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Report on
Preliminary Geotechnical Assessment

Proposed Residential Subdivision
Lot 1 DP707300, Lot 5 DP740252,
Part Lots 101 & 102 DP1077617, Lot 8 DP258605 &
Part of Unnamed Road Reserve, South Kiama

Prepared for
White Constructions (NSW) Pty Ltd

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The undersigned, on behalf of Douglas Partners Pty Ltd, confirm that this document and all attached drawings, logs and test results have been checked and reviewed for errors, omissions and inaccuracies.

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Report on Preliminary Geotechnical Assessment
Proposed Residential Subdivision
Lot 1 DP707300, Lot 5 DP740252, Part Lots 101 & 102 DP1077617, Lot 8 in DP258605 and Part of Unnamed Road Reserve, South Kiama

1. Introduction

This report presents the results of a preliminary geotechnical assessment undertaken for a proposed residential subdivision at South Kiama. The work was requested by White Constructions (NSW) Pty Ltd, potential purchasers and developers of the site and undertaken in liaison with Unicomb Development Services Pty Ltd, project managers for the development.

It is understood that the construction of a residential subdivision is proposed. An assessment of geotechnical issues is required by the client for 'due-diligence' purposes and for submission to Kiama Council with a Rezoning Application. Assessment was undertaken to provide information on the geotechnical suitability of the site and to provide comment on site preparation measures, stability assessment, likely lot classifications, foundation options and pavement thickness design.

The investigation comprised a review of available information and field mapping by a Principal Geotechnical Engineer, engineering analysis and reporting. Details of the work undertaken and the results obtained are given in the report together with preliminary comments relating to design and construction practice.

An aerial photo indicating a conceptual layout overview was provided by the client for the assessment. A draft report was forwarded in an email dated 27 February 2017. This report supersedes all previous verbal advice and written correspondence.

2. Site Description and Regional Geology

The site, which includes Lot 1 in DP 707300, Lot 5 in DP 740252, Part Lots 101 & 102 in DP 10777617, Lot 8 in DP258605 and Part of an Unnamed Road Reserve, is an irregular-shaped area of approximately 40 ha with maximum plan dimensions of 360 m and 1550 m (refer Drawing 1). It is bounded to the north by Saddleback Mountain Road, to the east by the Princes Highway, to the south by residential dwellings and rural land, and to the west by rural land. An existing historic cemetery (Lot 3 DP 258605) is located in about the centre of the site, with pedestrian access from the highway via the "unnamed road reserve".

Surface levels fall predominantly in the easterly direction (ie towards the Princes Highway) at grades of 1 in 4 to 1 in 40 (with locally steeper sections adjacent to creek lines and drainage depressions). The overall difference in level is estimated to be about 80 m from the highest part of the site to the lowest.

The Kiama 1:50 000 Geological Series Sheet (Ref 1) indicates that the site is underlain by an almost horizontally bedded sequence of rocks of the Shoalhaven Group of Permian age. The typical lithologies comprise the Blow Hole Latite Member, a mid-grey, typically aphanitic latite which underlies the Budgong Sandstone (known locally as Kiama Sandstone), a red brown to grey volcanic sandstone.

Both formations typically weather to form clays of high plasticity. In the lower sections of the site within the creek lines and drainage depressions, the rock sequence can be overlain by colluvium or alluvium of recent (in geological terms) age.

The results of the assessment were consistent with the broadscale mapping with extensive areas of latite outcrop observed in the lower slopes and in the South Kiama Drive and Princes Highway cuttings to the south east of the site. Sandstone (consistent with the Budgong/Kiama Member) was observed in the Princes Highway cutting at Saddleback Mountain Road to the north-east of the site. Reference to web-based mapping indicates that the site is in an area of *"no known occurrence of acid sulfate materials".*

3. Field Work

3.1 Methods

The field assessment comprised a site walkover and field mapping by a Principal Geotechnical Engineer to provide an assessment of the distribution of rock types, soil depths and stability considerations. The locations of features observed during the walkover assessment are shown on Drawing 2. Various features observed during the site inspection are shown on the colour photoplates also in Appendix B.

3.2 Results

A walkover of the site by a Principal Geotechnical Engineer indicated:

- Uniform surface slopes over most of the site (refer Photos 1 – 3, 5 – 7, 9 – 13, 15, 16 & 19 – 21, 23 – 25, 32 – 36, 38 – 39, 41, 42 & 45 – 49);
- Areas of latite outcrop (refer Photos 3, 7, 10, 21, 23, 27, 37 & 42 – 44);
- Probable colluvial deposition within the gully and creek lines (refer Photos 4, 9, 26 & 27);
- Near-vertical scarps up to 2 m high in the creekbanks (refer Photos 8, 18 & 22);
- A number of farm dams (refer Photos 11, 20, 25 & 26) which are probably fed by both overland flow and spring activity);
- Existing cemetery in the centre of the site (refer Photos 12 & 16);
- Lush grass growth (refer Photos 13, 26, 28 & 31) possibly indicative of spring activity;
- Erosion and scour in steeper sections probably exacerbated by stock movement (refer Photos 22, 29 & 37);
- Irregular, hummocky surface and lush grass cover (refer Photos 28 & 31) indicative of either near-surface soil creep or deeper seated instability associated with groundwater movement;
- Isolated fill mound (refer Photo 30);
- A 10 – 15 m high embankment for Princes Highway encroaches into the south western section of the site (refer Photo 40);

- Boulder and cobble accumulation directly over latite outcrop (refer Photo 44) in the southern most creek-line;
- Possible talus debris present in the near-surface soils (refer Photo 45) in the south-eastern section of the site.

4. Comments

4.1 General

The following comments are based on the results of site inspection and our involvement in similar projects. It is understood that the report is for conceptual planning purposes and for submission to Kiama Council with a Rezoning Application. Further investigation will be required at the appropriate times as the planning and design of the subdivision proceeds. Accordingly this report must be considered as being preliminary in nature.

4.2 Slope Stability Assessment

The following assessment is based on the results of the geological mapping and Douglas Partners involvement in similar projects. Aspects included in the slope stability assessment are the bedrock geology, observed or anticipated soil depth, steepness of slope relative to historical or ancient slope failures in similar materials, the disturbance of soil and vegetation cover during development, the influence of groundwater or surface saturation, and the effects of earthquake forces.

Stability of slopes is typically dependent on a number of key factors, including the ground and bedrock inclination, soil profile characteristics, available shear strength of soil and rock, groundwater conditions and site history with respect to instability on a geological timescale. While an area may be assessed as being currently stable, unsuitable developments or poor construction techniques may trigger instability. Alternatively, sites which are assessed as having some risk of instability may be improved by installation of such features as subsurface drains or retaining structures.

As a result of the surface observations, the site has been qualitatively assessed with reference to the Australian Geomechanics Society Landslide Taskforce "Practice Note for Landside Risk Management" (Ref 2), relevant extracts of which are given in Appendix C.

The site has been divided into three general risk of instability zones (low, moderate and high risk of instability) as summarised below. The approximate interpreted zone boundaries are shown on Drawing 3. It is noted that the boundary between risk zones will commonly be transitional and as such dual classifications (eg. low to moderate and moderate to high risk of instability) have been adopted in some areas of transitional change in slope, also in areas where small areas of lesser surface slope are included within overall steeper areas.

4.2.1 Low Risk

This zone is characterised by gently sloping footslopes and the broader crests of some ridge crests with slopes generally less than 10°. Some degree of water-logging or minor soil creep within steeper slope sections may occur, but would generally be anticipated to have overall better drainage characteristics due to topographically higher location.

Instability should not generally be expected within the zone unless major changes to site conditions occur. Minor instability may locally occur where concentrated seepage and erosion occurs in areas of deep soil profiles. The provision of subsurface drainage may be locally required in zones of seepage.

4.2.2 Moderate Risk

This zone is characterised by moderate slopes generally in the range 10° to 15° in side slope locations, some ridge crests and on larger natural benches within overall steeper slopes. Evidence of minor soil creep may also be present.

Some steeper sections of slopes with very high strength outcrops of latite, or underlain at shallow depth by latite, a moderate risk classification has been adopted due to the inherent stability and strength of the underlying materials.

In areas of otherwise gentler slope, but with possible seepage lines, a low to moderate or moderate risk has been included. Similarly, moderate to high risk zoning has also been included to indicate transition zones of increased assessed risk, generally associated with moderate slope angle and deeper soil profiles potentially affected by periodic seepage lines or erosion of gully banks, in locations with deeper colluvium where it is not clear whether this colluvium is the product of slow downslope creep or from landslide activity of indeterminate age.

Instability in the zone can be expected if development does not have regard to site conditions, with the most likely areas of instability being in gully heads and in areas of thick soil accumulation affected by seepage.

4.2.3 High Risk

This zone is generally characterised by the steep gully lines and the Princes Highway embankment. The risk of zoning includes steep to very steep sections in the south eastern part of the site. It is considered that localised instability may occur during and after extreme rainfall events. Any development requires detailed planning and care in construction, particularly related to cutting and filling of slopes and the control of groundwater seepage. It is noted however, that the high risk zoning would preclude construction of residential structures.

4.3 Acid Sulfate Soil Assessment

Based on the results of the investigation and previous experience in similar geological settings, the following comments are provided with respect to acid sulfate potential:

- Reference to web-based mapping indicates that the site is located in an area mapped as *'no known occurrences of acid sulfate soil materials'*;
- The site is located in a topographically-elevated area (ie RL 12 – 86 m AHD), above the typical elevation below which acid sulfate soils could have developed or be encountered (ie below about RL 12 m AHD);
- The site is in an area mapped on the 1:50 000 Kiama Geological Series Sheet (Ref 1) as being underlain by Budgong Sandstone or Blow Hole Latite both belonging to the Shoalhaven Group (ie not underlain by Quaternary alluvium within which acid sulfate conditions can occur);

In summary, the geological setting is inconsistent with the occurrence of acid sulfate soil conditions and therefore, there considered to be negligible (if any) risk of acid sulfate soils being encountered on the site.

