Geotechnical Consultants Australia

Infinity Eight Holdings Pty Ltd

# Geotechnical Investigation Report

Proposed Development at:

105 Letitia Street

Oatley NSW 2223

G23267-1

4th July 2023

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**Report Distribution**

Geotechnical Investigation Report

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GCA Geotechnical Consultants Australia

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## APPENDICES

# 1. INTRODUCTION

## 1.1 Background

This geotechnical engineering report presents the results of a geotechnical investigation undertaken by Geotechnical Consultants Australia Pty Ltd (GCA) for a proposed development at No. 105 Letitia Street Oatley NSW 2223 (the site). The investigation was commissioned by Mr. Mat Dervish of Infinity Eight Holdings Pty Ltd (the client) and was carried out on the 3rd July 2023.

The purpose of the investigation was to assess the subsurface conditions over the site at the selected boreholes and testing locations (where accessible and feasible) and provide necessary recommendations from a geotechnical perspective for the proposed development.

The findings presented in this report are based on our subsurface investigation and our experience with subsurface conditions in the area and local region. This report presents our assessment of the geotechnical conditions and has been prepared to provide preliminary geotechnical advice and recommendations to assist in the preparation of designs and construction of the ground structures for the proposed development.

For your review, **Appendix A** contains a document prepared by GCA entitled "Important Information About Your Geotechnical Report", which summarises the general limitations, responsibilities and use of geotechnical engineering reports.

## 1.2 Proposed Development

Information provided by the client indicates the proposed development comprises demolition of the existing infrastructures of the site, followed by construction of new two (2) storey dual occupancy.

The Finished Floor Levels (FFL)s for the proposed development are set to be at Reduced Levels (RL)s of:

- Lower ground floor level: RL24.00m Australian Height Datum (AHD).
- Ground floor: 27.70m AHD.

Based on this information and the existing site levels and topography, cut and fill is expected to be required for construction of the development. Locally deeper excavations for the building footings and service trenches are also anticipated to be required.

It should be noted that excavation depths are expected to vary across the site and are inferred off the FFLs shown on the architectural drawings and existing levels on the site survey plan, referenced in Section 1.3 below.

## 1.3 Provided Information

The following relevant information was provided to GCA prior to the geotechnical investigation and during preparation of this report:

- Architectural drawings prepared by Cornerstone Design, titled "Proposed Dual Occupancy at 105 Letitia Street Oatley Lot 39, Section 34, DP 6848", and referenced project No. CD1502.
- Site survey plan prepared by PK Surveys Pty Ltd, titled "Detail and Level Survey of 105 Letitia Street, Oatley Lot 39 of Sec 34 In DP 6848", referenced job No. 61441 and dated 9th September 2021.

## 1.4 Geotechnical Assessment Objectives

The objective of the geotechnical investigation was to assess the site surface and subsurface conditions at the selected boreholes and testing locations within the site (where accessible and feasible), and to provide professional geotechnical advice and recommendations on the following based on requirements provided to GCA by the client:

- General assessment of any potential geotechnical issues that may affect any surrounding infrastructures, buildings, council assets, etc., along with the proposed development.
- Excavation conditions and recommendations on excavation methods in soils and rock to restrict any ground vibrations.
- Design parameters based on ground conditions within the site for retaining walls.
- Recommendations on suitable foundation types and design for the site.
- End bearing capacities and shaft adhesion for shallow and deep foundations based on ground conditions within the site.
- Groundwater levels which may be determined during the geotechnical investigation.
- Preliminary site lot classification in accordance with Australian Standards (AS) 2870-2011.
- General geotechnical advice on site preparation, filling and subgrade preparation.

## 1.5 Scope of Works

Fieldwork for the geotechnical investigation was undertaken by an experienced geotechnical engineer/engineering geologist, following in general the guidelines outlined in AS 1726-2017. The scope of works included:

- Service locating carried out using electromagnetic detection equipment to ensure the area is free of any underground services at the selected boreholes and testing locations.
- Review of site plans and drawings to determine appropriate testing locations (where accessible and feasible), and identify any relevant features of the site.
- Hand augering of two (2) boreholes at selected locations within the site (where accessible and feasible), identified as BH1and BH2, and carried out using hand operated equipment to practical refusal depths of approximately 0.5m to 0.6m below the existing ground level within the site (bgl).
- Dynamic Cone Penetrometer (DCP) testing immediately adjacent to borehole BH1 and BH2, and at selected locations within the site (where accessible and feasible), using hand operated equipment to varying practical refusal depths of approximately 0.36m to 0.97m bgl. The DCP tests are identified as DCP1 to DCP4 inclusive.
    - The approximate locations of the boreholes and DCP tests are shown on **Figure 1, Appendix B** of this report.
- Collection of soil samples during fieldwork for any laboratory testing which may be required.
- Reinstatement of the boreholes with available soil displaced during augering.
- Preparation of this geotechnical engineering report.

## 1.6 Constraints

The discussions and recommendations provided in this report have been based on the results obtained at the selected boreholes and testing locations within the site (where accessible and feasible). It is recommended that further geotechnical inspections be carried out during construction to confirm the subsurface conditions across the site and foundation bearing capacities have been achieved.

# 2. SITE DESCRIPTION

## 2.1 Overall Site Description

The overall site description and its surrounding are presented in Table 1 below.

**Table 1. Overall Site Description and Site Surroundings**

| Information | Details |
|---|---|
| **Overall Site Location** | The site is located within a residential area along Letitia Street carriageway, approximately 250m south-east of Yarran Road thoroughfare. |
| **Site Address** | 105 Letitia Street Oatley NSW 2223 |
| **Calculated Site Area[1]** | 1,003m$^2$ |
| **Local Government Authority** | Georges River Council |
| **Site Description** | At the time of the investigation, a residential dwelling was present within the site, accompanied by associated concrete pavements and a detached garage/shed. The remaining site area was mainly covered in grass, vegetation and some mature trees scattered throughout.<br><br>Sandstone outcrops were present throughout the site, falling within the proposed development footprint. In addition, we note the presence of a cliff edge to the rear of the existing dwelling where access was not feasible during our investigation. |
| **Approximate Distances to Nearest Watercourses (i.e. rivers, lakes, creeks, etc.)** | • Oatley Bay – 330m east of the site. |
| **Site Surroundings** | The site is located within an area of residential use and is bounded by:<br>• Residential property at No. 103 Letitia Street to the north.<br>• Letitia Street carriageway to the east.<br>• Residential property at No. 107 Letitia Street to the south.<br>• Residential property at No. 17 Wyong Street to the west. |

[1][1]Site area is approximate and obtained from Mecone Mosaic (https://meconemosaic.au/).

## 2.2 Topography

The local and site topography generally falls towards the west to north-west. Levels within the site vary from approximately RL17m to RL28m AHD.

It should be noted that the site topography, levels and slopes are approximate and based off observations made during the geotechnical investigation and reference to NSW Six Maps (https://maps.six.nsw.gov.au/) and Mecone Mosaic (https://meconemosaic.au/). The actual topography in areas inaccessible during the site investigation, including areas under the existing infrastructures, along with the site and local topography and levels are expected to vary from those outlined in this report.

## 2.3 Regional Geology

Information obtained on the local regional subsurface conditions, referenced from the Department of Mineral Resources, Sydney 1:100,000 Geological Series Sheet 9130 First Edition, dated 1983, by the Geological Survey of New South Wales, indicates the site is located within a geological region generally underlain by Triassic Aged Hawkesbury Sandstone (Rh). The Hawkesbury Sandstone (Rh) generally comprises "medium to coarse-grained quartz sandstone, very minor shale and laminite lenses".

Furthermore, reference made to MinView by the State of New South Wales through Regional NSW 2021 specifies the site is positioned within a geological region underlain by Sandstone (Tuth).

A review of the regional maps by the NSW Government Environment and Heritage shows the site is set within the Hawkesbury (ha) landscape group. The Hawkesbury (ha) landscape group is normally recognised by rugged, rolling to very steep hills on Hawkesbury Sandstone. Local reliefs are generally 40m to 200m and slopes typically greater than 25% in gradient. Soils of the Hawkesbury group typically have extreme soil erosion hazards, steep slopes, rock outcrops, shallow, stony, highly permeable soils and low soil fertility. Soils of the Hawkesbury group are generally slightly (pH 6.0) to strongly (pH 4.0) acidic.

The site is also located near the Lucas Heights (lh) and Warriewood (wa) landscape groups.

The Lucas Heights (lh) landscape group is typically recognised by gently undulating crests and ridges on plateau surfaces of the Mittagong formation (alternating bands of shale and fine grained sandstone). Local reliefs are generally up to 30m and slopes typically less than 10% in gradient, with absent rock outcrops. Soils of the Lucas Heights group typically have stony soil, low fertility and low available water capacity. Soils of the Lucas Heights group are also generally slightly (pH 6.0) to strongly (pH 4.0) acidic.

The Warriewood (wa) landscape group is typically level to undulating swales, depressions and infilled lagoons on Quaternary sands. Local reliefs are typically less than 10m and slopes of less than 3% in gradient, with water tables at depths of generally less than 2m. Soils of the Warriewood group have localised flooding and run-on, high water tables and highly permeable soils. Soils of the Warriewood group are also generally neutral (pH 7.0) to strongly (pH 4.5) acidic.

The Hawkesbury (ha), Lucas Heights (lh) and Warriewood (wa) landscape group reports are attached in **Appendix G.**

## 3. SUBSURFACE CONDITIONS AND ASSESSMENT RESULTS

### 3.1 Stratigraphy

A summary of the surface and subsurface conditions within the investigation area of the proposed development are summarised below and in the detailed engineering borehole logs presented in **Appendix D**, and should be read in conjunction with the geotechnical explanatory notes detailed in **Appendix C**. Rock description has been based on Pells P.J.N, Mostyn G. & Walker B.F. Foundations on Sandstone and Shale in the Sydney Region, Australian Geomechanics Journal, December 1998, and also in accordance with AS 1726-2017.

It should be noted that estimated soil consistency/strength assessed by DCP testing in the site during the geotechnical investigation are approximate and variances should be expected throughout. Due to the variable ground conditions throughout the site, it is recommended that confirmation of the subsurface materials be carried out during construction by inspection.

It should also be noted that ground conditions within the site are expected to differ from those encountered and inferred in this report, since no geotechnical or geological exploration program, no matter how comprehensive, can reveal and identify all subsurface conditions underlying the site.

From the boreholes (BH1 and BH2) carried out within the site, the subsurface conditions at the test locations (where accessible and feasible) generally comprised:

- (Unit 1): Silty SAND fill material, gravel inclusions, from the existing ground level within the site and extending to depths of approximately 0.3m to 0.6m bgl, underlain by:
- (Unit 2): Natural Clayey SAND (BH2 only), fine to medium grained, medium plasticity clay, gravel inclusions, estimated medium dense to dense, and present to at least 0.5m bgl.

Based on the geotechnical investigation at the selected testing locations, along with our experience and observations made within the site and local region, it is inferred that bedrock of variable composition, strength and weathering is underlying majority of the site area at varying depths of approximately 0.4m to 1.0m bgl (expected to vary throughout).

In addition, variable composition and consistency/strength natural soils are also likely to be present throughout the site, predominately at locations and depths not assessed during the geotechnical investigation.

Sandstone outcrops were present throughout the site, falling within the proposed development footprint. Limited visual geotechnical assessment of the outcrops indicated highly weathered and medium estimated strength sandstone, which we anticipate to becoming moderately weathered and higher estimated strength with depth (subject to confirmation by a geotechnical engineer/engineering geologist).

In addition, we note the presence of a cliff edge to the rear of the existing dwelling where access was not feasible during our investigation. A detailed assessment must be undertaken by a geotechnical engineer/engineering geologist following clearing of vegetation within the proposed development area. This assessment should outline any remedial/stabilisation options which may be necessary (i.e. rock bolts, shotcreting, etc.) and include confirmation of the stability of the rockface (largely at any undercuts/overhangs), including supporting structures.

A summary of the inferred subsurface conditions encountered and inferred during DCP testing are summarised in Table 2 below, with the DCP testing results attached in **Appendix E**. Ground conditions depicted in Table 2 below are inferred based on DCP testing results and assumes a similar subsurface profile observed during the geotechnical investigation to be present over the remainder of the site and throughout the testing depths indicated.

It should be noted that DCP testing and higher blow counts encountered may be affected by factors such as gravels, ironstone bands, well consolidated soils and highly cemented sands, and other deleterious materials which may be present within the underlying soils, along with tree rootlets extending throughout the soils from trees and vegetation within the vicinity. These results should be read in conjunction with the boreholes and geotechnical confirmation should be made during construction by inspection, as site conditions may vary.

**Table 2. Summary of Inferred Subsurface Conditions From DCP Testing**

<table>
<tr><th></th><th>DCP ID</th><th>DCP1</th><th>DCP2</th><th>DCP3 (BH1)</th><th>DCP4 (BH2)</th></tr>
<tr><th>Unit</th><th>Unit Type</th><th colspan="4">Depth/Thickness of Unit (m bgl)</th></tr>
<tr><td>1</td><td>Inferred Fill[1]</td><td rowspan="2">0.0 – 0.58</td><td rowspan="2">0.0 – 0.36</td><td rowspan="2">0.0 – 0.97</td><td>0.0 – 0.3</td></tr>
<tr><td>2</td><td>Natural Soil[2]</td><td>0.3 – 0.55</td></tr>
<tr><td>3</td><td>Inferred Bedrock[3]</td><td>0.6</td><td>0.4</td><td>1.0</td><td>0.6</td></tr>
</table>

[1]Thickness of the fill layer is expected to vary from those indicated in Table 2.
[2]Estimated soil consistency/strength is based on DCP testing to the maximum practical refusal depths at the selected testing locations within the site. The potential for weak or softer layers throughout the unit should be considered.
[3]Inferred bedrock composition, continuity, strength and depth should be confirmed by a geotechnical engineering prior to construction by additional borehole drilling and rock strength testing, or during construction by inspection. Bedrock inferred to be present at or shortly below the practical DCP testing refusal depths at the selected testing locations within the site.

