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TECHNICAL REPORT

on

GEOTECHNICAL FEASIBILITY STUDY

at

ARINA ROAD, BARGO, NSW

Prepared For

Wollondilly Shire Council

Project No.: 2022-098

August 2022

Document Revision Record

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0	10 June 2022	Draft Issued for Comment
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EXECUTIVE SUMMARY

A Geotechnical Study has been undertaken to identify assess the suitability of proposed rezoning from Primary Production (RU1) to light commercial/industrial use within 15 lots located to the west of Arina Road, Bargo, NSW.

The study comprised a desktop review of available maps, plans and online resources followed by a walkover assessment of the area proposed for rezoning to identify potential constraints to the proposal.

The study identified several potential geotechnical conditions which need to be considered and are detailed in this report. However, the constraints are not considered to represent significant constraints based on the probable type of structures proposed and can be further mitigated with site specific subsurface investigation prior to design and construction of both the subdivision layout and proposed new structures.

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Date: 24 August 2022
Project No: 2022-098

TECHNICAL REPORT ON GEOTECHNICAL FEASIBILITY STUDY AT ARINA ROAD, BARGO, NSW

1. INTRODUCTION:

This report details the results of a geotechnical feasibility assessment carried out at Arina Road, Bargo, NSW. The assessment was undertaken by Crozier Geotechnical Consultants (CGC) at the request of and in combination with Metech Consulting for Wollondilly Shire Council.

The geotechnical assessment and reporting are required to support a proposed rezoning of several currently rural zoned (RU1 - Primary Production) properties to light industrial/commercial use. Development proposals have not been finalised. For the purposes of this study, the new structures/developments have been assumed to comprise warehouse type buildings with on grade slabs and parking areas. Deep basements, large commercial/retail structures or multistorey buildings are not anticipated.

A fee proposal (Fee Proposal P22-134, Dated: 14 March 2022) was submitted and subsequently accepted by the client to undertake the nominated scope of works. The assessment was undertaken in accordance with the Fee Proposal. This report is one of three geotechnical feasibility studies compiled for Wollondilly Shire Council (Locations within Silverdale and Picton being the other two study areas) which were included in the requested scope of works.

This study comprised:

- Desktop review of geological, soil landform, topographic maps
- Air-photo interpretation and mapping of the site and adjacent land
- A walkover inspection and geomorphological mapping of the properties proposed for rezoning by a Senior Engineering Geologist

The following document was supplied and relied upon for the preparation of the proposal:

- RFQ – Employment Land Rezoning – Technical Study (Reference: 13494)

Specific detailed guidelines or required deliverables to be included within the Technical Study Report have not been provided by Wollondilly Shire Council. Based on our understanding of the purpose of the Technical Study it is considered that information on the following 'key' elements will need to be addressed to adequately inform Council, stakeholders and the public of the proposed rezoning impacts.

- What are likely to be the most significant geotechnical constraints/considerations relating to commercial/industrial developments within the study area.
- What potential impact could the geotechnical constraints/considerations have on the feasibility of the rezoning proposal.
- Can the constraints/considerations be controlled/further delineated if required.

1.1 Methodology

To address the key elements required to be fulfilled, the following methodology was adopted:

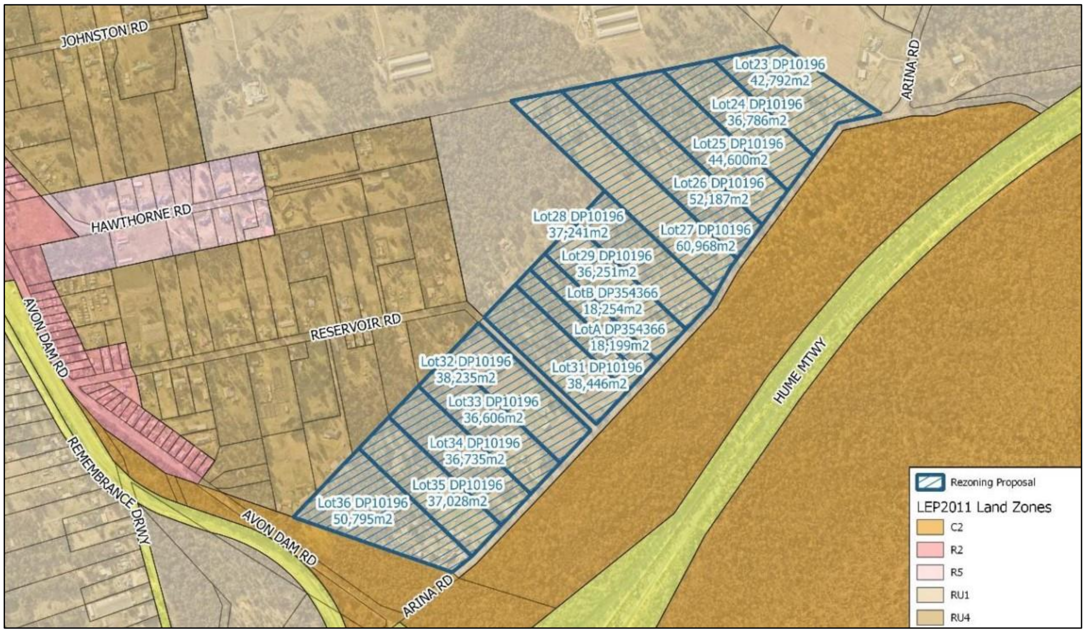
- Undertake desk top review of available geological/landform maps, Lotsearch information, arial photographs and online resources.
- Site walkover of proposed subdivision lots to assess erosion potential, slope stability, terrain, vegetation, bedrock outcrops/soil cuttings and drainage conditions.
- Outline any identified constraints relevant to the proposed subdivision.
- Assess the significance of those constraints based on severity and distribution.