4.4 Site Development

Assessment of the residential capability of the site has principally been carried out on the basis of geotechnical considerations, specifically risk of slope instability and foundation conditions. Items such as environmental considerations such as vegetation cover, flooding hazard and water logging associated with the creek systems, are also noted as these may be locally overcome by appropriate design and construction.

Areas classified as *low* risk are generally considered suitable for residential development provided the site works are in accordance with sound engineering practice. Areas classified as *low to moderate* and *moderat*e risk are also considered generally suitable for residential development provided siteworks are in accordance with accepted practice for hillside development and site-specific investigations. General guidelines (refer Appendix D) and development considerations would require the classification of residential lots to comply with the requirements of AS2870, Residential Slabs and Footings.

Low to moderate and *moderate* risk zones include areas of steepening slopes, possible seepage considerations and variable soil thickness, which locally may give rise to slope instability, especially if excavation of deeper road cuttings are required in areas of deep clay soils. It is recommended that all proposed developments in these zones be investigated by appropriately qualified geotechnical practitioners.

Site specific items indicated below should be considered in investigation and design programs:

- orientation of access roads, residential structures and services to minimise requirements for excavation, filling and possible retaining structures. In moderate risk area unsupported cuts should be limited to less than 1.5 m.
- the maximisation and/or replacement of tree cover.
- the creation of larger lots to permit more sensitive development of the individual site.

- the programming of development, particularly roadworks, which would be the main activity to expose potentially erodible colluvial and residual soils, to minimise time of exposure and also the inclusion of techniques (e.g. spray coating) to minimise erosion.
- installation of site specific surface and subsurface drainage.
- founding of residential and retaining structures in stratum of appropriate strength.
- selection of residential design to minimise the requirement for excavation.

It is anticipated that the identified section of *moderate to high* risk could be reduced to *moderate* risk, thus enabling residential development provided installation of subsurface drains into bedrock to intercept and control groundwater is undertaken, possibly in conjunction with removal of creep-affected material and replacement with controlled filling.

4.5 Excavation Conditions

Based on the results of the walkover, it is anticipated that a wide range of materials will be encountered underlying topsoil and clay near the surface, grading to weathered latite and sandstone bedrock rapidly becoming high strength (or greater). It would be expected that excavation could be readily carried out using conventional hydraulic excavation equipment possibly with some light ripping in the upper weathered sandstone. Medium or greater strength rock will require heavy rock breaking, rock grinding, ripping equipment and/or blasting for removal in bulk.

The excavation of rock is dependant both upon rock mass characteristics, primarily the spacing and orientation of jointing and rock strength, as well as the equipment used and skill of the operator. Where the proposed excavation depths are likely to intersect medium strength or greater rock, it is suggested that borehole drilling in conjunction with continuous rock core sampling be undertaken during the detailed design phase. This will enable assessment of rock quality and strength is undertaken as part of tenderer's consideration for excavation methods.

4.6 Site Classification

Classification of individual allotments within the site should comply with the requirements of AS 2870 – 2011 *"Residential Slabs and Footings"* (Ref 3).

Based on previous experience in similar geological settings, the subsurface profiles would most likely be equivalent to Class M (moderately reactive) to Class H2 (highly reactive). P-class lots would be in areas where the presence of variable soil strength exists, in areas of steeper topography (ie within low to moderate and moderate risk zone) and in areas underlain by existing uncontrolled filling and deep topsoils classification.

It is noted however that the final classifications will be dependent on soil reactivity, soil strength and site preparation methodology. Residential construction should be relatively straightforward utilising underlying stiff clays or controlled filling (following site preparation in accordance with Section 4.7) or weathered rock for foundation support. The final classifications will be dependent on soil reactivity, soil strength and filling methodology.

4.7 Site Preparation

Site preparation for pavement and dwelling construction should include the removal of topsoils and other deleterious materials (such as uncontrolled filling) from the proposed building areas and roadways.

In areas that require filling, the stripped surfaces should be test rolled in the presence of a geotechnical engineer. Any areas exhibiting significant deflections under proof rolling should be treated by over-excavation and replacement with low plasticity filling placed in near-horizontal layers no thicker than 250 mm compacted thickness. Each layer should be compacted to a dry density ratio in the range 98% to 102% relative to standard compaction, with placement moisture contents maintained within 2% of standard optimum. In pavement areas, the upper 0.5 m should be compacted to at least 100% dry density ratio relative to standard compaction. All fill batters should be constructed no steeper than 2.5:1 (horizontal:vertical) and appropriately vegetated to reduce the effects of erosion.

It is expected that the upper soils would be adversely affected by inclement weather. Whilst the soils are typically of stiff to very stiff consistency when dry, they can rapidly lose strength during rainfall and saturation, and result in difficult traffickability. As such, surface drainage which directs runoff away from work areas should be installed prior to construction, possibly in conjunction with the designation of construction equipment haul routes to minimise trafficking of stripped areas. Notwithstanding this, 300 – 500 mm thick coarse, granular bridging layers may be required in areas of water-logged soils, the extent of which is best determined on site during construction.

To validate bearing pressures within controlled filling, field inspections and in-situ testing of future earthworks must be undertaken in order to satisfy the requirements of a Level 1 inspection and testing services as defined in AS 3798 – 2007 (Ref 4).

Filling methodology over the floodplain will be primarily dependent on exposed site conditions following site stripping. Where site inspection indicates relatively stiff conditions, filling could be undertaken in accordance with the above requirements, which will not have a detrimental effect to lot classifications. It is noted however, that the presence of loose and water charged alluvium, will likely preclude satisfactory compaction of filling. In this instance, the incorporation of a thicker initial layer of filling, possibly in conjunction with extensive subsurface drainage will result in Class P classicisation.

Where Class P conditions are determined at the commencement of construction, site filling in these areas could be undertaken under reduced (Level 2) control as described in AS 3798 – 2007 (Ref 4).

The following general guidelines are also provided:

- It is anticipated that the clayey, colluvial and residual soils from higher site elevations will generally be suitable for use as filling provided oversize materials (generally >100 mm) are removed from the spread materials. It is noted that oversize, very high strength latite is unlikely to be easily broken down by compaction plant.
- Unsupported excavations and filling should generally be limited to a height of 1 m. All such batters should be constructed no steeper than 2.5H:1V and appropriately vegetated to reduce face erosion. Excavations and filling in soil materials deeper than 1 m should be supported by engineer-designed retaining walls.

- Latite can be expected at shallow depths in the vicinity of rock outcrops, and also as rock fragments in the overlying residual clay soil. The latite will probably be fresh to slightly weathered, closely fractured and require heavy ripping or rock breaking, possibly by the use of popping explosives. Groundwater seepages could be present at the interface of the sandstone and latite.
- Road subgrades should be keyed into side cuts; partial side cutting and side filling are undesirable.

Conventional sediment and erosion control measures should be implemented during the construction phase with exposed surfaces to be topsoiled and vegetated as soon as practicable following the completion of earthworks.

4.8 Retaining Structures

It is suggested that active earth pressures on cantilever or gravity retaining walls (if proposed) due to the retained soils be estimated using a triangular pressure distribution calculated as follows:

$$\exists_z = \uparrow.Ka.z$$

where	$\exists_z$	=	horizontal pressure at depth z
	$\uparrow$	=	unit weight of retained soil
		=	20 kN/m^3
	Ka	=	active earth pressure coefficient
		=	0.3 for stiff clay and compacted filling (horizontal backfill only)

The angle of inclination of the retained soils must be taken into account when determining the active earth pressure coefficient. Design of retaining walls should make allowance for a partial hydrostatic head over the top 1 m of wall (to accommodate short-term inundation during storm events) and for all superimposed or surcharge loads that will occur.

4.9 Foundation Options

All footing systems for residential structures should be designed and constructed in accordance with AS 2870 – 2011 (Ref 3) for the appropriate classification. Subject to the nature of the proposed structures and the design loads, stiff residual clays, controlled filling and weathered rock will most likely be available for foundation support. Suitable footing systems will comprise strip and pad footings, raft slabs and pier and beam/pier and slab systems, dimensioned to the requirements of AS 2870 – 2011.

Allowable bearing pressures appropriate for the range of material types available for foundation support would be as follows:

Compacted filling	100 – 150 kPa
Stiff clay	150 kPa
Extremely weathered rock (extremely low strength)	500 kPa
Highly to slightly weathered rock (low strength)	1200 kPa

Where cut and fill benches are proposed for individual structures, localised deepening of footings will be necessary to ensure uniform bearing is achieved. Inspection of footing excavations must be undertaken by a geotechnical consultant to confirm the appropriateness of all bearing stratums for the nominated design bearing pressures. The selection of bearing stratum will be dependent on the type of structures, the proposed loads, the resultant settlements and the topographical location. Project-specific geotechnical investigation with subsurface profiling should be undertaken at the appropriate time as planning proceeds in order to determine appropriate foundation systems for the various structures. Notwithstanding the above, the principal requirement for hillside lots is for all footings to found in weathered rock.

4.10 Site Maintenance and Drainage

The developed lots should be maintained in accordance with the CSIRO publication *"Guide to Home Owners on Foundation Maintenance and Footing Performance"*, a copy of which is included in Appendix C. Whilst it must be accepted that minor cracking in most structures is inevitable, the guide describes suggested site maintenance practices aimed at minimising foundation movement to keep cracking within acceptable limits.

Surface drainage should be installed and maintained at the site. All collected stormwater, groundwater and roof runoff should be discharged into the stormwater disposal system. The possible need for subsurface drainage installation as part of individual dwelling construction (particularly within the moderate risk zone) is noted, the extent of which is best determined once site-specific development details are determined.

4.11 Pavement Thickness Designs

Table 1 (following page) summarises a range of pavement thickness designs based on the procedures given in Austroads (Ref 5) for varying traffic loadings and subgrade CBR values. Based on previous experience in the local area and the presence of high plasticity clays as subgrade material, typical lower bound CBR values would be approximately 2% – 5%.

