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## **Kingborough Council**

Report for Technical Review for  
Taroona Landslide

Risk Assessment & Mitigation  
Stage 1

March 2012



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## 1. Introduction

At the request of Mineral Resources Tasmania (MRT), acting on behalf of Kingborough Council - Tasmania, GHD have undertaken a staged program of works to assist Kingborough Council in managing the risk due to landslide activity in the Taroona area.

The work undertaken by GHD forms the initial stage of a project that aims to quantify and address the impacts of landslide activity on existing community assets and future developments.

GHD have been awarded the initial or Stage 1 component of this project, which involves a validation study. This validation study included the following services:

- ▶ **Collation** and interpretation (to verify relevance to the landslide behaviour) of **available geotechnical and infrastructure information**, including reported damage, to feed into a single database repository. The principal data suppliers are listed below:
  - Department of Infrastructure, Energy and Resources (Mineral Resources Tasmania, Roads and Traffic Branch)
  - Southern Water (sewer and water)
  - Aurora Energy
  - Kingborough Council (stormwater and roads)
  - Department of Education (school infrastructure)

Telstra provided limited pdf (rather than GIS) output of individual requests for much reduced areas. This meant that the collation process became too timely and inefficient to proceed and so it was agreed with MRT that this be postponed to a later stage.

GHD dedicated around six man-weeks for this task, and involved a number of meetings and site visits, besides electronic and hard copy search of documents. This was also augmented during work progress to include site inspections with MRT to identify signs of damage.

Close liaison was maintained with MRT during undertaking of this task.

Further information is presented in Section 5.2.

- ▶ Developing a GIS based **single data repository** of landslide related information. This task involved the development of a GIS based dataset to compile the existing and ongoing landslide related data in a single repository to inform future management decisions and strategies. The database was also utilised to develop 3D viewing templates to assist visualisation of the landslide activity. MRT provided a significant amount of time contributing to this task.
- ▶ Development of **3D digital models**: These “are representations of features in three dimensions that allow visualisation from any perspective and limited analysis (e.g. determination of volumes and geometric relationships). Key layers in the 3D model will include a digital elevation model of the land surface (raster format), and a



number of vector layers such as the probable extent of the landslide slip surface, all significant infrastructure such as roads, underground services, overhead services, major buildings, major geological units, drill holes etc.

MRT contributed significantly to this task.

- ▶ A **re-survey** of a previous road survey (Channel Highway close to the primary school) to establish long-term movement. This task required the engagement of an experienced surveyor, Peacock Darcy and Anderson, to locate previous survey marks that were used to define landslide movement and if possible calculate net movement since then to present day. It is a one-off exercise for this project.
- ▶ During undertaking this task, it was extended significantly in lateral ground extent, the number of points/assets to be surveyed, and the need for permanent benchmarks (even the State benchmarks could not be confirmed that they were on stable ground i.e. outside landslide activity, in this region).
- ▶ **Technical review:** This project is essentially a validation study for the existing data that relates to the geological setting and behaviour of the landslide. The outcome of this technical review and validation will form the basis of the interim advice to the Council and to other stakeholders.
- ▶ Preparation of **images (e.g. poster displays)** that allow technical and non-technical individuals to readily conceptualise the geometry and location of the landslide and related features with respect to the natural and built environment and assets at risk.

During undertaking this task, additional work was requested from GHD (e.g. fly over).

- ▶ Preparation of an **interim advice for planning scheme amendments** to be discussed through a **presentation for the Council planning officers** to address risk mitigation measures on existing and future developments.
- ▶ **Presentation** of the findings and recommendations through a workshop **for stakeholders.**

This report outlines the technical review component of the services listed above. The program of stakeholder workshops, interim planning advice and preparation of images is delivered separately.



## 2. Background

The area of land in the Taroona district situated between the Channel Highway and the Derwent River in the vicinity of the Taroona Primary and High Schools has a recorded history of land instability since the 1970's.

Although it had been known for many years that buildings in the area have required periodic structural repairs, the continuing program of repairs to a section of the Channel Highway appear to have prompted more critical investigation in the mid 1970's.

Several early reports concluded that expansive clay soils combined with settlement and drainage problems were the likely cause of building damage in the area. However, a series of investigations beginning in 1977 indicated that a significant landslide problem was likely to exist in the area.

A number of subsequent investigation programs have collected a range of surface and subsurface data in the wider Taroona area, and analysis of causal factors has been undertaken. Although this data has improved our understanding of the possible landslide activity in the area, this collection of evidence has not provided a clear unambiguous model of the landslide(s) at this site.

This lack of clarity in the landslide models is mainly due to the very slow and intermittent rate of movement of the landslide mass(es), coupled with very few real movement data locations.



### 3. Previous Studies

Ground movement and observed structural damage in the Taroona area has been the subject of a significant range of published and unpublished reports since 1976. These reports have included major investigations and reviews. These major previous collations and reviews at this site have been examples of excellent work and the major issues outlined in them are still relevant. In particular the TGS 2001/01 Record by Latinovic et. al. and the 2002 Risk Assessment by Coffey Geosciences have identified the major site features and issues. The main studies and reports that have contributed to awareness and understanding of the Taroona ground movements are listed below. This is not a comprehensive listing of previous studies and reports, but is designed to identify the main contributors to recognition and knowledge of the ground movement issue.

A comprehensive bibliography of known previous studies and reports is included in Appendix J. It is a listing of technical reference material, as at March 2012, relevant to the understanding of the School Creek Landslide that mainly encompasses the fields of geology, geotechnical investigations and site history. The bibliography is maintained and periodically updated by Mineral Resources Tasmania.

- ▶ Stevenson, P.C.; (1975) – Ground movement at Taroona, Unpublished report Department of Mines Tasmania UR1975\_69. *Recognised potential for landslide hazard in Taroona area.*
- ▶ Donaldson, R.C.; (1977) – Road foundation failures, Channel Highway, Taroona. Unpublished report Department of Mines Tasmania UR1977\_36. *Recognised that landslide has developed, with potential to cause house damage.*
- ▶ Donaldson, R.C.; (1977) – Foreshore instability near Taroona High School. Unpublished report Department of Mines Tasmania UR1977\_41. *Recognised landslide along foreshore between Karingal Court and High School.*
- ▶ Cromer, W.C.; (2001) – 2 Belhaven Avenue, Taroona. Geotechnical opinion on structural damage. William Cromer Pty Ltd. *This damage assessment reports that structural damage to this property became more apparent after 1967.*
- ▶ Latinovic, M. et.al.; (2001) – An Investigation of land stability in the Taroona area. Record Tasmanian Geological Survey 2001/01. – *This report identified large, slow moving landslide complex within Tertiary sediments, with possible extension offshore. The report recommended a program of investigation to clarify nature and extent of landslide complex, and recommended possible remedial measures.*
- ▶ Moon, A.T.; McDowell, B.; (2002). Landslide risk assessment and management in Taroona, vol. HO104/3-AC. Report by Coffey Geosciences Ltd. Hobart prepared for MRT. *This report of a major review and investigation concluded that the recent landslide movements are associated with a large landslide complex with active onshore components and inactive components that extend offshore. The report recommends a monitoring and management program, and regular review and continuing investigation to refine the landslide model(s).*



- ▶ Mazengarb, C.; Flentje, P.N.; Miner, A.S.; (2009). Taroona Landslide Technical Overview. Presentation to the Taroona Risk Assessment Workshop, May 2009, Kingborough Council. Mineral Resources Tasmania: Kingston, Hobart. *This review of updated information utilised monitoring data gathered since 2002 together with evaluation of historical photography and rainfall records to present a reinterpretation of the previous landslide models.*
- ▶ Mazengarb, C.; Stevenson, M.D. (2009). Additional technical information following the Taroona Landslide Risk Assessment Workshop, May 2009. Mineral Resources Tasmania: Hobart. *This additional information provided updated and corrected versions of key data to support the landslide modelling.*



## 4. Site Geology

Previous review and investigation reports (Latinovic et al 2001, Moon and McDowell 2002) have described the geology of Taroom in detail. The reader is referred to Moon and McDowell 2002 for discussion of the site geomorphology and geology as it is relatively complex and cannot be summarised easily. However, the geology of the Taroom area has been recently revised by MRT (see Appendix A, Revised Geology of Taroom, 1:2000 scale map, Mazengarb, June 2011). The revised geology is a result of recent field mapping and reinterpretation of the available surface and subsurface information (including several drillholes spudded post 2002). This revised geology has resolved some of the structural difficulties present within previous interpretations, specifically the poorly defined fold and fault structures previously proposed for the Tertiary sequence.

The major modifications to the previous geology involve adjustments to the subdivision of the Tertiary sedimentary units, and the inclusion of a north-east trending fault boundary between the Tertiary fluvial sandstones and conglomerates in the northern part of the site, and the Tertiary lacustrine sediments to the south. Adjustments have also been made to the extent of the Quaternary alluvial fan deposits.

Although the recent modification of the geological map of the Taroom area provides a much clearer interpretation of the surface geological model, there remains a considerable degree of uncertainty, especially within the Tertiary and Quaternary units. The Tertiary sediments in particular appear to be highly variable both vertically and laterally, principally due to their modes of deposition but also in part due to the similar source materials derived from the Permian and Jurassic formations to the west. The presence of dolerite boulder talus in deposits from the Tertiary through to the Quaternary deposits can result in difficulties in differentiating geological units.

An additional source of difficulty in outlining the distribution and structure of the geological materials is the degree of anthropogenic disturbance within the Taroom area.

It is difficult to see how the geological model can be further refined without the supplement of more detailed subsurface information. The potential sources of further geological information comprise:

- ▶ Review of existing drill core and disturbed samples. Although this exercise is seen as a valuable task, the limited core available and its condition may mean that this exercise may yield limited usable additional information.
- ▶ Drilling of additional investigation bores. This would provide targeted geological information to assist interpretation of subsurface geological structure.

From the present state of site geological knowledge, it appears that the more pronounced landslide movements are located within the Quaternary alluvial fan and debris flow deposits and the finer grained (lacustrine) component of the Tertiary sediments.



The focus of ongoing investigation at this site is likely to be in defining the extent of the moving masses rather than concentrating on refining the geological model. However, subsurface investigations to define movement zones should also include gathering as much geological information as possible.



## 5. Recent GHD Study

### 5.1 Geological Mapping

As part of the initial phase of this project, MRT geologists conducted geological mapping traverses. The geological mapping traverses concentrated on reassessing the exposures along the coast and the limited exposures of tuff and dolerite boulder beds within the High School.

The lithologies and bedding variations observed during this field mapping enabled reassessment of the subdivision of the Tertiary sedimentary units and broad structural trends.

The revised geology is presented in Appendix A (Revised Geology of Tarooma, 1:2000 scale map, Mazengarb, June 2011).

### 5.2 Development of Damages Database

The MRT Tasmania Geohazards (Landslides) Database has been adapted by GHD to provide a user interface in Microsoft Access to enable the collation and interpretation of all reported damage information into a single repository.

#### 5.2.1 Sources of Damage Information

GHD has undertaken a survey of infrastructure organisations to identify potential sources of infrastructure damage reports. The responses were reviewed and collated by GHD, and where appropriate incorporated into the damages database. In conjunction with MRT, GHD has also undertaken a walkover survey of the Tarooma area to identify any visible evidence of ground movement damage (see section 5.2.6). This survey is not considered comprehensive. It included observations on surface damage to roads, footpaths and kerbs and was not a systematic study of the dwellings and school structures, which will form part of future studies.

The source of all damage information currently incorporated in the damages database is discussed in further detail below.

#### 5.2.2 Kingborough Council Assets (Roads and Stormwater)

Initial discussions were held over the phone with Andrew Coombe of the Kingborough Council on the 8th June 2011. Maintenance records for stormwater assets were not readily available. It was noted that there had generally been very little maintenance over the years.

Contact details were provided for Malcolm Cowen, a Council employee with 25 years of experience on stormwater maintenance issues. However it was noted that he was on long service leave throughout the duration of Stage 1. It is recommended these further discussions be undertaken during later stages of the project to determine if such maintenance records are accessible.



A summary of maintenance of Taroona roads was provided to GHD by email on the 10th June 2011, sourced from the Council Works Department. This comprised brief comments of maintenance on specified dates for all council roads in Taroona. Given the brevity of the records this information has not been captured in the damages database. In the absence of any additional information, it was not possible to determine the factors associated with each of the repairs and/or reinstatements. It is noted that this maintenance summary is available for review if desired.

### **5.2.3 Southern Water Assets (Sewer and Water)**

Meetings were held with the following contacts at Southern Water, provided by Luke Ellis of Southern Water.

*Southern Water Depot, 2 Hornby Rd, Goodwood - 10am-11am 20th June 2011*

Discussions were held with Steve James of Southern Water regarding sewer assets. Steve recalled significant breakages that could be attributed to potential ground movement. Information included approximate location, approximate date, nature of break, composition and diameter of pipe, approximate depth and ground condition. Steve's work extended back to 1980. Significant uncertainty is noted with this anecdotal evidence. This information has been incorporated into the damages database (refer to Appendix D for plot of damage points).

*Southern Water Depot, 20 Patriach Drive, Huntingfield - 9am-11am 21st June 2011*

Discussions were held with Dale Nicolson, Stewart Cockerill and Kevin Cooper of Southern Water regarding water assets. They recalled significant breakages that could be attributed to potential ground movement. Information included approximate location, approximate date, nature of break, composition and diameter of pipe, approximate depth and ground condition. The meeting attendees working careers extended back to the following dates: Dale Nicolson - May 1998, Stewart Cockerill - late 1998 and Kevin Cooper - August 1990. Significant uncertainty is noted with this anecdotal evidence. This information has been incorporated into the damages database (refer to Appendix D for plot of damage points). It should also be noted that work diaries are available at this depot which extend back to 1999. These provide a maintenance history of all breakages, although without specific detail on the nature of the break and potential causes and so it may not prove very useful.

*Southern Water, 169 Main Rd, Moonah - 10am-11am 27th June 2011*

A meeting was held with Heather McKillop of Southern Water regarding potentially relevant records and reports that were passed over from Kingborough Council. This involved sorting through information that had been collated by Heather prior to the meeting to determine whether any additional damage information could be extracted. A number of documents were copied to GHD systems for review. Damage information was identified and this has been incorporated into the damages database.



#### **5.2.4 Aurora Energy Assets**

Malcolm Conway of Aurora Energy was contacted on two separate occasions by GHD regarding potential maintenance information. Malcolm advised that Aurora Energy had no issues that could be attributed to landslide movement.

#### **5.2.5 Department of Education**

Hard copy archives at Taroona High School were reviewed on site by GHD and no references to damage information were identified.

A meeting was held with Brian Smith at the Department of Education from 10am-11am on the 18th August 2011. This involved sorting through documents on their system for any references to damage to Taroona High School. A number of documents were copied to the GHD systems for review. Damage information was identified and this has been incorporated into the damages database.

#### **5.2.6 GHD/MRT Damage Survey**

A survey of surface damage to roads, footpaths and kerbs was conducted within the landslide zone by GHD and MRT on the 14th June 2011 (refer to Appendix F for plot of damage points). This survey identified damage attributed to movement of the underlying ground, although it was not clear whether this was related to landslide movement or reactive soils. Damage included cracking of retaining walls, footpaths, roads, kerbs and gutters, and also displacement in joints between sections of kerb and gutter. The nature and magnitude of the displacement was recorded, along with locations and photographic logs. This information has been incorporated into the damages database. It should be noted that the thresholds established to decide whether surface damage was recorded were subjective.

#### **5.2.7 Tender CD provided by Mineral Resources Tasmania**

Documents provided by MRT were reviewed in detail by GHD and all references to damage have been incorporated into the damages database. These primarily revealed damage to residential houses, the Channel Highway and associated underground infrastructure (refer to Appendix E, Appendix F and Appendix G for plot of damage points).

#### **5.2.8 Database Record Format**

The Microsoft Access Damages Database provides a user interface form which enables the entry of reported damage details. These fields are listed as follows:

- ▶ **GHD\_Damage\_ID:** Identification assigned by GHD to the reported damage.
- ▶ **Damage:** Type of feature that has been damaged. Options include the following:
  - Building (Commercial, Residential, Outbuilding or Public);
  - Road (Arterial, Minor or Private);
  - Infrastructure (Water, Gas, Sewer, Stormwater, Power, Phone, Wharf, Water Storage or Treatment Plant);



- Minor Structure (Footpath, Retaining Wall or Kerb/Gutter);
- Fence;
- Railway;
- Vehicle; or
- Not known.
- ▶ **Actual\_Damage:** Reports the uncertainty of the classification: indicates whether the damage is Actual (A) or Presumed (P).
- ▶ **Cause:** Cause of the damage. Options include Landslide (Debris or Movement), Reactive Soils, Settlement or Unknown.
- ▶ **Severity:** Qualitative measures of consequence to feature. Options include the following:
  - 1 (Insignificant): Small amount of damage, not necessarily requiring repair works.
  - 2 (Minor): Damage limited to part of structure or site requiring minor reinstatement or stabilisation works.
  - 3 (Medium): Moderate damage to some of structure or site requiring significant reinstatement or stabilisation works.
  - 4 (Major): Extensive damage to structure or site requiring major reinstatement or stabilisation works.
  - 5 (Catastrophic): Complete destruction of structure, or large scale damage requiring demolition or complete rebuild.
  - None: Feature inspected for damage, but no damage identified.
  - Unknown: Unknown damage severity.
- ▶ **Damage\_Start\_Date\_Mod** and **Damage\_End\_Date\_Mod:** Records the precision of the start date. Options include the following:
  - Before: Before the start and end data indicated.
  - After: After the start and end date indicated.
  - Circa: Around the start and end date indicated.
  - Unknown.
- ▶ **Damage\_Start\_Date:** Date when damage to this structure was first recorded.
- ▶ **Damage\_End\_Date:** Date when new damage ceased to occur.
- ▶ **Damage\_Start\_Date\_Acc** and **Damage\_End\_Date\_Acc:** Qualifier that indicates the accuracy of the damage date.
- ▶ **Damage\_Details:** General description of damage caused to the structure.
- ▶ **GHD\_Damage\_Source:** Source of damage details obtained by GHD.
- ▶ **GHD\_Damage\_Source\_Link:** Link to relevant documents (i.e. reports, letters, papers, etc) associated with damage.
- ▶ **Construction\_Type:** Type of construction. Options include the following:
  - Brick (Solid or Veneer);
  - Concrete;
  - Weatherboard;



- Asphalt;
  - PVC/uPVC;
  - Cast Iron;
  - Poly; or
  - Copper.
- ▶ **Construction\_Date** and **Construction\_Year**: Date and year of construction.
  - ▶ **X** and **Y**: Easting and northing coordinates of damage feature.
  - ▶ **Datum**: Map datum used to define easting and northing coordinates.
  - ▶ **Accuracy**: Accuracy of easting and northing coordinates (in metres).
  - ▶ **GHD\_Location\_Information**: Information about where the damage has occurred.
  - ▶ **GHD\_Photo\_Link**: Link to relevant photos associated with damage.

The damages database and associated linked documents and photos were provided to MRT as a deliverable at the conclusion of the project.

### 5.2.9 Limitations on Data Quality

During the collection and compilation of data on infrastructure damage it became apparent that the records contain two constraints that may affect data quality. In addition, in order to compile the data into a form suitable for interrogation at a single interface, qualitative assessments of the data needed to be made.

For many of the data relating to records of damage to residential services infrastructure (e.g. sewer and water mains), the available records were often anecdotal, and not based on maintenance records. Although this data is useful in assessing the potential spatial relationships of damage to landslide features, the possible bias introduced by anecdotal data must be recognised.

An additional source of uncertainty with this data is possible bias in the area covered. Although the recollections of damage to infrastructure were sought for the larger Taroom area, the obvious focus on the School Creek and Channel Highway area may have influenced recollections of past damage in more distant but still relevant areas.

In compiling the available data into a suitable series of fields for incorporation into the database, qualitative assessments were required. Examples of these qualitative assessments are in assigning severity and cause classes to damage instances.

## 5.3 Surface Survey

Following the recognition of major landsliding in the Taroom area (Donaldson, 1977) a monitoring network of marker points along the Channel Highway was commenced in 1977. This monitoring was discontinued in 1994 when anomalous and contradictory displacement measurements led to doubts over the validity of the survey results. It has since been discovered that the reference points of this network were possibly also within the mobile area.



In 1999, a network of surface reference points was established with the aim of re-establishing a regular monitoring program to investigate the extent of the landslide affected area. The survey network comprised the surface collar capping of all new and existing boreholes. Monitoring of this network was discontinued in 2000.

During the Stage 1 work for this project a surface survey exercise was undertaken to locate previous survey marks and establish an improved surface network. This task was undertaken to attempt to define landslide movement since the previous survey work terminated in 2000.

### **5.3.1 Survey Methodology**

The work was undertaken by Peacock Darcey and Anderson Pty Ltd (PDA) and comprised the survey or re-survey of 34 permanent stations (being State Permanent Marks (SPM), rivets in kerbs or iron bars 0.6 m long in rapid set concrete to 0.3 m) and 10 inclinometer monitoring holes (see Section 5.3.1.1).