Notes:

- Inferred bedrock estimated strength is expected to vary across the site, due to the limited investigation carried out.
- Clay seams, defects and fractured/extremely weathered zones are expected to be present throughout the underlying inferred bedrock, predominately at depths and locations unobserved during the geotechnical investigation.
- Ground conditions are expected to vary across the site and should be confirmed by a geotechnical engineer, predominately in areas unobserved during the geotechnical investigation.

### 3.2 Groundwater

No groundwater was encountered or observed during augering of borehole BH1 and DCP3 testing to maximum depths of approximately 0.6m and 0.97m bgl, respectively. We note that no groundwater seepage was also observed through the sandstone outcrops within the site.

It is noted that the boreholes were immediately backfilled following completion of fieldwork which precluded longer term monitoring of groundwater levels.

Thus, based on observations made at the selected boreholes and testing locations and geological position of the site, groundwater which may be present within the site is *expected* to be in the form of seepage through voids within the underlying fill material and pore spaces between particles of unconsolidated natural soils, or through networks of fractures and solution openings in consolidated inferred bedrock underlying the site.

It should be noted that groundwater levels have the potential to elevate during daily or seasonal influences such as tidal fluctuations, heavy rainfall, damaged services, flooding, etc., and moisture content within soils may be influenced by events within the site and adjoining properties. Groundwater monitoring should be carried out during construction to assess any groundwater inflow throughout the excavation areas.

We note that no provision was made for longer term groundwater monitoring within the site. Where groundwater conditions vary from those outlined in this report, GCA should be contacted for further advice.

# 4. GEOTECHNICAL ASSESSMENT AND RECOMMENDATIONS

## 4.1 Dilapidation Survey

It is recommended that prior to demolition, excavation and construction, a detailed dilapidation survey be carried out on all adjacent buildings, structures, council assets, road reserves and infrastructures that fall within the "zone of influence" of the proposed excavations and vicinity of the proposed development. A dilapidation survey will record the condition of existing defects prior to any works being carried out within the site. Preparation of a dilapidation report should constitute as a "Hold Point".

## 4.2 General Geotechnical Issues

The following aspects have been considered main geotechnical issues for the proposed development:

- Preliminary site lot classification.
- Excavation conditions.
- Stability of excavation and retention of adjoining properties and infrastructures.
- Foundations.

Based on results of our assessment, a summary of the geotechnical aspects above and recommendations for construction and designs are presented below.

## 4.3 Preliminary Site Lot Classification

Based on the geotechnical investigation and observations made at the selected testing locations within the site, fill and natural soils are expected to be underlain by inferred bedrock at varying depths throughout the site.

The governing site lot classification in accordance with AS 2870-2011 has been identified as "Class P" (Problematic Site) for the overall site, due to:

- The presence of existing infrastructures and trees adjoining the site, causing abnormal and changing moisture conditions.
- The presence of deep fill material in certain areas of the site, considered as "uncontrolled fill".

Based on the boreholes and DCP tests carried out within the site, AS 2870-2011 indicates the site may be classified as a "Class M" site for design and construction of the proposed development foundation system, founded below any soft/loose soils, topsoil, slopewash, fill or other deleterious material, being entirely on bedrock underlying the proposed development area (subject to confirmation).

The above classification is solely based on assessment of the subsurface conditions at the selected boreholes and testing locations/depths within the site and current architectural drawings, and confirmation should be carried out as outlined in this report. It should be noted that the classification given above is appropriate for the undeveloped lot at the time of this report and as such, AS 2870 recommends that the classification of a site should be reconsidered if the depth of subsequent cutting exceeds 0.5m or depth of subsequent filling exceeds 0.4m.

Foundation design and construction should be carried out as outlined in Section 4.7 below, with reference made to AS 2870-2011. Geotechnical inspections and confirmation of the actual depth of underlying fill material, natural soils and inferred bedrock should be made during construction by inspection.

GCA should be contacted where ground conditions vary from those outlined in this report at the boreholes and testing locations. Where the building foundations are not proposed to be constructed on bedrock underlying the site, GCA should also be contacted immediately and the building foundations be designed and constructed as a "Class P" site.

Footing designs should take into consideration the effect of recent removal and planting of trees, along with any future tree removal within the vicinity of the proposed development on soil moisture conditions. Sufficient time should be given for soil moisture to re-equilibrate following any removal or planting of trees within the proposed development area, or specific engineering assessment and design will be required on the foundation design.

Although trees and vegetation are considered to contribute to the stability of the site, we recommend that planting of trees around the development area (i.e. in close proximity to the proposed building foundations) be limited as they can also affect moisture changes within the soil and cause significant displacement/damage within the building foundations by extensive tree root system movement.

Based on the preliminary site lot classification outlined above, it is recommended that reference is made to the recommendations provided by CSIRO "Guide to Home Owners on Foundation Maintenance and Footing Performance", attached as **Appendix F**.

## 4.4 Excavation

Cut and fill is expected to be required for construction of the development. Locally deeper excavations for the building footings and service trenches are also anticipated to be required.

Based on this information and existing ground conditions as encountered during the geotechnical investigation, it is anticipated that excavations will extend predominately through fill material, natural soils and sandstone bedrock of variable composition, strength and weathering throughout majority of the proposed development area, as discussed in Section 3 above.

Therefore, consultation should be made with subcontractors to discuss the feasibility and capability of machinery for the proposed development for the existing site conditions.

### 4.4.1 Excavation Assessment

Excavation through softer soils and extremely low to low estimated strength bedrock should be feasible using conventional earth moving excavators, typically medium to large hydraulic excavators. Smaller sized excavators may encounter difficulty in high strength bands of soils and rocks which may be encountered. Where high strengths bands are encountered, rock breaking or ripping should be allowed for. Removal of the existing pavements and associated infrastructures within the site are also expected to require larger excavators and rock breaking and ripping.

Excavation of medium to higher estimated strength bedrock which is anticipated to be encountered during construction would necessitate higher capacity excavators, bulldozers or similar, for effective removal of the rock. This excavation will require the use of heavy ripping and rock breaking equipment or vibratory rock breaking equipment. Furthermore, excavation for the proposed building footings and service trenches may require the use of heavy ripping and rock breaking equipment or vibratory rock breaking equipment, with the possibility of rock saw cutting.

Should rock hammering be used for the excavation in the underlying bedrock, excavation should be carried out away from the adjoining structures, with vibrations transmitted being monitored to maintain vibrations within acceptable limits. Rock saw cutting should be carried out (where required) around the perimeter of excavations, prior to any rock breaking commencing.

All excavations should be carried out under supervision, with implementation of the following maximum temporary batter slopes (H:V)[1] and accompanied by surface protection against erosion (i.e. plastic sheets):

- (Unit 1) and (Unit 2): 2:1 for fill material and natural sandy soils.
- (Unit 3):
  - 0.75:1 for extremely low to very low estimated strength bedrock.
  - 0.5:1 for low estimated strength bedrock.

[1]Subject to inspection and confirmation by a geotechnical engineer and/or engineering geologist. Remedial options may be required (i.e. soil nailing, rock bolting, shotcreting, etc.).

The plastic sheets should be positioned and fastened to prevent any water infiltration onto or into the batter slopes. Other applicable methods may be adopted for temporary surface protection, and all surface protection should be placed following inspection of the temporary batters by a geotechnical engineer.

All batter slopes within the site should remain stable providing all surcharge and construction loads are kept out of the "zone of influence" (obtained by drawing a line 45º above horizontal from the base of the proposed excavations) plus an additional 1.0m. A geotechnical engineer and/or engineering geologist should inspect the batter slopes within the site.

It should be noted that steeper batter slopes may be considered for higher strength (i.e. low to medium estimated strength, or better) and intact bedrock underlying the site, subject to confirmation by a geotechnical engineer during construction by inspection, and by additional borehole drilling and rock strength testing. Consideration should be given to shotcreting and soil nailing where steeper batter slopes are to be used.

An appropriately designed retaining wall by a suitably qualified structural engineer should be implemented and constructed around excavation perimeters following any temporary batter slopes within the site. All retaining walls should be constructed on appropriate bedrock material underlying the site, and should take into consideration the lateral earth pressures induced by soil movement along the interface between soils and bedrock.

In areas where there is insufficient space between the proposed excavations and adjoining infrastructures, or where adjacent infrastructures are located within the "zone of influence" of the proposed development, consideration should be given to a suitable retention system suitable carefully assessed by a suitably qualified structural engineer for the subject site. In this case, GCA should be contacted for further advice.

Appropriate drainage should also be incorporated into the design of the proposed development and installed behind all retaining walls, and if required, beneath slabs. This should be carefully assessed, designed and detailed by the project stormwater engineer. Groundwater monitoring of seepage should be implemented during the excavation stage to confirm the capacity of the drainage system and groundwater entering the excavation area. This should be monitored by the project geotechnical engineer, in conjunction with the project stormwater engineer.

Demolition, excavation and construction activities (or the like) will generate both vibration and noise, predominately whilst being carried out within the underlying bedrock. Therefore, vibration control measures should be considered as part of the construction process, mainly where excavations are expected to be conducted within the underlying bedrock of higher estimated strength and fall within the "zone of influence" of adjoining infrastructures.

If considered, retaining walls can be designed using the recommended design parameters provided in Section 4.6. Bulk excavation and foundations (including pile installations) should be supervised, monitored and inspected by a geotechnical engineer, with all structural elements of the development by a structural engineer. Inspections should be considered as "Hold Points" to the project.

All excavation works should be carried out in accordance with the NSW WorkCover code of practice for excavation work. Should the proposed development change and excavation depths exceed those inferred in this report, GCA should be made aware.

### 4.5 Vibration Monitoring and Controls

Particular care will be required to ensure that adjacent buildings and infrastructures (i.e. road reserves, buildings, etc.), are not damaged during demolition, excavation and construction activities (or the like) due to excessive vibrations. Therefore, appropriate excavation and construction methods should be adopted which will limit ground vibrations to limits not exceeding the following maximum Peak Particle Velocity (PPV) for adjacent structures, as outlined in AS 2187.2-2006:

- Sensitive and/or historical structures – 2mm/sec.
- Residential and/or low rise structures – 5mm/sec.
- Unreinforced and/or brick structures – 10mm/sec.
- Reinforced and/or steel structures – 25mm/sec.
- Commercial and/or industrial buildings – 25mm/sec.

In order to reduce resonant frequencies, rock hammers should be used in short bursts and oriented away from the site boundaries and adjoining structures, and into the proposed excavation area.

Vibrations transmitted by the use of rock hammers are unacceptable and not recommended. To minimise vibration transmission to any adjoining infrastructures, and to ensure vibration limits remain within acceptable limits, rock saw cutting using a conventional excavator with a mounted rock saw (or similar) should be carried out as part of excavation prior to any rock breaking commencing.

Although rock hammering is unacceptable and not recommended, if necessary during excavation, it is recommended that hammering be carried out horizontally along pre-cut rock boulders or blocks provided by rock saw cutting, and should remain within limits acceptable. This should be monitored at all times during excavation.

The effectiveness of all the above-mentioned approaches must be confirmed by the results of vibration monitoring. The limits of 5mm/sec and 10mm/sec are expected to be achievable if rock breaker equipment or other excavations are restricted to the values indicated in Table 3 below.

**Table 3. Rock Breaking Equipment Recommendations**

| Distance From Adjoining Structures (m) | Maximum PPV 5mm/sec | | Maximum PPV 10mm/sec[1] | |
|---|---|---|---|---|
| | Equipment | Operating Limit (Maximum Capacity %) | Equipment | Operating Limit (Maximum Capacity %) |
| 1.5 to 2.5 | Jack Hammer Only (hand operated) | 100 | 300kg Rock Hammer | 50 |
| 2.5 to 5.0 | 300kg Rock Hammer | 50 | 300kg Rock Hammer | 100 |
| | | | 600kg Rock Hammer | 50 |
| 5.0 to 10.0 | 300kg Rock Hammer | 100 | 600kg Rock Hammer | 100 |
| | 600kg Rock Hammer | 50 | 900kg Rock Hammer | 50 |

[1]Vibration monitoring is recommended for the use of a maximum PPV of 10mm/sec.

Consideration should be given to a vibration monitoring plan to monitor construction activities and their effects on adjoining infrastructures, mainly where excavations are expected to be conducted within the underlying bedrock of higher estimated strength and fall within the "zone of influence" of adjoining infrastructures.

A vibration monitoring plan may be carried out attended or unattended. An unattended vibration monitoring must be fitted with alarms in the form of strobe lights, sirens or live alerts sent to the vibration monitoring supervisor, which are activated when the vibration limit is exceeded. If adopted/considered, consultation should be made with appropriate subcontractors/consultants for the installation of vibration monitoring instruments.

A geotechnical engineer should be contacted immediately if vibrations during construction or in adjacent structures exceed the values outlined above and work should immediately cease. Rock excavation methodology should also consider acceptable noise limits as per the "Interim Construction Noise Guideline" (NSW EPA). It is recommended a dilapidation report be carried out prior to any excavation or construction, as discussed in Section 4.1. This should be considered a "Hold Point".

