MINERAL RESOURCES TASMANIA

LANDSLIDE RISK ASSESSMENT AND MANAGEMENT IN TAROONA

Taroona, Tasmania

HO104/3-AC

6 June 2002

HO104/3-AC AM
6 June 2002

Mineral Resources Tasmania
Po Box 56
ROSNY PARK TAS 7018

Attention: Ms Carol Bacon

Dear Madam,

RE: LANDSLIDE RISK ASSESSMENT AND MANAGEMENT IN TAROONA

Please find enclosed our report on landslide risk assessment and management in Taroona. This report incorporates comments received on a draft report circulated to MRT and Kingborough Council.

Please contact the undersigned if you have any questions on the report or want further information.

For and on behalf of

COFFEY GEOSCIENCES PTY LTD

BARRY MCDOWELL	**ALAN MOON**
HOBART MANAGER	**SENIOR PRINCIPAL**

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SUMMARY

At the request of Mineral Resources Tasmania (MRT) Coffey Geosciences Pty Ltd (Coffey) have conducted an assessment of landslide activity, hazard and risk in part of Taroona in the Kingborough Municipality. A major part of the study has involved reviewing evidence from previous investigations in the area.

Understanding the geological setting and geological and geomorphological history helps to understand where and why landslides may occur, their likely age and their degree of activity. The major landslides in the area are located in sediments and volcanics (both soil and rock in engineering terms) of Tertiary age, which have been deposited adjacent to major faults. The sediments have been tilted, folded, faulted and disrupted by past landslides and volcanic activity. Channels have been cut in the Derwent Estuary during periods of low sea level associated with glaciations. The Tertiary deposits are underlain by dolerite of Jurassic age and mudstone and sandstone of Permian age.

We have concentrated on trying to understand the scale and extent of major landslides that have occurred or may occur in the study area. There is evidence to suggest that recent landslide movements in the area may be associated with a very large landslide complex in which there may be a long history of landslide activity. The Taroona Landslide Complex may have been triggered by under cutting of the slopes of an old river channel at least 800m off the present coast. Most of the Taroona Landslide Complex is offshore and most of the onshore parts of the complex have probably been inactive for many years.

We have referred to the recently active onshore parts of the Taroona Landslide Complex as the School Creek Landslide. The School Creek Landslides includes four smaller landslides (Archery Field, Foreshore, Car Park and Dixons Beach) within or at its boundary. The headscarp and northern boundary of the School Creek Landslide is reasonably well defined. The southern boundary is difficult to define and recent movements may have occurred in local zones of distortion, shear or tension rather than along a single sheared surface. The landslide is slow moving and annual rates of movement in the headscarp in the past 50 years probably vary between 1mm and 30mm. Most movement is probably associated with prolonged periods of above average rainfall. The erosion by wave action may have reduced the stability of some of the smaller landslides.

Future movements of the landslides in the School Creek Landslide are likely to be small and slow. The major risk of damage to property is in the headscarp area and along the southern boundary where buildings, roads and other infrastructure are vulnerable to damage. The sewer line may be damaged by movement of the smaller landslides. In our opinion it is very unlikely that rapid movements of the major landslides will occur and the risk to life is very low.

Preliminary landslide hazard zones have been defined to include the boundaries and body of the School Creek Landslide.

Effective landslide risk management will involve:

- Many different organisations, groups and individuals working together.
- Continuously improving knowledge and understanding of the landslide hazard.
- Continuously monitoring future landslide movement.
- Having a risk management plan and structure in place that can, and will act promptly to changing circumstances.

- Taking actions, where possible to reduce risk.
- Finding the funds to make it happen.

It is clearly essential for one organisation to take on the role of coordination.

We recommend that, initially, a larger area than the assumed boundaries of the Taroona Landslide Complex be included in the monitoring and management program.

Knowledge of the geotechnical model can be improved by reviewing available core and other samples, and by palynological analysis. History of the past movements can be obtained by unblocking an existing inclinometer, reviewing problems with services, reviewing a Parliamentary Public Works Committee report on Taroona High School (and associated material) and a review of current and past damage on private property. The value of further subsurface investigations should be considered following review of the additional evidence.

The people in the best position to detect early signs of landslide movement are those that spend most time in the area (residents etc.) It is essential that people in the area are aware of warning signs of landslide movement, and that damage is reported, reviewed and, where necessary, appropriate action taken. Regular field review by a landslide expert, regular ground survey and inclinometer readings should be part of the monitoring program. Additional monitoring should be carried out if unusual movements are reported or there is a long period of above average rainfall.

It is possible to reduce landslide risk by improving drainage and protection from wave erosion. The consequences of landslide movements can be reduced with flexible structures and risk can be avoided by not locating buildings on or near the boundaries of the landslide. Constraints on development can also reduce risk.

While there are costs associated with landslide risk management, the long term cost of inaction is likely to be greater. Many people live and work on slow moving landslides in many parts of the world. Where the risk is well understood and well managed there is usually little significant disruption to most peoples lives.

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1. INTRODUCTION

1.1 Original Brief And Proposal

At the request of Mineral Resources Tasmania (MRT), Coffey Geosciences Pty Ltd (Coffey) have conducted an assessment of landslide activity, hazard and risk in part of the Taroona district of the Kingborough Municipality. The project was divided by MRT (letter dated 3 August 2001, Reference 1AW079:AB) into three sub projects as follows:

Sub Project 1: Review of landslide monitoring data from Taroona;

Sub Project 2: Bathymetric survey of shallow inshore waters off Taroona;

Sub Project 3: Geomorphological mapping and interpretation of landslide activity at Taroona.

Briefs for the sub projects, prepared by MRT, were attached to the above letter. During discussions on the brief (Waite / Moon, August 2001) it was acknowledged that the available funds would be insufficient to fully assess and document landslide risk of Taroona and that the study should concentrate on trying to understand the extent and degree of activity of any major landslides in the area.

Coffey's proposal to carry out the project (Reference HO104/1P-AA) is dated 17 August 2001. Coffey was awarded the project on 6 September 2001 (letter Reference 1AW097:DS).

1.2 Changes In Scope

The original brief for Sub project 2 was to carry out a bathymetric survey of the shallow inshore waters off Taroona and to interpret the geomorphology of the area. During our work on Sub project 1 we became aware that bathymetry and seismic reflection testing had recently been carried out in the Derwent River off Taroona by David Gibbons as part of an honours project at the University of Tasmania. In our report on Sub project 1 (letter, 19 October 2001, Reference HO104/1-AD) we recommended that no further bathymetric work (or seismic reflection work) be carried out, at least until completion of the current project. In subsequent discussions MRT agreed with our recommendation. We also pointed out in our report on Sub project 1 that improved base maps of the project area would greatly assist the study and be an invaluable resource to all those involved in long term landslide risk management and other activities in the area. Following discussions with Hydro Tasmania, MRT advised us (letter 15 November 2001, Reference 1AW126:AB) to engage Hydro Tasmania to produce digital orthophotograph information of the project area based on 2001 and 1946 aerial photographs. The contoured orthophotographs became available to us in January 2002.

In the original brief it was envisaged that a structural survey of buildings would be carried out (by others) during the project. Following discussions between Coffey and MRT it was agreed that such a survey would be postponed and that comments on the value, purpose, scope and extent of such a survey would be included in our report.

2. SCOPE

This study has included:

- Initial site visits (Barry McDowell) on 13 September 2001 in the company of geologists and engineers and managers from MRT, Kingborough Council, The Department of Education, Department of Transport (DOT) and Pitt and Sherry Ltd.
- Preliminary review of reports, plans and other documents provided by MRT, DOT, Pitt and Sherry Ltd, Geoff Benn (surveyor) and William C Cromer Pty Ltd including:
  - Reports on reactive soils, cracked houses and stability problems in the area dating back to 1975;
  - Borehole logs;
  - Test pit logs;
  - Cone penetrometer results;
  - Laboratory test results;
  - Inclinometer records and analyses;
  - Survey results;
  - Copies of colour slides (from 1975).
- Review of published geological maps, memo reports, orthophotographs and stereopair aerial photographs taken in 1946, 1957, 1967, 1973, 1976, 1977, 1984, 1989 and 2001.
- Review of old photographs and maps and information on geology in “Taroona 1808-1986, farmlands to a garden suburb” published by the Taroona Historical Group (1988).
- Discussions with officers from MRT and engineers, geologists and others familiar with the area including:
  - Ralph Rallings and Joe Giedl (Pitt and Sherry, and ex DOT) on the site history, survey and inclinometer results.
  - Ric Donaldson (ex MRT) in the site history and past landslide movement.
  - David Leaman (Leaman Geophysics) on the regional geology, faults, depth of Tertiary basins and fault related slope stability.
  - Barry Weldon (ex MRT and ex DOT) on the site history and previous investigations.
  - Local residents on building damage (information volunteered, no systematic survey).
- Review of “A geophysical investigation of the Derwent Estuary” a University of Tasmania honours thesis and discussions with the author, David Gibbons (Gibbons 2001)
- Brief viewing of core obtained by drilling at the site by MRT.
- Field review of the geology and geomorphology of the site (Barry McDowell and Alan Moon) on 4 October 2001.

- Discussions with Keith Stove and Chris Spotswood of Hydro Tasmania on the feasibility, cost, timing and specifications for producing contoured orthophotographs based on 2001 and 1946 aerial photographs.
- Geological and geomorphological mapping of the project area (Barry McDowell and Alan Moon, February and March 2002).
- Brief field review of damage to roads, pavements and buildings (private houses viewed from the street only).
- Interpretation of the geological and geomorphological history of the area.
- Preparation of maps and across section.
- Documentation of the landslide history of the area.
- Assessment of the relationship between rainfall and landslide movement.
- Interpretation of the area affected by past landslide activity.
- Landslide risk assessment and hazard zoning.
- Assessment and preparation of advice on further work, monitoring and risk management.
- Meetings and discussions with MRT (Carol Bacon, Adrian Waite and Miladin Latinovic).
- Preparation of progress reports.
- Preparation of a draft report.

3. GEOLOGICAL AND GEOMORPHOLOGICAL HISTORY

References on the geology of the Hobart area are given in Section 7. Latinovic et al (2001) describe the geology of the project area (part of Taroona) based on recent work by MRT and Gibbons (2001) has provided useful information on the geology (and bathymetry) off the coast. In this study we have supplemented the existing information with our own observations and interpretations of the geology and geomorphology.

The MRT geological mapping (Latinovic 2001) is the most recent and most detailed geological mapping in the project area. We have not attempted to systematically review the geological boundaries or the stratigraphy but our observations and interpretations are in broad agreement with the MRT work. Minor differences in interpretation (based on our observations and additional information) are shown on maps and/or discussed in the text where relevant to the landslide risk assessment.

