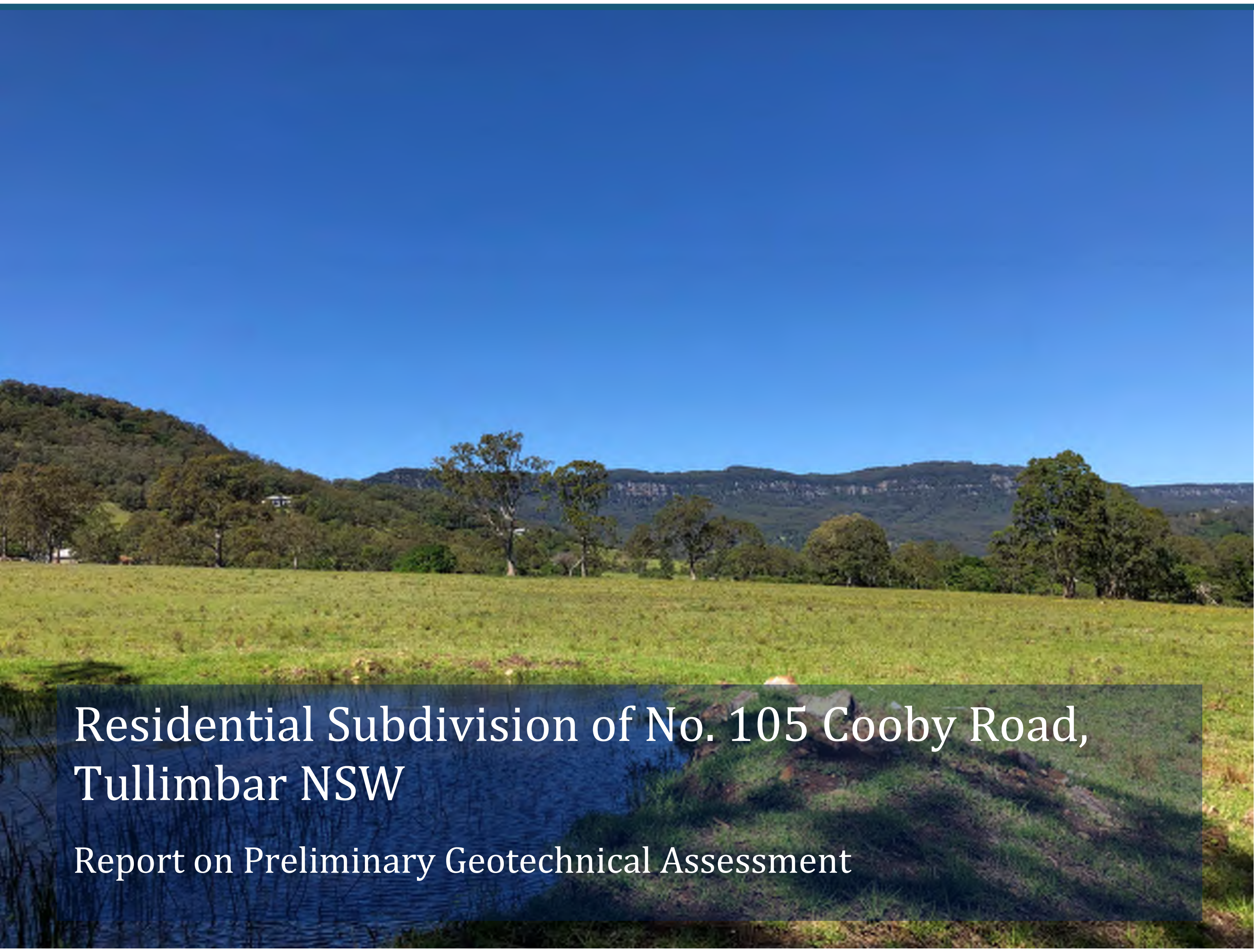


Residential Subdivision of No. 105 Cooby Road, Tullimbar NSW

Report on Preliminary Geotechnical Assessment

Prepared for:

Indesco

Our Ref: TERRA18320.Rep1.Rev1

Prepared for:
Urbanco Pty Ltd
C/ Indesco Pty Ltd
No 25 Athison Street
WOLLONGONG NSW 2500

15 August 2019

Attention: Mr G Glanville

RE: Residential Subdivision of No. 105 Cooby Road, Tullimbar NSW
Report on Preliminary Geotechnical Assessment

Dear Greg,

Please find enclosed our geotechnical report for the above site in relation to its proposed residential subdivision. This report should be read in conjunction with the attached document 'About Your Report' in Appendix A. Should you have any questions please contact the undersigned.

For and on behalf of Terra Insight

Karen Gates
Principal Engineer/ Director
CPEng MIEaust BEng MEngSc(Geot) MEnvMgt MBA

Contents

Tables

Figures

Appendices

1. Introduction

Urbanco is proposing to develop No 105 Cooby Road, Tullimbar (hereafter referred to as the site) as a residential subdivision. To support the preliminary planning of the site and to facilitate conceptual civil design of the site, preliminary geotechnical assessment of the site was required. At the request of Indesco Pty Ltd, TerraInsight Pty Ltd (Terra) has performed this preliminary geotechnical assessment for the proposed subdivision with the following objectives:

- Provide a geotechnical characterisation of the Site based on a desktop review of available information;
- Identify geotechnical constraints and opportunities which may impact the development; and
- Provide advice on the management and mitigation of geotechnical risks.

This report details the results of this preliminary geotechnical assessment.

2. Scope of work

The scope of work was divided into three components as detailed in the following sections.

2.1. Geotechnical desktop study

The geotechnical desk study involved the following:

- Review of aerial photographs;
- Review of published information including geology, soil landscape, topography, slope stability (if available), land use, urban capability maps / reports (if available), soil landscape maps, and information held by the NSW Office of Water and the NSW Soil and Landscape Information Systems; and
- Collation of the broad scale information available above for the site to allow preliminary characterisation of the geomorphological conditions likely to be encountered within the site;

2.2. Site walkover and Site Geotechnical Characterisation

- Truth sensing of the information gathered during the desk study phase by undertaking a walkover of the site, to observe surface conditions including mapping of main features including noting slope gradients, slope stability aspects, rock outcrops, evidence of filling, and water logging/seepages; and
- Dividing the site plan into areas of similar geomorphology (eg similar units of terrain/landform in terms of geological formation and slope conditions).

2.3. Reporting

Documentation of the results of the desk studies and site walk over in a report which included geotechnical advice on the following:

- Assess the suitability of the site for residential development, providing advice on
    - Likely subsurface conditions by geomorphological terrain units and how these may impact on earthworks and foundations, such as the depth to rock and the reactivity of the near surface soils respectively;
    - Preliminary assessment of land slide risk and identification of areas where the risk needs further investigation;
    - Indicative site classifications to AS2870 – 2011 “Residential slabs and footings”;
    - Likely subgrade conditions for pavement design; and
    - Identification of other relevant geotechnical constraints and opportunities;

3. Desk Study Findings

3.1. Site details

The site includes an area of approximately 29 ha located on the southern edge of the Tullimbar development area as shown in Figure 1 and detailed in Table 3.1. The site is located approximately 2.2 km south-west of Albion Park Town Centre. The site is also known as Lot 240 of deposited plan DP 828854.

The site is bounded by Cooby Road to the west, residential property to the south and rural land use on all other boundaries. The site is currently in rural use. A plan showing the proposed development of the site is provided on Figure 2. Access to the residential development will be via Cooby Road.

Table 3.1: Summary of site identification information

Street Address	Off Cooby Road, Tullimbar NSW	
Title Identifiers	Lot 240 DP 828854	
Area (approximate)	29 ha	
Local Government Area	Shellharbour City Council	
Parish	Jamberoo	
County	Camden	
Current Zoning	Residential	
Proposed Site Use	Low density residential	
Current Site Use(s)	The site is currently vacant rural land.	
Surrounding Land Use	East	Rural properties
	West	Cooby Road
	North	Rural land
	South	Residential land

3.2. Local and regional geology and soil formation

The 1:250,000 geology sheet for Wollongong indicates the site is underlain by rock formations from the Shoalhaven Group, as shown in Figure 3. This includes the following:

- The higher elevated parts of the site are underlain by Bumbo Latite;
- The lower elevated parts of the site are underlain by the Berry Formation which includes siltstone, shale and sandstone.

The Kiama 1:50,000 Soil Landscape map (9028) (refer Figure 3) indicates that the site is underlain by the following main soil types:

- The southern part of the site is underlain by Bumbo Latite (Soil landscape referred to as Bumbo). Bombo latite is an igneous extrusive rock similar to basalt with little to no quartz present. Soils are comprised of shallow loams typically less than 50cm in depth on the crest of hills. On the upper hill slopes, the soils comprised of Krasnozems. Podzolic soils occur on mid and lower slopes;
- The northern part of the site is underlain by the Budgong Sandstone of the Berry Formation (Soil landscape referred to as Albion Park). The Budgong Sandstone comprises red, brown and grey volcanic-clastic sediments. Soils are typically comprised of brown Podzolic soils along crests with yellow Podzolic soils on mid-slopes. Soloths occur on foot-slopes and drainage lines.

The descriptions of the Bumbo and Albion Park Soil landscapes are provided in Appendix B. The main limitations to development associated with these soil landscapes are:

- Bumbo Soil landscape- Southern part of the site:
  - Low wet bearing strength
  - Typically moderate but some areas of high shrink swell potential
  - Low permeability
  - Hard setting
  - Sodicity
  - High erodibility
  - Steep slopes
  - Rock fall
  - Localised slope movement
- Albion Park Soil landscape - Northern part of the site:
  - Low wet bearing strength
  - Moderate Shrink swell potential
  - Hard setting
  - Sodicity
  - High erodibility
  - Localised steep slopes
  - Localised water logging
  -

The soil formation mapping which covers the site, indicates the main soil types encountered on the site are defined as erosional (refer figure 4).

The NSW EPA 'ESPADE site shows an existing borehole (154) located to the east of the site. This borehole encountered a shallow layer of cobbles underlain by dark brown clay loam to 0.3m depth and then dark brown sandy Clay.

3.3. Hydrogeology and groundwater useage

The surface hydrology (refer Figure 5) shows two un-named tributaries of Hazelton Creek flow through the site. One creek (Creek West) is located on the western part of the site, with two headwaters drainage depression located south of Cooby Road. A dam has been constructed on this tributary (Dam West). The other creek is located on the eastern part of the site (Creek East). This creek has a dam located within its headwaters (Dam East). Surface waters flow to the north-east, towards Hazelton Creek.

The depth to groundwater on the site is unknown. Perched water is likely to occur near the surface in some areas at the soil rock interface or within the topsoil with surface seepages generally associated with farm dams and drainage paths. A survey of groundwater bores (within a 500m radius of the site) registered with the NSW Office of Water indicates that a registered bore is located immediately of the west of Cooby Road as shown on Figure 6. This groundwater bore is known as GW017620.1.1. The subsurface profile encountered within this borehole identified rock (described as Marl, shale and sandstone) at depths below approximately 4m. Rock with extractable water was identified at approximately 7m to 44m depth. The borehole was terminated at approximately 44m depth.

3.4. Desktop salinity assessment

Based on reference to the NSW National Resources Atlas website (11/05/15), there is no evidence of salting in soil profiles located within 5km from site.

3.5. Acid Sulfate Soils

Review of the NSW Department of Lands acid sulfate soil (ASS) mapping showed no potential for ASS material to be naturally present on the site (refer Figure 7).

3.6. Topography, Slope Heat Mapping and Land Stability

The site is located on a ridgeline on the foot slopes of Stockyard mountain east of the Illawarra Escarpment. The ridgeline is typically south-east to north-west trending. Figure 8 shows the topography of the site as follows:

- Area 1: The middle southern part and western edge of the site are comprised of gentle sloping terrace. The main terrace located on the southern part of the site (Terrace 1A) is about 350m in width, falling to the north from an elevation of about 105m AHD to an elevation of about 80m AHD. Terrace 1A has been designated for residential and environmental living. The terrace located on the western part of the site is aligned with Cooby Road (Terrace 1B). Terrace 1B has been designated for rural interface. These terraces conjoin to the south of the site. The average fall in slope on both terraces is typically less than 4 degrees, but locally up to 8 degrees.
- Area 2: Immediately to the north, east, and west of Terrace 1A and east of Terrace 1B, the ridgeline falls at extremely steep to steep escarpment like slopes. The average fall on this slope is about 26 degrees but locally is up to 52 degrees. The ground level falls from about 80m to 44m AHD over a length of approximately 150m. This area has been designated for rural interface where adjacent to Terrace 1B and riparian zones where adjacent to Terrace 1A.
- Area 3: Immediately to the north, west and east of Terrace 1B is a gently sloping terraced area with an elevation between 44m and 40m AHD. The average slopes on this terrace are typically less than 5 degrees. This part of the site has been designated for residential and environmental living.
- Area 4: On the north-eastern corner of the site is a small hill. The hill has an elevation of about 70m AHD. This part of the site has been designated for residential living.

Slope heat mapping for the site is shown on Figure 9. This mapping shows:

- The site is mainly comprised of a large gentle sloping terrace (Terrace 1A) located within the middle southern part of the site. Another ridgeline from this terrace (Terrace 1B) is also located along the western site boundary and Cooby Road. Between these two terraces is a drainage depression.
- The slopes around Terrace 1A and Terrace 1B are between 25 and 60 degrees (eg steep to extremely steeply sloping) with some localised cliff-like slopes.
- The lower Terrace (Area 3) on the northern and eastern part of the site is gently to moderately sloping.
- The two dams on the site are visible within this figure. Dam West is located within the drainage depression between the two terraces.
- The hill on the north-eastern part of the site (Area 4) is surrounded by steep to extremely steeply falling slopes

The slopes of the Illawarra escarpment have been mapped on several occasions for landslide risk, since the early 1970s. The area for proposed development has been mapped by Neville in 1977 (Ref: Land Stability Assessment of the Kiama Area, Geological Survey of NSW- Dept. of Mines M76/2202). The definition of stability defined by Neville applicable to this site is as follows:

- Stable Land: Regions with slopes of 3 to 10 degrees. Includes minor areas with slightly steeper gradients, eg, near drainage courses. Slope instability is unlikely in the zone except where exceptional seepage occurs in thicker alluvial soils and/or plastic clays. The Terraces (Terrace 1A and 1B and area 3) have been mapped by Neville as within this category.
- Inherently Stable Land: Regions with moderate slopes of 10 to 15 degrees. Some areas of land instability to be expected. Instability most likely associated with thick accumulations of soil occurring at the head of gullies and at the toe of slopes, and in areas with slightly steeper slopes and/or exceptional seepage. Geotechnical investigation should precede development. Area 3 has been mapped by Neville as within this category.
- Potentially Unstable Land: Regions with steep slopes of 15 to 20 degrees. Excavation and/or fill placement or seepage could cause instability. Urban development is not recommended. Detailed geotechnical investigation must precede individual developments. Area 2 and Area 4 have been mapped by Neville as within this category

No areas within the site were mapped as "Unstable Land". Unstable land includes regions with slopes typically greater than 20 degrees where extensive and detail geotechnical investigation are required prior to development.

Figure 10 shows the mapping of the site as detailed by Neville. No recorded landslides were identified on or near the site (refer Figure 11)

3.7. Aerial Images

Historical aerial photography of the site (refer Appendix C) indicates the following:

- 1963: The site was in rural use. Area 2 and 4 were heavily vegetated with dense forests. Area 1 and 3 were cleared and vegetated with grasses.
- 1974: Creek West is visible on the site as an incised channel. A small dam is visible on the site to the south-west of Dam East. This dam is located within Terrace 1A and hereafter referred to as Dam South. The steep slopes within Areas 2 and 4 are still well vegetated.
- 1984: Creek West appears to be more incised into the ridgeline. There are some minor changes along the toe of the slopes within Area 2, possible associated with minor slope slippages along the toes of these slops.
- 1997: Dam West has been constructed. The area around Dam West and within the drainage depression has been cleared and is now vegetated with grasses. Dam East has also now been constructed. Dam South has reduced in size (possible due to silting). Vegetation within Area 2 and 4 has been reduced to open forest and shrubland.
- 2010: This image shows the extremely steep to cliff like ridgelines within Area 2. The density of vegetation within Area 2 and 4 has increased. Residential development is visible to the south of the site. Some erosion is visible to the east of Dam West, potentially associated with localised slope slippage.
- 2018: An access track has been constructed within Area 3. Erosion (possible Slippage to the east of Dam west appears to have transitioned further to the north. This may be associated with a track used by animals to assess the dam for water.

3.8. Site Observations

Observations of the site were made at the time of the site inspection. Photographs taken of the general site conditions are provided in Appendix D. The site can be divided into four areas. Observations within these areas are as follows:

Area 1 (refer Figure 12 and photographs 1 to 31) which includes Terrace 1A and Terrace 1B:

- The middle southern part and western edge of the site are comprised of gentle sloping terraces.
- The main terrace located on the southern part of the site (Terrace 1A) is about 350m in width, falling to the north from an elevation of about 105m AHD to an elevation of about 80m AHD (refer Photographs 1 to 14).
- Terrace 1A total area is about 5 Hectares and has been designated for residential and environmental living. It is proposed for potentially 50 to 100 residential lots of 300sqm to 600sqm and 6 to 20 environmental living lots between 1000sqm and 4000sqm in area.
- A dam (Dam South) is located on the northern part of Terrace 1A. The dam wall is typically less than 1m in height. There is active seepage downgradient to the north of the dam wall (refer photographs 1 to 5).
- Along the northern edge of the terrace (at the transition from Area 1 to Area 2), latite rock was visibly outcropping in many locations. The slopes were also extremely steep, with some rock outcroppings resulting in cliff /escarpment like slopes (refer Photographs 6 to 14). On the north-western corner of Terrace 1A, some seepage was also observed flowing along the shallow rock surface.
- The second terrace is located on the western part of the site and is aligned with Cooby Road (Terrace 1B). Terrace 1B is about 6ha in area and has been designated for rural interface with approximately 6 to 15 lots of an average of 1 Hectare. This terrace has an elevation in the south of about 105m, falling to about 75m AHD in the north. The fall across the site (from west to east) is typically less than 10m.
- Terrace 1B is comprised of two wider areas to the south (refer photographs 18-28) and north (refer photographs 29-31) connected by a narrow section of land (refer photographs 15-17).

- Along the western edge of the terrace (at the transition from Area 1 to Area 2), latite rock was visibly outcropping in many locations. The slopes were also extremely steep, with some rock outcroppings resulting in cliff / escarpment like slopes (refer Photographs 15-24). However, no active zones of seepages were observed.
- A dam appears to have been present on Terrace 1B within the middle of the terrace. This is visible as a slight surface depression.
- Terrace 1A and 1b conjoin to the south of the site. The average fall in slope on both terraces is typically less than 4 degrees, but locally up to 8 degrees.
- No signs of mass slope movement were visible (eg groups of leaning trees, tension cracks, debris piles). This is most likely due to the shallow depth to rock on this part of the site. However, where area 1 transitions to Area 2 (eg along the crest of the escarpment), seepage and near vertical rock slopes were visible indicating the potential for localised slippage and/or soil creep.

Area 2 (refer Figure 13) Extremely steep slope which transitions between Area 1 and Area 2:

- This part of the site is located immediately to the north, east, and west of Terrace 1A and east of Terrace 1B.
- To the north, east and west of Terrace 1A, this part of the site has been designated as a riparian zone. To the east of Terrace 1B, this part of the site has been designated for rural interface.
- The ridgeline within Area 2 typically falls at extremely steep to escarpment like slopes. The average fall on this slope is about 26 degrees but locally is up to 52 degrees. The ground level falls from about 80m to 44m AHD over a length of approximately 150m.
- Dense vegetation and cliff like slopes in places, made access to this part of the site restricted, accept for the tracks which had been constructed on the slope to allow access between Area 1 and Area 3.
- No signs of mass slope movement were visible (eg groups of leaning trees, tension cracks, debris piles). This is most likely due to the shallow depth to rock on the site. However, along the toe of Area 2, cobbles and small boulders were visible, indicating potential rock falls from the escarpment like slopes. And localised soil slippage. The slopes within this part of the site are likely to be subject to erosion and regression due to exposure to the environment.

Area 3 (refer Figure 14 and photographs 31 to 53) which includes the lower lying terraces on the northern part of the site and between Terrace 1A and 1B, down gradient of extreme steep slopes within Area 2:

- This part of the site is comprised of two sub areas designated for residential and environmental living as follows:
  - Lower valley slopes: these areas are comprised of gently to moderately sloping terraces with elevations that typically fall from about 60m AHD to 45m AHD. The average slopes on these lower terraces are typically less than 5 degrees. Residential living is proposed for these lower valley slopes within an area of about 4 ha, allowing development of between 75 and 150 lots.
  - Upper valley slopes: these are comprised of moderately to steeply falling slopes which are located where the site transition between Area 2 and the lower valley slopes. Environmental living is proposed along these upper valley slopes (eg along the toe of area 2) within an area of approximately 7 ha, allowing for development of between 18 and 65 lots between 1000sqm and 4000sqm in area.
- Several existing dams were visible within Area 3 as follows:
  - The main dam (Dam West - refer photographs 37-41) is located within a drainage depression between Terrace 1A and 1B, down gradient of Area 2. To the north-east of Dam West, a channel was visible which appears to form a spillway. Erosion and scour was visible along the channel. Along the toe of Dam West was an access road. A culvert had been constructed under the access road, and part cut into the toe of the downgradient dam embankment. Erosion was visible around this culvert. Downstream of the Dam West, is a creek. The creek was dry post heavy rainfall the week before, indicating it is most likely ephemeral to intermittently flowing. Erosion and scour were also visible within parts of this creek bed (refer photographs 42-44). No seepage was visible along the toe of the dam. Some hydrophilic vegetation was visible.
  - Two dams are located on the north-eastern part of Area 3 (refer photographs 48-52). These dams were mainly dry. No seepage was visible down stream of the dam. Some minor erosion was visible.
  - A dam (named Dame South-East) is located on the eastern part of the site (refer photograph 53). This dam was partly full of water. No signs of seepage were visible down stream. There were minimal signs of erosion.

- Several small intermittent/ephemeral drainage paths were visible flowing from Area 2 into Area 3. These flowed under the farm access road in some locations through culverts (refer photographs 45-47).
- There were no visible signs of large scale landslide or localised soil movement. Soil creep was visible on the slopes. Exposures within the slopes showed a subsurface profile comprised of colluvium and residual soils. Small boulders and cobbles were visible within the colluvium and on the ground surface. Localised soil slippage is deemed likely to occur in this area in association with steeper slopes and poor site drainage measures.

Area 4 (refer Figure 15 and photographs 61-64): Includes a small hill on the north-eastern corner of the site.

- The hill has an elevation of about 70m AHD.
- The slopes were typically moderate to steep. Boulders and cobbles of latite rock were visible on the ground surface.
- No signs of mass slope movement were visible (eg groups of leaning trees, tension cracks, debris piles). This is most likely due to the shallow depth to rock on the site. However, cobbles and small boulders were visible, indicating potential local slippage and rock fall from the slopes.

4. Review of geotechnical reports for nearby sites

Terra Insight has access to geotechnical information for the development of Lot 662 on the Illawarra Highway, Tullimbar which is located to the north-east of the site at an elevation of about 20m below Area 3. The geotechnical information available for this site is detailed in the following section.

4.1. Lot 662 DP1168919 Illawarra Highway, Tulimbar NSW

The general subsurface conditions encountered during this investigation comprised the following:

- Topsoil: 0.1 to 0.3 thick
- Alluvium: only encountered locally up to 2.4m thick associated with natural drainage paths;
- Colluvium: only encountered locally up to 1.3m thick associated with lower slopes;
- Residual soil / extremely weathered rock; encountered to depths between 0.4 and 2.6m, deeper where colluvium and alluvium is present. Typically, 1.0 to 1.7m thick.

The subsurface conditions encountered during this investigation were found to be generally consistent with the 1:2500,000 geology for the area. The alluvium and colluvium were typically derived from the residual soils / weathered rock found within the more elevated parts of the property or uphill of the property. No significant wet zones or groundwater inflows were observed in the test pits undertaken during the site investigation. However extensive seepages were observed over the site associated with farm dams. Erosion was visible and typically associated with surface drainage paths evident on the property. In some of these areas, the ground surface was saturated and boggy.

