 31.60 M TO 35.40 M
FILM No. N/A FRAME No. N/A
0.15m CORE LOSS
33.10m
34.60m

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - LV_IBH1_2005 (LV_ARE_2005_1)

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)
SW				
SC	CLAYEY SAND - fine to medium, yellowish brown, iron oxide, reddish brown, flecked quartz.		MD	2.2
CH	CLAY - high plasticity, grey.	M	S	2.6
SW	SAND - medium, yellowish brown.		MD	0.6
CH	CLAY - high plasticity, grey to dark grey.		F	4.0
SC	CLAYEY SAND - fine to medium, dark grey, yellowish brown.		MD	6.0
	NO CORE			
CH	CLAY - high plasticity, greyish brown.	D	F	2.6
SC	CLAYEY SAND - fine to medium, yellowish brown.	M	MD	3.1
CH	CLAY - high plasticity, grey, dark grey.		F	3.8
MH	CLAYEY SILT - yellowish brown.	D	H	10.8
SC	CLAYEY SAND - fine, yellowish brown, reddish, brown, banded clay, high plasticity, dark grey.	D/M	MD/D	7.6

Depth in Meters: 36 – 40

Sample: DC

REMARKS, and defect descriptions:

Shear box test
Sample SB2
37.95 to 38.05 m
MRT Sample ID
E201621

Atterberg limits
Sample LL4
38.38 to 38.42 m
MRT Sample ID
E201615

38.78 m
organic wood
rough
4 mm

Shear box test
Sample SB3
39.95 to 40.05m
MRT Sample ID
E20162

70 mm Inclinometer casing

Cement / Bentonite Grout


36.10m
37.60m
39.10m
0.20m CORE LOSS


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 10 SAMPLE No. N/A
DEPTH FROM 35.40 M TO 39.30 M
FILM No. N/A FRAME No. N/A
36.10m
37.60m
39.10m
0.20m CORE LOSS

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - LV_IBH1_2005 (LV_ARE_2005_1)

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
40.00–41.15	DC	SC		D/M	MD/D	7.6		Shear box test Sample SB4 41.00 to 41.15 m MRT Sample ID E20163
41.15–41.40	DC	SM	SILTY SAND - fine, yellowish red.					41.15 m 33 degrees rough irregular 1mm
41.40–42.10	DC	SC	CLAYEY SAND - fine to medium, dark grey, flecked grey, dark greenish grey.	D	D	8.1		41.40 m 29 degrees rough irregular 1 mm 41.98 m rough irregular
42.10–42.83	DC	SM	SILTY SAND - fine, grey, banded organics, black.					42.72 m organic irregular
42.83–44.00	DC		CLAYSTONE - black, banded organics, black.		H		Fr	43.30 m 24 degrees organics smooth planar 1mm

70 mm Inclinometer casing

Cement / Bentonite Grout


40.60m
failure cracks
42.10m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 11 SAMPLE No. N/A
DEPTH FROM 39.30 M TO 42.83 M
FILM No. N/A FRAME No. N/A
40.60m
failure cracks

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - LV_IBH1_2005 (LV_ARE_2005_1)

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

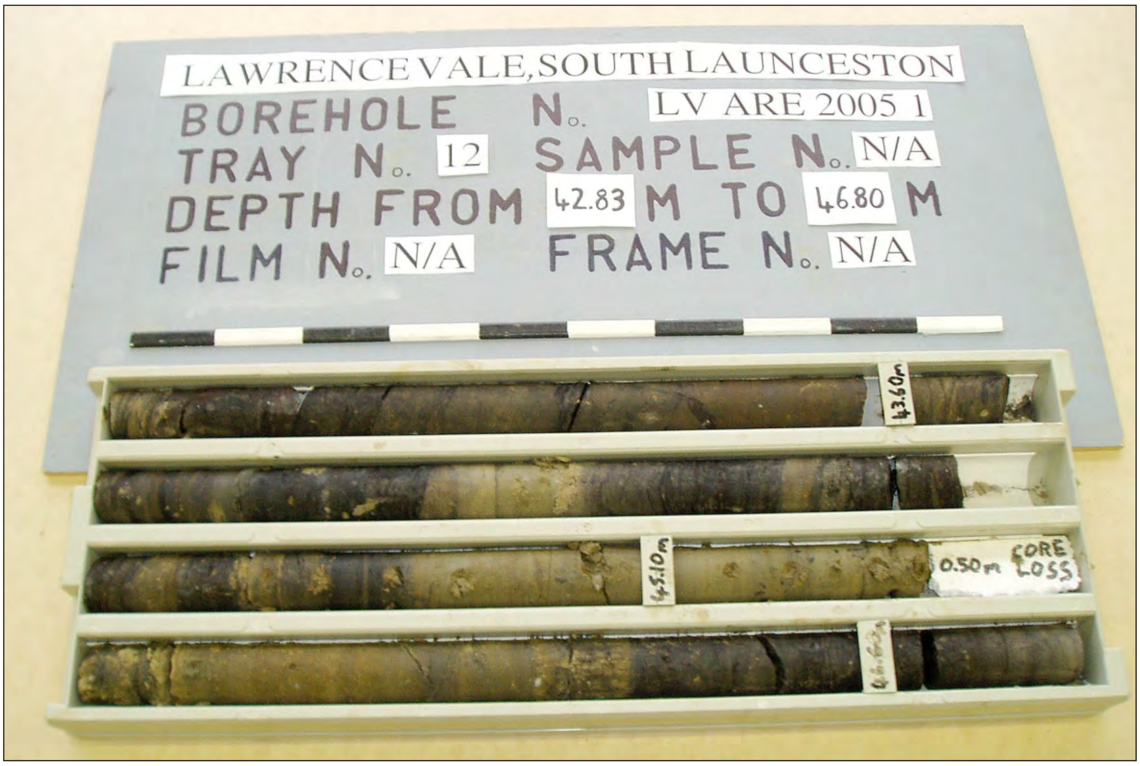
Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
44	DC			D	H		Fr	
		SM	SILTY SAND - fine, grey.	M	D			
			CLAYSTONE - black, banded organics, black.		H		Fr	44.51 m 20 degrees rough irregular slickenside
45		SM	SILTY SAND - fine, grey.	M	VD			
			NO CORE					Soft drilling, 45.35 to 45.85 m.
		SM	SILTY SAND - fine, grey.	M	VD			
46		CL	CLAY - medium plasticity, greenish grey.	D				Atterberg limits Sample LL5 46.11 to 46.19 m MRT Sample ID E201616
		CO	COAL - black.		H		Fr	46.50 m 28 degrees smooth slickenside
47			GRAVEL - Poorly graded, SANDY CLAYSTONE - grey to black. organics, black.					46.64 m 4 degrees smooth slickenside
48								

70 mm Inclinometer casing

Cement / Bentonite Grout


43.60m
45.10m
0.50m CORE LOSS
46.60m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 12 SAMPLE No. N/A
DEPTH FROM 42.83 M TO 46.80 M
FILM No. N/A FRAME No. N/A
43.60m
45.10m
0.50m CORE LOSS

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - **LV_IBH1_2005** **(LV_ARE_2005_1)**

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

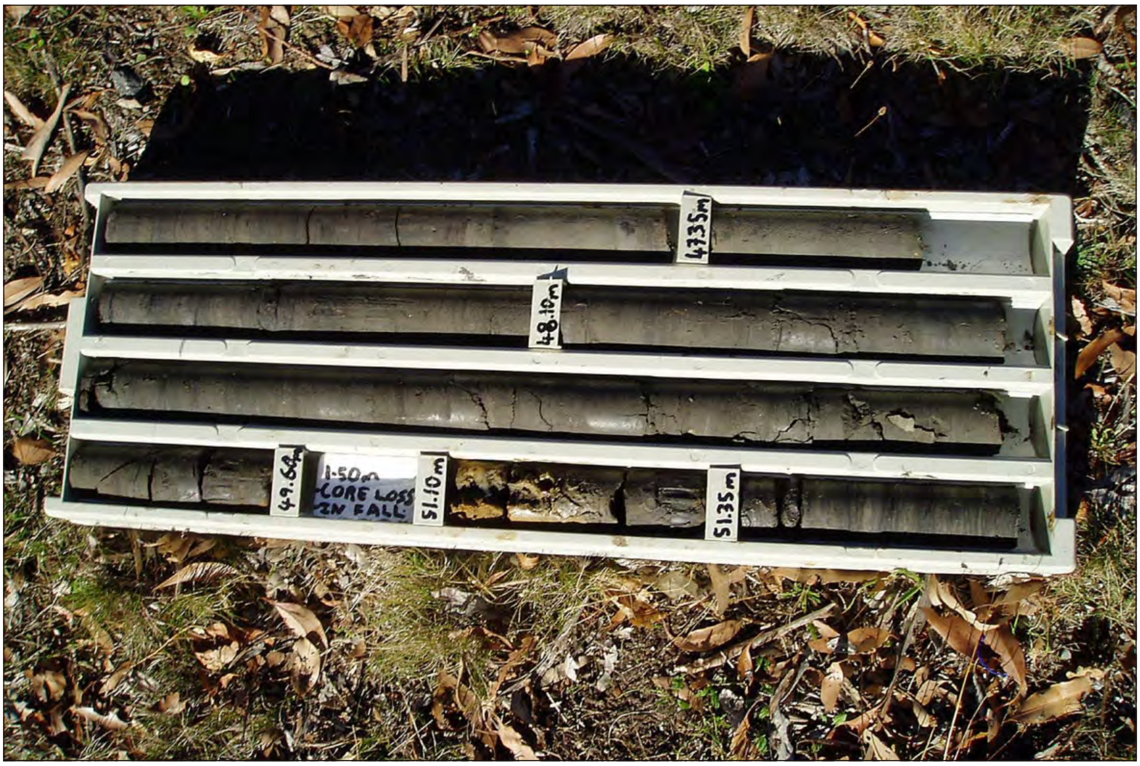
Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	GRAPHIC	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
48.00–49.60	DC					H			
49.60–51.10				NO CORE					Sudden increase in drilling difficulty. Sample barrel returned empty on several attempts. Rods pulled and reinstalled. In fall removed from hole.
51.10–52.00				SANDY CLAYSTONE - grey to black. organics, black.		H			51.90 m 8 degrees rough

Depth scale: 48, 49, 50, 51, 52

70 mm Inclinometer casing

Cement / Bentonite Grout


47.35m
48.10m
49.64m
1.50m
CORE LOSS
IN FALL
51.10m
51.35m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 13 SAMPLE No. N/A
DEPTH FROM 46.80 M TO 51.61 M
FILM No. N/A FRAME No. N/A
47.35m
48.10m
1.50m
CORE LOSS
IN FALL
51.10m
51.35m

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - LV_IBH1_2005 (LV_ARE_2005_1)

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
52.00–52.36	DC							
52.36–52.60	DC		SANDSTONE - fine to coarse, greenish grey, flecked quartz, coarse, moderately sorted.		H			52.83 m smooth polished slickenside
52.60–53.10	DC	CO	COAL - black.		H		Fr	52.89 m 14 degrees smooth polished spacing 3 mm slickensides
53.10–53.45	DC		CLAYSTONE - dark grey to black.		H			53.01 m 4 degrees smooth
53.45–53.90	DC		NO CORE					
53.90–55.00	DC		CLAYSTONE - black, organics, black.		H		Fr	53.95 m 11 degrees smooth; 54.15 m 10 degrees mainly rough
55.00–55.40	DC		CLAYSTONE - dark greenish grey.		H		Fr	
55.40–55.50	DC		SANDSTONE - (dark) greenish grey, fine to coarse, moderately sorted.		H		Fr	
55.50–55.90	DC		NO CORE					
55.90–56.00	DC		SANDSTONE - (dark) greenish grey, fine to coarse, moderately sorted.		H			

70 mm Inclinometer casing

Cement / Bentonite Grout


52.60m
0.45m
CORE LOSS
53.45


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 14 SAMPLE No. N/A
DEPTH FROM 51.61 M TO 55.40 M
FILM No. N/A FRAME No. N/A
52.60m
0.45m
CORE LOSS
53.45

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - LV_IBH1_2005 (LV_ARE_2005_1)

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
56	DC				H			Start drilling 21/04/05.
57		SC	CLAYEY SAND - fine, greenish grey.	M	D	2.1		
			SANDSTONE - (dark) greenish grey, fine to coarse, moderately sorted.		H			
		SC	CLAYEY SAND - fine, greenish grey.	M	D	2.1		Shear box test Sample SB5 57.55 to 57.60 m MRT Sample ID E20164
			SANDSTONE - (dark) greenish grey, fine to coarse, moderately sorted.					
58			CONGLOMERATE SANDSTONE - very dark grey, blueish grey, rounded sand, pebbles.		H		Fr	
			CONGLOMERATE - very dark grey, pebbles, sub- rounded, rounded.					
59			SANDSTONE - dark greenish grey.					
			CONGLOMERATE - very dark grey, dark greenish grey, pebbles, rounded.					
60			SANDSTONE - greenish grey.				SW	

70 mm Inclinometer casing

Cement / Bentonite Grout


55.50m
0.40 m
CORE LOSS
57.00m
57.80m
58.60m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 15 SAMPLE No. N/A
DEPTH FROM 55.40 M TO 59.45 M
FILM No. N/A FRAME No. N/A
55.50m
0.40 m
CORE LOSS
57.00m
57.80m
58.60m

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - LV_IBH1_2005 (LV_ARE_2005_1)

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	Weathering	REMARKS, and defect descriptions
60	DC		CONGLOMERATE - very dark grey, pebbles, sub-angular, sub-rounded.		H		Fr	60.05 to 60.25 m banded clay spacing 50 mm thickness 4 to 12 mm
		CH	CLAY - high plasticity, dark greenish grey.	M	S	1.2		
			SANDSTONE CONGLOMERATE - dark greenish grey, pebbles, sub-angular.				Fr	
61			DOLERITE - dark greenish grey, highly weathered boulder.					
62			SANDSTONE CONGLOMERATE - dark greenish grey, pebbles, sub-angular.		H		Fr	62.01 m irregular 3mm
63			CLAYSTONE - weak red, dark grey.		Fb			62.80 to 63.20 m smooth irregular polished slickensides
64			SANDSTONE - weak red, greenish grey, pebbles, sub-rounded.		H			

70 mm Inclinometer casing

Cement / Bentonite Grout


60.00m
60.50m
61.60m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 16 SAMPLE No. N/A
DEPTH FROM 59.45 M TO 62.85 M
FILM No. N/A FRAME No. N/A
60.00m
60.50m
61.60m

MINERAL RESOURCES TASMANIA

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ENGINEERING LOG - **LV_IBH1_2005** **(LV_ARE_2005_1)**

Easting Coord.	: 55 512572	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410480	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 18/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 21/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	GRAPHIC	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penertrometer (kg)	Weathering	REMARKS, and defect descriptions
64	DC				D	H			
65									
66									
67									
68									

70 mm Inclinometer casing

Cement / Bentonite Grout

70mm Inclinometer cap


63.10m
64.50m
E.O.H.


