Isle of Wight Council

Ventnor to Niton Options Study

Undercliff Drive Geotechnical Options Appraisal

December 2009

Halcrow Group Limited

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Executive Summary

This geotechnical assessment report presents a range of options for maintaining a viable A-grade route through the western Undercliff, between St. Lawrence and Niton. The western section of the Undercliff is particularly vulnerable to ground movement and episodic landslide events due to the effects of coastal erosion and excess groundwater levels. As a consequence, the impact of land instability along this section has been significant, resulting in the need for regular road maintenance, traffic management and route realignment where the road has been breached in the past, and most recently in 2001. Future damage due to land instability is anticipated to have a significant impact on the integrity and future sustainability of Undercliff Drive.

The assessment presented herein has involved review of geotechnical information and site monitoring data collected by the council and their consultants from a previous phase of works between 2001 and 2006, and by the council since 2006.

For the purposes of this assessment, sufficient existing geotechnical and site monitoring data are available to construct preliminary ground models for five locations where ground movement has caused rupture and/or settlement of the road carriageway. One of these areas, Beauchamp, was subject to emergency road re-alignment in 2002 following a major landslip in March 2001. This area is included in the review to assess the performance of the scheme and ground stability since construction, as this provides valuable information and experience in determining remedial options for other areas/locations affected by land instability.

Four areas/locations are identified in this assessment requiring remedial works to maintain the serviceability of the Undercliff Drive in its current condition. Two of these sites have been identified at risk from the impacts (undermining) of retrogressive mudslides on the downslope side of the road. In these cases, patch and mend of the roadway on its own is unlikely to provide an effective solution in the short term; local structural improvements in the form of soil nails and piles will be needed to extend the life of the road and restore two-way flows.

The stabilisation and road improvement options presented for each site include:

- No active intervention: continuation of low cost patch and mend solutions.

- Minimal intervention: Installation of localised mitigation measures to reduce the impact of shallow movements and improve the sustainability of the road in its current state.
- Structural intervention: Installation of engineering options within the current road alignment to reinstate 2-lane flow, reduce the impact of shallow ground movement and improve the sustainability of the road.

The options appraisal considers the potential negative and positive impacts of each option and presents outline costs associated with their implementation. This appraisal should be used to inform the economic assessment of the potential inland road schemes.

It is recommended that any scheme adopted for Undercliff Drive should be undertaken in conjunction with a landslide monitoring and management plan designed to reduce the risk of potential larger landslides causing harm to the road users. Specific recommendations are provided for regular walk-over surveys, updating of the landslide geomorphology mapping and continued investment and maintenance of the geotechnical monitoring systems installed at these sites.

1 Introduction

1.1 *Context*

The Isle of Wight Council (IWC) is currently reviewing options to retain a sustainable traffic route between Ventnor and Niton on the south coast of the Isle of Wight. The route along Undercliff Drive (formerly the A3055) has provided a strategic transport link which connects Ventnor with St Lawrence, Niton and the west Wight, and Bonchurch and Shanklin to the east. The A3055 also provides an important route for Island Tour Buses and tourists wishing to visit numerous areas of outstanding beauty and other attractions within the Undercliff.

The existing highway has been subjected to ground movement and a number of landslide events in recent times which has resulted in temporary closures and road realignment works. One section of the road has been reduced to a single lane carriageway as a result of a landslide event in the winter of 2000/01. Ongoing ground movement and landslide hazards are anticipated to have a significant impact on the integrity and future sustainability of Undercliff Drive. Previous work carried out by consultants suggested a preferred option comprising large scale engineering works along Undercliff Drive including extensive drainage measures in the natural woodlands. It is understood that this is no longer the preferred option and the IWC wish to review other, less intrusive and costly, options to retain a sustainable traffic route.

Halcrow Group Limited was commissioned by the Isle of Wight Council to investigate options for:

- Sustaining and maintaining a viable A-grade route through the western Undercliff which is vulnerable to ground movement and episodic landslide events, and
- Identifying alternative options and required highway improvement works for a traffic route landward of the Undercliff to connect the strategic road network and the A3055 to Ventnor, Niton and Whitwell.

This report provides a geotechnical appraisal of the potential stabilisation and road improvement works to identify preferred options for Undercliff Drive. These road improvement works have been indentified as preliminary options which may extend the serviceable life of the existing road accounting for the engineering and

environmental constraints that have led to the dismissal of previous schemes. These include restricting the area of engineering stabilisation works to within the working area of the road at each site and not including drainage options previously rejected on environmental grounds.

1.2 Scope of this study

The broad scope of works undertaken comprises:

- Review of existing Undercliff Drive consultant reports and monitoring data provided by IWC
- Updating/validation of existing ground models of sections of the Undercliff Drive previously impacted by ground movement informed by recent site monitoring data on ground movement and groundwater levels
- Site inspection/walkover of five sites and adjacent areas (where access was possible), where movement has caused rupture or settlement of the current roadway, to assess existing conditions and collect evidence of any deterioration across the site which may impact on the stability risk
- Consideration of future options for the road including:
    a. Patch and mend maintenance of the road to maintain its current function
    b. Localised stability improvements to sustain and extend the serviceable life of Undercliff Drive
    c. Managed reduction of the road use such as single lane working, closure of high risk and breached sections and eventual down-grading of the road to 'Greenway' status

The sources of information used in the compilation of this report are described in the text and include consultant reports, maps, documents and data provided to Halcrow by the council and third parties, and from Halcrow's own records and knowledge of the Undercliff. It should be noted that, where Halcrow has relied upon information from third parties, Halcrow accepts no responsibility for the accuracy or completeness of that information.

2 Background

2.1 *Site location*

The Undercliff Drive (formerly the A3055) is located on the south coast of the Isle of Wight in an area known locally as the 'Undercliff'. The Undercliff extends 1km landward from the shoreline and extends 12km from Luccombe in the east to Blackgang in the west. It represents one of the deepest and largest ancient landslide complexes in the UK. Undercliff Drive is located within the western part of the Undercliff and forms the main transport link between Ventnor, St Lawrence, and Niton, as well as forming a section of the strategic road network linking Ventnor to the southeast and southwest coasts of the Island. The road also services a number of local businesses and tourist attractions including numerous nature reserves, Isle of Wight Glass and the Botanical Gardens, which are important to the local economy.

2.2 *Regional geology*

The Undercliff is situated on the southern limb of the Southern Downs of the Isle of Wight and comprises a sequence of interbedded sedimentary rocks which dip seaward by about 1.5° – 2°. The sedimentary rocks were laid down in the Cretaceous period, approximately 80 to 120 million years ago. Parts of the Lower Chalk and Upper Greensand Formations are exposed in the rear scarp of the Undercliff. A summary of the key geological units is provided in Table 2.1.

This geological sequence has been heavily disrupted along much of the Undercliff as a result of deep seated and shallow ground instability with some areas of strata being lost as a result of landslides and other key geological units being displaced by large block movements.

2.3 *Geomorphology*

The Undercliff is one of the most unstable geological settings in the UK and, as a consequence, faces substantial challenges from costal instability. This instability is largely a result of the unique geological setting of the Undercliff together with its environmental history.

Whilst the exact age of the landslides is still debated it is clear by the size and their current resistivity to coastal erosion that the Undercliff landslide complex stands out as the oldest in the UK. Hutchinson and Bromhead (2002) suggest that the

current landslide systems most likely initiated some distance off the current shoreline. The shoreline of the Undercliff runs parallel with a submerged depression or valley feature, known as 'St Catherine's Deep', with its axis lying some 2km offshore and with an average sea floor depth of over 60m. Offshore seismic surveys and field data from the intertidal zone have indicated the presence of planed-off remnants of landslide blocks on the seabed, seaward of the sea cliffs.

Formation	Description
Lower Chalk	Comprising the Chalk Marl Member (Grey marly chalk with no flints) underlain by Glauconitic Marl Member (Calcareous glauconitic sand heavily bioturbated at base)
Upper Greensand	Comprising Chert Beds (Weak to moderately weak green grey sandstone to grey limestone) underlain by Malm Rock (Very weak to moderately weak green sandstone to very strong grey limestone) underlain by Passage Beds (Weak to moderately weak green brown sandstone/ siltstone with glauconitic speckling)
Gault	Very stiff dark grey to brown silty clay
Carstone	Dark grey green brow slightly silty medium to coarse sand
Sandrock	Comprising units of both permeable light to dark grey sands and sandy clays impermeable grey sandy clay units
Ferruginous Sands	A number of coarsening-upward units of dark grey sandy clays and silts passing up into fine to medium, grey-green glauconitic sands (Insole et al., 1998)

Table 2.1 - Summary geological description of the Undercliff (after Lee and Moore, 1991)

Previous studies (e.g. Lee and Moore, 1991; Hutchinson and Bromhead 2002; Moore *et al.*, 2007) suggest that the current Undercliff landscape was shaped as a result of two main phases of landsliding, which took place after the last Ice Age around 8,000-4,500 and 2,500-1,800 years ago. These periods were characterised by major changes in climate and sea level and consequent effects on marine erosion, Island wide. Although the Isle of Wight has never been glaciated the area has been subjected to severe periglacial conditions which in turn are likely to have caused the development of solifluction deposits and periglacially triggered landslides (Hutchinson and Bromhead, 2002).

The lithological and structural geology of Cretaceous rocks make the Undercliff particularly prone to coastal landsliding. Hard competent rocks such as cherts and sandstones overly overconsolidated clays which are underlain by permeable

sandstones. The Gault Formation, comprising overconsolidated clays is of particular significance, and outcrops above sea level along the central section of the Undercliff. The Gault is underlain by the Sandrock below sea level, comprising alternating sand and thin clay layers, both of which control basal sliding and the hydrogeology of the Undercliff landslides (e.g. Lee, Moore, Hutchinson, op. cit.).

Similarly structural analysis of rock joints has revealed that the exposed Cretaceous rocks are dissected by steeply dipping, orthogonal joint sets which exert a primary control on the morphology of rock masses involved in landslide events along the coastline. The large failed blocks of Upper Greensand observed along the Undercliff and beneath Gore Cliff, are dominant features in shaping the morphology of the coastline.

The geomorphology of the Undercliff was mapped over the period 1990-1995 as part of the Department of the Environment's initial pilot study of central Ventnor and the council's extension of this work to include the entire Undercliff. The maps were produced to a scale of 1:2,500 and define the landslide geomorphology and ground behaviour, and also provide guidance on future planning and development.

The key geomorphological features apparent in the study area are:

- the Chalk Downs, landward of the Undercliff, which are mostly unaffected by landsliding;
- a high near-vertical rear escarpment above the existing road which delimits the landward extent of the Undercliff which is largely formed of exposed Chalk and Upper Greensand;
- an upper-tier landslide on which the existing road is located of apparent multiple-rotational and translational blocks of Upper Greensand and Chalk, giving rise to large linear benches and steep scarp slopes, and
- a lower-tier landslide system comprising a sequence of compound and complex slides, resulting in block displacements and the development of retrogressive mudslides and associated run-out onto the shoreline.

2.4 Implications for Undercliff Drive

Undercliff Drive has been subject to ongoing ground movement and a number of previous episodes of deep-seated and shallow ground instability which have led to the temporary closure and realignment of the road in the past. The ground instability has generally been classified as slow moving 'creep' along pre-existing

shear surfaces with periods of accelerated ground movement and/or landslide events which have led to rupture and significant damage along the road network.

The present Undercliff Drive broadly follows the route taken when the road was first established some 200 years ago between 300 to 500m upslope from the shoreline. Previous investigations have identified a number of sites along Undercliff Drive that have been repeatedly affected by ground movement and landsliding in the recent past. These can be summarised as:

- **Area 1- Beauchamp:** approximately 1km east of Niton where the road was catastrophically breached by landslip in the winter of 2000-01 and was impassable by through traffic. Emergency works were implemented to realign the road landward of the active landslip headscarp.
- **Area 2- Mirables:** located to the east of Beauchamp where significant rupture and settlement of the road has occurred since 2001 due to deep-seated ground movements.
- **Area 3- Undercliff Glen:** approximately 1.5km west of St Lawrence where a previous landslide event in 1926 resulted in the relocation of the road to its present position. A large elongate mudslide occurred in the winter of 2000-01 which resulted in retrogression of a steep headscarp to within 2m of the road and tension cracking and settlement of the west bound carriageway. The west bound carriageway was closed as a consequence of this event and a traffic management system installed.
- **Area 4- Woodlands:** east of Undercliff Glen where the road has been subjected to ongoing settlement and rupture due to ground movements beneath the road.
- **Area 5- St Lawrence West**: east of woodlands where current and previous observations of cracks in the road surface have been recorded although no stabilisation measures have previously been considered.

2.5 Sources of information

Information from previous stages of the investigation and design for Undercliff Drive has been made available to Halcrow Group Limited by the Isle of Wight Council and Merrett Surveys. A list of information and data provided is presented in Appendix B. In summary, these comprise:

- Factual reports including borehole logs, geotechnical testing data and installation details for site monitoring instruments for ground investigations undertaken in areas 1-5

- Interpretative reports of the ground conditions, ground models and causes and mechanisms of instability for areas 1-4
- Groundwater, ground movement and rainfall monitoring data collected by the IWC along the Undercliff. These records include automated and hand read piezometers, automated tiltmeters and settlement cells, inclinometers and rainfall records collected at the Ventnor weather station.
- Topographic survey data for areas 1-4.
- Design reports and design drawings associated with preferred slope stabilisation schemes for areas 1-4.

In addition, a site inspection was conducted on the 30th and 31st July 2009 by a Senior Geotechnical Engineer and an Engineering Geomorphologist. The site inspection involved:

- Inspections of the previous areas of instability along Undercliff Drive to identify key landform features, observation of recent and current land instability and ground movement, and recording of any significant features and observations of change which may impact the landslide ground models and assessment of stability risk.
- Damage inspections along Undercliff Drive and recording of significant observations.

3 Area 1- Beauchamp

3.1 *Location*

Area 1, Beauchamp, is located in the western part of Undercliff Drive, approximately 0.6km east of Niton village centre, at National Grid Reference (NGR) SZ 511761.

3.2 *History of instability*

In March 2001, a major failure of Undercliff Drive occurred south of Beauchamp House, severing the road between Niton and Ventnor. Prior to this landslide, distress had previously been noted in the road in this area. Past remedial works had included the installation of stone buttresses and gabion baskets downslope of an existing 2-3m high, 60m long retaining wall which supported Undercliff Drive at this location. During the weekend of 31 March 2001, the road was breached at this elevated location (High-Point Rendel, 2001).

3.3 *Remedial measure undertaken*

A new section of road was constructed north of Beauchamp House, 250m in length, with new junctions connecting to a campsite in the west and to the old road in the east, leading to The Orchard (Orchard Close and Orchard Dene). To accommodate the emergency works, Beauchamp House and Beauchamp Cottage were acquired by the Council and demolished. Both structures had been previously affected by ground movement. Beauchamp Cottage was demolished to make way for the realignment of the A3055.

No drainage or engineering slope stabilisation measures were undertaken in conjunction with the construction of the road. Geotextile fabric was incorporated into the road construction to accommodate small tension cracks, if any were to open up, and avoid reflective cracking at the road surface.

3.4 *Site inspection 2009*

During a walkover of the new length of road in July 2009, no evidence of cracking or change in gradient of the new section of road surface was evident (Plate 1). Walkover inspection of the 2001 landslide headscarp identified that localised ground movement is still occurring both around the headscarp and lower down the slope within the landslide body (below the grounds of The Orchard) and this was observed in December 2008 (Halcrow, 2008). The evidence includes open tension

cracks, dislevelment and gross subsidence of the ground, upslope recession of active land instability and disrupted 'natural' drainage associated with mass instability of the entire lower Undercliff. Features are shown on Figure 1.2, Ground Behaviour – Area 1.

3.5 Ground conditions appraisal

3.5.1 Geomorphology

The geomorphology of the Undercliff at Beauchamp is illustrated in Figure 3.1 and summarised in Table 3.1 below.

Feature	Description
Lower cliff active mudslides	The lower cliff slopes consist of a series of active mudslides associated with the long term degradation of a compound landslide of considerable age. The mudslides are largely seasonally active and associated with elevated groundwater levels and longer term marine erosion of the coastal cliff frontage.
Gault clay scarp slope	Immediately above the lower cliff slopes is a large, exposed escarpment of Gault clay. The steep scarps are degraded with evidence of shallow mudslide failures, rotational failures and localised ground instability particularly in wet periods.
Translational landslide benches and scarp slopes	Above the Gault clay scarp slope is a series of landslide bench and scarp features indicative of deep seated rotational instability where the current road is located. This bench and scarp topography runs parallel to the current coastline with localised areas of soft ground.
Landslide headscarp	A large landslide headscarp is evident immediately beneath the old road at Beauchamp. This feature developed during the landslide activity in March 2001 which ultimately led to the loss of the previous road and the realignment of the road to its present location. The geomorphological evidence suggests that the movement was caused by development of a retrogressive mudslide from the Gault clay escarpment.

Table 3.1 Summary key geomorphological features, Area 1

3.5.2 Material description

Ground investigations were undertaken at Area 1 as detailed in Table A1 in Appendix A.

Above the current alignment of the road, ground conditions encountered in BH3 (Soil Mechanics Ltd, 2001) were as follows (metres below ground level):

- Topsoil 0.00m to 0.20m
- Brown sandy clay 0.20m to 1.20m
- Upper Greensand debris? 1.20m to 6.11m

  Described as clayey gravel and cobbles of sandstone
- Gault clay 6.11m to 47.74m

  Typically stiff grey-black clay with lithorelicts of weak mudstone becoming moderately weak grey-black mudstone below 14.36m. Widely to very widely spaced fractures, smooth, planar, occasional polishing.
- Carstone 47.74m to 52.30m (end of borehole)

  Grey-brown locally orange-brown clayey medium-grained sand

Similar sequences of materials were encountered in other boreholes throughout the area.

Below the current alignment of the road and above the headscarp of the 2001 landslide, BH1 (Soil Mechanics Ltd, 2001) encountered "landslip" materials to 10.63m bgl and Gault clay to the base of the borehole at 40.30m bgl. Other exploratory holes in this area, BH1/1/04 and BH2/1/04, recorded Upper Greensand Debris to 14.75m bgl (67.55mAOD) and 8.2m bgl (67.88m AOD) respectively, Gault clay debris to 19.00m bgl (63.30m AOD) and 12.45m bgl (63.63mAOD) and Carstone at 47.90m bgl (34.40m AOD) and 43.05m bgl (33.03mAOD).

Within and adjacent to the body of the 2001 landslide, a number of exploratory holes were drilled. BH3/1/04 and BH4/1/04 encountered the following materials:

- Topsoil and Upper Greensand debris (typically firm to stiff sandy gravelly clays and sand, gravel and cobbles of weak sandstone) to 8.60m bgl/8.30m bgl, respectively

- Gault clay debris in BH3/1/04 only (stiff fissured clay with many lithorelicts of mudstone) to 9.25mbgl
- Gault clay (very stiff becoming hard fissured dark grey clay with closely to widely spaced fissures) to 25.90m bgl/25.40m bgl
- Carstone (mixed sands and clays) to 30.20m bgl/30.50m bgl (end of borehole)

3.5.3 *Ground movement*

Analysis of the historical and recent subsurface inclinometer data confirms movement at the following locations and depths:

Inclinometer reference	Installation depth	Movement depth	Movement rate (mm/yr)	Monitoring period	Stratum
BH1, west of Beauchamp House	40.30m	Installation problem- casing misaligned	-	-	
BH2, near western edge of landslide	38.40m	10.0 – 12.0	60	24.4.01 – 17.7.02*	Firm-stiff grey/black SILT/CLAY with lithorelicts of weak mudstone
BH3, north of realigned road	52.30m	16.25 – 17.1	28	15.5.01 – 8.12.03	Mod weak grey black MUDSTONE with widely spaced thin beds of firm to stiff grey black clay (GC)
BH1R, west of Beauchamp House	Approx 21m	13.5 - 14.25	33	28.12.02 – 5.10.04	From BH1: Weak black grey MUDSTONE (GC)
BH1/1, north of Little Orchard	40.0m	No significant movement shown – possibly slight movement at 15-16mbgl	-	17.7.02 – 6.10.04	
BH1/1/04	50.0m	No significant movement shown	-	-	-
BH3/1/04	30.20m	No data available	-	-	-

Table 3.2. Inclinometer data, Area 1

* Data only available for BH2 over the period shown, further monitoring may have taken place

3.5.4 *Groundwater monitoring*

Groundwater monitoring has been undertaken over some years at Area 1. The maximum and minimum water level results for each instrument are shown in Table 3.3 below.