The pavements should be placed and compacted in layers no thicker than 150 mm, with control exercised over placement moisture contents. If layer thicknesses greater than 150 mm are proposed, it may be necessary to test the top and bottom of the layer to ensure that the minimum level of compaction has been achieved through the layer. Suggested material quality and compaction requirements are given in Table 2 (following page).

Table 1: Preliminary Pavement Thickness Design

Traffic Loading (ESA)	Total Pavement Thickness (mm)			
	CBR < 3%	CBR 3%	CBR 4%	CBR 5%
1 x 10^4	325 (475)	325	280	245
5 x 10^4	370 (520)	370	315	280
1 x 10^5	385 (535)	385	330	295
5 x 10^5	480 (630)	480	410	365

Note: Bracketed figures indicate total boxing depth, taking into account 150 mm of subgrade replacement.

Table 2: Pavement Material Quality and Compaction

Layer	Material Quality	Minimum Compaction
Wearing Course	To conform to Austroads requirements	To conform to Austroads requirements
Base Course	To conform to Austroads requirements Soaked CBR ∣ 80%, PI ™6%	Minimum dry density ratio of 98% Modified (AS 1289 Test 5.2.1)
Sub-base Course	To conform to APRG requirements Soaked CBR ∣ 50%, PI ™12%	Minimum dry density ratio of 95% Modified (AS 1289 Test 5.2.1)
Subgrade Replacement	Soaked CBR ∣ 15%	Minimum dry density ratio of 100% Standard (AS 1289 Test 5.1.1)
Subgrade		Minimum dry density ratio of 100% Standard AS 1289 Test 5.1.1)

Where: PI = Plasticity Index
CBR = California bearing ratio

Whilst the use of lesser quality pavement materials than that detailed in Table 2 may be feasible, some compromise in either performance and/or pavement life must be anticipated and accepted. It is also suggested that advice be sought from Council if lesser quality pavement materials are proposed.

4.12 Pavement Drainage

Surface and subsurface drainage should be provided to prevent moisture ingress into the pavement materials. It is suggested that subsurface drains, constructed with an invert level at least 0.5 m below subgrade level, should be installed where appropriate. As a minimum, subsurface drainage should be incorporated along the cut sides of the roads. This aspect and the need for additional subsurface drainage should be reviewed on site during construction and should take into consideration the significance of other engineered drainage work proposed for the project. Guidelines on the arrangements of subsurface drainage are given on Page 20 of ARRB – SR41 (Ref 6). It should be noted that if the sub-base is of lower permeability relative to the base layer, then the subsurface drain should intersect all pavement layers as shown in ARRB – SR41.

Since it is typically some time before the final AC layer is placed (where it is placed in two layers), it is also suggested that diversion mounds be constructed as part of the initial AC layer to ensure that all sheet flow during inclement weather is directed into the kerbs and guttering. If such mounds are not constructed, most flows will run within the pavement (as the 'lip' acts as a barrier) with the most likely result being premature pot-holing and localised pavement failure due to saturation in the wheel path adjacent to the kerb.

4.13 Further Investigations

It is anticipated that following confirmation of the subdivision layout, further investigations would include:

- Subsurface investigation to confirm the geotechnical conditions, further refine stability zone boundaries and slope remedial works;
- Test pitting and sampling to address subgrade conditions along the alignments of the proposed road system.
- Laboratory testing of selected samples from road alignments to determine subgrade design parameters for individual road sections as the limited testing to date indicates the potential for poor subgrade conditions over at least the alluvial areas.
- At subdivisional stage, test pitting in proposed building envelopes to provide appropriate classification of individual lots for residential development and to provide recommendations for precautionary works (eg subsurface drainage to be included in the site preparation works.

5. Summary

The preliminary geotechnical assessment has indicated that the site is geotechnically suitable for a residential subdivision. Stability assessment has results in the site being dived into 5 stability zones ranging from low to high. Areas of deep clay soils and potential or identified groundwater seepage have been classified *moderate to high* risk. Residential building envelopes are generally not recommended in moderate—to-high or high risk areas, although the risk classification of some sections of the *moderate to high* risk areas could be revised to *moderate* risk following installation of surface and subsurface drains.

Comments are given within the report on likely site classification, stability, foundation design and pavement thicknesses. General comments on design and construction aspects are also given in the report.

Detailed geotechnical investigation and assessment (including additional subsurface excavation and laboratory testing of selected samples) will be required as the design of the development proceeds and as such, this report must be considered as being preliminary in nature.

6. References

1. Geology of Kiama 1:50 000 Geological Series Sheet No 9028 – 1, Department of Mines, (1977).
2. *AGS Landslide Taskforce – "Practice Note Guidelines for Landslide Risk Management 2007" Australian Geomechanics Vol 42 No.1 March 2007*
3. Australian Standard AS 2870 – 2011 *Residential Slabs and Footings.*
4. Australian Standard AS 3798 – 2007 *Guidelines on Earthworks for Commercial and Residential Developments.*
5. *Guide to Pavement Technology- Part 2: Pavement Structural Design,* Austroads 2018
6. ARRB – SR41 – A Structural Design Guide for Flexible Residential Street Pavements, Australian Road Research Board, Special Report No. 41, 1989.

7. Limitations

Douglas Partners (DP) has prepared this report for this project at Lot 1 DP707300, Lot 5 DP740252, Part Lots 101 & 102 DP1077617, Lot 8 DP258605 & Part of Unnamed Road Reserve, South Kiama in accordance with DP's proposal dated 16 January 2017 and acceptance received White Constructions (NSW) Pty Ltd dated 24 January 2017. The work was carried out under DP's Conditions of Engagement. This report is provided for the exclusive use of White Constructions (NSW) Pty Ltd for this project only and for the purposes as described in the report. It should not be used by or relied upon for other projects or purposes on the same or other site or by a third party. Any party so relying upon this report beyond its exclusive use and purpose as stated above, and without the express written consent of DP, does so entirely at its own risk and without recourse to DP for any loss or damage. In preparing this report DP has necessarily relied upon information provided by the client and/or their agents.

The results provided in the report are indicative of the sub-surface conditions on the site only at the specific sampling and/or testing locations, and then only to the depths investigated and at the time the work was carried out. Sub-surface conditions can change abruptly due to variable geological processes and also as a result of human influences. Such changes may occur after DP's field testing has been completed.

DP's advice is based upon the conditions encountered during this investigation. The accuracy of the advice provided by DP in this report may be affected by undetected variations in ground conditions across the site between and beyond the sampling and/or testing locations. The advice may also be limited by budget constraints imposed by others or by site accessibility.

This report must be read in conjunction with all of the attached and should be kept in its entirety without separation of individual pages or sections. DP cannot be held responsible for interpretations or conclusions made by others unless they are supported by an expressed statement, interpretation, outcome or conclusion stated in this report.

This report, or sections from this report, should not be used as part of a specification for a project, without review and agreement by DP. This is because this report has been written as advice and opinion rather than instructions for construction.

The contents of this report do not constitute formal design components such as are required, by Health and Safety Legislation and Regulations, to be included in a Safety Report specifying the hazards likely to be encountered during construction of all works (not just geotechnical components) and the controls required to mitigate risk. This report does, however, identify hazards associated with the geotechnical aspects of development and presents the results of risk assessment associated with the management of these hazards. It is suggested that the developer's principal design company may wish to include the geotechnical hazards and risk assessment information contained in this report, in their own Safety Report. If the principal design company, in the preparation of its project Design Report, wishes to undertake such inclusion by use of specific extracts from this subject DP report, rather than by appending the complete report, then such inclusion of extracts should only be undertaken with DP's express agreement, following DP's review of how any such extracts are to be utilised in the context of the project Safety Report. Any such review shall be undertaken either as an extension to contract for the works associated with this subject DP report or under additional conditions of engagement, with either option subject to agreement between DP and the payee

Douglas Partners Pty Ltd

Appendix A

About This Report

About this Report

Introduction

These notes have been provided to amplify DP's report in regard to classification methods, field procedures and the comments section. Not all are necessarily relevant to all reports.

DP's reports are based on information gained from limited subsurface excavations and sampling, supplemented by knowledge of local geology and experience. For this reason, they must be regarded as interpretive rather than factual documents, limited to some extent by the scope of information on which they rely.

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Borehole and Test Pit Logs

The borehole and test pit logs presented in this report are an engineering and/or geological interpretation of the subsurface conditions, and their reliability will depend to some extent on frequency of sampling and the method of drilling or excavation. Ideally, continuous undisturbed sampling or core drilling will provide the most reliable assessment, but this is not always practicable or possible to justify on economic grounds. In any case the boreholes and test pits represent only a very small sample of the total subsurface profile.

Interpretation of the information and its application to design and construction should therefore take into account the spacing of boreholes or pits, the frequency of sampling, and the possibility of other than 'straight line' variations between the test locations.

Groundwater

Where groundwater levels are measured in boreholes there are several potential problems, namely:

- In low permeability soils groundwater may enter the hole very slowly or perhaps not at all during the time the hole is left open;
- A localised, perched water table may lead to an erroneous indication of the true water table;
- Water table levels will vary from time to time with seasons or recent weather changes. They may not be the same at the time of construction as are indicated in the report; and
- The use of water or mud as a drilling fluid will mask any groundwater inflow. Water has to be blown out of the hole and drilling mud must first be washed out of the hole if water measurements are to be made.

More reliable measurements can be made by installing standpipes which are read at intervals over several days, or perhaps weeks for low permeability soils. Piezometers, sealed in a particular stratum, may be advisable in low permeability soils or where there may be interference from a perched water table.

Reports

The report has been prepared by qualified personnel, is based on the information obtained from field and laboratory testing, and has been undertaken to current engineering standards of interpretation and analysis. Where the report has been prepared for a specific design proposal, the information and interpretation may not be relevant if the design proposal is changed. If this happens, DP will be pleased to review the report and the sufficiency of the investigation work.