In addition to this report, an additional Technical Studies Outcome Paper has also been prepared which summarises the key geotechnical constraints and considerations in the assessment of the rezoning proposal.

1.2 Proposed Land Rezoning Study Area

The site is approximately 59 hectares and is located to the southeast of Bargo approximately 300m from the Hume Motorway. The site consists of large lot rural residential properties and is surrounded by bush land to the south and west and large lot residential properties to the north and east.

An aerial view of the study area with the lot boundaries/references shown is provided as Photograph 1 which was included in the Council RFQ documentation.



Photograph 1: Aerial view of the study area with lots overlain

2.0 OVERVIEW OF STUDY AREA

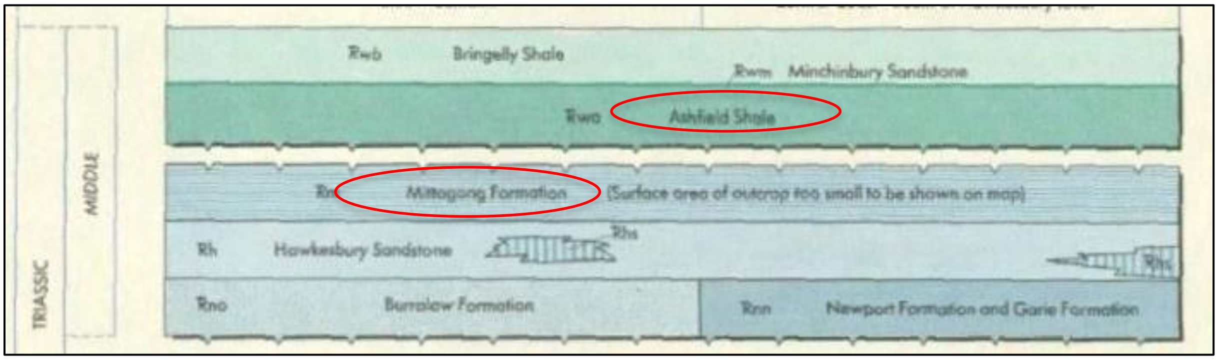
2.1 Geological Setting

Reference to the Wollongong – Port Hacking 1:100,000 Geological Series sheet (9029 - 9129) indicates that the majority of the study area is underlain by the Hawkesbury Sandstone (Rh) with a narrow section of the overlying Ashfield Shale in the extreme north east indicated underlying the study area.

The Hawkesbury Sandstone typically comprises medium to coarse grained quartz sandstone with minor lenses of shale and laminite. Morphological features often associated with the weathering of Hawkesbury Sandstone are the formation of near flat ridge tops with steep angular side slopes. These slopes often consist of sandstone terraces and cliffs with steep colluvial slopes below. The outline of the cliff areas is often rectilinear in plan view, controlled by large bed thickness and wide spaced near vertical joint pattern, many cliff areas are undercut by differential weathering. Slopes below these cliffs are often steep 15 to 23° with moderately thick sandy colluvial soil profile that are randomly covered by sandstone boulders.

Ashfield Shale rocks are dominated by shales with occasional thin laminite or siltstone beds, they often form rounded low angle convex ridge tops with undulating low angle (<10°) side slopes. These side slopes can be either concave or convex depending on geology, internally they comprise either thinly bedded shales or interbedded shale and siltstone beds with close spaced bedding partings that have either close spaced or large discontinuous vertical joints. The siltstone often forms deeply weathered silty sandy clay profiles while the shale forms medium to high plasticity soil profiles with moisture reactive properties, both can have thick silty colluvial topsoil cover.

Extracts of the relevant geological map sheet are provided below. It should be noted that the locations of the geological boundaries indicated on the map should be considered approximate at a scale of 1:100,000.



Extract 1: Key to Geological Map

Extract 2: Extract from the Wollongong – Port Hacking Geological Series sheet (9029 - 9129) with site outlined red

2.2 Study Area and Surrounding Topography

The study area lies within gently north sloping topography and varies between a high of RL360m adjacent to the south boundary and a low of RL334m adjacent to the north boundary. An extract of a topographic map of the area is provided as Extract 3 with a contour map provided as Extract 4.

