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Report on
Geotechnical Assessment

Jumping Creek Estate
Lot 5, DP 1199045, Greenleigh

Prepared for
Spacelab Studio Pty Ltd

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Douglas Partners Pty Ltd
ABN 75 053 980 117
www.douglaspartners.com.au
Unit 2, 73 Sheppard Street
Hume ACT 2620
PO Box 1487
Fyshwick ACT 2609
Phone (02) 6260 2788
Fax (02) 6260 1147

Table of Contents

Page

Report on Geotechnical Assessment
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1. Introduction

This report presents the results of a geotechnical assessment undertaken for a proposed residential development referred to as Jumping Creek at Lot 5, DP 1199045, Greenleigh in Queanbeyan. The investigation was commissioned by Spacelab Studio Pty Ltd and was undertaken in accordance with Douglas Partners' proposal CAN180081 dated 11 April 2018.

It is understood that consideration is being given to a development application for the future residential subdivision. Assessment was carried out to provide preliminary information on geotechnical aspects of the site to assist in planning of the development and for submission to Queanbeyan City Council with the development application.

The assessment comprised a review of published information, field mapping by a Senior Geotechnical Engineer, engineering analysis and reporting. Details of the work undertaken are given in the report, together with preliminary comments relating to the regional and geological setting, site classifications, preliminary pavement designs, potential geotechnical constraints and mitigation /management methods and advice on extent of future subsurface investigations.

A lot layout and site survey plans were provided by the client for the purpose of the assessment.

This report must be read in conjunction with the notes “About this Report” which are included in Appendix A.

2. Site Description

The overall Jumping Creek Estate comprises an irregularly shaped parcel of land covering approximately 95 ha. The site measures approximately 1.1 km and 1.2 km in maximum east-west and north-south dimensions. The site is bounded to the west by the Queanbeyan River, to the north-west by the Ellerton Drive Extension construction works and to the north-east, east and south by undeveloped woodland, see Drawing 1 (Appendix B).

The estate lies within an enclosed valley within the Queanbeyan River corridor and is moderately to highly undulating and includes ridgelines and steep sided valleys. Valley Creek flows through the estate from south-east to the north-west before meandering through a narrow gorge to join the Queanbeyan River along the central part of the western site boundary. A separate unnamed tributary flows into Valley Creek from the north which separates two high ridgelines present in the north and east of the site and other ridges are present in the north-west, south-east and south-west.

The elevation of the site ranges from approximately 580 m Australian Height Datum (AHD) in the west of the site to 690 m AHD in the north-east corner of the site.

The site of this assessment lies within the northern half of the proposed Jumping Creek Estate; see Drawing 2 (Appendix B). The site comprises three separate development areas. These areas are located in the north-west, east and central parts of the site. The north-western and eastern areas are irregular in shape and covering 13 hectares and 12.8 hectares respectively. The smaller central development area is rectangular shaped and covers approximately 1.5 ha. The north western area measures about 560 m and 540 m in maximum east-west and north-south dimensions, whilst the eastern and central areas measure about 430 m by 620 m and 160 m by 100 m in maximum east-west and north-south dimensions.

The site is partially cleared of trees and moderately to heavily grassed with a variable tree and weed density. Weeds, including blackberry and bramble are generally located within valley or gully areas and were dense. Extensive rock outcropping and/or cobbles/boulders sub cropping were noted across most of the site. Uncontrolled filling was present in existing access tracks (including motor bike mounds) and mining and quarrying activities. Several areas were noted to contain scrap metal and dumped car bodies.

Site levels in the development areas fall in variable directions away from a number of ridgelines and hill tops at grades ranging from 1 in 3 to 1 in 25 (vertical:horizontal) towards Valley Creek and its unnamed tributary but overall fall is generally to the west. An overall difference in level from the highest part of the urban development site to the lowest has been estimated to be about 35 – 40 m.

3. Assessment Methods

3.1 Information Review

The assessment included a review of available information from previous assessments and investigations undertaken for the Jumping Creek Estate pertinent to the site of this assessment defined in Drawing 2 (Appendix B).

3.2 Regional Geology and Hydrogeology

A review of existing geological, soil landscape and hydrogeological maps was undertaken as part of the assessment. The relevant maps reviewed were as follows:

- 1:100 000 Geological Series Sheet for Canberra (Ref 1),
- 1:100 000 Hydrogeology of the Australian Capital Territory (Ref 2),
- 1:100 000 Soil Landscape Sheet for Canberra (Ref 3).

3.3 Site Inspection

A site inspection was undertaken by a Senior Geotechnical Engineer on 14 August 2018, which included qualitative assessment of site stability considerations and mapping of site features. Photographs from the site inspection are presented in Appendix C.

4. Assessment Results

4.1 Previous Geotechnical Works

4.1.1 Geotechnical Terrain Assessment

Coffey and Partners Pty Ltd (Coffey) completed a geotechnical terrain assessment for the Jumping Creek Estate.

- *Geotechnical Terrain Assessment, for the Proposed South Queanbeyan Rural-Residential Development,* dated January 1988

The objective of the assessment was to assess the site features including: landform, geology, soils and hydrology and then use the results to comment on site constraints to aid design. The general constraints to development included: slope, rock outcrop and shallow soil, soil erodibility and flooding.

4.1.2 Deferred Areas – Jumping Creek Geotechnical Assessment

Douglas Partners Pty Ltd (DP) completed a geotechnical assessment for the neighbouring proposed development areas that are known as the deferred areas of the Jumping Creek development.

- *Report on Geotechnical Assessment – Urban Capability, Proposed Subdivision – Deferred Areas, Stage 3 Jumping Creek, Queanbeyan,* Project No. 88224.00, dated September 2015

The deferred development areas are located in the south and south west potion of the Jumping Creek Estate and to the south of the site of this assessment. The assessment comprised the excavation of fourteen test pits to depths of 0.3 – 4.0 m using a Kubota KX057.4 (5.7 tonne) mini-excavator fitted with a 450 mm wide bucket and laboratory testing for Emerson class number. The test pit locations encountered relatively variable subsurface conditions underlying the site which are broadly summarised as follows:

- TOPSOIL: silty sand and silty sandy gravel with rootlets to depths of 0.05 – 0.2 m.
- SILTY/SANDY GRAVEL: medium dense, dry to moist silty and sandy gravel with some clay in parts to depths of 0.2 – 0.7 m
- SILTY/SANDY CLAY: firm to very stiff silty clay and sandy clay to 1.1 m depth and to the limit of investigation depth of 4.0 m.
- SILTY SAND: loose then dense (lightly cemented), dry to moist silty sand in between two clayey layers from 0.9 m to 2.4 m depth.
- BEDROCK: variably extremely low to high strength, extremely to slightly weathered bedrock encountered in all pits except one below depths of 0.05 – 1.1 m to the refusal depths of 0.3 – 2.5 m.

No free groundwater was observed during the excavation of the test pits. Groundwater conditions rarely remain constant and can change seasonally due to variations in rainfall and other factors.

The samples tested in the laboratory for measurement of Emerson class number for dispersion potential. The results indicated that the samples have a slight to non-dispersion potential and are similar to those obtained in the surrounding region.

4.2 Previous Relevant Environmental Works

4.2.1 Stage 3 Contamination Assessment

Coffey Environments Australia Pty Ltd (Coffey Env) undertook a Stage 3 Contamination Assessment of the proposed Jumping Creek Residential Estate.