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 1
TRAY No. 17 SAMPLE No. N/A
DEPTH FROM 62.85 M TO 64.50 M
FILM No. N/A FRAME No. N/A
63.10m
64.50m
E.O.H.

MINERAL RESOURCES TASMANIA

Tasmania
DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - **LV_IBH2_2005** **(LV_ARE_2005_2)**

(Page 1 of 7)

Easting Coord.	: 55 512412	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410774	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 26/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 27/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penertrometer (kg)	REMARKS, and defect descriptions
0	SA	ML	CLAYEY SILT - brown.	D			Solid stem auger drilling, 0 to 0.75 m.
		SC	CLAYEY SAND - fine, mottled brownish yellow, light grey.		D		
1	SS	CL	SANDY CLAY - medium plasticity, mottled brownish yellow, grey, brown, tree roots.		St	11+	Hollow stem auger drilling, 0.75 to 6.00 m, split spoon sampling.
2		CH	CLAY - high plasticity mottled banded yellowish brown, grey, black, dark grey, dark red.			9.8	1.85 to 2.85 m, 50 to 60 degrees dip on clay bands.
3		CL	CLAY - medium plasticity, light olive brown, organic fragments.		VSt	9.9	
		ML	SILT - pale yellow.		D		3.53 m, smooth to irregular
		CL	CLAY - medium plasticity, light olive brown, organic fragments.		VSt	11+	
			IRONSTONE - strong brown.		H		Hard ground, cutting bit changed on auger set up.
4		SC	SAND - fine to medium, pale yellow, organics black.		MD		

Well construction: Cement; 70 mm Inclinometer casing; Cement / Bentonite Grout


0.50m
0.75m
1.50m
2.25m
3.00m
3.75m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 2
TRAY No. 1 SAMPLE No. N/A
DEPTH FROM 0 M TO 4.00 M
FILM No. N/A FRAME No. N/A
0.50m
0.75m
1.50m
2.25m
3.00m
3.75m

MINERAL RESOURCES TASMANIA

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ENGINEERING LOG - **LV_IBH2_2005** **(LV_ARE_2005_2)**

Easting Coord.	: 55 512412	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410774	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 26/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 27/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	REMARKS, and defect descriptions
4	SS	SC		D	MD		
		SC	SANDY CLAY - banded, brownish yellow, light grey, organics, black.		St	3.9	
		SM	SILTY SAND - fine, yellowish brown.		MD		
5		SM	SILTY SAND - fine, brownish yellow, flecked texture, banded thin ironstone.		D		
		SM	SILTY SAND - fine, yellowish brown.		MD		
		SM	SILTY SAND - fine, brownish yellow, flecked texture, banded thin ironstone.				
6	DC		NO CORE				Start triple tube HQ3 diamond drilling.
		CH	CLAY - high plasticity, dark yellowish brown.	M	F	6.9	
		SC	CLAYEY SAND - fine, dark yellowish brown.		MD	2.1	
		CH	CLAY - high plasticity, yellowish brown.		F	5.7	
		CH	CLAY - high plasticity, grey, ironstone, brown (hard).		S	3.2	
		CH	CLAY - high plasticity, grey, ironstone, brown (hard)			1.4	
7		SC	SAND - fine, flecked white, grey, brown, black, organics, black.		MD		
8		SC	SAND - fine, flecked white, grey, brown, black, organics, black, banded ironstone, strong brown.				

70 mm Inclinometer casing

Cement / Bentonite Grout


4.50m
5.25m
6.00m
0.10m CORE LOSS
6.50m
7.00m
7.55m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 2
TRAY No. 2 SAMPLE No. N/A
DEPTH FROM 4.00 M TO 7.70 M
FILM No. N/A FRAME No. N/A
4.50m
5.25m
6.00m
0.10m CORE LOSS
6.50m
7.00m
7.55m

MINERAL RESOURCES TASMANIA

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ENGINEERING LOG - **LV_IBH2_2005** **(LV_ARE_2005_2)**

Easting Coord.	: 55 512412	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410774	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 26/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 27/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	REMARKS, and defect descriptions
8 – 9.75	DC	SC		M	MD		
9.75 – 11.35	DC	SC	SAND - fine, brownish yellow.	M	MD		Shear box test Sample SB6 9.90 to 10.00 m MRT Sample ID E201625
11.35 – 12	DC	SC	CLAYEY SAND - fine, brownish yellow, light brownish grey.	M	D	8.4	

Installation: 70 mm Inclinometer casing; Cement / Bentonite Grout


8.30m
9.05m
10.05m
10.55m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 2
TRAY No. 3 SAMPLE No. N/A
DEPTH FROM 7.70 M TO 11.30 M
FILM No. N/A FRAME No. N/A
8.30m
9.05m
10.05m
10.55m

MINERAL RESOURCES TASMANIA

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ENGINEERING LOG - **LV_IBH2_2005** **(LV_ARE_2005_2)**

Easting Coord.	: 55 512412	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410774	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 26/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 27/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	REMARKS, and defect descriptions
12	DC	SC				8.4	
		SC	SAND - fine, yellowish brown, dark grey brown.		D		12.72 m 22 degrees ironstone rough 1mm
13							
		CH	CLAY - high plasticity, very dark greyish brown.		F	5.0	Atterberg limits Sample LL6 13.45 to 13.55 m MRT Sample ID E201617
14		SC	CLAYEY SAND - fine to medium, flecked brownish yellow, light grey, quartz .	M	MD	2.3	
15		SC	CLAYEY SAND - fine to medium, flecked brownish yellow, grey, quartz, organics, black.			7.3	Start drilling 27/04/05.
16							

70 mm Inclinometer casing

Cement / Bentonite Grout


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 2
TRAY No. 4 SAMPLE No. N/A
DEPTH FROM 11.30 M TO 15.20 M
FILM No. N/A FRAME No. N/A

MINERAL RESOURCES TASMANIA

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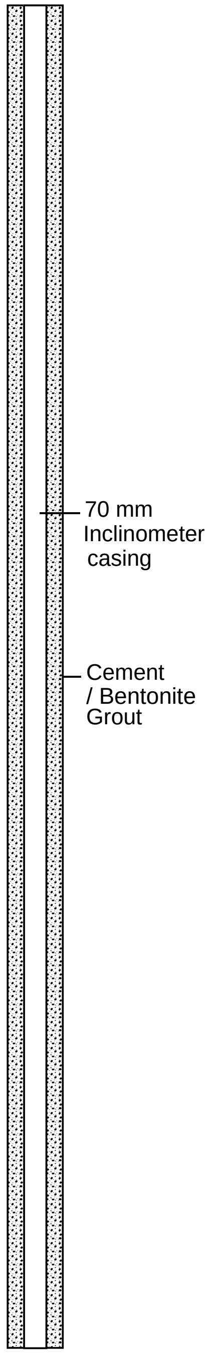
ENGINEERING LOG - **LV_IBH2_2005** **(LV_ARE_2005_2)**

Easting Coord.	: 55 512412	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410774	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 26/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 27/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	GRAPHIC	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	REMARKS, and defect descriptions
16			CH	CLAY - high plasticity, dark greyish brown.	D	F	3.5	
			SC	CLAYEY SAND - fine, dark yellowish brown.	M	MD	5.3	
			CH	CLAY - high plasticity, dark greyish brown.		F	3.5	
			SC	CLAYEY SAND - fine, dark yellowish brown.	D	MD	5.3	
			CH	CLAY - high plasticity, brownish yellow,sand, fine.		St	5.8	
17								
18	DC		CH	CLAY - high plasticity, greyish brown, brownish yellow .	M	F	4.4	
19			CL	SANDY GRAVELLY CLAY - medium plasticity, yellowish brown.			5.2	Shear box test Sample SB7 19.00 to 19.10 m MRT Sample ID E201626
			CH	CLAY - high plasticity, brownish yellow, sand, fine.		St	11+	
			CH	CLAY - high plasticity, yellowish brown, banded ironstone 5 to 20 mm (hard), dark reddish brown.			8.9	19.45 m iron oxide rough 2 mm
			SC	CLAYEY SAND - fine to medium, light and dark yellowish brown, banded ironstone.		MD	3.6	
20								




16.55m
18.05m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 2
TRAY No. 5 SAMPLE No. N/A
DEPTH FROM 15.20 M TO 19.05 M
FILM No. N/A FRAME No. N/A

MINERAL RESOURCES TASMANIA

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ENGINEERING LOG - **LV_IBH2_2005** **(LV_ARE_2005_2)**

Easting Coord.	: 55 512412	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410774	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 26/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 27/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters: 20 – 24; Sample: DC

USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	REMARKS, and defect descriptions
SC		M	MD	3.6	
CH	CLAY - high plasticity, light brownish grey.	M	F	6.4	
SC	CLAYEY SAND - fine to medium, light and dark yellowish brown, banded ironstone.	M	MD	3.6	21.17 m iron oxide rough irregular 2 mm
CH	CLAY - high plasticity, light olive brown.	M	F	8.6	
SC	CLAYEY SAND - fine to medium, light and dark yellowish brown, banded ironstone.	M	MD	3.6	
CH	CLAY - high plasticity, light olive brown.	M	F	8.6	
SC	CLAYEY SAND - fine, light olive brown.	M	VD	10.8	
CH	CLAY - high plasticity, light olive brown.	M	F		
SC	CLAYEY SAND - fine, light olive brown.	M	VD	10.8	
SC	CLAYEY SAND - fine, light olive brown, organics, black.	M	MD	4.8	
SC	SILTY CLAYEY SAND - fine, light olive brown, organics, black.	M	MD	5.2	
CH	CLAY - high plasticity, light olive brown.	M	F	3.5	23.20 to 23.25 m rough irregular 2 mm
CH	CLAY - high plasticity, dark yellowish brown.	M	F	9.8	
CH	CLAY - high plasticity, olive brown, browhish yellow.	M	St	6.3	Atterberg limits Sample LL7 23.53 to 23.58 m MRT Sample ID E201618

70 mm Inclinometer casing

Cement / Bentonite Grout


19.55m
21.05m
22.55m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 2
TRAY No. 6 SAMPLE No. N/A
DEPTH FROM 19.05 M TO 22.75 M
FILM No. N/A FRAME No. N/A
21.05m
22.55m

MINERAL RESOURCES TASMANIA

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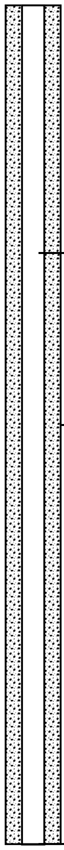
ENGINEERING LOG - **LV_IBH2_2005** **(LV_ARE_2005_2)**

Easting Coord.	: 55 512412	Drill fluid	: Drilling mud / detergent
Northing Coord.	: 5410774	Hole Diameter	: 96 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 26/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 27/04/05
Drilling Method	: Hollow auger\HQ3 Diamond	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	REMARKS, and defect descriptions
24	DC	CH		M	St	6.3	
			IRONSTONE - dark brown		H		
		CH	CLAY - high plasticity, very dark greyish brown.	M	F	5.5	24.88 m 12 degrees iron oxide rough irregular 3 mm
25			IRONSTONE - dark brown		H		
		CH	CLAY - high plasticity, very dark greyish brown.		F	5.5	
		CH	CLAY - high plasticity, dark grey.	M		6.8	
		CH	CLAY - high plasticity, light to dark grey, organics, black, sand, fine.		St	11+	
26		CH	CLAY - high plasticity, dark grey.		F	3.8	
		CH	CLAY - high plasticity, yellowish brown.			4.8	
27							
28							




24.05m
25.55m
26.50
E.O.H


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 2
TRAY No. 7 SAMPLE No. N/A
DEPTH FROM 22.75 M TO 26.50 M
FILM No. N/A FRAME No. N/A

MINERAL RESOURCES
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ENGINEERING LOG - **LV_PBH3_2005 (LV_ARE_2005_3)**

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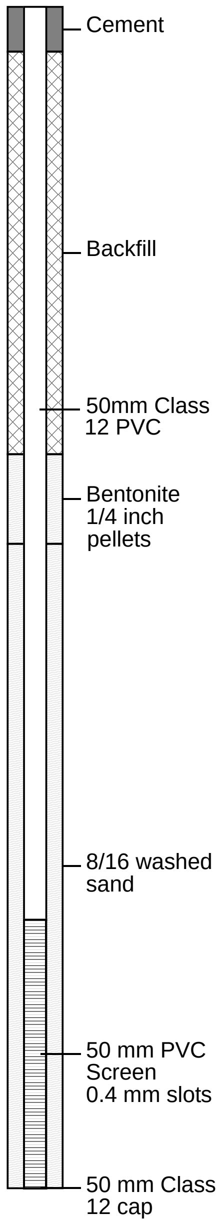
Easting Coord.	: 55 512411	Drill fluid	: Nil
Northing Coord.	: 5410773	Hole Diameter	: 100 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 27/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 27/04/05
Drilling Method	: Hollow stem auger	Logged By	: Mr Andrew Ezzy

Sample Condition
▧ Disturbed
▥ Undisturbed

Sampler Type
SA Solid stem
SS Split Spoon
DC Diamond Core

Depth in Meters	Sample	GRAPHIC	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	REMARKS, and defect descriptions
0				Drilling log as LV_ARE_2005_2.				Solid stem auger drilling, 0 to 13.5 m. No samples collected. Due to the stiffness of the ground, blade bit drilling would be more suitable when drilling for the first aquifer level.
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								