Every care is taken with the report as it relates to interpretation of subsurface conditions, discussion of geotechnical and environmental aspects, and recommendations or suggestions for design and construction. However, DP cannot always anticipate or assume responsibility for:

- Unexpected variations in ground conditions. The potential for this will depend partly on borehole or pit spacing and sampling frequency;
- Changes in policy or interpretations of policy by statutory authorities; or
- The actions of contractors responding to commercial pressures.

If these occur, DP will be pleased to assist with investigations or advice to resolve the matter.

About this Report

Site Anomalies

In the event that conditions encountered on site during construction appear to vary from those which were expected from the information contained in the report, DP requests that it be immediately notified. Most problems are much more readily resolved when conditions are exposed rather than at some later stage, well after the event.

Information for Contractual Purposes

Where information obtained from this report is provided for tendering purposes, it is recommended that all information, including the written report and discussion, be made available. In circumstances where the discussion or comments section is not relevant to the contractual situation, it may be appropriate to prepare a specially edited document. DP would be pleased to assist in this regard and/or to make additional report copies available for contract purposes at a nominal charge.

Site Inspection

The company will always be pleased to provide engineering inspection services for geotechnical and environmental aspects of work to which this report is related. This could range from a site visit to confirm that conditions exposed are as expected, to full time engineering presence on site.

Appendix B

Colour Photoplates
Drawings

Photo 1 & 2 – Panorama view to the southern section of the site.

Photo 3 – High strength latite outcrop.

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89260.00
	Proposed Residential Subdivision	PLATE No:	1
	Saddleback Mountain Road, Kiama	REV:	
	CLIENT: White Constructions (NSW) P/L	DATE:	Feb 2017

Photo 4 –Boulders and probable colluvium accumulation in the creek line.

Photo 5 – View east towards Princes Highway.

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89260.00
	Proposed Residential Subdivision	PLATE No:	2
	Saddleback Mountain Road, Kiama	REV:	
	CLIENT: White Constructions (NSW) P/L	DATE:	Feb 2017

Photo 6 – View south towards Weir Street.

Photo 7 – Rock outcrop leading to lower alluvial terrace.

Photo 8 – Near-vertical erosion scarps up to 1.5 m high in creekline.

Photo 9 – 2 m high embankment across drainage depression.

Photo 10 – High strength latite outcrop. View towards existing cattle yard and Princes Highway.

Photo 11 – Farm dam (possibly spring fed).

Photo 12 – View towards Kendall Cemetery.

Photo 13 – Lush grass growth possibly indicative of spring activity.

Photo 14 – View upslope of western boundary wall. Some boulders embedded in surface.

Photo 15 – View to north east.

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89260.00
	Proposed Residential Subdivision	PLATE No:	7
	Saddleback Mountain Road, Kiama	REV:	
	CLIENT: White Constructions (NSW) P/L	DATE:	Feb 2017

Photo 16 – View east towards cemetery.

Photo 17 – 3 m high embankment immediately upslope of western site boundary.

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89260.00
	Proposed Residential Subdivision	PLATE No:	8
	Saddleback Mountain Road, Kiama	REV:	
	CLIENT: White Constructions (NSW) P/L	DATE:	Feb 2017

Photo 18 – 2 m high scarps in creekline downslope of farm dam, exposing clays and silts

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Photo 19 – View towards northern boundary (ie at Saddleback Mountain Road)

Photo 20 – Farm dam.

Photo 21 – Rock outcrop and view along drainage depression.

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89260.00
	Proposed Residential Subdivision	PLATE No:	10
	Saddleback Mountain Road, Kiama	REV:	
	CLIENT: White Constructions (NSW) P/L	DATE:	Feb 2017

Photo 22 – Scarps in creek banks probably exacerbated by stock movements.

Photo 23 – High strength latite outcrop in creek banks and creek bed.

Photo 24 – View toward western boundary.

Photo 25 – Farm dam.

Photo 26 – View of breached dam and likely debris flow or colluvium within drainage depression.

Photo 27 – Latite exposure adjacent to drainage depression.

Photo 28 – Irregular, hummocky surface indicative of spring activity and near-surface soil creep.

Photo 29 – Scour in steep creek bank of residual soils and extremely weathered rock.

Photo 30 – Fill mound.

Photo 31 – View of area of likely spring activity and creep-affected soils.

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89260.00
	Proposed Residential Subdivision	PLATE No:	15
	Saddleback Mountain Road, Kiama	REV:	
	CLIENT: White Constructions (NSW) P/L	DATE:	Feb 2017

Photo 32 – View to north eastern section of the site. (Note: Powerline running along Saddleback Mtn Rd).

Photo 33 – View to south east towards Princes Highway.

Photo 34 – View south across the site from Saddleback Mountain Road.

Photo 35 – View east towards Princes Highway.

Photo 36 –View south. Approximate location of western boundary shown.

Photo 37 – Rills adjacent to drainage depression exposing residual soils and weathered bedrock.

Photo 38 – View along maintained path providing access to cemetery.

Photo 39 – View towards western boundary (approximate location shown).

Photo 40 – View of highway embankment and cutting in high strength latite.

Photo 41 – View of site to the north from Weir Street.

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**		PROJECT:	89260.00
	Proposed Residential Subdivision		PLATE No:	20
	Saddleback Mountain Road, Kiama		REV:	
	CLIENT:	White Constructions (NSW) P/L	DATE:	Feb 2017

Photo 42 – High strength latite outcrop.

Photo 43 – High strength latite outcrop at base of steep slope and in the creek bed.

Photo 44 – Boulders and gravel directly overlying latite outcrop within the creek bed.

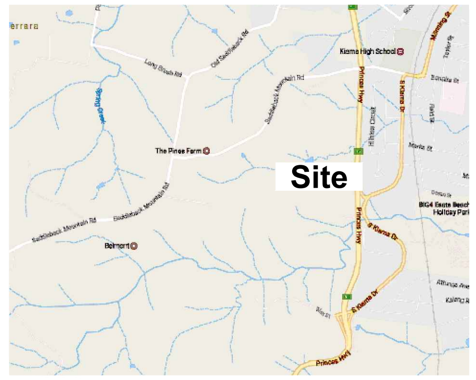
Photo 45 – Some latite gravel and cobbles, possibly indicative of a talus slope.

Photo 46 – View to south-eastern section of the site.

Photo 47 – View towards a possible building area in the south-eastern section of the site.

Photo 48 – View to west.

Photo 49 – View of section of the site to the south of Weir Street.



Locality Plan

NOTE: Base drawing from Site Plus Pty Ltd, Drawing 15158.RZ.C01, Dated 09.05.2018

LEGEND

- Approximate Site Boundary
- Existing Lot Boundary
- Proposed Lot Boundary
- 2.0m Contour

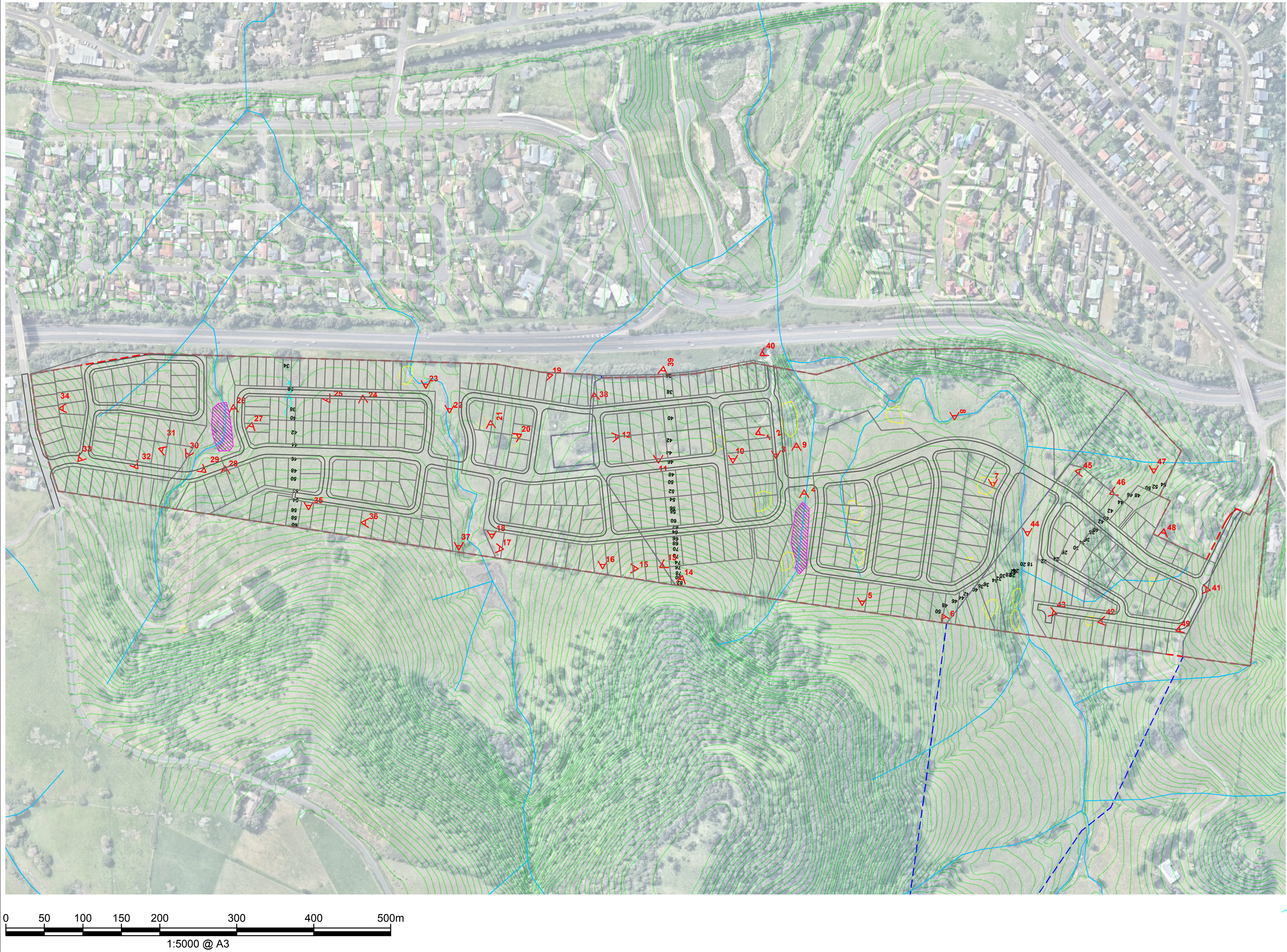
0 50 100 150 200 300 400 500m

1:5000 @ A3

Douglas Partners
Geotechnics / Environment / Groundwater

CLIENT: White Constructions (NSW) Pty Ltd		TITLE: **Site Layout**	PROJECT No: 89260.00
OFFICE: Wollongong	DRAWN BY: RJH	**Proposed Residential Subdivision**	DRAWING No: 1
SCALE: 1: 5000 @ A3	DATE: 18.12.2019	**Saddleback Mtn Road, South Kiama**	REVISION: 1