### 4.6 Design Parameters (Earth Pressures)

Support system designed using the earth pressure approach may be based on the parameters given in Table 4 below for soils and rock horizons underlying the site. Table 4 also provides preliminary coefficients of lateral earth pressure for the soils and rock horizons encountered in the site. These are based on fully drained conditions and that the ground behind the retention walls is horizontal.

**Table 4. Preliminary Geotechnical Design Parameters**

| Material | Fill (Unit 1) | Natural Sandy Soils (Unit 2) | Inferred Bedrock[3, 5] (Unit 3) |
|---|---|---|---|
| | | | VL or better |
| Unit Weight ($kN/m^3$)[4] | 16 | 17 | 20 |
| Effective Cohesion c' (kPa) | 0 | 0 | 20 |
| Angle of Friction $\phi'$ (°) | 24 | 26 | 28 |
| Modulus of Elasticity $E_{sh}$ (MPa) | 3 | 10 (medium dense, or better) | 65 |
| Earth Pressure Coefficient At Rest Ko[1] | 0.59 | 0.56 | 0.53 |
| Earth Pressure Coefficient Active Ka[2] | 0.42 | 0.39 | 0.36 |
| Earth Pressure Coefficient Passive Kp[2] | 2.37 | 2.56 | 2.77 |
| Poisson Ratio $v$ | 0.4 | 0.35 | 0.3 |

[1]Earth pressure coefficient at rest (Ko) can be calculated using Jacky's equation.
[2]Earth pressure coefficient of active (Ka) and passive (Kp) can be calculated using Rankine's or Coulomb's equation.
[3]The values for rock assume no defects of adverse dipping is present in the bedrock and sandstone bedrock underlies the site. All excavation rock faces should be inspected on a regular basis by an experienced engineering geologist or geotechnical engineer.
[4]Above groundwater levels.
[5]Subject to confirmation by a geotechnical engineer by additional borehole drilling and rock strength testing, or during construction by inspection. Conforming to at least Class V Sandstone (or better).

Notes:

- VL = Very Low estimated strength.
- VL bedrock should conform to at least Class V Sandstone in accordance with Pells P.J.N, Mostyn G. & Walker B.F.

### 4.7 Foundations

Following excavation depths to the FFLs of the proposed development and based on the boreholes and DCP tests carried out within the site, we expect varying ground conditions comprising predominately fill material, natural soils and bedrock of variable estimated strength and weathering to be exposed at bulk excavation level (depending on the actual amount of excavation required).

Variable composition and consistency/strength natural soils and fill material are likely to result in total and differential settlement under working load, and not adequately support shallow foundations for the proposed development within the site. Removal of the fill material within the proposed development area should be carried out prior to construction of the proposed building foundation system.

It is noted that ground conditions within the site is expected to differ from those encountered and inferred in this report, since no geotechnical or geological exploration program, no matter how comprehensive, can reveal and identify all subsurface conditions underlying the site. It is therefore recommended that confirmation of the underlying ground conditions be confirmed by a geotechnical engineer during construction by inspection.

#### 4.7.1 Geotechnical Assessment

Based on the proposed development and assessment of the subsurface conditions, a suitable foundation system comprising combination of shallow foundations typically comprising pad and/or strip footings, and a piled foundation system are likely to be adopted for the proposed development, and should be constructed and sufficiently embedded into consistent and competent strength bedrock underlying the site.

All piles should be sufficiently embedded into consistent and competent strength bedrock in areas where bedrock is not exposed at bulk excavation level and should fully support the building/infrastructures. Shallow foundations should only be considered in areas where bedrock is expected to be exposed at or shortly below bulk excavation level and should include local slab thickening to support internal walls and columns for shallow foundations, with consideration given to settlement reducing piles. Foundations should not be founded on any soft/weak bands (i.e. clay seams and/or extremely weathered/fractured zones) underlying the site.

Installation of piles and foundation construction should be complemented by inspections carried out by a geotechnical engineer during construction, to confirm ground conditions are consistent throughout and allowable bearing capacities have been achieved. The actual depth and embedment of the piles should be assessed by the project structural engineer, with all structural elements of the proposed development also inspected and approved by a suitably qualified structural engineer. GCA should be present to witness the initial drilling stage.

Given the potential for variable ground conditions and soil reactivity across the site, it is recommended that all foundations are constructed on consistent and competent bedrock throughout, in order to provide uniform support and reduce the potential for differential settlements. This could be attained by strip or pad footings where the suitable bearing capacity is achieved or exposed at bulk excavation level, and pile foundations elsewhere. Reference should be made to the estimated levels of the subsurface conditions outlined in this report, and compared to the final bulk excavation levels across the site.

Installation of piles may be required where the axial and working loads transmitted through the building walls and columns exceed the bearing pressure of the bedrock exposed at the proposed developments FFLs. These should be socketed into consistent and appropriate bedrock underlying the site. For cases where resistance against lateral loading induced by earthquakes or winds, and to achieve higher bearing capacities, piles may also be required.

Piles sufficiently socketed into higher strength bedrock may achieve greater allowable bearing capacities, subject to confirmation by a geotechnical engineer during construction. Where higher estimated strength bedrock is present within the site, or where ground conditions vary from those encountered during the geotechnical investigation, GCA should be contacted for further advice.

Table 5 provides preliminary recommended geotechnical design parameters.

**Table 5. Preliminary Recommended Geotechnical Design Parameters**

| Unit Type/Material | | Maximum Allowable (Serviceability) Values (kPa) | | |
|---|---|---|---|---|
| | | End Bearing Pressure[1] | Shaft Adhesion (Compression) | Shaft Adhesion (Tension) |
| Fill (Unit 1) | | N/A | N/A | N/A |
| Natural Soils (Unit 2) | | N/A | N/A | N/A |
| Inferred Bedrock (Unit 3)[2] | VL | 700 | 50 | 25 |
| | L or better[3] | 1,000 | 100 | 50 |

[1]Minimum embedment of 0.4m for shallow foundations and 0.5m for deep foundations. Assumes the presence of sandstone bedrock underlying the entire site area.
[2]The composition, class, depth and estimated strength of the underlying bedrock material should be confirmed prior to construction by further borehole drilling and rock strength testing, or during construction by inspection.
[3]Conforming to at least Class IV Sandstone (or better).
Notes:

- VL = Very Low estimated strength, L = Low estimated strength.
- VL and L bedrock should conform to at least Class V and Class IV Sandstone, respectively, in accordance with Pells P.J.N, Mostyn G. & Walker B.F.
- Higher allowable bearing capacities may be attained for higher estimated strength rock assessed and confirmed by a geotechnical engineer.
- All shaft adhesion parameters are based on adequately clean and rough sockets of category "R2", or better.
- N/A = Not Applicable. Not recommended for the proposed development.
- It is recommended that geotechnical inspections on the foundations are completed by a geotechnical engineer to determine the material and confirm the required bearing capacity has been achieved.

A reduced bearing capacity of 500kPa should be adopted for any structures constructed on or near the sandstone cliff edge to the rear of the existing dwelling, which we anticipate portions of the proposed development to fall within.

Footings designed using ultimate values and limit state design will need to consider serviceability which usually governs designs in these cases. For pile designs, a basic geotechnical reduction factor ($\Phi_{gb}$) should be calculated by the structural engineer from AS 2159-2009, taking into consideration the design, installation method and associated risk rating. Furthermore. the design structural engineer should check both 'piston' pull-out and 'cone' pull-out mechanics in accordance with AS 4678-2002.

### 4.7.2 Geotechnical Comments

Bearing capacity and settlement behaviour varies according to foundation depth, shape and dimensions. Consultation should be made with specialist subcontractors to discuss the feasibility of piles for the existing site conditions. It should be noted that higher bearing capacities may be justified for the proposed foundations subject to confirmation by inspection during construction, and by additional borehole drilling and rock strength testing.

Specific geotechnical advice should be obtained for footing deigns and end bearing capacities, and design of the foundation system (shallow and pile foundations) should be carried out in accordance with AS 2870-2011 and AS 2159-2009.

Foundations located within the "zone of influence" of any services or sensitive structures should be supported by a piled foundation. The depths of the piles should extend below the "zone of influence" and should ignore any shaft adhesion. Appropriate measures should be taken to ensure that any services or sensitive structures located within the "zone of influence" of the proposed development are not damaged during and following construction.

It is recommended that suitable drainage and the use of impermeable surfaces be implemented as a precaution as part of the design and construction of the proposed development in order to divert surface water away from the building, and help eliminate or minimise surface water infiltration to minimise moisture within the soils. Although trees and vegetation are considered to contribute to the stability of the site, we recommend that planting of trees around the development area (i.e. in close proximity to the proposed building foundations) be limited as they can also affect moisture changes within the soil and cause significant displacement/damage within the building foundations by extensive tree root system movement.

The design and construction of the foundations should take into consideration the potential of flooding. All foundation excavations should be free of any loose debris and wet soils, and if groundwater seepage or runoff is encountered dewatering should be carried out prior to pouring concrete in the foundations. Due to the possibility of groundwater being encountered and possible groundwater seepage during installation of bored piles within the site, it is recommended that consideration be given to other piling methods such as Continuous Flight Auger (CFA) piles.

Shaft adhesion may be applied to socketed piles adopted for foundations provided the socketed shaft lengths conform to appropriate classes of bedrock (subject to confirmation) in accordance with Pells et. al, and shaft sidewall cleanliness and roughness are to acceptable levels. Shaft adhesion should be ignored or reduced within socket lengths that are smeared or fail to satisfy cleanliness requirements (i.e. at least 80%). It is recommended that where piles penetrate expansive soils present within the site, which are susceptible to shrink and swell due to daily and seasonal moisture, shaft adhesion be ignored due to the potential of shrinkage cracking. Pile inspections should be complemented by downhole CCTV camera.

We recommend that geotechnical inspections of foundations be completed by an experienced geotechnical engineer to determine that the designed socket materials have been reached and the required bearing capacity has been achieved. The geotechnical engineer should also determine any variations between the boreholes carried out and inspected locations. Inspections should be carried out in dewatered foundations for a more accurate examination, and inspections should be carried out under satisfactory WHS requirements. Geotechnical inspections for verification capacities of the foundations should constitute as a "Hold Point".

### 4.8 Filling

Where filling is required, the following recommended compaction targets should be considered:

- Place horizontal loose layers not more than 150mm thickness over the prepared subgrade.
- Compact to a minimum dry density ratio not less than 98% of the maximum dry density for the building platforms.
- The moisture content during compaction should be maintained at ±2% of the Optimal Moisture Content (OMC).
- The upper 150mm of the subgrade should be compacted to a dry density ratio not less than 100% of the maximum dry density.

Any soils which are imported onto the site for the purpose of filling and compaction of the excavated areas should be free of deleterious materials and contamination. The imported soils should also include appropriate validation documentation in accordance with current regulatory authority requirements. The design and construction of earthworks should be carried out in accordance with AS 3798-2007 and AS 1289. Inspections of the prepared subgrade should be carried out by a geotechnical engineer, and should include proof rolling as a minimum. These inspections should be established as "Hold Points".

### 4.9 Subgrade Preparation

The following are general recommendations on subgrade preparation for earthworks, slab on ground constructions and pavements:

- Remove existing fill and topsoil, including all materials which are unsuitable from the site.
- Excavate natural soils and rock.
    - Excavated rock may be considered for engineered fill and rock for subgrade material underlying pavements, providing appropriate geotechnical inspections and laboratory testing of the material is undertaken to confirm its suitability.
- Any natural soils (predominately clayey soils) exposed at the bulk excavation level should be treated and have a moisture condition of 2% OMC. This should be followed by proof rolling and compaction of the upper 150mm layer.
    - Any soft or loose areas should be removed and replaced with engineered or approved fill material.
- Any rock exposed at the bulk excavation level should be clear of any deleterious materials (and free of loose or softened materials). As a guideline, remove an additional 150mm from the bulk excavation level.
- Ensure the foundations and excavated areas are free of water prior to concrete pouring.
- Areas which show visible heaving under compaction or proof rolling should be excavated at least 300mm and replaced with engineered or approved fill, and compacted to a minimum dry density ratio not less than 98% of the maximum dry density.

## 5. ADDITIONAL GEOTECHNICAL RECOMMENDATIONS

Furthermore, following completion of the geotechnical investigation and report, GCA recommends the following additional work to be carried out:

- Dilapidation survey report on adjacent properties and infrastructures.
- Monitoring and supervision of all excavations within the site, including appropriate inspections and approvals on any batter slopes adopted.
- Detailed assessment of the rockface by a geotechnical engineer/engineering geologist following clearing of vegetation within the proposed development area.
- The composition, class, depth and estimated strength of the underlying inferred bedrock material should be confirmed prior to construction by further borehole drilling and rock strength testing, or during construction by inspection, predominately in areas and at depths not assessed during the geotechnical investigation.
- Geotechnical inspections of exposed materials at bulk excavation level.
- Geotechnical inspections of foundations (shallow and pile foundations) to confirm the preliminary bearing capacities have been achieved.
- Monitoring of any groundwater inflows into the excavation areas within the site.
- Classification of all excavated material transported from the site.
- A meeting to be carried out to discuss any geotechnical issues and inspection requirements.
- Final architectural and structural design drawings are provided to GCA for further assessment.