The work employed a mixed survey technique that included Static Post-process GPS of 12 GPS observable points, in various loop configurations, using three independent GNSS units plus one continuously monitoring base station, to give absolute and relative coordinates of 10 points to an order of approximately 3 mm. The survey was then tightened in the vertical plane by implementing a two way levelling run using a Trimble DiNi digital level and folding staff with a measurement resolution of 0.3 mm. A two way level run along the Channel Highway achieved a 1 mm misclose over a double run (1 km each way). This is in line with the manufacturers specifications, with 3 other bracing loops from the main spine levels to an order of 1 mm achieved on all control points. Further infill and bracing of the horizontal network was to be done using a 1" Trimble S8 theodolite with a 1 mm + 1 ppm accuracy Electronic Distance Measuring (EDM).

By incorporating these methods it was possible to coordinate all control points to an accuracy of  $\pm 2-4$  mm horizontally and  $\pm 1$  mm vertically. Measurements to eccentric points such as the inclinometer monitoring points have an additional level of uncertainty in the order of 1 mm both vertically & horizontally.

SPM9432, which is situated at the corner of the Channel Highway & Coolamon Drive, was used as the MGA1994 & AHD1983 (TAS) datum point. Published coordinates as per the DPIW Survey Control Marks Register (SurCOM) were used (see final survey report for these figures). All other coordinates were then calculated from this origin as it was deemed that other SPMs may be within the slip zone and should hence be calculated and used as a permanent reference station for future surveys.

Data has been provided as MGA1994 coordinates, and as such a combined scale factor will need to be applied to calculate actual plane distances between control points.

The field work took about 5 working days, after which processing and adjustment was undertaken using minimally constrained Least Squares methods.



The survey data output is included in Appendix I, and detailed comments are provided in Section 7.

#### **5.3.1.1 Inclinerometers**

The inclinometers were located by placing a 1.5mm drill hole in the casing pipe offset slightly to the instrument guide channels. In most cases these represented uphill/downhill and up river/down river as a generic reference system for each individual inclinometer. The inclinometer centre point was then calculated by creating a circle using three of these surveyed locations and using the fourth as a check of the calculated radius & centre. This check proved to be within 1-2mm in all cases. The published inclinometer coordinate is the centre point calculated from the above method. The level of the inclinometer has always been taken as the down hill (or eastern most if downhill direction is not clear) drill hole as the casing pipes were irregular in level in some cases.

In the case of I91-10 the casing pipe was broken and too loose for a repeatable measurement so in this case the drill holes were placed in the surrounding outer casing pipe. The same technique was used for the calculation of the centre for this inclinometer.

It is apparent that some of the bores have had an amount of the casing pipe cut off to bring them flush with the level of the ground, and no effort has been made in this report to verify the amounts cut off each pipe.



## 6. Evidence for Landslide

### 6.1 Historic Information

The historic evidence for landslide activity in the Tarooma area has been comprehensively summarised by Moon and McDowell (2002). The earliest reported possible landslide activity relates to structural damage to a residential property (2 Belhaven Ave) in 1967 (reported by Cromer, 2001). Several subsequent reports from 1975 detail ground movement along a section of the Channel Highway and structural damage within the residential area at Tarooma. Displacements were also described for several smaller landslides (1977, 1988 and 1989) along the coastal cliff line.

Moon and McDowell (2002) undertook a comparison of aerial photography dating from 1946. These photos indicate that deformations to the surface of the Channel Highway have been occurring at least as far back as 1946.

This historic information suggests that a landslide stretching eastward from the Channel Highway has been intermittently active for several decades. The information also illustrates that several of the smaller landslides along the coastline have also been active.

### 6.2 Physiographic Evidence

Previous landslide studies (Latinovic et al 2001, Moon and McDowell 2002) of the Tarooma area have noted a large number of key physical features that indicate a significant history of landslide activity.

This evidence consists principally of active and fossil headscarps, the presence of hummocky ground and sudden changes in slope.

The most obvious of these features is the ongoing deformation and cracking along and to the west of a section of the Channel Highway (refer to Appendix A for street location). Estimated total movements in this headscarp area are in the region of 3 m (Moon and McDowell 2002) of which approximately 200 mm movement may have occurred since 1977. This headscarp area is the most compelling evidence of active landsliding in the area.

A series of prominent headscarp-like features are present along and immediately west of the coastal cliff line. These headscarp-like features extend from north (Flinders Esplanade) of the Tarooma High School area to the south (Melinga Place). The smaller of these features are probably recent landslides initiated by coastal erosion at the toe of the cliffs. The origin of the larger of these features (Melinga Place) is uncertain. It may represent the headscarp of a large offshore landslide but there is no evidence that it has been active since European settlement. Alternatively, the feature it could be the expression of a coastal terrace and cliff.

The majority of the Tarooma area east of the Channel Highway occupies a broad shallow slope that dips east towards the Derwent River. The topography within much of this area, particularly within and to the north of the High School grounds, has been



obscured by development. However, the area to the south of the High School is principally occupied by residential development, and much of this topography shows a number of hummocky features. These breaks in slope are relatively subtle, but can be observed by viewing down the east-west trending streets (e.g. Belhaven Avenue and Norwood Avenue). These breaks in a broad shallow slope are typical of landslide areas, and may reflect deeper seated ground movements. Such features are unlikely to be attributable to reactive soils.

The existence of offshore landsliding has been proposed by Moon and McDowell (2002) on the basis of submarine landforms outlined by bathymetric contours. The evidence for the offshore landsliding comprises variations in the seafloor slope, particularly steeper sections of slope interpreted as fossil landslide headscarps. Moon and McDowell proposes that these submarine landforms represent the offshore components of a large landslide complex with its westerly limit at the Channel Highway. The landslide complex involves several large and smaller landslide components, including the Melinga Place landslide.

### **6.3 Infrastructure Damage**

There has been a long history of infrastructure and property damage within the Taroom area. Along a limited section of the Channel Highway where it passes through the Taroom area the bitumen surface has shown severe deformation for many years. Aerial photographs indicate that deformations to the surface of the Channel Highway have been occurring at least as far back as 1946. The deformations in this area have forced relocation of the local water supply main to a position upslope from the highway. This history of continuous resurfacing has also been experienced in a number of local residential property access roads in the area.

There have been several reports of structural damage to A Block of the Taroom High School (refer to Appendix F for location) since the early 1970's. Although structural surveys of the damage have not attributed the damage to landslide movements, it is possible that the damage may have been caused by a combination of differential settlements, the action of expansive soil and landslide activity.

A 1977 survey of structural damage to 46 houses in the Norwood and Meath Avenue areas (refer to Appendix F for street locations) concluded that the cause of the damage was expansive soils.

As outlined in section 5.2.6 of this report, a survey of surface damage to roads, footpath and kerbs was conducted within the landslide zone by GHD and MRT in 2011 (refer to Appendix F for plot of damage points). This survey identified damage attributed to movement of the underlying ground, although it was not clear whether this was related to landslide movement or reactive soils.

This infrastructure damage information outlined above has been incorporated into the damages database.



## 6.4 inSAR

As part of a review of the Taroona landslide in 2009, technicians from Curtin University analysed SAR satellite data sets from 2007 and 2009. Although this analysis failed to identify any significant movement between the data sets, the inclinometer results also show no significant movement over this period.

The inSar data sets from 2007 and 2009 provide a baseline for future displacement analysis. With the indications from the inclinometers of approximately 60mm movement since 2008, analysis including inSar data collected in 2011/12 should provide some identifiable displacements and possibly outline the extent of landslide movement across the site. Information of this type may resolve uncertainties with respect to landslide models.

## 6.5 Inclinometer Monitoring

A series of inclinometers have been installed across the Taroona area in an attempt to define the position and displacement characteristics of any landslide movement surfaces (refer to Appendix I for inclinometer locations). These inclinometers have been installed in a series of investigation programs dating from 1991 up to 1999. A total of ten inclinometers were installed over this time.

In 2008 a near-real-time landslide monitoring facility was installed by the University of Wollongong and Mineral Resources Tasmania and funded from the Natural Disaster Mitigation Programmes on the slope above the Taroona Primary School. This new facility includes a ~24m inclinometer hole (MRT108-01 equipped with two in-place-inclinometers) that has been placed sufficiently deep to encounter the inferred slip surface and enables more accurate, and up to the minute movements to be recorded on this slip. The facility is also equipped to measure hourly rainfall and groundwater pressures (2 installed vibrating wire piezometers) that has allowed displacement data to be analysed against piezometric pressures and rainfall. Results to date suggest that landslide movement is strongly related to groundwater pressure fluctuations associated with 150 day antecedent rainfall patterns. As a result of the real-time installation, the older inclinometers have not been measured with the same frequency as occurred up until 2008. Furthermore, the amount of deformation that has occurred since installation, has meant that the inclinometers are near – or at the end - of their useful life. One inclinometer (I92-14) was abandoned as a manual inclinometer probe could not penetrate past the deformed casing interval in October 2010 (monitoring report from AS Miner Geotechnical 2010 held by MRT).

Monitoring of the **pre 1999 inclinometers** has been intermittent, with several extended intervals without readings;

- ▶ **Three** of the inclinometers are located close to the shoreline (I91-8, I91-9 and I91-10),
- ▶ **Three** are located in a north-south line approximately mid-way between the shore and the Channel Highway (IBH1-99, IBH2-99 and IBH3-99), and



- ▶ the remaining **Five** are located in close proximity to the section of the Channel Highway that has experienced ongoing surface deformations (MRT108-01, I92-11, I92-12, I92-13 and I92-14).

Although several of these inclinometers are not functioning reliably for a variety of reasons, the overall results of monitoring have highlighted ongoing translational movements in a consistent easterly direction adjacent to the Channel Highway. These inclinometers indicate total seaward movement of up to 85 mm between 1991 and 2008, with 60 mm of movement being recorded since 2008 (MRT108-01). The depth of movement is variable, with a steeply dipping sliding surface consistent with a headscarp zone of a landslide at the western margin, and a deep seated sliding surface (depth of 53.5 m) midway between the headscarp and the shoreline.

Only one of the three mid-slope inclinometers has recorded movements (up to 21.7 mm between 1999 and 2008) at a depth of 53.5 m (IBH1-99). This inclinometer provides the only clear indication of a deep seated landslide east of the Channel Highway. The other mid-slope inclinometers are either outside the landslide area or are not deep enough to intersect a sliding surface. It must be mentioned that the most southerly of these inclinometers (IBH2-99) has a buckled casing at a depth of 37.5 m, which is unlikely to correspond to deformation caused by landslide movement. Possible buckling of the casing occurs at 63.5-64m but is not enough to impede the inclinometer probe (monitoring report from AS Miner Geotechnical 2010). The cause of this deformation (landslide movement or some other reason) is presently unknown and independent tests, such as a repeat survey measurement of the collar position, is required to distinguish between these possibilities.

MRT's Colin Mazengarb provided the following comments: When movement directions were first determined for IBH1-99 it was recognised that the azimuth was significantly different (by about 45 degrees) from all of the other functioning inclinometers that were recording movement on the School Creek Landslide. This anomaly led to speculation, over many years, that the landslide could be composed of several compartments not all moving in the same direction. The 2009 Risk Assessment Workshop contained a diagram showing a possible model incorporating these concepts. However, the external technical advisors to the workshop (Dr Flentje and Mr Miner) recommended that a twist survey be undertaken to determine whether the anomaly was real or could be an error if the casing was twisted. A twist survey was undertaken by MRT staff immediately after the 2009 workshop which indicated that a twist of ~43 degrees in the casing existed between the ground surface and the location of the basal landslide shear plane at 53.5m depth. The factoring of the twist into the azimuth calculation resulted in it now having a similar alignment to the other inclinometers. The removal of the azimuth anomaly led Mr Mazengarb to propose a simpler model than the 2009 one, and which is contained in this report.

The three near shore inclinometers have variously recorded minor, relatively shallow (1.4 to 12 m depth range) movements. These results are generally discounted as recording significant landslide movements due to the presence of reactive clays within the near surface subsoil profile. These inclinometers were installed at depths of 20.5 to 21 m, and may be too shallow to intercept deep seated landslide movement surfaces.



## 7. Comments on Survey Results

### 7.1 Channel Highway

PDA was provided with a previous road survey of the Channel Highway close to the primary school. This survey monitored the change in distances and offsets between multiple chainage marks (typically ramset or nails in the kerb or bitumen) between 1988 and 1991. The intention of the current survey was to locate previous survey marks that were used to define landslide movement and if possible calculate net movement since then to the present day. However, only one previous survey mark could be located (re-named PDA53) and so, unfortunately, it is not possible to calculate long-term relative movements using this previous road survey.

### 7.2 State Permanent Marks

The current survey included a total of 10 state permanent marks (SPMs), comprising 8 along the Channel Highway, extending from Coolamon Road to just south of Karingal Court, and 2 along Flinders Esplanade. As discussed in section 5.3.1, SPM9432 (corner of the Channel Highway and Coolamon Road) was used as the MGA1994 & AHD1983 (TAS) datum point with a stated accuracy of 44mm. All other SPMs were calculated relative to this origin.

At the completion of the current survey, PDA sourced accessible historical survey records of the SPMs. The intention was to determine long-term movement of the SPMs that may lie within the landslide zone (relative to datum point SPM9432). The SPM movement analysis is discussed in detail below.

#### 7.2.1 Original 1960-1963 Survey

SPM coordinates from a survey between 1960 and 1963 were located on PDA's historical field books. They are SPM4712, SPM4303, SPM4706, SPM4707, SPM4302, SPM4708, SPM1252, SPM4714, SPM4307, SPM2331 and SPM4). The record shows the historical survey method used distances and bearings relative to each other. PDA could not locate more recent survey information for these SPMs since that time. The accuracy of the original survey is unknown, therefore some differences in survey accuracy would be expected due to the nature of both the survey methodology and technology.

Due to the fact this old survey of the SPMs was done relative to each other, a new survey was attempted to establish northing and easting coordinates for them. For this attempt, SPM4307 was used as the origin to re-survey the remaining SPMs within the group (and it happens to be the closest to the newly adopted datum for the overall survey which is SPM9432).

The calculated original coordinates are included in Appendix I.



It should be noted that although the PDA historical records identified 11 SPMs from the original 1960-1963 survey, only 6 of these have been re-surveyed in the most recent field work, as the remaining 5 SPMs could not be located on site.

A comparison of the SPM coordinates from the calculated 1960-1963 traverse data and the current coordinate survey has revealed the displacements vectors plotted in Appendix I, and listed below:

- ▶ 50mm at a bearing of 131 degrees (south easterly direction) for SPM4714;
- ▶ 57mm at a bearing of 126.5 degrees (south easterly direction) for SPM2331;
- ▶ 57mm at a bearing of 103.3 degrees (south easterly direction) for SPM4;
- ▶ 398mm at a bearing of 84.4 degrees (easterly direction) for SPM4303; and
- ▶ 73mm at a bearing of 206.9 degrees (south westerly direction) for SPM4707.

The displacement vector for SPM4303 has revealed a long-term (in the order of 50 years) movement of 398mm, taking place in an approximately easterly direction. This detected movement appears to be consistent with landslide movement recorded by the inclinometers and observations. The remaining SPMs have indicated much smaller movements but in directions that could be consistent with a landslide movement, and could push its boundary further south, for a lesser risk area.

### **7.2.2 Other SPMs**

Published coordinates as per the DPIPWE Survey Control Marks Register (SurCOM) were obtained for SPM9438 and SPM8365. DPIPWE advised that the coordinates of SPM9438 were recorded using GPS between 1992 and 1996 with a stated accuracy of +/- 44mm. SPM8365 has no stated accuracy. PDA advised that the published coordinates of SPM8365 are far too unreliable to consider any comparison to the current surveyed position.

A comparison of the SPM coordinates from the published data relative to the current survey of SPM9438 has revealed 60mm displacement at a bearing of 303.4 degrees (north westerly direction). The displacement vector for this movement is plotted in Appendix I, and may be anomalous.

### **7.3 Inclinometers**

PDA was provided with an earlier survey of the inclinometer locations from February 2000 ("Taroona Excel Graphs Based on G.Benn's Surface Borehole Survey", MRT), however no information was available as to the methodology, accuracy or datum origin of the supplied coordinates.

A comparison of the inclinometer coordinates from the previous and current survey has revealed a number of anomalous results in the implied displacements (both bearing and distance). This is not surprising given the uncertainty of the original survey and it is recommended that conclusions not be made through comparison of old and new survey information. It is recommended that the current survey results form a baseline for future repeatable survey exercises.



## 8. Landslide Models

Previous investigations of this site have concluded a range of possible landslide configurations. The definition of the zones of movement at the site included evidence from observations of surface displacements and tension cracks, deformations recorded in inclinometer installations, and interpretation of infrastructure damage.

However, this collection of evidence has not provided a clear unambiguous model of the landslide(s) at this site. There have been at least 3 separate and possibly equally feasible interpreted models of the landslide configuration at the site. There is no compelling evidence to enable selection of one of these models as most likely. Further evidence may result in clarification of the model uncertainties.

The models range from:

1. the **Moon and McDowell (2002) landslide model**, with several landslides superimposed on a large landslide mass that extends well offshore,
2. a restricted '**School Creek**' (2011) **landslide model** (with several minor coastal landslides due to coastal erosion), with a range of interpreted extent, mainly due to lack of definition of the southern margin, and
3. an **alternative landslide (2009) model** with a complex set of separate smaller landslides with differing rates and directions of movement (the Mazengarb, Flentje and Miner model, 2009), possibly also superimposed on a larger landslide mass, With this model, much of the infrastructure damage within the wider Tarooma area is attributed to possible localised soil movement due to moisture fluctuation in reactive soils within filled natural drainage lines.

This lack of clarity in the models is mainly due to the very slow and intermittent rate of movement of the landslide mass(es), coupled with very few real movement data locations. For example, how can the large scale offshore extended landslide model be verified when it is possible that this larger scale landslide was activated in a lower sea level glacial period, and is currently either marginally stable or at limiting equilibrium.

### 8.1 Moon and McDowell (2002) Model

The Tarooma Landslide Complex model outlined by Moon and McDowell in the 2002 Coffey report is composed of an extremely large landslide that extends up to a kilometre offshore (up to 20 million m<sup>3</sup>), with several smaller (but some still extremely large) components both onshore and offshore. The presence of the offshore landslides has been interpreted from seismic reflection and bathymetry data. It is proposed that this landslide formed at a time of lower sea levels during a past glacial period when the River Derwent presented a steep sided valley. The model proposes that this larger offshore landslide is currently inactive due to sea level rise and sedimentation within the offshore channel.

The model includes a major extension offshore for the Melinga Place landslide, and the extension of the major complex to the south as far as Seaview Avenue. This model



also proposes that the currently active component of the complex is the 'School Creek' landslide, similar in extent to the 2011 model below.

The major uncertainties with this model relate to the difficulty in providing clear evidence of the existence of major offshore landslide masses, particularly as they are currently inactive. It is also noted that more recent bathymetric data does not confirm the presence of morphology consistent with landslide features (MRT's Colin Mazengarb indicated that they were able to reference a superior bathymetric dataset that was compiled for the State Emergency Service for the purposes of tsunami modelling and which is not in the public domain).

Although the uncertainties with respect to the 'School Creek' landslide component are similar to those outlined below, the current bore, inclinometer and surface movement data do not provide any evidence of a large offshore complex.

## **8.2 School Creek 2011 Model**

With the recent reinterpretation of the geological evidence (see Appendix A, Revised Geology of Taroona, 1:2000 scale map, Mazengarb, June 2011) together with consideration of more recent inclinometer data, the landslide model outlined in the above geological map ('School Creek' model) is regarded as the most suitable model with which to advance the project. The methodology used by the MRT geologists in developing this model is supported as the most suitable approach considering the extent and quality of available data.

This model is a refinement of previous 'School Creek' models (Moon and McDowell 2002), and has been used to develop the current 3D visualisations (see Appendix B and Appendix C).

The School Creek landslide is an extremely large landslide with a volume probably exceeding 4 million m<sup>3</sup>. The toe of the landslide in this model is poorly constrained, however for the presentation of the model it is assumed to be located approximately 100 m offshore. The westerly extent (headscarp) of this model is formed by the clearly defined failure surface coincident with the Channel Highway deformations. Several inclinometers in this area have provided unequivocal definition of the western boundary of the movement.

Another support to this assessment is that State Permanent Mark SPM4303 (within the perceived headscarp area of the School Creek landslide) has detected a clear seaward movement of approximately 400 mm in five decades (refer to Section 7.2.1). It is known that the Channel Highway has undergone multiple reconstruction in this area from frequent cracking and pavement damage and subsidence. However, the northern and southern extents of the landslide are still poorly defined (this is discussed later in the section).

The School Creek landslide appears to be moving intermittently. Although inclinometer monitoring prior to 2008 suggests an average rate of movement of between 2 and 6 mm per year at the main headscarp along the Channel Highway, recent monitoring by the near-real-time installation in the same area indicates movement may fluctuate up to 30 mm per year (Oct. 2008 to Oct 2009). The general rate of movement (up to 6 mm



per year) rates the landslide as an extremely slow (Class 1 of Cruden and Varnes (1996) velocity scale i.e. less than 15 mm per year) moving landslide. However, the more recent data (up to 30 mm per year) indicates that under unfavourable conditions, the landslide may experience a period of increased velocity. This higher velocity phase would rate the landslide as very slow (Class 2 of Cruden and Varnes (1996) velocity scale i.e. between 15 mm and 1.6 m per year). It should be noted here that the future rate of movement may increase beyond the observed speed range given sufficiently unfavourable conditions (i.e. extended period of high rainfall and consequent elevated piezometric pressure).