Understanding the geological setting and geological and geomorphological history helps to understand where and why landslides may occur, their likely age and their degree of activity. Table 1 is a summary of the relevant history of the project area. Figures 1 and 2 are a sketch map and sketch section respectively showing some of the features referred to in Table 1. For ease of reference we have named some of the creeks and other features in the project area.

It must be emphasised that both the maps and cross section involve a great deal of interpretation. Although drawn to a natural scale, the cross section should be regarded as diagrammatic. The main purpose is to illustrate the relationship between the difference geological units and the scale and type of past and present landslides. Landslide and landslide history are discussed in Section 5.

4. GEOMORPHOLOGY, SUBSURFACE MATERIALS AND STRUCTURAL GEOLOGY

4.1 Geomorphological Units And Surface Conditions

For ease of reference we have divided the project area into broad geomorphological units. These units are shown on Figure 1 and 3 and summarised in Table 2.

Most previous investigations and most of the evidence of past or current landslides are on the Coastal Bench. More information on the geomorphology (gullies, ridges, slopes etc.) of the Coastal Bench is given on Figure 3. Although there is an overall slope towards the coast the geomorphology of the Coastal Bench is complicated by a number of factors and processes including:

- Variations in resistance to erosion of the Quaternary and Tertiary age sediments and volcanics which underlie the Coastal Bench (e.g. soils and rocks of varying strength, boulder beds).
- Variation in structures within the soils and rocks (dipping beds, folds and faults etc).
- Erosion by creeks.
- Erosion by wave action during periods of higher sea level.
- Deposition in alluvial fans and creeks.
- Slope processes including landslides of various scales.
- Cuts and fills and other man made activity.

The geomorphological evidence for landslide activity on the Coastal Bench and elsewhere is discussed in Section 5.

Most of the project area is developed and is occupied by residential development, roads, schools and playing fields.

Table 1. SUMMARY OF GEOLOGICAL AND GEOMORPHOLOGICAL HISTORY

Geological period/time (approximate)	Event
Pre Permian (more than 300 million years ago	Deposition of sediments, burial, transformation into rocks, faulting, uplift and erosion.
Permian (280 to 230 million years ago)	Deposition of silts and sands, burial, transformation into siltstone and sandstone.
Jurassic (190 to 140 million years ago)	Initial break up to Gondwana, rift faulting, intrusion of dolerite, volcanism. Followed by uplift and erosion.
Tertiary (65 to 2 million years ago)	Continued fault movement (in the order of 300 to 600m of movement on the Taroona Fault?) with associated earthquakes, ground ruptures and fault scarps. Deposition of Sediments in the fault basin. Deposits include: • Slope deposits (some from landslides including rock, debris and earth slides, flows, falls and topples); • River deposits including boulders, gravel sand and clay • Lake and swamp deposits including silt, clay and organic material (now lignite or coal) There was also volcanic activity including lava flows and ash falls (tuff). Periods of warmer climate, uplift and erosion. Fault movements, landslides and volcanic activity result in tilting, folding, faulting and slumping of the sedimentary and volcanic soils and rocks. The structure is complicated by east west faults not shown on the cross section (Figure 2).
Quaternary (2 million years ago to present)	During the Quaternary there have been many periods of colder climate. These have resulted in repeated glaciations in temperate parts of the world and many oscillations of sea level. During colder periods, when sea levels are low and the coast was well south of Taroona the River Derwent would have cut channels in the floor of the present estuary. Some of these channels were probably at least 100m below present sea level and some may have been close to the present foreshore at Taroona. Investigations at the Tasman and Bowen Bridge show that side slopes of at least 30 degrees occur in places on these channels. Landslides probably occurred on the sides of these channels. Mechanical erosion and landslides probably occurred on steeper slopes elsewhere (e.g. Fault Stop) as a result of frost action and less vegetation. This would result in the accumulation of sand, gravel, cobbles and boulders in valleys and alluvial fans. During warmer periods when the sea level is higher, river, estuarine and marine deposits fill the deeper channels.
Last Interglacial (warmer part 130,000 to 120,000 years ago)	During the Last Interglacial the sea level on the Derwent Estuary was at least 20m higher than present in the Derwent Estuary. It is possible that erosion along the higher shoreline contributed to the present topography.
Last Glacial (120,000 years to 10,000 years ago)	During the coldest part of the Last Glacial (about 18000 years ago) the sea level dropped to at least 100m below the present level. The River Derwent cut a channel up to at least 48m and 52m below present sea level at the Bowen Bridge and Tasman Bridge respectively. Off the coast at Taroona the channel would have been deeper (perhaps at least 60m below present sea level). Landslides may have occurred on the sides of the channel. Gibbons (2001) work in the Derwent Estuary indicate that Holocene (post glacial) estuarine sediments occur within about 800m of the coast of the project area. Gibbons also interpreted a “slump deposit” (from seismic reflections) about 400m off the coast. It is possible that the “slump deposit” is a large landslide at the edge of the Last Glacial (or an earlier low sea level) channel. The bathymetry is consistent with this interpretation.
Holocene (10000 years ago to present)	During the Holocene (or post glacial period) the sea level returned to its present level. The sea has been at its present level for about 5000 years. Wave erosion has occurred along the coast during that period.
Modern (since European settlement)	In the past 200 years slopes in the project area have been modified by human activity. Cuts and fills associated with roads, building and playing fields and changes to vegetation and drainage may affect stability.

TABLE 2. SUMMARY OF GEOMORPHOLOGICAL UNITS

Geomorphological Unit	Brief description/typical slopes/comments
FAULT SCARP	Steeper slopes uphill (west) of the Taroona Fault. Dissected by gullies. Typical slopes are 10 to 20 degrees on ridges and 20 to 40 degrees on sides of gullies. Underlain by dolerite (of Jurassic age) and siltstone and sandstone (of Permian age). Lower slopes underlain by bouldery colluvium.
ALLUVIAL FAN	Gently sloping fan where gullies discharge at the base of the fault scarp. Typical slopes are 5 to 7 degrees. The School Creek Alluvial Fan is flatter and less well defined. Underlain by alluvium and colluvium (creek and slope deposits over older soils and rocks)
COASTAL BENCH	Sloping bench, typically 300m to 600m wide between the Taroona Fault and the sea. Natural slopes are typically 4 to 10 degrees, locally steeper at the sides of gullies and at Melinga Place. Includes gullies, ridges and local variations in slope. Modified by cuts and fills.
COASTAL SCARP	Includes coastal cliffs and steeper slopes north of Hunsby and Taroona Beaches. Slopes are typically 15 to 45 degrees (locally steeper). Cliffs in project area are generally less than 10m high. Higher cliffs occur to the north and south.
SHALLOW INSHORE PLAIN	Gently sloping sea floor typically extending between 400m and 600m off shore. Typical slopes are 1 to 2 degrees. Outcrops of soil and rock can be observed at low tide in some places.
OFFSHORE SLOPES	Steeper sea floor slopes beyond shallow Inshore Plain. Typical slopes are 2 to 10 degrees. Deepest part of Derwent Estuary east of project area is about 25m.

4.2 Subsurface Materials

In Table 3 we summarise observed and inferred subsurface materials in the project area, with particular emphasis on the engineering properties of the materials of Tertiary and Quaternary age in which most landslides are likely to occur. The information in the Table 3 is based on:

- The geological map, stratigraphic column and descriptions in Latinovic et al (2001).
- Other published and unpublished geological information.
- The results of the ten subsurface investigations in the project area listed in Appendix A.
- Our own site observations.
- Our experience in similar situations elsewhere.

The stratigraphy described in Latinovic et al (2001) provides a useful framework for understanding the broad distribution of different materials in the project area. However, the general poor exposure in the area and the lateral and vertical variability in the distribution of materials means that the map produced by Latinovic et al cannot be expected to accurately predict subsurface conditions everywhere. As discussed in Section 3 the geological history of the area has been dramatic. Factors and processes that contribute to the lateral and vertical variability in the materials of Tertiary and Quaternary age include:

- Many deposits were not original continuous and not necessarily laid down in horizontal surfaces (e.g. debris flows, alluvial fans, river, lake and swamp deposits).
- There is likely to have been repeated cycles of events and associated deposits. For example there is likely to have been many large debris flows resulting in many large discontinuous boulder beds. Also the volcanic tuff is probably the result of several eruptions and therefore there may be several layers.
- The whole sequence of deposits of Tertiary age have been disrupted by tilting, folding, faulting, earthquakes, landslides and volcanic activity.

There have also been some difficulties in interpreting and comparing the result of previous investigations. At least seven different people (over a period of 26 years) have been involved in describing the soils and rocks encountered in the investigations listed in Appendix A. There are variations in the quality and level of detail and inconsistency in terms used to describe similar materials. For example, different people may use the term hard clay, mudstone or siltstone to describe the same material. Bedding dips, which may have been helpful in working out the stratigraphy and structure were not recorded on the cored bore hole logs (bedding would have only been visible in some of the materials). Several of the deeper boreholes were open hole drilled, with logging of chip samples only. The potential to improve the understanding of the site geology by reviewing all available core and other samples (from both MRT and the Department of Transport, assembled and laid out together) is discussed in Section 6.2.4.

TABLE 3. SUMMARY OF OBSERVED AND INFERRED SUBSURFACE MATERIALS

Material type/geological origin	Brief description	Occurrence/comments
POST TERTIARY OFFSHORE MATERIALS		
HOLOCENE ESTUARINE SEDIMENTS	Likely to consist of soft to very soft normally consolidated, organic clay and silt	Likely to occur in channel, up to 60m below sea level. Edge of channel may be within 800m of coast of project area
PLEISTOCENE SEDIMENTS	Likely to consist of firm to stiff over consolidated clay with some beds of sandier material.	Earlier estuary, marine and river deposits. Channels deeper than 100m below present sea level may have occurred in the past close to the present coastline
SLUMP DEPOSIT	Likely to consist of transported and disturbed sediments and volcanics (both soil and rock) of Tertiary age	Interpreted by Gibbons (2001) from seismic reflection data. May represent landslide into Last Glacial Derwent Channel
POST TERTIARY ONSHORE DEPOSITS		
FILL	Various mixture of boulders, gravel, sand, silt and clay	Up to, at least 5m deep. Associated with roads, buildings, playing fields and other human activity.
TOPSOIL AND RESIDUAL SOIL	Composition and thickness depends on underlying material. Typically includes dark grey or brown high plasticity clay	Highly reactive in places (large volume changes associated with wetting and drying)
COLLUVIUM	Composition and thickness vary but typically includes boulders and clay when derived from steeper dolerite slopes	Formed by transport down slopes include material transported by landslides (e.g. debris flows). In this report landslides are described separately in Section 5.
ALLUVIUM	Various material including boulders, sand and silt	Deposited by water in creek beds and on alluvial fans
TERTIARY DEPOSITS - COMMENTS ON DISTRIBUTION INCLUDED IN TEXT		
CLAY	Typically high plasticity, stiff to hard, brown, red brown, green brown or green clay. Contains polished sheared surfaces (especially the green clay).	Appears to make up a high proportion of Tertiary sediments south of School Creek (to depths of at least 70m). Likely to have very low residual shear strength.
MUDSTONE	Typically described as of extremely low strength. (Hard soil in engineering terms). Contains polished sheared surfaces.	Likely to have very low residual shear strength.
SILTSTONE	Typically described as very low or low strength rock. Includes carbonaceous material and thin coal seams. Also includes polished sheared surfaces.	May have low residual shear strength in places.

