Mornington Peninsula Shire

Flinders Township and Tanti Creek Geotechnical Information Pack

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Geotechnical assessment for landslip susceptibility and investigation zoning: Flinders Foreshore Mornington Peninsula, January 2008

LanePiper

Geotechnical & Environmental Engineers
Hydrogeologists & Environmental Scientists

GEOTECHNICAL ASSESSMENT FOR LANDSLIP SUSCEPTIBILITY AND INVESTIGATION ZONING

FLINDERS FORESHORE MORNINGTON PENINSULA

For

MORNINGTON PENINSULA SHIRE COUNCIL

JANUARY 2008

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www.lanepiper.com.au

DOCUMENT CONTROL

Lane Piper Pty Ltd (ACN 120 109 935)
Bldg 2, 154 Highbury Road, Burwood Vic 3125
Tel: (03) 9888 0100 Fax: (03) 9808 3511

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GEOTECHNICAL ASSESSMENT OF LANDSLIP SUSCEPTIBILITY AND INVESTIGATION ZONING

FLINDERS FORESHORE
MORNINGTON PENINSULA

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GEOTECHNICAL ASSESSMENT OF LANDSLIP SUSCEPTIBILITY AND INVESTIGATION ZONING

FLINDERS FORESHORE
MORNINGTON PENINSULA

1 INTRODUCTION

At the request of Mr John Ault-Connell of Mornington Peninsula Shire Council in Purchase Order No. 053370 dated 30th May 2007 a limited geotechnical assessment was undertaken to assess the areas of potential landslip and provide landslip susceptibility and investigation zoning of the Flinders Foreshore area. The work was conducted in accordance with our fee proposal 24063-2.0 dated 26th September 2006. The work was slightly delayed whilst waiting for the latest digital terrain model to be completed together with the low-level aerial photography of the Flinders area.

Landslip susceptibility zoning involves the classification, area and spatial distribution of the existing and potential landslips in the study area. Landslide susceptibility zoning usually involves developing an inventory of landslides, which have occurred in the past together with an inventory of areas that have the potential to experience landsliding in the future. No assessment of the frequency of the occurrence of landslides was undertaken nor any assessment of the areas of the debris flow, but an allowance for landslip regression was made.

Due to the lack of definitive geotechnical information or history of movements or landslips in the area, it was decided to limit the assessment to areas of different geotechnical investigation with landslip susceptibility mapping within the study area rather than develop a map of landslide zoning or risk zoning. It is proposed that these assessments would be made for the individual property owners for the proposed development. In some areas within the study area, ancient or active landslides were identified, while in other areas, there was little evidence of landslip despite being steeper with similar geology. A geotechnical investigation may reveal that due to different geotechnical soil profiles such as shallow bedrock or absence of shallow groundwater, there is a tolerable risk to landslip and we were not able to assess this risk with definitive site-specific geotechnical information. This report does not include any assessment of risk to either property or life.

A glossary of the terminology of landslips is included in Appendix D.

The assessment consisted of the following:

- Review of the previous literature
- Review of any further geotechnical reports that the council have in their records
- Further geotechnical inspections and analysis to define the different zones
- Preparation of documentation to support the preparation of an Erosion Management Overlay for inclusion in the Mornington Peninsula Planning Scheme by way of a future Planning Scheme Amendment. The

documentation includes the designation of three investigation areas with specified requirements for geotechnical assessment.

1.1 LIMITATIONS OF THE REPORT

The purpose of this report is to provide a landslide inventory and susceptibility to inform the Council and the public and provide guidance on the level of geotechnical investigation to be conducted. It is not a detailed landslip assessment of individual sites and detailed examination may reveal the potential and susceptibility of landslip may be greater or less than indicated. The report indicates the level of investigation required together with the landslip potential. General limitations of geotechnical investigations are in Appendix G.

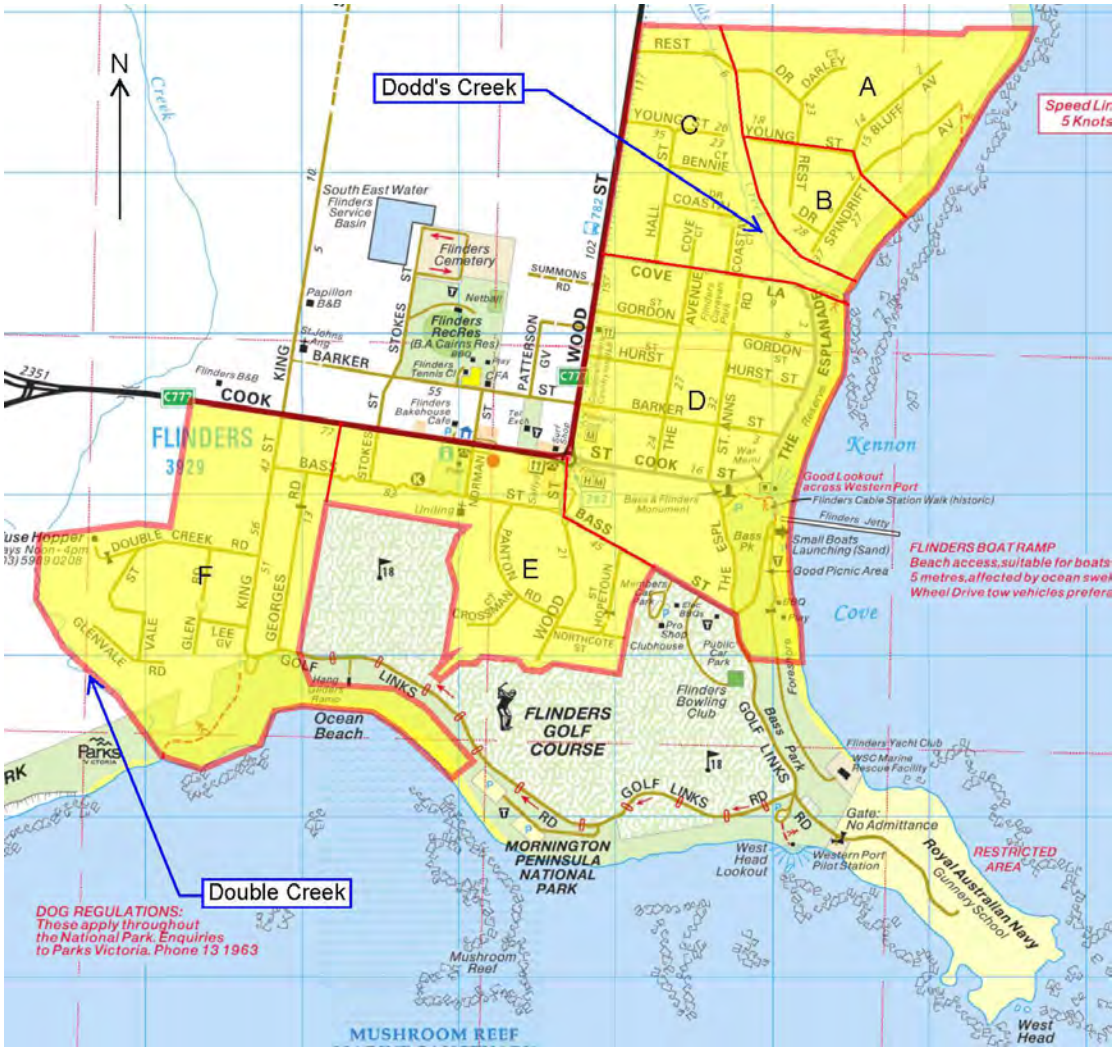
1.2 AREAS ASSESSED

The areas assessed are as follows:

A. The northern end of Spindrift Avenue, north of its intersection with Young Street
B. The southern end of Spindrift Avenue, south of the intersection with Young Street
C. The banks of Dodd's Creek and the area between Dodd's Creek and Wood Street
D. The area between Wood Street and The Esplanade (including the foreshore) from Cove Lane to Bass Street
E. The residential area between Cook Street and the golf course
F. The area to the west of the golf course bounded by Double Creek, Double Creek Road and Cook Street.

The approximate location of the study is shown in Figure 1.1 together with the designated areas A – F.