The major uncertainties with this model are that;

- ▶ Only one inclinometer appears to have clearly intersected a sliding surface (inclinometer IBH1-99 encountering a sliding surface at a depth of 53.5 m) east of the headscarp area. Two of the inclinometers located near the shoreline (I91-09 and I91-10) are probably too shallow to intersect the sliding surface of this model. Inclinometer I91-08, with movement indicated at 11 and 18 m below the ground surface, may have intersected the sliding surface of this model near its southern boundary.
- ▶ The northern and southern boundaries of the slide are poorly defined in the evidence. The northern boundary has been assumed to coincide with the gully formed by School Creek. The southern boundary is poorly defined, with the exception of small movements detected by SPM4, SPM2331 and SPM4714; see Section 7.2.1). Surface deformation (infrastructure damage) is not unambiguous, with the observed damage possibly related to reactive soils or settlements due to filling of pre-settlement drainage lines. The damage location plots do not provide a clear boundary zone. Information from the more southerly inclinometer (IBH2-99) is not reliable due to a buckled casing.

Difficulty in definition of the southern boundary may be due to movement of this landslide being non-uniform in that the movement along this boundary may be by a combination of localised zones of shear or tension over a broader linear zone leading to diffused surface indications. It is also possible that the landslide mass may not move as a coherent mass, but may move as a series of discrete parts that do not move at the same time or at the same rate.

In developing this model, **spatial interrogation of the damages database** was utilised. A series of plots were generated from the database, showing spatial distribution of damage classes. The plots generated include:

- ▶ Appendix D. *Damage to Southern Water Assets*. This plot shows major and medium damage broadly coinciding with the interpreted boundaries of the School Creek landslide, although other damage points plot both to the north (Karingal Court) and to the south (west of Hensby Road). The damage located to the south occurs within an area of Jurassic dolerite, and its causal factors may be related to the local geological and slope conditions in this area.
- ▶ Appendix E. *Damage to Kingborough Council Stormwater Assets*. There are very few records available for this plot, and the only two occurrences (major and



medium damage) are located adjacent to the headscarp zone west of the Primary School.

- ▶ Appendix F and Appendix G. *Damage to Buildings and Surface Structures*. These plots show a wide spread of minor damage points, although there is a noticeable cluster within the area of the School Creek landslide in the Meath Avenue area. The majority of the major and medium damage points are focussed in the headscarp zone and southern boundary of the School Creek landslide. Two major and two medium damage points are situated in the High School and northern boundary of the School Creek landslide adjacent to the shoreline. This pattern of damage points is a relatively strong indicator of ground movement coincident with the proposed School Creek landslide. A single major damage point is located above the coastal cliff in the Karingal Court area, and this is consistent with small localised landslides along the coastal cliff initiated by coastal erosion. It is of interest that Appendix G shows a concentration of damage in the Hinsby Beach area to the south of the project area. The relationship of this area to past landsliding is unknown.

In general, although there is some spread of minor damage points possibly related to expansive soils and coastal cliff erosion, the majority of the damage points tend to confirm the major modern instability to be associated with the proposed School Creek landslide.

The 3D images of the proposed School Creek landslide are presented as Appendix B and Appendix C. Appendix B is a north view block model showing the geological units with the proposed School Creek landslide overlaid. This model shows a non-circular and translational failure mode with the toe of the landslide projected offshore. Appendix C is a 3D view of the interpreted landslide mass, viewed from the north.

These 3D views are developed from the revised geological interpretation, with the landslide shape interpreted from bore and inclinometer data and observations of damaged infrastructure. This model will be subject to reinterpretation as further data and monitoring results are collected.

### **8.3 Alternative Landslide (2009) Model**

During the Tarooma Landslide Workshop in May 2009, an alternative landslide model was proposed (the Mazengarb, Flentje and Miner model, 2009). This model separated the landslide complex into several components with either north easterly or south easterly movement directions (see Appendix H). This alternative model seeks to explain the different rates and directions of movement observed within the area of the complex.

This model proposes that the most rapidly moving section of the landslide complex (between the Channel Highway and the Primary School sports oval) is a local response to excavation of the hillside to create the oval, leading to failure of the highway embankment. The model also proposes that much of the ground deformation observed as structural damage within the Tarooma area is in response to poor drainage



and subsequent soil volumetric changes within fill placed over pre-existing natural drainage lines.

Consideration of recent movement data (post 2008) and correction to inclinometer casing twist (IBH1-99), tends to indicate that the landslide mass within the greater School Creek area is currently moving at a consistent rate and direction. In light of the correction to inclinometer casing twist (see section 6.5 for more details), this alternative landslide model has now been superseded. The formerly observed differing rates of movement can be related to internal strain partitioning of a single moving landslide mass.

With the possible complex mechanism outlined in this model, a much greater density of reliable movement data is required to support the model uncertainties.



## 9. Uncertainties

Although there has been recorded history of land instability in the Taroom area since the 1970's, the collation of existing evidence and collection of additional surface and subsurface data in the past 35 years has failed to provide a clear and unambiguous knowledge of the extent of land movement and its causes.

This inability to develop a precise and unequivocal landslide model is principally due to the probable complex arrangement and very slow and intermittent rate of movement of the unstable mass(es), and their possible very large extent compared to the relatively few movement data locations.

The major uncertainties in developing a clearer understanding of the landslide risk centre on:

- ▶ The difficulty in defining the boundaries of the active and inactive landslides within the Taroom landslide complex. Although the headscarp of the School Creek landslide at and adjacent to the Channel Highway is relatively well defined, the southern and northern boundaries and the depth of base of the moving landslide mass are difficult to define. The toe of this landslide is also assumed to be offshore, without any real data. Several smaller landslides can be observed along and adjacent to the shoreline, however their movement history and the factors that may lead to their reactivation are not well understood. The proposed large offshore (and apparently inactive) landslide complex and offshore extension of the Melinga Place landslide (Moon and McDowell 2002) have been postulated on the basis of landforms and seafloor topography, with no direct observational data.
- ▶ Lack of quantitative definition of the groundwater regime in the Taroom landslide area, and consequently poor understanding of the relationship between rainfall, groundwater response and landslide movement. As it is broadly accepted that the common trigger for landslide movement is rainfall and consequent piezometric pressure increases, an improved understanding of this relationship is imperative in developing any numerical slope stability analysis of the identified landslides. It will also be important to gain an improved knowledge of the groundwater regime to enable effective design of any future proposed subsurface drainage systems.
- ▶ Although the geology of the Taroom area has been reinterpreted based on detailed mapping of surface exposures together with reassessment of limited subsurface data, there remains a considerable degree of uncertainty, especially within the Tertiary and Quaternary units. Both these units appear to be highly variable both vertically and laterally, principally due to their modes of deposition but also in part due to the similar source materials derived from the Permian and Jurassic formations to the west. The relationship between the geological units, their subsurface distribution (and engineering properties) and the landslide boundaries will be an important input into any numerical slope stability analysis. An additional source of difficulty in outlining the distribution and structure of the geological materials is the degree of anthropogenic disturbance within the Taroom area.



## 10. Recommendations for Additional Investigation/ Monitoring

In order to develop clear strategies for managing the landslide risk in the Taroona area, an improved knowledge and therefore understanding of the landslide hazard is required. It is clearly not possible to refine definition of the extent and movement characteristics of the instability using the available information.

In order to take appropriate decisions in risk management especially concerning strategies for mitigation it is important to analyse the relation between groundwater fluctuations and displacement velocities and other controlling factors of this deep seated landslide. This is to allow for the following questions to be addressed:

- ▶ Are we able to forecast an increasing or decreasing trend in the rate of movement of the landslide?
- ▶ Can we expect extreme meteorological or other (e.g. seismic) conditions, which could lead to intolerable damaging magnitudes and rates of movements of the landslide?

The following actions are considered the most practical techniques in refining our knowledge of the landslide complex.

### 10.1 Continuously Monitor Landslide Movement

#### 10.1.1 Inclinometer Monitoring

- ▶ In order to provide ongoing information to monitor the rate and direction of landslide movement, the inclinometers should be monitored at a frequency no less than once a year. Additional monitoring frequency may be required if anomalous displacements are observed. However, it is noted that each reading of the existing manual reading inclinometers incurs a significant funding requirement. Additionally, these inclinometers are currently nearing their expected displacement limits, after which time they will become unserviceable (estimated 2 years at most). It is recommended that the funding contributing parties (together with technical advice from MRT) need to review the maintenance requirements of the existing inclinometer network to establish an agreed management strategy, and possibly develop a new MOU for funding provision.
- ▶ As the area monitored by the existing functioning inclinometers is very restricted in comparison to the possible landslide areas outlined in the landslide models, additional inclinometers should also be considered. As a minimum, an additional deep (>70m) inclinometer should be installed in approximate position of 528900E, 5245350N. This inclinometer should be designed to provide confirmation of the deep seated School Creek landslide model.



- ▶ To provide a more positive indication of the southern boundary of the School Creek landslide, the inclinometer IBH2-99 (blocked at 37.5m) should be rehabilitated or a new inclinometer installed nearby.

### **10.1.2 Surface Survey Network**

- ▶ It is recommended that the surface survey displacement monitoring network re-established as part of Stage 1 of this project be maintained and monitored at an appropriate frequency. This survey network should be monitored at least annually, with more frequent monitoring if indications of acceleration in landslide movement are detected (e.g. reported surface displacements or extended periods of high or persistent rainfall). This network consists of the pre-existing network of surface reference points and bore and/or inclinometer collar cappings, together with additional survey points set into pavement surfaces or other structures. It is important that the monitored area include the wider Taroom area, especially to the south as far as Taroom Crescent. It is critical that this monitoring network be capable of achieving  $\pm 2-4$  mm horizontal and vertical precision. The funding implications of continuing monitoring of this network require clarification and consideration together with an inclinometer management strategy as discussed above.

### **10.1.3 inSAR**

As outlined in section 6.4 of this report, acquisition and analysis of 2011/2012 SAR satellite data should be considered. The newly acquired data can be analysed against the inSAR data sets from 2007 and 2009 to provide relative surface displacements over this interval.

This analysis may outline the extent of landslide movement across the site. Information of this type may resolve uncertainties with respect to landslide models.

## **10.2 Further Investigation of Subsurface Material Distribution**

A range of additional investigations should be considered to improve the understanding of the extent and behaviour of the unstable ground at Taroom. Although these recommendations will involve significant funding commitments, their consideration is important to the project aims.

The following investigation actions are recommended.

### **10.2.1 Additional Bores/ Inclinometers**

Drilling of additional investigation bores by techniques that will provide superior sample recovery in the range of materials expected to be present at this site. The drilling technique should be carefully considered, and may comprise either rotary triple tube coring or sonic drilling. The aim of this drilling is to provide targeted geological information to assist interpretation of subsurface geological structure and landslide distribution, and provide better understanding of the engineering behavior of those



materials. This drilling should also be designed to permit installation of inclinometers and high accuracy piezometers.

#### **10.2.2 Piezometers**

In line with the above recommendation, the installation of a number of piezometers should be considered (e.g. vibrating wire). The aim of the piezometer installations is to improve knowledge of the groundwater regime, and facilitate numerical slope stability analysis of the identified landslides, and potentially enable effective design of any future proposed subsurface drainage systems. To enable near-real-time monitoring of the piezometer readings, it is recommended that installation of vibrating wire piezometers be considered.

#### **10.2.3 Seismic Survey**

The application of seismic tomography surveying should be considered to provide subsurface profile information across interpreted landslide zones. Recent advances in high resolution seismic refraction tomography techniques may have the capability to clarify the distribution of subsurface lithologies, and also to assist identification of lower density disturbed masses typical of landslide material.

#### **10.2.4 CCTV Survey**

Video camera survey of critically located stormwater and sewer pipes is recommended, to assess potential damage that has not yet been identified.

### **10.3 Additional Technical Actions**

The following recommended actions are already contained within the proposed Stage 2 and 3 of this project. However, it is considered important to stress their value in light of projected advances in technical knowledge of the site.

#### **10.3.1 Slope Stability Analysis**

Following the collection and interpretation of the above technical information, it is recommended that a series of stability analyses (back analysis) be undertaken to provide some insight of potential landslide behaviour. The information collected, particularly improved subsurface profiles, material properties and groundwater conditions will enable numerical stability analysis to be undertaken with a degree of confidence. The analyses should also include provision for the effects of dynamic forces (earthquake analysis).

#### **10.3.2 Landslide Risk Assessment**

Following clarification of the geotechnical model(s) of the landslide complex, it is important to conduct an up-to-date landslide risk assessment (an initial risk assessment was completed during the 2009 workshop). This risk assessment will benefit from improved understanding of the hazard (landslide mechanism and extent),



the probability (triggering factors), and the consequences (potential damage zones and severity) resulting from the identified landslide complex.

This assessment will highlight the possible infrastructure implications, and guide consideration of risk management strategies. The options may include both stabilisation treatments (reduction of likelihood of landslide) and/or avoidance (reduction of consequence) strategies. Combinations of risk treatment measures may be appropriate.

### **10.3.3 Potential Planning Controls**

The risk management strategies developed as an outcome of the risk assessment may include possible amendments to the council planning scheme.

It is recommended that the risk assessment identify and zone areas susceptible to landslide damage, and these be considered for implementation of planning controls by Kingborough Council.

Consideration of planning scheme controls should proceed on the basis of the real extent and movement characteristics of the 'School Creek 2011 landslide model'. It is anticipated that results from Stage 2 tasks of this project may refine knowledge of the physical parameters governing the landslide characteristics at this site.

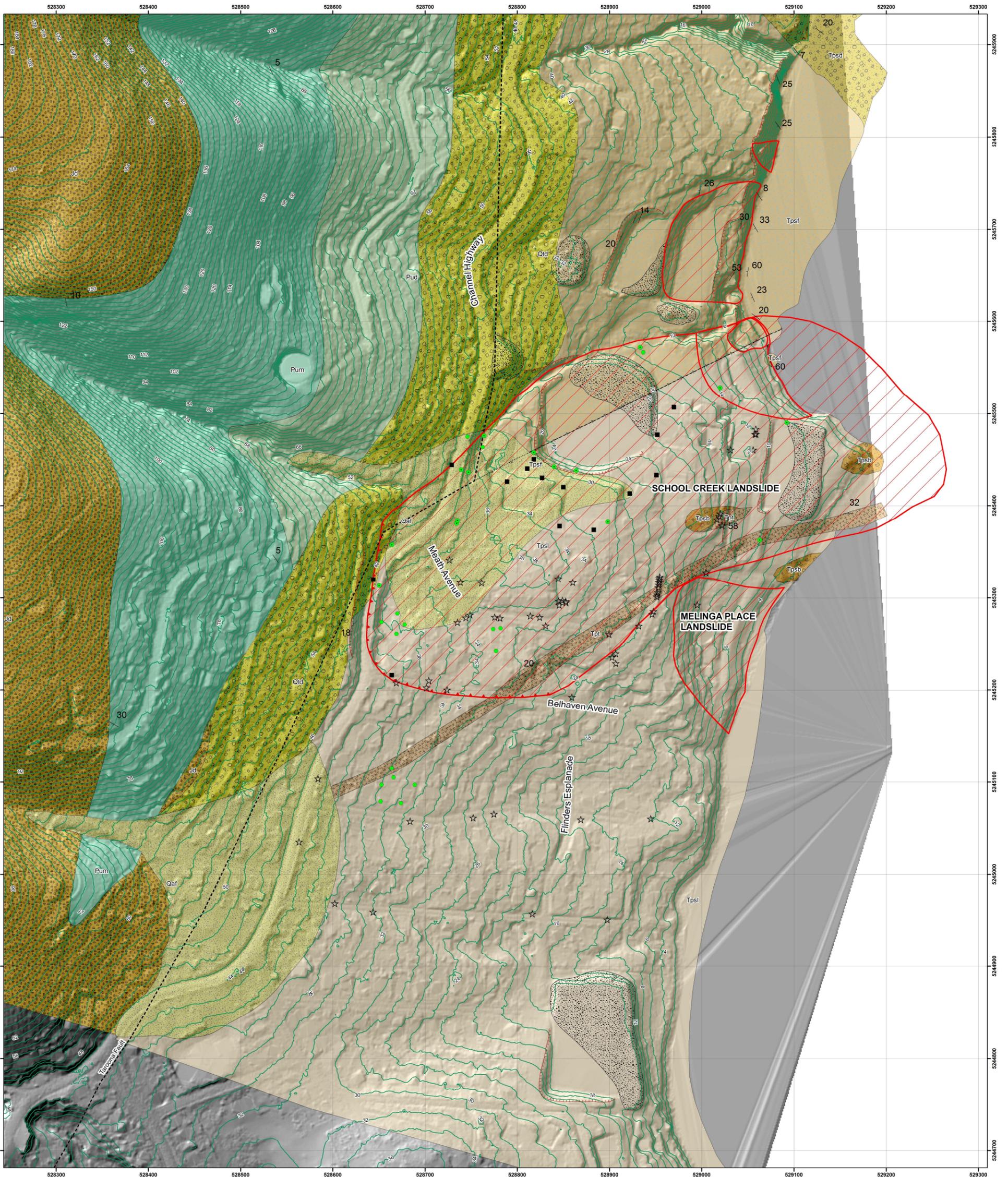
The extent of planning control that is appropriate will depend on the outcome of the landslide risk assessment process. Improved understanding of the extent and movement characteristics of the active components of landslide complex may enable zoning of the potential damage areas and their severity.

It should be noted that an Interim Planning Advice is being reported separately.



Appendix A

# Revised Geology Map of Taroona, by Colin Mazegarb – MRT, scale 1:2000, June 2011



# Revised geology of Tarooma

Preliminary revision by Colin Mazengarb for the purposes of the Tarooma Landslide Project and 3D model construction, June 2011

Map grid: GDA94 Zone 55 MGA

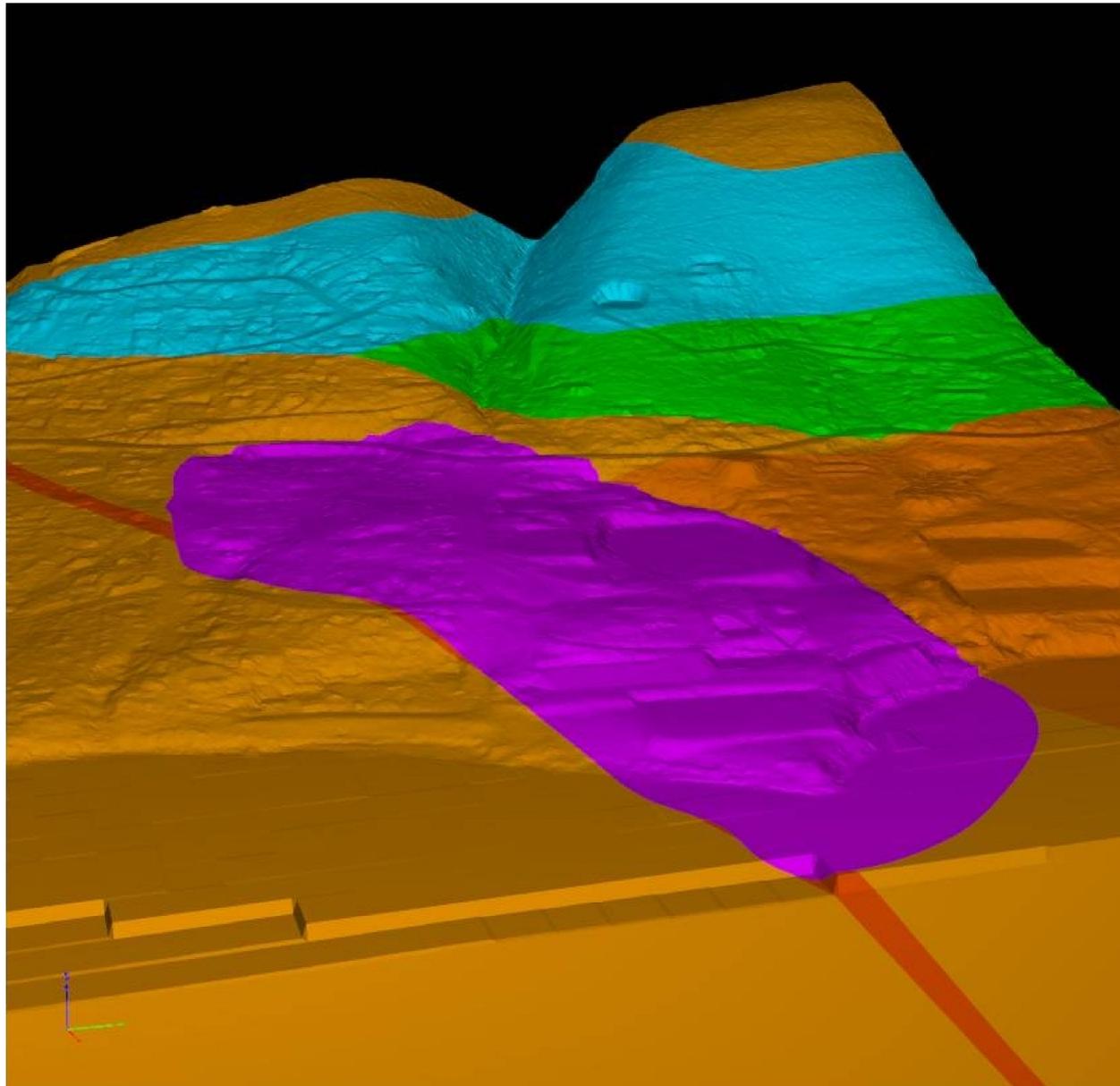
1:2,000

## Legend

- |  |  |
|--|--|
| ☆ Damaged features, unspecified cause                  | <b>Landslide</b>                                       |
| <b>Drill holes</b>                                     | ▭ Landslide headscarp                                  |
| ● Auger  | <b>Artificial fill</b>                                 |
| ● Hollow Flight Auger                                  | ▨ Artificial fill                                      |
| ● Diamond  | <b>Revised geology</b>                                 |
| ● Diamond, Hollow Flight Auger                         | ▨ Qaf Alluvial fan                                     |
| ■ Test Pit   | ▨ Qtd Pleistocene dolerite talus                       |
| — Contours from LiDAR                                  | ▨ Tpsf Paleogene fluvial sands, conglomerate           |
| — Convex break-in-slope                                | ▨ Tpsd Paleogene boulder beds in fluvial sequence      |
| <b>Faults</b>  | ▨ Tpsl Undifferentiated Paleogene lacustrine sediments |
| ----- Normal fault, approximately located, concealed   | ▨ Tpt Paleogene tuff                                   |
| - - - - - Fault inferred, approximately located        | ▨ Tpsb Paleogene dolerite boulder beds in clay         |
| ..... Fault inferred, approximately located, concealed | ▨ Jd Jurassic dolerite                                 |
|  | ▨ Pum Permian sandstone                                |
|  | ▨ Pud Permian siltstone                                |