Continued Over …

TABLE 3. SUMMARY OF OBSERVED AND INFERRED SUBSURFACE MATERIALS (Contd.)

TERTIARY DEPOSITS - COMMENTS ON DISTRIBUTION INCLUDED IN TEXT (Contd.)

SANDSTONE AND CONGLOMERATE	Typically very low to medium strength rock. Sandstone and conglomerate are interbedded.	Higher proportion of conglomerate in north of project area, particularly north of Karingal Creek. Unlikely to contain very low shear strength surfaces.
BOULDERS	Mainly variably weathered dolerite of varying strength (from extremely high strength rock to hard soil).	Occurs in beds or as individual boulders within the other units.
TUFF	Typically brown very low to medium strength rock.	May be several layers. May not be continuous.

PRE TERTIARY MATERIALS

DOLERITE	Very high to extremely high strength rock when fresh. Weaker when weathered. Extremely weathered dolerite is typically a hard clay.	Generally occurs to the west of the Taroona Fault.
PERMIAN SILTSTONE AND SANDSTONE	Typically medium to high strength rock.	Occurs to the west of the Taroona Fault.

In spite of the poor exposures, lateral and vertical variability and the variable quality of the existing information it has been possible to confirm the following broad trends in distribution of the materials of Tertiary age, which underlie the Coastal Bench.

- North of Karingal Creek coastal exposures indicate that most of the material consists of rock (conglomerate and sandstone) dipping gently towards the southwest.
- Between Karingal Creek and School Creek coastal exposures and Borehole IBH/99 (70m deep) indicate a high proportion of siltstone and sandstone (low strength rock) with some clay. The beds dip gently towards the southwest or more steeply towards the west. Several faults are exposed in the cliff.
- Between School Creek and the south west trending outcrops of tuff (Figure 2 and 3) there appears to be a high proportion of high plasticity clay in the sequence (boreholes, testpits and exposures on Dixons Beach). Some of the clay is green or greenish clay and contains many polished sheared surfaces. Boulders also occur in this sequence.
- To the south east of the clay rich area there appears to be a layer, or several layers of tuff. Most of the tuff is a very low to medium strength rock. Where observed (in three exposures between the foreshore near the school and Belhaven Avenue) the tuff dips between 20 and 60 degrees towards the northwest.
- South of the tuff the boreholes indicate that there is a variable sequence of mudstone, siltstone, clay and boulder beds to depths of at least 70m.

4.3 Structural Geology

Bedding and faults, where observed are shown on Figure 3. The soils and rocks of Tertiary age are clearly tilted, folded and faulted. The coastal exposures north of the mouth of School Creek and the bedding observations in the tuff are consistent with the presence of a south west plunging syncline. Alternatively, the changes in the bedding could be associated with faults or very old landslides. There are not enough bedding observations to accurately define the structure.

5. LANDSLIDES AND LANDSLIDE HISTORY

5.1 Definition, Size Terms And Types Of Landslide

Landslides may be defined as “the movement of a mass of rock, debris or earth down a slope” (Australian Geomechanics Society, 2000). This broad definition includes falls, topples, slides, flows and spreads from both natural and artificial slopes.

There is a wide range in the size of landslide that has occurred or may occur in the project area. For ease of reference in this report we have used the following terms to describe landslide sizes:

Relative size term	Volume range (m^3)	Typical dimensions (length, width and depth, m)
Extremely large	Greater than 1,000,000	400 x 300 x 20
Very large	100,000 to 1,000,000	250 x 150 x 15
Large	10,000 tp 100,000	100 x 60 x 10
Medium	1000 to 10,000	40 x 30 x 6
Small	100 to 1,000	18 x 15 x 3
Very small	10 to 100	8 x 5 x 2
Extremely small	Less than 10	3 x 2 x 1

In this report we have referred to medium, large, very large and extremely large landslides as major landslides.

Terms used to describe landslides are explained in Appendix B of Australian Geomechanics Society (2000).

5.2 Focus Of This Study And Landslides In The Project Area.

Previous workers at Taroona have raised concerns about the possible existence of major landslides in the project area. In view of these concerns we have concentrated on trying to understand the scale and extent of major landslides that have occurred or may occur in the study area.

Attempting to understand the bigger picture and the possible extent of active and inactive landslides has involved a lot of interpretation and judgement. Defining the extent and activity of landslides is difficult because:

- Landslide movements that have occurred recently (e.g. last 50 years) have been small.
- Evidence of past landslide movements has been masked by development. In this study we have made most of our observations of private property from the street only.
- Most of the soils in the study area are highly reactive and cracking in brickwork, footings, kerbs and pavements are common.

It must be understood that further evidence (of ground movements in the past or new ground movements) may lead to new interpretations of the extent and activity of the major landslides.

In the following sections we describe a series of major debris (with some associated smaller) landslides which may be part of a single landslide complex with a long history of landslide activity. In this report we have referred to this landslide complex as the Taroona Landslide Complex. On Figures 1 and 3 we have shown our interpretation of the possible extent of the Taroona Landslide Complex.

It is important to emphasise that most of the Taroona Landslide Complex is almost certainly inactive and much of the complex may not have moved for many thousands of years. The evidence for the existence of the complex, and the age, history, extent and amount of movement of the individual landslides that make up the complex are described in Section 5.3.

Other, generally smaller, landslides have occurred in the past and may occur in the future in the project area both inside and outside of the Taroona Landslide Complex. These smaller landslides include:

- Very small to medium rock earth or debris slides from the Coastal Scarp (e.g. The Karingal Court Landslide east of Karingal Court and other landslides near Hinsby Beach) or from the sides of gullies (on the Fault Scarp or Coastal Beach).
- Extremely small to small debris flows originating from the Coastal Scarp, or steep sided gullies (on the Fault Scarp or Coastal Bench).
- Extremely small rock, earth or debris falls or topples from cliffs or very steep slopes on the Coastal Scarp.
- Extremely small to very small earth or debris slides and flows from poorly constructed or retained cuts and fills.

We have not attempted to assess the risk associated with the above landslides within the funds available for this study.

5.3 The Taroona Landslide Complex

5.3.1 The Component Landslides

The possible extent of the Taroona Landslide Complex and some of the major landslides, which make up the complex are shown in Figure 1. The complex may extend for at least 1000 m off shore. Figure 2 is a cross section through the complex. The possible extent of the complex onshore and landslides within the complex are shown in Figure 2 & 3.

For ease of reference we have labelled the different landslides. The relationship between the landslides and possible landslides within the Taroona Landslide Complex is summarised below:

Extremely large landslides within the complex	**Large landslides within the School Creek Landslide**	**Small or Medium landslides within the large landslides**
Offshore Landslide		
Melinga Place Landslide		
School Creek Landslide	Archery Field Landslide	Foreshore Landslide
	School Creek Landslide	Dixons Beach Landslide

5.3.2 Evidence For, Extent, Age And Movement History Of The Component Landslides.

5.3.2.1 Offshore Landslide

The evidence for the existence of the Offshore Landslide is summarised in Table 1 (under Last Glacial Events). Gibbons (2001) interpreted a "slump deposit" from seismic reflection data (Line 27, p142). The slump deposit on Line 27 was between about 400 m and 800 m off shore. The base of the deposit is about 60 m below sea level of and the deposit is underlain by tilted sediments and volcanics of Tertiary age. On the basis of the onshore geology the slump deposit probably consists of sediments and volcanics of Tertiary age although it may include some younger (Quartenary age) sediments.

The extent of the landslide away from the seismic line has been interpreted on the basis of the bathymetry which indicates a steeper slope in shore, a flatter slope on the landslide and a seaward bulge in the contours (Figure 1). The toe of the landslide extends into the area interpreted by Gibbons (2001) to be underlain by estuarine sediments of Holocene age (Figures 1 and 2).

The offshore landslide is probably an extremely large (10 million to 20 million m^3) debris slide. It probably formed during a glacial period when the sea level was much lower than present and the River Derwent cut a weak, steep sided valley/channel. During the coldest part of the Last Glacial this channel was probably about 60 m deep off the coast of Taroona. Evidence from elsewhere (e.g. Bowen Bridge, Colhoun and Moon, 1984) shows that side slopes on these channels can be steep (e.g. at least 30°). If the offshore landslide occurred during the Last Glacial it is likely to be, at least 10,000 years old. If it occurred during an earlier glacial it may be many hundreds of thousands of years old. It is likely that little or no movement has occurred in the past 5000 years (since the channel was back filled with estuarine sediments and sea level reached its present level).

It is possible that other offshore landslides occurred during periods of lower sea level. The steeper slope about 600 m east south east of Crayfish Point may be the headscarp of another landslide (Figure 1).

5.3.2.2 Melinga Place Landslide

The steep slope west of Melinga Place may represent the headscarp of another old extremely large debris slide. As shown on Figures 1 and 2 it may extend offshore as far as the Offshore Landslide. On the basis of the possible extent shown on Figure 2 and 3 the Melinga Place Landslide may have a volume of between 3 million and 6 million m^3.

The present shallow inshore plain and offshore slopes are very flat and the Melinga Place Landslide is unlikely to have formed, or be active, under present condition. It probably formed during periods of lower sea level and may represent an inland (western extension) of the Offshore Landslide. This would indicate that the Melinga Place Landslide is also likely to be at least 10,000 years old. In this study we did not come across any evidence to suggest that the Melinga Place Landslide has been active since European Settlement (in the past 200 years).

The Offshore and Melinga Place Landslides represent a significant proportion of the Taroona Landslide complex. In view of the overall flat slopes it is also likely that the Taroona Landslide Complex was only active as a whole (if it has every been active as a whole) during periods of lower sea level.

5.3.2.3 School Creek Landslide

The School Creek Landslide includes four smaller landslides (Archery Field, Foreshore, Car Park and Dixons Beach) within, or at its boundaries (Figure 2 & 3). The four smaller landslides and other parts of the School Creek Landslide have been active in the past 50 years.