Extract 3: Extract of the topographic map obtained from OpenStreetMap©

Extract 4: Extract of a contour map of the study area obtained from Mecone Mozaic

2.3 Acid Sulphate Soils

According to information contained within the Lotsearch Report obtained for the study area (Reference: LS031589 EP), the majority of the site is within an area of low chance (6% to 70%) with a small section near the north of the study area of extremely low chance (1% - 5%) of encountering acid sulphate soils.

2.4 Salinity

According to information contained within the Lotsearch Report obtained for the study area (Reference: LS031589 EP), the site does not lie in an area where dryland salinity has been identified previously.

2.5 Mine Subsidence

According to information contained within the Lotsearch Report obtained for the study area (Reference: LS031589 EP), the site lies within the Bargo Mine Subsidence area.

Based on the information provided within the NSW Government ePlanning Spatial Viewer, the following building requirements (Guideline 5) apply to new residential constructions:

'Single or two storey clad frame or brick veneer on footings/slabs to minimum H2 AS 2870 site classification and design features. Maximum length of 24m and maximum footprint of 400sqm'

However, no construction requirements are specified for commercial developments.

3.0 FIELD MAPPING/DETAIL DESK STUDY RESULTS

3.1 Methods:

The fieldwork comprised a walk over inspection of the study area and adjacent properties on the 20 May 2022 by a Senior Engineering Geologist.

The walk over inspection comprised geological/geomorphological field mapping and observation of structures/conditions within the study area to assess topography, slopes and existing structures. The inspection was restricted to observations made from the ground surface of the site or adjacent, accessible land. Photographs of relevant observations were taken for inclusion in the report and to allow the creation of a photographic record to be made prior to commencement of construction works within the site.

Access to all parts of every site was not available predominately due to either the physical site conditions, or uncontactable property owners. Where possible assessments from the adjacent properties or public land adjacent to the inaccessible properties was undertaken. The list below indicates the properties where limited access was available:

- No.560, No.580, No.590, No.610, No.630, No.636, No.660 and No.690 Arina Road and No.120 Reservoir Road

Detail survey information was not available at the time of reporting. Lot measurements and elevation information has been determined from a combination of information provided by Council, NSW Government Six Maps website, Google Earth, the relevant Lotsearch Report (Provided by Metech Consulting) and various other open source/spatial data/mapping websites.

Where appropriate (and where access was available) the mapping results are provided on a lot-by-lot basis, where limited information (or limited access) was available for a particular lot, the lot descriptions have been combined. Detail desk study information is also included where relevant.

Aerial images have been provided in the following section to highlight lot features. A key to the symbols provided on aerial images is provided below.

Wet areas	Minor drainage path
Dip Direction with slope (White on images)	Major drainage path
Ponds	Fill areas (various shapes)
Sandstone bedrock outcrops	

3.1.1 Number 560 Arina Road (Lot 23 DP10196) to Number 600 Arina Road (Lot 27 DP10196)

There are five properties within this assessed section that are located within the north end of the study area and share common features. The overall ground surface of the lots displayed a gentle dip from south to north with an overall crossfall of approximately 14m from a high of RL348m adjacent to the south boundary of Lot 27 DP10196 to a low of RL334m adjacent to the north boundary of Lot 26 DP10196. The five lots combined occupy an area of approximately 23.9 hectares.

The lots are thin and narrow in shape and are occupied by residential properties with numerous horse compounds scattered throughout the lots. The majority of the areas within each of the lots appear undeveloped and comprise open paddocks or areas of bushland containing mature trees. Significant cut/fill earthworks do not appear to have been undertaken within the lots with the exception of some limited excavation works associated with ponds located within Lots 23, 25 and 26. Minor fill is also anticipated around the existing residences however it is expected to be relatively shallow and localised.

Photograph 2: View of an existing pond within Lot 23 DP10196

With the exception of the ponds, standing water or boggy areas were not observed during the site walkover However, it is understood from the occupants of the lots that various portions of the properties are soft underfoot, particularly following rainfall events.

Photograph 3: View of the front of Lot 24 DP10196 looking broadly northwest

Inspection of the existing structures did not indicate any significant cracks to indicate excessive shrink swell movements of the founding soils. No signs of excessive surface erosion or potential landslip movements were observed. No areas of discoloured grass or vegetation were observed to indicate the presence of potential contaminants or elevated salinity.

Photograph 4: View of Lot 25 DP10196 looking west

Photograph 5: View of Lot 27 DP10196 looking broadly north from near the lot residence.

Photograph 6: Aerial view of Lot 23 DP10196 to Lot 27 DP10196

3.1.2 Number 610, 620, 630 and 636 Arina Road (Lot 28 and 29 DP10196, Lot B and A DP354366) and 115 Reservoir Road (Lot 31 DP10196)

There are five properties within this assessed section, and they are located within the north end of the study area and share common features. The overall ground surface of the lots displayed a gentle dip from south to north with an overall crossfall of approximately 8m from a high of RL350m adjacent to the south boundary of Lot 31 DP10196 to a low of RL342m adjacent to the north boundary of Lot 28 DP10196. The five lots combined occupy an area of approximately 14.8 hectares in plan.

