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# Management of a Suburban Landslide

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**Summary** A case history describing a slow moving deep seated landslide that was damaging houses at Rosetta in Tasmania is presented, including a geological model, the management plan developed to cope with the situation, details of stabilisation works and the results of monitoring.

## 1. INTRODUCTION

In 1990, rupture of pavements and services and developing structural damage in houses was observed in and around Hone Road in Rosetta, a suburb of the City of Glenorchy adjacent to Hobart, in Tasmania. The pattern of damage suggested that about 40 recently constructed, substantial brick and tile dwellings were being affected by a slow moving landslide.

This paper describes the technical management of the situation from the perspective of a consulting engineering geologist retained by Glenorchy City Council.

## 2. BACKGROUND

A number of parties were involved in the issue, including Glenorchy City Council, the State Government, the State Bank (which was involved in financing the subdivision), the Tasmanian Department of Mines, a residents pressure group, individuals living in or around the landslide, legal and political advisors to the various parties, independent consultants, and the media. Geotechnical investigations were carried out by some of the parties, particularly the Tasmanian Department of Mines (Donaldson, 1991). At an early stage in the proceedings a protocol was established that all of the investigation information would be shared by those involved, following in part the guidelines produced by the Geomechanics Society for members involved in litigation (Australian Geomechanics Society, 1991). This tended to produce a convergence of technical opinions, which reduced the potential for an adversarial approach.

The investigations included reviews of records and aerial photographs, surface mapping, subsurface investigations using test pits and cored boreholes, installation of standpipes and piezometers, groundwater monitoring, analysis of damage patterns, measurements of movement, laboratory testing etc. An interpretation of the results of the investigations follows.

The landslide is located adjacent to part of an inactive fault system that bounds a Tertiary graben, the graben forming the valley in which greater Hobart is located. During the development of the fault system, in the early Tertiary, slope deposits including plastic clays, clayey gravels and boulders, and blocks of rock with dimensions of several meters, accumulated against an active fault scarp. Progressive fault movements during the accumulation of the slope deposits may well have induced shear surfaces within some of the weaker materials. As the landscape developed a remnant of the slope deposit was preserved against a ridge of more competent in-situ rock and the effects of weathering and incision, probably combined with an unusually wet period during the Pleistocene, led to the formation of a deep seated landslide. With time, the surface expression of the landslide, such as the backscarp and the toe bulge, became degraded by superficial slope processes, and no obvious geomorphological evidence of the landslide was discernible when subdivision was approved. This geological model is illustrated in Figure 1.

During development relatively minor earthworks associated with road and house construction, and progressive changes to groundwater levels associated with modifications to surface drainage, garden watering and leaking services, led to a reactivation of the landslide. Ground movements then ruptured services and pavements leading to the ingress of additional water, and movement accelerated. Massive structural damage occurred in houses that straddled the landslide boundary, but those houses entirely within the landslide mass tended to suffer much less damage.

A sketch plan and section through the landslide is presented in Figures 2 and 3. The piezometric surface indicated in Figure 3 is the surface that was measured prior to the commencement of stabilisation works, which was a maximum of a few metres above the basal shear plane and a limitation on the potential for drainage to improve stability.