The School Creek Landslide is an extremely large debris slide (volume probably between 2 million and 4 million m^3). The smaller landslides are debris or earth slides with approximate volumes as follows:

Archery field	50,000 to 100,000 m^3 (large)
Foreshore	600 to 1200 m^3 (small to medium)
Car Park	40,000 to 80,000 m^3 (large)
Dixons Beach	5000 to 10,000 m^3 (large)

The age of the School Creek Landslide is uncertain. As it is part of the Taroona Landslide Complex it may have first formed during periods of lower sea level more than 10,000 years ago. However, total movements of the School Creek Landslide do not appear to have been large and there may have been long periods of inactivity since it first formed. Recent activity may have been triggered by coastal erosion. The potential effects of changes since (European settlement are discussed in Section 5.3.2.4).

The four smaller landslides are probably relatively recent. They may have been triggered by coastal erosion since the sea level has been at its present level (about 5000 years). It is possible that they first moved as recently as the past 50 or 100 years.

The movement history of the School Creek Landslide is given in Appendix B. The location of the evidence is referred to as headscarp, including Channel Highway (extent shown on Figure 3), northern boundary, southern boundary or by reference to the smaller landslide within, or at the boundary of the School Creek Landslide.

Present knowledge of the extent and movement history of the School Creek Landslide is summarised below:

Boundaries

- The headscarp at, and west of the Channel Highway, is relatively well defined.
- The western section of the northern boundary is probably close to School Creek.
- We have assumed that the eastern end of the northern boundary corresponds with the headscarp of the Archery Field Landslide.
- The southern boundary is difficult to define. Rather that a single sheared surface, deformation may have occurred by a combination of distortion and local zones of shear or tension.
- We have assumed that the southern boundary includes the four buildings shown on Figure 2 & 3 (three houses and the High School) which may have suffered unusual horizontal movements or stress. We emphasise that further evidence may result in changes to this interpretation.
- The southern boundary appears to be north of the outcrop of volcanic tuff. We have seen no geomorphological evidence, or evidence of unusual horizontal movement in structures south of the volcanic tuff.
- The toe of the Archery field, Foreshore and Dixons Beach Landslides appear to be at, or above present sea level.

- The toe of parts of the Car Park Landslide and other parts of the School Creek Landslide may be offshore.

Overall Movement

- Overall movement of the School Creek Landslide has not been uniform. There has probably been more movement in the north than in the south.
- Different parts of the landslide may move at different times. The smaller landslides may move independently of the larger landslides.
- Not all movements have been in the same direction. Rotational components to the movement can occur.
- Local distortion is usually concentrated at the edge of the landslide. Buildings and other infrastructure located on sections of landslide moving uniformly may show no damage.
- Headscarp movements are relatively well defined because of the presence of the Channel Highway and survey and inclinometer results in the past 25 years.

Headscarp movement

- Total movements of about 3 m may have occurred in the headscarp area (based on sections reconstructed from detailed topography).
- Vertical movements of up to 600 mm may have occurred in the last 100 to 150 years.
- Horizontal movements of up to 130 mm and vertical movements of up to 100 mm may have occurred between 1977 and 1988.
- Up to 57mm of movement has been detected in inclinometers since 1992.
- Annual rates of movement in the headscarp in the past 50 years probably vary between 1 mm and 30 mm.

Northern boundary movement

- The only quantitative information on the northern boundary are Donaldson’s observations in 1977 horizontal and vertical displacements of between 0.15 m and 0.3 m.

Southern boundary movements

- The lack of geomorphological expression probably indicates that total movement along the southern boundary have been less than at the headscarp or northern boundary.
- Movement on the southern boundary may occur in localised zones of distortion, tension or shear.

Toe movements

- Movements of the toe of Dixons Beach Landslide of 5 m to 10 m occurred in 1989.
- Movements of the toe of the other smaller landslides have been less.
- We have no evidence of offshore movement of the toe of the Car Park or School Creek Landslides.

5.3.2.4 Effect Of Changes Since European Settlement

Changes to vegetation and drainage and construction of cuts and fills since European settlement may have affected the stability of the School Creek and associated landslides. With the present state of knowledge it is difficult to quantify the effects of these changes. However, it seems likely that the School Creek Landslide existed before European development and the scale of the landslide is such that changes in geometry associated with cuts and fills are likely to have had a marginal effect.

Minor changes in drainage can have significant effects in areas of marginal stability. As discussed in Section 6.2.6 it is essential that drainage in the area is effective and well maintained.

Erosion of the toe of the landslides by wave action can reduce stability. Toe erosion has had a significant effect on the stability of the Dixons Beach Landslide and smaller effects on the Foreshore, Archery Field and Car Park landslides. The overall effect of the School Creek Landslide is probably very small.

5.3.2.5 Possible Landslides Identified By MRT Outside Of The School Creek Landslide.

Latinovic et al (2001) identified two possible landslides (MS3 and MS6) outside the School Creek Landslide.

MS3 may have been a small shallow earth slide. The stability of the area has been recently improved by landscaping and drainage.

The hummocky surface of MS6 is probably associated with fill and not the result of a landslide. Fill can be seen on the 1973 aerial photographs.

5.4 The Relationship Between Rainfall And Landslide Movement.

The most common trigger for landslide movement is rainfall. While movement of major landslides may be triggered by prolonged periods of rainfall over many days, weeks or even months, experience elsewhere indicates that smaller landslides may be triggered by intense rainfall over much shorter periods.

Continuous rainfall records are available for Taroona since 1963. The mean annual rainfall in that period is 647 mm (lowest 411 mm and highest 888 mm).

The movement history of the School Creek Landslide given in Appendix B indicates movements occurred in the late 1960's and early 1970's. These movements may be related to the higher than average rainfall in that period. In the forty year period for which records are available at Taroona:

- 1975 (888 mm) was the wettest single calendar year.
- 1970 and 1971 (total 1753 mm) were the wettest two consecutive calendar years.
- 1969, 1970 and 1971 (total 2624 mm) were the wettest three consecutive calendar years.

The highest rate of movement picked up by the inclinometers was between readings taken on 6 October 1995 and 5 May 1997. This period included the wettest 4 month, 5 month, 6 month and 12 month aggregate (but not calendar year) on record. The wettest six months was between November 1995 and April 1996.

Not all landslide movements appear to be related to high monthly rainfall. The movements of Dixons Beach Landslide reported in July 1988 and September 1989 (DOT 1988b and 1989) do not appear to be related to high monthly rainfall. As the landslide is relatively small movement may have been related to shorter term daily (or even shorter) rainfall which can be localised in its distribution or it may have been triggered by human activity (Fill) or toe erosion.

Continuous rainfall records are available from Ellerslie Road (Battery Point) since 1882 (120 years). In the 40 year period overlap with the Taroona records the rainfall at Battery Point is about 10% lower. However, the long term average (120 years) at Battery Point (mean 620 mm) is only about 5% lower than Taroona. This indicates that the past 40 years may have been a little drier than the long term average.

The rainfall records from Battery Point indicate that the following six wettest calendar years all occurred before the Taroona rain gauge was established:

- 1916 1104 mm
- 1923 840 mm
- 1946 1004 mm
- 1947 983 mm
- 1956 933 mm
- 1958 929 mm

6. LANDSLIDE RISK ASSESSMENT AND MANAGEMENT

6.1 Landslide Risk Assessment

6.1.1 Principles And Role Of Hazard Zoning

Risk assessment and management principles applied to landslides can be interpreted as answering the following questions:

- What are the issues and who cares? (SCOPE DEFINITION).
- What might happen? (HAZARD IDENTIFICATION).
- How likely is it? (LIKELIHOOD).
- What damage or injury might result? (CONSEQUENCE).
- How important is it? (RISK EVALUATION).
- What can be done? (RISK TREATMENT).

The risk is the combination of the likelihood and the consequences for the hazard in question. Thus both likelihood and consequences are taken into account when evaluating a risk and deciding whether treatment is required.

The above basic risk management principles can be applied to any activity. They are described in Standards Australian Standards New Zealand (1999). The application of these principles to landslide risk management is explained in Australian Geomechanics Society (2000).

Landslide hazard zoning has been used in Australia as a planning tool to help manage landslide risk for many years. In landslide hazard zoning the potential for landslides to occur in different areas is assessed. Those areas with higher potential are treated with more caution and/or development controls are applied. The “A” and “B” landslip areas in various parts of Tasmania are examples of landslide hazard zoning which have been linked to development controls.

6.1.2 Preliminary Landslide Hazard Zones

The location of hazard zones shown on Figure 3 are based on the observed and inferred behaviour of the Taroona Landslide Complex. A high hazard zone encompasses the boundaries of the School Creek

Landslide (and the smaller coastal landslides) where differential movement may occur. A medium hazard zone is defined within the main body of the School Creek Landslide where overall movements may occur but differential displacements are less likely. The remainder of the Taroona Landslide Complex is judged to be a low hazard area with respect to movement of major landslides within the complex.

The hazard zones should be reviewed after further work (discussed in Section 6.2) is carried out.

6.1.3 Risk Terms And A Risk Matrix For Property

There are many consequences of landslides including damage to property, the environment, social and political effects and loss of life or injury. In this section we discuss risk terms and a risk matrix which may be applied to the evaluation of risk to property. Risk of loss of life is discussed in Section 6.1.4.

The qualitative likelihood, consequence and risk terms used in this report for risk to property are given in Appendix C. The risk terms are defined by a matrix which brings together different combinations of likelihood and consequence. Risk matrices help communicate the results of risk assessment, rank risks, set priorities and develop transparent approaches to decision making.

The notes attached to the tables and terms and the comments on response to risk in Appendix C are intended to help explain the risk assessment and management process.

6.1.4 What Might Happen, Likelihood, Consequences And Risk.

In Section 5.3.2.3 we describe the School Creek Landslide. In Table 4 we list our judgements about the likelihood, consequences and risk to property associated with different movements of different parts of the School Creek Landslide using the terms given in Appendix C.

We have not included the Foreshore and Dixons Beach Landslides in Table 4. In our opinion it is very likely that further movements of these landslides of at least 1 m will occur. However, there are no buildings or other infrastructure on, or near the landslides.

It must be emphasised that the assessments in Table 4 are judgements based on our understanding of the landslide hazard in the study area and knowledge and experience from elsewhere. The assessment applies to the present situation. Further development may change the risk (e.g. building new houses in areas that might be affected by landslides may increase the consequences if landslides occurred).

In summary our judgement of the risk to property associated with movement of the School Creek Landslide is that:

- There is a high risk associated with small individual movements (less than 1 m) causing damage to buildings, roads and other infrastructure in the headscarp area and along the southern boundary of the main School Creek Landslide.
- The high risk extends to damage to block A of Taroona High School, which may lie across the southern boundary.
- There is a low risk associated with movements causing damage to buildings, roads and other infrastructure away from the boundaries of the School Creek Landslide and smaller associated landslide. This includes buildings at Taroona High and Taroona Primary School.
- There is a medium risk associated with movements of up to 10m causing damage to existing sewer lines crossing the Car Park and Archery Field Landslides.
- There is a low risk associated with movements causing damage to the existing sewer line crossing the northern boundary of the School Creek Landslide west of the Archery Field Landslide.