- Stage 3 *Contamination Assessment, Jumping Creek, Queanbeyan*, NSW, Coffey Environments Pty Ltd (2010) (Report ref ENVICANB00233AA-R01b, dated 16 June 2010).

The objective of the assessment was to undertake supplementary contamination assessment to information remediation and management planning for the proposed residential estate.

During the assessment, Coffey Env reviewed previous reports undertaken by IT Environmental (Australia) Pty Ltd (1999), Egis Consulting (2001) and Parsons Brinckerhoff (2007). The site history review indicated that the site had been used for a variety of potentially contaminating activities including the mining of metal ores, limestone quarrying and associated lime kiln, possible on-site processing of mineral ores and pastoral activities including one sheep dip complex.

Following review of previous reports and site inspections, Coffey Env identified three remnant mining sites were present at the site. These were named Mine Site 1, Mine Site 3 and Mine Site 4, and the locations of these areas are presented in Drawing 1, Appendix B. It should be noted that Mine Site 3 is located in Stage 3 and is not part of the site of this assessment. In addition, a possible mineral processing area was located to the north-west of Mine Site 4. Mine Sites 1 and 3 were described to comprise single mine shafts and associated stockpiles. Mine Site 4 was described as being comprised of an area of open cut pits, several shallow trench excavations and an open adit. The mineral processing area was described as containing the remnants of several structures, including several water troughs, open drains and drainage sump areas. Reference was made to two additional mine sites previously encountered by IT Environmental, however, at the time of investigation, Coffey Env were not able to locate these

The assessment also included the installation and sampling of eight groundwater monitoring wells, the wells were installed in the vicinity of the sheep dip, the possible mineral processing area and Mine Sites 3 and 4.

4.2.2 Site Audit Statement, Environmental Strategies

MR Rod Harwood of Environmental Strategies prepared a Site Audit Statement for the site,

- Environmental Strategies Pty Ltd (2010) NSW Site Auditor Scheme, Site Audit Statement for Jumping Creek Site (dated 25 August 2010).

Under Part II, Section B of the site audit statement, it was stated that the site can be made suitable for the following uses:

- Residential with accessible soil, including garden (minimal home-grown produce contributing less than 10% fruit and vegetable intake), excluding poultry;
- Day care centre, preschool, primary school;
- Secondary school; and

- Park, recreational open space, playing field.

The site must be remediated in accordance with the RAP prepared by Coffey Env. The following RAPs were referenced:

- Remediation Action Plan – Sheep Dip Area, Jumping Creek, Queanbeyan, NSW, Coffey Env Environments Australia Pty Ltd, dated 15 December 2009; and
- Remediation Action Plan – Jumping Creek, Queanbeyan, NSW, Coffey Env Environments Australia Pty Ltd, dated 4 June 2010

The audit statement was issued subject to compliance with the following conditions:

- Preparation of an Environment Management Plan for management of the Mine Site 3 and Mine Site 4 Areas following site remediation.

DP Comment: There was no evidence that any remediation works had been undertaken in the sheep dip, Mine Sites 1 and 4 or Mineral Processing Area/Stockpile Holding Area.

4.2.3 Site Environmental Management Plan – Mine Site Area 4,

Coffey Env prepared a site environment management plan (SEMP) for the area of the site known as Mine Site Area 4.

- *Jumping Creek Development – Site Environmental Management Plan, Mine Site Area 4* Coffey Env Environments Pty Ltd (Report ref ENAURHOD04744AA-R02, dated 2 November 2015).

The objective of the SEMP was to facilitate effective management of the capping structure installed on the Mine Site 4 area and was written to support the draft planning proposal for the development and to enable the local Council to appreciate the remediation and post-remediation management requirements for the Mine Site Area 4.

The SEMP indicated that remediation including off-site disposal of loose demolition wastes, tree and weed removal, placement of a geofabric layer and capping of the area identified as exceeding the adopted site criteria had been undertaken.

The area of Mine Site 4 that was capped was indicated to be approximately 7,120 m^2. The capping was identified to have involved placement of a layer of geofabric material and a layer of 30 mm square barrier mesh, overlain with a 300 mm thickness layer of clean validated soil place at the site. The report also indicated that shallow root grasses and/or plants were used to landscape the area.

DP Comment: It is considered that the SEMP was prepared in order to comply with the conditions of the Site Audit Statement. The observations of the area of Mine Site 4 and neighbouring mineral processing area were similar to that described in Coffey Env's 2010 Stage 3 assessment report (Section 4.2.1) comprising an area of open cut pits, several shallow trench excavations and an open adit, remnants of several structures, including several water troughs, open drains and drainage sump areas, loose demolition wastes, trees and weeds and fencing.

4.3 Regional Geology and Hydrogeology

Reference to the 1:100,000 Canberra Geology Sheet (Ref 1) indicates that the site is underlain by several rock units.

The north-eastern corner of the site is mapped as being underlain by the Pitman Formation of Ordovician age. The Pitman Formation typically comprises interbedded sandstone, siltstone shale and minor black shale.

The eastern part of the site is mapped as being underlain by a subgroup of the Colinton Volcanics and two subgroups of the Cappanana Formation both of late Silurian age. These rock subgroups typically comprise:

- dark green dacitic ignimbrite and minor volcaniclastic sediments;
- shale, siltstone and minor quartzite and tuff; and
- limestone.

The western part of the site, is mapped as being underlain by 3 subgroups of the Colinton Volcanics of late Silurian age. These rock subgroups typically comprise:

- dark green dacitic ignimbrite and minor volcaniclastic sediments;
- tuffaceous shale; and
- limestone and dolomitic limestone.

Reference to the Hydrogeology of the Australian Capital Territory and Environs Map (Ref 2) indicates that the site is located on fractured aquifers of late Silurian age. Based on the hydrogeology map the yield of aquifers increases from the east to the west from less than 0.5 l/s to 0.5 – 1.0 l/s. Total dissolved solids (TDS) are mapped as increasing from the west to the east from between 500-1000 mg/l close to the Queanbeyan River to greater than 1000 mg/l further to the east.

Surface water was not observed during the site inspection with the exception of ponded water from recent rain fall. The site is traversed by numerous intermittently flowing water courses and gully lines which run in variable directions but ultimately water flows are to the south and south-west and west towards Jumping Creek and the Queanbeyan River.

4.4 Soil Landscape

Reference to the Canberra Soil Landscape Sheet (Ref 3) indicates the site is mapped as being underlain by the Burra soil group.

The Burra soil group is characterised by undulating to rolling low hills and alluvial fans on Silurian Volcanics of Canberra Lowlands. Generally, waning and gently to moderately inclined hill slopes, foot slopes and fans. Soils are shallow, well drained earthy sands on crests and upper slopes, and are moderately deep, moderately well drained red podzolic soils on mid slopes and most lower slopes. Moderately deep, moderately well drained yellow podzolic soils are present along minor drainage lines and on some lower slopes. The Landscape Sheet lists this soil group as characterised by its strong acidity and low water holding capacity, its low permeability, sheet erosion risk, run-on and localised shallow soil.