Figure 1.1: Area of the Study



1.3 REVIEW OF EXISTING INFORMATION

The initial part of the assessment involved the following:

- Review of the geotechnical reports prepared by Piper and Associates and others in the Flinders area
- Review of the geological maps and previous geological reports in the area

2 GEOSPATIAL SURVEY

Geocomp-Suntac Pty. Ltd. as sub-contractors to Lane Piper Pty. Ltd. used computer modeling to create the following:

- A digital terrain model using the data supplied by the Mornington Peninsula Shire Council (MPSC)
- Assign the surface slope and direction values to the DTM triangles

3 PREVIOUS REPORTS

A number of geotechnical and geological reports have been prepared over the years that are applicable to this area, including those as follows (in chronological order):

Golder Moss Associates Pty. Ltd., *Letter report for Residence, 5 Spindrift Avenue, Flinders,* dated 19 December 1974

Lawrence C.E., & Associates (Vic.) Pty. Ltd., *Site Investigation No. 19 Spindrift Avenue, Flinders,* 3 April 1996

A.S. James Pty. Ltd., *Geotechnical Investigation for proposed Residence, Lot 2, Spindrift Avenue, Flinders,* Report No. 80638 dated 27 August 1996.

Dolphin P., *Onsite Observation at 9 Spindrift Avenue, Flinders since 1965,* dated 14 July 1998.

Piper & Associates Pty. Ltd., *Geotechnical Investigation for proposed Cable Station Boardwalk, The Esplanade, Flinders,* Report No. 99011 dated 2 September 1998.

Piper & Associates Pty. Ltd., *Geotechnical and Geological investigation of proposed Street Scheme, Spindrift Avenue, Flinders,* Ref. No. 99005 dated 14 September 1998

Piper & Associates Pty. Ltd., *Geotechnical Assessment of Inclinometer Readings, Mt. Eliza, Mt. Martha & Flinders*, Ref. No. 98109 dated 7 March 2001

Piper & Associates Pty. Ltd., *Landslip Movement Measurement Installation of Two Additional Inclinometers, Spindrift Avenue, Flinders*, Ref. No. 21109 dated 15 June 2001

Piper & Associates Pty Ltd., *Geotechnical Review of the Inclinometer Readings, Mornington Peninsula Shire*, Job No. 22033 dated 25 July 2001

Piper & Associates Pty. Ltd., *Geotechnical Comments of Lot 2 on Plan of Sub-division, LP222189D, Spindrift Avenue, Flinders*, Ref. No. 22034 dated 26 September 2001

BFP Consultants Pty. Ltd., *3 Spindrift Avenue, Flinders, Geotechnical Investigation*, Job No. 41035 dated September 2002

Piper & Associates Pty. Ltd., *Geotechnical Inspection of the Property, 17 Spindrift Avenue, Flinders*, Ref No. 23016 dated 23 September 2002

Piper & Associates Pty. Ltd., *Extent of Geotechnical Investigation for proposed Dwelling Extensions, 2A Spindrift Avenue, Flinders*, Ref. No. 23105 dated 24 March 2003

A.S. James Pty. Ltd., *Proposed Residential Development, 5 Spindrift Avenue, Flinders*, Report No. 104610Rev2., dated 10 December 2003

A.S. James Pty. Ltd., *Proposed New Residence, 17 Spindrift Avenue, Flinders*, Report No. 104933/A dated 30 March 2004

Connell Wagner Pty. Ltd., *Inclinometer Readings, Spindrift Avenue*, June 2004.

A.S. James Pty. Ltd., *Proposed Residential Development, 5 Spindrift Avenue, Flinders,* Report No. 104610/G1., dated 16 July 2004.

Piper & Associates Pty. Ltd., *Geotechnical Assessment for Landslip Risk, Flinders Foreshore (Draft)*, Report No. 24063/1 dated 9 September 2004.

BFP Consultants, *Geotechnical Investigation for Dodd's Creek Crossing, Flinders,* Job No. 1003384 dated March 2005

Connell Wagner Pty Ltd *Inclinometer Readings, Spindrift Avenue*, June 2004 and June 2005

BFP Consultants Pty. Ltd., *Geotechnical Investigation for Flinders Sewerage Project, Stage 2,* Job No. M6041 dated 7 November 2005.

Piper & Associates Pty. Ltd. *Geotechnical Assessment of the Inclinometer Readings for Mornington Peninsula Shire*, Report No. 24115-1.1 dated 23 December 2005

Piper & Associates Pty. Ltd., *Geotechnical Assessment for Proposed Sewer Construction, Flinders Backlog Sewerage Project*, Report No. 26049-1.2 dated 24 March 2006.

Lane Piper Pty Ltd., *Geotechnical Comments for Underground Power Line, Lot 2A Spindrift Avenue, Flinders*, Ref. No. 27082-Report1.1 dated 15 November 2006

4 AERIAL PHOTOGRAPHS

A copy of the aerial photograph of the area under investigation is shown below in Figure 4.1. The photographs used were part of the 2006-07 survey of the Mornington Peninsula by the Department of Sustainability and Environment *CIP 2006-07 Mornington Peninsula*.

The approximate locations of the different areas assessed are shown on the photograph.

Figure 4.1: Aerial Photograph of the Site (2003)

5 GEOLOGY OF THE FLINDERS AREA

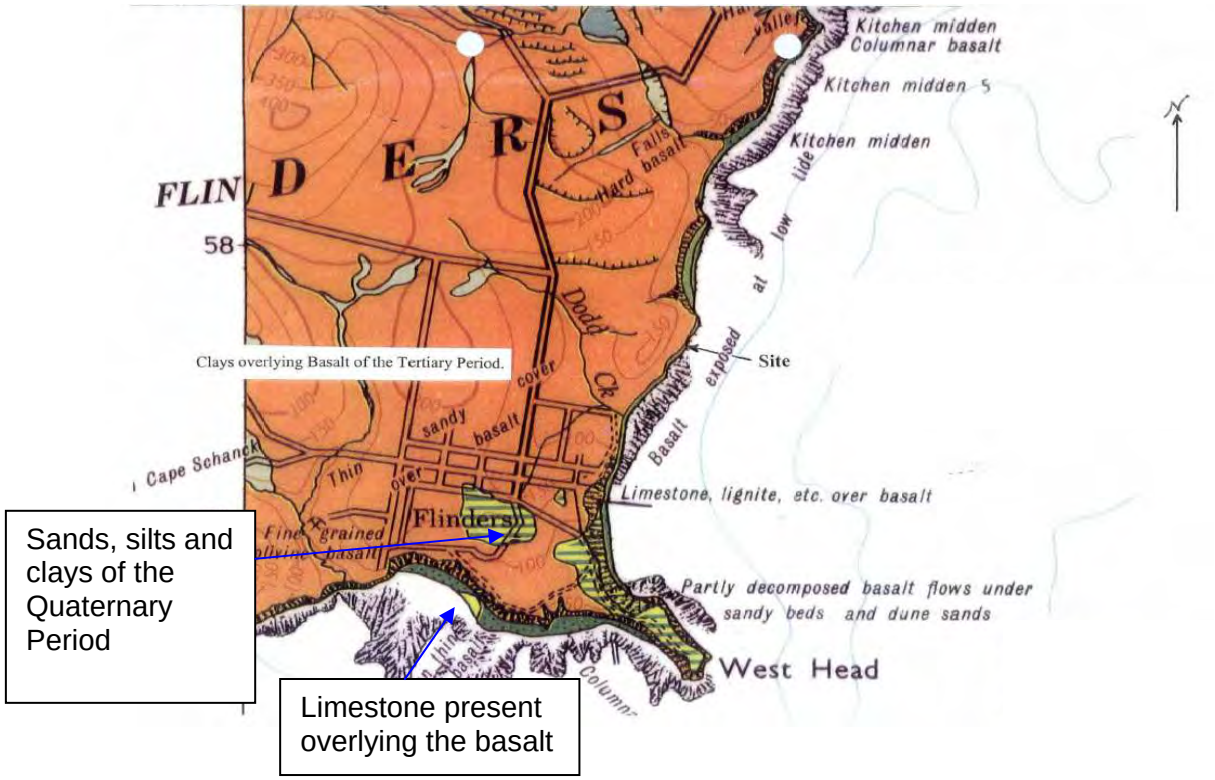
The Western Port 1: 63 360 Geological Survey map (1967) shows basaltic materials of the Lower Tertiary *Older Volcanics* to occur both at the surface and underlying the area being studied, with the words "Thin sandy cover over basalt" recorded on the map in the Flinders township area. A narrow beach of (quartz) sand is shown fringing the basaltic coastal cliffs, with basalt below the beach exposed at low tide. Neither the map nor the related Geological Survey Memoir 17 on the Mornington Peninsula (Keble, 1950) give any data on the degree of weathering of the basalt.