Laboratory tests on materials taken indicated that the alluvial soils on this property have a shrink swell index of about 5%; shrink swell is lower, about 3.5%, for the residual soils. The CBR test results varied from 1 to 3% with swells varying from 2.5% to 9%. The higher swells are associated with the lower CBR values.

5. Geotechnical Site Characterisation

5.1. Interpreted subsurface conditions by Terrain Units

The Site is located on a hill side area with the depth to rock expected to be relatively shallow. The soil profile likely to be encountered across the site will be comprised of:

- Topsoil: Comprised of a shallow (or absent) organic soil layer and a thin layer of topsoil (which form the O and A soil horizon layers respectively); underlain by
- Colluvium: A layer of silty clay with cobbles and gravels (found mainly in area 3) underlain by;

- Residual Soil: A shallow to moderate subsoil (within the B horizon) which grades into
- Weathered Material (the parent material also referred to as the C horizon) which grades into less weathered rock.

Some alluvium may also be locally encountered along the lower valley slopes and near drainage channels within Area 1. Some colluvium will also be encountered along the lower foot slopes of Area 2.

Geomorphology has been used to divide the Site into Terrain Units. These Terrain unit are used to define parts of the Site with similar:

- Topography;
- Landslide risk;
- Subsurface geology; and
- Subsurface soil profiles.

Review of the geology and surface observation indicates the site can be divided into the following terrain units:

- **Terrain Unit 1 - Elevated Terraces within Area 1:**
  Gently graded upper hill slopes and terraces underlain by shallow residual soils (< 1m thick) and Latite;
- **Terrain Unit 2 - Upper escarpment slopes within Area 2:**
  Steeply to extremely graded upper hill slopes underlain by shallow residual soils (1 m thick) and Latite. Rock may locally outcrop on the steeper parts of the slopes;
- **Terrain Unit 3A - Upper Valley slopes to lower escarpment slopes within Area 3 and Area 4:**
  Moderately to steeply graded upper valley slopes underlain by colluvial soils (< 1.5m thick), residual soils (< 1.0m thick) with rock (latite and rocks from the Berry Formation) expected at depths between 1.5 and 2.5m.
- **Terrain Unit 3B - Lower Valley Slopes within Area 3:**
  Gently to moderately graded lower hill slopes underlain by alluvial soils (< 1.5m thick) locally around drainage channels, colluvial soils (< 1.0m thick), residual soils (< 1.0m thick) and with rock from the Berry Formation expected at depths between 2.0 and 3.5m.

A summary of the Terrain Units is shown on Figure 12.

Residual soil within Area 1 (Unit 1) on the upper slopes were observed during the site walkover to be comprised of silty clays of medium plasticity. These soils are mapped on the Kiama Soil Landscape mapping as Krasozems (also known as red ferrosols). These soils are typically comprised of red to brown highly structured kaolinite mineral based clayey loams to loams that are typically of low reactivity. These soils are likely to be of shallow to moderate depth (< 0.5m on the crest of slopes increasing to 1.0m depth on upper slopes).

No surface soils were observed during the site walkover on the upper slopes with Area 2 due to the steep nature of the slopes. On the lower slopes of Area 2 and upper slopes of Area 3, the soils were comprised of are colluvial silty clays and sandy clays with cobbles. These near surface soil mapped on the Kiama soil Landscape map are comprised of brown Podzolic and yellow Podzolic soils (also known as Podosols). These soils typically have about 35% or more clay throughout the soil profile, are typically of low permeability, and slightly alkaline. The B horizon of these soils (below the organic and topsoils) is dominated by an accumulation of organic matter, aluminium and/or iron. Colluvial soils within 3A, derived from the latite rock upgradient, are expected to be of medium to high plasticity.

Within Unit 3B, the soils were observed to be comprised of colluvial silty clays and sandy clays with cobbles. These soils are mapped on the Kiama Soil Landscape map as comprised of Soloths. These soils are similar to solidic (sodosols) soils but typically are slightly acidic, containing appreciable exchangeable aluminium which makes them unlikely to disperse. However, significant erosion was visible on parts of the site within these soils, typically in association with drainage. Colluvial soils derived from the Berry Formation within Unit 3B are expected to be of low to moderate plasticity.

6. Preliminary Landslide Risk Assessment

6.1. Introduction

This landslide risk assessment relates to the proposed subdivision of site and was carried out generally in accordance with the risk assessment method described in Appendix C of the journal, Australian Geomechanics, Vol. 42, No. 1, dated March 2007. Important information in relation to the use of this risk assessment method is provided in Appendix E of this report.

Assessment of landslide risk considers the frequency and consequences of particular failure events. The landslide risks considered herein, are those that directly impact on existing and proposed development of the site.

The onus is on the owner (or potential owner or party) to decide whether the assessed level of risk is acceptable, considering possible economic consequences of the risk and geotechnical constraints. The following is noted:

- Terrain Unit 1 is typically located within regions of stable land;
- Terrain Unit 2 are typically in regions of inherently stable or potentially unstable land.
- Terrain Unit 3 is typically located within regions of stable land

6.2. Potential landslide risks

Desktop studies using aerial photo, stability maps, and survey from Google Earth do not show any obvious signs of past deep-seated instability within the site boundaries. However, this information does show potential landslide activity (small slips and rock falls) from within Area 2 and small slips and soil creep within Area 3 and 4.

Based on AGS 2007, recent site observations and knowledge of slope conditions in the general area, potential landslide hazards/ events that could affect this site at the time of the assessment include:

- Terrain Unit 1 (includes Terrace 1a and 1b within Area 1):
  - Localised soil creep;
  - Localised failure along crest of slope
  - Large scale slope failure within Area 2 (Terrain Unit 2).
- Terrain Unit 3A (includes upper valley slopes within Area 3, and Area 4):
  - Localised soil creep;
  - Local failure of slopes;
  - Rock fall; and
  - Large scale slope failure uphill or downhill the areas.
- Terrain Unit 3B (includes lower valley slopes within Area 3):
  - Localised soil creep;
  - Localised failure of slope within Area 2;
  - Rock falls from within Area 2;
  - Large scale slope failure uphill or downhill from the Area

The likelihood of the above hazards/landslide events occurring and the possible consequences to future property are assessed as follows in Table 5.1. This table does not include including locally steep banks of watercourse, access road embankment and farm dam batters. Landslide within Area 2/terrain unit 2 has not been considered as this area is not proposed for development. The impact of landslide from Area 2/Terrain unit 2 on areas adjacent, however, has been considered.

6.3. Risk to Property

Risk to property is assessed based on the proposed conditions of the site, including any risk management implemented as part of the proposed additions to the site. As there is no structure currently on this part of the site, the existing risk has not been assessed.

Risk assessment for property loss was undertaken using the Risk Matrix according to AGS (2007). The Risk Matrix defines a qualitative terminology for likelihood, consequence and risk. The frequency estimate is expressed as an annualised probability, considering the probability of spatial impact and is expressed qualitatively as likelihood.

The result of this assessment is summarised in Table 4.1. As the structures proposed are mainly residential buildings and residential infrastructure (roads and utilities), an assigned Importance Level of Structure of 'Two' has been adopted in accordance with AGS, 2007 (Appendix D, pg 86). This assessed level of risk post the proposed site works, is based on the advice provided within this report being implemented on the site (refer section 5).

Table 6-1: Landslide event - current and future likelihood and consequences to property

Case	Event	Likelihood	Consequences to property*	Level of Risk
Terrain Unit 1				
Localised soil creep		Possible	Insignificant	Very Low
Local failure of slopes along crest.		Likely	Minor	Moderate
Large scale slope failure		Rare	Major	Low
Terrain Unit 3A				
Localised soil creep		Likely	Minor	Moderate
Local failure of slopes.		Possible	Minor	Moderate
Rock Falls		Possible	Minor	Moderate
Large scale slope failure		Unlikely	Major	Moderate
Terrain Unit 3B				
Localised soil creep		Possible	Insignificant	Very Low
Local failure of slopes.		Unlikely	Minor	Low
Rock Falls		Unlikely	Minor	Low
Large scale slope failure		Rare	Major	Low

Note to Table: * It is assumed that the recommendations in Section 7 are adopted/implemented.

The risk assessment above has assumed the following:

- Dwellings will not be constructed on the crest of Terraces 1a and 1B. It is assumed a road corridor will be constructed with a reserve between the road and crest of the slope.
- Dwellings will not be constructed within Terrain Unit 2 (Area 2).
- Building envelops suitable for development will be identified by further investigation within Terrain Unit 3A.

7. Geotechnical Engineering Assessment

7.1. Geotechnical constraints and opportunities

The key issues to facilitate development of the Site are:

- Management of surface stormwater runoff and surface seepages across the Site; and
- Management of extremely steep to cliff like slopes within Terrain Unit 2;
- Establishment of building envelopes suitable for development with the steep slopes Terrain Unit 3A.

Terrain Unit 2 has a high risk of landslide. Parts of Terrain Unit 2 could be encompassed into allotments zone as rural buffer. However, inclusion of these areas within rural interface lots could result in vegetation removal which may result in localised destabilization of soils on the slopes within Terrain Unit 2 (Area 2). It is therefore recommended that most of Area 2 (terrain Unit 2) is utilised as a riparian zone or designated not for development and used as green space within the residential development. Parts of Area 2 can also be used for access roads, utility (service) corridors and non-habitable structures subject to recommendations in the following sections of this report.

Terrain Units 1 and 3B are assessed as most suitable for residential development. The following geotechnical constraints and opportunities have been identified for these parts of the site:

- Terrain Unit 1:
  - The shallow depth to rock (potentially < 1.0m) on the upper terraces provides reasonably shallow foundation depths on these parts of the site and provides a potential source of low reactivity fill, depending on the extent of earthworks in these areas;
  - Soft wet and saturated soils and extensive reed/weed growth will need to be removed from each of the farm dams after de-watering. The extent of material requiring removal will need to be assessed after dewatering;
  - Early de-watering of farm dams and provision of shallow open drains to assist in drainage of surface seepages is recommended;
- Terrain Unit 3B:
  - Low subgrade CBR values for the clay soils with high swells are likely to govern pavement design, unless subgrades can be formed wholly in the weathered rock;
  - High shrink swell indices for soils on the lower lying areas could result in Site Classifications of H1 or greater;
  - The composition and moisture condition of the fill below the pavement in the access road embankment and in the dam embankments will need to be assessed for potential re-use;
  - Soft wet and saturated soils and extensive reed/weed growth will need to be removed from each of the farm dams after de-watering. The extent of material requiring removal will need to be assessed after dewatering;
  - Early de-watering of farm dams and provision of shallow open drains to assist in drainage of surface seepages is recommended;
  - The potentially moderate depth to rock (< 2 to 3m) provides reasonably foundation depths. On the upper hill slopes, the shallow to moderate depth to rock provides a potential source of low reactivity fill, depending on the extent of earthworks in these areas.

Development within Terrain Unit 3A is also deemed possible but should be limited to larger environmental living and rural interface allotments. The following geotechnical constraints and opportunities have been identified for these parts of the site:

- Terrain Unit 3A:
  - The potentially moderate depth to rock (< 2 to 3m) provides reasonably foundation depths. On the upper hill slopes, the shallow to moderate depth to rock provides a potential source of low reactivity fill, depending on the extent of earthworks in these areas.
  - This part of the site is most at risk from rock falls from slopes within Area 2 / Terrain Unit 2. A catch berm or trench along the toe of slopes within area 2 is recommended to capture any small boulders or cobbles that may detach from the extremely steep slopes upgradient from Terrain Unit 3A. This ditch or berm could potentially be constructed as part of a road and drainage system (eg the access road could be constructed on the upper slope rather than lower slopes on the northern part of the site).

7.2. Landslide Risk Evaluation and Management

The qualitative measure of the consequences to property will depend on the final design and construction methods adopted for the residential development. However, for this assessment, assuming recommendations provided in this report are followed, the implied level of risk to property is assessed as :

- Low for residential dwellings constructed within Terrain Units 1 and 3B;

- Moderate for road infrastructure constructed within Terrain Unit 1 but near the boundary between Terrain Units 1 and 2; and
- Moderate for residential building constructed within Terrain Units 3A.

Localised instability of the existing access road embankment and farm dam batters, and the steep creek banks could occur, although these batters are likely to be modified or removed during development. **Geological mapping of the rock exposed within Terrain Unit 2 should be undertaken to identify the potential for rock falls and slips and to access potential travel distance.**

For residential habitable buildings (Importance level 2 structures), the AGS recommends a 'low' level of risk associated with damage to property. Residential development in Terrain Unit 1 and 3B is therefore deemed to be associated with an acceptable level of risk. It is also common for many council to accept a moderate level of risk where the risk of landslide is managed as low as reasonable practical (ALARP). Consequently, residential development within Terrain Unit 3A is deemed to be within the tolerable range. Construction of non-habitable structures (roads etc) are classed as Importance level 1 structures and can accept a moderate level of risk. Construction of these structures within Zone 3A and Zone 2 is therefore deemed tolerable

Guidance on the good hill side practice for residential developments on sloping Site is provide in LR08 AGS guide (refer Appendix F) and should be followed.

7.3. Surface Protection, Storm Water and Vegetation

On-site disposal of storm-water by concentrated soakage is not recommended within Terrain Unit 3A based on the increased risk of slope instability and potential for reactive clay movement. Subsoil drainage is recommended on the upslope side of pavements to limit the ingress of seepage into subgrades and pavement materials.

Surface water flows, which could occur downhill toward developed areas, should be diverted around these areas and trained to flow away from proposed areas to be residentially developed.

Exposed soil within Terrain Unit 3A will need to be protected from erosion, by means of directing surface water to the lower part of the slopes and revegetating the surface with grasses or small to medium sized plants. Sick or dying trees, which may fall, should be removed before they can impact on the slope.

7.4. Footings Design Considerations

7.4.1. Site classification

Site classification, in accordance with AS2780, requires detailed investigation of each proposed residential lot, which at the conceptual stage is not feasible. In addition, the site classification of lots is likely to change because of earthworks undertaken on the site during residential sub-division and development.

At this stage, a preliminary assessment of site classifications likely to be associated with the site has been undertaken. This preliminary assessment has identified the following:

- Terrain Unit 1: The limited depth of residual soil overlying rock on this part of the site should result in site classifications of Class A where less weathered latite rock is exposed. Where rock is not exposed, building envelopes which provide site classifications within the Class S to Class M range should be feasible.
- Terrain Unit 2: Parts of this Terrain Unit will not be suitable for development due to landslide risk.
- Terrain Unit 3A: Parts of this Terrain Unit will have a moderate landslide risk. Further investigation should be targeted at identifying suitable building envelopes with low landslide risk. As this part of the site is located on sloping ground with some risk of slope instability, a site classification of P is appropriate at this stage. The hill slopes are underlain by colluvial and residual clay soils typically of low to medium plasticity with thickness typically less than 2.0m. Seasonal movements are expected to be within the range of 20 to 60mm.

- Terrain Unit 3B: The low lying portions of the site contain clays of medium to high plasticity and of thickness typically greater than 1.5m. Within these areas, fill is also likely to be placed. Where possible, low plasticity fill should be placed in the upper fill layers towards the final ground surface to optimise the site classifications for this part of the site. Site classifications for lots within this portion of the site will likely range from M to H2 and will be highly dependent on the type and depth of fill placed.

7.4.2. Footing design parameters

Shallow footings should be feasible within Terrain Units 1 and 3B. Suspended slabs supported on piers should be feasible within parts of Terrain Units 3B. Piers should be able to bear on stiff residual clayey material or weathered rock. **Geotechnical investigation should be undertaken to confirm the strength/consistency and reactivity/plasticity of the soils which underlie the site.**

7.4.3. Footing maintenance

Appendix B of AS 2870-2011 indicates that to reduce but not eliminate the possibility of damage, trees should be restricted to a distance from proposed building of at least ¾ × the mature height. Where rows or groups of trees are proposed, the distance from the building should be increased.

Designs and design methods presented in AS 2870-2011 are based on the performance requirement that significant damage can be avoided if Site conditions are properly maintained. Performance requirements and foundation maintenance are outlined in Appendix B of AS 2870.

Design of street scape vegetation should consider the proximity of vegetation to building envelopes. To avoid extremes of wetting and drying, details on appropriate Site and foundation maintenance practices are presented in Appendix B of AS 2870-2011 and in CSIRO Information Sheet BTF 18, Foundation Maintenance and Footing Performance: A Homeowner's Guide, which is attached as Appendix G.

7.5. Pavement Design considerations

7.5.1. Design subgrade CBR

Shellharbour City Council's Engineering Design Specification D2 'Pavement Design' (November 2004) requires assessment of design CBR for each subgrade area using the following formula:

Design CBR = Least of estimated equilibrium CBRs, for less than five results

The proposed design CBR documented herein assume good drainage conditions for the clayey soils and that drainage is maintained throughout the pavement design life. **Based on field observations, a design CBR of 3 to 5% should be achievable for internal roads within Terrain Units 1, 2 and 3A. A conservative design CBR of 1% for the internal roads within Terrain Unit 3B should be adopted.**

The design CBR for Terrain Unit 3B is based on pavement investigations for a similar site to the north where the soils were comprised of medium to high plasticity silty clays of similar geological setting. Laboratory testing on these soils included three (3) CBRs with test results ranging from 1.0% to 3.0%. It is noted that swells were also recorded during this CBR testing, indicating that the high plasticity clay soils are highly sensitive to moisture ingress, and therefore we recommend that these soils should be removed where encountered and be replaced with a select subgrade material or alternatively the subgrade should be stabilised by the use of lime.

It is recommended that a detailed pavement investigation be conducted on the site when the proposed alignment and design subgrade profiles of the roads are confirmed.

7.5.2. Shellharbour City Council subdivision design code

This report provides specific guidance on pavement requirements from the geotechnical perspective. This report does not provide a comprehensive overview of all the pavement requirements as per the Shellharbour City Council Subdivision Code. The Shellharbour City Council Subdivision Design Code (SCCSDC) provides guidance on pavement construction works within the Shellharbour LGA and should be referred to by constructors and civil designers of pavements within the subdivision. Pavements for roads and accessways within the site will need to consider projected traffic movements and the subgrade conditions following preliminary earthworks.

A preliminary pavement thickness design based on Austroads (2008) design guidelines using the unimproved design subgrade CBR of 1% over an assumed traffic loading (ESAs) for a *minor* (6×10^4), *local access* (3×10^5) and *collector* (1×10^6), the total minimum thicknesses of unbound subbase and base materials would be >470mm, >550mm, and >640mm, respectively.

We note that the assumed design subgrade CBR is relatively very low, other treatment measures such as thicker asphalt, lime stabilisation of the subgrade or over-excavation /subgrade replacement may be required.

7.5.3. Pavement construction requirements

Construction of flexible pavements should comply with the following recommendations:

- In areas where poor subgrade conditions exist, replacement of the upper 300mm to 500mm may be required using coarse well graded crushed rock materials(75mm minus), in combination with geotextile and geogrid. Alternatively the clay subgrade material will need to be stabilised in situ. Once the subgrade soils are exposed they may soften and deteriorate rapidly if exposed to rain or experience significant cracking if allowed to dry in warm dry weather;
- Where General Fill is required it should be placed to the required thickness in layers, using either a method specification (if coarse materials are used) or using a testing specification (if finer materials are used). If a testing specification is used, layers should be maximum 200mm thick compacted thickness, and materials should be compacted to the required density ratio at a moisture content of -2% to + 2% of OMC.

For General Fill Zone materials, the use of imported or borrow materials from the site could be considered as follows:

<u>General Fill Zone Option 1 – use of 75mm minus quarry product as General Fill</u>

If during boxing of the subgrade in readiness for pavement construction, the remaining clayey subgrade soils are significantly over-moist or water inflows occur and there is a requirement for significant 'over-excavation' of unsuitable materials, then a 75mm minus quarry product (or other product in liaison with the Geotechnical Engineer) can be considered for use as a replacement material. This product should be well graded, should allow compaction to be readily achieved with a tight surface and very low air voids. This material should be placed to a thickness sufficient to achieve adequate proof rolling performance with a 12 tonne static mass smooth drum roller.

<u>General Fill Zone Option 2 – use of imported or site borrow material achieving CBR of at least 10%</u>

If during stripping of topsoils and box-out to subgrade level in readiness for pavement construction, the exposed clayey subgrade soils are not significantly over-moist, and there is no requirement for significant 'over-excavation' of unsuitable materials, then the use of material having a minimum CBR of 10% could be considered for use as General Fill comprising:

- Well graded crushed rock or natural gravel or weathered rock materials that can be tested for in situ density by the nuclear density gauge, or alternatively be assessed using a method specification such as proof rolling and observation by an experienced geotechnician;
- Materials having a maximum particle size of 75mm, with not greater than 20% of the material larger than the 37.5mm sieve; and
- Materials approved for use by the Geotechnical Testing Authority prior to construction.

7.5.4. Drainage measures and pavement performance

Standard pavement lives of 20 years for flexible pavements and 40 years for rigid pavements are suggested as baseline values for typical pavements in Austroads (2008). However, the SCC pavement design life typically adopted is 50 years. The practicality of designing a pavement to last for a 50 year design life constructed over clayey subgrades which may occur within Terrain Unit 3, is heavily dependent on long term control and maintenance of the moisture content of the subgrade materials and maintenance of good drainage at this site.

In order to achieve a 50 year design life, it is important that table drains (where there is no kerb and gutter) or subsoil drains (where kerb and gutter is proposed) are provided along both sides of each road where the road surface is close to or below the surrounding ground levels. Subsoil drains should outlet into the nearest stormwater drainage pit, provided there is sufficient fall. Details of subsurface drainage requirements should be further refined once the extent of groundwater seepages encountered during road and drainage construction has been assessed.

Surface maintenance of any asphalt wearing course and table drains will be periodically required. This would include localised infilling of minor surface cracks in the wearing course with emulsion routinely applied as part of normal pavement maintenance measures. Trees and vegetation should be excluded from pavement verge areas or traffic islands if their roots are assessed as likely to enter subgrade areas beneath the road during the design life of the pavement.

7.6. Earthworks

7.6.1. Waste minimisation

Waste materials are likely to be generated as a result of initial site earthworks and during the construction of roads and service trenches.

Site cut and fill earthworks should be balanced where possible to reduce the amount of waste materials produced which need offsite disposal. Weathered rock exposed during earthworks on the upper hill slopes could provide a suitable source of fill of low reactivity. However, this material is likely to be of limited supply and should be used wisely.

To minimise the costs associated with pavement construction and the installation of services (including off-site disposal of materials), it is preferable to minimise the disturbance of the in situ soils and/or re-use these in situ materials where possible.

The clayey alluvium and colluvium soils underlying the site would generally not be considered suitable for use as general or select fill due to low CBR values and high plasticity. These clayey materials would require further treatment if they are to remain in situ. This treatment may include in lime stabilisation in roads.

7.6.2. Site preparation

Vibratory rollers should not be used within 40 m of any existing residential structures or similar structure, unless a trial is conducted with vibration monitoring occurring at the nearest residence. Static rolling of fill and pavements should be carried out within 40 m of any existing buildings. At present, only a few buildings to the south of the site are likely to be affected by vibrating rollers.

The installation of stormwater drains and the sewer will involve some trenching under or close to roads and within residential lots along or close to boundaries. Drainage or sewer trenches deeper than 1 m may need to be benched or may require temporary support (shoring).

Backfilling of trenches should be carried out to Shellharbour City Council's subdivision design specification (SCCSDS) or the pipe manufacturer's specification using suitable select materials around the pipe and fill approved by the geotechnical engineer. Suitable backfill above the pipe would include soils or rock (less than 100 mm maximum particle size) excavated from the trenches subject to separation and discarding of any vegetation, topsoils, saturated soils or large rock fragments before placement.

Zones of seepages were noted near existing dams. Any areas where groundwater seepages are discovered during the earthworks may require subsoil drainage or other treatment to allow earthworks to proceed in the area. Clay soils exposed during construction may become soft and wet during and following rain.

Subsoil drainage should be provided at least along the uphill edge of all roads, with additional lines (possibly on both sides) where roads are aligned perpendicular to the contours, or where groundwater seepages occur randomly over the hillside.

7.6.3. Excavation

The ease with which materials can be excavated on site has been assessed in accordance with Kirsten's "Classification for the excavation of natural materials" (1992), as shown in Table 7.1.