4.5 Site Inspection

4.5.1 General Site Observations

- The site was accessed on the northern boundary through the Ellerton Drive Extension works which were currently underway at the time of the site visit. Access was through an unsealed "four wheel drive" track;
- The site generally comprises undulating to steeply undulating undeveloped land which was lightly to moderately grassed, and with variable covering of trees, shrubs, and weeds;
- Areas of the site were extensively covered with thick stands of weeds (mainly bramble and blackberry);
- Semi-mature to mature trees were scattered across the site. The trees were a mixture of exotic and native species;
- Surface cobbles and boulders and rock outcropping were observed across the entire site mainly on hill ridgelines and flanks;
- Minimal topsoil on hill ridgelines and flanks;
- The flanks of the ridgelines and hills are generally moderately to steeply sloping with the ridgelines, foot slopes and gullies gently to moderately sloping in parts;
- Localised areas plateauing on top of ridge lines comprising gently to moderately sloping terrain in the northeast and northwest parts;
- The lower lying areas at the base of foothills and in particular in drainage gullies are significantly rutted. It is likely these areas have deeper topsoils, silty / sandy slopewash soils and possibly sand and gravel filled pedoderm layers which may retain water seepages;
- The creek bed of the Valley Creek comprised cobbles and boulders which in places were covered in a layer of finer grained sediments. The creek bed in the eastern / south eastern portions of the site it is quite broad whilst in the western portion of the site the creek passes through more narrow steeply sided gorge before connecting to the Queanbeyan River of the western side of the site;
- An extensive network of dirt tracks crossed the site. The tracks appeared to be used for four wheel driving and motorbike riding;
- Earthen mounds had been created in some areas presumably for motor bike jumps;
- Evidence of erosion was observed in gully lines where the natural grass and/vegetation cover has been removed;
- Minimal erosion in areas where the grass/vegetation is intact;
- No obvious signs of creep movements within near-surface soils were noted, nor any signs of deep-seated instability;
- No obvious signs of salinity (such as salt deposits and tree die back) or deep-seated instability within the site was observed;

- Anthropogenic wastes were scattered across most areas of the site. Wastes ranged from piles of building and demolition wastes, burned car bodies, small stockpiles of soil and general household wastes. A small stockpile located on the ridge-line in the north-west of the site was observed to contain pieces of possible asbestos containing material;
- A few areas appear to have been previously disturbed however the reason for which or total extent was difficult to determine; and
- With the exception of access tracks, motor bike mounds and other areas of modification mentioned above and in the following sections below, the site is generally undisturbed.

4.5.2 Sheep Dip Area

The sheep dip area identified in previous reports was identified in the north western part of the site, adjacent to the main access track. The following observations were made:

- The remnant sheep dip structure comprised the concrete sheep dip trough with small concrete pads present at each end of the trough;
- The trough was approximately 10 m long and 0.5 m wide. The area was heavily overgrown with the trough obscured by trees and shrubs;
- Building and demolition rubble comprised corrugated metal sheet, brick and concrete boulders scattered on the ground surface;
- Low wooden posts were observed driven into the ground;
- Several pieces of potentially asbestos containing materials were observed on the ground surface to the north of the sheep dip;
- The sheep dip was located on a broad ridge line dropping to the north and south. Extensive weeds (brambles and blackberry) were present on the north slope of the ridge; and
- A monitoring well was observed to the south-west of the sheep dip. The location was consistent with that noted in the Coffey Env Stage 3 contamination assessment (Section 4.2.1). The top of the monitoring well was broken and no well cap was present.

4.5.3 Mine Site 1

Mine Site 1 identified in previous reports was identified in the north-eastern part of the site adjacent to an access track. The following observations were made:

- The mine site comprised an open shaft with stockpiled spoil present on the eastern, southern and western sides of the shaft;
- A wire gate and hi-vis mesh temporary fencing had been placed over the open shaft in an attempt to make the shaft safe;
- The depth of the shaft was measured to be greater than 6 m deep;
- Sparse grass cover was present in the vicinity of the shaft; and
- The mine shaft appeared in similar condition to that noted in the Coffey Env Stage 3 assessment report (Section 4.2.1).

4.5.4 Mine Site 4

Mine Site 4, identified in previous reports, was identified in the central part of the site adjacent to an access track. The following observations were made:

- The mine site comprised a disturbed area of ground approximately 110 m long by 40 m wide and was located on a hillside that sloped down towards the north and east, on an inside bend of Jumping Creek;
- Two areas of open cut excavation and stockpiles of mining spoil were located in the north-western part of the area of disturbed ground;
- Several smaller stockpiles were located in the eastern part of the disturbed ground sloping towards the east along with two short open trenches. The stockpiles and trenches were overgrown with weeds and bushes;
- An adit (horizontal shaft) was located on the lower eastern sloping part of the disturbed ground above Valley Creek. The opening of the adit was overgrown, but it was observed that the adit opened into a passage, however, it was not possible to ascertain the length of the adit; and
- Two monitoring wells were present in the eastern part of the disturbed ground area.

4.5.5 Mineral Processing Area / Stock Holding Area

The mineral processing area/stock holding area was identified to the north-west of Mine Site 4 and south of Valley Creek. The following observations were made:

- The area was heavily overgrown with trees, bushes and bramble present limiting access to the area and reducing areas that could be directly observed;
- Evidence of former structures was observed including concrete slabs and low courses of brickwork. Several reinforced concrete troughs were observed throughout the area. The troughs were approximately 1.5 m long and 0.5 m wide. Building and demolition rubble was present throughout the area, including brick, metal, concrete and timber fragments. Timber posts driven into the ground were also present. Remnants of an above ground storage tank were also present, which appeared to be filled with waste materials;
- An open concrete drain was present leading to a concrete sump. It was not possible to closely observe the concrete lined drainage sump due to dense overgrowth;
- A monitoring well was present to the north east of the Mineral Process/Stock Holding Area. The monitoring well was located in a position consistent with the location of monitoring well MW7 identified in the Coffey Env Stage 3 assessment report; and
- The remaining features of the former structures appeared generally consistent with the photographs of the area provided in the Coffey Env Stage 3 assessment report (Section 4.2.1).

4.5.6 Kiln and Limestone Quarry

The kiln and limestone quarry identified in previous reports was identified in the south-eastern corner of the site. The following observations were made:

- The remains of the kiln building were heavily overgrown with weeds and only limited parts of the structure could be observed;

- The limestone quarry was noted in the south-east corner of the site on the lower eastern slopes adjacent to Valley Creek;
- The quarry was approximately 60 m long, 15 m wide and 5 m deep. A car body was present within the quarry area; and
- Large stockpiles of spoil and fill embankments were present to the north and west of the quarry.

4.5.7 Additional Mine and Quarry Site

- A previously unidentified mine shaft and small quarry site were present in the north-western part of the site, located to the south-west of the sheep dip area, on the north-eastern slope of a ridgeline;
- The small quarry site was approximately 20 m wide and 20 m long and was cut into the slope. Stockpiled spoil and fill embankments was located to east of the quarry area consisting of boulder sized fragments of rock;
- The mine shaft was located to the south-west of the small quarry. The mouth of the shaft was heavily overgrown and it was not possible to assess the depth of the shaft. Stockpiled spoil was present on the northern, eastern and southern sides of the shaft.

5. Proposed Development

Based on the information provided, it is understood that the Jumping Creek Estate subdivision comprises the construction of standard residential blocks and associated pavement and infrastructure for the development area. At this stage design levels have not been determined however some cut and fill will be required to modify current levels for roadways.

6. Comments

6.1 General

The following comments are based on the results of review of existing information and site reconnaissance and our involvement in similar projects.