At the southern end of Flinders within the cliff faces, there is the presence of limestone breccia overlying the basalt rock and underlying basaltic clays.

There are two areas of silts, sands and clays of the Quaternary Period, probably alluvium overlying the Tertiary Basalt at the southern end of Flinders.

The geological map of the area is shown below in Figure 5.1.

Figure 5.1: Excerpt of the Geological Map of the Area



Along the foreshore, there are beach and coastal dune sands overlying the Lower Tertiary *Older Volcanics.*

In 1911, the Geological Survey of Victoria drilled a bore to 1300ft (396m) near the mouth of Dodd's creek, north of the jetty, commencing at about 4m above the sea water level. This bore revealed 6.25m thickness of clay, overlying 34m of decomposed basalt and overlying 'hard, jointy basalt' of 257m thickness. (Keble,

1950). The deep weathering and decomposed basalt layers of the shallower soils are consistent with the borings (Piper & Associates, BFP Partners, Golder Moss, & A.S. James)

South of Dodd's Creek on the eastern foreshore, the coastal cliffs show low strength moderately weathered basalt in parts of the top portion of the cliffs but this is far from universal. A borehole at the cliff summit above the Flinders jetty found 9.4 m of very stiff basaltic clay immediately sub-surface (Piper & Associates, 1998). The cliffs in this section of the coast have been eroded and steepened by marine erosion but there are no major slope failures apart from an extensive *probable* past landslide directly behind the Flinders jetty. Elsewhere there are shallow down-slope movements and towards Dodd's Creek, a rockfall zone: none of these threaten the properties along The Esplanade and private property to the west.

6 EXISTING SLOPE FAILURES

6.1 AERIAL PHOTOGRAPHIC INTERPRETATION

The aerial photographs were studied for evidence of slope instability. Areas that were identified as possible landslips were then confirmed on site.

The slope failures identified after the field visit are shown on the accompanying plan, Figures No. 1 - 8, Appendix A.

North of Dodd's Creek hard basalt is commonly not visible in the coastal cliffs, with basaltic clay as the common material seen. Drilling along Spindrift Avenue (Piper & Associates, 1998) found at least 9.0 m of basaltic clay in landslips there and this is probably typical for this part of the coast. Major old landslides with earth-flow type features at their toes characterize this coastal zone, with somewhat near level, benched areas forming the surface of failed areas.

The lower reaches of Dodd's Creek display steep slopes, which are even with few undulations present. No indications of major slope instability were found, although there are minor failures and creep movements in close proximity of the creek.

The southern foreshore is similar to the eastern foreshore with coastal cliffs along the entire length within the study area. There are several small and medium size slips within this area as well as erosion gullies and rockfall zones. There is one large *probable* past landslip within the cliff at the end of Georges Road that appears to be active although to our knowledge, no detailed investigation of this slip has been conducted.

The banks along Double Creek show significant signs of movement, especially creep and translational slides. East of the creek there are several large *probable* past landslips although again we are not aware of any detailed investigation of these slips.

The areas away from the coastline, Dodd's Creek and Double Creek tend to have gentle to moderate slopes with minimal sign of instability although in between Bass Street and the golf course there are several ridges with associated steep slopes.

Moderate and gentle slopes are characteristic of the study area behind the coast away from Dodd's Creek.

The landslide earth-flows shown north of Dodd's Creek are the most serious failures in the area. They are, with one exception, classed as *certain*. There is a possibility that some of them might be in danger of further movement. The landslide shown curving around near the mouth of Dodd's Creek is classified as *probable*.

South of Dodd's Creek near the mouth of Dodd's Creek a landslide, curving westwards without an earth-flow toe, is shown as *possible* only. Adjoining it to the south, a rockfall with topple and shallow slide features is active but presents no medium-term threat to The Esplanade and private property to the west. A fan-like feature composed apparently of clayey material and probably some concealed hard basalt boulders is adjacent as a *certain* slope failure.

The steep slope of about 70° extending south towards the Flinders monument has an irregular profile, with minor rock fall and wasting of clayey materials still active at a very low rate. It is a *certain*, but shallow failure zone. The major triangular scar in the cliff behind the Flinders jetty has an uneven profile and is classed as a *probable* past landslide. Any earth-flow zone at its toe has been removed by wave action.

Along the southern foreshore there are several *possible* landslides and one large *probable* past landslide at the end of Georges Road. The earth-flow zones of these slips have been removed by wave action.

There are two large bowl shaped landslips with zones of depletions with associated accumulation zones to the east of Double Creek. One between Vale Street and Glen Road, the other to the south of the southern end of Glen Road. Both of these are classed as *probable* past landslips. There is a *possible* shallow slip to the north of Double Creek Road. Between Vale Street and the creek there are some smaller *possible* slips.

Along the creek itself there are numerous slumps and minor slips while directly east of the creek to the south-west of the 'Hopper' there is a significant *probable* past landslip.

6.2 FIELD WALKOVER

A field walkover of the study area was conducted on 17 August 2007 and 28 September 2007. The purpose of the walkover was to confirm the presence of landslips that were identified in the aerial photographs as well as to locate other potential slips that were not identified in the photographs.

The landslips were identified by features such as scarps and accumulation zones with associated features such as hummocky ground, leaning trees, boggy ground and tension cracks.

Details of the findings of the walkover are shown on Figures 2 to 8, Appendix A and are discussed in Sections 7 to 12.

7 NORTH SPINDRIFT AVENUE (AREA 'A')

The northern section of Spindrift Avenue extends from Young Street to the end of Spindrift Avenue to the north. This area has been the subject of considerable geotechnical investigations and monitoring over the last 10 years.

7.1 REVIEW OF THE DATA AND REPORTS FOR NORTHERN SPINDRIFT AVENUE

The review is based on several letters and geotechnical reports from private sources (dated between 1974 and 2004) and inclinometer monitoring, which concern a number of allotments along Spindrift Avenue, were examined. They reveal the following information of importance:

- The possibility of localised slips occurring at 5 Spindrift Avenue was mentioned in the Golder Moss Associates Pty. Ltd. geotechnical investigation in December 1974, and a borehole log recorded about 3m of residual basaltic clay above very variably weathered basalt down to 17.0m. They recommended that the dwelling be founded on piles founded at least 1.5m into the highly weathered basalt.

- An area of slip of undefined size at 15 Spindrift Avenue was recorded in a Council letter dated February 1989, with flow of water down an adjacent gully thought to be the major cause.

- At 17 Spindrift Avenue, Statewide Geotechnical Services carried out a site classification for a proposed dwelling in April 1989. The boreholes were drilled to a depth of between 0.25 - 0.40m of fill overlay silty clay down to at least 1.5m; slope instability was not mentioned. The site was classified as "M" in accordance with AS2870.1 – 1988, possibly incorrectly.

- A high-risk area of slope instability was recognised at 19 Spindrift Avenue by C.E. Lawrence and Associates in April 1996. They emphasised the need to avoid cuts and filling and recommended a cut-off drain. The site was classified as "P" (Problem) due to slope instability. The house was recommended to be founded on a driven pile and beam system with the garage founded on a stiffened raft. The piles were to be founded at a depth of at least 6.5m.