We anticipate that excavation depths over the site will be relatively minor, up to approximately 1m below existing surface levels. Some localised deeper excavations may be required for service trenches and other associated infrastructure.

The fill, topsoil, alluvium, colluvium and residual materials encountered on site are expected to be Class 2 to 3 materials and should be readily excavated by backhoe or small excavator, whilst the highly weathered rock below is expected to be Class 4 to 5. Our local experience indicates that a Class 4 or 5 materials can be excavated with a 25 to 30 Tonne excavator with a rock hammer or ripped with a D7 to D8 dozer. Rock strength will increase with depth. **Further investigation should be undertaken to confirm the depth to highly weathered rock.**

Table 7.1: Kirsten's Eight Point Excavation Classification System

Class	Material Type	Description of Excavatability
1	Soil / Detritus	Hand spade (Dozer D3)
2		Hand pick and spade
3		Power tools
4	Rock	Easy ripping (Dozer D7)
5		Hard ripping (Dozer D8)
6		Very hard ripping (Dozer D9)
7		Extremely hard ripping / blasting (Dozer D10)
8		Blasting

7.6.4. Filling

Fill materials to be placed on the site are likely to comprise:

- general fill;
- select or structural fill;
- trench backfill materials; and
- pavement materials.

Fill should be placed in accordance with the following:

- Density and compaction testing should be undertaken on all fill placed in road formations, building lots and stormwater / sewer trenches. Where filling is proposed within building lots and road formations, the proposed fill material should be approved by a geotechnical engineer prior to placement. Density and compaction testing of the fill should be carried out on each 200mm thick layer of the compacted fill. Proof rolling of each layer should also be carried out using a smooth drum or pad foot roller of at least 12 tonne mass, without vibration;
- Density testing of fill should be carried out at the rate of three tests per visit or one test every 2000m2, whichever is the greater. If full time geotechnical supervision of the fill occurs then a minimum three tests per day will be sufficient;
- Density testing should be undertaken on pavement subgrades, subbase and base layers;
- Benkelman Beam testing of pavements on completion of pavement base is recommended.
- Where fill is to be placed continuously in lots or roads, geotechnical supervision to 'Level 1' is recommended, as defined in AS3798 – Guidelines on Earthworks for Commercial and Residential Developments. However, where the placement of fill occurs in small stages or placement is slow or delayed due to weather or other restrictions, geotechnical supervision to Level 2 could occur;
- For roadworks (other than general filling) and for stormdrain and sewer trench backfills, geotechnical supervision to Level 2 is recommended as defined in AS3798.
- Where the fill material has a grading with more than 20% coarser than 37.5mm, a method specification should apply; and
- Where the fill has less than 20% of particles coarser than 37.5mm and can be tested for in situ density by nuclear gauge, then the materials should be tested in accordance with the SCCSDC.

Fill materials should be placed at the required compaction ratios as set by the SCCSDC as outlined in Table 7.2.

Table 7.2: Minimum Compaction Requirements

Description	Compaction Requirements
Pavement - Base	Minimum 98% Modified
Pavement - Sub-base	Minimum 95% Modified
Subgrade (top 300mm) and Select Material Zone	Minimum 100% Standard
General Fill Zone (deeper than 300mm below top of subgrade)	Minimum 98% Standard
General fill placed within residential lots at least 0.3m below final design level	Minimum 95% Standard

7.6.5. Site preparation

Ground preparation should allow for the stripping of topsoil and uncontrolled fill (if deemed required) from structural footprints. Stripped soil would not be suitable for structural fill and must be processed to exclude cobbles and foreign material (where present) and then used for landscape applications if determined to be suitable for this purpose.

Surplus excavated materials may need to be exported or disposed of off the Site. Structural fill should be compacted in layers not exceeding 200mm thick compacted thickness to achieve a minimum density ratio of not less than 98% standard dry density (SDD).

Construction during Site preparation works may impact on the existing trees. This may result in disturbance to the soil and changes to in situ moisture regimes which will need to be considered in the preparation of subgrades for pavements on the western side of the Site.

7.6.6. Temporary and permanent retention of slopes

Temporary and permanent slopes may be required for the development as recommended in Table 7.3. Cut and fill batters in excess of 1.0m in height may require retention by structural retaining walls.

Table 7.3: Design Slopes for Cut/fill Slopes

MATERIAL DESCRIPTION	PERMANENT SLOPES	TEMPORARY SLOPES
Fill	1V:3H	1V:2H
Topsoil	1V:3H	1V:2H
Alluvium/Colluvium	1V:3H	1V:2H
Residual Clay	1V:3H	1V:2H
Extremely Weathered Rock	1V:2H	1V:1.5H
Highly to Moderately Weathered Rock	1V:1H	1V:1.5H

8. Conclusions and Recommendations for Further Assessment

The site can be divided into four areas based on topography (refer Figure 8) and the proposed development (refer Figure 2) as follows:

- Area 1: The middle southern part and western edge of the site are comprised of gentle sloping terrace. The main terrace located on the southern part of the site (Terrace 1A) is about 350m in width, falling to the north from an elevation of about 105m AHD to an elevation of about 80m AHD. Terrace 1A has been designated for residential and environmental living. The terrace located on the western part of the site is aligned with Cooby Road (Terrace 1B). Terrace 1B has been designated for rural interface. These terraces conjoin to the south of the site. The average fall in slope on both terraces is typically less than 4 degrees, but locally up to 8 degrees.
- Area 2: Immediately to the north, east, and west of Terrace 1A and east of Terrace 1B, the ridgeline falls at extremely steep to steep escarpment like slopes. The average fall on this slope is about 26 degrees but locally is up to 52 degrees. The ground level falls from about 80m to 44m AHD over a length of approximately 150m. This area has been designated for rural interface where adjacent to Terrace 1B and riparian zones where adjacent to Terrace 1A.
- Area 3: Immediately to the north, west and east of Terrace 1B is a gently sloping terraced area with an elevation between 44m and 40m AHD. The average slopes on this terrace are typically less than 5 degrees. This part of the site has been designated for residential and environmental living.
- Area 4: On the north-eastern corner of the site is a small hill. The hill has an elevation of about 70m AHD. This part of the site has been designated for residential living.

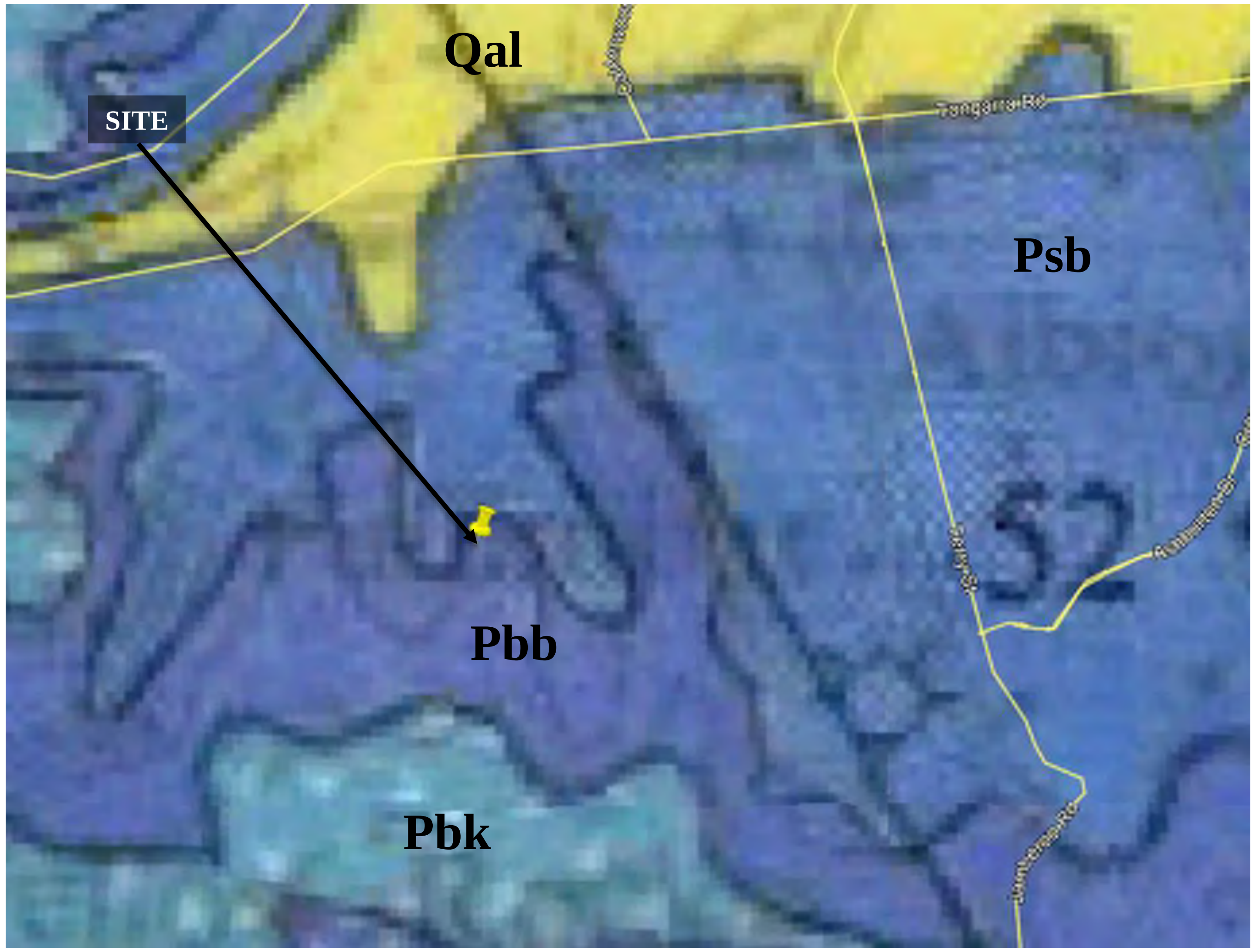
Based on the results of landslide risk, subsurface geology, and site observations, the conditions likely to be encountered on the site have been classified into the following Terrain Units (refer Figure 16):

- **Terrain Unit 1 - Elevated Terraces within Area 1:**
  This includes gently graded upper hill slopes and terraces underlain by shallow residual soils (< 1m thick) and Latite. These areas typically have a low risk of landslide and are deemed suitable for residential development (except for areas immediately adjacent to the transition between Terrain Unit 1 and Terrain Unit 2 which can be adopted for road corridors). The limited depth of residual soil overlying rock on this part of the site should result in site classifications of Class A where less weathered latite rock is exposed. Where rock is not exposed, building envelopes which provide site classifications within the Class S to Class M range should be feasible. A design CBR of 3% should be adopted for conceptual pavement design;
- **Terrain Unit 2 - Upper escarpment slopes within Area 2:**
  This includes steeply to extremely falling (sometimes escarpment like) upper hill slopes underlain by shallow residual soils (typically < 1 m thick) and Latite. Rock may locally outcrop on the steeper parts of the slopes. This area is assessed as unsuitable for residential development. Although parts of Terrain Unit 2 can be accommodated within rural interface and environmental living allotments, it is recommended that most of this land is and should be utilised as greenspace and/or riparian zone due to a high risk of localised land instability and rock fall.
- **Terrain Unit 3A - Lower escarpment slopes within Areas 2 and 4 and upper valley slopes within Area 3:**
  This includes moderately to steeply graded upper valley slopes underlain by colluvial soils (< 1.5m thick), residual soils (< 1.0m thick) with rock (latite and rocks from the Berry Formation) expected at depths between 1.5 and 2.5m. These areas typically have a moderate risk of landslide and are deemed suitable for environmental living residential development (except for areas immediately adjacent to the transition between Terrain Unit 2 and Terrain Unit 3A which can be adopted for road corridors and drainage). As this part of the site is located on sloping ground with some risk of slope instability. A site classification of P is appropriate at this stage. Seasonal movements are expected to be within the range of 20 to 60mm. A design CBR of 3% should be adopted for conceptual pavement design.
- **Terrain Unit 3B - Lower Valley Slopes within Area 3:**
  This includes gently to moderately graded lower hill slopes underlain by alluvial soils (< 1.5m thick locally around drainage channels), colluvial soils (< 1.0m thick), residual soils (< 1.0m thick) and rock from the Berry Formation (expected at depths between 2.0 and 3.5m). These areas typically have a low risk of landslide and are deemed suitable for residential development. The low lying portions of the site contain clays of medium to high plasticity of thickness typically greater than 1.5m. Within these areas, fill is also likely to be placed. Where possible, low plasticity fill should be placed in the upper fill layers towards the final ground surface to optimise the site classifications for this part of the site. Site classifications for lots within this portion of the site will likely range from M to H2. A design CBR of 1% should be adopted for conceptual pavement design.

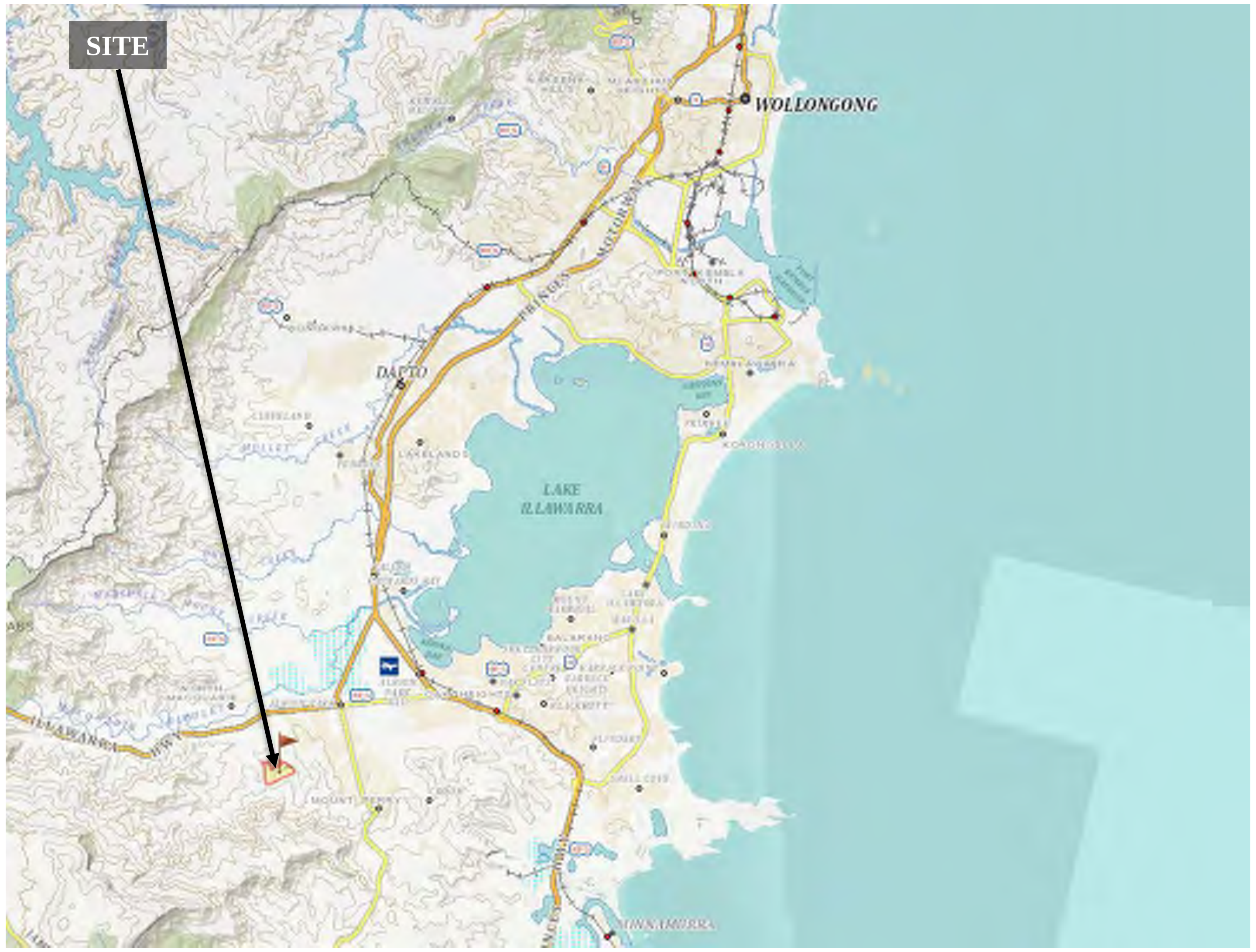
The following is recommended:

- A subsurface investigation to confirm the subsurface conditions within the Terrain Units including the strength/consistency and plasticity/reactivity of the soils which underlie the site;
- A detailed pavement investigation to confirm subgrade conditions and design CBRs when the proposed alignment and design subgrade profiles of the roads are confirmed.
- Geological mapping of the rock exposed within Terrain Unit 2 should be undertaken to identify the potential for rock falls and slips and to allow assessment of potential travel distance.
- Further investigation targeted at identifying suitable building envelopes with low landslide risk within Terrain Unit 3a.

Figures



Site Geology



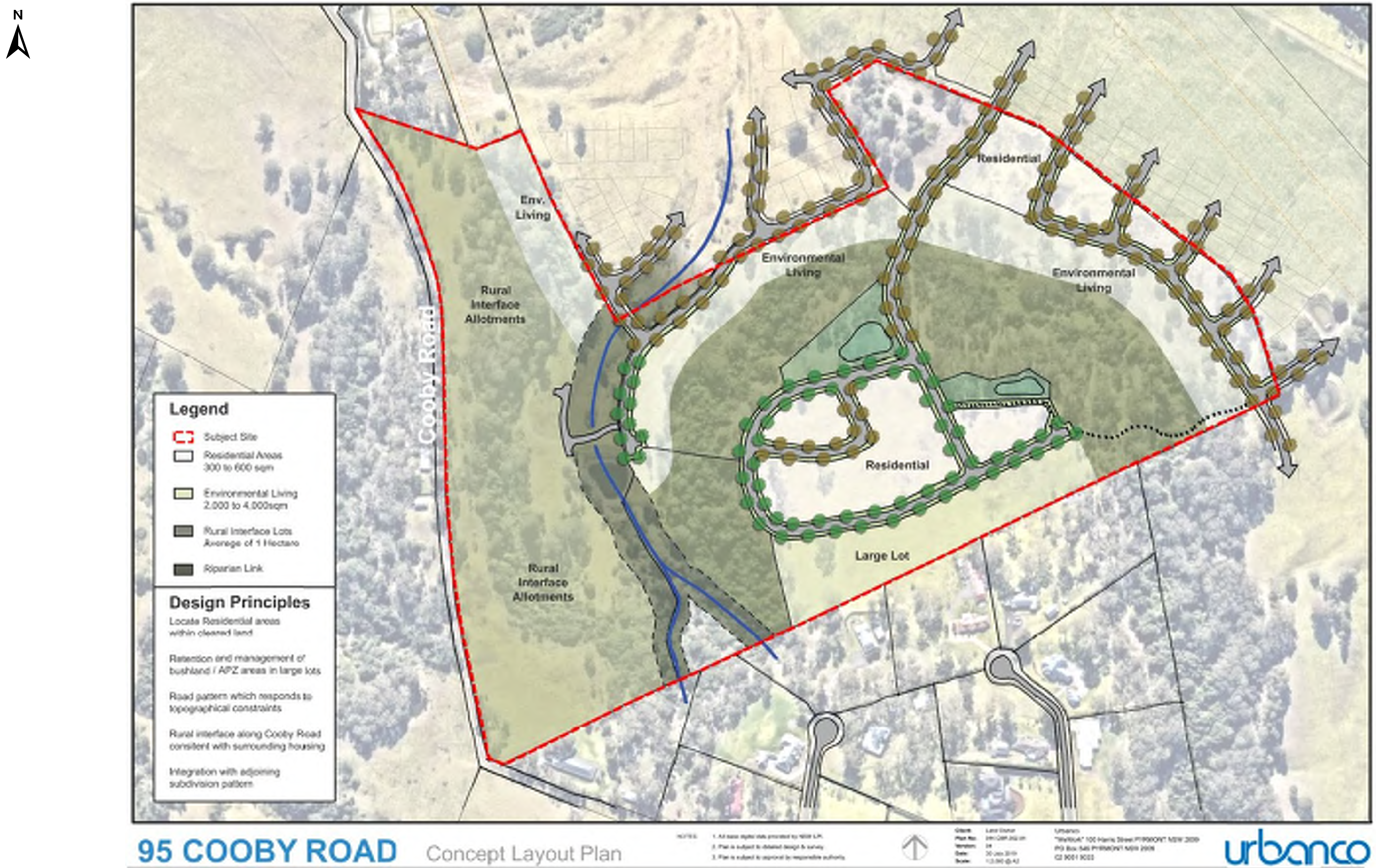
Site Location

Symbol	Group	Sub-group	Unit	Lithology
Qal	-	-	-	Alluvium, gravel, swamp deposits and sand dunes
Pbb	Shoalhaven Group	Gerringong Volcanics	Bumbo Latite	Latite
Pbk	Shoalhaven Group	Gerringong Volcanics	Kiama Tuff	Trachytic Tuff with pebbly bands
Psb	Shoalhaven Group	Berry Formation	Undifferentiated	Siltstone, shale, sandstone

revision	description	drawn	approved	date
	Site location	HJP	KEG	26/11/18

TERRA INSIGHT

client:	Indesco
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar nSW
scale	NTS
title:	Site Location
original size	A3
project no:	TERRA18320
figure no:	FIGURE 1