It is understood that a future residential subdivision is proposed and that further investigations will be undertaken prior to construction of the proposed subdivision. Accordingly, this report and the comments given within must be considered as being preliminary in nature.

6.2 Development Considerations

6.2.1 Site Classification

Classification of residential blocks within the site should comply with the requirements of AS 2870 – 2011 "Residential Slabs and Footings" (Ref 4). Likely lot classifications would range from Class A (sand/rock sites), Class S (slightly reactive) to Class M (moderately reactive) or Class H1/H2 (highly reactive), with the final classification dependent on soil reactivity, the presence of trees, filling and rock depth. The topographic slope in parts of the proposed development site ranges from intermediate to steep and accordingly, it is anticipated that these lots will need to consider design and construction techniques that take account of the ground slope and possible Class P conditions. It must be noted that some areas within blocks with steep terrain may not be considered suitable for development. Classifications within these areas would also be dependent on the extent of bulk earthworks proposed.

Areas in and adjacent to former underground ground mine workings and areas containing uncontrolled filling, would warrant Class P conditions to those affected blocks. Further investigations of the mine works will be required to assess the extent and possible impacts as well as rehabilitation works.

Any areas where adverse moisture conditions are present i.e.: gully lines and low lying areas are also likely to be classified as Class P without engineering modification.

6.2.2 Stability Assessment

The site has been assessed with reference to the Australian Geomechanics Society Sub-Committee on Landslide Risk Management: *"Landslide Risk Management Concepts and Guidelines"* (Ref 5). Based on the observations made during the inspection, an assessment of risk to property has been undertaken for each of four distinct zones as follows:

Zone 1: areas of gently sloping land i.e.: flatter than 1V:10H (vertical:horizontal) or 5 – 6°;

Zone 2: areas of moderately sloping land i.e.: generally between 1V:10H and 1V:5H or 6 – 12°;

Zone 3: areas of moderately to steeply sloping land i.e.: generally between 1V:5H and 1V:3.3H or 12 – 17°;

Zone 4: areas of steeply sloping land i.e.: steeper than 1V:3.3H or 17°.

The results of the assessment for each of these areas are outlined in Tables 1 – 4.

Table 1 – Slope Stability Assessment – Zone 1 (Gently Sloping Areas)

Hazard	Likelihood	Consequence to Proposed Development	Risk to Proposed Development
Creep of surface soils	Barely credible	Minor	Very Low
Near surface slumping	Barely credible	Medium	Very Low
Active / deep seated slide	Barely credible	Major	Very Low

Table 2 – Slope Stability Assessment – Zone 2 (Moderately Sloping Areas)

Hazard	Likelihood	Consequence to Proposed Development	Risk to Proposed Development
Creep of surface soils	Unlikely	Minor	Low
Near surface slumping	Unlikely	Medium	Low
Active / deep seated slide	Rare	Major	Low

Table 3 – Slope Stability Assessment – Zone 3 (Moderately to Steeply Sloping Areas)

Hazard	Likelihood	Consequence to Proposed Development	Risk to Proposed Development
Failure during construction	Possible	Medium	Moderate
Creep of surface soils	Possible	Minor	Moderate
Near surface slumping	Possible	Medium	Moderate
Active / deep seated slide	Rare	Major	Low

Table 4 – Slope Stability Assessment – Zone 4 (Steeply Sloping Areas)

Hazard	Likelihood	Consequence to Proposed Development	Risk to Proposed Development
Failure during construction	Likely	Medium	High
Creep of surface soils	Likely	Minor	Moderate
Near surface slumping	Likely	Medium	High
Active / deep seated slide	Unlikely	Major	Moderate

In summary, it is considered that based on the proposed development the central development area and the parts of the north-west and eastern development areas are classified as very low risk of damage to property occurring as a result of slope instability. Large parts of the north-western and eastern areas have an increased risk varying from low to high risk. The more elevated parts of the eastern area and some localised parts of the north-western area are considered to be of moderate or high risk of causing property damage due to the steep ground slopes and possible unsuitable design and construction practice.

Notwithstanding the various risk categories nominated, development of the site for residential purposes is considered feasible in areas of gently and moderately sloping land (very low and low instability risk) with erosion control measures and suitable dwelling design. In areas of moderately sloping land, standard practices for hillside development must be incorporated into designs.

Areas designated as moderately to steeply sloping land (low and moderate risk), could be developed for residential purposes however would have to the subject of site and development specific geotechnical investigations to establish a site model and provide geotechnical limitations and design parameters.

Areas of steeply sloping land (moderate and high risk) are not recommended for residential development at this stage. A detailed site stability assessment including subsurface investigations must be undertaken in these areas to establish an appropriate site model for analysis purposes to assess whether development is feasible in the high risk zones.

It is noted that revisions to the above risk classifications may be necessary following completion of bulk earthworks. It is recommended that if development is proposed within the moderate and high risk areas, further delineation and assessment be undertaken.

6.2.3 Soil Erosion

Based on the results on previous Emerson class testing, our walkover inspection and our experience on the majority of subdivision sites the Canberra and Queanbeyan region, it is considered that the erosion hazard within the areas proposed for development would be within accepted limits and could be managed by good engineering and land management practices which will also be required to address flood hazard and localised waterlogging limitations of soils along gully lines and low lying flat areas. These hazards are considered to impose only a minor constraint to development, on the basis they are addressed as mentioned above with good engineering and land management practice.

It is anticipated that the treatment of the existing erosion gullies as part of an overall site development would include:

- Filling using select materials (i.e. non – dispersive or erodible) placed under controlled conditions;
- Provision of temporary surface cover (e.g. pegged matting) during the period of valley floor revegetation;
- Channel lining in sections of rapid change in gully floor grade;
- Piping of flow where appropriate; and
- The re-establishment of a zone of vegetation and tree cover along gully banks.

6.2.4 Footings

All footing systems for standard residential dwellings should be designed and constructed in accordance with AS 2870 – 2011 (Ref 4) for the appropriate classification. For hillside lot construction (low risk or greater), reference should be made to the publication by AGS (Ref 5), relevant extracts of which are included in Appendix D.

For preliminary sizing of footings, allowable base bearing pressures for the various strata likely to be encountered including controlled filling are given below:

- Stiff or loose to medium dense natural soils: 100 kPa
- Controlled Filling: 150 kPa
- Very stiff or medium dense natural soils: 150 kPa
- Extremely low and very low strength bedrock: 500 kPa
- Low strength bedrock: 1000 kPa

6.3 Site Preparation and Earthworks

6.3.1 Stripping

Site preparation for the construction of roadways and structures should include the removal of vegetation, topsoils, silty sandy soils, existing filling and other deleterious materials from the proposed building areas. Deep excavations (such as in gullies) could occur should localised deeper topsoils or unsuitable materials/filling be encountered, if inclement weather precedes construction or if the contractor adopts inappropriate stripping methods.

It is expected that the site is underlain at least in parts by deep silty sands/sandy silts (beneath the topsoils). This material is usually difficult to handle and compact and would require extremely careful moisture control. It is recommended that allowance be made for at least partial stripping of this material (say 0.3 m following topsoil stripping), with inspection undertaken by a suitably qualified geotechnical engineer to assess the depth of removal required at the time of construction. Where possible (i.e.: in deep fill areas) this material could be designated to remain insitu, however if considered unsuitable would be required to be removed. Also, if stripping of deep silty material is needed, it be limited to 0.4 m only as it is unlikely to improve with depth. The excavated material should be replaced with a granular bridging layer.