- At 1A Spindrift Avenue, A.S. James Pty. Ltd. conducted a geotechnical investigation in August 1996. They recognised significant past slope instability, thought to have occurred more then 30 years ago, and indicated a potential problem of shallow movement or creep. Drilling to 6.2m found 2.0m of stiff to very stiff, residual, basaltic clay above extremely to highly weathered basalt. A.S. James Pty. Ltd. recommended that the site be classified as "P" (Problem) due to slope instability and recommended that the structures be founded on bored piers within the weathered basalt.

- In 1998, Piper and Associates conducted a geotechnical and geological investigation and assessment of the area for a proposed street scheme and retaining walls. Slope instabilities were identified and a monitoring system of the ground movement was commenced. The street scheme was postponed.

- The owner of 9 Spindrift Avenue in a letter dated July 1998 suggested that the road in the front of 7 and 9 Spindrift Avenue rests on an extensive clay landslide, with observations of down slope movements since 1965 of 0.64 - 0.76m at No. 7 and 0.45-0.76m at No. 9. They also indicate that a landslip occurred at the northern end of Nos. 7 and 9, with gradual soil movement at the base of No. 9.

- BFP Consultants Pty. Ltd. conducted a geotechnical investigation for a new dwelling at 3 Spindrift Avenue Flinders in 2002. They concluded that the ancient landslip to the north of this site has apparently occurred due to differing subsurface ground conditions than the site at 3 Spindrift Avenue. The shallow depth of the rock on the subject site is somewhat less (1 – 4.5m compared with 11.8m). They concluded that the site is relatively stable as a result of computer analysis and appropriate sensitivity analyses.

- In 2004, AS James conducted a geotechnical investigation for a new dwelling at 5 Spindrift Avenue. They identified the presence of active creep but concluded that the house can be constructed at this location with an appropriate risk.

- Also in 2004, AS James conducted a geotechnical investigation for a new dwelling at 17 Spindrift Avenue. Due to the presence of an excavation for the tennis court below this steep site, considerable retaining works with ground anchors are proposed for the house development.

7.2 SITE DESCRIPTION

Spindrift Avenue runs along the edge of the steep sloping hillside running down to the beach, north of Flinders. The area of this investigation is confined to the area north of Young Street. The street is mostly an unsealed gravel road cut into the existing hillside. The slopes of the sites to the west and east of the road are variable, but generally steep. The sites are mostly vegetated with trees, shrubs and blackberries. At either end of the street, there are large pine trees. Most of the sites contain dwellings. The dwellings were not available for inspection, nor was it part of the scope of this investigation to see if there is any distress in the existing structures.

7.3 GEOLOGY AROUND NORTHERN SPINDRIFT AVENUE

The geological unit exposed from the inter-tidal zone to the ridge top north-west of Spindrift Avenue is weathered basalt of the Lower Tertiary aged Older Volcanics. Exposures are very limited and mainly confined to road cuts, which reveal brown to dark grey residual basaltic clays, mainly very stiff and with fissuring. Some of the fissuring was pronounced and suggestive of material that had once moved under slope failure. Several boulders of hard moderately weathered basalt were seen between the road and the sand line, but the clayey surface soil is ubiquitous.

There are no observable structural features to indicate any tectonic disturbance and good exposures of basalt along the coast west of Flinders indicate conditions of flat-lying flows of basalt, which should continue at the site.

The boreholes along Spindrift Avenue and on the slope, north-west of the street, recorded very stiff basaltic clay to the depth of drilling at about 9.0m in the four boreholes. When extruded, the samples commonly showed fabric weaknesses associated with fissuring, indicative of possibly structurally weak and failed materials.

The depth of hard basaltic rock and the shape of the interface between surface clay and hard rock in this area remain unknown. The boreholes along or adjacent to Spindrift Avenue indicate a deeply weathered clay and extremely or completely weathered basalt.

Capping the ridge top immediately north-west of Spindrift Avenue are some dark grey slightly clayey fine to medium quartz sands, which are estimated to be about 3 metres thick, but the thickness is uncertain and may be irregular: if important it would need to be established by drilling. The sands are of wind-blown origin of the Quaternary period.

Normal slope processes have caused some sand to migrate down the upper part of the slopes and mix with basaltic clay in the upper soil profile.

Slumped materials from slope failures found below Spindrift Avenue include some quartz sand, which probably originated from the ridge top referred to above by slope failure. This sand appears to be limited in occurrence to slumped material, making its origin through slope failure more likely rather than from wind-blown beach sand.

7.4 Topography and Slope Instability in North Spindrift Avenue area

The slopes above and below Spindrift Avenue, to the northeast of its junction with Young Street, are initially steep but generally become rather flat to gently undulating in the vicinity of Spindrift Avenue. Below Spindrift Avenue, the slopes are irregular and finally fairly steep towards the beach, with some almost flat benches interrupting this steep descent.

There are several steep cuspate scarps rising above Spindrift Avenue with the typical appearance of elements of a *main scarp* at the head of a *landslide*. The gently undulating surface below the cuspate main scarp elements is the surface of *displaced material*, which has slid by shear failure on a *surface of rupture.* The surface of rupture begins at the complex main scarp exposed above. Spindrift Avenue crosses the main scarp about 50m north- east of Young Street and continues thereafter on the surface of displaced material. There is a fairly wide but uneven *zone of accumulation* of the displaced failed material, on which houses are built, with the *toe*, marking the down slope limit of the landslide, well below the road towards the sea. The landslide is complex, and may represent several slides in combination. The nomenclature used above is from Turner and Schuster (1996), based on the IAEG Commission (1990) after Varnes (1978) and is shown below.

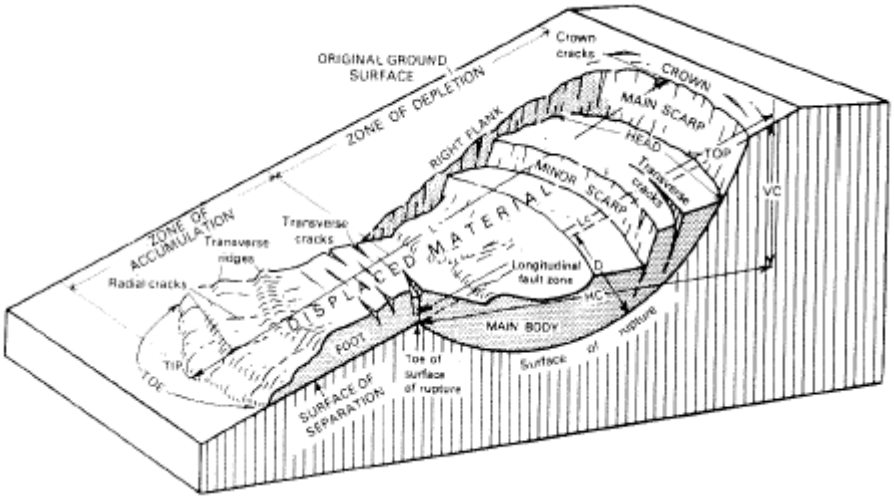


Figure 7.1: Landslide Features.

The Figure No. 8, Appendix A shows the extents of the landslips in the area. No attempt has been made to show the extent of the down slope limit of the failure or debris flow, but often this has been removed by sea erosion. Boundaries are shown as approximations only, based on field notes and examination of aerial photographs. The failures are generally arcuate type of failures with a zone of accumulation on the slopes below.

The visible failed and displaced materials in the *zone of accumulation* are basaltic clays, apparently more than 9m thick and there is no evidence to indicate whether or not some extremely or highly weathered basalt might also be included amongst the failed materials.

One of the four boreholes (Bore 4, Piper & Associates, 1998) was located on one of the cuspate *main scarp* elements. This borehole indicated at least 9.0m of basaltic clay there, still in the unfailed material. Another borehole (Bore 5, Piper & Associates, 1998) appears to be above the main scarp (but might still be on it, because the scarp has not been accurately mapped), and likewise revealed at least 9.0m of basaltic clay. Fabric weaknesses in bore samples are possibly indications of structural weakness in these steep slopes above the failed material of the zone of accumulation.

The depth and shape of the *surface of ruptures* are also unknown, but they are likely to be deep and arcuate. Some quartz sand among the basaltic clay in parts of the lower zone of displaced material appears to have originated from near the ridge top above the head scarp and is suggestive of complex shear movements and probable flow subsequent to the initial stage of failure.