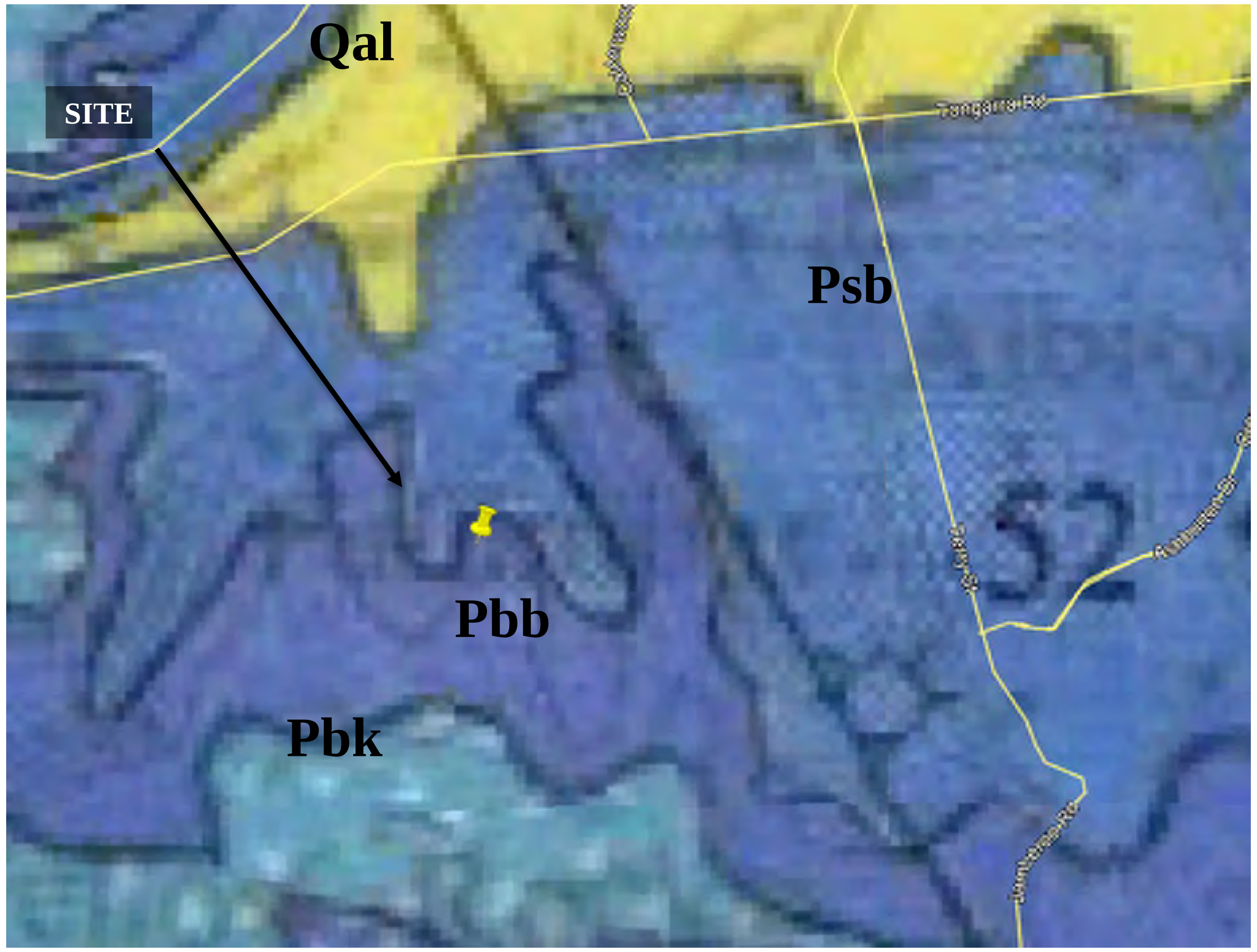


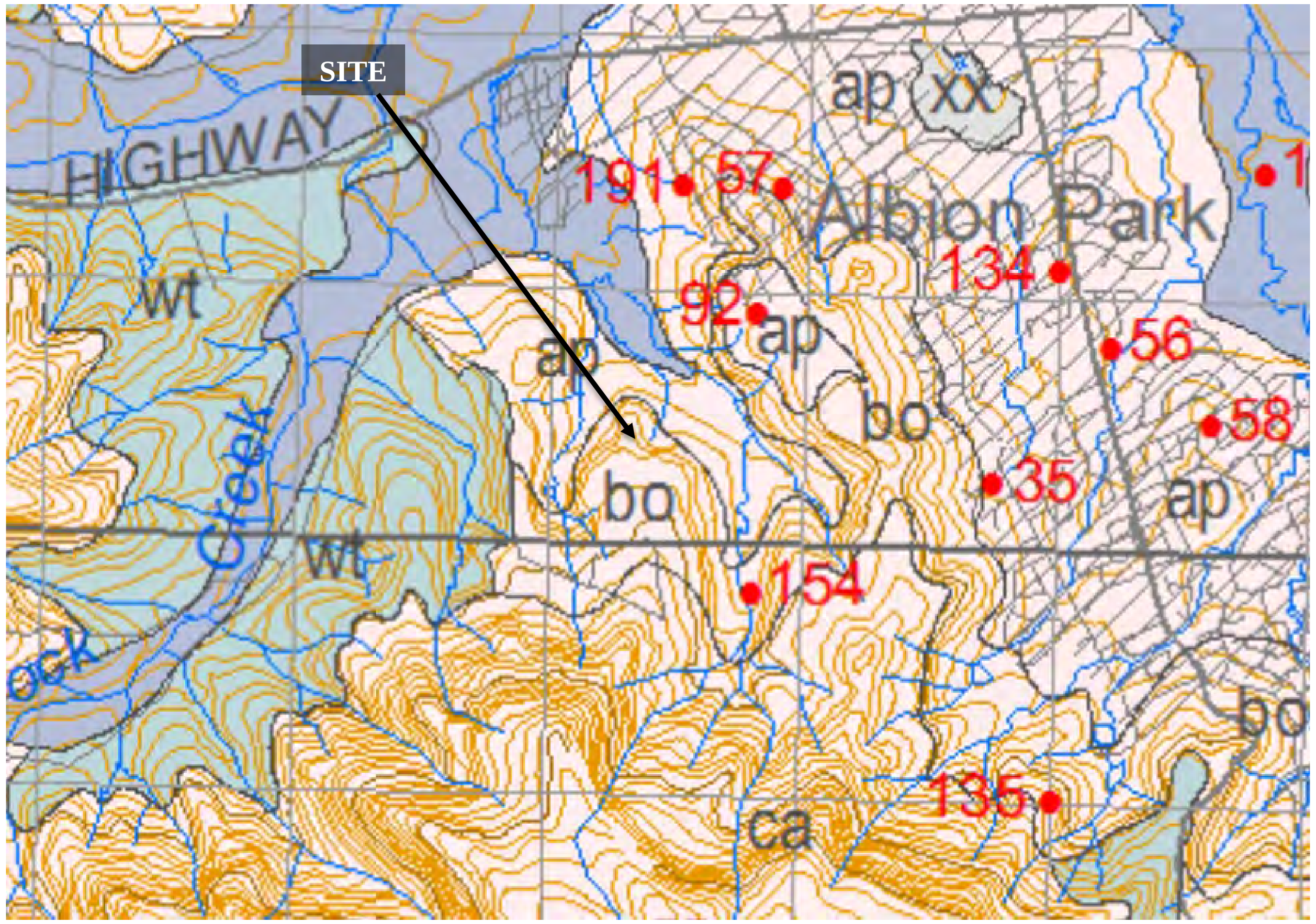
revision	description	drawn	approved	date
	Site Plan	XJ	KEG	15/08/2019

TERRA INSIGHT

scale	NTS
original size	A3

client:	Indesco
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW
title:	Site Plan
project no: TERRA18320	figure no: FIGURE 2





Symbol	Group	Sub-group	Unit	Lithology
Qal	-	-	-	Alluvium, gravel, swamp deposits and sand dunes
Pbb	Shoalhaven Group	Gerringong Volcanics	Bumbo Latite	Latite
Pbk	Shoalhaven Group	Gerringong Volcanics	Kiama Tuff	Trachytic Tuff with pebbly bands
Psb	Shoalhaven Group	Berry Formation	Undifferentiated	Siltstone, shale, sandstone

Symbol	Description
bo	Rolling hills with benched slopes with extensive platfomrs of Bumbo Latite. Relief 40 to 100m. Slope gradients 15% to 25%. Extensively cleared with stands of closed-forerst and tall open forest. Soils are shallow (< 50cm) structured loams occur on crests. Moderately deep (50-100cm) Krasnozems occur on upper slopes and benches. Brown Podzolic soils and red Podzolic soils occur on mid and lower slopes.
Ap	Short steep upper slopes with gentle long foot slopes on Berry Formation. Relief between 60 to 100m. Foot slopes 5 to 15% with upper slopes 15 to 50%. Mostly cleared with stands of open tall forest. Soils moderately deep (50-100cm) of brown Podzolic soils occur of crests with yellow Podzolic soils on mid-slopes. Soloths occur on foot-slopes and drainage lines.

revision	description	drawn	approved	date
	Site Geology	HJP	KEG	26/11/18

Ref: Wollongong 1:250,000 geological map

TERRA INSIGHT

client: Indesco

project: Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar nSW

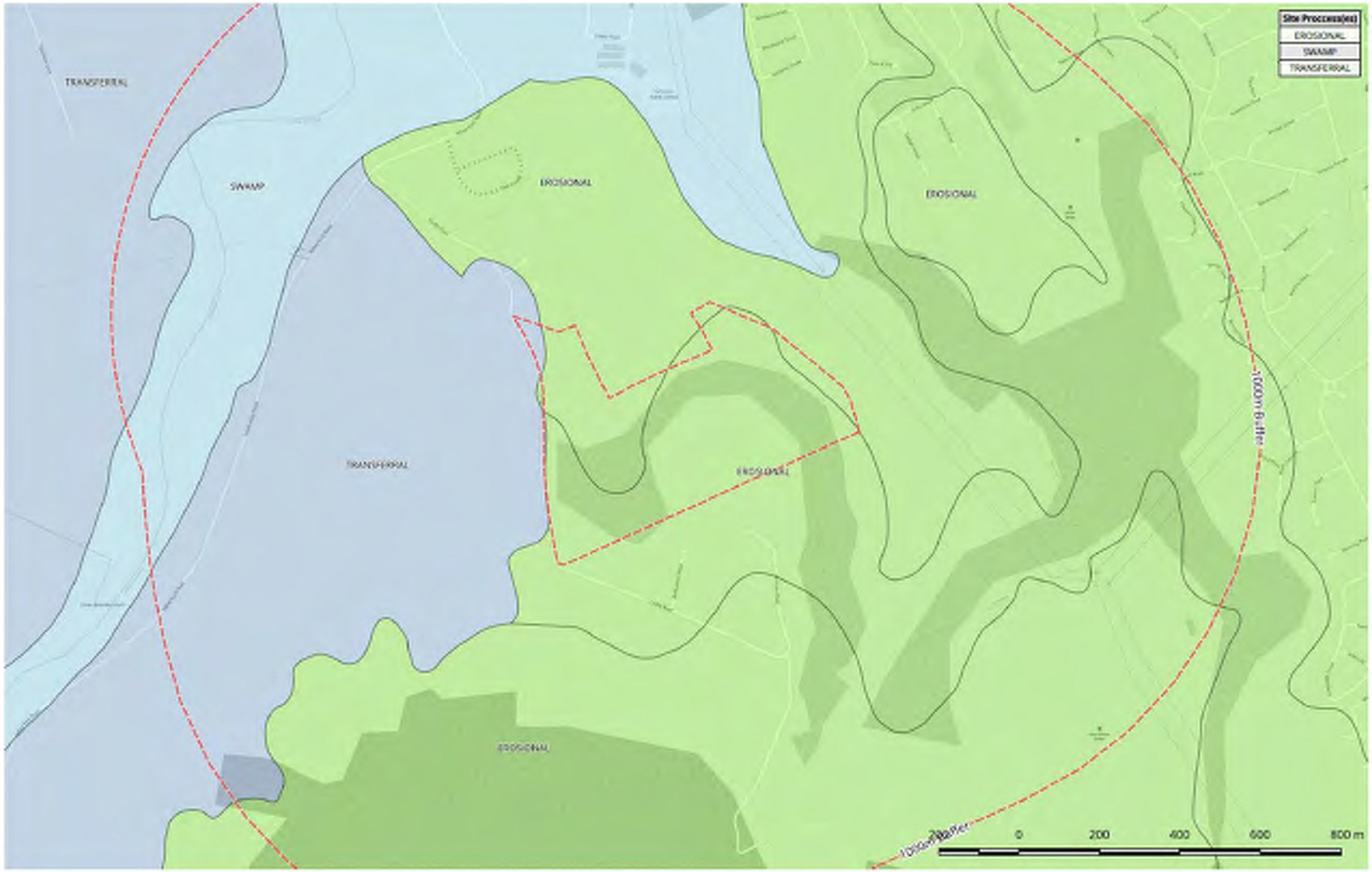
scale: NTS

original size: A3

title: Site Geology

project no: TERRA18320

figure no: FIGURE 3

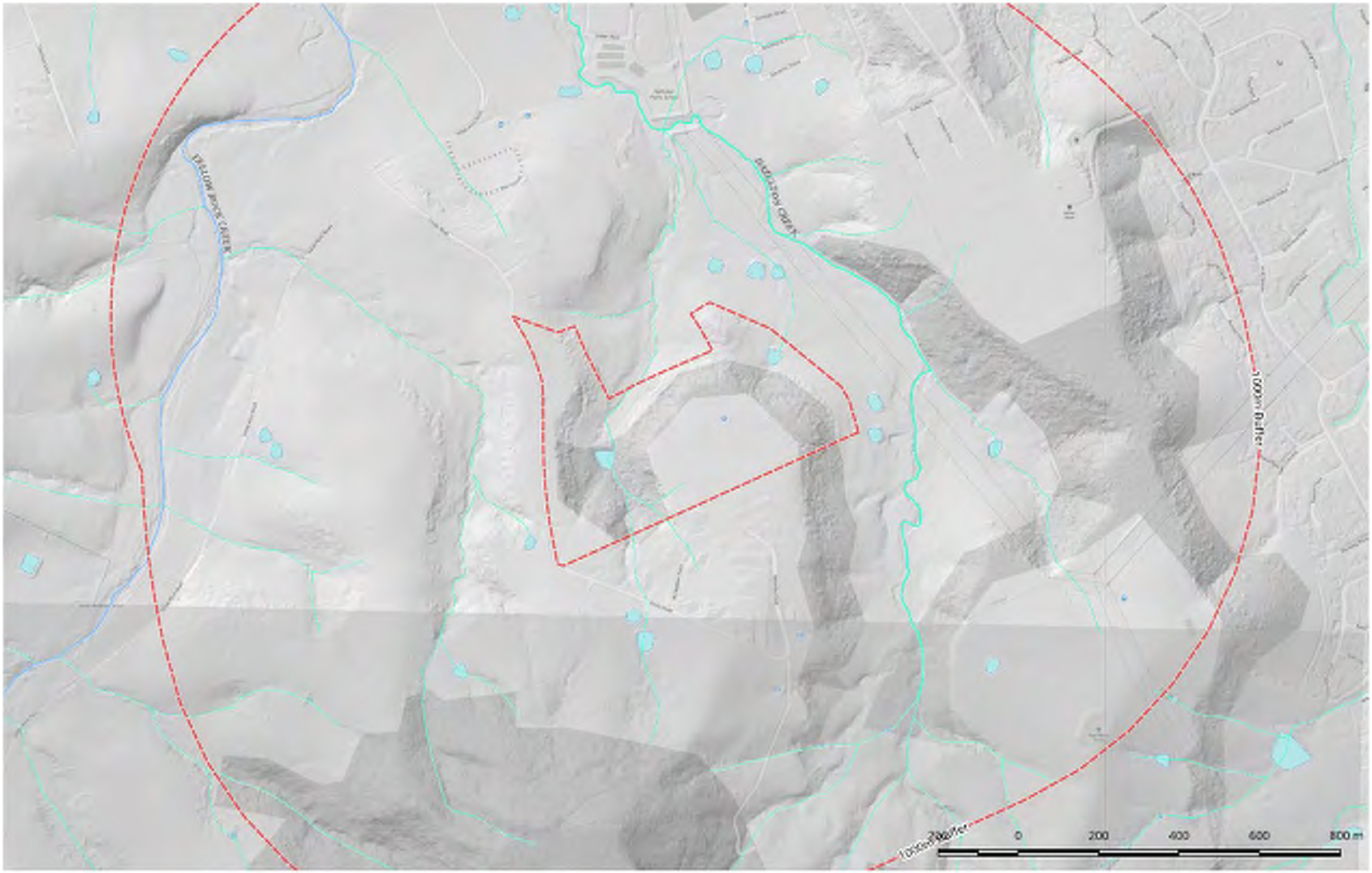


revision	description	drawn	approved	date
	Site location	HJP	KEG	26/11/18

Data Source
Office of Environment and Heritage | Obtained on 18.07.2018
Creative Commons 3.0 - State of NSW and Office of Environment and Heritage

TERRA INSIGHT

client:	**Indesco**
project:	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar nSW**
scale	NTS
title:	**Soil Formation**
original size	**A3**
project no: **TERRA18320**	figure no: **FIGURE 4**

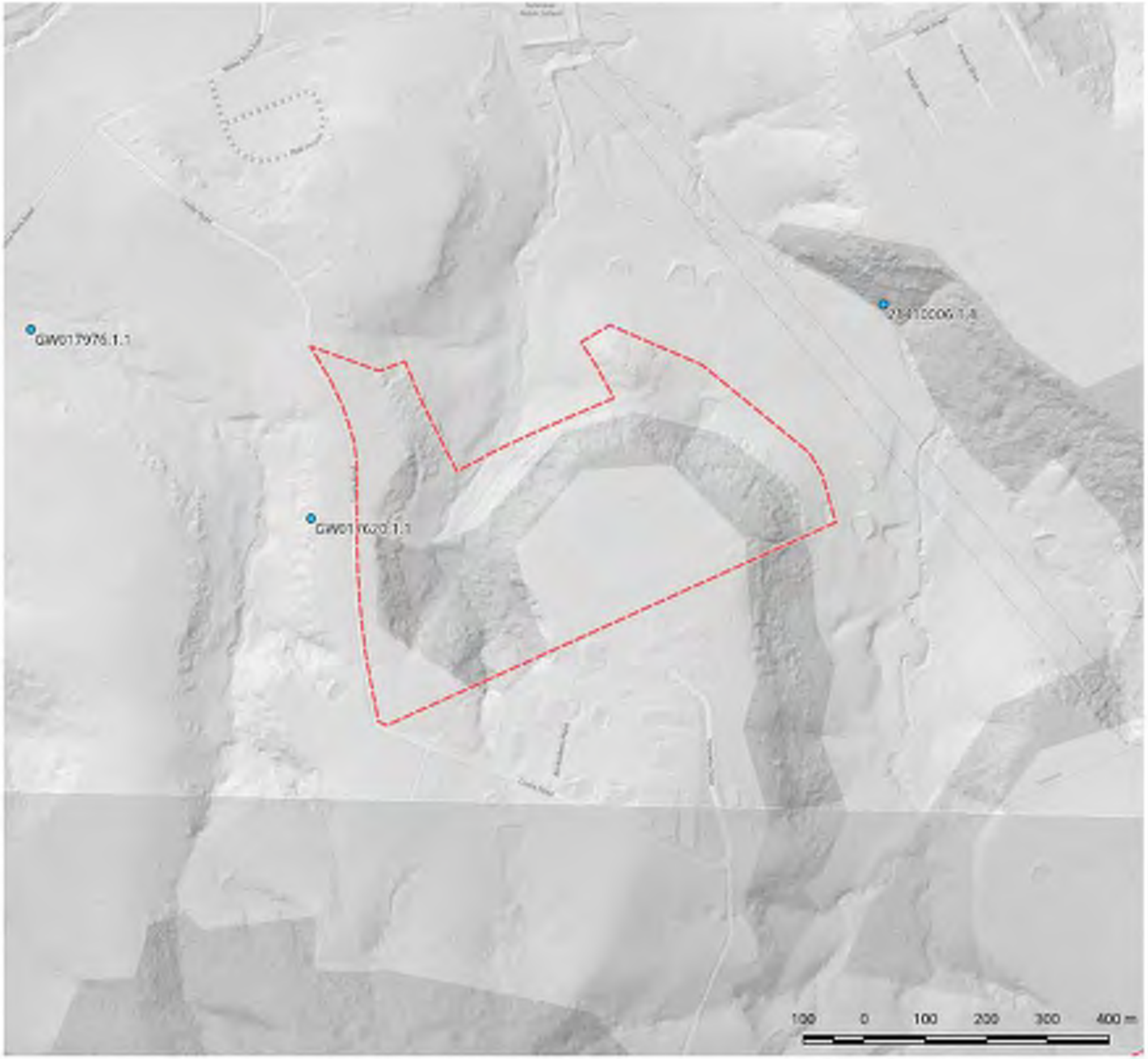


revision	description	drawn	approved	date
	Site location	HJP	KEG	26/11/18

Data Source
Department of Finance, Services & Innovation | Obtained on 9.11.2018

TERRA INSIGHT

scale	NTS
original size	A3
client:	**Indesco**
project:	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar nSW**
title:	**Water Courses and Hydrogeology**
project no: **TERRA18320**	figure no: **FIGURE 5**



HydroCode	Depth	Strata Description	Bore Data
21410006.1.1			Ref Elevation: 54.38 AHD Purpose: Unknown
GW017620.1.1	0m - 0.6m 0.6m - 2.74m 2.74m - 3.96m 3.96m - 4.26m 4.26m - 4.87m 4.87m - 6.09m 6.09m - 6.7m 6.7m - 43.89m	Topsoil Boulders Marl yellow Sandstone yellow Shale soft water supply Shale hard Boulders Rock water supply	Date Drilled: [illegible] Ref Elevation: 70.34 AHD Drill Depth: 43.8m Purpose: Stock and Domestic SWL: 0m
GW017976.1.1	0m - 11.88m 11.88m - 15.24m 15.24m - 18.80m	Clay stones Rock volcanic Basalt water supply	Date Drilled: [illegible] Ref Elevation: 40.37 AHD Drill Depth: 18.8m Purpose: Stock and Domestic SWL: 0m

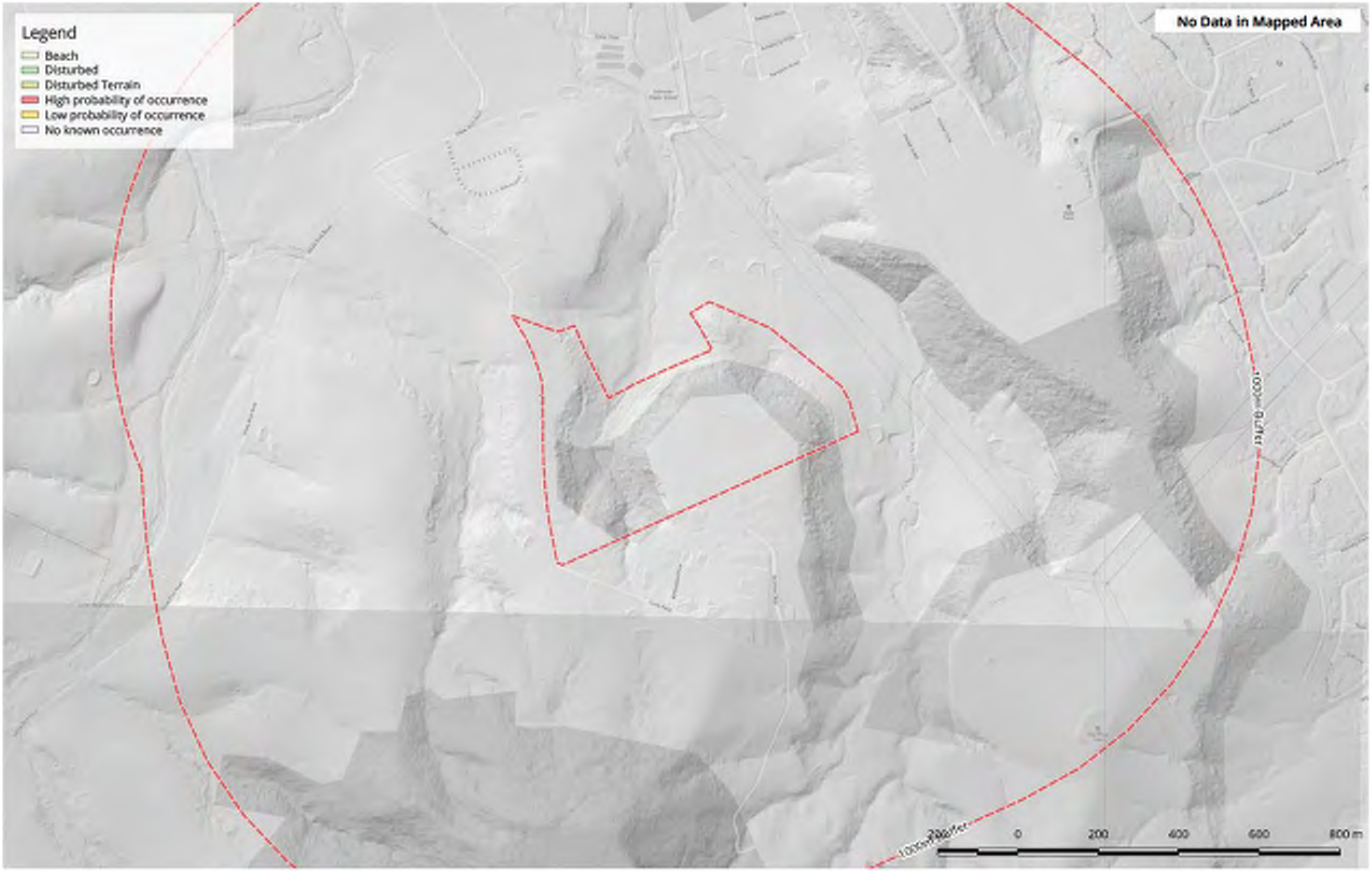
revision	description	drawn	approved	date
	Site location	HJP	KEG	26/11/18

Data Source
NSW Planning and the Environment | Obtained on 18.07.2018
Creative Commons 3.0 - Commonwealth of Australia

TERRA INSIGHT

scale: NTS
original size: A3

client: **Indesco**
project: **Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**
title: **Groundwater Bores**
project no: **TERRA18320**
figure no: **FIGURE 6**