The lots are rectangular in shape and are occupied by residential properties with animal compounds scattered throughout the lots. The majority of the areas within each of the lots appear undeveloped and comprise open paddocks or areas of bushland containing mature trees. The vegetation typically became denser within the north end of each of the lots. Significant cut/fill earthworks do not appear to have been undertaken within the lots with the exception of some limited excavation works associated with ponds located within Lots 28, B DP354366 and Lot 31 DP10196.

Photograph 7: View of the rear of Lot 610 DP10196 looking broadly west

Photograph 8: View of the center and south of Lot 29 DP10196 looking broadly south

Photograph 9: View of the center and south of Lot 31 DP10196 looking broadly east

No obvious signs of erosion (gullying etc.) were observed, although discussions with one of the tenants/owners indicated that areas of soft ground exist within the majority of the lots in the area however this is not confirmed.

Inspection of the existing structures within the lot did not indicate any significant cracks to indicate excessive shrink swell movements of the founding soils. No areas of discoloured grass or vegetation were observed to indicate the presence of potential contaminants or elevated salinity.

Photograph 10: Aerial view of lots 28 and 29 DP10196, Lot B and A DP354366 and Lot 31 DP10196

3.1.3 Number 120 Reservoir Road (Lot 32 DP10196) and Number 660 to 690 Arina Road (Lot 33 DP10196 to Lot 36 DP10196)

These lots are within the south end of the study area and comprise residential properties. The overall ground surface of the lots displayed a gentle dip from south to north with a crossfall of approximately 13m from a high of RL359m within Lot 36 DP10196 to a low of RL346m adjacent to the north boundary of Lot 34 DP10196. Combined, the lots cover an area of approximately 19.6 hectares.

The majority of the areas within each of the study area appear undeveloped and comprise open paddocks or areas of bushland containing mature trees. Significant cut/fill earthworks do not appear to have been undertaken within the lots with the exception of some limited excavation works associated with ponds within Lot 32 and Lot 36.

Inspection of the existing structures within the lot did not indicate any significant cracks to indicate excessive shrink swell movements of the founding soils. Signs of surface erosion or potential landslip movements were not observed. No areas of discoloured grass or vegetation were observed to indicate the presence of potential contaminants or elevated salinity.

Photograph 11: Lot 32 DP10196 looking broadly west from Reservoir Road

Photograph 12: View of the north of Lot 34 DP10196 looking broadly south

The surface of the area appeared generally well drained with no uncontrolled water/erosion observed however it is understood from field discussions that one on the owners has imported granular fill to surface the driveway so that vehicle use could be maintained following rainfall.

Photograph 13: Aerial view of Lot 32 DP10196 to Lot 36 DP10196

4.0 GEOTECHNICAL ASSESSMENT

4.1 Potential Constraints

Based on the results of the desk study and site walkover, the following potential constraints have been identified within the study area and are discussed in the following sections.

- Soft/loose or filled ground
- Potential shrinkable clay soils
- Shallow/variable bedrock depths
- Poorly drained areas
- Existing vegetation
- Potential Mine Subsidence

4.1.1 Soft/Loose or Filled Ground

It is envisaged that soft or loose soil will be encountered within the existing ponds within the study area and may be encountered in other areas based on anecdotal evidence. The depth of the ponds unlikely exceeds 1m-2m however this would require confirmation should development occur. The areas directly adjacent to the ponds are likely to comprise fill soils from the pond excavation works.

It is unlikely the fill soils are controlled and placed to an engineering specification therefore potential for adverse variation exists in both the composition and degree of compaction of the fill. The presence of voids within uncontrolled fill as well as potential soft/loose zones or inclusions of deleterious materials may lead to potentially significant future total and differential settlements, occurring possibly over relatively short distances. This will likely only be of concern where fill soils are left in place and utilised for foundation or subgrade.

It is probable that, as part of any future development works, all uncontrolled fill present in settlement sensitive areas would either require removal and replacement with controlled fill of low 'reactivity' or any new structures should be supported on foundations extending through the fill and founding in suitable materials.

Due to the anticipated type of developments proposed, if the proposed change of use is successful, it is anticipated that if soft/fill soils are encountered around the existing ponds, the impact could be mitigated via relatively minor earthworks and/or modifications in footing design.

4.1.2 Expansive Clay Soils

The majority of the site is underlain by the Hawkesbury Sandstone according to the Wollongong – Port Hacking 1:100,000 Geological Series sheet which will likely have an overlying clay/sandy clay weathered upper horizon within the uppermost 1-2m. This geological unit is not associated with highly reactive clays, however the overlying Ashfield Shale as indicated underlying the northeast of the study area has a tendency towards reactivity. Where shrinkable clay soils are identified underlying a site, an estimation of the potential magnitude of movement should be undertaken as part of preliminary subsurface investigations. The magnitude of shrink swell movements and variation may significantly increase where the effect of mature trees and wet areas create abnormal moisture content profiles below structures.