Appendix B  
3D Visualisation – View 1



Kingborough City Council  
 Taroona Landslide Risk Assessment  
 and Mitigation Plan

Job Number	32-15950
Revision	A
Date	09 Dec 2011

3D Visualisation (View 1)

Appendix B



CLIENTS | PEOPLE | PERFORMANCE

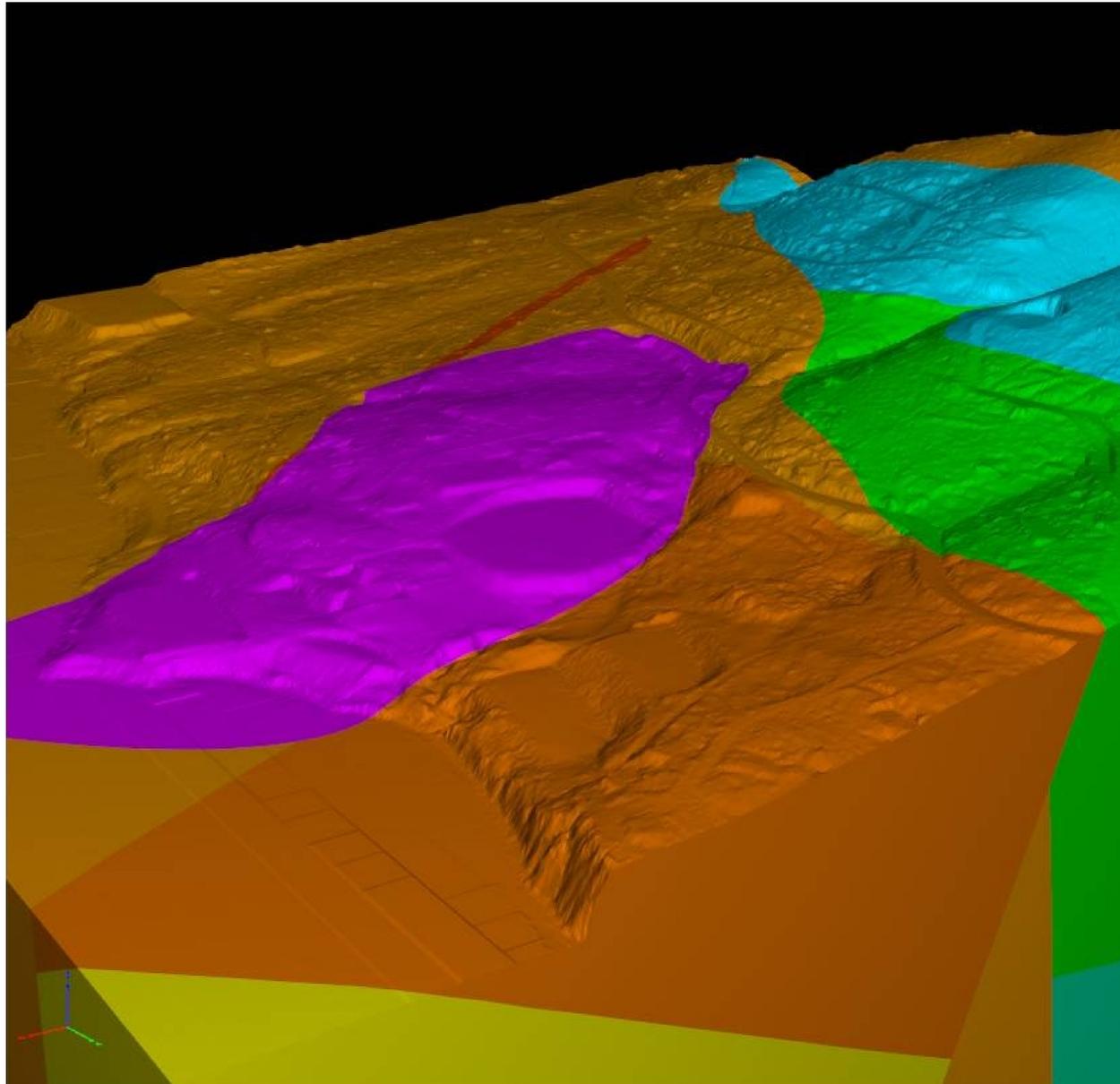


LEGEND

 Tpt	 Tpsf	 Dolerite
 Tpsl	 Slide	 Pum
 Tpsd	 Pud	



Appendix C  
3D Visualisation – View 2



CLIENTS | PEOPLE | PERFORMANCE



**LEGEND**

 Tpt	 Tpsf	 Dolerite
 Tpsl	 Slide	 Pum
 Tpsd	 Pud	

Kingborough City Council  
Taroona Landslide Risk Assessment  
and Mitigation Plan

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Revision	A
Date	09 Dec 2011

3D Visualisation (View 2)

Appendix C



Appendix D  
Damage to Southern Water Assets



**LEGEND**

**Tarooma Damage Points 2011 (Severity)**

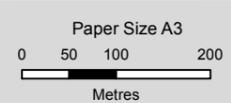
- INSIGNIFICANT - Small amount of damage, not necessarily requiring repair
- MINOR - Damage limited to a part of structure or site requiring minor reinstatement or stabilisation works
- MEDIUM - Moderate damage to some of structure or site requiring significant reinstatement/stabilisation works
- MAJOR - Extensive damage to structure or site requiring major reinstatement or stabilisation works

**Southern Water Network**

- Water
- Sewer
- School Creek Landslide
- Cadastre

**Note:**

- Damage points based only on anecdotal evidence from Southern Water
- Numbers refer to entries within the damages database (separate to report)



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Kingborough City Council  
Tarooma Landslide Risk Assessment  
and Mitigation Plan

Job Number | 32-15950  
Revision | A  
Date | 02 Apr 2012

**Damage to Southern Water Assets Appendix D**



Appendix E

# Damage to Kingborough Council Stormwater Assets



LEGEND

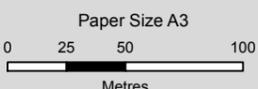
Tarona Damage Points 2011 (Severity)

- INSIGNIFICANT - Small amount of damage, not necessarily requiring repair
- MINOR - Damage limited to a part of structure or site requiring minor reinstatement or stabilisation works
- MEDIUM - Moderate damage to some of structure or site requiring significant reinstatement/stabilisation works
- MAJOR - Extensive damage to structure or site requiring major reinstatement or stabilisation works

- Kingborough Council Stormwater Network
- School Creek Landslide
- Cadastre

Note:

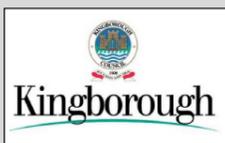
- Damage points based only on historical information
- Numbers refer to entries within the damages database (separate to report)



Map Projection: Transverse Mercator  
 Horizontal Datum: GDA 1994  
 Grid: GDA 1994 MGA Zone 55



CLIENTS | PEOPLE | PERFORMANCE



Kingborough City Council  
 Tarona Landslide Risk Assessment  
 and Mitigation Plan

## Damage to Kingborough Council Stormwater Network

Job Number | 32-15950  
 Revision | A  
 Date | 02 Apr 2012

### Appendix E



Appendix F

# Damage to Buildings and Surface Structures - North



LEGEND

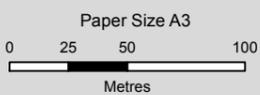
Tarooma Damage Points 2011 (Severity)

- INSIGNIFICANT - Small amount of damage, not necessarily requiring repair
- MINOR - Damage limited to a part of structure or site requiring minor reinstatement or stabilisation works
- MEDIUM - Moderate damage to some of structure or site requiring significant reinstatement/stabilisation works
- MAJOR - Extensive damage to structure or site requiring major reinstatement or stabilisation works

- School Creek Landslide
- Cadastre

Note:

- Damage points based only on historical information and current site walkover
- Damage survey limited to roads, footpaths and kerbs.
- Numbers refer to entries within the damages database (separate to report)



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Kingborough City Council  
 Tarooma Landslide Risk Assessment  
 and Mitigation Plan

## Damage to Buildings and Surface Structures (North)

Job Number | 32-15950  
 Revision | A  
 Date | 02 Apr 2012

## Appendix F



Appendix G

# Damage to Buildings and Surface Structures – South



**LEGEND**

**Taroona Damage Points 2011 (Severity)**

- INSIGNIFICANT - Small amount of damage, not necessarily requiring repair
- MINOR - Damage limited to a part of structure or site requiring minor reinstatement or stabilisation works
- MEDIUM - Moderate damage to some of structure or site requiring significant reinstatement/stabilisation works
- MAJOR - Extensive damage to structure or site requiring major reinstatement or stabilisation works

- School Creek Landslide
- Cadastre

**Note:**

- Damage points based only on historical information
- Numbers refer to entries within the damages database (separate to report)



Paper Size A3  
 Map Projection: Transverse Mercator  
 Horizontal Datum: GDA 1994  
 Grid: GDA 1994 MGA Zone 55



CLIENTS | PEOPLE | PERFORMANCE



Kingborough City Council  
 Taroona Landslide Risk Assessment  
 and Mitigation Plan

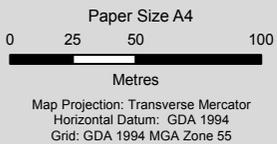
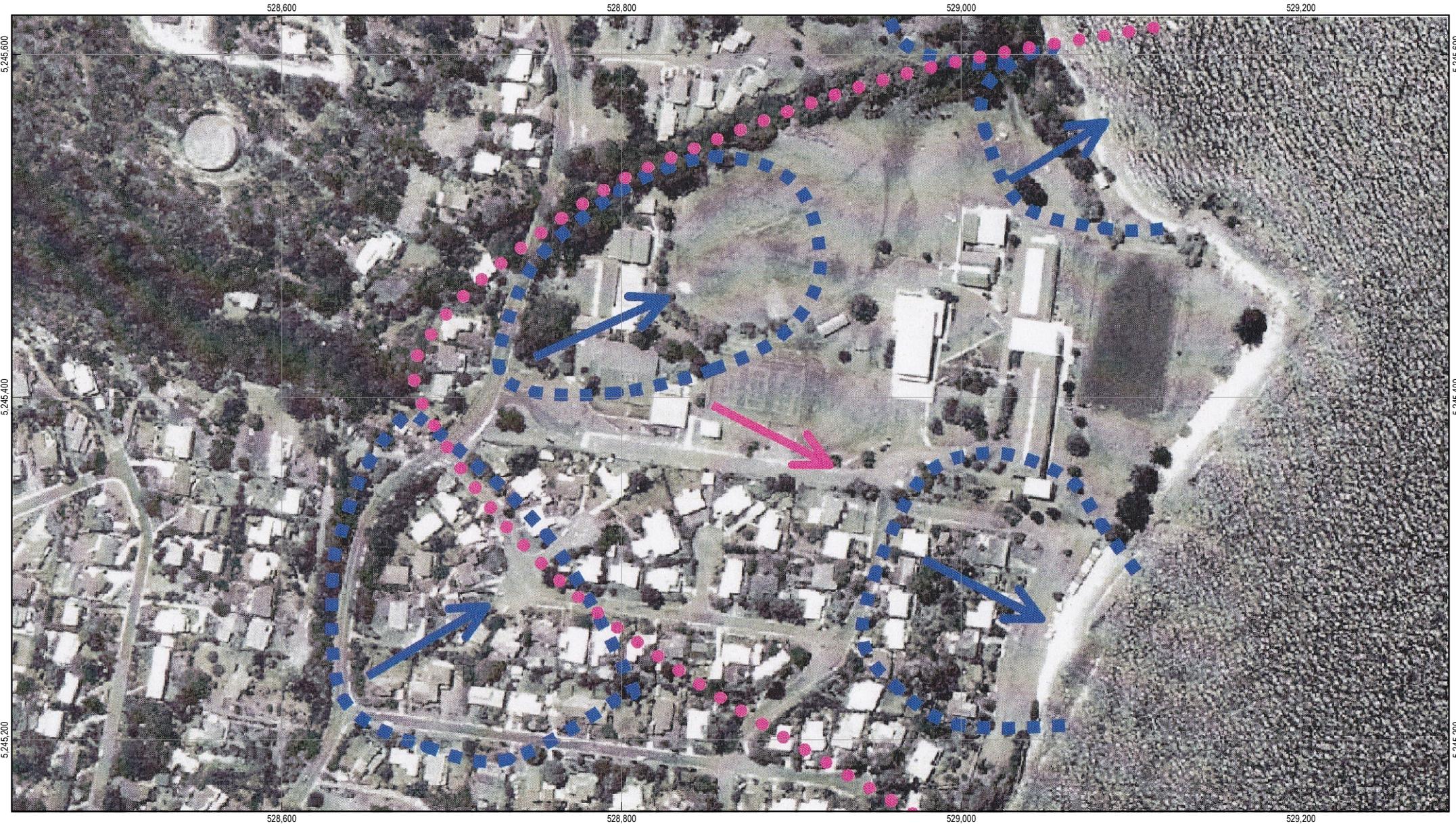
**Damage to Buildings and  
 Surface Structures (South)**

Job Number | 32-15950  
 Revision | A  
 Date | 02 Apr 2012

**Appendix G**



Appendix H  
**Alternative Landslide Model**



Sourced from 'Mazengarb, Flentje and Miner, May 2009, Tarooma Landslide Technical Overview.'  
Note: This model has been superseded following corrections to inclinometer casing twist (refer to report for more details).



Kingborough City Council  
Tarooma Landslide Risk Assessment  
and Mitigation Plan

Job Number	32-15950
Revision	A
Date	02 Apr 2012

Alternative Landslide Model **Appendix H**



Appendix I

# Survey Information – Peacock Darcy & Anderson P/L

# SURVEY CONTROL STATION

NAME: SPM9432

E: 528535.544

N: 5244997.760

RL: 44.410

Est'd Accuracy:

Horizontal: NA

Vertical: NA

General location: Cnr Channel Highway & Coolman Ave, Taroona

Mark type: Brass plug in kerb

Placed by: AC on 27/10/11

Instrument: R8, S8, DiNi

Reference Station: YES - MGA94 & AHD83 (TAS) ORIGIN PER SURCOM

Remarks:



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# SURVEY CONTROL STATION

NAME: SPM9438

E: 528768.222

N: 5245579.804

RL: 41.584

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

General location: Opposite #129 Channel Highway, Tarooma

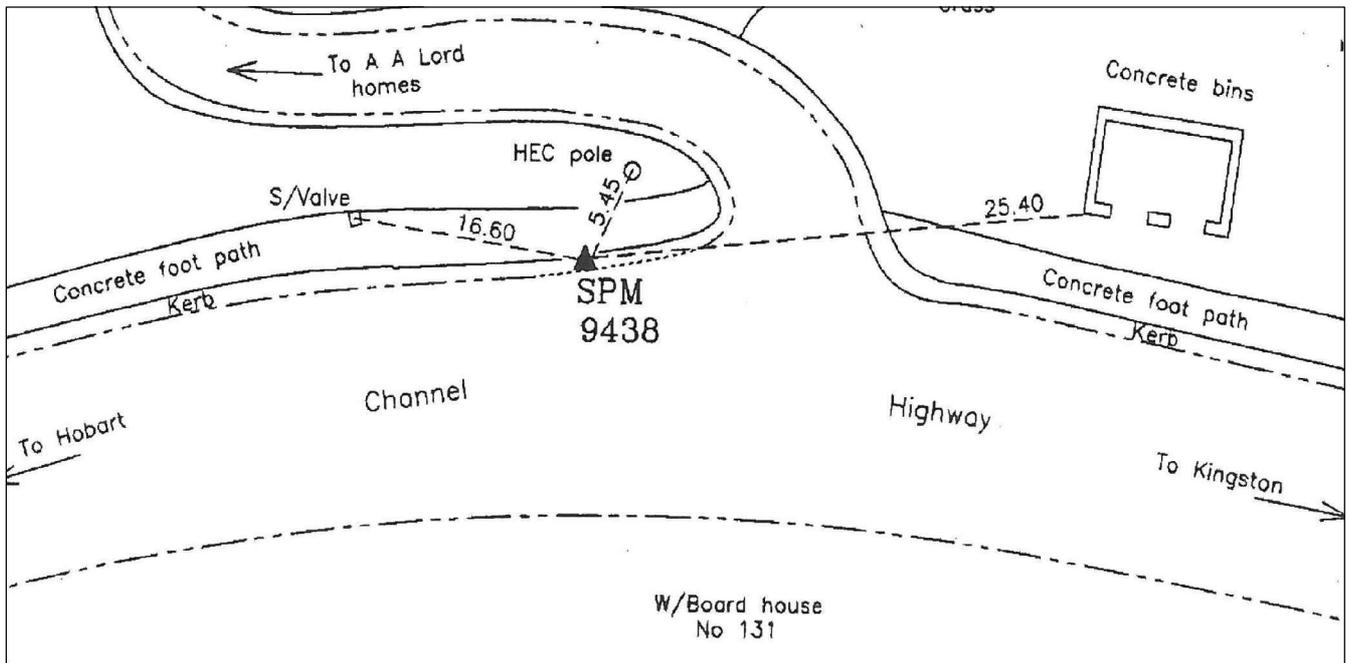
Mark type: Brass plug in kerb

Placed by: AC on 27/10/11

Instrument: S8, DiNi

Reference Station:

Remarks:



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# SURVEY CONTROL STATION

NAME: PDA BASE

E: 528813.695

N: 5244835.622

RL: 17.723

Est'd Accuracy:

Horizontal: 0.007

Vertical: 0.013

General location: RESERVE @ END OF KELVEDON AVE & FLINDERS ESPLANADE

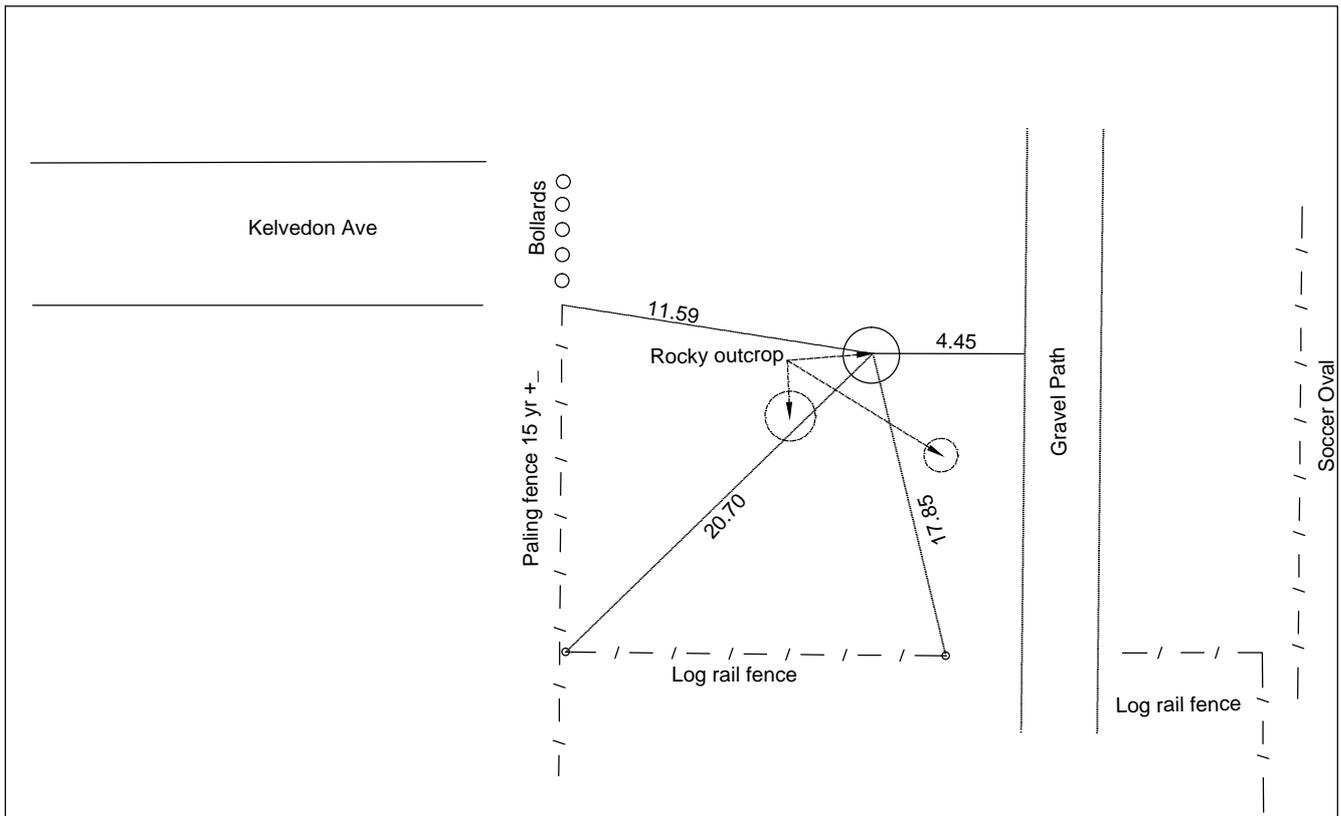
Mark type: Aluminium rivet placed in rocky outcrop