MINERAL RESOURCES TASMANIA

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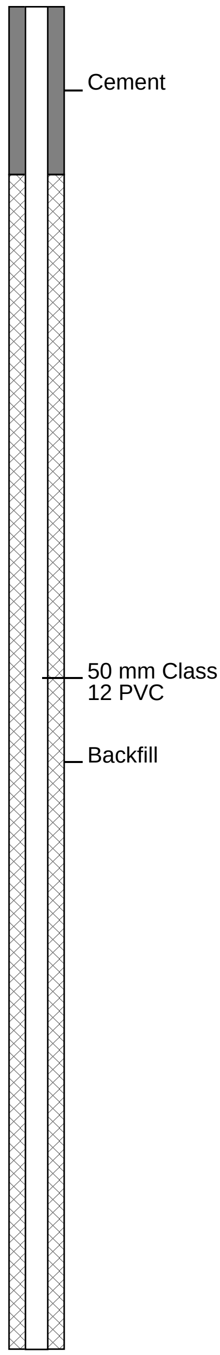
ENGINEERING LOG - LV_PBH4_2005 (LV_ARE_2005_4)

Easting Coord.	: 55 512548	Drill fluid	: Nil
Northing Coord.	: 5410497	Hole Diameter	: 100 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 28/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 28/04/05
Drilling Method	: Hollow stem auger	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	REMARKS, and defect descriptions
0	SA	OH	CLAY - high plasticity, black.	D	S		Solid stem auger drilling, 0 to 0.75 m.
	SS	SM	SILTY SAND - fine, brown.		MD		Hollow stem auger drilling 0.75 to 12.75 m, split spoon sampling.
1		SM	SILTY SAND - fine, yellowish red, banded ironstone to 10mm (hard).		D		
		SM	SILTY SAND - fine, very pale brown.				
		CH	CLAY - high plasticity, mottled grey, brown, yellowish brown, red.	M	VSt	9.0	
		CH	CLAY - high plasticity, mottled grey, brown, red.		VS	0.8	
		SC	CLAYEY SAND - fine, yellowish brown.		MD	0.6	Atterberg limits Sample LL8 1.86 to 1.94 m MRT Sample ID E201619
2		CL	SANDY CLAY - medium plasticity, mottled yellowish brown, grey, brown.	D	S	2.1	
		SC	CLAYEY SAND - medium, brownish yellow.		D	1.8	
		CL	SANDY CLAY - medium plasticity, mottled yellowish brown, red, grey.		St	9.4	
		CL	SANDY CLAY - medium plasticity, mottled yellow, brownish yellow.		VS	3.1	
		SC	SILTY CLAYEY SAND - fine, brown.		MD	4.2	
3		CL	CLAY - medium plasticity, yellowish brown.		St	6.1	
		SM	SILTY SAND - fine, yellowish brown.		MD		
		SW	SAND - medium, pale yellow.				
		CL	CLAY - medium plasticity, light yellowish brown.		F	2.2	
		SC	CLAYEY SAND - fine, flecked pale yellow, strong brown.		MD		
			NO CORE				
4		SM	SILTY SAND - fine, brownish yellow.	D	D		




LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 4
TRAY No. 1 SAMPLE No. N/A
DEPTH FROM 0 M TO 3.75 M
FILM No. N/A FRAME No. N/A
1.50m
2.25m
3.00m
3.75m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 4
TRAY No. 2 SAMPLE No. N/A
DEPTH FROM 3.75 M TO 6.75 M
FILM No. N/A FRAME No. N/A
4.50m
5.25m
6.00m
6.75m

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - **LV_PBH4_2005** **(LV_ARE_2005_4)**

Easting Coord.	: 55 512548	Drill fluid	: Nil
Northing Coord.	: 5410497	Hole Diameter	: 100 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 28/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 28/04/05
Drilling Method	: Hollow stem auger	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	REMARKS, and defect descriptions
4	SS	SM		D	D		
		SM	SAND - fine, brownish yellow.	D	MD		
		SC	CLAYEY SAND - fine, yellow.	D	MD	2.8	
		SC	CLAYEY SAND - fine, yellow.	D	VD	10.2	
		SC	CLAYEY SAND - fine, yellowish brown.	D	MD	1.8	
		SC	CLAYEY SAND - fine, light grey, brown.	D	MD	2.2	
5		SC	CLAYEY SAND - fine, yellowish brown.	D	MD	4.5	
6		CH	CLAY - high plasticity, light grey, yellowish red, yellowish brown.	M	St	8.2	
		CH	CLAY - high plasticity, dark grey brown, organics, black.	M	St	4.8	Shear box test Sample SB8 6.40 to 6.60 m MRT Sample ID E201627
		CH	CLAY - high plasticity, grey, mottled dark brown, dark red.	M	St	5.7	
7		CH	CLAY - high plasticity, brown.	M	F	8.5	
8							

Well construction: Backfill; 50 mm Class 12 PVC; Bentonite 1/4 inch pellets

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT *of* INFRASTRUCTURE, ENERGY *and* RESOURCES

ENGINEERING LOG - **LV_PBH4_2005** **(LV_ARE_2005_4)**

Easting Coord.	: 55 512548	Drill fluid	: Nil
Northing Coord.	: 5410497	Hole Diameter	: 100 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 28/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 28/04/05
Drilling Method	: Hollow stem auger	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	REMARKS, and defect descriptions
8		SP	GRAVELLY SAND, fine, dark red.	D	D	2.2	
		CH	CLAY - high plasticity, brown.		St	10.2	
		CL	CLAY - medium plasticity, yellowish brown.	M	F	2.4	
		CH	CLAY - high plasticity, dark yellow brown.			8.7	Shear box test Sample SB9 8.70 to 8.90 m MRT Sample ID E201628
9		CL	SANDY CLAY, medium plasticity, light brownish grey, mottled yellowish brown.	D	St	1.7	
		CL	SILTY CLAY - medium plasticity, light brownish grey.	M	F	7.3	
			NO CORE				
		CH	CLAY - high plasticity, light brownish grey.	M	St	9.3	
10	SS	SM	SAND - fine, light grey.	D	MD		
		SC	CLAYEY SAND - fine, light grey.	M		1.3	
		SC	CLAYEY SAND - fine, pale yellow.			1.9	
		CL	SANDY CLAY - medium plasticity, light yellowish brown.		F	4.8	
		SC	CLAYEY SAND - fine, brownish yellow.	D	MD	3.4	
		SM	SILTY SAND - fine, very pale brown.			0.8	
		SC	CLAYEY SAND - fine, yellowish brown.	M		1.8	
11		SC	CLAYEY SAND - fine, brownish yellow.	D		2.6	
		CL	SANDY CLAY - medium plasticity, dark yellowish brown.	M	F	3.6	
			NO CORE				
		CL	SANDY CLAY - medium plasticity, olive brown.	M	F	3.8	
		SM	SILTY SAND - fine, brownish yellow.	D	MD	1.4	
		CL	SANDY CLAY - medium plasticity, yellow.	M	F	2.4	
12		SC	CLAYEY SAND - fine, brownish yellow.	D	MD	5.1	

Bentonite 1/4 inch pellets

50 mm Class 12 PVC

8/16 washed sand

50 mm PVC Screen 0.4 mm slots


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 4
TRAY No. 3 SAMPLE No. N/A
DEPTH FROM 6.75 M TO 9.75 M
FILM No. N/A FRAME No. N/A
7.50m
8.25m
9.75m


LAWRENCE VALE, SOUTH LAUNCESTON
BOREHOLE No. LV ARE 2005 4
TRAY No. 3 SAMPLE No. N/A
DEPTH FROM 6.75 M TO 9.75 M
FILM No. N/A FRAME No. N/A
10.50m
12.75m
E.O.H

MINERAL RESOURCES TASMANIA

Tasmania

DEPARTMENT of INFRASTRUCTURE, ENERGY and RESOURCES

ENGINEERING LOG - LV_PBH4_2005 (LV_ARE_2005_4)

Easting Coord.	: 55 512548	Drill fluid	: Nil
Northing Coord.	: 5410497	Hole Diameter	: 100 mm
Drilling Company	: KMR Dilling Pty Ltd	Date Commenced	: 28/04/05
Drill Type	: Mobile Drill B40	Date Completed	: 28/04/05
Drilling Method	: Hollow stem auger	Logged By	: Mr Andrew Ezzy

Sample Condition: Disturbed; Undisturbed

Sampler Type: SA Solid stem; SS Split Spoon; DC Diamond Core

Depth in Meters	Sample	GRAPHIC	USCS	DESCRIPTION	Moisture condition	Consistency Density index	Average hand penetrometer (kg)	REMARKS, and defect descriptions
12	SS			NO CORE				10 litres of town water poured into hole to extract rods.
			SC	CLAYEY SAND - fine, brownish yellow.	D	MD	5.1	
			CH	CLAY - high plasticity, dark yellowish brown.		F	3.5	
			SC	CLAYEY SAND - fine, brownish yellow.	M	MD	1.7	
			CL	SANDY CLAY - medium plasticity, yellowish brown.		F	6.5	
13								
14								
15								
16								

50 mm PVC Screen

8/16 washed sand
0.4 mm slots

50 mm Class 12 cap

APPENDIX 3
Geotechnical test results

Client: A. Ezzy
Sample Location: Lawrence Vale
Analysis: Physical Properties
Method: Shear Box Tests, Atterberg Limits

Results

Sample	Reg No.	LL	PL	LS	RFA	RC
LL1	E201612	118	29	25		
LL2	E201613	103	31	24		
LL3	E201614	86	30	22		
LL4	E201615	93	29	23		
LL5	E201616	54	24	15		
LL6	E201617	61	27	16		
LL7	E201618	73	28	18		
LL8	E201619	104	30	24		
SB1	E201620	117	28	26	13	2.5
SB4	E201623	53	26	12	29	1.0
SB8	E201627	131	33	27	11	2.0
SB9	E201628	89	30	22	24	4.0
SB10	E201629	34	22	5	34	0.5

LL = Liquid Limit
PL = Plastic Limit
LS = Linear Shrinkage
RFA = Residual Friction Angle (degrees)
RC = Residual Cohesion (to nearest 0.5 kPa)

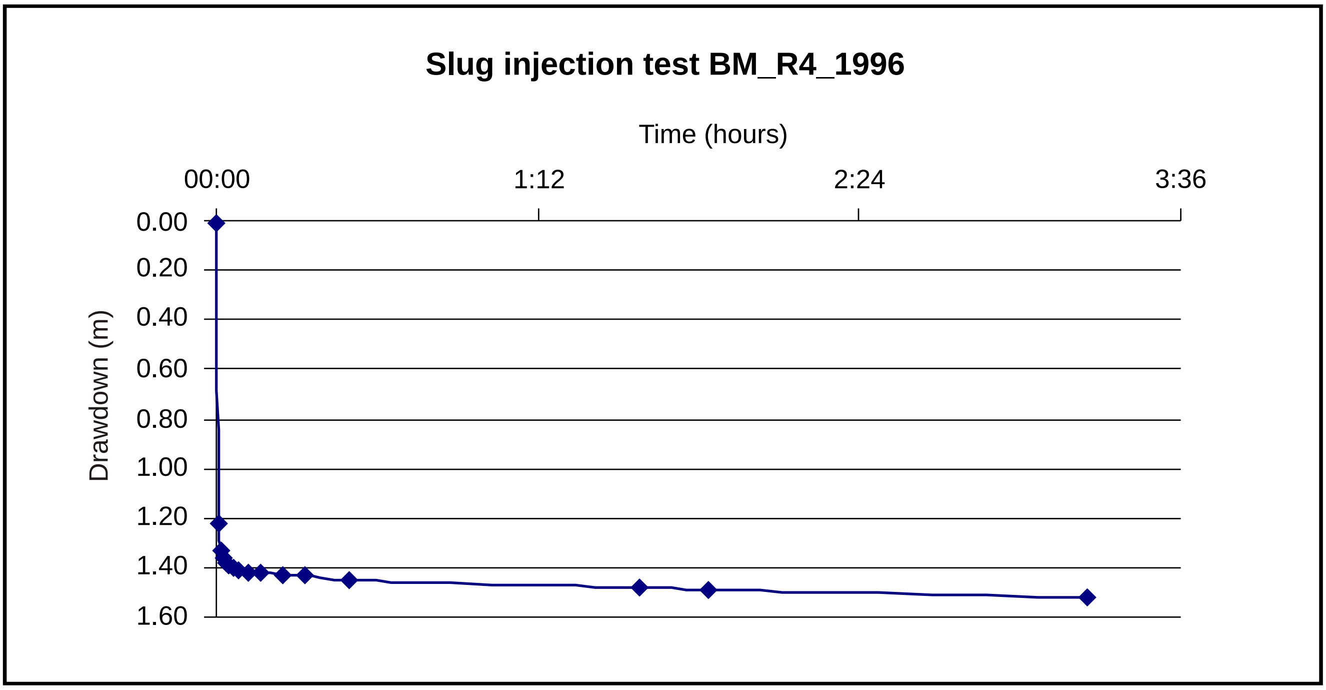
Analyst: R. N. Woolley, Mineral Resources Tasmania
Date: 27 November 2005