Based on the determined magnitude of shrink swell movements, a variety of measures can be adopted to prevent structural damage to new buildings including:

- Designing new structures to be tolerant of potential movements via flexible building materials, expansion/slip joints etc.
- Reinforcement, thicker floor slab, deeper footings
- Fully suspended floor slab
- Replacement of expansive clay below floor slabs with inert, granular fill

Regardless of the proposed design to accommodate movement, protection of the new structures requires the prevention of abnormal moisture contents developing below structures therefore ongoing maintenance, landscaping, surface/subsurface drainage and proposed vegetation must all be designed to control water throughout the design life of the building.

Due to the climate in Bargo, the depth of seasonal moisture variation is unlikely to exceed 2.0m below ground level which reduces the magnitude of likely shrink swell movements in comparison to other states in Australia. Additionally, due to the nature of the probable structures, some tolerance to movement may be accommodated, however where high shrink swell movements are anticipated, construction of some structure types (brick/masonry, low movement tolerant structures) may not be economically feasible.

The significance of expansive clay impacting proposed future constructions will vary across the study area and will require subsurface investigation to further assess.

4.1.3 Shallow/Variable Bedrock Depth

The Hawkesbury Sandstone underlying the majority of the study area is likely to exhibit some variation in depth across the study area. Where bedrock is located near the existing ground surface additional requirements for bedrock removal may be required to construct new footings, service trenches etc. Subject to the strength and depth to bedrock, additional excavation requirements may be necessary.

In addition, where variable depth to bedrock is encountered underlying a single structure, additional footing/slab requirements may be necessary to reduce the potential for differential settlement (i.e., a footing founded on/off low strength or stronger bedrock will settle far less under an applied load than a footing founded in clay soils).

The impact of shallow bedrock on project costs can be reduced, provided the location and variation are known prior to construction.

4.1.4 Topography

The majority of the study area is underlain by the Hawkesbury Sandstone and the area comprised gently dipping topography which is not prone to landslip hazards or potential instability.

The residual soils of the weathered Hawkesbury Sandstone are anticipated at a shallow depth below the existing ground surface and very limited thicknesses of superficial/colluvial soils are anticipated. This reduces the probability of widespread low angle slump/sliding failures developing at the interface of superficial/residual soils resulting in development of slope stability problems.

4.1.5 Existing Vegetation

Mature trees are present within the study area and range from densely populated woodland to lawn areas with sparsely distributed trees. It is envisaged where development is to occur within these areas, the roots ball/system as well as any affected soils would require removal prior to construction. The majority of the densely vegetated areas occur within the north of the study area which may be underlain by a limited amount of soil (<1.0m depth) underlain by sandstone bedrock. The depth of the affected soils requiring removal may therefore be determined by the depth to bedrock which is unlikely to be significantly affected by tree roots/vegetation.

4.1.6 Drainage

Surface water appears to flow generally from the south to the north of the study area to the lower lying areas. Based on the topography, anticipated soil types and discussions with lot residents, it appears drainage is a problem within the area leading to soft/waterlogged ground. Significant erosion/drainage gullies were not observed, and it is considered the drainage may be a result of relatively flat/gently dipping topography which is not conducive to rapidly shedding surface water into established drainage channels.

Where highly expansive clay soils underlie the site, anticipated within the north east end of the study area, drainage systems need to be sufficient to prevent abnormal moisture conditions in the vicinity of structures constructed on expansive clay soils. Inadequate drainage in conjunction with expansive clays can lead to significant long-term problems therefore an adequate drainage system will need to be in-place prior to development in individual lots such that adverse impacts to buildings in adjacent lots is controlled.

4.1.7 Mine Subsidence District

The study area falls within the Bargo Mine District and has minimum requirements pertaining to the construction of residential dwellings and slab dimensions and rigidity for residential constructions. This requirement may be due to the potential for larger, on ground slabs to increase the depth of the zone of influence below ground level, therefore are more likely to be impacted by subsidence where a portion of the load is supported in potentially unstable ground. Although the slab requirements relate to residential dwellings, clarification with the Subsidence Advisory Committee NSW should be sought to determine if large commercial type developments are required to adhere to any construction conditions or whether any additional works are required to confirm status/extent of prior workings. It is recommended this potential constraint is further assessed at an early stage as it may have significant financial implications.

4.2 Severity of Anticipated Geotechnical Constraints/Conditions

To enable the identified constraints to be assessed, a system of assessing the impact of those constraints on the feasibility of the rezoning proposal is required. A framework of assessing the constraints has not been specified by Wollondilly Shire Council however for preliminary purposes the following framework is proposed:

- Identify constraint

- Determine the distribution of constraint within study area where:

Rating	Definition
1	occurs within <10% of total study area
2	occurs between 10% and 20% of total study area
3	occurs between 20% and 50% of total study area
4	occurs between 50% and 70% of total study area
5	occurs within greater than 70% of total study area

- Assess the impact of constraint on feasibility of development where:

Rating	Definition
1	Minor Impact – Typically allowed for in design, no significant additional costs
2	Low Impact - Proposed structures/layout can be readily modified to suit conditions
3	Moderate Impact – Elements of the development may require specialist engineering solutions/significant design modification during construction or may require significant additional earthworks/structural design to address constraint
4	High Impact – The constraint has a significant impact on the financial feasibility of the development or the construction timetable
5	Project Wide Impact – The constraint is such that it is a key element in determining the future of the project.