TABLE 4. LANDSLIDE RISK ASSESSMENT FOR THE SCHOOL CREEK LANDSLIDE

Part of landslide	What might happen	Likelihood	Consequence	Risk	Comments
Headscarp and southern boundary of main School Creek Landslide	Slow – Individual movement less than 10 mm Slow – Individual movement 10 mm to 100 mm Slow – Individual movement 0.1 to 1 m Slow – Individual movement 1 m to 10 m Slow – Individual movement greater than 10 m Rapid – Individual movement greater than 1 m	Very likely Likely Possible Unlikely Very unlikely Very unlikely	Minor Moderate Severe Severe Severe Severe	High High High Medium Low Low	Structures at risk include private houses, the road, sewers, water mains and other services. The southern boundary may also go through Block A of Taroona High School. Although total movements of the southern boundary may be less than at the headscarp individual movements at particlar locations may be of the same order of magnitude.
Main body of School Creek Landslide away from the boundaries and the smaller landslides	Slow – Individual movement less than 10 mm Slow – Individual movement 10 mm to 100 mm Slow – Individual movement 0.1 to 1 m Slow – Individual movement 1 m to 10 m Slow – Individual movement greater than 10 m Rapid – Individual movement greater than 1 m	Very likely Likely Possible Unlikely Very unlikely Very unlikely	Insignificant Insignificant Minor Moderate Severe Severe	Low Low Low Low Low Low	Damage to structures within the main body of the landslide may be associated with localised zones of internal shear, tension or distortion.
Car Park and Archery Field Landslides	Slow – Individual movement less than 10 mm Slow – Individual movement 10 mm to 100 mm Slow – Individual movement 0.1 to 1 m Slow – Individual movement 1 m to 10 m Slow – Individual movement greater than 10 m Rapid – Individual movement greater than 1 m	Very likely Very likely Likely Possible Unlikely Unlikely	Insignificant Insignificant Minor Moderate Moderate Moderate	Low Low Medium Medium Low Very Low	The main structure at risk is the sewer line, It is also possible that the boat shed or archery field building may suffer some damage.
Northern boundary of main School Creek Landslide west of the Archery Field Landslide.	Slow – Individual movement less than 10 mm Slow – Individual movement 10 mm to 100 mm Slow – Individual movement 0.1 to 1 m Slow – Individual movement 1 m to 10 m Slow – Individual movement greater than 10 m Rapid – Individual movement greater than 1 m	Very likely Likely Possible Unlikely Very unlikely Very unlikely	Insignificant Insignificant Minor Moderate Moderate Moderate	Low Low Low Low Very low Very low	The main structure at risk in this area appears to be the sewer line.

NOTE: For the purposes of this report the boundary between slow and rapid movement is defined as 10 mm per hour.

6.1.5 Risk To Life

Australian Geomechanics Society (2000) makes it clear that risk to life should be considered when assessing landslide risk.

The landslide record from Australia and elsewhere indicates that most deaths and injuries are associated with fast landslides which travel some distance when there is insufficient warning for people present to take evasive action. People are most vulnerable if buried in open space, trapped in vehicles which are buried and crushed or in a building which collapses or is inundated with debris.

Past individual movements of the parts of the School Creek Landslide on which building are located have been small (probably less than 30 mm in any one year) and slow. In our opinion it is very unlikely that rapid movements will occur. If the risks associated with the School Creek Landslide are managed in the ways discussed in Section 6.2 it is our judgement that risk of loss of life due to the landslide is very low. We have insufficient evidence on which to base a realistic quantitative assessment of the actual risk. However, our judgement based on experience elsewhere, is that the risk associated with landslides is very much less than the average risk that people are exposed to from many other sources (including car travel and accidents at home) and appear to accept.

6.2 Landslide Risk Management

6.2.1 Parties Involved And Roles

Organisations, groups and individuals who have been affected, or may be affected by landslide risk, or have been involved in assessing or managing landslide risk in the study area include:

- Residents
- School children
- Parents
- Teachers
- The Kingborough Council
- The Department of Education
- The Department Of Infrastructure Energy and Resources (DIER)
- MRT
- Consultants

For landslide risk management to be effective it is essential that many of the above organizations, groups and individuals work constructively together.

As technical advisers Coffey's main role is to recognise, understand and explain the risks. Final decisions on how to treat and manage risks are the responsibility of local and state government departments and planning authorities, owners and other affected parties.

The main purpose of the following sections of this report is to provide preliminary suggestions and recommendations on risk management which can be reviewed by MRT, the Kingborough Council and other affected and involved parties.

6.2.2 Essential Requirements

Essential requirements of landslide risk management in the study area include:

- Continuously improving knowledge and understanding of the landslide hazard. It is particularly important that past knowledge (of geology and earlier movements) is not lost. The Thredbo Coroner's report pointed out how evidence, knowledge and understanding of the landslide hazard at the site of the fatal Thredbo Landslide was *"lost, ignored or forgotten"*.
- Continuously monitoring future landslide movement.
- Having a risk management plan and structure in place that can, and will ensure that appropriate action is taken promptly in response to changing circumstances.
- Taking actions, wherever possible to reduce risk.
- Finding the funds necessary to make it happen.

While many people will be involved in landslide risk management it is clearly essential that one organisation take on the role of coordination. That organisation should ensure that relevant information is assembled, is accessible to involved parties and periodically reviewed as new evidence comes to light.

6.2.3 Area To Be Monitored

The likely extent of the School Creek Landslide and associated smaller landslides is shown on Figure 2 and 3. The possible onshore extent of other parts of the Taroona Landslide Complex (in which no evidence of activity has been observed) is also shown on the Figure 1 and 3.

At this stage we recommend that a slightly larger area (shown on Figure 2 and 3) be included in the monitoring and management program. This larger area reflects the present uncertainty in some of the boundaries. Further work may enable the area to be monitored to be reduced.

6.2.4 Improving Knowledge Of The Geology, Past Movements And Location Of Landslide Boundaries.

6.2.4.1 Geology And The Geotechnical Model

Improving knowledge of the geology will help improve understanding of why landslides have occurred, their likely geometry, how they move and how they might behave in the future (i.e. improve the geotechnical model). As discussed in Section 4.2 there have been some difficulties in comparing the results of previous investigations.

Knowledge of the geotechnical model (including stratigraphy, structure and engineering properties of the materials) would be improved if available core and samples from previous investigations are assembled and laid out simultaneously in one place. The core and samples could then be reviewed and compared. This would allow inconsistencies in description to be identified and the stratigraphy to be reviewed and revised. Observations of bedding and sheared surfaces and other defects would results in an improved understanding of the geology. We recommend that the review be carried out by MRT and Coffey but that others with knowledge of the study area be invited to review the samples (e.g. Ralph Rallings, Bill Cromer etc.). In our experience simultaneous review of all available core is very effective in reviewing and improving the geotechnical model. To allow sufficient time to carry out the review, revise the geotechnical model and incorporate the knowledge of others it may be necessary to have the core laid out for several days.

Another way to improving knowledge of the stratigraphy would be to use palynological analysis to date the sediments. We understand that the University of Tasmania may be interested in carrying out this work. If the work is carried out as part of an honours or research project if may be possible to greatly improve knowledge of the stratigraphy at relatively little cost to MRT. Samples could also be obtained from coastal exposures.

6.2.4.2 Inclinometers And Movement History

The existing inclinometers provide evidence of past movement. It is essential that all existing inclinometers are secure and protected with locked caps if necessary. At the time of our fieldwork Inclinometer I92-13 was open and vulnerable to damage or blockage (since capped by Council). We understand that inclinometer I92-12 is blocked at about 8m. Every effort should be made to unblock this inclinometer as soon as possible. Even if the upper part is damaged it may be possible to obtain valuable information on past movements at depth.

Unusual lateral movements may be associated with shear, tension or distortion at the boundaries of the landslide. Significant vertical movements may also occur, particularly at the headscarp. Present knowledge of the movement history is given in Appendix B and summarised in Section 5.3.2.3. Further knowledge on the location of the landslide boundaries and movement history can be obtained by:

- Assembling and reviewing records of problems with services (e.g. sewer, water mains).
- Reviewing the 1992 Parliamentary Public Works Committee (PPWC) report on Taroona High School.
- Assembling and reviewing reports and evidence referred to in the PPWC report and other documents on foundation movement and damage at Taroona High School.
- Discussing evidence and knowledge of movement and damage at the school with those involved in the PPWC and those with past knowledge of the school.
- Review current damage and the history of damage on private property. As past damage is often masked by repairs and renovations it will be necessary to talk to residents and, in some cases former residents. This work is best carried out by engineering geologists or geotechnical engineers with knowledge of landslide behaviour (landslide experts).

Landslide risk assessment in the study area should be reviewed (including the hazard zoning) when the above work has been carried out. The value of any further subsurface investigations should be considered as part of that review.

6.2.5 Monitoring Future Landslide Movements

In Section 6.2.4 we discussed means of improving knowledge of past landslide movements. It is also essential that future movements are monitored.

The people in the best position to detect early signs of landslide movement are usually those that spend most time in the area (residents, teachers, students etc.). Recognising small landslide movements in an area underlain by highly reactive soils is difficult. It is essential that people in the area are aware of warning signs of landslide movement. The most likely warning sign is lateral ground movement as indicated by vertical cracks in footings, walks, kerbs etc. and continuous cracks in roads or pavements. Evidence of horizontal stress affecting footings may also be associated with landslide movement. Continuous vertical displacements may be associated with movements at the headscarp.

Warning signs should be reported (e.g. via the Kingborough Council, Department of Education etc.) to the organization responsible for co-ordinating risk management. The evidence should be reviewed in the field by a landslide expert to evaluate whether landslide movement may be involved. If there are concerns about safety a building inspector or structural engineer should review the situation immediately and appropriate action taken.

Damage to infrastructure (roads, pipes etc) should be treated in the same way.

Other means of monitoring landslide movement should include:

- Field review by a landslide expert. The field review will probably take about two days. One day would involve a general review of the area (public land, school grounds and buildings, roads etc.) for evidence of landslide movement. The second day would involve reviewing particular private properties where landslide damage is known, or suspected, to have occurred. These reviews should be carried out once a year with additional reviews as discussed below.
- A survey network should be set up. The extent and design of the network should be discussed with a surveyor. The survey should be carried out twice in the first year and annually thereafter, with additional surveys as discussed below:
- Existing inclinometers should be monitored twice a year with additional monitoring as discussed below.