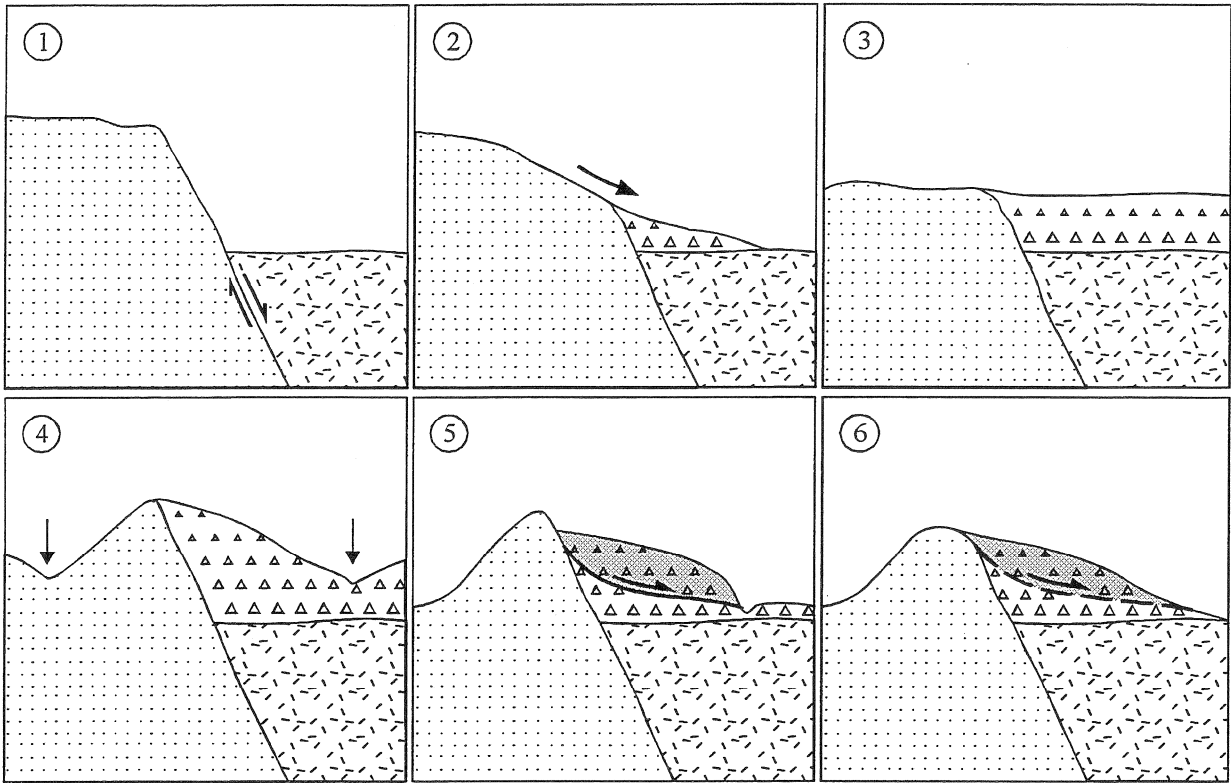


Figure 1. The Geological Model, 1 - early Tertiary faulting, 2 - accumulation of slope deposits, 3 - development of a mid-Tertiary surface, 4 - incision of the surface, 5 - deep seated landslide, 6 - degradation of landslide features.