Using the above assessment methods, the identified constraints to development have been assessed below:

Constraint	Distribution	Rating	Impact	Rating	Score (max 10)
Very soft/loose/filled ground	<10%	1	Minor to low	1 to 2	**2 to 3**
Expansive Clay Soils	<10%	1	Minor to Low	1 to 2	**2 to 3**
Shallow/Variable Depth to Bedrock	20% - 50%	4	Minor	1	**5**
Steeply Sloping Ground	<10%	1	Moderate	3	**4**
Existing Vegetation	10% - 20%	2	Low	2	**4**
Poorly Drained areas	10% - 20%	2	Minor	1	**5**
Mine Subsidence	Requires Clarification with Mine Subsidence Advisory				

5.0 RECOMMENDATIONS

Based on the results of the desk study and walkover assessment it appears that there are limited significant geotechnical constraints to developing the study area based on the anticipated type of proposed structures.

It appears drainage may result in localised softening of the several of the lots within the study area which will need to be addressed as part of the civil design of the wider area.

It is considered likely that moderately expansive clay soils will underlie the north end of site however the degree of expansion will need to be assessed with intrusive works.

The geotechnical properties of the areas underlain by potentially loose/soft/filled ground should also be determined to enable better assessment of likely development impacts.

Depth to bedrock underlying the lots should be determined prior to proposed subdivision layout design.

Additionally, detailed elevation survey of the study area should be undertaken to enable accurate assessment of topography/sloping terrain.

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6. REFERENCES:

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2. C. W. Fetter 1995, "Applied Hydrology" by Prentice Hall. V. Gardiner & R. Dackombe 1983, "Geomorphological Field Manual" by George Allen & Unwin

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Appendix 1

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NOTES RELATING TO THIS REPORT

Introduction

These notes have been provided to amplify the geotechnical report in regard to classification methods, specialist field procedures and certain matters relating to the Discussion and Comments section. Not all, of course, are necessarily relevant to all reports.

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

Description and classification Methods

The methods of description and classification of soils and rocks used in this report are based on Australian Standard 1726, Geotechnical Site Investigation Code. In general, descriptions cover the following properties - strength or density, colour, structure, soil or rock type and inclusions.

Soil types are described according to the predominating particle size, qualified by the grading of other particles present (eg. Sandy clay) on the following bases:

Soil Classification	Particle Size
Clay	less than 0.002 mm
Silt	0.002 to 0.06 mm
Sand	0.06 to 2.00 mm
Gravel	2.00 to 60.00mm

Cohesive soils are classified on the basis of strength either by laboratory testing or engineering examination.
The strength terms are defined as follows:

Classification	Undrained Shear Strength kPa
Very soft	Less than 12
Soft	12 - 25
Firm	25 – 50
Stiff	50 – 100
Very stiff	100 - 200
Hard	Greater than 200

Non-cohesive soils are classified on the basis of relative density, generally from the results of standard penetration tests (SPT) or Dutch cone penetrometer tests (CPT) as below:

Relative Density	SPT “N” Value (blows/300mm)	CPT Cone Value (Qc – MPa)
Very loose	less than 5	less than 2
Loose	5 – 10	2 – 5
Medium dense	10 – 30	5 -15
Dense	30 – 50	15 – 25
Very dense	greater than 50	greater than 25

Rock types are classified by their geological names. Where relevant, further information regarding rock classification is given on the following sheet.

Sampling

Sampling is carried out during drilling to allow engineering examination (and laboratory testing where required) of the soil or rock.

Disturbed samples taken during drilling to allow information on colour, type, inclusions and, depending upon the degree of disturbance, some information on strength and structure.

Undisturbed samples are taken by pushing a thin-walled sample tube into the soil and withdrawing a sample of the soil in a relatively undisturbed state. Such samples yield information on structure and strength, and are necessary for laboratory determination of shear strength and compressibility. Undisturbed sampling is generally effective only in cohesive soils.

Drilling Methods

The following is a brief summary of drilling methods currently adopted by the company and some comments on their use and application.

Test Pits – these are excavated with a backhoe or a tracked excavator, allowing close examination of the insitu soils if it is safe to descent into the pit. The depth of penetration is limited to about 3m for a backhoe and up to 6m for an excavator. A potential disadvantage is the disturbance caused by the excavation.

Large Diameter Auger (eg. Pengo) – the hole is advanced by a rotating plate or short spiral auger, generally 300mm or larger in diameter. The cuttings are returned to the surface at intervals (generally of not more than 0.5m) and are disturbed but usually unchanged in moisture content. Identification of soil strata is generally much more reliable than with continuous spiral flight augers, and is usually supplemented by occasional undisturbed tube sampling.

Continuous Sample Drilling – the hole is advanced by pushing a 100mm diameter socket into the ground and withdrawing it at intervals to extrude the sample. This is the most reliable method of drilling soils, since moisture content is unchanged and soil structure, strength, etc. is only marginally affected.