Additional field reviews, surveys and inclinometer monitoring should be carried out if unusual movements are reported or there is a long period of above average rainfall. Based on available rainfall records from Taroona initial criteria for additional observations should be:

Period	Additional observation if rainfall exceeds
1 month	200 mm
2 months	300 mm
3 months	400 mm
4 months	500 mm
5 months	600 mm
6 months	650 mm
Calendar year	850 mm

These criteria should be reviewed as knowledge of landslide behaviour improves.

6.2.6 Management Structure And Actions To Reduce Risk

Knowledge of past landslide behaviour and monitoring of future movements is of no value if appropriate actions are not taken when required. As discussed in Section 6.2.2 it is essential that a risk management plan and structure is in place which will respond promptly to changing circumstances.

A full review of possible actions to reduce risk is outside the scope of this report. The following comments provide brief advice on some of the approaches that may be appropriate to the study area.

- There is potential for reducing the likelihood of landslide movement by improving the stability. Improvements to drainage would improve the stability of all landslides. It is essential the drainage in the area is effective and well maintained. Protection from wave erosion could improve the stability of the Dixons Beach and Car Park Landslides.

- It is possible to reduce the consequences of landslide movement. Some buildings are more flexible than others. Single storey buildings usually involve less risk than multi storey buildings.
- Risk can be avoided by removing existing buildings and not locating new buildings on or near the boundaries of the landslides.
- Constraints on development can also reduce risk. In most of Australia local government has most responsibility for the development and administration of development controls related to landslide risk. We would be happy to discuss the role of development constraints with the Kingborough Council. The council may also need to seek legal and insurance advice on the issue. Clearly new development along the boundary would increase the landslide risk by increasing the consequences of future movement.

6.2.7 Cost Of Risk Management And Living On Slow Moving Landslides

There will be costs involved in developing the risk management plan and informing, and interacting with the relevant parties. Successful implementation will involve action by many different parties.

What is clear from our experience elsewhere and the experience of others is that the long term cost of taking no action or inadequate action to manage landslide risk is likely to be greater than the cost of developing and implementing a risk management plan. The existence of houses, schools and other infrastructure on slow moving landslides is not unusual. Thousands of people live and work on slow moving landslides in many parts of the world (McInnes, 2000). In some places whole towns are located on active landslides. Where the risk is well understood and well managed there is usually little significant disruption to most peoples lives.

For and on behalf of

COFFEY GEOSCIENCES PTY LTD

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Information

As a client of Coffey you should know that site subsurface conditions cause more construction problems than any other factor. These notes have been prepared by Coffey to help you interpret and understand the limitations of your report.

Your report is based on project specific criteria

Your report has been developed on the basis of your unique project specific requirements as understood by Coffey and applies only to the site investigated. Project criteria typically include the general nature of the project; its size and configuration; the location of any structures on the site; other site improvements; the presence of underground utilities; and the additional risk imposed by scope-of-service limitations imposed by the client. Your report should not be used if there are any changes to the project without first asking Coffey to assess how factors that changed subsequent to the date of the report affect the report's recommendations. Coffey cannot accept responsibility for problems that may occur due to changed factors if they are not consulted.

Subsurface conditions can change

Subsurface conditions are created by natural processes and the activity of man. For example, water levels can vary with time, fill may be placed on a site and pollutants may migrate with time. Because a report is based on conditions which existed at the time of the subsurface exploration, decisions should not be based on a report whose adequacy may have been affected by time. Consult Coffey to be advised how time may have impacted on the project.

Interpretation of factual data

Site assessment identifies actual subsurface conditions only at those points where samples are taken and when they are taken. Data derived from literature and external data source review, sampling and subsequent laboratory testing are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact on the proposed development and recommended actions. Actual conditions may differ from those inferred to exist, because no professional, no matter how qualified, can reveal what is hidden by earth, rock and time. The actual interface between materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but steps can be taken to reduce the impact of unexpected conditions. For this reason, owners should retain the services of Coffey through the development stage, to identify variances, conduct additional tests if required, and recommend solutions to problems encountered on site.

Your report will only give preliminary recommendations

Your report is based on the assumption that the site conditions as revealed through selective point sampling are indicative of actual conditions throughout an area. This assumption cannot be substantiated until project implementation has commenced and therefore your report recommendations can only be regarded as preliminary. Only Coffey, who prepared the report, is fully familiar with the background information needed to assess whether or not the report's recommendations are valid and whether or not changes should be considered as the project develops. If another party undertakes the implementation of the recommendations of this report there is a risk that the report will be misinterpreted and Coffey cannot be held responsible for such misinterpretation.

Your report is prepared for specific purposes and persons

To avoid misuse of the information contained in your report it is recommended that you confer with Coffey before passing your report on to another party who may not be familiar with the background and the purpose of the report. Your report should not be applied to any project other than that originally specified at the time the report was issued.

Coffey

Interpretation by other design professionals

Costly problems can occur when other design professionals develop their plans based on misinterpretations of a report. To help avoid misinterpretations, retain Coffey to work with other project design professionals who are affected by the report. Have Coffey explain the report implications to design professionals affected by them and then review plans and specifications produced to see how they have incorporated the report findings.

Data should not be separated from the report*

The report as a whole presents the findings of the site assessment and the report should not be copied in part or altered in any way.

Logs, figures, drawings etc. are customarily included in our reports and are developed by scientists, engineers or geologists based on their interpretation of field logs (assembled by field personnel) and laboratory evaluation of field samples. These logs etc. should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

Geoenvironmental concerns are not at issue

Your report is not likely to relate any findings, conclusions, or recommendations about the potential for hazardous materials existing at the site unless specifically required to do so by the client. Specialist equipment, techniques, and personnel are used to perform a geoenvironmental assessment. Contamination can create major health, safety and environmental risks. If you have no information about the potential for your site to be contaminated or create an environmental hazard, you are advised to contact Coffey for information relating to geoenvironmental issues.

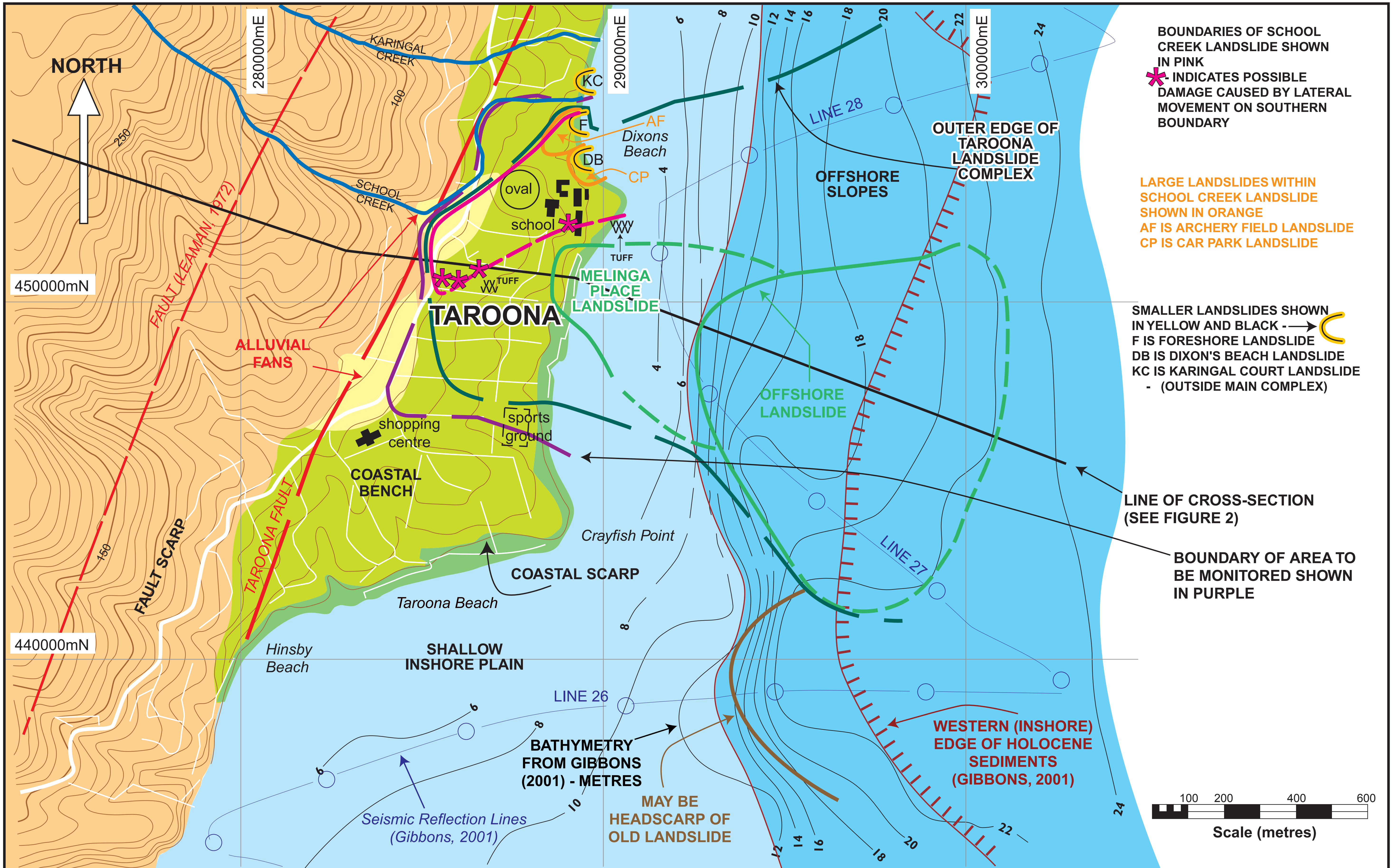
Rely on Coffey for additional assistance

Coffey is familiar with a variety of techniques and approaches that can be used to help reduce risks for all parties to a project, from design to construction. It is common that not all approaches will be necessarily dealt with in your site assessment report due to concepts proposed at that time. As the project progresses through design toward construction, speak with Coffey to develop alternative approaches to problems that may be of genuine benefit both in time and cost.

Responsibility

Reporting relies on interpretation of factual information based on judgement and opinion and has a level of uncertainty attached to it, which is far less exact than the design disciplines. This has often resulted in claims being lodged against consultants, which are unfounded. To help prevent this problem, a number of clauses have been developed for use in contracts, reports and other documents. Responsibility clauses do not transfer appropriate liabilities from Coffey to other parties but are included to identify where Coffey's responsibilities begin and end. Their use is intended to help all parties involved to recognise their individual responsibilities. Read all documents from Coffey closely and do not hesitate to ask any questions you may have.