APPENDIX 4

Data collected during in situ permeability testing

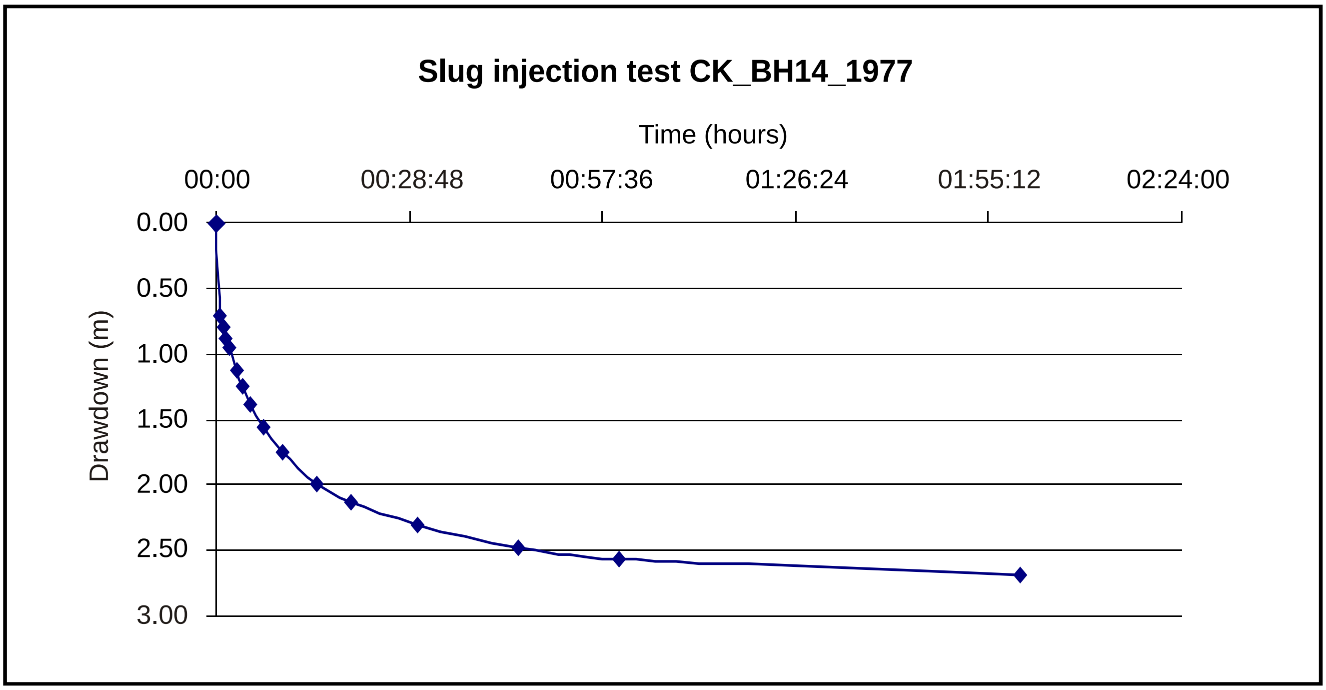
Bore: **BM_R4_1996**
Date: 24/01/2006
Start time: 14:36
Starting SWL_gl: 3.92

Real time	Elapsed time	Drawdown	s
15:36	00:00:01	0.01	3.91
15:37	00:00:30	1.22	2.70
15:37	00:01:00	1.33	2.59
15:38	00:01:30	1.36	2.56
15:38	00:02:00	1.38	2.54
15:39	00:03:00	1.39	2.53
15:40	00:04:00	1.40	2.52
15:41	00:05:00	1.41	2.51
15:43	00:07:00	1.42	2.50
15:46	00:10:00	1.42	2.50
15:51	00:15:00	1.43	2.49
15:56	00:20:00	1.43	2.49
16:06	00:30:00	1.45	2.47
16:21	01:35:00	1.48	2.44
16:36	01:50:00	1.49	2.43
17:36	03:15:00	1.52	2.40



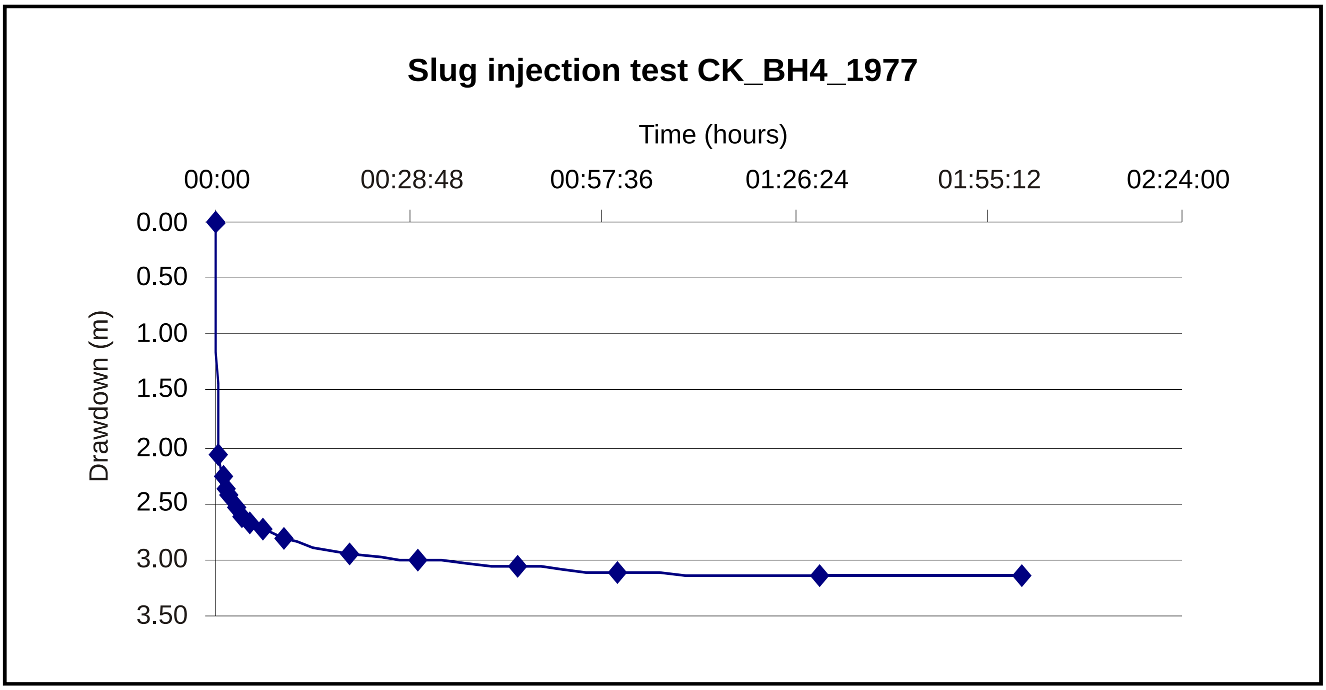
Bore: **CK_BH14_1977**
Date: 24/01/2006
Start time: 15:36
Starting SWL_gl: 3.94

Real time	Elapsed time	Drawdown	s
15:36	00:00:01	0.01	3.93
15:37	00:00:30	0.71	3.23
15:37	00:01:00	0.79	3.15
15:38	00:01:30	0.88	3.06
15:38	00:02:00	0.96	2.98
15:39	00:03:00	1.13	2.81
15:40	00:04:00	1.24	2.70
15:41	00:05:00	1.38	2.56
15:43	00:07:00	1.56	2.38
15:46	00:10:00	1.76	2.18
15:51	00:15:00	1.99	1.95
15:56	00:20:00	2.14	1.80
16:06	00:30:00	2.31	1.63
16:21	00:45:00	2.48	1.46
16:36	01:00:00	2.57	1.37
17:36	02:00:00	2.68	1.26



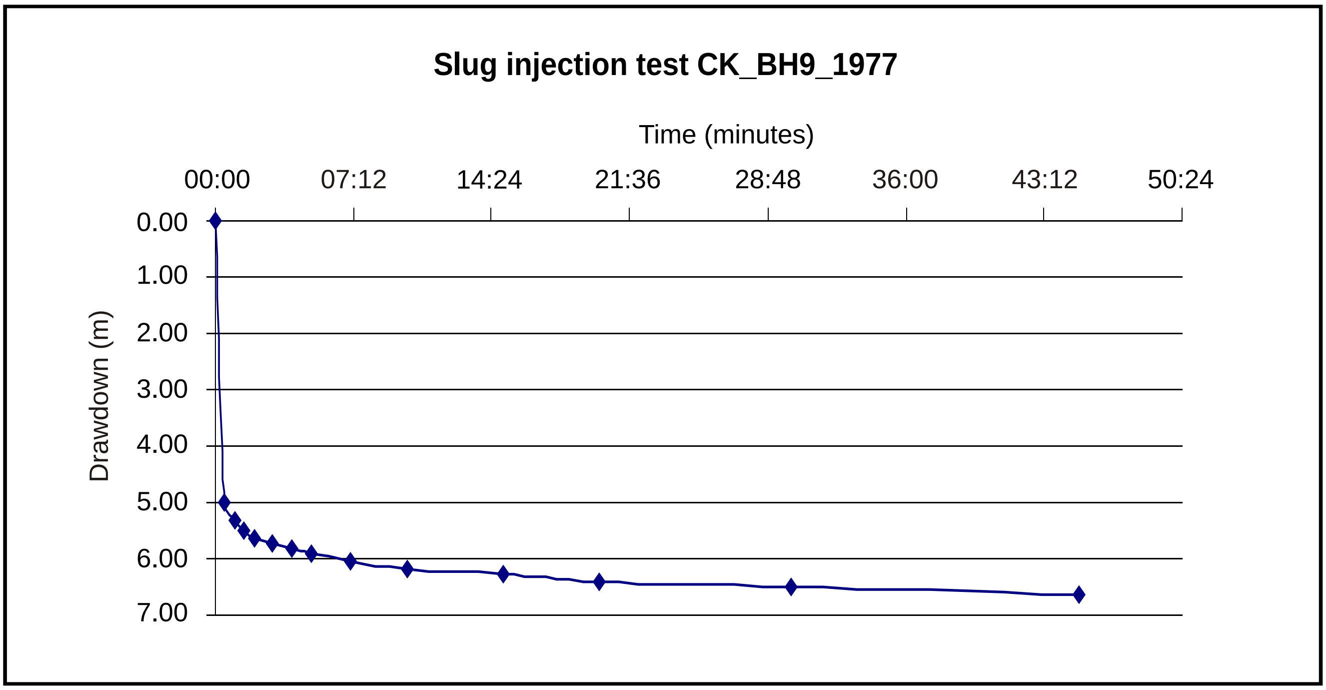
Bore: **CK_BH4_1977**
Date: 24/01/2006
Start time: 11:50
Starting SWL_gl: 4.00

Real time	Elapsed time	Drawdown	s
11:50	00:00:00	0.00	9.10
11:50	00:00:30	2.07	7.03
11:51	00:01:00	2.26	6.84
11:51	00:01:30	2.36	6.74
11:52	00:02:00	2.42	6.68
11:53	00:03:00	2.54	6.56
11:54	00:04:00	2.61	6.49
11:55	00:05:00	2.66	6.44
11:57	00:07:00	2.73	6.37
12:00	00:10:00	2.82	6.28
12:10	00:20:00	2.95	6.15
12:20	00:30:00	3.00	6.10
12:35	00:45:00	3.07	6.03
12:50	01:00:00	3.12	5.98
13:20	01:30:00	3.13	5.97
13:50	02:00:00	3.14	5.96



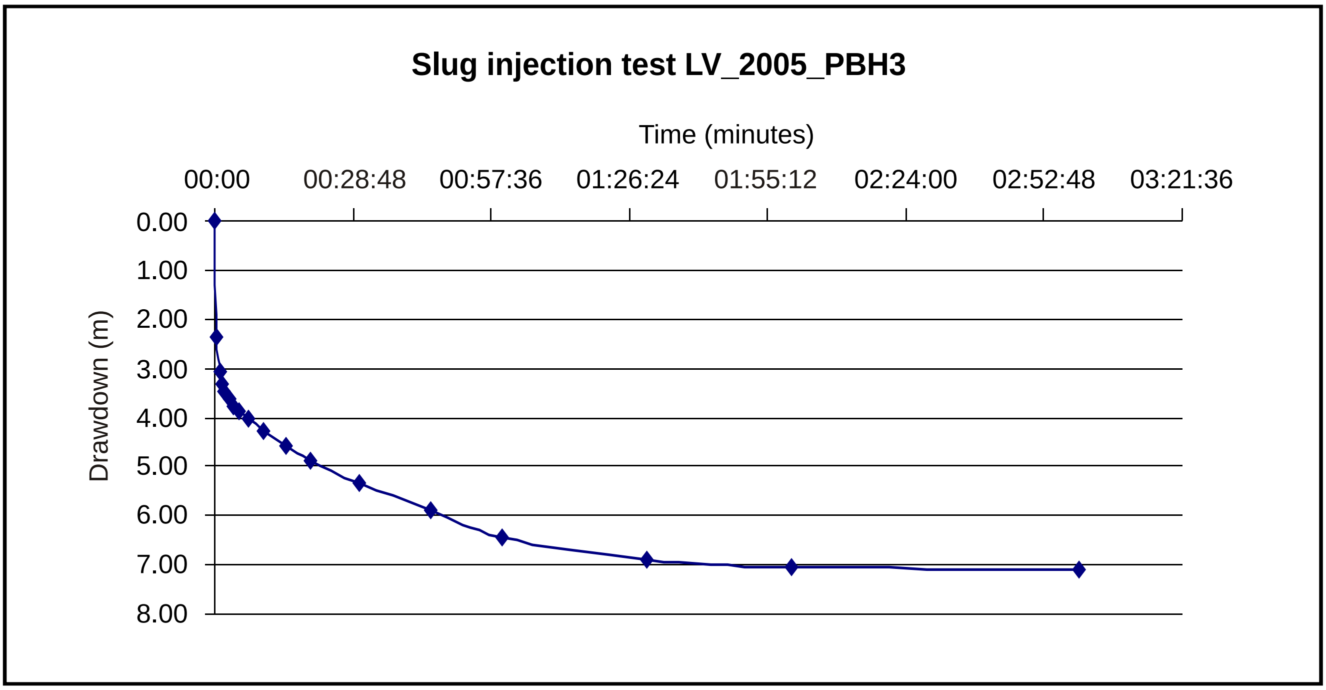
Bore: **CK_BH9_1977**
Date: 24/01/2006
Start time: 10:10
Starting SWL_gl: Dry_6.78

Real time	Elapsed time	Drawdown	s
10:10	00:00:00	0.00	6.78
10:10	00:00:30	5.02	1.76
10:11	00:01:00	5.32	1.46
10:11	00:01:30	5.50	1.28
10:12	00:02:00	5.62	1.16
10:13	00:03:00	5.74	1.04
10:14	00:04:00	5.82	0.96
10:15	00:05:00	5.91	0.87
10:17	00:07:00	6.04	0.74
10:20	00:10:00	6.16	0.62
10:25	00:15:00	6.29	0.49
10:30	00:20:00	6.39	0.39
10:40	00:30:00	6.52	0.26
10:55	00:45:00	6.63	0.15