## 6. LIMITATIONS

Geotechnical Consultants Australia Pty Ltd (GCA) has based its geotechnical assessment on available information obtained prior and during the site inspection/investigation. The geotechnical assessment and recommendations provided in this report, along with the surface, subsurface and geotechnical conditions are limited to the inspection and test areas during the site inspection/investigation, and then only to the depths investigated at the time the work was carried out. Subsurface conditions can change abruptly, and may occur after GCA's field testing has been completed.

It is recommended that if for any reason, the site surface, subsurface and geotechnical conditions (including groundwater conditions) encountered during the site inspection/investigation vary substantially during construction, and from GCA's recommendations and conclusions, GCA should be contacted immediately for further testing and advice. This may be carried out as necessary, and a review of recommendations and conclusions may be provided at additional fees. GCA's advice and accuracy may be limited by undetected variations in ground conditions between sampling locations.

GCA does not accept any liability for any varying site conditions which have not been observed, and were out of the inspection or test areas, or accessible during the time of the investigation. This report and any associated information and documentations have been prepared solely for **Infinity Eight Holdings Pty Ltd,** and any misinterpretations or reliances by third parties of this report shall be at their own risk. Any legal or other liabilities resulting from the use of this report by other parties can not be religated to GCA.

This report should be read in full, including all conclusions and recommendations. Consultation should be made to GCA for any misundertandings or misinterpretations of this report.

For and behalf of

**Geotechnical Consultants Australia Pty Ltd (GCA)**

GeorgeA

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## 7. REFERENCES

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MinView. State of New South Wales through Regional NSW 2021.

NSW Planning Portal.

NSW Six Maps.

Mecone Mosaic.

eSPADE NSW Environment & Heritage.

# APPENDIX A

GCA
Geotechnical Consultants Australia

## Important Information About Your

# Geotechnical Report

This geotechnical report has been prepared based on the scopes outlined in the project proposal. The works carried out by Geotechnical Consultants Australia Pty Ltd (GCA), have limitations during the site investigation, and may be affected by a number of factors. Please read the geotechnical invesitgation report in conjunction with this "Important Information About Your Geotechnical Report".

**Geotechnical Services Are Performed for Specicif Projects, Clients and Purposes.**
Due to the fact that each geotechnical investigation is unique and varies from sites, each geotechnical report is unique, and is prepared soley for the client. A geotechnical report may satisfy the needs of structural engineer, where is will not for a civil engineer or construction contractor. No one except the client should rely on the geotechnical report without first conferring with the specific geotechnical consultant who prepared the report. The report is prepared for the contemplated project or original purpose of the investigation. No one should apply this report to any other or similar project.

**Reading The Full Report.**
Do not read selected elements of the report or tables/figures only. Serious problems have occurred because those relying on the specially prepared geotechnical invesitgation report did not read it all in full context.

**The Geotechnical Report is Based on a Unique Set of Project And Specific Factors.**
When preparing a geotechnical report, the geotechnical engineering consultant considers a number of unique factors for the specific project. These typially include:

- Clients objectives, goals and risk management preferences;
- The general proposed development or nature of the structure involved (size, location, etc.); and
- Future planned or existing site improvements (parking lots, roads, underground services, etc.);

Care should be taken into identifying the reason of the geotechnical report, where you should not rely on a geotechnical engineering report that was:

- Not prepared for your project;
- Not prepared for the specific site;
- Not prepared for you;
- Does not take into consideration any important changes made to the project; or
- Was carried out prior to any new infrastructure on your subject site.

Typical changes that can affect the reliabiliy if an existing geotechical investigation report include those that affect:

- The function of the proposed structure, where it may change from one basement level to two basement levels, or from a light structure to a heavy loaded structure;
- Location, size, elevation or configuration of the proposed development;
- Changes in the structural design occur; or
- The owner of the proposed development/project has changed.

The geotecnical engineer of the project should always be notified of any changes – even minor – and be asked to evaluate if this has any impact. GCA does not accept responsibility or liability for problems that occur because its report did not consider developments which it was not informed of.

**Subsurface Conditions Can Change**
This report is based on conditions that existed at the time of the investigation, at the locations of the subsurface tests (i.e. boreholes) carried out during the site investigation. Subfurface conditions can be affected and modified by a number of factores including, but not limited to, the passage of time, man-made influences such as construction on or adjacent to the site, by natural forces such as floods, groundwater fluctuations or earthquakes. GCA should be contacted prior to submitting its report to determine if any further testing may be required. A minor amount of additional testing may prevent any major problems.

**Geotechnical Findings Are Professional Opinions**
Results of subsurface conditions are limited only to the points where the subsurface tests were carried out, or where samples were collected. The field and laboratory data is analysed and reviewed by a geotechnical engineer, who then applys their professional experience and recommendations about the site's subsurface conditions. Despite investigation, the actual subsurface conditions may differ – in some cases significantly – from the results presented in the geotechnical investigation report, since no subsurface exploration program, no matter how comprehensive, can reveal all subsurface anomalies and details.

Therefore, the recommendations in this report can only be used as preliminary. Retaining GCA as your geotechnical consultants on your project to provide construction observations is the most effective method of managing the risks associated with unanticipated subsurface conditions.

**Geotechnical Report's Recommendations Are Not Final**
Because geotechnical engineers provide recommendations based on experience and judgement, you should not overrely on the recommendations provided – they are not final. Only by observing the actual subsurface conditions revealed during construction may a geotechnical engineer finalise their recommendations. GCA does not assume responsibility or liability for the report's recommendations if no additional observations or testing is carried out.

**Geotechnical Report's Are Subject to Misinterpretations**
The project geotechnical engineer should consult with appropriate members of the design team following submission of the report. You should review your design teams plans and drawings, in conjunction with the geotechnical report to ensure they have all be incorporated. Due to many issues arising from misinterpretation of geotechnical reports between design teams and building contractors, GCA should participate in pre-construction meetings, and provide adequate construction observations.

**Engineering Borehole Logs And Data Should Not be Redrawn**
Geotechnical engineers prepare final borehole and testing logs, figure, etc. based on results and interpretation of field logs and laboratory data following the site investigation. The logs, figure, etc. provided in the geotechnical report should never be redrawn or altered for inclusion in any other documents from this report, includined architectural or other design drawings.

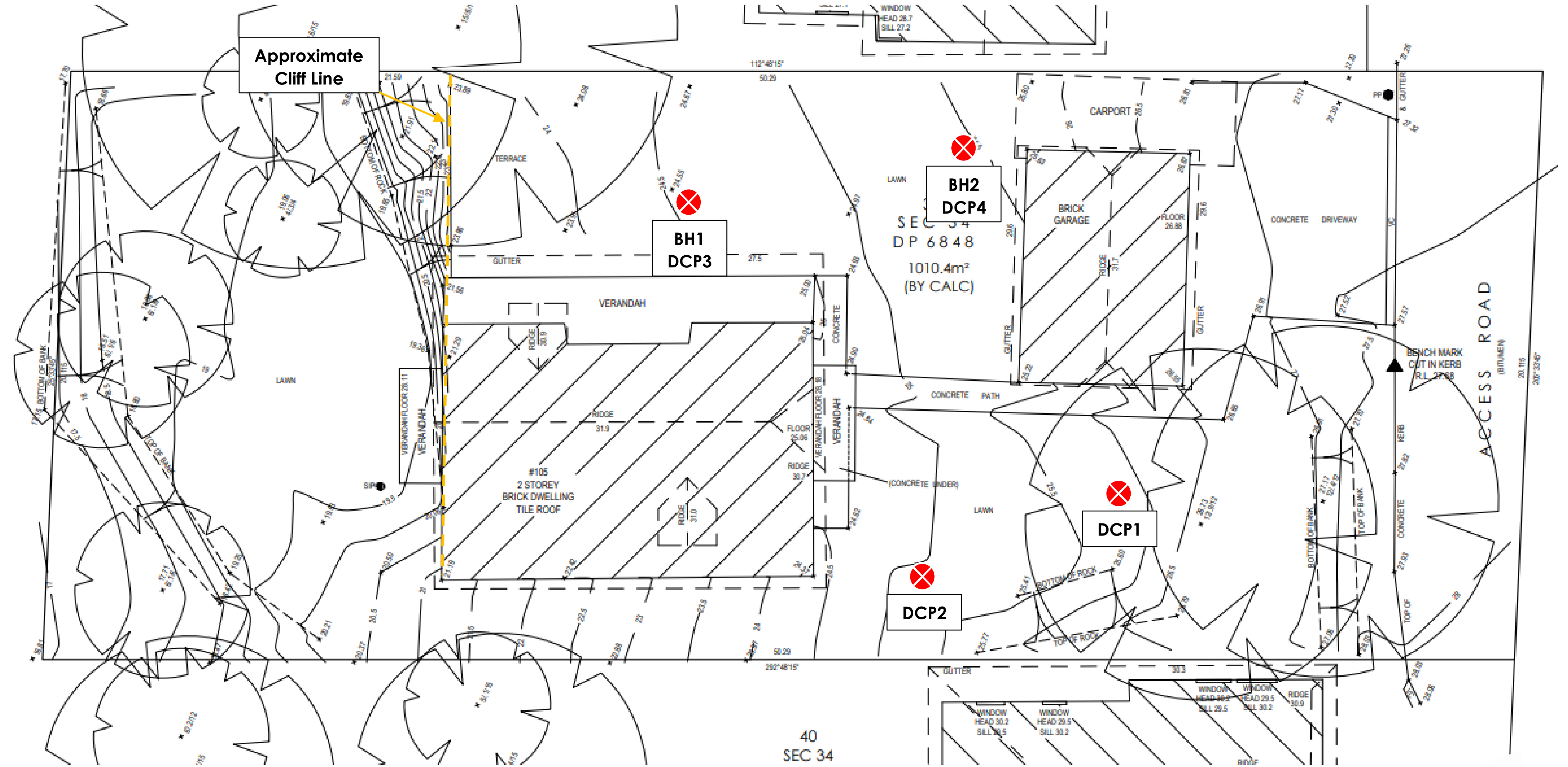
**Providing The Full Geotechnical Report For Guidance**
The project design teams, subcontactors and building contractors should have a copy of the full geotechnical investigation report to help prevent any costly issues. This should be prefaced with a clearly written letter of transmittal. The letter should clearly advise the aforementioned that the report was prepared for proposed development/project requirements, and the report accuracy is limited. The letter should also encourage them to confer with GCA, and/or carry out further testing as may be required. Providing the report to your project team will help share the financial responsibilities stemming from any unanticipated issues or conditions in the site.

**Understanding Limitation Provisions**
As some clients, contractors and design professionals do not recognise geotechnical engineering is much broader and less exact than other engineering disciplines, this creates unrealistic expectations that lead to claims, disputs and other disappointments. As part of the geotechnical report, (in most cases) a 'limitations' explanatory provision is included, outlining the geotechnical engineers' limitations for your project – with the geotechnical engineers responsibilites to help other reduce their own. This should be read closely as part of your report.

**Other Limitations**
GCA will not be liable to revise or update the report to take into account any events or circumstances (seen or unforeseen), or any fact occurring or becoming apparent after the date of the report. This report is the subject of copyright and shall not be reproduced either totally or in part without the express permission of GCA. The report should not be used if there have been changes to the project, without first consulting with GCA to assess if the report's recommendations are still valid. GCA does not accept any responsibility for problems that occur due to project changes which have not been consulted.

# APPENDIX B

Legend: Approximate Borehole/DCP Testing Location




| GCA Geotechnical Consultants Australia | Figure 1 Site Plan | Geotechnical Investigation | Drawn: NW/JS |
|---|---|---|---|
| | | Infinity Eight Holdings Pty Ltd | Date: 04/07/2023 |
| | Job No.: G23267-1 | 105 Letitia Street Oatley NSW 2223 | Scale: NTS |

Image source: Site survey plan prepared by PK Surveys, titled "Detail and Level Survey of 105 Letitia Street, Oatley Lot 39 of Sec 34 In DP 6848", referenced job No. 61441 and dated 9th September 2021.

# APPENDIX C

# Explanation of Notes, Abbreviations and Terms Used on Borehole and Test Pit Reports

## DRILLING/EXCAVATION METHOD

| Method | Description |
|---|---|
| AS | Auger Screwing |
| BH | Backhoe |
| CT | Cable Tool Rig |
| EE | Existing Excavation/Cutting |
| EX | Excavator |
| HA | Hand Auger |
| HQ | Diamond Core – 63mm |
| JET | Jetting |
| NMLC | Diamond Core – 52mm |
| NQ | Diamond Core – 47mm |
| PT | Push Tube |
| RAB | Rotary Air Blast |
| RB | Rotary Blade |
| RT | Rotary Tricone Bit |
| TC | Auger TC Bit |
| V | Auger V Bit |
| WB | Washbore |
| DT | Diatube |
| CC | Concrete Coring |

## PENETRATIION/EXCAVATION RESISTANCE

These assessments are subjective and dependant on many factors including the equipment weight, power, condition of the drilling tools or excavation, and the experience of the operator.

L **Low Resistance.** Rapid penetration possible with little effort from the equipment used.

M **Medium Resistance.** Excavation possible at an acceptable rate with moderate effort required from the equipment used.

H **High Resistance.** Further penetration is possible at a slow rate and required significant effort from the equipment.

R **Refusal or Practical Refusal.** No further progress possible within the risk of damage or excessive wear to the equipment used.

## WATER

▽ Water level at date shown

◁ Partial water loss

▷ Water inflow

◀ Complete water loss

***Groundwater not observed:*** The observation of groundwater, whether present or not, was not possible due to drilling water, surface seepage or cave in of the borehole/test pit.