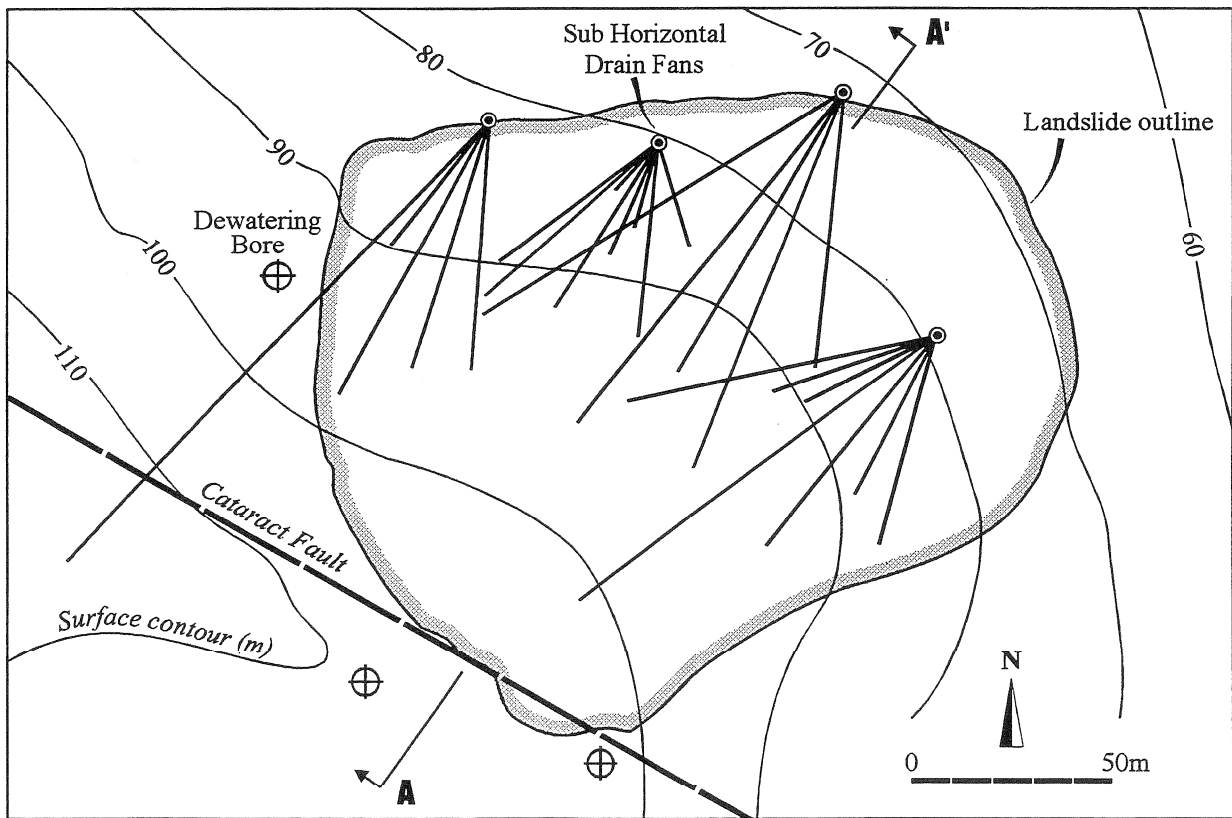


Figure 2. Plan of Landslide and Stabilisation Works - details of housing omitted.