MGA

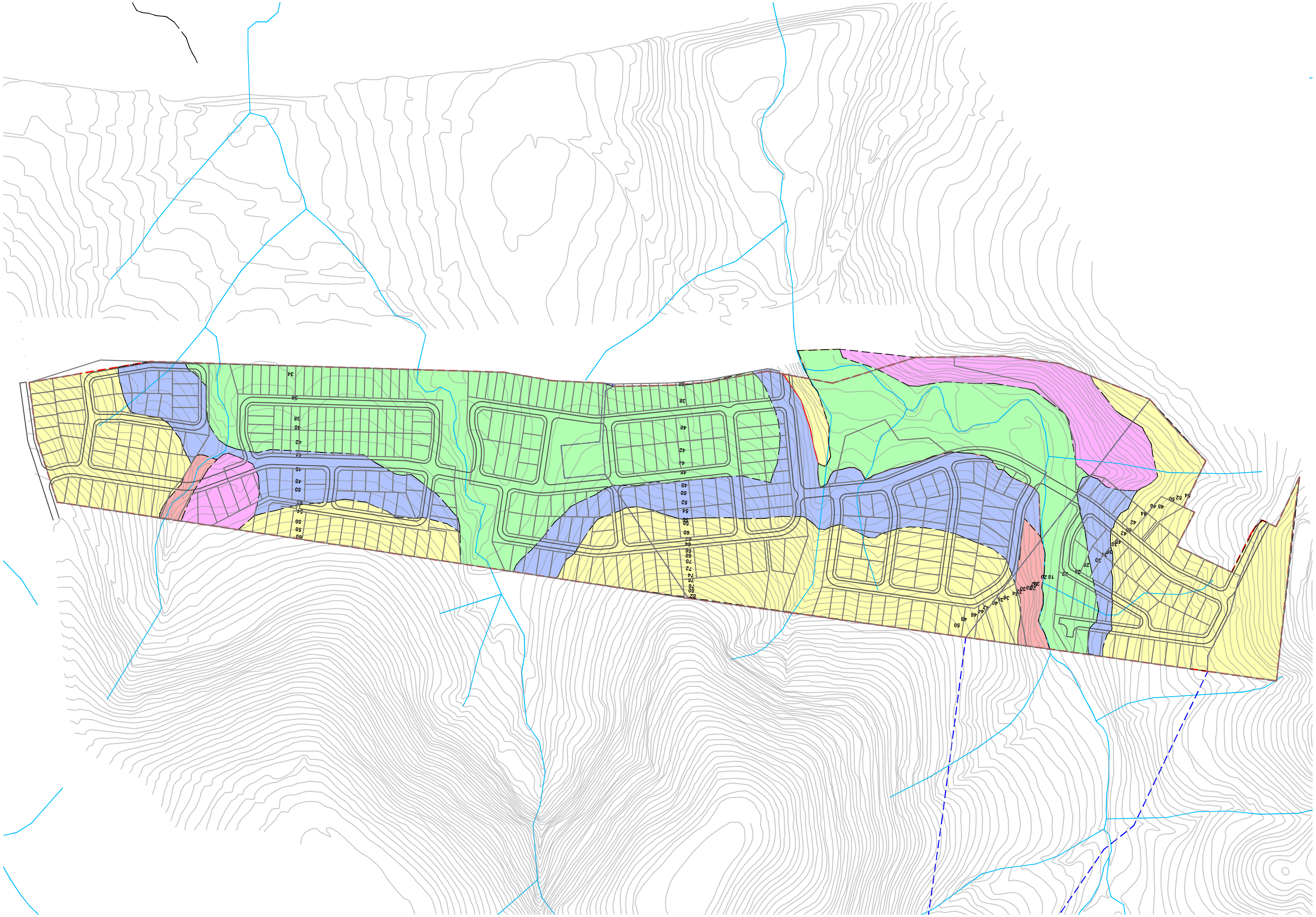


NOTE: Base drawing from Site Plus Pty Ltd, Drawing 15158.RZ.C01, Dated 09.05.2018

LEGEND

- Approximate Site Boundary
- Existing Lot Boundary
- Proposed Lot Boundary
- 2.0m Contour
- Photo Location and Orientation
- Feature: Outcrop
- Feature: Debris Flow
- Feature: Spring

Douglas Partners Geotechnics / Environment / Groundwater	CLIENT: White Constructions (NSW) Pty Ltd	TITLE: **Location of Features** **Proposed Residential Subdivision** **Saddleback Mtn Road, South Kiama**	PROJECT No: 89260.00
	OFFICE: Wollongong / DRAWN BY: GRR		DRAWING No: 2
	SCALE: 1: 5000 @ A3 / DATE: 18.12.2019	MGA	REVISION: 1



NOTE: Base drawing from Site Plus Pty Ltd, Drawing 15158.RZ.C01, Dated 09.05.2018

0 50 100 150 200 300 400 500m

1:5000 @ A3

LEGEND

- Approximate Site Boundary
- Existing Lot Boundary
- Proposed Lot Boundary
- 2.0m Contour

Stability Risk

- Low
- Low to Moderate
- Moderate
- Moderate to High
- High

Douglas Partners
Geotechnics / Environment / Groundwater

CLIENT: White Constructions (NSW) Pty Ltd		TITLE: **Stability Assessment**	PROJECT No: 89260.00
OFFICE: Wollongong	DRAWN BY: RJH	**Proposed Residential Subdivision**	DRAWING No: 3
SCALE: 1: 5000 @ A3	DATE: 18.12.2019	**Saddleback Mtn Road, South Kiama**	REVISION: 1

MGA

Appendix C

AGS Extracts
CSIRO Publication

APPENDIX C: – QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY (CONTINUED)

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD		CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage)				
	Indicative Value of Approximate Annual Probability	1: CATASTROPHIC 200%	2: MAJOR 60%	3: MEDIUM 20%	4: MINOR 5%	5: INSIGNIFICANT 0.5%
A – ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or **L** (5)
B - LIKELY	10^{-2}	VH	VH	H	M	**L**
C - POSSIBLE	10^{-3}	VH	H	M	M	**VL**
D - UNLIKELY	10^{-4}	H	M	**L**	**L**	**VL**
E - RARE	10^{-5}	M	**L**	**L**	**VL**	**VL**
F - BARELY CREDIBLE	10^{-6}	**L**	**VL**	**VL**	**VL**	**VL**

Notes: (5) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.
(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

Risk Level		Example Implications (7)
VH	VERY HIGH RISK	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
H	HIGH RISK	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	MODERATE RISK	May be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable.
L	LOW RISK	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note: (7) The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

APPENDIX C: LANDSLIDE RISK ASSESSMENT

QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		**Implied Indicative Landslide Recurrence Interval**		**Description**	**Descriptor**	**Level**
Indicative Value	**Notional Boundary**					
10^{-1}	$5x10^{-2}$	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}		100 years		The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-3}$	1000 years	200 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-4}$	10,000 years	2000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-5}$	100,000 years	20,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}	$5x10^{-6}$	1,000,000 years	200,000 years	The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

Note: (1) The table should be used from left to right; use Approximate Annual Probability or Description to assign Descriptor, not *vice versa*.

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Approximate Cost of Damage		**Description**	**Descriptor**	**Level**
Indicative Value	**Notional Boundary**			
200%	100%	Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	CATASTROPHIC	1
60%	40%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	MAJOR	2
20%	10%	Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	MEDIUM	3
5%	1%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%		Little damage. (Note for high probability event (Almost Certain), this category may be subdivided at a notional boundary of 0.1%. See Risk Matrix.)	INSIGNIFICANT	5

Notes: (2) The Approximate Cost of Damage is expressed as a percentage of market value, being the cost of the improved value of the unaffected property which includes the land plus the unaffected structures.