Continuous Spiral Flight Augers – the hole is advanced using 90 – 115mm diameter continuous spiral flight augers which are withdrawn at intervals to allow sampling or insitu testing. This is a relatively economical means of drilling in clays and in sands above the water table. Samples are returned to the surface, or may be collected after withdrawal of the auger flights, but they are very disturbed and may be contaminated. Information from the drilling (as distinct from specific sampling by SPT's or undisturbed samples) is of relatively lower reliability, due to remoulding, contamination or softening of samples by ground water.

Non-core Rotary Drilling - the hole is advanced by a rotary bit, with water being pumped down the drill rods and returned up the annulus, carrying the drill cuttings. Only major changes in stratification can be determined from the cuttings, together with some information from 'feel' and rate of penetration.

Rotary Mud Drilling – similar to rotary drilling, but using drilling mud as a circulating fluid. The mud tends to mask the cuttings and reliable identification is again only possible from separate intact sampling (eg. From SPT).

Continuous Core Drilling – a continuous core sample is obtained using a diamond-tipped core barrel, usually 50mm internal diameter. Provided full core recovery is achieved (which is not always possible in very weak rocks and granular soils), this technique provides a very reliable (but relatively expensive) method of investigation.

Standard Penetration Tests

Standard penetration tests (abbreviated as SPT) are used mainly in non-cohesive soils, but occasionally also in cohesive soils as a means of determining density or strength and also of obtaining a relatively undisturbed sample. The test procedures is described in Australian Standard 1289, "Methods of Testing Soils for Engineering Purposes" – Test 6.3.1.

The test is carried out in a borehole by driving a 50mm diameter split sample tube under the impact of a 63kg hammer with a free fall of 760mm. It is normal for the tube to be driven in three successive 150mm increments and the 'N' value is taken as the number of blows for the last 300mm. In dense sands, very hard clays or weak rock, the full 450mm penetration may not be practicable and the test is discontinued.

The test results are reported in the following form.

- In the case where full penetration is obtained with successive blow counts for each 150mm of say 4, 6 and 7
  as 4, 6, 7 then N = 13
- In the case where the test is discontinued short of full penetration, say after 15 blows for the first 150mm and 30 blows for the next 40mm then as 15, 30/40mm.

The results of the test can be related empirically to the engineering properties of the soil. Occasionally, the test method is used to obtain samples in 50mm diameter thin wall sample tubes in clay. In such circumstances, the test results are shown on the borelogs in brackets.

Cone Penetrometer Testing and Interpretation

Cone penetrometer testing (sometimes referred to as Dutch Cone – abbreviated as CPT) described in this report has been carried out using an electrical friction cone penetrometer. The test is described in Australia Standard 1289, Test 6.4.1.

In tests, a 35mm diameter rod with a cone-tipped end is pushed continually into the soil, the reaction being provided by a specially designed truck or rig which is fitted with an hydraulic ram system. Measurements are made of the end bearing resistance on the cone and the friction resistance on a separte 130mm long sleeve, immediately behind the cone. Transducers in the tip of the assembly are connected buy electrical wires passing through the centre of the push rods to an amplifier and recorder unit mounted on the control truck.

As penetration occurs (at a rate of approximately 20mm per second) their information is plotted on a computer screen and at the end of the test is stored on the computer for later plotting of the results.

The information provided on the plotted results comprises: -

- Cone resistance – the actual end bearing force divided by the cross-sectional area of the cone – expressed in MPa.
- Sleeve friction – the frictional force on the sleeve divided by the surface area – expressed in kPa.
- Friction ratio - the ratio of sleeve friction to cone resistance, expressed in percent.

There are two scales available for measurement of cone resistance. The lower scale (0 – 5 MPa) is used in very soft soils where increased sensitivity is required and is shown in the graphs as a dotted line. The main scale (0 – 50 MPa) is less sensitive and is shown as a full line. The ratios of the sleeve friction to cone resistance will vary with the type of soil encountered, with higher relative friction in clays than in sands. Friction ratios 1% - 2% are commonly encountered in sands and very soft clays rising to 4% - 10% in stiff clays.

In sands, the relationship between cone resistance and SPT value is commonly in the range: -

Q_c (MPa) = (0.4 to 0.6) N blows (blows per 300mm)

In clays, the relationship between undrained shear strength and cone resistance is commonly in the range: -

Q_c = (12 to 18) C_u

Interpretation of CPT values can also be made to allow estimation of modulus or compressibility values to allow calculations of foundation settlements.

Inferred stratification as shown on the attached reports is assessed from the cone and friction traces and from experience and information from nearby boreholes, etc. This information is presented for general guidance, but must be regarded as being to some extent interpretive. The test method provides a continuous profile of engineering properties, and where precise information on soil classification is required, direct drilling and sampling may be preferable.

Dynamic Penetrometers

Dynamic penetrometer tests are carried out by driving a rod into the ground with a falling weight hammer and measuring the blows for successive 150mm increments of penetration. Normally, there is a depth limitation of 1.2m but this may be extended in certain conditions by the use of extension rods.

Two relatively similar tests are used.