** For further information on this aspect reference should be made to "Guidelines for the Provision of Geotechnical Information in Construction Contracts" published by the Institution of Engineers Australia, National Headquarters, Canberra, 1987.*

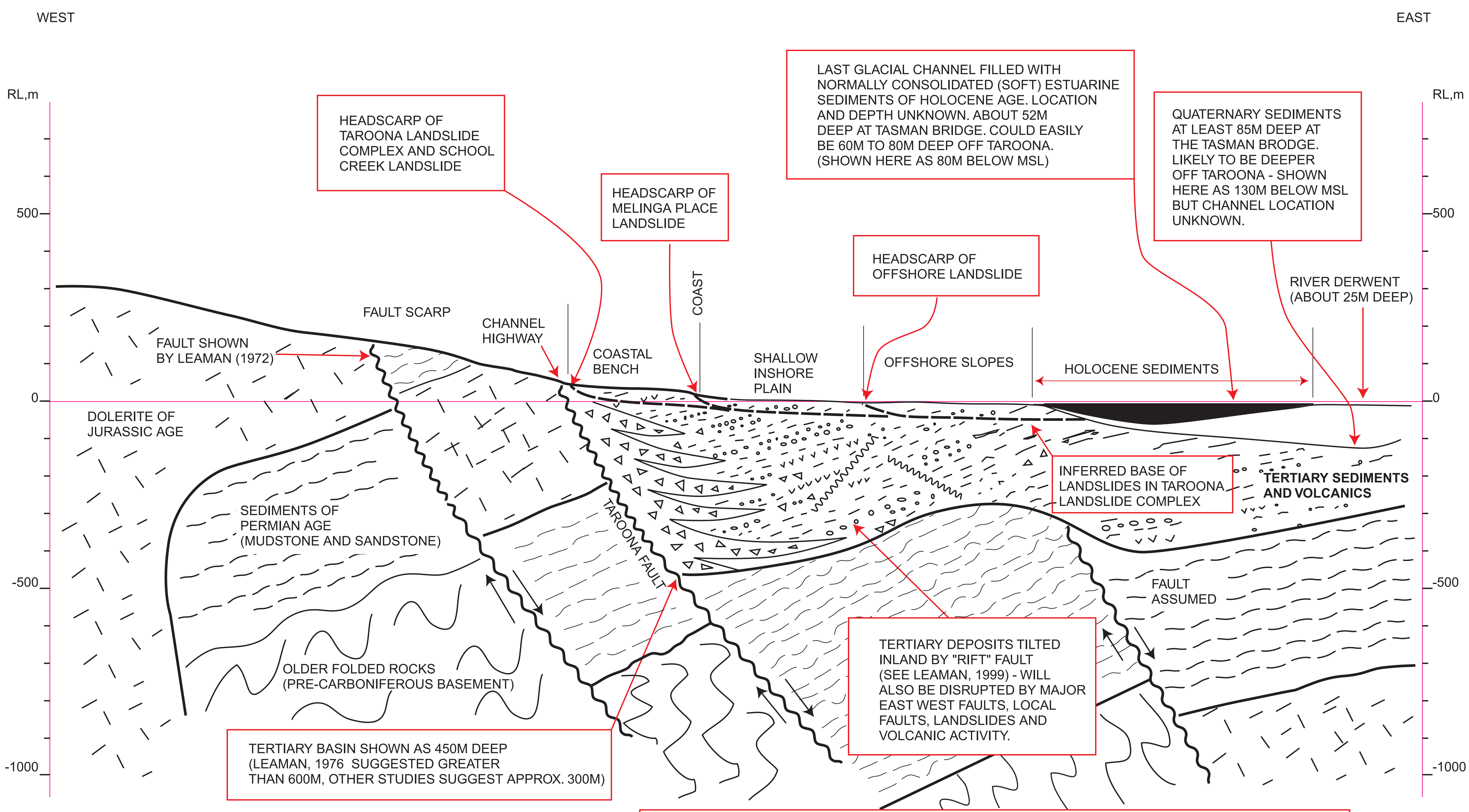


REVISION No.	Description	Drawn	Approved	Date
0	Report to MRT	SB	B McD	15/5/02

Coffey Geosciences Pty Ltd ACN 056 335 516

Geotechnical | **Resources** | Environmental | **Technical** | Project Management

Drawn	SB	MINERAL RESOURCES TASMANIA	Drawing No. : FIG. 1
Approved	B McD	LANDSLIDE RISK ASSESSMENT AND MANAGEMENT IN TAROONA	
Date	MAY 2002	REGIONAL GEOLOGY AND GEOMORPHOLOGY	
Scale	AS SHOWN		Job No. : HO104/3



NOTE: LOCATION OF CROSS-SECTION SHOWN ON FIGURE 1.

REVISION No.	Description	Drawn	Approved	Date
0	Report to MRT	SB	B McD	21/5/02

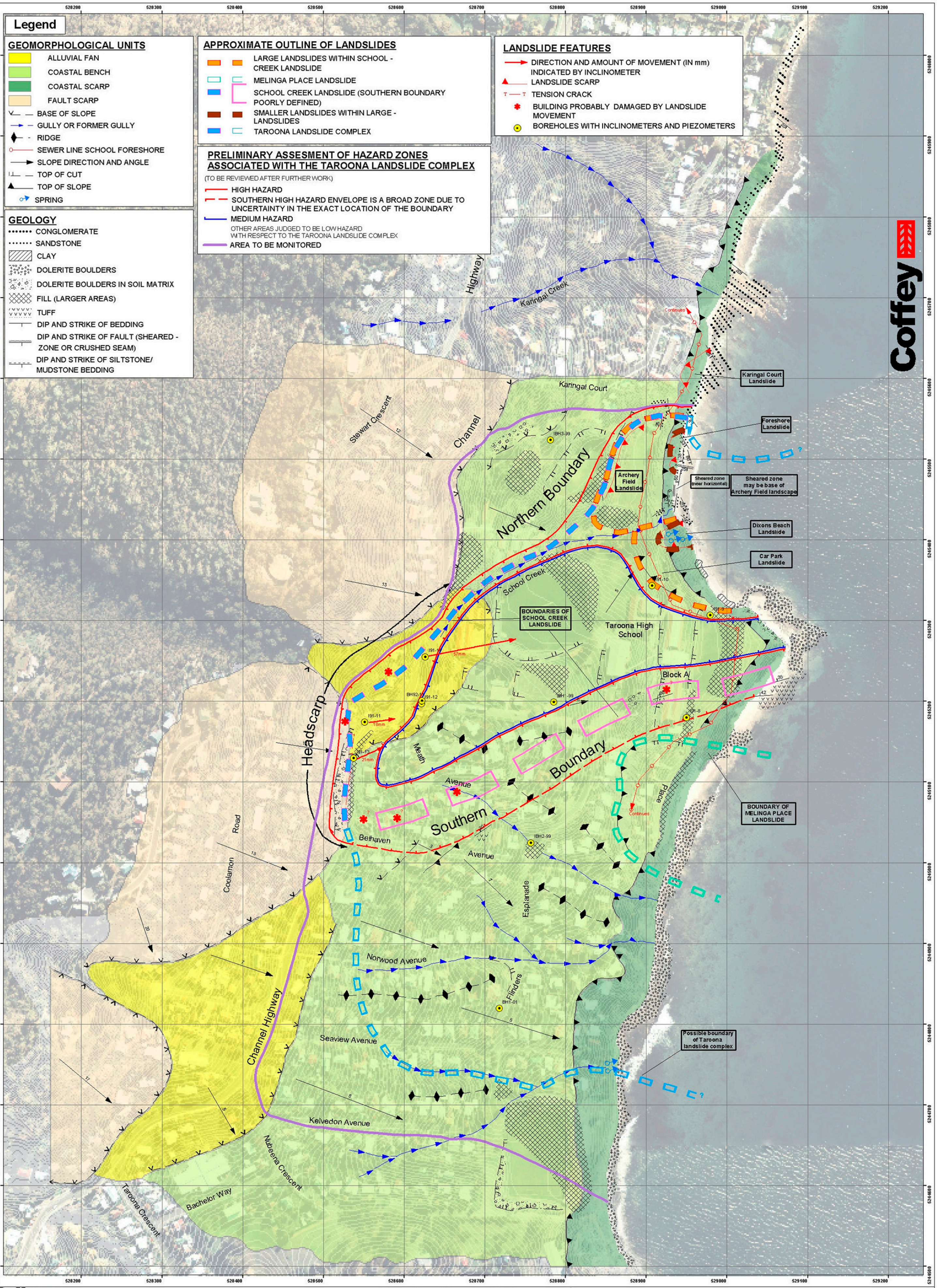
Coffey Geosciences Pty Ltd ACN 056 335 516

Geotechnical | **Resources** | Environmental | **Technical** | Project Management

Drawn	SB	MINERAL RESOURCES TASMANIA LANDSLIDE RISK ASSESSMENT AND MANAGEMENT IN TAROONA REGIONAL CROSS SECTION
Approved	B McD	
Date	MAY 2002	
Scale	As Shown	

Drawing No. : FIG. 2

Job No. : HO104/3



Coffey Geosciences Pty Ltd ACN 056 335 516

Geotechnical | **Resources** | Environmental | **Technical** | Project Management

Revision No.	Description	Drawn	Approved	Date
0		AM	BMD	May 2002

Drawn	AM
Approved	BMD
Date	May 2002
Scale	1:2000

Mineral Resources Tasmania
Landslide Risk Assessment And Management In Taroona
Geomorphology and Landslide Hazard Plan

Drawing No. Figure 3

Job no: Ho104/3

0 15 30 60 90 120 Metres

Hydro Tasmania

Survey & Geographic Information Services

G3446_9

APPENDIX A

List of earlier subsurface investigations in the Taroona area reviewed in this study.