Local information indicates that minor and irregular movement of at least parts of displaced material (comprising the *zone of accumulation)* is still taking place. The extent, direction, rate and variability with time and water content of any ground movements remain unknown in the absence of monitoring.

The steep slopes of the main scarp elements at the head of the landslide are probably potentially unstable. No cuts into their profiles should be made. Any cuts into slopes in the area of displaced material of the zone of accumulation would endanger their stability. The ground water conditions on the site have not been studied, but the groundwater is below 10m. To maximise ground stability, good drainage is nonetheless essential.

Plate 7.1: Scarp of landslip between Spindrift Avenue and Bluff Avenue

7.5 INCLINOMETERS ALONG NORTHERN SPINDRIFT AVENUE

Three inclinometers have been installed along and adjacent to Spindrift Avenue, north of Young Street. The results of the movements are summarised in the Piper & Associates report 24116-1.1 dated 23rd December 2005 as well as the more recent inclinometer reading in January 2006. The surveyors took the readings using an inclinometer supplied and operated by Connell Wagner. The Inclinometer No 1 at the southern end of Spindrift Avenue has been destroyed in 2005 as a result of road grading. This inclinometer was installed to a depth of 15m and first read in February 1998 and has been read annually to June 2004. The movements are small and do not indicate any shear planes present. However, there appears to be creep movement of about 9mm towards the sea over this period. This equates to movement in the upper 3 – 4m of about 1.4mm per year.

Inclinometer No 2 was installed to a depth of 18m and first read in June 2001. This inclinometer is showing greater movement with some 27mm of movement at the head of the inclinometer towards the beach from June 2001 to June 2005. Again this appears to be creep movement over the upper 8 – 9m. This equates to about 6.75mm per year, but decreased to about 2mm per year from June 2005 to January 2006.

Inclinometer 3 is showing very little movement and movement from June 2001 to June 2005 has shown movement of less than 1 – 1.5mm and is too small to be accurate. The incremental displacements are not showing any distinct pattern and it can be considered that little, if any, movement has occurred since June 2001. This inclinometer was not able to be read in 2006 due to construction materials being placed over the head of the inclinometer.

Overall, the inclinometer results support the conclusion that movements towards the sea can be expected. There is no evidence of any slope failure planes and the movements are typically creep, varying from nil to 6.75 mm per year. Such movement is consistent with the identified ancient landslips present along Spindrift Avenue. The movements are likely to be intermittent and in part a reflection of the recent rainfalls.

7.6 CONCLUSIONS FOR NORTHERN SPINDRIFT AVENUE

The investigations to date have highlighted that Spindrift Avenue in the section north of Young Street is located within a previous landslip(s). This landslip(s) has been identified by aerial photograph interpretation, site inspections, geological mapping and computer slope stability analyses. The area is part of an ancient landslip formation.

Beyond about 50m from Young Street, Spindrift Avenue lies on failed material of a former landslide(s). Limited drilling has revealed at least 10.0m of very stiff basaltic clay, but deeper drilling might show a more complex pattern of basaltic materials including some hard rock. Borehole 1 (P & A, 98033 dated February 1998) showed completely weathered rock at a depth of 14.8m to the full depth explored of 15.4m. The depth and shape of the surface of rupture beneath are unknown.

Some continuing movement of the failed material of the landslide is occurring, but the precise areas of such movement and their rates are almost unknown. The inclinometer installed is indicating ground creep movement in the upper 3 – 4m but could be as great as 8m. However, insufficient time has elapsed for this movement to be conclusive or determine the rate of movement with any accuracy relative to the age of the landslip. Nonetheless, the inclinometer suggests a maximum rate of movement of the order of 6 - 7mm per year. Therefore over a 30-year period, the expected movement could be as great as 210mm, which is similar to the previous owner's observations at 7 and 9 Spindrift Avenue and could be greater towards the steeper section of the Lots.

The steep slopes above the zone of accumulation of the landslide are believed to be in a weakened condition and cuts into these should be avoided. The geological mapping has indicated major and minor scarps, which suggest that the soils in some areas are approaching the residual condition with increasing strain. Further movements can be expected to continue to occur, albeit erratically, and could be associated with sustained rainfall events.

Any engineering works involving cuts into the surface of the failed material in the zone of accumulation of the landslide could be in material that could be reduced to the residual strength. It is expected this will induce some movement, particularly in the slopes above the road. In some locations, Spindrift Avenue is located within the failed displaced material and unloading of the toe of this material must be avoided.

The failed displaced material is probably undergoing creep movement and any disturbance to these failed materials could induce accelerated creep movements.

8 SOUTHERN SPINDRIFT AVENUE, BETWEEN YOUNG STREET AND DODD'S CREEK (AREA 'B')

The section of Flinders township between southern Spindrift Avenue and the strandline is typically at a grade of 40 - 50% to the base of the cliff with some areas at a slope of 60 – 70% with a few sections up to a grade of 80 – 90%. Apart from either end of this section of Spindrift Avenue, many of the lots are graded at 10 – 30%. See Figure No. 3, Appendix B.

Two arcuate landslips have been detected along this section at either end of southern Spindrift Avenue. These landslips have a benched area of failed material with minor earth flow in the lower section. It is likely that some of the lower section has been eroded in the past.

These landslips do not extend to Spindrift Avenue. However, in the area to just south of Young Street intersection with Spindrift Avenue and the southern end of Spindrift Avenue on the banks of Dodd's Creek, there is the potential for landslips due to the steepness of the ground.

In our opinion, there is likely to be little likelihood of a slope failure extending to Spindrift Avenue in this location, although creep movement to the south could occur.

9 DODD'S CREEK TO WOOD STREET (AREA 'C')

There are two landslips to the east of Spindrift Avenue in the vicinity of Dodd's Creek. There are signs of landslip movement in the area of 39 Spindrift Avenue but these are mostly creep movements in recent times. There is evidence of toe erosion in the creek bed, tending to destabilise the slope.

There is no evidence of major landslips west of Spindrift Avenue along Dodd's Creek despite the steepness of the slope. However there is evidence of near surface small landslips in the vicinity of the creek and creep movement within the creek banks. Erosion of the bed of Dodd's Creek is causing increased slope instability.

The southern creek banks are very steep with undulations indicative of shallow creep movements and shallow slope failures. On the southern bank, there appears to be evidence of debris flow at the base of the creek bank.

BFP Consultants drilled five boreholes in the location of the Dodd's Creek crossing in March 2005. Refusal was encountered in all of the boreholes on basalt bedrock at a depth of between 1m and 13.7m.

Groundwater was encountered in boreholes 1 and 5 on either side of Dodd's Creek at a depth of 12.7m and 10.7m respectively.

The basalt rock is likely to be close to base of the creek bed, typically moderately to highly weathered.

BFP Consultants consider slope instability on the banks of the creek unlikely even with creek bank slopes of 25^{o} (45 – 50%). We agree generally with this conclusion provided the groundwater remains suppressed, but cannot preclude creep movements in the near surface soils.

Whilst we agree that a major global instability of the creek banks is unlikely due to the presence of the basalt rock in or close to the creek bed, it cannot be precluded as there are slopes elsewhere in the Flinders locale, that have failed at similar or even less steep slopes. It is more likely that a shallow slope failure may result, particularly on the southern steep banks, but the depth of groundwater is critical to the slope stability.

With increased development of the area in the last few decades and increased size of dwellings and surrounding paving, the intensity of the runoff of the stormwater within Dodd's Creek has probably increased. This can result in increased erosion of the toe of the creek banks, with potential deepening of the creek bed and undermining of the creek banks. However, the deepening of the creek bed is likely to be limited in parts by the presence of the basalt bedrock.

The areas away from Dodd's Creek towards Wood Street tend to have gentle to moderate slopes. These areas are unlikely exhibit any large scale landslip and creep movement is considered to be minimal.

10 THE AREA INCLUDING THE ESPLANADE TO WOOD STREET, & SOUTH OF DODD'S CREEK TO BASS STREET (AREA 'D')

This section includes the area from the Esplanade from Cove Lane to Bass Street along the foreshore and inland to Wood Street. The Esplanade is set back from the cliff edge that overlooks the foreshore.