Depending on prior weather conditions it may also be necessary to use a geofabric separation layer.

6.3.2 Excavation Conditions

It is expected that the subsurface profile will comprise a variable soil profile underlain by bedrock which in parts may be of very high to extremely high strength.

The site soils and weathered bedrock up to low strength could be expected to be removed using conventional large earthmoving plant. The presence of outcropping rock or boulders at the surface may preclude effective use of scrapers in some areas.

Excavation of the bedrock will largely be dependent on the degree of fracturing/jointing and the strike and dip of bedding within the rock relative to the excavation. Depending on excavation depths, heavy ripping or heavy rock hammering may be required but would have low production rates; blasting would be recommended to further fracture the bedrock to expedite ripping activities.

The extent of groundwater inflow would be dependent on prior weather conditions. Given the extent of gully lines and relatively flat topography over some parts of the site, groundwater seepages should be anticipated, which would increase following rainfall. Groundwater springs may also arise following stripping and excavation works.

6.3.3 Filling Placement

In areas that require filling, the stripped surfaces must be test rolled in the presence of a geotechnical engineer. Any areas exhibiting significant deflections under test rolling must be appropriately treated by over-excavation and replacement with suitable non-reactive filling. All filling material must be placed in horizontal layers of maximum 250 mm loose thickness. The material must have a moisture content within the range of ±2% of modified optimum at the time of placement.

All permanent fill batters must be constructed no steeper than 1:3 (vertical:horizontal), appropriately protected against erosion with toe and spoon drains constructed as a means of controlling surface flows on the batters and vegetation of the batter.

6.3.4 Filling Compaction

All filling placed within construction platforms must be compacted to a minimum 90% modified maximum dry density, except for the upper 1.0 m within pavement areas, which must be compacted to a minimum of 95% modified maximum dry density.

To validate future site classifications, field inspections and in-situ testing of future earthworks must be undertaken on any controlled filling placed in residential blocks in order to satisfy the requirements of a Level 1 inspection and testing service as defined in AS 3798 – 2007 (Ref 6).

6.4 Drainage

Parts of the site have poor natural subsurface drainage. Infiltrated rainwater can become contained in the upper semi-pervious silty/sandy stratum and deeper sandy/gravelly pedoderm layers. Seepage water may also enter fractures in the bedrock at locations where the bedrock outcrops or is at shallow depth. Seepage water in the subsurface profile may rise to the ground surface further downslope as springs.

In order to reduce the downslope seepage flow volume into residential areas, it is recommended that:

- A contour drain be constructed along the upslope boundary of the development areas extending to at least 0.5 m depth below the bedrock surface;
- Floodways be constructed along natural drainage lines;
- Deep subsurface gravel drains to installed along the invert of gullies to be infilled and through any spring areas; and
- Subsurface drains be installed along both sides of roads constructed in cut and/or at about natural grade. Some sections of road subgrades may need to be provided with cross-drains or a drainage blanket to control upward seepages.

The extent of site drainage can only be determined and undertaken effectively onsite during construction.

6.5 House Site Maintenance

The developed blocks 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 E. 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.

6.6 Pavements

Whilst subsurface investigations along roadways and design of pavements have yet to be undertaken, based on the results of the site inspection and previous experience in the nearby area, Table 5 gives indicative design CBR values for the various likely subgrade conditions.

Table 5 – Design CBR Values

Subgrade Material	Design CBR (%)
Clay (high plasticity)	1 – 2
Sandy/Gravelly Soils	3 – 4
Recompacted (sedimentary) Weathered Rock	3 – 5
Recompacted (Igneous) Weathered Rock	5 – 7
Insitu Weathered Rock	7 – 10

There may be construction advantages in undertaking subgrade replacement in those areas where any high plasticity clay subgrades occur. Detailed investigations will be required following finalisation of subdivision layout to confirm and delineate, if possible the variation in subgrade conditions. Surface and subsurface drainage must be installed and maintained to protect the pavement and subgrade. The subsurface drains should extend a minimum of 0.5 m depth below the subgrade level.

6.7 Salinity

No visual signs of salinity were observed during the site inspection. It is suggested as part of future detailed investigations that some samples be collected of site soils for laboratory testing of electrical conductivity and pH values to enable further screening comment to be made on salinity. It is envisaged that a full salinity assessment is not required given the lack of supporting evidence on this site and surrounding parts of Queanbeyan for significant salinity issues.

6.8 Development Constraints

The assessment has identified a number of constraints on the development, which are:

- Potential for waterlogging in several areas including spring activity;
- Potential for erosion in areas where vegetation cover is removed;
- Areas of moderate and high risk of damage to property with respect to slope instability;
- Uncontrolled filling associated with stockpiles and fill embankments, tracks, mounds and fly tipping (car bodies);
- Outcropping and shallow very high strength bedrock;
- Mine workings and quarrying both aboveground and underground work; and
- Site Contamination.

Waterlogging: There is evidence of previous wet, soft and/or boggy conditions within several areas identified as potential for waterlogging. These areas are characterised by slightly greener grass and contain grass species which from Douglas Partners experience indicates previous or current presence of elevated soil groundwater levels. They appear to be limited to gully lines and low lying areas.

Erosion: Where the previous vegetation cover has been removed, which is mostly in gully lines and disturbed areas, evidence of erosion ranging from slight to severe was observed.

Stability: A portions of the north-western and eastern development areas has been assessed as having a potential moderate to high risk of damage to property from land instability.

Uncontrolled Filling: Uncontrolled filling is unsuitable to support structural loading including pavements. Removal of uncontrolled fill can be included as part of the site regrading or site clean-up during construction of the development and would only pose a minor constraint to development.

High Strength Bedrock: The presence of outcrops and shallow very high strength bedrock would prove difficult to excavate should design levels require cutting.

Mine Workings: The stabilisation and/or backfilling of open excavations and the grouting and/or backfilling of horizontal and vertical shafts is likely to pose a significant constraint to the localised areas of the workings.

Site Contamination: Site investigation and remediation of the identified impacted areas is likely to pose a significant constraint to the affected areas.

After the above constraints are addressed, the site would be considered suitable for the proposed development.

6.9 Remedial Measures/Site Controls

The main activities or methods to enable effective development of the site, from a geotechnical perspective, would be:

- Planning/layout of development areas;
- Extensive drainage measures;
- Erosion management;
- Timing of works;
- Development restrictions from a slope instability perspective;
- Minimising cut-fill on hillside; and
- Detailed planning of remediation works of the identified impacted areas (mine workings and contamination).

6.9.1 Planning/Layout of Development

Gully lines and possibly low lying areas should be avoided for standard residential construction without engineering modification as these areas would require extensive drainage works and/or bulk earthworks. Where possible, roads should be positioned over the top of gully lines to enable the construction of subsurface drainage lines. If development of the low lying areas is being considered, controlled filling would be required to raise surface levels to assist in drainage design. Should residential areas be proposed over drainage areas, Class P site classifications would be warranted with special advice required on foundation design and construction as not to interfere with the drainage measures. Pending prior weather conditions, earthworks on low lying areas may be extremely problematic.