LIST OF EARLIER SUBSURFACE INVESTIGATIONS IN THE TAROONA AREA

REVIEWED IN THIS STUDY

Date (approximate)	Reference	Summary of subsurface work
1977	Knights (1977)	13 shallow boreholes
1977	Donaldson (1977a)	2 shallow boreholes
1977	Donaldson (1977b)	3 shallow boreholes
1988	Weldon (2002)	2 test pits 1 borehole (to about 20m)
1988	DOT (1988)	4 penetrometer probes
1989	DOT (1989)	2 penetrometer probes 4 test pits
1991	Latinovic et al (2001) Weldon (2002)	4 boreholes (to about 20m) 1 shallow borehole 3 inclinometers
1992	DOT (1992)	5 boreholes (up to 40m deep) 4 inclinometers (1piezometer)
1999	Latinovic et al (2001)	3 boreholes (up to 70m deep) 3 inclinometers
2001	Waite (2001)	1 borehole to 70m piezometer at 45m

APPENDIX B

Summary of Movement History of School Creek Landslide

SUMMARY OF MOVEMENT HISTORY OF SCHOOL CREEK LANDSLIDE

Event Number and Date	Evidence of Movement of School Creek Landslide
1 - Pre 1946	The break in slope of the headscarp, although modified by the fill associated with the Channel Highway indicates total movement of the landslide may be about 3 m. The break in slope near School Creek indicates that total movement along the northern boundary may be of similar magnitude. The southern boundary is not readily apparent from the geomorphology and total movement along this boundary may be less. Old maps indicate that the Channel Highway in the project area has been in its present position for at least 100 years (Taroona Historical Group 1988)
2 – 1946	There is a dark area on the Channel Highway near the present position of the primary school. It may be partly due to shadow or it may represent a hollow or patched area at the headscarp of the School Creek Landslide.
3 – 1957	There is a dark area on the Channel Highway in the same position as on the 1946 aerial photograph.
4 – 1967	There are patches on the Channel Highway near the intersection of Meath Avenue.
5 – 1967	A 1967 photograph in Taroona Historical Group (1988) shows a fallen eucalypt at the toe of Dixons Beach Landslide. The tree may indicate that the landslide had moved recently.
6 – After 1967	Cromer (2001) reports that structural damage at 2 Belhaven Avenue become more apparent after 1967.
7 – Between 1967 and 1973	Comparison of aerial photographs indicates that the toe of the Dixons Beach Landslide extended seawards between 1967 and 1973. Some of the apparent movement may be the result of placing fill. It is possible that the Car Park Landslide also moved at this time. 1969 and 1971 was the wettest three year period at Taroona (40 years of records available).
8 – 1975	Stevenson (1975) reported that there were *"longitudinal cracks up to 5 mm wide"* with a *"total horizontal deformation about to 30 mm"* on the Channel Highway north of Belhaven Avenue. He also reported that there was *"some vertical movement"* and that 2 Belhaven Avenue had a *"history of cracking".*
9 – 1976	Leaman and Cromer (1976) reported that erosion was occurring north of the Taroona High School (at the toe of the four smaller landslides).
10 – 1976	Cromer (2001) reports that there was *"severe differential settlement"* at 2 Belhaven Avenue and that underpinning was carried out.
11- 1977	Knights (1977) reported on house damage in the Norwood Avenue, Belhaven Avenue and Meath Avenue area. The report indicates that *"46 show no structural damage, 22 exhibit light structural damage, and 15 have had major damage."* The report includes descriptions of five of the houses with major damage. Original descriptions are no longer available. Of the five houses described three (2 and 4 Belhaven Avenue and 15 Meath Avenue) appeared

to show lateral movement not usually associated with expansive soils The damage to these houses may be associated with movements on the southern boundary of School Creek landslide. Knights also refers to a stormwater drain from Harrow Place being *"repeatedly fractured"*.

12 - 1977 Donaldson (1977a) describes road failures on the Channel Highway north of Belhaven Avenue and above the primary school Donaldson reported that the sections of roads had been a *"source of trouble for a considerable period of time and has required continuous maintenance"* Donaldson reported both horizontal and vertical movements and also referred to the *"long history of movement"* and remedial works at 147 Channel Highway. The damage to the house and highway is almost certainly due to movement of the headscarp of School Creek Landslide.

13 - 1977 Donaldson (1977b) describes the Archery Field and Foreshore Landslides. Donaldson reports *"horizontal and vertical displacements of between 0.15 m and 0.3 m are typical".*

14 - 1988 Weldon (2002) logged two test pits where the headscarp crosses Channel Highway. Across the headscarp above the primary school the total vertical displacement of the lowest road fill appeared to be about 600mm. The age of the lowest road fill is not known, but it is probably between 100 years and 150 years old.

Soil layers appeared to be tilted and disturbed in the test pit further south (at the western of the highway about 30 m south of 153 Channel Highway) but it was not possible to estimate the amount of vertical displacement.

15 - 1988 The Department of Transport (DOT, 1988a) reported that survey lines along the Channel Highway established in 1977 between the Primary School and Belhaven Avenue had moved. Downhill (east) movements of between 100 mm and 130 mm appeared to have occurred in front of 147 and 149 Channel Highway. Movements south of 153 Channel Highway were 50 mm to 60 mm. It was reported that vertical movements may have been up to 100 mm.

The DOT also reported on other evidence of landslide movement at the headscarp including variations in asphalt thickness where the road had been patched, movement in stormwater papers and damage to 147 Channel Highway.

16 - 1988 The DOT (1988b) reported movement of the Dixon Beach Landslide and evidence for the existence of the Car Park Landslide.

17 - 1989 The DOT (1989) reported further movement of the Dixons Beach Landslide. Vertical movements at the head were 2 m to 3 m and the toe encroached 5 m to 10 m on to the beach. The DOT provided *"strong evidence that there has been large downward movement"* across what we have interpreted to be the headscarp of the Car Park Landslide.

18 - 1991	In 1991 the DOT installed inclinometers to about 20 m in three boreholes drilled by MRT near the Taroona High School (Inclinometers I9I-8 , 9 and 10).
19 - 1992	In 1992 the DOT (1992) installed four inclinometers and one piezometer in and near the Channel Highway (Inclinometers I92-11, 12, 13 and 14 and Borehole BH 92-11).
20 - 1992	In 1992 a Parliamentary Public Works Committee reviewed the history of instability at Taroona High School. We understand that evidence was presented which indicates horizontal movements and horizontal stresses may have occurred under Block A (southern most large building). The horizontal movements and stresses may have been associated with movements along the southern boundary of the School Creek Landslide.
21 - 1993	The DOT (1993) reported that *"asphalt resurfacing (1991 – 1992) between Meath and Belhaven Avenue is showing signs of cracking"* indicating further movement of the headscarp.
22 – 1992 - 1995	The inclinometers indicate small downhill movements (less than 10 mm) in inclinometers I92-13 and I92-14 at depths of about 5.5 m and 8.5 m respectively.
23 – 1995 to 1997	Between 6 October 1995 and 5 May 1997 Inclinometer I92-14 moved about 25 mm (depth 8.5 m). Inclinometers I92-11 (depth 12 m) and I92-13 (depth 5.5 m) moved about 5 mm in the same period. The period included the wettest 4 month, 5 month, 6 month and 12 month aggregate rainfall recorded at Taroona (40 years of records available). There was also indication of a possible small movement at a depth of 30 m in I92-12.
24 – 1997 to present	Further movements have occurred in Inclinometers I92-11, 13 and 14. Inclinometer I92-12 is blocked. The total translation movement identified by Pitt and Sherry (2001) are: I92-11 18 mm at 83° (grid) depth 12 m I92-13 21 mm at 66° depth 5.5 m I92-14 57 mm at 79° depth 8.5 m No definite movements have occurred in the three inclinometers installed to about 20 m in 1991 near the High School by MRT.
25 – 1999 to present	MRT installed three inclinometers to 70 m deep (IBH1-99, 2-99, 3-99) in the study area (Latinovic et al, 2001). No definite movements have been detected in these inclinometers.
25 – 2000 to 2001	Repeated surveys of the positions and heights of the inclinometers by Geoff Benn have shown no differences outside the estimated accuracy of the survey.

26 - 2001	MRT attempted to install another inclinometer to 70 m in the study area. The attempt was unsuccessful but a piezometer was installed at a depth of 45 m (Waite, 2001)
27 – 2001 - 2002	Longitudinal cracks were observed in the Channel Highway north of Belhaven Avenue.
28 - 2002	There has probably been 2 m to 3 m of erosion of the clay exposed at the toe of the Car Park Landslide and the Dixons Beach Landslide since 1989 (compare present coast with sketch map in DOT, 1989).

APPENDIX C

Likelihood, consequence and risk terms for property.

LIKELIHOOD TERMS

Judged likelihood of landslide in the next 50 years (design life) based on evidence from the site (present condition), past performance and experience from elsewhere.

TERM	JUDGED INDICATIVE LANDSLIDE RECURRENCE INTERVAL	IMPLIED LIKELIHOOD OF LANDSLIDE IN NEXT 50 YEARS BASED ON JUDGED RECURRENCE INTERVAL
Very likely	Less than 50 years	More than 60%
Likely	50 to 500 years	10% to 60%
Possible	500 to 5000 years	1% to 10%
Unlikley	more than 5000 years	less than 1%
Very unlikely	very much more than 5000 years	very much less 1%

QUALITATIVE CONSEQUENCE TERMS

TERM	EXAMPLES OF CONSEQUENCES TO STRUCTURES
Severe	Extensive damage to most of structure.
Moderate	Moderate damage to some of the structure
Minor	Limited damage to part of structure
Insignificant	Little or no damage

NOTE: *The assessment of consequences involves judgement based on the knowledge and experience of the assessor. The relative consequence terms are value judgements related to how the potential consequences may be perceived by those affected by the risk. Explicit descriptions of potential consequences (e.g. rocks up to 0.5 m across may fall on to parked car) will help the stakeholders understand the consequences and arrive at their judgement.*

RISK MATRIX

LIKELIHOOD	CONSEQUENCES TO PROPERTY			
	Severe	**Moderate**	**Minor**	**Insignificant**
Very likely	**Very high**	**Very high**	**High**	**Low**
Likely	**Very high**	**High**	**Medium**	**Low**
Possible	**High**	**Medium**	**Low**	**Very low**
Unlikely	**Medium**	**Low**	**Very low**	**Very low**
Very unlikely	**Low**	**Very low**	**Very low**	**Very low**

NOTE: 1. *We have defined the risk associated with insignificant consequences, however likely as low or very low*

2. The main purpose of a risk matrix is to help rank risks and set priorities and help the decision making process.

CONTINUED OVERLEAF

RESPONSE TO RISK

In general, it is the responsibility of the client and/or regulatory and/or others who may be affected to decide whether to accept or treat the risk. The risk assessor and/or other advisers may assist by making risk comparisons, discussing treatment options, explaining the risk management process, advising how others have reacted to risk in similar situations and making recommendations. Attitudes to risk vary widely and risk evaluation often involves considering more than just property damage (eg environmental effects, public reaction, business confidence etc).

In some situations development control decisions (e.g. by local government authorities) are related to qualitative risk (or hazard) ranking terms. For example, some regularity authorities will not allow new development where the risk (or hazard) has been described as "high" (according to particular definitions included in the development controls).

The following is a guide to typical responses to assessed risk based on our experience.

ASSESSED RISK	TYPICAL RESPONSE OF CLIENT/OWNER/REGULATOR/PERSON AFFECTED
Very High, high	Treats seriously. Usually requires action to reduce risk. May avoid development of new site.
Medium	May look for ways to reduce risk if reasonably achievable. May accept risk.
Low, Very low	Usual regards as acceptable.
NOTE: *The distinctions between very high and high and between low and very low are usually used to help set priorities.*	

GENERAL COMMENTS ON RISK TERMS AND RISK MATRICES

Other risk terms and risk matrices (if both are defined and explained) may be used if preferred. It is also possible to assess and manage risks without using a risk matrix.