The aerial photograph interpretation of this area identified landslips on the eastern side of the Esplanade to the foreshore. Whilst no landslips encroach into the road reserve, in two locations, the scarp of the landslips appears to become close to the Esplanade between Cove Lane and Gordon Streets and between Cook and Bass Streets. The landslips are variable in type from arcuate slope failures, rock falls and topples, earth flow fans and minor falls with down slope movements.

BFP Consultants drilled one borehole to a depth of 3m in October 2005 in this area (BFP, Nov 2005). Very stiff, red-brown, silty CLAY(CH), presumably basaltic, was encountered to a depth of at least 3m which was the full depth explored. No basalt rock was encountered.

10.1 BOARDWALK INVESTIGATION ABOVE THE PIER

Piper & Associates conducted a geotechnical investigation for the timber boardwalk in September 1998. The boardwalk followed a pre-existing track from the Esplanade to the footpath leading to the pier access road. Borehole 1 close to the Esplanade was drilled to a depth of 9.8m. Dark brown, silty CLAY(CH) was encountered to a depth of 5m, whereupon remnant rock structures were present with the clay to a depth of 7m. Below 7m, completely weathered BASALT(CW) was encountered with visible remnant rock structure, becoming highly weathered toward the full depth explored of 9.8m. A further 4 handauger holes were drilled along the proposed boardwalk.

The borehole at the top of the slope revealed 9.4m of very stiff dark grey-brown clay, which is a residual clay derived from the weathering of basalt. Several of the lower samples had a distinctive basaltic texture. No trace of hard or moderately weathered basaltic rock was found.

The hand augering went to depths of between 1.0m and 1.7m. The samples were fairly uniform, very stiff, dark grey-brown clays with some variegation and minor changes of colour. Some showed basaltic texture. The minor content of quartz sand noted in the surface soils was completely absent, apart from in the highest auger hole (HA-A), where the top sample at 0.7m depth contained a minor content of rounded fine quartz grains.

The sub-surface work has found very stiff basaltic clay to a minimum depth of between 1.0m and 1.7m on the slope. The thickness of more than 9.4m of basaltic clay found at the summit of the slope indicates that the thickness of clay down the slope might be at least 9.4m. The absence of the hard basaltic rock detritus on the slope suggests that such rock will, at a minimum, be of moderate depth, but there is a lack of firm data on which to base any conclusion on the weathering profile beneath the slope.

The aerial photographs reveal a U-shaped depression down the slope and some

slope irregularity in the area to be crossed by the then proposed boardwalk. This is suggestive of a scar from an old slope failure, which had a mechanism of shear failure or flowage of basaltic clay, or a combination of these. No failed material at the foot of the slope is to be found, although such material would have been readily removed by wave action. The presence of a former slope failure here remains uncertain due to the eroded features.

No cracks or fissures in the soil were seen on the slope, nor were any notable slope irregularities found. There are no signs of any existing slope weakness.

It is possible that "*creep*", i.e. the down-slope movement of the colluvial basaltic clay in the surface zone at an infinitesimal or imperceptible rate, is taking place, but in the absence of slope monitoring over a period of years nothing definitive can be said about its occurrence.

Our site inspection of the Esplanade Road itself did not reveal the presence of major ground movement although there is one location near Gordon Street where there are thin cracks in the road surface running parallel to the escarpment. These cracks are possibly due to movement within the escarpment but could also possibly be attributed to other causes such as trees.

Movement was also possibly detected in the area of Cove Road adjacent to the tributary to Dodd's Creek.

There are also a few confined areas away from the Esplanade where the slope increases to greater than 20% and in the south east where Bass Street and the Esplanade meet the slope becomes greater than 20%. These areas are unlikely to exhibit large scale movements. However, creep movement in these areas can not be precluded.

As with the area between Dodd's Creek and Wood Street, the majority of the area west of The Esplanade is generally gently to moderately sloping, especially to the north of Cook Street. These areas are unlikely to exhibit any large scale landslip and creep movement is considered to be minimal.

11 COOK STREET TO THE GOLF COURSE (AREA 'E')

There is a residential area that is inset into the northern boundary of the golf course and bounded by Bass Street to the north. The properties in this area are well developed with houses on nearly all of the properties. Although there are trees throughout the area there are areas that have been cleared of trees and the natural slopes have been altered in several locations with features such as retaining walls.

Minimal previous geotechnical investigation information was available for this area and there are no reported landslips in the area.

The area is undulating and typified by moderate slopes increasing to steep along the slopes of a series of ridges. The geological map of the area indicates that the area is partially underlain by Quaternary Age sands, silts and clays. Observations of road cuttings in the area confirmed this geology with sands of at least 1.0m deep observed in several locations. It is possible that the ridges are a series of sand dunes or they are basalt hills overlain by Quaternary sands. However, neither of these stratigraphies has been confirmed.

Signs of creep such as leaning trees were observed on the steep sides of the ridges at several locations indicating the potential for further creep movement. However, no significant signs of movement were observed.

In our opinion, there is likely to be little likelihood of a slope failure occurring within this area, although creep movement could occur, especially along the steep slopes of the ridges.

The area between Cook Street and Bass Street tends to have gentle to moderate slopes. This area is unlikely to exhibit any large-scale landslip and any creep movement is likely to be minimal.

Plate 11.1: Steep Slope below Ridge

12 DOUBLE CREEK AREA (AREA 'F')

The Double Creek area extends from Double Creek in the west to the golf course in the east and from the southern coastline to Cook Street. The topography of this area is highly variable.

Minimal investigation has been conducted to date in this area and as such there is little information on the landslips that were identified as part of this investigation. Should detailed information on any of these landslips be required then it is recommended that further investigation be carried out for each particular landslip.

12.1 GEOLOGY AROUND DOUBLE CREEK

As with a majority of the Flinders area, the geological map identifies this area as being underlain by soils weathered from the basalt of the Lower Tertiary aged Older Volcanics. At the time of the preparation of this report there were no records of boreholes conducted in the area so the depth to rock is unknown.

Along the coastline limestone breccias are noted in several locations overlying the basalt. This was confirmed on site with several outcrops of limestone within the cliffs.

Plate 12.1: Exposed Limestone Breccias

In general the cliffs and creek beds in these areas are overgrown with vegetation and little basalt bedrock was observable. However, around the mouth of Double Creek basalt outcrops were visible in varying degrees of weathering.

12.2 TOPOGRAPHY AND SLOPE INSTABILITY IN DOUBLE CREEK AREA

The slopes in the Double Creek area can be separated into four distinct types as discussed below.

Cliffs

The cliffs along the southern coastline are very similar to those along the eastern coastline in the vicinity of Spindrift Avenue and The Esplanade. The cliffs tend to have an average slope of approximately 70%. However there is a large variability in the cliffs ranging from as little as 25% up to greater than 100%. The cliffs are typified by small shallow slumps and numerous erosion gullies.

There were several minor landslips observed with widths in the order of 20-30m. In addition there were two large slips, one with a width of approximately 70m and the other with a width of approximately 100m.

These landslips typically had evident scarps. However the zone of accumulation was generally not present, most probably due to wave erosion of the cliffs.

There are numerous leaning trees along the cliffs and narrow cracks were observed in the surface of Golf Links Road where the road was in the vicinity of the cliffs. A possible tension crack was observed in vicinity of the larger landslip and a recent slump was observed within the scarp of that slip.

There is significant evidence that movement is still occurring within the cliffs. This movement is most probably predominantly creep. However, larger scale arcuate landslips can not be ruled out, especially in the vicinity of the two larger landslips.

As well as the potential for landslides along the cliffs there is potential for toppling and block failures of the cliffs in the vicinity of the limestone breccias.

Creek Banks

The creek banks of Double Creek from its mouth north to Double Creek Road show significant signs of instability. The creek itself was generally inaccessible by foot, however observations from the nearby properties indicated numerous slumps within the creek itself and a significant creep zone above the creek banks. In particular, there were two vacant properties in between Glenvale Road and the creek where the lower reaches of the property showed significant signs of creep, including hummocky and boggy ground.