6.9.2 Drainage Measures

Engineered drainage both to divert overland flow and intercept subsurface flow combined with bulk earthworks to raise surface levels and or contour the surface level to improve drainage will be required if permanent structures are to be constructed in gully and/or low lying areas.

A network of drainage lines would be required across the sites to intercept and provide a controlled transportation pathway for groundwater flows. Main drainage lines would be located at the base of gullies and within the low lying areas with interceptor drainage lines constructed as and where required across the site feeding into the main drainage lines. The drainage lines could either be subsurface or surface (floodway) type structures depending on surface levels.

6.9.3 Erosion Management

One of the existing limitations to development of the site is considered to be areas of gully erosion. Soil and water management is an integral part of the development process and should adopt a preventative rather than a reactive approach to the site limitations, such that the work can proceed without undue pollution of receiving streams.

A detailed soil and water management plan (SWMP) will be required and should be incorporated into the engineering design of the development methods for:

- Minimising water pollution due to erosion of soils or the development of saline conditions;
- Minimisation of soil erosion during and after construction; and
- Maximising the re-use of materials on site.

6.9.4 Timing of Works

Timing of the site works could also be a critical aspect that will require careful consideration. Bulk earthworks activities is suggested to be undertaken in the warmer months of the year and not the winter months when ground moisture is higher due to the negative evapotranspiration effect experienced in winter. If moist soils are encountered and require drying to enable reuse in controlled filling areas, the warmer months would allow more expedited processing negating the potential for several weeks of drying time expected during winter.

6.9.5 Development Restrictions

Development within areas of medium risk of instability is technically feasible though would be required to be undertaken with geotechnical guidance. Site specific and development specific geotechnical investigation and advice would be required for individual structures.

At this stage, it is understood that development in the high risk areas of instability is not proposed. Should development be proposed in these areas in the future a comprehensive site stability assessment will be required.

6.9.6 Cut – Fill Minimisation on Hillside

It is standard hillside development practice to minimise the depths of cutting and filling though feasible to undertake significant works with geotechnical approval and guidance. All proposed modification of the ground slope in hillside areas must be subject to geotechnical review and comment.

6.9.7 Detailed Planning of Remediation Works

The planning of remediation options to reduce the contamination and mine working constraints on the proposed development will depend on the results of further investigations.

6.10 Geotechnical Subsurface Investigations

Detailed subsurface investigation and laboratory testing will be required as the conceptual design/planning progresses, and during the design and construction phases. Specific investigation would include but not necessarily be limited to:

- Detailed geotechnical investigation and assessment of areas of steeply sloping land should development be desired in these areas;
- Detailed geotechnical investigation on a stage by stage basis as development proceeds to determine excavation conditions and support, road subgrade CBR values and confirm site classifications for each lot; and
- Detailed geotechnical assessment of the mine workings and the limestone quarry should be undertaken to determine the current stability of the excavations and for further remedial works for safety and/or for further development of residential lots to proceed over the mine workings.

6.11 Summary

The site assessment undertaken as described above has indicated that the majority of the site planned to be included in the site redevelopment of the subdivision is suitable from a geotechnical perspective for residential development. Comments have been given on the various geotechnical aspects of the proposed development and the identified development constraints and subsequent remedial and control measures. Conceptual comments on design and construction aspects are also given in the report. Further testing and assessment will be required as the design of the subdivision proceeds and as such, this report must be considered as being preliminary in nature.

7. References

1. Geology of Canberra 1:100 000 Geological Series Sheet 8727, Bureau of Mineral Resources, (1992).

2. Bureau of Mineral Resources, Geology and Geophysics (1984): 'Hydrogeology of the Australian Capital Territory and Environs' 1:100,000 scale map.

3. Soil Landscape of Canberra 1:100 000 Soil Landscape Series Sheet 8727, NSW Dept of Land and Water Conservation, (2000).

4. Australian Standard AS 2870 – 2011 Residential Slabs and Footings.

5. AGS – Landslide Risk Management Concepts and Guidelines, Australian Geomechanics Society, Sub-committee on Landslide Risk Management, 2007.

6. Australian Standard AS 3798 – 2007 Guidelines on Earthworks for Commercial and Residential Developments.

8. Limitations

Douglas Partners (DP) has prepared this report for this project at Lot 5, DP 1199045, Greenleigh in accordance with DP's proposal dated 11 April 2018 and acceptance received from Spacelab Studio Pty Ltd dated 22 June 2018. The work was carried out under the terms and conditions of the sub-consultancy agreement, dated August 2018. This report is provided for the exclusive use of Spacelab Studio 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 surface conditions on the site only, and at the time the work was carried out. 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 scope for work for this investigation/report did not include the assessment of surface or sub-surface materials or groundwater for contaminants, within or adjacent to the site. Should evidence of filling of unknown origin be noted in the report, and in particular the presence of building demolition materials, it should be recognised that there may be some risk that such filling may contain contaminants and hazardous building materials.

The contents of this report do not constitute formal design components such as are required, by the Health and Safety Legislation and Regulations, to be included in a Safety Report specifying the hazards likely to be encountered during construction and the controls required to mitigate risk. This design process requires risk assessment to be undertaken, with such assessment being dependent upon factors relating to likelihood of occurrence and consequences of damage to property and to life. This, in turn, requires project data and analysis presently beyond the knowledge and project role respectively of DP. DP may be able, however, to assist the client in carrying out a risk assessment of potential hazards contained in the Comments section of this report, as an extension to the current scope of works, if so requested, and provided that suitable additional information is made available to DP. Any such risk assessment would, however, be necessarily restricted to the geotechnical components set out in this report and to their application by the project designers to project design, construction, maintenance and demolition.

Douglas Partners Pty Ltd

Appendix A

About This Report

About this Report

Douglas Partners

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.

Copyright

This report is the property of Douglas Partners Pty Ltd. The report may only be used for the purpose for which it was commissioned and in accordance with the Conditions of Engagement for the commission supplied at the time of proposal. Unauthorised use of this report in any form whatsoever is prohibited.

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

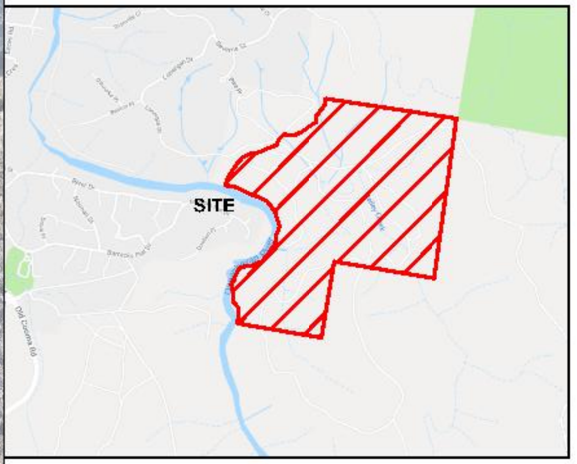
Site Anomalies
In the event that conditions encountered on site during construction appear to vary from those which were expected from the information contained in the report, DP requests that it be immediately notified. Most problems are much more readily resolved when conditions are exposed rather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