Exploratory hole and instrument	Ground level (mAOD)	Tip level (mbgl)	Monitoring period	Maximum groundwater level (mAOD)	Minimum groundwater level (mAOD)
Automatic					
BH2/1/04 VW1*	76.21	10.00	19.8.04- 31.8.07	71.78	71.70
BH2/1/04 VW2	76.21	24.50	19.8.04-24.3.08	53.23	53.13
BH2/1/04 VW3	76.21	47.00	18.8.04-11.4.07	29.27	29.21
BH4/1/04 VW1#	55.71	6.50	19.8.04-11.4.07	49.64	49.52
Manual					
O1/1	83.65	13.90	21.11.02-6.7.04	76.49	75.65
O1/2	83.65	17.05	21.11.02-6.7.04	72.56	72.25
WS1/1/04	59.70	3.90	1.9.04-19.12.05	57.15	56.66
WS2/1/04	60.97	6.50	1.9.04-19.12.05	56.14	55.69

Table 3.3 Groundwater monitoring results, Area 1

3.6 *Preliminary ground model*

The preliminary ground model for Area 1 is shown on Figure 3.3. This shows a cross-section through Area 1 down to the Gault clay scarp.

Historically, movement has been observed at 16.25 to 17.1mbgl in BH3 north of the new road, although there is no current evidence of distress to the new road. The ground model shows the existing road located on upper landslide benches and across one scarp slope. The bench comprises Greensand and Gault clay landslide debris, overlying Gault clay. Inclinometer records for BH3 from 2001 to 2003 show movement at 16.25m to 17.1m bgl (67.75m to 66.9mAOD, assuming a ground level of 84m AOD) with movement in the upper part of the Gault clay (movement at 30.6m to 31.5m above the base of the Gault clay). The inclinometer in BH3 extended to a depth of 52.3m bgl into the Carstone and movement was not recorded below 16.25m to 17.1m bgl.

The landslide bench downslope was the location of the former Beauchamp House. The bench comprises Upper Greensand and Gault clay landslide debris, overlying Gault clay. Movement was recorded in BH1R at 13.5m to 14.25m bgl (65.0m to 64.25mAOD, assuming a ground level of 78.5m AOD) in the upper part of the

Gault clay. BH2/1/04 encountered Carstone at 33.03mAOD – assuming the same elevation for the Carstone below BH1/BH1R gives movement at 31.2 to 32.0 m above the base of the Gault clay). This elevation is similar to the elevation of movement described above and would appear lithologically controlled. Movement is anticipated to be triggered by a combination of toe-unloading and elevated groundwater levels.

Within the slipped mass of the 2001 landslide, no movement data from the inclinometer in BH3/1/04 was available to Halcrow. Movement was recorded in BH2 on the western flank of the landslide in 2001 to 2002 at a depth of 10.0-12.0m bgl. This corresponds to an elevation of 16.0 to 18.0m above the base of the Gault clay.

Bromhead *et al.* (1991) found for a landslide at Gore Cliff (west of Niton) that movement typically occurred some 18m above the base of the Gault clay. At Beauchamp, it appears that there are two horizons within the Gault clay that movement has occurred: at a lower level of 16 to 18m above the Carstone (corresponding with the elevation noted by Bromhead *et al.* 1991) for the 2001 landslip and at a higher elevation of 30 to 32m above the Carstone for the landslide benches closer to the Undercliff rear scarp. Note, the inclinometer in BH3 extended through the complete sequence of the Gault clay to the Carstone and did not record movement corresponding to a level of 16-18m bgl.

3.7 Remediation options

The current road at Beauchamp was constructed in 2002. As noted above, no distress is currently evident to the road, although there is evidence of ongoing instability on the Undercliff rear scarp and lower slopes below the Orchard which may in time impact the realigned section of Undercliff Drive.

No remediation options are recommended at this time, but recommendations for regular walk-over surveys, updating of the landslide geomorphology mapping and continued investment and maintenance of the geotechnical monitoring systems are recommended.

3.8 Recommendations

Recommendations for further works associated with Area 1 are included in Section 8.3.

4 Area 2- Undercliff Drive, west of Mirables

4.1 *Location*

Area 2, west of Mirables, is located approximately 1.1km east of Niton village centre, at NGR SZ 516761. The area of concern is located approximately 250m west of the driveway from Undercliff Drive to Mirables Cottages. At this location, Undercliff Drive is supported by a retaining wall to the south (seaward side) of the road, with a maximum retained height of 3m.

4.2 *History of instability*

The Undercliff Drive at Area 2 has been subject to repeated cracking, rupture and differential settlement of the road surface resulting in abrupt changes in gradient - the site is referred to by locals as the 'hump'. Cracking and bulging in the retaining wall beneath the road were also recorded in March 2001 (High-Point Rendel, 2004a). Bracegirdle (2007) reported that there has been no evidence of shallow active mudsliding in the upper tier landslides seaward of the road since 1961, although he notes that damage to the road and inclinometer measurements indicate gradual movement of deep-seated shear surfaces (15 to 20m below ground level) on a regular basis. He records that a cottage in the area below the road was destroyed by landsliding in 1960/61.

4.3 *Remedial measures undertaken*

No remedial measures have been undertaken at this location, other than to patch and mend the cracks in the road.

4.4 *Site inspection 2009*

A site inspection was conducted along the road and, where safe and free access was possible, along the retaining wall immediately beneath the road (Plate 2). Areas of surface cracking and one significant change in gradient were identified along the road; these were recorded and are shown in Figure 4.1.

Arcuate tension cracking across the existing road surface marks the position of a major inter-block shear surface where differential movement and rupture has occurred; such features are common within the Undercliff and are described by Lee and Moore (1991) and Moore *et al.* 2005. Such features are characterised by lateral and vertical shear displacement (similar to strike-slip faulting) which results in differential rates of ground movement and separation between adjacent

landslide blocks. The ground forces involved in these inter-block movements are considerable and will result in sever damage to any structure or services that cross the zones of rupture.

The shear surface extends across the road carriageway and through the lower retaining wall which is also damaged (cracking and bulging) as a result of ongoing ground movement; vegetation growing from the wall has exacerbated the damage and pre-failure/collapse of the wall. Deep seated ground movement is affecting the slopes immediately beneath the wall.

Feature	Description
Lower cliff active mudslides	The unprotected costal cliffs consist of multiple active mudslide units similar to those identified in Area 1. The mudslides appear to be largely seasonally active and associated with elevated groundwater levels and longer term marine erosion of the coastal cliff frontage.
Gault clay scarp slope	Above the mudslide units, the Gault clay scarp feature identified at Area 1 is also evident, although largely degraded by landsliding and localised ground movement. These landslide features appear to be acting to unload the upper tier landslide units which comprise of a series of rotational landslide benches and associated steep scarp slopes resulting from previous deep seated instability. Retrogression of the mudslides is particularly acute in the central slope immediately below Area 2 which is acting to unload the slopes supporting the road.
Rotational landslide benches and scarp slopes	Undercliff Drive, at Area 2, is located on a rotational landslide block. There is evidence of some back-tilted slopes inland of Area 2. The slopes beneath the road comprise steep rotational landslide scarps, formed by movement downslope of the road. To the west of the site where the road crosses a lateral shear of two rotational benches resulting in dislevelment and an abrupt change in the road gradient
Undercliff rear scarp	Upslope of the road is the near vertical Undercliff rear-scarp which delimits the landward extent of coastal landslip and historical ground instability; the rear scarp is composed of Chalk and Upper Greensands (chert beds and Malm Rock).

Table 4.1 Summary key geomorphological features, Area 2

4.5 *Ground conditions appraisal*

4.5.1 *Geomorphology*

The geomorphology of the site is illustrated in Figure 4.2 and summarised in Table 4.1.

4.5.2 *Material descriptions*

Ground investigations were undertaken at Area 2 as detailed in Table A2 in Appendix A.

Ground conditions encountered in BHI2/1 drilled from the road were as follows (metres below ground level):

- Made Ground 0.00m to 1.00m
- Upper Greensand 1.00m to 11.00m approx (59.35mAOD)

  Typically beds of dark grey-green sandy silt/silty sand matrix with angular gravel of limestone or sandstone, and strong grey green glauconitic calcareous fine to medium grained sandstone, slightly to moderately weathered.

- Gault clay 11.00m to 40.00m (end of borehole)

  From 11.00 to 11.30m (59.05mAOD), 15.55m to 15.70m, 18.90 to 19.20m firm to stiff dark grey clay with matrix with many fine to coarse gravel size clasts of dark grey clay. Some clasts highly polished. Below 11.30m, typically very stiff to hard dark grey calcareous clay/very weak mudstone with a trace of shell fragments. Extremely closely to closely jointed, joints closed, surfaces generally irregular, a few polished. Weak to moderately strong siltstone recorded from 16.50m to 18.90m and 35.70m to 37.50m.

A similar sequence of materials was encountered in BH1/2/04, although the Upper Greensand materials were described as Upper Greensand debris, with underlying Gault clay debris to 12.46mbgl (58.56mAOD) over the Gault clay.

BH2/2/04 encountered similar materials: Upper Greensand debris to 5.1mbgl (58.79mAOD), Gault clay debris to 12.85mbgl (51.04mAOD) and Gault clay beneath.

BH3/2/04 was drilled 70m south of the road, within a rotational landslide bench. This encountered:

- topsoil and Upper Greensand debris (typically sand, and gravel and cobbles of weak sandstone) to 7.40mbgl
- Gault clay debris (soft to firm sandy clay to 10.55mbgl, very stiff sandy clay to 11.05mbgl)
- Gault clay (weak indistinctly thinly laminated dark grey slightly sandy mudstone, with widely spaced fractures, irregular and planar, rough, locally smooth and tight) to 25.90mbgl. Occasional laminae of sand and occasional pieces of fine siliceous gravel were recorded from 22.80mbgl.
- Carstone 25.90mm to 35.10m (end of borehole)

  Mixed sands, sandstones and clays: layers of very weakly cemented grey and grey-brown sand, grey slightly clayey to very clayey sand, firm to very stiff indistinctly fissured dark grey clay, weak to moderately weak sandstone.

4.5.3 *Ground movement*

Analysis of the historical and recent inclinometer data has recorded movement at the following locations and depths.

Inclinometer	Installation depth	Movement depth (mbgl)	Movement rate (mm/yr)	Monitoring period	Stratum
I2/1, on road		Possibly at 5.0m (unlikely given geology), 11.8-12.3m and 16.4-16.8mbgl.	17.7.02 – 6.10.04 13mm/year 2.3.05 – 24.7.08 4mm/year	17.7.02 – 24.7.08	5.0m – grey green fine SAND with sandstone fragments 11.8-12.3m –v stiff to hard dark grey calcareous clay/very weak MUDSTONE (GC) 16.4-16.8m – MUDSTONE/ SILTSTONE interface (GC)
BH3/2/4, S of road within landslide	19.95m	9.5-10.0m	3mm/year	14.1.05 – 20.5.09	Soft to firm grey brown and brown slightly gravelly slightly sandy CLAY (GC debris)

Table 4.2 Inclinometer data, Area 2

4.5.4 *Groundwater monitoring*

Groundwater monitoring has been undertaken over some years at Area 2. The maximum and minimum groundwater levels (GWL) recorded for each instrument are shown in Table 4.3 below.

Exploratory hole and instrument	Ground level (mAOD)	Tip level (mbgl)	Monitoring period	Maximum groundwater level (mAOD)	Minimum groundwater level (mAOD)
Automatic					
BH1/2/04 VW1*	71.02	9.50	2.9.04 – 28.9.05	61.80	61.71
Manual					
S2/1 Deep	83.65	29.10	20.3.02 – 6.7.04	76.70	68.62
TP3A/2/04	49.82	3.00	1.9.04 – 7.3.05	47.77	47.68
WS1/2/04	68.79	5.00	1.9.04 – 19.12.05	66.97	66.92
WS2/2/04	50.56	2.50	1.9.04 – 19.12.05	48.97	48.92

Table 4.3 Groundwater monitoring results, Area 2

* Step in data recorded in April 2005 – zero error? Relatively small (<0.05m) so all data included here.

4.6 ***Preliminary ground model***

The preliminary ground model for Area 2 is shown on Figure 4.3. This shows a cross-section through Area 2 to approx 200m downslope of the road. The model illustrates the mudslides associated with the Gault clay scarp at the southern edge of the section. These mudslides act to unload the toe of the multiple rotational-landslide system above (the upper tier of the Undercliff landslide system). The unloading combined with elevated groundwater levels act in combination to cause movement of the system which may affect the road. Depth of movement recorded is between 11.8m and 16.8m in the upper part of the landslide system (BHI2/1), at the location of Undercliff Drive, and 9.50 to 10.0m depth in the lower part of the system (BH3/2/04). The movement recorded by the inclinometers is located within the upper Gault clay layers.

Bromhead *et al.* (1991) found for a landslide at Gore Cliff (west of Niton) that movement typically occurred some 18m above the base of the Gault clay. Assuming a similar level for the base of the Gault clay in BH I2/1 as found in nearby BH1/2/04, gives the movement at this location between 26 and 31m above the base of the Gault clay. In BH3/2/04 the movement is recorded at 15.9 to 16.4m above the base of the Gault clay.

It appears that there are two horizons within the Gault clay that movement has occurred at Area 2: at a lower level of approximately 16m above the Carstone for the landslide benches seaward of the road (similar to the levels in Area 1 for the 2001 landslip) and at a higher elevation of 26 to 31m above the Carstone at the location of the road (again similar to the elevation in the Gault clay for the upper landslide benches in Area 1). Note, the inclinometer in BHI2/1 extended nearly through the complete sequence of the Gault clay (to within 3m of the estimated top of the Carstone) and did not record movement corresponding to a level of 16m above the base of the Gault clay.

The materials subject to movement are Upper Greensand debris (from previous movement events) overlying Gault clay debris/intact Gault clay.

The rate of movement is relatively slow from current monitoring records (up to 5mm per year).

It should be noted that the movements described above are based on the instrumentation and records obtained from previous ground investigations at the site. Movement has also been recorded in clay layers within the Sandrock (beneath the Carstone) at other sites along the Undercliff.

4.7 ***Remedial options***

Remedial options recommended for Area 2 include the following:

4.7.1 *Patch and mend*

This option will allow continued use of the road until a major rupture occurs or until the rate and degree of differential settlement occurs to an extent that the gradient over the 'hump' in the road is no longer suitable for vehicular use. Grounding of vehicles is already evident from damage to the road surface.

4.7.2 *Localised re-grading*

Locally the road can be re-graded to reduce the abrupt change in gradient. Use of lightweight fill will avoid loading the head of the landslide system. Incorporation of geotextile reinforcement within the base of the repair will provide a longer life to the repair, accommodating a degree of differential movement and reducing the incidence of reflective cracking at the surface of the road.

4.7.3 *Survey of the wall*

The dry stone retaining wall beneath the road at this location shows evidence of bulging and cracking. A structural survey of the wall is recommended to determine the extent of distress to the wall, its cause and whether or not it is detrimental to the performance of the wall. Distress to the wall may be a result of its age, ground movement, vegetation, dynamic loading from passing traffic, or a combination of all of these and other factors. Once the results of the structural wall survey are known, appropriate maintenance of the wall and repairs should be incorporated within the highways maintenance schedule, if needed. If the cause of the distress is in part due to ground movement, the ground model of the site should be borne in mind when options are considered i.e. the design of any repairs should be flexible and accommodate as much ground movement as possible.

Removal/trimming of vegetation growing from the wall will reduce the continued distress to the wall from roots and tree trunks and this should be undertaken on a regular basis.

Cosmetic improvements for a dry-stone wall can include pointing (incorporating weep holes and leaving some joints unpointed). Larger scale repair techniques include grouting, soil nailing, thickening the retaining wall and permanent buttressing. The option of constructing an embankment downslope would provide support to the wall, but would add additional load onto the upper tier of the landslide system and so would not be appropriate.

4.7.4 *Reconstruction of the road and retaining wall*

If the survey shows that reconstruction of the wall is required, a technology should be used which can accommodate differential ground movement. Reconstruction systems could incorporate rebuilding the wall as a dry stone wall, use of gabions or use of reinforced earth systems with a stone facing. Lightweight fill could be incorporated in the road construction and geotextile or steel strip reinforcement may be used to provide tensile reinforcement where movement can be expected to occur. Recommendations for regular walk-over surveys, updating of the landslide geomorphology mapping and continued investment and maintenance of the geotechnical monitoring systems are recommended.

4.8 Recommendations

Recommendations for further works associated with Area 2 are provided in Section 8.3.

5 Area 3- Undercliff Glen

5.1 *Location*

Area 3, Undercliff Glen, is located to the west of St Lawrence, approximately 1.6km east of Niton village centre, at NGR SZ 521761 and lies immediately west of the Undercliff Glen Caravan Park.

5.2 *History of instability*

In March 2001, the ground seaward of the road at Undercliff Glen failed catastrophically due to undermining of a retrogressive elongate mudslide, the rear scarp of which reached to within 2m of Undercliff Drive (High-Point Rendel, 2001). At the same time, a series of tension cracks were indentified on the westbound carriageway of the road surface. The road at this location has undergone several minor realignments in the past as a result of ground instability. The current alignment was constructed in 1939 (Bracegirdle, 2007).

5.3 *Remedial measures undertaken*

No drainage or remedial measures have been undertaken at this location, except general road maintenance including patching and mending of cracks in the road surface. Since 2001, the road has been reduced to single-carriageway at this location when traffic lights were installed to control vehicle flows using the eastbound carriageway only.

5.4 *Site inspection 2009*

Arcuate tension cracks were recorded on both the westbound and eastbound lanes with evidence of previous patch repairs. The tension cracks have re-opened on the westbound lane providing evidence that ongoing ground movement is continuing in this area (Plate 3). Inspection of the mudslide beneath the road revealed little evidence of any recent significant movement, although the oversteepened scarp slopes adjacent to the caravan park are continuing to retrogress locally (Plate 4).

5.5 *Ground conditions appraisal*

5.5.1 *Geomorphology*

The geomorphological map for Undercliff Glen is illustrated in Figure 5.1 and summarised in Table 5.1 below.

Feature	Description
Lower cliff active coastal mudslides	The unprotected costal cliffs consist of multiple active mudslide units similar to those identified in Area 1. The mudslides appear to be largely seasonally active and associated with elevated groundwater levels and longer term marine erosion of the coastal cliff frontage.
Retrogressive mudslide	A large retrogressive elongate mudslide can be observed immediately below the slope. The mudslide has a distinctive, near vertical, arcuate headscarp along the road and down slope along the boundary of the caravan park. The mudslide has formed a channelised flow track downslope which runs out over the beach forming a debris lobe at the toe.
Rotational landslide benches and scarps	Observed above the major Gault clay scarp as a series of large landslide block features with a distinctive shallow bench and steep scarp topography.

Table 5.1 Summary key geomorphological features, Area 3

5.5.2 *Materials description*

Ground investigations were undertaken at Area 3 as detailed in Table A3 in Appendix A.

Ground conditions encountered in BH2/3/04 drilled from the road were as follows (metres below ground level):

- Made Ground - Tarmac and hardcore 0.00m to 0.50m
- Upper Greensand debris 0.50m to 9.60m

  Typically beds of dark grey-green sandy cobbles, very soft sandy gravelly clay, and weak dark grey siltstone, slightly to moderately weathered.
- Gault clay debris 9.60m to 11.20m

  Described as non-intact very weak and weak dark grey fractured mudstone or soft to stiff slightly sandy clay with occasional to some mudstone lithorelicts.
- Gault clay 11.20m to 43.30m

Very weak to weak dark grey mudstone. Closely and very closely spaced fractures. Locally polished. Occasional thin interbed of extremely closely fissured clay. Slightly sandy from 18.10m. Becoming hard/very stiff clay from 37.70m.

- Carstone 43.30m to 45.00m (end of borehole)

  Hard green-grey/blue-grey sandy slightly gravelly clay, occasional lenses of very stiff dark grey clay.

A similar sequence of materials was encountered in the boreholes north of the road, with a slightly greater depth of Upper Greensand debris. No holes penetrated the Carstone north of the road.