Placed by: AC

Instrument: R8

Reference Station:

Remarks: GPS observations only, placed to be outside slip area



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# SURVEY CONTROL STATION

NAME: PDA01

E: 528826.768

N: 5245792.920

RL: 46.043

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

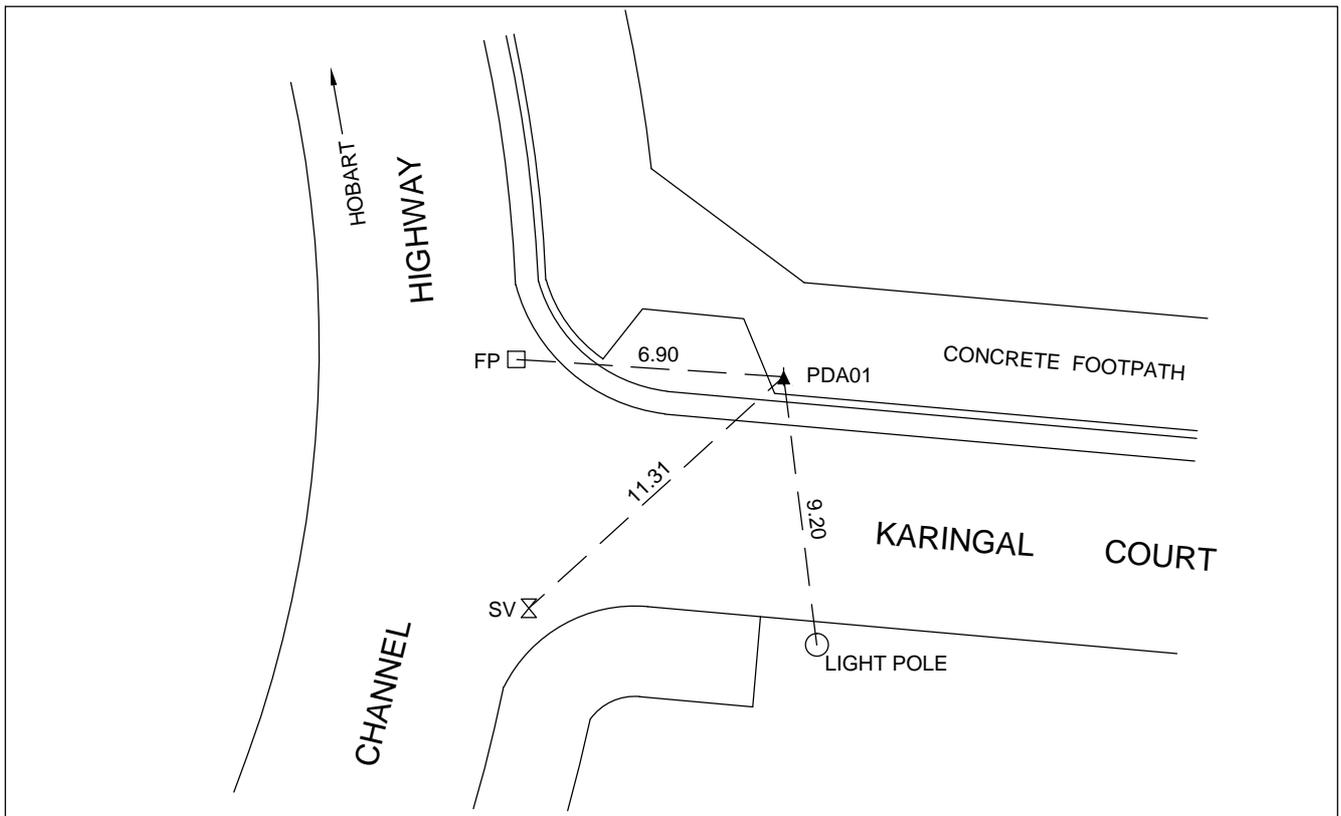
General location: Northern corner of Karingal Court & Channel Highway

Mark type: Aluminium rivet in concrete path Placed by: AC

Instrument: R8 (GPS), S8, DiNi

Reference Station:

Remarks:



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# SURVEY CONTROL STATION

NAME: PDA 06

E: 528713.155

N: 5245375.967

RL: 40.779

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

General location: Centre of Footpath - Cnr Meath Ave and Channel Highway

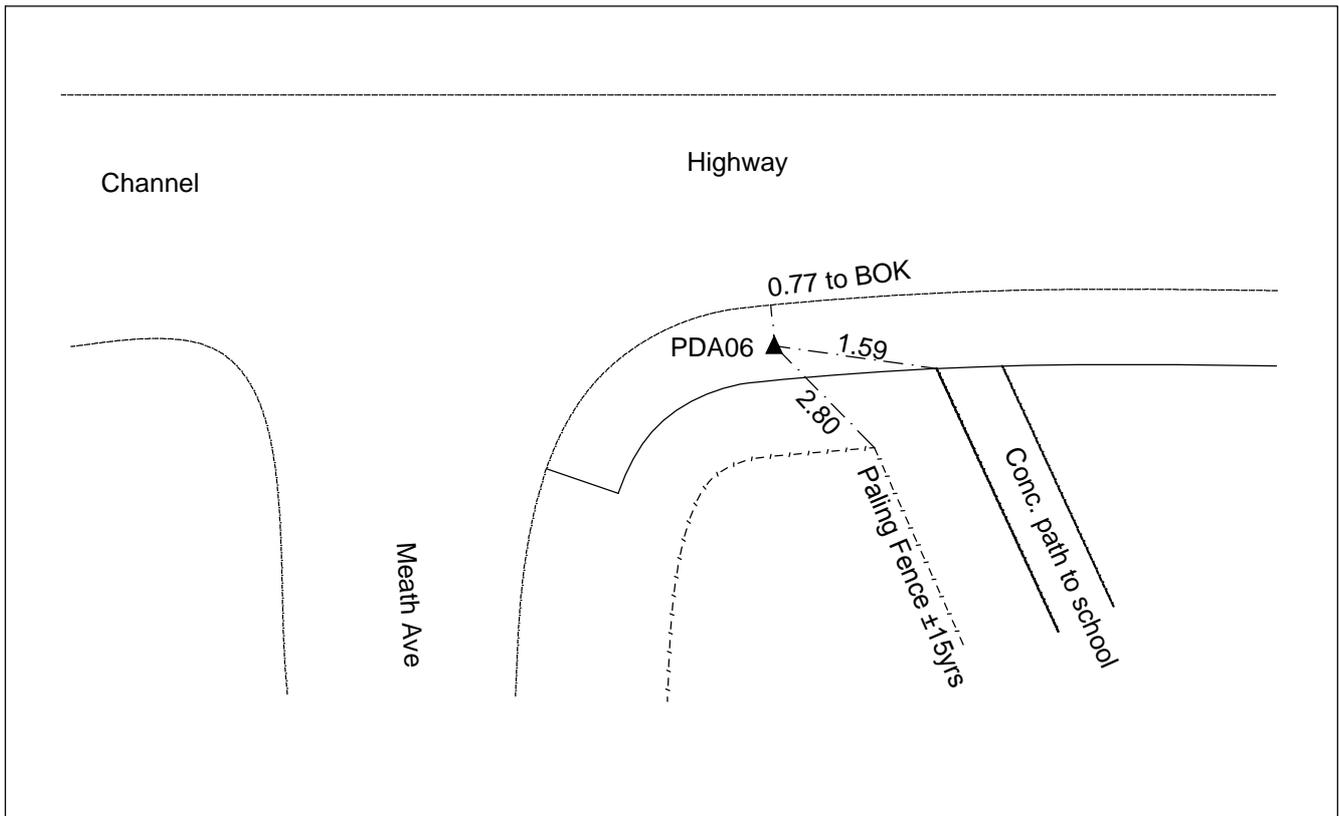
Mark type: Rivet in Concrete Footpath

Placed by: AC on 27/10/11

Instrument: R8, S8, DiNi

Reference Station:

Remarks: Rivet in Concrete Footpath



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# SURVEY CONTROL STATION

NAME: PDA 12

E: 528892.747

N: 5245704.616

RL: 28.988

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

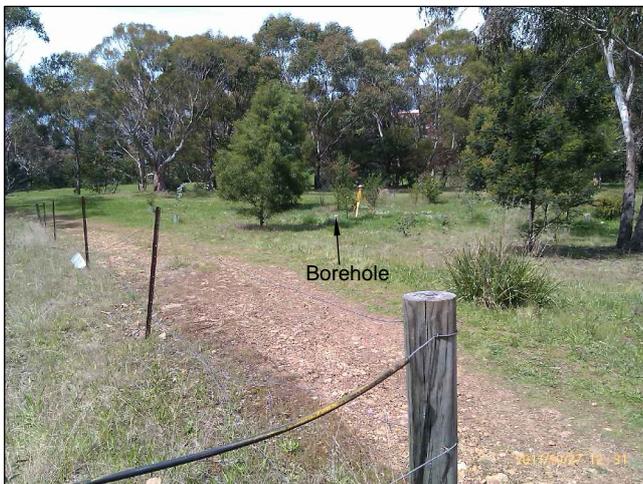
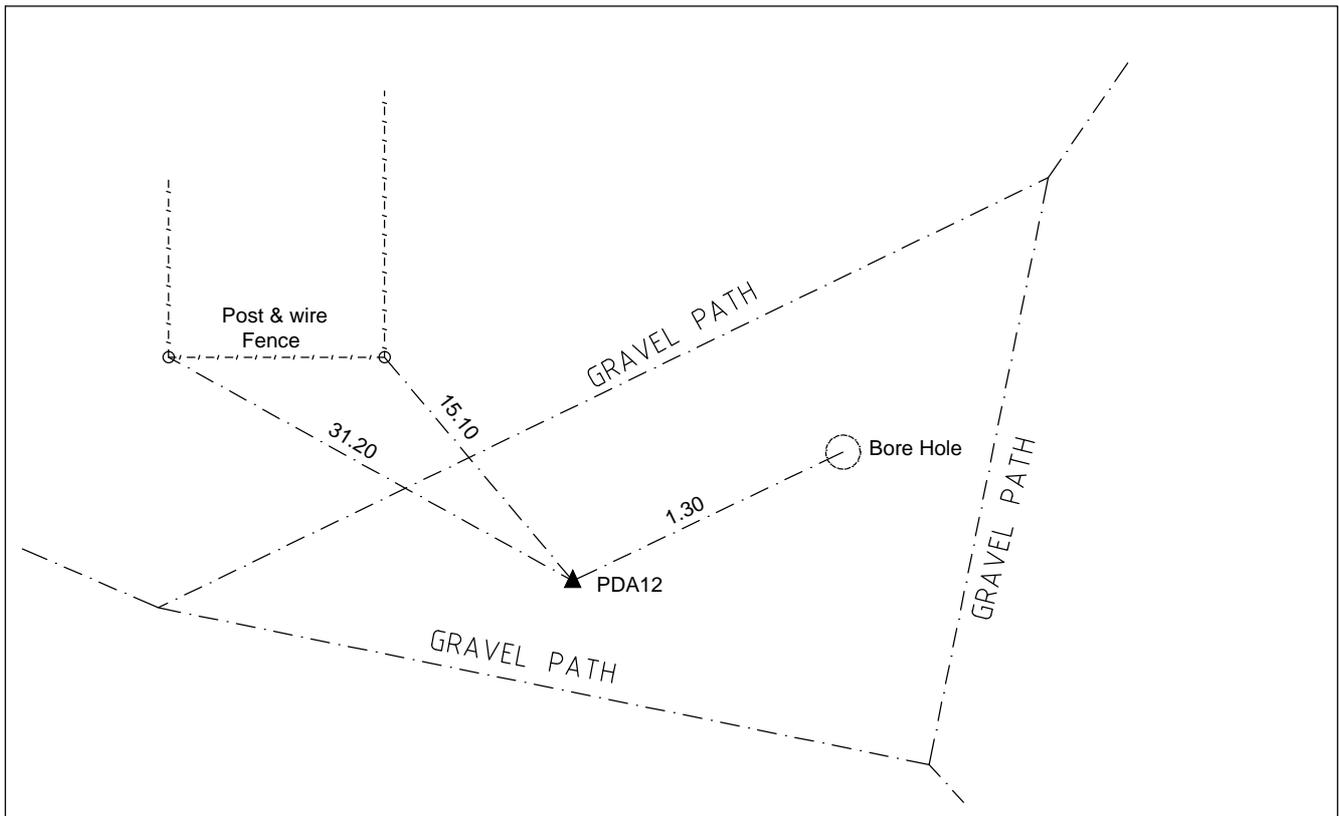
General location:

Mark type: Iron Bar in Conc.

Placed by: AC on 27/10/11 Instrument: R8, S8, DiNi

Reference Station:

Remarks: Iron Bar in Concrete



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# SURVEY CONTROL STATION

NAME: PDA 14

E: 528936.237

N: 5245535.681

RL: 21.700

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

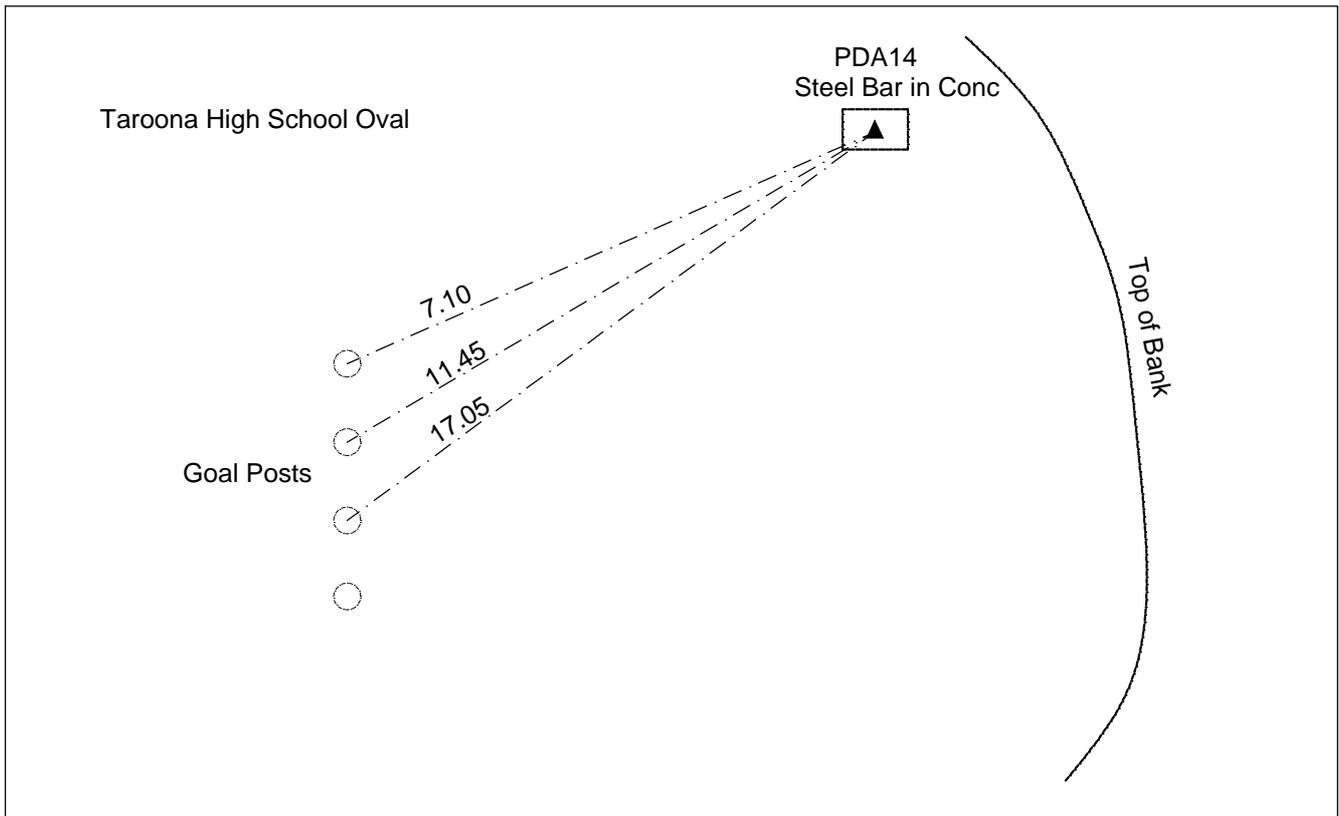
General location:

Mark type: Steel Bar in Conc.

Placed by: AC on 27/10/11 Instrument: R8, S8, DiNi

Reference Station:

Remarks:



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# SURVEY CONTROL STATION

NAME: PDA 15

E: 529017.977

N: 5245520.058

RL: 14.390

Est'd Accuracy:

Horizontal:

Vertical: 0.001

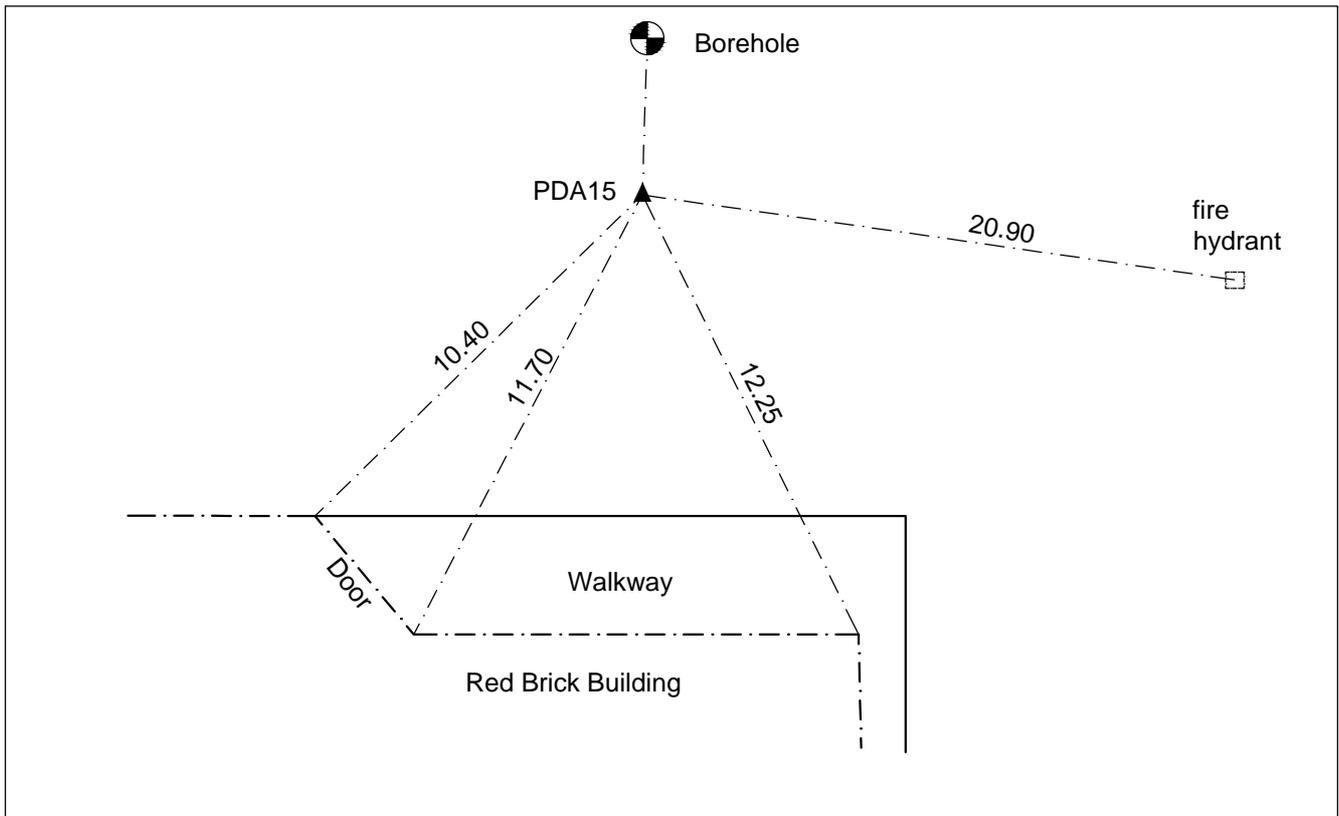
General location:

Mark type: Iron Bar in Conc.