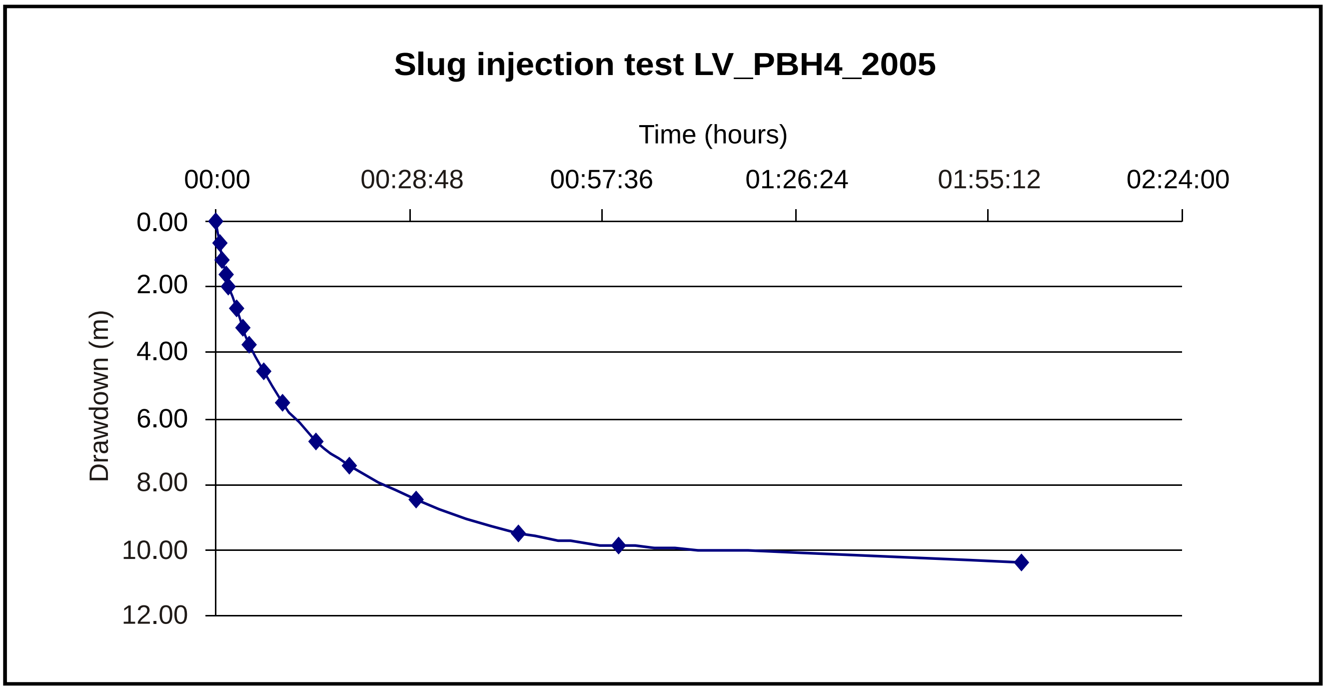
Bore: **LV_2005_PBH3**
Date: 24/01/2006
Start time: 10:05
Starting SWL_gl: Dry_13.55

Real time	Elapsed time	Drawdown	s
10:05	00:00:00	0.00	13.55
10:05	00:00:30	2.35	11.20
10:06	00:01:00	3.08	10.47
10:06	00:01:30	3.31	10.24
10:07	00:02:00	3.46	10.09
10:08	00:03:00	3.63	9.92
10:09	00:04:00	3.75	9.80
10:10	00:05:00	3.86	9.69
10:12	00:07:00	4.05	9.50
10:15	00:10:00	4.27	9.28
10:20	00:15:00	4.60	8.95
10:25	00:20:00	4.87	8.68
10:35	00:30:00	5.31	8.24
10:50	00:45:00	5.91	7.64
11:05	01:00:00	6.43	7.12
11:35	01:30:00	6.87	6.68
12:05	02:00:00	7.02	6.53
13:05	03:00:00	7.10	6.45



Bore:	**LV_PBH4_2005**
Date:	24/01/2006
Start time:	16:57
Starting SWL_gl:	Dry_12.52

Real time	Elapsed time	Drawdown	s
16:57	00:00:01	0.01	12.51
16:58	00:00:30	0.67	11.85
16:58	00:01:00	1.21	11.31
16:59	00:01:30	1.63	10.89
16:59	00:02:00	1.99	10.53
17:00	00:03:00	2.64	9.88
17:01	00:04:00	3.22	9.30
17:02	00:05:00	3.73	8.79
17:04	00:07:00	4.58	7.94
17:07	00:10:00	5.54	6.98
17:12	00:15:00	6.67	5.85
17:17	00:20:00	7.42	5.10
17:27	00:30:00	8.50	4.02
17:42	00:45:00	9.48	3.04
17:57	01:00:00	9.88	2.64
18:57	02:00:00	10.37	2.15



APPENDIX 5

Slope Stability Analysis by Coffey Geotechnics

Lawrence Vale Landslide Investigations: Slope Stability Analysis

1. INTRODUCTION

Coffey Geotechnics Pty Ltd (Coffey) was commissioned by MRT to conduct preliminary slope stability analysis on the Lawrence Vale Landslide. The analysis is based on landslide models developed by MRT following investigation of the stratigraphy, groundwater conditions and material strength on the landslide and surrounding areas.

The purpose of the analysis is to provide an assessment of the 'validity' of the landslide model and illustrate the sensitivity of the landslide to key slope parameters (geometry, material strength, groundwater).

2. LANDSLIDE MODEL

The analysis has been based on an interpretive cross section of the Lawrence Vale Landslide. The cross section shows a sequence of Tertiary sedimentary deposits that dip sub parallel to the hill slope, with the historic landslide occurring within a fissured clay unit (LF1) that is underlain by interbedded clayey sand and sand/gravel layers (LF2).

The section used for analysis (see attachments) is similar to the model section and shows 6 stratigraphic units, LF1 to LF6 as follows:

- **LF 1 (Pale Yellow)**
  Medium to high plastic clays with banded silt, fine clayey sand and ironstone (dominant colours greys and reds — streaked appearance) belonging to the Launceston Group.
- **LF 2 (Pale Green)**
  Dominantly clayey sand layers with banded gravel, ironstone, clay, and silt (dominant colours greys and yellowish brown) belonging to the Launceston Group.
- **LF 3 (Orange)**
  Claystone and sandstone with banded coal, silty sand and clay (dominant colours greys and black) belonging to the Launceston Group.
- **LF 4 (Yellow)**
  Conglomerate and sandstone with banded claystone (dominant colours greenish grey and red) belonging to the Launceston Group.
- **LF 5 (Jurassic Dolerite — Pink)**
  Weathered and fresh dolerite basement rock.
- **LF 6 (Green)**
  Clay, gravel and sand deposited in alluvial valley floor setting during the Holocene.

Input parameters for analysis were based on MRT reported laboratory testing of undisturbed samples recovered from boreholes, combined with the textural descriptions of the units. The base input parameters are as follows.

Material	Cohesion (kPa)	Friction Angle (degrees)	Density (kN/m^3)
LF1	2	11	16
LF2	5	34	18
LF3	50	30	20
LF4	50	35	22
LF5	200	40	28
LF6	0	30	20

Throughout the history of study of the Lawrence Vale Landslide a key factor in the landslide models has been groundwater in sandy aquifers in unit LF2 immediately below the landslide base in unit LF1. Piezometers within LF2 show rapid response to rainfall recharge form upslope of the landslide head scarp and then slow dissipation of pore pressures. Conceptually this varying aquifer pressure is seen as the main driving force for landslide movement events.

It is understood that drainage in the toe of the landslide was achieved by construction of deep slot trenches backfilled with free draining gravels (and pipes?). Therefore groundwater levels measured in the recent investigations may not be typical of the types of levels and changes in level experienced in the landslide prior to the drainage works.

3. LIMIT EQUILIBRIUM ANALYSIS

3.1 General

The slope stability analysis undertaken is a 2 dimensional deterministic method utilising the commercial software SLIDE developed by Rocscience in Canada. The software performs analyses using various "method of slice" methods that assess the balance between driving and resisting forces across the modelled geometry. The factor of Safety (FOS) is the sum of the resisting forces divided by the sum of the driving forces, therefore a FOS >1 result means no movement (in theory). The software searches for minimum FOS surfaces constrained by the adopted parameters. Groundwater surfaces and/or piezometric pressures can be assigned to any or all of the model layers.

It is important to note that the absolute FOS obtained from limit equilibrium analysis of a complex natural slope should be interpreted with caution. In simple engineer analysis of fill batters and soil slopes a FOS of 1.5 is generally accepted as an adequate engineering design as it allows for unknown factors in the slope and statistical variation in the material parameters. The natural slope failure on larger scale is possibly several orders of magnitude more complex than the simple soil batter.

The power of the analysis is in comparisons between cases where varying shear strength, groundwater levels and slope shapes can be assessed for sensitivity to change.

3.2 Results

The slope model used in all cases is the existing slope profile with the MRT interpreted stratigraphy (LF1 to LF6). Shear strengths and material densities have not been changed in these preliminary analyses, which address different groundwater conditions and modes of failure.

The 14 results print outs attached illustrate a process of assessing slope failure as follows:

- **Model A** starts with maximum groundwater conditions as inferred by MRT comprising artesian pore pressures in the LF2 aquifer and near surface water levels in LF1. The results indicate deep failure through LF2 at a greater depth than the known landslide.
- **Model B** has a lower pore pressure in the LF2 aquifer, which results in very low FOS in LF1 materials on the nose of the slide mass, but FOS >1 for larger scale failures through LF2. This scenario is closer to the observed landslide behaviour.
- **Model C** further lowers the LF2 aquifer pressure to below the ground surface. Circular failures within the LF1 unit are still FOS <1.
- **Model D** drops the LF2 aquifer down to the base of the LF1 unit and illustrates that this change has little effect on the potential failures in the upper unit. The implication is that subartesian movement of LF2 aquifer is not as critical to slope stability as movement of the LF2 aquifer from sub-artesian to artesian levels.
- **Model E and F** illustrate that critical circular failure is possible on the existing geometry with the LF1 aquifer drained or part full. The aquifer scenarios shown on Model e and F are approximate to the measured levels in 2005 and 2006, therefore using a homogeneous shear strength of 2 kPa and 11° for the LF1 materials with circular failure planes may not be a reasonable approximation of the actual conditions. Model F also shows how a small rise in water levels at the toe of the LF1 material is sufficient to reduce FOS from approx 1 (equilibrium) to 0.89 (failure).
- Plane failure considers a scenario based on the following observations –
  - Movement has occurred from full head to toe of the slide mass with the current slope geometry. This is not shown by circular failure analysis.
  - Circular failures in homogeneous material indicate movement should be occurring under current conditions where there is no observed movement.
  - Plan failure approximates sliding along residual strength planes at the base of the LF1 unit with break out at the head and toe.
- Plane failure and plane failure 2 and 3 show basal failure with FOS approx 1 for drained LF1 and LF2 aquifer at the base of LF1. This appears to be reasonable approximation of the existing 'in equilibrium' state of the landslide.
- Plane failure 4 and 5 show similar sensitivity of planar failures to circular failures with regard to increasing water levels in the LF1 aquifer.

3.3 Conclusions

The current groundwater conditions appear to be drained within the LF1 unit and a water level at or below the base of the LF1 unit for the LF2 sandy aquifers. In this condition the landslide is in approximate equilibrium and no significant movement is observed.

Modelling of plane failure in the LF1 material with a shear strength of cohesion 2 kPa and friction 11°, and the above groundwater conditions gives a reasonable approximation of the existing conditions.

Landslide movement (FOS reduced significantly below 1) is very sensitive to modest increases in groundwater in the toe area of LF1. Increases in groundwater in LF2 aquifers from sub-artesian to artesian will also significantly lower FOS.

The postulated worst case artesian head in LF2 aquifers is unlikely to have ever been achieved. If it had been then larger and deeper seated failures should be observable. The modelling suggest that LF2 aquifers varying from sub artesian to 1 or 2m above ground level is sufficient to drive the observed slope movements.

In the current slope geometry the interpreted landslide, material shear strengths and aquifer levels are sufficient to explain the observed landslide features and behaviour.

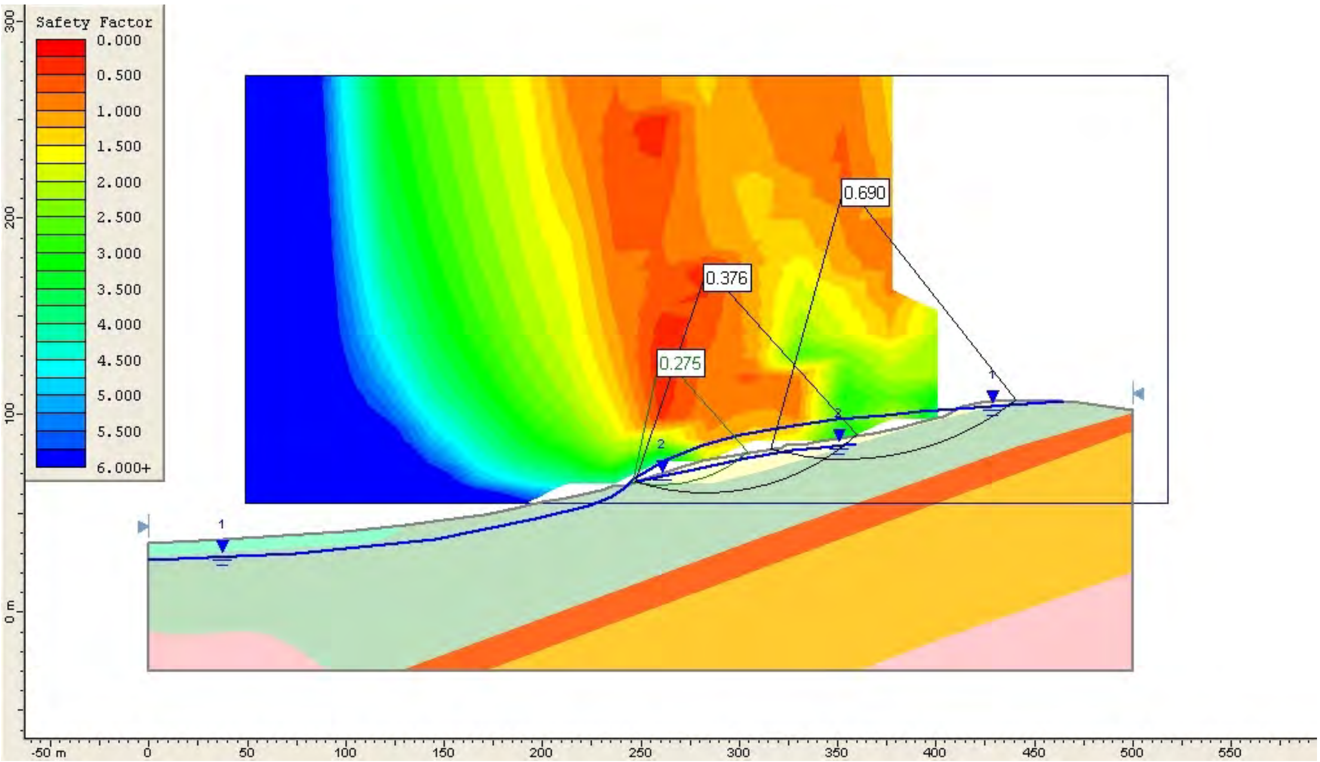
The analysis indicates that maintaining drained conditions, via slot drains in the toe of the landslide mass and down slope into the LF2 units is critical to preventing future movements of the landslide.