In addition, a property near the mouth of the creek had evidence of a landslip with a width of approximately 65m. The scarp and zone of accumulation of this slip were evident although there appears to have been some earthworks around the scarp by either the existing or previous owners of the property. There are several large pine trees to the rear of the scarp that are leaning away from the scarp, possibly indicating that some movement has occurred during the life of the trees.

There are possibly other slips and scarps along the banks of the creek. However at the time of the investigation these areas were inaccessible.

Escarpment Area

There is a large escarpment that extends from near the coast at the southern end of King Street and runs parallel to Double Creek in a north-westerly direction until No. 4 Glen Road where it turns toward the creek in a westerly direction an eventually joins the creek bank at No. 6 Vale Street.

The escarpment is tiered into several terraces with the main upper escarpment as mentioned above and several smaller lower escarpments. The upper escarpment tends to have a slope in the order of 30-40% with localised areas increasing to 50%. The lower escarpments tend to have similar slopes. The benches in between the escarpments tend to be much flatter with slopes in the order of 0-10%.

There are three large possible to probable past landslips associated with the upper escarpment while the lower escarpments have less evidence of landslip. No detailed investigation has been conducted of these landslips. However, the field observations are included below.

The first probable past landslip is to the south of Glen Road. This slip has a width of approximately 180m and extends over several properties. The general direction of the slip is to the south. The scarp extends from No. 16 Glen Road to No. 82 King Street while the zone of accumulation possibly extends as far south as No. 92 King Street. In the vicinity of the scarp there were numerous leaning trees while downslope from the scarp the ground was hummocky and there were boggy zones. There is at least one dwelling within this probable past landslip. The age of the landslip is unknown but there is evidence that some movement, possibly creep as a minimum, is still occurring.

The second probable past landslip is to the west of Glen Road. This slip has a width of approximately 150m and extends over at least 10 properties. The slip forms a large bowl with a general direction to the south-west. The scarp extends from No. 1 Vale Street to No. 6 Glen Road in an easterly direction and then to No. 14 Glen Road and No. 18 Glenvale Road in a southerly direction. The zone of accumulation covers the southern part of Vale Street with several properties within the zone. Considerable development has occurred within the landslip so it is possible that evidence of the landslip has been removed and the slopes modified. However, there are still hummocky zones and leaning trees evident at several locations. This probable past landslip has the potential of affecting several dwellings.

The third probable past landslip is to the south of Double Creek Road and to the rear of Nos. 2 – 6 Vale Street. This slip is smaller than the above two slips with a width of approximately 80m. The slip is generally located within one undeveloped property identified as No. 21 Double Creek Road. The scarp forms a bowl around the north-east of the property and approaches the rear of Nos. 4 – 6 Vale Street and No. 39 Glenvale Road. The zone of accumulation possible extends to Double Creek. There is no development within. However, the houses within the properties to the rear of the scarp have the potential to be affected if the scarp regresses.

The age of these landslips is unknown but does not appear to be recent. There is evidence that some movement, possibly creep as a minimum, is still occurring.

Above the Escarpment

The areas above and away from the escarpment are typically gently to moderately sloping and show minimal signs of slope instability.

12.3 Conclusions for Double Creek Area

The different areas within the Double Creek Area are each affected differently by landslip varying from significant movement in the vicinity of the cliffs, creek and upper escarpment to minimal movement above and away from the upper escarpment. Each of the different areas should be treated on a case by case basis.

Cliffs

There are no houses in the immediate vicinity of these slips, with the main amenities being Golf Links Road and the golf course.

The field study identified numerous locations where movement may still be occurring. At this stage this movement is expected to have minimal impact on the residential properties. However, Golf Links Road and the golf course have the potential to be affected should the movement continue.

Plate 12.2: Scarp with Active Erosion and Movement

Should further development be required in the vicinity of the cliffs, then a high level of geotechnical investigation is recommended.

Creek Banks

The properties along the banks of the creek show a moderate level of development with approximately half of the properties having existing dwellings. None of the dwellings were inspected for evidence of damage due to slope instability. However

where these houses are in the vicinity of the creep affected zone or any existing landslips it is possible that some distress may occur in the future, if it has not already occurred.

Future development on these properties can be expected to be similarly affected without appropriate development constraints and therefore a high level of geotechnical investigation is recommended prior to such development occurring.

Escarpment Area

Significant development has occurred within the escarpment area. The houses within this area were not inspected but there is a possibility that some of the houses have already some evidence of damage due to slope instability. There is a possibility that houses in this area will be affected to some extent by future movement, especially those either within or in the vicinity of the existing landslips.

Future development on these properties can be expected to be similarly affected without appropriate development constraints and therefore a high level of geotechnical investigation is recommended prior to such development occurring.

Above the Escarpment

The areas above and away from the escarpment, especially to the north-east of Glen Road and Lee Grove are unlikely to exhibit any large scale landslip and creep movement is considered to be minimal.

13 PREVIOUS EROSION MANAGEMENT OVERLAY

The Mornington Peninsula Planning Scheme includes an Erosion Management Overlay (EMO) that has two schedules. : The classification ‘EMO1’ within the EMO relates ‘Erosion Prone Slopes’ while ‘EMO2’ relates to ‘Unstable Slopes’. This overlay was translated into the Planning Scheme from former Planning Schemes applying in the area that had their genesis in the Westernport Regional Planning Authority’s “Conservation Plan” for the southern Peninsula. The “erosion prone slopes” and “unstable slopes” classifications were based on studies that are referred to in Environmental Resources of Australia (1974) A Natural Systems Study of the Southern Mornington Peninsula,.

The EMO was inspected for any EMO1 or EMO2 classifications within the study area, however none were identified.

14 CONCLUSIONS AND RECOMMENDATIONS

The Flinders area is characterised by geological and geotechnical issues and topographic features that affect the stability of the foreshore area. The major features affecting the slope stability are:

1. Pre-existing slope failures, mostly ancient, although some more recent.
2. Variably steep slopes from gentle to very steep
3. The often considerable depth of the residual highly plastic clay overlying the extremely and deeply weathered basalt. However, the depth to the basalt does vary
4. Heavy rainfalls over a sustained period
5. The direction of the slope
6. Undermining of the toe of the slope by construction or erosion
7. The placement of fills and cut and heavily loaded structures
8. The height of the slope
9. Mostly uncontrolled discharge of stormwater on the ground areas and road gutters, soakage pits and the use of septic tanks often with absorption trenches to raise the groundwater.
10. The presence of underground services that can be a source of water ingress
11. An accumulation of surface runoff on roads
12. Seismic activity

In recent times, there have been no large documented landslips in the study area, although there is considerable evidence of creep movements and smaller slope failures. There is evidence of ancient large landslips in the study area

Appropriate management controls are required to ensure that no significant landslips occur within the study area. The likelihood of a significant landslip could increase if uncontrolled development should occur.

The geology in the area of the foreshore is relatively consistent across the study area and with residual highly plastic clays weathered from the underlying Tertiary aged basalt. At the southern end of the study area, there is limestone between the basalt layers.

It is important to understand that the assessment to date is to determine the zoning of landslip susceptibility. It does not consider the hazard of the landslip, which can change over time and with the particular land use of a site, or the risk of the landslip which involves an assessment of the potential damage to persons or property after accounting for temporal, and spatial probability and vulnerability. See Appendix D for terminology.

The purpose of the study is to define areas for appropriate geotechnical investigation across the study area alone. Furthermore, debris flows or other issues have not been considered and should form part of a detailed risk assessment for a particular property.

14.1 TYPES OF LANDSLIPS

The landslips are mostly of four types:

- Rotational Landslip
- Rockfall and possible Toppling Failure
- Earth Flow
- Creep

The types of the landslips are discussed in Appendix E.

14.2 RATIONALISATION FOR THE LANDSLIP SUSCEPTIBILITY CLASSIFICATION

The selection of the zones for the particular classifications are based on the following criteria in order of importance:

- Presence of pre-existing slope failure
- Documented or anecdotal evidence of movement from site inspections, maps and aerial photographs
- The slope of the land
- The depth of the groundwater
- The height of the slope
- The direction of the slope
- Other factors such as the potential for toe erosion.