Placed by: AC on 27/10/11 Instrument: S8, DiNi

Reference Station:

Remarks: Iron Bar in Concrete



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# SURVEY CONTROL STATION

NAME: PDA17

E: 529150.740

N: 5245453.242

RL: 5.709

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

General location: Taroona High School - Foreshore

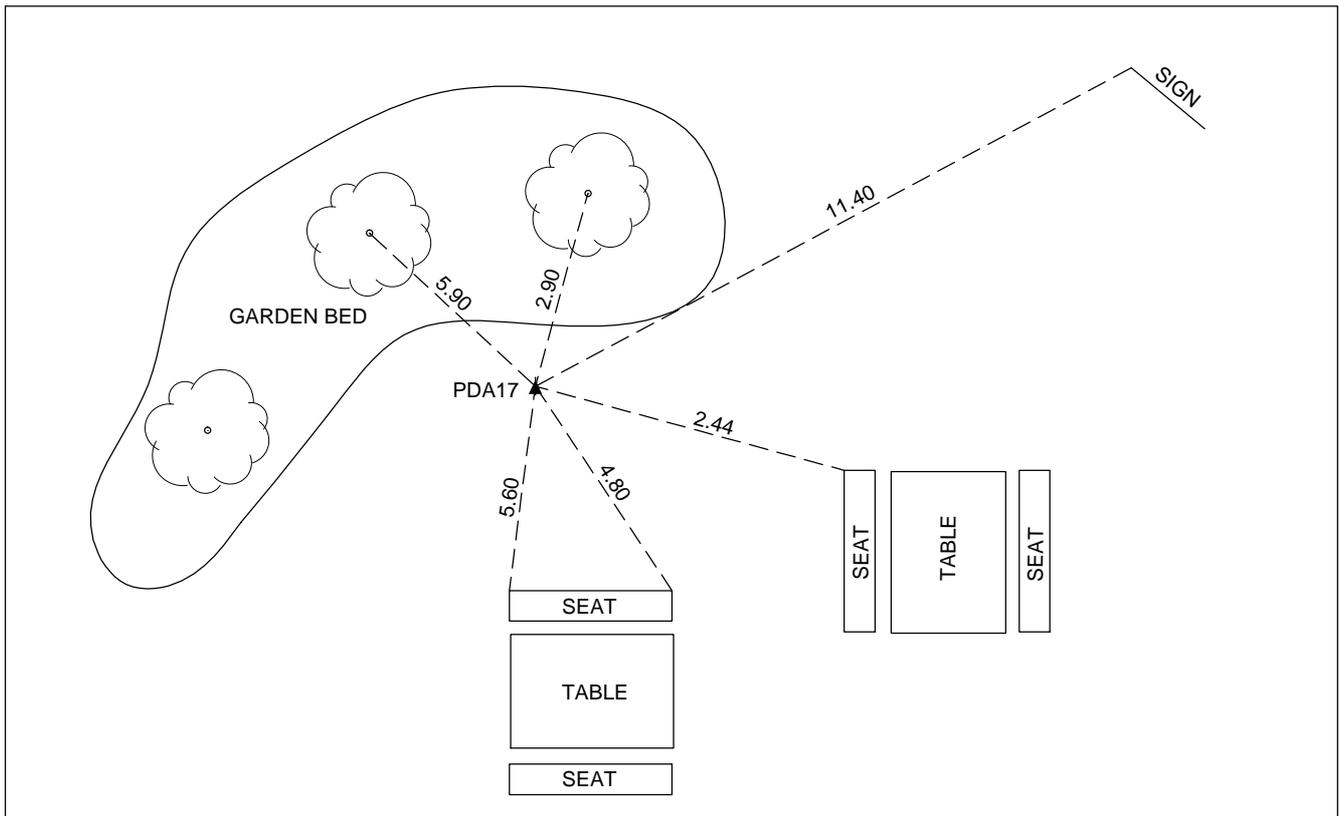
Mark type: Iron bar in concrete

Placed by: AC

Instrument: R8, S8, DiNi

Reference Station:

Remarks:



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# SURVEY CONTROL STATION

NAME: PDA 18

E: 529052.820

N: 5245325.491

RL: 7.807

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

General location: Melinga Place Tarooma

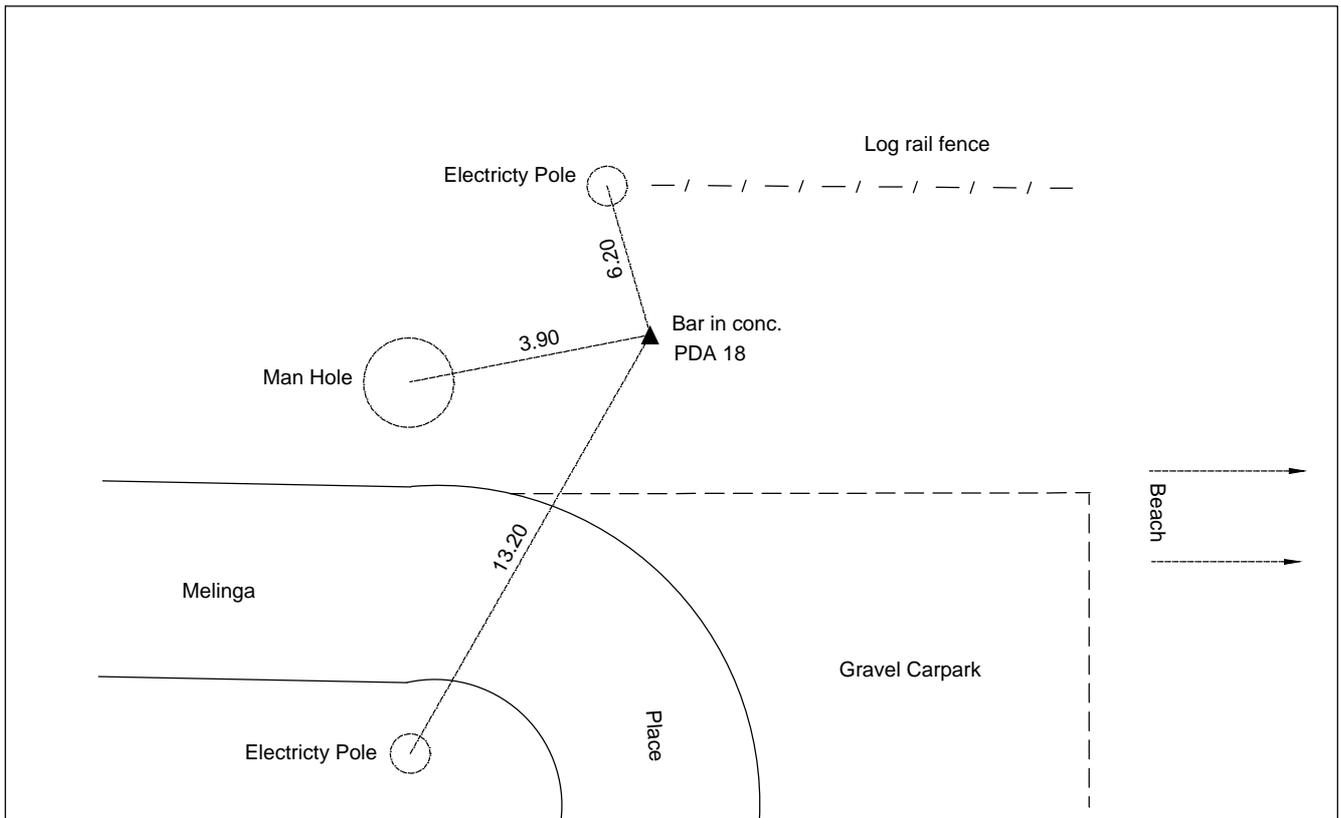
Mark type: Steel bar in concrete

Placed by: AC on 27/10/11

Instrument: R8, S8, DiNi

Reference Station:

Remarks: Bar in Concrete



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# SURVEY CONTROL STATION

NAME: PDA 19

E: 528950.293

N: 5245341.912

RL: 24.705

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

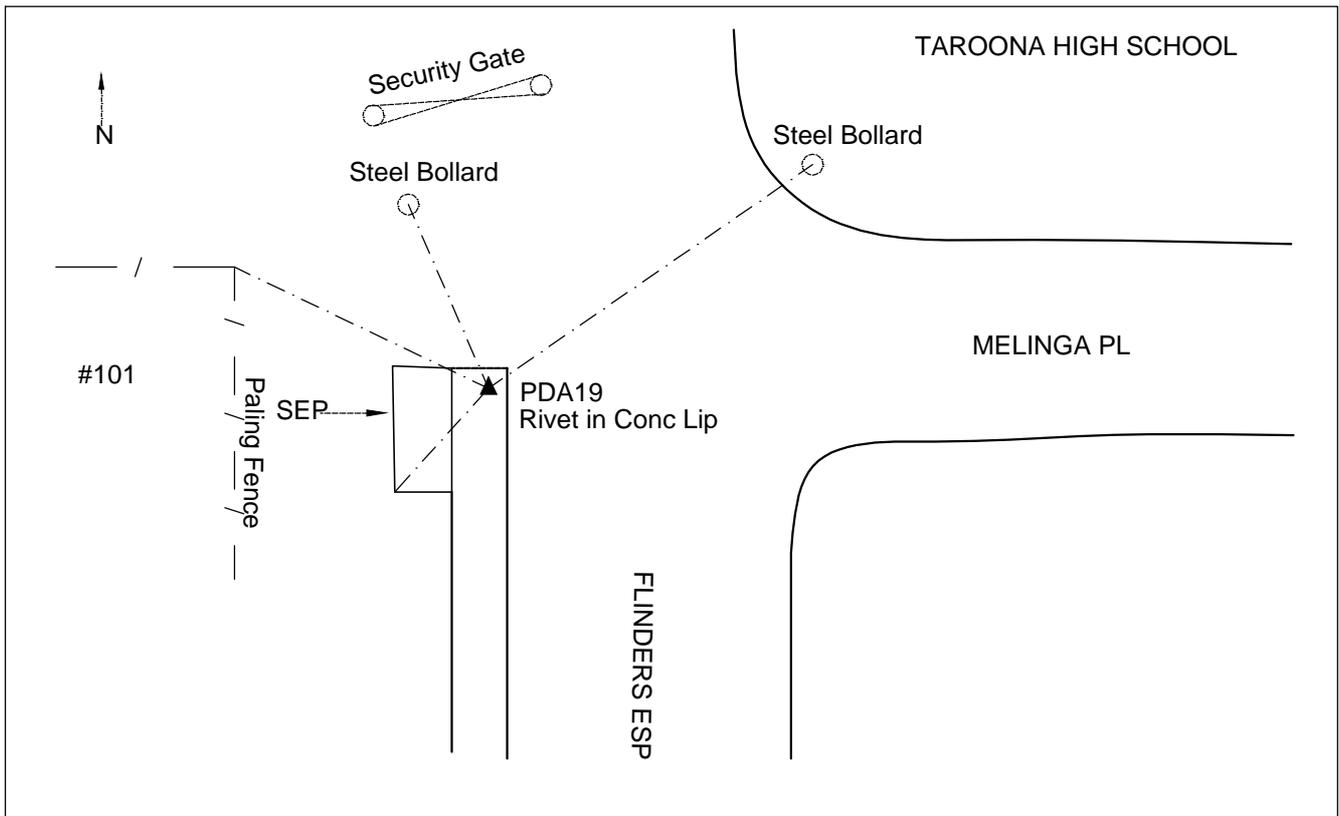
General location:

Mark type: Rivet in Conc.

Placed by: AC on 27/10/11 Instrument: S8, DiNi

Reference Station:

Remarks: Rivet in Lip of kerb and channel



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# SURVEY CONTROL STATION

NAME: PDA 20

E: 528900.607

N: 5245366.815

RL: 30.899

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

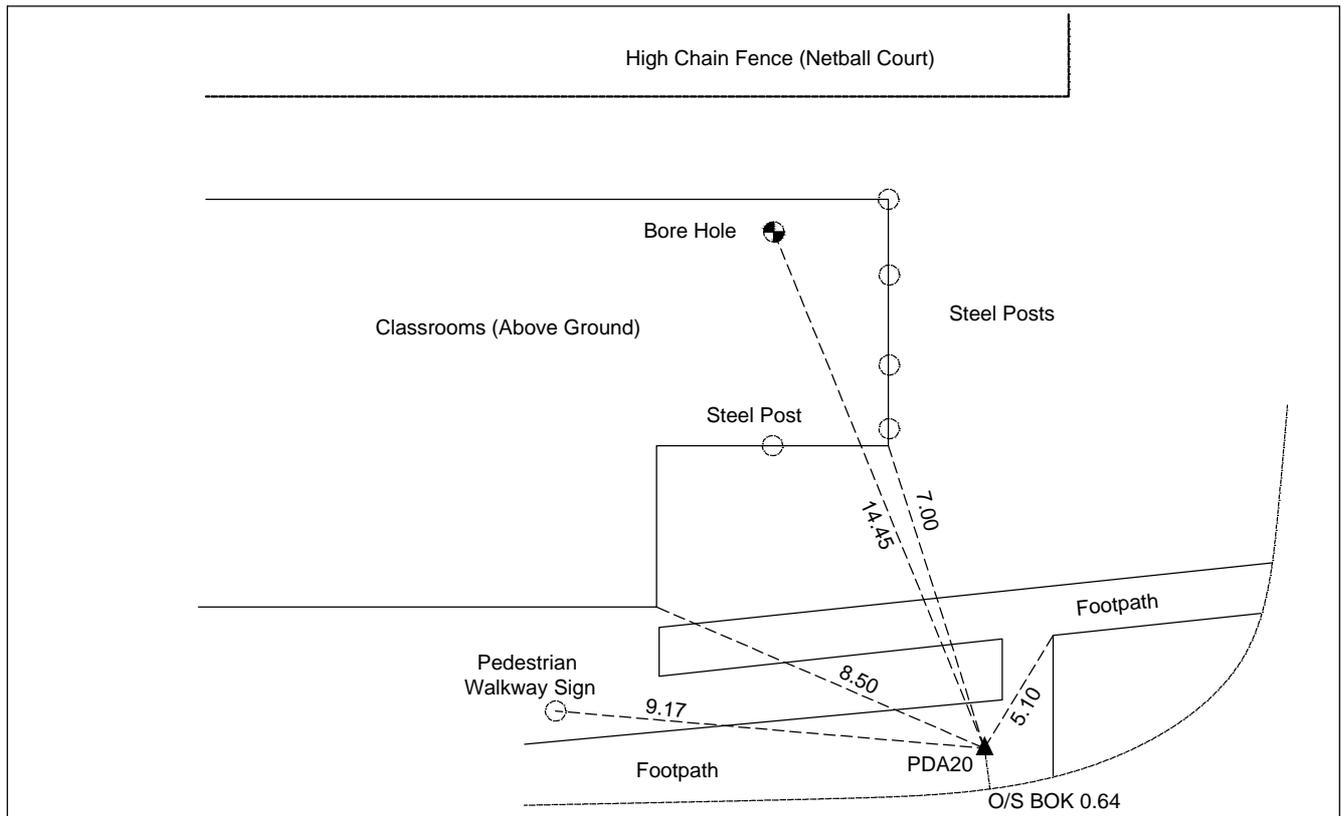
General location: School staff carpark / netball courts

Mark type: Rivet

Placed by: AC on 27/10/11 Instrument: R8, S8, DiNi

Reference Station:

Remarks: Rivet in F/Path



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# SURVEY CONTROL STATION

NAME: PDA 51

E: 528571.823

N: 5245058.257

RL: 43.429

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

General location: Cnr Channel Highway and Norwood Ave

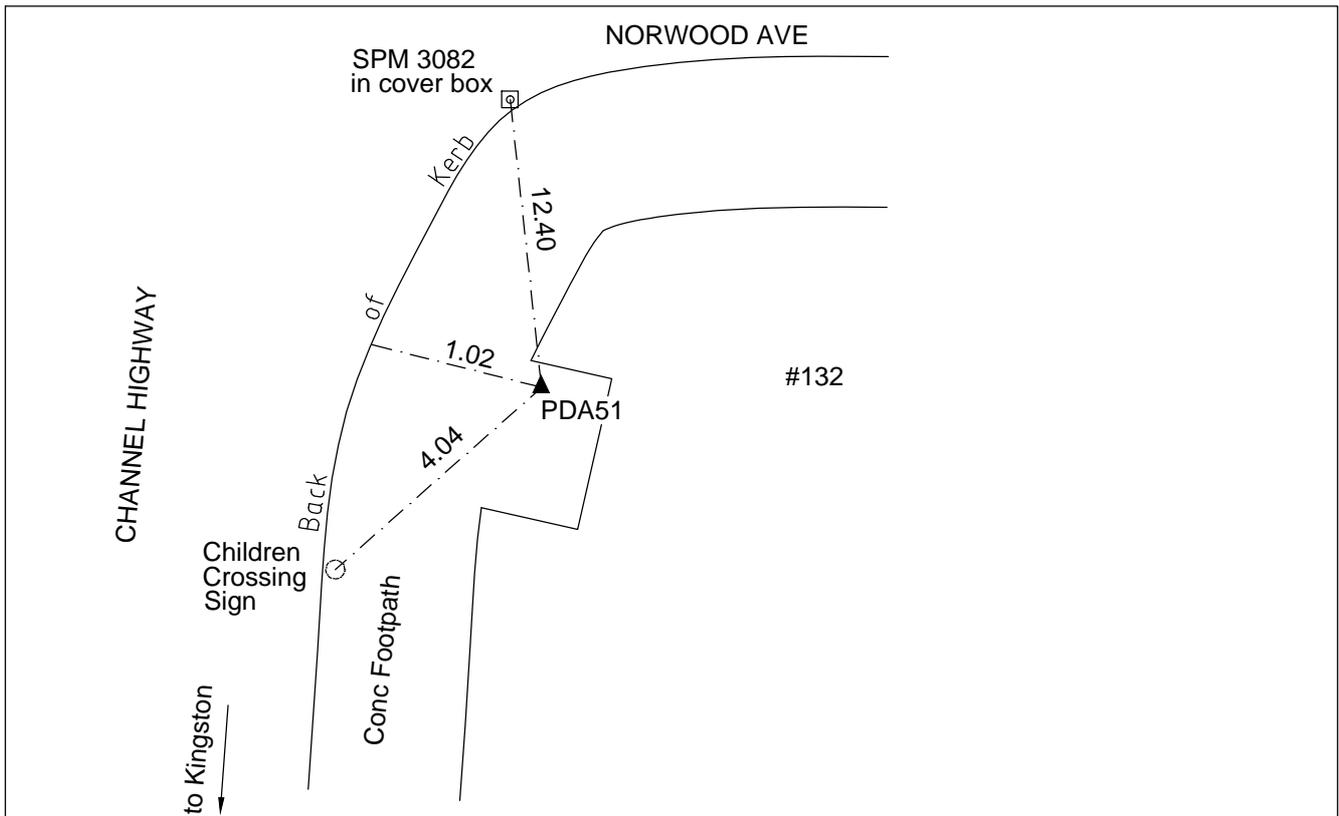
Mark type: Rivet

Placed by: AC on 27/10/11

Instrument: S8, DiNi

Reference Station:

Remarks: Rivet in pit surround outside #132 Channel Higway



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# SURVEY CONTROL STATION

NAME: PDA 52

E: 528588.776

N: 5245142.999

RL: 43.928

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

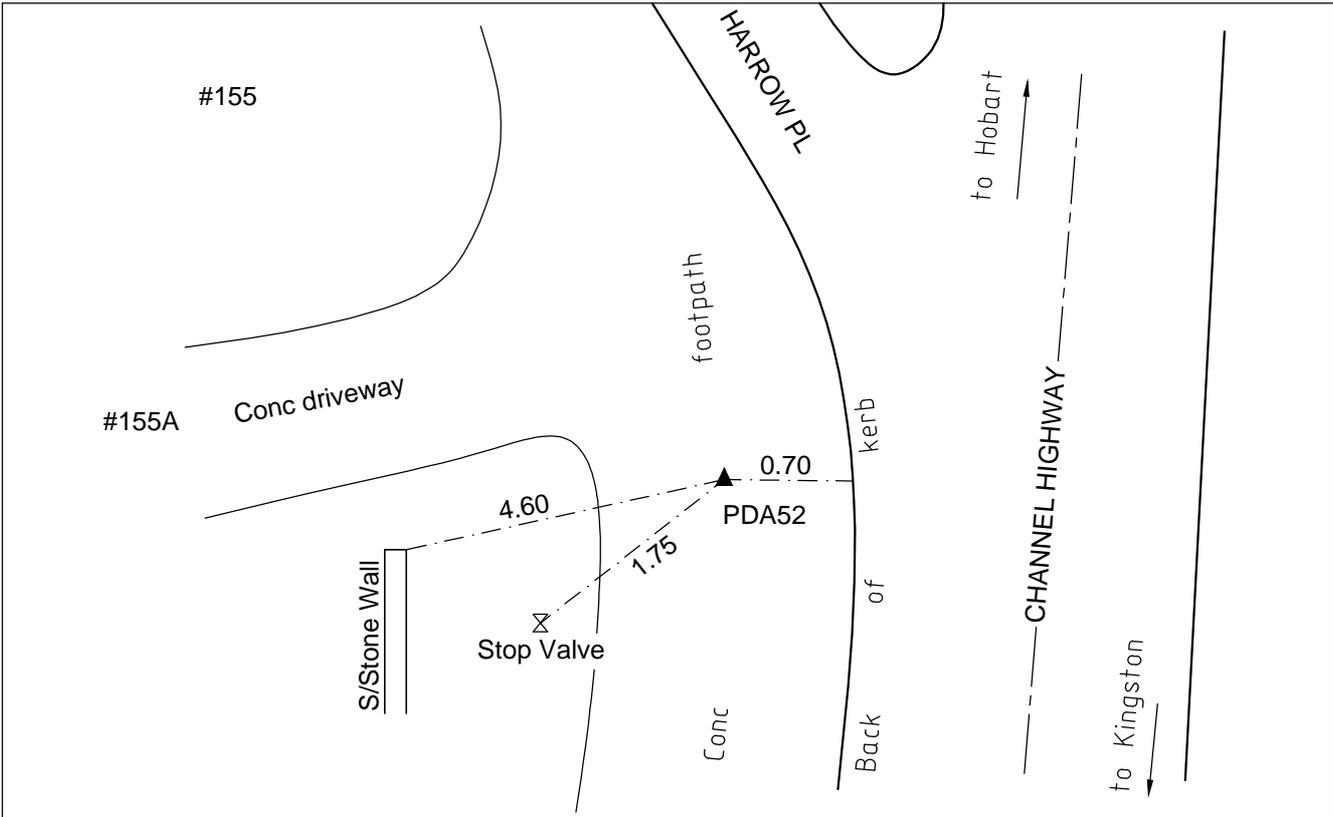
General location: Intersection of Harrow Place & Channel Highway

Mark type: Rivet

Placed by: AC on 27/10/11 Instrument: S8, DiNi

Reference Station:

Remarks: Rivet in footpath outside #155A Channel Highway



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# SURVEY CONTROL STATION

NAME: PDA 55

E: 528859.167

N: 5245192.027

RL: 24.003

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

General location: Cnr Norwood Ave. and Flinders Esp.