- Perth sand penetrometer – a 16mm diameter flattened rod is driven with a 9kg hammer, dropping 600mm (AS1289, Test 6.3.3). The test was developed for testing the density of sands (originating in Perth) and is mainly used in granular soils and filling.
- Cone penetrometer (sometimes known as Scala Penetrometer) – a 16mm rod with a 20mm diameter cone end is driven with a 9kg hammer dropping 510mm (AS 1289, Test 6.3.2). The test was developed initially for pavement sub-grade investigations, and published correlations of the test results with California bearing ratio have been published by various Road Authorities.

Laboratory Testing

Laboratory testing is generally carried out in accordance with Australian Standard 1289 "Methods of Testing Soil for Engineering Purposes". Details of the test procedure used are given on the individual report forms.

Borehole Logs

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

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

Details of the type and method of sampling are given in the report and the following sample codes are on the borehole logs where applicable:

D	Disturbed Sample	E	Environmental sample	DT	Diatube
B	Bulk Sample	PP	Pocket Penetrometer Test		
U50	50mm Undisturbed Tube Sample	SPT	Standard Penetration Test		
U63	63mm " " " " "	C	Core		

Ground Water

Where ground water levels are measured in boreholes there are several potential problems:

- In low permeability soils, ground water although present, may enter the hole slowly or perhaps not at all during the time it is left open.
- A localised perched water table may lead to an erroneous indication of the true water table.
- Water table levels will vary from time to time with seasons or recent weather changes. They may not be the same at the time of construction as are indicated in the report.
- The use of water or mud as a drilling fluid will mask any ground water inflow. Water has to be blown out of the hole and drilling mud must first be washed out of the hole if water observations are to be made. More reliable measurements can be made by installing standpipes which are read at intervals over several days, or perhaps weeks for low permeability soils. Piezometers, sealed in a particular stratum, may be interference from a perched water table.

Engineering Reports

Engineering reports are prepared by qualified personnel and are based on the information obtained and on current engineering standards of interpretation and analysis. Where the report has been prepared for a specific design proposal (eg. A three-storey building), the information and interpretation may not be relevant if the design proposal is changed (eg. to a twenty-storey building). If this happens, the Company will be pleased to review the report and the sufficiency of the investigation work.

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

- unexpected variations in ground conditions – the potential for this will depend partly on bore spacing and sampling frequency,
- changes in policy or interpretation of policy by statutory authorities,
- the actions of contractors responding to commercial pressures,

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

Site Anomalies

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

Reproduction of Information for Contractual Purposes

Attention is drawn to the document "Guidelines for the Provision of Geotechnical Information in Tender Documents", published by the Institution of Engineers Australia. Where information obtained from this investigation is provided for tendering purposes, it is recommended that all information, including the written report and discussion, be made available. In circumstances where the discussion or comments section is not relevant to the contractual situation, it may be appropriate to prepare a special ally edited document. The Company would be pleased to assist in this regard and/or to make additional report copies available for contract purposes at a nominal charge.

Site Inspection

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

CROZIER
GEOTECHNICAL CONSULTANTS

Appendix 2

APPENDIX A

DEFINITION OF TERMS

INTERNATIONAL UNION OF GEOLOGICAL SCIENCES WORKING GROUP ON LANDSLIDES, COMMITTEE ON RISK ASSESSMENT

Risk – A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

Hazard – A condition with the potential for causing an undesirable consequence (*the landslide*). The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the likelihood of their occurrence within a given period of time.

Elements at Risk – Meaning the population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Probability – The likelihood of a specific outcome, measured by the ratio of specific outcomes to the total number of possible outcomes. Probability is expressed as a number between 0 and 1, with 0 indicating an impossible outcome, and 1 indicating that an outcome is certain.

Frequency – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability.

Likelihood – used as a qualitative description of probability or frequency.

Temporal Probability – The probability that the element at risk is in the area affected by the landsliding, at the time of the landslide.

Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

Consequence – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

Risk Analysis – The use of available information to estimate the risk to individuals or populations, property, or the environment, from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification, and risk estimation.

Risk Estimation – The process used to produce a measure of the level of health, property, or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis, and their integration.

Risk Evaluation – The stage at which values and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk Assessment – The process of risk analysis and risk evaluation.

Risk Control or Risk Treatment – The process of decision making for managing risk, and the implementation, or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

Risk Management – The complete process of risk assessment and risk control (*or risk treatment*).

Individual Risk – The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

Societal Risk – The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental, and other losses.

Acceptable Risk – A risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

Tolerable Risk – A risk that society is willing to live with so as to secure certain net benefits in the confidence that it is being properly controlled, kept under review and further reduced as and when possible.

In some situations risk may be tolerated because the individuals at risk cannot afford to reduce risk even though they recognise it is not properly controlled.

Landslide Intensity – A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, kinetic energy per unit area.

Note: Reference should also be made to Figure 1 which shows the inter-relationship of many of these terms and the relevant portion of Landslide Risk Management.

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}	5×10^{-2}	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}	5×10^{-3}	100 years	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	5×10^{-4}	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	5×10^{-5}	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	5×10^{-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.