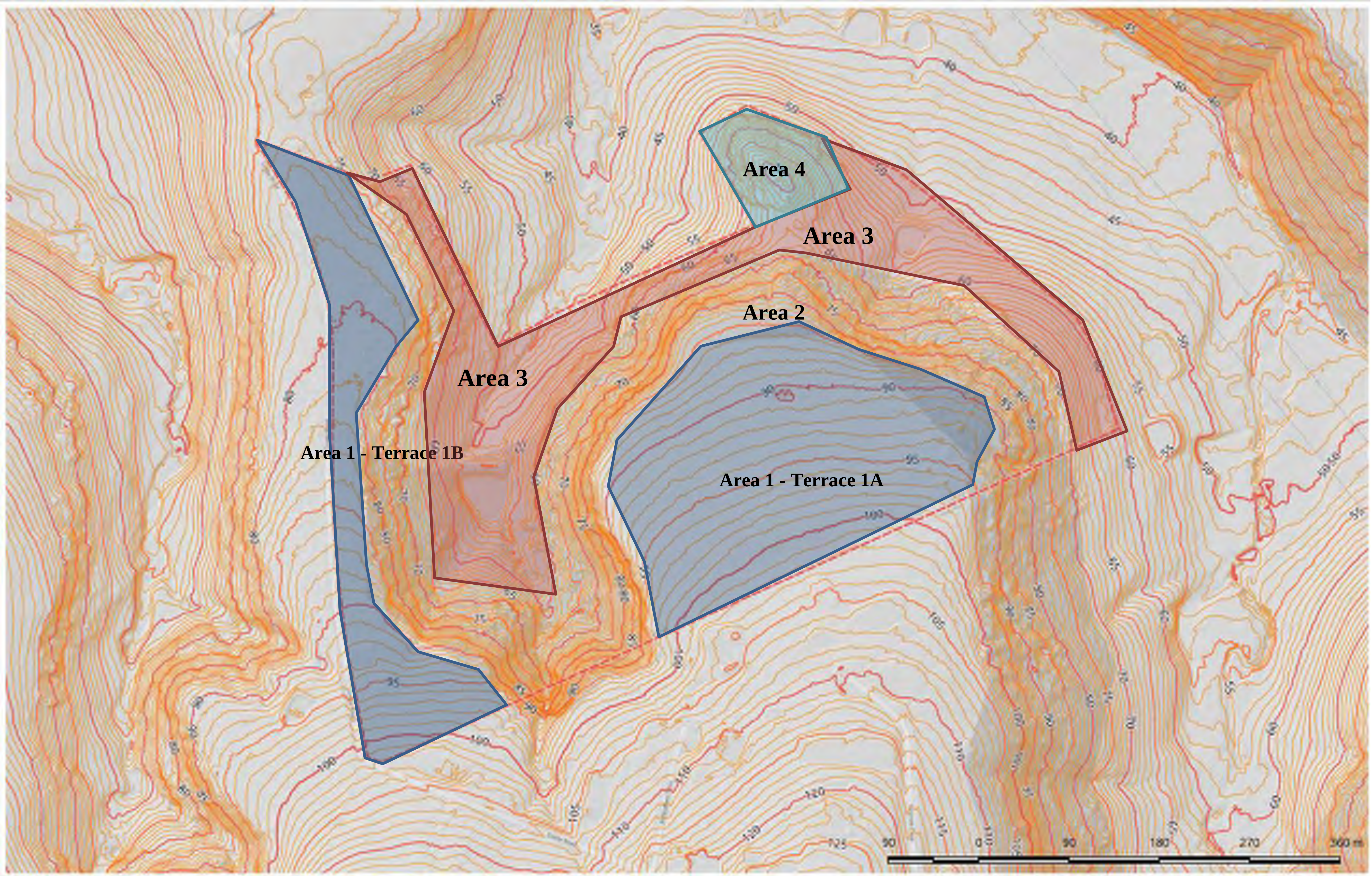
revision	description	drawn	approved	date
	Acid Sulfate Soils	HJP	KEG	26/11/18

Data Source
Derived from LIDAR Data | Geoscience Australia | Obtained on 18.07.2018
Creative Commons 3.0 - Commonwealth of Australia

TERRA INSIGHT

scale	NTS
original size	A3

client:	**Indesco**	
project:	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**	
title:	**Acid Sulfate Soils**	
project no: **TERRA18320**		figure no: **FIGURE 7**



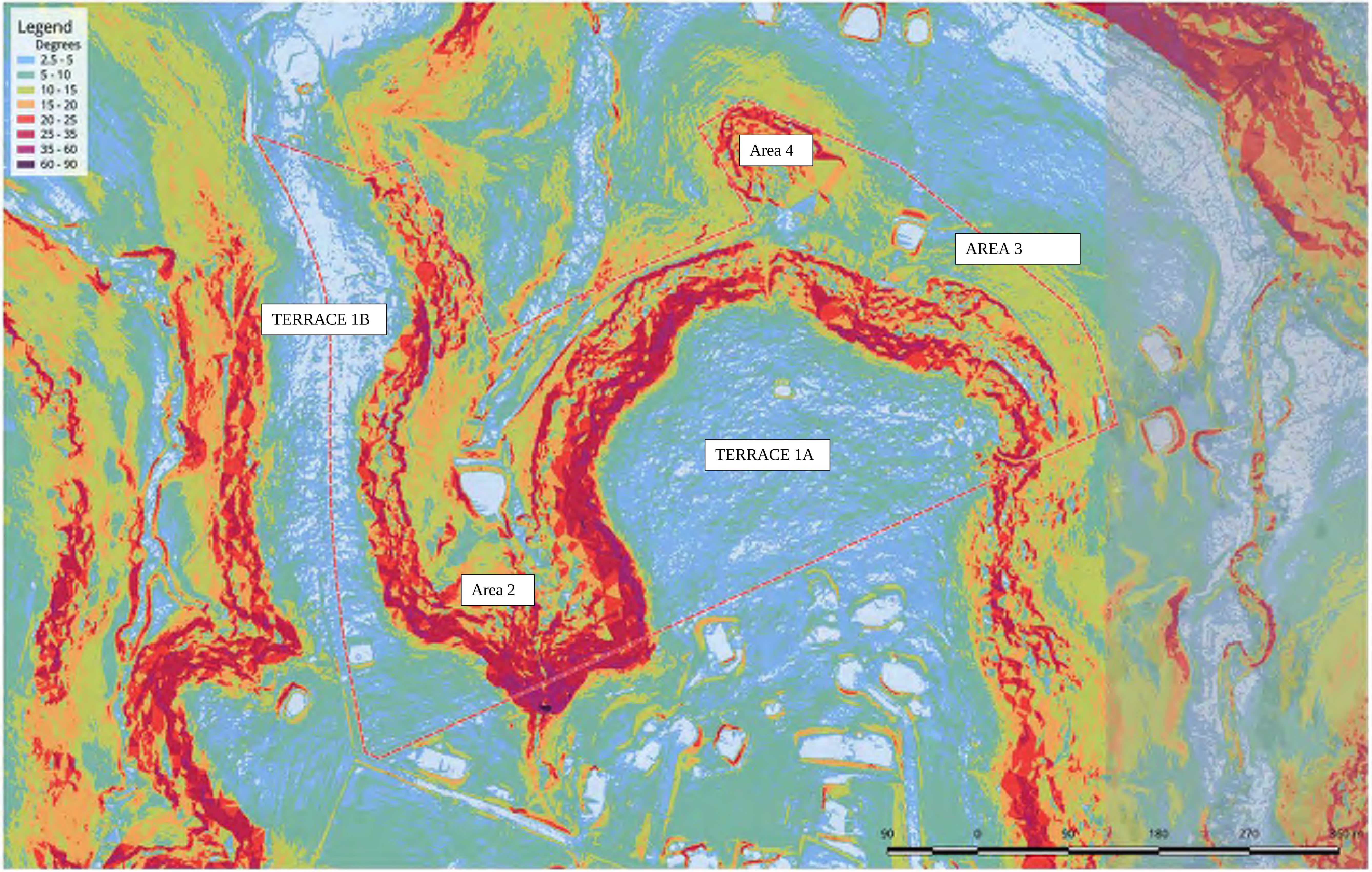
revision	description	drawn	approved	date
	Topography	HJP	KEG	26/11/18

Data Source
Derived from LiDAR Data | Geoscience Australia | Obtained on 18.07.2018
Creative Commons 3.0 - Commonwealth of Australia

TERRA INSIGHT

scale: NTS
original size: A3

client: **Indesco**
project: **Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**
title: **Topography**
project no: **TERRA18320**
figure no: **FIGURE 8**



revision	description	drawn	approved	date
	Slope Heat Mapping	HJP	KEG	26/11/18

Data Source
Derived from LIDAR Data | Geoscience Australia | Obtained on 18.07.2018
Creative Commons 3.0 - Commonwealth of Australia

TERRA INSIGHT

scale	NTS
original size	**A3**

client:	**Indesco**
project:	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**
title:	**Slope Heat Mapping**
project no: **TERRA18320**	figure no: **FIGURE 9**

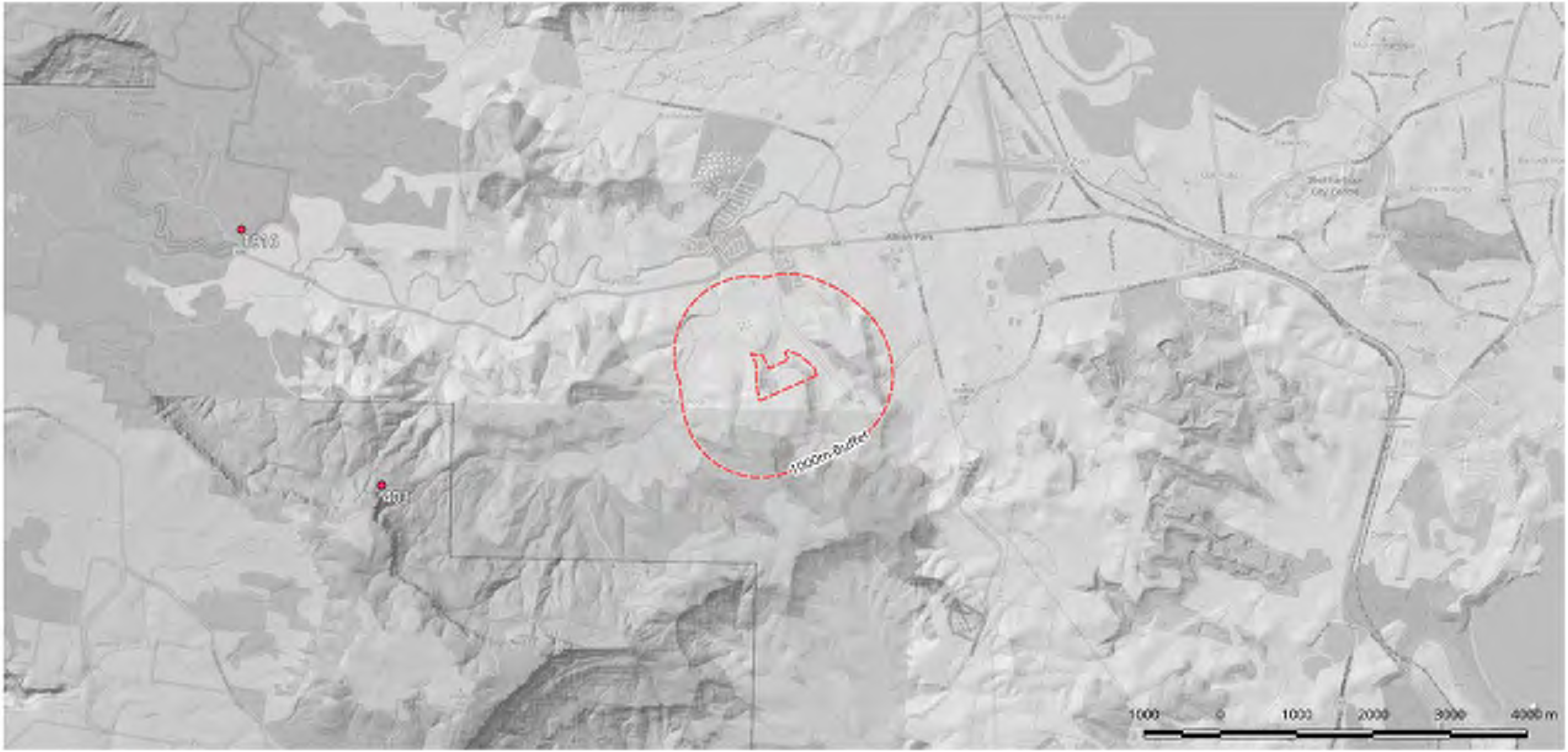
revision	description	drawn	approved	date
	Landslide Risk Mapping	HJP	KEG	26/11/18

Data Source
Derived from LIDAR Data | Geoscience Australia | Obtained on 18.07.2018
Creative Commons 3.0 - Commonwealth of Australia

TERRA INSIGHT

scale	NTS
original size	A3

client:	**Indesco**
project:	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**
title:	**Landslide Risk Mapping**
project no: **TERRA18320**	figure no: **FIGURE 10**



ID	Date	Hazard	Synopsis	Impact Comments
403	14-03-1997	Landslide	A debris slump caused tarmac to collapse, closing one lane of the road after several days of rain. The damage caused the road to be closed for about 2 weeks for repairs in March 1997. The landslide happened between 12 midnight and 1.30 am after several days of rain. One lane of the road was closed because the tarmac collapsed. A retaining wall and the fill behind it slumped back to a previous retaining wall.	Road collapsed
433	22-05-1961	Landslide	A Richter magnitude 5.4 earthquake triggered this landslide, which blocked the road for a week. Its volume was about 8000 cubic metres. The Robertson-Bowral earthquake, Richter magnitude ML 5.4, triggered this landslide.	Road blocked
1916	05-06-2016	Landslide	Heavy rain was the probable trigger of a landslide on the road. There was a length limit of 14m on vehicles, and alternating traffic control by portable traffic signals. During the period 3-6 June 2016, over 300mm of rain was recorded at Robertson and 241mm at Albion Park. The landslide most probably happened on 4 or 5 June 2016. The situation was unchanged as of early morning on 10 June 2016.	Landslide on road. Length limit on vehicles. Portable traffic signals in place.

revision	description	drawn	approved	date
	Site location	HJP	KEG	26/11/18

TERRA INSIGHT

client: **Indesco**

project: **Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**

title: **Recorded Landslides**

scale: NTS

original size: **A3**

project no: **TERRA18320**

figure no: **FIGURE 11**

N

Dam East

Dam South with visible seepage down gradient (photograph 5)

Rock outcropping(photograph 14 and 15). Steep drop off of rock along crest of slope (photograph 16)

Steep rock face along edge of slope crest (Photograph 8)

Rock outcropping and visible seepage at ground surface level (photograph 7 and 8) on and upgradient from crest

Rock outcropping and steep drop off of rock along crest of slope (photograph 21-24)

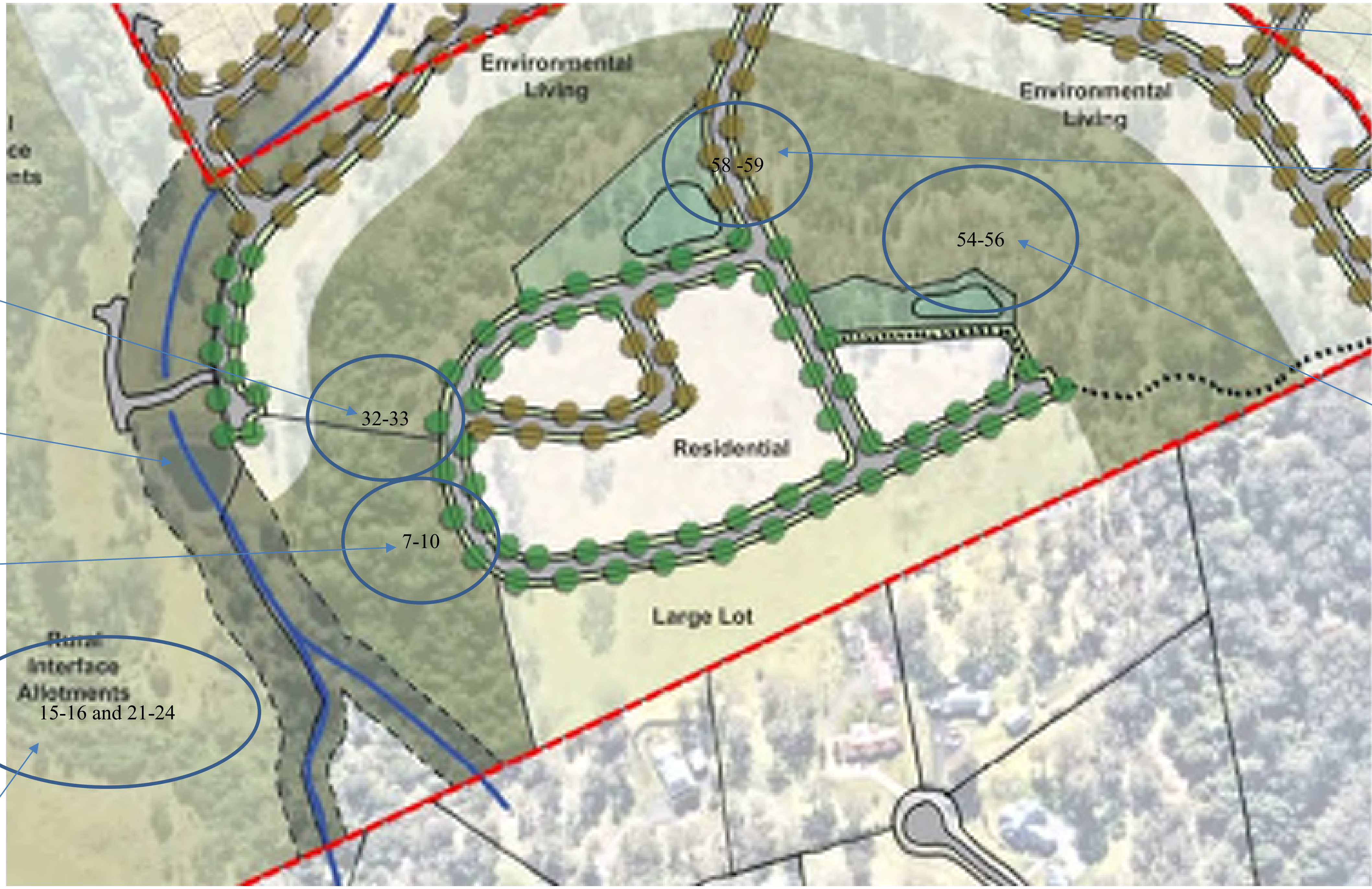
Steep rock face along edge of slope crest (Photographs 10 and 11)

revision	description	drawn	approved	date
	Site Plan	XJ	KEG	15/08/2019

TERRA INSIGHT

client:	**Indesco**
project:	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**
scale	NTS
title:	**Site Observations- Area 1**
original size	**A3**
project no:	**TERRA18320**
figure no:	**FIGURE 12**

N



Dam East

Steep access track with loose latite photograph 58), in-situ latite on the access track (photograph 59)

Very steep hill face with loose latite (photograph 54). Very steep hill face with loose latite under vegetation (photographs 55 and 56)

Thick vegetation over steep rock face (photograph 32), steep gradient with vegetation (photograph 33)

Dam West

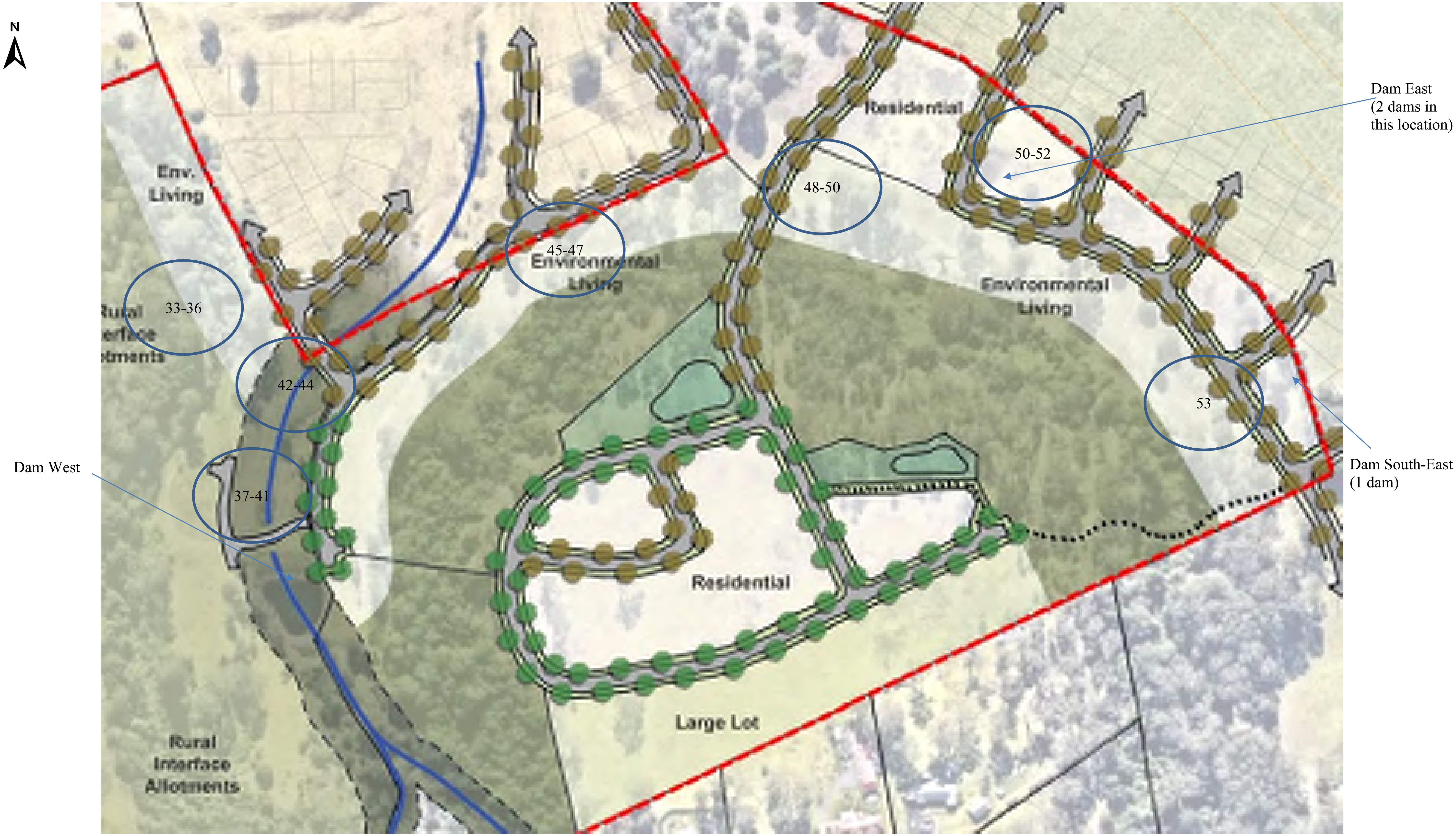
In-situ latite, steep drop off, and water seepage (photographs 7 and 8) Latite boulders and steep slope (photographs 9 and 10)

Outcropping latite, steep slope and thick vegetation (photographs 15 and 16)

revision	description	drawn	approved	date
	Site Plan	XJ	KEG	15/08/2019

TERRA INSIGHT

client:	Indesco
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW
scale	NTS
title:	Site Observations- Area 2
original size	A3
project no:	TERRA18320
figure no:	FIGURE 13