Drawing 1 – Site Features Plan
Drawing 2 – Proposed Estate Development Plan



Locality Plan

LEGEND

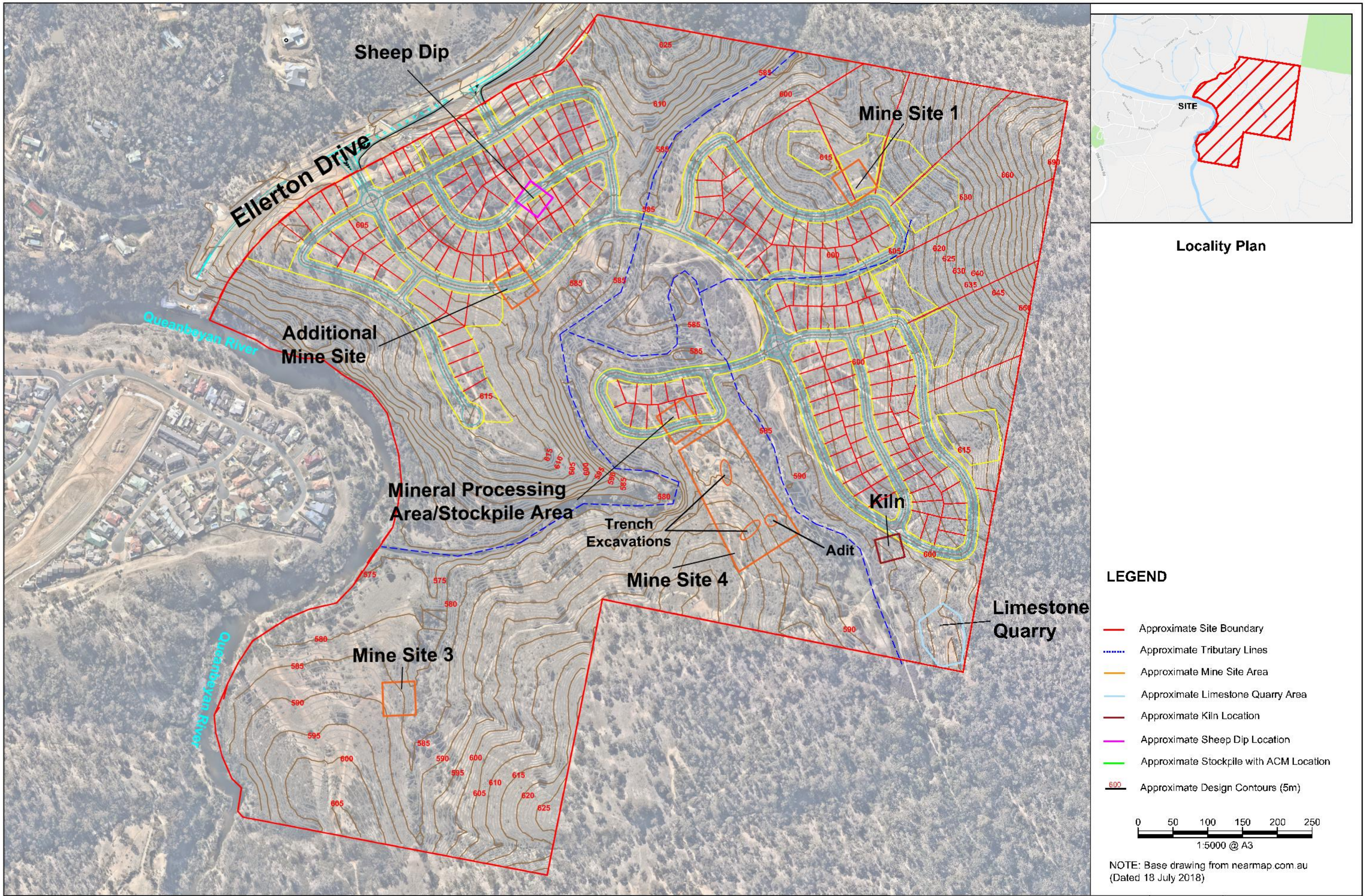
- Approximate Site Boundary
- Approximate Tributary Lines
- Approximate Mine Site Area
- Approximate Limestone Quarry Area
- Approximate Kiln Location
- Approximate Sheep Dip Location
- Approximate Stockpile with ACM Location

0 50 100 150 200 250

1:5000 @ A3

NOTE: Base drawing from nearmap.com.au (Dated 18 July 2018)

Douglas Partners Geotechnics / Environment / Groundwater	CLIENT: Spacelab Studio Pty Ltd		TITLE: **Site Features Plan**	PROJECT No: 88224.02
	OFFICE: Canberra	DRAWN BY: SDG	**Jumping Creek Estate**	DRAWING No: 1
	SCALE: As Shown	DATE: 21.03.2019	**Lot 5, DP1199045, Greenleigh**	REVISION: 1



Douglas Partners Geotechnics / Environment / Groundwater	CLIENT: Spacelab Studio Pty Ltd		TITLE: **Proposed Development Estate Plan**
	OFFICE: Canberra	DRAWN BY: SDG	**Jumping Creek Estate**
	SCALE: As Shown	DATE: 21.03.2019	**Lot 5, DP1199045, Greenleigh**

PROJECT No:	88224.02
DRAWING No:	2
REVISION:	1

Appendix C

Site Photographs

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	88224.02
	Jumping Creek Estate	PLATE No:	1
	Lot 5, DP 1199045, Greenleigh	REV:	1
	CLIENT: Spacelab Studio Pty Ltd	DATE:	21-Mar-19

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	88224.02
	Jumping Creek Estate	PLATE No:	2
	Lot 5, DP 1199045, Greenleigh	REV:	1
	CLIENT: Spacelab Studio Pty Ltd	DATE:	21-Mar-19

Douglas Partners
Geotechnics | Environment | Groundwater

Site Photographs		PROJECT:	88224.02
Jumping Creek Estate		PLATE No:	3
Lot 5, DP 1199045, Greenleigh		REV:	1
CLIENT:	Spacelab Studio Pty Ltd	DATE:	21-Mar-19

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	88224.02
	Jumping Creek Estate	PLATE No:	4
	Lot 5, DP 1199045, Greenleigh	REV:	1
	CLIENT: Spacelab Studio Pty Ltd	DATE:	21-Mar-19

Photo 9 ent area

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	88224.02
	Jumping Creek Estate	PLATE No:	5
	Lot 5, DP 1199045, Greenleigh	REV:	1
	CLIENT: Spacelab Studio Pty Ltd	DATE:	21-Mar-19

Appendix D

AGS Guidelines Extract

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}	$5x10^{-3}$	100 years	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-4}$	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-5}$	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-6}$	100,000 years	200,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}		1,000,000 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 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