For and on behalf of Coffey Geotechnics Pty Ltd

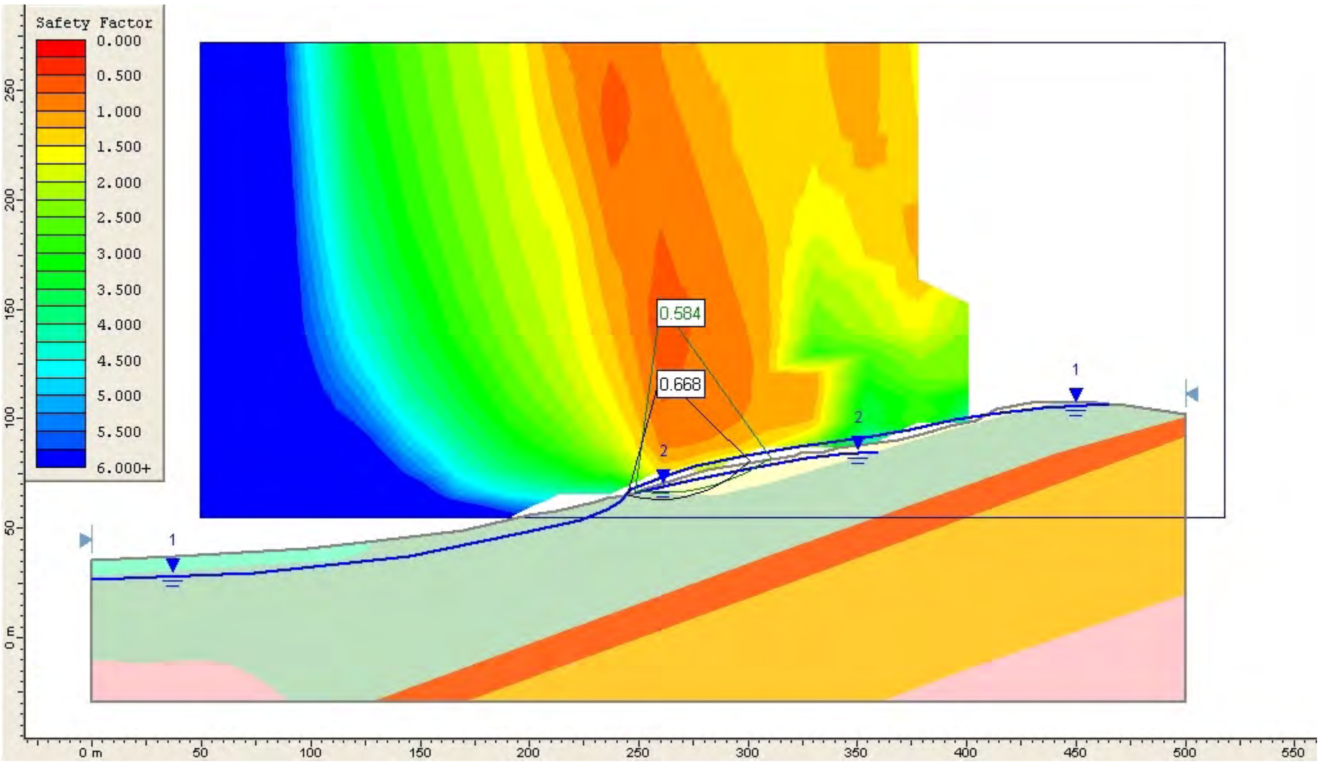
Barry McDowell
Principal Engineering Geologist

10 November 2006

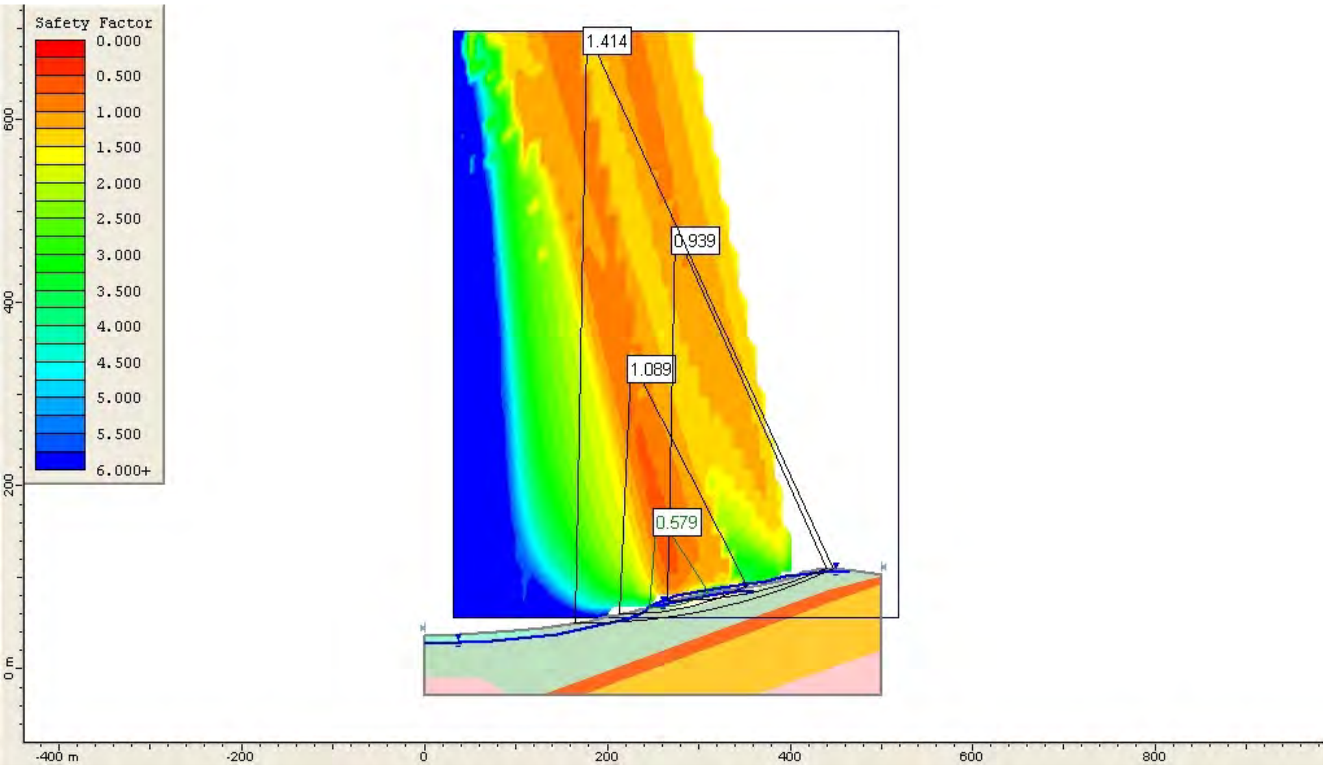
SLIDE output results Models A to E varying groundwater levels and Plan failure models