***Groundwater not encountered:*** No free-flowing (springs or seepage) was intercepted, although the soil may be moist due to capillary water. Water may be observed in low permeable soils if the test pits/boreholes had been left open for at least 12-24 hours.

## MOISTURE CONDITION (AS 1726-2017)

Dry - Cohesive soils are friable or powdery
Cohesionless soil grains are free-running

Moist - Soil feels cool, darkened in colour
Cohesive soils can be moulded
Cohesionless soil grains tend to adhere

Wet - Cohesive soils usually weakened
Free water forms on hands when handling

For cohesive soils the following codes may also be used:

| | |
|---|---|
| MC>PL | Moisture Content greater than the Plastic Limit. |
| MC~PL | Moisture Content near the Plastic Limit. |
| MC<PL | Moisture Content less than the Plastic Limit. |

## SAMPLING AND TESTING

| Sample | Description |
|---|---|
| B | Bulk Disturbed Sample |
| DS | Disturbed Sample |
| Jar | Jar Sample |
| SPT* | Standard Penetration Test |
| U50 | Undisturbed Sample – 50mm |
| U75 | Undisturbed Sample – 75mm |

*SPT (4, 7, 11 N=18). 4, 7, 11 = Blows per 150mm. N= Blows per 300mm penetration following 150mm sealing.
SPT (30/80mm). Where practical refusal occurs, the blows and penetration for that interval is recorded.

## ROCK QUALITY

The fracture spacing is shown where applicable and the Rock Quality Designation (RQD) or Total Core Recovery (TCR) is given where:

$$TCR\ (\%) = \frac{\text{length of core recovered}}{\text{length of core run}}$$

$$RQD\ (\%) = \frac{\text{sum of axial lengths of core > 100mm long}}{\text{length of core run}}$$

## ROCK STRENGTH TEST RESULTS

● Diametral Point Load Index test

■ Axial Point Load Index test

## SOIL ORIGINS

It is often difficult to accurately determine the origin of a soil. Soils can generally be classified as:

- **Residual soils**: derived from in-situ weathering of the underlying rock (see "rock material weathering" below).
- **Transported soils**: formed somewhere else and transported by nature to the site.
- **Filling**: moved/placed by man.

Transported soils may be further subdivided into:

- **Alluvium/alluvial**: river deposits.
- **Lacustrine**: lake deposits.
- **Aeolian**: wind deposits.
- **Littoral**: beach deposits.
- **Estuarine**: tidal river deposits.
- **Talus**: scree or coarse colluvium.
- **Slopewash or colluvium/colluvial**: transported downslope by gravity assisted by water. Often includes angular rock fragments and boulders.

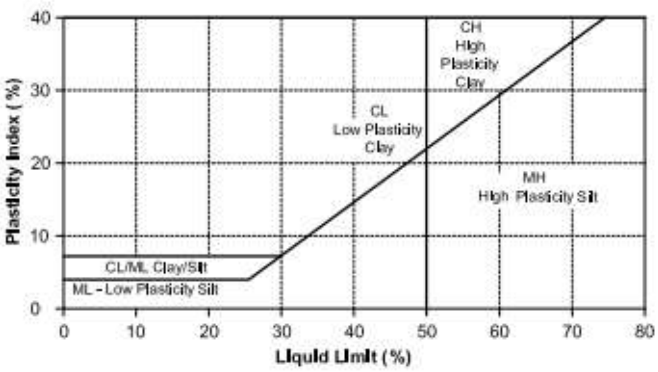
# Method and Terms for Soil and Rock Descriptions Used on Borehole and Test Pit Reports

Soil and Rock is classified and described in reports of boreholes and test pits using the preferred method given in AS 1726-2017, Appendix A. The material properties are assessed in the field by visual/tactile methods. The appropriate symbols in the Unified Soil Classification are selected on the result of visual examination, field tests and available laboratory tests, such as, sieve analysis, liquid limit and plasticity index.

**COHESIONLESS SOILS PARTICLE SIZE DESCRIPTIVE TERMS**

| Name | Subdivision | Size |
|---|---|---|
| Boulders | | >200mm |
| Cobbles | | 63mm to 200mm |
| Gravel | coarse | 20mm to 63mm |
| | medium | 6mm to 20mm |
| | fine | 2.36mm to 6mm |
| Sand | coarse | 600µm to 2.36mm |
| | medium | 200µm to 600µm |
| | fine | 75µm to 200µm |

**PLASTICITY PROPERTIES**




**COHESIVE SOILS – CONSISTENCY (AS 1726-2017)**

| Strength | Symbol | Undrained Shear Strength, $C_u$ (kPa) |
|---|---|---|
| Very Soft | VS | < 12 |
| Soft | S | 12 to 25 |
| Firm | F | 25 to 50 |
| Stiff | St | 50 to 100 |
| Very Stiff | VSt | 100 to 200 |
| Hard | H | > 200 |
| Friable | Fr | Easily crumbled or broken into small pieces by hand |

**PLASTICITY**

| Description of Plasticity | LL (%) |
|---|---|
| Low | <35 |
| Medium | 35 to 50 |
| High | >50 |

**COHESIONLESS SOILS - RELATIVE DENSITY**

| Term | Symbol | Density Index | N Value (blows/0.3 m) |
|---|---|---|---|
| Very Loose | VL | 0 to 15 | 0 to 4 |
| Loose | L | 15 to 35 | 4 to 10 |
| Medium Dense | MD | 35 to 65 | 10 to 30 |
| Dense | D | 65 to 85 | 30 to 50 |
| Very Dense | VD | >85 | >50 |

**UNIFIED SOIL CLASSIFICATION**

| USC Symbol | Description |
|---|---|
| GW | Well graded gravel |
| GP | Poorly graded gravel |
| GM | Silty gravel |
| GC | Clayey gravel |
| SW | Well graded sand |
| SP | Poorly graded sand |
| SM | Silty sand |
| SC | Clayey sand |
| ML | Silt of low plasticity |
| CL | Clay of low plasticity |
| OL | Organic soil of low plasticity |
| MH | Silt of high plasticity |
| CH | Clay of high plasticity |
| OH | Organic soil of high plasticity |
| Pt | Peaty Soil |

**ROCK MATERIAL WEATHERING**

| Symbol | Term | Definition |
|---|---|---|
| RS | Residual Soil | Soil definition on extremely weathered rock; the mass structure and substance are no longer evident; there is a large change in volume but the soil has not been significantly transported |
| EW | Extremely Weathered | Rock is weathered to such an extent that it has 'soil' properties, i.e. It either disintegrates or can be remoulded in water |
| HW } *DW* | Highly Weathered<br>*Distinctly Weathered (as per AS 1726)* | The rock substance is affected by weathering to the extent that limonite staining or bleaching affects the whole rock substance and other signs of chemical or physical decomposition are evident. Porosity and strength is usually decreased compared to the fresh rock. The colour and strength of the fresh rock is no longer recognisable. |
| MW | Moderately Weathered | The whole of the rock substance is discoloured, usually by iron staining or bleaching, to the extent that the colour of the fresh rock is no longer recognisable |
| SW | Slightly Weathered | Rock is slightly discoloured but shows little or no change of strength from fresh rock |
| FR | Fresh | Rock shows no sign of decomposition or staining |

**ROCK STRENGTH (AS 1726-2017 and ISRM)**

| Term | Symbol | Point Load Index $Is_{(50)}$ (MPa) |
|---|---|---|
| Extremely Low | EL | <0.03 |
| Very Low | VL | 0.03 to 0.1 |
| Low | L | 0.1 to 0.3 |
| Medium | M | 0.3 to 1 |
| High | H | 1 to 3 |
| Very High | VH | 3 to 10 |
| Extremely High | EH | >10 |

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**ABREVIATIONS FOR DEFECT TYPES AND DECRIPTIONS**

| Term | Defect Spacing | Bedding |
|---|---|---|
| Extremely closely spaced | <6mm | Thinly Laminated |
| | 6mm to 20mm | Laminated |
| Very closely spaced | 20mm to 60mm | Very Thin |
| Closely spaced | 0.06m to 0.2m | Thin |
| Moderately widely spaced | 0.2m to 0.6m | Medium |
| Widely spaced | 0.6m to 2m | Thick |
| Very widely spaced | >2m | Very Thick |

| Type | Definition |
|---|---|
| B | Bedding |
| J | Joint |
| HJ | Horizontal to Sub-Horizontal Joint |
| VJ | Vertical to Sub-Vertical Joint |
| F | Fault |
| Cle | Cleavage |
| SZ | Shear Zone |
| SM | Shear Seam |
| FZ | Fractured Zone |
| CZ | Crushed Zone |
| CS | Crushed Seam |
| MB | Mechanical Break |
| HB | Handling Break |

| Planarity | Roughness |
|---|---|
| P – Planar | C – Clean |
| Ir – Irregular | Cl – Clay |
| St – Stepped | VR – Very Rough |
| U – Undulating | R – Rough |
| | S – Smooth |
| | Sl – Slickensides |
| | Po – Polished |
| | Fe – Iron |

| Coating or Infill | Description |
|---|---|
| Clean (C) | No visible coating or infilling |
| Stain | No visible coating or infilling but surfaces are discoloured by mineral staining |
| Veneer | A visible coating or infilling of soil or mineral substance but usually unable to be measured (<1mm). If discontinuous over the plane, patchy veneer |
| Coating | A visible coating or infilling of soil or mineral substance, >1mm thick. Describe composition and thickness |
| Iron (Fe) | Iron Staining or Infill. |

# APPENDIX D

Geotechnical Consultants Australia Pty Ltd
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(02) 9788 2829

# BOREHOLE NUMBER BH1



**CLIENT** Infinity Eight Holdings Pty Ltd
**PROJECT NAME** Geotechnical Investigation
**PROJECT NUMBER** G23267-1
**PROJECT LOCATION** 105 Letitia Street Oatley NSW 2223

**DATE STARTED** 3/7/23 **COMPLETED** 3/7/23 **R.L. SURFACE** **DATUM**
**DRILLING CONTRACTOR** Geotechnical Consultants Australia Pty Ltd **SLOPE** 90° **BEARING** ---
**EQUIPMENT** Hand Operated Equipment **HOLE LOCATION** Refer To Site Plan (Figure 1) For Test Locations
**HOLE SIZE** 100mm Diameter **LOGGED BY** NW/JS **CHECKED BY** JN
**NOTES** RL To The Top Of The Borehole & Depths Of The Subsurface Conditions Are Approximate

| Method | Water | RL (m) | Depth (m) | Graphic Log | Classification Symbol | Material Description | Samples Tests Remarks | Additional Observations |
|---|---|---|---|---|---|---|---|---|
| HA | Not Encountered During Drilling | | 0.5 | | | Silty SAND, fine to medium grained, brown to dark brown, with fine to medium gravel, grass rootlets, moist. | | FILL |
| | | | 1.0<br>1.5<br>2.0 | | | Borehole BH1 terminated at 0.6m | | Practical hand auger refusal at 0.6m bgl. |

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# BOREHOLE NUMBER BH2



**CLIENT** Infinity Eight Holdings Pty Ltd
**PROJECT NAME** Geotechnical Investigation
**PROJECT NUMBER** G23267-1
**PROJECT LOCATION** 105 Letitia Street Oatley NSW 2223

**DATE STARTED** 3/7/23 **COMPLETED** 3/7/23 **R.L. SURFACE** **DATUM**
**DRILLING CONTRACTOR** Geotechnical Consultants Australia Pty Ltd **SLOPE** 90° **BEARING** ---
**EQUIPMENT** Hand Operated Equipment **HOLE LOCATION** Refer To Site Plan (Figure 1) For Test Locations
**HOLE SIZE** 100mm Diameter **LOGGED BY** NW/JS **CHECKED BY** JN
**NOTES** RL To The Top Of The Borehole & Depths Of The Subsurface Conditions Are Approximate

| Method | Water | RL (m) | Depth (m) | Graphic Log | Classification Symbol | Material Description | Samples Tests Remarks | Additional Observations |
|---|---|---|---|---|---|---|---|---|
| HA | Not Encountered During Augering | | | | | Silty SAND, fine to medium grained, brown to dark brown, with fine to medium gravels, grass rootlets, moist. | | FILL |
| | | | 0.5 | | SC-SM | Clayey SAND, fine to medium grained, brown to pale brown, medium plasticity clay, some fine gravel, moist, estimated medium dense to dense. | | NATURAL SOILS |
| | | | 1.0 | | | Borehole BH2 terminated at 0.5m | | Practical hand auger refusal at 0.5m bgl. |
| | | | 1.5 | | | | | |
| | | | 2.0 | | | | | |