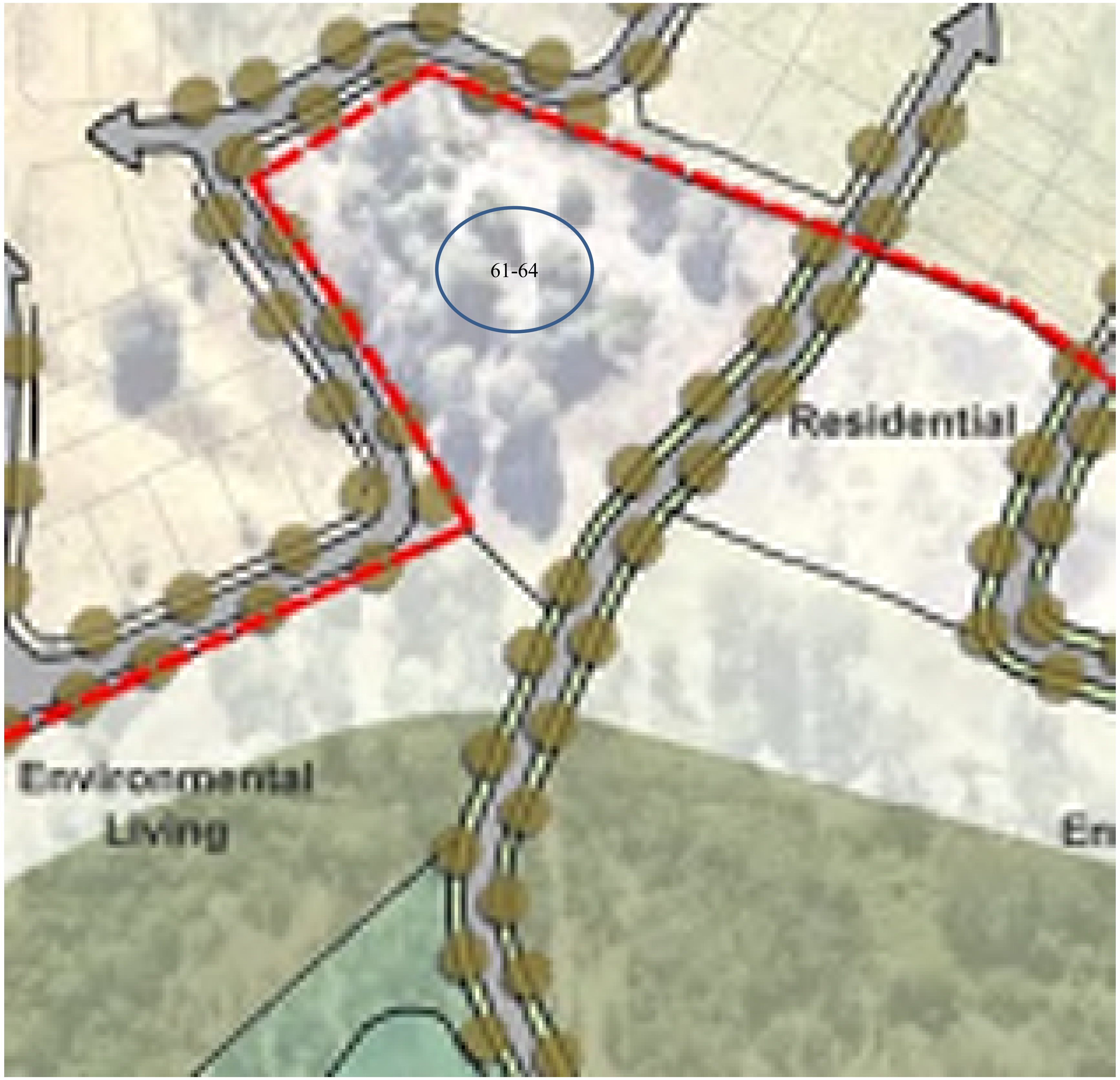


revision	description	drawn	approved	date
	Site Plan	XJ	KEG	15/08/2019

TERRA INSIGHT

client:	Indesco
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW
scale	NTS
title:	Site Observations- Area 3
original size	A3
project no:	TERRA18320
figure no:	FIGURE 14

N



	description	drawn	approved	date
revision	Site Plan	XJ	KEG	15/08/2019

TERRA INSIGHT

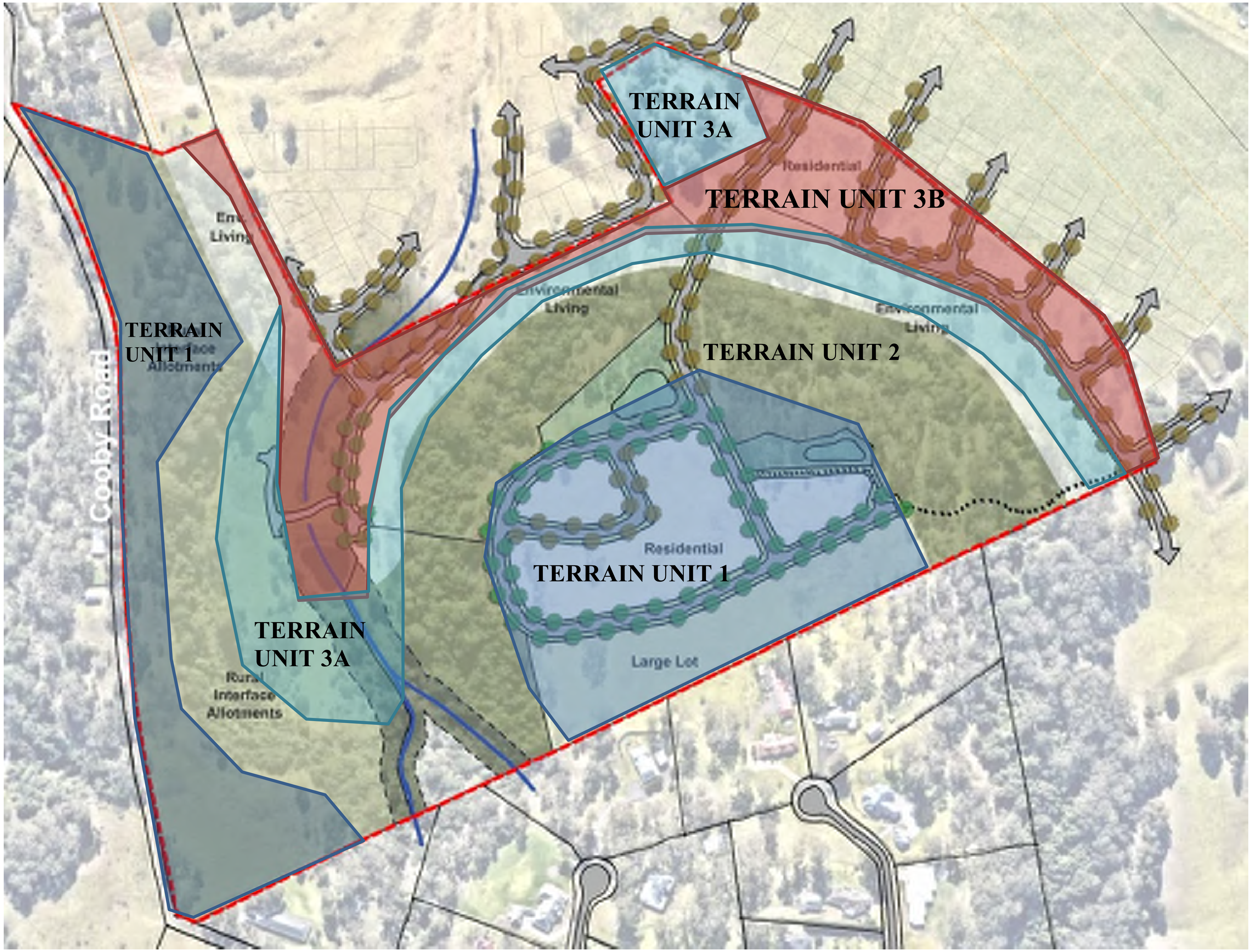
scale	NTS
original size	A3

client: **Indesco**

project: **Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**

title: **Site Observations- Area 4**

project no: **TERRA18320** figure no: **FIGURE 15**



revision	description	drawn	approved	date
	Topography	XJ	KEG	15/08/19

Data Source
Derived from LiDAR Data | Geoscience Australia | Obtained on 18.07.2018
Creative Commons 3.0 - Commonwealth of Australia

TERRA INSIGHT

scale	NTS
original size	A3

client:	Indesco
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW
title:	Terrain Units
project no: TERRA18320	figure no: FIGURE 16

Appendix A: Your Report

Your Report

These notes have been prepared to help you understand the advice provided in Your Report and its limitations.

Your Report is based on what you tell us

Your Report has been developed based on the information you have provided such as the scope and size of your project. It applies only to the site investigated. If there are changes to the proposed works, then the advice provided within Your Report may need to be reviewed

Your Report is written with your needs in mind

The advice provided within Your Report is also not relevant to another purpose other than that originally specified at the time the report was issued. Please seek advice from Terra Insight before you share Your Report with another third party – except for the purpose for which the report was written.

Terra Insight assumes no responsibility and will not be liable to any other person or organisation for, or in relation to, any matter dealt with or conclusions expressed in the report, or for any loss or damage suffered by any other person or organisation arising from matters dealt with or conclusions expressed in Your Report.

Your Report is based on what we observed

The advice provided within Your Report assumes that the site conditions, revealed through selective point sampling (undertaken in accordance with normal practices and standards) at a particular point in time, are indicative of the actual conditions on your site. However, the nature of the materials underlying your site is affected by natural processes and the activity of man. Under no circumstances can it be considered that these findings represent the actual state at all points. The subsurface conditions may vary significantly on the other parts of the site, particularly where no nearby sampling and testing work has been carried out.

As a result conditions on your site can change with time; they can also vary spatially. As a result, the actual conditions encountered may differ from those detailed within Your Report. Although nothing can be done to change the actual site conditions which exist, steps can be taken to gain a better understanding of the subsurface conditions underlying your site and reduce the potential for unexpected conditions to be encountered

The advice within Your Report also relies on interpretation of factual information based on judgement and opinion and has a level of uncertainty attached to it. Only Terra Insight is fully familiar with the background information needed to assess whether or not the report's recommendations are valid and whether or not changes should be considered as the project develops. If the details of your project have changed, the site conditions have changed or a significant amount of time as elapsed since our report was written, the advice provided within Your Report may need to be reviewed.

Your Report has been written by a Professional

The report has been prepared using accepted procedures and practices of the consulting profession at the time it was prepared, and the opinions, recommendations and conclusions set out in the report are made in accordance with generally accepted principles and practices of that profession.

Your Report is better when it is kept together

Your Report presents all the findings of the site assessment and should not be copied in part or altered in any way. Keeping Your Report intact reduces the potential for yourself or other design professionals to misinterpret the report.

Your Geo-Environmental Report

If Your Report is for geotechnical purposes only, it will not relate any findings, conclusions, or recommendations about the potential for hazardous materials to exist at the site unless you have specifically asked us to do so. If your report is written for Geo-Environmental purposes the following should be noted in addition to the above:

- Advancements in professional practice regarding contaminated land and changes in applicable statues and/or guidelines may affect the validity of this report. Consequently, the currency of conclusions and recommendations in Your Report should be verified if you propose to use this report more than 6 months after its date of issue;
- Your Report is based on information gained from environmental conditions (including assessment of some or all of soil, groundwater, vapour and surface water) and supplemented by reported data of the local area and professional experience. The assessment has been scoped with consideration to industry standards, regulations, guidelines and your specific requirements, which includes budget and timing;
- The characterisation of site conditions is an interpretation of information collected during assessment, in accordance with industry practice. Any interpretation in Your Report is not a complete description of all material on or in the vicinity of the site, due to the inherent variation in spatial and temporal patterns of contaminant presence and impact in the natural environment.
- We may have relied on data and other information provided by you and other qualified individuals in preparing Your Report. We have not verified the accuracy or completeness of such data or information except as otherwise stated in Your Report. For these reasons Your Report must be regarded as interpretative, in accordance with industry standards and practice, rather than being a definitive record.
- For each purpose, a tailored approach to the assessment of potential soil and groundwater contamination is required. In most cases, a key objective is to identify, and if possible quantify, risks that both recognised and potential contamination posed in the context of the agreed purpose. If the proposed use of the site changes, the assessment may no longer be valid and will need to be reviewed.

* For further information on this aspect reference should be made to "Guidelines for the Provision of Geotechnical information in Construction Contracts" published by the Institution of Engineers Australia, National headquarters, Canberra, 1987.

Appendix B: Soil Landscape Definitions

ap ALBION PARK

Landscape—short steep upper slopes with long gentle footslopes on Berry Formation. Relief 60–100 m. Footslopes 5–15%. Upper slopes 15–50%. Mostly cleared with stands of tall open-forest.

Soils—moderately deep (50–100 cm) Brown Podzolic Soils (Db4.11) occur on crests, Yellow Podzolic Soils (Dy3.21) on midslopes. Soloths (Dy3.41) occur on footslopes and drainage lines.

Limitations—waterlogging, seasonally high watertable, shrink-swell, hardsetting (topsoil), sodicity, low wet bearing strength (subsoil), high available water-holding capacity (topsoil and subsoil).

LOCATION

Short steep upper slopes grading into long gentle footslopes on Berry Formation on the Coastal Plain. Examples include Albion Park, Yallah, Oak Flats, Dapto and Broughton Creek.

LANDSCAPE

Geology

Berry Formation—mid grey to dark grey siltstone, mudstone and fine sandstone with localised outcrops of Budgong Sandstone (red brown and grey lithic volcanic sandstone) on mid to upper slopes. Localised outcrops of Bumbo Latite occasionally occur on crests.

Topography

Short steep upper slopes grading into long gently inclined footslopes. Relief 60–100 m. Upper slopes 15–50%, footslopes 5–15%. Drainage lines incised on upper slopes grading into broad drainage plains on lower slopes.

Vegetation

Extensively cleared with remnant stands of tall open-forest. Common species include thin-leaved stringybark (*Eucalyptus eugenioides*), cabbage gum (*Eucalyptus amplifolia*), northern boobialla (*Myoporum acuminatum*). Forest red gum (*Eucalyptus tereticornis*), woollybutt (*Eucalyptus longifolia*), decorative paperbark (*Melaleuca decora*) and prickly-leaved paperbark (*Melaleuca styphelioides*) grow on poorer drained areas.

Land Use

Urban areas include Albion Park, Oak Flats and Dapto. There is coalmining at Marshall Mount. Rural activities include dairying, cattle grazing and horse agistment on improved pastures.

Existing Erosion

There is localised minor gully erosion.

Included Soil Landscapes

Small areas of Shellharbour **(sh)**, Bombo **(bo)** and Fairy Meadow **(fa)** soil landscapes occur.

SOILS

Dominant Soil Materials

ap1—Friable brownish black sandy clay loam (topsoil)

Colour	brownish black (7.5YR 3/2)
Texture	sandy clay loam
Structure	strongly pedal, <2 mm crumb peds
Fabric	rough-faced, porous
pH	6.5
Stones	nil
Roots	common, ex-ped

ap2—Hardsetting weakly pedal dark brown loam (topsoil)

Colour	dark brown (10YR 3/3)
Texture	loam to fine sandy loam
Structure	weakly pedal, <2 mm crumb peds
Fabric	rough-faced, porous
pH	6.5
Stones	nil
Roots	few

ap3—Mottled moderately pedal greyish brown light clay (subsoil)

Colour	greyish brown (5YR 4/2) red and brown mottles (50%) or brown (10YR 4/4) without mottles
Texture	light clay
Structure	moderately pedal, 50–100 mm angular blocky peds
Fabric	rough-faced, porous
pH	6.0
Stones	nil
Roots	nil

ap4—Weakly pedal bright yellowish brown sandy loam (subsoil)

Colour	bright yellowish brown (10YR 7/6) to dull yellow orange (10YR 7/3)
Texture	sandy loam to loamy sand
Structure	weakly pedal, <2 mm crumb peds
Fabric	rough-faced, porous
pH	6.0
Stones	nil
Roots	nil

ap5—Mottled moderately pedal yellow orange heavy clay (subsoil)

Colour	yellow orange (10YR 7/8) yellow and grey mottles (40%)
Texture	heavy clay
Structure	moderately pedal, 20–50 mm subangular blocky peds
Fabric	rough-faced, porous
pH	5.5
Stones	nil
Roots	nil

Associated Soil Materials

Dark reddish brown (2.5YR 3/4) heavy clay with grey mottles occurs occasionally on midslopes.

Occurrence and Relationships

Crests and upper slopes. Up to 30 cm friable brownish black sandy clay loam **ap1** overlies latite [Structured Loams (Um6.41)]. Where deeper weathering occurs, <20 cm **ap1** overlies <80 cm mottled moderately pedal greyish brown light clay **(ap3).** Boundary is clear [Brown Podzolic Soils (Db4.11)]. Total soil depth is <100 cm.

Midslopes. Up to 40 cm hardsetting weakly pedal dark brown loam **(ap2)** overlies <10 cm weakly pedal bright yellowish brown sandy loam **(ap4)** which in turn overlies <50 cm mottled moderately pedal yellow orange heavy clay **(ap5).** Boundaries are clear to sharp [Yellow Podzolic Soils (Dy3.21)]. Total soil depth is <100 cm. Up to 20 cm **ap1** overlies associated soil material. Boundary is clear [Red Podzolic Soils (Dr5.11)]. Total depth is >100 cm.

Footslopes and drainage lines. Up to 20 cm of **ap2** overlies <20 cm of **ap4** which overlies <120 cm of **ap3**. Boundaries are clear [Soloths (Dy3.41)]. Total soil depth is <150 cm.

LIMITATIONS TO DEVELOPMENT

Soil Limitations

ap1 Shrink-swell potential
High erodibility
Sodicity
Strongly acid
High available water-holding capacity

ap2 Hardsetting
Very high aluminium toxicity
High available water-holding capacity

ap3 Low permeability
Shrink-swell potential
Low wet bearing strength
Sodicity
Strongly acid
High available water-holding capacity

ap4 High aluminium toxicity
Sodicity
Strongly acid
High available water-holding capacity

ap5 Low permeability
Shrink-swell potential
Low wet bearing strength
Sodicity
Strongly acid
Very high available water-holding capacity

Fertility

Moderate to high fertility. **ap2** is hardsetting. **ap1, ap3, ap4** and **ap5** are moderately structured with moderate to high CEC and very high base saturation.

Erodibility

ap1 has a low erodibility rating. **ap2,** which is hardsetting, has high erodibility. The subsoils **(ap3, ap4** and **ap5)** have moderate erodibility.

Erosion Hazard

Erosion hazard for non-concentrated flows is moderate to high. The calculated soil loss for the first 12 months of urban development ranges up to 60–300 t/ha for topsoils and 300 t/ha for exposed subsoils. The erosion hazard for concentrated flows is high.

Surface Movement Potential

The moderately deep clay soils are moderately reactive.

Landscape Limitations

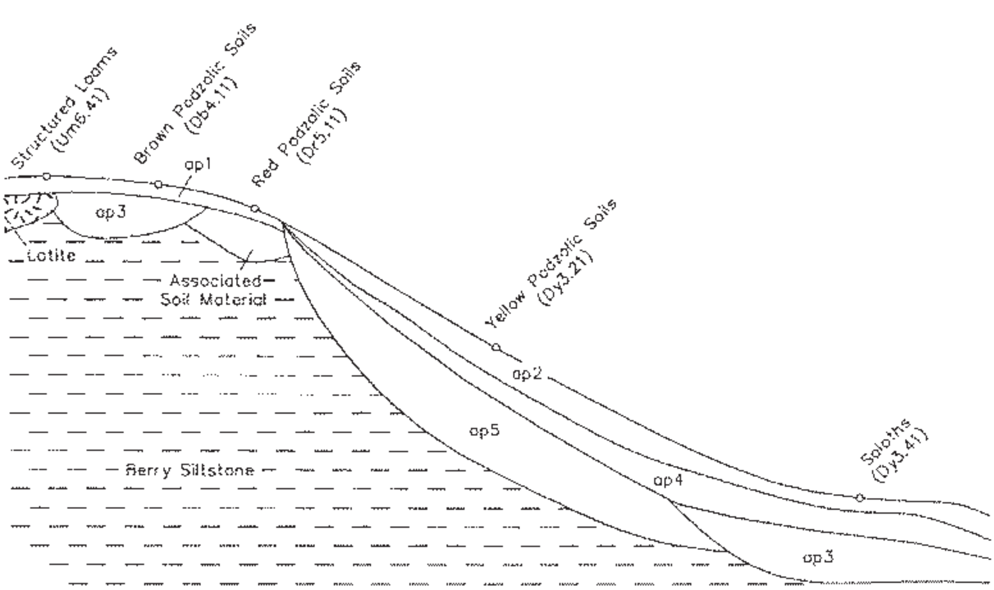
Waterlogging (localised)
Seasonal waterlogging
Water erosion hazard
Steep slopes (localised)
Shallow soil (localised)
Run-on (localised)
Rock outcrop (localised)

Urban Capability

Generally moderate limitations for urban development, but localised high to severe limitations on slopes greater than 20%.

Rural Capability

Generally high to severe limitations for regular cultivation. Low to moderate limitations for grazing.



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

bo BOMBO

Landscape—rolling low hills with benched slopes and sea cliffs with extensive rock platforms on Bumbo Latite. Relief 40–100 m. Slope gradients 15–25%. Extensively cleared with stands of closed-forest and tall open-forest.

Soils—shallow (<50 cm) Structured Loams (Um6) occur on crests, moderately deep (50–100 cm) Krasnozems (Gn4.11) on upper slopes and benches. Brown Podzolic Soils (Db1.11, Db1.21) and Red Podzolic Soils (Dr2.21) occur on mid and lower slopes.

Limitations—rock fall hazard, wave erosion hazard, rock outcrop, hardsetting, low wet bearing strength, sodicity.

LOCATION

Rolling low hills with benched slopes and sea cliffs with extensive rock platforms on latite and basalt on the Coastal Plain. Examples include Bombo, Dunmore and extensive areas within Jamberoo Valley.

LANDSCAPE

Geology

Bumbo Latite Member—alphanitic to porphoryitic latite.

Topography

Rolling low hills. Relief 40–100 m. Slope gradients 15–25%. Crests are narrow. Convex ridges are long and gently inclined. Moderately inclined slopes with isolated steep (25–40%) slopes. Scattered benches and terracettes on upper slopes. Narrow incised drainage lines. Coastal headlands with cliffs and extensive rock platforms. Springs may occur on the mid and footslopes—for example, Rose Valley.

Vegetation

Extensively cleared with remnant stands of closed-forest and tall open-forest. Common closed-forest species include cabbage tree palm (*Livistona australis*), bastard rosewood (*Synoum glandulosum*), red cedar (*Toona australis*), brush cherry (*Syzygium australe*), bolly gum (*Litsea reticulata*), white cedar (*Melia azedarach* var. *australasica*), northern boobialla (*Myoporum acuminatum*), smooth mock olive (*Notelaea venosa*), snow-wood (*Parachidendron pruinsom*), celery wood (*Polyscias elegans*), black apple (*Planchonella australis*), plum pine (*Polocarpus elatus*), yellowwood, moreton bay fig (*Ficus macrophylla*), port jackson fig (*Ficus rubiginosa*) and flintwood (*Scolopia braunii*).

Common tall open-forest species include turpentine (*Syncarpia glomulifera*), grey ironbark (*Eucalyptus paniculata*), pittosporum (*Pittosporum* spp.) and sydney blue gum /bangalay (*Eucalyptus saligna/botryoides*). Forest red gum (*Eucalyptus tereticornis*) and prickly-leaved paperbark (*Melaleuca styphelioides*) are found in poorly drained areas.

The vegetation on the associated soil mater-ial includes coastal tea-tree (*Leptospermum laevigatum*), coastal banksia (*Banksia integrifolia*), swamp oak (*Casuarina glauca*), bracelet honey-myrtle (*Melaleuca armillaris*) and drooping she-oak (*Allocasuarina verticillata*).

Land Use

Dairying, grazing and hobby farms on improved pasture, recreation areas including Jamberoo Recreation Park and quarrying of latite at Bombo and Dunmore.

Existing Erosion

Evidence of minor mass movement (terracettes) on moderately steep lower slopes. Moderate rill erosion on batters of footslopes where soils have been disturbed.

Included Soil Landscapes

Small areas of Fountaindale **(fo)** and Jamberoo **(ja)** soil landscapes occur.

SOILS

Dominant Soil Materials

bo1—Friable reddish brown sandy clay loam (topsoil)

Colour	reddish brown (5YR 4/6)
Texture	sandy clay loam
Structure	apedal massive to weakly pedal, <2 mm crumb peds
Fabric	earthy and rough-faced, porous
pH	5.5
Stones	nil
Roots	abundant, ex-ped

bo2—Hardsetting brownish black sandy loam (topsoil)

Colour	brownish black (5YR 3/1) to dark reddish brown (5YR 3/3) occasionally at depth
Texture	sandy loam
Structure	weakly pedal, <2 mm crumb peds
Fabric	rough-faced, porous
pH	6.0
Stones	2–10% 2–6 mm angular, dispersed
Roots	abundant, ex-ped

bo3—Reddish brown light medium clay (subsoil)

Colour	reddish brown (2.5YR 4/8)
Texture	light medium clay
Structure	moderately pedal, 5–10 mm polyhedral peds
Fabric	rough-faced, porous
pH	4.0
Stones	nil (but can be localised rounded basalt or latite stones 20–60 mm 2–10% dispersed)
Roots	few, ex-ped

bo4—Reddish brown sandy clay (subsoil)

Colour	reddish brown (2.5YR 4/6)
Texture	sandy clay
Structure	moderately pedal, 5–10 mm polyhedral peds
Fabric	rough-faced, porous
pH	5.0
Stones	nil
Roots	many, ex-ped

bo5—Brown strongly pedal medium clay (subsoil)

Colour	brown (7.5YR 4/6)
Texture	medium clay
Structure	strongly pedal, 5–10 mm polyhedral and crumb peds
Fabric	rough-faced, porous
pH	4.0
Stones	nil
Roots	nil

Associated Soil Materials

Very shallow (<50 cm) indurated beach and fine grey Quaternary sands occur (Bass Point).