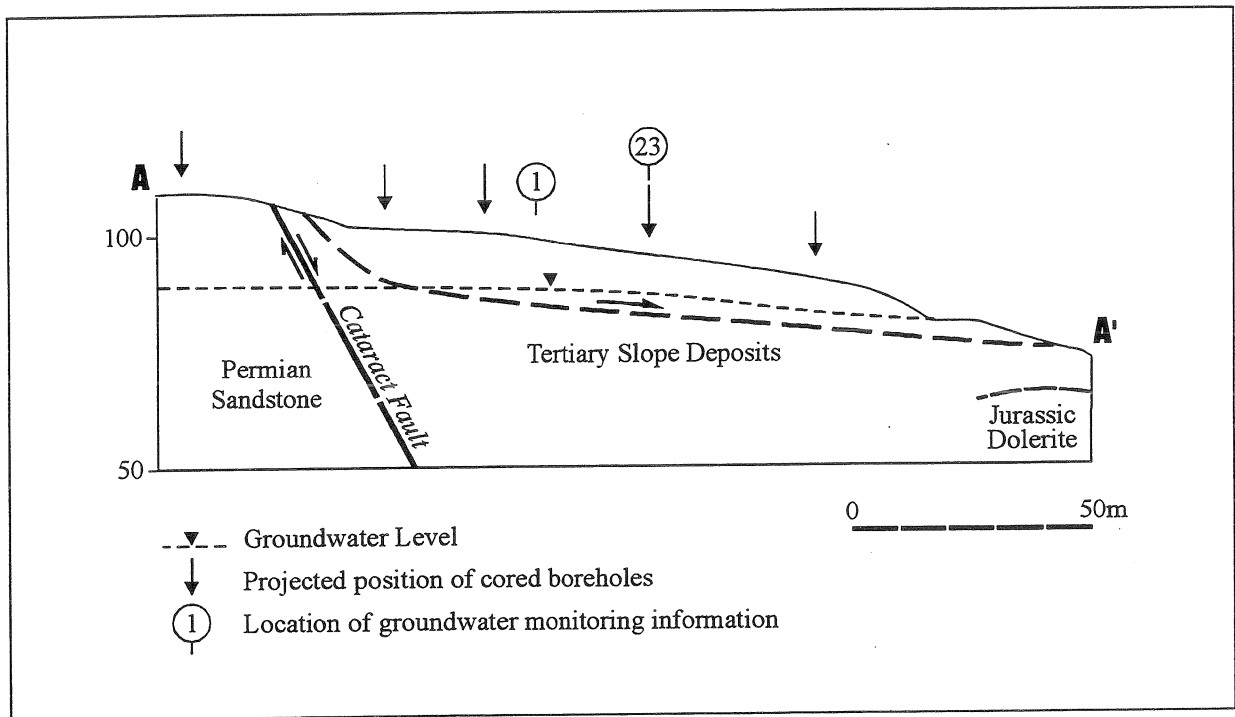


Figure 3. Interpretative Cross Section

### 3. MANAGEMENT

In Tasmania an important precedent exists, as in three previous instances where groups of houses have been destroyed by landslides the State Government has paid compensation to the owners (Stevenson, 1975). On the basis of this precedent an expectation developed within the community that if houses affected by the landslide became uninhabitable and had to be demolished, then the owners would receive some compensation, and at an early stage the State Government, Glenorchy City Council and the State Bank agreed to jointly fund some form of compensation package for the owners of houses made uninhabitable by the landslide.

As Glenorchy City Council was involved in the compensation package, managed the services, and was the level of government in closest contact with the community, the Council became very active in managing the situation. This involved dealing with a variety of technical, social and political issues in a pro-active manner, the strategy being progressively defined via a series of objective driven management plans. The overall aim of the management method was to minimise the social and financial cost to all of the parties concerned.

At the time that this approach was adopted, in late 1990, the rate of movement of the landslide was around 1 mm every 4 days and appeared to be accelerating, two houses had been demolished, and the demolition of at least 40 houses was being considered.

The initial consideration was for the safety of people in and around the landslide. It was neither practical nor desirable to immediately evacuate the area, as it was not known if this would be necessary in the long term, and such an approach certainly ran counter to community expectations. However in the early stages of investigation the nature of the landslide was unknown and the movement record could be interpreted as accelerating. Accordingly, an "Emergency Management Plan" was formulated, established, and discussed with the appropriate authorities, following Tasmanian local government guidelines. The plan dealt with various scenarios, including what was considered to be a worst case, which was that during an extreme rainfall event the landslide could accelerate, rupture services, break up and partially degenerate into a mudflow. As part of this plan alarms were installed to detect large sudden movements of the landslide mass and arranged to alert a security group, who would then contact the Council's 24 hour service maintenance crew and an engineering geologist.

Considerations of the potential cost of compensation payments, the difficulty of evacuating and demolishing houses that were still habitable, and the threat to adjacent housing, service corridors and thoroughfares if the movement continued, suggested that attempting to stabilise the landslide would be the most cost effective approach. This conclusion formed the basis for planning technical actions and civil works to achieve the following initial objectives:

Objective 1 - to reduce the likelihood of acceleration of the landslide by preventing additional water from extreme rainfall events and/or ruptured services entering the landslide mass. The works carried out to achieve this objective included the location of water services in flexible mains on the surface, sealing pavement cracks, diversion of stormwater pipes with substantial catchments to avoid crossing the landslide, and the inspection and repair of any underground services that remained in use within the landslide. In addition a surface water management plan was implemented to reduce infiltration of water from excessive garden watering, as water balance assessments suggested that garden watering could make a significant contribution to groundwater levels.

Objective 2 - to slow down the rate of landslide movement until the landslide stopped, and then avoid further movement, largely by drainage of the landslide mass and surrounding ground. The works carried out to achieve this objective consisted of the installation of arrays of sub-horizontal drainage holes and, at a later stage, minor pumping from vertical drill holes and some unloading earthworks.