# APPENDIX E

# DYNAMIC CONE PENETOMETER RESULTS

| **Client:** | Infinity Eight Holdings Pty Ltd | **Test Date:** | 3/07/2023 |
|---|---|---|---|
| **Address:** | 105 Letitia Street Oatley NSW 2223 | **Job No.:** | G23267-1 |

| **Depths (mm bgl)** | **DCP No.** | | | | **Depths (mm bgl)** | **DCP No.** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | | | | | |
| 0-100 | 1 | 2 | 1 | 1 | 0-100 | | | | |
| 100-200 | 3 | 3 | 2 | 1 | 100-200 | | | | |
| 200-300 | 4 | 3 | 2 | 7 | 200-300 | | | | |
| 300-400 | 3 | 25/60mm | 7 | 10 | 300-400 | | | | |
| 400-500 | 10 | **Bouncing** | 5 | 18 | 400-500 | | | | |
| 500-600 | 25/80mm | | 5 | 25/50mm | 500-600 | | | | |
| 600-700 | **Bouncing** | | 4 | **Bouncing** | 600-700 | | | | |
| 700-800 | | | 4 | | 700-800 | | | | |
| 800-900 | | | 3 | | 800-900 | | | | |
| 900-1000 | | | 25/70mm | | 900-1000 | | | | |
| 1000-1100 | | | **Bouncing** | | 1000-1100 | | | | |
| 1100-1200 | | | | | 1100-1200 | | | | |
| 1200-1300 | | | | | 1200-1300 | | | | |
| 1300-1400 | | | | | 1300-1400 | | | | |
| 1400-1500 | | | | | 1400-1500 | | | | |
| 1500-1600 | | | | | 1500-1600 | | | | |
| 1600-1700 | | | | | 1600-1700 | | | | |
| 1700-1800 | | | | | 1700-1800 | | | | |
| 1800-1900 | | | | | 1800-1900 | | | | |
| 1900-2000 | | | | | 1900-2000 | | | | |
| 2000-2100 | | | | | 2000-2100 | | | | |
| 2100-2200 | | | | | 2100-2200 | | | | |
| 2200-2300 | | | | | 2200-2300 | | | | |
| 2300-2400 | | | | | 2300-2400 | | | | |
| 2400-2500 | | | | | 2400-2500 | | | | |
| 2500-2600 | | | | | 2500-2600 | | | | |
| 2600-2700 | | | | | 2600-2700 | | | | |
| 2700-2800 | | | | | 2700-2800 | | | | |
| 2800-2900 | | | | | 2800-2900 | | | | |
| 2900-3000 | | | | | 2900-3000 | | | | |
| 3000-3100 | | | | | 3000-3100 | | | | |
| 3100-3200 | | | | | 3100-3200 | | | | |
| 3200-3300 | | | | | 3200-3300 | | | | |
| 3300-3400 | | | | | 3300-3400 | | | | |
| 3400-3500 | | | | | 3400-3500 | | | | |
| 3500-3600 | | | | | 3500-3600 | | | | |
| 3600-3700 | | | | | 3600-3700 | | | | |
| 3700-3800 | | | | | 3700-3800 | | | | |
| 3800-3900 | | | | | 3800-3900 | | | | |
| 3900-4000 | | | | | 3900-4000 | | | | |

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| **Tested:** | **NW/JS** | **©Geotechnical Consultants Australia Pty Ltd** | **Sheet:** | **1 of 1** |
|---|---|---|---|---|

# APPENDIX F

# 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).

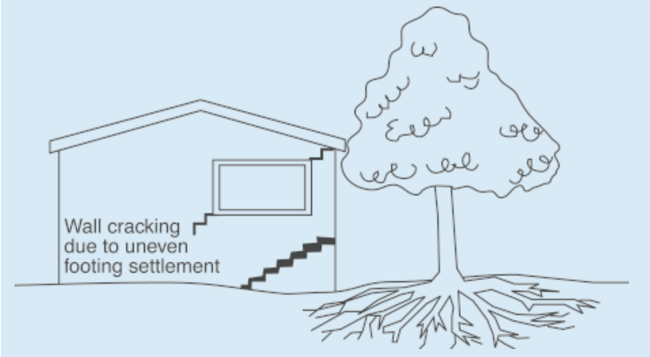
Isolated piers affected by erosion or saturation of foundations will eventually lose contact with the bearers they support and may tilt or fall over. The floors that have lost this support will become bouncy, sometimes rattling ornaments etc.

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.

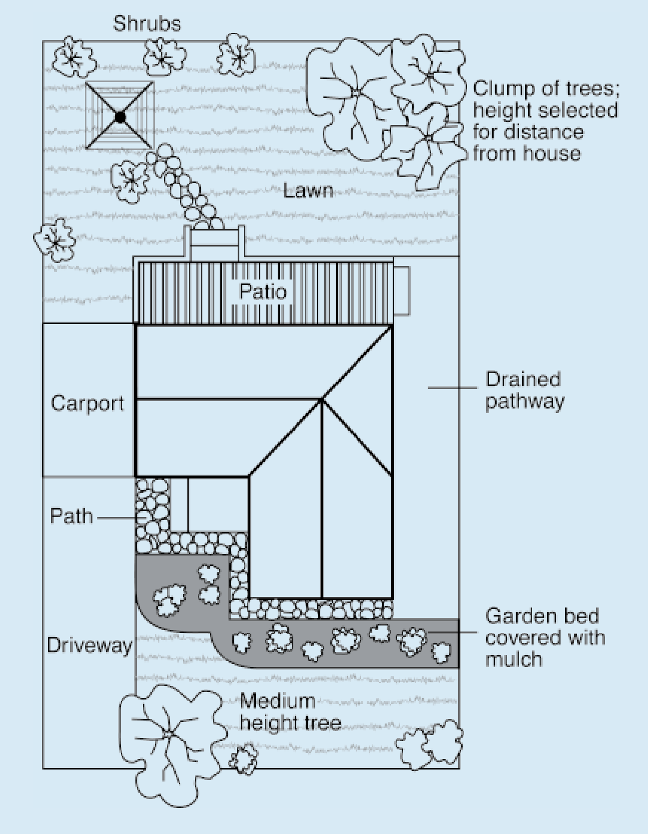
Protection of the building perimeter
It is essential to remember that the soil that affects footings extends well beyond the actual building line. Watering of garden plants, shrubs and trees causes some of the most serious water problems.

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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# APPENDIX G

| ha | HAWKESBURY | Colluvial |
| --- | --- | --- |

*Source:* Soil and Land Resources of the Hawkesbury-Nepean Catchment *interactive DVD*

**Landscape**—rugged, rolling to very steep hills on Hawkesbury Sandstone. Local relief 40–200 m, slopes >25%. Rock outcrop >50%. Narrow crests and ridges, narrow incised valleys, steep sideslopes with rocky benches, broken scarps and boulders. Mostly uncleared eucalypt open-woodland (dry sclerophyll forest) and tall open-forest (wet sclerophyll forest).

**Soils**—shallow (>50 cm), discontinuous Lithosols/Siliceous Sands (Uc1.21) associated with rock outcrop; Earthy Sands (Uc5.11, Uc5.23), Yellow Earths (Gn2.24) and some Yellow Podzolic Soils (Dy4.11) on inside of benches and along joints and fractures; localised Yellow and Red Podzolic Soils (Dy4.11, Dy5.21, Dy5.11, Dr5.21) associated with shale lenses; Siliceous Sands (Uc1.2) and secondary Yellow Earths (Gn2.41) along drainage lines.

**Limitations**—extreme soil erosion hazard, steep slopes, rock outcrop, shallow, stony, highly permeable soil, low soil fertility.

## LOCATION

Steep, rugged Hawkesbury Sandstone slopes and ridges of the Macdonald Ranges, Hornsby Plateau and Hawkesbury Valleys. Examples occur in Muogamarra Nature Reserve, Brisbane Water National Park and Ku-ring-gai Chase National Park. Within the metropolitan area, examples are found adjacent to Port Jackson, Georges River, Cowan Creek, Deep Creek and the upper reaches of the Lane Cove River.

## LANDSCAPE

### Geology

Hawkesbury Sandstone consisting of medium to coarse-grained quartz sandstone with minor shale and laminite lenses. Sandstones are either massive or cross-bedded sheet facies with vertical or subvertical joint sets. The combination of bedding planes and widely spaced joints gives sandstone outcrops a distinctive blocky appearance.

### Topography

Rolling to very steep hills. Local relief varies from 40–200 m. Slope gradients range from 25–70%. Crests and ridges are convex and narrow, at >300 m wide. Slopes are moderately inclined to precipitous. Rock outcrop occurs as horizontal benches and broken scarps up to 10 m high. Boulders and cobbles cover up to 50% of the ground surface. Valleys are narrow and incised.

### Vegetation

Mostly uncleared open-woodland (dry sclerophyll) with pockets of tall open-forest (wet sclerophyll) and closed-forest (rainforest).

On exposed crests and ridges there is usually a low open-woodland containing red bloodwood *Eucalyptus gummifera,* narrow-leafed stringybark *E. oblonga,* scribbly gum *E. haemostoma,* brown stringybark *E. capitellata* and old man banksia *Banksia serrata.* On the more sheltered sideslopes, a dry sclerophyll open-forest containing black ash *E. sieberi,* sydney peppermint *E. piperita,* smooth-barked apple *Angophora costata* and black sheoak *Allocasuarina littoralis* predominate. The understorey is dominated by shrub species of the families Epacridaceae, Myrtaceae, Fabaceae and Proteaceae.

Within sheltered gullies, wet sclerophyll closed-forests of blackbutt *Eucalyptus pilularis,* Sydney blue gum *E. saligna,* water gum *Tristania laurina* and occasionally coachwood *Ceratopetalum apetalum* occur. Black wattle *Callicoma serratifolia,* native myrtle *Backhousia myrtifolia* and bracken *Pteridium esculentum* form a closed scrubby understorey. Many sheltered valley floors are overrun with weeds (garden escapes washed in with sediment). Weed species include small and large-leaved privets *Ligustrum spp.,* lantana *Lantana camara,* morning glory *Ipomoea indica* and wandering jew *Tradescantia albiflora.*

### Landuse

Mostly national parks (Ku-ring-gai Chase and Brisbane Water) and nature reserve (Muogamarra), which are used for education and recreation. Small areas under private ownership. Maroota State Forest occurs in the far north-west. Population pressures, scenic views and bushland settings have contributed to the urbanisation of this landscape.

### Existing Erosion

Severe sheet erosion often occurs during storms and after ground cover is destroyed by bushfires (Atkinson, 1984). Minor gully erosion occurs along unpaved tracks and fire trails, especially those used regularly by four wheel drive vehicles, motorcycles and horses.

### Associated Soil Landscapes

Small areas of Faulconbridge (**fb**) soil landscape occur on some crests, whilst Lambert (**la**) and Oxford Falls (**of**) occur on some sideslopes and Deep Creek (**dc**) is found in some valley floors.

## SOILS

### Dominant Soil Materials

**ha1—Loose, coarse quartz sand.** This is a sand to sandy loam with loose, apedal single-grained structure and porous sandy fabric. It generally occurs as topsoil (A1 horizon).

Colour varies from brownish-black (10YR 2/2) when abundant organic matter is present, to dull yellow orange (10YR 7/2). Colour often becomes lighter with depth. The pH ranges from strongly acid (pH 4.0) to slightly acid (pH 6.0). Weakly weathered sandstone fragments may be present whilst charcoal fragments and roots are common. This material is commonly water repellent.

**ha2—Earthy, yellowish-brown sandy clay loam.** This is a clayey sand to sandy clay loam with apedal massive or occasionally weakly pedal structure and a distinctly porous, earthy fabric. It generally occurs as subsoil, often in association with sandstone bedrock (B or C horizon).

Where peds are present they are large sub-angular blocky and rough-faced. Ped sizes range from 30 mm to 60 mm. Common colours include yellow orange (10YR 7/8), bright yellowish-brown (10YR 6/8, 6/6) and yellowish-brown (l0YR 5/6). The pH ranges from strongly acid (pH 4.0) to moderately acid (pH 6.0). Gravels, stones and ironstone-plated sandstone fragments are common, but roots and charcoal fragments are rare.

**ha3—Pale, strongly pedal light clay.** This is fine sandy clay loam to medium clay with strongly-pedal structure and rough-faced ped fabric. It commonly occurs as subsoil derived from shale lenses within the Hawkesbury Sandstone (B or C horizons).

Structure is strongly pedal when dry and apedal when saturated. Peds range in size from 20–60 mm and are sub-angular blocky to angular blocky in shape. Colours are most often pale, but can vary according to site drainage characteristics. Colour ranges from bright reddish-brown (5YR 5/6) in well drained areas to a light grey (10YR 8/1) in poorly drained areas. Red, orange and grey mottles are often present. The pH ranges from strongly acid (pH 4.0) to slightly acid (pH 6.0). Stratified ironstone gravels are common but roots and charcoal fragments are usually rare or absent.

### Associated Soil Materials

**Litter and decomposing organic debris.** Surface litter consists of decomposing remnants of leaves and twigs, fungal and root mats, and quartz sand grains. Distribution depends on site productivity, fire regime, location of nearby species and surface wetness. Over 10 cm of decomposing organic debris often accumulates in debris dams and small fans on breaks of slope, as well as in joint crevices of rock outcrops. There is usually a sharp boundary with the mineral soil.

**White loose sand.** This material is found on the surface and is composed of quartz sand grains found in recently deposited surface washes such as small debris dams and fans found on breaks of slope. This material is often mixed with litter and charcoal fragments.

### Occurrence and Relationships

**Crests and ridges.** Up to 20 cm of loose, coarse quartz sand (**ha1**) overlies either bedrock [Lithosols (Uc1.21)] or <30 cm of earthy, yellowish-brown sandy clay loam subsoil (**ha2**) [Earthy Sands (Uc5.11), Yellow Earths (Gn2.24, Gn2.31)]. Total soil depth is <50 cm. The boundary between soil materials is usually gradational. Texture often increases slowly with depth.

**Sideslopes and benches.** Soils are discontinuous. Sandstone outcrop and boulders may cover over 50% of the ground surface. Usually 10–30 cm of **ha1** overlies bedrock [Lithosols and Siliceous

Sands (Uc1.22)] on outsides of benches whilst 5–15 cm of **ha1** overlies up to 50 cm of **ha2** on higher sides of benches. Boundaries between soil materials are either gradual or clear and total soil depth, although variable, is usually <70 cm. In some instances, especially along joint lines, soil depth may exceed 2 m [Yellow Earths (Gn2.24) to clear Yellow Podzolic Soils (Dy 4.11)]. Often **ha2** is found along bedding planes in the sandstone.