Occurrence and Relationships

Crests. Up to 15 cm friable reddish brown sandy clay loam **(bo1)** overlies bedrock [Structured Loams (Um6)].

Upper slopes and benches. Up to 15 cm **bo1** overlies <50 cm reddish brown sandy clay **(bo4)** which overlies <60 cm reddish brown light medium clay **(bo3)**. The boundaries are gradual [Krasnozems (Gn4.11)]. Total soil depth is <120 cm.

Midslopes and lower Slopes. Up to 10 cm hardsetting brownish black sandy loam **(bo2)** overlies

<15 cm **bo4**. Up to 40 cm brown strongly pedal medium clay **(bo5)** is overlain by <35 cm **bo3**. The boundaries are clear to gradual [Brown Podzolic Soils (Db1.11, Db1.21), Red Podzolic Soils (Dr2.21)]. Total depth is <120 cm.

LIMITATIONS TO DEVELOPMENT

Soil Limitations

bo1 High organic matter
Low wet bearing strength
High shrink-swell
Sodicity
High aluminium toxicity

bo2 Stoniness
Hardsetting
Low permeability
Sodicity

bo3 Strongly acid
Sodicity

bo4 Sodicity

bo5 Strongly acid
Sodicity

Fertility

General fertility is moderate to low. The topsoil **(bo1)** is friable. The soils are deep, well structured, freely drained on crests and upper slopes. They are strongly acid with low to moderate CEC.

Erodibility

bo1 has high erodibility. **bo2** has moderate erodibility, and the strongly structured subsoils **(bo3, bo4** and **bo5)** have low erodibility.

Erosion Hazard

Erosion hazard for non-concentrated flows is extreme. The calculated soil loss for the first 12 months of urban development ranges up to 100 t/ha for topsoils and 100 t/ha for exposed subsoils. The erosion hazard for concentrated flows is moderate to high.

Surface Movement Potential

These soils are generally stable; however, there are localised occurrences of moderately reactive soils.

Landscape Limitations

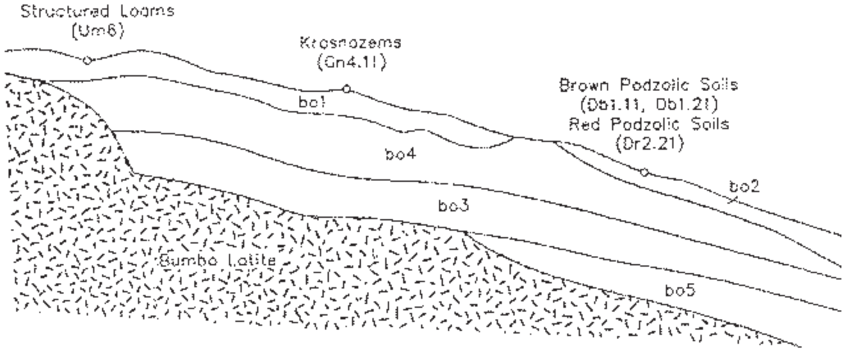
Steep slopes (localised)
Mass movement hazard (localised)
Rock fall hazard
Wave erosion hazard (coasts)
Rock outcrop
Run-on (localised)

Urban Capability

Generally moderate limitations for urban development. High to severe limitations on slopes greater than 20%.

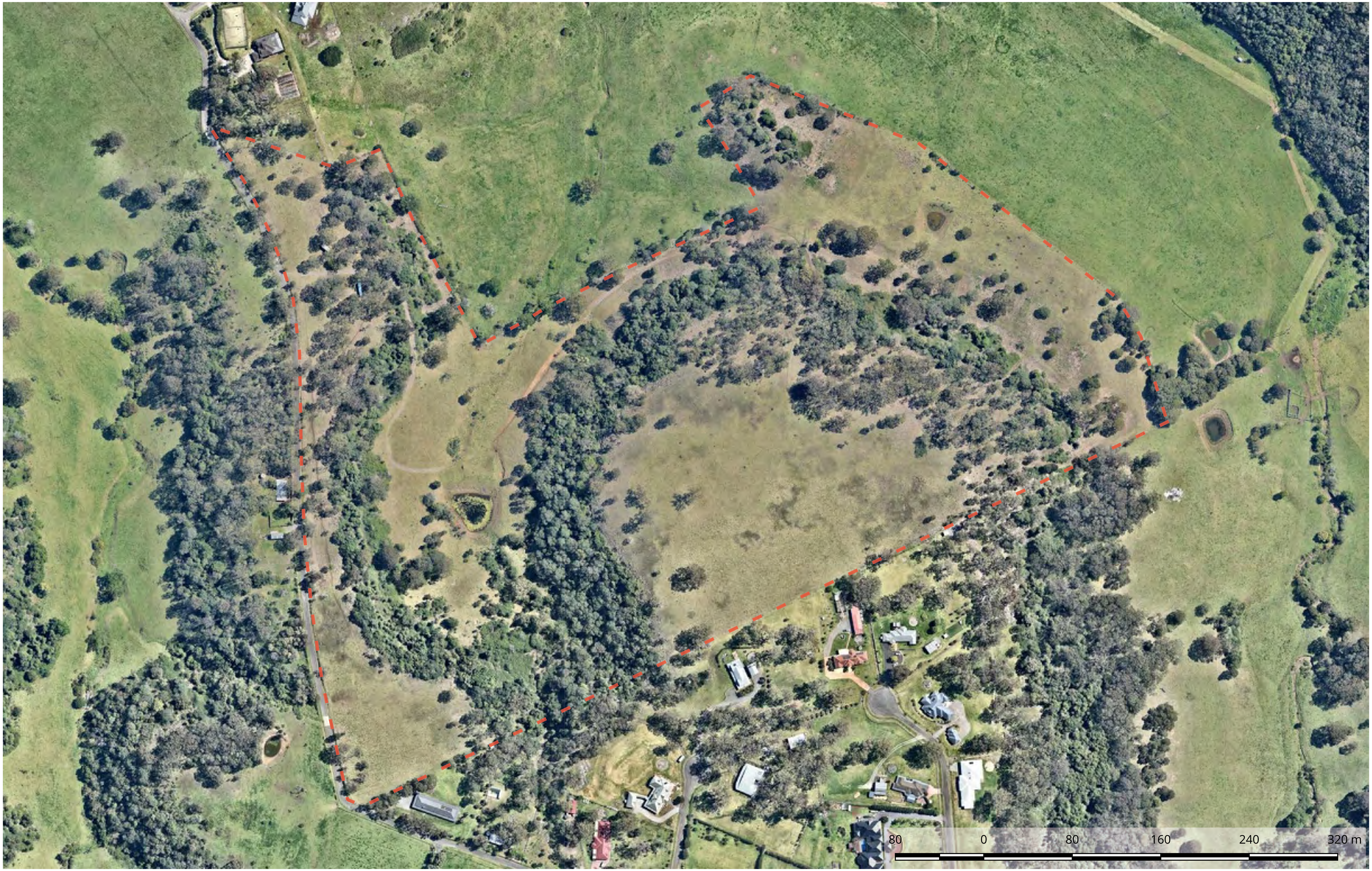
Rural Capability

Generally high to severe limitations for regular cultivation. Generally low to moderate limitations for grazing but high to severe limitations for grazing on steep slopes.



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

Appendix C: Historical Aerial Images



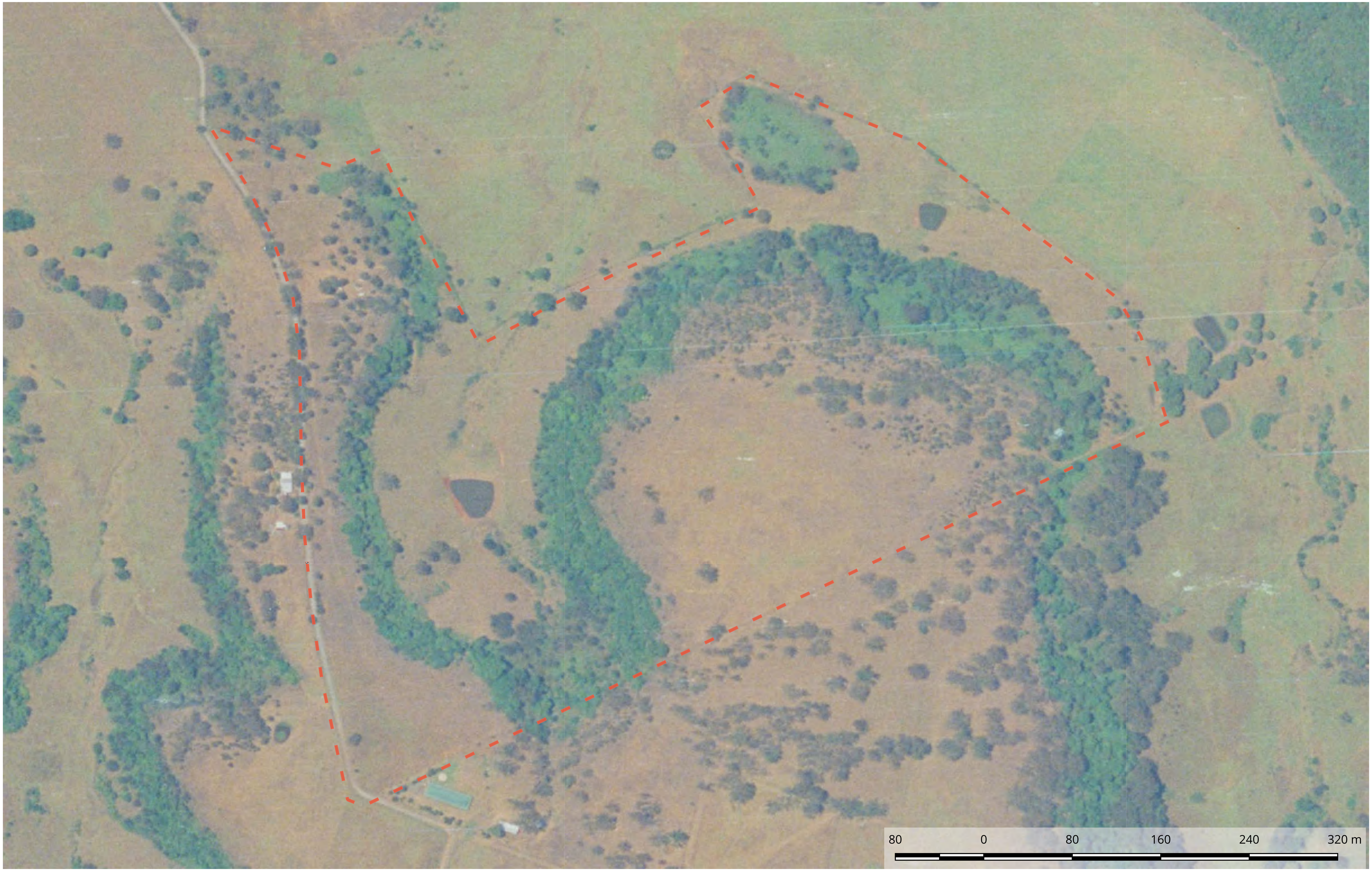
BROADCREST MAPPING AND SPATIAL SERVICES broadcrest.com.au | contact@broadcrest.com.au |1300 554 945 **Broadcrest Consulting Pty Ltd | ABN: 622 508 187**	**Client** TerraInsight	**Date** 2018	**Data Source** Department of Finance, Services & Innovation Copyright: Department of Finance, Services & Innovation	**Scale** 1:3000
	Location 105 Cooby Rdoa, Tullimbar	**LOT** 240 DP 828854	**Base map (shown in blue)** Department of Finance, Services & Innovation Copyright: Department of Finance, Services & Innovation	**Page**

BROADCREST
MAPPING AND SPATIAL SERVICES
broadcrest.com.au | contact@broadcrest.com.au |1300 554 945
Broadcrest Consulting Pty Ltd | ABN: 622 508 187

Client TerraInsight	**Date** 2010
Location 105 Cooby Rdoa, Tullimbar	**LOT** 240 DP 828854

Data Source
Department of Finance, Services & Innovation
Copyright: Department of Finance, Services & Innovation
Base map (shown in blue)
Department of Finance, Services & Innovation
Copyright: Department of Finance, Services & Innovation

Scale
1:3000
Page

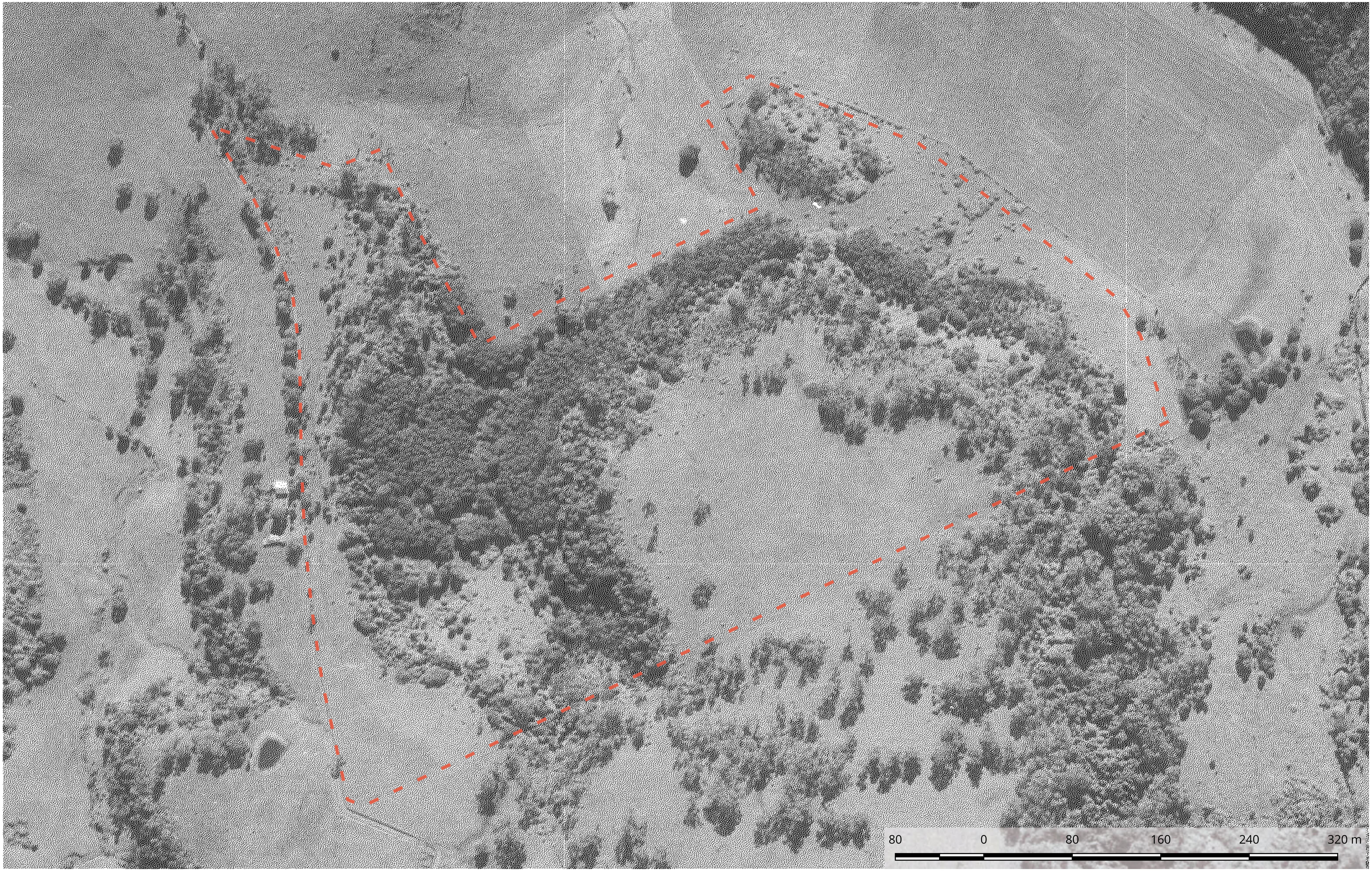


BROADCREST
MAPPING AND SPATIAL SERVICES
broadcrest.com.au | contact@broadcrest.com.au |1300 554 945
Broadcrest Consulting Pty Ltd | ABN: 622 508 187

Client	Date
TerraInsight	1997
Location	**LOT**
105 Cooby Rdoa, Tullimbar	240 DP 828854

Data Source
Department of Finance, Services & Innovation
Copyright: Department of Finance, Services & Innovation
Base map (shown in blue)
Department of Finance, Services & Innovation
Copyright: Department of Finance, Services & Innovation

Scale
1:3000
Page



BROADCREST
MAPPING AND SPATIAL SERVICES
broadcrest.com.au | contact@broadcrest.com.au | 1300 554 945
Broadcrest Consulting Pty Ltd | ABN: 622 508 187

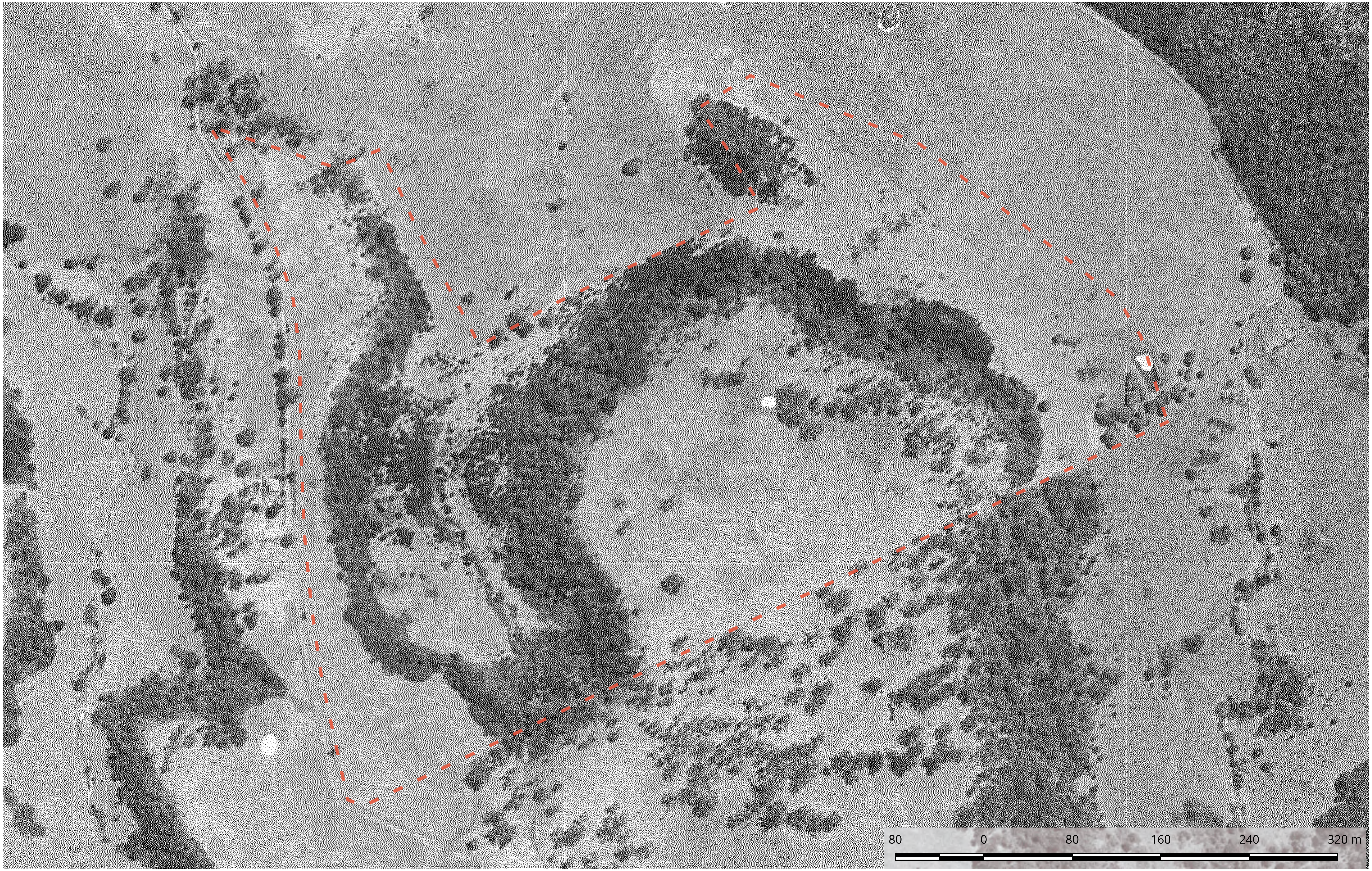
Client	Date
TerraInsight	1984
Location	**LOT**
105 Cooby Rdoa, Tullimbar	240 DP 828854

Data Source
Department of Finance, Services & Innovation
Copyright: Department of Finance, Services & Innovation

Base map (shown in blue)
Department of Finance, Services & Innovation
Copyright: Department of Finance, Services & Innovation

Scale
1:3000

Page

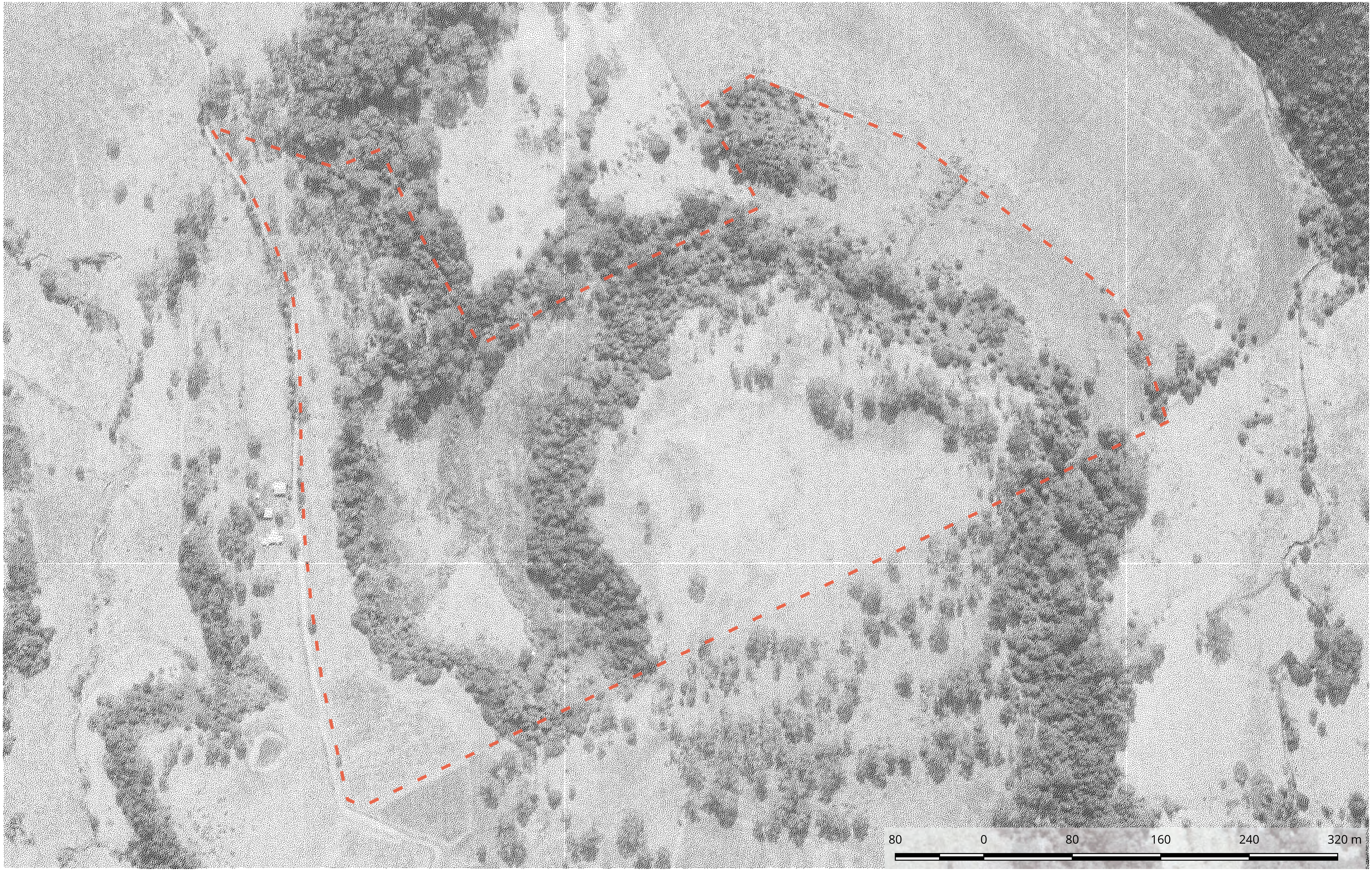


BROADCREST
MAPPING AND SPATIAL SERVICES
broadcrest.com.au | contact@broadcrest.com.au | 1300 554 945
Broadcrest Consulting Pty Ltd | ABN: 622 508 187