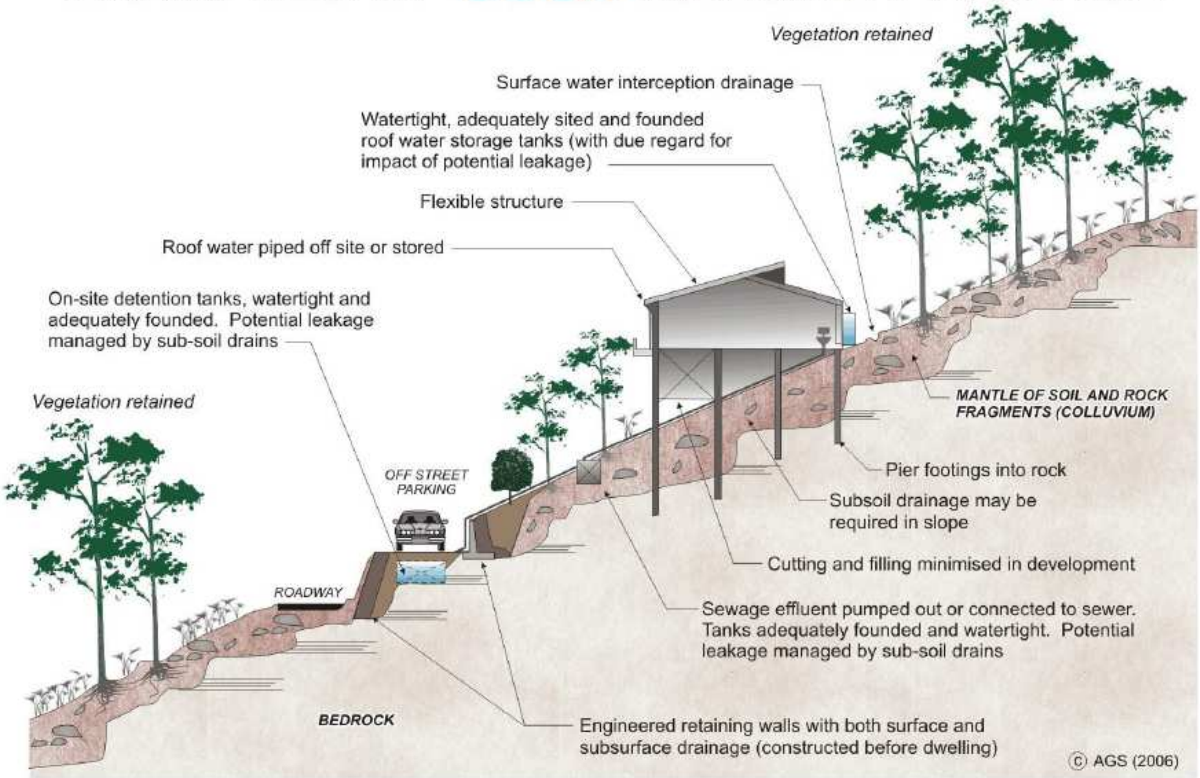
(3) The Approximate Cost is to be an estimate of the direct cost of the damage, such as the cost of reinstatement of the damaged portion of the property (land plus structures), stabilisation works required to render the site to tolerable risk level for the landslide which has occurred and professional design fees, and consequential costs such as legal fees, temporary accommodation. It does not include additional stabilisation works to address other landslides which may affect the property.

(4) The table should be used from left to right; use Approximate Cost of Damage or Description to assign Descriptor, not vice versa

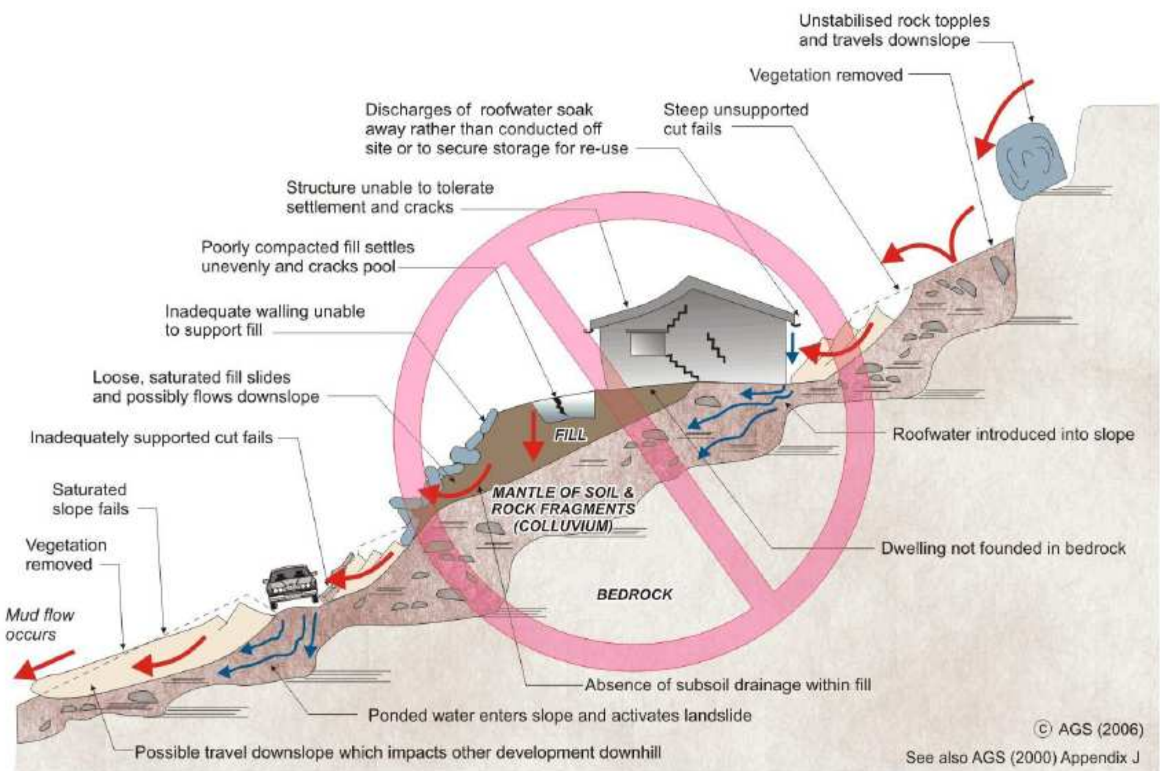
APPENDIX G - SOME GUIDELINES FOR HILLSIDE CONSTRUCTION

	GOOD ENGINEERING PRACTICE	*POOR ENGINEERING PRACTICE*
ADVICE		
GEOTECHNICAL ASSESSMENT	Obtain advice from a qualified, experienced geotechnical practitioner at early stage of planning and before site works.	Prepare detailed plan and start site works before geotechnical advice.
PLANNING		
SITE PLANNING	Having obtained geotechnical advice, plan the development with the risk arising from the identified hazards and consequences in mind.	Plan development without regard for the Risk.
DESIGN AND CONSTRUCTION		
HOUSE DESIGN	Use flexible structures which incorporate properly designed brickwork, timber or steel frames, timber or panel cladding. Consider use of split levels. Use decks for recreational areas where appropriate.	Floor plans which require extensive cutting and filling. Movement intolerant structures.
SITE CLEARING	Retain natural vegetation wherever practicable.	Indiscriminately clear the site.
ACCESS & DRIVEWAYS	Satisfy requirements below for cuts, fills, retaining walls and drainage. Council specifications for grades may need to be modified. Driveways and parking areas may need to be fully supported on piers.	Excavate and fill for site access before geotechnical advice.
EARTHWORKS	Retain natural contours wherever possible.	Indiscriminatory bulk earthworks.
CUTS	Minimise depth. Support with engineered retaining walls or batter to appropriate slope. Provide drainage measures and erosion control.	Large scale cuts and benching. Unsupported cuts. Ignore drainage requirements
FILLS	Minimise height. Strip vegetation and topsoil and key into natural slopes prior to filling. Use clean fill materials and compact to engineering standards. Batter to appropriate slope or support with engineered retaining wall. Provide surface drainage and appropriate subsurface drainage.	Loose or poorly compacted fill, which if it fails, may flow a considerable distance including onto property below. Block natural drainage lines. Fill over existing vegetation and topsoil. Include stumps, trees, vegetation, topsoil, boulders, building rubble etc in fill.
ROCK OUTCROPS & BOULDERS	Remove or stabilise boulders which may have unacceptable risk. Support rock faces where necessary.	Disturb or undercut detached blocks or boulders.
RETAINING WALLS	Engineer design to resist applied soil and water forces. Found on rock where practicable. Provide subsurface drainage within wall backfill and surface drainage on slope above. Construct wall as soon as possible after cut/fill operation.	Construct a structurally inadequate wall such as sandstone flagging, brick or unreinforced blockwork. Lack of subsurface drains and weepholes.
FOOTINGS	Found within rock where practicable. Use rows of piers or strip footings oriented up and down slope. Design for lateral creep pressures if necessary. Backfill footing excavations to exclude ingress of surface water.	Found on topsoil, loose fill, detached boulders or undercut cliffs.
SWIMMING POOLS	Engineer designed. Support on piers to rock where practicable. Provide with under-drainage and gravity drain outlet where practicable. Design for high soil pressures which may develop on uphill side whilst there may be little or no lateral support on downhill side.	
DRAINAGE		
SURFACE	Provide at tops of cut and fill slopes. Discharge to street drainage or natural water courses. Provide general falls to prevent blockage by siltation and incorporate silt traps. Line to minimise infiltration and make flexible where possible. Special structures to dissipate energy at changes of slope and/or direction.	Discharge at top of fills and cuts. Allow water to pond on bench areas.
SUBSURFACE	Provide filter around subsurface drain. Provide drain behind retaining walls. Use flexible pipelines with access for maintenance. Prevent inflow of surface water.	Discharge roof runoff into absorption trenches.
SEPTIC & SULLAGE	Usually requires pump-out or mains sewer systems; absorption trenches may be possible in some areas if risk is acceptable. Storage tanks should be water-tight and adequately founded.	Discharge sullage directly onto and into slopes. Use absorption trenches without consideration of landslide risk.
EROSION CONTROL & LANDSCAPING	Control erosion as this may lead to instability. Revegetate cleared area.	Failure to observe earthworks and drainage recommendations when landscaping.
DRAWINGS AND SITE VISITS DURING CONSTRUCTION		
DRAWINGS	Building Application drawings should be viewed by geotechnical consultant	
SITE VISITS	Site Visits by consultant may be appropriate during construction/	
INSPECTION AND MAINTENANCE BY OWNER		
OWNER'S RESPONSIBILITY	Clean drainage systems; repair broken joints in drains and leaks in supply pipes. Where structural distress is evident see advice. If seepage observed, determine causes or seek advice on consequences.	