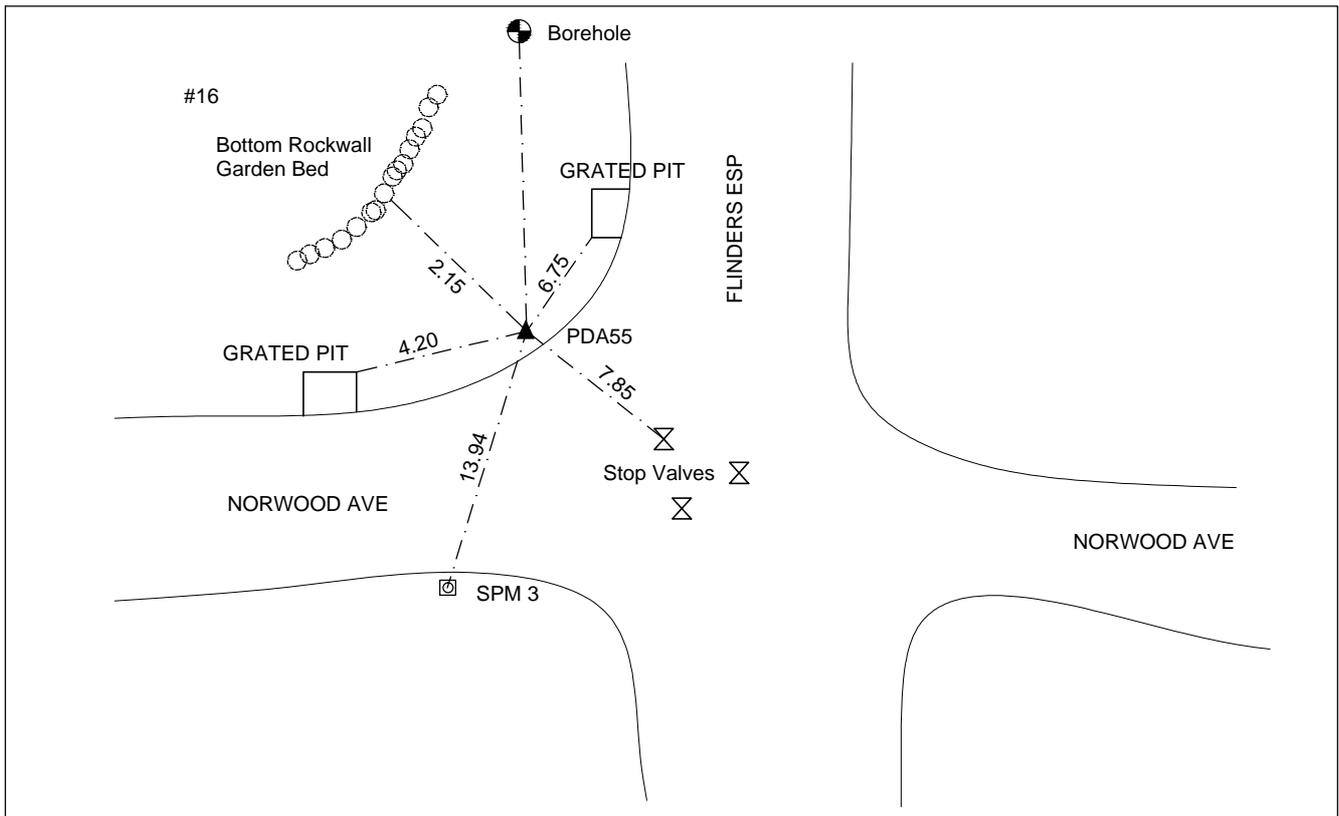
Mark type: Old Ramset

Placed by: AC on 27/10/11

Instrument: S8, DiNi

Reference Station:

Remarks: Old Ramset in top of kerb



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# SURVEY CONTROL STATION

NAME: PDA 58

E: 528654.957

N: 5245349.075

RL: 40.754

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

General location: Channel Highway outside #153 Channel Highway

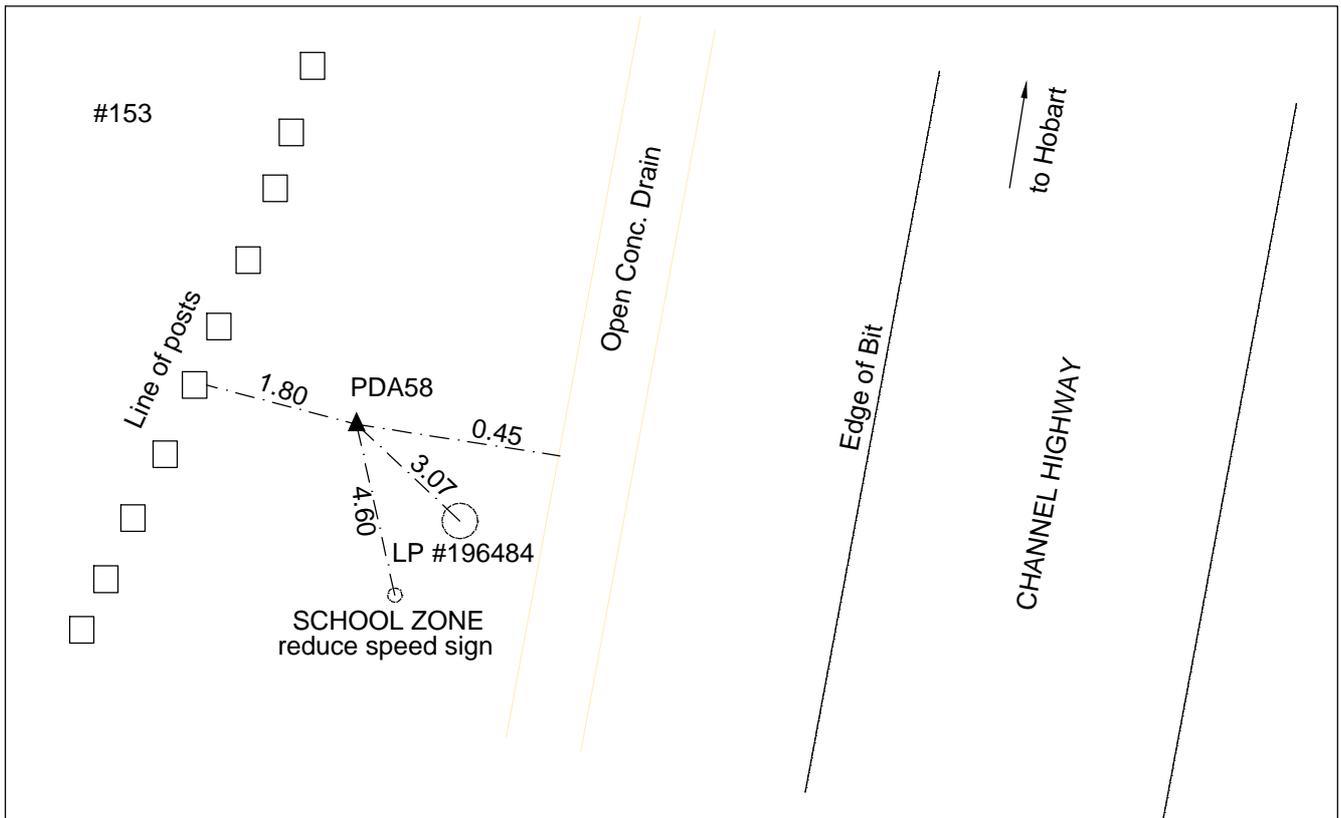
Mark type: Steel Bar in conc

Placed by: AC on 27/10/11

Instrument: S8, DiNi

Reference Station:

Remarks: Steel bar in conc



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# SURVEY CONTROL STATION

NAME: PDA 59

E: 528643.856

N: 5245281.328

RL: 42.396

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

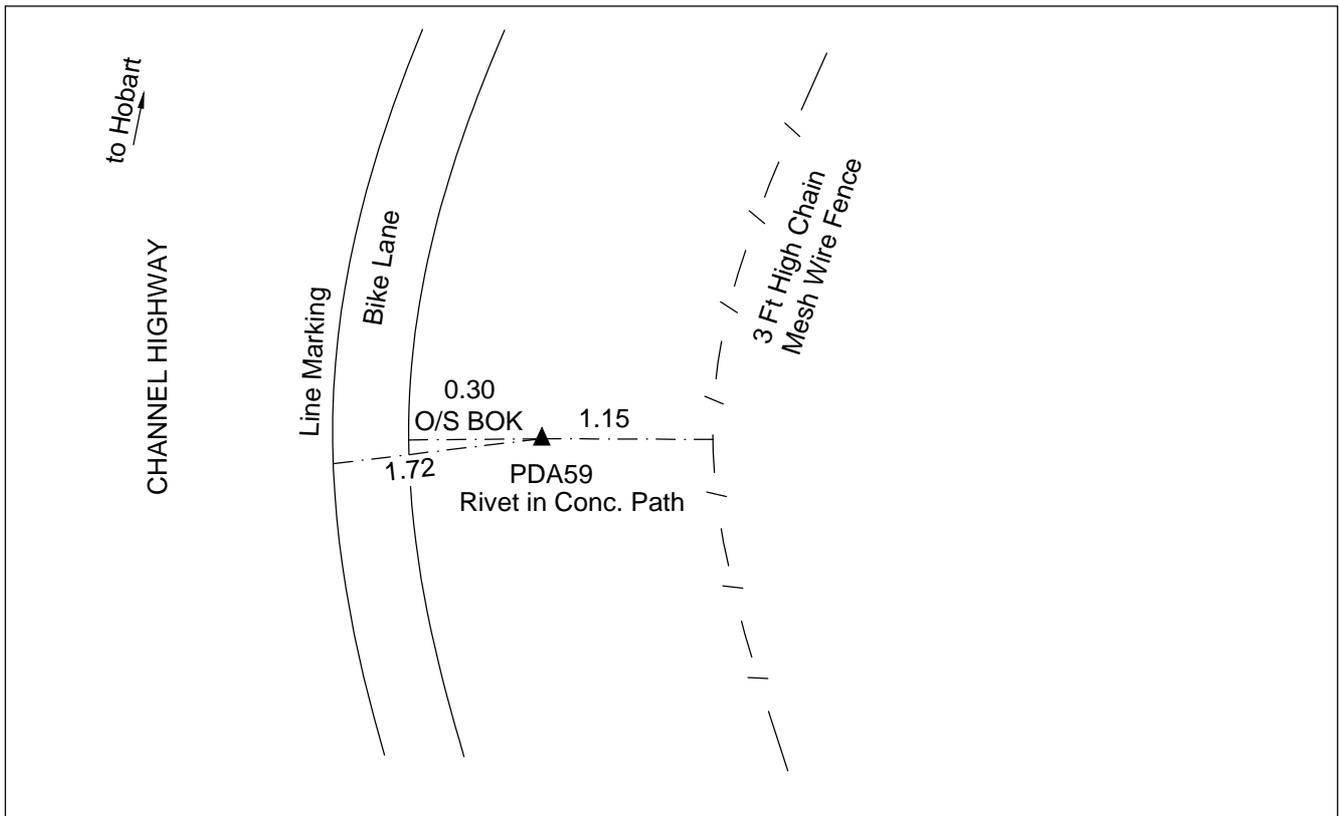
General location: Outside #116 Channel Highway

Mark type: Rivet

Placed by: AC on 27/10/11 Instrument:

Reference Station:

Remarks: Rivet in Conc. Path on Channel Highway



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# SURVEY CONTROL STATION

NAME: PDA 61

E: 528751.927

N: 5245480.517

RL: 40.783

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

General location: Taroona Primary School on Channel Highway

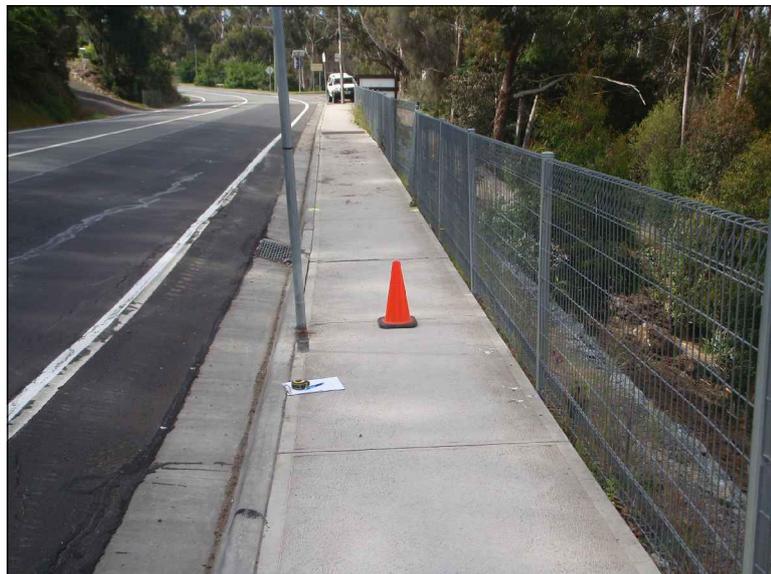
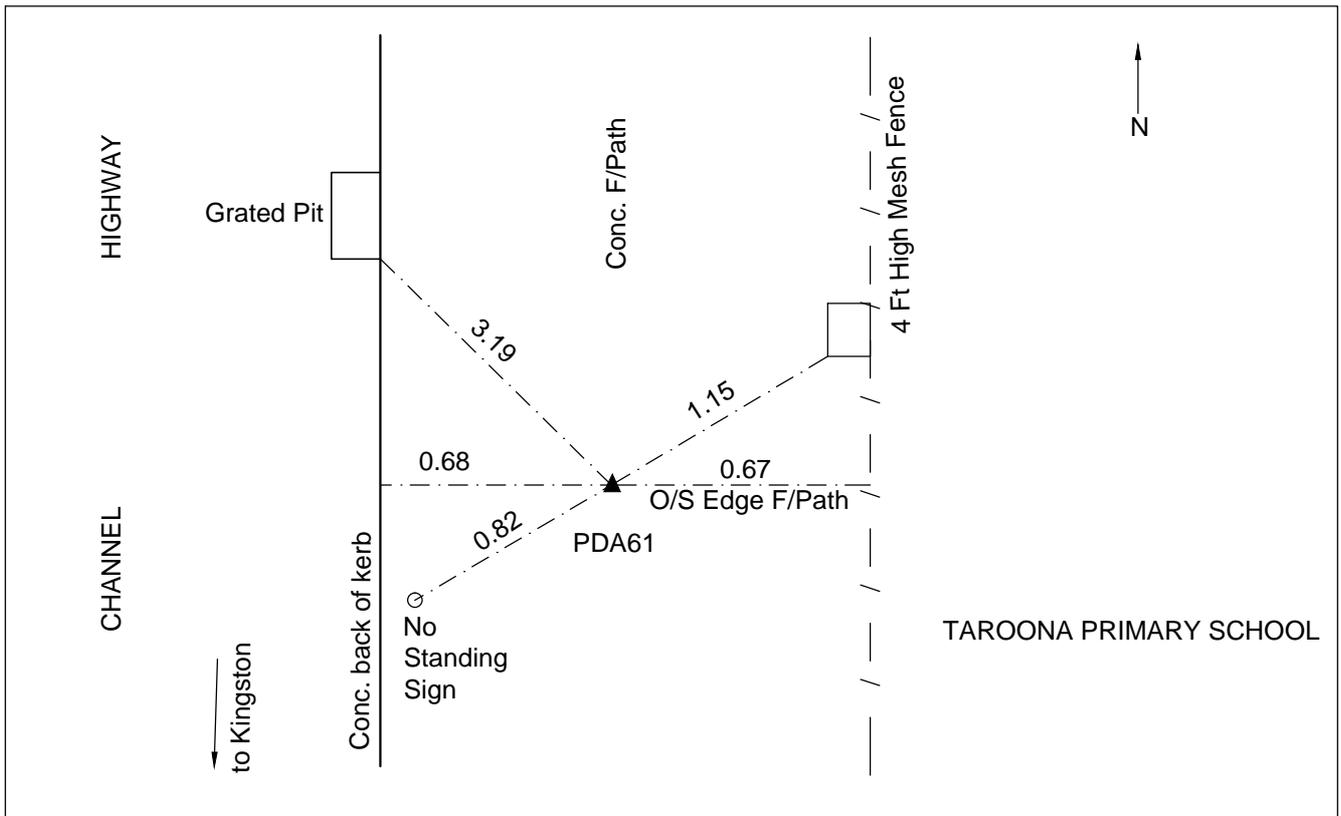
Mark type: Rivet

Placed by: AC on 27/10/11

Instrument: S8, DiNi

Reference Station:

Remarks: Rivet in Conc. Path generally above Taroona School Oval



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# SURVEY CONTROL STATION

NAME: PDA62

E: 528743.591

N: 5245449.163

RL: 40.807

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

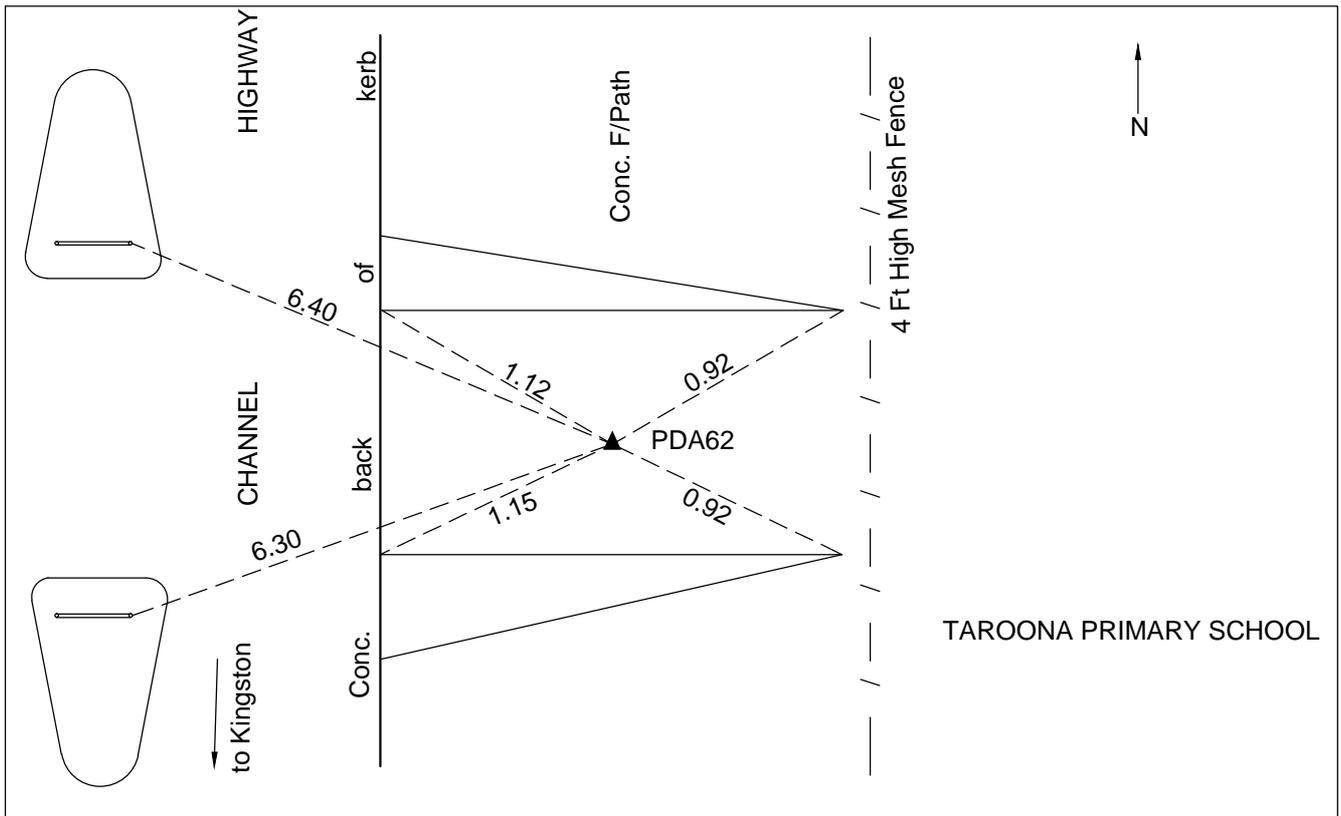
General location:

Mark type: Rivet in conc Path

Placed by: AC on 27/10/11 Instrument: S8, DiNi

Reference Station:

Remarks: Rivet in conc path at pedestrian crossing to Bus stop No 37



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# SURVEY CONTROL STATION

NAME: PDA70

E: 528957.516

N: 5245768.972

RL: 28.745

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

General location: Front of number #14 Karingal Crt

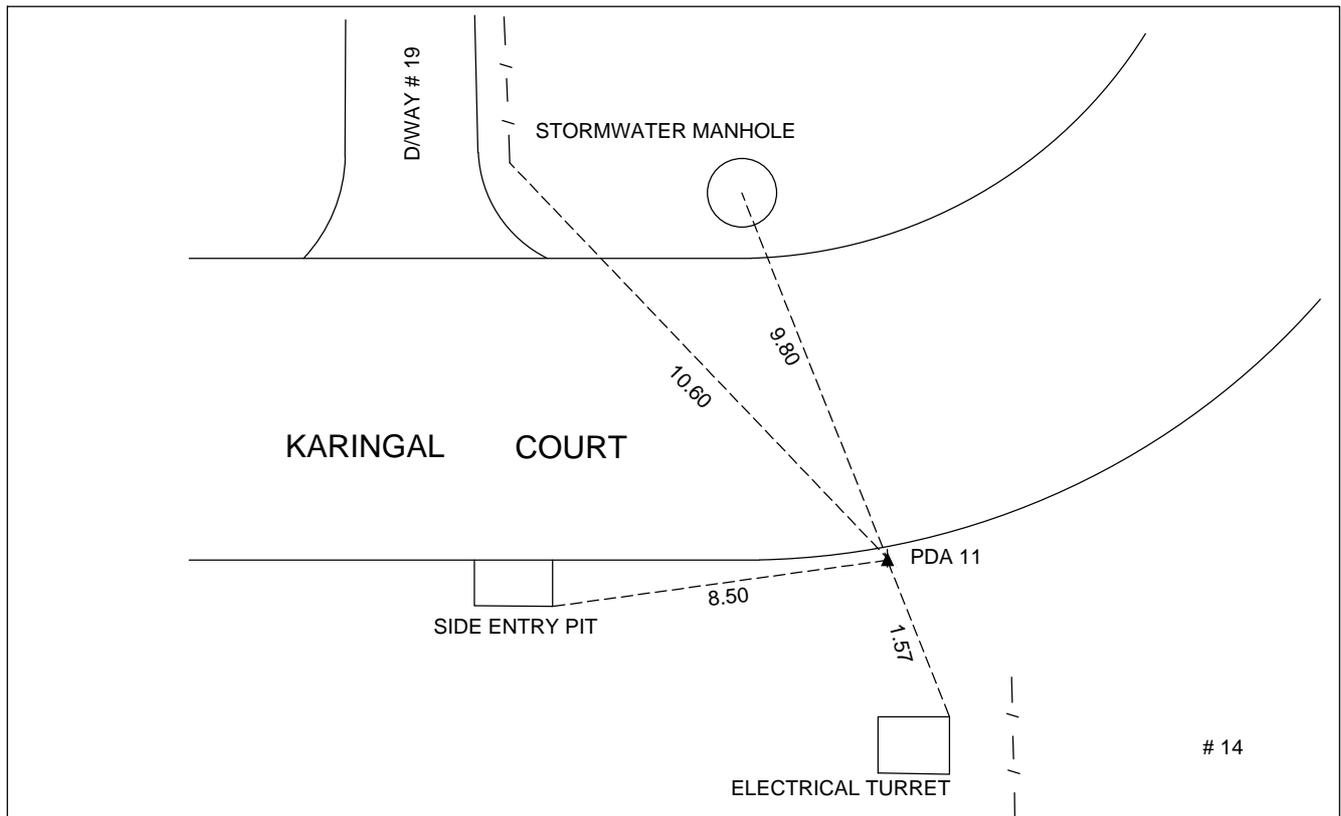
Mark type: Aluminium rivert inTop of Kerb

Placed by: AC

Instrument: S8, DiNi

Reference Station:

Remarks:



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# SURVEY CONTROL STATION

NAME: PDA71

E: 528797.528

N: 5245718.129

RL: 44.942

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

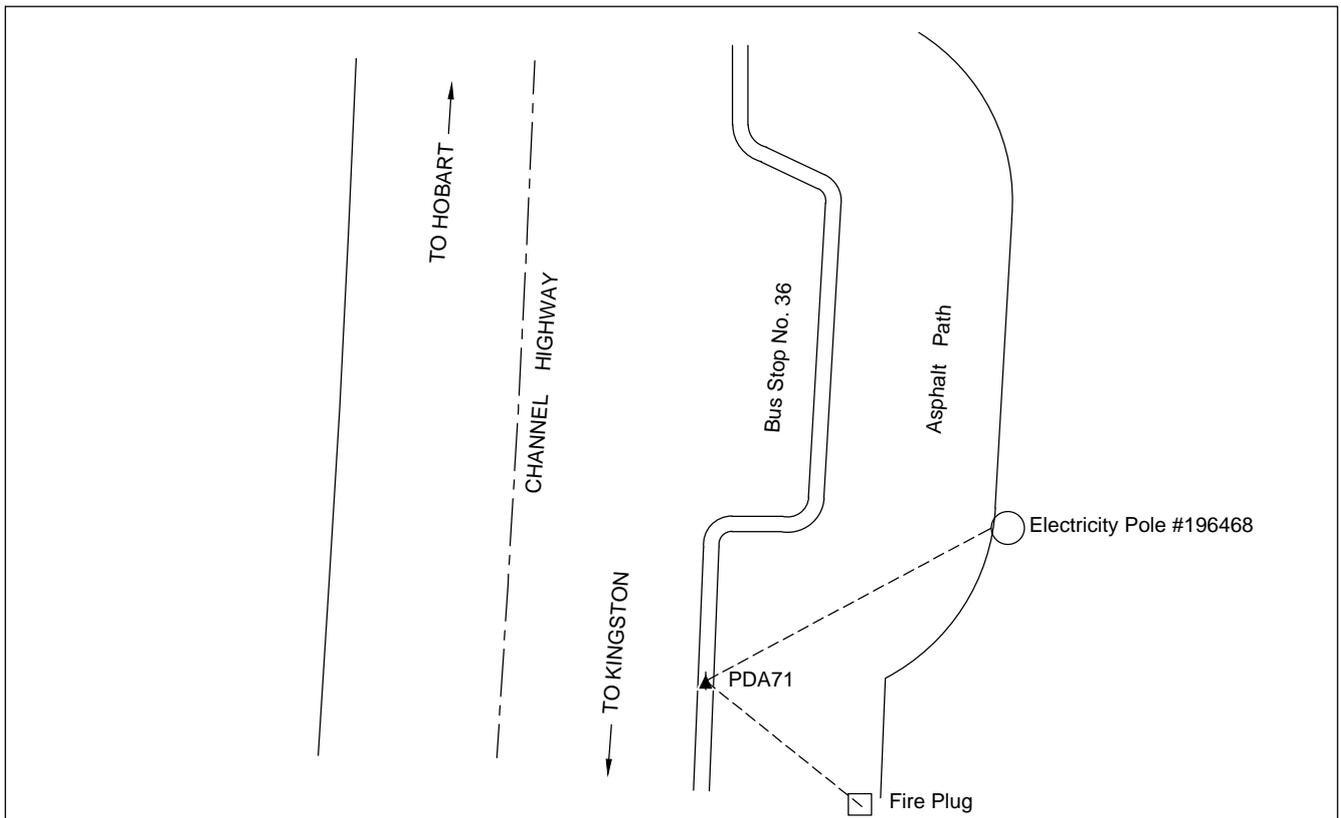
General location: Opposite #117 Channel Highway

Mark type: Rivet

Placed by: AC on 27/10/11 Instrument: S8, DiNi

Reference Station:

Remarks: Rivet in back of kerb generally opposite #117 Channel Highway & south of bus stop 36



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# SURVEY CONTROL STATION

NAME: SPM 4

E: 528849.670

N: 5245181.836

RL: 25.298

Est'd Accuracy:

Horizontal: 0.004

Vertical: 0.001

General location: Outside #106 and #108 Flinders Esp

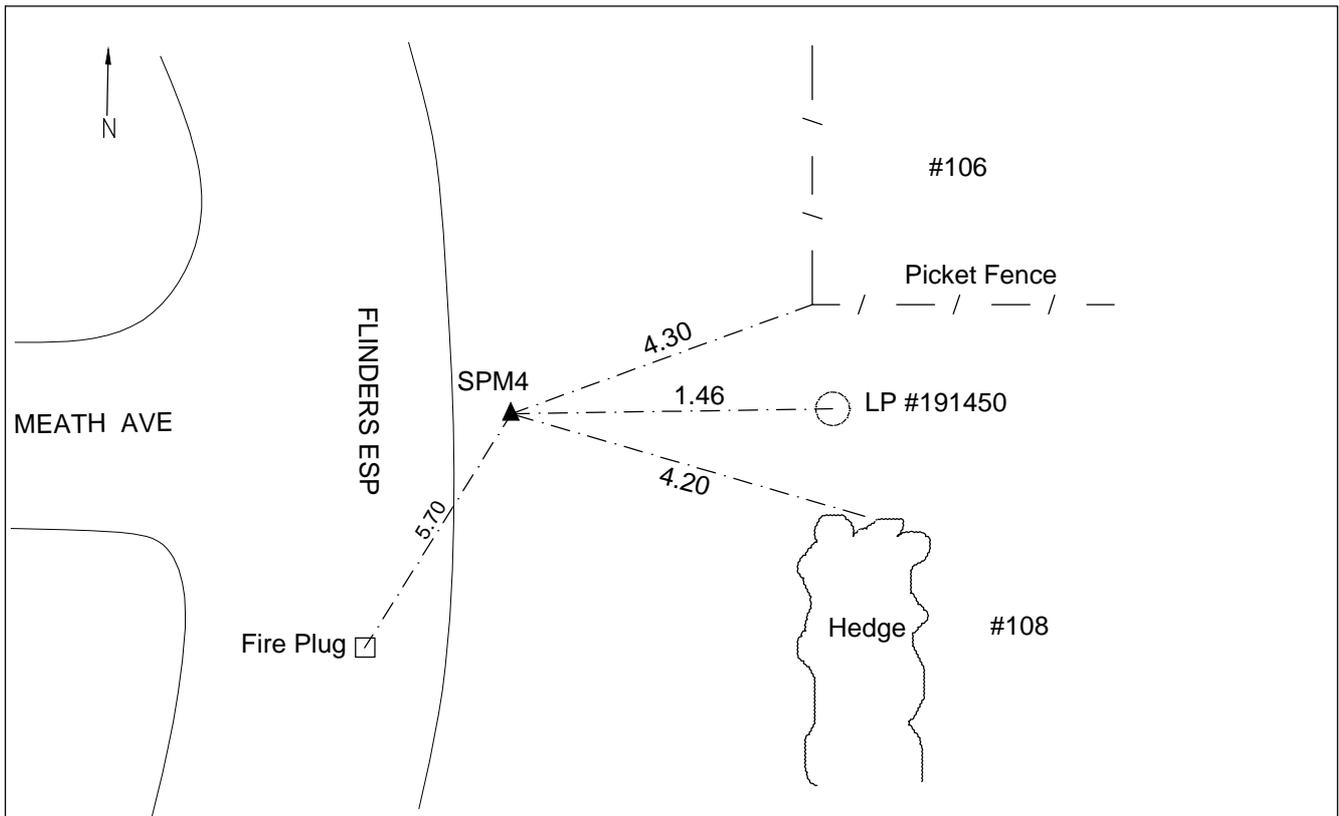
Mark type: Brass Rod (State Permanent Mark)

Placed by:

Instrument: S8 & DiNi

Reference Station:

Remarks: Brass Rod in cover box in driveway crossover of #106 Flinders Esplanade



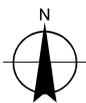
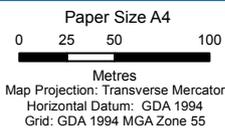
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**LEGEND**

-  State Permanent Mark
-  Surface Horizontal Displacement Vector
- Displacement
- Bearing
- Original Survey Period



Kingborough City Council  
 Tarooma Landslide Risk Assessment  
 and Mitigation Plan

Job Number 32-15950  
 Revision 0  
 Date 24 Feb 2012

**State Permanent Marks (SPM) Appendix I**

**N857M - COMPARISON OF COORDINATES FROM ORIGINAL SURVEYS TO CURRENT MONITORING SURVEY**

Original traverse 1690-1963			Current Travesse			Diff in Coordinates	
	Easting	Northing		Easting	Northing	East	North
SPM4712	528733.789	5245418.931	DESTROYED				
SPM4303	528691.948	5245360.987	SPM4303	528692.343	5245361.026	0.395	0.0385
SPM4706	528761.172	5245518.042	DESTROYED				
SPM4707	528758.241	5245657.619	SPM4707	528758.208	5245657.554	-0.033	-0.065
SPM4302	528658.784	5245330.917	DESTROYED				
SPM4708	528646.489	5245289.35	DESTROYED				
SPM1252	528638.319	5245207.68	DESTROYED				
SPM4714	528597.803	5245131.847	SPM4714	528597.841	5245131.814	0.038	-0.033
SPM4307	528541.634	5245006.313	SPM4307	528541.634	5245006.313	0	0
SPM2331	528849.624	5245181.87	SPM2331	528849.67	5245181.836	0.046	-0.034
SPM	528935.713	5245257.498	SPM4	528935.768	5245257.485	0.055	-0.013

Surcom Cordinates (published)			Current Travesse				
SPM9438	528768.272	5245579.771	SPM9438	528768.222	5245579.804	-0.05	0.033
SPM8365	528820.510	5245774.770	SPM8365	528820.32	5245774.919	-0.19	0.149

SPM 4307 has been adopted as the MGA origin for the 1960-1963 survey per adjusted current coordinates (traverse rotated by -41' ie standard trav v MGA)

Note: Original survey coordinates has been compiled from original fieldbooks, held by PDA Surveyors. The accuracy of this data has not been verified, some diifferences in survey accuracy would be expected due to the nature of both the survey methodoly and technology.

Published accuracy of SPM9438 is 0.044m (2nd Order), SPM8365 is provisonal and has no stated accuracy as there are no redundant measurements

## **BOREHOLE COORDINATE COMPARISON**

(Datum - MGA94 AHD83 (Tas)), Origin SPM9432

<b>Borehole Number</b>	<b>Easting (m)</b>	<b>Northing (m)</b>	<b>Elevation of Instrument casing (m)</b>
I91-10PDA	529019.602	5245525.064	13.799
I91-8PDA	529062.222	5245362.164	9.863
I91-9PDA	529091.785	5245488.612	8.006
I92-11PDA	528663.475	5245356.223	41.782
I92-12PDA	528733.809	5245379.371	38.818
I92-13PDA	528649.671	5245311.633	41.427
MRT-108-1PDA	528747.266	5245436.243	37.816
IBH1-99PDA	528897.642	5245380.958	30.741
IBH2-99PDA	528869.397	5245206.67	23.884
IBH3-99PDA	528893.552	5245705.592	29.08

Instrument casing level has been taken on the downhill or eastern most drill hole placed at the four quadrants of the casing pipe, see final survey report for more details.

N857M - TAROONA LANDSLIP MONITORING SURVEY  
 ADJUSTED COORDINATES  
 DATUM: MGA94 & AHD83 (TAS)  
 ORIGIN POINT = SPM9432 PER SURCOM

Pt No	EAST	NORTH	HEIGHT		Description
SPM9432	528535.544	5244997.760	44.410		Brass plague in kerb
BASE02	528813.695	5244835.622	17.723	#	Rivet in rock outcrop
PDA01	528826.768	5245792.920	46.043		Rivet in conc pedestrian crossing
PDA06	528713.155	5245375.967	40.779		Rivet in conc footpath
PDA12	528892.747	5245704.616	28.988		Steel bar in conc
PDA13	528940.578	5245561.025	15.498		Steel bar in conc
PDA14	528936.237	5245535.681	21.700		Steel bar in conc
PDA15	529017.977	5245520.058	14.390		Steel bar in conc
PDA17	529150.740	5245453.242	5.709		Steel bar in conc
PDA18	529052.820	5245325.491	7.807		Steel bar in conc
PDA19	528950.293	5245341.912	24.705		Rivet in lip of kerb
PDA20	528900.607	5245366.815	30.899		Rivet in conc footpath
PDA51	528571.823	5245058.257	43.429		Rivet in manhole surround
PDA52	528588.776	5245142.999	43.928		Rivet in conc footpath
PDA53	528637.348	5245204.582	43.845		Old Ramset in back of kerb
PDA54	528643.056	5245208.916	43.303	*	Rivet in pedestrian crossing
PDA55	528859.167	5245192.027	24.003		Old Ramset in back of kerb
PDA58	528654.957	5245349.075	40.754		Steel Bar in conc
PDA59	528643.856	5245281.328	42.396		Rivet in conc footpath
PDA60	528764.107	5245526.526	41.298		Rivet in conc footpath
PDA61	528751.927	5245480.517	40.783		Rivet in conc footpath
PDA62	528743.591	5245449.163	40.807		Rivet in conc footpath
PDA70	528957.516	5245768.972	28.745		Rivet in top of Kerb
PDA71	528797.528	5245718.129	44.942		Rivet in back of kerb
PDA72	528747.370	5245655.632	43.890		SH Nail in bitumen
SPM4714	528597.841	5245131.814	43.518	*	Brass rod in cover box
SPM2331	528849.670	5245181.836	24.407	#	Brass rod in cover box
SPM4	528935.768	5245257.485	25.298	*	Brass rod in cover box
SPM4307	528541.634	5245006.313	43.965	*	Brass plague in kerb
SPM4707	528758.208	5245657.554	43.225		Brass plague in kerb
SPM4303	528692.344	5245361.026	40.646		Brass plague in kerb
SPM8366 RM1	528726.307	5245387.612	40.893		Brass plague in kerb
SPM8365	528820.320	5245774.919	46.174		Brass plague in kerb
SPM9438	528768.222	5245579.804	41.584		Brass plague in kerb

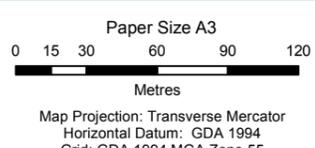
\* denotes trig heighting only

# denotes GPS heights only

Rev A - SPM names updated



- LEGEND**
-  Inclinator Locations
  -  Survey Control Points



Kingborough City Council  
Taroona Landslide Risk Assessment  
and Mitigation Plan  
**Survey Control Network  
and Inclinator**

Job Number | 32-15950  
Revision | 0  
Date | 24 Feb 2012

**Appendix I**



Appendix J  
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**Document Status**

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
draft	Graham Granger/ A Ahmed-Zeki	A Ahmed-Zeki		M Daley		
Draft 2	Graham Granger/ A Ahmed-Zeki	A Ahmed-Zeki		M Daley		9/12/11
Draft 3	Graham Granger/ A Ahmed-Zeki	A Ahmed-Zeki		M Daley		24/2/12
Rev 0	Graham Granger/ A Ahmed-Zeki	A Ahmed-Zeki	*on file	M Daley	*on file	8/3/12
Rev 1	Graham Granger/ A Ahmed-Zeki	A Ahmed-Zeki	<i>A Ahmed-Zeki</i>	M Daley	<i>[Signature]</i>	<i>01/05/12</i>