Within the landslide itself, WS1/3/04, WS1B/3/04, WS1D/3/04, WS2/3/04, WS2A/3/04, WS3/3/04 and WS4A/3/04 encountered Upper Greensand debris to a maximum depth of 4.00m. WS5/3/04 located centrally within the landslide some 100m south of the road encountered Upper Greensand debris to a depth of 0.85m, underlain by Gault clay debris to 3.50m (end of exploratory hole).

Inclinometer	Installation depth	Movement depth (mbgl)	Movement rate (mm/yr)	Monitoring period	Stratum
BH01, north of the road	40.45m	"Sheared" Dec 2002 15.5-16.3mbgl	No records available. Source of data: ground model drawing in High Point Rendel, March 2006.	Unknown	Dark grey MUDSTONE weak with sub-horizontal to 20° extremely closely to closely spaced planar smooth tight fractures (Gault clay)
Inclinometer 3/3/04, on road N of caravan park	50.00m	No significant movement shown*	-	16.12.04 – 23.7.08	-
Inclinometer 4/3/04, on road E of caravan park	52.50m	No significant movement shown*	-	13.1.05 – 23.7.08	

Table 5.2 Inclinometer records, Area 3

*Movement – a spike in the cumulative deflection readings occurs in both inclinometers at 20-25m/17.2-22.5m respectively. Net movement at the surface is less then 10mm at both instruments.

5.5.3 *Ground movement*

Analysis of the historical and recent inclinometer data in Area 3 has shown movement at the locations and depths summarised in Table 5.2.

5.5.4 *Groundwater monitoring*

Groundwater monitoring has been undertaken over some years at Area 3. The maximum and minimum groundwater levels (GWL) recorded for each instrument is shown in Table 3.3 below.

Exploratory hole and instrument	Ground level (mAOD)	Tip level (mbgl)	Monitoring period	Maximum groundwater level (mAOD)	Minimum groundwater level (mAOD)
Automatic					
BH1/3/04 VW1*	70.66	15.50	2.9.04 – 9.4.07	56.28	56.13
Manual					
BH2	68.42	17.00	10.4.01 – 7.3.05	63.20	62.65
O3/1	67.90	13.10	21.11.02 – 6.7.04	65.21	64.96
WS1/3/04	59.25	5.50	1.9.04 – 19.12.05	55.47	55.25
WS2/3/04	54.13	4.50	1.9.04 – 19.12.05	51.19	51.17
WS3/3/04	54.39	4.50	1.9.04 – 19.12.05	51.19	50.64

Table 5.3 Groundwater monitoring results, Area 3

* Unreliable data recorded after 13.2.07 excluded

5.6 *Preliminary ground model*

The preliminary ground model for Area 3 is illustrated in Figure 3.3.

The current position of the road is shown on the geomorphological map to cross the edge of a rotational landslide block on the upper slopes, beneath the rear scarp of the Undercliff.

Assuming a similar level for the base of the Gault Clay in BH 1 as found in nearby BH2/3/04, gives the movement at Area 3 north of the road between 10.4 and 11.2m above the base of the Gault clay. This is lower within the Gault clay sequence than movement has been recorded in Areas 1 or 2.

Within the mudslide, the nature of the failure as evidenced by the shape of the mudslide suggests that a shallower movement has occurred, typically up to 5m depth. However, given the types of failure evident elsewhere along the Undercliff,

it is likely that deeper seated rotational landslide blocks exist beneath the upper mantle of mudslide debris.

The road at Undercliff Glen is at risk of:

- Retrogressive shallow mudsliding downslope of the road resulting in formation of a steep scarp slope immediately below the road. The steep scarp will continue to degrade, due to the oversteepening of the slope. Movement of the mudslide has reduced support to the road, opening up tension cracks within the road, and
- Deep ground movements of the upper tier rotational landslide blocks, as recorded by the inclinometer in BH1 upslope of the road.

Inclinometers 3/3/04 and 4/3/04 installed along the road, east of the site, have not shown any significant movement (see Table 3.2 above).

5.7 ***Remedial options***

Remedial options recommended for Undercliff Glen Area 3 are outlined below:

5.7.1 *Patch and mend*

This option would allow continued use of the road until either a major failure occurs or until ongoing ground movement continues to an extent that the crack width/gradients on the road are no longer suitable for patch repairs or vehicular use. Given the current condition of the road and stability risk assessment, it is unlikely this option will permit continuation of the existing single carriageway running scheme beyond a few years. Without engineering intervention, the road is at risk of collapse at any time due to the loss of support on the seaward side.

5.7.2 *Localised re-grading and re-surfacing*

Locally the road can be re-graded and re-surfaced as appropriate to take out changes in gradient and permit incorporation of geotextile reinforcement within the base of the repair. This will provide a longer life to the repair, reducing the incidence or reflective cracking at the surface of the road. This option will permit continuation of the existing single carriageway running scheme for a short period of time but is unlikely to offer a solution in the longer term.

5.7.3 *Reinforce the existing road structure*

Soil nails installed beneath the road on the seaward side could be used to reinforce the road in its current location, providing support to the oversteep scarp slope

south of the road and preventing further degradation and upslope retrogression of mudslide head scarp. Soil nails may be installed using long reach plant which could be sited on the road and reduce the access requirements to the unstable slopes below. Access to the mudslide, however, would still be required for small plant to install facing plates. Continued maintenance may be required as episodic ground movement below the road continues. It is anticipated therefore that further nailing may be required as and when the scarp slope is further exposed. This remedial option could be combined with localised resurfacing and re-grading works as described above. Following detailed design this option may permit the use of the road in both directions by re-opening the westbound carriageway.

5.7.4 *Local stabilisation of the landslide block*

Given the depth of failure at this location, a structural solution incorporating an array of piles through the road could be considered. This would provide support to the landslide block underlying the road and "anchor" it to the intact ground beneath. Prior to the decision as to whether or not to adopt this approach, additional inclinometers should be installed north of and within the road and a period of monitoring (one year, or at least through a winter/spring period) undertaken, to investigate the rate and depth of movement of the block. This option will permit use of the road in both directions by re-opening the southern carriageway. Groundwater monitoring should also be undertaken concurrently.

In addition there would be a need to provide support to the slope immediately below the road which forms the current mudslide headscarp. A soil nailing system as described above in section 5.7.3 could be used or alternatively a contiguous piled wall immediately down slope of the road could be considered. Soil nailing would require continued maintenance, in terms of the installation of additional nails as the mudslide continues. Piling the road may provide a permanent solution to the shallow ground movements although eventually the piles may become exposed as a result of ongoing movements on the lower slope. Such a local stabilisation solution (pile array plus facing) may also be undermined in the long term by deeper-seated ground movement.

Recommendations for regular walk-over surveys, updating of the landslide geomorphology mapping and continued investment and maintenance of the geotechnical monitoring systems are also recommended.

5.8 *Recommendations*

The recommendations for further works associated with Area 3 are provided in Section 8.3.

6 Area 4- Woodlands

6.1 *Location*

Area 4, Woodlands, is located east of the Undercliff Glen Caravan Park near St Lawrence, approximately 1.9km east of Niton village centre, at NGR SZ 524762.

6.2 *History of instability*

The section of Undercliff Drive adjacent to Woodlands is characterised by a marked depression in the road which has been subjected to ongoing settlement for many years (HPR, 2001). During the winter of 2000/2001 the westbound carriageway ruptured with over 500mm of differential settlement, leading to closure of the lane (since re-opened). More recent cracking and patch repairs are evident at Area 4 (July 2009).

6.3 *Remedial measures undertaken*

No drainage or remedial measures have been undertaken at this location, except for repeated re-grading and re-surfacing of the area and patching and mending cracks in the road as they appear. The thickness of asphalt and fill has built up over the years – BH1 (FES, 1995) encountered evidence of tarmac to a depth of 1.6m below the (then) road surface, which has since been buried. BH2/4/04 at a similar location encountered asphalt to 2.35mbgl and made ground to a depth of 4.2m in 2004.

6.4 *Site inspection 2009*

Arcuate tension cracks and patching of previous cracks were observed across the road at Woodlands, as shown on Figures 4.1 and 4.2 and Plate 5. The road cambers in a seawards direction, in the direction of the mudslide movement downslope of the road. There is a significant drop in elevation across the site, which is evident in Plate 6.

6.5 *Ground conditions appraisal*

6.5.1 *Geomorphology*

The geomorphology of the Woodlands site is illustrated in Figure 6.1 and summarised in Table 6.1.

Feature	Description
Lower cliff active coastal mudslides	The unprotected sea cliffs consist of multiple active mudslide units similar to those identified in Area 1 and 3. The mudslides appear to be largely seasonally active and associated with elevated groundwater levels and longer term marine erosion of the coastal cliff frontage.
Gault clay scarp	A major Gault clay scarp slope is located immediately upslope of the sea cliffs and divides the lower active mudslides from a series rotational landslide benches and scarp slopes.
Retrogressive mudslide	Immediately below the road is a mudslide complex which is superimposed upon the deeper rotational landslide blocks. The mudslide would appear to be a retrogressive feature which is subject to ongoing instability. The crosses immediately above the mudslide headscarp which has resulted in the development of a distinct depression in the road.
Rotational landslide benches and scarps	Observed above the major Gault clay scarp as a series of large landslide block features with a distinctive shallow bench and steep scarp topography.

Table 6.1 Summary key geomorphological features, Area 4

6.5.2 *Materials description*

Ground investigations were undertaken at Area 4 as detailed in Table A4 in Appendix A.

Ground conditions encountered in BH2/4/04 drilled from the road were as follows (metres below ground level):

- Made Ground - Tarmac and gravel 0.00m to 4.20m
- Upper Greensand debris 4.20m to 9.50m

  Described as firm to stiff off-white mottled light grey slightly sandy gravelly clay, and weak light grey non-intact siltstone, slightly to moderately weathered.
- Gault clay debris 9.50m to 14.15m

Described as non-intact very weak and weak dark grey fractured mudstone or soft to very stiff slightly sandy clay with occasional to some mudstone lithorelicts.

- Gault clay 14.15m to 45.65m

  Very weak to moderately weak dark grey slightly micaceous mudstone. Closely and very closely spaced fractures. Locally polished, occasional clay infill. Occasional thin interbed of extremely closely fissured clay. Described as stiff to very stiff friable fissured clay from 19.05 m to 20.05m. Becoming very stiff / hard clay from 34.80m.

- Carstone 45.65m to 50.45m (end of borehole)

  Very stiff/hard dark grey sandy locally slightly gravelly clay and very weak to weak blue-grey fine to coarse grained sandstone.

A similar sequence of materials was encountered in the boreholes north of the road, with a slightly greater depth of Upper Greensand and Gault clay debris. BHI4/1 identified Passage Beds between the Upper Greensand and Gault clay. Three larger diameter boreholes (BHP4/1, BHO4/1 and BHO4/2) identified chalk deposits (Lower Chalk landslide debris) to a maximum depth of 8.60m, overlying Upper Greensand.

Within the mudslide complex, downslope of the road, WS1/4/04, WS2/4/04, and WS3/4/04 encountered Upper Greensand debris to a maximum depth of 3.00m, generally described as soft to very soft clay.

6.5.3 *Ground movement*

Analysis of the historical and recent inclinometer data at Area 4 has shown movement at the locations and depths summarised in Table 6.2.

6.5.4 *Groundwater monitoring*

Groundwater monitoring has been undertaken over some years at Area 4. The maximum and minimum groundwater levels (GWL) recorded for each instrument is shown in Table 6.3.

Inclinometer	Installation depth	Movement depth (mbgl)	Movement rate (mm/yr)	Monitoring period	Stratum
BHI4/1, north of the road	49.20m	Possibly 21.25 to 22mbgl* and 46 to 47mbgl	4mm/year <2mm/year	18.7.02 – 5.10.04	Hard dark grey CLAY with trace silty lenses (Gault clay)
Inclinometer 2/4/04, on road	50.45m	Lateral movement evident at 18mbgl Deep-seated movement at 41 to 43mbgl	3mm/year 6mm/year	17.12.04 – 23.7.08	-

Table 6.2 Inclinometer records, Area 4

* Apparent movement is also evident on the inclinometer plot at 15-16mbgl, but this is within very weak fine-medium grained sandstone (Upper Greensand) and therefore unlikely to be a true reflection of movement.

Note: both these inclinometers are outside the landslide below the road and are therefore not indicative of the relatively shallow and frequent movements which affect the road on a regular basis.

Exploratory hole and instrument	Ground level (mAOD)	Tip level (mbgl)	Monitoring period	Maximum groundwater level (mAOD)	Minimum groundwater level (mAOD)
Automatic					
BH1/4/04 VW1*	65.30	9.50	19.8.04 – 9.4.07	55.95	55.83
BH1/4/04 VW2	65.30	19.00	19.8.04 – 16.6.09	47.25	47.09
BH1/4/04 VW3	65.30	49.50	19.8.04 – 28.10.07	16.69	16.62
Manual					
O4/2	68.25	10.00	21.11.02 – 6.7.04	65.37	64.97
WS1/4/04	60.43	4.50	1.9.04 – 19.12.05	57.19	56.76
WS2/4/04	54.22	3.40	1.9.04 – 19.12.05	52.36	51.35
WS3/4/04	47.39	3.50	1.9.04 – 19.12.05	46.27	45.28

Table 6.3 Groundwater monitoring results, Area 4

*Anomalous data 12-14.10.06 excluded.

6.6 *Preliminary ground model*

The preliminary ground model for Area 4 is illustrated in Figure 4.3.

The road at Woodlands is affected by two of the geomorphological processes.

Firstly, tension cracking observed on the road to the west of Woodlands is interpreted to be related to the lateral shear zone of the deep seated landslide system. Inclinometer readings in BHI4/1 have recorded movement at 21.25m to 22.0m below ground level. Assuming a similar level for the base of the Gault clay in BHI4/1 as found in nearby BH2/4/04, suggests ground movement north of the road at Area 4 is occurring between 29.6m and 30.4m above the base of the Gault clay. This is similar to the elevation in the Gault clay for the upper landslide benches in Areas 1 and 2. Deeper movement has also been recorded towards the base of the inclinometer, from 46 to 47mbgl. Deeper-seated movement has also been recorded in the inclinometer in BH2/4/04. Apparent lateral displacement has occurred at approx. 18m bgl (47.0mAOD, 26.3m above the base of the Gault clay). Displacement has also been recorded from 41.0 to 43.0mbgl (2.65m to 4.65m above the base of the Gault clay).

Secondly, the depression observed in the road and the thickness of made ground encountered in BH2/4/04 are interpreted to have been caused by continual mudslide movements directly downslope of the road which are likely to be driven by seasonal excess groundwater levels. Subsequent repairs have involved building up the level of the road surface with fill. There is evidence within the area below the road and above Old Park Hotel of a failed shallow drainage system which discharges significant quantities of water on to the slope surface, even in July 2009 (see Plate 6). Small pond(s) are also present at the toe of the Undercliff rear scarp itself, in the garden of Woodlands. These features could contribute to the discharge of water into the landslide system if damaged or leaking. The mudslide has formed a channelised flow feature and a distinct debris lobe within the wooded area above the Old Park Hotel. This suggests that the movement within the mudslide is likely to be shallow, maximum 5m deep, rather than of deeper-seated origin.

6.7 *Remedial options*

Remedial options recommended for Woodlands Area 4 include the following

6.7.1 *Patch and mend*

This option will allow continued use of the road until a major deep-seated failure occurs or until shallow movement results in crack width/gradients of sufficient extent that are no longer suitable for patch repairs or vehicular use. It is unlikely this option will provide an effective solution to the problem beyond present.

6.7.2 *Localised re-grading and re-surfacing*

Locally the road can be re-graded and re-surfaced as appropriate to take out changes in gradient and permit incorporation of geotextile reinforcement within the base of the repair. This will provide a longer life to the repair, reducing the incidence of reflective cracking at the surface of the road. Use of lightweight fill will avoid loading the head of the landslide system. This solution, whilst improving the integrity of the road pavement against cracking will be at risk of ongoing seasonal mudslide movement beneath the road.

6.7.3 *Support to the road mitigating against the mudslide movement*

Use of a retaining system along the southern edge of the road would provide support to the road within the upper landslide block, and mitigate the impacts of downslope mudslide movements on the road. Possible systems could include the use of a row (s) of piles to provide a retaining system, while still allowing free drainage between them, or soil nailing as described in Section 5.7.3. As more slope is exposed beneath the road due to continued movement of the mudslide, then more of the piles will gradually be exposed. Soil nailing would require continued maintenance, in terms of the installation of additional nails as the mudslide continues. Either of these local stabilisation solutions may be undermined in the long term by deeper-seated ground movement.

This option may be used in combination with road improvement works, to reduce carriageway gradients and potentially replace the existing made ground with a more appropriate lightweight fill. Geotextile reinforcement should be included in the new road construction to reduce the incidence of reflective cracking at the surface of the road and reduce the current frequency of road repairs.

Further recommendations for regular walk-over surveys, updating of the landslide geomorphology mapping and continued investment and maintenance of the geotechnical monitoring systems are also recommended.

6.8 *Recommendations*

Recommendations for further works associated with Area 4 are provided in Section 8.3.

7 Area 5 - St Lawrence West

7.1 *Location*

Area 5 is located to the west of St Lawrence, approximately 2.1km east of Niton village centre, at NGR SZ 526763.

7.2 *History of instability*

Area 5 was identified as being of concern in HPR's 2001 report, following a series of tension cracks developing and opening up along a 60m length of road following the 2000/2001 winter period. The report also mentions that significant distress was apparent in several properties along Hunts Road, which is located south of Undercliff Drive.

Within the Environmental Statement (High-Point Rendel, 2004a) it was stated that movements in Area 5 are shallow and associated with the slope immediately beneath the road, therefore no remedial measures were proposed at this location.

7.3 *Remedial measures undertaken*

No drainage or remedial measures have been undertaken at this location, except for patching and mending cracks in the road as they appear.

7.4 *Site inspection 2009*

During the site inspections and walkover undertaken in July 2009, a 180m length of road was identified as affected by cracking. The locations are shown on Figures 5.1 and 5.2. Temporary barriers have been put in place along the southern side of Undercliff Drive from 'High Trees' to 'Carosel', presumably due to cracks opening up in recent months. The barriers are shown on Plates 7 and 8. Observations made during visits to the site over the past few years indicate that the severity of cracking has increased at this location. It is now possible to see a slight displacement in elevation across the road.

7.5 *Ground conditions appraisal*

7.5.1 *Geomorphology*

The geomorphology of Area 5 is illustrated in Figure 5.1 and summarised in Table 3.1 below.

Feature	Description
Sea cliff compound failure zone	The unprotected sea cliffs are cut into compound landslide blocks which comprise a series of elongate ridge features of back tilted chalk and upper Greensands blocks with locally steep reverse slopes. A number of currently inactive mudslide features and contemporary local stream valley features have been observed within the compound failure zone.
Gault clay scarp	A Gault clay scarp slope is located immediately upslope of the compound failure zone and separates the lower tier compound landslides from the upper tier rotational landslide blocks.
Rotational landslide benches and scarps	Rotational landslide features can be observed above the major Gault clay scarp. These comprise a series of large landslide block features with a distinctive shallow bench and steep scarp topography. The road crosses a large landslide block in this area with a steep block scarp running close to the seaward edge of the carriageway.

Table 3.1 Summary key geomorphological features, Area 5

7.5.2 *Materials description*

Ground investigations were undertaken at Area 5 as detailed in Table A5 Appendix A.

Ground conditions encountered in BH I5/1 located on the road were:

- Made Ground 0.00m to 1.00m
- Lower Chalk Formation, Grade VI 1.00m to 1.55m

  Structureless pale brown chalk, composed of silt, sand and gravel-sized fragments
- Upper Greensand 1.55m to 13.70m

  Typically weak and very weak grey green glauconitic calcareous fine to medium grained sandstone and grey green mottled orange brown sand with varying proportions of sandstone gravel, with a bed of stiff clay from 10.55 to 10.90m depth and strong limestone from 12.6 to 13.10m depth

- Passage Beds 13.70m to 21.5m

  Weak to strong sandstones, mudstones, sandy silts and stiff to hard clays.

- Gault clay 21.50m to 40.00m (end of borehole)

  Typically stiff to hard dark grey calcareous slightly micaceous clay becoming sandy below 24.80m and weak dark grey slightly micaceous mudstone below 35.40m.

Ground conditions in BHS5/1were similar, with mudstone recorded from 13.50m.