Client	Date
TerraInsight	1974
Location	**LOT**
105 Cooby Rdoa, Tullimbar	240 DP 828854

Data Source
Department of Finance, Services & Innovation
Copyright: Department of Finance, Services & Innovation
Base map (shown in blue)
Department of Finance, Services & Innovation
Copyright: Department of Finance, Services & Innovation

Scale
1:3000
Page



BROADCREST
MAPPING AND SPATIAL SERVICES
broadcrest.com.au | contact@broadcrest.com.au | 1300 554 945
Broadcrest Consulting Pty Ltd | ABN: 622 508 187

Client	Date
TerraInsight	1963
Location	**LOT**
105 Cooby Rdoa, Tullimbar	240 DP 828854

Data Source
Department of Finance, Services & Innovation
Copyright: Department of Finance, Services & Innovation

Base map (shown in blue)
Department of Finance, Services & Innovation
Copyright: Department of Finance, Services & Innovation

Scale
1:3000

Page

Appendix D: Site Images

Photograph 1: View of Terrace 1A looking south from the northern end of Terrace 1A

Photograph 2: View looking east across the northern boundary of Terrace 1A

Photograph 3: View of Dam South on Terrace 1A looking south east

Photograph 4: looking south west at the northern wall of Dam South

revision	description	drawn	approved	date
	Plate 1	HJP	KEG	03/12/18

TERRA INSIGHT

client:	Indesco		
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW		
scale	NTS	Title	Images of the site
original size	A3	project no: **TERRA18320**	Plate no: **1**

Photograph 5: View looking south east at the northern wall of Dam South showing dam seepage

Photograph 6: View looking west over Terrace 1A

Photograph 7: looking west on the western edge of Terrace 1A, showing water and latite rock on Area 2s escarpment edge

Photograph 8: Close up of photo 45 with water to the left and in-situ latite

revision	description	drawn	approved	date
	Plate 2	HJP	KEG	03/12/18

TERRA INSIGHT

client:	Indesco
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW
scale	NTS
Title	Images of the site
original size	A3
project no:	TERRA18320
Plate no:	2

Photograph 9: View looking north along the boundary between Area 2 and Terrace 1A

Photograph 10: View looking west from Terrace 1A showing the steep nature of Area 2

Photograph 11: looking north west over area 3 toward the northern section of Terrace 1B

Photograph 12: view of Terrace 1A looking east

revision	description	drawn	approved	date
	Plate 03	HJP	KEG	03/12/18

TERRA INSIGHT

client:	**Indesco**
project:	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**
scale	NTS
Title	**Images of the site**
original size	**A3**
project no: **TERRA18320**	Plate no: **3**

Photograph 13: View looking north over Terrace 1A

Photograph 14: View looking east from the middle section of Terrace 1B

Photograph 15: Outcropping latite in the middle section of Terrace 1B

Photograph 16: View looking east down Area 2 from Terrace 1B

revision	description	drawn	approved	date
	Plate	HJP	KEG	03/12/18

TERRA INSIGHT

client:	**Indesco**		
project:	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**		
scale	NTS	Title	**Images of the site**
original size	**A3**	project no: **TERRA18320**	Plate no: **4**

Photograph 17: View looking south west across Terrace 1B

Photograph 18: View looking south east across Terrace 1B and the boundary of Area 2

Photograph 19: View looking east from Terrace 1B over Areas 2 and 3 to Terrace 1A

Photograph 20: View looking east over the southern section of Terrace 1B

revision	description	drawn	approved	date
	Plate 5	HJP	KEG	03/12/18

TERRA INSIGHT

client:	Indesco
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW
scale	NTS
Title	Images of the site
original size	A3
project no:	TERRA18320
Plate no:	5

Photograph 21: Outcropping latite on the south eastern boundary between Terrace 1B and Area 2

Photograph 22: Looking down area 2 from Terrace 1B north toward Area 3

Photograph 23: View from the southern section of Terrace 1B looking north. Showing the steep drop and thick vegetation of Area 2

Photograph 24: Rock outcropping on the boundary of Terrace 1B and Area 2

revision	description	drawn	approved	date
	Plate 6	HJP	KEG	03/12/18

TERRA INSIGHT

client:	Indesco		
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW		
scale	NTS	Title	Images of the site
original size	A3	project no: TERRA18320	Plate no: 6

Photograph 25: View from Cooby Rd looking north over the southern area of Terrace 1B

Photograph 26: View from Cooby Rd looking north west over Terrace 1B

Photograph 27: View from Cooby Rd looking south east at neighbouring farm

Photograph 28: View from Cooby Rd looking west to the escarpment in the distance

revision	description	drawn	approved	date
	Plate1	HJP	KEG	03/12/18

TERRA INSIGHT

client:	Indesco
Project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW
scale	NTS
Title	Images of the site
original size	A3
project no:	TERRA18320
Plate no:	7

Photograph 29: View of the north western end of Terrace 1B

Photograph 30: View looking north east over Terrace 1B from near the road access gate

Photograph 31: View looking south down Terrace 1B from road access gate

Photograph 32: View of Dam West in Area 3 looking south east. Shows the steep nature of Area 2 as it steps up to Terrace 1A

revision	description	drawn	approved	date
	Plate 8	HJP	KEG	03/12/18

TERRA INSIGHT

client:	**Indesco**
project:	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**
scale	NTS
Title	**Images of the site**
original size	**A3**
project no: **TERRA18320**	Plate no: **8**

Photograph 33: View of area 3 looking north from farm road at the base of Area 2. Shows the steep hill face of Area 2 up to Terrace 1A

Photograph 34: View of the slope on the western side of Area 3 looking north

Photograph 35: Looking up the slope on the western side of area 3. Looking south west. Showing latite gravel on the surface.

Photograph 36: Looking west at the slope of Area 3 up to Area 2 and Terrace 1B

revision	description	drawn	approved	date
	Plate9	HJP	KEG	03/12/2018

TERRA INSIGHT

		client:	**Indesco**
		project :	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**
scale	NTS	Title	**Images of the site**
original size	**A3**	project no: **TERRA18320**	Plate no:**9**

Photograph 37: Looking south at Dam West in Area 3. Depicts the steep nature of Area 2 surrounding the gully

Photograph 38: View of spill way for Dam West. Located north east of Dam West in Area 3

Photograph 39: View of heavy erosion of spill way on Dam West

Photograph 40: View of colluvial sediments exposed by spill way erosion. Gravel and cobbles largely consist of sandstone with some latite from escarpments above

revision	description	drawn	approved	date
	Plate 10	HJP	KEG	03/12/2018

TERRA INSIGHT

client:	**Indesco**
project:	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**
scale	NTS
original size	**A3**
Title	**Images of the site**
project no:	**TERRA18320**
Plate no:	**10**

Photograph 41: View looking south west at storm water culvert north of the dam wall


Photograph 42: View of the storm water culvert looking north from the Dam West

Photograph 43: looking south west showing the storm water channel through Area 3 looking back towards the culvert


Photograph 44: looking north showing the storm water channel through the base of Area 3

revision	description	drawn	approved	date
	Plate 11	HJP	KEG	03/12/18

TERRA INSIGHT

client:	Indesco		
Project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW		
scale	NTS	Title	Images of the site
original size	A3	project no: TERRA18320	Plate no: 11

Photograph 45: View from western side of Area 3 looking east

Photograph 46: View looking south west across the western side of Area 3 toward Dam West

Photograph 47: Showing latite boulders and cobbles in Area 3 from Area 2s escarpment above

Photograph 48: View looking north at Area 4 from Area 3

revision	description	drawn	approved	date
	Plate 6	HJP	KEG	03/12/18

TERRA INSIGHT

client:	Indesco		
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW		
scale	NTS	Title	Images of the site
original size	A3	project no: TERRA18320	Plate no: 12

Photograph 49: View from the southern side of Area 4 looking south east over the eastern section of Area 3

Photograph 50: View looking east over the eastern section of Area 3 showing Dam East

Photograph 51: View looking south from Dam East looking at the storm water culverts under the farm road

Photograph 52: View looking east in Area 3 showing medium sized latite boulder from Area 2 to the south

revision	description	drawn	approved	date
	Plate 13	HJP	KEG	03/12/18

TERRA INSIGHT

client:	**Indesco**
project:	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**
scale	NTS
Title	**Images of the site**
original size	**A3**
project no:	**TERRA18320**
Plate no:	13

Photograph 53: View of south eastern section of Area 3.

Photograph 54: looking south west up the steep slope of Area 2 from the eastern section of Area 3

Photograph 55: View looking south from the eastern section of Area 3 up at Area 2. Showing an access track through Area 2 to Terrace 1A

Photograph 56: North eastern Area 2, vegetated with boulders

revision	description	drawn	approved	date
	Plate 14	HJP	KEG	03/12/18

TERRA INSIGHT

client:	Indesco
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW
scale	NTS
Title	Images of the site
original size	A3
project no:	TERRA18320
Plate no:	14

Photograph 57: View looking south west in Area 3 looking toward the culverts under the farm road

Photograph 58: looking south up an access track from area 3 up through Area 2 to Terrace 1A

Photograph 59: Latite rock outcropping on access road in Area 2

Photograph 60: looking east from the boundary between Area 2 and Terrace 1A

revision	description	drawn	approved	date
	Plate 15	HJP	KEG	03/12/18

TERRA INSIGHT

client:	**Indesco**
project :	**Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW**
scale	NTS
Title	**Images of the site**
original size	**A3**
project no: **TERRA18320**	Plate no: **15**

Photograph 61: View from the top of Zone 4 looking down the western slope

Photograph 62: View looking north from the top of Zone 4. Showing the thick vegetation and latite cobbles and boulders

Photograph 63: View looking east at the northern side of Area 4

Photograph 64: Looking south down the western side of Area 4

revision	description	drawn	approved	date
	Plate 13	HJP	KEG	03/12/18

TERRA INSIGHT

client:	Indesco		
project:	Geotechnical Investigation for Proposed Subdivision No. 105 Cooby Road, Tullimbar NSW		
scale	NTS	Title	Images of the site
original size	A3	project no: **TERRA18320**	Plate no: **16**

Appendix E: Appendix C of the journal, Australian Geomechanics, Vol. 42, No. 1, dated March 2007

APPENDIX C: LANDSLIDE RISK ASSESSMENT

QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

QUALITATIVE MEASURES OF LIKELIHOOD

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

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

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

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

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

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

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

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

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

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

Notes: (5) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.

(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

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

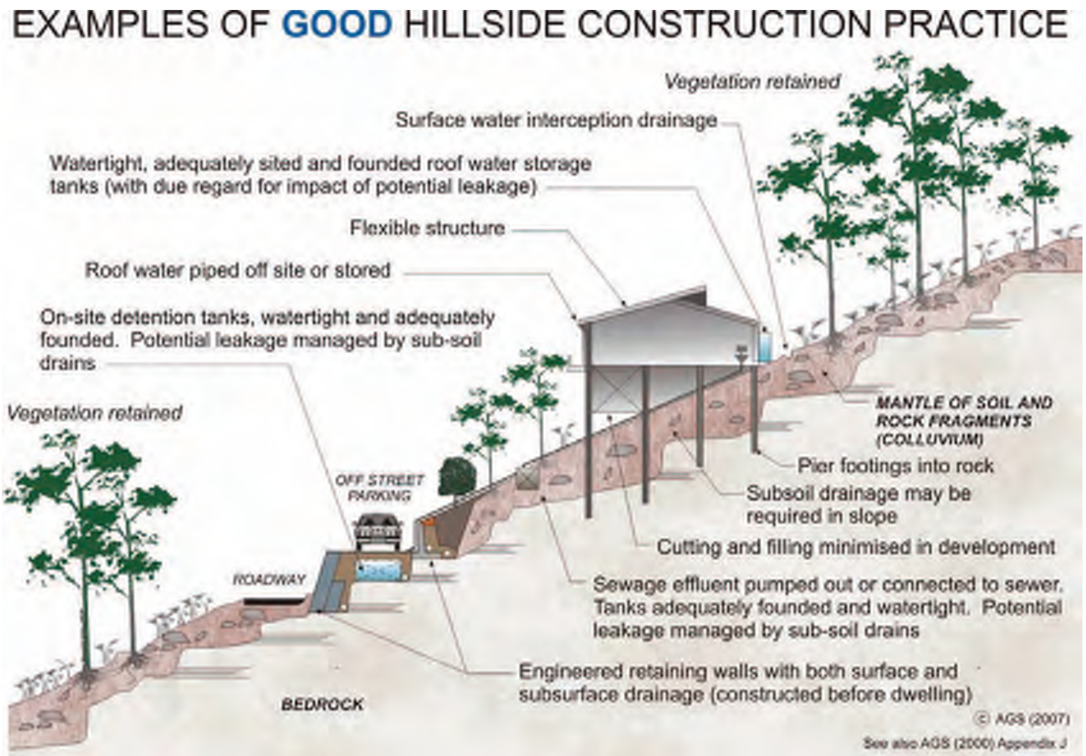
Note: (7) The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

Appendix F: GeoGuide Good Hillside practice guidelines LR08

AUSTRALIAN GEOGUIDE LR8 (CONSTRUCTION PRACTICE)

HILLSIDE CONSTRUCTION PRACTICE

Sensible development practices are required when building on hillsides, particularly if the hillside has more than a low risk of instability (GeoGuide LR7). Only building techniques intended to maintain, or reduce, the overall level of landslide risk should be considered. Examples of good hillside construction practice are illustrated below.



WHY ARE THESE PRACTICES GOOD?

Roadways and parking areas - are paved and incorporate kerbs which prevent water discharging straight into the hillside (GeoGuide LR5).

Cuttings - are supported by retaining walls (GeoGuide LR6).

Retaining walls - are engineer designed to withstand the lateral earth pressures and surcharges expected, and include drains to prevent water pressures developing in the backfill. Where the ground slopes steeply down towards the high side of a retaining wall, the disturbing force (see GeoGuide LR6) can be two or more times that in level ground. Retaining walls must be designed taking these forces into account.

Sewage - whether treated or not is either taken away in pipes or contained in properly founded tanks so it cannot soak into the ground.

Surface water - from roofs and other hard surfaces is piped away to a suitable discharge point rather than being allowed to infiltrate into the ground. Preferably, the discharge point will be in a natural creek where ground water exits, rather than enters, the ground. Shallow, lined, drains on the surface can fulfil the same purpose (GeoGuide LR5).

Surface loads - are minimised. No fill embankments have been built. The house is a lightweight structure. Foundation loads have been taken down below the level at which a landslide is likely to occur and, preferably, to rock. This sort of construction is probably not applicable to soil slopes (GeoGuide LR3). If you are uncertain whether your site has rock near the surface, or is essentially a soil slope, you should engage a geotechnical practitioner to find out.

Flexible structures - have been used because they can tolerate a certain amount of movement with minimal signs of distress and maintain their functionality.

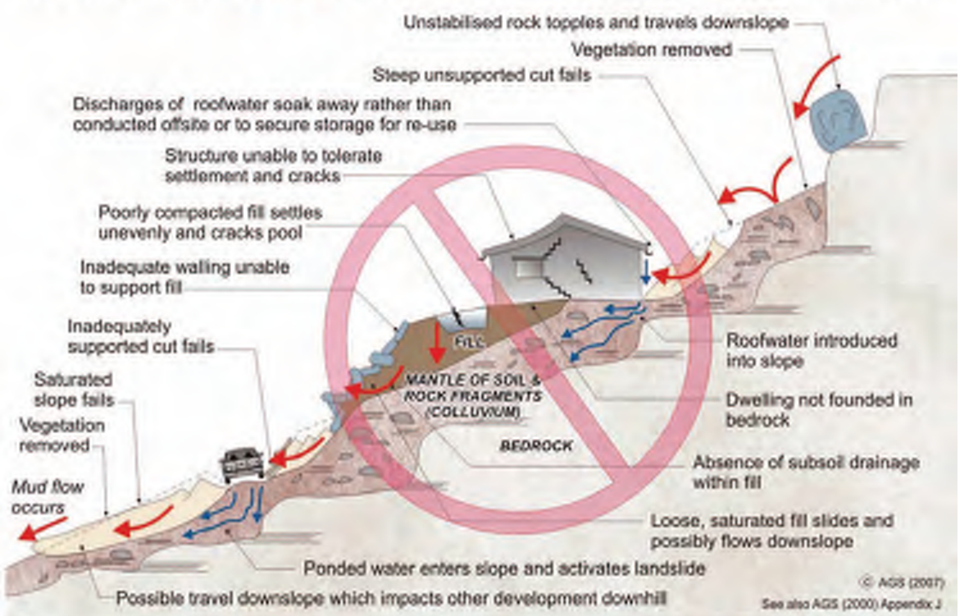
Vegetation clearance - on soil slopes has been kept to a reasonable minimum. Trees, and to a lesser extent smaller vegetation, take large quantities of water out of the ground every day. This lowers the ground water table, which in turn helps to maintain the stability of the slope. Large scale clearing can result in a rise in water table with a consequent increase in the likelihood of a landslide (GeoGuide LR5). An exception may have to be made to this rule on steep rock slopes where trees have little effect on the water table, but their roots pose a landslide hazard by dislodging boulders.

Possible effects of ignoring good construction practices are illustrated on page 2. Unfortunately, these poor construction practices are not as unusual as you might think and are often chosen because, on the face of it, they will save the developer, or owner, money. You should not lose sight of the fact that the cost and anguish associated with any one of the disasters illustrated, is likely to more than wipe out any apparent savings at the outset.

ADOPT GOOD PRACTICE ON HILLSIDE SITES

AUSTRALIAN GEOGUIDE LR8 (CONSTRUCTION PRACTICE)

EXAMPLES OF POOR HILLSIDE CONSTRUCTION PRACTICE



WHY ARE THESE PRACTICES POOR?

Roadways and parking areas - are unsurfaced and lack proper table drains (gutters) causing surface water to pond and soak into the ground.

Cut and fill - has been used to balance earthworks quantities and level the site leaving unstable cut faces and added large surface loads to the ground. Failure to compact the fill properly has led to settlement, which will probably continue for several years after completion. The house and pool have been built on the fill and have settled with it and cracked. Leakage from the cracked pool and the applied surface loads from the fill have combined to cause landslides.

Retaining walls - have been avoided, to minimise cost, and hand placed rock walls used instead. Without applying engineering design principles, the walls have failed to provide the required support to the ground and have failed, creating a very dangerous situation.

A heavy, rigid, house - has been built on shallow, conventional, footings. Not only has the brickwork cracked because of the resulting ground movements, but it has also become involved in a man-made landslide.

Soak-away drainage - has been used for sewage and surface water run-off from roofs and pavements. This water soaks into the ground and raises the water table (GeoGuide LR5). Subsoil drains that run along the contours should be avoided for the same reason. If felt necessary, subsoil drains should run steeply downhill in a chevron, or herring bone, pattern. This may conflict with the requirements for effluent and surface water disposal (GeoGuide LR9) and if so, you will need to seek professional advice.

Rock debris - from landslides higher up on the slope seems likely to pass through the site. Such locations are often referred to by geotechnical practitioners as "debris flow paths". Rock is normally even denser than ordinary fill, so even quite modest boulders are likely to weigh many tonnes and do a lot of damage once they start to roll. Boulders have been known to travel hundreds of metres downhill leaving behind a trail of destruction.

Vegetation - has been completely cleared, leading to a possible rise in the water table and increased landslide risk (GeoGuide LR5).

DON'T CUT CORNERS ON HILLSIDE SITES - OBTAIN ADVICE FROM A GEOTECHNICAL PRACTITIONER

More information relevant to your particular situation may be found in other Australian GeoGuides:

- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR3 - Landslides in Soil
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR7 - Landslide Risk
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR10 - Coastal Landslides
- GeoGuide LR11 - Record Keeping

The Australian GeoGuides (LR series) are a set of publications intended for property owners; local councils; planning authorities; developers; insurers; lawyers and, in fact, anyone who lives with, or has an interest in, a natural or engineered slope, a cutting, or an excavation. They are intended to help you understand why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local council approval (if required) to remove, reduce, or minimise the risk they represent. The GeoGuides have been prepared by the Australian Geomechanics Society, a specialist technical society within Engineers Australia, the national peak body for all engineering disciplines in Australia, whose members are professional geotechnical engineers and engineering geologists with a particular interest in ground engineering. The GeoGuides have been funded under the Australian governments' National Disaster Mitigation Program.

Appendix G: CSIRO BTF 18 Guidelines

Foundation Maintenance and Footing Performance: A Homeowner's Guide

CSIRO

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).

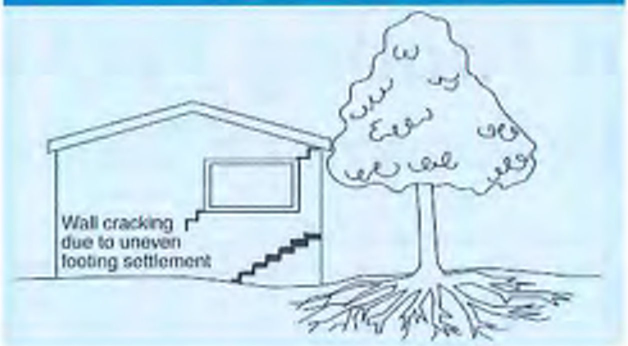
Isolated piers affected by erosion or saturation of foundations will eventually lose contact with the bearers they support and may tilt or fall over. The floors that have lost this support will become bouncy, sometimes rattling ornaments etc.

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.

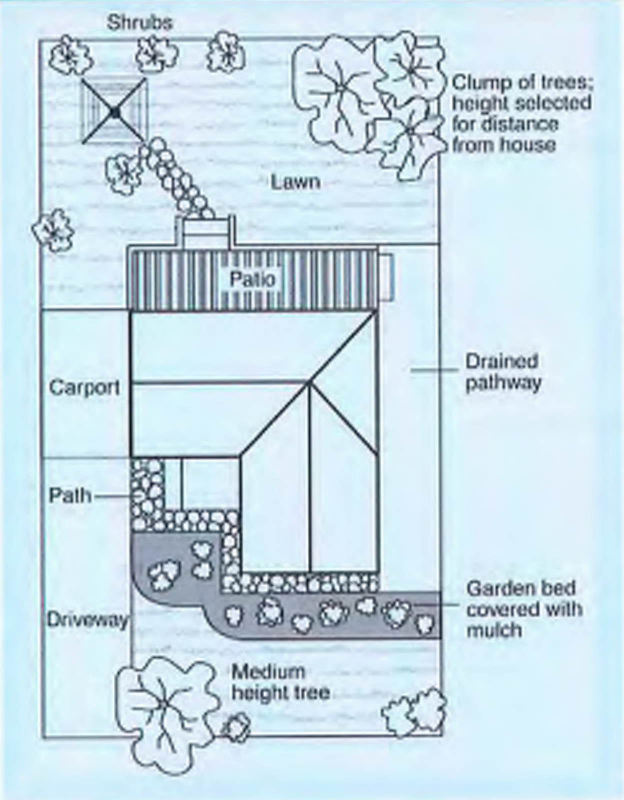
Protection of the building perimeter
It is essential to remember that the soil that affects footings extends well beyond the actual building line. Watering of garden plants, shrubs and trees causes some of the most serious water problems.

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.

Distributed by

CSIRO PUBLISHING PO Box 1139, Collingwood 3066, Australia

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

Email: publishing.sales@csiro.au