EXAMPLES OF GOOD HILLSIDE PRACTICE



EXAMPLES OF POOR HILLSIDE PRACTICE



Foundation Maintenance and Footing Performance: A Homeowner's Guide

BTF 18 replaces Information Sheet 10/91

Buildings can and often do move. This movement can be up, down, lateral or rotational. The fundamental cause of movement in buildings can usually be related to one or more problems in the foundation soil. It is important for the homeowner to identify the soil type in order to ascertain the measures that should be put in place in order to ensure that problems in the foundation soil can be prevented, thus protecting against building movement.

This Building Technology File is designed to identify causes of soil-related building movement, and to suggest methods of prevention of resultant cracking in buildings.

Soil Types

The types of soils usually present under the topsoil in land zoned for residential buildings can be split into two approximate groups – granular and clay. Quite often, foundation soil is a mixture of both types. The general problems associated with soils having granular content are usually caused by erosion. Clay soils are subject to saturation and swell/shrink problems.

Classifications for a given area can generally be obtained by application to the local authority, but these are sometimes unreliable and if there is doubt, a geotechnical report should be commissioned. As most buildings suffering movement problems are founded on clay soils, there is an emphasis on classification of soils according to the amount of swell and shrinkage they experience with variations of water content. The table below is Table 2.1 from AS 2870, the Residential Slab and Footing Code.

Causes of Movement

Settlement due to construction
There are two types of settlement that occur as a result of construction:

- Immediate settlement occurs when a building is first placed on its foundation soil, as a result of compaction of the soil under the weight of the structure. The cohesive quality of clay soil mitigates against this, but granular (particularly sandy) soil is susceptible.
- Consolidation settlement is a feature of clay soil and may take place because of the expulsion of moisture from the soil or because of the soil's lack of resistance to local compressive or shear stresses. This will usually take place during the first few months after construction, but has been known to take many years in exceptional cases.

These problems are the province of the builder and should be taken into consideration as part of the preparation of the site for construction. Building Technology File 19 (BTF 19) deals with these problems.

Erosion
All soils are prone to erosion, but sandy soil is particularly susceptible to being washed away. Even clay with a sand component of say 10% or more can suffer from erosion.

Saturation
This is particularly a problem in clay soils. Saturation creates a bog-like suspension of the soil that causes it to lose virtually all of its bearing capacity. To a lesser degree, sand is affected by saturation because saturated sand may undergo a reduction in volume – particularly imported sand fill for bedding and blinding layers. However, this usually occurs as immediate settlement and should normally be the province of the builder.

Seasonal swelling and shrinkage of soil
All clays react to the presence of water by slowly absorbing it, making the soil increase in volume (see table below). The degree of increase varies considerably between different clays, as does the degree of decrease during the subsequent drying out caused by fair weather periods. Because of the low absorption and expulsion rate, this phenomenon will not usually be noticeable unless there are prolonged rainy or dry periods, usually of weeks or months, depending on the land and soil characteristics.

The swelling of soil creates an upward force on the footings of the building, and shrinkage creates subsidence that takes away the support needed by the footing to retain equilibrium.

Shear failure
This phenomenon occurs when the foundation soil does not have sufficient strength to support the weight of the footing. There are two major post-construction causes:

- Significant load increase.
- Reduction of lateral support of the soil under the footing due to erosion or excavation.
- In clay soil, shear failure can be caused by saturation of the soil adjacent to or under the footing.

GENERAL DEFINITIONS OF SITE CLASSES

Class	Foundation
A	Most sand and rock sites with little or no ground movement from moisture changes
S	Slightly reactive clay sites with only slight ground movement from moisture changes
M	Moderately reactive clay or silt sites, which can experience moderate ground movement from moisture changes
H	Highly reactive clay sites, which can experience high ground movement from moisture changes
E	Extremely reactive sites, which can experience extreme ground movement from moisture changes
A to P	Filled sites
P	Sites which include soft soils, such as soft clay or silt or loose sands; landslip; mine subsidence; collapsing soils; soils subject to erosion; reactive sites subject to abnormal moisture conditions or sites which cannot be classified otherwise

Tree root growth
Trees and shrubs that are allowed to grow in the vicinity of footings can cause foundation soil movement in two ways:

- Roots that grow under footings may increase in cross-sectional size, exerting upward pressure on footings.
- Roots in the vicinity of footings will absorb much of the moisture in the foundation soil, causing shrinkage or subsidence.

Unevenness of Movement

The types of ground movement described above usually occur unevenly throughout the building's foundation soil. Settlement due to construction tends to be uneven because of:

- Differing compaction of foundation soil prior to construction.
- Differing moisture content of foundation soil prior to construction.

Movement due to non-construction causes is usually more uneven still. Erosion can undermine a footing that traverses the flow or can create the conditions for shear failure by eroding soil adjacent to a footing that runs in the same direction as the flow.

Saturation of clay foundation soil may occur where subfloor walls create a dam that makes water pond. It can also occur wherever there is a source of water near footings in clay soil. This leads to a severe reduction in the strength of the soil which may create local shear failure.

Seasonal swelling and shrinkage of clay soil affects the perimeter of the building first, then gradually spreads to the interior. The swelling process will usually begin at the uphill extreme of the building, or on the weather side where the land is flat. Swelling gradually reaches the interior soil as absorption continues. Shrinkage usually begins where the sun's heat is greatest.

Effects of Uneven Soil Movement on Structures

Erosion and saturation
Erosion removes the support from under footings, tending to create subsidence of the part of the structure under which it occurs. Brickwork walls will resist the stress created by this removal of support by bridging the gap or cantilevering until the bricks or the mortar bedding fail. Older masonry has little resistance. Evidence of failure varies according to circumstances and symptoms may include:

- Step cracking in the mortar beds in the body of the wall or above/below openings such as doors or windows.
- Vertical cracking in the bricks (usually but not necessarily in line with the vertical beds or perpends).

Isolated piers affected by erosion or saturation of foundations will eventually lose contact with the bearers they support and may tilt or fall over. The floors that have lost this support will become bouncy, sometimes rattling ornaments etc.

Seasonal swelling/shrinkage in clay
Swelling foundation soil due to rainy periods first lifts the most exposed extremities of the footing system, then the remainder of the perimeter footings while gradually permeating inside the building footprint to lift internal footings. This swelling first tends to create a dish effect, because the external footings are pushed higher than the internal ones.

The first noticeable symptom may be that the floor appears slightly dished. This is often accompanied by some doors binding on the floor or the door head, together with some cracking of cornice mitres. In buildings with timber flooring supported by bearers and joists, the floor can be bouncy. Externally there may be visible dishing of the hip or ridge lines.

As the moisture absorption process completes its journey to the innermost areas of the building, the internal footings will rise. If the spread of moisture is roughly even, it may be that the symptoms will temporarily disappear, but it is more likely that swelling will be uneven, creating a difference rather than a disappearance in symptoms. In buildings with timber flooring supported by bearers and joists, the isolated piers will rise more easily than the strip footings or piers under walls, creating noticeable doming of flooring.

Trees can cause shrinkage and damage

As the weather pattern changes and the soil begins to dry out, the external footings will be first affected, beginning with the locations where the sun's effect is strongest. This has the effect of lowering the external footings. The doming is accentuated and cracking reduces or disappears where it occurred because of dishing, but other cracks open up. The roof lines may become convex.

Doming and dishing are also affected by weather in other ways. In areas where warm, wet summers and cooler dry winters prevail, water migration tends to be toward the interior and doming will be accentuated, whereas where summers are dry and winters are cold and wet, migration tends to be toward the exterior and the underlying propensity is toward dishing.

Movement caused by tree roots
In general, growing roots will exert an upward pressure on footings, whereas soil subject to drying because of tree or shrub roots will tend to remove support from under footings by inducing shrinkage.

Complications caused by the structure itself
Most forces that the soil causes to be exerted on structures are vertical – i.e. either up or down. However, because these forces are seldom spread evenly around the footings, and because the building resists uneven movement because of its rigidity, forces are exerted from one part of the building to another. The net result of all these forces is usually rotational. This resultant force often complicates the diagnosis because the visible symptoms do not simply reflect the original cause. A common symptom is binding of doors on the vertical member of the frame.

Effects on full masonry structures
Brickwork will resist cracking where it can. It will attempt to span areas that lose support because of subsided foundations or raised points. It is therefore usual to see cracking at weak points, such as openings for windows or doors.

In the event of construction settlement, cracking will usually remain unchanged after the process of settlement has ceased.

With local shear or erosion, cracking will usually continue to develop until the original cause has been remedied, or until the subsidence has completely neutralised the affected portion of footing and the structure has stabilised on other footings that remain effective.

In the case of swell/shrink effects, the brickwork will in some cases return to its original position after completion of a cycle, however it is more likely that the rotational effect will not be exactly reversed, and it is also usual that brickwork will settle in its new position and will resist the forces trying to return it to its original position. This means that in a case where swelling takes place after construction and cracking occurs, the cracking is likely to at least partly remain after the shrink segment of the cycle is complete. Thus, each time the cycle is repeated, the likelihood is that the cracking will become wider until the sections of brickwork become virtually independent.

With repeated cycles, once the cracking is established, if there is no other complication, it is normal for the incidence of cracking to stabilise, as the building has the articulation it needs to cope with the problem. This is by no means always the case, however, and monitoring of cracks in walls and floors should always be treated seriously.

Upheaval caused by growth of tree roots under footings is not a simple vertical shear stress. There is a tendency for the root to also exert lateral forces that attempt to separate sections of brickwork after initial cracking has occurred.

The normal structural arrangement is that the inner leaf of brickwork in the external walls and at least some of the internal walls (depending on the roof type) comprise the load-bearing structure on which any upper floors, ceilings and the roof are supported. In these cases, it is internally visible cracking that should be the main focus of attention, however there are a few examples of dwellings whose external leaf of masonry plays some supporting role, so this should be checked if there is any doubt. In any case, externally visible cracking is important as a guide to stresses on the structure generally, and it should also be remembered that the external walls must be capable of supporting themselves.