Friable sandstone (**la6**) may occur as deep subsoil in poorly drained pockets and along joint lines.

Minor lenses of shale are occasionally **ha3** associated with higher sides of benches and have up to 30 cm of **ha1** which overlies up to 50 cm of strongly pedal clay subsoil (**ha3**). There is a clear to sharp boundary between soil materials. Total soil depth is usually <150 cm [Yellow Podzolic Soils (Dy4.11, Dy5.21) and occasional Red Podzolic Soils (Dr5.11, Dr5.21)].

**Drainage lines.** Drainage lines are either on exposed bedrock or have deposits of gravel or loose quartz sands (**ha1**) [Siliceous Sands (Uc1.2)] which occasionally overlie **ha2** [Yellow Earths (Gn2.41)]. Total soil depth is usually <100 cm.

**Associated Soils.** Occasional shale crests that occur in the unit have approximately 30 cm of a brown hardsetting loam or clay loam topsoil overlying up to 100 cm of a pedal red or brown clay subsoil [Yellow Podzolic Soils (Dy3.21) and Red Podzolic Soils (Dr3.21)].

## LIMITATIONS TO DEVELOPMENT

### Urban Capability

Generally not capable of urban development.

### Rural Capability

Not capable of being cultivated or being grazed.

### Landscape Limitations

Mass movement hazard
Rockfall hazard
Steep slopes
Severe erosion hazard
Rock outcrop
Shallow soils

### Soil Limitations

**ha1** High permeability
Low available water capacity
Stoniness
High organic matter
Low fertility
Extremely acid
Very high aluminium toxicity

**ha2** Low available water capacity
Stoniness
Very low fertility
Strongly acid
Very high aluminium toxicity
Low available water capacity
Low wet strength (localised)

Low permeability (localised)
Very low fertility
Strongly acid
High aluminium toxicity

**Fertility**

General fertility is very low. The soils of this unit are extremely to strongly acid with a low to very low nutrient status. The soils are severely deficient in nitrogen and phosphorus and they have very low CEC. They are also shallow and stony with low available water capacities and high aluminium toxicity.

**Erodibility**

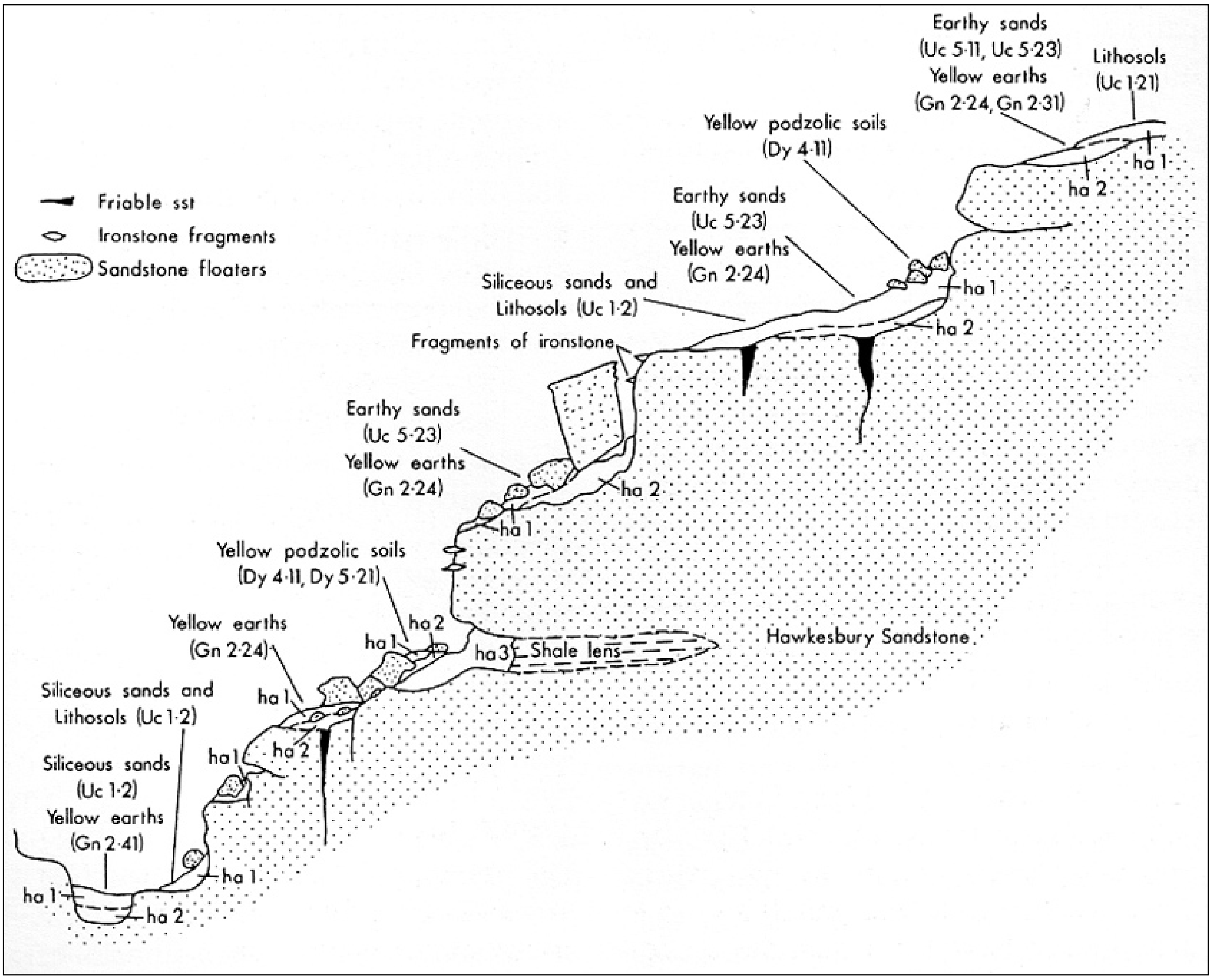
The topsoil **ha1** has low erodibility. It consists of highly permeable, loose, coarse sands and organic matter. **ha1** is highly susceptible to concentrated flow erosion, especially when the organic matter is removed by hot bushfires. **ha2** and **ha3** have moderate erodibility. They have low organic matter contents and weak fabrics.

**Erosion Hazard**

Erosion hazard for non-concentrated flows is generally very high and ranges from moderate to extreme. The calculated soil loss for the first twelve months of urban development ranges up to 109 t/ha for topsoil and 394 t/ha for subsoil. The soil erosion hazard for concentrated flows is extreme.

**Surface Movement Potential**

The shallow sandy soils are stable to slightly reactive.




***Schematic cross-section of Hawkesbury soil landscape illustrating the occurrence and relationship of the dominant soil materials.***

| lh | LUCAS HEIGHTS | Residual |
|---|---|---|

*Source:* Soil and Land Resources of the Hawkesbury-Nepean Catchment *interactive DVD*

**Landscape**—gently undulating crests and ridges on plateau surfaces of the Mittagong formation (alternating bands of shale and fine-grained sandstones). Local relief to 30 m, slopes <10%. Rock outcrop is absent. Extensively or completely cleared, dry sclerophyll low forest and woodland.

**Soils**—moderately deep (50–150 cm), hardsetting Yellow Podzolic Soils and Yellow Soloths (Dy2.41); Yellow Earths (Gn2.24) on outer edges.

**Limitations**—stony soil, low soil fertility, low available water capacity.

## LOCATION

Ridge and plateau surfaces on Mittagong Formation. Occurrences are most common in the Macdonald Ranges and on the Hornsby Plateau. Most extensive occurrences are located at Berowra, Forest Glen, Glenorie, Fiddletown, Dural and Glenhaven. Other examples occur at St Ives, South Turramurra, South Gordon, Beacon Hill, Northbridge, Kogarah and Riverwood.

## LANDSCAPE

### Geology

Mittagong Formation—interbedded shale, laminite and fine to medium grained quartz sandstone. The Mittagong Formation is located stratigraphically between the Ashfield Shale and Hawkesbury Sandstone. It is often relatively shallow. Minor areas of Hawkesbury Sandstone and minor areas of Ashfield Shale may occur.

### Topography

Gently undulating plateau, 200–1 000 m in width, with level to gently inclined slope gradients of <10%. Local relief is <30 m. Rock outcrop is absent.

### Vegetation

Extensively cleared to completely cleared low, eucalypt open-forest and low eucalypt woodland with a sclerophyll shrub understorey. Dominant tree species include turpentine *Syncarpia glomulifera*, smooth-barked apple *Angophora costata*, red bloodwood *Eucalyptus gummifera*, thin-leaved stringybark *E. eugenioides* and scribbly gum *E. haemastoma*. Small scattered areas of native vegetation remain. Larger undisturbed occurrences are found in Ku-ring-gai Chase National Park and Muogamarra Nature Reserve.

### Land use

Rural land uses include citrus orchards, market gardens and poultry farms. Grazing of horses and dairy cattle is common on improved, kikuyu dominated pastures. Small rural subdivisions and hobby farms occur on the urban fringes of the metropolitan area. The unit has been developed for urban use at Berowra and St. Ives. Areas of natural bushland, such as Muogamarra Nature Reserve, Ku-ring-gai Chase National Park and crown lands are used for passive recreation.

### Existing Erosion

Erosion on this unit is generally low. Minor gully and sheet erosion occurs occasionally along unpaved roads.

### Associated Soil Landscapes

Small areas of Faulconbridge (**fb**) soil landscape occur near the edge of this unit.

## SOILS

### Dominant Soil Materials

**lh1—Loose, yellowish-brown sandy loam.** This is a loose sandy loam with apedal single-grained structure and porous sandy fabric. It usually occurs as topsoil (A1 horizon). Texture is commonly sandy loam but may range from a loamy sand to a light sandy clay loam. Sand is usually fine. Surface condition is commonly loose but may be friable when organic matter is common. Colour is usually dull yellowish-brown (10YR 4/3), or occasionally very dark brown (7.5YR 2/3). The pH ranges from very strongly acid (pH 4.5) to slightly acid (pH 6.5). Common inclusions are iron coated, platy, fine sandstone rock fragments and charcoal fragments. Roots are also common.

**lh2—Bleached, stony, hardsetting sandy clay loam.** This is a bleached, stony, sandy clay loam that has a hardsetting surface, apedal massive structure and slowly porous earthy fabric. This material commonly occurs as an A2 horizon. Textures commonly range with depth from clayey sand to fine sandy clay loam. Sand is generally fine-grained. Colour is commonly dull yellowish-brown (10YR 5/4) and is bleached when dry (10YR 7/3) but may range from brown (7.5YR 4/3) to bright yellowish-brown (10YR 6/6). Pale yellow and brown mottles are often present and are commonly associated with faunal casts and burrows. The pH ranges from strongly acid (pH 4.0) to slightly acid (pH 6.0). Fine sandstone fragments and rounded iron nodules are abundant and are often concentrated at depth. Platy, iron coated stones are stratified, reoriented and angular to subrounded. Traces of charcoal are commonly present, but roots are rare.

**lh3—Earthy, yellowish-brown sandy clay loam.** This is a yellowish-brown sandy clay loam with apedal massive structure and earthy porous fabric. It generally occurs as subsoil (B horizon) developed on coarse sandstone. Texture, which is commonly a sandy clay loam on the surface, may increase gradually with depth to sandy clay. Colour is commonly a yellowish-brown (2.5Y 5/6-5/8, 10YR 5/8) or bright yellowish-brown (10YR 6/6, 6/8). Orange mottles may occur with depth. The pH ranges from strongly acid (pH 4.5) to slightly acid (pH 6.0). Iron coated sandstone fragments are common. They are usually stratified and reoriented. Charcoal fragments and roots are rare.

**lh4— Pedal, yellowish-brown clay.** This is yellowish-brown sandy clay to heavy clay with strongly pedal sub-angular blocky or prismatic structure and smooth-faced, dense ped fabric. This material usually occurs as subsoil (B and C horizons) developed on fine-grained sandstone. Peds are smooth-faced, dense and range in size from 10–20 mm. Colour is commonly bright yellowish-brown (10YR 6/8) but may range from reddish-brown (5YR 4/6) to bright yellowish-brown (10YR 7/6). Yellow, red and orange mottles are occasionally present. The pH ranges between strongly acid (pH 4.0) and moderately acid (pH 5.0). Undisturbed, stratified bands of platy, iron coated, fine sandstone rock fragments are common. Charcoal fragments and roots are rarely present.

**Occurrence and Relationships**

Up to 30 cm of loose, yellowish-brown sandy loam (**lh1**) overlies 10–30 cm of bleached, stony, hardsetting sandy clay loam (**lh2**) and up to 100 cm of yellowish-brown, pedal clay (**lh4**) [Yellow Podzolic Soils and Soloths (Dy2.41)]. The boundary between the soil materials is generally clear. The total soil depth is commonly <100 cm. Occasionally **lh1** material is absent.

Near the boundaries to sandstone landscapes up to 15 cm of **lh1** overlies up to 30 cm of **lh2** and up to 30 cm of earthy, yellowish-brown sandy clay loam (**lh3**) [Yellow Earths (Gn2.24)].

## LIMITATIONS TO DEVELOPMENT

**Urban Capability**

High capability for urban development.