Objective 3 - to manage the vacation and demolition of severely damaged housing such that potentially leaking services were removed and any earthworks that might improve stability could be carried out.

Objective 4 - to minimise further damage to housing associated with continuing ground movements by cutting slots in concrete slabs or stiff structures that were obviously pushing into and damaging house structures.

The civil works associated with Objectives 1 and 2 were relatively easy to plan and implement, although the heating of household water in services exposed on the surface during the summer proved to be a source of concern. However works associated with Objectives 3 and 4 were less easy to pursue, as conflicts developed between the technical objectives and house owners rights and wishes e.g. although it might have been technically desirable for some houses to be demolished, the wishes of the owners with regard to when the house might be vacated took precedence.

Following completion of the stabilisation works the management plan was revised to form an operational guide which defined the responsibilities of the various parties involved, indicated reporting requirements, established a long term monitoring programme and prescribed responses to the monitoring, and programmed reactive maintenance.

A detailed account of the management of all of the various social, political and legal aspects of the problem is well beyond the scope of this paper. However the technical approach was formulated under the scrutiny of public meetings, legal and political representatives, and the media, and required the communication of fairly sophisticated technical concepts in a clear and concise fashion. In general, concepts such as management by objectives, geological models, reducing pore pressures and unloading above the neutral point were well received when simply explained, presumably because individuals felt empowered by being party to the technical considerations. Greater difficulty was encountered by all parties dealing with subjective terms such as uninhabitable, stable, risk of instability, low/medium/high risk etc.

#### 4. STABILISATION WORKS

The sub horizontal drainage holes were drilled using an airtrack rig fitted with diamond drilling rods, to increase the stiffness of the drill string, a tungsten carbide fishtail or rock roller bit, and an air flush. Holes were drilled nominally at 5 degrees down on fanned arrays from locations suited to access, gravity drainage of the water table, and the construction of permanent headworks for the drain outlets. The holes, which were generally drilled as far as possible, were not cased, and the drill string was swiftly removed and slotted PVC was inserted to complete the drain. In some cases it took several attempts before the hole remained stable for long enough to complete the installation. A geotextile sock was not placed on the PVC, partly to increase the ease of casing installation, and partly because of fears that the geotextile might increase the chances of drain holes clogging. The work was carried out by an experienced contractor on a unit rate basis. The drainage array is illustrated in Figure 2. Several holes encountered small pockets of water resulting in significant flows for short periods upon completion of the drains, and the array at the base of the slope flowed continuously at a rate of several litres per minute for many months. The deflections of the holes from their planned alignments were not known but were assumed to be considerable, and thus where each hole ended up was largely uncontrolled. The occurrence of water appeared to be unpredictable with one instance where a 150 meter hole encountered no water, yet water was encountered in an adjacent hole that was 25 meters long.

An initial trial using a water flush rig led to slight localised ground movements when the drill hole collapsed and the flush water pressurised a part of the landslide mass; this approach was rapidly abandoned.