In BHOW5.3, the same sequence of materials was encountered with a chalk to a lower depth (3.8m bgl) overlying Upper Greensand. Passage beds are not identified in the logging and Gault clay is recorded from 13.00m bgl.

Two further exploratory holes were drilled, as observation wells, by Structural Soils Ltd in 2006. These are located 200m and 350m east of the main location of Area 5.

7.5.3 *Ground movement*

Analysis of the historical inclinometer data has shown possible movement at the following location and depth at Area 5.

Inclinometer	Installation depth	Movement depth (mbgl)	Movement rate (mm/yr)	Monitoring period	Stratum
BHI5/1, within the road	40.00m	Possibly 21.7-22.4mbgl*	4mm/year	18.7.02 – 6.10.04	V stiff to hard dark grey CLAY (Gault clay)

Table 5.1Inclinometer records, Area 5

* Apparent movement is also evident on the inclinometer plot at 15.7-16.2mbgl, but this is within sandy gravelly silt (Passage Beds) and therefore unlikely to be a true reflection of movement.

7.5.4 *Groundwater monitoring*

Groundwater monitoring has been undertaken over some years at Area 5. The maximum and minimum groundwater levels (GWL) recorded for each instrument is shown in Table 5.2 below.

Exploratory hole and instrument	Ground level (mAOD)	Tip level (mbgl)	Monitoring period	Maximum groundwater level (mAOD)	Minimum groundwater level (mAOD)
Manual					
S5/1 Shallow	70.00	12.95	17.4.02 – 7.3.05	57.88	57.46
S5/1 Deep	70.00	38.05	17.4.02 – 7.3.05	57.67	57.20

Table 5.2 Groundwater monitoring results, Area 5

7.6 ***Preliminary ground model***

A study of the geomorphological mapping for Area 5 and surrounding land shows that the site is located on/above rotational landslide benches of the upper tier of the Undercliff. Possible movement identified in inclinometer BHI5/1 during the period July 2002 to October 2004 was at a depth of approximately 22m below ground level. It should be noted that monitoring of the inclinometer ceased in 2004. It is since this time that the cracks at Area 5 have become more pronounced.

No boreholes have penetrated the Carstone at this location therefore it is not possible accurately to assess the depth of movement recorded in relation to the base of the Gault clay. As Area 5 is located only 250m east of Area 4, it is possible to estimate the depth of movement in relation to the base of the Gault clay by taking the Carstone at 19.34m (as found in BH2/4/04). This gives movement in Area 5 at approx. 28.3 to 29.0m above the base of the Gault clay. This appears to correspond with movement at similar levels above the base of the Gault clay in Areas 1, 2 and 4.

It is possible that there has been a reactivation of movement in relation to the landslide blocks in recent years, the evidence of which is manifest as surface cracking due to ground movement now visible on Undercliff Drive.

There is a steep scarp slope directly beneath the road and to the rear of properties along Hunts Road. During the walkover, distortion was evident in steps down from Undercliff Drive to the garden of one of these properties. It is considered probable that the slope has been artificially steepened over the years by property-owners to landscape their gardens.

There was no evidence of movement or cracking during the walkover along Hunts Road in July 2009.

7.7 Remedial options

7.7.1 Continued patch and mend

The existing patch and mend strategy should be continued at Area 5. If the cracks develop significantly, it may be necessary to re-grade the road across the cracks and re-surface. It would be prudent to incorporate a geotextile/geosynthetic reinforcement to give a longer life to the repair.

The cracks at Area 5 could develop if accelerated rates of displacement occur. It is recommended that regular walk-over surveys and continued investment and maintenance of the geotechnical monitoring systems are carried out; the landslide geomorphology mapping should also be periodically updated.

7.8 Recommendations

Recommendations for further works associated with Area 5 are included in Section 8 .3.

8 Undercliff Drive options appraisal

8.1 *Landslide mechanism*

This geotechnical assessment has reviewed five sites where ongoing ground instability has had a significant impact on the Undercliff Drive. Previous site ground investigation data has been reviewed and brought up-to-date with recent monitoring data and site inspection in 2009 to construct preliminary ground models for each site and perform an assessment of the causes and mechanisms of ground instability which may impact the road in the short and long term.

The results of the assessment reveal that Areas 1-5 are affected by:

- Deep-seated (>20mbgl) ground instability associated with pre-existing deep-seated rotational landslides. This is illustrated by the presence of rotational bench and scarp topography above and below the road. Deep-seated ground movement appears to be associated with ongoing 'creep' along pre-existing shear surfaces as a result of elevated groundwater levels.
- Shallow (<20mbgl) ground instability associated with retrogressive mudslides from the mid- to lower Undercliff slopes below the road. The mudslides tend to be seasonally active in response to peak winter effective rainfall. In the long-term, they are also caused by coastal erosion and loss of toe support from the Gault clay scarp which can lead to episodic landslide events.

8.2 *Stability options review*

Based on the ground conditions appraisal undertaken for each site recommended road improvement options have been identified. These include:

- Options requiring no active intervention- such as continued patch and mend of the existing carriageway in its current state (restricted 1-lane flow at Area 3)
- Options of minimal engineering interventions including localised improvements and strengthening to the road surface and minimal structural support to improve the life expectancy of the road in its current state (restricted 1-lane flow at Area 3)

- Options of structural interventions to mitigate against shallow ground movement, to reinstate 2-lane flow at Area 3 and improve the life expectancy of the road.

The options identified for each site, together with potential advantages, disadvantages, and preliminary estimates of contractor's costs of each item are summarised in Table 8.1. Design costs and an allowance for contractor's preliminaries/insurances/profit would need to be added; this will depend on the scope of the contract.

Option number	Conceptual scheme description	Advantages	Disadvantages	Estimated Contractor's Cost (£)
Area 1- Beauchamp				
1	Not required	Not applicable	Not applicable	
Area 2- Mirables				
1	Patch and mend	Relatively low cost, simple, incorporated in existing highways maintenance scheme	Requires continued maintenance and visits, does not tolerate much ground movement	Included in highways maintenance budget
2	Localised re-grading	Increased life of the road at this location Reduced maintenance, if incorporating basal geotextile reinforcement Improved gradients for vehicular traffic	Disposal of planings and arisings	£5,000
3	Survey of retaining wall	Structural survey of the wall to assess effect of evident bulging/cracking on stability	None	£2,500
4	Retaining wall repair techniques – • Grouting • Soil nailing • Thickening • Buttressing	If needed as outcome of 3 above, techniques will provide a way of supporting the wall/road and accommodating ground movement. Soil nailing – provides support to the wall without significant additional loading.	Grouting – difficult to control flow of grout to specific places, proof drilling needed to investigate grout take. May increase groundwater levels due to reduced permeability. Thickening – provides additional loading on landslide system Buttressing – provides additional local loading onto landslide system	Soil nailing £40,000 to £50,000 Thickening £39,000 Buttressing £8,500

Option number	Conceptual scheme description	Advantages	Disadvantages	Estimated Contractor's Cost (£)
4	Reconstruction of road and retaining wall – techniques – • Dry stone wall • Gabions • Reinforced earth with stone facing	A new system will be designed to provide a flexible construction which can accommodate a certain amount of movement	Relatively high cost. Early large expenditure may not provide required cost-benefit analysis.	Dry stone wall £320,000 Gabions £185,000 Reinforced earth £160,000
Area 3- Undercliff Glen				
1	Patch and mend	Relatively low cost, simple, incorporated in existing highways maintenance scheme	Requires continued maintenance and visits, does not tolerate much ground movement	Included in highways maintenance budget
2	Localised re-grading and re-surfacing	Increased life of the road at this location Reduced maintenance, if incorporating basal geotextile reinforcement Improved gradients for vehicular traffic	Disposal of planings and arisings Allows continuation of single-lane road use only Does not address issue of continued degradation of mudslide downslope which will continue to remove support to edge of road	£50,000 for 100m, 7m wide
3	Reinforce the existing road structure • Soil nailing	Flexible construction which can accommodate a certain amount of movement Provides support to the side of the road, which is currently experiencing degradation Design should allow reinstatement of two-way traffic	Limited ongoing work as the mudslide continues to degrade, comprising installation of additional nails and facing system	£45,000 to 50,000 for 100m length, 2m high

Option number	Conceptual scheme description	Advantages	Disadvantages	Estimated Contractor's Cost (£)
4	Local stabilisation of the landslide block using pile array plus facing option – • Soil nailing • Piled wall	Design should allow reinstatement of two-way traffic	Whole stabilisation system may be undermined by deeper-seated movement If soil nailed facing system is chosen, there will be limited ongoing work as the mudslide continues to degrade, comprising installation of additional nails and facing system. Ongoing inclinometer and groundwater monitoring required. If piled facing system is chosen, there will be limited ongoing work once the mudslide has degraded to a particular depth, when additional means such as ground anchors would be needed. Or such anchors could be designed as part of the original system.	Soil nailing facing £45,000 to 50,000 for 100m length, 2m high, plus pile array £410,000 (40m deep) Piled wall (20m deep) £360,000 plus pile array (40m deep) £410,000
Area 4- Woodlands				
1	Patch and mend	Relatively low cost, simple, incorporated in existing highways maintenance scheme	Requires continued maintenance and visits, does not tolerate much ground movement	Included in highways maintenance budget
2	Localised re-grading and re-surfacing	Increased life of the road at this location Reduced maintenance, if incorporating basal geotextile reinforcement Improved gradients for vehicular traffic	Disposal of planings and arisings Allows continuation of single-lane road use only Does not address issue of continued degradation of mudslide downslope which will continue to remove support to edge of road	£50,000 for 100m, 7m wide
3	Support to the road mitigating against the	Design should allow continued two-way traffic flow and	Whole stabilisation system may be undermined by deeper-seated movement	Soil nailing facing £45,000 to 50,000 for 100m length

Option number	Conceptual scheme description	Advantages	Disadvantages	Estimated Contractor's Cost (£)
	mudslide movement. Options include: • Soil nailing • Piling	reduce maintenance costs	If soil nailed system is chosen, there will be limited ongoing work as the mudslide continues to degrade, comprising installation of additional nails and facing system Ongoing inclinometer and groundwater monitoring required	Piled wall(20m deep) £360,000
Area 5- St Lawrence west				
1	Patch and mend	Relatively low cost, simple, incorporated in existing highways maintenance scheme	Requires continued maintenance and visits, does not tolerate much ground movement	Included in highways maintenance budget

Table 8.1. Summary of road improvement options

8.3 *Monitoring and survey recommendations*

A number of potential options have been identified for each site which, subject to detailed design, may be carried out to improve the longer term condition of Undercliff Drive. These preliminary options have been specifically considered to improve the condition of the existing carriageway and, in Areas 3 and 4, reduce the impact of ongoing shallow mudslide movements which are affecting both sites.

It is recommended that any scheme adopted for Undercliff Drive should be undertaken in conjunction with a landslide monitoring and management plan designed to reduce the risk of potential larger landslides causing harm to the road users. This should comprise specific elements including:

- Updating the geomorphological mapping surveys which were undertaken by the DOE and local authority between 1990 and 1995. Significant ground movement and localised landslide events have occurred since these maps were produced which provide essential information and understanding about the Undercliff landslide mechanisms, behaviour and associated risks;
- Monitoring of surface movement, subsurface movement, groundwater levels and rainfall at specific locations, to improve understanding of ground movement and potential landslide trigger events as has been successfully implemented at Ventnor; such monitoring systems already exist at the sites considered in this assessment and it is recommended the council continue to regularly monitor and maintain these for future analysis and engineering design.
- Regular site walkover and carriageway inspections, including retaining structures (e.g. retaining walls), should be carried out by appropriately qualified engineers to assess their condition and suitability as a retaining wall within the local scheme;
- Survey of road drainage networks to consider whether further improvements can be made to prevent uncontrolled drainage on to the lower Undercliff slopes, and
- Improving the awareness of local residents to ground movement issues and the steps that they can take (controlled drainage, ensuring ponds, pool do not have leaks etc.) to reduce ground movement risk.

The site monitoring strategy should include the continuation of groundwater and inclinometer monitoring at all locations along Undercliff Drive. In review of the available monitoring information we can advise that:

- Groundwater monitoring data provided to Halcrow for Area 1 appears to have been terminated in 2008 (Table 3.3 above), although inclinometer monitoring appears to be ongoing at BH1/1/04.
- Groundwater monitoring data provided to Halcrow for Area 2 appears to have been terminated in 2005 (Table 4.3 above), although inclinometer monitoring appears to be ongoing at BH3/2/4.
- Groundwater monitoring data provided to Halcrow for Area 3 appears to have been terminated in 2007 (Table 5.3 above) and inclinometer monitoring appears to have been terminated in 2008.
- Groundwater monitoring data provided to Halcrow for Area 4 appears to have been terminated in 2007 except for one instrument which was still being monitored in 2009 - BH1/4/04 VW2 (Table 4.2 above). Inclinometer monitoring appears to have been terminated in 2008.
- If possible the inclinometer in BHI5/1 should be brought back into service and monitored, initially on a monthly basis. If this is not possible, consideration should be given to the installation of a new inclinometer. In order to understand the depth of movement in relationship to the base of the Gault clay, the borehole should prove the base of the Gault clay and extend into the Carstone beneath.
- Groundwater monitoring should be undertaken at Area 5, either by re-using S5/1, both shallow and deep installations, or by installation of a new borehole.

9 Conclusion

A geotechnical assessment of land instability and range of remedial measures has been conducted to identify preferred options for sustaining a viable traffic route through the western Undercliff.

The review of site data provided by IWC has comprised detailed assessment at five sites where ground movement has caused significant historical and contemporary damage to the road and where further ground movement and associated damage is anticipated in the future. These sites include:

- Area 1, Beauchamp
- Area 2, Mirables
- Area 3, Undercliff Glen
- Area 4, Woodlands
- Area 5, St Lawrence west

The geotechnical assessment supports the option to seek an alternative A road traffic route inland of the current Undercliff in the long-term, combined with localised stabilisation and road improvement works at four key sites (Areas 2 to 5) along the western Undercliff Drive; implementation of these works is designed to extend the life of the current road alignment in the short to medium term providing singular or two-way traffic for local access and sustaining a light vehicle traffic route between Ventnor, St Lawrence and Niton.

A range of stabilisation and road improvement options aimed at improving the design life of the existing road route have been identified without the need for major engineering works which are likely to be costly and have an adverse impact on the environment.

The assessment presents specific options for each site at each site which include:

- No active intervention options and continuation of patch and mend practices along the existing carriageway in its current state;
- Minimal intervention to mitigate against shallow ground movement and improve the sustainability of the road in its current state, and

- Structural intervention options located within the footprint of the current road alignment to reinstate 2-lane flow, mitigate against shallow ground movement and improve the future sustainability of the road.

The options for each site, their associated advantages and disadvantages and their outline costs are summarised in Table 8.1, Section 8.2. These options should be used to inform the economic assessment of any potential inland road schemes.

Whilst the options outlined will improve the serviceability of the current route there remains a risk that deep-seated ground movement could cause significant damage to Undercliff Drive which may place the road and users at risk. Based on this observation it is recommended that any scheme adopted for the road should be incorporated within a broader landslide management strategy for Undercliff Drive to mitigate the landslide risk. Detailed recommendations for a scheme are provided in Section 8.3. In summary, this should include an update of the geomorphological mapping for the western Undercliff, continued maintenance and monitoring of existing ground movement and groundwater levels and regular condition inspections of the existing retaining walls and the carriageway.

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Appendices

A Ground Investigation Data

Table A1: Ground investigation data at Area 1

Contractor	Date of GI	Scope	Availability of data to Halcrow Group Ltd
Soil Mechanics	April 2001	3 no. rotary cored boreholes to a max. depth of 52.30m, with inclinometer installations: BH1, BH2, BH3.	A copy of the report was available (Soil Mechanics, 2002). The second volume of core photographs was unavailable.
Structural Soils	Feb – March 2002	Beauchamp was investigated as part a larger Undercliff Drive GI. Scope at Beauchamp: 3 no. trial pits: TP1/1, TP1/2 and TP1/3 4 no. boreholes, one used as a pumped well and three as observation wells for a pumping test: BHP1/1, BHO1/1, BHO1/2 and BHO1/3. Moisture content, plasticity testing and particle size distribution tests were undertaken and some chemical testing.	A copy of Draft 3 of the report was available (Structural Soils Ltd, 2002).
C J Associates	2003	Installation of inclinometer BH1R to replace BH1	Unavailable.
Geotechnical Engineering Limited	July - Aug 2004	Beauchamp was investigated as part a larger Undercliff Drive GI. Scope at Beauchamp: 4 no. rotary cored boreholes to 50.40m max. depth. Inclinometers were installed in BH1/1/04 and BH3/1/04; vibrating wire piezometers were installed in BH2/1/04 and BH4/1/04. 4 no. trial pits 2 no. window sampler holes with drive-in standpipe piezometers.	A copy of Volume 1 of 3 only was available (Geotechnical Engineering Ltd, 2004).

Table A2: Ground investigation data at Area 2

Contractor	Date of GI	Scope	Availability of data to Halcrow Group Ltd
Structural Soils	Feb – March 2002	Mirables was investigated as part of a larger Undercliff Drive GI. Scope at Mirables: 1 no. rotary cored borehole and 1 no. rotary open hole, both to 40.0m. An inclinometer was installed in BHI2/1 and two no. standpipe piezometers in	A copy of Draft 3 of the report was available (Structural Soils Ltd, 2002).

		BHS2/1. Some laboratory testing was undertaken.	
Geotechnical Engineering Limited	July - Aug 2004	Mirables was investigated as part of a larger Undercliff Drive GI. Scope at Mirables: 3 no. rotary cored boreholes to 50.00m max. depth. An inclinometer was installed in BH3/2/04 and vibrating wire piezometers were installed in BH1/2/04 and BH2/2/04. 3 no. trial pits 3 no. window sampler holes with drive-in standpipe piezometers.	A copy of Volume 1 of 3 only was available (Geotechnical Engineering Ltd, 2004).

Table A3: Ground investigation data at Area 3

Contractor	**Date of GI**	**Scope**	**Availability of data to Halcrow Group Ltd**
Geotechnical Engineering	April 2001	2 no. rotary cored boreholes to a max. depth of 40.46m, with an inclinometer installation in BH01 and a standpipe piezometer in BH02.	Window sample logs were missing from the copy of the report and no plan was included.
Structural Soils	Feb – March 2002	Undercliff Glen was investigated as part of a larger Undercliff Drive GI. Scope at Area 3: 3 no. trial pits: TP3/1, TP3/2 and TP3/3 3 no. rotary open-hole boreholes to a max depth of 20.60mbgl, one used as a pumped well and two as observation wells for a pumping test: BHP3/1, BHO3/1 and BHO3/2 Some laboratory testing. All exploratory holes were located north of the road.	A copy of Draft 3 of the report was available (Structural Soils Ltd, 2002).
Geotechnical Engineering Limited	July - Aug 2004	Undercliff Glen was investigated as part of a larger Undercliff Drive GI. Scope at Area 3: 4 no. rotary cored/open hole boreholes to 52.50m max. depth. Inclinometers were installed in BH3/3/04 and BH4/3/04; vibrating wire piezometers were installed in BH1/3/04 and BH2/3/04. 6 no. trial pits 4 no. window sampler holes with drive-in standpipe piezometers. Exploratory holes were located north and south of the road and within the road.	A copy of Volume 1 of 3 only was available (Geotechnical Engineering Ltd, 2004).

Table A4: Ground investigation data at Area 4

Contractor	Date of GI	Scope	Availability of data to Halcrow Group Ltd
Foundation and Exploration Services	1995	2 no. rotary boreholes to 30.0 and 45.75m with groundwater monitoring wells; 8 no. trial pits excavated to between 2.0 and 7.1m; laboratory testing including index and residual shear tests; instrumentation including a settlement cell and a tiltmeter (scope of GI as recorded in HPR, 2001).	Logs for BH1 and BH3 only available, reproduced in HPR, 2004b.
Structural Soils	Feb – March 2002	Area 4 was investigated as part of a larger Undercliff Drive GI. Scope at Area 4: 1 no. rotary cored borehole to 49.3mbgl with inclinometer installed to 49.2m, BHI4/1. 3 no. rotary open-hole boreholes to a max depth of 11.60mbgl, one used as a pumped well and two as observation wells for a pumping test: BHP4/1, BHO4/1 and BHO4/2. Some laboratory testing. All exploratory holes were located north of the road.	A copy of Draft 3 of the report was available (Structural Soils Ltd, 2002).
Geotechnical Engineering Limited	July - Aug 2004	Area 4 was investigated as part of a larger Undercliff Drive GI. Scope at Area 4: 2 no. rotary cored boreholes to 50.45m max. depth. An inclinometer was installed in BH2/4/04 and vibrating wire piezometers were installed in BH1/4/04. 3 no. trial pits 3 no. window sampler holes with drive-in standpipe piezometers. Exploratory holes were located south of the road and within the road.	A copy of Volume 1 of 3 only was available (Geotechnical Engineering Ltd, 2004).