**Rural Capability**

Generally capable of supporting grazing with some localised areas capable of regular cultivation.

**Landscape Limitations**

Localised surface movement potential.

**Soil Limitations**

**lh1** Stoniness
High permeability
Low available water capacity
Low fertility

**lh2** High erodibility
Stoniness
Low available water capacity
Hardsetting surface
Very low fertility
Localised sodicity

**lh3** Stoniness
Low available water capacity
Very low fertility
Sodicity

**lh4** Low wet strength
Stoniness

Low permeability
Low available water capacity (localised)
Very low fertility
Strongly acid
High aluminium toxicity

**Fertility**

General fertility is low. The soils have low available water capacity and CEC as well as low to very low intrinsic nitrogen and phosphorus values. Topsoils are hardsetting and stony. The subsoils are occasionally sodic and impermeable.

**Erodibility**

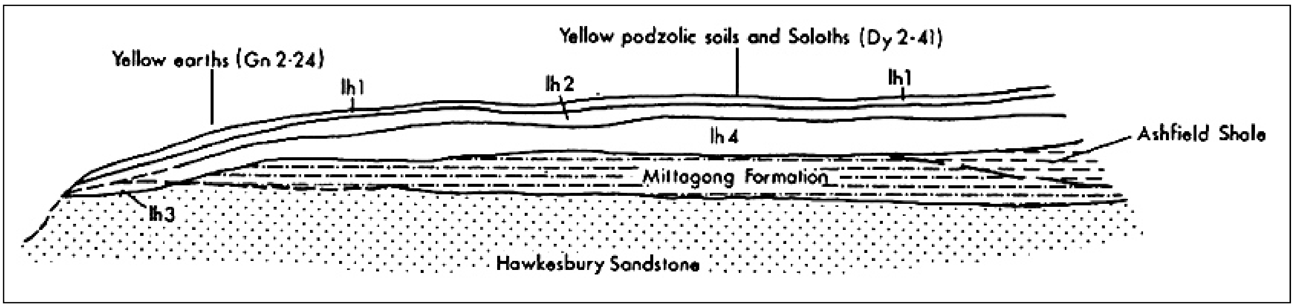
**lh1** is moderately erodible as it consists of loose, fine sand grains and moderate amounts of organic matter. **lh2** is low in organic matter and has a very high erodibility rating as it consists of fine sand and some silt grains held in a clay matrix. **lh3** has a high erodibility as it has fine sand and silt grains and a low organic matter content. **lh4** is moderately erodible consisting of fine sand and clay with a very low organic matter content.

**Erosion Hazard**

The erosion hazard for non-concentrated flows is generally moderate, but ranges from slight to extreme. Calculated soil loss during the first twelve months of development ranges up to 103 t/ha for topsoil, and 97 t/ha for exposed subsoil. Soil erosion hazard for concentrated flows is high.

**Surface Movement Potential**

Soils are generally slightly reactive or moderately reactive where they exceed 1.5 m.




*Schematic cross-section of Lucas Heights soil landscape illustrating the occurrence and relationship of the dominant soil materials.*

**Landscape**—level to gently undulating swales, depressions and infilled lagoons on Quaternary sands. Local relief <10 m, slopes <3%. Watertable at <2 m. Mostly cleared of native vegetation.

**Soils**—deep (>150 cm), well sorted, sandy Humus Podzols (Uc2.32) and dark, mottled Siliceous Sands (Uc1.21), overlying buried Acid Peats (O) in depressions; deep (>200 cm) Podzols (Uc2.12, Uc2.32) and pale Siliceous Sands (Uc1.2) on sandy rises.

**Limitations**—localised flooding and run-on, high watertables, highly permeable soil.

## LOCATION

Swales and infilled coastal lagoons. Typical examples are found at Warriewood, Kyeemagh, Rockdale, Matraville, Manly Vale, Curl Curl, Dee Why, Narrabeen, Mona Vale, Newport and Avalon.

## LANDSCAPE

### Geology

Holocene silty to peaty quartz sand. Medium to fine marine sand with podzols.

### Topography

Level to gently undulating plains with local relief <10 m and slope gradients <5%. In-filled coastal barrier dunes, lakes and lagoons as well as swale depressions in dunefields. Most drainage is by subsurface flow, with the watertable <200 cm.

**Vegetation**

Extensively cleared, sclerophyll scrub and woodland. Remaining native tree species include broad-leaved paperbark *Melaleuca quinquenervia*, coastal banksia *Banksia integrifolia*, swamp oak *Casuarina glauca* and swamp mahogany *Eucalyptus robusta*. Remaining scrub and understorey species include coastal teatree *Leptospermum laevigatum*, spike rushes *Eleocharis* spp., and tall swamp sedge *Gahnia sieberiana*.

**Land use**

Market gardening occasionally using greenhouses, for example at Warriewood and Kyeemagh, is the most intensive rural land use. Areas of improved kikuyu pasture are used for horse grazing.

**Existing Erosion**

Minor gully and streambank erosion on this unit is associated with clearing and drainage of land for market gardens.

**Associated Soil Landscapes**

Ettalong (**et**) soil landscape merges with Warriewood soil landscape in areas of very poor drainage.

Tuggerah (**tg**) soil landscape merges with Warriewood soil landscape in many areas.

## SOILS

**Dominant Soil Materials**

**wa1—Loose, speckled, dark grey loamy sand.** This is dark grey loamy sand with loose apedal single-grained structure and sandy fabric. It generally occurs as topsoil (A1 horizon).

This material consists of a speckled mixture of dark organic materials and clean quartz sand grains. The colour ranges from brownish-grey (10YR 4/1) to brownish-black (10YR 2/3) to black (10YR 2/1) with increasing organic matter. The pH ranges from strongly acid (pH 4.5) to neutral (pH 7.0) and lime has often been applied. This material is often water repellent. Roots are abundant and charcoal fragments are often present, but there are no stones.

**wa2—Bleached massive sand.** This is bleached sand with apedal single-grained structure and sandy fabric. It commonly occurs as an A2 horizon.

This material is composed almost entirely of clean quartz sand grains that have been compacted over time. It is weakly coherent with apedal massive structure when moist and non-cohesive with loose apedal single-grained structure when dry. The surface condition is loose. Dry colours are bleached and moist colour ranges from light grey (10YR 7/1) to dull yellow orange (10YR 6/3). The pH ranges from moderately acid (pH 5.5) to neutral (pH 7.0). Charcoal and stones are absent whilst roots are few.

**wa3—Pale mottled massive sand.** This is commonly saturated pale mottled sand with apedal single-grained structure and sandy fabric. This material occurs as deep subsoil usually below the watertable (B horizon).

Texture varies from sand to less commonly clayey sand. This material has apedal massive structure and sandy fabric. It is usually weakly cohesive. The colour varies from dull yellow (2.5Y 6/4) to brownish-grey (10YR 5/1) and grey, yellow or brown mottles are common with depth. The pH ranges from moderately acid (pH 5.5) to neutral (pH 7.0). Roots are rare and charcoal and stones are absent.

**wa4—Black sticky peat.** This is commonly saturated, black organic rich silt loam or silty clay loam with apedal massive structure. It generally occurs as topsoil in low lying areas or as a buried soil (P or D horizon).

Fibrous plant remains dominate this material which is moderately sticky and distinctly spongy. The colour is commonly black (10YR 1.7/1) or brownish-black due to the organic material present. It may become extremely hardsetting when dry. The pH ranges from strongly acid (pH 4.5) to moderately acid (pH 5.5). Roots are common and stones are absent.

**wa5—Brown soft iron pan.** This is commonly brown, iron-stained, sand to loamy sand with apedal massive structure and sandy fabric. It commonly occurs as subsoil above the watertable (B horizon).

Fabric is occasionally earthy. This material consists of quartz sand grains coated and weakly cemented with yellow to red sesquioxides. It requires up to a moderate force to disrupt. Colour varies from dull yellow orange (10YR 6/4) to brown (7.5YR 4/4). Dark orange, yellow and brown mottles are common. The pH ranges from moderately acid (pH 5.5) to neutral (pH 7.0). Roots are rare and stones and charcoal fragments are absent.

**wa6—Dark brown soft organic pan.** This is dark brown sand to loamy sand with apedal massive structure and sandy fabric. It usually occurs as subsoil (B horizon).

Fabric is occasionally earthy. This material consists of quartz sand grains coated and weakly cemented with black organic aluminium compounds. It requires up to a moderate force to disrupt. The colour ranges from black (10YR 1.7/1) to dark brown (10YR 3/3). The pH ranges from moderately acid (pH 5.5) to neutral (pH 7.0). Stones and charcoal are absent, and roots are rare.

**Occurrence and Relationships.**

**Well drained areas.** Up to 30 cm of loose speckled dark grey loamy sand (**wa1**) overlies 30–100 cm of bleached, massive sand (**wa2**). **wa2** overlies 30–80 cm of convoluted and often intermixed, brown soft iron pan (**wa5**) and black soft organic pan (**wa6**). Below the pan materials there is >100 cm of pale mottled massive sand (**wa3**). Total soil depth is >300 cm. Boundaries between soil materials are clear [Podzols (Uc2.12, Uc2.32)].

**Poorly drained areas.** Up to 40 cm of **wa1** overlies 20–50 cm of **wa6** and/or >100 cm of **wa3**. A watertable when present occurs at <150 cm. Often **wa6** is absent and **wa1** directly overlies **wa2**. Total soil depth is >300 cm. Boundaries between soil materials are generally clear [Humus Podzols (Uc2.32)].

Occasionally, **wa2** is inter-stratified with layers of buried peat **wa4** [Siliceous Sands (Uc 1.21), Acid Peats (O)].

## LIMITATIONS TO DEVELOPMENT

### Urban Capability

Generally low to moderate capability for urban development. Localised swampy areas are not capable for urban development.

### Rural Capability

Generally capable of regular cultivation and grazing.
Landscape Limitations.
Flood hazard (localised)
Permanently high watertables
Waterlogging (localised)

Seasonal waterlogging (localised)
Wind erosion hazard
Non-cohesive soil

**Soil Limitations**

**wa1** Salinity (localised)

**wa2** High permeability
Low available water capacity
Very low fertility
Strongly acid

**wa3** High permeability
Low available water capacity
Very low fertility

**wa4** High organic matter
Low wet strength (localised)
Extremely acid
High aluminium toxicity

**wa5** Low available water capacity
Hardsetting surface
Very low fertility
Very strongly acid
Saline (localised)
High aluminium toxicity

**wa6** Low available water capacity
Hardsetting surface
Low fertility
High organic matter

**Fertility**

The general fertility ranges from very low to high. The topsoil **wa1** has a low to moderate fertility with low to moderate available water capacity, low organic matter, low CEC, and intrinsically low nutrient status. **wa2**, **wa3**, and **wa5** all have very low fertilities with low waterholding capacities, very low CEC, low or very low organic matter contents, and low nutrient status. **wa4** is moderately to highly fertile with very high organic matter contents, high to very high available water capacity, high CEC, and intrinsically moderate nutrient status. **wa6** has a low fertility with low available water capacity, low organic matter, very low CEC, and low nutrient status. Soils of this unit have often been fertilised.

**Erodibility**

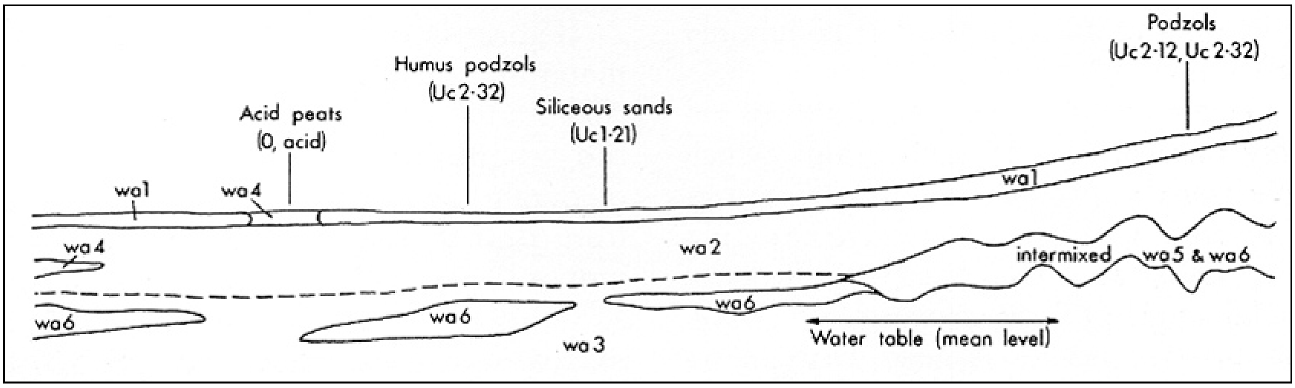
Soil materials **wa1–wa3**, **wa6** have very low erodibility, while **wa4** and **wa5** have low erodibilities. These materials are relatively stable and consist of well drained stable coarse sands (**wa1–wa3**) or coarse sand grains weakly held together by organic matter (**wa4**, **wa6**) or iron compounds (**wa5**).

**Erosion Hazard**

The erosion hazard for non-concentrated flows is low. Calculated soil loss for the first twelve months of urban development ranges up to 1 t/ha of topsoil and 5 t/ha of exposed subsoil. The erosion hazard for concentrated flows is moderate to high and for wind erosion is low to moderate.

**Surface Movement Potential**

Slight to moderate reactivity occurs with peat, otherwise stable.




*Schematic cross-section of Warriewood soil landscape illustrating the occurrence and relationship of the dominant soil materials.*