14.3 PROPOSED LANDSLIP SUSCEPTIBILITY ZONES FOR THE FLINDERS FORESHORE

The geotechnical investigation level required for the different zones of landslip susceptibility has been determined. The survey and inspection from the roads and aerial photography are not sufficiently accurate to define the precise extent of each of the zones. Therefore, the nominated boundaries are based on limited information. In most cases, a conservative approach has been adopted with a buffer of approximately 20m applied between any identified landslips and the zone boundaries.

The classification is not to restrict development on any lot. The purpose is to define the extent of geotechnical investigation required based on defined criteria. It is considered possible that the detailed geotechnical investigation and risk assessment may reveal that some areas are classified conservatively and the risk of landslip is less than the limited interpretation to date has revealed. A review of the classifications should be conducted after a period of 5 years to include the investigations conducted over the next few years. The Council should maintain an inventory of geotechnical investigations conducted within the study area.

It is important that the owners understand that lots classified as 'Higher level of Investigation" of landslip may not indicate that the lot is in imminent risk of landslip, but does indicate that in certain unfavourable circumstances, a landslip could occur and creep movements may already be occurring and is therefore susceptible to landslip. Furthermore higher risk does not preclude development of these lots, but needs to be considered in the development.

The proposed classification system adopted is as follows:

Low Susceptibility of Landslip – These areas are shown as 'green' on the plan showing the areas of 'Low Level Investigation Requirements', see Figure No 1, Appendix B. The dwellings or structures located within these green areas need not consider slope stability issues in detail, except to the extent as nominated by Australian Standard 2870-1996 *Residential Slabs and Footings – Construction* and providing that the development does not precipitate unstable slope conditions. Slope stability issues can be restricted to a site inspection and possibly, a limited geotechnical assessment

Medium Susceptibility of Landslip - These areas are shown as 'yellow' on the plan showing the areas of 'Medium level Investigation Requirements', see Figure No. 1, Appendix B. In this area, a more detailed geotechnical investigation is required consisting of deeper boreholes, piezometers, appropriate sampling, limited geotechnical testing, slope stability analysis and reporting. Peer review and formal risk assessments are not required.

Higher Susceptibility of Landslip - These areas are shown as 'red' on the plan showing the areas of 'High Level Investigation Requirements', see Figure No. 1, Appendix B. These areas are considered to be the highest risk of landslip within the study area. It emphasised again that it does not preclude any development in these areas nor does it always indicate that a landslip is evident. However, it does indicate that slope stability needs to be seriously considered in the geotechnical design and on-going management of the sites.

In these areas, a detailed geotechnical investigation is essential. The geotechnical investigation will need to consist of deep boreholes, appropriate sampling and insitu testing, geotechnical laboratory testing, slope stability analysis and reporting, risk assessment and an on-going site management plan.

The geotechnical requirements for each of the classified areas are shown in the following section.

14.4 GEOTECHNICAL INVESTIGATION REQUIREMENTS FOR EACH CLASSIFICATION

The geotechnical investigation relates to the requirements for slope stability and the other geotechnical issues such as fill and soil reactivity need to be considered as well.

Low Level of Investigation
The geotechnical investigation should consist as a minimum of the following:

- Site classification in accordance with AS2870- Residential Slabs and Footings
- 3 boreholes to a typical depth of 2m

- Appropriate sampling
- A site inspection by an experienced geotechnical professional to assess whether there are any slope stability issues and a statement to this effect should be included in the report.

Medium Level of Investigation
The geotechnical investigation should consist of at a minimum, the following:

- Develop a site history from previous owners
- Review the aerial photographs and any other relevant literature
- At least 3 boreholes to a minimum depth of 5m but may need to be considerably deeper on some sites
- Appropriate undisturbed sampling, Standard Penetrometer testing and coring of the rock, if encountered
- Appropriate geotechnical testing in a NATA accredited soil laboratory to confirm the geotechnical shear strength design parameters, at least by established correlations
- Computer modelling of the slope with the imposed structures, fill and cuts to determine that there is an adequate factor of safety for the proposed development
- Conduct a detailed inspection of the site for any signs of movement or other geomorphological features
- Reporting and discussion of any site restrictions or on-going site management as required by the geotechnical engineer. The analysis and reporting to be conducted by an experienced geotechnical engineer or engineering geologist who is experienced in slope stability assessments. Appropriate geotechnical declarations are required

High Level of Investigation
A detailed and comprehensive geotechnical investigation is considered to be mandatory in these lots. The geotechnical investigation should consider at a minimum, the following:

- Develop a site history from previous owners
- Review the aerial photographs and any other relevant literature
- Assess the likelihood of any pre-existing slope failures on the site, even if disguised by onsite developments and erosion
- Conduct a detailed inspection of the site for any signs of movement or other geomorphological features
- Conduct deep and detailed geotechnical investigation
- Drill at least 3 boreholes to a minimum depth of 12m (but may need to be greater) with appropriate undisturbed sampling and insitu testing
- Conduct appropriate geotechnical testing in a NATA accredited soils laboratory and may typically consist of direct shear tests, appropriate triaxial compression tests, Atterberg limits and others
- Conduct a computer slope stability assessment of the site including the proposed development, any cuts or filled areas
- Conduct a quantitative risk assessment of the site in accordance with the AGS(2007) procedures. The robustness of the risk assessment for the proposed development for the particular geotechnical conditions needs to be considered
- Develop an on-going site management plan including consideration of site creep, stormwater and sewerage disposal and implications on the slope

stability, any vegetation removal and the impact or restrictions on any works at the toe of the slopes.

- The assessment should be approved by an experienced geotechnical engineer who is a registered building practitioner, NPER accredited and experienced in slope stability. In medium to higher level investigation areas, the geotechnical declaration and verification for the development, construction certificate application, geotechnical application minor impact and final structural and final geotechnical certificates should be provided.
- In most circumstances, the Council may consider that a peer review is warranted.

A typical checklist for a slope stability assessment is included in Appendix C.

14.5 SITE MANAGEMENT REQUIREMENTS

In all the areas, and in particular in the areas of medium to high levels of landslip susceptibility, development controls are required to ensure that the stability of the site does not deteriorate. The development controls should consist of (at a minimum):

- Professional geotechnical engineering advice on the site prior to starting work
- Limitations on the fills and cut slopes within the site and any retaining walls. Maximum unsupported cut depths and fill thicknesses of not greater than 2m should be battered at a slope of not greater than 1V:2H. Prior to the placement of any fill, the vegetation, rootmatter and any upper silts should be stripped and fill keyed into the underlying natural clays or sands as appropriate and compacted to a level suitable for the proposed use
- On the more sensitive sites, the depth of unsupported fills or cuts should be limited to less than 1.5m or 1m as appropriate. Deeper fills and the cuts should be supported with appropriately designed retaining walls
- Any retaining walls or structures should be drained and designed by a professional engineer
- Limitations on changes to the natural site profile
- Minimise any vegetation removal
- Control surface water and sub-surface groundwater and direct the water collected in addition to the roof and pavement runoff, into pipes to the stormwater system. The pipes should be flexible to accommodate creep or ground movements and be designed to prevent blockage and energy dissipators may be required
- Avoid structures that are sensitive to movement, such as pools and spas
- Consider carefully the location of the soakage pits and any absorption trenches
- Specific details are often required for water retention structures such a swimming pools, spas, and water tanks. Depending on the site, these structures may need to be piled or with foundation designed to accommodate movement. An under-drainage system is often needed

Within some lots, the risk of landslip is higher on some sections than others. The development of these lots should avoid the higher risk areas.

The Australian Geomechanics Geoguides LR1 – LR5, LR7 & LR8 and LR10 are included in Appendix E. These are also downloadable from the AGS website www.australiangeomechanics.org.

If you have any questions, Lane Piper Pty Ltd would be pleased to answer your queries.

15 REFERENCES

Australian Geomechanics Society, *Landslide Risk Management*, Vol. 42, No. 1, Australian Geomechanics March 2007.

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