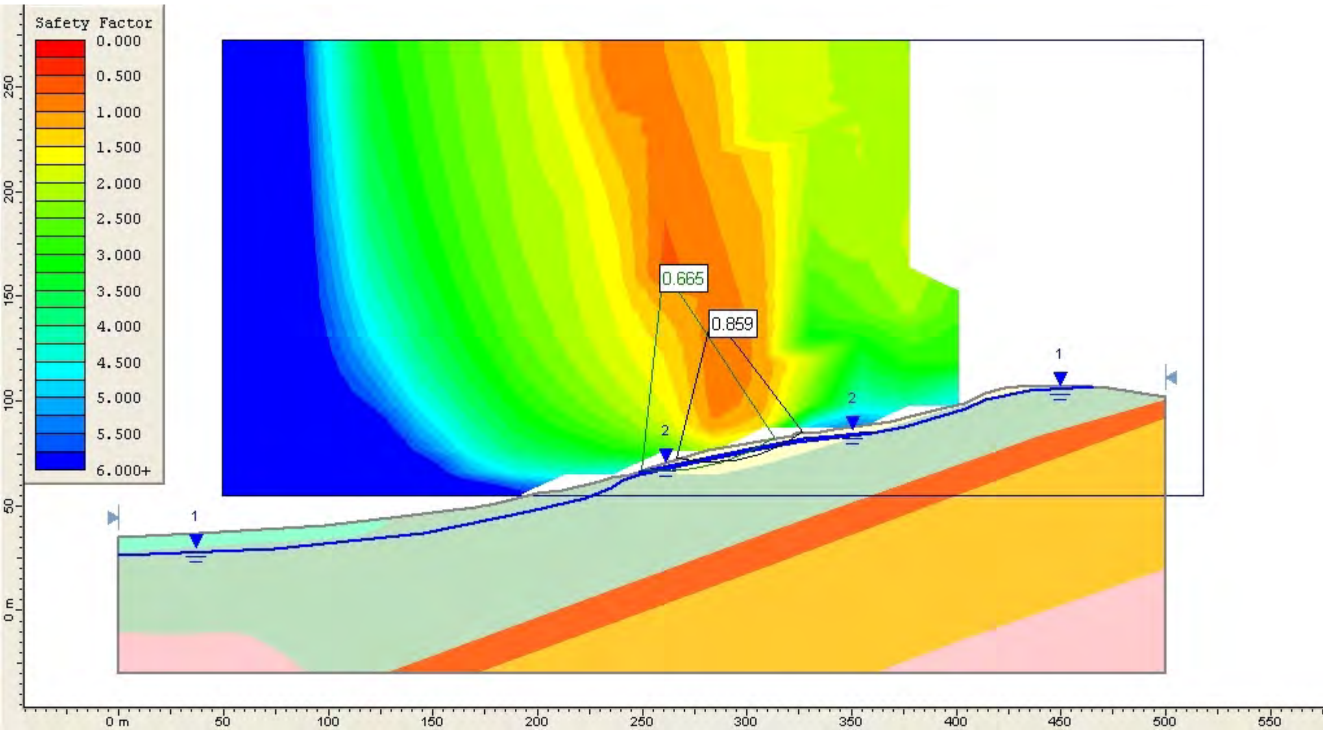
Model A



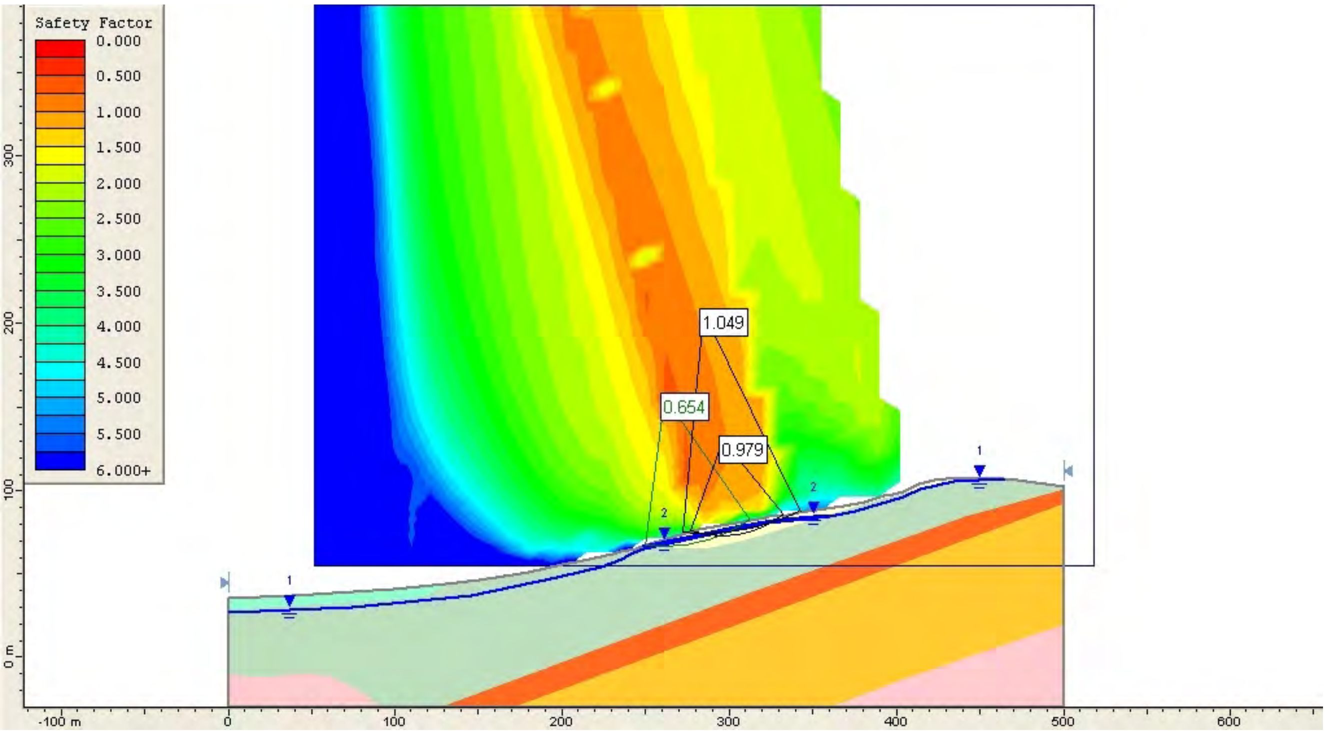
Model B



Model B-2



Model C



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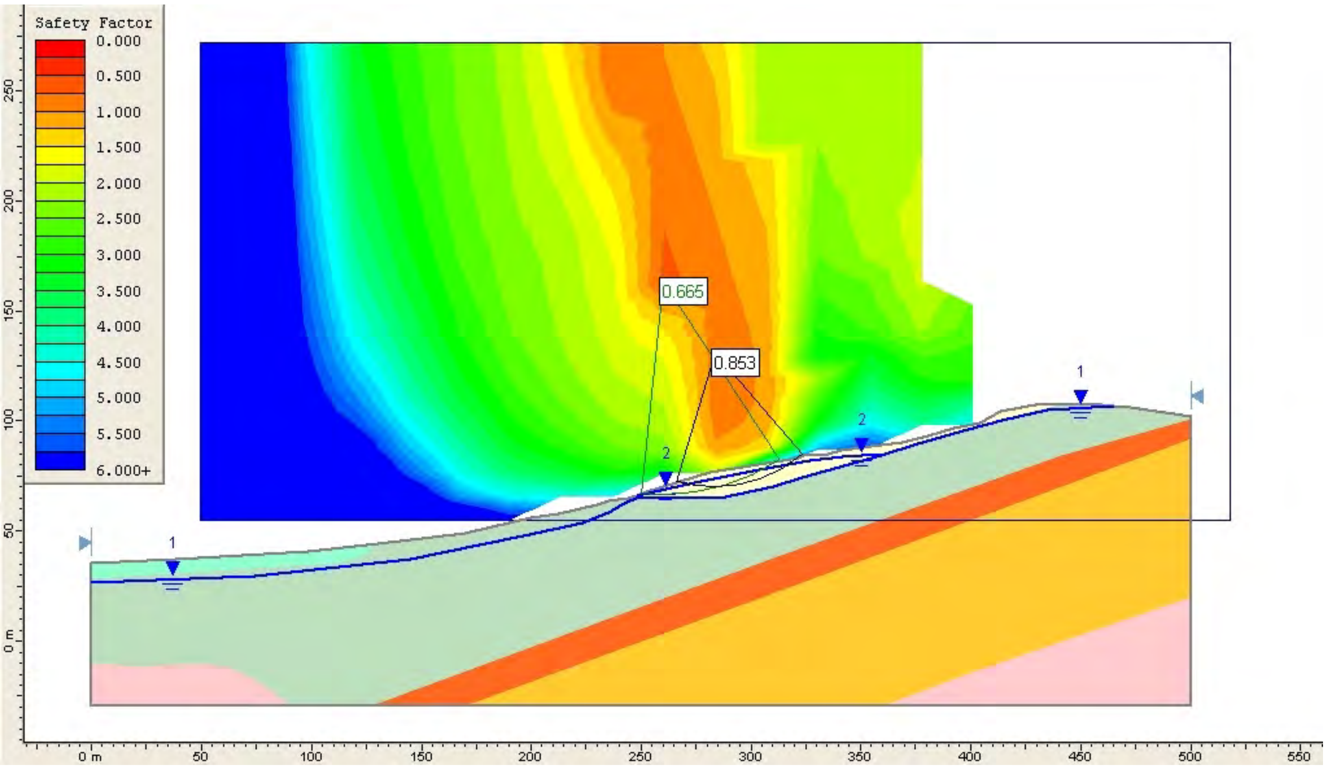
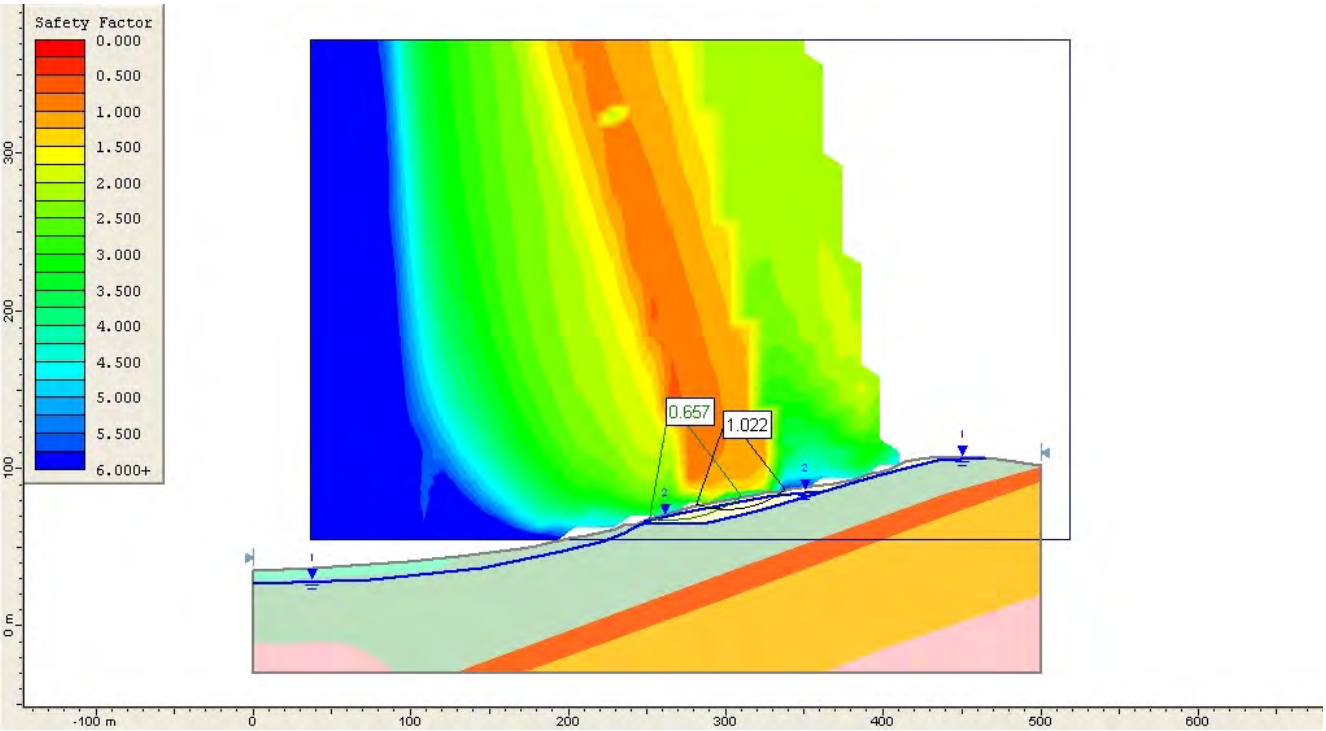


Model D



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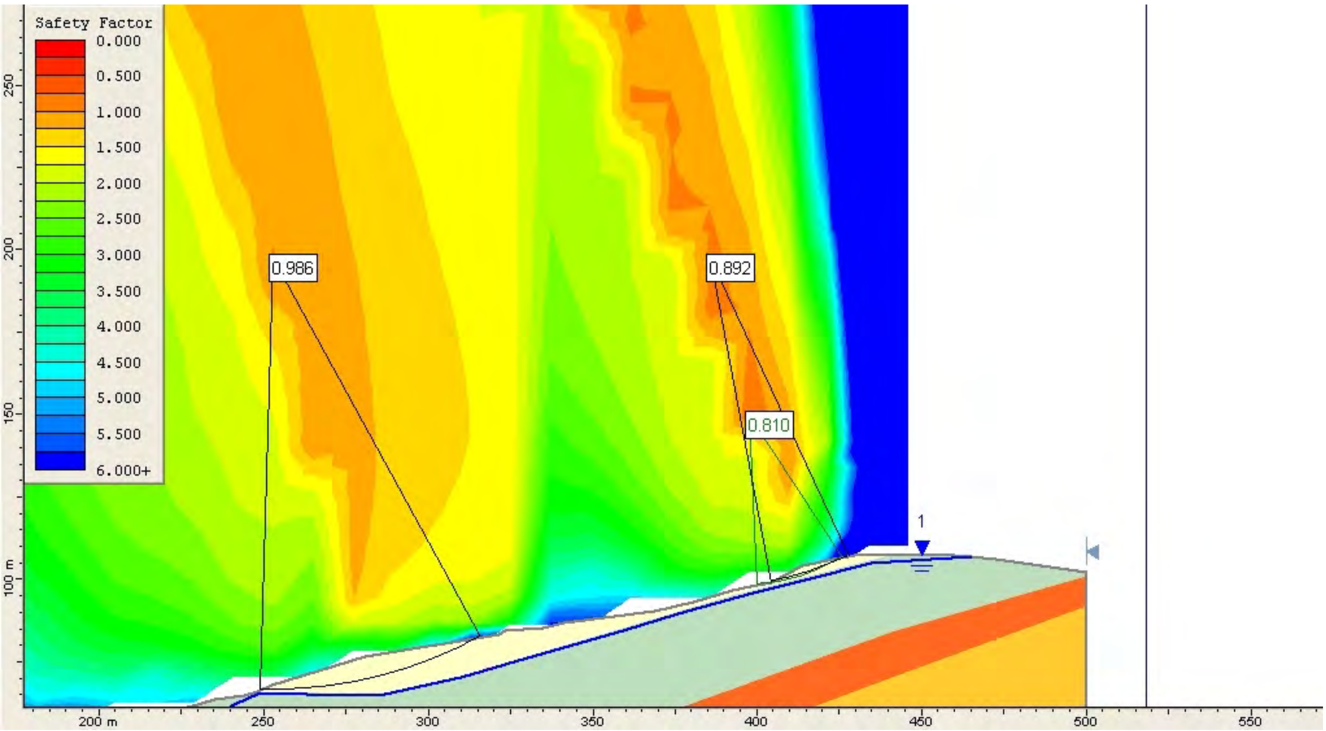
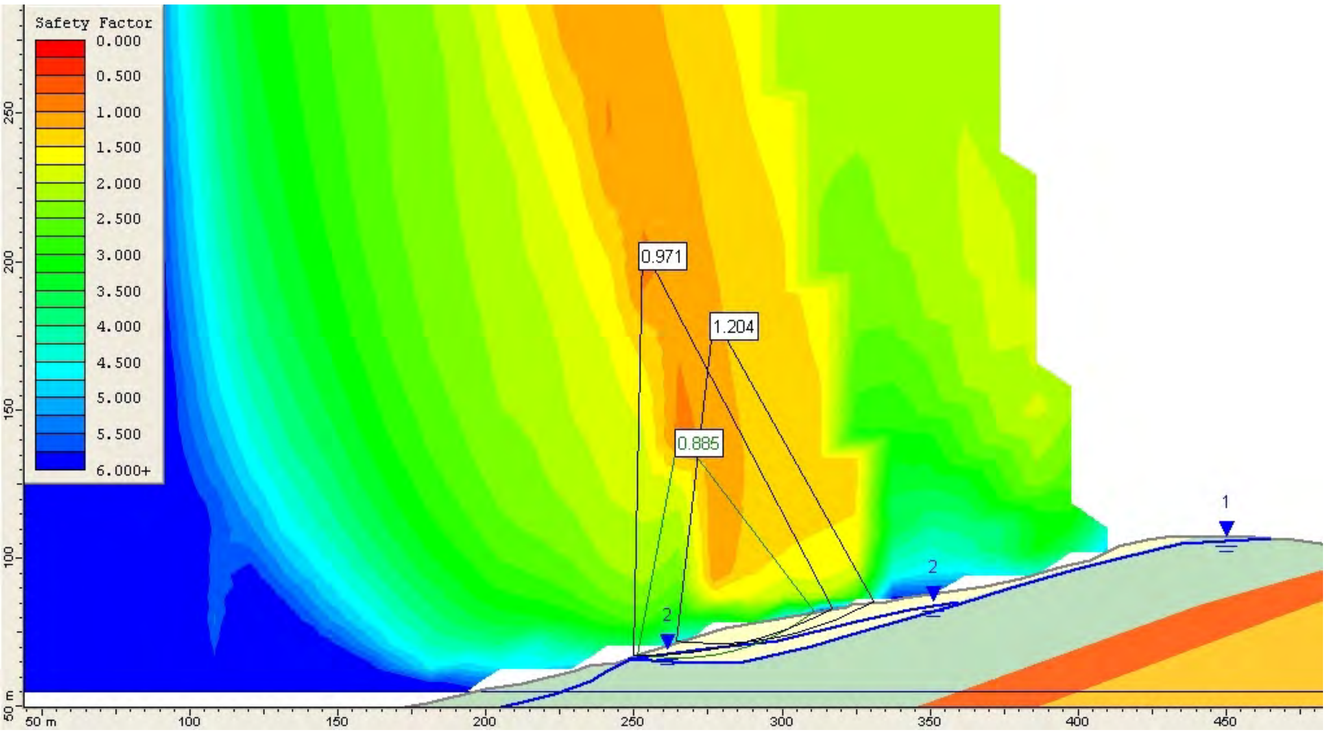
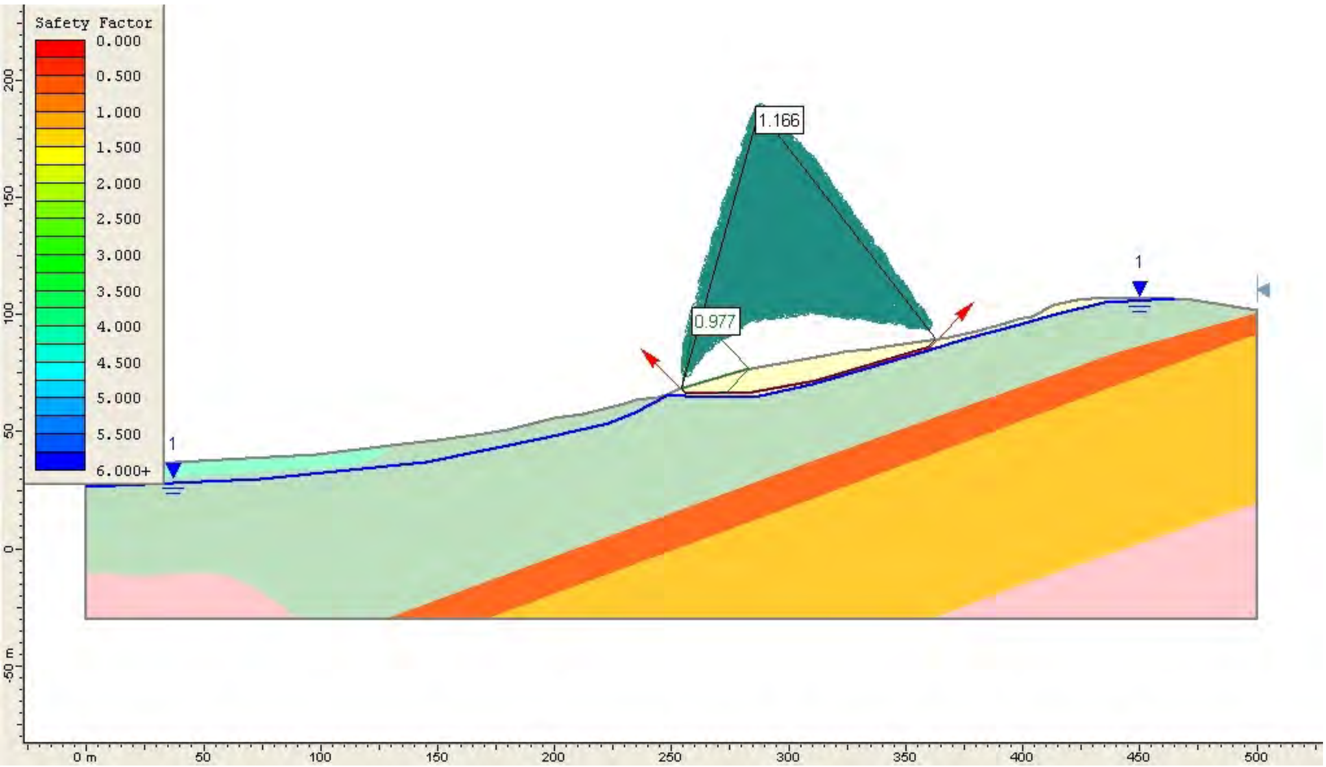