Effects on framed structures
Timber or steel framed buildings are less likely to exhibit cracking due to swell/shrink than masonry buildings because of their flexibility. Also, the doming/dishing effects tend to be lower because of the lighter weight of walls. The main risks to framed buildings are encountered because of the isolated pier footings used under walls. Where erosion or saturation cause a footing to fall away, this can double the span which a wall must bridge. This additional stress can create cracking in wall linings, particularly where there is a weak point in the structure caused by a door or window opening. It is, however, unlikely that framed structures will be so stressed as to suffer serious damage without first exhibiting some or all of the above symptoms for a considerable period. The same warning period should apply in the case of upheaval. It should be noted, however, that where framed buildings are supported by strip footings there is only one leaf of brickwork and therefore the externally visible walls are the supporting structure for the building. In this case, the subfloor masonry walls can be expected to behave as full brickwork walls.

Effects on brick veneer structures
Because the load-bearing structure of a brick veneer building is the frame that makes up the interior leaf of the external walls plus perhaps the internal walls, depending on the type of roof, the building can be expected to behave as a framed structure, except that the external masonry will behave in a similar way to the external leaf of a full masonry structure.

Water Service and Drainage

Where a water service pipe, a sewer or stormwater drainage pipe is in the vicinity of a building, a water leak can cause erosion, swelling or saturation of susceptible soil. Even a minuscule leak can be enough to saturate a clay foundation. A leaking tap near a building can have the same effect. In addition, trenches containing pipes can become watercourses even though backfilled, particularly where broken rubble is used as fill. Water that runs along these trenches can be responsible for serious erosion, interstrata seepage into subfloor areas and saturation.

Pipe leakage and trench water flows also encourage tree and shrub roots to the source of water, complicating and exacerbating the problem.
Poor roof plumbing can result in large volumes of rainwater being concentrated in a small area of soil:

- Incorrect falls in roof guttering may result in overflows, as may gutters blocked with leaves etc.
- Corroded guttering or downpipes can spill water to ground.
- Downpipes not positively connected to a proper stormwater collection system will direct a concentration of water to soil that is directly adjacent to footings, sometimes causing large-scale problems such as erosion, saturation and migration of water under the building.

Seriousness of Cracking

In general, most cracking found in masonry walls is a cosmetic nuisance only and can be kept in repair or even ignored. The table below is a reproduction of Table C1 of AS 2870.

AS 2870 also publishes figures relating to cracking in concrete floors, however because wall cracking will usually reach the critical point significantly earlier than cracking in slabs, this table is not reproduced here.

Prevention/Cure

Plumbing
Where building movement is caused by water service, roof plumbing, sewer or stormwater failure, the remedy is to repair the problem. It is prudent, however, to consider also rerouting pipes away from the building where possible, and relocating taps to positions where any leakage will not direct water to the building vicinity. Even where gully traps are present, there is sometimes sufficient spill to create erosion or saturation, particularly in modern installations using smaller diameter PVC fixtures. Indeed, some gully traps are not situated directly under the taps that are installed to charge them, with the result that water from the tap may enter the backfilled trench that houses the sewer piping. If the trench has been poorly backfilled, the water will either pond or flow along the bottom of the trench. As these trenches usually run alongside the footings and can be at a similar depth, it is not hard to see how any water that is thus directed into a trench can easily affect the foundation's ability to support footings or even gain entry to the subfloor area.

Ground drainage
In all soils there is the capacity for water to travel on the surface and below it. Surface water flows can be established by inspection during and after heavy or prolonged rain. If necessary, a grated drain system connected to the stormwater collection system is usually an easy solution.

It is, however, sometimes necessary when attempting to prevent water migration that testing be carried out to establish watertable height and subsoil water flows. This subject is referred to in BTF 19 and may properly be regarded as an area for an expert consultant.

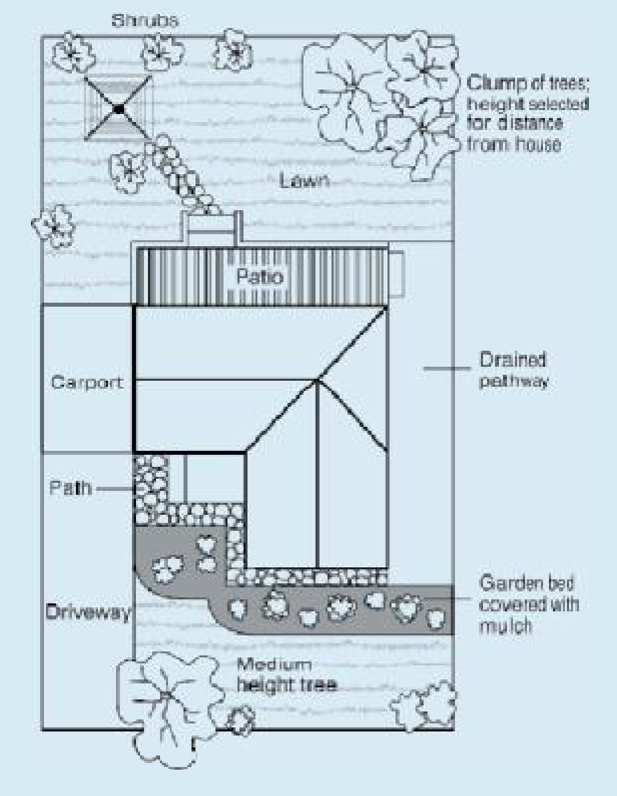
Protection of the building perimeter
It is essential to remember that the soil that affects footings extends well beyond the actual building line. Watering of garden plants, shrubs and trees causes some of the most serious water problems.

For this reason, particularly where problems exist or are likely to occur, it is recommended that an apron of paving be installed around as much of the building perimeter as necessary. This paving

CLASSIFICATION OF DAMAGE WITH REFERENCE TO WALLS

Description of typical damage and required repair	Approximate crack width limit (see Note 3)	Damage category
Hairline cracks	<0.1 mm	0
Fine cracks which do not need repair	<1 mm	1
Cracks noticeable but easily filled. Doors and windows stick slightly	<5 mm	2
Cracks can be repaired and possibly a small amount of wall will need to be replaced. Doors and windows stick. Service pipes can fracture. Weathertightness often impaired	5–15 mm (or a number of cracks 3 mm or more in one group)	3
Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Window and door frames distort. Walls lean or bulge noticeably, some loss of bearing in beams. Service pipes disrupted	15–25 mm but also depend on number of cracks	4

Gardens for a reactive site



should extend outwards a minimum of 900 mm (more in highly reactive soil) and should have a minimum fall away from the building of 1:60. The finished paving should be no less than 100 mm below brick vent bases.

It is prudent to relocate drainage pipes away from this paving, if possible, to avoid complications from future leakage. If this is not practical, earthenware pipes should be replaced by PVC and backfilling should be of the same soil type as the surrounding soil and compacted to the same density.

Except in areas where freezing of water is an issue, it is wise to remove taps in the building area and relocate them well away from the building – preferably not uphill from it (see BTF 19).

It may be desirable to install a grated drain at the outside edge of the paving on the uphill side of the building. If subsoil drainage is needed this can be installed under the surface drain.

Condensation
In buildings with a subfloor void such as where bearers and joists support flooring, insufficient ventilation creates ideal conditions for condensation, particularly where there is little clearance between the floor and the ground. Condensation adds to the moisture already present in the subfloor and significantly slows the process of drying out. Installation of an adequate subfloor ventilation system, either natural or mechanical, is desirable.

Warning: Although this Building Technology File deals with cracking in buildings, it should be said that subfloor moisture can result in the development of other problems, notably:

- Water that is transmitted into masonry, metal or timber building elements causes damage and/or decay to those elements.
- High subfloor humidity and moisture content create an ideal environment for various pests, including termites and spiders.
- Where high moisture levels are transmitted to the flooring and walls, an increase in the dust mite count can ensue within the living areas. Dust mites, as well as dampness in general, can be a health hazard to inhabitants, particularly those who are abnormally susceptible to respiratory ailments.

The garden
The ideal vegetation layout is to have lawn or plants that require only light watering immediately adjacent to the drainage or paving edge, then more demanding plants, shrubs and trees spread out in that order.

Overwatering due to misuse of automatic watering systems is a common cause of saturation and water migration under footings. If it is necessary to use these systems, it is important to remove garden beds to a completely safe distance from buildings.

Existing trees
Where a tree is causing a problem of soil drying or there is the existence or threat of upheaval of footings, if the offending roots are subsidiary and their removal will not significantly damage the tree, they should be severed and a concrete or metal barrier placed vertically in the soil to prevent future root growth in the direction of the building. If it is not possible to remove the relevant roots without damage to the tree, an application to remove the tree should be made to the local authority. A prudent plan is to transplant likely offenders before they become a problem.

Information on trees, plants and shrubs
State departments overseeing agriculture can give information regarding root patterns, volume of water needed and safe distance from buildings of most species. Botanic gardens are also sources of information. For information on plant roots and drains, see Building Technology File 17.

Excavation
Excavation around footings must be properly engineered. Soil supporting footings can only be safely excavated at an angle that allows the soil under the footing to remain stable. This angle is called the angle of repose (or friction) and varies significantly between soil types and conditions. Removal of soil within the angle of repose will cause subsidence.

Remediation

Where erosion has occurred that has washed away soil adjacent to footings, soil of the same classification should be introduced and compacted to the same density. Where footings have been undermined, augmentation or other specialist work may be required. Remediation of footings and foundations is generally the realm of a specialist consultant.

Where isolated footings rise and fall because of swell/shrink effect, the homeowner may be tempted to alleviate floor bounce by filling the gap that has appeared between the bearer and the pier with blocking. The danger here is that when the next swell segment of the cycle occurs, the extra blocking will push the floor up into an accentuated dome and may also cause local shear failure in the soil. If it is necessary to use blocking, it should be by a pair of fine wedges and monitoring should be carried out fortnightly.

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