Table A5: Ground investigation data at Area 5

Contractor	Date of GI	Scope	Availability of data to Halcrow Group Ltd
Structural Soils	Feb – March 2002	Area 5 was investigated as part of a larger Undercliff Drive GI. Scope at Area 5: 1 no. rotary cored borehole to 40.5mbgl with inclinometer installed to 40.0m, BHI5/1. 1 no. rotary open-hole boreholes to 40.0mbgl, with two standpipe piezometers installed. Some laboratory testing. All exploratory holes were located within the road.	A copy of Draft 3 of the report was available (Structural Soils Ltd, 2002).
Structural Soils	Apr – May 2006	3 no. boreholes (window samples continued with rotary coring) to 27.5mbgl with 63mm OD slotted well pipes, BHOW5.1, OW5.2 and OW5.3. Some in situ and laboratory testing. Data loggers were installed in each well. The exploratory holes were located within Undercliff Drive and Old Park Road.	A copy of the report was available (Structural Soils Ltd, 2006).

B Information provided by Isle of Wight Council

Box 1 of 6

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
1/1	-	-	20.8.07	High-Point Rendel	Letter to Glanvilles Solicitors re CPO areas and topographic survey	
1/2	R/2388/EA/001	1 Draft	Nov 2004	High-Point Rendel	A3055 Undercliff Road Stabilisation. Report on the potential impacts on the groundwater source at St Lawrence, Isle of Wight	Looks at potential impacts of a row of wells at Area 4. Appendices included. Includes some ground models and logs. See HGL Item No. 2/8, 3/13 and 4/8.
1/3	2303A & 2303B	-	Feb 2002	Cartographical Surveys Ltd	Castlehaven and Undercliff Drive, Isle of Wight. Survey Control Report.	No mapping included in boxes from IOWC. A1 maps were prepared by Cartographical Surveys – missing.

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
1/4	16364	-	3.12.04	Geotechnical Engineering Ltd	A3055 Undercliff Drive Stabilisation. Main ground investigation for stabilisation programme.	Only contains text and site plans. All appendices missing, including exploratory hole data.(Duplicate of HGL Item No. 2/2. See also 2/3 and 1/5) Stapled not bound. Labelled as S6.27 – Geo-Technical Survey See 1/5, most complete version.
1/5	16364	-	3.12.04	Geotechnical Engineering Ltd	A3055 Undercliff Drive Stabilisation. Main ground investigation for stabilisation programme. Hand labelled as Part 2	Only contains text, site plans, logs and in situ tests. See HGL item nos1/4, 2/2 and 2/3. NB Vols 2 and 3 of original report (lab test data etc) are missing. 1/5 is the most complete version.
1/6	11187	-	May 2002	Structural Soils Ltd	Ground Investigation Report – A3055 Undercliff Drive, Isle of	GI covered Areas 1-5. Unbound copy of Structural Soils GI undertaken in early

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
					Wight	2002. Rather thin, so data missing, but does have the only colour core photos. See HGL Items No. 2/4 and 2/5, also 1/7.
1/7	11187	Draft 3	May 2002	Structural Soils Ltd	Ground Investigation Report – A3055 Undercliff Drive, Isle of Wight	GI covered Areas 1-5. Unbound copy of Structural Soils GI undertaken in early 2002. No cover sheet. (See HGL Items No. 2/4 and 2/5, also 1/6.)1/7 is the most complete version – see 1/6 for core photos.

Box 2 of 6

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
2/1	-	-	June 2002	HSI	Undercliff Drive Stage 1. Supplementary GI. Evaluation of pumping test results and dewatering.	Tests undertaken at Areas 1, 3 and 4. Bound. Duplicate, unbound, is in Box 3.
2/2	16364	-	3.12.04	Geotechnical Engineering Ltd	A3055 Undercliff Drive Stabilisation. Main ground investigation for stabilisation programme.	Only contains text and site plans. All appendices missing, including exploratory hole data.(See HGL Item No. 2/3) Stapled not bound. Labelled as Document No. 6.28. See 1/5, most complete version.
2/3	16364	-	3.12.04	Geotechnical Engineering	A3055 Undercliff Drive Stabilisation. Main ground investigation for	Logs only. See HGL item no. 2/2. NB Vols 2 and 3 of original report (lab test

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
				Ltd	stabilisation programme. Hand labelled as Part 2	data etc) are missing. See 1/5, most complete version.
2/4	11187	Draft 3	2002	Structural Soils Ltd	Ground Investigation Report – A3055 Undercliff Drive, Isle of Wight	GI covered Areas 1-5. Cover sheet missing. This is the text and logs (to end of Appendix B) of the Structural Soils GI undertaken in early 2002. See HGL Items No. 1/6, 1/7 and 2/5. 1/6 appears to be a later version although incomplete.
2/5	11187	Draft 3	2002	Structural Soils Ltd	Ground Investigation Report – A3055 Undercliff Drive, Isle of Wight	GI covered Areas 1-5. Cover sheet missing. This is Appendix C onwards of the Structural Soils GI undertaken in early 2002. See HGL Items No. 1/6, 1/7 and 2/4. 1/6 appears to be a later version although incomplete.
2/6	R/H922/1	1 Draft	17.6.96	High-Point	Landslide Forecast	Looks at 4 month antecedent effective rainfall.

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
				Rendel		Labelled as Document 6.5.
2/7	R/2388/HR/001	2 Final	June 2004	High-Point Rendel	A3055 Undercliff Drive Stabilisation. Report on Hydrogeological Impacts	Contains drawings of ground models and summaries of information for each Area. NB Area 4 ground model missing. Labelled as Document 6.2.
2/8	R/2388/EA/001	1 Draft	Nov 2004	High-Point Rendel	A3055 Undercliff Road Stabilisation. Report on the potential impacts on the groundwater source at St Lawrence, Isle of Wight	Looks at potential impacts of a row of wells at Area 4. Appendices missing. Labelled as Document 6.3. See HGL Item No. 1/2, 3/13 and 4/8
2/9	R/2388/EA/002	2 Final	17.12.04	High-Point Rendel	A3055 Undercliff Drive Stabilisation Scheme. Performance review of drainage measures adopted for the Castlehaven Coast Protection Scheme	Labelled as Document 6.4.

Box 3 of 6

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
3/1	R/2388/GMA/001	4	Undated Latest date on footer is 09.03 06	High-Point Rendel	A3055 Undercliff Drive Stabilisation Scheme, Isle of Wight. Groundwater Monitoring Scheme	Drawings and some information missing from appendices. 3 copies received. Part of Document 7.4. S/S by 4/10.
3/2	-	-	March 2006	Mark Lee	Review of A3055 Undercliff Drive Stabilisation Scheme Groundwater Drainage Systems Management Agreement	Part of Document 7.4.
3/3	R/2388/GMA/001	5	Undated. Footer date is 28.03.06	High-Point Rendel	A3055 Undercliff Drive Stabilisation Scheme, Isle of Wight. Groundwater Monitoring Scheme	Drawings and some information missing from appendices. Part of Document 7.4.

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
						S/S by 4/10.
3/4	R/2388/GMA/001	3	20.2.06	High-Point Rendel	A3055 Undercliff Drive Stabilisation Scheme, Isle of Wight. Groundwater Drainage Systems – Monitoring Plan	Drawings and some information missing from appendices. 3 copies received. Part of Document 7.4. S/S by 4/10.
3/5	-	-	Nov 2005	Mark Lee	Review of A3055 Undercliff Drive Stabilisation Scheme Groundwater Drainage Systems Monitoring Plan	Part of Document 7.4.
3/6	-	-	26/09/05	HPR	Draft minutes of meeting with EN held on 13.9.09	Part of Document 7.4.
3/7	-	2	July 2004	English Nature	Field guidance – Carrying out the assessment. Maritime Cliff and Slope	Part of Document 7.4.

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
3/8	-	-	16.1.04	English Nature	Common standards for monitoring. Generic guidance on objective setting and condition assessment. Maritime cliff and slope.	Part of Document 7.4.
3/9	-	-	1/3/05	HPR	Draft minutes of meeting with EN held on 1.3.05	Part of Document 7.4.
3/10	Various emails and letters					Part of Document 7.4.
3/11	-	-	June 2002	HSI	Undercliff Drive Stage 1. Supplementary GI. Evaluation of pumping test results and dewatering.	Tests undertaken at Areas 1, 3 and 4. Unbound. Duplicate, bound, is in box 2.
3/12	51324	2 Final	September 2006	Structural Soils	Factual Report on Ground Investigation at A3055 Undercliff Drive. Stabilisation Scheme – East of Area 4.	Covers Area 5.

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
3/13	R/2388/EA/001	1 Draft	25.11.04	High-Point Rendel	A3055 Undercliff Road Stabilisation. Report on the potential impacts on the groundwater source at St Lawrence, Isle of Wight	Labelled as Document 6.30. Contains a number of logs and location plan for boreholes at Woodlands. Duplicated as1/2, 2/8 and 3/13, Contains FES logs.
3/14	R/2388/GMA/001	5	28.3.06	High-Point Rendel	A3055 Undercliff Drive Stabilisation Scheme. Groundwater Drainage Systems Monitoring Plan	More complete version including some drawings than HGL Item No. 3/3 above. Duplicate of 4/10.
3/15	-	-	-	IOWC?	List of documents from Nick Gallin's office (Environment Services) regarding Undercliff Drive Scheme	List is incomplete in terms of not giving full references to the documents
3/16	Drgs HP1179/A1/03 Rev 02 HP1179/A2/01a		Jan 2005	Merrett Survey Partnership	Area 1 A3055 Undercliff Drive Stabilisation Survey; Area 2 A3055 Undercliff Drive Stabilisation	Enquiries made regarding obtaining original CAD files 10.9.09. CAD files obtained from

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
	Rev 1 and 1179/A34/00 Rev A		30.9.04 13.10.04		Survey; Areas 3 and 4 A3055 Undercliff Drive Stabilisation Survey	MSP.
3/17	Drawings 002388/PA/317 002388/T/181 002388/T/281 002388/T/381 002388/T/382 002388/T/481	 0 0 0 0 0 0	 - 17.12.04 17.12.04 17.12.04 17.12.04 17.12.04	High-Point Rendel	Various landscaping drawings – Areas 1, 2, 3 and 4.	S/S by 4/1
3/18	Drawings 2388-PA-001 2388-PA-002	 0 0	 24.6.04 24.6.04	High-Point Rendel	Various drawings of proposed stabilisation works, Areas 1, 2, 3 and 4	S/S by 4/1

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
	2388-PA-003	0	24.6.04			
	2388-PA-005	0	24.6.04			
	2388-PA-006	0	24.6.04			
3/19	Drawings			High-Point Rendel	Various drawings of Existing arrangement, services and site boundary	S/S by 4/1
	002388/T/101	0	17.12.04			
	002388/T/201	0	17.12.04			
	002388/T/301	0	17.12.04			
	002388/T/302	0	17.12.04			
	002388/T/401	0	17.12.04			

Box 4 of 6

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
4/1	2388/TD/V5	Issue 3	August 2006	High-Point Rendel	A3055 Undercliff Drive Stabilisation Scheme Tender Documents, Vol 5 Drawings	Labelled as Document 6.7
4/2	R/002388/DR/001	Issue 1a Working draft	January 2006	High-Point Rendel	A3055 Undercliff Road Stabilisation. Design Statement Report.	Useful summary area by area.
4/3	-	Draft Version 1.2	-	A Bracegirdle	Proof of Evidence: Geotechnical and Drainage	S/S by 5/3.
4/4	R/1489-2/GS/1	2 Draft	September 2003	High-Point Rendel	A3055 Undercliff Drive: Remediation Proposals. Government Appraisal Document	Includes GOMMMS methodology. Not much geotechnics!
4/5	R1489/ES/1	Issue 6 Final	July 2004	High-Point Rendel	A3055 Undercliff Drive: Highway Stabilisation Works. Environmental Statement	See Chs 3 & 4 particularly

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
4/6	R/2388/MP/4	Issue 5, Final	October 2006 (cover sheet shows Aug 2005)	High-Point Rendel	A3055 Undercliff Drive Stabilisation Scheme. Management Plan	Covers proposed post-construction ecological management and groundwater monitoring. S/S by 4/7 below.
4/7	R/2388/MP/1-9	Issue 9, 5th Revision	February 2007	High-Point Rendel	A3055 Undercliff Drive Stabilisation Scheme. Management Plan	Covers proposed post-construction ecological management and groundwater monitoring
4/8	R/2388/EA/001	1 Draft	November 2004	High-Point Rendel	A3055 Undercliff Road Stabilisation. Report on potential impacts on the groundwater source at St Lawrence, Isle of Wight.	Duplicate of 1 /2 and 2/8.
4/9	R/1489-2/ES/1	3 3rd draft	September 2003	High-Point Rendel	A3055 Undercliff Drive – Remediation Options. Environmental Statement	S/S by 4/5 above.
4/10	R/2388/GMA/001	5 Revised draft	March 2006	High-Point Rendel	A3055 Undercliff Drive Stabilisation Scheme. Groundwater Drainage Systems Monitoring Plan	Supersedes or duplicates 3/1, 3/3, 3/4, 3/14.

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
4/11	-	-	-	?	Statement of Case in respect of the IOWC (Undercliff Drive Highway Realignment) CPO 2006 and IOWC A3055 (Undercliff Drive – Highway Realignment Classified Road) (Side Roads) Order 2006	Contains a summary of the scheme evolution and design and options appraisal
4/12	Various				Various scheme drawings	S/S by 4/1

Box 5 of 6

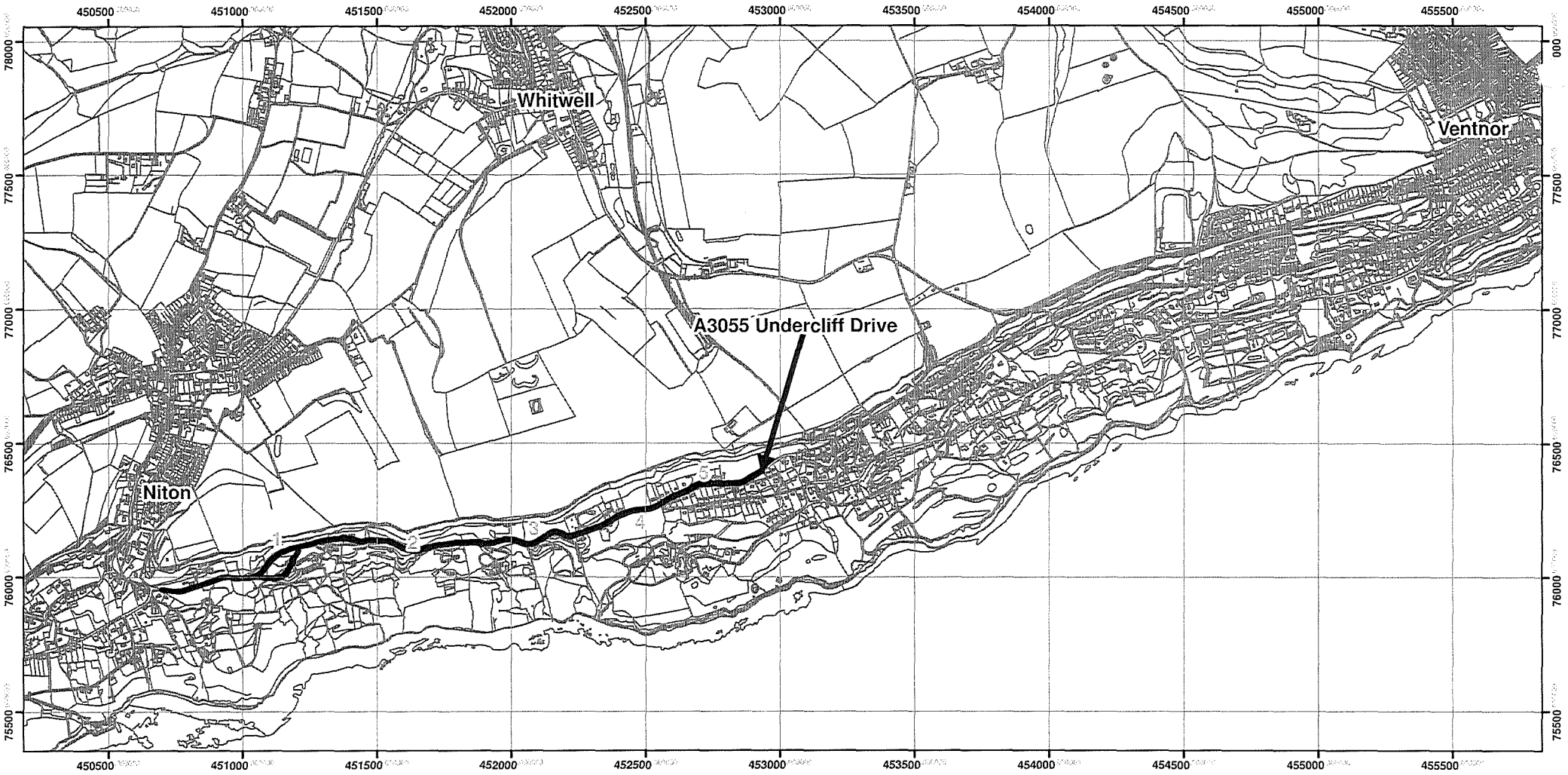
HGL Item no.	Document No	Rev	Date	Author	Title	Other info
5/1	R/1489/ES/1	Issue 6 Final	July 2004	High-Point Rendel	A3055 Undercliff Drive: Highway Stabilisation Works. Environmental Statement	Chs 3 and 4 are relevant. Duplicate of 4/5 above.

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
5/2	Various				Various scheme drawings	S/S by 4/1
5/3	-	Draft Version 2	-	A Bracegirdle	Proof of Evidence: Geotechnical and Drainage	Includes figures except 21, 36 and 39.
5/4	-	-	-	?	Description of geotechnical concerns	Summary of objections to previous schemes
5/5	-	-	20.10.2003	Mark Lee	Review of Undercliff Drive Remediation Works Environmental Statement	
-	Other docs in Box 5					Generally correspondence and docs relating to CPO.

Box 6 of 6

HGL Item no.	Document No	Rev	Date	Author	Title	Other info
6/1	R/1489-2/GS/1	Issue 2 Draft	September 2003	High-Point Rendel	A3055 Undercliff Drive: Remediation Proposals. Government Appraisal Document.	Duplicate of 4/4.
6/2	101036	-	January 2002	Soil Mechanics	Ground Investigation at Undercliff Drive, Niton, Isle of Wight	Early GI report for Beauchamps. Includes logs of BH1, BH2 and BH3. Not a very good quality copy.
6/3	12157	-	12 April 2001	Geotechnical Engineering Ltd	Ground Investigation, A3055 Undercliff Drive, St Lawrence, Ventnor, Isle of Wight. Emergency Landslide Investigation. Vol 1 of 1.	Window Sample logs missing from the copy of the report. No plan. BH were located at Area 3 Undercliff Glen.
-	Other docs in Box 6					Generally correspondence and docs relating to CPO.