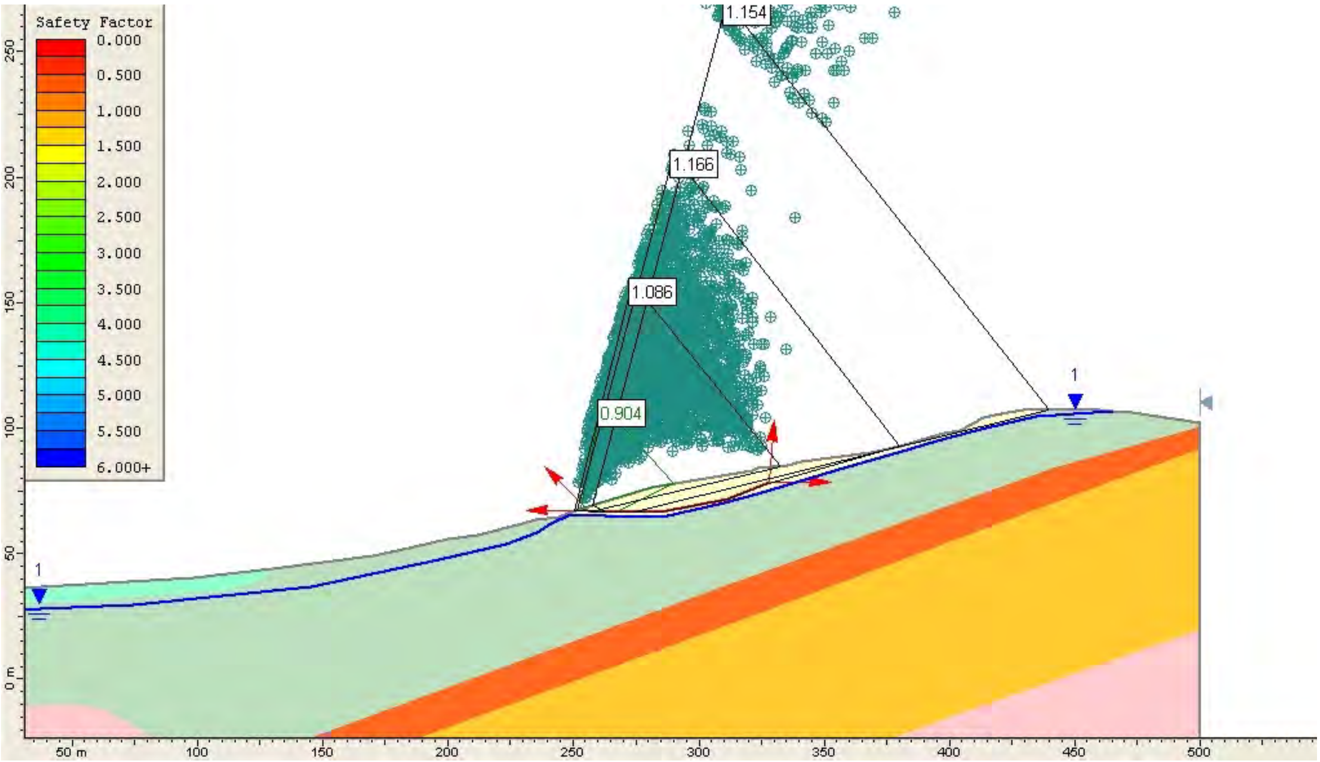
Model E



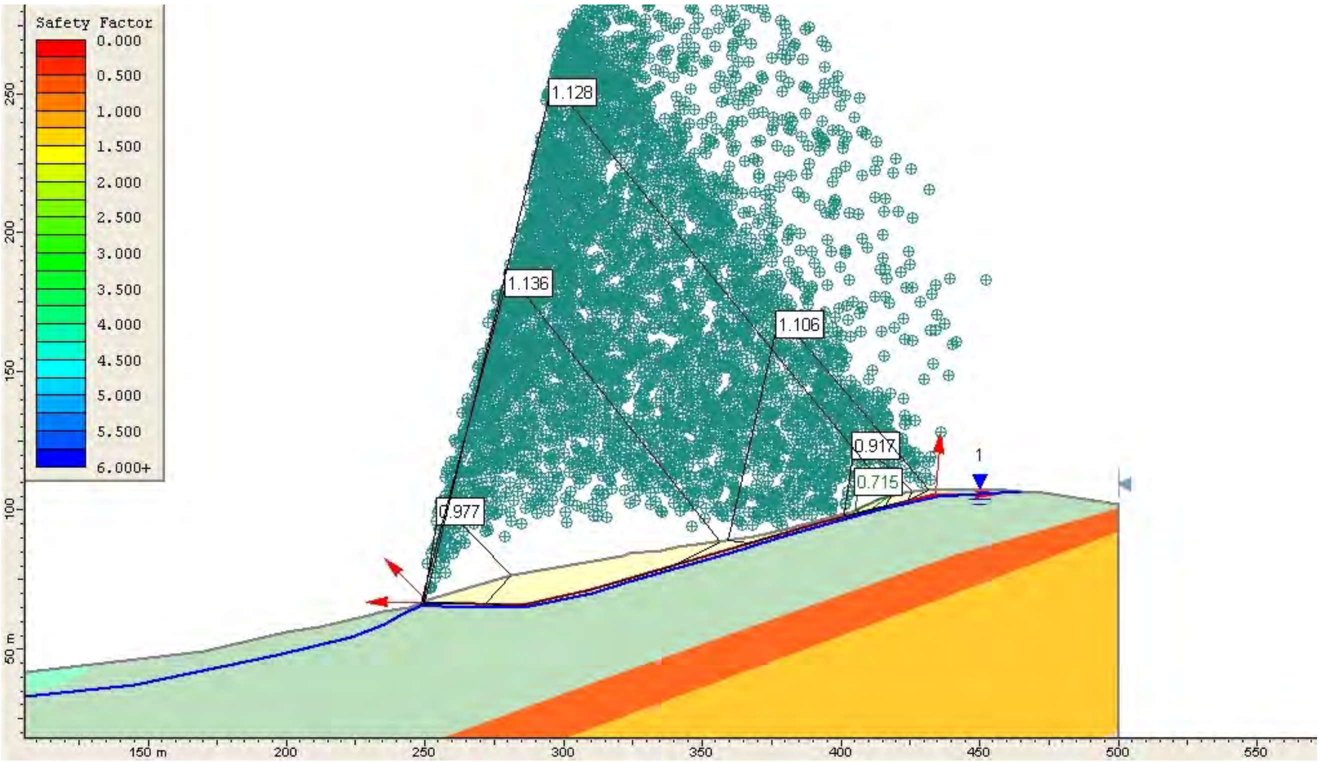
Model F



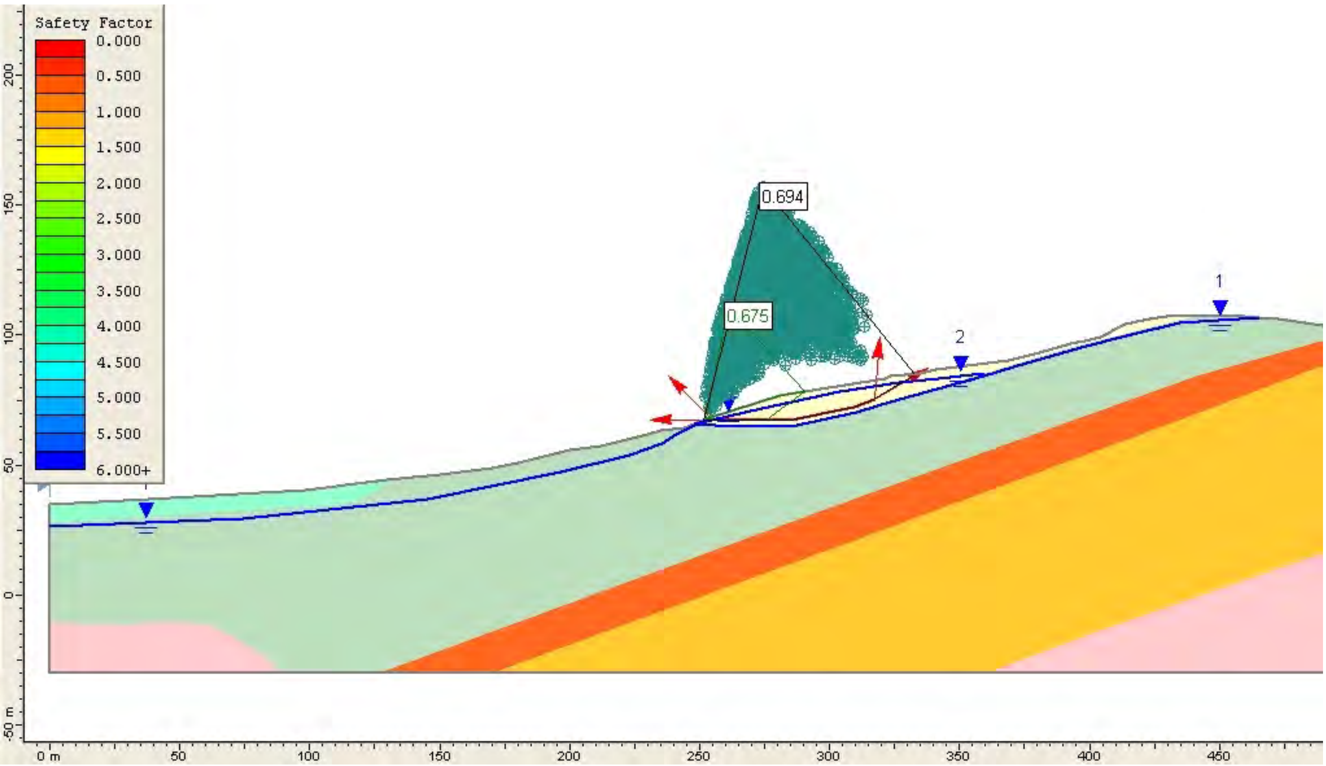
Plane Failure



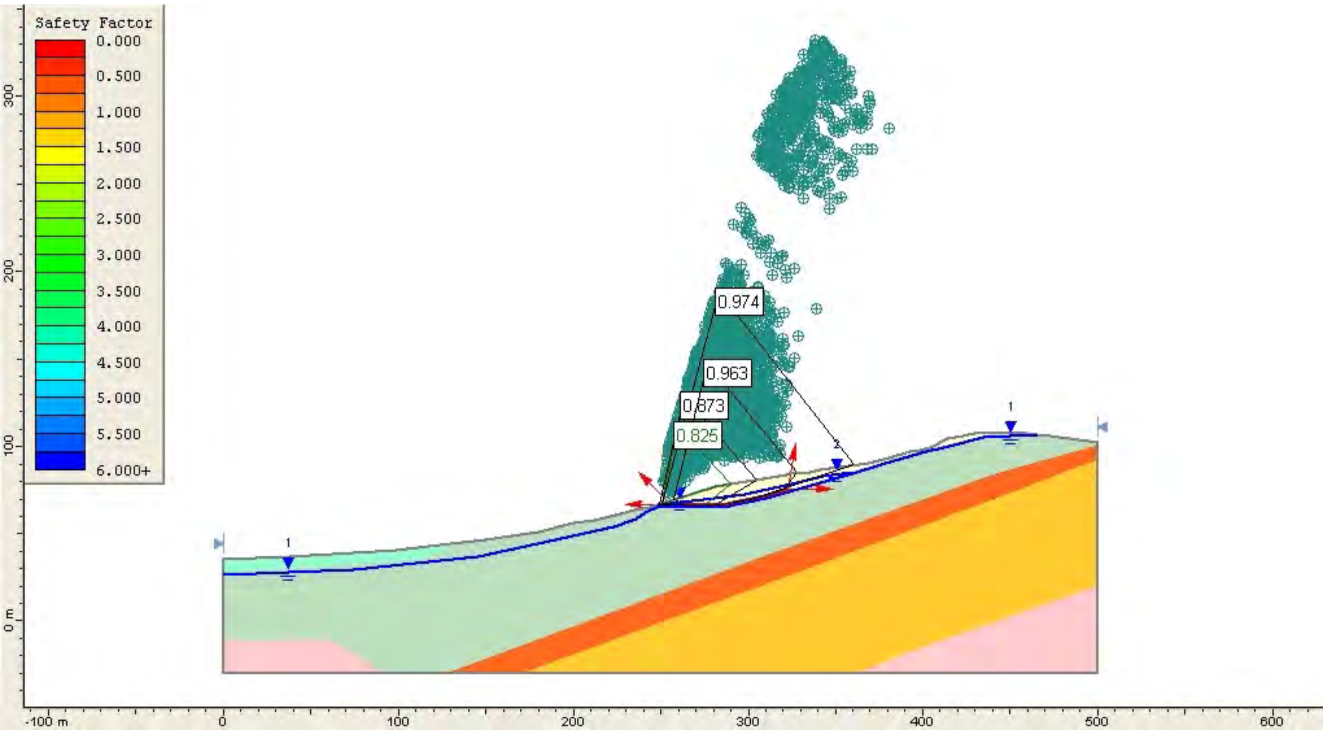
Plane Failure 2



Plane Failure 3



Plane failure 4



Plane failure 5