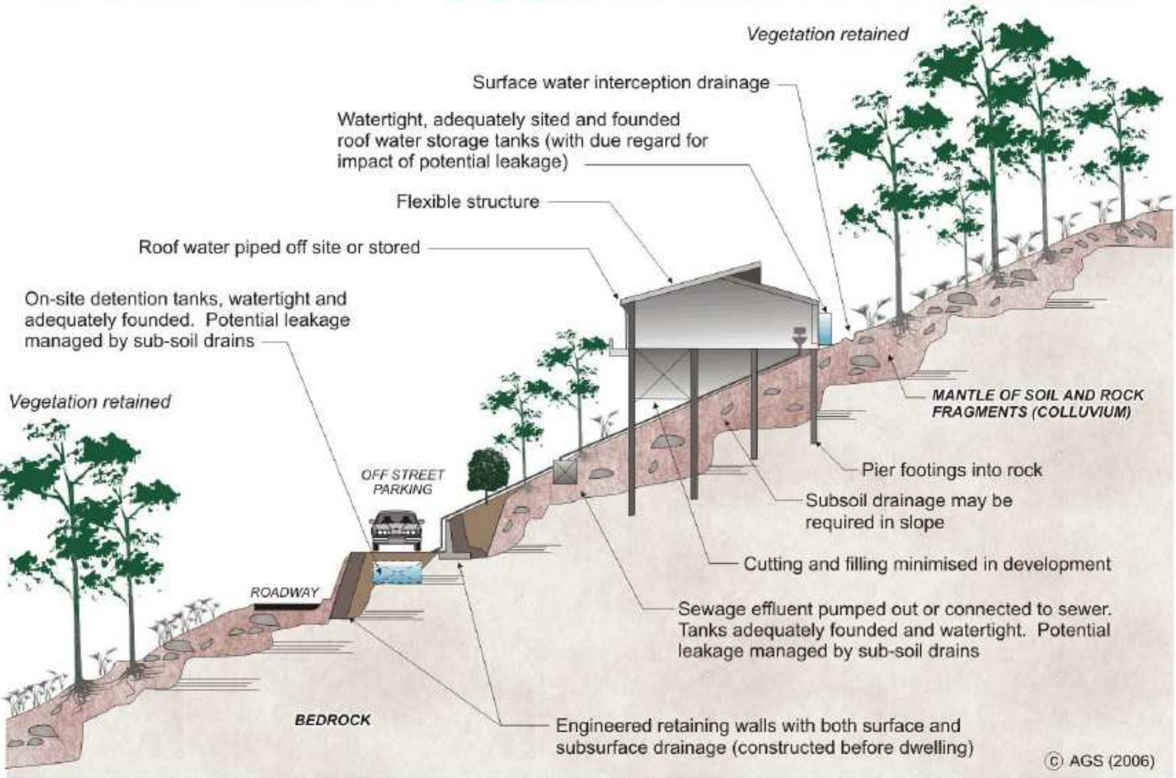
Risk Level		Example Implications (7)
VH	VERY HIGH RISK	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
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.

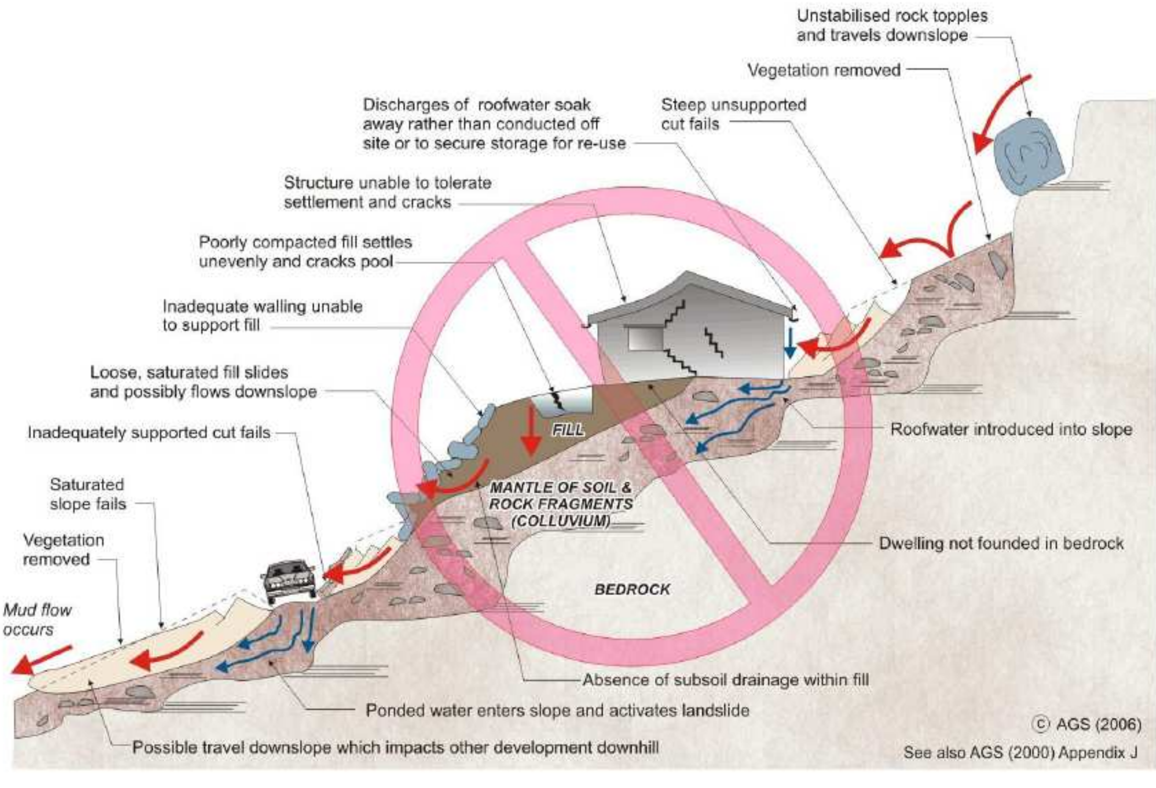
APPENDIX G - SOME GUIDELINES FOR HILLSIDE CONSTRUCTION

	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



Appendix E

CSIRO Publication

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.

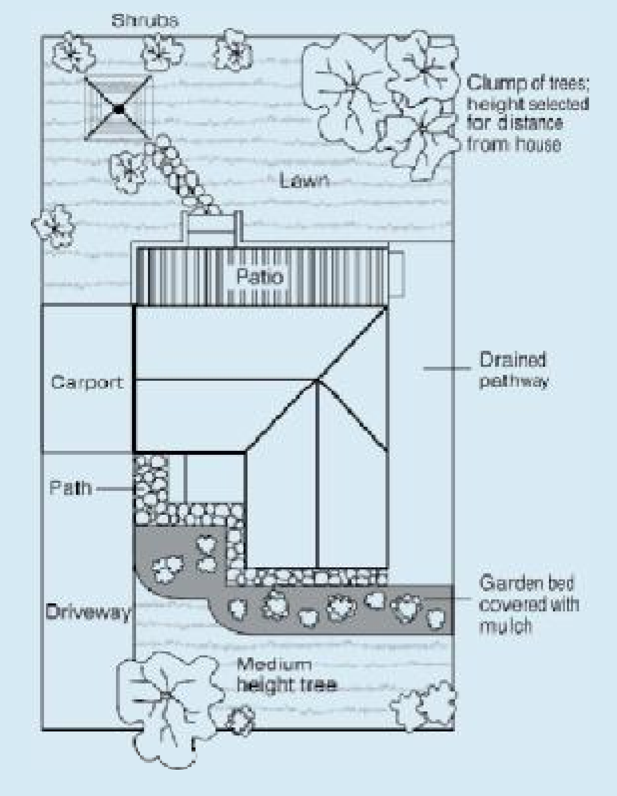
Protection of the building perimeter
It is essential to remember that the soil that affects footings extends well beyond the actual building line. Watering of garden plants, shrubs and trees causes some of the most serious water problems.

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.

This BTF was prepared by John Lewer FAIB, MIAMA, Partner, Construction Diagnosis.

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CSIRO PUBLISHING PO Box 1139, Collingwood 3066, Australia

Freecall 1800 645 051 Tel (03) 9662 7666 Fax (03) 9662 7555 www.publish.csiro.au

Email: publishing.sales@csiro.au