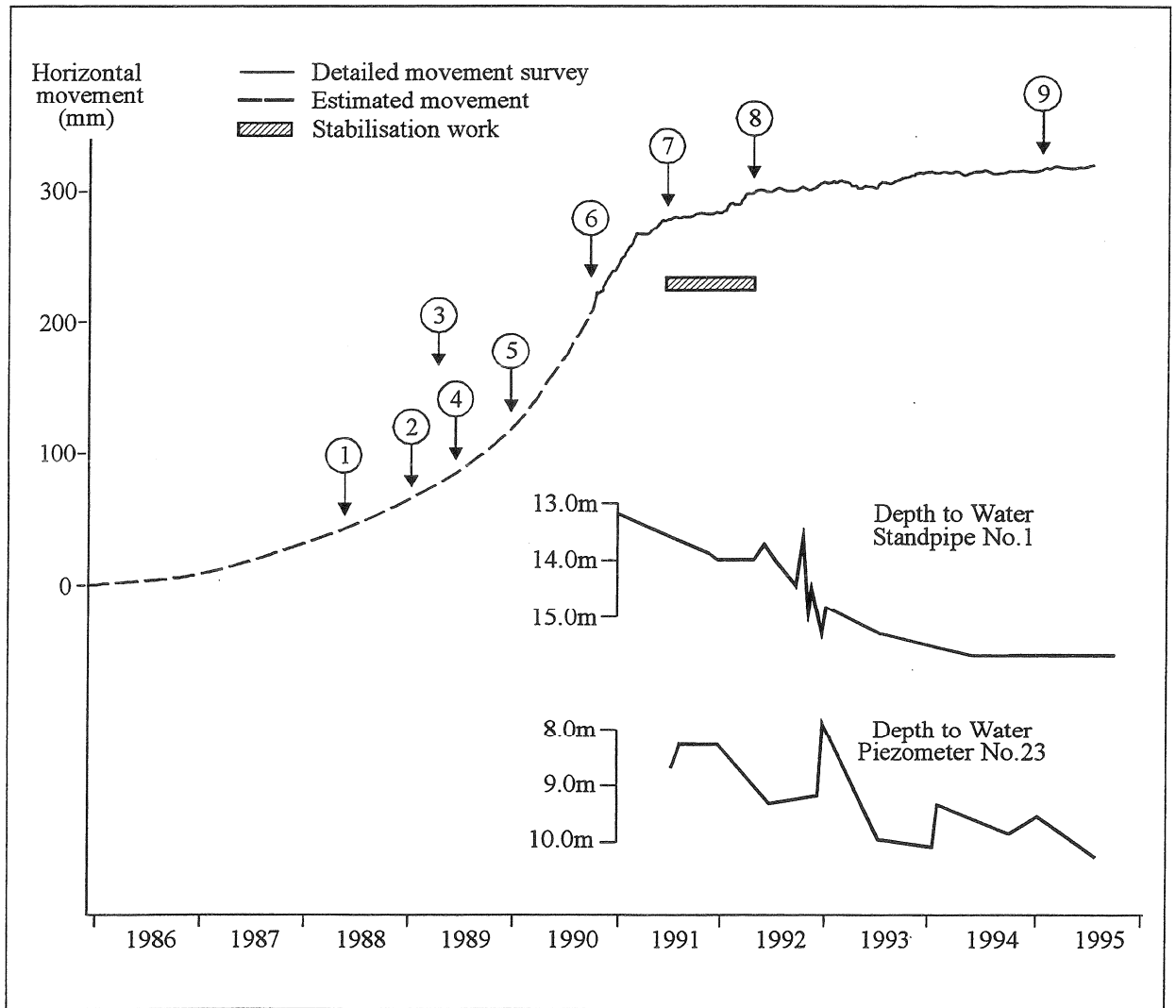


Figure 4. Results of Monitoring, 1 - some house cracking noticed, 2 - obvious signs of structural distress, 3 - majority of house construction finishes, 4 - water main leak, 5 - water main leak, 6 - detailed survey commences, 7 - stabilisation work commences, 8 - stabilisation work finishes, 9 - small movements still discernible.

Three vertical water bores fitted with low volume pumps were also installed to drain the Tertiary slope deposits to the south-east of the landslide and Permian and Triassic strata below the landslide. The bores were located outside the landslide mass to avoid being sheared if movement continued (Figure 2).

Earthworks involving the removal of about 2000 tonnes of material to unload the top part of the landslide were incorporated into the landscaping of areas where houses had been demolished.

## 5. MONITORING AND RESPONSE

Monitoring consisted of the measurement of surface movements, assessment of the depth of movement using steel rods suspended in PVC casings installed in boreholes, and the measurement of groundwater levels in standpipes and piezometers and the rate at which drains flowed.

Surface movements were measured relative to a theodolite sight line between stable base stations outside the landslide, using arrays of pins along the roads. It was estimated that the survey accuracy was plus or minus 4 mm, and thus a degree of interpretation of the measurements was required. The stability of the main base station was assessed from electrical distance measurements to stations well outside the landslide and away from sloping ground.