Figures

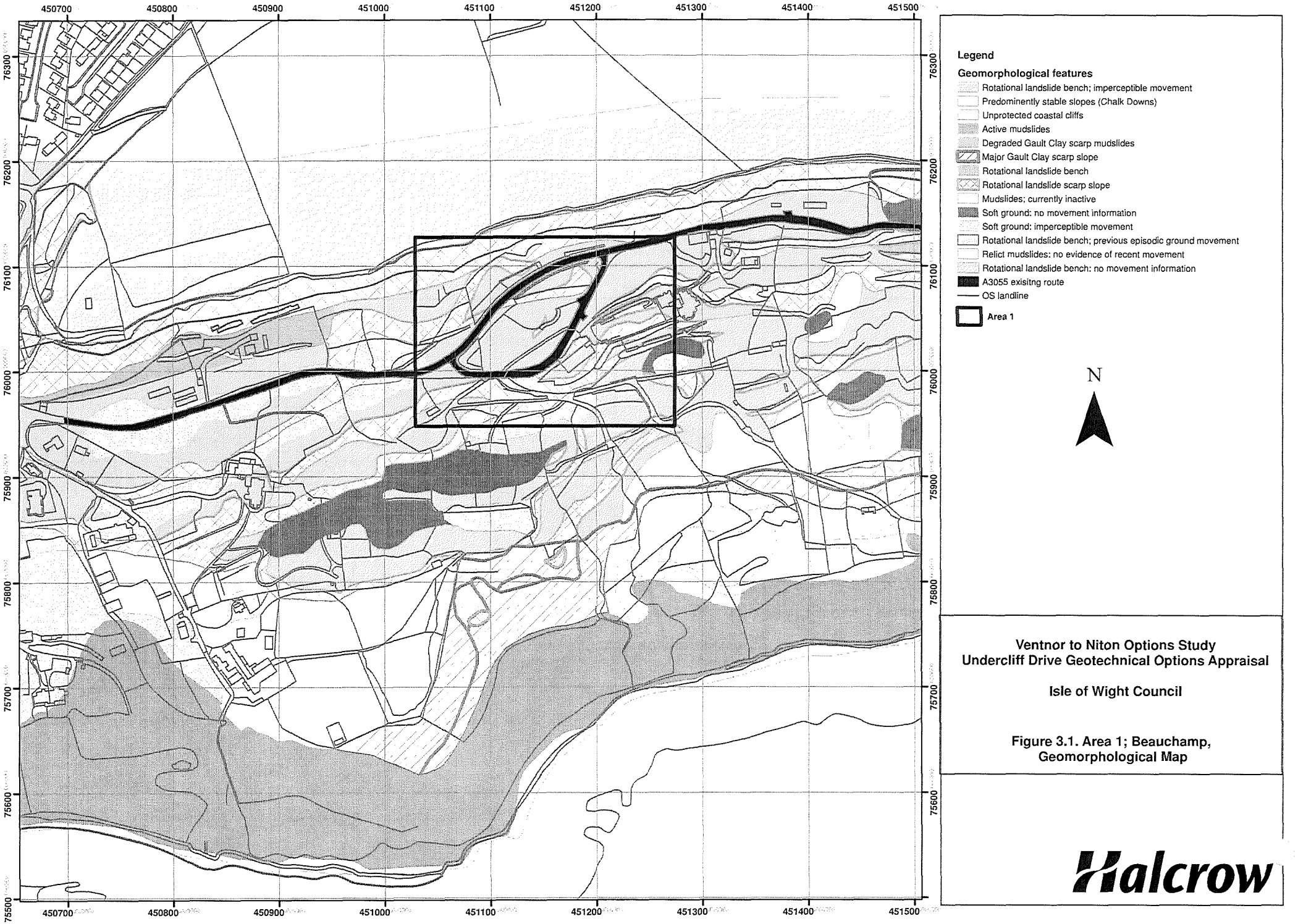


1 Area 1, Beauchamp	4 Area 4, Woodlands
2 Area 2, Mirables	5 Area 5, St Lawrence West
3 Area 3, Undercliff Glen	

Undercliff Drive Geotechnical Options Appraisal Report

Figure 1.1. Site location

Halcrow



Ventnor to Niton Options Study
Undercliff Drive Geotechnical Options Appraisal

Isle of Wight Council

Figure 3.1. Area 1; Beauchamp, Geomorphological Map

Halcrow

Key Plan:

Notes:

1. No road improvement options are proposed at this location because the road has already been re-aligned
2. No log available for BH1R. Movement recorded in BH1R has been shown on the log for BH1 (BH1R was a replacement for BH1)

Key:

- BH1/2/04 Borehole
- TP1/2/04 Trial Pit
- WS1/2/04 Window Sample hole

Key:

- Topsoil
- Clay
- Made ground
- Lower Chalk
- Upper Greensand debris
- Passage Beds
- Gault clay debris
- Gault clay
- Carstone
- No core recovery
- Projected shear surface

Rev	By	Chkd	Apprvd	Date	Description
-	-	-	-	-	

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Project

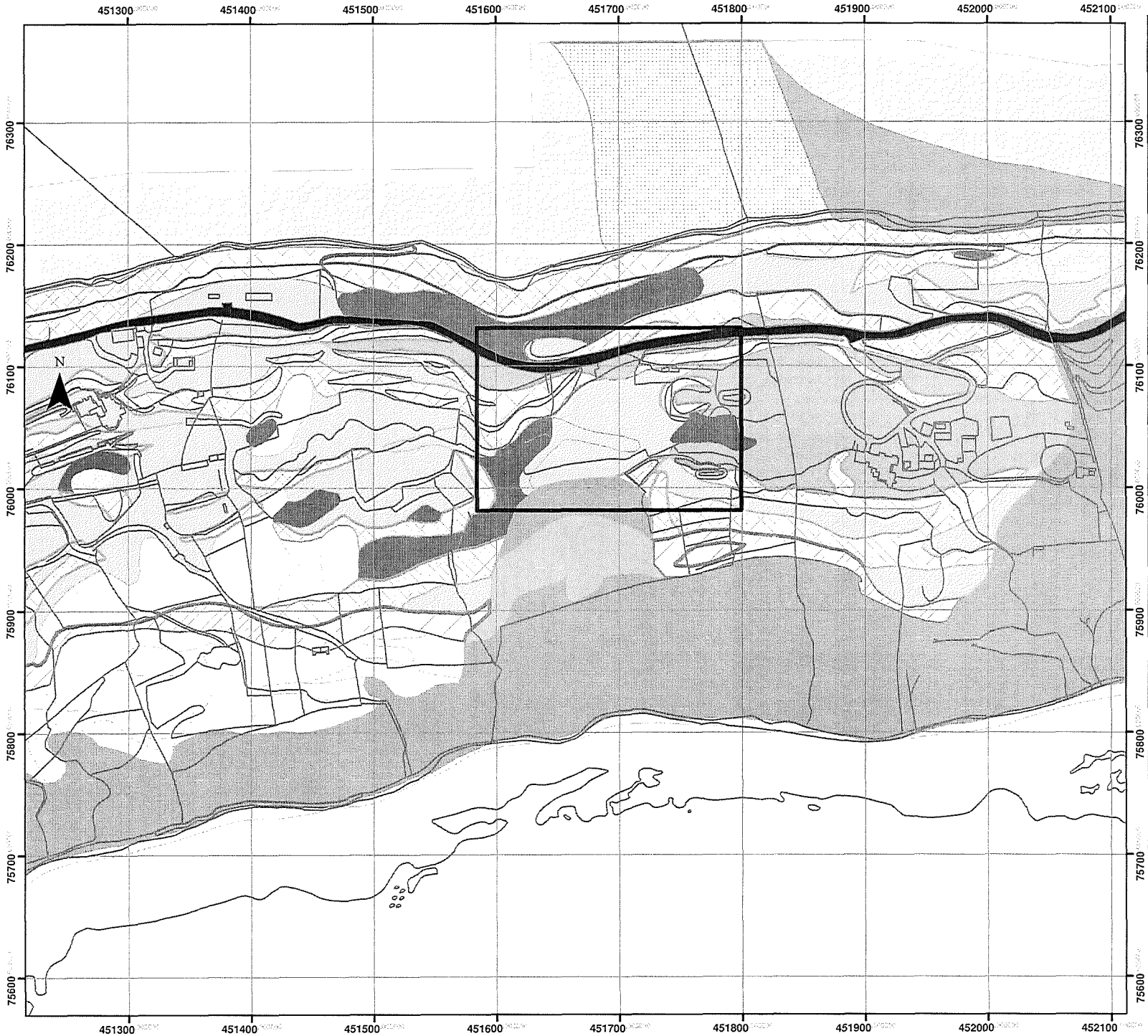
VENTNOR TO NITON OPTIONS STUDY
UNDERCLIFF DRIVE
GEOTECHNICAL OPTIONS APPRAISAL

Drawing

AREA 1, BEAUCHAMP
PRELIMINARY GROUND MODEL

Drawn by: NR	Date: 27.11.09
Checked by: SKT	Date: NOV 09
Approved by: JMC	Date: NOV 09
Drawing No. FIGURE 3.2	Revision -

Drawing Scale: AS SHOWN



Legend

Geomorphological features

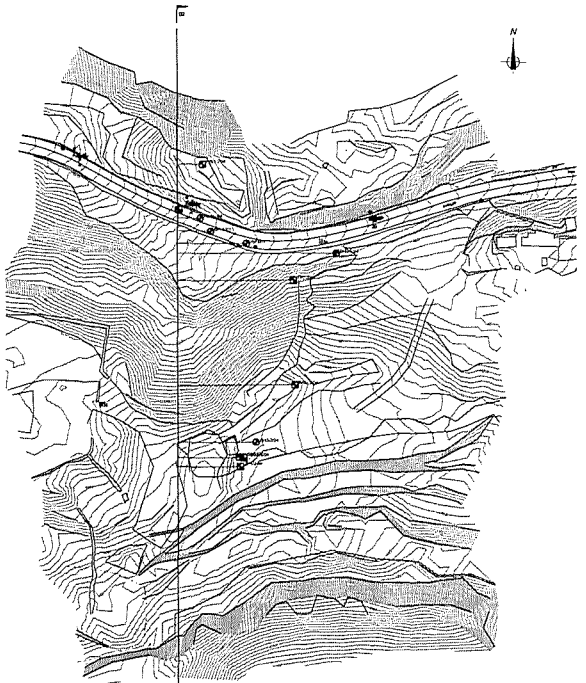
- Upper Greensand bench: Areas prone to slow settlement, probably
- Chalk Down slopes suceptible to flash flooding
- Chalk Down slopes susceptible to shallow translational slides
- Compound slides elongated ridges and scarps; no information is
- Rotational landslide bench; imperceptible movement
- Predominently stable slopes (Chalk Downs)
- Unprotected coastal cliffs
- Active mudslies
- Degraded Gault Clay scarp mudslides
- Major Gault Clay scarp slope
- Rotational landslide bench
- Rotation landslide scarp slope
- Mudslides; currently inactive
- Soft ground: No movement informaiton
- Soft ground: imperceptible movement
- Rotational landslide bench; previous episodic ground movement
- Relict mudslides: no evidence of recent movement
- Rotational landslide bench: no movement information
- A3055 exisitng route
- OS landline
- Area 2

Ventnor to Niton Options Study
Undercliff Drive Geotechnical Options Appraisal

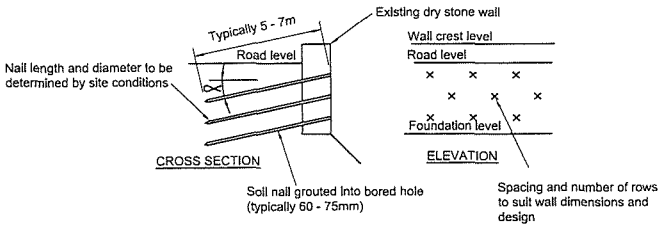
Isle of Wight Council

Figure 4.2. Area 2; Mirables Geomorphological map

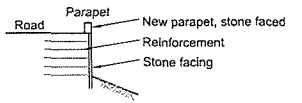
Halcrow



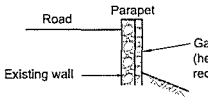
PLAN - 1:1000 SCALE



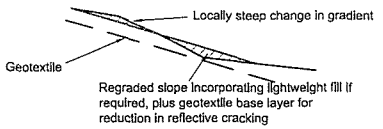
WALL REPAIR - SOIL NAILING OPTION



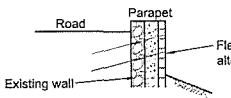
WALL AND ROAD RECONSTRUCTION - REINFORCED EARTH OPTION



WALL REPAIR - BUTTRESS OPTION

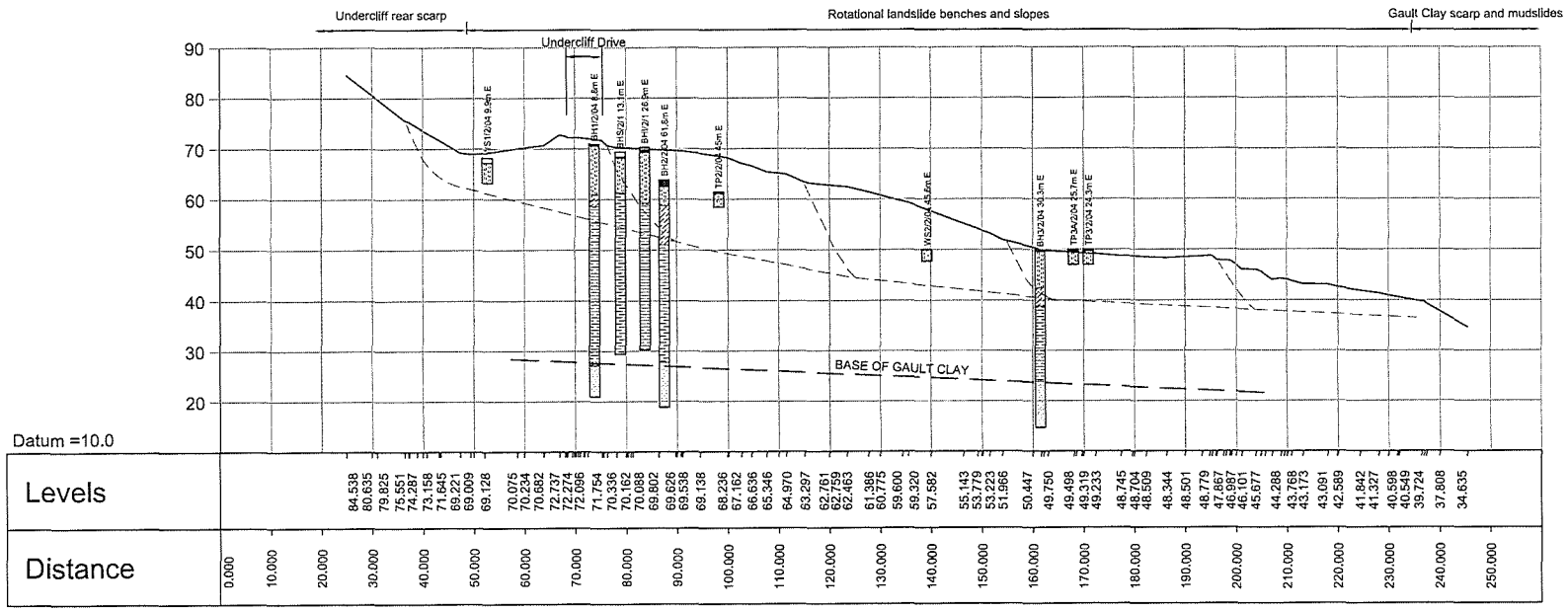


LOCALISED REGRADING



WALL REPAIR - THICKENING OPTION

ROAD IMPROVEMENT OPTIONS



Section B - B

Key Plan:

Notes:

1. Locations of exploratory holes are shown on Figure No. ????

Key:

BH1/2/04 Borehole
TP1/2/04 Trial Pit
WS1/2/04 Window Sample hole

Key:

- Topsoil
- Clay
- Made ground
- Lower Chalk
- Upper Greensand debris
- Passage Beds
- Gault clay debris
- Gault clay
- Carstone
- No core recovery
- Projected shear surface

Rev	By	Chkd	Apprvd	Date	Description
-	-	-	-	-	-

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Project

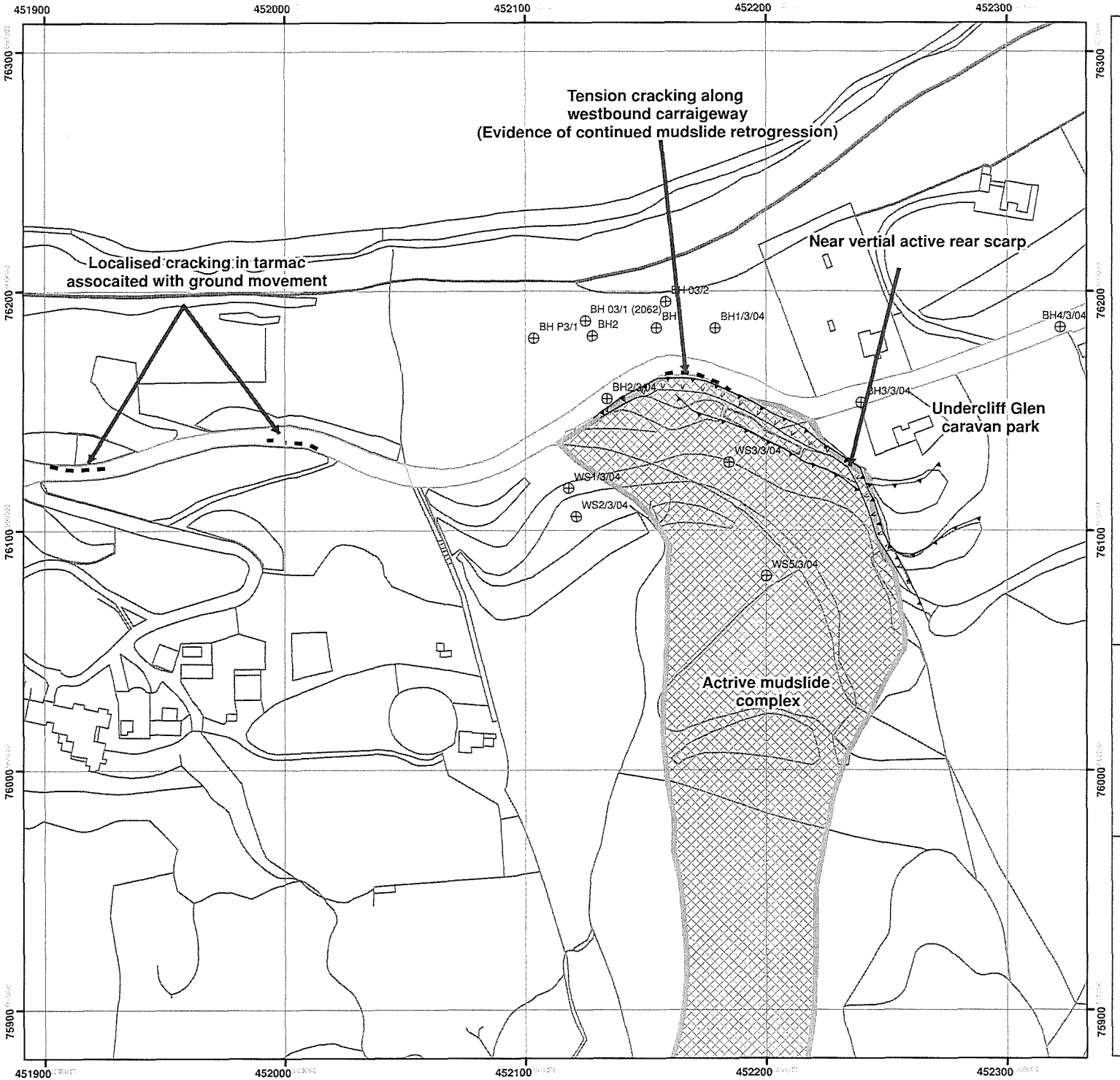
VENTNOR TO NITON OPTIONS STUDY
UNDERCLIFF DRIVE
GEOTECHNICAL OPTIONS APPRAISAL

Drawing

AREA 2 MIRABLES
PRELIMINARY GROUND MODEL
& ROAD IMPROVEMENT OPTIONS

Drawn by: NR	Date: 26.11.09
Checked by: SKT	Date: NOV 09
Approved by: JMC	Date: NOV 09
Drawing No. FIGURE 4.3	Revision -

Drawing Scale: AS SHOWN



Legend

- Explorotory_Holes
- A3055 exisitng route
- Undercliff Glen mudslide

Slope morphology

- sharp concave break of slope
- sharp convex break of slope
- smooth break of slope
- smooth concave break of slope
- tension crack
- OS landline

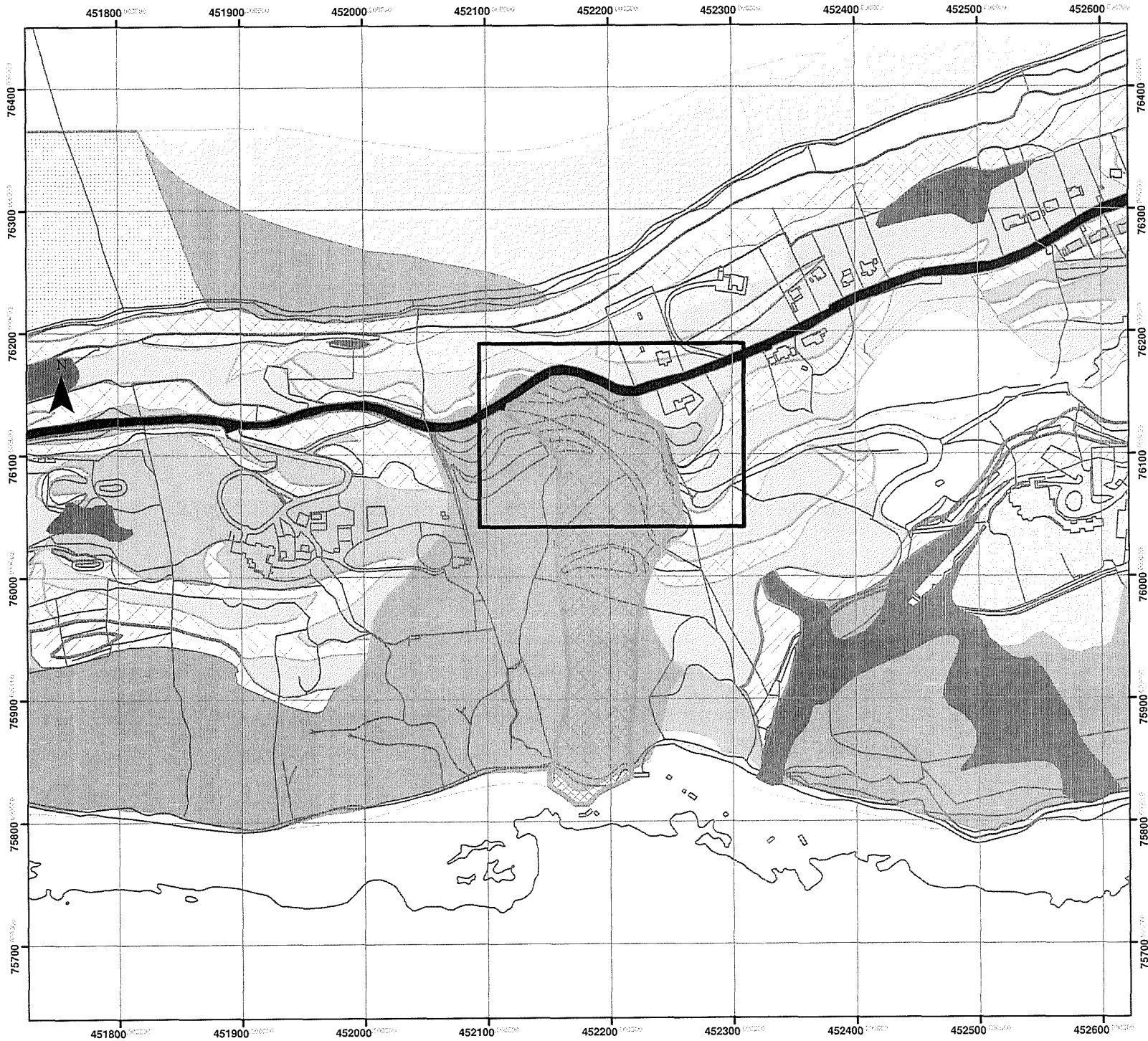
N

Ventnor to Niton Options Study
Undercliff Drive Geotechnical Options Appraisal

Isle of Wight Council

Figure 5.1. Area 3; Undercliff Glen,
Site inspection map

Halcrow



Legend

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- Upper Greensand bench: Areas prone to slow settlement, probably
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- *Predominently stable slopes* (Chalk Downs)
- Unprotected coastal cliffs
- Active mudslies
- Degraded Gault Clay scarp mudslides
- Major Gault Clay scarp slope
- Rotational landslide bench
- Rotation landslide scarp slope
- Mudslides; currently inactive
- Soft ground: No movement informaiton
- Soft ground: imperceptible movement
- Rotational landslide bench; previous episodic ground movement
- Relict mudslides: no evidence of recent movement
- Rotational landslide bench: no movement information
- Undercliff garden mudslide
- A3055 exisitng route
- OS landline
- Area 3

Ventnor to Niton Options Study
Undercliff Drive Geotechnical Options Appraisal

Isle of Wight Council

Figure 5.2. Area 3; Undercliff Glen
Geomorphological map

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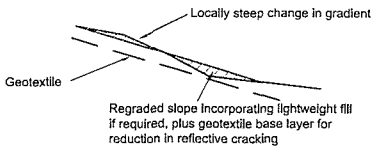
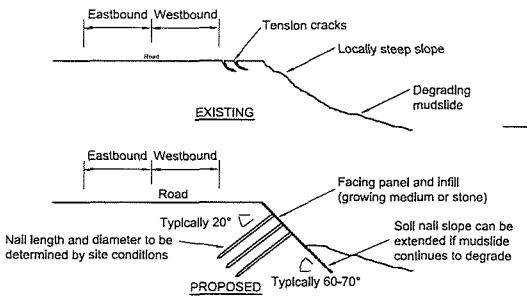
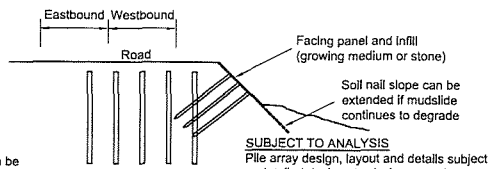
PLAN - 1:2000 SCALE



LOCALISED REGRADING



REINFORCE EXISTING ROAD STRUCTURE - SOIL NAILING

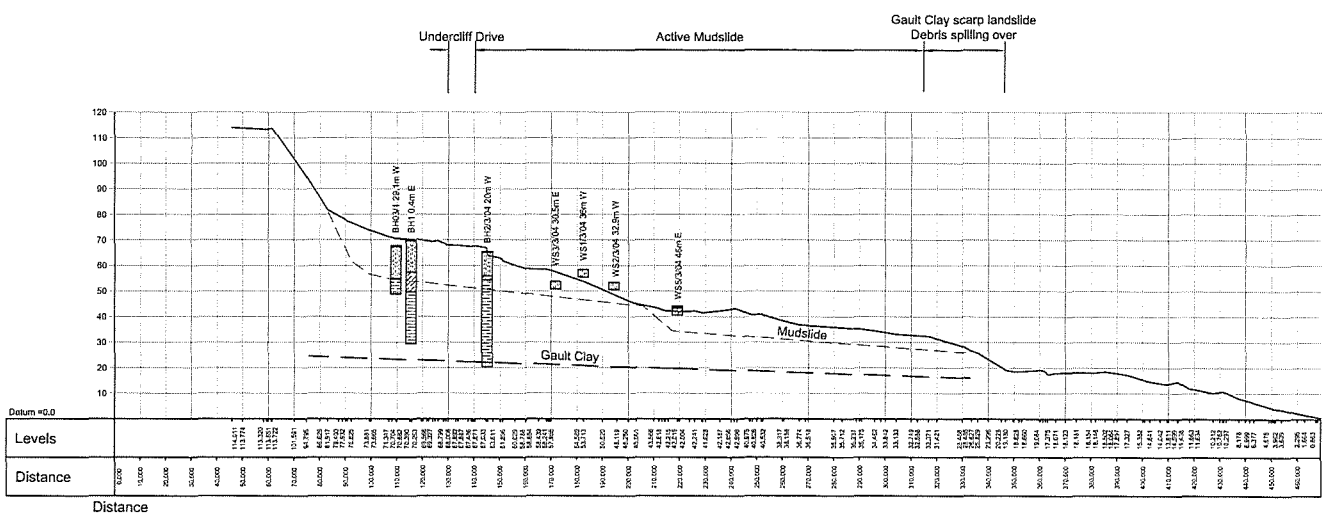


LOCAL STABILISATION OF THE LANDSLIDE BLOCK

SUBJECT TO ANALYSIS

Pile array design, layout and details subject to detailed design. Analysis as required to assess the effects of the imposed drainage constraints (ie no drainage measure permitted) on the proposed conceptual design

ROAD IMPROVEMENT OPTIONS



Section C - C

PRELIMINARY

Key Plan:

Notes:

1. Locations of exploratory holes are shown on Figure No. ????

Key:

- BH1/2/04 Borehole
- TP1/2/04 Trial Pit
- WS1/2/04 Window Sample hole

Key:

- Topsoil
- Clay
- Made ground
- Upper greensand debris
- Gault clay debris
- Gault clay
- Carstone
- Passage Beds
- Projected shear surface

Rev	By	Chkd	Apprvd	Date	Description
-	-	-	-	-	-

Client

ISLE of WIGHT COUNCIL

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Project

VENTNOR TO NITON OPTIONS STUDY
UNDERCLIFF DRIVE
GEOTECHNICAL OPTIONS APPRAISAL

Drawing

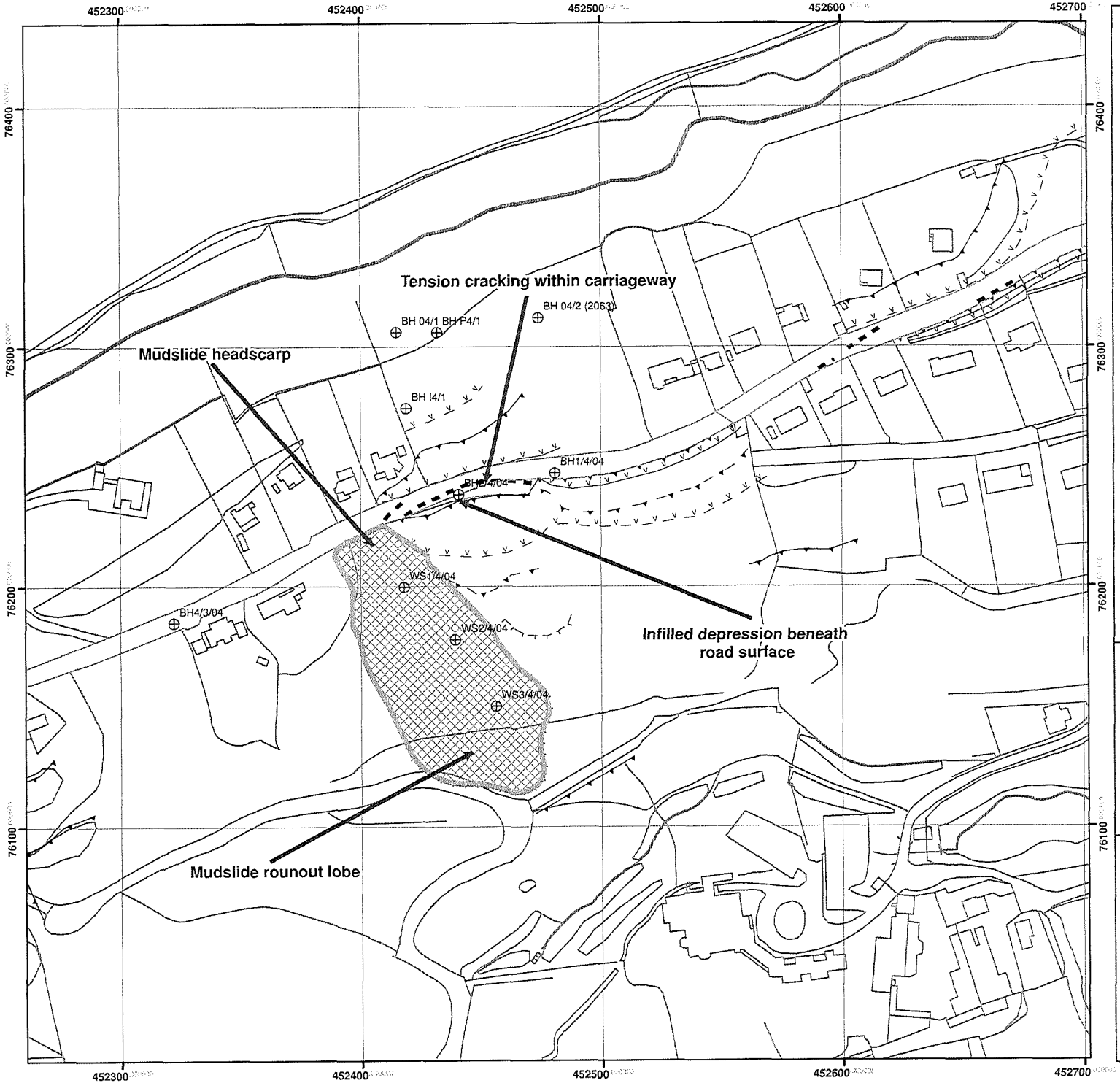
AREA 3 UNDERCLIFF GLEN
PRELIMINARY GROUND MODEL
& ROAD IMPROVEMENT OPTIONS

Drawn by: NR	Date: 25.11.09
Checked by: SKT	Date: NOV 09
Approved by: JMC	Date: NOV 09

Drawing No. FIGURE 5.3

Revision -

Drawing Scale: AS SHOWN



Legend

- Explorotory holes
- Active mudslide
- A3055 exisitng route

Slope morphology

- sharp concave break of slope
- sharp convex break of slope
- smooth break of slope
- smooth concave break of slope
- smooth convex break of slope
- tension crack
- OS landline

N

Ventnor to Niton Options Study
Undercliff Drive Geotechnical Options Appraisal

Isle of Wight Council

Figure 6.1. Area 4; Woodlands, Site inspection map

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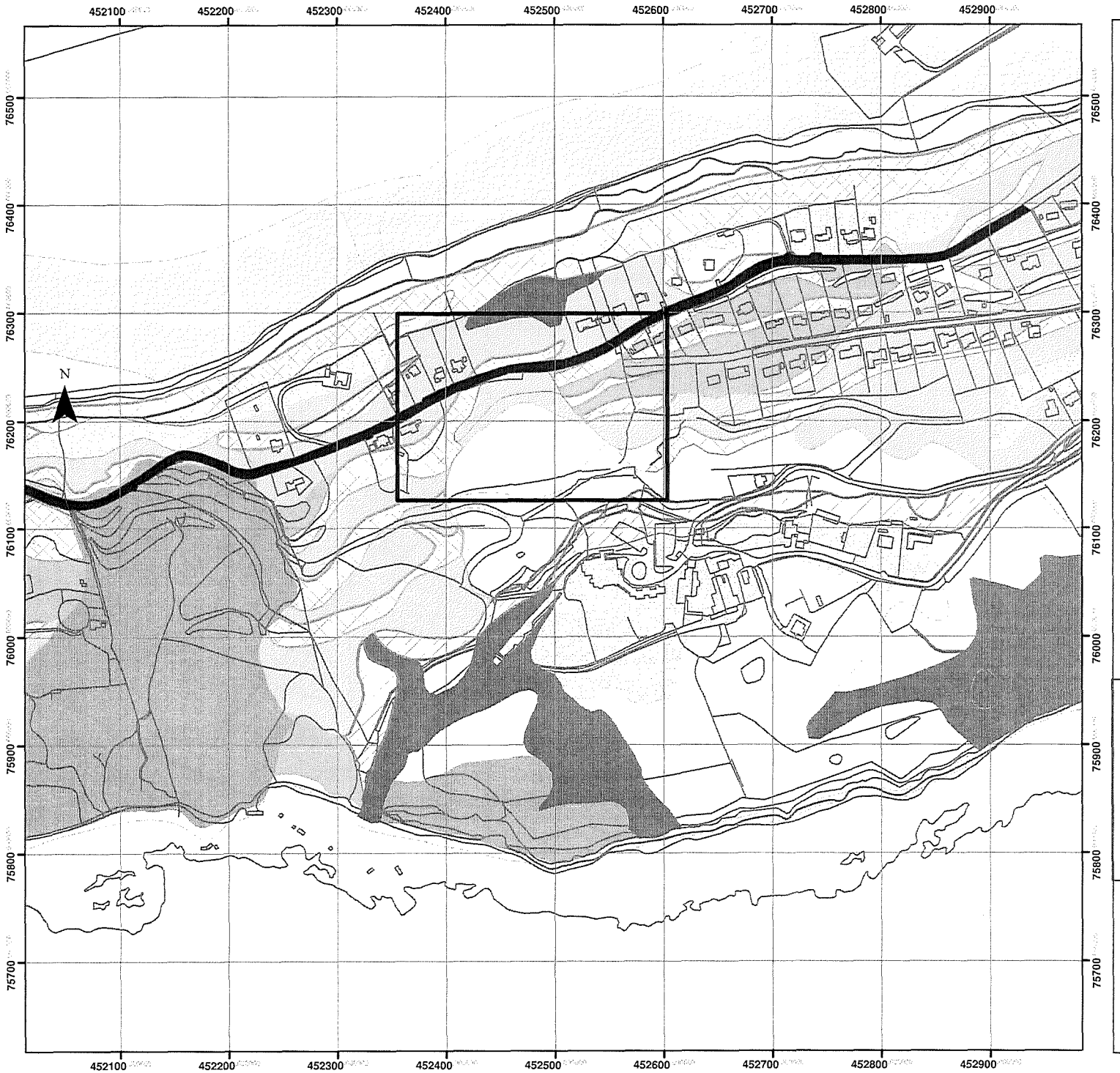

Legend

Geomorphological features

- Rotational landslide bench; imperceptible movement
- Predominently stable slopes (Chalk Downs)
- Unprotected coastal cliffs
- Active mudslides
- Degraded Gault Clay scarp mudslides
- Major Gault Clay scarp slope
- Rotational landslide bench
- Rotation landslide scarp slope
- Mudslides, currently inactive
- Soft ground: No movement information
- Soft ground: imperceptible movement
- Rotational landsldie bench; previous episodic ground movement
- Relict mudslides: no evidence of recent movement
- Rotational landslide bench: no movement information
- A3055 exisitng route
- OS landline
- Area 4

Ventnor to Niton Options Study
Undercliff Drive Geotechnical Options Appraisal

Isle of Wight Council

Figure 6.2. Area 4; Woodlands, Geomorphological Map

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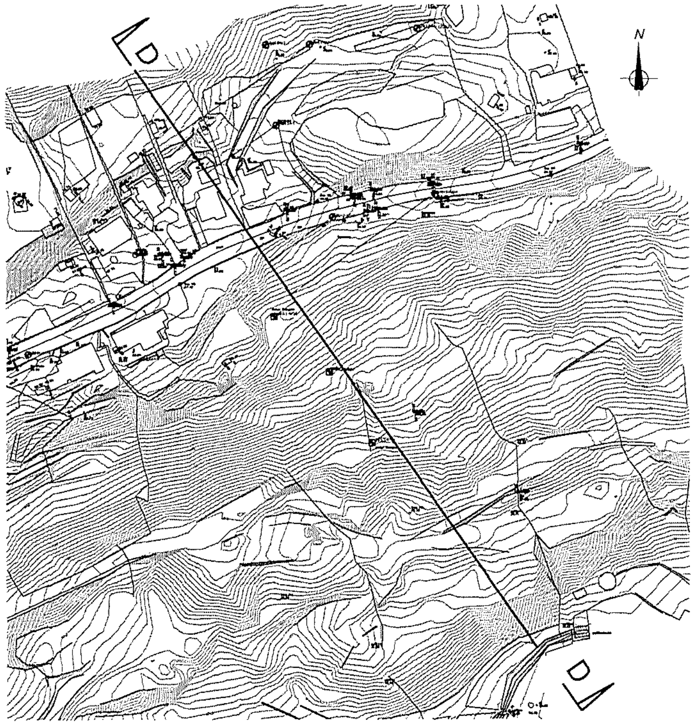
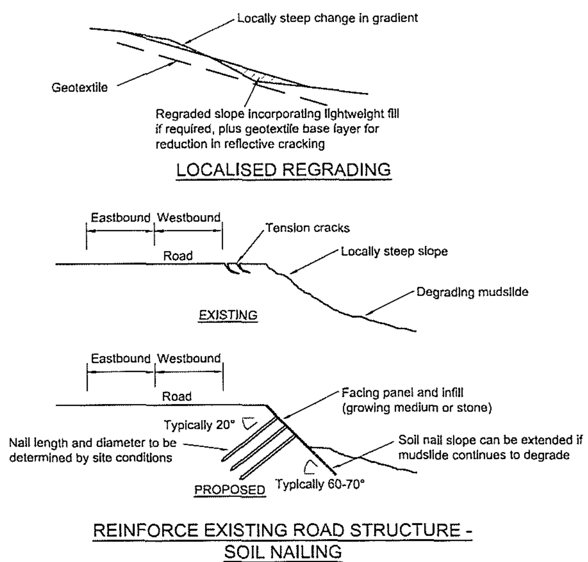
Key Plan:

Notes:
1. Locations of exploratory holes are shown on Figure No. ????