The survey results were a fundamental management tool, as the results of the monitoring were the measure of compliance with the objectives. As part of the management plan various responses to the results of the monitoring were defined, ranging from continued monitoring and programmed maintenance when there was no discernible movement, increased monitoring and investigation if movement rates similar to those before

stabilisation works started to develop, and an immediate response involving a high level assessment to decide whether or not evacuation was necessary and if any immediate stabilisation works could be implemented, if movement rates increased beyond the maximum rate known to date.

Groundwater levels were plotted from critical installations and used to assess the progress of the drainage and the effect of rainfall. Planned responses included increases in the rate of monitoring and inspections, triggered by unusually intense rainfall events of various levels and/or changes in the groundwater levels. An incident in December 1992 illustrated the value of such responses. A routinely measured piezometric level inexplicably rose to a nominated response level immediately before Christmas. It was found that the rise coincided with the unauthorised filling of an indoor swimming pool. The pool was subsequently emptied, and decommissioned, and the piezometric levels dropped.

The horizontal movement of a typical survey point in the upper part of the landslide and the interpreted history of movement prior to monitoring is presented in Figure 4 together with the changes in water levels in some critical boreholes

## 6. DISCUSSION AND CONCLUSIONS

The results of the monitoring show that the landslide movement rate has progressively reduced following the implementation of the management plan. However, a careful examination of the time plot suggests that the rate of movement may have actually reduced prior to the main stabilisation work, and thus it is not clear which part of the management plan resulted in the reduced rate of movement, although it seems likely that the general reduction in piezometric levels caused the reduction in movement rates.

Piezometric levels in the central part of the landslide mass gradually dropped by about 2 meters following the installation of the drains and the rate of movement has reduced as piezometric levels reduced. However three years after completion of stabilisation works occasional small movements of up to a couple of millimetres every six months can be discerned if the overall record is considered, although such movements are within the error range of any particular set of measurements. It is not clear if these small movements represent landslide activity, movement that the ancient landslide exhibited prior to subdivision, some form of natural hillside creep that could be measured on other slopes if they were to be monitored, or perhaps a consolidation of ground that was in an active state,

in response to the change in stress brought about by the stabilisation works.

This raises the question as to how the current condition of the Rosetta landslide should be described, as it has not necessarily been "stabilised". However, the rate of movement is barely perceptible, much of the housing that could have been destroyed remains in good condition and occupied, and community concerns have largely faded away. Thus despite the uncertainty regarding the stabilisation of the landslide, the management plan has succeeded in limiting its social and financial impact. At a technical level the current condition could perhaps best be described in terms of the stabilisation work having significantly reduced the probability of a certain level of movement. How this relatively sophisticated concept should be expressed to the community in simple unequivocal terms remains a challenge.

A detailed technical understanding of the landslide was essential in formulating the management plan. This involved consideration of the geological model, the landslide geometry, the likely causes of movement, the practicalities of what could be done, and the application of basic principles such as drainage; quantitative stability analyses were not found to be particularly relevant. However, despite the importance of the technical understanding, with hindsight, the successful implementation of the plan proved to be far more dependent upon the communication and management skills, and the pragmatism, of a variety of individuals involved in the issue.

## 7. ACKNOWLEDGEMENTS

This paper is published with the permission of Glenorchy City Council.

## 8. REFERENCES

- Donaldson, R.C. (1991). *Rosetta Landslide Geological investigation and Slope Risk Assessment*, Report 1991/20, Tasmanian Mines Department.
- Australian Geomechanics Society (1991). Guidelines for Members Reviewing the Work of Other Engineers for the Purposes of Litigation, *Australian Geomechanics* No. 21, pp 45-46.
- Stevenson, P.C. (1975). A Predictive Landslip Survey and its Social Impact, *Proceedings of the Second Australian - New Zealand Conference on Geomechanics*, Brisbane, pp 10 - 15.