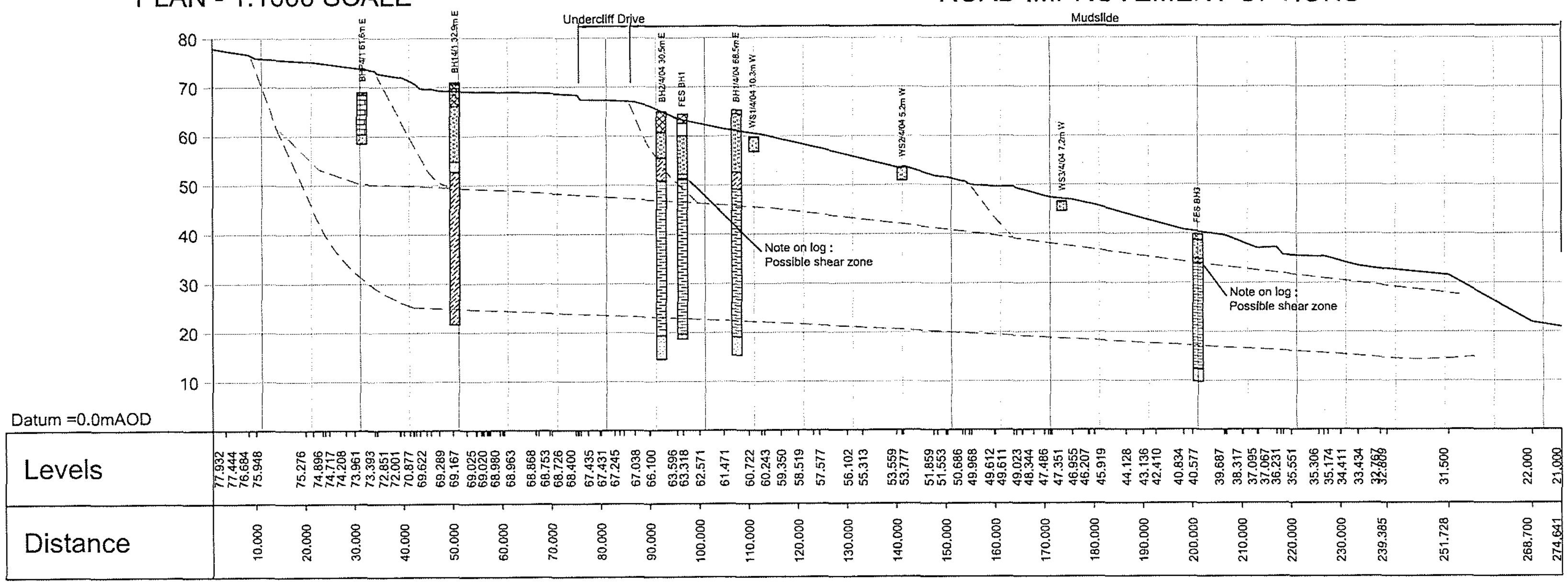
Key:
BH1/2/04 Borehole
TP1/2/04 Trial Pit
WS1/2/04 Window Sample hole



PLAN - 1:1000 SCALE



ROAD IMPROVEMENT OPTIONS



Section D - D

PRELIMINARY

Key:
- Topsoil
- Clay
- Made ground
- Lower Chalk
- Upper Greensand debris
- Passage Beds
- Gault clay debris
- Gault clay
- Carstone
- No core recovery
- Projected shear surface

Rev	By	Chkd	Apprvd	Date	Description
-	-	-	-	-	

Client: ISLE of WIGHT

Halcrow Group Limited

Halcrow

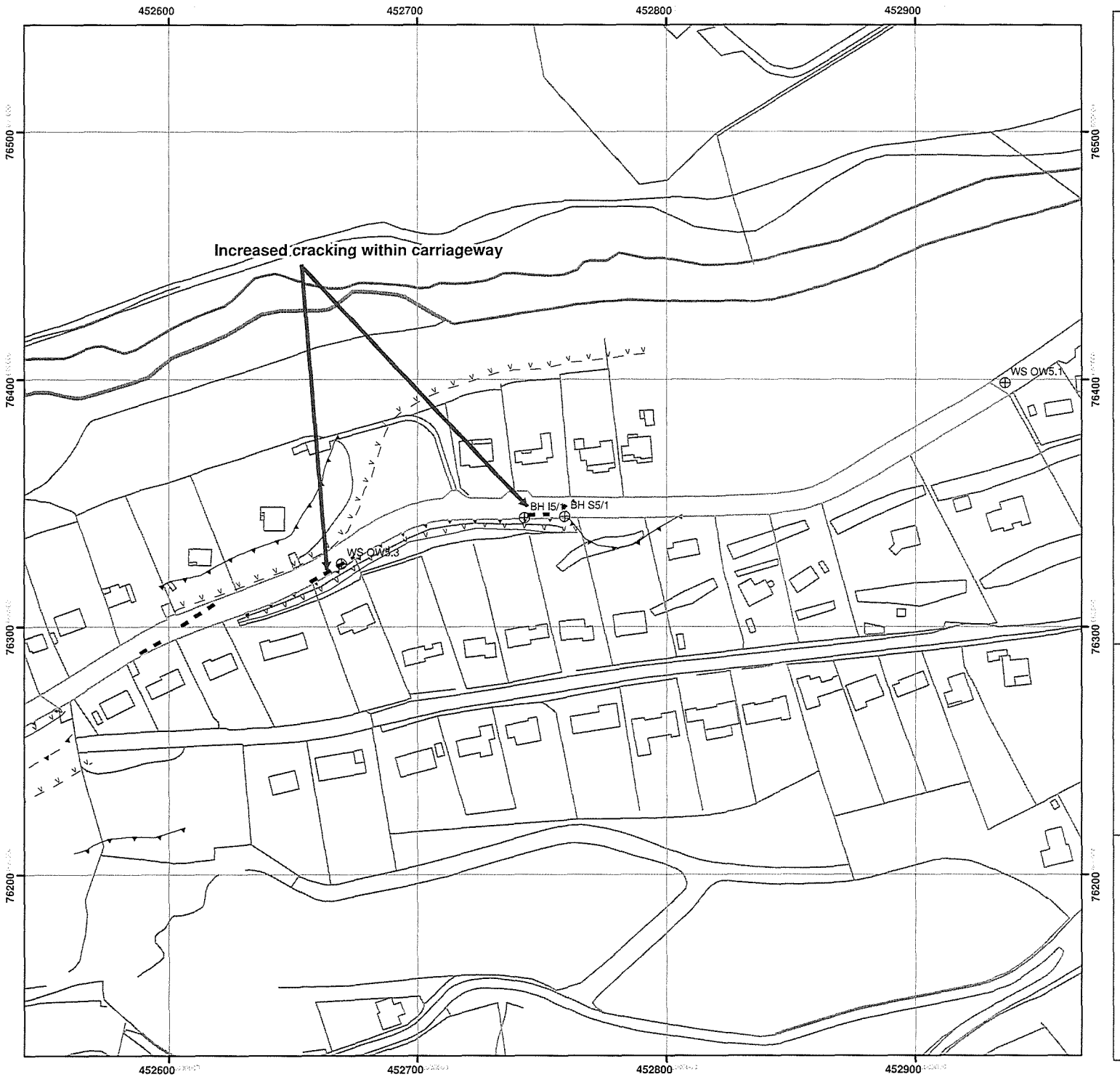
Project: VENTNOR TO NITON OPTIONS STUDY UNDERCLIFF DRIVE GEOTECHNICAL OPTIONS APPRAISAL

Drawing: AREA 4, WOODLANDS PRELIMINARY GROUND MODEL & ROAD IMPROVEMENT OPTIONS

Drawn by: NR Date: 23.11.09
Checked by: SKT Date: NOV 09
Approved by: JMC Date: NOV 09

Drawing No. FIGURE 6.3 Revision -

Drawing Scale: AS SHOWN



Legend

- Explorotory holes
- A3055 exisitng route

Slope morphology

- sharp concave break of slope
- sharp convex break of slope
- smooth break of slope
- smooth concave break of slope
- smooth convex break of slope
- tension crack
- OS landline

N

Ventnor to Niton Options Study
Undercliff Drive Geotechnical Options Appraisal

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Figure 7.1. Area 5; St Lawrence West, Site inspection map

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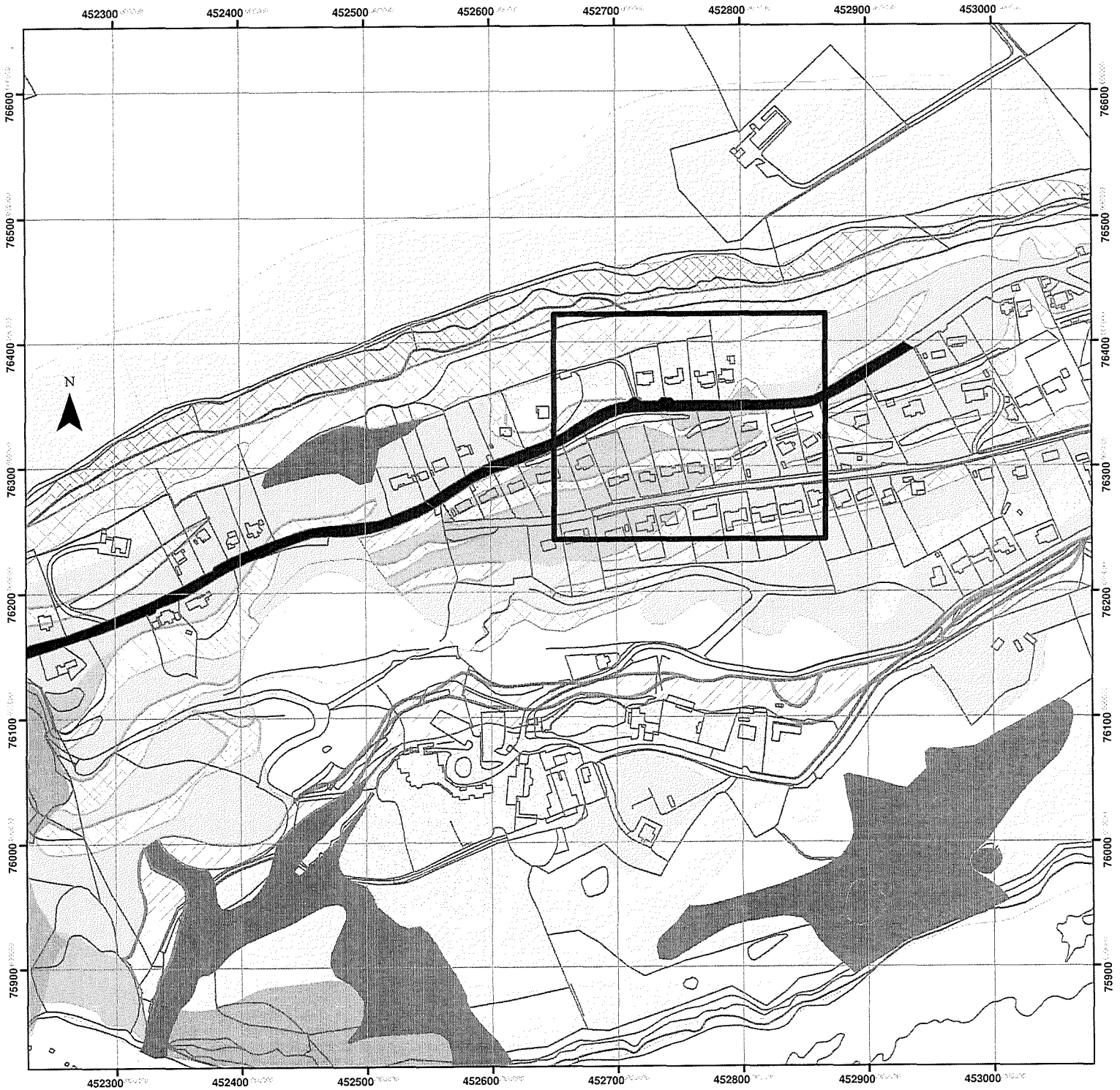

Legend

Geomorphological features

- Chalk Downs: Areas susceptible to shallow translational slides
- Rotational landslide bench; imperceptible movement
- Predominently stable slopes (Chalk Downs)
- Uprotected coastal cliffs
- Active mudslides
- Degraded Gault Clay scarp mudslides
- Major Gault Clay scarp slope
- Rotational landslide bench
- Rotation landslide scarp slope
- Mudslides; currently inactive
- Soft ground: No movement information
- Soft ground: imperceptible movement
- Rotational landslide bench; previous episodic ground movement
- Relict mudslides: no evidence of recent movement
- Rotational landslide bench: no movement information
- Compound slides: Elongated ridges and scarps, ground movement
- *Compound slides: Elongated ridges and scarps; no information is*
- A3055 exisitng route
- OS landline
- Area 5

Ventnor to Niton Options Study
Undercliff Drive Geotechnical Options Appraisal

Isle of Wight Council

Figure 7.2. Area 5; St Lawrence West, Geomorphological map

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Plates

Plate 1: Road condition, Area 1 Beauchamp

Plate 2: Retaining wall, Area 2 Mirables

Plate 3: Crack damage observed in the westbound carriageway, Area 3 Undercliff Glen

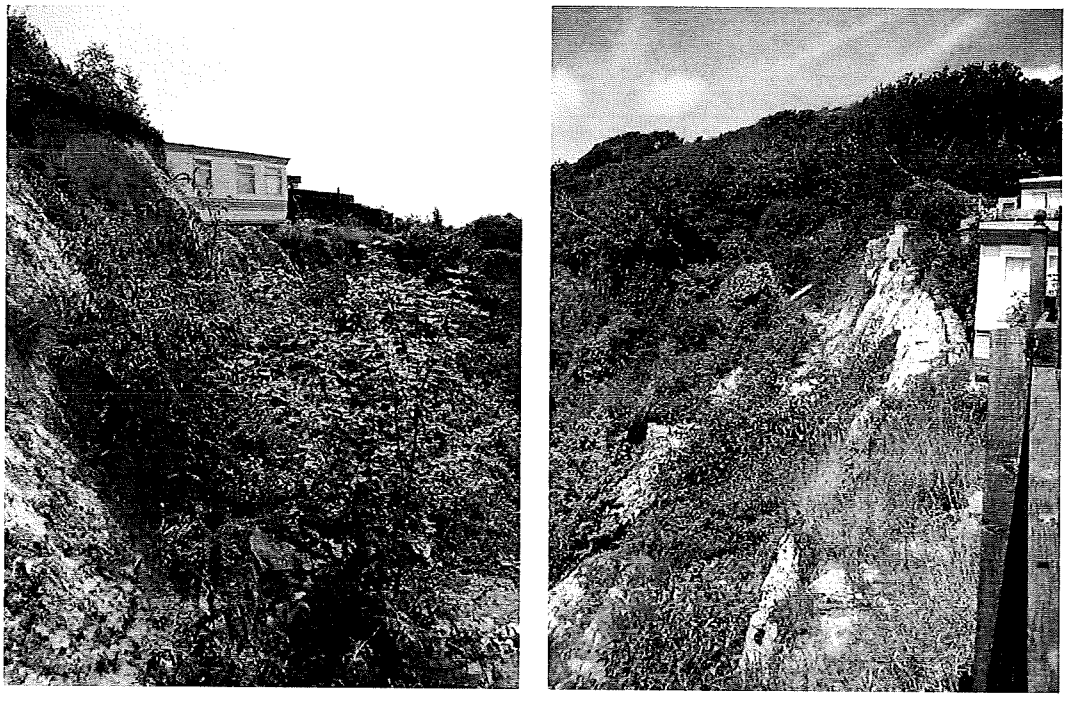

Plate 4: Landslide headscarp, Area 3 Undercliff Glen

Plate 5: Cracking along lateral shear, Woodlands Area 4

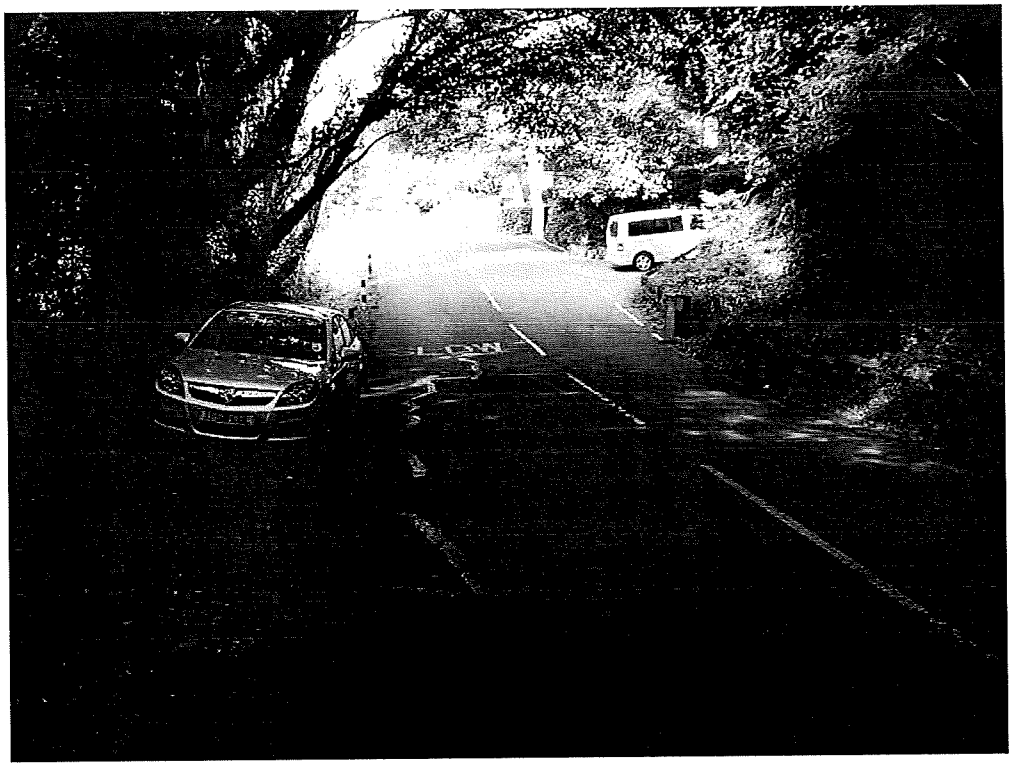

Plate 6: Depression at mudslide headscarp, Woodlands Area 4

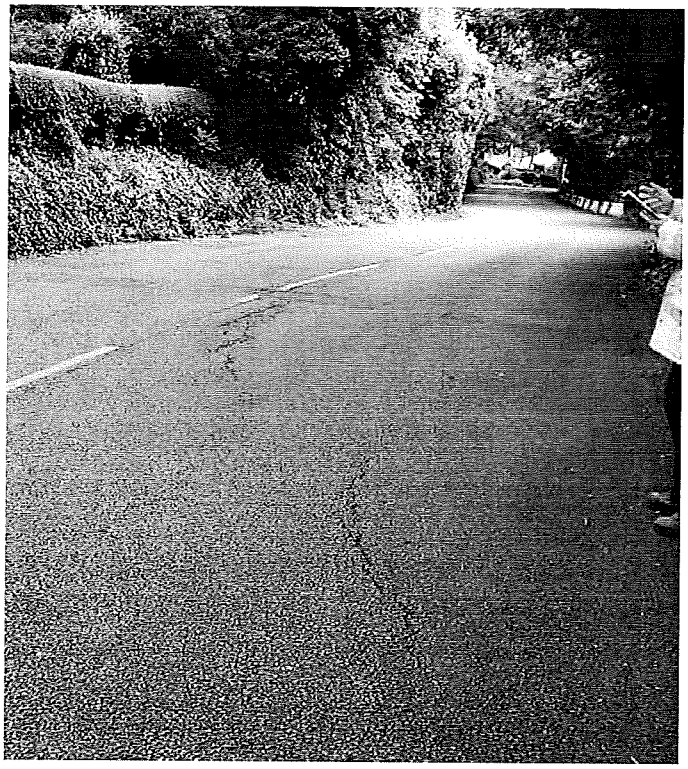

Plate 7: Localised cracking in westbound carriageway, Area 5 St Lawrence West

Plate 8: Localised cracking in westbound carriageway, Area 5 St Lawrence West